Advanced Energy Design Guide for K-12 School Buildings

Achieving 30% Energy Savings Toward a Net Zero Energy Building

Developed by:
American Society of Heating, Refrigerating, and Air-Conditioning Engineers
The American Institute of Architects
Illuminating Engineering Society of North America
U.S. Green Building Council
U.S. Department of Energy

Advanced Energy Design Guide for K-12 School Buildings

This is an ASHRAE Design Guide. Design Guides are developed under ASHRAE's Special Publication procedures and are not consensus documents. This document is an application manual that provides voluntary recommendations for consideration in achieving greater levels of energy savings relative to minimum standards.

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Paul Torcellini
SP-111 Chair
December 2007

Abbreviations and Acronyms

A	=	area, ft^2
ACCA	=	Air Conditioning Contractors of America
AEDG-SR	=	*Advanced Energy Design Guide for Small Retail Buildings*
AFUE	=	annual fuel utilization efficiency, dimensionless
AHU	=	air-handling unit
AIA	=	American Institute of Architects
ANSI	=	American National Standards Institute
ASHRAE	=	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	=	American Society for Testing and Materials
AV	=	audiovisual
BAS	=	building automation system
BF	=	ballast factor
BPA	=	Bonneville Power Administration
Btu	=	British thermal unit
C-Factor	=	thermal conductance, $Btu/(h \cdot ft^2 \cdot °F)$
CA	=	census area
CD	=	construction documents
CFL	=	compact fluorescent lamp
cfm	=	cubic feet per minute
CHPS	=	Collaborative for High Performance Schools
CHW	=	chilled water
c.i.	=	continuous insulation
CM	=	construction manager
CMH	=	ceramic metal halide
CMU	=	concrete masonry unit
CO_2	=	carbon dioxide
COP	=	coefficient of performance, dimensionless
CPE	=	chlorinated polyethylene
CPSE	=	chlorosulfonated polyethylene
CRI	=	color-rendering index
CRRC	=	Cool Roof Rating Council
Cx	=	commissioning

CxA	=	commissioning authority
CU	=	coefficient of utilization, dimensionless
D	=	diameter, ft
DCV	=	demand-controlled ventilation
DL	=	Advanced Energy Design Guide code for “daylighting”
DOAS	=	dedicated outdoor air system
DOE	=	U.S. Department of Energy
DSP	=	daylighting saturation percent
DX	=	direct expansion
E_c	=	efficiency (combustion), dimensionless
E_t	=	efficiency (thermal), dimensionless
E	=	emittance
EER	=	energy efficiency ratio, Btu/W·h
E	=	efficiency
EF	=	energy factor
EIA	=	Energy Information Agency
EL	=	Advanced Energy Design Guide code for “electric lighting”
EMCS	=	energy management control systems
EN	=	Advanced Energy Design Guide code for “envelope”
EPA	=	U.S. Environmental Protection Agency
EPDM	=	ethylene propylene diene monomer
EPRI	=	Electric Power Research Institute
ERV	=	energy recovery ventilator
ESP	=	external static pressure, dimensionless
EX	=	Advanced Energy Design Guide code for “exterior lighting”
F-Factor	=	slab-edge heat loss coefficient per foot of perimeter, Btu/(h·ft·°F)
FFR	=	daylighting fenestration to floor area ratio, dimensionless
ft	=	feet
FWR	=	vertical fenestration to gross exterior wall area ratio, dimensionless
GC	=	general contractor
GSHP	=	ground-source heat pump
Guide	=	*Advanced Energy Design Guide for K-12 School Buildings*
HC	=	heat capacity, Btu/(ft^2·°F)
HID	=	high-intensity discharge
HO	=	high-output lighting
H_2O	=	water
HP	=	high performance
hp	=	horsepower
HSPF	=	heating season performance factor, Btu/Wh
HV	=	Advanced Energy Design Guide code for “HVAC systems and equipment”
HVAC	=	heating, ventilating, and air-conditioning
HW	=	hot water
IAQ	=	indoor air quality
IEEE	=	Institute of Electrical and Electronics Engineers
IESNA	=	Illuminating Engineering Society of North America
in.	=	inches
IPLV	=	integrated part-load value
IR	=	infrared
ISO	=	International Standards Organization
K	=	kindergarten
kBtuh	=	thousands of British thermal units per hour
kW	=	kilowatt

LBNL	=	Lawrence Berkeley National Laboratory
LCD	=	liquid crystal display
LED	=	light-emitting diode
LEED™	=	Leadership in Energy and Environmental Design
lm	=	lumens
LPD	=	lighting power density, W/ft^2
M	=	million
MERV	=	minimum efficiency reporting values
MLPW	=	mean lumens per watt
MPM	=	monitor power management
MTC	=	Massachusetts Technology Collaborative
MZS	=	multiple-zone recirculating ventilation system
N/A	=	not applicable
NBI	=	New Buildings Institute
NCEF	=	National Clearinghouse for Educational Facilities
NEMA	=	National Electrical Manufacturers Association
NFRC	=	National Fenestration Rating Council
NIBS	=	National Institute of Building Sciences
NREL	=	National Renewable Energy Laboratory
NZEB	=	net zero energy buildings
OA	=	outdoor air
O&M	=	operations and maintenance
OPR	=	owner's project requirements
PAR	=	parabolic aluminized reflector
PF	=	projection factor
PIR	=	passive infrared
PL	=	Advanced Energy Design Guide code for “plug loads”
ppm	=	parts per million
psf	=	pounds per square foot
PV	=	photovoltaic
PVC	=	polyvinyl chloride
QA	=	quality assurance
QMH	=	quartz metal halide
R-Value	=	thermal resistance, (h·ft^2·°F)/Btu
RCR	=	room-cavity ratio
RFP	=	request for proposal
RFQ	=	request for qualifications
RPI	=	Rensselear Polytechnic Institute
SBIC	=	Sustainable Buildings Industry Council
SEER	=	seasonal energy efficiency ratio, Btu/W·h
SHGC	=	solar heat gain coefficient, dimensionless
SP	=	standard series lamps
SPx	=	premium series lamps
sq	=	square
SRI	=	solar reflectance index, dimensionless
SSPC	=	standing standards project committee
SWH	=	service water heating
TC	=	technical committee
TDV	=	thermal displacement ventilation
TSO	=	thermoplastic polyolefin
TV	=	television
U-Factor	=	thermal transmittance, Btu/(h·ft^2·°F)

UPS	=	uninterruptible power supply
USGBC	=	U.S. Green Building Council
VAV	=	variable-air-volume
VFD	=	variable-frequency drives
VLT	=	visible light transmission
VSD	=	variable speed drive
W	=	watts
w.c.	=	water column
WH	=	Advanced Energy Design Guide code for “water heating systems and equipment”
WSHP	=	water source heat pump

Foreword: A Message to School Administrators and School Boards

The *Advanced Energy Design Guide for K-12 School Buildings* can help you use *ANSI/IESNA/ASHRAE Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings* as a benchmark to build new schools that are 30% more energy efficient than current industry standards. This saves energy and, perhaps more importantly, helps you enhance your school's educational mission.

IMPROVED LEARNING ENVIRONMENT

A better environment that includes favorable light, sound, and temperature can help students learn better. In many cases, improving these attributes can also reduce energy use. In *Greening America's Schools: Costs and Benefits*, Greg Kats provides 17 studies that demonstrate productivity increases of 2% to more than 25% from improved indoor air quality, acoustically designed indoor environments, and high-performance lighting systems.[1]

Some of these studies show that daylighting, which uses the sun to produce high-quality, glare-free lighting, can improve academic performance by as much as 20%. Because it requires little or no electrical lighting, which can increase cooling loads, daylighting is also a key strategy for achieving energy savings. Quality lighting systems include a combination of daylighting and energy-efficient electric lighting systems. These complement each other by reducing visual strain and providing better lighting quality.

Advanced energy-efficient heating and cooling systems provide thermal comfort and are quiet. This produces quieter, more comfortable, and more productive spaces. Various studies show that noise exposure—even modest levels of ambient noise—negatively affects educational outcomes. The impact on learning is magnified for younger children.

Advanced, energy-efficient heating and cooling systems create cleaner, healthier indoor environments that lower student and staff absentee rates and improve teacher retention. This translates into higher test scores and lower staff costs. For example, Ash Creek Intermediate School in Oregon has reduced absenteeism (compared to the previous facility) by 15%.

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1. Greening America's Schools Costs and Benefits, A Capital E Report, October 2006. Report prepared by Gregory Kats. Sponsoring organizations include American Federation of Teachers, American Institute of Architects, American Lung Association, Federation of American Scientists, and the U.S. Green Building Council. www.cap-e.com.

REDUCED OPERATING COSTS

Many schools spend more money on energy each year than on school supplies. By using energy efficiently and lowering a school's energy bills, millions of dollars each year can be redirected into facilities, teachers' salaries, computers, and textbooks. Strategic up-front investments in energy efficiency provide significant long-term savings. Durant Road Middle School in Raleigh, North Carolina, uses many of the recommendations in this Guide. The school saves thousands of dollars annually, and recouped its initial investment within two years. The total annual energy cost in 2006 was only $1.01/ft^2. Smart use of a site's climatic resources and more efficient envelope design are keys to reducing a building's overall energy requirements. Efficient equipment and energy management programs then help meet those requirements more cost effectively. Because of growing water demand and shrinking aquifers, the price of water is escalating at 10% per year or greater in some areas. Saving energy generally means saving water. Lower operating costs mean less fluctuation in budgets because of price instabilities of energy. Purchasing energy efficiency is buying into energy futures at a known fixed cost.

LOWER CONSTRUCTION COSTS/FASTER PAYBACK

Ideally, energy-efficient schools would cost the same or less to build than a typical school. We have been trained to think that energy efficiency must cost more; however, thoughtfully designed, energy-efficient schools can cost less to build. For example, optimizing the envelope to match the climate can substantially reduce the size of the mechanical systems. A school with properly designed north-south glazing will have lower mechanical costs than one with the same amount of glazing on an east-west orientation and will cost less to build. The heating systems at the Topham Elementary School in Langley, British Columbia, requires half as much heat as the next most efficient school in its district, costs half as much to maintain, and was less expensive to install. More efficient lighting means fewer lighting fixtures are needed. Better insulation and windows mean heating systems can be downsized. Likewise, cooling systems can often be downsized with a properly designed daylighting system and a better envelope.

Some strategies may cost more up front, but the energy they save means they often pay for themselves within a few years.

MORE SUPPORT FOR CONSTRUCTION FUNDING

Lower construction and operating costs also signify responsible stewardship of public funds. This translates into greater community support for school construction financing, whether through local district bonds or state legislative action.

ENHANCED ENVIRONMENTAL CURRICULUM

Schools that incorporate energy efficiency and renewable energy technologies make a strong statement about the importance of protecting the environment. They also provide hands-on opportunities for students and visitors to learn about these technologies and about the importance of energy conservation. Figure 1 shows a student at Desert Edge High School in Goodyear, Arizona, accessing information from an educational kiosk.

ENERGY SECURITY

Building an energy-conserving school reduces its vulnerability to volatile energy pricing. The price of natural gas increased more than 270% between 1994 and 2004. The price of oil continues to climb as part of an upward trend. Additionally, approximately 60% of US oil is now imported. The United States is also importing electricity and natural gas. Using less energy contributes to a more secure future for our country and our communities.

Photo courtesy of Agua Fria school district and Quality Attributes Software /Green Touchstone

Figure 1. A student at Desert Edge High School in Goodyear, Arizona, accesses information from an education kiosk.

WATER AS A RESOURCE

Water is a rapidly depleting natural resource. Though this Guide deals only with direct building-related energy conservation measures, water savings result in related energy savings. Water savings from low-flow fixtures and reduced water use from efficient landscaping result in related energy savings from pumping and waste disposal. Potable water savings also result in water supply and processing energy savings of 10–25 Btu per gallon of water saved.[2] Water is also used to produce electricity and to extract and process fossil fuels. Saving energy saves water.

REDUCED GREENHOUSE GAS EMISSIONS

According to the U.S. Environmental Protection Agency, buildings are responsible for almost half (48%) of all greenhouse gas emissions annually in the United States. Carbon dioxide, which is produced when fossil fuel is burned, is the primary contributor to greenhouse gas emissions. School districts can be a part of the solution when they reduce their consumption of fossil fuels for heating, cooling, and electricity. Students and their parents will appreciate this forward-thinking leadership.

ACHIEVING THE 30% ENERGY SAVINGS GOAL

Building a new school to meet or exceed a 30% energy savings goal is not difficult, but it does take some thought. First and foremost, it requires that the school system commit to the goal. A commitment that is incorporated in district policy is helpful. An individual from the school with decision-making power needs to act as a champion for the goal. The team must be willing and able to produce a design that meets the energy savings goals. It must also ensure that the building is constructed as designed and that school system staff is trained to operate the energy systems properly.

Design Team

To help optimize your design, reference your energy goal and this Guide in your request for qualifications/request for proposals (RFQ/RFP). Ideally, your prospective design team is already familiar with the Guide. Regardless, the team you select should have an established record of constructing buildings that operate with significant energy savings.

2. Energy Index Development for Benchmarking Water and Wastewater Utilities. Report prepared by Steven W. Carlson and Adam Walburger, CDH Energy Corp. Published by the AWWA Research Foundation, 2007.

Design firms that successfully coordinate project team members, bring in building users and facilities staff for input, and use an iterative process to test design concepts are more likely to achieve the 30% goal cost-effectively.

If you use the prescriptive measures recommended in this Guide, you can realize energy savings of at least 30% without computer building energy modeling. However, properly performed computer building energy modeling can help you optimize your design and will result in lower up-front construction costs and energy savings that often exceed 50%. Consider the design team's energy modeling capabilities during the architect/engineer selection process to achieve even greater savings.

Good daylighting can contribute to the 30% goal; however, it requires good technical daylighting design. If the design team does not have experience with a well-balanced daylighting design, a daylighting consultant should probably be added to the team. Some universities and utilities provide daylighting consulting at low or no cost.

Commissioning Authority (aka Commissioning Agent)

A building can have the best possible design for achieving energy savings, but unless it is constructed as designed and is operated according to the design intent, it will not realize energy savings. A commissioning authority (CxA) ensures that the energy- and water-saving methods and devices selected by the design team are incorporated in the building plans and specifications; that everything is built and tested accordingly; and that school personnel, including those occupying the building, are provided the necessary documentation and training to operate the building properly after it is occupied. The CxA can be an independent member of the design firm, the school's facility staff, or a third-party consultant. Some prefer to use third-party consultants for this role to ensure that the work is done independently of the design team and that the results are not biased. More information on commissioning is available in Chapter 5 and Appendix B.

School Personnel

Operations and maintenance personnel and teachers must be trained in the proper operation of a school's energy systems when the building is occupied. Initial training should be backed up by a long-term commitment to maintain an informed staff, including administrative, instructional, and facilities personnel, and to fund proper upkeep over the life of the installed systems. Scheduling and monitoring are important to ensure timely preventative maintenance. In addition, we recommend that any substantive changes made by facilities personnel be well documented and reviewed in the context of the original design.

A GOAL WITHIN REACH

Saving 30% or more on energy is within the reach of any school district with the will to do so. It is a good deal for students, teachers, administrators, and taxpayers. Join us in the goal to save energy, save money, protect the environment, and create a more secure energy future. We look forward to learning about your new energy-efficient schools through the case study database at www.ashrae.org/aedg.

1 Introduction

The *Advanced Energy Design Guide for K-12 School Buildings* was written to help owners and designers of elementary, middle, and high school buildings achieve energy savings of at least 30% compared to the minimum requirements of *ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings,* which serves as a baseline. This baseline is consistent with other Advanced Energy Design Guides in the series. One significant addition is the inclusion of daylighting options in the recommendations. This Guide contains recommendations only and is not a code or standard.

The Guide is intended to show that achieving the 30% target is not only possible, but easy. Case studies showcase schools around the country that have achieved or exceeded the target—the technologies are available to do the job.

By specifying a target goal and identifying paths for each climate zone to achieve the goal, the Guide provides some ways to meet the 30% target and build K-12 schools that use substantially less energy than those built to minimum energy-code requirements. This Guide provides *a* way, but not the *only* way to achieve the 30% energy savings target, and since there may be other ways of achieving this goal, we hope the Guide generates ideas for innovation.

The Guide was developed by a project committee that represents a diverse group of professionals. Guidance and support was provided through a collaboration of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IESNA), the U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE). Members of the project committee come from these partner organizations: the ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1), the ASHRAE Technical Committee on Educational Facilities (TC 9.7), the Sustainable Building Industry Council (SBIC), the Collaborative for High Performance Schools Project (CHPS), and the National Clearinghouse for Educational Facilities (NCEF) at the National Institute of Building Sciences (NIBS).

The 30% energy savings target is the first step toward achieving *net zero energy schools*—schools that, on an annual basis, draw from outside sources less or equal energy than they generate on site from renewable energy sources. For more information on net zero energy buildings, see the references in Appendix E, "Additional Resources."

Other Guides in this series include the *Advanced Energy Design Guide for Small Office Buildings*, the *Advanced Energy Design Guide for Small Retail Buildings*, and the soon-to-be-pulished *Advanced Energy Design Guide for Small Warehouses and Self Storage Buildings* (www.ashrae.org/aedg).

SCOPE

This Guide applies to K-12 (classified as elementary, middle, and high schools) buildings with administrative and office areas, classrooms, hallways, restrooms, gymnasiums, assembly spaces, food preparation spaces, and dedicated spaces such as media centers and science labs. This Guide does not consider specialty spaces such as indoor pools, wet labs (e.g., chemistry), "dirty" dry labs (e.g., wood-working or auto shop), or other unique spaces with extraordinary heat or pollution generation. It is primarily intended for new construction, but it may be equally applicable to many school renovation, remodeling, and modernization projects.

Included in the Guide are recommendations for the design of the building envelope; fenestration; lighting systems (including electrical lights and daylighting); heating, ventilation, and air-conditioning (HVAC) systems; building automation and controls; outside air (OA) treatment; and service water heating (SWH). Additional savings recommendations are also included but are not necessary for 30% savings. Additional savings recommendations are provided for electrical distribution, plug loads, renewable energy systems, and using the building as a teaching tool.

The recommendation tables do not include all the components listed in, ASHRAE Standard 90.1-1999. Though this Guide focuses only on the primary energy systems within a building, the underlying energy analysis presumes that all the other components are built to the criteria in Standards 90.1 and 62.1.

Certain aspects of energy-efficient school design, including steam heat, modular classrooms, vehicle and maintenance areas, domestic water well piping, kitchen process loads (e.g., ovens, coolers, freezers), and sewage disposal are excluded from the Guide. Significant energy-efficiency opportunities may be available in these areas, and Guide users are encouraged to take advantage of these opportunities and treat them as bonuses beyond the 30% target. In addition, the Guide is not intended to substitute for rating systems or references that address the full range of sustainable issues in schools, such as acoustics, productivity, indoor air quality (IAQ), water efficiency, landscaping, and transportation, except as they relate to energy use. This Guide is not a design text; rather, it presumes good design skills and expertise in school design.

SCHOOL PROTOTYPES

To provide a baseline for this Guide, three school prototype designs with a variety of envelope, lighting, and HVAC configurations were developed and analyzed by using hourly building simulations in eight climate zones. The designs include a 74,500 ft^2 elementary school, an 112,000 ft^2 middle school, and a 205,000 ft^2 high school, each of which was carefully assembled to be representative of construction for schools of that class. Information was drawn from a number of sources and various school templates from around the country. The space types included in the prototype designs are shown in Table 1.1.

Two sets of hour-by-hour simulations were run for each prototype. The first set meets the minimum requirements of ASHRAE Standard 90.1-1999, and the second uses the recommendations in this Guide to achieve 30% energy savings. This process was repeated for all climate zones. All materials and equipment used in the simulations are commercially available from two or more manufacturers.

Energy savings for the recommendations vary depending on climate zones, daylighting options, HVAC system type, and school type, but in all cases are at least 30% when compared to ASHRAE 90.1-1999. The savings as compared to ASHRAE 90.1-1999 for

Table 1.1. Prototype Designs Space Types

Space Types	Elementary	Middle	High
Classrooms	×	×	×
Library	×	×	×
Media center	×	×	×
Computer lab	×	×	×
Science lab		×	×
Music	×	×	×
Arts/crafts	×	×	×
Multipurpose room	×		×
Auditorium/theater			×
Special ed/resource	×	×	×
Gymnasium		×	×
Auxiliary gymnasium			×
Offices	×	×	×
Infirmary/clinic	×	×	×
Cafeteria	×	×	×
Kitchen	×	×	×
Hall lockers		×	×

the options with daylighting but without high efficiency electrical lighting ranged from 34%–50%. The savings for the options without daylighting but with high efficiency electrical lighting, ranged from 32%–45%.

Analysis was also made to determine energy savings of at least 30% when compared to ASHRAE Standard 90.1-2004. The savings as compared to ASHRAE 90.1-2004 for the options with daylighting but without high efficiency electrical lighting ranged from 30%–45%. The savings for the options without daylighting but with high efficiency electrical lighting ranged from 24%–41%. Complete results of the prototype school simulations are presented in the *Technical Support Document: Development of the Advanced Energy Design Guide for K-12 School Buildings*, available at www.ashrae.org/aedg.

ACHIEVING 30% ENERGY SAVINGS

Meeting the 30% energy savings goal is not difficult, but it requires more than doing business as usual. Here are the essentials.

1. *Obtain school district buy-in.* There must be strong buy-in from the school district's leadership and staff. The more they know about and participate in the planning and design process, the better they will be able to help achieve the 30% goal after the school becomes operational. See the NCEF resource list, "School Energy Savings," at www.ncef.org for one source of information about obtaining support for building energy-efficient, high-performance schools. The building owner must decide on the goals and provide the leadership to make the goals reality.
2. *Assemble an experienced, innovative design team.* Interest and experience in designing energy-efficient buildings, innovative thinking, and the ability to work together as a team are all critical to meeting the 30% goal. The team achieves this goal by creating a school that maximizes daylighting, minimizes heating and cooling loads, and has highly efficient lighting and HVAC systems. Energy goals should be communicated in the RFP and design team selection based in part on the team's ability to meet the goals. The design team implements the goals for the owner.
3. *Adopt an integrated design approach.* Cost-effective, energy-efficient design requires trade-offs among potential energy-saving features. This requires an integrated approach

to school design. A highly efficient lighting system, for instance, may cost more than a conventional one, but because it produces less heat, the building's cooling system can often be downsized. The greater the energy savings, the more complicated the trade-offs become and the more design team members must work together to determine the optimal mix of energy-saving features. Because many options are available, the design team will have wide latitude in making energy-saving trade-offs. This Guide uses an integrated approach to achieve the energy savings by creating an envelope that can provide most of the heating, cooling, and lighting for the building.

4. *Consider a daylighting consultant.* Daylighting can be an important energy savings strategy that has additional academic benefits; however, it requires good technical daylighting design. If the design team does not have experience with a well-balanced daylighting design, it may need to add a daylighting consultant. Some universities and utilities provide daylighting consultations at low or no cost.
5. *Consider energy modeling.* This Guide is designed to help achieve energy savings of 30% without energy modeling, but energy modeling programs that simulate hourly operation of the building and provide annual energy usage data make evaluating energy-saving trade-offs faster and far more precise. These programs have learning curves of varying difficulty, but energy modeling for school design is highly encouraged and is considered necessary for achieving energy savings beyond 30%. See DOE's "Building Energy Software Tools Directory" at http://www.eere.energy.gov/buildings/tools_directory for links to energy modeling programs. Part of the key to energy savings is using the simulations to make envelope decisions first and then evaluating heating, cooling, and lighting systems. Developing HVAC load calculations is *not* energy modeling and is *not* a substitute for energy modeling.
6. *Use building commissioning.* Studies verify that building systems, no matter how carefully designed, are often improperly installed or set up and do not operate as efficiently as expected. The 30% goal can best be achieved through building commissioning (Cx), a systematic process of ensuring that all building systems—including envelope, lighting, and HVAC—perform as intended. The Cx process works because it integrates the traditionally separate functions of building design, system selection, equipment startup, system control calibration, testing, adjusting and balancing, documentation, and staff training.

   The more comprehensive the Cx process, the greater the likelihood of energy savings. A commissioning authority (CxA) should be appointed at the beginning of the project and work with the design team throughout the project. Solving problems in the design phase is more effective and less expensive than making changes or fixes during construction. See Appendix B and the "Commissioning" section of Chapter 5 of this Guide for more information, as well as Appendix E for additional resources.
7. *Train building users and operations staff.* Staff training can be part of the building Cx process, but a plan must be in place to train staff for the life of the building to meet energy savings goals. The building's designers and contractors normally are not responsible for the school after it becomes operational, so the school district must establish a continuous training program that helps occupants and operations and maintenance (O&M) staff maintain and operate the school for maximum energy efficiency. This training should include information about the impact of plug loads on energy use and the importance of using energy-efficient equipment and appliances. One source of information about staff training is the NCEF resource list "School Facilities Management" at www.ncef.com.
8. *Monitor the building.* A monitoring plan is necessary to ensure that energy goals are met over the life of the building. Even simple plans, such as recording and plotting monthly utility bills, can help ensure that the energy goals are met. Buildings that do not meet the design goals often have operational issues that should be corrected.

HOW TO USE THIS GUIDE

- Review Chapter 2 to understand how an integrated design approach is used to achieve 30% or greater energy savings. Checklists show how to establish and maintain the energy savings target throughout the project.
- Use Chapter 3 to select specific energy saving measures by climate zone. This chapter provides a prescriptive path that does not require modeling for energy savings. These measures also can be used to earn credits for CHPS, LEED®, and other building rating systems.
- Review the case studies in Chapter 4 to see how the 30% energy savings goal has been met in schools in climate zones across the country.
- Use Chapter 5 to apply the energy saving measures in Chapter 3. This chapter has suggestions about best design practices, how to avoid problems, and how to achieve additional savings with energy-efficient appliances, plug-in equipment, and other energy saving measures.

An Integrated Design Approach to Achieve Savings

2

The integrated design process strives to minimize the building loads by selecting an appropriate building site and increasing envelope thermal efficiency. This usually reduces the demand on subsystems such as HVAC, lighting, plumbing, and power. Integration encourages the right-sizing of building systems and components that allows for reduced first and life-cycle costs. A successful integrated design approach provides the best energy performance at the least cost and is characterized as follows:

- *It is resourceful.* Integrated design begins with site assessment and selection. Site selection is an opportunity to obtain free energy resources. Daylighting can provide most lighting needs in many locations, passive solar heat can reduce mechanical heating loads, external overhangs can reduce cooling loads, and photovoltaic (PV) panels can reduce the amount of electricity that needs to be produced by fossil fuels. Proper building orientation, form, and layout provide substantial energy savings.
- *It is multidisciplinary.* Integrated design goes beyond the conventional practice of a kick-off meeting with the designers and their consultants. Instead, it involves the owner, designers, technical consultants, construction manager (CM), CxA, facility staff, and end users in all phases of the project. The process requires cross-disciplinary design and validation at all phases of the process.
- *It is goal driven.* A goal-setting session early in the design process can identify strategies to meet energy-efficiency and other sustainable building goals in relation to the school's mission. Goals must be quantifiable and measurable. Insisting on a well-defined Basis of Design at the beginning of the project will help ensure that the energy goals and objectives are integrated into the design and considered throughout the project. By including school district representatives, parents, and, when appropriate, students in this session, the likelihood of generating integrated, creative solutions is greatly increased. Aligning design goals with learning and including those invested in the school's mission are key to a successful project.
- *It is iterative.* A goal-setting session is just the beginning. As the design concept takes shape, it needs to be tested to determine which strategies will result in desired energy performance, optimized maintenance requirements, and reduced life-cycle costs. Preferably, this takes the form of energy modeling at key points in the design process. It also requires that time be set aside during design reviews to discuss system-level energy use.

The CxA, who may be a member of the school district's facility staff, an independent staff member from the design firm, or an outside consultant, is an integral part of this iterative process. He or she validates that the design documents meet the energy savings goals, that the building is constructed as designed, and that the school staff knows how to use, operate, and maintain the building to achieve the energy savings goals.

The following presentation of an integrated process for achieving energy savings in new school buildings is valuable for designers and builders who want to augment and improve their practices so that energy efficiency is deliberately considered at each stage of the development process from project conception through building operation. The tasks to be completed in each design, construction, and operation phase are identified, and responsibilities are assigned in Tables 2.1–2.4.

PRE-DESIGN PHASE

Adopting measurable energy goals at the beginning of the project will guide the team and provide a benchmark throughout the project's life. General strategies that relate to these goals will be identified at this phase as part of the goal discussions. Strategies will be further refined and confirmed during the design phase. Because of the nature of school buildings, goal setting should include consideration of the community context and curriculum opportunities. One example is to prioritize an energy strategy that also teaches. Another example would be to identify synergies with other facility uses to avoid constructing unnecessary buildings. Daylighting, as an energy-saving strategy that is uniquely important to classroom design, needs to be decided on early in the process so it can be integrated into the whole building design.

Emphasize goals that relate to large energy uses and can produce the most savings. Priorities are likely to vary significantly from one climate zone to another and may vary between schools in the same climate zone. Site conditions can significantly affect energy performance. For example, differences in building application, climate, and orientation will affect the selection of various energy goals and strategies. Figure 2.1 shows the baseline energy use for a 74,500 ft^2 elementary school in the 15 climate zones. It demonstrates that cooling and lighting energy predominates in climate zone 1 (Miami is in 1A, a subset of climate zone 1), so the goals and strategies for cooling and lighting should

Table 2.1. Energy Goals in the Context of the Pre-Design Phase

Activities	Responsibilities
Select the core team • Include energy goals in the RFP • Designers (including project architect and engineer and other design consultants) • CxA • CM	Owner
Adopt energy goals	Owner and designers
Assess the site • Evaluate centrality to the community • Evaluate access to public transportation • Identify on-site energy opportunities • Identify best building orientation	Owner, designers, CM
Define functional and spatial requirements	Owner and designers
Define energy efficiency and budget benchmarks	Owner, designers, CM, estimator
Prepare the design and construction schedule	Owner, designers, CM
Determine building envelope and systems preferences	Owner, designers, CM
Perform cost/benefit analysis for energy strategies	Owner and designers
Identify applicable energy code requirements	Owner and designers

Table 2.2. Energy Goals in the Context of the Design Phase

Activities	Responsibilities
Prepare diagrammatic building plans that satisfy functional program requirements	Designers
Develop specific energy strategies	Owner, designers, CM, CxA
Develop the site plan to make best use of building orientation and daylighting strategies	Designers
Select building systems, taking into account their desired energy efficiency	Owner, designers, CM
Develop building plans, sections, and details incorporating the above strategies	Designers
Develop architectural and lighting details (for example, lighting, fenestration, exterior sun control, taking into account their energy implications)	Designers
Refine the design (for example, refine the building elevations to reflect the appropriate location and size of windows)	Designers
Perform design reviews at each phase of the project to verify that the project meets functional and energy goals	Owner, designers, CM, CxA
Calculate building HVAC loads AND run energy models to optimize design at each design stage (schematic, design development, and construction drawings) to ensure that energy goals are being met; use recommended loads for lighting power density from this Guide.	Designers
Match capacity of HVAC systems to design loads to avoid costly overdesign, specify equipment efficiency as recommended by this Guide	Designers
Perform final coordination and integration of architectural, mechanical, and electrical systems	Designers
Prepare specifications for all systems	Designers
Integrate Cx specifications into project manual	Designers and CxA
Prepare cost estimates at each phase of design	CM, CxA, estimator
Review and revise final design documents	Owner, designers, CxA

Table 2.3. Energy Goals in the Context of the Bidding and Construction Phase

Activities	Responsibilities
At the pre-bid conference, emphasize energy-efficiency measures and the Cx process	Owner, designers, CM, CxA
At all job meetings, review energy efficiency measures and Cx procedures	Owner, designers, CM, CxA
Verify that building envelope construction carefully follows the drawings and specifications	Designers, CxA
Verify that HVAC and electrical systems meet specifications	Designers, CxA

Table 2.4. Energy Goals in the Context of the Acceptance Phase

Activities	Responsibilities
Prepare pre-occupancy punch list	Owner, designers, CM, CxA
Conduct system performance tests	Designers, CM, CxA, general contractor, subcontractor
Submit completed O&M manuals	CxA, general contractor, subcontractor
Provide O&M training for school staff	CxA, general contractor, subcontractor
Establish building O&M program	CxA, general contractor, subcontractor, facility staff
Resolve any remaining Cx issues identified during the construction or occupancy phase	Owner, CM, CxA, general contractor, subcontractor
Certify building as substantially complete	Owner, designers, CM, CxA
Purchase computers and other energy using appliances that meet ENERGY STAR® efficiency to reduce plug loads	Owner, facility staff
Monitor post-occupancy performance for one year	CxA, facility staff
Create post-occupancy punch list	CxA, facility staff
Grant final acceptance	Owner, designers, CM, CxA

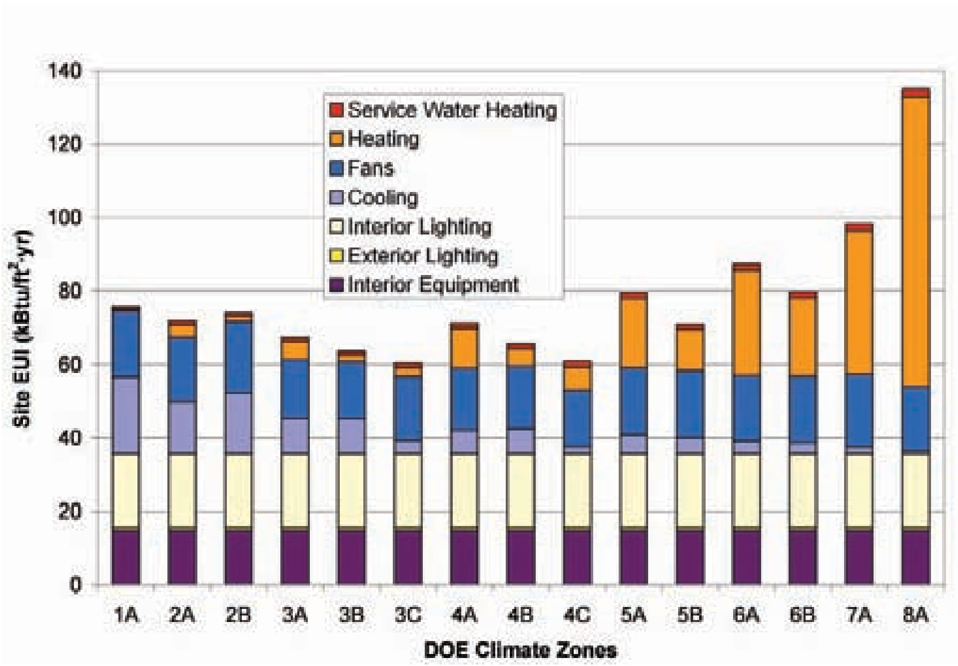


Figure 2.1. Elementary school annual baseline end uses across climate zone.

receive the highest priorities. In climate zone 8 (Fairbanks), the goals and strategies for heating and lighting should receive the highest priority. Table 2.1 lists strategies to follow to keep the pre-design phase in line with energy design goals.

DESIGN PHASE

In the design phase, the project team develops and incorporates energy strategies into building plans and specifications. This will have a major impact on the overall energy performance of the building as constructed. Design choices should be in order as follows:

1. Optimize on-site resources, especially daylighting
2. Reduce energy loads
3. Size systems properly
4. Incorporate efficient equipment

At each point, the decisions should take into account other priorities and systems decisions. For example, cooling system sizing should take into account daylighting measures, glazing sizes, and building orientation.

The CxA reviews the design to verify that the project goals are being met. The CxA should also verify that the assumptions for HVAC load calculations and other modeling assumptions are based on actual design parameters rather than on rule of thumb. Information about how to integrate the Cx process into your project is included in Chapter 5. Table 2.2 lists strategies to follow to keep the design phase in line with energy design goals.

BIDDING AND CONSTRUCTION

Even the best design will not yield the expected energy savings if the construction plans and specifications are not correctly executed. Table 2.3 lists strategies that the project team can use to keep the construction process in line with energy design goals.

OCCUPANCY: EVALUATE PERFORMANCE AND TRAIN USERS

Occupancy is a critical time in the process and is often neglected by the project teams. Energy savings are difficult to attain if the occupants and O&M staff do not know how to use, operate, and maintain the building. The CxA should ensure timely submittals of the O&M manuals through specifications and regular reminders at construction meetings, and ensure adequate and timely training of all school personnel.

A performance review should be conducted during the first year of building operation. The building operator should discuss any systems that are not performing as expected with the design and construction team so they can be resolved during the warranty period. Over time, the building's energy use, changes in operating hours, and any addition of energy-consuming equipment should be tracked and documented by school facilities staff. This information can be used to determine how well the building is performing and can provide lessons to take back to the design table for future projects. Performance evaluations should take place on a schedule specified in a maintenance manual provided to the owner as part of final project acceptance. Ongoing training of school personnel, including facilities staff, administrators, and instructional staff, should be provided to address changes and staff turnover. Table 2.4 lists strategies to help keep the acceptance phase in line with energy design goals. Additional information about energy-efficient operation and ongoing energy management is available in Appendix E.

3

Recommendations by Climate

This chapter contains a unique set of energy-efficiency recommendations for each climate zone. The recommendation tables represent some—but not all—ways to reach the 30% energy savings target over ASHRAE Standard 90.1. Other approaches may also save energy, but they are not part of the scope of this Guide; assurance of those savings is left to the user. The recommendation tables do not include all the components listed in ASHRAE Standard 90.1, since the Guide focuses only on primary energy systems. Future editions of energy codes may have more stringent values. In these cases, the more stringent values are recommended.

You should determine the recommendations for your construction project by first locating the correct climate zone. The U.S. DOE has identified eight climate zones for the United States. Each is defined by county borders, as shown in Figure 3.1 and as listed below the individual climate zone maps that follow. These climate zones are based on temperature and, in some cases, are divided into subzones based on humidity levels. Humid subzones are A zones, dry subzones are B zones, and marine subzones are C zones. This Guide uses these zones to define the energy recommendations. Tables with the climatic zones for locations in Mexico and Canada are in Appendix C.

Each climate zone recommendation table includes a set of common items arranged by building subsystem: envelope, daylighting, lighting, HVAC systems, and SWH. Recommendations are included for each item, or subsystem, by component within that subsystem. For some subsystems, recommendations depend on the construction type, HVAC system type, and daylighting type. For example, insulation values are given for mass, steel-framed, and wood-framed wall types. For others, recommendations are given for each attribute. For example, glass recommendations are given for size, thermal transmittance, solar heat gain coefficient (SHGC), and exterior sun control.

Electric lighting is one of the largest energy users in schools. Depending on climate, lighting energy use can be as high as 40% of the total energy use of a basic, energy code-compliant school. Because lighting-related improvements can be inexpensive and offer rapid payback, they top the list of recommendations for meeting an overall target of 30% energy savings. Lighting design also affects the HVAC system. Two distinctly different approaches, either of which can be used to meet the recommendations in this chapter, can be used to reduce lighting energy:

- *Design a daylighted school.* If carefully designed, vertical fenestration and skylights can provide interior illumination without excessive solar heat gain. Electric lighting systems can then be extinguished or dimmed for most school hours, saving significant energy and maintenance costs. The key to daylighting is an integrated design in which HVAC and electric lighting controls are optimized to take full advantage of and harvest energy savings, and added first costs of fenestration are offset by reduced costs in HVAC equipment. Because of daylighting's additional non-energy benefits (see Foreword), a design that uses daylighting should be pursued whenever possible. Proper daylighting design requires an integrated approach and good design skills. If these are possible, lighting and daylighting design can provide predictable and persisting lighting energy savings of up to 43%.

  For the daylighting options, recommendations are given for classrooms and gyms/multipurpose rooms. There are three classroom daylighting patterns: a toplighted pattern, a sidelighted pattern, and a combined toplighted and sidelighted pattern. For the gym/multipurpose rooms, there are a roof monitor pattern and a skylight pattern. Recommendations are provided for both north- and south-facing versions, and whichever are applicable to your design would apply. East- and west-facing daylighting systems are not recommended because solar gains and glare are difficult to manage. Recommended patterns are also provided by climate zone. See the daylighting recommendations for DL1–37 of Chapter 5, "How to Implement Recommendations."
- *Use efficient, state-of-the art products and techniques to design electric lighting.* Site constraints or program requirements may preclude daylighting solutions. Therefore, a nondaylighted path is provided to meet the recommendations in Chapter 3. The recommendations provided in this section include lighting systems that use the most current, energy-efficient lamps, ballasts, and integrated controls. Because lighting energy savings also produce cooling savings, HVAC energy savings of 10% to 15% are also possible in cooling-dominated climates. Moreover, even though the cost of high-performance lighting may be about the same or more than a basic solution, the cost of HVAC capacity can also be reduced. See the general lighting recommendations for EL1–16 in Chapter 5, "How to Implement Recommendations."

There are six possible HVAC system types from packaged direct expansion (DX) rooftops to water-source heat pumps to central variable-air-volume (VAV) air handlers with chillers and boilers (see HV1–6 in Chapter 5 for detailed descriptions). Some system types, however, are not recommended for certain humid climate zones because of the energy impact of humidity control. Unique recommendations are included for each HVAC system type based on practicality of implementation and the 30% energy reduction goal. For example, air-side economizers are recommended for packaged DX rooftops in many climate zones because they are easy to implement and they help achieve the desired energy savings. However, higher chiller and boiler efficiencies are recommended for fan-coil systems because air-side economizers are less practical for this system type. In some cases, recommended HVAC equipment efficiencies are based on system size (capacity). Because conditioning OA for ventilation is such a big contributor to energy use in a K-12 school building, either exhaust-air energy recovery or demand-controlled ventilation (DCV) is recommended.

Where "Comply with Standard 90.1" is indicated in the "Recommendation" column of the tables, you must meet at least the minimum requirements of the most current version of ASHRAE Standard 90.1 or the requirements of local codes whenever they exceed the requirements of ASHRAE Standard 90.1.

The fourth column in each table lists references to how-to tips for implementing the recommended criteria. The tips are found in Chapter 5 under separate sections coded for envelope (EN), daylighting (DL), electric lighting (EL), HVAC systems and equipment

(HV), and SWH systems and equipment (WH) suggestions. In addition to design and maintenance suggestions that represent good design practice, these tips include cautions for what to avoid. Each tip in Chapter 5 is tied to the applicable climate zones. The final column is provided as a simple checklist to identify the recommendations that are being used for a specific building design and construction.

Chapter 5 provides additional recommendations and strategies for energy savings over and above the 30% recommendations contained in the eight climate regions. These additional savings are in the areas of plug loads, alternative HVAC systems, renewable energy systems, and others.

The recommendations presented are either minimum or maximum values. Minimum values include the following:

- R-values
- mean lumens/watt (MLPW)
- seasonal energy efficiency ratio (SEER)
- solar reflectance index (SRI)
- energy efficiency ratio (EER)
- integrated part-load value (IPLV)
- annual fuel utilization efficiency (AFUE)
- heating season performance factor (HSPF)
- coefficient of performance (COP)
- efficiency (E_c and E_t)
- energy factor (EF)
- insulation thicknesses

Maximum values include the following:

- fenestration U-factors
- fenestration SHGC
- total fenestration to gross wall area ratio
- lighting power density (LPD)
- hp/1000 cfm
- external static pressure (ESP)
- friction rate

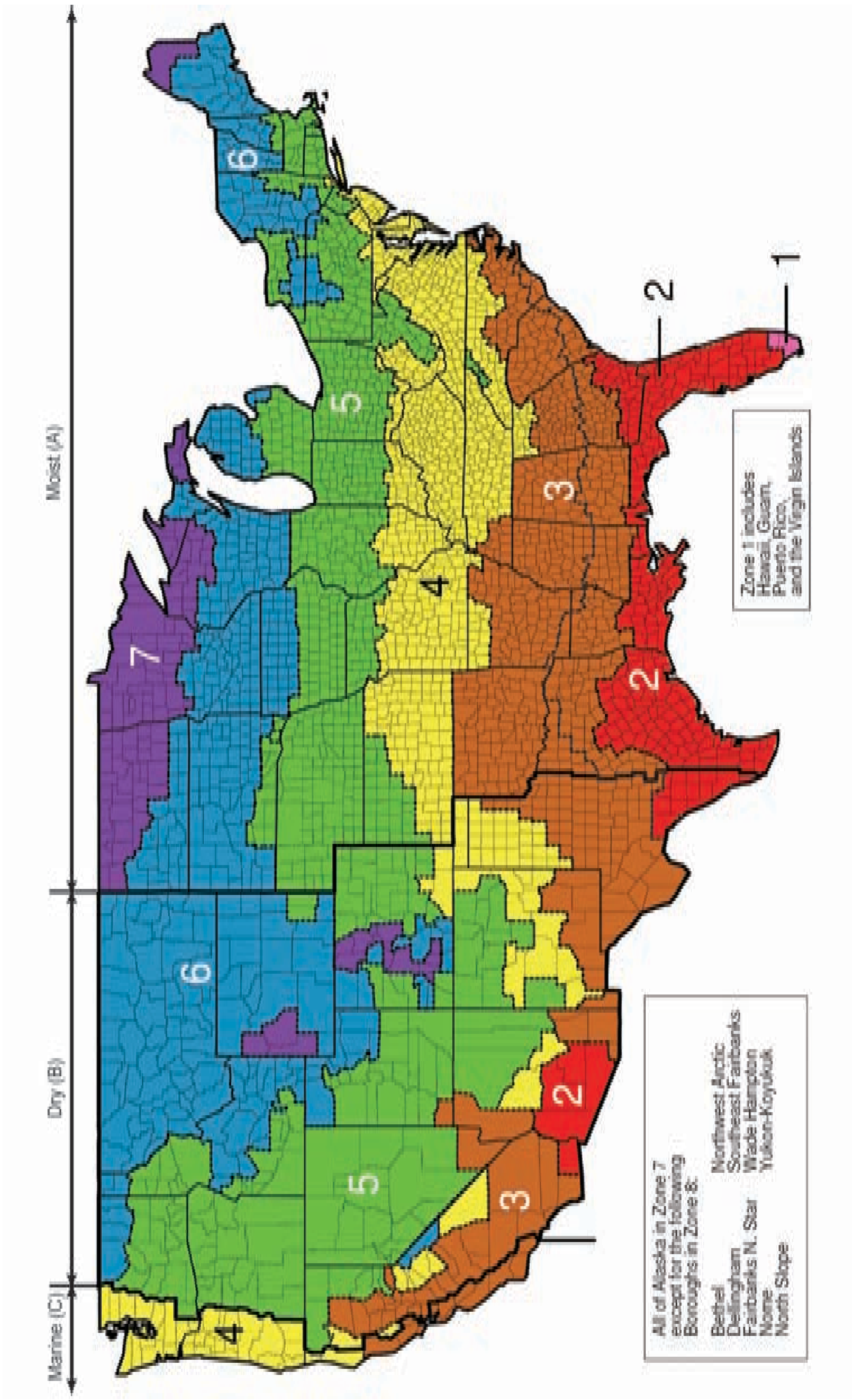
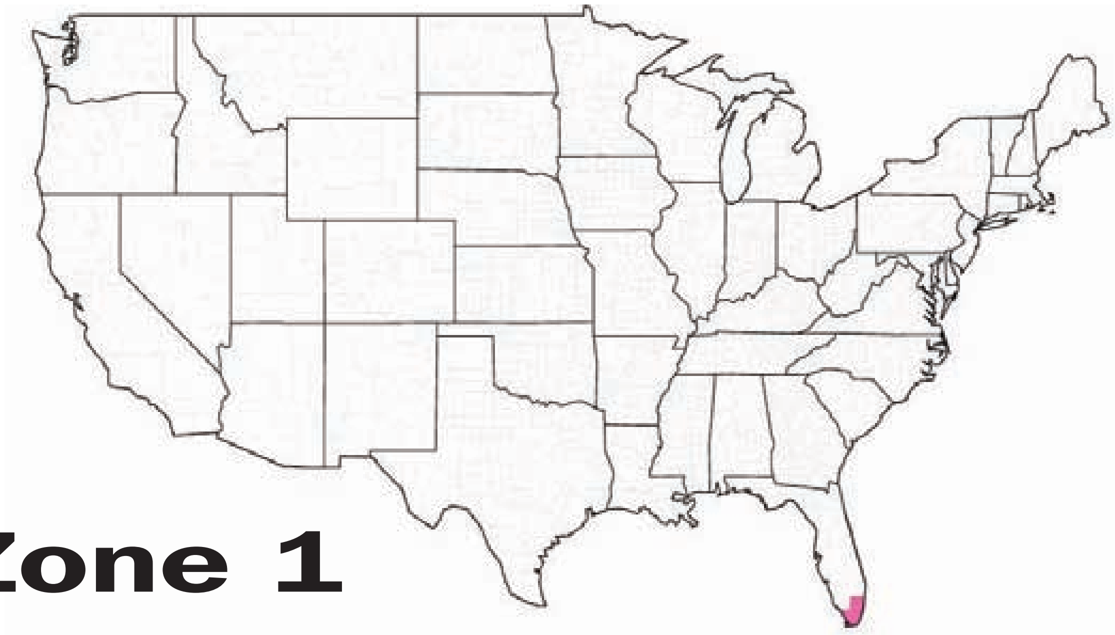


Figure 3.1. Climate zone map.



Zone 1

Florida

Broward
Miami Dade
Monroe

Guam

Hawaii

Puerto Rico

U.S. Virgin Islands

Climate Zone 1 Recommendation Table for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-30	EN3, EN15–16, EN18	
		Metal building	R-19	EN3–4 EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-5.7 c.i.	EN5, EN15, EN18	
		Steel framed	R-13	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-4.2 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-19	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-7.5 for 12 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.56	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2, EL3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4, EL5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2, EL3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4, EL5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 1 Recommendation Table for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.5 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		Ground-source heat pump (GSHP) (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	System type not recommended	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency		HV3, HV7–8, HV10, HV25	
		Gas boiler		HV3, HV7, HV10, HV26	
		Economizer		HV13	
		Ventilation		HV9, HV11–12, HV14	
		Pressure drop		HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	80% E_c	HV5, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	80% E_c	HV6–7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × Volume	WH1–5	
		Pipe insulation (*d* < 1.5 in./*d* ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the applicable version of ASHRAE Standard 90.1 or the local code requirements.

Zone 2

Alabama

Baldwin
Mobile

Arizona

La Paz
Maricopa
Pima
Pinal
Yuma

California

Imperial

Florida

Alachua
Baker
Bay
Bradford
Brevard
Calhoun
Charlotte
Citrus
Clay
Collier
Columbia
DeSoto
Dixie
Duval
Escambia
Flagler
Franklin
Gadsden
Gilchrist
Glades
Gulf
Hamilton
Hardee
Hendry
Hernando
Highlands
Hillsborough
Holmes
Indian River
Jackson
Jefferson
Lafayette
Lake
Lee
Leon
Levy
Liberty
Madison
Manatee
Marion
Martin
Nassau
Okaloosa
Okeechobee
Orange
Osceola
Palm Beach
Pasco
Pinellas
Polk
Putnam
Santa Rosa
Sarasota
Seminole
St. Johns
St. Lucie
Sumter
Suwannee
Taylor
Union
Volusia
Wakulla
Walton
Washington

Georgia

Appling
Atkinson
Bacon
Baker
Berrien
Brantley
Brooks
Bryan
Camden
Charlton
Chatham
Clinch
Colquitt
Cook
Decatur
Echols
Effingham
Evans
Glynn
Grady
Jeff Davis
Lanier
Liberty
Long
Lowndes
McIntosh
Miller
Mitchell
Pierce
Seminole
Tattnall
Thomas
Toombs
Ware
Wayne

Lousiana

Acadia
Allen
Ascension
Assumption
Avoyelles
Beauregard
Calcasieu
Cameron
East Baton Rouge
East Feliciana
Evangeline
Iberia
Iberville
Jefferson
Jefferson Davis
Lafayette
Lafourche
Livingston
Orleans
Plaquemines
Pointe Coupee
Rapides
St. Bernard
St. Charles
St. Helena
St. James
St. John the Baptist
St. Landry
St. Martin
St. Mary
St. Tammany
Tangipahoa
Terrebonne
Vermilion
Washington
West Baton Rouge
West Feliciana

Mississippi

Hancock
Harrison
Jackson
Pearl River
Stone

Texas

Anderson
Angelina
Aransas
Atascosa
Austin
Bandera
Bastrop
Bee
Bell
Bexar
Bosque
Brazoria
Brazos
Brooks
Burleson
Caldwell
Calhoun
Cameron
Chambers
Cherokee
Colorado
Comal
Coryell
DeWitt
Dimmit
Duval
Edwards
Falls
Fayette
Fort Bend
Freestone
Frio
Galveston
Goliad
Gonzales
Grimes
Guadalupe
Hardin
Harris
Hays
Hidalgo
Hill
Houston
Jackson
Jasper
Jefferson
Jim Hogg
Jim Wells
Karnes
Kenedy
Kinney
Kleberg
La Salle
Lavaca
Lee
Leon
Liberty
Limestone
Live Oak
Madison
Matagorda
Maverick
McLennan
McMullen
Medina
Milam
Montgomery
Newton
Nueces
Orange
Polk
Real
Refugio
Robertson
San Jacinto
San Patricio
Starr
Travis
Trinity
Tyler
Uvalde
Val Verde
Victoria
Walker
Waller
Washington
Webb
Wharton
Willacy
Williamson
Wilson
Zapata
Zavala

Climate Zone 2 Recommendation Table for K-12 Schools

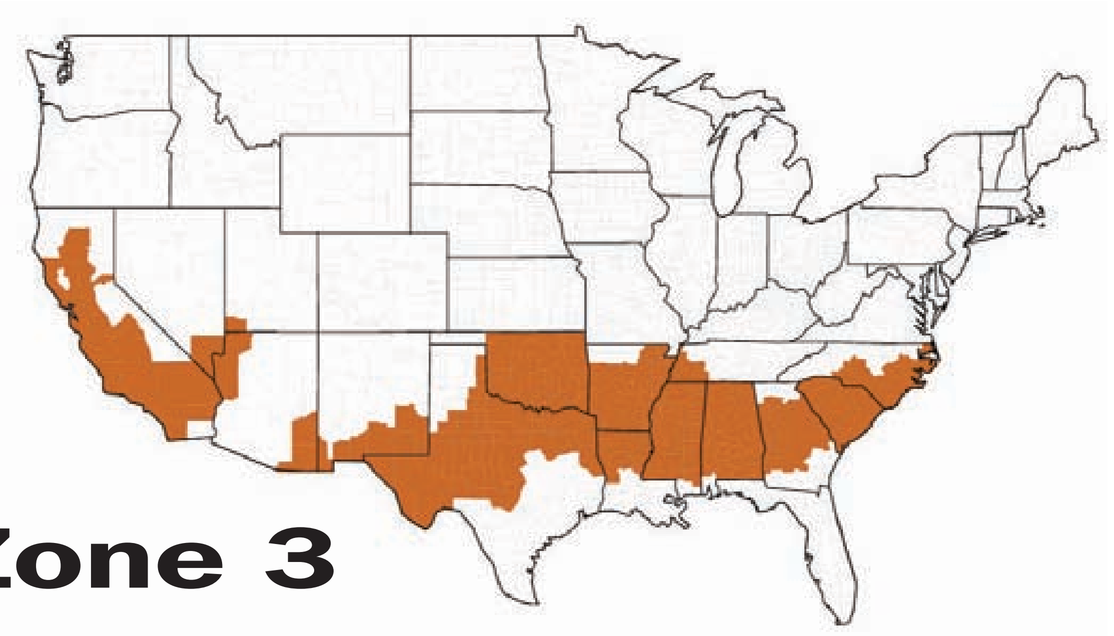
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1, EN2	
		Attic and other	R-38	EN3–4, EN15–16, EN18	
		Metal building	R-13 + R-13	EN3, EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-7.6 c.i.	EN5, EN15, EN18	
		Steel framed	R-13	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-6.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-19	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-7.5 for 12 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.45	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2, EL 3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 2 Recommendation Table for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.5 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, V10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System		A (humid) zones: System not recommended; B (dry) zones:		
		Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	No recommendation	HV3, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV3, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_20	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	80% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	80% E_c	HV5, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	80% E_c	HV6–7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the applicable version of ASHRAE Standard 90.1 or the local code requirements.



Zone 3

Alabama
All counties except::
Baldwin
Mobile

Arizona
Cochise
Graham
Greenlee
Mohave
Santa Cruz

Arkansas
All counties except:
Baxter
Benton
Boone
Carroll
Fulton
Izard
Madison
Marion
Newton
Searcy
Stone
Washington

California
All counties except:
Alpine
Amador
Calaveras
Del Norte
El Dorado
Humboldt
Imperial
Inyo
Lake
Lassen
Mariposa
Modoc
Mono
Nevada
Plumas
Sierra
Siskiyou
Trinity
Tuolumne

Georgia
All counties except:
Appling
Atkinson
Bacon
Baker
Banks
Berrien
Brantley
Brooks
Bryan
Catoosa
Camden
Charlton
Chatham
Chattooga
Clinch
Colquitt
Cook
Dade
Dawson
Decatur
Echols
Effingham
Evans
Fannin
Floyd
Franklin
Gilmer
Glynn
Gordon
Grady
Habersham
Hall
Jeff Davis
Lanier
Liberty
Long
Lowndes
Lumpkin
McIntosh
Miller
Mitchell
Murray
Pickens
Pierce
Rabun
Seminole
Stephens
Tattnall
Thomas
Toombs
Towns
Union
Walker
Ware
Wayne
White
Whitfield

Louisiana
Bienville
Bossier
Caddo
Caldwell
Catahoula
Claiborne
Concordia
De Soto
East Carroll
Franklin
Grant
Jackson
La Salle
Lincoln
Madison
Morehouse
Natchitoches
Ouachita
Red River
Richland
Sabine
Tensas
Union
Vernon
Webster
West Carroll
Winn

Mississippi
All counties except:
Hancock
Harrison
Jackson
Pearl River
Stone

New Mexico
Chaves
Dona Ana
Eddy
Hidalgo
Lea
Luna
Otero

Nevada
Clark

Texas
Andrews
Archer
Baylor
Blanco
Borden
Bowie
Brewster
Brown
Burnet
Callahan
Camp
Cass
Childress
Clay
Coke
Coleman
Collingsworth
Collin
Comanche
Concho
Cottle
Cooke
Crane
Crockett
Crosby
Culberson
Dallas
Dawson
Delta
Denton
Dickens
Eastland
Ector
El Paso
Ellis
Erath
Fannin
Fisher
Foard
Franklin
Gaines
Garza
Gillespie
Glasscock
Grayson
Gregg
Hall
Hamilton
Hardeman
Harrison
Haskell
Hemphill
Henderson
Hood
Hopkins
Howard
Hudspeth
Hunt
Irion
Jack
Jeff Davis
Johnson
Jones
Kaufman
Kendall
Kent
Kerr
Kimble
King
Knox
Lamar
Lampasas
Llana
Loving
Lubbock
Lynn
Marion
Martin
Mason
McCulloch
Menard
Midland
Mills
Mitchell
Montague
Morris
Motley
Nacogdoches
Navarro
Nolan
Palo Pinto
Panola
Parker
Pecos
Presidio
Rains
Reagan
Reeves
Red River
Rockwall
Runnels
Rusk
Sabine
San Augustine
San Saba
Schleicher
Scurry
Shackelford
Shelby
Smith
Somervell
Stephens
Sterling
Stonewall
Sutton
Tarrant
Taylor
Terrell
Terry
Throckmorton
Titus
Tom Green
Upshur
Upton
Van Zandt
Ward
Wheeler
Wichita
Wilbarger
Winkler
Wise
Wood
Young

Utah
Washington

North Carolina
Anson
Beaufort
Bladen
Brunswick
Cabarrus
Camden
Careret
Chowan
Columbus
Craven
Cumberland
Currituck
Dare
Davidson
Duplin
Edgecombe
Gaston
Greene
Hoke
Hyde
Johnston
Jones
Lenoir
Martin
Mecklenburg
Montgomery
Moore
New Hanover
Onslow
Pamlico
Pasquotank
Pender
Perquimans
Pitt
Rnadolph
Richmond
Robeson
Rowan
Sampson
Scotland
Stanly
Yrrell
Union
Washington
Wayne
Wilson

Oklahoma
All counties except:
Beaver
Cimarron
Texas

South Carolina
All counties

Tennessee
Chester
Crockett
Dyer
Fayette
Hardemon
Hardin
Haywood
Henderson
Lake
Lauderdale
Madison
McNairy
Shelby
Tipton

Climate Zone 3 Recommendations for K-12 Schools

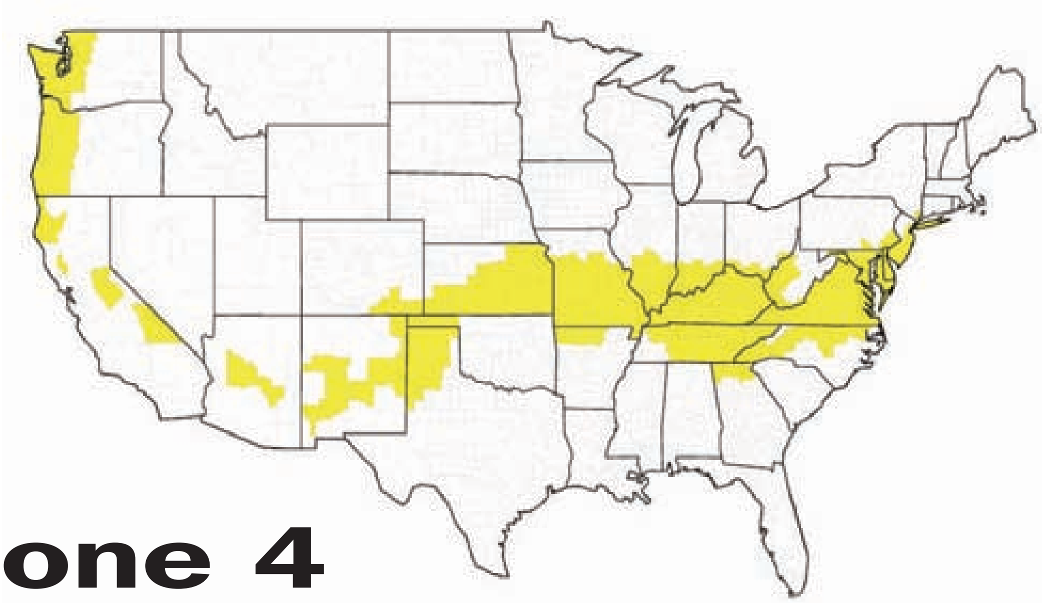
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-13	EN3–4, EN15, EN18	
		SRI	0.78	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-7.6 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-3.8 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-16	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-8.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-19	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-10 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-1.45	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.45	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.25	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10% Only skylights: 2%–4%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto-off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Non-Daylighted Option	LPD	0.9 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135) and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 3 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER/11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System		A (Humid) Zones: System not recommended B (Dry) and C (Marine) Zones: (below)		
		Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_20	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99–0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 4

Arizona
Gila
Yavapai

Arkansas
Baxter
Benton
Boone
Carroll
Fulton
Izard
Madison
Marion
Newton
Searcy
Stone
Washington

California
Amador
Calaveras
Del Norte
El Dorado
Humboldt
Inyo
Lake
Mariposa
Trinity
Tuolumne

Colorado
Baca
Las Animas
Otero

Delaware
All counties

District of Columbia

Georgia
Banks
Catoosa
Chattooga
Dade
Dawson
Fannin
Floyd
Franklin
Gilmer
Gordon
Habersham
Hall
Lumpkin
Murray
Pickens
Rabun
Stephens
Towns
Union
Walker
White
Whitfield

Illinois
Alexander
Bond
Brown
Christian
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jasper
Jefferson
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saline
Shelby
St. Claire
Union
Wabash
Washington
Wayne
White
Williamson

Indiana
Clark
Crawford
Daviess
Dearborn
Dubois
Floyd
Gibson
Greene
Harrison
Jackson
Jefferson
Jennings
Knox
Lawrence
Martin
Monroe
Ohio
Orange
Perry
Pike
Posey
Ripley
Scott
Spencer
Sullivan
Switzerland
Vanderburgh
Warrick
Washington

Kansas
All counties except:
Cheyenne
Cloud
Decatur
Ellis
Gove
Graham
Greeley
Hamilton
Jewell
Lane
Logan
Mitchell
Ness
Norton
Osborne
Phillips
Rawlins
Republic
Rooks
Scott
Sheridan
Sherman
Smith
Thomas
Trego
Wallace
Wichita

Kentucky
All counties

Maryland
All counties except:
Garrett

Missouri
All counties except:
Adair
Andrew
Atchison
Buchanan
Caldwell
Chariton
Clark
Clinton
Daviess
DeKalb
Gentry
Grundy
Harrison
Holt
Knox
Lewis
Linn
Livingston
Macon
Marion
Mercer
Nodaway
Pike
Putnam
Ralls
Schuyler
Scotland
Shelby
Sullivan
Worth

New Jersey
All counties except:
Bergen
Hunterdon
Mercer
Morris
Passaic
Somerset
Sussex
Warren

New Mexico
Bernalillo
Cibola
Curry
DeBaca
Grant
Guadalupe
Lincoln
Quay
Roosevelt
Sierra
Socorro
Union
Valencia

New York
Bronx
Kings
Nassau
New York
Queens
Richmond
Suffolk
Westchester

North Carolina
Alamance
Alexander
Bertie
Buncombe
Burke
Caldwell
Caswell
Catawba
Chatham
Cherokee
Clay
Cleveland
Davie
Durham
Forsyth
Franklin
Gates
Graham
Granville
Guilford
Halifax
Harnett
Haywood
Henderson
Hertford
Iredell
Jackson
Lee
Lincoln
Macon
Madison
McDowell
Nash
Northampton
Orange
Person
Polk
Rockingham
Rutherford
Stokes
Surry
Swain
Transylvania
Vance
Wake
Warren
Wilkes
Yadkin

Ohio
Adams
Brown
Clermont
Gallia
Hamilton
Lawrence
Pike
Scioto
Washington

Oklahoma
Beaver
Cimarron
Texas

Oregon
Benton
Clackamas
Clatsop
Columbia
Coos
Curry
Douglas
Jackson
Josephine
Lane
Lincoln
Linn
Marion
Multnomah
Polk
Tillamook
Washington
Yamhill

Pennsylvania
Bucks
Chester
Delaware
Montgomery
Philadelphia
York

Tennessee
All counties except:
Chester
Crockett
Dyer
Fayette
Hardeman
Hardin
Haywood
Henderson
Lake
Lauderdale
Madison
McNairy
Shelby
Tipton

Texas
Armstrong
Bailey
Briscoe
Carson
Castro
Cochran
Dallam
Deaf Smith
Donley
Floyd
Gray
Hale
Hansford
Hartley
Hockley
Hutchinson
Lamb
Lipscomb
Moore
Ochiltree
Oldham
Parmer
Potter
Randall
Roberts
Sherman
Swisher
Yoakum

Virginia
All counties

Washington
Clallam
Clark
Cowlitz
Grays Harbor
Island
Jefferson
King
Kitsap
Lewis
Mason
Pacific
Pierce
San Juan
Skagit
Snohomish
Thurston
Wahkiakum
Whatcom

West Virginia
Berkeley
Boone
Braxton
Cabell
Calhoun
Clay
Gilmer
Jackson
Jefferson
Kanawha
Lincoln
Logan
Mason
McDowell
Mercer
Mingo
Monroe
Morgan
Pleasants
Putnam
Ritchie
Roane
Tyler
Wayne
Wirt
Wood
Wyoming

Climate Zone 4 Recommendations for K-12 Schools

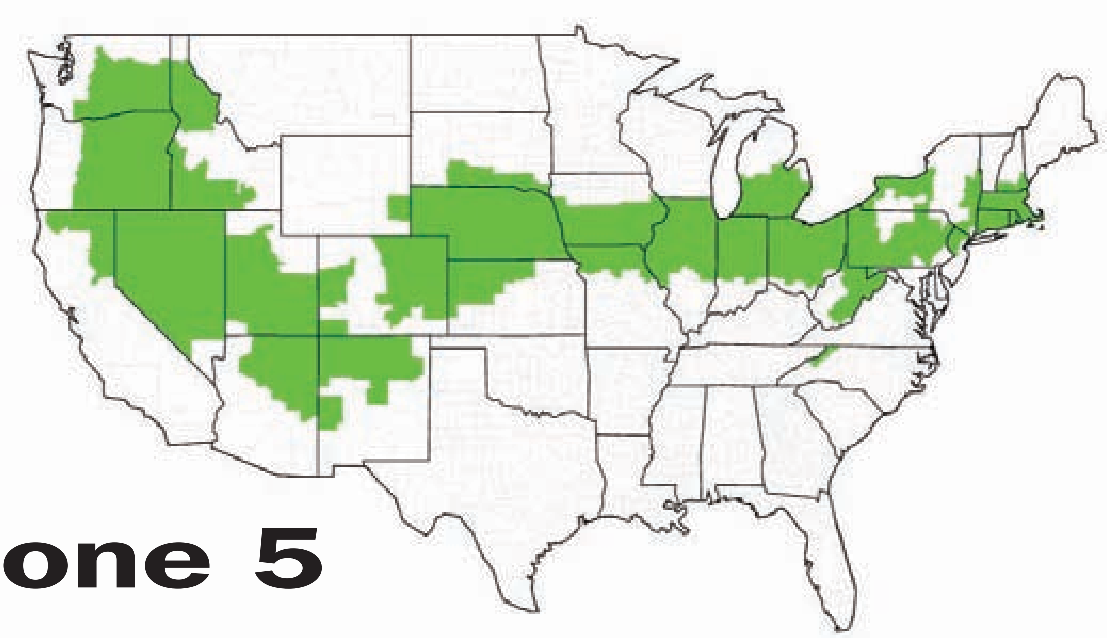
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-9.5 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13	EN7, EN15, EN18	
		Metal building	R-19	EN7, EN15, EN18	
		Below-grade walls	Comply with Standard 90.1*	EN8, EN15, EN18	
	Floors	Mass	R-8.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC—0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted—South-facing roof monitors: 8%–11%; North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted—South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10% Only skylights—3%–4%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym, and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	0.9 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.3 EER		
		Air conditioner (≥135 and <240 kBtu/h)	11.0 EER		
		Air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 4 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER and 11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, V10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV3, HV7–8, V10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.6 EER and 11.2 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	10.0 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. /d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 5

Arizona
Apache
Coconino
Navajo

California
Lassen
Modoc
Nevada
Plumas
Sierra
Siskiyou

Colorado
Adams
Arapahoe
Bent
Boulder
Cheyenne
Crowley
Delta
Denver
Douglas
Elbert
El Paso
Fremont
Garfield
Gilpin
Huerfano
Jefferson
Kiowa
Kit Carson
La Plata
Larimer
Lincoln
Logan
Mesa
Montezuma
Montrose
Morgan
Phillips
Prowers
Pueblo
Sedgwick
Teller
Washington
Weld
Yuma

Connecticut
All counties

Idaho
Ada
Benewah
Canyon
Cassia
Clearwater
Elmore
Gem
Gooding
Idaho
Jerome
Kootenai
Latah
Lewis
Lincoln
Minidoka
Nez Perce
Owyhee
Payette
Power
Shoshone
Twin Falls
Washington

Illinois
All counties except:
Alexander
Bond
Brown
Christian
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jasper
Jefferson
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saline
Shelby
St. Clair
Union
Wabash
Washington
Wayne
White
Williamson

Indiana
All counties except:
Clark
Crawford
Daviess
Dearborn
Dubois
Floyd
Gibson
Greene
Harrison
Jackson
Jefferson
Jennings
Knox
Lawrence
Martin
Monroe
Ohio
Orange
Perry
Pike
Posey
Ripley
Scott
Spencer
Sullivan
Switzerland
Vanderburgh
Warrick
Washington

Iowa
All counties except:
Allamakee
Black Hawk
Bremer
Buchanan
Buena Vista
Butler
Calhoun
Cerro Gordo
Cherokee
Chickasaw
Clay
Clayton
Delaware
Dickinson
Emmet
Fayette
Floyd
Franklin
Grundy
Hamilton
Hancock
Hardin
Howard
Humboldt
Ida
Kossuth
Lyon
Mitchell
O'Brien
Osceola
Palo Alto
Plymouth
Pocahontas
Sac
Sioux
Webster
Winnebago
Winneshiek
Worth
Wright

Kansas
Cheyenne
Cloud
Decatur
Ellis
Gove
Graham
Greeley
Hamilton
Jewell
Lane
Logan
Mitchell
Ness
Norton
Osborne
Phillips
Rawlins
Republic
Rooks
Scott
Sheridan
Sherman
Smith
Thomas
Trego
Wallace
Wichita

Maryland
Garrett

Massachusetts
All counties

Michigan
Allegan
Barry
Bay
Berrien
Branch
Calhoun
Cass
Clinton
Eaton
Genesee
Gratiot
Hillsdale
Ingham
Ionia
Jackson
Kalamazoo
Kent
Lapeer
Lenawee
Livingston
Macomb
Midland
Monroe
Montcalm
Muskegon
Oakland
Ottawa
Saginaw
Shiawassee
St. Clair
St. Joseph
Tuscola
Van Buren
Washtenaw
Wayne

Missouri
Adair
Andrew
Atchison
Buchanan
Caldwell
Chariton
Clark
Clinton
Daviess
DeKalb
Gentry
Grundy
Harrison
Holt
Knox
Lewis
Linn
Livingston
Macon
Marion
Mercer
Nodaway
Pike
Putnam
Ralls
Schuyler
Scotland
Shelby
Sullivan
Worth

Nebraska
All counties

Nevada
All counties except:
Clark

New Hampshire
Cheshire
Hillsborough
Rockingham
Strafford

New Jersey
Bergen
Hunterdon
Mercer
Morris
Passaic
Somerset
Sussex
Warren

New Mexico
Catron
Colfax
Harding
Los Alamos
McKinley
Mora
Rio Arriba
Sandoval
San Juan
San Miguel
Santa Fe
Taos
Torrance

New York
Albany
Cayuga
Chautauqua
Chemung
Columbia
Cortland
Dutchess
Erie
Genesee
Greene
Livingston
Monroe
Niagara
Onondaga
Ontario
Orange
Orleans
Oswego
Putnam
Rensselaer
Rockland
Saratoga
Schenectady
Seneca
Tioga
Washington
Wayne
Yates

North Carolina
Alleghany
Ashe
Avery
Mitchell
Watauga
Yancey

Ohio
All counties except:
Adams
Brown
Clermont
Gallia
Hamilton
Lawrence
Pike
Scioto
Washington

Oregon
Baker
Crook
Deschutes
Gilliam
Grant
Harney
Hood River
Jefferson
Klamath
Lake
Malheur
Morrow
Sherman
Umatilla
Union
Wallowa
Wasco
Wheeler

Pennsylvania
All counties except:
Bucks
Cameron
Chester
Clearfield
Delaware
Elk
McKean
Montgomery
Philadelphia
Potter
Susquehanna
Tioga
Wayne
York

Rhode Island
All counties

South Dakota
Bennett
Bon Homme
Charles Mix
Clay
Douglas
Gregory
Hutchinson
Jackson
Mellette
Todd
Tripp
Union
Yankton

Utah
All counties except:
Box Elder
Cache
Carbon
Daggett
Duchesne
Morgan
Rich
Summit
Uintah
Wasatch
Washington

Washington
Adams
Asotin
Benton
Chelan
Columbia
Douglas
Franklin
Garfield
Grant
Kittitas
Klickitat
Lincoln
Skamania
Spokane
Walla Walla
Whitman
Yakima

Wyoming
Goshen
Platte

West Virginia
Barbour
Brooke
Doddridge
Fayette
Grant
Greenbrier
Hampshire
Hancock
Hardy
Harrison
Lewis
Marion
Marshall
Mineral
Monongalia
Nicholas
Ohio
Pendleton
Pocahontas
Preston
Raleigh
Randolph
Summers
Taylor
Tucker
Upshur
Webster
Wetzel

Climate Zone 5 Recommendations for K-12 Schools

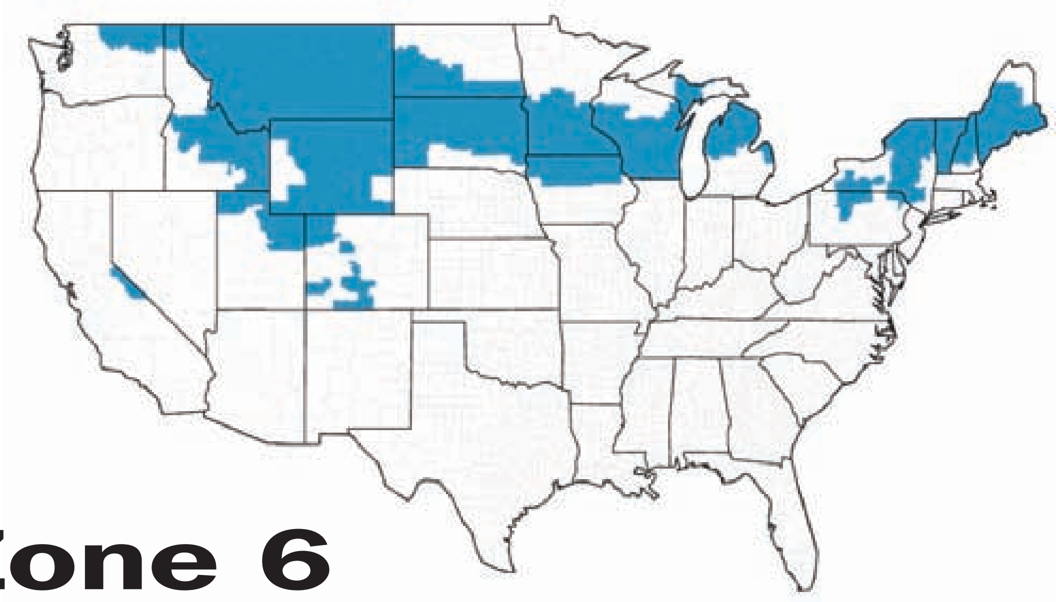
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-11.4 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-3.8 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-10.4 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	Comply with Standard 90.1*	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13% Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	11.0 EER		
		Air conditioner (≥135 and <240 kBtu/h)	10.8 EER		
		Air conditioner (≥240 kBtu/h)	10.0 EER and 10.4 IPLV		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 5 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	10.6 EER/3.2 COP	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	10.1 EER and 11.0 IPLV/3.1 COP		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86F Heating: 4.5 COP at 68F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86F Heating: 4.2 COP at 68F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	10.0 EER and 10.4 IPLV	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	85% E_c	HV6–7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in. /d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 6

California
- Alpine
- Mono

Colorado
- Alamosa
- Archuleta
- Chaffee
- Conejos
- Costilla
- Custer
- Dolores
- Eagle
- Moffat
- Ouray
- Rio Blanco
- Saguache
- San Miguel

Idaho
- Adams
- Bannock
- Bear Lake
- Bingham
- Blaine
- Boise
- Bonner
- Bonneville
- Boundary
- Butte
- Camas
- Caribou
- Clark
- Custer
- Franklin
- Fremont
- Jefferson
- Lemhi
- Madison
- Oneida
- Teton
- Valley

Iowa
- Allamakee
- Black Hawk
- Bremer
- Buchanan
- Buena Vista
- Butler
- Calhoun
- Cerro Gordo
- Cherokee
- Chickasaw
- Clay
- Clayton

Delaware
- Dickinson
- Emmet
- Fayette
- Floyd
- Franklin
- Grundy
- Hamilton
- Hancock
- Hardin
- Howard
- Humboldt
- Ida
- Kossuth
- Lyon
- Mitchell
- O'Brien
- Osceola
- Palo Alto
- Plymouth
- Pocahontas
- Sac
- Sioux
- Webster
- Winnebago
- Winneshiek
- Worth
- Wright

Maine

All counties except:
- Aroostook

Michigan
- Alcona
- Alger
- Alpena
- Antrim
- Arenac
- Benzie
- Charlevoix
- Cheboygan
- Clare
- Crawford
- Delta
- Dickinson
- Emmet
- Gladwin
- Grand Traverse
- Huron
- Iosco
- Isabella
- Kalkaska
- Lake
- Leelanau
- Manistee
- Marquette
- Mason
- Mecosta
- Menominee
- Missaukee
- Montmorency
- Newaygo
- Oceana
- Ogemaw
- Osceola
- Oscoda
- Otsego
- Presque Isle
- Roscommon
- Sanilac
- Wexford

Minnesota
- Anoka
- Benton
- Big Stone
- Blue Earth
- Brown
- Carver
- Chippewa
- Chisago
- Cottonwood
- Dakota
- Dodge
- Douglas
- Faribault
- Fillmore
- Freeborn
- Goodhue
- Hennepin
- Houston
- Isanti
- Jackson
- Kandiyohi
- Lac qui Parle
- Le Sueur
- Lincoln
- Lyon
- Martin
- McLeod
- Meeker
- Morrison
- Mower
- Murray
- Nicollet
- Nobles
- Olmsted
- Pipestone
- Pope
- Ramsey
- Redwood
- Renville
- Rice
- Rock
- Scott
- Sherburne
- Sibley
- Stearns
- Steele
- Stevens
- Swift
- Todd
- Traverse
- Wabasha
- Waseca
- Washington
- Watonwan
- Winona
- Wright
- Yellow Medicine

Montana

All counties

New Hampshire
- Belknap
- Carroll
- Coos
- Grafton
- Merrimack
- Sullivan

New York
- Allegany
- Broome
- Cattaraugus
- Chenango
- Clinton
- Delaware
- Essex
- Franklin
- Fulton
- Hamilton
- Herkimer
- Jefferson
- Lewis
- Madison
- Montgomery
- Oneida
- Otsego
- Schoharie
- Schuyler
- Steuben
- St. Lawrence
- Sullivan
- Tompkins
- Ulster
- Warren

Wyoming

North Dakota
- Adams
- Billings
- Bowman
- Burleigh
- Dickey
- Dunn
- Emmons
- Golden Valley
- Grant
- Hettinger
- LaMoure
- Logan
- McIntosh
- McKenzie
- Mercer
- Morton
- Oliver
- Ransom
- Richland
- Sargent
- Sioux
- Slope
- Stark

Pennsylvania
- Cameron
- Clearfield
- Elk
- McKean
- Potter
- Susquehanna
- Tioga
- Wayne

South Dakota

All counties except:
- Bennett
- Bon Homme
- Charles Mix
- Clay
- Douglas
- Gregory
- Hutchinson
- Jackson
- Mellette
- Todd
- Tripp
- Union
- Yankton

Utah
- Box Elder
- Cache
- Carbon
- Daggett
- Duchesne
- Morgan
- Rich
- Summit
- Uintah
- Wasatch

Vermont

All counties

Washington
- Ferry
- Okanogan
- Pend Oreille
- Stevens

Wisconsin

All counties except:
- Ashland
- Bayfield
- Burnett
- Douglas
- Florence
- Forest
- Iron
- Langlade
- Lincoln
- Oneida
- Price
- Sawyer
- Taylor
- Vilas
- Washburn

Wyoming

All counties except:
- Goshen
- Platte
- Lincoln
- Sublette
- Teton

Climate Zone 6 Recommendations for K-12 Schools

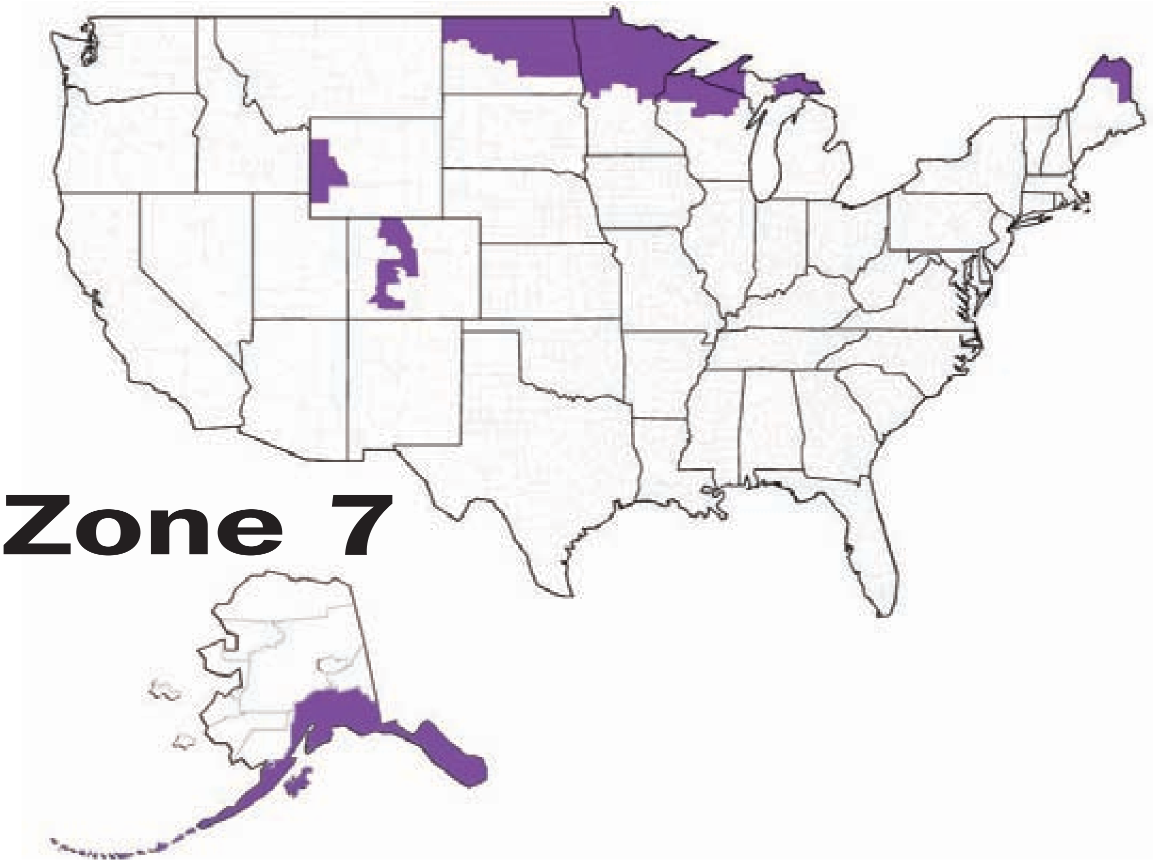
	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-38	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft²·°F)	R-13.3 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-7.5 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-13.3 c.i.	EN9, EN15, EN18	
		Steel framed	R-30	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-10 for 24 in.	EN11, EN17–18	
		Heated	R-15 for 24 in.	EN12, EN17–18	
	Doors	Swinging	U-0.70	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% max	EN20	
		Thermal transmittance—all types and orientations	U-0.42	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.40	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8%, Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors: 7%–10%	DL1–19, DL36, DL37	
		LPD	1.2 W/ft² maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft²	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 6 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6–8, HV10, HV25	
		Gas boiler	85% E_c	HV6–7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (*d* < 1.5 in. /*d* ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.



Zone 7

Alaska
- Aleutians East
- Aleutians West (CA)
- Anchorage
- Angoon (CA)
- Bristol Bay
- Denali
- Haines
- Juneau
- Kenai Peninsula
- Ketchikan (CA)
- Ketchikan Gateway
- Kodiak Island
- Lake and Peninsula
- Matanuska-Susitna
- Prince of Wales-Outer
- Sitka
- Skagway-Hoonah-
- Valdez-Cordova (CA)
- Wrangell-Petersburg (CA)
- Yakutat

Colorado
- Clear Creek
- Grand
- Gunnison
- Hinsdale
- Jackson
- Lake
- Mineral
- Park
- Pitkin
- Rio Grande
- Routt
- San Juan
- Summit

Maine
- Aroostook

Michigan
- Baraga
- Chippewa
- Gogebic
- Houghton
- Iron
- Keweenaw
- Luce
- Mackinac
- Ontonagon
- Schoolcraft

Minnesota
- Aitkin
- Becker
- Beltrami
- Carlton
- Cass
- Clay
- Clearwater
- Cook
- Crow Wing
- Grant
- Hubbard
- Itasca
- Kanabec
- Kittson
- Koochiching
- Lake
- Lake of the Woods
- Mahnomen
- Marsh all
- Mille Lacs
- Norman
- Otter Tail
- Pennington
- Pine
- Polk
- Red Lake
- Roseau
- St. Louis
- Wadena
- Wilkin

North Dakota
- Barnes
- Benson
- Bottineau
- Burke
- Cass
- Cavalier
- Divide
- Eddy
- Foster
- Grand Forks
- Griggs
- Kidder
- McHenry
- McLean
- Mountrail
- Nelson
- Pembina
- Pierce
- Ramsey
- Renville
- Rolette
- Sheridan
- Steele
- Stutsman
- Towner
- Traill
- Walsh
- Ward
- Wells
- Williams

Wisconsin
- Ashland
- Bayfield
- Burnett
- Douglas
- Florence
- Forest
- Iron
- Langlade
- Lincoln
- Oneida
- Price
- Sawyer
- Taylor
- Vilas
- Washburn

Wyoming
- Lincoln
- Sublette
- Teton

Climate Zone 7 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-60	EN3, EN15–16, EN18	
		Metal building	R-13 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2·°F)	R-15.2 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-7.5 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-7.5 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-5.6 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-7.5 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-12.5 c.i.	EN9, EN15, EN18	
		Steel framed	R-38	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-15 for 24 in.	EN11, EN17–18	
		Heated	R-15 for full slab	EN12, EN17–18	
	Doors	Swinging	U-0.50	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.33	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.45	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft, 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8% Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–L37	
		LPD	1.2 W/ft^2 maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft^2	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 7 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Vriable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, V10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8,HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-6	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (*d* < 1.5 in./*d* ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Alaska

Bethel (CA)

Dillingham (CA)

Fairbanks North Star

Nome (CA)

North Slope

Northwest Arctic

Southeast Fairbanks (CA)

Wade Hampton (CA)

Yukon-Koyukuk (CA)

Climate Zone 8 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
Envelope	Roofs	Insulation entirely above deck	R-25 c.i.	EN1–2	
		Attic and other	R-60	EN3, EN15–16, EN18	
		Metal building	R-19 + R-19	EN3–4, EN15, EN18	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2·°F)	R-15.2 c.i.	EN5, EN15, EN18	
		Steel framed	R-13 + R-21.6 c.i.	EN6, EN15, EN18	
		Wood framed and other	R-13 + R-10 c.i.	EN7, EN15, EN18	
		Metal building	R-19 + R-11.2 c.i.	EN7, EN15, EN18	
		Below-grade walls	R-15 c.i.	EN8, EN15, EN18	
	Floors	Mass	R-16.7 c.i.	EN9, EN15, EN18	
		Steel framed	R-38	EN10, EN15, EN18	
		Wood framed and other	R-30	EN10, EN15, EN18	
	Slabs	Unheated	R-20 for 24 in.	EN11, EN17–18	
		Heated	R-15 for full slab	EN12, EN17–18	
	Doors	Swinging	U-0.50	EN13, EN18	
		Nonswinging	U-0.50	EN14, EN18	
	Vertical Fenestration	Total fenestration to gross wall area ratio	35% Max	EN20	
		Thermal transmittance—all types and orientations	U-0.33	EN19, EN24, EN28	
		SHGC—all types and orientations	SHGC-0.45	EN19, EN24, EN28	
		Exterior sun control (S, E, W only)	Projection factor > 0.5	EN21, EN23, EN26	
Lighting	Interior Finishes	Interior room surface average reflectance	70%+ on ceilings and walls above 7 ft 50%+ on walls below 7 ft	DL14, EL1	
	Interior Lighting—Daylighted Option	Classroom daylighting (daylighting fenestration to floor area ratio)	Toplighted— South-facing roof monitors: 8%–11% North-facing roof monitors: 12%–15%	DL1–19, DL28–35	
			Sidelighted— South-facing: 8%–11% North-facing: 15%–20%	DL1–19, DL20–27	
			Combined toplighted and sidelighted— South-facing sidelighted: 6%–8%, Toplighted: 2%–3% North-facing sidelighted: 9%–13%, Toplighted: 3%–5%	DL1–19, DL20–35	
		Gym toplighting (daylighting fenestration to floor area ratio)	South-facing roof monitors: 5%–8% North-facing roof monitors 7%–10%	DL1–19, DL36–37	
		LPD	1.2 W/ft^2 maximum	EL9–16	
		Light source system efficacy (linear fluorescent)	75 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim all fixtures in classrooms and gym and other fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	DL16	
	Interior Lighting—Nondaylighted Option	LPD	1.1 W/ft^2	EL9–16	
		Light source system efficacy (linear fluorescent)	85 mean lm/W minimum	EL2–3, EL5	
		Light source system efficacy (all other sources)	50 mean lm/W minimum	EL4–5	
		Occupancy controls—general	Manual on, auto off all zones	EL6, EL8, DL16	
		Dimming controls daylight harvesting	Dim fixtures within 15 ft of sidelighting edge, and within 10 ft of toplighting edge	DL16	
HVAC	Packaged DX Rooftops (or DX Split Systems)	Air conditioner (<65 kBtu/h)	13.0 SEER	HV1, HV7–8, HV10	
		Air conditioner (≥65 and <135 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥135 and <240 kBtu/h)	Comply with Standard 90.1*		
		Air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*		
		Heat pump (<65 kBtu/h)	13.0 SEER/7.7 HPSF		

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Climate Zone 8 Recommendations for K-12 Schools

	Item	Component	Recommendation	How-To Tip	✓
HVAC	Packaged DX Rooftops (or DX Split Systems)	Heat pump (≥65 and <135 kBtu/h)	Comply with Standard 90.1*	HV1, HV7–8, HV10	
		Heat pump (≥135 kBtu/h)	Comply with Standard 90.1*		
		Gas furnace (<225 kBtu/h)	80% AFUE or E_t		
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	Constant volume: 1 hp/1000 cfm Variable volume: 1.3 hp/1000 cfm	HV19	
	WSHP System	Water-source heat pump (<65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.5 COP at 68°F	HV2, HV7–8, HV10	
		Water-source heat pump (≥65 kBtu/h)	Cooling: 12.0 EER at 86°F Heating: 4.2 COP at 68°F		
		GSHP (<65 kBtu/h)	Cooling: 14.1 EER at 77°F and 17.0 EER at 59°F Heating: 3.5 COP at 32°F and 4.0 COP at 50°F	HV2, HV7–8, HV10, AS4	
		GSHP (≥65 kBtu/h)	Cooling: 13.0 EER at 77°F and 16.0 EER at 59°F Heating: 3.1 COP at 32°F and 3.5 COP at 50°F		
		Gas boiler	85% E_c	HV2, HV7, HV10	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		WSHP duct pressure drop	Total ESP <0.2 in. H_2O	HV19	
	Unit Ventilator and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV3, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV3, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Fan Coil and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV4, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV4, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV4, HV7, HV10, HV26	
		Economizer	Comply with Standard 90.1*	HV13	
		Ventilation	DOAS with either energy recovery or demand control	HV9, HV11–12, HV14	
		Pressure drop	Total ESP < 0.2 in. H_2O	HV19	
	Packaged Rooftop VAV System	Rooftop air conditioner (≥240 kBtu/h)	Comply with Standard 90.1*	HV5, HV7–8, HV10	
		Gas furnace (≥225 kBtu/h)	80% E_c		
		Gas boiler	85% E_c	HV5, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11, HV12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	VAV and Chiller System	Air-cooled chiller efficiency	9.6 EER and 11.5 IPLV	HV6, HV7–8, HV10, HV25	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV6, HV7–8, HV10, HV25	
		Gas boiler	85% E_c	HV6, HV7, HV10, HV26	
		Economizer	>54 kBtu/h	HV13	
		Ventilation	Energy recovery or demand control	HV9, HV11–12, HV14	
		Fans	1.3 hp/1000 cfm	HV19	
	Ducts and Dampers	Outdoor air damper	Motorized	HV11, HV13	
		Friction rate	0.08 in. w.c./100 ft	HV16	
		Sealing	Seal Class B	HV18	
		Location	Interior only	HV16	
		Insulation level	R-8	HV17	
SWH	SWH	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
		Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
		Electric (storage or instantaneous)	EF > 0.99 – 0.0012 × volume	WH1–5	
		Pipe insulation (d < 1.5 in./d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

* **Note:** If the table contains "Comply with Standard 90.1" for a component, the user must meet the more stringent of either the most current version of ASHRAE Standard 90.1 or the local code requirements.

Case Studies

4

The case studies in this chapter illustrate techniques and methods that are discussed in this Guide. They are presented in order of climate zone, from warmest to coldest. Energy numbers are provided to benchmark these buildings against future buildings; however, all these case studies predate the publication of the Guide, and they were not developed using the recommendations in Chapter 3. These schools may or may not have achieved the 30% level if they had been constructed entirely according to the recommendations in this Guide. You are encouraged to view additional case studies and submit your own at www.ashrae.org/aedg. Case studies provide motivation and examples for others to follow.

ZONE 1—WAIPAHU INTERMEDIATE SCHOOL

Waipahu, Hawaii

The Hawaii Department of Education piloted the Waipahu Intermediate School (WIS) cafeteria as a LEED project in educational facilities to support its commitment to conserve resources and provide better facilities. The 19,200 ft^2 cafeteria, opened for the 2006–2007 school year, is designed to serve 750 people at a time.

Daylighting features include shaded north- and south-facing clerestories and jalousies designed to bounce indirect daylight deep into the dining area. This reduces the electric lighting requirements by more than 55%. The roof was designed to create a thermal chimney for stack-effect ventilation, which, in addition to cross-ventilation, eliminates the need for ceiling fans and ductwork.

The State of Hawaii Department of Business, Economic Development, and Tourism Report, *Analyses of Economic, Environmental and Occupant Benefits of Sustainable Design*, and LEED Certification for State of Hawaii and Public School Facilities, included the development of two energy-use scenarios for the cafeteria example: a base case (built to code) and a green case (incorporating high-performance features). The green case resulted in a 16% energy reduction. The kitchen area in the cafeteria example was primarily designed with conventional methods, so its energy use is assumed to be the same for both cases.


Figure 4.1. Cafeteria building exterior views.

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Figure 4.2. Cafeteria interior view.

Table 4.1. Waipahu Intermediate School Cafeteria

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Lighting		
Lighting Systems Used	T-8s	EL2
Daylighting		
Window Design	Clerestories with overhangs	DL1–10
HVAC	Natural cooling and ventilation	EN22, HV32
SWH	High-efficiency boiler	WH1–6
System Controls		
Commissioning	Fully commissioned	HV23, CX1–13
Additional Savings		
Kitchen Equipment	High-efficiency gas equipment	AS2
Energy-Use Characteristics		
Baseline Electric Energy Use	14.0 kBtu/ft^2·yr	
Simulated Electric Energy Use	11.7 kBtu/ft^2·yr	

Photos and data are provided by the Hawaii Department of Business, Economic Development, and Tourism.

ZONE 2—DESERT EDGE HIGH SCHOOL

Goodyear, Arizona

Desert Edge High School, west of downtown Phoenix, was constructed in two phases for a total of 218,783 ft^2 and a student capacity of 1600. Phase II was certified LEED Silver in 2006. The total build cost of the school was \$21.3 million at an average of \$97/ft^2. Phase one was opened in time for the 2002–2003 school year, and phase two opened in time for the 2005–2006 school year. This climate zone 2 facility includes classrooms, administrative areas, a media center, a gymnasium, a 522-seat fine arts auditorium, a career technology area, and a student bookstore in the core. An in-school kiosk showcases many of the unique features of the high school through a virtual tour and the display of electricity, water, and carbon dioxide (CO_2) savings. The kiosk also displays real-time animations of the heating and cooling systems, an interactive building directory, bus routes and schedules, real-time weather conditions, and more.

Desert Edge is about 28% more energy efficient than other comparable high schools. The energy efficiency equates to roughly \$58,000 in cost savings per year. The school showcases high-performance building strategies and features for a hot/dry climate zone, including an improved building envelope, daylighting, demand-controlled ventilation, and high-efficiency water-cooled chillers with a water-side economizer. The masonry walls include R-19 cavity insulation, and R-30 insulation is used on the built-up metal deck roof. The windows are high performance, low-e dual-paned glass windows with a U-factor of 0.33. The lighting system takes advantage of daylighting and uses a low-lighting power density to reduce the amount of artificial lighting. Lighting power density is 1.09 W/ft^2 in classrooms and 1.04 W/ft^2 in the gymnasium. Daylighting controls and occupancy sensors further reduce lighting loads. Multiple light switches are used to allow the teachers and students to light only the occupied space when daylighting is not sufficient. A high-efficiency central cooling and heating system uses two centrifugal chillers with a water-side economizer cycle and plate-and-frame heat exchanger. The water-based cooling towers include a chiller bypass to take advantage of indirect evaporative cooling possible in the dry climate. Classrooms have CO_2 sensors that control outdoor air for the fan-coil units.

Figure 4.3. Building exterior with window shading.

Figure 4.4. Building exterior.

(a)

(b)

Figure 4.5. (a) Centrifugal chiller and (b) cooling tower.

Table 4.2. Desert Edge High School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Concrete block with R-19 insulation and R-30 built-up roof	EN5
Vertical Glazing	Low-e glass with a grey tint; assembled U-factor of 0.33	EN19–20
Lighting		
Lighting Systems Used	T-8 lighting in most of the school with a lighting power density of 1.09 W/ft^2 in classrooms, 1.04 W/ft^2 in the gym, and 1.27 W/ft^2 in the auditorium	EL1–2, EL9–12
Controls	Dual technology occupant sensors used in offices, administrative, and support areas; wall switch occupancy sensors are installed in small offices, storage, or other similar areas	EL6, EL8
Daylighting		
Window Design	Low-e with double glazing and a third pane for integral microblinds	DL1–4, DL9–12
Controls	Daylight sensors used in conjunction with motion sensors	DL13, DL17–18
HVAC		
Equipment	HVAC central cooling and heating use high-efficiency centrifugal chillers with a hydronic economizer cycle with plate and frame heat exchanger and variable-speed pumps	HV10
System Controls		
Measurement and Verification	DDC system with Web-based metering and feedback	
Temperature Control	Individual room controls	
CO_2 Sensors	Installed in each zone of the building to for demand controlled ventilation	
Energy-Use Characteristics	28% better than ASHRAE Standard 90.1-1999	

Photos and data are provided by Emc2 Group Architects Planners, Inc.

ZONE 3—HOMEWOOD MIDDLE SCHOOL

Homewood, Alabama

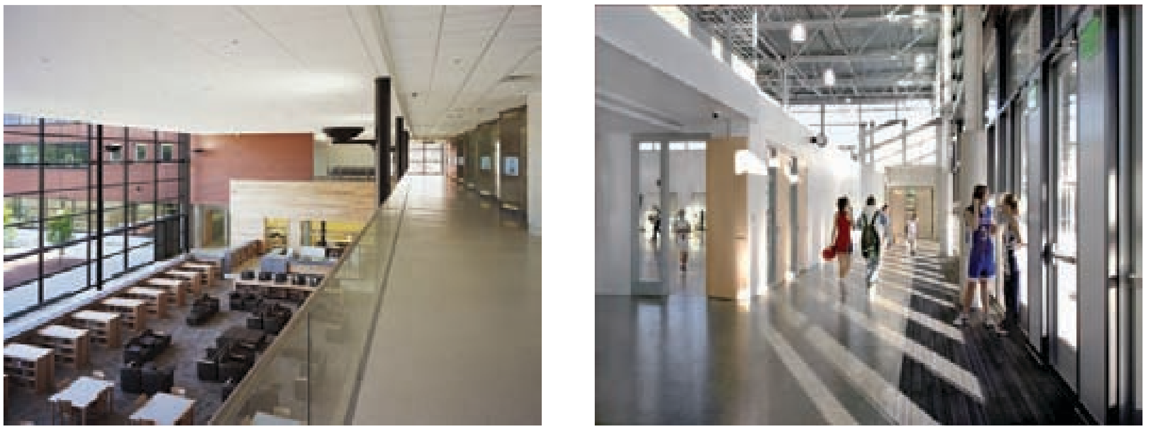
Homewood Middle School in climate zone 3 is a 190,000 ft^2 facility with a capacity of 1000 students. The school consists of a classroom wing, an administration wing, and an activity wing. The cost to build the school was $23 million, or $121/ft^2. Homewood opened in January 2005, replacing an old school on the same site that was originally built in 1955. When the time came to design the new building, the designers and school district worked together to create an energy-efficient, sustainable building. The result is a school that is 36% more energy efficient than ASHRAE Standard 90.1-1999.

Daylighting is is used throughout the building as one of the primary strategies to achieve energy-efficiency goals. Ninety-five percent of the school utilizes daylighting, and all classrooms in the school have exterior windows. Shading devices, such as overhangs, are used on the south side of the school to reduce solar heat gain and glare in the school. Light shelves are used to project light deeper into the school. Windows on the north side of the school are large to increase the amount of indirect daylight in the school. Electrical lighting is controlled by photo sensors and occupancy sensors to make use of available daylighting and reduce electricity usage. Additional strategies include the following:

- Mass walls are insulated with R-10 continuous insulation
- CO_2 sensors in the gym control the local HVAC system
- A 9.8 EER central chiller VAV HVAC system utilizes air-side economizers

Figure 4.6. Homewood Middle School.

Figure 4.7. Building exterior with light shelves.



(a) **(b)**

Figure 4.8. (a) Large north-side windows and (b) school corridor.

Table 4.3. Homewood Middle School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Mass walls R-10 c.i.	EN5
Lighting		
Controls	Occupancy sensors and photocell dimmable control	EL6, EL8
Daylighting		
Window Design	Daylighting in all classrooms, gym	DL1–4
HVAC		
Equipment	9.8 EER chiller, VAV	HV5
Cooling Tower	Air cooled	
System Controls		
Measurement and Verification	Yes	HV23
Energy Use Characteristics	36% savings over ASHRAE Standard 90.1-1999	
Measured Energy Cost	1.24 $/ft^2·yr	
Measured Energy Use	64.4 kBtu/ft^2·yr	
Years of Measured Data	2 years	

ZONE 4—KNIGHTDALE HIGH SCHOOL

Knightdale, North Carolina

Knightdale High School in climate zone 4 is part of the Wake County School District. The 281,000 ft^2 building was completed for the 2004–2005 school year at a project cost of $26.5 million, or about $95/$ft^2$. The school was built for 1600 students and includes classrooms, offices, public assembly areas, a cafeteria, a gymnasium, athletic fields, and restrooms. The Triangle "J" High Performance Guidelines Version 1.0 guided the design and construction of this building.

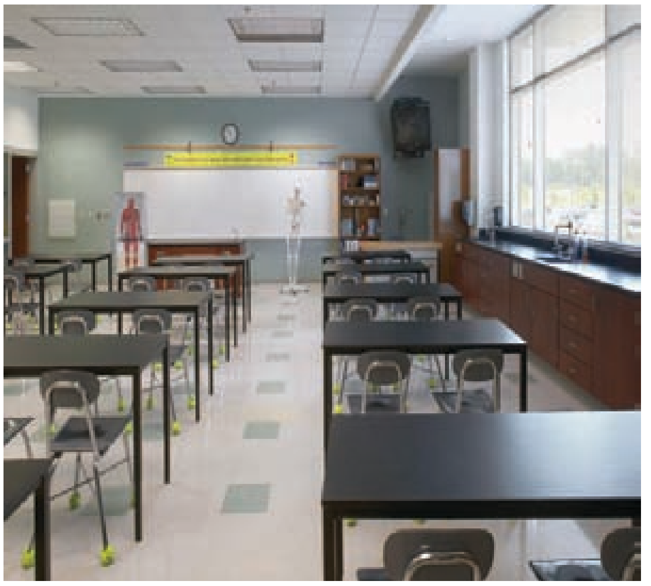
The building team committed to high-performance design from the beginning. The project was designed to use 58.7 kBtu/ft^2, and after three years it is operating at 54.4 kBtu/ft^2, annually.

Clerestories provide daylighting in the main entry, the dining commons, and the media center. Additional daylighting is provided by skylights in the dining area and gym corridor. The classrooms in the three-story wing feature large windows to provide daylighting, exterior shading devices on the south-facing windows to control direct sunlight and reduce solar heat gain, dimmable and independently controlled lighting to control daylighting, and multiswitching modes for general classroom lighting.

The building is heated and cooled with a four-pipe chilled- and hot-water system. Hot water is supplied by five high-efficiency condensing boilers, and the chilled water is supplied by standard-efficiency air-cooled chillers. Conditioned air is provided to the classrooms and administration areas with VAV AHUs through a VAV terminal box and hot-water reheat coil in each space. Relative humidity is monitored in the AHU return duct and controlled via AHU fan speed, cooling coils, and heating coils. The HVAC system is controlled through a DDC system.

Figure 4.9. Knightdale High School.

(a)



(b)

Figure 4.10. (a) Clerestory at main entrance and (b) classroom lighting system.

Table 4.4. Knightdale High School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	North-south	DL9
Opaque Components	Roof/ceiling R-26; walls R-16	EN3, EN7
Vertical Glazing	Door/window assemblies U = 0.81	EN13
Lighting		
Controls	Dimmable controls in classroom; separate general purpose lighting controls	EL2, EL8
Daylighting		
Window Design	Large windows in three-story section	DL1–DL4
	Exterior light shading on south-facing windows	DL12, DL20, DL22
	Clerestories and skylights in common areas	
HVAC		
Equipment	Standard chiller with variable-frequency drive pumps	HV25
Boilers	Condensing boilers	HV26
Natural Ventilation	VAV system with humidity-controlled cooling and reheat coils; air-handling units (AHUs) use variable-frequency drives and are outfitted with OA economizers for cooling with OA when possible	HV5–6
SWH	Natural gas-fired atmospheric water heater with storage tank, mixing valves and hot water recirculation pumps. SWH system is connected to a digital direct control system or scheduling of operation.	WH1–2
System Controls		
Ventilation	Direct digital control system; OA and CO_2 intake is monitored for each AHU	HV23
Additional Savings		
Exterior/Field/Parking Lot Lighting	The sports field lighting fixtures are provided with internal louvers and hood visors to reduce glare and light trespass off of school property.	EX1–2
Energy Use Characteristics		
Simulated Energy Use	58.7 kBtu/ft^2·yr	
Measured Energy Use	54.4 kBtu/ft^2·yr	
Years of Measured Data	3 years	

Photos and data are provided by the Boney Architects and Wake County Public Schools System.

ZONE 4—THIRD CREEK ELEMENTARY SCHOOL

Statesville, North Carolina

Third Creek Elementary School in Statesville is located in a suburban setting in climate zone 4. The 92,000 ft^2 building was completed in July 2002 at a total project cost of \$8.7 million, or \$95/ft^2 (land purchase excluded). This new construction project consolidated and replaced two aging schools. The finished school was the first K-12 school to earn a LEED v2.0 Gold Certification from the USGBC. Spaces include classrooms, offices, public assembly spaces, cafeteria, gymnasium, athletic field, and restrooms.

The building team made a commitment to high-performance design from the beginning of the project. Examples are the gymnasium, stage, and dining room, which are located so they operate on separate systems for after-hours community use while the academic portion of the school is secured and not using energy. Energy demand was lowered though energy-efficient equipment and design, including extensive daylighting. Third Creek has an east-west axis orientation, with most classrooms facing either north or south. The southern façade has overhangs on the windows to shade from the summer sun. Each of the classrooms makes use of lightshelves to promote the dispersion of daylight. In addition to the lightshelves, reflective ceiling tiles were used to increase the effectiveness of daylighting. Also, in addition to the lighting systems employed within the school, Third Creek makes use of efficient exterior lighting.

Energy modeling shows a reduction in annual energy costs of 25% over ASHRAE Standard 90.1-1999. After the first year of operation, energy reduction increased each year to a 33% reduction in 2005.

Figure 4.11. Floorplan showing north- and south-facing classroom wings.

(a)

(b)

Figure 4.12. (a) Full exterior with view of main entrance and (b) classroom with internal light shelves.

Table 4.5. Third Creek Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis, classrooms facing north and south	DL9
Opaque Components	R-45 roof, R-22 walls	EN3, EN7
Vertical Glazing	Aluminum windows low-e; view glass 46% transmittance center of glass; light shelves glass; 70% transmittance center of glass	EN24
Lighting	Classroom T8	EL2
Controls	Four levels of control per classroom	EL8
	Occupancy sensors	EL6, DL13, L16–18
Daylighting		
Window Design	Overhangs on southern façade	DL20
	Interior light shelves in all classrooms	DL22
HVAC		
Equipment	High-efficiency water-source heat pumps w/ variable-frequency drives—14.5 EER; COP of 4.5	HV2
Boilers	97% thermal efficiency—condensing	HV26
Cooling Tower	5 levels of control to match loads with minimal energy output	
Energy Recovery Ventilators	Control humidity not to exceed 55%	HV8–9
System Controls		
Measurement and Verification	Direct digital control system	HV23
Temperature Control	Classroom by classroom basis	
Additional Savings		
Computers	ENERGY STAR	AS2
Energy Use Characteristics		
Simulated Energy Use	59.6 kBtu/ft²·yr	
Measured Energy Use	59.8 kBtu/ft²·yr (purchased)	
Years of Measured Data	3 years	

Photos are provided by Spark Productions and data is provided by Moseley Architects.

ZONE 5—BOLINGBROOK HIGH SCHOOL

Bolingbrook, Illinois

Bolingbrook High School in Bolingbrook, Illinois, is located in a suburban setting in climate zone 5. The 569,000 ft^2 building has a rated capacity of 3600. A master plan for the district included the new high school and renovations to two other high schools, one of which became a middle school. The total project cost for the new school was $96 million, or about $169/$ft^2$. With a commitment to high-performance design, the building team registered the project with the USGBC.

The educational planning concept of school-within-a-school was used in the design, with two academic houses in distinct wings and interior courtyards to maximize exterior views and daylight. In addition, the school incorporated a theatrical performance auditorium, a physical education gym, and a field house that is partially buried to reduce scale. Energy and environmental features include use or inclusion of the following:

- A fully automated digital control system that allows for automatic control of HVAC systems turning on/off via a time schedule set according to the projected use of the different areas
- Fans that do not run unless scheduled and room thermostats that are digitally programmed between 68°F and 74°F so as to optimize energy savings
- Lights equipped with override switches that automatically turn on via a programmed schedule before school starts and automatically turn off after school
- Lights that are equipped with daylight harvesting sensors in the upper levels of the main concourse
- A condensate recovery system projected to save 360,000 gallons of water annually that collects and reuses water from the rooftop chillers
- Bio-swales to filter impurities from surface-water runoff
- A well-irrigation system for athletic fields and indigenous plantings

Figure 4.13. Bolingbrook High School interior courtyard.

(a) (b) (c)

Figure 4.14. Daylighting and lighting views of (a) main corridor, (b) media center, and (c) cafeteria.

Table 4.6. Bolingbrook High School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Classrooms facing courtyards	
Opaque Components	2 in. rigid wall insulation in cavity with core insulation in CMU	
Vertical Glazing	1 in. insulated low-e glass	EN19
Roofing System	PVC membrane with white reflectance	EN1
Lighting	T-8 lamps in classrooms, metal halide in hallways	EL2, EL5
Controls	Automatic turnoff based on schedule with override capability in one-hour increments Hallways: light sensors to auto turn off when daylight is sufficient; Classrooms: two switches to allow for 33%, 67% and 100% lighting	EL1–2, EL5, EL8, DL16–17
Daylighting		
Window Design	90% of occupied spaces have daylighting; controls on main corridor with clerestory	DL1–4, DL16–17
HVAC		
Pumps	Constant primary pumping and secondary VSD pumping	HV5–6
System Controls		
Cx	Full Cx included	HV23
Temperature Control	Individual classrooms	
Additional Savings		
Exterior/Field/Parking Lot Lighting	Metal halide cut-off with 0 ft candles at lot line	EX1–2
Energy Use Characteristics		
Simulated Energy Use	86.6 kBtu/ft^2·yr (from LEED submittal)	
Measured Energy Use	91.4 kBtu/ft^2·yr	
Years of Measured Data	3 years (school operates 13 or more hours per day, 7 days per week)	

Photos and data are provided by Wight & Company.

ZONE 5—WHITMAN-HANSON REGIONAL HIGH SCHOOL

Whitman, Massachusetts

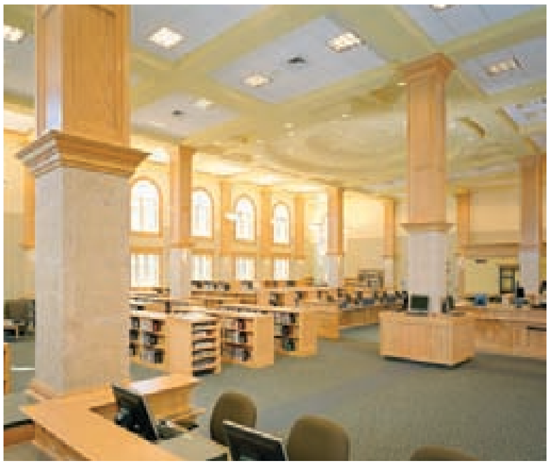
Whitman-Hanson Regional High School in climate zone 5 is a 234,500 ft^2 building designed for 1350 students. The total construction cost was $41 million, or $175/$ft^2$. The school is a pilot project for the Massachusetts Green Schools Initiative, a partnership between the Massachusetts School Building Authority and the Massachusetts Technology Collaborative (MTC).

Whitman-Hanson is 39% more efficient than ASHRAE Standard 90.1-1999. It makes use of daylighting, a well-insulated envelope, energy-efficient mechanical systems, a white roof, and energy-efficient appliances to reduce energy use. Natural light is used in the library, a two-story lecture hall, the classrooms, a performing arts center, and a double gymnasium to reduce the electrical lighting. The cafeteria is lit with natural light through skylights and daylight harvesting. Daylighting sensors are used in each classroom and the gymnasium to control electrical lighting, which comes from high-efficiency fluorescent fixtures, including pendant-mounted, direct/indirect lighting fixtures. The average lighting power density in the school is 1.15 W/ft^2. The exterior walls are insulated with R-10 continuous insulation and 6 in. wall-cavity insulation. Under-slab insulation is used on the floors. The windows are highly insulated and low-e coated to reduce heat loss. They are designed to allow natural light to penetrate further into the building spaces.

The HVAC system helps reduce energy use. Occupancy sensors are used throughout the building to provide adequate heating and cooling. Based on the occupancy, heating and air conditioning of each classroom is controlled by ventilation dampers and VAV boxes. A high-efficiency hybrid chiller is used. The primary base load chiller is a high-efficiency water-cooled chiller, and an air-cooled chiller provides additional capacity for peak periods. High-efficiency condensing boilers, demand-controlled ventilation with an energy recovery system, and variable-flow pumping are additional HVAC energy saving features.

A 51-kW PV system on the roof supplies approximately 5% of the annual energy that is consumed and has become part of the students' curriculum. The school uses the money it saves on energy to purchase high-tech (state of the art) educational aids, including interactive whiteboards and LCD projectors for all classrooms. Other teaching aids include a distance-learning center, cyber cafes, and instructional kiosks.

Figure 4.15. Whitman-Hanson regional high school exterior.



(a)

(b)

Figure 4.16. (a) Daylighted library and (b) classroom.

Table 4.7. Whitman-Hanson Regional High School

Energy Saving Measures	Description of Elements	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components—Exterior Walls	R-10 c.i. plus 6 in. wall cavity insulation	EN7
Opaque Components—Floors	Under slab insulation	EN10
Vertical Glazing	Low-e	EN19
Lighting		
Lighting System	High-efficiency fluorescent fixtures including pendant-mounted direct-indirect lighting fixtures	EL1–2
LPD	1.15 W/ft^2 average in the school	EL9
Controls	Photosensors in each classroom and the gymnasium	DL17
Daylighting		
Window Design	Highly insulated and low-e coated	
Natural Light	Used in the library, two-story lecture hall, classrooms, performing arts center, and double gymnasium to reduce the use of electrical lighting	DL36
Skylights	Used in the cafeteria with daylight harvesting	DL28
HVAC		
Equipment	Water-cooled chiller for base load; air-based chiller used only for peaking	HV25
Boilers	High-efficiency condensing boiler	HV26
System Controls		
Temperature Control	Occupancy sensors control ventilation dampers and VAV boxes to adjust the heating and A/C in each classroom.	HV5–6
Additional Savings		
Renewable Energy	51 kW PV system on the roof	AS6
Green Technology Cost Information		
Total Capital Cost	2.83% of the total cost	
Incremental Cost	$4.85/ft^2	
Incentives Received	$475,000 of the total $580,000 PV system from MTC	
Expected Payback (w/o Incentives)	Nine years (excluding the solar electric generation)	
Expected Payback (w/Incentives)	Almost immediate (incentives paid most of the initial cost for the green technology)	
Energy Use Characteristics	39% better than ASHRAE Standard 90.1-1999	
Measured Energy Use	60.5 kBtu/ft^2·yr (utility bills)	
MeasuredEnergy Cost	1.80 $/ft^2·yr	
Years of Measured Data	3 years	

ZONE 6—WESTWOOD ELEMENTARY SCHOOL

Zimmerman, Minnesota

Westwood Elementary School is located in a mixed suburban/rural setting in climate zone 6. The 75,000 ft^2, two-story building has a current capacity of 500 students, and the core facilities have a capacity of 750 students. The school opened in the fall of 2004 and was built at a cost of $12 million, or $160/ft^2. Spaces include classrooms, offices, public assembly areas, cafeteria, gymnasium, and athletic field. The school used LEED as the design guidance and was the first K-12 school in Minnesota and the fourth in the nation to earn LEED v2.1 certification.

The building was oriented on the site to maximize solar and wind patterns. The high-performance design included increased insulation, daylighting, energy-efficient lighting with occupancy sensors, low-e glass to control heat gain and loss, displacement ventilation, energy-efficient gas kitchen equipment, and a condensing boiler for heating needs. Operable windows add to the energy-saving features and allow for passive ventilation. The building was designed to meet multiple community and school needs. The gymnasium, stage, and dining room are located strategically so they operate on separate systems after hours.

In order to cut energy use and peak loads, Westwood uses energy recovery ventilators (ERVs). ERVs can recover as much as 80% of the energy from the exhaust airstream and transfer it to the supply airstream for heating and humidification in the winter months. The use of ERVs in the winter can cut humidification costs by up to 60%. The ERVs are used in the opposite manner for cooling in the summer months and transfer sensible and latent energy from the ventilation air to the exhaust airstream.

The original design projected an energy use of 53.7 kBtu/ft^2 annually; however, the actual building operation has been modified from what was modeled due to year-round cooling. During the first three years of operation, the actual annual energy used to operate this building has been 75.9–84.0 kBtu/ft^2, with an average of 78.4 kBtu/ft^2.

Figure 4.17. Westwood Elementary School aerial photo.

Figure 4.18. Pulse condensing boiler.

Table 4.8. Westwood Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west orientation for classrooms	DL9
Opaque Components	Roof insulation: R-22 Wall insulation: R-18	EN3, EN7
Roofing	5-ply built up roof	
Vertical Glazing	U-factor: 0.29 SHGC: 0.49 Visual transmittance: 0.69	EN19,
Lighting		
Controls	Occupancy and daylighting sensors	EL6, DL17
Fixture Design	15% direct/85% indirect T5 pendent fixtures	EL3
HVAC		
Equipment	Fan-powered VAV w/displacement ventilation	HV5–6
Boilers	94% efficiency HW condensing	HV26
Cooling	Air-cooled chiller (10.7 EER)	HV25
Pumping	Variable-frequency drives (VFDs) on hot-water and chilled-water loops.	HV25–26
Window Design	Operable for natural ventilation	HV32
Energy Recovery	Desiccant well	HV9
SWH	94% efficient condensing (gas)	WH1–2
System Controls		
Measurement and Verification	Systems Cx	HV23
Temperature Control	Web-based building automation system (BAS)	
Demand-Controlled Ventilation	Gymnasium and cafeteria AHUs	
Additional Savings		
Kitchen Equipment	Energy-efficient equipment (gas)	AS2
Energy Use Characteristics		
Simulated Code Base	113.7 kBtu/ft^2·yr	
Simulated Design Model	53.7 kBtu/ft^2·yr (original design—no summer operation)	
Measured Energy Use	78.4 kBtu/ft^2·yr (actual operation)	
Years of Measured Data	3 years	

Photos and data are provided by Elk River Area School District ISD 728 and Johnson Controls.

ZONE 6—ALDER CREEK MIDDLE SCHOOL

Truckee, California

Alder Creek Middle School near Lake Tahoe is located in a rural setting in climate zone 6. The 87,000 ft^2 building opened in 2004. The school was designed to serve 1000 students with an initial capacity of 700 students in sixth through eighth grades. The project was a CHPS demonstration school with a construction cost of $24 million ($30 million with contingency and soft costs), or $275/$ft^2$.

The school is a showcase of high-performance building strategies, including daylighting, energy efficiency, healthy IAQ, proper acoustics, building Cx, sustainable materials, waste reduction, preventive maintenance, site protection, and water conservation. The spaces in the school include classrooms, offices, public assembly spaces, cafeteria, gymnasium, athletic fields, and restrooms.

Classroom light fixtures are 60% uplight and 40% downlight. The top row of windows is designed to provide daylight to the space. Ground-source heat pumps (GSHPs) operate with an energy savings of more than 51% compared to the typical four-pipe boiler chiller system previously installed. The school uses 288 wells that are drilled 300 ft deep beneath the soccer field.

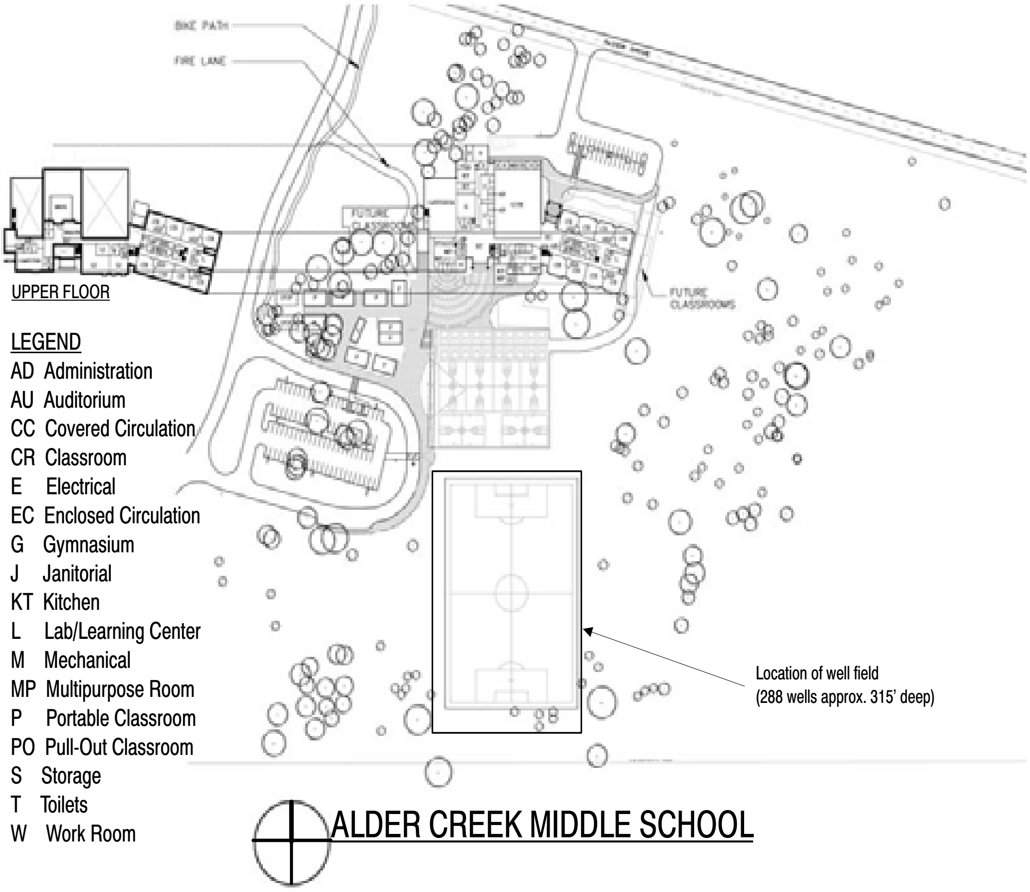


Figure 4.19. Site plan showing geothermal well field location

(a)

(b)

Figure 4.20. Alder Creek Middle School (a) classroom lighting system and (b) daylighted gym.

Table 4.9. Alder Creek Middle School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	Roof and walls R-19; cool roof	EN1, EN3, EN7
Vertical Glazing	Low-e	EN19
Lighting		
Lighting Systems Used	T5 direct/indirect in classrooms and offices; T5 HO in gym; T8 in all other areas	EL2–3
Controls	Sensor on row of lights near windows; Room occupancy sensors	EL6
Daylighting		
Window Design	Low-e with dual glazing	DL1–4
Controls	Blinds inside windows act as light shelves	DL12
Skylights	Located in stairwells in classroom wing	
HVAC		
Equipment	GSHPs	HV2
Boilers	Backup and peak use only	HV26
SWH	Dedicated domestic boiler for hot water	WH1–2
System Controls		
Measurement and Verification	EMCS system used district wide	HV23
Temperature Control	Individual room controls with a 5° limit on user control	
CO_2 Sensors	Used in gym and cafeteria	
Additional Savings		
Computers	ENERGY STAR features enabled	AS2
Exterior/Field/Parking Lot Lighting	Metal halide lamps	EX1–3
Energy Use Characteristics		
Simulated Energy Use	25% below Title 24 in California	
Measured Energy Use	54 kBtu/ft^2·yr	
Years of Measured Data	2.75 years	

Photos and data are provided by the Tahoe Truckee Unified School District, CHPS case study, and Lionakis Beaumont Design Group, Inc.

ZONE 7—SILVERTHORNE ELEMENTARY SCHOOL

Silverthorne, Colorado

Silverthorne Elementary in Silverthorne, Colorado, is located in Summit County in climate zone 7. Silverthorne is a 62,500 ft^2 building that houses 430 students ranging from K-5. The school opened in the fall of 2004. The build cost of the school was $9.3 million, or $148/$ft^2$, which is in line with the typical cost of area schools. The building was designed by OZ Architecture of Denver in collaboration with BOORA of Portland Oregon.

At an elevation of 9100 ft, the extreme climate was a factor in the design. By optimizing the building orientation, using daylighting to the fullest, increasing insulation levels, and using natural ventilation and economizers, the design team developed a design that will save the district $27,000 per year that would otherwise be spent on high utility bills. On warm days, outdoor air enters through the windows and rises to the top floor atria where it is vented by exhaust fans. When windows are closed, efficient mechanical ventilation is used. VAV air handlers deliver fresh air to the rooms and are regulated by CO_2 sensors to ensure adequate ventilation. This design also keeps air-handler noise away from the classrooms, improving acoustics in learning areas.

The design team's goal was for daylighting to provide most of the light needed in classrooms, even on overcast days. In addition to ample windows, daylight is directed to illuminate the back wall of each classroom using light shafts. Daylighting controls in the classrooms and gyms control lights in response to the available daylighting.

Figure 4.21. Interior view of skylights.

(a)

(b)

Figure 4.22. (a) Silverthorne Elementary School exterior and (b) classroom lighting system.

Table 4.10. Silverthorne Elementary School

Energy Saving Measures	Description	Tips
Envelope		
Building Orientation	Long east-west axis	DL9
Opaque Components	60 mil EPDM roof with R-30 polyiso insulation and R-19 wall insulation	EN1, EN7
Vertical Glazing	Clear double pane with spectrally selective low-e coating	EN19
Lighting	T-5 linear indirect classrooms and offices; high bay metal halide in gym	EL3, EL5
Controls	Occupancy sensors in all rooms and offices	EL6
Daylighting Controls	Automatic dimming and separate controls for each row of lights in classrooms	EL8
Daylighting		
Window Design	Aluminum frame windows that are thermally broken	DL1–4
Daylighting Design	Light shelves on exterior southern exposure; clerestories for interior hallways; light shafts in back of every classroom; skylight spines along central circulation path, gym and admin offices (see photos)	DL12
HVAC		
Equipment	AHUs have VAV with reheat; cooling is by outdoor air economizer cycle	HV6
Boilers	Condensing boilers with 90+% efficiency	HV26
Cooling Tower	None	
Economizer	Economizer cycle for all cooling	HV13
Service Water Heating	Solar preheat for domestic hot water	WH1, WH3, WH5–6, AS7
System Controls	HVAC controls include limiting outdoor air during unoccupied hours, optimum start/stop and outdoor air reset on heating hot water.	HV21
Cx	Partial commissioning	HV23
OA Control	Individual rooms with CO_2 sensors	
Additional Savings		
Computers	ENERGY STAR	AS2
Renewable Energy	Solar preheat for hot water	AS7
Energy Use Characteristics		
Simulated Energy Use	76.7 $kBtu/ft^2 \cdot yr$	
Measured Energy Use	88.0 $kBtu/ft^2 \cdot yr$	
Years of Measured Data	2 years	

5 How to Implement Recommendations

Recommendations are contained in the individual tables in Chapter 3, "Recommendations by Climate." The following information is intended to provide good-practice guidance for implementing the recommendations, as well as notes of caution to avoid known problems in energy-efficient construction. The sections are divided into *Commissioning*, *Envelope*, *Lighting*, *HVAC*, *Service Water Heating*, and *Additional Savings*. The "Additional Savings" section includes bonus savings—good practice items, which, if implemented, will achieve additional savings above the 30% level.

COMMISSIONING

To reduce project risk, Cx offers a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets the defined objectives and criteria. The CxA is a dedicated person (one with no other project responsibilities) who can execute this process systematically. An independent party, whether a third-party Cx professional or a capable member of the organization, is recommended to help ensure that the strategies and recommendations contained herein and adopted by the owner are implemented in accordance with this Guide and other documented objectives, criteria, and requirements. Cx practice recommendations are offered below. Appendix B summarizes the Cx scope and responsibilities.

Good Design Practice

CX1 Selection of a Commissioning Authority

The selection of a CxA should include the same evaluation process the owner would use to select other project team members. The owner should investigate and consider qualifications in providing Cx services, past performance of projects, costs of services, and availability when making a selection.

Owners may select a member of the organization, the design team, or the construction team as the CxA. Although there are exceptions, most designers are not comfortable operating and testing assemblies and equipment, and few contractors have the technical background or time necessary to thoroughly evaluate performance. Cx requires in-depth technical knowledge of the building envelope; mechanical, electrical, and plumbing systems; and operational and construction experience. The CxA function is best performed by an entity responsible to the owner because political issues often prevent a member of the design or construction organizations from fulfilling this responsibility.

CX2 Design and Construction Schedule

The inclusion of Cx activities in the construction schedule fulfills a critical role in delivering a successful project. The activities and time required for design review and performance verification must be identified to minimize the time and effort needed to accomplish activities and correct deficiencies.

CX3 Design Review

A second pair of eyes provided by the CxA offers a fresh perspective that allows identification of issues and opportunities to improve the quality of the construction documents. Issues identified can be more easily corrected early in the project, providing potential savings in construction costs and reducing risk to the team.

CX4 Defining Commissioning Process at Pre-Bid

The building industry has traditionally delivered buildings without using a verification process. Changes in traditional design and construction procedures and practices require that the construction team be educated about how the Cx process will affect the various trades bidding on the project. The Cx process must be reviewed with the bidding contractors to facilitate understanding of and to help minimize apprehension associated with new practices. Teams who have participated in the Cx process typically appreciate the process because they can resolve problems while their manpower and materials are still on the project. This significantly reduces delays, callbacks, and costs, and enhances their delivery capacity.

CX5 Verifying Building Envelope Construction

The building envelope is a key element of an energy-efficient design. Compromises in assembly performance are common and are caused by a variety of factors that can easily be avoided. Improper placement of insulation, improper sealing or lack of sealing around air barriers, incorrect or poorly performing glazing and fenestration systems, incorrect placement of shading devices, misplacement of daylighting shelves, and misinterpretation of assembly details can compromise the energy performance of the building (see "Cautions" throughout this chapter). The value of the Cx process is that it offers an extension of the quality control processes of the designer and contractor as the team works together to produce quality energy-efficient projects.

CX6 Verifying Electrical and HVAC Systems Construction

Performance of electrical and HVAC systems are key elements of this Guide. How systems are installed will affect how efficiently they can be serviced and how well they will perform. Observations during construction identify problems while they are easy to correct.

CX7 Testing

Systems must be tested to ensure that a project following this Guide will attain the energy savings that can be expected from the recommended strategies and recommendations. If the contractors use the Cx recommendations as intended, systems can be tested quickly, and minor but important issues can be resolved. Owners can use the functional testing process as a training tool to educate their O&M staff about how the systems operate and for system orientation before training.

CX8 Substantial Completion

Substantial completion generally means that the life safety systems are completed and accepted. Contractors typically do not test the systems' performance at substantial completion, nor do we recommend that. The systems may be operational, but they probably do not yet operate as intended. They cannot perform as expected unless all systems operate interactively to provide the desired results. As contractors finish their work, they will identify and resolve many performance problems. The CxA helps to resolve remaining issues.

CX9 Maintenance Manual Submitted and Accepted

The Cx process includes communication of activities that the owner will be responsible for completing to maintain the manufacturers' warranties. Information on the owner's requirements and expectations should be provided to the O&M staff for an understanding of the original objectives and criteria for the project. A systems manual that provides the operators the information needed to optimally operate the building should also be made available.

CX10 Resolve Quality Control Issues Identified Throughout the Construction Phase

Issues identified during the construction process are documented in an issues log and presented to the team for collaborative resolution; they are then tracked and reviewed at progress meetings until they are resolved. Typically the CxA develops and maintains the issues log. The owner's completion and acceptance of the systems and assemblies will be contingent on issues that are still outstanding at the end of the project. Minor issues may be tracked by the owner's O&M staff; others will need to be resolved before the work is accepted. The Cx process finishes with verification that the issues identified have been resolved, and the owner provides direction to the team to resolve issues.

CX11 Final Acceptance

Final acceptance generally occurs after Cx issues in the issues log have been resolved, except for minor issues the owner is comfortable addressing during the warranty period.

CX12 Establish a Building Maintenance Program

Continued performance and control of O&M costs require a maintenance program. O&M manuals provide information that the O&M staff uses to develop this program. Detailed O&M system manual and training requirements are defined in the Cx process and are executed by the project team to ensure O&M staff has the necessary tools and skills. The CxA can help bridge the knowledge gaps of the O&M staff and help the owner develop a program to ensure continued performance. The benefits associated with energy-efficient buildings are realized when systems perform as intended through proper design, construction, and O&M.

CX13 Monitor Post-Occupancy Performance

Establishing measurement and verification procedures with a performance baseline can help a CxA identify when corrective action or repair is required to maintain energy

Table 5.1. Examples of Cool Roofs

Category	Product	Reflectance	Emissivity	SRI
Single-Ply	White PVC (polyvinyl chloride)	0.86	0.86	107
Single-Ply	White CPE (chlorinated polyethylene)			
Single-Ply	White CPSE (chlorosulfonated polyethylene)	0.85	0.87	106
Single-Ply	White TSO (thermoplastic polyolefin)	0.77	0.87	95
Liquid-Applied	White elastomeric, polyurethane, acrylic coating	0.71	0.86	86
Liquid-Applied	White paint (on metal or concrete)	0.71	0.85	86
Metal Panels	Factory-coated white finish	0.90	0.87	113

performance. Utility energy use and factors that affect it should be monitored and recorded to establish building performance during the first year of operation. Tools such as ENERGY STAR's Portfolio Manager[1] can help track energy use and costs.

Variations in utility use can be justified based on changes in conditions, such as weather, occupancy, operational schedule, maintenance procedures, and equipment operations required by these conditions that typically affect energy use. Tracking specific parameters allows the owner to quickly review utility bills and changes in conditions. Poor performance is generally obvious to the reviewer when comparing the various parameters. The CxA can typically help owners understand when operational tolerances are exceeded and can help define the actions that may be required to return the building to peak performance.

ENVELOPE

Good Design Practice

EN1 *Cool Roofs* (Climate Zones: 1 2 3)

To be considered a cool roof, a solar reflectance index (SRI) of 78 or higher is recommended. A high reflectance keeps much of the sun's energy from being absorbed while a high thermal emittance radiates away solar energy that is absorbed, allowing the roof to cool more rapidly. Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single-ply, liquid-applied, and metal panels. Examples are presented in Table 5.1.

The solar reflectance and thermal emittance property values represent initial conditions as determined by a laboratory accredited by the Cool Roof Rating Council.

An SRI can be determined by the following equations:

$$SRI = 123.97 - 141.35(\chi) + 9.655(\chi^2)$$

where

$$\chi = \frac{20.797 \times \alpha - 0.603 \times \varepsilon}{9.5205 \times \varepsilon + 12.0}$$

and

α = solar absorptance = 1 – solar reflectance
ε = thermal emissivity

1. http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

These formulas were derived from ASTM E1980 assuming a medium wind speed. Note that cool roofs are not an alternative to the appropriate amount of insulation.

EN2 *Roofs, Insulation Entirely Above Deck* (Climate Zones: all)

The insulation entirely above deck should be continuous insulation (c.i.) rigid boards. Continuous insulation is important because no framing members are present that would introduce thermal bridges or short circuits to bypass the insulation.

When two layers of c.i. are used in this construction, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation is placed above the membrane and a maximum of one layer is placed beneath the membrane.

EN3 *Roofs, Attics, and Other Roofs* (Climate Zones: all)

Attics and other roofs include roofs with insulation that is entirely below (inside) the roof structure (attics and cathedral ceilings) and roofs with insulation both above and below the roof structure. Ventilated attic spaces need to have the insulation installed at the ceiling line. Unventilated attic spaces may have the insulation installed at the roof line. When suspended ceilings with removable ceiling tiles are used, the insulation needs to be installed at the roof line. For buildings with attic spaces, ventilation should be provided equal to 1 ft^2 of open area per 100 ft^2 of attic space. This will provide adequate ventilation as long as the openings are split between the bottom and top of the attic space. Additional ventilation can further improve the performance of the building.

In metal roof building construction, purlins are typically z-shaped, cold-formed steel members, although steel bar joists are sometimes used for longer spans.

The thermal performance of metal building roofs with fiberglass blankets is improved by addressing the thermal bridging associated with compression at the purlins. The two types of metal building roofs are standing seam roofs and through-fastened roofs. Standing seam roofs have very few exposed fasteners and utilize a concealed clip for the structural attachment of the metal roof panel to the purlins. The larger gap between the purlin and the roof sheets, along with the thermal spacer block, provides a thermal break that results in improved performance compared to the standard through-fastened metal roofs. It is recommended that the thermal resistance between the purlin and the metal deck be at least R-8. One means to accomplish this is by using a 3/4 × 3 in. foam block (R-5) over 3/4 in. of compressed fiberglass blanket (R-3). Alternatively, a 2 in. space filled with compressed fiberglass insulation will provide roughly R-8.

Through-fastened metal roofs are screwed directly to the purlins and have fasteners that are exposed to the elements. The fasteners have integrated neoprene washers under the heads to provide a weathertight seal. Thermal spacer blocks are not used with through-fastened roofs because they may diminish the structural load carrying capacity by "softening" the connection and restraint provided to the purlin by the metal roof panels. To meet the performance recommendations of this guide, through-fastened roofs will generally require insulation over the purlins in the conventional manner, with a second lay of insulation added to the system. The second layer of insulation can be placed either parallel to the purlins (on top of the first layer) or suspended below the purlins.

In climate zone 1 the recommended construction is standing-seam roofs with R-19 insulation blankets draped over the purlins.

In climate zones 2 through 8, the recommended construction is standing-seam roofs with two layers of blanket insulation. The first layer is draped perpendicularly over the purlins with enough looseness to allow the second insulation layer to be laid above it, parallel to the purlins.

In any case, continuous rigid insulation or other high performance insulation systems may be used to meet the U-facors listed in Appendix A.

EN4 *Roofs, Single Rafter* (Climate Zones: All)

Single-rafter roofs have the roof above and ceiling below both attached to the same wood rafter, and the cavity insulation is located between the wood rafters. Continuous insulation, when used, is installed on the bottom of the rafters and above the ceiling material. Single rafters can be constructed with solid wood framing members or truss-type framing members. The cavity insulation should be installed between the wood rafters and in intimate contact with the ceiling to avoid the potential thermal short-circuiting associated with open or exposed air spaces.

EN5 *Walls, Mass* (Climate Zones: all)

Mass walls are defined as those with a heat capacity exceeding 7 Btu/ft^2·°F. Insulation may be placed either on the inside or the outside of the masonry wall. When insulation is placed on the exterior, rigid c.i. is recommended. When it is placed on the interior, a furring or framing system may be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

The greatest advantages of mass can be obtained when insulation is placed on its exterior. In this case, the mass absorbs heat from the interior spaces that are later released in the evenings when the buildings are not occupied. The thermal mass of a building (typically contained in the building envelope) absorbs heat during the day and reduces the magnitude of indoor air temperature swings, reduces peak cooling loads, and transfers some of the absorbed heat into the night hours. The cooling load can then be covered by passive (natural) cooling techniques when the outdoor conditions are more favorable. An unoccupied building can also be pre-cooled during the night by natural or mechanical ventilation to reduce the cooling energy use.

Thermal mass also has a positive effect on thermal comfort. High-mass buildings attenuate interior air and wall temperature variations and sustain a stable overall thermal environment. This increases thermal comfort, particularly during mild seasons (spring and fall), during large air temperature changes (high solar gain), and in areas with large day/night temperature swings.

A designer should keep in mind that the occupant will be the final determinant factor on the extent of the usability of any building system, including thermal mass. Changing the use of internal spaces and surfaces can drastically reduce the effectiveness of thermal storage. The final use of the space must be considered when making the cooling load calculations and incorporating possible energy savings from thermal mass effects.

EN6 *Walls, Steel Framed* (Climate Zones: all)

Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as c.i. is the preferred method to upgrade the wall thermal performance because it will increase the overall wall thermal performance and tends to minimize the impact of the thermal bridging.

Alternative combinations of cavity insulation and sheathing in thicker steel-framed walls can be used, provided that the proposed total wall assembly has a U-factor that is less than or equal to the U-factor for the appropriate climate zone construction listed in Appendix A. Batt insulation installed in cold-formed steel-framed wall assemblies is to be ordered as full width batts and installation is normally by friction fit. Batt insulation should fill the entire cavity and not be cut short.

EN7 *Walls, Wood Frame, and Other* (Climate Zones: all)

Cavity insulation is used within the wood-framed wall; rigid c.i. is placed on the exterior side of the framing. Alternative combinations of cavity insulations and sheathings in thicker walls can be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A. Batt insulation should fill the entire cavity and not be cut short.

In metal building wall construction in climate zones 1–4, a single layer of fiberglass batt insulation is recommended. The insulation is installed continuously, perpendicular to the exterior of the girts, and is compressed as the metal skin is attached to the girts. In climate zones 5–8, one layer of fiberglass batt insulation is recommended along with a layer of rigid continuous insulation (c.i.). The fiberglass layer is installed continuously perpendicular to the exterior of the girts. The rigid c.i. insulation is installed over the fiberglass layer. The fiberglass layer is compressed as the metal skin is attached to the girts.

EN8 *Below-Grade Walls* (Climate Zones: all)

Insulation, when recommended, may be placed either on the inside or the outside of the below-grade wall. If placed on the exterior of the wall, rigid c.i. is recommended. If placed on the interior wall, a furring or framing system is recommended, provided the total wall assembly has a C-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

EN9 *Floors, Mass* (Climate Zones: all)

Insulation should be continuous and either integral to or above the floor. It should be purchased by the conductive R-value. This can be achieved by placing high-density extruded polystyrene as c.i. above the slab with either plywood or a thin layer of concrete on top. An exception: buildings or zones in buildings that have durable floors for heavy machinery or equipment could have insulation placed below the deck.

When heated slabs are placed below grade, below-grade walls should meet the insulation recommendations for perimeter insulation according to the heated slab-on-grade construction.

EN10 *Floors, Steel Joist, or Wood Frame* (Climate Zones: all)

Insulation should be installed parallel to the framing members and in intimate contact with the flooring system supported by the framing member to avoid the potential thermal short-circuiting associated with open or exposed air spaces. Nonrigid insulation should be supported from below, no less frequently than 24 in. on center.

EN11 *Slab-on-Grade Floors, Unheated* (Climate Zones: 6 7 8)

Rigid c.i. should be used around the perimeter of the slab and should reach the depth listed in the recommendation or to the bottom of the footing, whichever is less. In climate zones 5–8 and in cases where the frost line is deeper than the footing, c.i. should be placed beneath the slab as well.

EN12 *Slab-on-Grade Floors, Heated* (Climate Zones: all)

When slabs are heated, rigid c.i. should be used around the perimeter of the slab and should reach to the depth listed in the recommendation or to the bottom of the footing, whichever is less. Additionally, in climate zones 5–8, c.i. should be placed below the slab. The conductive R-value must be used for the insulation, as radiative heat transfer is small in this application.

Note: In areas where termites are a concern and rigid insulation is not recommended for use under the slab, a different heating system should be used.

EN13 *Doors—Opaque, Swinging* (Climate Zones: all)

A U-factor of 0.37 corresponds to an insulated double-panel metal door. A U-factor of 0.61 corresponds to a double-panel metal door. If at all possible, single swinging doors should be used. Double swinging doors are difficult to seal at the center of the doors unless there is a center post. Double swinging doors without a center post should be minimized and limited to areas where width is important. Vestibules can be added to further improve energy efficiency.

EN14 *Doors—Opaque, Roll-Up, or Sliding* (Climate Zones: all)

Roll-up or sliding doors are recommended to have R-4.75 rigid insulation or meet the recommended U-factor. When meeting the recommended U-factor, the thermal bridging at the door and section edges is to be included in the analysis. Roll-up doors that have solar exposure should be painted with a reflective paint (or high emissivity) and should be shaded. Metal doors are a problem in that they typically have poor emissivity and collect heat, which is transmitted through even the best insulated door and causes cooling loads and thermal comfort issues.

Options

EN15 *Alternative Constructions* (Climate Zones: all)

The climate zone recommendations provide only one solution for upgrading the thermal performance of the envelope. Other constructions can be equally effective, but they are not shown in this document. Any alternative construction that is less than or equal to the U-factor, C-factor, or F-factor for the appropriate climate zone construction is equally acceptable. A table of U-factors, C-factors, and F-factors that correspond to all the recommendations is presented in Appendix A.

Procedures to calculate U-factors and C-factors are presented in the *ASHRAE Handbook—Fundamentals*, and expanded U-factor, C-factor, and F-factor tables are presented in ASHRAE Standard 90.1, Appendix A.

Cautions

The design of building envelopes for durability, indoor environmental quality, and energy conservation should not create conditions of accelerated deterioration, reduced thermal performance, or problems associated with moisture, air infiltration, or termites. The following cautions should be incorporated into the design and construction of the building.

EN16 *Truss Heel Heights* (Climate Zones: all)

When insulation levels are increased in attic spaces, the truss heel height should be raised to avoid the eave compression. Roof insulation should extend to the exterior of the walls to minimize edge effects.

EN17 *Slab-Edge Insulation* (Climate Zones: all)

Use of slab-edge insulation improves thermal performance, but problems can occur in regions that have termites.

EN18 *Air Infiltration Control* (Climate Zones: all)

The building envelope should be designed and constructed with a continuous air barrier system to control air leakage into or out of the conditioned space. An air barrier system should also be provided for interior separations between conditioned space and space designed to maintain temperature or humidity levels that differ from those in the conditioned space by more than 50% of the difference between the conditioned space and design ambient conditions. If possible, a blower door should be used to depressurize the building to find leaks in the infiltration barrier. The air barrier system should have the following characteristics:

- It should be continuous, with all joints made airtight
- Air barrier materials used in frame walls should have an air permeability not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. water (1.57 lb/ft^2) when tested in accordance with ASTM E 2178
- The system should be able to withstand positive and negative combined design wind, fan, and stack pressures on the envelope without damage or displacement, and should transfer the load to the structure; it should not displace adjacent materials under full load
- It should be durable or maintainable
- The air barrier material of an envelope assembly should be joined in an airtight and flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection
- Connections should be made between
    - (a) foundation and walls
    - (b) walls and windows or doors
    - (c) different wall systems
    - (d) walls and roof
    - (e) walls and roof over unconditioned space
    - (f) walls, floor, and roof across construction, control, and expansion joints
    - (g) walls, floors, and roof to utility, pipe, and duct penetrations
- All penetrations of the air barrier system and paths of air infiltration/exfiltration should be made airtight

Good Design Practice — Vertical Fenestration

EN19 *Vertical Fenestration Descriptions* (Climate Zones: all)

Fenestration refers to the light-transmitting areas of a wall or roof, mainly windows and skylights, but also including glass doors, glass block walls, and translucent plastic panels. Vertical fenestration includes sloped glazing if it has a slope equal to or more than 60° from the horizontal. If it slopes less than 60° from the horizontal, the fenestration falls in the skylight category. This means that clerestories, roof monitors, and other such fenestration fall in the vertical category.

The recommendations for vertical fenestration are listed in Chapter 3 by climate zone.

To be useful and consistent, the U-factors for windows should be measured over the entire window assembly, not just the center of glass. Look for a label that denotes the window rating is certified by the National Fenestration Rating Council (NFRC). The selection of high-performance window products should be considered separately for each orientation of the building and for daylighting and viewing functions.

To meet the SHGC recommendations for vertical fenestration in Chapter 3, use the SHGC multipliers for permanent projections, as provided in Table 5.5.4.4.1 in ASHRAE Standard 90.1-2004. These multipliers allow for a higher SHGC for vertical fenestration with overhangs. For an overhang with a projection factor greater than 0.5, the recommended SHGC can be increased by 64%. For example, the recommended SHGC in climate zone 1 is 0.25. With an overhang with a projection factor of 0.5, an SHGC of 0.4 is acceptable (see Figure 5.1). Using the SHGC multipliers for vertical fenestration with overhangs makes it easier to meet the high visible transmittance recommendations needed for daylighting (see DL5).

EN20 Fenestration to Gross Wall Area Ratio (Climate Zones: all)

The fenestration to gross wall area ratio (FWR) is the percentage resulting from dividing the total vertical fenestration area by the gross exterior wall area. The total vertical fenestration area includes both the view fenestration below 7 ft and the vertical daylighting fenestration (including vertical components of roof monitors and clerestories) above 7 ft. The total vertical fenestration area is the rough opening, i.e., it includes the frame, sash, and other nonglazed window components. The gross exterior wall is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof. The gross exterior wall area includes below-grade as well as above-grade walls.

The FWR over all the exterior gross wall area of the school should not exceed 35%. A reduction in the view fenestration will also save energy, especially if glazing is significantly reduced on the east and west facades. The smallest glazed area should be designed in a way that is still consistent with needs for view, daylighting, and passive solar strategies.

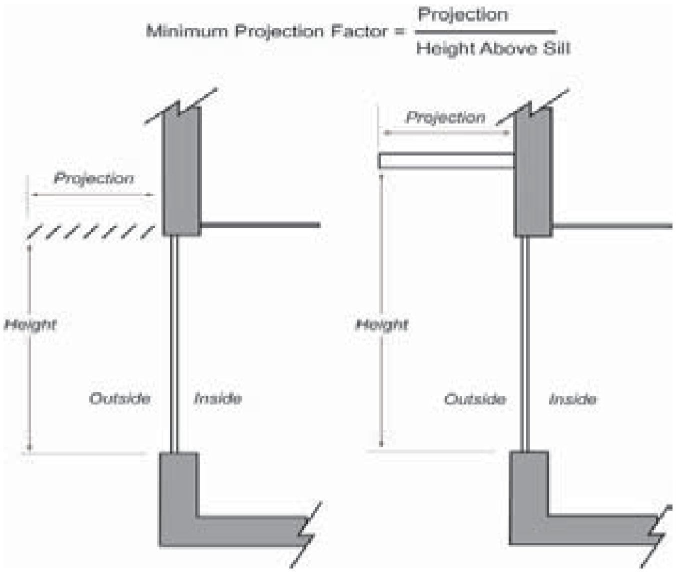


Figure 5.1. Horizontal overhangs.

Window Design Guidelines for Thermal Conditions

Uncontrolled solar heat gain is a major cause of energy use for cooling in warmer climates and thermal discomfort for occupants. Appropriate configuration of windows according to the orientation of the wall on which they are placed can significantly reduce these problems.

EN21 *Unwanted Solar Heat Gain Is Most Effectively Controlled on the Outside of the Building* (Climate Zones: all)

Significantly greater energy savings are realized when sun penetration is blocked before it enters the windows. Horizontal overhangs at the top of the windows are most effective for south-facing facades and must continue beyond the width of the windows to adequately shade them (see Figure 5.1). Vertical fins can be problematic in schools from the perspective of vandalism. Consider louvered or perforated sun control devices, especially in primarily overcast and colder climates, to prevent a totally dark appearance in those environments.

EN22 *Operable Versus Fixed Windows* (Climate Zones: all)

Operable windows offer the advantage of personal comfort control and beneficial connections to the environment. However, individual operation of the windows not in coordination with the HVAC system settings and requirements can have extreme impacts on the energy use of a building's system. Advanced energy buildings with operable windows should strive for a high level of integration between envelope and HVAC system design. First, the envelope should be designed to take advantage of natural ventilation with well-placed operable openings. Second, the mechanical system should use interlocks on operable windows to ensure that the HVAC system responds by shutting down in the affected zone if the window is opened. The window interlock zones need to be designed to correspond as closely as possible to the HVAC zone affected by the open window. See HV32 for more information.

Warm Climates

EN23 *Building Form and Window Orientation* (Climate Zones: 1 2 3 4)

In warm climates, north- and south-facing glass can be more easily shielded and can result in less solar heat gain and glare than can east- and west-facing glass. During site selection, preference should be given to sites that permit elongating the building in the east-west direction and permit orienting more windows to the north and south. A good design strategy avoids areas of glass that do not contribute to the view from the building or to the daylighting of the space. If possible, configure the building to maximize north- and south-facing walls and glass by elongating the floor plan. Since sun control devices are less effective on the east and west facades, the solar penetration through the east- and west-facing glazing should be minimized. This can be done by reducing the area of glazing or, if the glass is needed for view or egress, by reducing the SHGC. For buildings where a predominantly east-west exposure is unavoidable, more aggressive energy conservation measures will be required in other building components to achieve an overall 30% energy savings.

EN24 *Glazing* (Climate Zones: 1 2 3 4)

For north- and south-facing windows, select windows with a low SHGC and an appropriate visible light transmission (VLT) (see EN19). Certain window coatings, called selective low-e, transmit the visible portions of the solar spectrum selectively, rejecting the non-visible infrared sections. These glass and coating selections can provide a balance between VLT and solar heat gain. Window manufacturers market special "solar low-e" windows for warm climates. For buildings in warm climates that do not use a daylight design, north- and south-window glazings should be selected with an SHGC no higher than 0.35. East- and west-facing windows in warm climates should be selected for an SHGC no higher than 0.25. All values are for the entire fenestration assembly in compliance with NFRC procedures and are not simply center-of-glass values. For warm climates, a low SHGC is much more important for low energy use than the window assembly U-factor. Windows with low SHGC values will tend to have a low center-of-glass U-factor because they are designed to reduce the conduction of the solar heat gain absorbed on the outer layer of glass through to the inside of the window. (See also EN19 and DL5.)

EN25 *Obstructions and Planting* (Climate Zones: all)

Adjacent buildings, trees, shrubs, or other plantings effectively shade glass on south, east, and west facades. For south-facing windows, remember that the sun is higher in the sky during the summer, so shading plants should be located high above the windows to effectively shade the glass. Also, be careful to not block south light that is being counted on for daylighting. The glazing of fully shaded windows can be selected with higher SHGC ratings without increasing energy use. The solar reflections from adjacent buildings with reflective surfaces (metal, windows, or, especially, reflective curtain walls) should be considered in the design. Such reflections may modify shading strategies, especially on the north facade.

Cold Climates

EN26 *Window Orientation* (Climate Zones: 5 6 7 8)

Only the south glass receives much sunlight during the cold winter months. If possible, maximize south-facing windows by elongating the floor plan in the east-west direction and relocate windows to the south face. By facing the glazing south and placing it vertically, it is easy to implement overhangs and simple sun control devices that allow for passive heating when desired but prevent unwanted glare and solar overheating in the warmer months. Glass facing east and west should be significantly limited. Areas of glazing facing north should be optimized for daylighting and view. During site selection, preference should be given to sites that permit elongating the building in the east-west direction and permit orienting more windows to the south.

EN27 *Passive Solar* (Climate Zones: 5 6 7 8)

Passive solar energy saving strategies should be limited to non-classrooms or office spaces, such as lobbies and circulation areas, unless those strategies are designed so that the occupants are not affected by direct beam radiation. To use passive solar heating in classrooms, the solar radiation must be diffused as it enters into the classrooms. Consider light-colored blinds, blinds within the fenestration, light shelves, or diffusing films to control solar heat gain. In spaces where glare is not an issue, the usefulness of the solar heat gain collected by these windows can be increased by using hard, massive, and dark-color floor surfaces such as tile or concrete in the locations where the transmitted sunlight will fall. These floor surfaces absorb the transmitted solar heat gain and release it slowly over time to provide a more gradual heating of the structure. Consider higher SHGC, low-e glazing with optimally designed exterior overhangs.

EN28 *Glazing* (Climate Zones: 5 6 7 8)

Higher SHGCs are allowed in colder regions, but continuous horizontal overhangs are still necessary to block the high summer sun angles.

LIGHTING

Energy-efficient lighting systems in schools can be designed with or without daylighting. There are many daylighted options, but this Guide provides guidance on three classroom options, one gymnasium daylighted option, and one non-daylighted option. The daylighted options are as follows:

- Classroom with sidelighting
- Classroom with toplighting
- Classroom with sidelighting and toplighting
- Gym with toplighting

Good Design Practice

Electric Lighting

EL1 *Light-Colored Interior Finishes* (Climate Zones: all)

For electrical lighting to be used efficiently, spaces must have light-colored finishes. Ceiling reflectance should be at least 70% (preferably 80% to 90%), which in general means using smooth white acoustical tile or ceiling paint. The average reflectance of the walls should be at least 50%, which in general means using light tints or off-whites for the wall surface, as the lower reflectance of doors, tack surfaces, and other objects on the walls will reduce the average. Floor surfaces should be at least 20%, for which there are many suitable surfaces. In addition, take the shape and finish of the ceiling into account. A flat painted or acoustical tile ceiling is the most efficient; sloping ceilings and exposed roof structures, even if painted white, may significantly reduce the effective ceiling reflectivity. Lighting systems with indirect components are recommended, but if the ceiling cavity includes exposed structures or exposed ductwork, a higher percentage of downlight may be required. Make sure the ceiling and all components are painted a high-reflectance white.

EL2 *Linear Fluorescent Lamps and Ballasts* (Climate Zones: all)

T8 lamps and electronic ballasts are the standard commercial fluorescent lighting system in the United States. The light-source efficacy and LPD requirements in Chapter 3 can be achieved as long as the more efficient versions of T8 lamps and ballasts are used.

To evaluate the efficacy (lumens per watt) of a lighting system, the mean lamp lumens in typical manufacturers' catalogs are divided by the ballast's rated input power. In these catalogs, the mean lumens are lower than the initial lumens. Mean lumens represent the average light output of the lamp over its rated life, which better characterize actual performance. See Table 5.2.

Also, the mean lumens vary according to color temperature and between standard series (SP) and premium series (SPX) lamps. Low-mercury fluorescent lamps are avail-

Table 5.2. Typical T8 Lamp Catalog Data

T8 Lamp Description	Lumens		Color Temp, K
	Initial	Mean	
F32T8/SP30/ECO	2800	2660	3000
F32T8/SP35/ECO	2800	2660	3500
F32T8/SP41/ECO	2800	2660	4100
F32T8/SP50/ECO	2750	2610	5000
F32T8/SP65/ECO	2700	2565	6500
F32T8/SPX30/ECO	2950	2800	3000
F32T8/SPX35/ECO	2950	2800	3500
F32T8/SPX41/ECO	2950	2800	4100
F32T8/SPX50/ECO	2800	2660	5000

Table 5.3. Low Mercury T8 Lamps Showing CRI and Lumen Variations

Lamp General Description	Minimum CRI	Mean Lumens
Standard Generic F32T8 Low Mercury	75	2520
Efficient Standard F32T8 Low Mercury	78	2610
Premium Standard F32T8 Low Mercury	82	2710
Efficient Premium F32T8 Low Mercury	82	2850
High Efficiency F32T8 Low Mercury	82	2945

able from the major lamp manufacturers and have become the standard for sustainable design projects. Among low-mercury 32-W T8 lamps, there are several choices, as shown in Table 5.4.

The color rendering index (CRI) is a scale measurement identifying a lamp's ability, generally, to adequately reveal color characteristics. The scale maximizes at 100, which indicates the best color-rendering capability. Lamps specified for ambient lighting should have a CRI of 80 or greater to allow the occupants to effectively examine the color characteristics. As shown in Table 5.3, standard T8 lamps are available with lower CRI values than recommended, which may compromise the lighting solution.

Next, select the ballast. This is not trivial, as there are several choices:

- *Standard "generic" instant start electronic ballasts.* The most common and least expensive ballast; the typical input power for a two-lamp normal light level (0.87 ballast factor [BF]) is about 59 W. If you do not specify the ballast, this is what you will receive.
- *Low light level version of standard ballasts.* Similar to the standard ballast, this version operates at 0.78 BF and has input power of about 54 W for a two-lamp ballast. The resulting light level is about 10% less than the standard ballast, but the watts are 10% lower.
- *High light level version of standard ballasts.* Similar to the standard ballast, this version operates at 1.15–1.20 BF and has input power of 74–78 W for a two-lamp ballast. The resulting light level is about 32% higher than the standard ballast, but the watts are 32% higher.
- *Program start ballasts.* Available in low power and normal power models, program start ballasts use an additional watt per lamp to perform programmed starting, which makes lamps last longer when frequently switched.

Table 5.4. Efficacy Values for Different Lamp/Ballast Combinations

Ballasts	Lamps				
	F32T8 Generic Standard	F32T8 Efficient Standard	F32T8 Premium Standard	F32T8 Efficient Premium	F32T8 High Efficiency
Generic Standard Instant Start (59 W, 0.87 BF)	74	77	80	84	87
Low Light Level Instant Start (54 W, 0.78 BF)	73	75	78	82	85
High Light Level Instant Start (74 W, 1.15 BF)	78	81	84	89	92
Program Start (61 W, 0.87 BF)	72	74	77	81	84
Low Light Level Program Start (56 W, 0.78 BF)	70	73	75	79	82
Dimming Rapid Start (64 W max, 0.88 BF max)	69	72	75	78	81
Efficient Instant Start Normal Light Level (54 W, 0.87 BF)	81	84	87	92	95
Efficient Instant Start Low Light Level (48 W, 0.78)	82	85	88	93	96
Efficient Instant Start High Light Level (70 W, 1.15 BF)	83	86	89	94	97
Efficient Dimming (58 W, 0.87 BF max)	76	78	81	86	88

Does not meet efficacy criteria — Meets 75 MLPW efficacy criteria — Meets 75 and 85 MLPW efficacy

- *Dimming ballasts.* Dimming ballasts are also rapid start, which is less efficient than either instant or programmed starting. At 0.87 BF, most dimming ballasts require 62–64 W for two lamps. The added power is used to add extra heat to the lamp cathodes to permit proper dimming operation.
- *High-efficiency versions of all of the above.* Efficient electronic ballasts are now available for almost every type listed above. Better electronics require 1–3 fewer watts per lamp to deliver similar performance, but they cost more and are less common.

To determine the system efficacy, multiply the lamp mean lumens by the number of lamps and the BF, then divide by the ballast input watts. For example, using two standard generic lamps and a generic two-lamp ballast, the system efficacy is as follows:

$$\frac{2 \text{ lamps} \times 2520 \text{ mean lumens} \times 0.87 \text{ ballast factor}}{59 \text{ Watts}} = 74.3 \text{ MLPW}$$

Table 5.4 shows combinations of various lamps and ballasts (with two lamp ballasts; values for one-, three-, and four-lamp ballasts will be slightly different). Use this table to select T8 lamps and ballasts to meet the LPD and efficacy recommendations of Chapter 3. Low-wattage (“energy-saving”) T8 lamps may also be considered, but may result in lower ambient light levels or an increased number of fixtures or lamps to achieve recommended light levels. Because they cannot be dimmed and have other limitations, these lower wattage lamps are not recommended for new construction.

EL3 *Fluorescent T5 Sources* (Climate Zones: all)

As an alternative to T8 lamps, T5HO and T5 lamps may also be used. Standard T5 lamps offer at least 85 MLPW with any ballast (their actual rating is greater than 90). T5HO lamps offer at least 75 MLPW on any ballast, including dimming ballasts, but because of their high output, they offer superior overall performance in several key applications.

Other than size, the key difference between T5 and T8 lamps involves performance at rated temperature. T5 lamps reach peak light output and efficacy when surrounding air is 35°C (about 95°F) compared to 25°C (77°F) for T8 lamps. In other words, T8 lamps are better suited for suspended classroom lighting systems; T5 and T5HO lamps are better suited for enclosed luminaires and for luminaires in tall spaces, such as gyms.

An advantage of T5s is reduced use of natural resources (glass, metal, phosphors) in the lamp, plus the ability to use smaller luminaires than comparable T8 systems. However, because of their smaller size, the brightness of T5 and T5HO lamps is significantly higher than that of T8 lamps and may be a concern in open luminaires.

EL4 *Compact Fluorescent* (Climate Zones: all)

To achieve the LPD recommendations in Chapter 3, compact fluorescent lamps (CFLs) can be used for a variety of applications, such as utility lighting, downlighting, and wall-washing. Suitable lamps include twin tube, multiple twin tube, twist tube, and long twin tube lamps. Only pin-based CFLs are included in this group, since a screw-based lamp can be replaced with an incandescent lamp and is therefore not compliant with most energy codes. Suitable luminaires have integral hard-wired electronic ballasts.

Because the efficacy of CFLs is only 30–60 MLPW, they should not be used for general lighting in most space types. To meet the efficacy requirements of this Guide, some CFL-and-ballast combinations must be avoided (see Table 5.5).

EL5 *Metal Halide* (Climate Zones: all)

To achieve the LPD recommendations in Chapter 3, metal halide lamps may be used for general lighting in large spaces, outdoor lighting, and for accent lighting and wall-washing in low wattages. In the metal halide family, there are two primary types: ceramic metal halide (CMH) lamps and quartz metal halide (QMH) lamps. Both types

Table 5.5. System Efficacy of CFL-Ballast Systems

Lamp Type	Magnetic Ballast and Pre-Heat Lamp (2 Pin Lamps with Integral Starters)	Electronic Ballast (4 Pin Lamp) (Program Start Except † Instant Start)
5–13 W Twin Tube	All < 50	52–57 (13 W only)
10–26 W Double Twin Tube	All < 50	13 W 57† 18 W 52 26 W 53
13–42 Watt Triple and Quad Twin Tube and Most Twist Tube Lamps	N/A	13 W 53† 18 W 53 26 W 55 32 W 51 42 W 57
2D	28 W < 50	28 W 63
Long Twin Tube	18 W < 50 24/27 W < 50 36/39 W < 50	18 W 46
	40 W 53	24/27 W 61 36/39 W 64 40 W 60

Does not meet efficacy criteria

Meets 50 MLPW efficacy criteria for utility and special are high-intensity discharge lamps in which intense light energy is generated inside an arc tube made either of ceramic or quartz glass. The two types are comparably efficient. CMH lamps have very good color in the warm (3000 K) and neutral (4000 K) ranges; QMH lamps' color rendering quality is mediocre except in high color temperature lamps (5000 K and above).

Metal halide lamps may be further distributed into low-wattage (150 W and lower) and high-wattage (higher than 150 watts). All low-wattage lamps are "pulse start" and can be operated on either magnetic ballasts or more efficient electronic ballasts. High-wattage lamps are available in both probe start (less efficient) and pulse start (more efficient). Just recently, electronic ballasts have become practical for indoor use of pulse start metal halide; most ballasts for high-wattage lamps are magnetic.

With metal halide lamps, their apparent high efficacy is often undone by their high rate of lumen depreciation. Probe start metal halide lamps operated on magnetic ballasts will lose more than 45% of their rated lumen output over life; with pulse start lamps, the losses are at least 35% on magnetic ballasts but can be reduced to only about 20% by using electronic ballasts. Because MLPW take lumen depreciation into account, the type of ballast plays a significant role in system efficacy. As a result, a number of lamps and ballasts do not meet the efficacy criteria, as shown in Table 5.6 (not a comprehensive list).

Note:

- Metal halide lamps require a warm-up time and restrike time of up to 15 minutes if turned off during operations. Therefore, a supplemental emergency source is required that will provide light during the restrike time.
- Color consistency in appearance (color temperature) may be a problem, as QMH lamps age, especially if used in an indirect luminaire.

EL6 *Occupancy Sensors* (Climate Zones: all)

Use occupancy sensors in all classrooms, offices, mechanical rooms, restrooms, and special-use spaces like music practice rooms. The greatest energy savings are achieved with manual ON/automatic OFF occupancy sensors if daylight is present. This avoids unnecessary operation when

Table 5.6. System Efficacy for Metal Halide Lamp-Ballast Systems

Lamp	Type	Magnetic Ballast	Electronic Ballast (Minimum Efficacy, Some Ballasts Will Be Higher)
35/39-Watt CMH	Pulse start only	43	53
50-Watt QMH	Pulse start only	33	40
70-Watt CMH	Pulse start only	45	51
100-Watt CMH	Pulse start only	51	60
150-Watt CMH	Pulse start only	59	67
175-Watt QMH	Probe start	41	NA
	Pulse start	62	66
400-Watt QMH	Probe start	51	NA
	Pulse Start	71	75
400-Watt CMH	Pulse Start	72	76

Legend: Does not meet efficacy criteria | Meets 50 MLPW efficacy criteria for uility | Meets 75 and 85 MLPW efficacy electric lights are not needed and greatly reduces the frequency of switching. In non-daylighted areas, ceiling-mounted occupancy sensors are preferred. In every application, the occupant should not be able to override the automatic OFF setting, even if it is set for manual ON. Unless otherwise recommended, factory-set occupancy sensors should be set for medium to high sensitivity and a 15-minute time delay (the optimum time to achieve energy savings without excessive loss of lamp life). Review the manufacturer's data for proper placement and coverage.

The two primary types of occupancy sensors are passive infrared (PIR) and ultrasonic. PIR sensors can see only in a line-of-sight and should not be used in rooms where the user cannot see the sensor (e.g., storage areas with multiple aisles, restrooms with stalls). Ultrasonic sensors can be disrupted by high airflow and should not be used near air duct outlets. Dual-mode sensors that combine PIR with another technology, such as ultrasound or audible noise, should be considered for problem areas. The best solutions use both technologies.

Note:

- Motion sensors should not be used with high-intensity discharge (HID) lamps because of warm-up and restrike times.
- Fluorescent lamps and CFLs should use program start ballasts if short ON/OFF cycles are expected.
- In classrooms, consider a timer bypass for the motion sensor to prevent lights flashing when only the teacher is present and working quietly.

EL7 *Exit Signs* (Climate Zones: all)

Use LED exit signs or other sources that use no more than 5 W per face. The selected exit sign and source should provide the proper luminance to meet all building and fire code requirements.

EL8 *Circuiting and Switching* (Climate Zones: all)

In addition to the customary general lighting of classrooms, lighting and controls must now take into account the requirements of video images. For cost and other practical reasons, most classrooms will use a low-cost video projector connected to a personal computer, laptop, DVD, cable, or VCR. Teachers will use a combination of video and computer-generated images, ranging from slide presentations to recorded programs and streaming Internet, to teach classes at all levels. New schools should be designed with the anticipation of substantial daily classroom time with the lights dimmed and video replacing the white-board as the principal teaching medium.

This creates two substantially different "scenes":

- A "bright" scene in which classic qualities of classroom lighting and daylighting are appropriate. Light levels of 30–70 footcandles at every point, reasonably even surface brightness, and a cheerful feeling are the result of this type of design.
- An audiovisual (AV) scene in which the electric lighting and daylighting are controlled to limit the ambient light on the screen to less than 7–15 footcandles. This permits the average inexpensive projector to achieve at least 10:1 image contrast on an ordinary pull-down screen when it is properly sized for the room. Darkened ceilings and upper walls are essential, and daylighting must be controlled or eliminated. Use of darkening shades is generally recommended.

There are many ways to do this, but the challenge is to make the resulting situation as foolproof as possible. In particular, this involves the potential conflict between daylighting and the darkened AV scheme. There is the distinct chance that once shades are put in place for AV, they will be left there all day, effectively preventing daylighting. The preferred solution is to educate teachers about the importance of daylighting. An alternative and more foolproof solution is to use electrically operated shades that automatically retract when lights are turned on for the bright scene; unfortunately, this is considered too expensive for most projects. Another approach, designing the room for AV concurrent with daylighting, is very difficult to do and forces some very specific architectural decisions that some projects cannot include.

The California Public Interest Energy Research (PIER) research project addressed this situation and contains a number of reports and research data. For more information, see "Project 4.5: Integrated Classroom Lighting Systems—Goals and Objectives in the Advanced Lighting Luminaires and Systems Project Descriptions" at http://www.archenergy.com/lrp/index.htm.

For most other spaces in an education facility, the controls for switching and dimming of the lighting system should *not* be readily accessible. The controls should be located in a supervised location or one that is accessible by the building staff only. General use spaces, such as corridors, should be controlled by a time of day scheduling system and may be integrated with daylight harvesting. For gymnasiums and multipurpose rooms, consider a modern preset dimming or control system, especially if touch-screen control and other modern AV interfaces are planned.

For assembly spaces, the room needs to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system that can provide egress lighting for at least 90 minutes. The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires the use of automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.

EL9 *Electrical Lighting Design for Schools* (Climate Zones: all)

The 1.1 W/ft^2 LPD (shown in the recommendation tables in Chapter 3) for the non-daylighted options in climate zones 1, 2, and 5–8 represents an average LPD for the entire building. Individual spaces may have higher power densities if they are offset by lower power densities in other areas.

In climate zones 3 and 4, the recommended LPD is 0.9 W/ft^2. In these zones, the lighting load is a higher percentage of total energy use caused by smaller heating and cooling loads and must be reduced further to meet the whole building savings of 30%. The lighting savings for the non-daylighted option result from the higher performance electrical lighting system.

The daylighted options use a slightly higher LPD of 1.2 W/ft^2, as shown in Chapter 3. The increased LPD is recommended for the daylighted options because the lighting savings result from the lights dimming or turning off from the daylight rather than an aggressive lighting power reduction.

EL10 *Classroom Lighting* (Climate Zones: all)

Classrooms are typically designed for a single lighting scene in which conventional classroom lighting levels are maintained, and the lights are turned off for AV uses. However, classroom lighting design is changing rapidly because of computers and the Internet. The approach addressed in this Guide is to design classrooms with two lighting scenes: one for general lighting and one where stray lighting is controlled to permit maximum AV screen contrast. This approach specifically addresses classrooms where advanced teaching technologies (computers, video, computer projection, etc.) are to be used, but is appropriate for all classroom types.

For best results, provide a flat, white acoustical tile or gypsum board ceiling at least 9 ft 6 in. above the finished floor with a direct/indirect suspended lighting system. By using a classroom lighting system designed for this application, including energy-efficient ballasts and controls (see EL2), the lighting system can operate at an LPD lower than 1.0 W/ft^2, including supplemental whiteboard lighting. Choosing among the many options includes consideration of the grade level, teaching technology, budget, and whiteboard relevance.

Classroom lighting can be accomplished by using luminaries with indirect distribution, direct distribution, or a combination of both. These options include the following:

- *Direct*, in which all of the light is radiated downward. Direct lighting systems tend to have high efficiency but produce light of fair-to-poor visual comfort. Uniformity and shadowing problems can also result from direct lighting.
- *Indirect*, in which all the light is radiated upward, and, in turn, reflected downward by the ceiling. Indirect lighting systems are generally less efficient than direct lighting systems but usually produce light of superior quality, visual comfort, and uniformity.
- *Direct-indirect*, in which approximately equal (40%–60% to 60%–40%) amounts of light are radiated downward and upward. In general, direct/indirect lighting is used to provide comfortable but efficient illumination in spaces of medium room cavity ratios such as libraries and offices.
- *Semi-indirect*, in which a modest amount of light is directed downward (10%–40%) and a larger amount of light is directed upward (60%–90%). In general, semi-indirect lighting is used in large spaces, such as open office areas and classrooms, to provide comfortable lighting with relatively high efficiency.
- *Semi-direct*, in which a modest amount of light is directed upward (10%–40%) and a larger amount of light is directed downward (60%–90%). In general, semi-direct lighting is used in spaces with very high ceilings, low-reflectance ceiling surfaces, and open structures that result in poor ceiling cavity reflectance.

Lack of visual comfort has been identified as a major complaint of almost all direct lighting systems. The principal cause of discomfort is the contrast between a very bright luminaire and a comparatively dark adjacent ceiling. There is no way that a direct luminaire, including the so-called “recessed indirect” basket luminaires, can produce indirect light onto the ceiling to reduce this contrast. Totally indirect luminaries do provide a soft, glare-free lighting quality, but do not provide three-dimensional modeling and sparkle for visual interest. Therefore, suspended luminaries that provide a combination of indirect and direct distribution should generally be used. Low ceiling applications would be the exception.

Current products offer a wide range of quality, performance, and appearance. For projects on tight budgets, formed steel indirect luminaires are sufficiently inexpensive and efficient to compete with parabolics and many other types of lay-in direct lighting. For projects with slightly higher budgets, designers can choose from a variety of attractive, high-performance lighting systems.

These lighting systems are typically suspended 15–18 in. from the ceiling, depending on the specific luminaire. If the ceiling is not at least 9 ft 6 in., special consideration should be made.

Pendant indirect or direct/indirect lighting systems are particularly well suited for integration with daylight systems, since both approaches require higher ceilings and secondary reflective surfaces. In daylighted rooms, pendant systems should be run parallel to the primary windows or daylight source so they can be switched or dimmed in response to daylight gradients. In a classroom, three rows of pendants will allow a more gradual response to daylight than two rows. Daylight controls can then switch or dim each row separately. This would be the preferred choice if the budget allows.

For classrooms in which advanced teaching technologies, such as video and computer projection are to be used, the lighting system should provide two scenes, one for general lighting and one in which stray light is controlled to permit maximum screen contrast. This approach may also be used for all classroom types and is valid in primary classrooms where the ability to create a darkened room, such as for student calming and story time, is desired. Pendant luminaires equipped with optical controls or dimming ballasts allow relatively precise low-light level settings. The general lighting system should not exceed 1.1 W/ft^2, and the highly controlled lighting system should use less, with switching to prevent simultaneous use.

This system lends itself to three principal control scenes, as follows:

- *Night, general lighting scene.* All general lighting system lamps on.
- *Daytime, general lighting scene.* General lighting system lamps affected by available daylight, either switching or dimming. Switched daylighting scenes can be created by switching luminaire rows or rows of lamps.
- *Any time, low-level scene.* General lighting lamps off, controlled downlight lamps on or on with manual dimming controls. In a single lamp direct/indirect system, dimming to low level with extinguishing of luminaire closest to the screen is encouraged.

Acceptable performance can also be achieved with a direct/indirect luminaire with dimming, provided that the closest row of luminaires to the screen is switched off in the AV mode.

The key to achieving a suitable design is to reduce the ambient light level on the projection screen to 7–15 vertical footcandles or less. Some daylighting systems will create too much vertical illumination, so the ability to darken the room with shades is critical. However, even at night, a generic indirect lighting system tends to produce relatively high levels of vertical illumination. Simply switching off the lights in the front half of the room fails to reduce light levels on the screen enough—typically there will still be 6 to10 footcandles of vertical illumination on the screen in this condition—so with the exception of very low budget projects in which screens are a minor consideration, this guideline should be followed.

As the use of the teaching board evolves, it remains an important part of education at all levels. Studies have

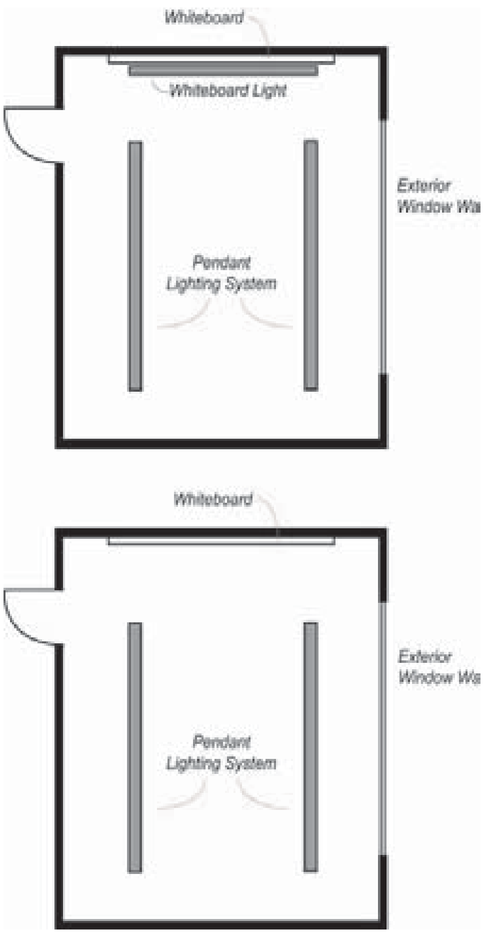


Figure 5.2. Recommended lighting system with (top) and without (bottom) whiteboard light.

shown a correlation between illumination of the teaching surface and retention of information. Researchers at the University of Illinois, Urbana, in studying the modern (2003) integrated classroom environment, determined that “attractors” aided in the learning process and “detractors” had the opposite effect. If the teaching board is used, additional lighting—with either normal lighting or in a dimmed setting for the rest of the room—serves as a significant “attractor.” Energy use is about the same, but the slightly more expensive system with board light (see Figure 5.2) is recommended for improved student attention with board activities.

To coordinate with a ceiling-mounted computer video projector, two rows of luminaires are recommended for classrooms up to about 30 ft wide, as shown in Figure 5.2. (For larger classrooms, consider these principles and make the necessary adjustments.)

Note:

- *Low Ceiling Solutions.* If the ceiling is lower than 9 ft and suspended fixtures may be accessible to students, recessed lighting “troffers” should be considered. The most efficient recessed lighting systems use T5 lamps with special lenses and reflectors to minimize glare (see Figure 5.3). Troffers are more efficient than pendant lighting systems, but produce light that is less comfortable and makes AV integration more difficult. The use of stepped or full dimming ballasts is recommended, and for better AV integration, switch the back of the room separately from the front.

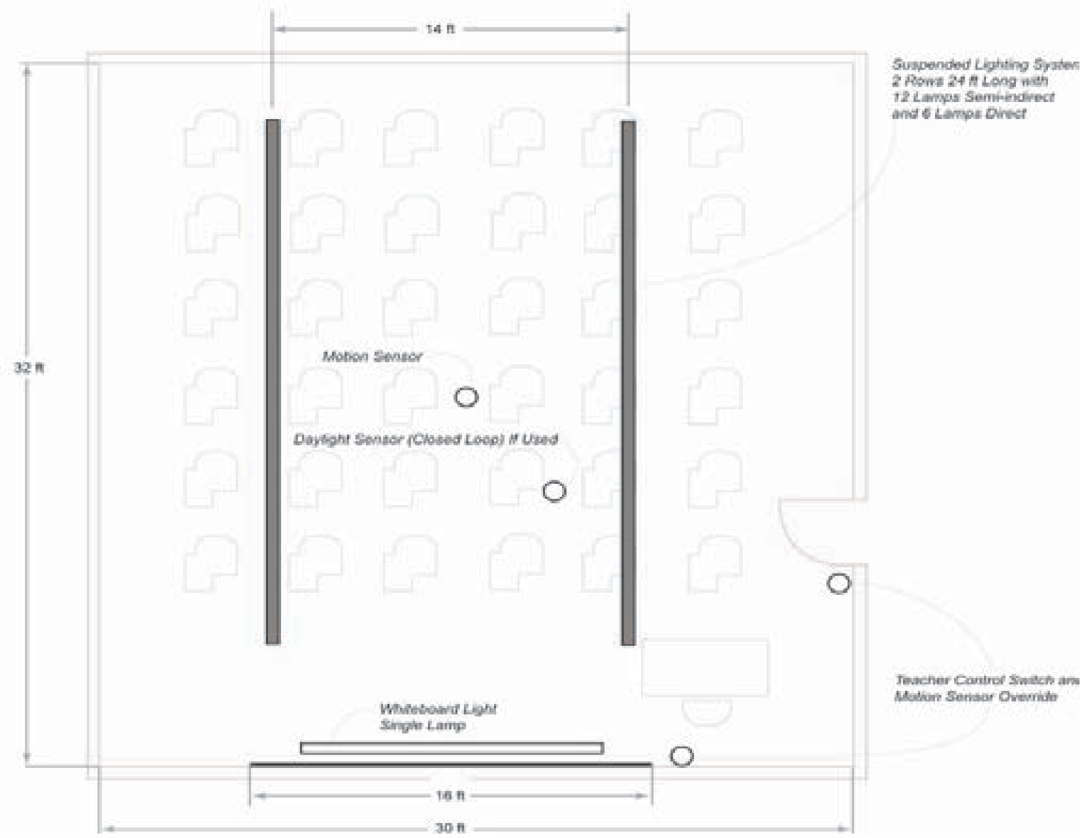


Figure 5.3. Classroom lighting design.

EL11 *Gym Lighting* (Climate Zones: all)

Most school gyms are simple, high- bay structures with open trusses or bar joists. Whenever possible, a combination of daylighting and electric lighting is desirable, but for many reasons electric lighting will be the principal design solution.

Daylighting design is especially well suited to the high ceilings and large open space of gymnasiums. Skylights over the center of the playing area, just like downlights, are preferred. Wall wash toplighting or high sidelighting with light shelves or louvers can be effective techniques for gyms, but care must be used to prevent very bright surfaces. Direct sun penetration into gyms should be prevented at all times. See DL36 and DL37 for further gym/multipurpose daylighting guidance.

For electric lighting, high bay luminaires are easily attached to the structure, with the luminaires suspended within the "truss space," such that the bottom of the luminaire is flush with the lowest beam or truss member. In the rare instance where the gym has a finished ceiling, recessed lighting might be considered, but basic high bay lighting systems are by far the most common approach. The height of the gym space's ceiling plays a major role in choosing gym lighting systems. Most gyms will have a room cavity ratio (RCR) of about 2.5. By comparing the coefficient of utilization (CU) of luminaires being considered, an efficient lighting system can be selected. For most gyms, luminaires with spacing to mounting height of less than 1.4 is appropriate.

Fluorescent systems that use multiple T5HO or T8 lamps are preferred for ordinary gyms and other high ceiling spaces. Superior color, elimination of flicker, and the ability to turn lights on and off as needed are major advantages over HID systems. The added cost of the fluorescent system is offset by much lower energy use, estimated to be as much as 50% less if the multiple light level capability of a fluorescent system is used. Systems that use multiple CFLs also provide these benefits, although without the high efficacy of the linear fluorescent lamps.

In general, metal halide high bay lighting systems tend to be more appropriate when ceilings are especially tall, such as in a field house. Long lamp life and a minimum number of luminaires keep costs down. The color of metal halide is suitable for television and everyday use. The long warm-up and restrike periods of metal halide lighting are drawbacks, since switching lights off regularly is not recommended for these systems. Be certain to use pulse-start lamps. These systems are compatible with daylighted gyms if they have switched lighting levels.

A separate downlight system that uses halogen lamps is highly recommended for two reasons:

- It is an instant-ON, instant-OFF system that can be dimmed inexpensively. This feature is especially important if metal halide lights are accidentally extinguished, as they will require a 5–10-minute cool-off and restrike delay.
- A dimmable tungsten downlighting system can make the gym more appealing for social events, and can serve as a "house" lighting system for many of the gym's performance and entertainment uses.

Note:

- Lighting quality is a crucial issue in gym spaces. Avoiding direct view of an extra bright light source, such as a metal halide lamp, high output lamp, or skylight, can be especially critical in a gymnasium where athletes must scan for the ball and react quickly. Even though a luminaire may normally be out of the line of sight, it can still create a devastating glare to a volleyball or basketball player.
- Choose luminaires with shields to protect lamps from inadvertent damage by sports equipment.

- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system that can provide egress lighting for at least 90 minutes.
- The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires an automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.
- Switching and dimming of the lighting system should *not* be readily accessible. Locate controls in a supervised location.
- Consider a modern preset dimming or control system, especially if touch-screen control and other modern AV interfaces are planned. Typical gym lighting systems and patterns are shown in Table 5.7 and Figure 5.4.

EL12 Lighting for a Multipurpose Room (Climate Zones: all)

Because multipurpose rooms often serve as cafeterias, study halls, social gathering spots, special event spaces, community meeting halls, and AV facilities, the lighting and controls must provide proper operation for every intended use of the room.

Multipurpose rooms can be successfully daylighted, either from high clerestories or toplighting approaches. However, near-blackout capability for the daylight system is probably most important in this type of space, so operable louvers or blinds are highly recommended. If the daylight system can be reduced to a minimum of 1–3 footcandles, most reduced light functions, including stage performances, can operate effectively. A small amount of sunlight can be a cheerful presence in a multipurpose room used as a cafeteria, as long as it can be blocked when needed. See DL36 and DL37 for further multipurpose room daylighting guidance.

At a minimum, a multipurpose room should have at least two independent lighting systems:

- A general lighting system that provides 20–30 footcandles of uniform illumination with standard T8 lamps
- A dimmable “house lighting” system that supports AV and social uses of the room, producing no more than five footcandles

Table 5.7. Gym Lighting Systems

Applications	Lighting Systems	Lamp Watts (Fixture Input Watts)	Spacing Area (Approx Grid)	Notes
PATTERN 1 HID Lighting	CMH or QMH metal halide lamp with proper electronic ballast ***Note:*** high frequency electronic for QMH and low frequency electronic for CMH	250 (275) 320 (345) 350 (370) 400 (425)	306 (17 ft × 18 ft) 383 (19 ft × 20 ft) 411 (20 ft 6 in. × 20 ft) 472 (21 ft 6 in. × 22 ft)	Mounting height at least 20 ft AFF. Set lamp height for proper spacing criterion (<1.1 W/ft^2)
PATTERN 2 High Bay Fluorescent T5HO	T5HO with high bay reflector system and ballast designed for at least 60°C ambient temperature and 80°C case temperature in a properly designed luminaire with spacing criterion of <1.3	(4) T5HO with BF = 1.0 IS ballast (226 W) (6) T5HO with BF = 1.05 IS ballast (344 W)	251 (16 × 15 ft, 9 in.) 382 (19 × 20 ft)	Mounting height at least 20 ft AFF Choose reflector for proper spacing criterion (<1.1 W/ft^2)

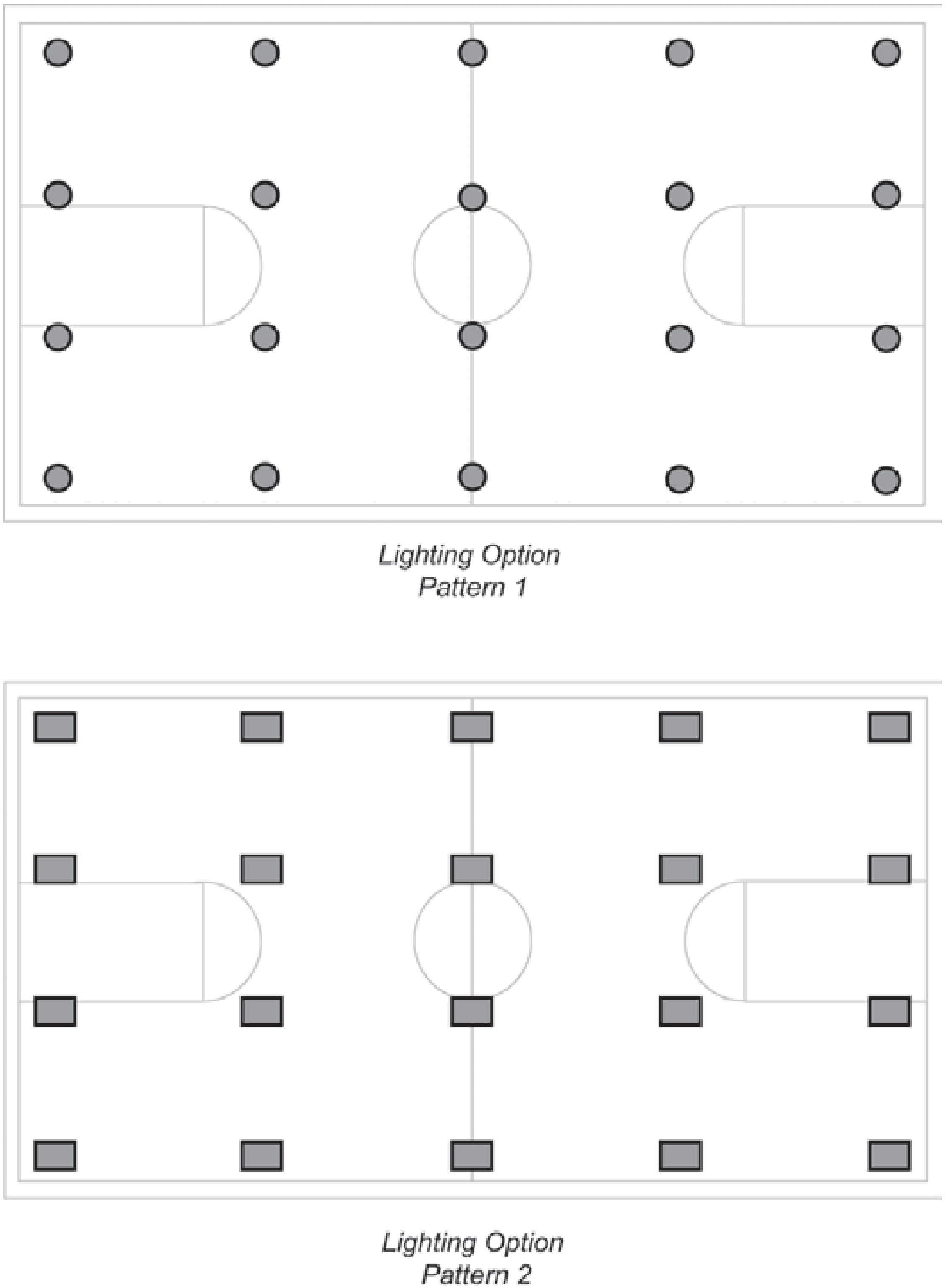


Figure 5.4. Gym lighting patterns.

In addition, theatrical lighting may be added to illuminate specific stage or performance locations. The lighting used for performance only is exempt from the LPD recommendations.

For the general lighting system, consider one of the types previously suggested for classroom lighting. If suspended luminaires are chosen, be careful to locate luminaries so as not to interfere with AV and other uses of the room. If the room use includes any sports or games, all lighting systems should be protected from damage.

For the house lighting system, consider recessed or surface downlights. Halogen lighting is recommended for its superior color, inexpensive dimming, and good light control. Luminaires should use standard infrared (IR) halogen parabolic aluminized reflector (PAR) lamps or T6 lamps. The lighting beam patterns should overlap at head height to provide excellent uniformity for a variety of functions. Black baffles or cone trims are recommended for AV applications. The house lighting system should be laid out to prevent light from striking walls or screens. Some general lighting systems might also serve as the house lighting system if properly laid out and equipped with electronic dimming ballasts, but most general lighting systems generate too much diffuse light, even when dimmed, for AV use and some social functions.

In general, two separate lighting systems, with one being a dimmed halogen system, is the most cost-effective. A single fluorescent lighting system with dimming system is usually more costly and less flexible.

A control system that activates the general lighting system according to a calendar program and employs motion sensing for off hours should be used. Rooms with plentiful daylight should have automatic daylight switching or dimming to reduce electric lighting by day. A manual override switch should be provided. Manual dimming of the house lighting system should be provided along with an interlock switch preventing simultaneous operation of both general and house lighting. Consider placing the lighting in zones that have individual manual override switches to permit an unoccupied zone to be deactivated.

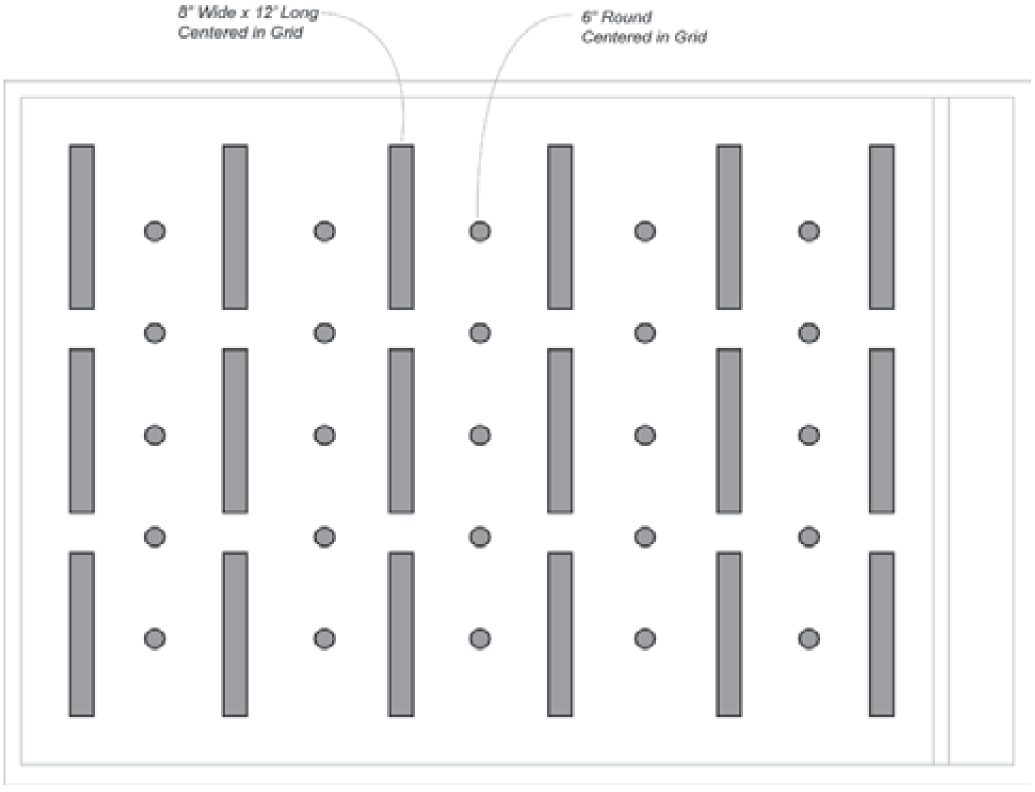
Figure 5.5 shows a typical multipurpose room with two lighting schemes. Figure 5.5a shows pendant-mounted luminaries, and Figure 5.5b shows recessed troffers. Both schemes have a separate system of downlights to serve as “house” lights for social and AV use.

Note:

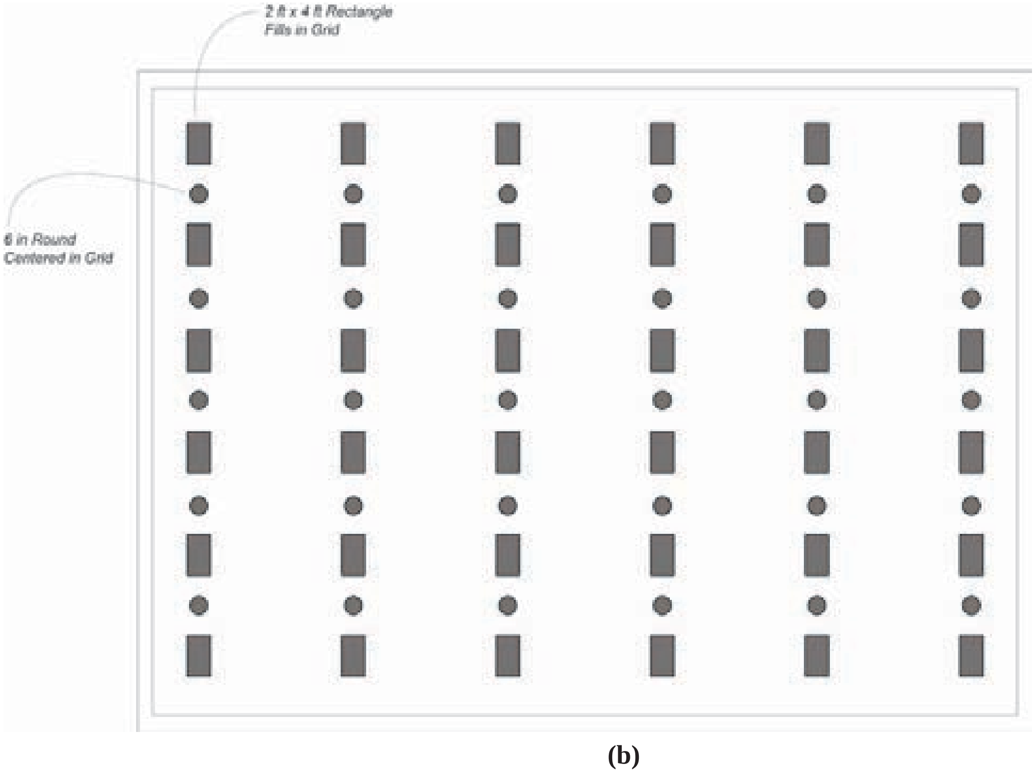
- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress.
- The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires use of automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.
- Switching and dimming of the lighting system should *not* be readily accessible. Locate controls in a supervised location.
- Consider a modern preset dimming or control system, especially if touch-screen control and other modern audio/video interfaces are planned.

EL13 Lighting for a Library or Media Center (Climate Zones: all)

The library or media center is a multipurpose space with a variety of tasks; therefore, it is an excellent space to consider a task ambient lighting system. Daylight is an excellent choice for providing basic ambient light in a library. Reading areas and storytelling niches especially benefit from gentle daylight and view windows. With thoughtful



(a)



(b)

Figure 5.5. (a) Multipurpose room indirect/direct lighting option and (b) multipurpose room direct lighting option.

daylight design, only the task lighting at checkout desks or stack areas needs to be on during the day. In addition, these can be connected to occupancy sensors to reduce their hours of operation.

Provide lighting for a library as follows:

- A lighting system with standard T8 lamps that provide 20–50 footcandles of general illumination in casual reading, circulation, and seating areas
- Overhead task lighting at locations such as conventional card files and circulation desks; in libraries where these tasks have been computerized, the general lighting system will provide proper illumination without overhead task lighting
- Task lighting (CFLs or T8 lamps) at carrels and other obvious task locations
- Stack lights with T8 or T5 lamps in areas where stack locations are fixed, and general overhead lighting in areas with high-density stack systems
- Special lighting for media rooms, as required

The general lighting system may be one of the types previously suggested for classroom lighting (EL10). With adequate ceiling height, suspended lighting systems are preferable. Overhead lighting systems for task locations should also be selected from among choices suitable for classrooms or offices. The general lighting system can be designed to become more “dense” in task areas such as circulation desks, thus minimizing the number of luminaire types. Or this may be an area where supplemental specialty luminaires are added for the additional benefit of navigating through the space.

Task lighting at carrels and other locations should be selected according to architecture and finish details. Two common options include the following:

- Under-shelf task lights with high color rendering T8 or T5 lamps
- Table or floor lamps equipped with CFLs up to 40 W

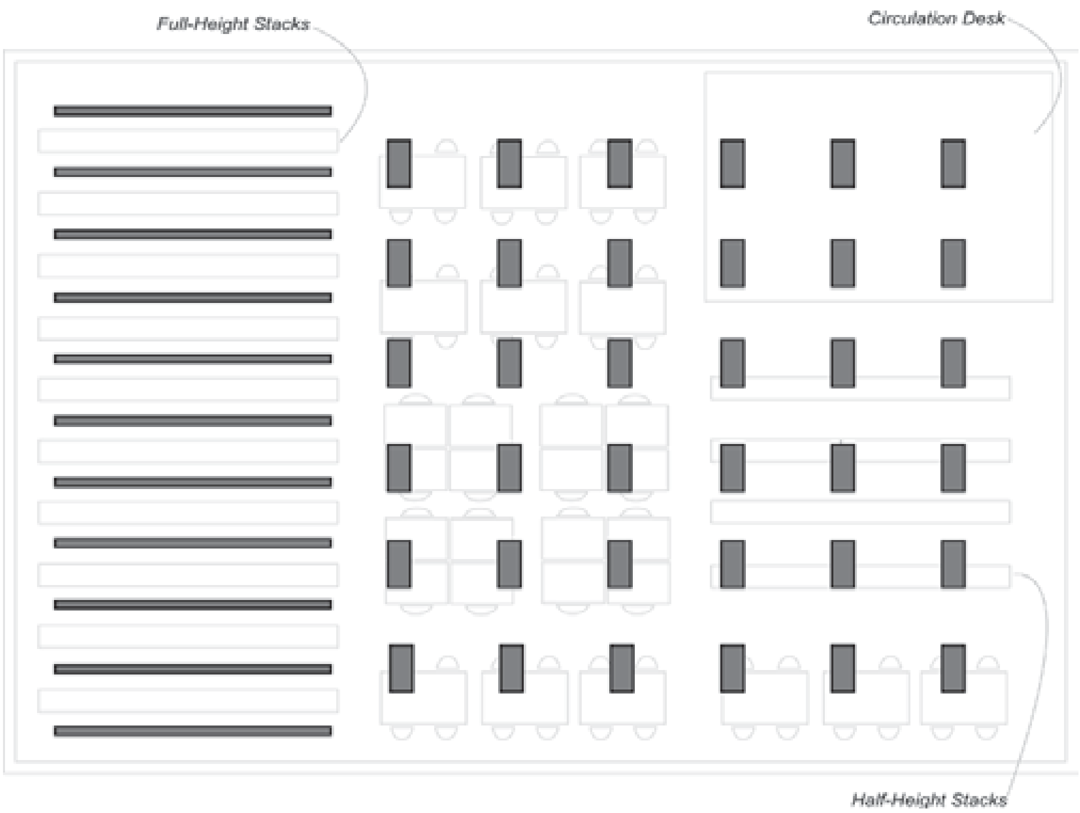
Stack lighting should use luminaires that are specifically designed for lighting stacks. There are several choices, but generally, a single continuous T8 or T5 lamp system will provide adequate illumination. Where the stack locations need flexibility (stacks relocated or placed off axis), an indirect lighting system or a linear stack light mounted from the stacks will provide the most flexibility.

Media rooms for video monitoring and editing, sound monitoring and editing, distance learning, and video teleconferencing have special requirements. Lighting must be designed to meet those specific needs and lighting controls must be provided to enable the room to be used for the varying needs.

Figure 5.6a shows a typical library lighting design. The design illustrates general lighting that uses troffers, table lights for study desks, task lights at kiosks, and stack lights. Using high ballast factor two-lamp troffers, this design works at an overall power density of 1.27 W/ft^2. Increasing stack lights to a high ballast factor increases overall connected power to 1.38 W/ft^2. The stacks to the right on the plan are half height. Figure 5.6b shows an indirect/direct lighting option for a library.

Library spaces tend to be among the most expensive to light. These recommendations provide a good balance between cost, energy efficiency, and good lighting practice.

A control system that activates the general lighting system according to a calendar program and uses motion sensing for off hours should be used. In areas with plentiful daylight, use automatic daylight switching or dimming to reduce electric lighting by day. In addition, in areas such as reference stacks that are less frequently used, consider providing individual motion sensors or digital time switches for stack aisles that are connected to dimming ballasts, producing low light levels (but not completely off) until



(a)

(b)

Figure 5.6. (a) Typical library lighting design and (b) library indirect/direct lighting option.

the aisle is occupied. Individual reading and study rooms should use motion sensors, with personal motion sensors and plug strips should be used at study carrels, especially those with fixed computers.

Note:

- As a place of assembly, the room needs to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system that can provide egress lighting for at least 90 minutes.
- The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires an automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.
- Switching and dimming of the lighting system should *not* be readily accessible. Locate controls in a supervised location.
- If the library has computers for research or card catalog searches, special care should be taken to avoid glare sources on the computer monitors from light fixtures or windows.
- Under-cabinet task lights should be specified carefully. Avoid traditional "inch light" systems with magnetic ballasts that use twin-tube CFLs and old-style linear lamps like the F6T5 (9 in.), F8T5 (12 in.), and F13T5 (21 in.). Use task lights employing modern F14T5 (22 in.), F21T5 (34 in.), F28T5 (46 in.), F17T8, F25T8, or F32T8 lamps. Always use electronic ballasts, and consider dimming for all task lights.
- Desk lamps and table lamps with linear fluorescent lamps or hardwired CFLs should be used. Medium based screw-in CFLs are not a good choice for new projects, since they can be replaced with incandescent lamps and therefore do not comply with most energy codes.

Technology Case Study:
Salem Middle School, Apex, NC

Salem Middle School in Apex, North Carolina, is a 158,000 ft^2 building completed in 2003. High-performance design features included in the design are the daylighting in common areas and photosensors that control interior lights in the daylit areas. T8 lamps and electronic ballasts are used to light the school. Figure S1-1 shows how clerestories/light monitors were used to provide daylighting for the media center.

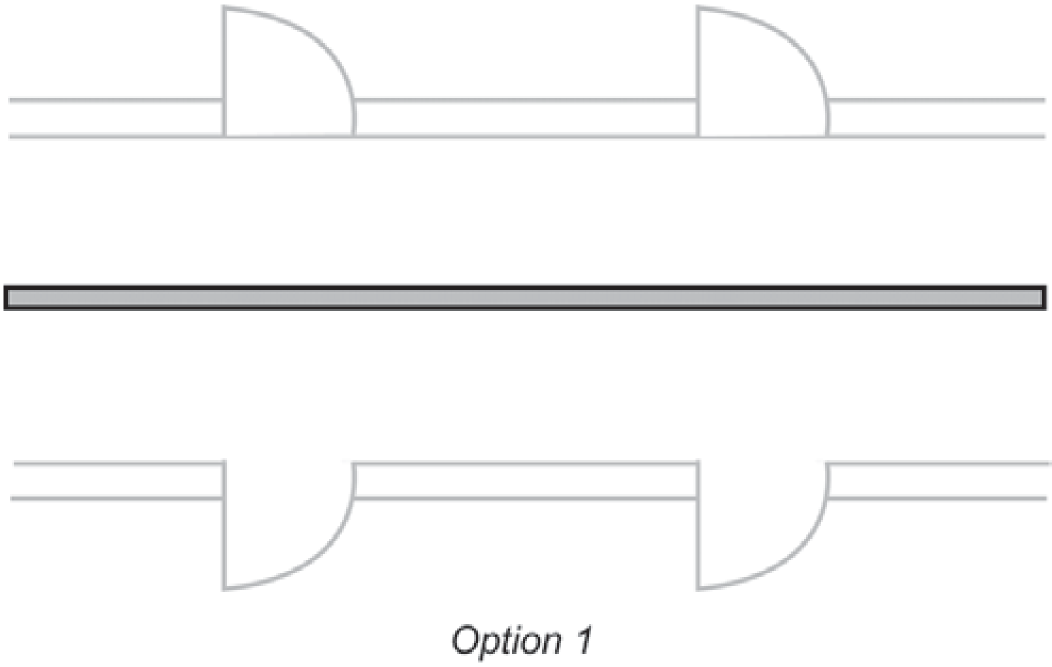
Figure S1.1. Media center daylighting.

EL14 Corridor Lighting (Climate Zones: all)

Corridor lighting in schools must provide lighting for wall-mounted lockers and information boards in addition to the normal corridor function. Vertical illuminance is important for these tasks and the corridor lighting system should provide light at high angles. Luminaires should be aligned parallel to the corridor walls to provide good quality light and to make light useful for lockers.

Given the choices of luminaires, an attractive solution that is suitable for any type of corridor ceiling construction, including indoor and outdoor corridors, acoustical tile or gypsum board ceilings, etc., should be possible.

Corridors are generally excellent spaces for daylighting. Furthermore, daylight in corridors provides an important safety feature of guaranteed lighting during any day-



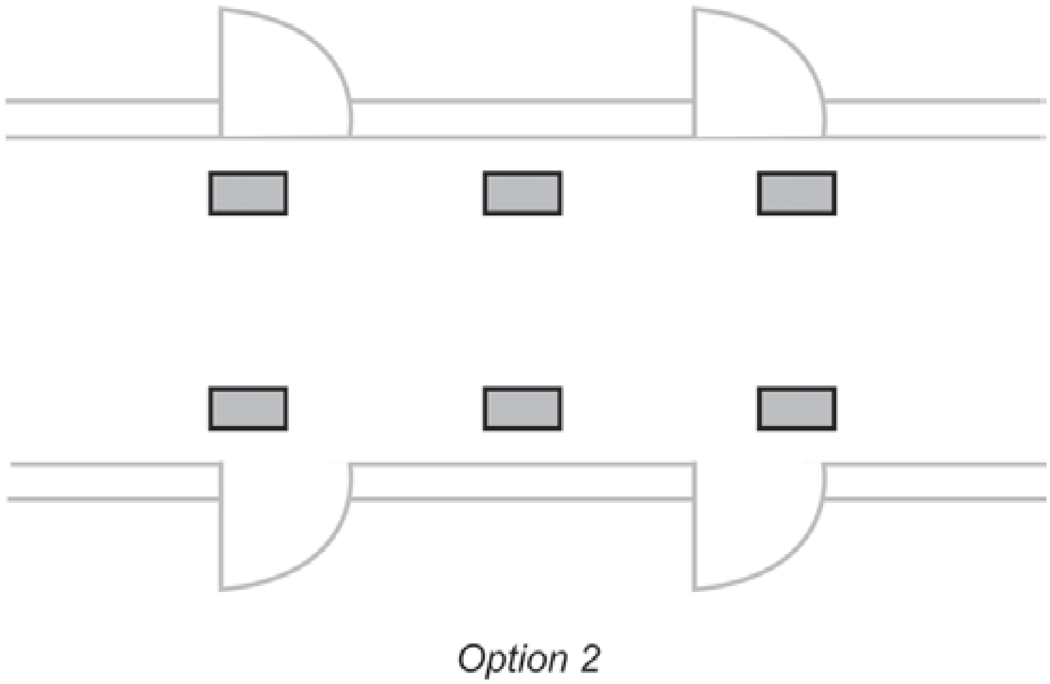


Figure 5.7. Corridor lighting options.

time emergency. For single-story or top-floor corridors, linear toplighting is especially appropriate. For corridors not directly under a roof or adjacent to an exterior wall, pools of light from intermittent sidelighting or toplighting borrowed from the floor above can create important social spaces, with higher levels of illumination than that provided by the electric lighting system. Daylight introduced at the end of a long corridor can have a glaring effect, making the corridor feel more like a tunnel. Daylight introduced from the side or above is generally more effective and has less glare. As with electric lighting, illuminating the corridor walls should be the primary objective. Several lighting systems are available:

- With high ceilings, a suspended lighting system similar to the classroom or library lighting may be used with an indirect or indirect/direct distribution.
- Interior corridors may use "recessed indirect" luminaires that should be oriented with the lamp along the corridor long axis. This design is suited for all ceiling types.
- As an alternative, especially for schools where vandalism is a concern, use surface ceiling wraparound luminaires, preferably vandal-resistant or high abuse types.
- Exterior corridors should use surface-mounted wraparounds or ceiling-mounted, high-abuse luminaires. In some cases, wall-mounted, high abuse luminaires may be acceptable.

Luminaires should use T5 or T8 lamps and electronic ballasts. Outdoor corridors and corridors with plentiful daylight should use automatic daylight switching or dimming to reduce electric lighting by day. Figure 5.7 shows typical lighting options for corridors.

Note:

- Ensure that the luminaires are not overly "institutional" in appearance. If required by the application, choose one of many modern "rough-service" luminaires that are attractive and durable.
- In general, recessed downlights have insufficient vertical illumination to provide good service in corridors. However, recessed downlights that use CFLs may be preferred for lobbies and similar applications where a dressier appearance is desired.

- The corridors need to be equipped with an emergency lighting system that can produce at least one footcandle, on average, along the path of egress. The controls must be designed such that, if a power emergency occurs, the proper lights are illuminated regardless of setting. This often requires an automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.
- Switching of the lighting system should *not* be readily accessible. In general, switching should use an automatic time-of-day control system with motion sensor override during normal off hours, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Technology Case Study: Salem Middle School, Apex, NC

Salem Middle School in Apex, North Carolina, is a 158,000 ft^2 building completed in 2003. High-performance features included in the design are the daylighting in common areas and photosensors that control interior lights in the daylit areas. T8 lamps and electronic ballasts are used to light the school. Figure S2.1 shows how clerestories/light monitors were used to provide daylighting in the corridors.

Figure S2.1. Corridor daylighting.

- In addition, provide automatic daylighting controls, including dimming or switching off lights in corridors having windows, skylights, or other forms of natural lighting.

EL15 *Lighting for Offices and Teacher Support Rooms* (Climate Zones: all)

The main office is another multifunction space. The administration staff provides services, including reception for visitors, reporting/record keeping (classroom lists, attendance records), support for the principal, support for the teaching staff, and care for students, when a nurse is not on site. As with most office workers today, computer work comprises a significant part of the day, and the lighting system must provide high-quality light.

In many schools the offices are located in the interior of the building and do not have windows to the exterior. The lighting system should provide some light on the vertical walls to help the space feel more open.

- With high ceilings, a suspended lighting system similar to the classroom or library lighting may be used with an indirect or indirect/direct distribution.
- For lower-ceiling office spaces, “recessed indirect” systems should be considered, as they provide visual comfort for the workers and light on the upper wall surfaces.
- For support areas, recessed fluorescent lens troffers with at least 78% fixture efficiency and using T8 premium lamps and electronic ballasts should be used.

Where offices are located on an exterior wall and daylight strategies are being implemented, the approach to daylighting control is similar to the classroom

For teacher support areas (making copies, work preparation) where computers are not in use, troffer lighting systems generally offer excellent efficiency but with some loss of visual comfort. They make excellent use of the low-cost, widely used T8 lamp system. Systems operating at about 1 W/ft^2 will generate 50–60 footcandles maintained average with very good uniformity. Separate task and ambient systems may create a more comfortable atmosphere.

For non-dimming applications, luminaire light and power can be varied by choice of ballast factor. Use the information in EL2, and specify ballasts accordingly.

Note:

- Lens troffer lighting systems are low cost, but their inexpensive appearance can be a drawback. Suspended lighting systems provide a high degree of cost-effectiveness and improved appearance in most applications.
- Recessed parabolics with a 45° cutoff provide glare control but will not provide light on the upper walls. This makes the office space seem dark.

EL16 *Lighting for Locker Areas and Restrooms* (Climate Zones: all)

These types of spaces are, historically, the most abused interior portions of school buildings. Durable lighting is unfortunately less attractive and less integrated than other lighting types.

Daylight is a welcome addition to any locker area or restroom. The high light levels from daylight promote good maintenance. For privacy and security reasons, daylight is often best provided in these spaces via diffusing skylights or other toplighting strategies. Often these spaces can be designed to need no additional electric light during the day.

This Guide generally recommends fluorescent luminaires that use standard T8 lamps or CFLs. These luminaires are part of a relatively new generation of vandal-resistant or "rough-service" lights that are considerably more attractive than previous products. These luminaires should be specified with UV-stabilized, prismatic polycarbonate lenses for maximum efficiency and resistance to abuse. Tamper-resistant hardware is also recommended. Wall mounted rough-service lights include the following:

- Linear lights that use T8 lamps and electronic ballasts
- Rectangular, oval, and round lights that can be equipped with CFLs (low-wattage HID lamps can also be used in these luminaires, but are not recommended)
- Recessed ceiling lights are generally troffers that use the polycarbonate lens and tamper-resistant hardware, as well as more robust components; these luminaires are available in 1 × 4 ft, 2 × 2 ft, and 2 × 4 ft versions with standard T8 lamps and electronic ballasts

For showers, use either surface or recessed luminaires designed for CFLs. Due to the long warm-up and restrike times, HID lamps should not be used. In either case, luminaires should be listed for wet applications.

In general, choose luminaires that are attractively styled to prevent an overly institutional appearance. For spaces that do not have daylighting, controls should perform in one of the following ways:

- Continuously on during normal school hours, with a night/emergency light on all the time.
- Continuously on during normal school hours, with both a night/emergency light on at all times and a motion sensor override for full lighting during off hours.

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Good Design Practice — Daylighting

DL1 *General Principles* (Climate Zones: all)

Daylighting is essential for the most energy-efficient and sustainable school design. Effective daylighting uses sunlight to offset electrical lighting loads. When properly designed, daylighting saves energy in lighting loads and reduces cooling loads. In addition to energy benefits, a number of studies have shown that daylight can also help improve learning.[2] From a student and teacher productivity standpoint, classrooms (particularly special needs classrooms) are the most beneficial spaces to daylight.

Daylighting must provide controlled, quality lighting. For daylighting to save energy, it must be "superior" to the electrical lighting. Otherwise, the habit of walking into a space

2. http://www.h-m-g.com/projects/daylighting/projects-PIER.htm

and turning on the lights will never be broken. Develop a daylighting strategy that will provide superior lighting for at least 50% of the hours of school operation. From an energy perspective, a daylighting strategy that is not quite good enough may not result in energy savings because the electric lights will not be turned off. If designed correctly, a daylighting strategy can reduce the following:

- Electricity for lighting and peak electrical demand
- Cooling energy and peak cooling loads
- Maintenance costs associated with lamp replacement

Cooling loads can be reduced by providing just the right amount of daylighting in a school. Because the lights are out, internal gains are reduced. The lumens per watt (efficacy) of a well-designed daylighting system is higher than that of electric lighting sources. In other words, to meet the same lighting need, daylighting produces less heat. However, to achieve this reduced cooling, the following criteria must be met:

- No more solar radiation is allowed to enter the building than is required to meet the lighting design criteria.
- Overhangs and other shading devices are properly sized to control solar radiation during peak cooling times.
- The electric lights, through the use of photosensors, are automatically dimmed or turned off.

DL2 *Consider Daylighting Early in the Design Process* (Climate Zones: all)

The most economic and effective daylighting strategies are very well integrated into the design from structural, mechanical, electrical, and architectural standpoints. To do it well, the many interrelated aspects of the school's architecture, landscape, and engineering must be considered. Properly integrated, mechanical cooling equipment can be reduced because overall cooling loads are reduced. To do so, the daylighting system needs to be optimized by developing a design to reduce peak cooling loads. This will allow for proper trade-offs between the daylighting and the sizing of the cooling system.

If properly integrated, common architectural components may serve dual functions, reducing first cost. An example is that white single-ply roofing can serve as a waterproofing membrane and increase radiation into a roof-mounted daylighting aperture (see DL30). Only a comprehensive, well thought-out-approach will provide a low-cost system that achieves the desired benefits.

The opposite is true without integrated design. If the daylighting system is designed and bid as an alternate, the daylighting strategy will probably not be nearly as cost-effective or resource smart. The problem arises if the designers think that the daylighting components will have a good chance of being eliminated. A designer with this mindset will be unlikely to risk designing a smaller mechanical cooling system, thinking that he or she may have to pay to redo the design.

The best way to guarantee a low-cost daylighting strategy is to fight against this instinct and integrate daylighting early in the schematic design phase. With good schematic design cost estimates that reflect the added daylighting components and the reduced cooling equipment and multi-use of building components, the designer will soon see that the net daylighting costs are very reasonable.

DL3 *Space Types* (Climate Zones: all)

Daylighting the classroom is most critical, since that is where the teachers and the students spend most of their time. In addition, the potential for savings is the greatest in the classrooms.

Table 5.8. Application for Daylighting Strategies

	Sidelighted Classrooms	Toplighted Classrooms	Sidelighted and Toplighted Classrooms	Toplighted Gym
Uniform Light Distribution	●	●●	●●	●●
Low Glare	●	●●	●●	●●
Top Floor/Single Story	●	●●	●●	●●
Middle/Ground Floors	●●	○○	○○	○○
Reduced Energy Costs	●	●●	●●	●●
Low First Cost	●	●	●	●
Cost-effectiveness	●	●	●	●
Low Maintenance	●	●	●	●

●● Etremely good application ● Good application ○○ Etremely poor application

Guidelines are also provided for the gymnasium/multipurpose room because this space is typically used for more hours. Specific guidelines are not provided, but daylighting should also be considered for the cafeteria, media center, administrative areas, and corridors.

DL4 *How to Select Daylighting Strategies* (Climate Zones: all)

For this Guide, four daylighting strategies are presented; three for classrooms and one for gymnasiums. For each strategy, there are several options and variations depending on climate and orientation. These strategies are designed to provide the recommended illuminance for the classrooms and gym over most of the occupied daytime hours.

These strategies are based on all classroom spaces being oriented so the windows face either north or south. Although daylighting can be achieved for other orientations, the recommendations in this document do not apply to those orientations. The four patterns are summarized below, and more specific information is provided in DL20–37. Table 5.8 summarizes the application criteria for each daylighting strategy.

- *Classrooms with sidelighting only.* Two variations of this are provided, one for north-facing and one for south-facing classrooms. South-facing classrooms are assumed to have overhangs and light shelves to bounce the daylighting deeper into the space.
- *Classrooms with toplighting only.* Only one option is provided for toplighting, which is a south-facing roof monitor positioned in the center of the space and coupled with light baffles to bounce and filter light.
- *Classrooms with a combination of sidelighting and toplighting.* This daylighting pattern combines the south- or north-facing classrooms described in the first bullet with top lighting at the back walls of the classrooms. The toplighting may be provided by either skylights or roof monitors, depending on climate and other design constraints.
- *Gyms with Toplighting.* Two variations of this daylighting pattern are provided, one with roof monitors and one with skylights.

DL5 *Recommended Daylighting Fenestration to Floor Area Ratios* (Climate Zones: all)

For view and a positive connection to the outdoors, provide view windows below the 7 ft height. East and west glass should be minimized, and shading should be provided on the south side. Overhangs and lightshelves are not needed on north view glass. See EN21 for more infor-

Table 5.9. Daylighting Fenestration to Floor Ratios

Daylighting Strategy	Classroom	Gymnasium/Multipurpose Room
South-Facing Roof Monitor	8%–11%	5%–8%
North-Facing Roof Monitor	12%–15%	7%–10%
South Light Shelf	8%–11%	
South Light Shelf with Blinds Between Glazing	15%–20%	
High, North Glazing	15%–20%	
Skylights		3%–5%
Tubular Daylighting Devices		2%–3%

mation. Glazing above 7 ft is designed to provide daylighting, and should be sized according to the daylighting fenestration to floor area ratios (FFR) in Table 5.9. These basic rules will help you determine the right amount of daylighting fenestration for particular systems. These numbers can be fine-tuned by using a daylighting analysis particular to the climate and the actual space configuration and use. These rules assume a VLT of the vertical daylighting fenestration of 65%–75%. For the horizontal daylighting fenestration (skylights), a 60% VLT is assumed. Further details about each daylighting strategy are provided in DL20–37.

DL6 *Separate View Windows from Daylighting Strategy* (Climate Zones: all)

In designing daylighting systems, the view glass must be separated from the daylighting glass. To maximize the energy efficiency, the daylighting glazing is sized and placed to provide good quality lighting to the space, independent of the view glass. Additional glazing can be added, but only for view glass. The larger the view glass, the lower the energy performance of the building.

Windows both for view and for daylighting should only be located on the north and south facades. Windows on the east and west should be minimized, as it causes excessive cooling loads and is not effective for heating because of the sun angles.

Visual comfort is strongly affected by the window location, shading, and glazing materials. Well-designed windows can be a visual delight, but poorly designed windows can create a major source of glare.

In schools, wall space is precious. As a result, view windows often serve as display areas. Additionally, these windows are almost always accompanied by blinds that can readily be closed by the teachers and students. Although view windows are recommended to provide a connection with the outdoors, they should not be considered as a contributor to daylighting. Even if they are not covered by artwork or blinds, they have limited benefit, lighting only the spaces very close to the window. Daylighting fenestration should only include that which is located above door height, about 7 ft. It is best to build the daylighting design around roof monitors; high, south-side light shelf apertures; or high, north glass transom windows.

DL7 *Lighting Design Criteria* (Climate Zones: all)

Design the daylighting system to provide enough—but not too much—lighting. Classroom daylighting systems should be designed to meet the following criteria[3]:

- 45–50 footcandles of average illumination for general instruction
- 30 vertical footcandles on the teaching wall (non-AV mode) with an uniformity illuminance ratio (maximum to minimum) not to exceed 8:1

3. See the “Overview” section of the “Lighting and Daylighting” chapter of the *CHPS Best Practices Manual*, 2006 Edition, pages 196–203, for more detail. See also the *IESNA Handbook*, Section 10, Figure 10.9, 9th edition.

- 7–15 footcandles on the teaching wall of average illumination for AV mode
- Uniformity illuminance ratio not to exceed 8:1
- Glare illuminance ratio not to exceed 20:1

The same criteria for lighting quality and quantity apply to electric lighting and daylighting. When the criteria cannot be met with daylighting, electric lighting will meet the illuminance design criteria. The objectives are to maximize the daylighting and to minimize the electric lighting. To maximize the daylighting, without oversizing the fenestration, in-depth analysis may be required.

For sunny climates, designs can be evaluated on a sunny day at the summer solar peak. For cloudy climates, a typical cloudy day should be used to evaluate the system. Typically, the glazing to floor ratio percentage will increase for cloudy climates. Daylighting can still work for a school in a cloudy climate. Cloudy climates can produce diffuse skies, which create good daylighting conditions and minimize glare and heat gain.

DL8 Use Daylighting Analysis Tools to Optimize Design (Climate Zones: all)

This Guide is designed to help achieve energy savings of 30% without energy modeling, but energy and daylighting modeling programs make evaluating energy-saving trade-offs faster and daylighting designs far more precise. To better optimize the daylighting and building design, a point-by-point model should be used to analyze typical classroom daylighting patterns to ensure the design criteria are met. (See CHPS, *Best Practices Manual, Volume II–Design*, pages 205–208 for a detailed description of available tools.) At a minimum, daylighting should be evaluated for multiple design conditions, including sunny and cloudy conditions, the summer and winter solstices, the peak cooling day, the equinox, and three times during the day: 9:00 a.m., noon, and 3:00 p.m. The analysis tool should be able to predict illumination and surface brightness for a grid of points within the space and to calculate performance during all hours of operation.

Annual savings will have to be calculated with an annual whole-building energy simulation tool after the daylighting design tools have been used to determine the footcandles in the classrooms and the window sizes have been appropriately sized. Current daylighting analysis tools do not help with heating and cooling loads or other energy uses. They predict only illumination levels and perhaps electric lighting use.

DL9 Building Orientation (Climate Zones: all)

Cost-effective daylighting starts with good orientation. For classrooms and most other spaces, the vertical facades that provide daylighting should be oriented within 15° of either north or south. Sidelighted daylighting solutions can be developed for other orientations, but they are beyond the recommendations provided in this document and are typically less effective. Orientation is less important if toplighting is used as the primary daylighting pattern, since roof monitors can be rotated on the roof. However, even with roof monitors, the main axis of the building should still be within 15° of north/south or east/west. East and west glass is problematic from a solar heat gain perspective, and provides nonuniform daylighting.

In integrating the building into the overall site, make sure that the daylighting apertures are not shaded by adjacent buildings, trees, or elements of the school building (self shading).

DL10 Ceiling Height (Climate Zones: all)

For all daylighted classrooms, a minimum 10 ft ceiling height is recommended. When daylighting must be provided entirely from sidelighting, a higher ceiling is recommended at the perimeter wall, and the ceiling should be sloped when possible. See DL26 for additional information.

DL11 *Outdoor Surface Reflectance* (Climate Zones: all)

Consider the reflectance of the roofs, sidewalks, and other surfaces in front of the glazing areas. The use of lighter roofing colors can increase daylighting concentration and in some cases reduce the glass area needed for roof monitors or clerestories. However, a light-colored walkway in front of view windows should be considered carefully. Although a light-colored surface may improve daylighting, depending on the design of the facade, it may also cause unwanted reflections and glare.

DL12 *Eliminate Direct Beam Radiation* (Climate Zones: all)

An essential component of any good daylighted school design is the elimination of uncontrolled, direct beam radiation onto the work plane. This is critical for all classrooms, libraries, media centers, and administrative spaces, but less critical for some gymnasiums, multipurpose spaces, and corridors. Use strategies that bounce, redirect, and filter sunlight so that direct radiation does not directly enter space. A good test is to evaluate sun angles at 9:00 a.m., noon, and 3:00 p.m. on the equinox and at the summer solar peak, and make sure that there is no direct solar radiation on the work plane[4] inside a band of 4 ft from the edges of the walls. If this criterion is met, interior shades will be unnecessary, except possibly to darken the space for AV purposes. With advances in AV technology, including flat screens and LCD projectors, room darkening is less important than it was in the past.

The purpose of shading is to prevent direct solar penetration into the space, which can be a source of glare and excess heat gain. There are various types of shading strategies that should be implemented in the following order:

- *External Shading.* Methods that optimize the amount of direct sun that reaches the glazing. These include major building and architectural elements such as overhangs, soffits, trellises, awnings, and external light shelves. This method is the most effective, as it prevents excess solar heat gain and glare.
- *Shading Integral with the Glazing.* Methods in which the glazing rejects unwanted solar gain. These include coloration (absorption), reflectivity, and selective transmission; opaque elements integral to the glazing, such as ceramic frit patterns or integrated PV; or baffles or blinds between glazing panels.
- *Internal Shading.* Methods for filtering and controlling solar gain that has already entered the space. These include baffles, louvers, rolling shades, blinds, and internal light shelves. Internal shading can be vertically mounted for a window or mounted in other planes such as skylight wells.

The success of daylighted schools depends on how occupants interact with the daylighting system. This is particularly true for blinds or shades that are available for adjustment by occupants. Occupants are motivated to close the blinds but not to reopen them. Occupants adjust blinds for the long term. If blinds are left closed, the daylighting potential will not be realized. If temporary darkening of a specific space is not functionally required, do not install shades or blinds on the daylighting glass. Unnecessary blinds will result in reduced performance, increased first costs, and higher long-term maintenance expenses.

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4. Typically, a surface 30 in. above the floor (maybe less for lower elementary grades).

DL13 *Daylighting Control for Audiovisual Activities* (Climate Zones: all)

If a classroom requires darkening for AV or other functions, consider motorized roller shades or motorized vertical blinds for apertures that are out of reach. This may seem to result in higher maintenance costs, but such controls can have the opposite effect. The mechanical stress placed on manual operators by the students and teachers (because of uneven cranking) limits the effective life of these devices to less than ten years. The inconvenience associated with the process also results in a number of these shades being left closed. Motorized shades, which cost more up front, will provide operators with greater ease of operation and result in a better performing daylighting design. Some motorized devices can also be programmed to reset in the open position at the beginning of each day.

Some teachers still use overhead projectors, but most use TV monitors or LCD projectors. All these teaching tools require that the light level at the specific location of the screen fall in the range of 5–7 footcandles for optimum contrast. Slightly higher levels (7–15 footcandles) should still provide acceptable light levels for the visual aids, but the reduced contrast will make them harder for the students to read.

As an option to shading the daylighting apertures, consider locating the screen or monitor in a part of the room that has less daylight and does not produce glare on the screen. This is typically easy to accomplish by locating the TV monitor high, in a corner of the space, and not adjacent to or facing a window.

Whiteboards need sufficient light (about 30 footcandles) with an illuminance ratio not exceeding 8:1. Whiteboards have a specular surface and should be carefully located so that there is no reflected glare from daylighting apertures or lighting fixture. Since the whiteboard is typically in the same location as the overhead projection screen, separate control of the teaching surface light is essential. To address both needs, intentionally darken the area of the teaching wall that has the screen and then use electric lighting to enhance the wall when the whiteboard is used.

DL14 *Interior Finishes for Daylighting* (Climate Zones: all)

Select light colors for interior walls and ceilings to increase light reflectance and reduce lighting and daylighting requirements. Minimum surface reflectances are shown in Table 5.10. The color of the ceiling, walls, floor, and furniture have a major impact on the effectiveness of the daylighting strategy. When considering finish surfaces, install light colors (white is best) to ensure the daylight is reflected throughout the space.

Consider a ceiling tile or surface that has a high reflectivity. Make sure that the ceiling tile reflectance includes the fissures within the acoustical tiles, as these irregularities affect the amount of light absorbed. Do not assume that the color of a tile alone dictates its reflectance. When selecting a tile, specify a minimum reflectivity. Most manufactures

Table 5.10. Minimum Reflectance

Location	Minimum Reflectance
Walls Above 7 ft	70%
Ceiling	70% (preferably 80%–90%)
Light Wells	70%
Floors	20%
Furniture	50%
Walls Below 7 ft	50%

will list the reflectance as if it were the paint color reflectance. The Cx provider should verify the reflectance.

DL15 *Calibration and Commissioning* (Climate Zones: all)

Even a few days of occupancy with poorly calibrated controls can lead to permanent overriding of the system and loss of savings. All lighting controls must be calibrated and commissioned after the finishes are completed and the furnishings are in place. Most photosensors require daytime and nighttime calibration sessions. The photosensor manufacturer and the quality assurance (QA) provider should be involved in the calibration. Document the calibration and Cx settings and plan for future recalibration as part of the school maintenance program.

DL16 *Dimming Controls* (Climate Zones: all)

For the classroom and gym daylighted options, daylighting controls are recommended in all classroom spaces and gyms/multipurpose spaces. For the non-daylighted option, view windows may still be included in the design. In this case, daylighting controls are still recommended for all zones within 15 ft of a sidelighted edge or within 10 ft of a toplighted edge.

In all regularly occupied daylighted spaces such as classrooms, gyms, and offices, continuously dim rather than switch electric lights in response to daylight to minimize occupant distraction. Specify dimming ballasts that dim to at least 20% of full output, with the ability to turn off when daylighting provides sufficient illuminance. Provide a means and a convenient location to override daylighting controls in spaces that are intentionally darkened to use overhead projectors or slides. The daylighting control system and photosensor should include a 15-minute time delay or other means to avoid cycling caused by rapidly changing sky conditions, and a one-minute fade rate to change the light levels by dimming. Automatic multilevel daylight switching may be used in non-regularly occupied environments, such as hallways, storage, restrooms, lounges, and lobbies.

DL17 *Photosensor Placement and Lighting Layout* (Climate Zones: all)

Correct photosensor placement is essential: consult daylighting references or work with the photosensor manufacturer for proper location. Mount the photosensors in a location that closely simulates the light level (or can be set by being proportional to the light level) at the work plane. Depending on the daylighting strategy, photosensor controls should be used to dim particular logical groupings of lights. Implement a lighting fixture layout and control wiring plan that complements the daylighting strategy. In sidelighted classrooms, locate luminaires in rows parallel to the window wall, and wire each row separately. Because of the strong difference in light that will occur close to the window and away from the window, having this individual control by bank will help balance out the space. In a space that has a roof monitor, install one photosensor that controls all the perimeter lights and a second that controls all the lights within the monitor well. In gymnasiums, ganged fluorescent fixtures coupled with dimmable ballasts are a great way of eliminating the problems typically associated with using metal halide fixtures (long-restrike time).

DL18 *Photosensor Specifications* (Climate Zones: all)

Photosensors used for classrooms should be specified for the appropriate illuminance range (indoor or outdoor) and must achieve a slow, smooth linear dimming response from the dimming ballasts.

In a *closed-loop system*, the interior photocell responds to the combination of daylight and electric light in the daylighted area. The best location for the photocell is above an unobstructed location, such as the middle of the classroom. If using a lighting system that provides an indirect component, mount the photosensor at the same height as the luminaire or in a location that is not affected by the uplight from the luminaire.

In an *open-loop system*, the photocell responds only to daylight levels but is still calibrated to the desired light level received on the work surface. The best location for the photosensor is inside the skylight/roof monitor well.

DL19 Select Compatible Light Fixtures (Climate Zones: all)

First consider the use of indirect lighting fixtures that more closely represent the same effect as daylighting. Indirect lighting spreads light over the ceiling surface, which then reflects the light to the task locations; with the ceiling as the light source, indirect lighting is more uniform and has less glare.

In addition, insist on compatibility between ballast, lamps, and controls. Ensure that the lamps can be dimmed and that the dimming ballasts, sensors, and controls will operate as a system.

Classroom Sidelighting

The sidelighting patterns shown in Figure 5.8 are appropriate for south- and north-facing classrooms, within 15° of true. Sidelighting strategies can be used in classrooms on any floor; Figure 5.8 shows sidelighting for a two-floor school. DL20–27 provide further information on sidelighting strategies.

DL20 South-Facing Classrooms—Configuration of Apertures (Climate Zones: all)

The choice of fenestration and the placement of the apertures are critical. If uncontrolled, direct beam radiation enters the classroom window. It can create glare and the teacher will simply close the blinds and negate the daylighting strategy.

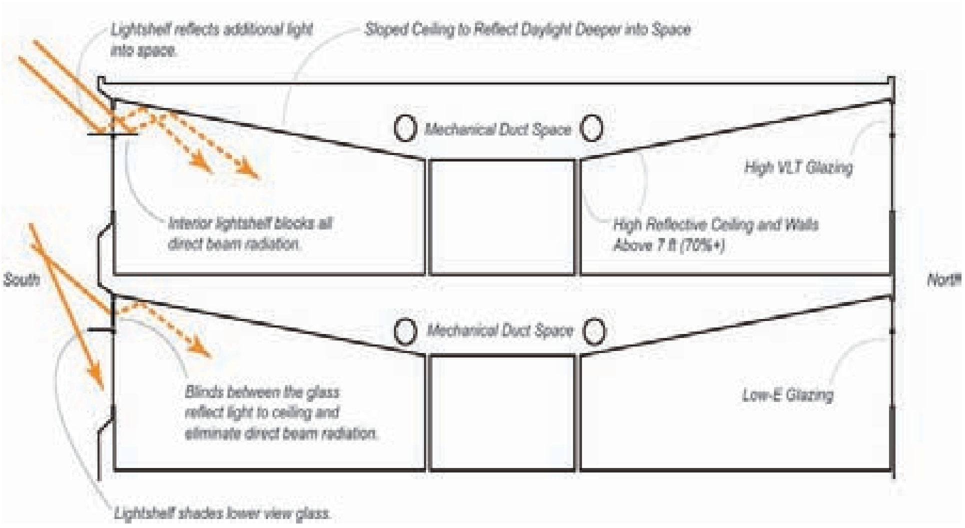

Figure 5.8. Classroom sidelighting.

A light shelf is recommended for south-facing walls. The daylighting windows above the light shelf should be as continuous as possible; the daylighting window is typically 3–5 ft high. The window should be positioned as close to the ceiling as possible, within structural constraints (see Figure 5.11).

An overhang should be positioned over the daylighting aperture and sized with the light shelf to prevent direct sun from entering the space. Set the cutoff angle of the light shelf or louvers to eliminate direct sun penetration at the back of the space during normal school hours. If there are operable shades on the upper glazing that are seasonally adjusted, the cutoff angle may be increased by 20° (see Figure 5.9).

An option to the light shelf would be to add mini-blinds between the panes of glass, and in cold climates, add a third pane. In this case, the interior portion of the light shelf may be eliminated, but the outer portion is still needed to shade the vision glass (see Figure 5.10).

For north-facing classrooms, a light shelf is not needed because its benefits are related to the reflection of direct solar radiation, and north facades experience little direct solar gain.

DL21 *South-Facing Classrooms—Glazing Area and Fenestration Type* (Climate Zones: all)

The area of the daylighting aperture should be in the range of 80–110 ft² for a typical 1000 ft² classroom. This recommendation is based on glazing with a light transmission of 65%–75%. Glazing with a lower light transmission may be used, but the aperture should be increased to maintain the same visible aperture. Where windows are used specifically for daylighting, consider the use of uncoated clear glass or low-e coated clear glass with a high VLT. A larger daylighting aperture with a lower VLT has the advantage of providing the same amount of daylight but with less glare and contrast. The disadvantage is that typically the costs associated with all the components of the daylighting system are higher.

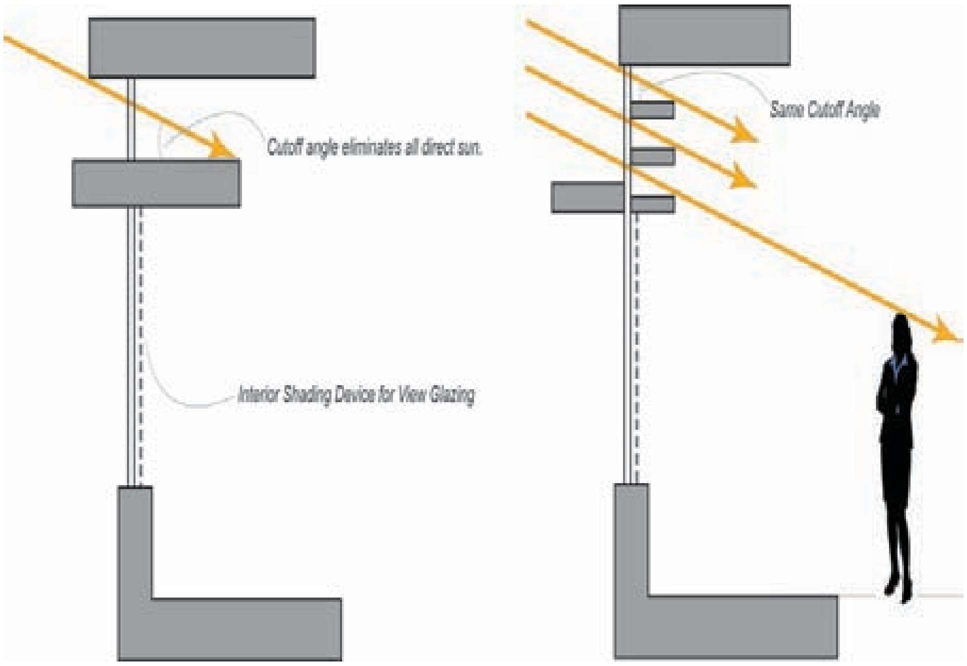

Figure 5.9. Overhang cut-off angle.

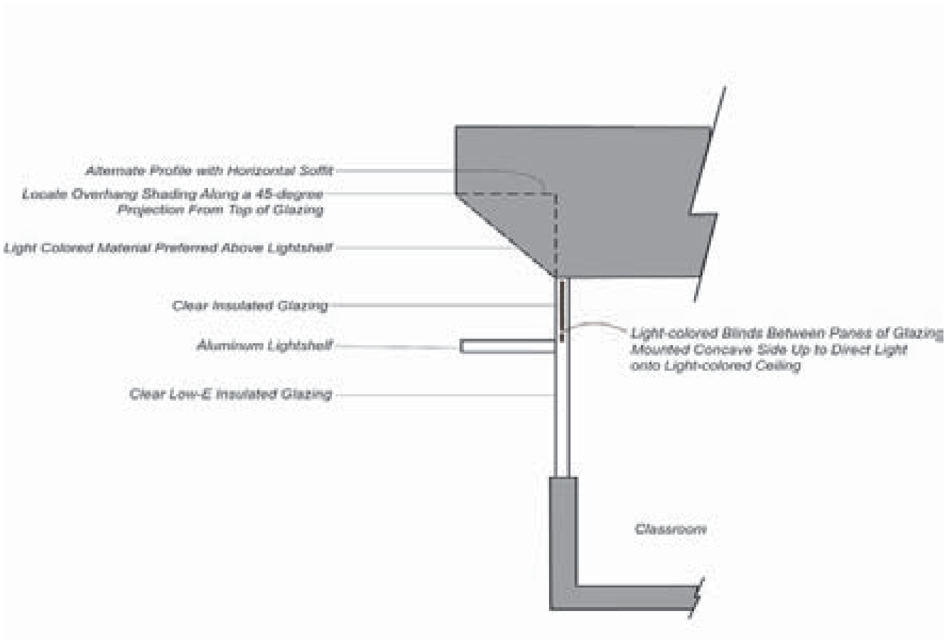

Figure 5.10. Light shelf details.

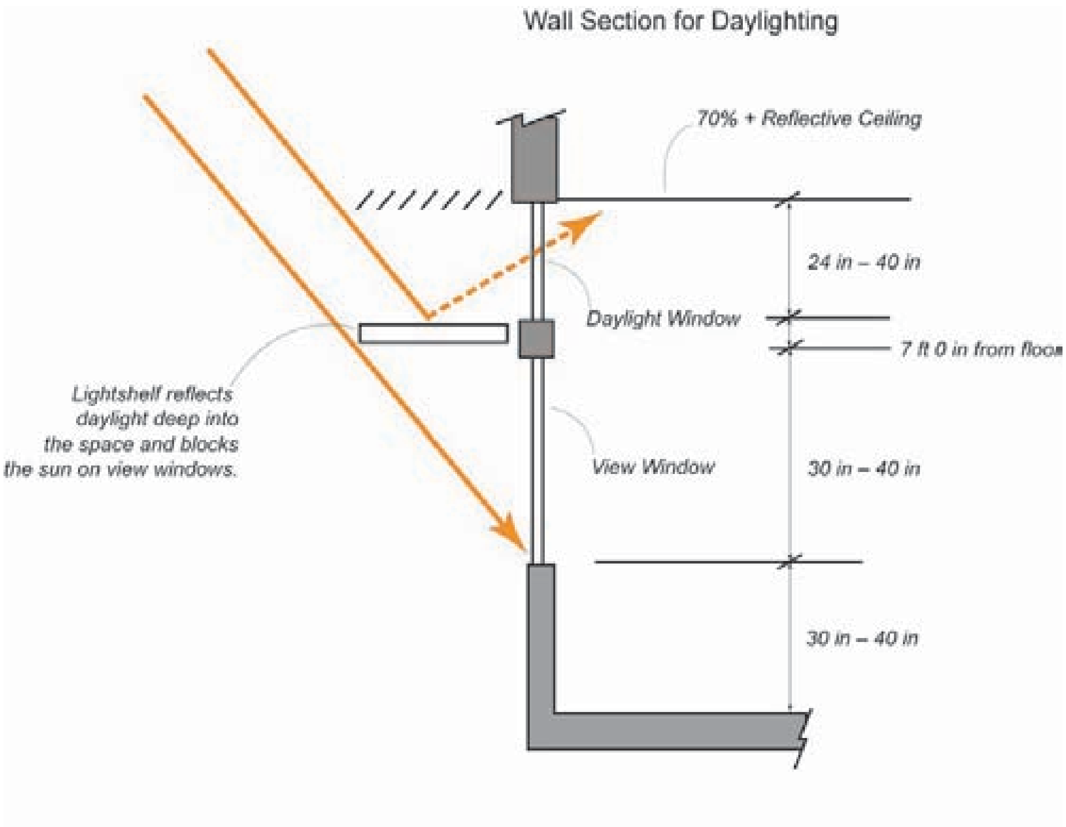

Figure 5.11. Light shelf details.

The view windows below 7 ft do not require high light transmission glazing, so values between 0.35 and 0.50 are acceptable. Higher VLTs are preferred in predominantly overcast climates. VLTs below 0.35 may appear noticeably tinted and dim, and may degrade luminous quality and views. However, lower VLTs should be used for higher FWRs. Lower VLTs may also be appropriate for other conditions of low sun angles or light-colored ground cover.

Thermal comfort can also be compromised by poor fenestration choice, especially for the view glazing, which is closer to occupants. Poorly insulated windows add to a winter chill or summer sweat, but windows with low U-factors keep glass surface temperatures closer to the interior air temperature, improving thermal comfort. In addition, east-west windows and unshaded south windows (if they cannot be avoided) can increase cooling loads.

In all cases, windows should be made of high-quality construction, incorporate thermal breaks, and include the appropriate glazing for the particular application.

Carefully consider the visible light, solar transmission, and insulation qualities of the particular daylighting glazing system, with particular emphasis on how much additional glazing will be needed to achieve the same VLT. If the design is to effectively address energy and create a good daylighting strategy, the size of the daylighting apertures needs to be minimized and the transmission maximized.

The desirable color qualities of daylighting are best transmitted by neutrally colored tints that alter the color spectrum to the smallest extent. In particular, avoid dark green and bronze glazing. To the greatest extent possible, avoid the use of reflective glass or low-e coatings with a highly reflective component, even for view glass. These reduce the quality of the view, and the mirrored effect is unpleasant to occupants after dark.

DL22 *South-Facing Classrooms—Make Light Shelf Durable and Reflective* (Climate Zones: all)

Select durable materials for interior and exterior light shelves and, if reachable, design them to be able to carry the weight of a person. Aluminum exterior light shelves are a good compromise between good reflectance with little or no maintenance and cost. Incorporate white finishes on the top of interior light shelves. Aluminized acrylic sheets applied to the top of the interior shelf allows light to bounce further back into spaces and can improve performance in deeper rooms without toplighting.

DL23 *South-Facing Classrooms—Horizontal Blinds between Glazing* (Climate Zones: all)

As an alternative to interior light shelves, consider horizontal blinds between glazings. The horizontal blinds should be highly reflective and have either flat or curved blades. If curved, they should be curved upward (turned opposite to how they are normally installed). Because of potential dirt buildup and maintenance, they should be placed between panes of glazing. If this option is used, consider the transmission of the blinds and increase the glazing area accordingly.

Most shades that are available today are operable and can be closed. However, if the space does not need to be temporarily darkened, the angle of the internal blinds should be fixed, angled up to the ceiling by the recommended cutoff angle for light shelves. By fixing the angle and not allowing the occupants to operate the blinds, there will less opportunity to override the daylighting benefits. If the internal blinds do need to be operated for darkening purposes, provide two fixed positions: the one described above and a second “closed” position.

DL24 *North-Facing Classroom—Configuration of Apertures* (Climate Zones: all)

The window should extend as close as possible to the ceiling. Window area below door height of about 7 ft should be considered as view glazing and not considered as a contributor to daylight. The daylighting glazing should be as continuous as possible along the façade. If continuous fenestration cannot be provided for structural or other reasons, the windows should be placed in the corners of the space with the opaque wall for shear or structure located in the center of the wall. This will light the walls perpendicular to the daylighting wall and provide better illuminance ratio and surface brightness.

From a daylighting perspective, high north glazing can be a good option into spaces up to a distance equal to 1.5–2.0 times the height of the top of the window. Like north-facing roof monitors, it takes more glazing than a south light shelf would to achieve the same annual contribution, so the energy performance is not quite as good. The most significant advantage is that controlling direct beam radiation is not usually a problem.

Often, when implementing a daylighting strategy in classrooms that face both north and south, the designer is faced with the challenge of establishing a common ceiling height. On the south side-light shelves that generally require less glazing than high, north transom apertures can be used, unless blinds between the glass or a south-facing fenestration with a lower VLT is used. In this case, the height of the south aperture will quite closely match the height of north transom glazing. To maintain a common ceiling height, consider some of the lower view glass on the north as an integral part of your daylighting strategy. Because blinds would typically not be needed on the north to block direct beam radiation, it is logical to include some lower view glass. The big drawback is that the window area could still be used as a display board, which blocks the light.

DL25 *North-Facing Classroom—Glazing Area and Fenestration Type* (Climate Zones: all)

For glazing with a VLT of 65%–75%, a daylighted area of 150–200 ft^2 is recommended for a typical 1000 ft^2 classroom. If glazing with a lower VLT is used, the area should be increased accordingly. Because of the lack of direct beam radiation on the north, light shelves provide no benefit and should not be used. Assuming that lower north side view glass is considered in your daylighting strategy, it would be advisable to use low-e glass in this case because of comfort, sacrificing the 10%–20% reduction in visible light benefit.

DL26 *South- and North-Facing Classrooms—Sloped Ceilings* (Climate Zones: all)

When daylight can be provided only from the side, the ceiling should be sloped down to the back wall. A sloped ceiling can achieve a higher window head, which will result in greater daylighting penetration into the space. The slope will also provide a brighter ceiling.

By sloping the ceiling from the outside wall to the back of the space, it is often possible to encroach into the ceiling cavity space just at the window area, not increase floor-to-floor dimensions, and still have enough space for ductwork.

DL27 *South- and North-Facing Classrooms—Recognize the Limits of Side Daylighting* (Climate Zones: all)

Sidelighting is an effective strategy for daylighting spaces in rooms with tall ceilings. For rooms with low ceilings, effective daylight can be provided only for spaces within 15–20 ft from the window. To daylight the whole classroom, consider wall washing skylights or roof monitors to supplement the sidelight.

Classroom Toplighting

One daylighting pattern is provided in this Guide for toplighting. Other options may be explored for specific school applications; however, they are beyond the scope of this Guide.

Roof monitors that incorporate vertical south glazing and properly sized overhangs and interior baffles have the following advantages:

- Create a very uniform lighting throughout the space
- Can be used to daylight spaces far from the perimeter of the building
- Create passive heating benefits, allowing more radiation to enter the space in the colder months
- Create a more diffuse, filtered lighting strategy
- Reduce glare and contrast

The limitation of roof monitors is that they can be used in single story designs only or on the top floors of multi-story designs (see Figure 5.12).

Technology Case Study:
Zach Elementary School
Fort Collins, CO

Zach Elementary School is located in Fort Collins, Colorado, and is part of the Poudre School District in climate zone 5. Zach, a 67,412 ft^2 facility with a capacity of 525 students, uses daylighting in all the classrooms with high north- or south-facing clerestories.Tinted view windows are separated from the clerestory windows. The south-facing clerestory windows make use of overhangs to provide shade and light shelves to reflect daylight deeper into the classrooms. North- facing windows have no shading or light shelves. The T-grid ceilings have also been sloped down from the clerestories to improve the daylighting effect, as shown in Figure S3.1.

Figure S3.1. North-facing classroom with daylighting and sloped ceilings.

DL28 *Sizing the Roof Monitors* (Climate Zones: all)

For a 1000 ft^2 classroom, the well opening of the roof monitors should be approximately 20 × 20 ft. The key to sizing the south-facing glazing in the monitor is to provide the desired level of daylighting illumination at the summer solar peak on a clear day. Size the glazing and the overhangs so that daylighting provides the required illumination (see DL7) during the summer peak cooling condition. With south-facing glazing, this strategy will result in more daylight entering the space during other times of the year, when the sun has a lower altitude—just what is needed. The glazing area, if south-facing, is typically 25% less than if north-facing to provide the same daylighting.

A fully daylighted 1000 ft^2 classroom should have an 8%–11% monitor FFR, with 65%–75% VLT for the daylighting fenestration. Glazing with a lower light transmission may be used, but the aperture should be increased to maintain the same effective visible aperture area (fenestration area × VLT). Where windows are used specifically for daylighting, consider the use of uncoated clear glass or low-e coated clear glass with a high VLT. A larger daylighting aperture with a lower VLT has the advantage of providing the same amount of daylight but with less glare and contrast. The disadvantage is that the costs associated with all the components of the daylighting system are typically higher.

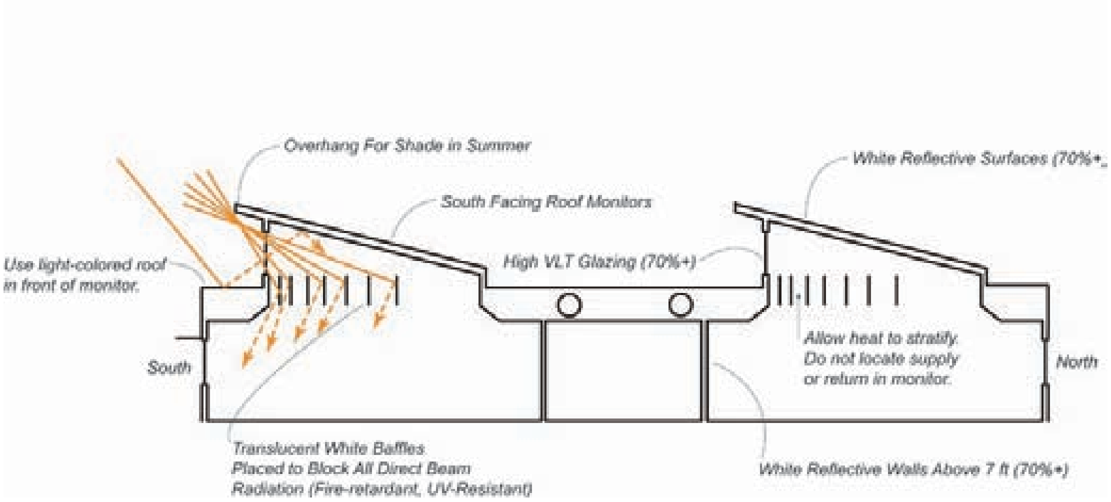

Figure 5.12. Classroom toplighting.

To provide optimal levels, the following process can be used:

- Determine the target lighting level (recommended illuminance).
- Multiply that level by two, which equals the target maximum (solar noon) daylight illuminance level.
- Evaluate winter maximum (solar noon); this number should no greater than twice (and preferably 1.5 times) the solar peak.

DL29 Overhang for Roof Monitor (Climate Zones: all)

Assuming the school is in a location that has a winter heating requirement, consider placing the overhang the same as if designing a passive solar building. Start by placing the outer point of the overhang at an angle about 45° from horizontal, above the head of the window. This will allow most of the solar gain to enter during the winter, even at noon when the altitude is low.

By moving the overhang in and out, and simulating these conditions during peak cooling times (as well as with annual simulations), you will be able to determine the correct, optimum location. The overhang should not allow any more radiation entering the space during peak cooling times than is necessary to deliver the footcandles necessary (see DL7). If during peak cooling time the space has higher footcandle levels than is necessary, this will increase your cooling loads.

Design the south-facing monitor to capture passive heating in the winter months. This will help to offset the heat not being provided when electric lights are off. Do not overextend the overhang. It will hurt the daylighting contribution as well as the passive heating benefit.

DL30 Use Light-Colored Roofing in Front of Monitors (Climate Zones: all)

Specify a light-colored roofing material to reflect additional light into the glazing. A white single-ply roofing material (aged reflectance of 69%) typically provides the best long-term reflectance.[5] This compares to black EPDM of 6%, a gray EPDM of 23%, or a light-colored rock ballast of 25%.

5. LBNL. 2005. Aging and weathering of cool roofing membranes. Report 58055, Lawrence Berkley National Laboratory, Berkeley, California, http://repositories.cdlib.org/cgi/viewcontent.cgi?article=3574&context=lbnl

When white single-ply roofing is placed directly in front of the south-facing roof monitors, the glazing area in the monitors is able to be reduced by up to 20% because of the additional reflected radiation entering the monitor.

The white color also provides an overall benefit by reflecting solar radiation that would otherwise be absorbed and re-radiated downward into the conditioned space. Energy savings also result as a benefit of a lowered cooling load.

DL31 *Use Baffles to Block Direct Beam Radiation and Diffuse Light* (Climate Zones: all)

In the roof monitor light well assemblies, white baffles should hang parallel to the glass and be spaced to ensure that no direct beam enters the space. The spacing and depth of the baffles should be determined so that when standing inside the room looking out, the occupants cannot see the sky. This will ensure that no direct beam light can strike the work plane. Baffles should have the following characteristics:

- The baffles should be fire-retardant and UV resistant.
- The baffles should be light-colored and translucent to reflect the sunlight into the space and help eliminate contrast from one side of the baffle to the other.

DL32 *Minimize Contrast at Well-Ceiling Intersection* (Climate Zones: all)

At the bottom of the light well, contrast is significantly reduced if there is a transition between the vertical and the horizontal planes. A 45°-angled plane is good, but a curved transition is even better. To achieve this curved effect, many designers now use fiber-reinforced plaster curved sections that nicely receive gypsum board.

DL33 *Address the Monitor Design* (Climate Zones: all)

To help reduce conductive gains and losses, the walls and ceiling of the roof monitor should be insulated and should incorporate appropriate insulation and moisture barriers as recommended in EN2 through EN18.

Make sure that the colors used within the monitor well are very light. White is best. Darker colors will result in a considerable loss in efficiency.

Also consider acoustic issues. If acoustical ceiling material is used, make sure that the reflectance and the acoustical properties are high. Often manufacturers, in presenting the reflectance of an acoustical tile, will specify the paint color. Remember to account for the reduced reflectance caused by the fissures in the tile.

DL34 *Let the Heat Stratify* (Climate Zones: all)

A key to achieving the desired cooling reductions is to rely on the stratification of heat within the monitor. Do not attempt to remove this heat by placing supply and return grilles in this area, but instead allow the heat to stratify. This benefit is often overlooked in designing daylighted spaces and comparing one strategy to another.

DL35 *Minimize the Depth of the Ceiling Cavity* (Climate Zones: all)

The depth of the well is very important. The deeper the well, the harder it is for the radiation to reflect down into the space. For example, in a 20 × 20 ft^2 sky well that is 7 ft deep and has 70% reflectance, the loss in effectiveness will be 50%.

Classroom Sidelighting Plus Toplighting

This daylighting pattern is appropriate for one-story buildings or for the top floor of a multistory school. It combines the sidelighting recommendations of the previous pattern with small interior skylights or roof monitors to balance daylighting across the space. Figure 5.13 shows a cross section for this pattern. See DL20–27 for recommendations for implementing this type of daylighting strategy. For an example of this type of daylighting, see the Silverthorne Elementary School climate zone 7 case study.

Gym Toplighting

For spaces with high ceilings, such as gyms, or for larger spaces, such as multipurpose rooms, cafeterias, and commons, a basic daylighting design that uses toplighting is recommended. Toplighting has the distinct advantage of providing useful daylight under most conditions, and allows for almost any orientation of the space.

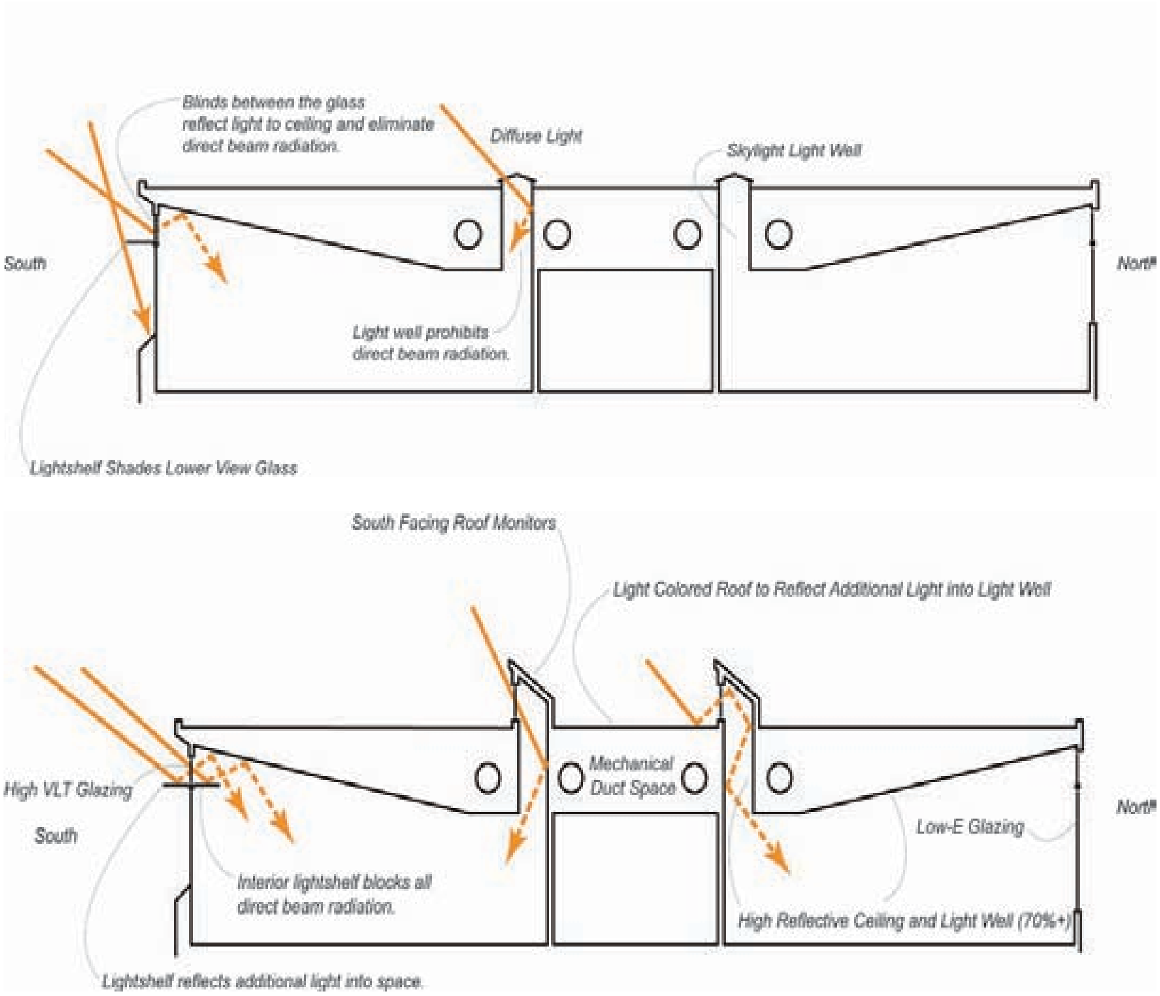

Figure 5.13. Sidelighted classroom enhanced with toplighted skylights or roof monitors.

DL36 Gym Toplighting Sizing

For those performing daylighting calculations using a daylighting program, the optimum daylighting performance will generally be achieved when the maximum average light level reached under winter conditions is no more than about 200 fc, and there is never any direct sun penetration. In the warmer peak cooling months, footcandle levels should average no more than 1.5 times the design footcandle level. This will produce useful daylight ranging from about 30–200 footcandles (30–70 footcandles for roof monitors) on average, from 9:00 a.m. until 3:00 p.m. in most climate zones.

To provide optimal levels the following process can be used:

- Determine the target lighting level (recommended illuminance).
- Multiply the target level by two; this will equal the target maximum (solar noon) daylight illuminance level.
- Evaluate winter maximum (solar noon); this number should no greater than twice (and preferably 1.5 times) the solar peak.

DL37 Gym Toplighting—Glazing Area (Climate Zones: all)

There are two recommended approaches for gym toplighting. The first is to use a grid of skylights. This approach works well in overcast and cool climates. A horizontal daylighting FFR of about 4%–5% is suggested using diffusing or prismatic skylights with VLT of at least 60%. If possible, skylights should be splayed to reduce glare. Many smaller skylights are better than a few larger ones. As a rule, the maximum dimension of a skylight should be about one-fourth the skylight's height above the floor. Use a point-by-point daylighting analysis tool (DL8) to determine the optimum size of the skylights.

The second option is to use a south- or north-facing roof monitor with clerestory. A north-facing clerestory is relatively simple in all climates, but requires a fairly large glazed area (7%–10% of the floor area) to produce enough daylight. A south-facing clerestory can be smaller (5%–8% of the floor area), but it must be carefully designed with an overhang to shade direct summer sunlight and interior baffles to diffuse direct sunlight and prevent glare. High north or south wall daylighting patterns are not recommended, as glare can easily be produced that affects sports performance. Figures 5.14–5.16 show typical toplighted gymnasium floor plans.

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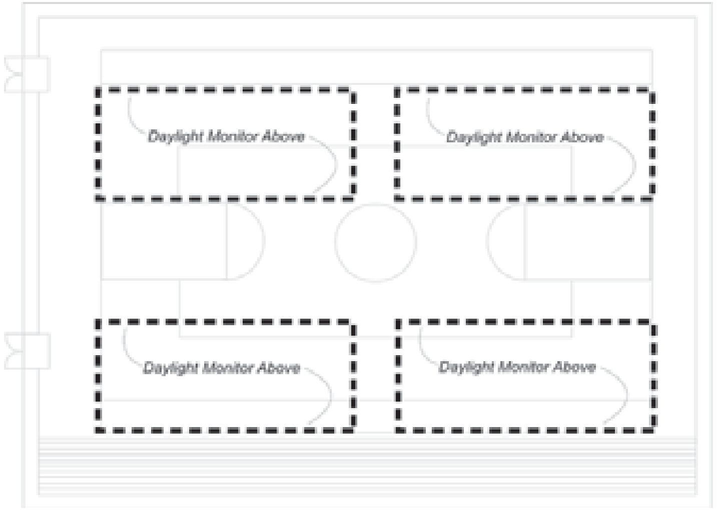

Figure 5.14. Typical 7600 ft^2 gymnasium floor plan with four roof monitors.

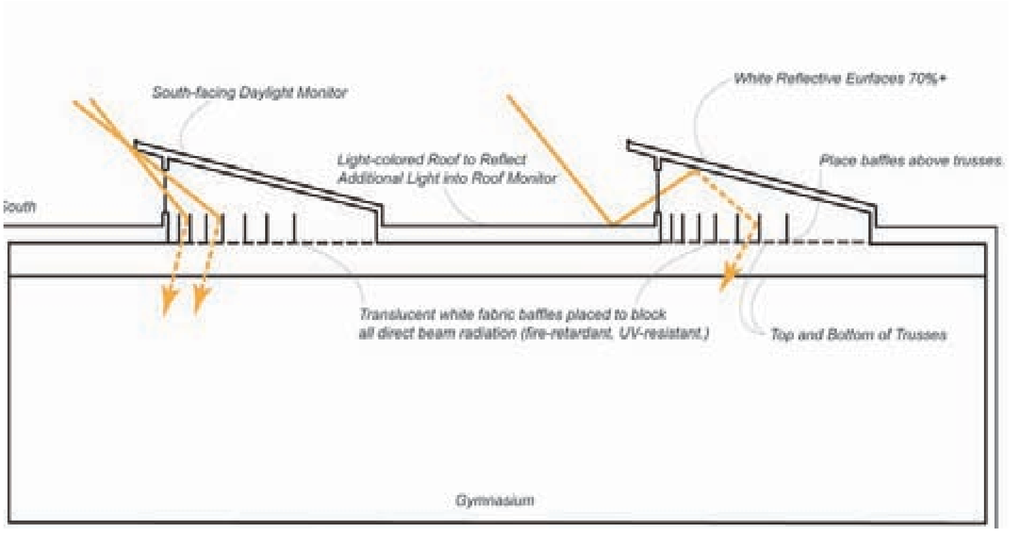

Figure 5.15. Typical 7600 ft^2 gymnasium floor plan with four roof monitors.

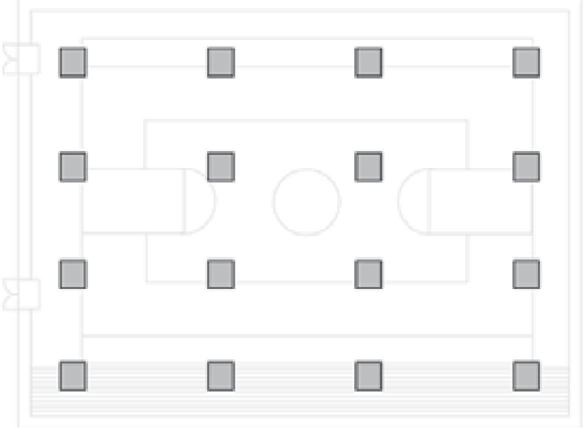

Figure 5.16. Typical 7600 ft^2 gymnasium floor plan with skylights.

Technology Case Study:
R.D. and Euzelle P. Smith Middle School
Chapel Hill, NC

The primary energy efficiency strategy used in the design of R.D. & Euzelle P. Smith Middle School in Chapel Hill, North Carolina, was daylighting. The school uses south-facing monitors to provide most of the daylighting in the classrooms, media center, and main corridor (see Figure S4.2). These monitors enable the electric lighting to be off most of the day, reducing peak cooling. Within the monitors are unevenly spaced fire-retardant, UV-resistant fabric baffles that help distribute the light uniformly and eliminate any potential glare problems (see Figure S4.3). The monitor allows hot air to stratify, keeping this air from entering the conditioned space of the room.

Recessed windows on the exterior classroom walls are equipped with clear, low emissivity double glazing. South facing windows contain a light shelf above the view windows (see Figure S4.1), allowing more light to come into the classroom without glare. North-facing windows do not have light shelves. The white roofing (cool roof) material reflects additional light to the light monitors. This daylighting strategy reduced the cooling load by 19%, or 78 tons.

As part of the daylighting system, the electric lighting system uses T8 lamps, dimming ballasts, and occupancy sensors, which add to the energy savings of the daylighting system. DOE-2 simulation models estimated a 64% reduction in electric lighting. Measured data show a reduction of 85% on sunny days and 60% on cloudy and partly cloudy days.

Daylighting in the gymnasium is also provided by south-facing roof monitors with translucent fabric baffles in the light wells. These features eliminate direct glare and effectively diffuse light throughout the space. Clear, double-pane glazing is used to maximize visible light transmittance and minimize glass to floor ratio. Adequate overhangs over the monitor windows protect the spaces from direct light during peak cooling periods.

Figure S4.1 Exterior light shelves.

Figure S4.2 South-facing monitors.

Figure S4.3. Classroom daylight monitors.

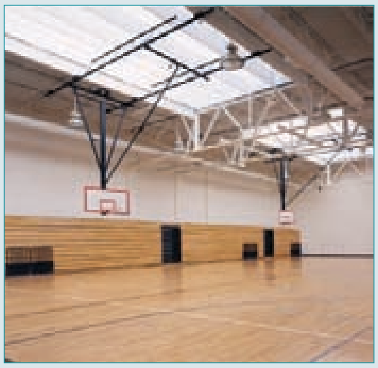

Figure S4.4. Gym toplighting.

Exterior Lighting

The following recommendations are not included in the recommendation tables in Chapter 3 because parking lots and grounds are often beyond the control of the individual school. If designing for parking lots and grounds, follow recommendations EX1–4.

Good Design Practice

EX1 *Exterior Lighting Power* (Climate Zones: all)

Limit exterior lighting power to 0.15 W/ft^2 for parking lot and grounds lighting. Calculate only for paved areas, excluding grounds that do not require lighting.

Limit exterior decorative facade lighting to 0.2 W/ft^2 of illuminated surface. This does not include lighting of walkways or entry areas of the building that may also light the building. Facade lighting can improve safety and security. Limit the lighting equipment mounting locations to the building and do not install floodlights onto nearby parking lot lighting poles. Use downward-facing lighting to comply with light trespass and light pollution concerns.

EX2 *Sources* (Climate Zones: all)

All general lighting luminaires should use pulse-start metal halide, fluorescent, induction, or compact fluorescent amalgam lamps with electronic ballasts.

- Standard high-pressure sodium lamps are not recommended because of their reduced visibility and poor color-rendering characteristics.
- Incandescent lamps are not recommended.
- For colder climates in climate zones 6–8, fluorescent lamps and CFLs must be specified with cold-temperature ballasts. Use CFL amalgams.

EX3 *Parking Lighting* (Climate Zones: all)

Parking-lot lighting locations should be coordinated with landscape plantings so that tree growth does not block effective lighting from pole-mounted luminaires.

Parking lot lighting should not be significantly brighter than lighting of the adjacent street. Follow IESNA RP-33-1999 recommendations for uniformity and illuminance recommendations.

Notes:

- For parking lot and grounds lighting, do not increase luminaire wattage to use fewer lights and poles. Increased contrast makes it harder to see at night beyond the immediate fixture location. Do not use floodlights and non-cutoff wallpacks, as they cause hazardous glare and encroach on neighboring properties. Limit lighting in parking and drive areas to not more than 360 W pulse-start metal halide lamps at a maximum 25 ft mounting height in urban and suburban areas. Use cutoff luminaries that provide all light below the horizontal plane and help eliminate light trespass.
- Consider PV-powered, grid-independent parking lot lighting when trenching over 200 ft is required to provide power to remote locations.

EX4 *Controls* (Climate Zones: all)

Use an astronomical time switch for all exterior lighting. Astronomical time switches can retain programming and the time setting during loss of power for at least ten hours. If a building energy management system is being used to control and monitor mechanical and electrical energy use, it can also be used to schedule and manage outdoor lighting energy use. Turn off exterior lighting not designated for security purposes when the building is unoccupied.

REFERENCES

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HVAC

Although many types of HVAC systems could be used in K-12 schools, this Guide assumes that one of the following six system types is to be used.

- HV-1: Single-zone, packaged DX units (or split DX systems) with indirect gas-fired heaters, electric resistance heat, or heat pump
- HV-2: WSHPs or GSHPs with a dedicated OA ventilation system
- HV-3: Unit ventilators with a water chiller and a water boiler or electric resistance heat
- HV-4: Fan coils with a water chiller and a water boiler or electric resistance heat and a dedicated OA ventilation system
- HV-5: Multiple-zone, VAV packaged DX rooftop units with a hot-water coil, indirect gas furnace, or electric resistance in the rooftop unit and a hot-water coil or electric resistance in the VAV terminals.
- HV-6: Multiple-zone, VAV air handlers with a water chiller and a hot-water coil, indirect gas furnace, or electric resistance in the air handler and a hot-water coil or electric resistance in the VAV terminals.

Unique recommendations are included for each HVAC system type in the climate-specific tables in Chapter 3. Some system types, however, are not recommended for certain climate zones because of the impact of humidity on energy use.

This Guide does not cover purchased chilled water for cooling, or solar, steam, or purchased steam for heating. These and other systems are alternative means that may be used to achieve the energy savings target of this Guide.

Good Design Practice

HV1 *Single-Zone, Packaged DX Units (or Split DX Systems)* (Climate Zones: all)

In this system, a separate packaged DX unit (or split DX system) is used for each thermal zone. This type of equipment is available in pre-established increments of capacity.

The components are factory designed and assembled and include outdoor-air and return-air dampers, fans, filters, heating source, cooling coil, compressor, controls, and air-cooled condenser. The heating source is provided by either an indirect-fired gas burner, electric resistance heat, or by reversing the refrigeration circuit to operate the unit as a heat pump. Gas heaters are part of the factory assembled unit. Electric resistance heaters can be part of the factory-assembled unit or can be installed in the duct system. Heat pump units may also use an auxiliary heat source (typically electric resistance heat) during the defrost cycle.

The components can be assembled as a single package (such as a rooftop unit) or a split system that separates the evaporator and condenser/compressor sections. Single packaged units are typically mounted on the roof or at grade level outdoors. Split systems generally have the indoor unit (including fan, filters, and coils) located indoors or in an unconditioned space, and the condensing unit located outdoors on the roof or at grade level. On smaller systems, the fan is commonly incorporated in an indoor furnace section. The indoor unit may also be located outdoors; if so, it should be mounted on the roof to avoid installing ductwork outside the building envelope. The equipment should be located to meet the acoustical goals of the space, while minimizing fan power, ducting, and wiring.

Performance characteristics vary among manufacturers, and the selected equipment should match the calculated heating and cooling loads (sensible and latent), also taking into account the importance of providing adequate dehumidification under part-load conditions (see HV8). The equipment should be listed as being in conformance with electrical and safety standards with its performance ratings certified by a nationally recognized certification program.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV2 Water-Source (or Ground-Source) Heat Pumps (Climate Zones: all)

In this system, a separate WSHP is used for each thermal zone. This type of equipment is available in pre-established increments of capacity. The components are factory-designed and assembled and include a filter, fan, refrigerant-to-air heat exchanger, compressor, refrigerant-to-water heat exchanger, and controls. The refrigeration cycle is reversible, allowing the same components to provide cooling or heating.

Individual WSHPs are typically mounted in the ceiling plenum over the corridor (or some other noncritical space) or in a closet next to the occupied space. The equipment should be located to meet the acoustical goals of the space and minimize fan power, ducting, and wiring. This may require that the WSHPs be located outside of the space.

In a traditional WSHP system, all the heat pumps are connected to a common water loop. A cooling tower and a hot water boiler are also installed in this loop to maintain the temperature of the water within a desired range.

A variation of this system takes advantage of the Earth's relatively constant temperature, and uses the ground instead of the cooling tower and boiler. GSHP systems (see AS3) do not actually get rid of heat, they store it in the ground for use at a different time. During the summer, the heat pumps extract heat from the building and transfer it to the ground. When the building requires heating, this stored heat can be recaptured from the ground. In a perfectly balanced system, the amount of heat stored over a given period of time would equal the amount of heat retrieved. This offers the potential to reduce (or eliminate) the energy used by a cooling tower and/or boiler, but installation costs may be higher because of the geothermal heat exchanger.

OA is conditioned and delivered by a separate dedicated ventilation system. This may involve ducting the outdoor air directly to each heat pump, delivering it in close proximity to the heat pump intakes, or ducting it directly to the occupied spaces. Depending on the climate, the dedicated OA unit may include components to filter, cool, heat, dehumidify, or humidify the OA (see HV12).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV3 *Unit Ventilators* (Climate Zones: 2B 3B 3C 4 5 6 7 8)

In this system, a separate unit ventilator is used for each thermal zone. The components are factory-designed and assembled and include OA- and return-air dampers, filters, a fan, heating and cooling coils, and controls.

Unit ventilators are typically installed in each conditioned space or in the ceiling plenum above the corridor (or in some other noncritical space). However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized. This may require that the unit ventilators be located outside the space.

All the unit ventilators are connected to a common water distribution system. Cooling is provided by a centralized water chiller. Heating is provided by a centralized boiler or by electric resistance heat located inside each unit ventilator.

OA is brought in through each unit ventilator, providing the opportunity for air-side economizer cooling. The selected equipment should match the calculated heating and cooling loads (sensible and latent), taking into account the importance of providing adequate dehumidification under part-load conditions (see HV8).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV4 *Fan-Coils* (Climate Zones: all)

In this system, a separate fan-coil unit is used for each thermal zone. The components are factory-designed and assembled and include filters, a fan, heating and cooling coils, controls, and possibly OA- and return-air dampers.

Fan-coils are typically installed in each conditioned space, in the ceiling plenum above the corridor (or some other noncritical space), or in a closet adjacent to the space. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized. This may require that the fan coils be located outside of the space.

All the fan-coils are connected to a common water distribution system. Cooling is provided by a centralized water chiller. Heating is provided by either a centralized boiler or by electric resistance heat located inside each fan-coil.

OA is conditioned and delivered by a separate dedicated ventilation system. This may involve ducting the outdoor air directly to each fan-coil or ducting it directly to the occupied spaces. Depending on the climate, the dedicated outdoor-air unit may include components to filter, cool, heat, dehumidify, or humidify the outdoor air (see HV12).

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

HV5 *Multiple-Zone, VAV Packaged DX Rooftop Units* (Climate Zones: all)

In this system, a packaged DX rooftop unit serves several individually controlled zones. Each thermal zone has a VAV terminal unit that is controlled to maintain temperature in that zone. The components of the rooftop unit are factory-designed and assembled and include OA- and return-air dampers, filters, fans, cooling coil, heating source, compressors, condenser, and controls. The components of the VAV terminal units are factory-designed and assembled and include an airflow-modulation device, controls, and possibly a heating coil, fan, or filter.

VAV terminal units are typically installed in the ceiling plenum above the occupied space or adjacent corridor. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized.

All the VAV terminal units served by each rooftop unit are connected to a common air distribution system (see HV20). Cooling is provided by the centralized rooftop unit. Heating is typically provided by an indirect-fired gas burner, a hot water coil, or an electric resistance heater inside the rooftop unit, individual heating coils (hot-water or electric resistance) located inside the VAV terminal units, or perimeter radiant heat located in the occupied space.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

For VAV systems, the minimum supply airflow to a zone must comply with local code, and the current versions of *ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality* (for minimum OA flow) and ASHRAE Standard 90.1 (for minimum turndown before reheat is activated).

HV6 Multiple-Zone, VAV Air Handlers (Climate Zones: all)

In this system, a central air handler serves several individually controlled zones. Each thermal zone has a VAV terminal unit that is controlled to maintain temperature in that zone. The components of the VAV air handler include OA- and return-air dampers, filters, fans, cooling coil, heating source, and controls. The components of the VAV terminal units are factory designed and assembled and include an airflow modulation device, controls, and possibly a heating coil, fan, or filter.

VAV terminal units are typically installed in the ceiling plenum above the occupied space or adjacent corridor. However, the equipment should be located to meet the acoustical goals of the space; fan power, ducting, and wiring should be minimized.

All the VAV terminal units served by each air handler are connected to a common air distribution system (see HV20). All the air handlers are connected to a common water distribution system. Cooling is provided by the centralized water chiller. Heating is typically provided by an indirect-fired gas burner, a hot-water coil, or an electric resistance heater located inside the VAV air handler; individual heating coils (hot water or electric resistance) located inside the VAV terminal units; or perimeter radiant heat located in the occupied space.

The cooling equipment, heating equipment, and fans should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level, where shown.

For VAV systems, the minimum supply airflow to a zone must comply with local code, and the current versions of ASHRAE Standards 62.1 (for minimum outdoor airflow) and 90.1 (for minimum turndown before reheat is activated).

HV7 Cooling and Heating Load Calculations (Climate Zones: all)

Accurate sizing of equipment leads to lower equipment costs, lower utility costs, better dehumidification performance, and more comfortable conditions.

Design cooling and heating loads must be calculated in accordance with generally accepted engineering standards and handbooks, such as the methods described in Chapter 30 in the *2005 ASHRAE Handbook—Fundamentals*. Safety factors should be applied cautiously to prevent oversizing of equipment. Oversized cooling equipment has limited ability to reduce capacity at part-load conditions, which causes short-cycling of compressors. This, in turn, limits the system's ability to dehumidify (see HV8). It can also result in large changes in supply-air temperature, which may affect occupant comfort.

Cooling and heating loads of OA must be included in the load calculations, as well as accurate lighting and plug loads. Separate load calculations must be performed on each thermal zone type, and on each occupancy/activity zone type.

HV8 *Part-Load Dehumidification* (Climate Zones: all)

Most basic, constant-volume systems (small packaged rooftop units, DX split systems, fan-coils, WSHPs, etc.) supply a zone with a constant amount of air regardless of the cooling load. The system must deliver warmer air under part-load conditions to avoid overcooling the space.

In a typical chilled-water application, a modulating valve reduces system capacity by throttling the water flow rate through the cooling coil. The warmer coil surface that results provides less sensible cooling (raising the supply-air dry-bulb temperature), but it also removes less moisture from the passing airstream (raising the supply-air dew point).

In a typical DX application, the compressor cycles off regularly to avoid overcooling. As the compressor operates for a smaller percentage of the hour, dehumidification capacity decreases significantly. The compressor does not run long enough for the accumulated condensate to fall into the drain pan, and it stays off for longer periods of time, allowing the remaining moisture on the coil surface to re-evaporate while the fan continues to run.

Briefly stated, a basic constant-volume system matches sensible capacity to the sensible load; dehumidification capacity is coincidental. As the load diminishes, the system delivers ever warmer supply air. Some dehumidification may occur, but only if the sensible load is high enough. As a result, the space relative humidity will tend to increase under part-load conditions. Therefore, select systems that minimize the number of hours that the space relative humidity remains above 60%. Following are some (but not all) of the possible methods for improving part-load dehumidification.

For Single-Zone, Packaged Units or Split DX Systems (see HV1). Packaged rooftop units (or split DX systems) could be equipped with reheat (using heat recovered from the refrigeration circuit) for direct control of space humidity. Alternatively, a dedicated OA system (see HV12) could be added and designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the local DX units.

For WSHPs or GSHPs (see HV2). The dedicated OA system (see HV12) should be designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the WSHP units. Alternatively, some WSHPs could be equipped with hot gas reheat for direct control of space humidity.

For Unit Ventilators (see HV3). Unit ventilators could be equipped with multiple-speed fans or face-and-bypass dampers for improved part-load dehumidification or with a reheat coil for direct control of space humidity. Consider using recovered heat when using reheat. Alternatively, a dedicated OA system (see HV12) could be added and designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the unit ventilators.

For Fan-Coil Units (see HV4). The dedicated OA system (see HV12) should be designed to dehumidify the OA so that it is dry enough (low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the fan-coil units. Alternatively, fan-coils could be equipped with multiple-speed fans for improved part-load dehumidification or a reheat coil for direct control of space humidity. Consider using recovered heat when using reheat.

For Multiple-Zone, Packaged VAV Rooftop Units (see HV5). VAV systems typically dehumidify effectively over a wide range of indoor loads, as long as the VAV rooftop unit continues to provide cool, dry air at part-load conditions. One caveat: use caution when resetting the supply air temperature (SAT) during the cooling season. Warmer supply air means less dehumidification at the coil and higher humidity in the space. If SAT reset is used, include one or more zone humidity sensors to disable the reset if the relative humidity within the space exceeds 60%.

For Multiple-Zone, VAV Air Handlers (see HV6). VAV systems typically dehumidify effectively over a wide range of indoor loads, as long as the VAV rooftop unit continues to provide cool, dry air at part-load conditions. One caveat: use caution when resetting the SAT or chilled water (CHW) temperature during the cooling season. Warmer supply air (or water) means less dehumidification at the coil and higher humidity in the space. If SAT or CHW reset is used in a humid climate, include one or more zone humidity sensors to disable reset if the relative humidity within the space exceeds 60%.

HV9 Exhaust Air Energy Recovery (Climate Zones: all)

Exhaust air energy recovery can provide an energy-efficient means of reducing the latent and sensible outdoor air cooling loads during peak summer conditions. It can also reduce the outdoor air heating load in mixed and cold climates. HVAC systems that use exhaust air energy recovery should be resized to account for the reduced outdoor air heating and cooling loads (see *ASHRAE Handbook—HVAC Systems and Equipment*).

For some HVAC system types, the climate-specific tables in Chapter 3 recommend either exhaust air energy recovery or DCV. If the energy recovery option is selected, this device should have a total effectiveness of at least 50% for A climate zones (humid) or a sensible effectiveness of at least v50% for B climate zones (dry). There is no recommendation for energy recovery for C climate zones (marine).

Sensible energy recovery devices transfer only sensible heat. Common examples include coil loops, fixed-plate heat exchangers, heat pipes, and sensible energy rotary heat exchangers (sensible energy wheels). Total energy recovery devices not only transfer sensible heat, but also moisture (or latent heat); that is, energy stored in water vapor in the airstream. Common examples include total energy rotary heat exchangers (also known as total energy wheels or enthalpy wheels) and fixed-membrane heat exchangers (see Figure 5.17).

An exhaust-air energy recovery device can be packaged in a separate energy recovery ventilator (ERV) that conditions the outdoor air before it enters the air-conditioning unit, or the device can be integral to the air-conditioning unit.

For maximum benefit, the system should provide as close to balanced outdoor and exhaust airflows as is practical, taking into account the need for building pressurization and any exhaust that cannot be ducted back to the energy recovery device.

Exhaust for energy recovery may be taken from spaces requiring exhaust (using a central exhaust duct system for each unit) or directly from the return airstream (as with a unitary accessory or integrated unit). (See also HV15, "Exhaust Air Systems.")

Where an air-side economizer is used along with an ERV, add bypass dampers (or a separate OA path) to reduce the air-side pressure drop during economizer mode. In addition, the ERV should be turned off during economizer mode, to avoid adding heat to the outdoor airstream. Where energy recovery is used without an air-side economizer, the ERV should be controlled to prevent the transfer of unwanted heat to the outdoor airstream dur-

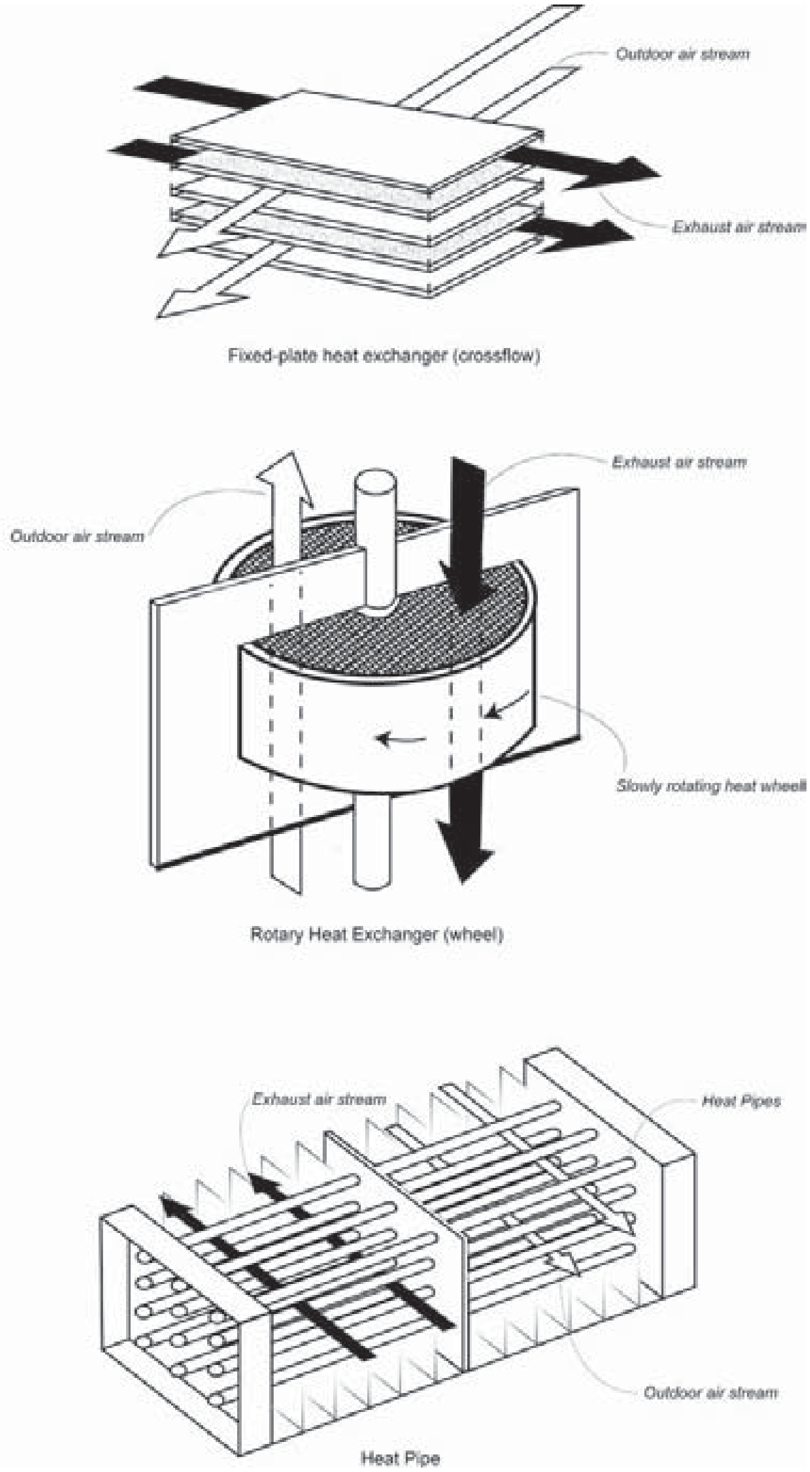

Figure 5.17. Examples of exhaust air energy recovery devices.

ing mild outdoor conditions. In cold climates, follow the manufacturer's recommendations for frost prevention.

HV10 HV Cooling and Heating Equipment Efficiencies (Climate Zones: all)

The cooling and heating equipment should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. The cooling equipment should also meet or exceed the part-load efficiency level where shown. In some cases, recommended equipment efficiencies are based on system size (capacity).

There are many factors in making a decision whether to use gas or electricity, such as availability of service, utility costs, operator familiarity, and impact of source energy use. Efficiency recommendations for both types of equipment are provided to allow the user to choose.

HV11 Ventilation Air (Climate Zones: all)

The zone-level outdoor airflows, and the system-level intake airflow, should be determined based on the current version of ASHRAE Standard 62.1, but should not be less than the values required by local code unless approved by the authority with jurisdiction. The number of people used in computing the breathing zone ventilation rates should be based on known occupancy, local code, or the default values listed in ASHRAE Standard 62.1.

For Single-Zone, Packaged Units, or Split DX Systems (see HV1). Each packaged DX unit (or indoor unit of a split DX system) should have an OA connection through which OA is introduced and mixes with the recirculated air. The OA can be mixed with the recirculated air either in the ductwork prior to the air-conditioning or heat pump unit, or at the unit's mixing plenum. In either case, the damper and duct/plenum should be arranged to promote mixing and to minimize temperature stratification. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone or to each individual packaged unit (or indoor unit in a split DX system).

For WSHPs or GSHPs (see HV2). The dedicated OA system (see HV12) should deliver the conditioned OA directly to each zone, to the intake of each individual heat pump (where it mixes with recirculated air, either in the ductwork prior to the heat pump or in a mixing plenum attached to the heat pump), or to the supply side of each WSHP (where it mixes with supply air from the heat pump before being delivered to the zone).

For Unit Ventilators (see HV3). Each unit ventilator should have an OA connection through which OA is introduced and mixes with the recirculated air. The dampers should be arranged to promote mixing and to minimize temperature stratification. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone or to each individual unit ventilator.

For Fan-Coil Units (see HV4). The dedicated OA system (see HV12) should deliver the conditioned OA directly to each zone, to the intake of each individual fan-coil (where it mixes with recirculated air, either in the ductwork prior to the fan-coil or in a mixing plenum attached to the fan-coil), or to the supply side of each fan-coil (where it mixes with supply air from the fan-coil before being delivered to the zone).

For Multiple-Zone, Packaged VAV Rooftop Units (see HV5). Each rooftop unit should have an OA intake through which OA is introduced and mixes with the recirculated air, prior to being delivered to the zones. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone, to individual dual-duct VAV terminals that serve each zone, or to the OA intake of one or more packaged VAV rooftop units.

For Multiple-Zone, VAV Air Handlers (see HV6). Each VAV air handler should have an OA intake through which OA is introduced and mixes with the recirculated air, prior to being delivered to the zones. Alternatively, a dedicated OA system (see HV12) could be used to deliver OA directly to each zone, to individual dual-duct VAV terminals that serve each zone, or to the OA intake of one or more VAV air handlers.

Notes:

- The occupant load, or exit population, used for egress design to comply with the fire code is typically much higher than the zone population used for ventilation system design. Using occupant load, rather than zone population, to calculate ventilation requirements can result in significant overventilation, oversized HVAC equipment, and excess energy use.
- Buildings with multiple-zone, recirculating ventilation systems (MZS) can be designed to account for recirculated OA, as well as system population diversity (D), using the equations found in ASHRAE Standard 62.1. In effect, the MZS design approach allows ventilation air to be calculated on the basis of how many people are in the building (system population at design) rather than the sum of how many people are in each space (sum-of-peak zone population at design). This can reduce the energy required to condition ventilation air in K-12 schools. Refer to the *Standard 62.1 User's Manual* (ASHRAE 2007) for specific guidance.
- For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

HV12 Dedicated Outdoor Air Systems (Climate Zones: all)

Dedicated outdoor air systems (DOAS) can reduce energy use by decoupling the heating, cooling, and dehumidification of OA for ventilation from sensible cooling and heating in the zone. The OA is conditioned by a separate dedicated OA unit that is designed to heat, cool, and dehumidify the OA, and to deliver it dry enough to offset space latent loads (Mumma and Shank 2001). Terminal HVAC equipment, which is located in or near each space, heats or cools recirculated indoor air to maintain space temperature. Terminal equipment may include fan-coil units, WSHPs, zone-level air handlers, radiant cooling panels, fan-powered VAV terminals, or a dual-fan, dual-duct arrangement. Dedicated OA systems can also be used in conjunction with multiple-zone recirculating systems, in which the ventilation system is sized based on ASHRAE Standard 62.1.

Consider delivering the conditioned OA cold (not reheated to neutral) whenever possible, and use recovered energy to reheat only when needed. Providing cold (rather than neutral) air from the dedicated OA unit offsets a portion of the space sensible cooling loads, allowing the terminal HVAC equipment to be downsized and use less energy. In addition, implementing system-level control strategies and exhaust air energy recovery (see HV9) can help minimize energy use.

There are many possible DOAS configurations (see Figure 5.18 for a few typical ones). The salient energy-saving feature of dedicated OA systems is the separation of ventilation air conditioning from zone air conditioning.

HV13 Economizer (Climate Zones: 3 4 5 6 7 8)

Economizers, when recommended, help save energy by providing free cooling when ambient conditions are suitable to meet all or part of the cooling load. In humid climates, consider using enthalpy-based controls (versus dry-bulb temperature controls) to help ensure that unwanted moisture is not introduced into the space. Economizers are not recommended in climate zone 1, but there may be some applicability in dry areas in climate zone 2.

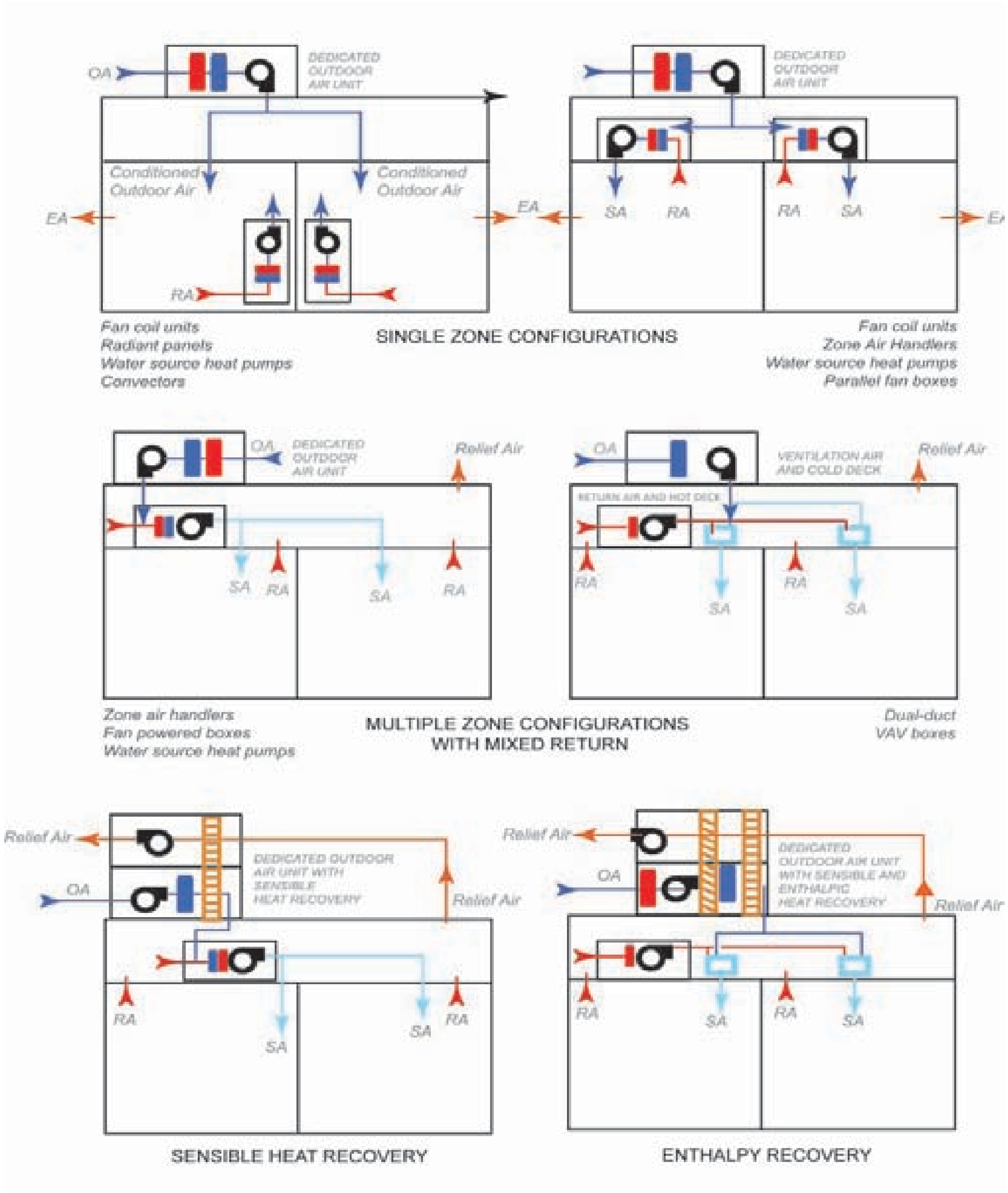

Figure 5.18. Examples of DOAS configurations.

Non-dedicated OA systems should be capable of modulating the OA, return air, and relief air dampers to provide up to 100% of the design supply air quantity as OA for cooling. (See HV12 for discussion of DOAS.) A motorized outdoor air damper should be used instead of a gravity damper to prevent unwanted OA from entering during the unoccupied periods when the unit may recirculate air to maintain setback or setup temperatures. The motorized OA damper for all climate zones should be closed during the entire unoccupied period, except when it may open in conjunction with an unoccupied economizer or pre-occupancy purge cycle.

Periodic maintenance is important with economizers, as dysfunctional economizers can cause substantial excess energy use because of malfunctioning dampers or sensors (see HV30).

HV14 *Demand-Controlled Ventilation* (Climate Zones: all)

DCV can reduce the energy required to condition OA for ventilation. To maintain acceptable IAQ, the setpoints (limits) and control sequence must comply with ASHRAE Standard 62.1. Refer to the *Standard 62.1 User's Manual* (ASHRAE 2007) for specific guidance.

For some HVAC system types, the climate-specific tables in Chapter 3 recommend either exhaust air energy recovery or DCV. If the DCV option is selected, the controls should vary the amount of OA in response to the need in a zone. The amount of OA could be controlled by (1) a time-of-day schedule in the BAS; (2) an occupancy sensor (such as a motion detector) that indicates when a zone is occupied or unoccupied; or (3) a CO_2 sensor, as a proxy for ventilation airflow per person, that measures the change in CO_2 level in a zone relative to the level in the OA. A controller will then operate the OA, return air, and relief air dampers to maintain proper ventilation.

CO_2 sensors should be used in zones that are densely occupied, with highly variable occupancy patterns during the occupied period, such as gymnasiums, auditoriums, multipurpose spaces, cafeterias, and some classrooms. For the other zones, occupancy sensors should be used to reduce ventilation when a zone is temporarily unoccupied. For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

Multiple-zone, recirculating systems (such as VAV systems) require special attention to ensure adequate OA is supplied to all zones under varying loads. Employing DCV in a DOAS requires an automatic damper and sensor for each DCV zone.

Selection of the CO_2 sensors is critical in both accuracy and response ranges. CO_2 sensors should be certified by the manufacturer to have an error of 75 ppm or less and be factory calibrated. Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer (see HV30).

Finally, when DCV is used, the system controls should prevent negative building pressure. If the amount of air exhausted remains constant while the intake airflow decreases, the building may be under a negative pressure relative to outdoors. When air is exhausted directly from the zone (art or vocational classrooms, science laboratories, kitchens, locker rooms, or even a classroom with a restroom connected to it), the DCV control strategy must avoid reducing intake airflow below the amount required to replace the air being exhausted.

HV15 *Exhaust Air Systems* (Climate Zones: all)

Zone exhaust airflows (for restrooms, janitorial closets, science laboratories, kitchens, art and vocational classrooms, locker rooms, etc.) should be determined based on the current version of ASHRAE Standard 62.1, but should not be less than the values required by local code unless approved by the authority having jurisdiction.

Central exhaust systems for restrooms, janitorial closets, and locker rooms should be interlocked to operate with the air-conditioning system, except during unoccupied periods. Such a system should have a motorized damper that opens and closes with the operation of the fan. The damper should be located as close as possible to the duct penetration of the building envelope to minimize conductive heat transfer through the duct wall and avoid having to insulate the entire duct. During unoccupied periods, it should remain closed and the exhaust fan turned off, even if the air-conditioning system is operating to maintain setback or setup temperatures. Consider designing exhaust ductwork to facilitate recovery of energy (see HV9) from Class 1 and Class 2 (e.g., restrooms) exhaust air, per the requirements of ASHRAE Standard 62.1.

Kitchens will generally have separate exhaust and make-up air systems according to the use of the kitchen and to the equipment manufacturers' suggestions. If showers are provided in locker rooms, exhaust must be increased during use and will generally require separate air intake (intake hood or make-up air unit). Science laboratories should have exhaust systems if noxious chemicals or preservatives are used. Make-up air will be necessary to prevent room pressure from becoming negative with respect to the outside.

HV16 Ductwork Design and Construction (Climate Zones: all)

Low-energy use ductwork design involves short, direct, and low pressure drop runs. The number of fittings should be minimized and should be designed with the least amount of turbulence produced. (In general, the first cost of a duct fitting is approximately the same as 12 ft of straight duct that is the same size as the upstream segment.) Unwanted noise in the ductwork is a direct result of air turbulence. Round duct is preferred over rectangular duct. However, space (height) restrictions may require flat oval ductwork to achieve the low turbulence qualities of round ductwork.

Air should be ducted through low-pressure ductwork with a system pressure classification of less than 2 in. of water. Rigid ductwork is necessary to maintain low pressure loss and reduce fan energy. Supply air should be ducted to diffusers in each individual space.

In general, the following sizing criteria should be used for duct system components:

- Diffusers and registers, including balancing dampers, should be sized with a static pressure drop no greater than 0.08 in. of water.
- Supply ductwork should be sized with a pressure drop no greater than 0.08 in. of water per 100 linear ft of duct run. Return ductwork should be sized with a pressure drop no greater than 0.04 in. of water and exhaust ductwork with a pressure drop no greater than 0.05 in. of water.
- Flexible ductwork should be of the insulated type and should be as follows:
    - Limited to connections between duct branch and diffusers
    - Limited to connections between duct branch and VAV terminal units
    - Limited to 5 ft (fully stretched length) or less
    - Installed without any kinks
    - Installed with a durable elbow support when used as an elbow
    - Installed with no more that 15% compression from fully stretched length

Hanging straps, if used, need to use a saddle to avoid crimping the inside cross-sectional area. For ducts 12 in. or smaller in diameter, use a 3 in. saddle; for those larger than 12 in. use a 5 in. saddle.

Long-radius elbows and 45° lateral take-offs should be used wherever possible. The angle of a reduction transition should be no more that 45° (if one side used) or 22.5° (if two sides are used). The angle of expansion transitions should be no more than 15° (laminar air expands approximately 7°).

Air should be returned or exhausted through appropriately placed grilles. Good practice is to direct supply air diffusers toward the exterior envelope and to locate return air grilles near the interior walls, close to the door.

Returning air to a central location (as in a multiple-zone, recirculating system) is necessary to reap the benefits of reducing ventilation air due to system population diversity (see HV11). Fully ducted return systems are expensive and must be connected to a single air handler (or the return ducts must be interconnected) to function as a multiple-zone recirculating system. Open plenum return systems are less expensive, but must be carefully designed and constructed to prevent infiltration of humid air from outdoors (Harriman 2001).

The ceiling plenum must also be well sealed to minimize air infiltration. Infiltration can be reduced by using a relief fan to maintain plenum pressure at about 0.05 in. of water higher than atmospheric pressure (see HV27), and lowering indoor humidity levels can reduce the risk of condensation (see HV8 and HV12). In addition, exhaust duct systems should be properly sealed to prevent infiltration.

Note:

- Plenum return systems in school buildings that have sloped roofs and eaves in cold, snowy climates requires special attention to insulation between the plenum and the roof. It must be continuous and well sealed. Leakage of warm air from the plenum to the roof can melt snow and form ice dams on the eaves. This can cause water to seep into the structure.
- Ductwork should not be installed outside the building envelope. Ductwork connected to rooftop units should enter or leave the unit through an insulated roof curb around the perimeter of the unit's footprint. Flexible duct connectors should be used to prevent sound transmission and vibration.
- Duct board should be airtight (duct seal level B, from ASHRAE Standard 90.1) and should be taped and sealed with products that maintain adhesion (such as mastic or foil-based tape).
- Duct static pressures should be designed, and equipment and diffuser selections should be selected, not to exceed noise criteria for the space (see HV29 for additional information on noise control).

HV17 Duct Insulation (Climate Zones: all)

The following ductwork should be insulated:

- All supply air ductwork
- All return air ductwork located above the ceiling and below the roof
- All outdoor air ductwork
- All exhaust and relief air ductwork between the motor-operated damper and penetration of the building exterior

In addition, all airstream surfaces should be resistant to mold growth and resist erosion, according to the requirements of ASHRAE Standard 62.1.

Exception: In conditioned spaces without a finished ceiling, only the supply air main ducts and major branches should be insulated. Individual branches and run-outs to diffusers in the space being served do not need to be insulated, except where it may be necessary to prevent condensation.

HV18 Duct Sealing and Leakage Testing (Climate Zones: all)

The ductwork should be sealed for Seal Class B from ASHRAE Standard 90.1. All duct joints should be inspected to ensure they are properly sealed and insulated, and the ductwork should be leak-tested at the rated pressure. The leakage should not exceed the allowable cfm/100 ft^2 of duct area for the seal and leakage class of the system's air quantity apportioned to each section tested. See HV22 for guidance on ensuring the air system performance.

HV19 *Fan Motor Efficiencies* (Climate Zones: all)

Motors for fans 1 hp or greater should meet National Electrical Manufacturers Association (NEMA) premium efficiency motor guidelines when available.

Fan systems should meet or exceed the efficiency levels listed in the climate-specific tables in Chapter 3. Depending on the HVAC system type, the efficiency level is expressed in terms of either a maximum horsepower (hp) per 1000 cfm of supply air or a maximum external static pressure (ESP) loss (for systems with integral, terminal fans).

HV20 *Thermal Zoning* (Climate Zones: all)

K-12 school buildings should be divided into thermal zones based on building size, orientation, space layout and function, and after-hours use requirements.

Zoning can also be accomplished with multiple HVAC units or a central system that provides independent control for multiple zones. The temperature sensor for each zone should be installed in a location that is representative of that entire zone.

When using a multiple-zone system (such as a VAV system) or a DOAS, avoid using a single air handler (or rooftop unit) to serve zones that have significantly different occupancy patterns. Using multiple air handlers allows air handlers serving unused areas of the building to be shut off, even when another area of the building is still in use. An alternate approach is to use the BAS to define separate operating schedules for these areas of the building, thus shutting off airflow to the unused areas while continuing to provide comfort and ventilation to areas of the building that are still in use.

HV21 *System-Level Control Strategies* (Climate Zones: all)

Control strategies can be designed to help reduce energy. Having a setback temperature for unoccupied periods during the heating season or a setup temperature during the cooling season can help to save energy by avoiding the need to operate heating, cooling, and ventilation equipment. Programmable thermostats allow each zone to vary the temperature setpoint based on time of day and day of the week. But they also allow occupants to override these setpoints or ignore the schedule altogether (by using the "hold" feature), which thwarts any potential for energy savings. A more sustainable approach is to equip each zone with a zone temperature sensor and then use a system-level controller that coordinates the operation of all components of the system. This system-level controller contains time-of-day schedules that define when different areas of the building are expected to be unoccupied. During these times, the system is shut off and the temperature is allowed to drift away from the occupied setpoint.

A pre-occupancy ventilation period can help purge the building of contaminants that build up overnight from the off-gassing of products and packaging materials. When it is cool at night, it can also help pre-cool the building. In humid climates, however, care should be taken to avoid bringing in humid OA during unoccupied periods.

Optimal start uses a system-level controller to determine the length of time required to bring each zone from the current temperature to the occupied setpoint temperature. Then, the controller waits as long as possible before starting the system, so that the temperature in each zone reaches occupied setpoint just in time for occupancy. This strategy reduces the number of hours that the system needs to operate, and saves energy by avoiding the need to maintain the indoor temperature at occupied setpoint even though the building is unoccupied.

CHW reset can reduce chiller energy use at part-load conditions. But it should be used only in a constant-flow (not variable-flow) pumping system, and it should be disabled when the outdoor dew point is above 55°F (for example) or if space humidity levels rise about 60% RH.

In a VAV system, SAT reset should be implemented to minimize overall system energy use. This requires considering the trade-off between compressor, reheat, and fan energy, as well as the impact on space humidity levels. If SAT reset is used in a humid climate, include one or more zone humidity sensors to disable reset if the RH in the space exceeds 60%.

HV22 *Testing, Adjusting, and Balancing* (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, the system should be tested, adjusted, and balanced in accordance with *ASHRAE Standard 111, Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems* or SMACNA's *Testing, Adjusting and Balancing* manual.

This procedure will help to ensure that the correctly sized diffusers, registers, and grilles have been installed, that each space receives the required airflow, and that the fans meet the intended performance. The balancing subcontractor should certify that the instruments used in the measurement have been calibrated within 12 months before use. A written report should be submitted for inclusion in the O&M manuals.

HV23 *Commissioning* (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, the system should be commissioned to ensure that the equipment meets the intended performance and that the controls operate as intended. See Appendix B, "Commissioning," for more information on Cx.

HV24 *Filters* (Climate Zones: all)

Particulate air filters are typically included as part of the factory-assembled HVAC equipment and should be at least MERV 8, based on *ANSI/ASHRAE Standard 52.2, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. Use a filter differential pressure gauge to monitor the pressure drop across the filters and send an alarm if the predetermined pressure drop is exceeded. Filters should be replaced when the pressure drop exceeds the filter manufacturer's recommendations for replacement, or when visual inspection indicates the need for replacement. The gauge should be checked and the filter should be visually inspected at least once each year.

If high-efficiency filters are to be used, consider using lower-efficiency filters during the construction period. When construction is complete, all filters should be replaced before the building is occupied.

HV25 *Chilled-Water System* (Climate Zones: all)

CHW systems can be an efficient way to move energy around the building, and with the load profile of many K-12 schools, they can be a great way to combine a thermal storage system (see AS4). CHW systems should generally be designed for variable flow through the building:

- Very small systems (<100 tons) may be designed for constant flow.
- Medium-sized systems (100–250 tons) may achieve variable flow by using two-way control valves on most of the cooling coils, with a few three-way valves to provide the required minimum flow through the chiller.
- Large systems (>250 tons) or systems with a significant water pressure drop (>75 ft of H_2O) are good candidates for variable primary flow.

Piping should be sized for a pressure drop of less than 3 ft of water per 100 ft of pipe. Using a smaller pipe size increases the pressure drop through the pipe, increases the velocity through the pipe, and may cause erosion to occur if velocity is too high. A larger pipe size results in additional pump energy savings, but increases the installed cost of the pipe. In systems that operate for longer hours, larger pipe sizes are often very economical.

VFDs on chillers can be beneficial in applications where condenser relief occurs for a significant number of hours. Air-cooled condensers are typically designed for 95°F ambient air condition, and water-cooled condensers are typically designed for 85°F entering water temperature. If a chiller will operate for a significant number of hours at temperatures at least 10°F below these conditions, a VFD should be considered. Not all chillers need to be equipped with a VFD; typically a VFD on the chiller that operates with the most amount of condenser relief will provide the most economical payback. Generally, climates that are hot and humid are not good candidates for VFDs on chillers.

CHW temperatures will vary depending on whether thermal storage is used. If thermal storage is used, the chiller must be selected for the most extreme temperatures, which typically occur during the charge mode.

To increase energy savings beyond 30%, use a CHW ΔT of 12°F–20°F. This will save pump energy, but it will also affect cooling coil performance. This can be overcome by lowering the chilled-water temperature to deliver the same air conditions leaving the coil. CHW temperature setpoints should be selected based on a life-cycle analysis of pump energy, fan energy, and desired air conditions leaving the coil.

HV26 *Water Heating Systems* (Climate Zones: all)

Condensing boilers can operate at up to 97% efficiency and can operate efficiently at part load. To achieve these high-efficiency levels, condensing boilers require that return water temperatures be maintained at 70°F–120°F, where the boiler efficiency is 97%–91%. This fits well with hydronic systems that are designed with ΔTs greater than 20°F (optimal ΔT is 30°F–40°F). The higher ΔTs allow smaller piping and less pumping energy. Because condensing boilers work efficiently at part load, VFDs can be used on the pumps to further reduce energy use.

Condensing boiler capacity can be modulated to avoid losses caused by cycling at less than full load. This encourages the installation of a modular (or cascade) boiler system, which allows several small units be installed for the design load, but allows the units to match the load for maximum efficiency of the system.

HV27 *Relief versus Return Fans* (Climate Zones: all)

Relief (rather than return) fans should be used when necessary to maintain building pressurization during economizer operation. Relief fans reduce overall fan energy use in most cases, as long as return dampers are sized correctly. However, if return duct static pressure drop exceeds 0.5 in. of water, return fans may be needed.

Cautions

HV28 *Heating Sources* (Climate Zones: all)

Many factors come into play in making a decision whether to use gas or electricity for heating, including availability of service, utility costs, operator familiarity, and the impact of source energy use.

Forced-air electric resistance and gas-fired heaters require a minimum airflow rate to operate safely. These systems, whether stand-alone or incorporated into an air-conditioning or heat pump unit, should include factory installed controls to shut down the heater when there is inadequate airflow that can result in high temperatures.

Ducts and supply-air diffusers should be selected based on discharge air temperatures and airflow rates.

HV29 Noise Control (Climate Zones: all)

Much of the education that takes place in K-12 classrooms hinges on oral communication. Less than optimal acoustical conditions in the classroom affect the academic performance of all students, but they pose a particular challenge for students learning in a non-native language, coping with learning disabilities, or hindered by impaired hearing.

The *ASHRAE Handbook–HVAC Applications* and *ANSI/ASA Standard S12.60, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools* are two potential sources for recommended background sound levels in the various spaces that make up K-12 school buildings.

Avoid installation of the HVAC equipment directly above classrooms. Consider locations above less critical spaces, such as storage areas, restrooms, and corridors, or in acoustically treated closets adjacent to the space. Acoustical requirements may necessitate attenuation of the noise associated with the supply and return air, or noise radiated from the HVAC equipment. Acoustical concerns may be particularly critical in short, direct runs of ductwork between the fan and supply or return outlet.

Refer to ASHRAE's *Practical Guide to Noise and Vibration Control for HVAC Systems* for specific guidance by system type.

HV30 Proper Maintenances (Climate Zones: all)

Regularly scheduled maintenance is an important part of keeping the HVAC system in optimum working condition. Neglecting preventive maintenance practices can quickly negate any energy savings expected from the system design.

Filters should be replaced when the pressure drop exceeds the filter manufacturer's recommendations for replacement, or when visual inspection indicates the need for replacement. ERVs need to be cleaned periodically to maintain performance. Dampers, valves, louvers, and sensors must all be periodically inspected and calibrated to ensure proper operation. This is especially important for OA dampers and CO_2 sensors. Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer.

A BAS can be used to notify O&M staff when preventive maintenance procedures should be performed. This notification can be triggered by calendar dates, run-time hours, the number of times a piece of equipment has started, or sensors installed in the system (such as a pressure switch that indicates when an air filter is too dirty and needs to be replaced).

HV31 Zone Temperature Control (Climate Zones: all)

The number of spaces in a zone and the location of the temperature sensor (thermostat) will affect the control of temperature in the various spaces of a zone. Locating the thermostat in one room of a zone with multiple spaces provides feedback based only on the conditions in that room. Locating a single thermostat in a large open area may provide a better response to the conditions of the zone with multiple spaces. Selecting the room or space that will best represent the thermal characteristics of the space due to both external and internal loads will provide the greatest comfort level.

To prevent misreading of the space temperature, zone thermostats should not be mounted on an exterior wall. Where this is unavoidable, use an insulated sub-base for the thermostat.

In spaces with high ceilings, consider using ceiling fans or high/low air distribution to reduce temperature stratification during the heating season. Six primary factors must be addressed when defining conditions for thermal comfort:

- Metabolic rate
- Clothing insulation
- Air temperature
- Radiant temperature
- Air speed
- Humidity

Appropriate levels of clothing, the cooling effect of air motion, and radiant cooling or heating systems, for example, can increase occupant comfort energy efficiently.

HV32 Operable Windows (Climate Zones: 2B 3 4 5 6 7 8)

Compared to buildings with fixed-position windows, buildings with properly applied and properly utilized operable windows can provide advantages in schools, including energy conservation and energy conservation education (see also EN22). Natural ventilation, natural cooling, and passive solar heating can have positive sustainability effects. Improper design and operation can have negative effects. Mechanical systems should be shut off when windows are opened. Operable window systems can be controlled manually or by interlock. Manual control provides the opportunity for energy-efficiency education in the classroom, but automatic controls (such as interlocks) are likely to save more energy.

A bottom window and a top window should be opened at the same time. This allows the stack effect to set up a convection current of airflow when the difference between the indoor and outdoor temperatures is 10°F or more.

Table 5.11 shows recommended setpoints for using operable windows. Using operable windows without proper sensor calibration can create moisture or comfort problems and may reduce energy savings.

Table 5.11. Operable Windows Recommended Set Points

Controller Type	Recommended Climate Zones	Cooling Setpoint	Heating Setpoint
Measuring Dry-Bulb Temperature Only	B and C zones	Window open when space temperature > outdoor temperature Window closed when space temperature < outdoor temperature	Window open when space temperature < outdoor temperature Window closed when space temperature > outdoor temperature
Measuring Temperature and Humidity	A zones	Window open when space temperature and humidity > outdoor temperature and humidity Window closed when space temperature and humidity < outdoor temperature and humidity	Window open when space temperature < outdoor temperature Window closed when space temperature > outdoor temperature

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SERVICE WATER HEATING (SWH)

Good Design Practice

WH1 Service Water Heating Types (Climate Zones: all)

This Guide assumes that the SWH equipment uses the same type of fuel source as is used for the HVAC system. This Guide does not cover systems that use oil, hot water, steam, or purchased steam for generating SWH, nor does it address the use of solar or site-recovered energy (including heat pump water heaters). These systems are alternative means that may be used to achieve 30% (or greater) energy savings over ASHRAE Standard 90.1-1999 and, where used, the basic principles of this Guide would apply.

The SWH equipment included in this Guide are the gas-fired water heater and the electric water heater. Natural gas and propane fuel sources are available options for gas-fired units.

Many factors come into play in making a decision whether to use gas or electricity, including availability of service, utility costs, operator familiarity, and the impact of source energy use. Efficiency recommendations for both types of equipment are provided to allow for choice.

WH2 System Descriptions (Climate Zones: all)

Gas-fired storage water heater. A water heater with a vertical or horizontal water storage tank. A thermostat controls the delivery of gas to the heater's burner. The heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Gas-fired instantaneous water heater. A water heater with minimal water storage capacity. The heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Electric resistance storage water heater. A water heater consisting of a vertical or horizontal storage tank with one or more immersion heating elements. Thermostats controlling heating elements may be of the immersion or surface-mounted type.

Electric resistance instantaneous water heater. A compact, under-cabinet, or wall-mounted type water heater with insulated enclosure and minimal water storage capacity. A thermostat controls the heating element, which may be of the immersion or surface-mounted type. Instantaneous, point-of-use water heaters should provide water at a constant temperature regardless of input water temperature.

WH3 Sizing (Climate Zones: all)

The water heating system should be sized to meet the anticipated peak hot-water load. Calculate the hot-water demand based on the sum of the building fixture units according to local code.

Local and state plumbing codes for water closets vary and range from 1 per 20–25 elementary female students to 1 per 30–45 secondary female students, and from 1 per 30 elementary male students to 1 per 40–90 secondary male students. Lavatories in the restrooms are generally in the ratio of 1 per 2 water closets installed in a general restroom. In many elementary schools, wet areas are provided in K-2 classrooms with hot water for hand washing. Some state codes and educational specifications may require sinks with hot water in laboratories, workshops, vocational classrooms, and art rooms.

Hot-water temperature requirements for restrooms and academic areas of a school vary by local and state code, within the range of 100°F–120°F. Hot water is also a requirement in the school kitchen, with a delivered temperature of 120°F–140°F. Use booster heaters on the dishwashers to bring the temperature to the 160°F–180°F required for sanitation.

In elementary schools, showers are normally specified in health/nurse rooms. In secondary schools, showers are normally specified for physical education locker rooms. In larger secondary schools, showers may be required for team sport areas. The temperature of the hot water provided to the showers should be 100°F–110°F.

In designing and evaluating the most energy-efficient hot-water system for a school and the associated life-cycle costs, consider installing tankless water heaters in most locations. Only areas where large volumes of hot water are required (such as the cafeteria, gymnasium, and culinary vocational classrooms) should large water heaters or smaller circulating hot-water systems be installed.

WH4 *Equipment Efficiency* (Climate Zones: all)

Efficiency levels are provided in the climate-specific tables in Chapter 3 for the four types of water heaters listed in WH2.

The gas-fired storage water heater efficiency levels correspond to condensing storage water heaters. High-efficiency, condensing gas storage water heaters (energy factor higher than 0.90 or thermal efficiency higher than 0.90) are alternatives to the use of gas-fired instantaneous water heaters.

For gas-fired instantaneous water heaters, the energy factor and thermal efficiency levels correspond to commonly available instantaneous water heaters.

Electric water heater efficiency should be calculated as 0.99 – 0.0012 × water heater volume (volume equals zero for instantaneous water heaters).

Instantaneous electric water heaters are an acceptable alternative to high-efficiency storage water heaters. Electric instantaneous water heaters are more efficient than electric storage water heaters, and point-of-use versions will minimize piping losses. However, their impact on peak electric demand can be significant and should be taken into account during design. Where unusually high hot-water loads (e.g., showers or laundry facilities) are present during peak electrical use periods, electric storage water heaters are recommended over electric instantaneous ones.

WH5 *Location* (Climate Zones: all)

The water heater should be close to the hot water fixtures to avoid the use of a hot-water return loop or of heat tracing on the hot water supply piping. Where electric resistance heaters are used, consider point-of-use water heaters with a low number of fixtures or where they can eliminate the need for a recirculating loop.

WH6 *Pipe Insulation* (Climate Zones: all)

All SWH piping should be installed in accordance with accepted industry standards. Insulation levels should be in accordance with the recommendation levels in the climate-specific tables in Chapter 3, and the insulation should be protected from damage. Include a vapor retardant on the outside of the insulation.

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ADDITIONAL SAVINGS

AS1 *Electrical Distribution System* (Climate Zones: all)

Energy-efficient distribution transformers should be provided in all construction/repair projects: new construction, renovation, or replacement. Minimum transformer specifications as of January 1, 2007, are classified by DOE as TP-1 and are the lowest efficiency available. Energy-efficient transformers that are 30% more efficient than the minimum TP-1 are classified by DOE as CSL-3.

The size of an educational building is a contributing factor in the determination of the electrical voltage service brought into the building. Electrical service from the utility in smaller schools is usually 120/208 three-phase voltage and in larger schools 277/480 three-phase voltage. When the 277/480 volt service is provided, 120/208 volt dry step down transformers are placed in key locations in the building to provide the power to the electrical outlets throughout. Electrical distribution systems in today's schools contribute to the energy inefficiency. The following good practices will help improve the energy efficiency of the electrical distribution system.

Electrical Service Voltage. School facilities smaller than 40,000 ft^2 should design the incoming electrical service from the utility for 120/208 V. Schools facilities larger than 40,000 ft^2 should have the incoming electrical service designed from the utility at 277/480 V. This design will require the placement of internal step down dry transformers 277/480 V to 120/208 V to provide the needed power for the plug load.

Energy-Efficient Transformers. DOE recognizes that current step-down transformers contribute to energy waste throughout the country. The CSL-3 standard has been established to improve the energy efficiency of distribution transformers. This standard recognizes the low loading, especially in schools, and the no-load losses with current transformer design. The standard CSL-3 design eliminates any impact for normal harmonics created by the loads in the school. Concentrating all larger computer loads on one transformer can be handled by a variation in the CSL-3 design and still keep the required efficiencies and no-load losses. The standard includes specifics on the no-load losses for specific sized transformers and specific percent efficiencies at given loadings. For example, a CSL-3 75 KVA 277/480 to 120/208 volt transformer maximum no load loss is 170 W/h versus the current industry average of more than 850 W/h. This same transformer will meet or exceed 98.4% efficiency at one-sixth loading. The efficiency of the standard transformers currently specified at one-sixth loading is 80% to 85%. This is an unregulated load at this time.

Specification of Energy-Efficient Transformers. Energy-efficient transformers should be specified using DOE's CSL-3 Standard as the basis. Specifications must include maximum no-load losses for specified transformers sizes and percent efficiency at 16.7% loading. A statement should be included in the specifications that requires the bid submission to include test data for the transformers being provided.

Electrical distribution equipment is usually provided by one supplier. This means the cost of the transformer is "buried" in the electrical distribution equipment price. The following statement should be included in the bid specifications: "The bid price for the dry distribution transformers specified (277/480 to 120/208 V) must be identified (priced) separately within the electrical bid and cannot be included in the bid pricing for other electrical distribution equipment that falls under Section 16 of the Standard AIA Specification Structure. If specified transformers are not separately identified in the bid pricing then the entire bid will be disqualified."

AS2 *Plug and Phantom Loads* (Climate Zones: all)

Plug Loads. Plug loads are devices or appliances that plug into a school's electrical system. A school typically has a 120/208 V electrical system and includes many loads. A load is anything that draws power from the system and requires electricity to work. Plug loads found in schools include computers, DVD players, VCRs, overhead and LCD projectors, boom boxes, CD players, printers, scanners, copiers, fax machines, radios, microwaves, coffee pots, popcorn poppers, fish tanks, desktop lights, stoves, refrigerators of all sizes, vending machines, smart boards, vocational equipment and tools, soda machines, drinking fountains, and many other devices for educational purposes and for the comfort of the students, faculty, and staff.

Technology Case Study:
Twenhofel Middle School
Independence, KY

Twenhofel Middle School in Kentucky installed both energy-efficient transformers (CSL-3) and typical specified transformers (CSL-1). Each of the three grade wings of the school had distribution transformers, the 6th grade wing had the energy-efficient transformer, and the other two wings had typical transformers. The following were the results:

1. The electric use in the 6th grade wing was continuous lower than the other wings
2. Testing of the transformers revealed that the loading for these transformers during the day were very low—between 2 and 3%.
3. The efficiency of the transformers at this loading was 79.5% for the typical transformer and 91.5% for the energy-efficient transformer. This meant an improvement in efficiency of more than 15% in addition to the no load loss improvement between 500–700 W/h.

The following illustrates the potential energy savings when specifying and installing energy efficient transformers, at current use of distribution transformers in schools and average electrical energy cost across the nation.

- Typical 73,000 ft^2 elementary school—$9000/year and more than $400,000 over a 50-year building life
- Typical middle school—$13,000/year and more than $600,000 over a 50-year building life
- Typical high school—$20,000/year or more than $1 million over a 50-year building life

Note: The 50-year life figures do not include any rate increase during the period.

Technology Case Study:
North Thurston Public Schools
Lacey, WA

Energy Star Power Management features—standard in Windows and Macintosh operating systems—place inactive monitors and computers (CPU, hard drive, etc.) into a low-power sleep mode. A simple touch of the mouse or keyboard “wakes” the computer and monitor in seconds.

Monitor power management (MPM) can save $10–30 per monitor annually by placing your inactive monitors into a low-power sleep mode.

Computer power management (CPM) places inactive computers (CPU, hard drive, etc.) into a low-power sleep mode, which can save $15–45 per desktop computer annually.

http://www.energystar.gov/index.cfm?c=power_mgt.pr_power_management

Read about how North Thurston Public Schools is saving $45,000 annually by activating computer and monitor sleep settings: http://www.energystar.gov/ia/products/power_mgt/North_Thurston_Case_Study.pdf.

Phantom Loads. A VCR that has been flashing "12:00 a.m." since it was installed in a classroom is a prime example of an electronic device in that consumes energy when the switch indicates it is off. This use of electrical energy is classified as a phantom load. Phantom loads are also known as standby power or leaking electricity. Phantom loads usually coincide with any electronic or electrical device or appliance. Equipment with electronic clocks or timers or remote controls, portable equipment and office equipment, with wall cubes (a small box that plugs into an AC outlet to charge cell phones or provide power to computers) all have phantom loads. Phantom loads can consume up to 5% of an electrical plug load.

Control on Plug Loads. Plug loads contribute up to 25% of the electrical load in a school. This estimation comes from plug load surveys conducted in schools over the past several years. Plug loads density can be 0.6–1.0 W/ft^2. A large contributor to this load is equipment and appliances left on after use, and equipment that has a phantom load when not in use. To reduce this load potential, consider controlling the top outlet of each duplex outlet with the occupancy sensor used to control the lighting in the room. The inclusion of this feature in future designs would reduce the plug load density from the current 0.6–1.0 to 0.4–0.6 W/ft^2. For a 100,000 ft^2 school, this would mean a reduction of 20–40 kW/h. Creating a personal appliance policy in the school district and conducting constant energy awareness training on equipment and appliance use should be undertaken.

Control of Phantom Loads. The best direct way to control phantom loads is to unplug items such as TVs, VCRs, and other similar items when not in use. In lieu of directly unplugging the item, all these items can be plugged into a power strip that is switched off at the end of each day, over the weekend, and during holidays and vacations.

ENERGY STAR Appliances/Equipment. A school board policy should be established that requires all electrical equipment and appliances placed in a school to have the ENERGY STAR Label (where there is an ENERGY STAR rating for the equipment or appliance). See Appendix D for a list of items with ENERGY STAR ratings.

The recommendations presented in Table 5.12 for the purchase and operation of plug load equipment are an integral part of this Guide, but the energy savings from these recommendations will be in addition to the targeted 30% savings.

Table 5.12. Recommendations for Efficient Plug Load Equipment

Equipment/Appliance Type	Purchase Recommendation	Operating Recommendation
Desktop Computer	ENERGY STAR only	Implement sleep mode software
TV/VCR	Purchase flat screens with sleep modes	Many of these items are only used during peak times and should be unplugged with occupancy sensors
Laptop Computer (use where practical instead of desktops to minimize energy use)	ENERGY STAR only	Implement sleep mode software
Computer Monitors	Energy Star flat screen monitors only	Implement sleep mode software
Printer	ENERGY STAR only	Implement sleep mode software
Copy Machine	ENERGY STAR only	Implement sleep mode software
Fax Machine	ENERGY STAR only	Implement sleep mode software
Water Cooler	ENERGY STAR only	N/A
Refrigerator	ENERGY STAR only	N/A
Vending Machines	ENERGY STAR only	Delamp display lighting
TV/VCR	ENERGY STAR only	

AS3 *Ground-Source Heat Pumps* (Climate Zones: all)

A variation of the WSHP system (see HV2), the GSHP takes advantage of the Earth's relatively constant temperature and uses the ground instead of a cooling tower and boiler. GSHP systems do not actually get rid of heat, but store it in the ground for use at a later time. During the summer, the heat pumps extract heat from the building and transfer it to the ground. When the building requires heating, this stored heat can be recaptured from the ground. In a perfectly balanced system, the amount of heat stored over a given period of time would equal the amount of heat retrieved.

GSHP systems offer the potential for saving energy because they can reduce or eliminate the energy needed to operate a cooling tower or boiler. Eliminating the cooling tower also has architectural and maintenance advantages, and eliminating the boiler frees up floor space in the building.

Although eliminating both the cooling tower and boiler will likely result in the greatest overall energy savings, for most applications this requires the largest (and more expensive) geothermal heat exchanger to account for the imbalance between heat stored and heat extracted.

For example, in a cooling-dominated climate, a large amount of heat must be rejected to the ground during the cooling season, but a much smaller amount of heat is extracted from the ground during the heating season. This imbalance can cause the temperature of the ground surrounding the geothermal heat exchanger to increase over time.

Conversely, in a heating-dominated climate, a relatively small amount of heat is rejected to the ground during the cooling season, but a much larger amount of heat must be extracted from of the ground during the heating season. In this case, the ground temperature can decrease over time. In either case, future operation of the heat pump is compromised by this change.

In many areas of the country, this imbalance requires the geothermal heat exchanger to be larger to prevent the ground temperature from changing over time. The first cost to install such a large heat exchanger often dissuades people from considering this approach. Using a hybrid approach, however, can often make GSHP systems more economical, opening up the possibility to reap the potential energy savings.

This hybrid approach involves adding a small cooling tower to the loop for a system that is installed in a cooling-dominated climate, or adding a small boiler to a system in a heating-dominated climate. In either case, the geothermal heat exchanger is sized based on the smaller of the two loads: for the total heat absorbed in a cooling-dominated climate or the total heat rejected in a heating-dominated climate. Then, a small cooling tower (or boiler) is added to reject (or add) the remaining heat.

This approach reduces the required size of the geothermal heat exchanger by avoiding the imbalance. The overall energy savings may not be as great as in a system with a larger heat exchanger, but this approach often results in a more acceptable return on investment.

AS4 *Peak Demand Reduction (Thermal Storage, Thermal Mass)* (Climate Zones: all)

Adding thermal storage to an HVAC system can reduce the utility costs associated with cooling by shifting operation of the chiller from times of high-cost electricity (daytime) to times of low-cost electricity (nighttime). This avoids, or reduces, the electricity required to operate the chiller during the daytime hours. Operation of the chiller is shifted to the off-peak period, during which the cost of electricity and the demand charge are lower. The chiller is used during that period to cool or freeze water inside storage tanks, storing the thermal energy until the on-peak period.

During the nighttime hours, the outdoor dry-bulb and wet-bulb temperatures are typically several degrees lower than during the day. This lowers the condensing pressure,

Technology Case Study: The Dalles Middle School The Dalles, OR

Figure S7.1. Water source heat pump.

The Dalles Middle School is located in a rural area along the Columbia River on the eastern slopes of the Cascades. The school had a subsurface geological problem that needed to be addressed. A landslide area adjacent to the school site was being dewatered through wells at a flow rate of about 130 gal/min. As part of the $12.5 million project to construct a new 96,500 ft^2 school, a geothermal system was installed based on this subsurface problem. Storage tanks and pipes were installed so that the water previously pumped directly to the Columbia River was now piped through GSHPs to provide either cooling or heating before being pumped to the river.

Photo and data provided by BOORA Architects, Oregon Energy Office, and Larry Schoff.

allowing the chiller to regain some of the capacity and efficiency it lost by producing colder fluid temperatures to recharge the storage tanks.

Another potential benefit of thermal storage is a reduction in the size and capacity of the chiller. When thermal storage is used to satisfy all or part of the design cooling load, the chiller may be able to be downsized as long as it has enough time to recharge the storage tanks.

An additional approach to reducing peak cooling demand is to take advantage of the building's thermal mass. Many school buildings are constructed of concrete or masonry walls. The thermal mass of these materials can absorb excess solar heat and stabilize indoor temperatures.

The principle is to precool the building during the nighttime (or morning off-peak) hours with cool OA. This cools the building's thermal mass and reduces the cooling load during on-peak hours.

In many climates, masonry walls are more efficient when insulation is located on the outside. This allows the wall to absorb excess heat from inside the building, and the insulation minimizes heat transfer to the outdoors. However, this is not common practice for most builders, and insulated masonry increases the width of a wall, making it difficult to finish at the edges of windows, roofs, and doors. Fortunately, new technologies have lowered the cost and increased options for insulated masonry.

AS5 *Thermal Displacement Ventilation* (Climate Zones: all)

Thermal displacement ventilation (TDV) systems are different from conventional overhead air delivery systems. TDV systems deliver air near the floor, at a low velocity, and at a temperature of about 65°F (compared to around 55°F with overhead air delivery). The goal of TDV systems is to cool the occupants, not the space. Cool air flows along the floor until it finds warm bodies. As the air is warmed, it rises around occupants, bathing them in cool fresh air.

Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone rather than being mixed in the space. Similarly, cooling loads decrease because much of the heat generated by occupants, lights, and computer equipment rises directly out of the occupied zone and is exhausted from the space. (This is especially true in classrooms designed for 100% OA.)

TDV is most appropriate for spaces with ceilings higher than 10 ft to permit temperature stratification. However, heating performance may be worse than with systems that deliver air at greater velocities, since mixing (not stratification) is desirable for heating. In non-arid climates, the supply air must be sufficiently dehumidified before it is reheated, or mixed with warm return air, to achieve the desired 65°F supply-air temperature.

AS6 Photovoltaic Systems

PV systems have become an increasingly popular option for energy production and for a teaching opportunity in schools. Currently, most PV systems in schools are relatively small compared to the total energy use of the school; this is due mainly to the initial cost of the PV system. Most PV systems in K-12 schools range from 1–50 kW.

One school using a larger system is Williamstown Elementary School in Williamstown, Massachusetts. Williamstown Elementary has a 24 kW roof-mounted PV system. It is estimated to produce roughly 30,000 kWh of electricity per year, which equates to 5%–10% of the school's annual energy use.

The actual energy production can be monitored at the Web site for the Massachusetts Technology Collaborative Renewable Energy Trust by viewing the trust funded projects and accessing the Williamstown Elementary project: http://www.mtpc.org/renewableenergy/index.html.

The Head-Royce School in Oakland, California, also uses a large PV system to generate significant energy savings. The school installed a 53 kW PV system on the roof of the gymnasium that provides a 25% savings in the electricity bill for the school and gymnasium.

The smaller PV systems are typically used mostly as teaching devices. They are usually installed in plain view to make them visible to the students, teachers, and the surrounding community. It is an attempt to inform the public of the importance of renewable energy sources and the technology involved.

Fossil Ridge High School in Fort Collins, Colorado, uses a smaller PV system. The 5.2 kW PV system is mounted outside the south entrance of the school on frames in front of the windows. The PV panels act as overhangs for the windows. Another school that uses a small PV system is Zeeland West High School in Zeeland, Michigan. This 1 kW

Technology Case Study:
Elmira High School
Elmira Oregon

Elmira High School in Elmira, Oregon, is a good example of how a school uses PV in its curriculum with a 0.6-kW PV system. Elmira is one of 15 schools in Oregon that is participating in a pilot PV program started by the Bonneville Power Administration (BPA) and Western SUN. The University of Oregon has put together a series of lesson plans for the schools that are participating in the program. These lesson plans are available in the educational resources on the University of Oregon Web site (http://solardata.uoregon.edu/).

- Lesson I—Solar cells introduces the students to the basic physics and chemistry that occur in a solar cell.
- Lesson II—Solar electric arrays shows the components of a solar electric system and the concept of a PV IV curve.
- Lesson III—Photovoltaics in arrays; solar cells generating electricity teaches the students about some of the variables that influence the effectiveness of the PV arrays in generating electricity.

Elmira can gather real-time information on the PV arrays at BPA's Energy Efficiency (EE) Web site (http://www.bpa.gov/Energy/N/), as one of the 15 solar schools with EE metering data in the Technologies section of the site.

system is mounted on poles on the ground, which aids in using the PV system as a teaching device.

There are many unique funding opportunities for PV systems in schools. In addition to the many rebate programs offered by state and local utility companies, there are often significant incentives, loans, grants, and buy-back programs for PV systems for K-12 schools. The following link shows some incentives and rebates that are available to schools in most states: http://www.dsireusa.org/Index.cfm?EE=0&RE=1. Some state and local utility companies offer rebates that range from $2.00–$6.00/W for school PV systems.

Technology Case Study: Twenhofel Middle School Independence, KY

Twenhofel Middle School in Independence, Kentucky, uses the green building techniques as a teaching aide. The students can monitor most of the systems that are used in the school through the online monitoring program available on the Internet (http://www.twhvac.kenton.kyschools.us/). The Web site allows the students to monitor the electrical energy, PV system, daylighting system, geothermal heating/cooling system, and the rainwater harvesting system. The program makes students aware of their daily energy use and is an opportunity for a hands-on learning experience with renewable energy. In the science classes, the students use the monitoring program to track the effects on daylighting from the sun, which teaches the students the patterns of the sun and earth throughout the course of a year.

The school encourages the students to conserve energy with a monthly contest between the 6th–8th grade students to see which grade can conserve the most energy over the course of a month. The students track their progress in the monthly contest every morning via a television mounted in the lobby.

Figure S9.1. Clerestory windows and 24 kW PV system.

AS7 *Solar Hot-Water Systems*

Because of the high hot-water demands associated with cafeterias, solar hot-water systems are often viewed as important strategies in reducing energy bills. It can be even more cost-effective in middle schools and high schools, which have additional significant load for gym class showers and sports programs. Several types of systems could be used for additional savings. Two of the more common are drainback and closed-loop systems.

Use *drainback solar hot-water systems* in small applications where the piping can be sloped back toward a collection tank. By draining the collection loop, freeze protection can be accomplished when the pump shuts down, either intentionally or non-intentionally.

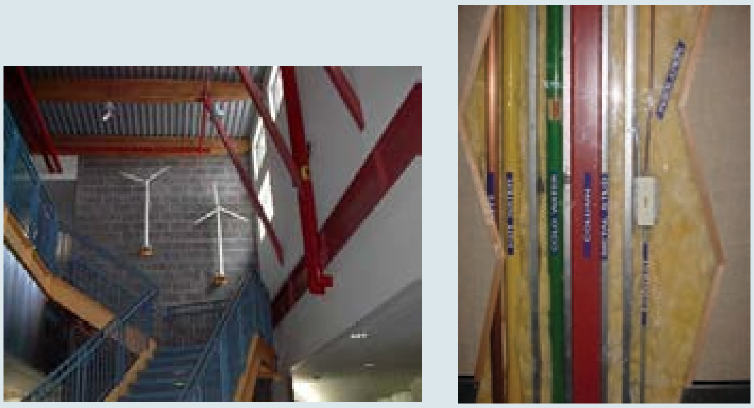
Select a *closed-loop, freeze-resistant solar system* if piping layouts make drainback options impractical. In closed-loop systems, a small pump circulates antifreeze protected fluids through the collection loop when there is adequate solar radiation and the differential between the collector fluid temperature and when the tank temperature justifies continuation of the collection mode.

AS8 *Energy-Efficient Schools as Teaching Tools*

Schools that incorporate energy efficiency and renewable energy technologies make a strong statement about the importance of protecting the environment. They also provide

Technology Case Study:
Zach Elementary School
Fort Collins, CO

Zach Elementary School in Fort Collins, Colorado, has left building systems and some piping exposed to teach students about the energy efficiency features in the school. All the electricity used in the school is purchased from wind power. Miniature wind turbines are mounted to the walls inside the school. The turbines are used to increase the awareness of the growing wind energy presence in Fort Collins. The school has also placed cutouts in some of the walls to allow the students to see inside and to learn about the construction techniques used to make the building energy efficient.



(a) **(b)**

Figure S10.1. (a) Example wind turbines and (b) exposed piping and insulation.

hands-on opportunities for students and visitors to learn about these technologies and the importance of energy conservation. The efforts to make a school building energy efficient are no longer being hidden within the walls and inside mechanical rooms. They are being used as teaching aids in the schools, allowing teachers to introduce curriculum that focuses on energy usage and environmental issues.

PV systems are a common area of interest for energy-efficient teaching tools. The PV systems allow real-time information that can be added to the school's curriculum.

Many schools that have installed PV systems have instituted programs for the students that allow them to monitor the real-time system performance. The monitoring programs are typically available through kiosks in the school or via the Internet. Examples of these monitoring systems are available at the following Web sites.

- The Massachusetts Technology Collaborative Renewable Energy Trust (http://www.mtpc.org/renewableenergy/index.html)
- The Missouri Department of Natural Recourses, Missouri Schools Going Solar (http://www.sunviewer.net/portals/MSGS/)
- The Energy Whiz program (http://www.energywhiz.com/index.htm)
- Individual schools including the following:
    - North Charleston Elementary School (http://northcharleston.greentouchscreen.com/)
    - Desert Edge High School (http://desertedge.greentouchscreen.com/)
    - Turner Falls High School (http://66.189.87.227/tfhs01/tfhsweb/home.html)
    - The Match School (http://www.matchschool.org/solar/home.html)
    - Williamstown Elementary School (http://buildingdashboard.com/clients/wtown/)

Energy-efficient teaching aids include more than just PV systems. Some schools have left HVAC equipment and plumbing exposed to allow the students to see and learn from the systems.

Resources for educational and training information on energy, energy efficiency, and renewable energy are available from the Department of Energy (DOE) on their Energy Education Web site (http://www1.eere.energy.gov/education/). The "Get Smart About Energy" page (http://www.eere.energy.gov/education/lessonplans/) offers more than 350 lesson plans and activities for grades K-12.

Appendix A
Envelope Thermal Performance Factors

Each climate zone recommendation table presents a prescriptive construction option for each opaque envelope measure. Table A.1 presents U-factors for above-grade components, C-factors for below-grade walls, and F-factors for slab-on-grade floors that correspond to each prescriptive construction option. Alternate constructions would be an equivalent method for meeting the recommendations of this guide provided they are equal to or better than the thermal performance factors listed in Table A1.

Table A1. Envelope Thermal Performance Factors

Opaque Construction Options

Roof Assemblies

Insulation Entirely Above Deck	
R	U
25	0.039
Metal Building	
R	U
19	0.065
13+13	0.055
13+19	0.049
19+19	0.046
Attic and Other	
R	U
30	0.032
38	0.027
60	0.017

Walls, Above Grade

Mass Walls	
R	U
5.7 c.i.	0.151
7.6 c.i.	0.123
9.5 c.i.	0.104
11.4 c.i.	0.090
13.3 c.i.	0.080
15.2 c.i.	0.071
Metal Building	
R	U
16	0.093
19	0.084
19+5.6 c.i.	0.057
19+11.2 c.i.	0.043
Steel Framed	
R	U
13	0.124
13+3.8 c.i.	0.084
13+7.5 c.i.	0.064
13+21.6 c.i.	0.034
Wood Framed and Other	
R	U
13	0.089
13+3.8 c.i.	0.064
13+7.5 c.i.	0.051
13+10 c.i.	0.045

Walls, Below Grade

Below Grade Walls	
R	C
7.5 c.i.	0.119
15 c.i.	0.063

Floors

Mass	
R	U
4.2 c.i.	0.137
6.3 c.i.	0.107
8.3 c.i.	0.087
10.4 c.i.	0.074
12.5 c.i.	0.064
16.7 c.i.	0.051
Steel Framed	
R	U
19	0.052
30	0.038
38	0.032
Wood Framed and Other	
R	U
19	0.051
30	0.033

Slabs

Unheated	
R-in	F
10-24	0.54
15-24	0.52
20-24	0.51
Heated	
R-in.	F
7.5-12	1.02
7.5-24	0.95
10-24	0.90
15-24	0.86
15-Full	0.44

Appendix B
Commissioning

A building can have the best possible design for achieving energy savings, but unless the building is built as designed and is operated according to the design intent, energy savings will not be achieved. A CxA ensures the energy- and water-saving methods and devices selected by the design team are incorporated in the building plans and specifications, that everything is built and tested accordingly, and that school personnel, including those occupying the building, are provided the necessary documentation and training to properly operate the building after it is occupied. The CxA can be an independent member of the design firm, the school's facility staff, or a third-party consultant. Some prefer to use third-party consultants for this role to ensure that the work is done independently of the design team to ensure that the results are not biased.

The Cx process is applicable to all buildings, but large and complex buildings require a correspondingly greater level of effort than is required for small, simple buildings. See Table B1 for more information.

Table B1. Commissioning Activities and Related Responsibilities

Item	Activity	Responsibility
1.	Create Owner's Project Requirements (OPRs)	CxA/owner
2.	Create project specific Cx plan (use this model, modify where necessary)	Owner/CxA
3.	Create the Basis of Design	Architect/engineer
4.	Review OPRs and Basis of Design	CxA
5.	Review schematic and design development documents, including load calculations	CxA
6.	Review construction documents before completion	CxA
7.	Incorporate Cx requirements into construction documents	Designers
8.	Review submittals for commissioned systems	Designer; CxA
9.	Develop project-specific construction checklists	CxA
10.	Implement construction checklists	Contractors
11.	Create and maintain Cx issues log	CxA
12.	Perform targeted inspections during rough-in phase	CxA/AE/O&M
13.	Witness pipe flushing and testing, duct testing	CxA
14.	Field-verify contractors' completed construction checklists	CxA/O&M
15.	Performance testing and demonstrations	Contractors
16.	Validate test and balance report	CxA
17.	Conduct periodic Cx meetings	CxA
18.	Develop functional performance test procedures	CxA
19.	Assist in contractor troubleshooting	CxA
20.	Identify air quality issues	CxA
21.	Direct and witness functional performance testing	CxA/O&M
22.	Issue final Cx report	CxA
23.	Develop systems manuals from O&M manuals including re-commissioning procedures	CxA
24.	Project manager coordinate and document owner training performed by contractors	Project manager
25.	Confirm training performed by contractors is per contract and adequate	CxA/O&M
26.	Recommend final system acceptance	CxA/O&M
27.	Perform post-occupancy review two months after occupancy	CxA/project manager/ facilities personnel/O&M
28.	Perform post-occupancy review and warranty inspections 10 months after occupancy per contract documents	CxA/project manager/ facilities personnel/ O&M/architect
29.	Create lesson-learned document for distribution to all project managers/planners	CxA

Note: Designer is an inclusive term that indicates project architect and engineers and other design consultants, such lighting, acoustics, landscape architects.

Appendix C
Climate Zones for Mexico and Canada

The following tables show the climate zone numbers for a wide variety of Mexican and Canadian locations. Additional information on international climatic zones can be found in ASHRAE Standard 90.1-2004, Normative Appendix B, "Building Envelope Climate Criteria." The information is from Tables B-2 and B-3 in that appendix.

Table C1. Mexican Climate Zones

Country		Country	
City	Zone	City	Zone
Mexico		**Mexico**	
Mexico City (Distrito Federal)	3	Tampico (Tamaulipas)	2
Guadalajara (Jalisco)	1	Veracruz (Veracruz)	4
Monterrey (Nuevo Laredo)	3	Merida (Yucatan)	1

Table C2. Canadian Climatic Zones

Province	
City	Zone
Alberta (AB)	
Calgary International Airport (A)	7
Edmonton International A	7
Grande Prairie A	7
Jasper	7
Lethbridge A	6
Medicine Hat A	6
Red Deer A	7
British Columbia (BC)	
Dawson Creek A	7
Ft Nelson A	8
Kamloops	5
Nanaimo A	5
New Westminster BC Pen	5
Penticton A	5
Prince George	7
Prince Rupert A	6
Vancouver International A	5
Victoria Gonzales Hts	5
Manitoba (MB)	
Brandon CDA	7
Churchill A	9
Dauphin A	7
Flin Flon	7
Portage La Prairie A	7
The Pas A	7
Winnipeg International A	7
New Brunswick (NB)	
Chatham A	7
Fredericton A	6
Moncton A	6
Saint John A	6

Province	
City	Zone
Newfoundland (NF)	
Corner Brook	6
Gander International A	7
Goose A	7
St John's A	6
Stephenville A	6
Northwest Territories (NW)	
Ft Smith A	8
Inuvik A	8
Yellowknife A	8
Nova Scotia (NS)	
Halifax International A	6
Kentville CDA	6
Sydney A	6
Truro	6
Yarmouth A	6
Nunavut	
Resolute A	8
Ontario (ON)	
Belleville	6
Cornwall	6
Hamilton RBG	5
Kapuskasing A	7
Kenora A	7
Kingston A	6
London A	6
North Bay A	7
Oshawa WPCP	6
Ottawa International A	6
Owen Sound MOE	6
Petersborough	6
St Catharines	5
Sudbury A	7
Thunder Bay A	7
Timmins A	7
Toronto Downsview A	6
Windsor A	5

Province	
City	Zone
Prince Edward (PE)	
Charlottetown A	6
Summerside A	6
Quebec (PQ)	
Bagotville A	7
Drummondville	6
Granby	6
Montreal Dorval Int'l A	6
Quebec A	7
Rimouski	7
Septles A	7
Shawinigan	7
Sherbrooke A	7
St Jean de Cherbourg	7
St Jerome	7
Thetford Mines	7
Trois Rivieres	7
Val d'Or A	7
Valleyfield	6
Saskatchewan (SK)	
Estevan A	7
Moose Jaw A	7
North Battleford A	7
Prince Albert A	7
Regina A	7
Saskatoon A	7
Swift Current A	7
Yorkton A	7
Yukon Territory (YT)	
Whitehorse A	8

Appendix D
ENERGY STAR® Appliances

The following equipment and appliances that are typically used in K-12 schools and are within the scope of the applicable ENERGY STAR program will have the ENERGY STAR label. For more information, visit the ENERGY STAR Web site at www.energystar.gov.

1. Appliances
   - battery chargers
   - clothes washers
   - dehumidifiers
   - dishwashers
   - refrigerators and freezers
   - room air conditioners
   - room air cleaners
   - water coolers

2. Heating and Cooling
   - air-source heat pumps (see also the energy-efficiency requirements in Chapter 3)
   - boilers (see also the energy-efficiency requirements in Chapter 3)
   - central air conditioners (see also the energy-efficiency requirements in Chapter 3)
   - ceiling fans
   - dehumidifiers
   - furnaces (see also the energy-efficiency requirements in Chapter 3)
   - geothermal heat pumps (see also the energy-efficiency requirements in Chapter 3)
   - programmable thermostats
   - room air conditioners
   - ventilating fans

3. Electronics
   - cordless phones
   - combination units (TV/VCR/DVD)
   - DVD products
   - audio

- televisions
- VCRs

4. Office Equipment
    - computers
    - copiers
    - fax machines
    - laptops
    - mailing machines
    - monitors
    - multifunction devices
    - printers
    - scanners

5. Lighting
    - CFLs
    - ceiling fans

6. Commercial Food Service
    - commercial fryers
    - commercial hot food holding cabinets
    - commercial solid door refrigerators and freezers
    - commercial steam cookers

7. Other Products
    - traffic signals
    - transformers
    - vending machines

Appendix E
Additional Resources

ORGANIZATIONS—GENERAL

American Institute of Architects (AIA)

1735 New York Ave., NW
Washington, DC 20006-5292
800-AIA-3837 or 1-202-626-7300
http://www.aia.org/

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

1791 Tullie Circle, NE
Atlanta, GA 30329
800-527-4723 or 1-404-636-8400
http://www.ashrae.org/
ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1)
ASHRAE Technical Committee on Educational Facilities (TC 9.7)

Illuminating Engineering Society of North America (IESNA)

120 Wall Street, Floor 17
New York, NY 10005
1-212-248-5000
http://www.iesna.org/

U.S. Department of Energy (DOE)

1000 Independence Ave., SW
Washington, DC 20585
800-dial-DOE (1-800-342-5363) or 1-202-586-5000
http://www.energy.gov/

U.S. Green Building Council (USGBC)

1800 Massachusetts Ave., NW, Suite 300
Washington, DC 20036
800-795-1747 or 202-742-3792
http://www.usgbc.org/

ORGANIZATIONS—HIGH PERFORMANCE SCHOOLS

Collaborative for High Performance Schools (CHPS)

142 Minna Street, Second Floor
San Francisco, CA 94105
887-642-CHPS
http://www.chps.net/

National Clearinghouse for Educational Facilities (NCEF)

1090 Vermont Ave., NW, Suite 700
Washington, DC 20005-4905
888-552-0624 or 202-289-7800
http://www.edfacilities.org/

National Institute of Building Sciences (NIBS)

1090 Vermont Ave., NW, Suite 700
Washington, DC 20005-4905
202-289-7800
http://www.nibs.org/

Sustainable Building Industry Council (SBIC)

1112 16th Street, NW, Suite 240
Washington, DC 20036
202-628-7400
http://www.sbicouncil.org/

COMMISSIONING

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Advanced Energy Design Guide for K-12 School Buildings

This Guide was prepared under ASHRAE Special Project 111.

The ASHRAE *Advanced Energy Design Guide for K-12 School Buildings* is the third in a series designed to provide recommendations for achieving 30% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999. The energy savings target of 30% is the first step in the process toward achieving a net zero energy building, which is defined as a building that, on an annual basis, draws from outside resources equal or less energy than it provides using on-site renewable energy sources. ANSI/ASHRAE/IESNA Standard 90.1-1999, the energy-conservation standard published at the turn of the millennium, provides the fixed reference point for all of the Guides in this series. The primary reason for this choice as a reference point is to maintain a consistent baseline and scale for all of the 30% AEDG series documents.

This Guide focuses on elementary, middle, and high school buildings. These buildings have a wide variety of heating and air-conditioning equipment, which is reflected in the recommendations contained in this Guide. There is also extensive information about lighting systems, including daylighting—an important energy-saving measure.

The *Advanced Energy Design Guide for K-12 School Buildings* will help school boards, school administrators, design professionals, and contractors build, operate, and maintain more energy-efficient schools.

The recommendations in this Guide will allow those involved in designing or constructing school buildings to easily achieve advanced levels of energy savings without having to resort to detailed calculations or analyses. All of the energy-saving recommendations for each of the eight U.S. climate zones are summarized in a single table, thus facilitating the Guide's use. Additional recommendations point to other opportunities to incorporate greater savings into the design of the building.

Those looking for help in implementing the recommendations of this Guide will find an expanded section of tips and approaches in the "How to Implement Recommendations" chapter of the Guide. To further facilitate its use, the Guide cross-references the how-to information with the numbered tips and the color-coded climate zone maps inside. Examples of advanced K-12 school building energy designs are also provided in numerous case studies to illustrate the recommendations and to demonstrate the flexibility offered in achieving the advanced energy savings levels provided within the Guide.

For more information on the entire Advanced Energy Design Guide series, please visit www.ashrae.org/aedg.

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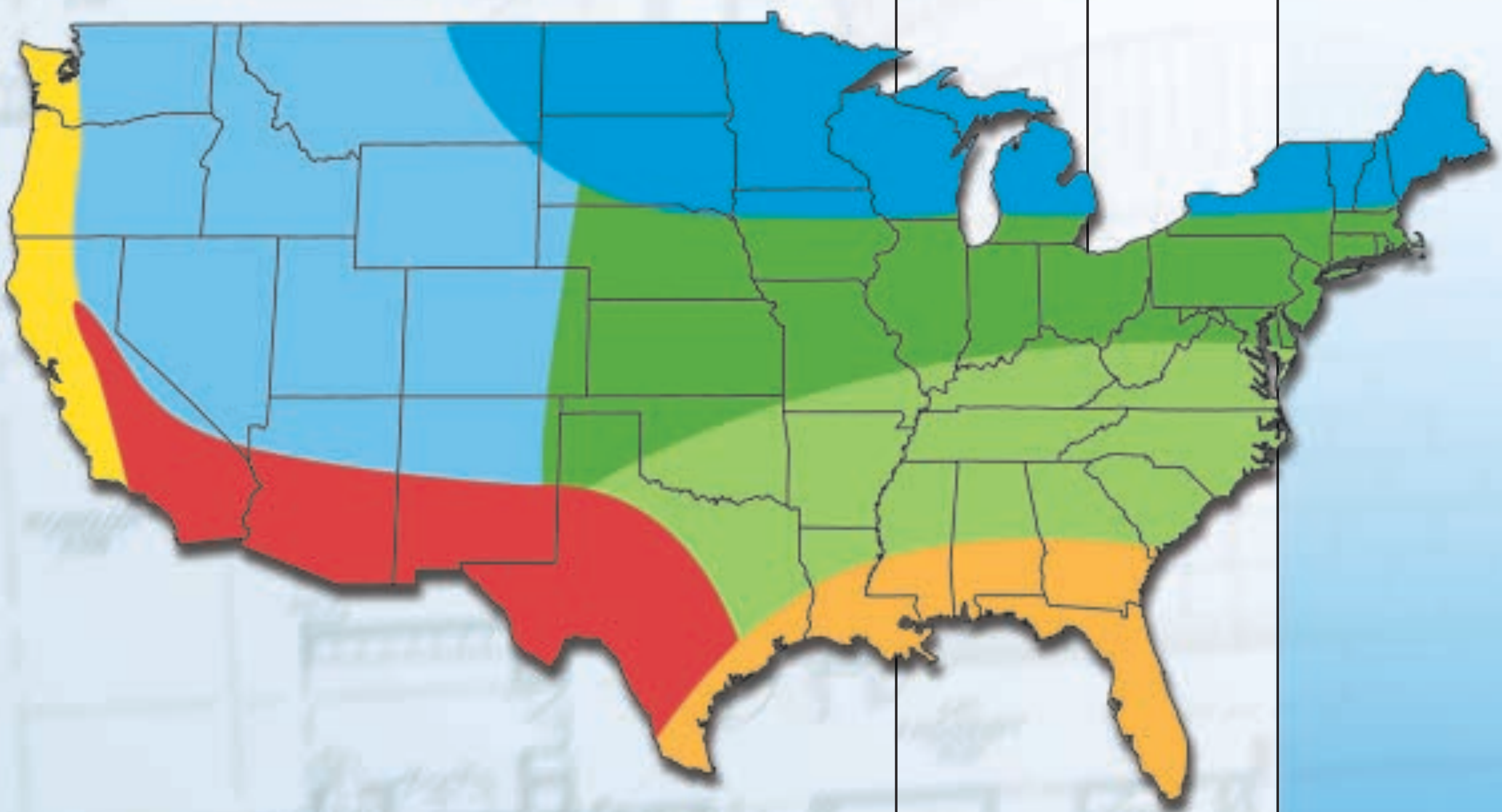
National Best Practices Manual

For Building High Performance Schools



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Available electronically at http://www.doe.gov/bridge.

Table of Contents

Introduction to the Manual

The U.S. Department of Energy's Rebuild America EnergySmart Schools program provides school boards, administrators, and design staff with guidance to help make informed decisions about energy and environmental issues important to school systems and communities. The *National Best Practices Manual for Building High Performance Schools* is a part of the suite of products developed to promote energy efficiency and renewable energy in schools. It was developed specifically for architects and engineers who are responsible for designing or retrofitting schools, and for the project managers who work with the design teams.

The *Energy Design Guidelines for High Performance Schools*, available for seven climate zones across the United States, was developed for school boards, administrators, and design staff to help make informed design decisions about energy and environmental issues important to school systems and communities. To obtain a copy of the *Energy Design Guidelines for High Performance Schools* for a particular climate zone (shown in the map on the following page), contact the U.S. Department of Energy's Energy Efficiency and Renewable Energy Clearinghouse (EREC) at 800-DOE-EREC (800-363-3732).

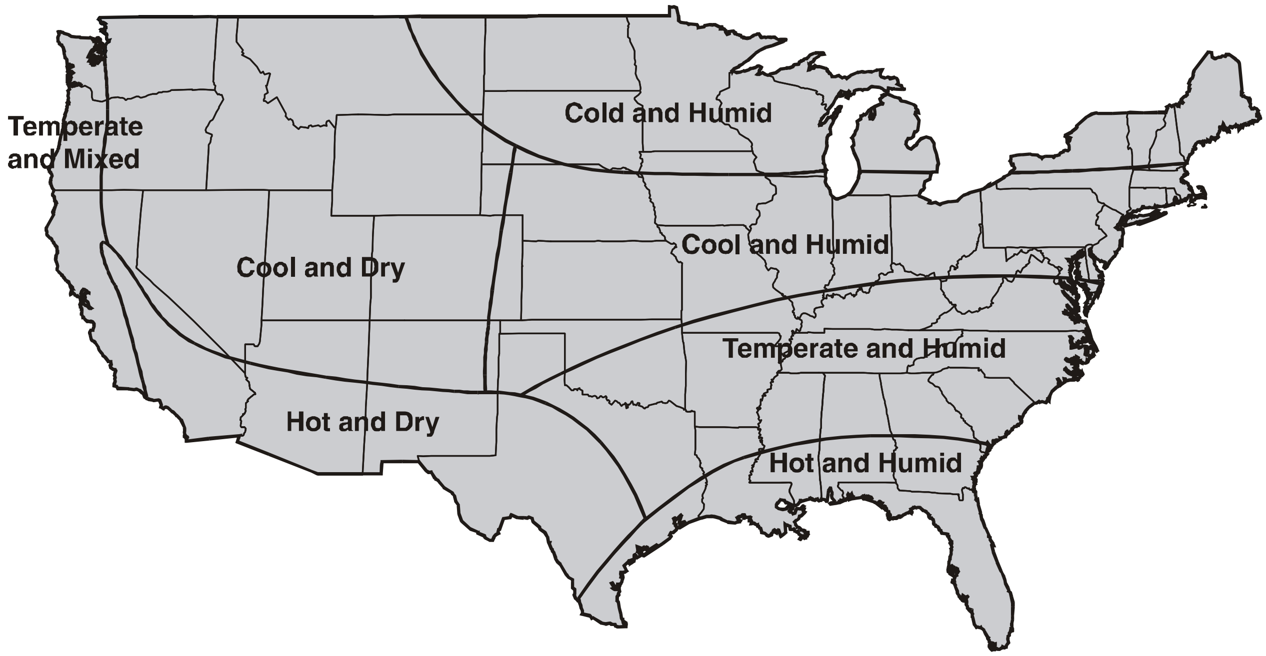

Figure 1 – Seven U.S. Climate Zones

The design strategies presented here are organized into 10 chapters covering important design disciplines and goals: site design; daylighting and windows; energy-efficient building shell; lighting and electrical systems; mechanical and ventilation systems; renewable energy systems; water conservation; recycling systems and waste management; transportation; and resource-efficient building products. An additional chapter addresses commissioning and maintenance practices. Applying these guidelines will result in schools that are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable, and easy to operate and maintain.

THE DESIGN PROCESS

The characteristics of a high performance school reflect a mix of environmental, economic, and social objectives. The design process used to achieve high performance schools is fundamentally different from conventional practice. To be most effective, this process requires a significant commitment on the part of design professionals to:

- Meet energy and environmental performance criteria.
- Maintain a view of the building and site as a seamless whole within the context of its community.
- Work with the understanding that the building exists within the context of a natural ecosystem even when the setting is urban.
- Incorporate interdisciplinary collaboration throughout the design and construction process.
- Maximize student performance by keeping standards high for air quality and increasing the use of daylighting.
- Integrate all significant building design decisions and strategies — beginning no later than the programming phase.

- Optimize design choices through simulations, models, or other design tools.
- Employ life-cycle cost analysis in all decision making.
- Design all systems to be easy to maintain and operate.
- Commission all building equipment and systems to assure continued optimum performance.
- Document high performance materials and techniques in the building so that maintenance and repairs can be made in accordance with the original design intent.
- Encourage resource-efficient construction operations and building maintenance.
- Provide clear guidance, documentation, and training for operation and maintenance staff.

The typical design process for schools begins with programming and selection of the architectural-engineering team. It then proceeds through schematic design, design development, contract documents, construction, commissioning, and occupancy. The sooner high performance goals are considered in the design process, the easier and less costly they are to incorporate. Many of the guidelines presented in this document must be considered early in the design process for them to be successful. Figure 2 below shows a timeline through the design process and indicates the types of measures and design strategies that can be considered along the way.

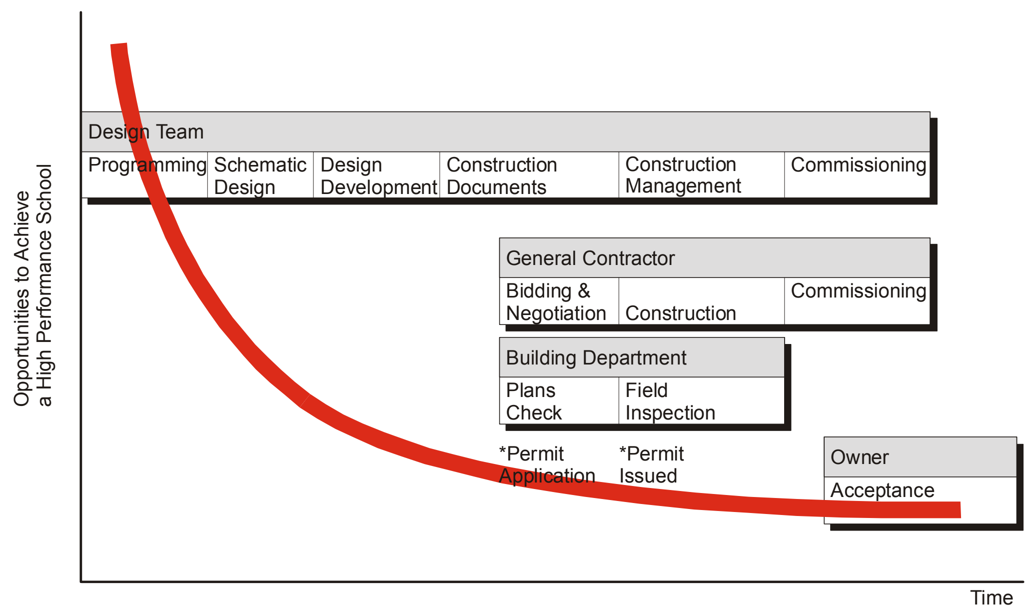

Figure 2 – Opportunities in the Design Process

For best results, these high performance goals should be reflected in all aspects of project documentation. High performance goals established during programming should be clearly stated in the educational specifications, in the request for proposals (RFP) to select the design team, in the instructions to bidders, and as part of the project summary. These goals are best expressed in terms of performance.

INTEGRATED DESIGN

Integrated design is the consideration and design of all building systems and components together. It brings together the various disciplines involved in designing a building and reviews their recommendations as a whole. It recognizes that each discipline's recommendations have an impact on other aspects of the building project. This approach allows for optimization of both building performance and cost. Too often, heating, ventilation, and cooling (HVAC) systems are designed independently of lighting systems, for example, and lighting systems are designed without consideration of daylighting opportunities. The architect, mechanical engineer, electrical engineer, contractors, and other team members each have their scope of work and often pursue it without adequate communication and interaction with other team members. This can result in oversized systems or systems that are optimized for non-typical conditions.

Even a small degree of integration provides some benefits. It allows professionals working in various disciplines to take advantage of efficiencies that are not apparent when they are working in isolation. It can also point out areas where trade-offs can be implemented to enhance resource efficiency. Design integration is the best way to avoid redundancy or conflicts with aspects of the building project planned by others.

The earlier that integration is introduced in the design process, the greater the benefit. For a high performance school, project team collaboration and integration of design choices should begin no later than the programming phase. In addition, the project team is likely to be more broadly defined than in the past, and may include energy analysts, materials consultants, lighting designers, life-cycle cost consultants, and commissioning agents. Design activities may expand to include charrettes, modeling exercises, and simulations.

This manual provides details and implementation rules for individual design strategies. Though these individual strategies can improve a building's energy efficiency, only through whole-building analysis and integrated design can energy and cost concerns be balanced most effectively.

Integrated Design and Portable Classrooms

Integrated design concepts should be used in all types of school construction: new buildings, renovations, and even portable classrooms. A feature of U.S. schools for years, portable—or "relocatable"—classrooms appeal to school districts because of their low initial cost and short time between specification and occupancy. They are intended to provide flexibility, enabling quick response to demographic changes and providing

This modular relocatable structure is a prototype and contains a variety of high performance features such as daylighting, high indoor air quality, significant energy savings, and resource efficient materials.

NREL/PIX 11440

the ability to be moved from one school to another as demographics change. However, in reality, relocatable classrooms are seldom moved and become permanent fixtures of the school.

While most high performance strategies tend to be overlooked in portables, the effects of poor indoor environmental quality (IEQ) in relocatable classrooms are no different from those in permanent classrooms. All school buildings use similar construction and furnishing materials, so the types of chemicals present in indoor air are not likely to be different for relocatable versus permanent classrooms. However, pressed-wood products (often with high concentrations of formaldehyde) are used more in the factory-built relocatable units than in buildings constructed on-site. As a result, levels of airborne chemicals may be higher in new relocatable classrooms, especially if ventilation is reduced.

The most common problems with relocatable classrooms include:

- Poorly functioning HVAC systems that provide minimal ventilation of outside air.
- Poor acoustics from loud ventilation systems.
- Chemical off-gassing from pressed wood and other high-emission materials, compounded by quick occupation after construction or installation of carpets.
- Site pollution from nearby parking lots or loading areas.

Relocatable classrooms should be subject to the same high performance goals and concepts as the main school building. The solutions to these problems are the same as the recommendations presented in this manual for permanent structures.

GOALS AND CROSS-CUTTING ISSUES

This manual is organized into 10 chapters that address the major high performance design goals and disciplines. The guidelines presented in each chapter are directed toward building schools that achieve the following goals, which are issues that cut across each of the major disciplines:

- Health and Indoor Air Quality (IAQ)
- Thermal Comfort
- Visual Comfort
- Acoustic Comfort
- Security and Safety
- Ecosystem Protection
- Energy Efficiency
- Water Efficiency
- Materials Efficiency
- Buildings as a Teaching Tool

Table 1 below shows which of the goals (or cross-cutting issues) apply to each of the chapters. The rest of this section describes these relationships in more detail and provides checklists that summarize the key high performance design strategies for each discipline.

Table 1 – Relationship Between Goals and Technical Chapters

	Goals/Cross-Cutting Issues									
Technical Chapters	**Health and IAQ**	**Thermal Comfort**	**Visual Comfort**	**Acoustic Comfort**	**Security and Safety**	**Ecosystem Protection**	**Energy Efficiency**	**Water Efficiency**	**Materials Efficiency**	**Building as a Teaching Tool**
Site Design	●	●	●	●	●	●	●	●	●	●
Daylighting and Windows		●	●		●		●		●	●
Energy-Efficient Building Shell		●		●			●		●	●
Lighting and Electrical Systems		●	●				●			●
Mechanical and Ventilation Systems	●	●		●	●		●	●	●	●
Renewable Energy Systems		●					●			●
Water Conservation								●		●
Recycling Systems and Waste Management						●			●	●
Transportation					●	●	●			
Resource-Efficient Building Products	●			●		●	●		●	●

Health and IAQ

> ***A Closer Look – Boscawen Elementary School, Boscawen, NH***
>
> *This 53,000 ft², 420-student school north of Concord, NH is the first in the country to use a combined displacement and demand-control ventilation system to provide superior IAQ and thermal comfort with reduced overall energy costs.*
>
> *In this system, students and teachers are constantly surrounded by outside air. Stale air rises above them and is then vented out. None of it is recirculated. The result is a school with exemplary IAQ that is, at the same time, energy and cost efficient.*
>
> *As Dr. G.W. Porter of the New Hampshire State Department of Education notes, "Despite the innovative engineering, its cost was equal, or possibly less than, other typical schools. Maintenance costs, such as heating, are expected to be lower; and even without air-conditioning, the building will be even cooler in spring and fall. Air quality, a problem that's plagued a number of our schools, will also be vastly improved."*

The quality of the air inside a school is critical to the health and performance of children, teachers, and staff. A high performance school should provide superior quality indoor air by: eliminating and controlling the sources of contamination; providing adequate ventilation; preventing unwanted moisture accumulation; and implementing effective operation and maintenance procedures.

According to the U.S. Environmental Protection Agency (EPA), the concentration of pollutants inside a building may be two to five times higher than outside levels. Children are particularly vulnerable to such pollutants because their breathing and metabolic rates are high relative to their size. Maintaining a high level of IAQ is therefore critical for schools. Failure to do so may, according to the EPA, negatively impact student and teacher performance; increase the potential for long- and short-term health problems for students and staff; increase absenteeism; accelerate deterioration; reduce efficiency of the school's physical plant; create negative publicity; and create potential liability problems.

To eliminate or control contamination, select materials that are low emitters of substances such as volatile organic compounds (VOCs) or toxins. Some of these building materials may be unfamiliar to custodial staff, so provide training to the staff, and select durable products and avoid products that unnecessarily complicate operation and maintenance. Any material can affect the acoustic and visual quality of a school; be sure to consider this when evaluating these materials. The following checklist summarizes strategies to improve a school's IAQ.

Eliminate or control contamination at the source

- ✓ *Require a construction IAQ plan.*
- ✓ *Test the site for sources of contamination such as radon, hazardous waste, or fumes from nearby industrial or agricultural uses.*
- ✓ *Locate sources of exhaust fumes (e.g., from vehicles) away from air intake vents.*
- ✓ *Use recessed grates, "walk off" mats and other techniques to reduce dirt entering the building.*

Avoid materials that contaminate indoor air

- ✓ *Use materials that pass the emissions limits in the Specifications Section 1350.*
- ✓ *Specify composite wood or agrifiber products containing no urea-formaldehyde resins.*

Provide adequate ventilation

- ✓ *Allow adequate time for installed materials and furnishings to "off-gas" before the school is occupied. Run the HVAC system continuously at the highest possible outdoor air supply setting for at least 72 hours after all materials and furnishings have been installed.*
- ✓ *Design the ventilation system to provide a minimum of 15 cfm/person of filtered outdoor air to all occupied spaces.*
- ✓ *Ensure that ventilation air is effectively delivered to and distributed through the rooms in a school.*
- ✓ *Provide local exhaust for restrooms, kitchens, labs, janitor's closets, copy rooms, and shop rooms.*

Prevent unwanted moisture accumulation

- ✓ *Design the ventilation system to maintain the indoor relative humidity between 30% and 50%.*
- ✓ *Design to minimize water vapor condensation, especially on walls, the underside of roof decks, around pipes or ducts.*
- ✓ *Design to keep precipitation out of the building, off the roof, and away from the walls.*

Operate and maintain the building effectively

- ✓ *Regularly inspect and maintain the ventilation system so that it continues to operate as designed.*
- ✓ *Install CO_2 sensors in large assembly areas for real-time monitoring of air quality.*
- ✓ *Minimize the use of toxic cleaning materials.*
- ✓ *Use the EPA's "Indoor Air Quality—Tools for Schools" to guide the operation and maintenance process.*
- ✓ *Use the EPA's "Mold Remediation in Schools and Commercial Buildings" to control moisture problems. http://www.epa.gov/iaq/molds or (800) 438-4318.*

Thermal Comfort

Thermal comfort is an important variable in student and teacher performance. Hot, stuffy rooms — and cold, drafty ones — reduce attention spans and limit productivity. They also waste energy, adding unnecessary cost to a school's bottom line. Excessively high humidity levels can also contribute to mold and mildew. Thermal comfort is primarily a function of the temperature and relative humidity in a room, but air speed and the temperature of the surrounding surfaces also affect it. A high performance school should ensure that rooms and HVAC systems are designed to allow temperature and humidity levels to remain within the "comfort zone" at all points in an occupied space. Thermal comfort guidelines are provided in the technical chapter on Mechanical and Ventilation Systems.

A Closer Look** – **Designing for Thermal Comfort

A design concept that provides superior thermal comfort through combining low velocity ventilation, room air stratification, and dehumidification cooling has been applied successfully at more than 20 schools in New England. This design approach, called The Advantage Classroom developed by The H. L. Turner Group in Concord, NH, reduces drafts and "hot spots," enhances efficiency and control by including thermostats in each room, reduces room noise, and ensures optimal temperature and humidity levels by ongoing monitoring of room conditions.

Kim Cheney, a teacher at one school built with this design concept, is very satisfied with the results: "Everything about it is incredible; the whiteboards eliminate chalk dust, the air is clean, the temperature is perfect, it's all so comfortable. In the old school . . . we'd be really cold, but if you turned on the heat it would get so hot the students would get tired in the afternoon. In moving into the new school we went from the 19th century straight to the 21st."

Thermal comfort is strongly influenced by how a specific room is designed (for example, the amount of heat its walls and roof gain or lose, the amount of sunlight its windows let in, whether the windows can be opened) and by how effectively the HVAC system can meet the specific needs of that room. Balancing these two factors — room design and HVAC system design — is a back-and-forth process that continues throughout all the stages of developing a new facility. In a high performance school, the process ends with an optimal blend of both components: rooms configured for high student and teacher productivity served by an energy-efficient HVAC system designed, sized, and controlled to maintain thermal comfort under all conditions.

Thermal Comfort Checklist

Design in accordance with ASHRAE standards

- ✓ *Design systems to provide comfort in accord with American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55–1992 (with 1995 Addenda) Thermal Environmental Conditions for Human Occupancy.*
- ✓ *When a design incorporates natural ventilation (e.g., operable windows to provide direct outdoor air during temperate weather), consider adjusting the requirements of ASHRAE Standard 55–1992 to account for the impact.*

Install controls and monitor system performance

- ✓ *Install controls in each classroom to give teachers direct control over thermal comfort. Evaluate the potential impact of such controls on the overall efficiency of the HVAC system.*
- ✓ *Consider providing a temperature and humidity monitoring system to ensure optimal thermal comfort performance.*
- ✓ *Consider including temperature and humidity monitoring as part of the building's overall energy management system.*

Analyze room and system layouts

- ✓ *Analyze room configurations and HVAC distribution layouts to ensure all parts of a room are receiving adequate ventilation.*
- ✓ *Analyze placement of windows and skylights and provide adequate, controllable shading to avoid "hot spots" caused by direct sunlight.*

Visual Comfort

Performing visual tasks is a central component of the learning process for both students and teachers. A high performance school should provide a rich visual environment — one that enhances, rather than hinders, learning and teaching — by carefully integrating natural and electric lighting strategies, by balancing the quantity and quality of light in each room, and by controlling or eliminating glare.

Students spend much of their day engaged in visual tasks — writing, reading printed material, reading from visual display terminals, or reading from blackboards, whiteboards, and overheads. They must constantly adjust their vision from a "heads-up" to "heads-down" position and back again. Inadequate lighting and/or glare can seriously affect a student's ability to learn. On the other hand, a comfortable, productive visual environment — one that takes into account more than simply the amount of light hitting the desktop — will enhance the learning experience for both students and teachers.

A Closer Look – Durant Road Middle School, Wake County, NC

Daylighting and electric lighting are seamlessly integrated in this 1,300-student school in Raleigh, NC. The design team repeatedly analyzed the interactions between the size and location of the roof monitors; the size and configuration of the electric lighting fixtures; the color and reflectance of the walls, floor, and ceiling; and the amount of light hitting the desks.

"We worked the problem using computer simulation tools until we had just the right combination. The result is a group of classrooms that are bright, fun places to be; that rely on natural sunlight for the bulk of their lighting needs; that virtually eliminate glare; and that save the school money on energy; all at the same time," notes Mike Nicklas, chief architect for the project.

Because of the school's exceptional daylighting design, it was featured on CNN's "Science and Technology Week" series.

Visual comfort results from a well-designed, well-integrated combination of natural and artificial lighting systems. Any strategy for enhancing the visual environment will therefore strongly affect the size and configuration of both these systems (for example, number, type, and placement of windows; number, type, and placement of light fixtures; etc.). The final configurations will, in turn, affect a school's HVAC systems.

An optimized overall design will provide a high quality luminous environment and will use daylight effectively to reduce the need for artificial lighting. Less artificial lighting means lower electricity bills and less waste heat that, in turn, means less demand for cooling and lower HVAC operating expenses.

Visual Comfort Checklist

Integrate natural and artificial lighting strategies

- ✓ *Take the amount of daylight entering a room into account when designing and sizing the artificial lighting system for that room.*
- ✓ *Provide controls that turn off lights when sufficient daylight exists.*
- ✓ *Consider dimming controls that continuously adjust lighting levels to respond to daylight conditions.*

Balance the quantity and quality of light in each room

- ✓ *Avoid excessively high horizontal light levels.*
- ✓ *Use the revised 9th edition of the Illuminating Engineering Society of North America (IESNA)'s Lighting Handbook: Design and Application as a guide.*
- ✓ *Design for "uniformity with flexibility."*
- ✓ *Illuminate spaces as uniformly as possible, avoiding shadows or sharp distinctions between dark and light.*
- ✓ *Provide task or accent lighting to meet specific needs (e.g., display areas, whiteboards, team areas).*
- ✓ *Develop individual lighting strategies for individual rooms or room types (e.g., classrooms, hallways, cafeteria, library, etc.). Avoid "one size fits all" approaches.*

Control or eliminate glare

- ✓ *Consider how light sources in a room will affect work surfaces. Design to avoid direct glare (from sources in front or to the side of a work area), overhead glare (from sources above the work area), and reflected glare (from highly reflective surfaces, including glossy paper and computer terminals).*
- ✓ *Consider increasing the brightness of surrounding surfaces, decreasing the brightness of light sources, or both as control methods.*
- ✓ *Consider interior (shades, louvers, blinds) or exterior (overhangs, trees) strategies to filter daylight and control glare from sunlight.*

Acoustic Comfort

Parents, students, teachers, and administrators across the country are increasingly concerned that classroom acoustics are inadequate for proper learning. Noise from outside the school (from vehicles and airplanes, for example), hallways (foot traffic and conversation), other classrooms (amplified sound systems and inadequate sound transmission loss), mechanical equipment (compressors, boilers, and ventilation systems), and even noise from inside the classroom itself (reverberation) can hamper students' concentration.

> ***A Closer Look – Sterling Montessori Academy, Morrisville, NC***
>
> *The roof monitors that bring daylight into the classrooms of this 200-student elementary school in a Raleigh, NC, suburb provide an added benefit: improved acoustics. The large, open space under the monitors, plus the baffles used to control glare, help dampen sound throughout the classroom. The result is an improved environment for teaching and learning.*
>
> *Though daylighting was expected to be the most noticeable change for teachers and students, one teacher said the improved acoustics was the best feature.*

Trying to hear in a poor acoustical environment is like trying to read in a room with poor lighting: stress increases, concentration decreases, and learning is impaired. This is especially true for younger students (the ability to sort meaningful sounds from noise is not fully developed until children reach their teens), those for whom English is a second language, and those with hearing impairments. Although little consideration has historically been given to acoustic design in classrooms — as opposed to lighting and ventilation — this situation is beginning to change. The information and tools needed to design classrooms for high acoustical performance now exist. They can be used to ensure that any newly constructed classroom provides an acoustic environment that positively enhances the learning experience for students and teachers.

Acoustic Comfort Checklist

Ensure a superior acoustical environment

- ✓ *Reduce sound reverberation time inside the classroom.*
- ✓ *Limit transmission of noise from outside the classroom.*
- ✓ *Minimize background noise from the building's HVAC system.*

Security and Safety

> ***A Closer Look – Boscawen Elementary School, Boscawen, NH***
>
> *"Room-like," non-institutional corridors, plenty of views out and in, and windows between the classrooms and the hallway, all combine to improve the safety and sense of security in this 53,000-ft^2, 420-student school north of Concord, NH.*

Safety and security have become critical concerns for students, teachers, and parents across the country. A high performance school should create a safe and secure environment by design. Opportunities for natural surveillance should be optimized; a sense of territoriality should be reinforced; access should be controlled; and technology should be used to complement and enhance, rather than substitute for, a facility's security-focused design features.

Crime and vandalism — and the fear they foster — are problems facing school populations throughout the United States. While better buildings alone cannot solve these problems, they can be powerful factors in helping reduce crime and other antisocial behavior. Thoughtful design that builds on basic "Crime Prevention through Environmental Design" principles is the key.

Security-based design strategies will influence a school's basic layout and site plan. If properly integrated from the beginning of the development process, these influences will complement and enhance other high performance design strategies used in the facility. For example, daylit classrooms can "share" their natural light with adjacent corridors through windows or glass doors provided primarily for surveillance purposes. This "free" natural light can, in turn, be used to offset the need for electrical lighting in the corridors. Security technology strategies will not strongly impact other systems in the school, unless they are incorporated into a comprehensive automated control system for the whole facility.

Security and Safety Checklist

Increase opportunities for natural surveillance

- ✓ *Design landscaping to minimize places that are hidden from view. Ensure that key areas — parking, bicycle storage, drop-off points, play equipment, entries — are easily observable from inside the building.*
- ✓ *Design exterior lighting to facilitate nighttime surveillance.*
- ✓ *Consider providing views through glazed doors or windows from classrooms into circulation corridors.*
- ✓ *Design to minimize areas within the building that are hidden from view.*
- ✓ *Consider open stairwells.*

Reinforce a sense of territoriality

- ✓ *Foster a sense of "ownership" of the school for students and teachers by clearly defining borders — what is part of the school and what is not.*
- ✓ *Consider decorative fencing and special paving treatments to delineate the boundaries of the school grounds.*
- ✓ *Consider designing common areas, particularly corridors, so that they are less institutional and more "room-like."*

Design for easy maintenance

- ✓ *Consider graffiti-resistant materials and finishes.*

Control access to the building and grounds

- ✓ *Consider decorative fencing to control access to school grounds.*
- ✓ *Limit the number of entries to the building. Allow visual surveillance of all entries from inside the school.*
- ✓ *Provide capability to "lock-down" parts of the school when the facility is used for after-hours activities.*

Integrate security technology

- ✓ *Consider incorporating interior and exterior surveillance cameras.*
- ✓ *Ensure that all high-risk areas (office, cafeteria, shops, labs, etc.) are protected by high security locks.*
- ✓ *Consider metal detectors and other security technologies as appropriate.*
- ✓ *Motion sensors for lighting can also provide effective security control.*

Ecosystem Protection

A high performance school protects the natural ecosystem. As much as possible, the school incorporates products and techniques that do not introduce pollutants or degradation at the project site or at the site of extraction, harvest, or production. Give preference to materials that are locally extracted or harvested or locally manufactured to eliminate potential air pollution due to petroleum-based transportation.

Some of these building materials may be unfamiliar to custodial staff. Avoid products that unnecessarily complicate operation and maintenance procedures, and provide training to ensure proper upkeep and ensure full service life. When evaluating materials, be sure to consider their impact on the acoustic and visual quality of a school.

A Closer Look – Sakai Intermediate School, Bainbridge Island, WA

This new facility is an excellent example of a school project that went the extra mile to protect the natural environment. The building and sports field's footprint was reduced to increase a buffer zone far beyond what was required in order to protect an adjacent wetland and salmon stream. A culvert that blocked salmon passage was removed. A system separating groundwater from stormwater allowed the groundwater to recharge the natural wetland, and allowed designers to reduce the size of the stormwater retention pond.

Students and other community members were involved in restoring the salmon stream and building an outdoor classroom platform, and they acted as tour guides for the open house explaining the special site protection features.

High performance school design is environmentally responsive to the site, incorporating natural conditions such as wind, solar energy, and moisture to enhance the building's performance. Natural features and areas of the site should be preserved; damaged areas should be restored. Take steps to eliminate stormwater runoff and erosion that can affect local waterways and adjacent ecosystems.

Using these strategies can help teach students about the importance of protecting natural habitats and the impact of human activities on ecological systems.

Ecosystem Protection Checklist

Specify indigenous materials

- ✓ *Specify materials appropriately adapted for the building and site, such as native landscaping and locally extracted building materials.*

Specify wood products that are harvested responsibly

- ✓ *Set a goal of having 50% of the school's wood-based materials certified in accordance with the Forest Stewardship Guidelines for wood-based components.*

Avoid materials that harm the ecosystem

- ✓ *Eliminate materials that harm the natural ecosystem through toxic releases or by producing unsafe concentrations of substances.*
- ✓ *Eliminate the use of ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) as refrigerants in all HVAC systems.*
- ✓ *Give preference to locally manufactured materials and products to eliminate air pollution due to transportation.*
- ✓ *Eliminate products that pollute water, air, or other natural resources where they are extracted, manufactured, used, or disposed of.*
- ✓ *Evaluate the potential impact of specified site materials on natural ecosystems located on site or adjacent to the site.*

Preserve and restore natural features and areas on, and near, the site

- ✓ *During construction, develop and implement a construction operations plan to protect the site.*
- ✓ *Develop the site to prevent stormwater runoff and erosion.*
- ✓ *Restore damaged natural areas.*
- ✓ *Maintain connection to nearby natural ecosystems.*

Energy Efficiency

Energy-efficient schools cost less to operate, which means that more money can be used for books, computers, teacher salaries, and other items essential to the educational goals of schools. Energy-efficient schools also reduce emissions to the environment, since energy use is related to emissions of carbon dioxide (CO_2), sulfur oxides (SO_x), nitrous oxides (NO_x), and other pollutants. Smaller air conditioners also reduce the likelihood of ozone-depleting gases escaping to the atmosphere. All the chapters and guidelines in this manual relate to energy efficiency in some meaningful way.

Guidelines explicitly related to energy efficiency are provided in five of the chapters: daylighting and windows; lighting and electrical systems; energy-efficient building shell; mechanical and ventilation systems; and renewable energy systems. The key issues are summarized below.

Daylighting and Fenestration Design

Daylighting is the controlled admission of natural light into a space through windows, skylights, or roof monitors. A high performance school should use as much daylight as possible, especially in classrooms, while avoiding excessive heat loss, heat gain, and glare.

Access to natural light may be one of the most important attributes of a high performance school. Daylight is the highest quality light source for visual tasks, enhancing the color and appearance of objects. Studies clearly indicate that daylighting can enhance student performance. Views from windows also provide a connection with the natural world and contribute to eye health by allowing frequent changes in focal distance.

Daylighting can also save schools money. Properly designed systems can substantially reduce the need for electric lighting, which can account for 35% to 50% of a school's electrical energy consumption. As an added benefit, waste heat from the lighting system is reduced, lowering demands on the school's cooling equipment. The savings can be as much as 10% to 20% of a school's cooling energy use. And daylight provides these savings during the day when demand for electric power is at its peak and electricity rates are at their highest.

A Closer Look – Dena Boer Elementary School, Salida, CA

Skylights are used to distribute natural daylight to the classrooms, library, multipurpose room and offices of this 800-student, K-5 school near Modesto, CA. Louvers installed in the skylight wells help control daylight levels and can be used to darken rooms when necessary. Classroom windows provide additional daylight and are protected by deep overhangs to control direct sunlight and glare.

All these "extras" were provided within the standard construction budget for the school, which was completed in 1997. The key was making daylighting a priority for the school and then shifting funds from elsewhere in the budget to pay for it.

The extra sunlight has proven very popular. "The skylights create an open, bright work environment. We just seem to have more room. Visitors say it sure is a pleasant place to come into," notes school principal Rick Bartkowski.

Energy Efficiency Checklist for Daylighting

Avoid direct beam sunlight and glare

- ✓ *Consider interior (shades, louvers, or blinds) and exterior (overhangs, trees) strategies to control glare and filter daylight.*
- ✓ *Consider skylights (horizontal glass), roof monitors (vertical glass), light from two sides, and/or clerestory windows.*
- ✓ *Lay out the room to take advantage of daylight. Consider sloped ceilings. Consider light-colored ceiling surfaces to help reflect daylight within the room.*

Design for diffuse, uniform daylight that penetrates deep into the space

- ✓ *Use a daylighting analysis tool to help guide the design process.*
- ✓ *Design windows to allow daylight to penetrate as far as possible into a room. Consider using light shelves (solid horizontal elements placed above eye level, but below the top of the window) to reflect daylight deep into a room.*

Integrate daylighting with the electric lighting system

- ✓ *Provide controls that turn off lights when sufficient daylight exists. Consider dimming controls that continuously adjust light levels to respond to daylight conditions.*

Electric Lighting

Electric lighting systems interact closely with a school's daylighting and HVAC systems. Daylighting strategies that are well integrated with lighting equipment and controls will reduce the demand for electric light. This decrease in demand, if it is met by a combination of high efficiency electric lighting equipment and controls, can substantially lower a school's electricity usage.

An added benefit: more efficient lighting produces less waste heat, reducing the need for cooling and further reducing operating costs. Cooling equipment can be downsized, resulting in first cost and operating cost savings to the school.

These savings are achievable now — in any school — using readily available equipment and controls.

A Closer Look – Ross Middle School, Ross, CA

This 200-student facility north of San Francisco, CA incorporates a full range of high performance electric lighting features. Direct/indirect pendant luminaires provide high quality light at low footcandle levels. In the daylit classrooms, dimming ballasts and photosensors are also used, so light output can vary depending on daylight availability. Used properly, this strategy alone can save up to 60% of the electrical energy needed for lighting these rooms.

Lights have two bulbs that are separately switched, so that half the lamps can be turned off at one time, further reducing energy consumption. Some lights are also tied to occupancy sensors so that they automatically turn off when a room is unoccupied. Finally, the entire lighting system is on a timer to ensure all lights are shut off at night.

These features, combined with daylighting, create a total system that delivers high quality lighting that is energy and cost efficient. Architect Scott Shell hopes that these features, "…will not only make the school a better place for teaching and learning, but will also be used as tools that help make children more aware of how buildings and their use of energy impact the environment." Electric lighting can account for 30% to 50% of a school's electric power consumption. Even modest efficiency improvements can mean substantial bottom-line savings.

Energy Efficiency Checklist for Electric Lighting

Design for high efficiency and visual comfort

- ✓ *Develop individual lighting designs for individual rooms or room types (classrooms, hallways, cafeteria, etc.). Avoid overlighting any space.*
- ✓ *Consider a mix of direct and indirect light sources for each design.*
- ✓ *Optimize each design so that overall lighting levels (W/ft^2) are as low as possible while still providing optimal task illumination.*
- ✓ *Analyze the impact of the lighting system on the HVAC system and resize the HVAC system as appropriate.*
- ✓ *Design systems to facilitate cleaning/lamp replacement.*

Specify high efficiency lamps and ballasts

- ✓ *Use "Super" T-8 fluorescent lamps with electronic ballasts for most general lighting applications (classrooms, offices, multipurpose rooms, cafeterias). Consider using T-5 lamps if justified by life-cycle cost.*
- ✓ *Consider dimmable ballasts, especially in daylit rooms.*

Optimize the number and type of luminaires

- ✓ *Use suspended indirect or direct/indirect luminaires in classrooms to provide soft uniform illumination.*
- ✓ *Consider using additional accent and directional task lighting for specific uses (such as display areas).*
- ✓ *Consider using a smaller number of higher efficiency luminaires to light specific spaces, resulting in fewer fixtures to purchase, install, maintain, and clean.*

Incorporate controls to ensure peak system performance

- ✓ *Use occupancy sensors with manual overrides to control lighting (on-off) in classrooms, offices, restrooms, and other intermittently occupied spaces. Consider scheduled dimming and/or time clocks in other rooms.*
- ✓ *Consider incorporating lighting controls into the facility's overall energy management system.*

Integrate electric lighting and daylighting strategies

- ✓ *Treat the electric lighting system as a supplement to natural light. Design for daylighting first and use the electric system to add light as needed during the day and provide sufficient illumination at night.*
- ✓ *Provide controls to dim or turn off lights at times when daylight is sufficient. Consider photoelectric controls that are sensitive to levels of daylight.*
- ✓ *Consider controls that provide continuous, rather than stepped, dimming.*

Building Enclosures

The building enclosure (walls, roofs, floors, and windows) of a high performance school should enhance energy efficiency without compromising durability, maintainability, or acoustic, thermal, or visual comfort. An energy-efficient building enclosure is one that integrates and optimizes moisture control, insulation levels, glazing, shading, thermal mass, air leakage control, and light-colored exterior surfaces. An energy-efficient building enclosure will reduce a school's overall operating expenses and will also help the environment. Many of the techniques employed — high performance glazing, shading devices, light-colored surfaces — are easy for students to understand and can be used as instructional aids.

The key to optimizing the building enclosure is an integrated approach to design that considers how all the components of the building shell interact with each other and with the building's HVAC systems. Tools to analyze these interactions are readily available and can be used to create the optimal building enclosure based on total system performance. As part of an integrated approach, consider the actions described below.

A Closer Look – Oquirrh Hills Elementary School, Kearns, UT

Well-insulated metal stud and brick veneer walls, a light-colored roof with R-30 rigid insulation, and windows with low-e glass all contribute to the superior energy performance of this elementary school near Salt Lake City.

The school, completed in 1996, replaced a previous facility that had been destroyed by fire. The new building saves roughly $22,000 per year in operating costs compared to its predecessor—a result of careful design combined with high performance systems and an energy-efficient building enclosure.

Based on its experience with Oquirrh Hills, the Jordan School District has embraced high performance as a procurement goal and has gone on to build six more energy-efficient schools.

"High performance, energy smart school design means going 'beyond code'…cost effectively. That's just what the architects did at Oquirrh Hills," notes Duane Devey, Director of Energy and Utility Resources for Jordan School District.

Energy Efficiency Checklist for the Building Enclosure

Specify high performance glazing

- ✓ *Specify glazing that offers the best combination of insulating value, daylight transmittance, and solar heat gain coefficient for the specific application.*

Control heat gain and glare

- ✓ *Consider exterior shading devices to reduce solar heat gain and minimize glare.*
- ✓ *Consider using light-colored materials for walls and roofs to reflect, rather than absorb, solar energy.*
- ✓ *Provide an appropriate level of insulation for each climate zone.*

Control moisture

- ✓ *Provide a drainage plane in the outside layer to ensure that moisture has a path to exit the wall.*
- ✓ *Provide an appropriate moisture barrier and ensure that it is in direct thermal contact with the warm wall surface.*

Consider high mass materials, like concrete or brick

- ✓ *Use the building's thermal mass to store heat and temper heat transfer.*
- ✓ *Consider adding thermal mass to increase the storage capacity and energy efficiency of the building.*
- ✓ *Do not substitute thermal mass for insulation.*

Control air leakage

- ✓ *Consider air retarder systems (also referred to as "air infiltration barriers") as a means to improve energy performance and comfort.*
- ✓ *Ensure that an air barrier is continuous from the foundation to the ceiling.*

Efficient HVAC Systems

A school's HVAC system provides the heating, ventilating and air-conditioning necessary for the comfort and well-being of students, staff, and visitors. To ensure peak operating efficiency, the HVAC system in a high performance school should: use high efficiency equipment, be "right sized" for the estimated demands of the facility, and include controls that boost system performance.

> ***A Closer Look** – **Newport Mesa Elementary School, Costa Mesa, CA***
>
> *After careful analysis of first costs versus performance benefits, high efficiency heat pumps—one for each classroom—were selected for this 400–700 student school south of Los Angeles. The equipment was designed and sized to work well with the natural ventilation systems built into each classroom. Controls for both systems are provided in each classroom so that teachers can maintain optimal conditions at all times. The result is a school that provides a high performing HVAC system and empowers teachers to run it at peak efficiency.*

The HVAC system is one of the largest energy consumers in a school. Even modest improvements in system efficiency can represent relatively large savings to a school's operating budget. With the highly efficient systems available today — and the sophisticated analysis tools that can be used to select and size them — there's no reason why every school HVAC system can't be designed to the highest levels of performance.

The key to optimizing HVAC system performance is an integrated design approach that considers the building as an interactive whole rather than as an assembly of individual systems. For example, the benefits of an energy-efficient building enclosure may be wasted if the HVAC equipment is not sized to take advantage of it. Oversized systems, based on rule-of-thumb sizing calculations, will not only cost more, but will be too large to ever run at peak efficiency and will waste energy every time they turn on. An integrated approach, based on an accurate estimate of the impact of the high efficiency building enclosure, will allow the HVAC system to be sized for optimum performance. The resulting system will cost less to purchase, will use less energy, and will run more efficiently over time.

Energy Efficiency Checklist for HVAC Systems

Use high efficiency equipment

- ✓ *Specify non-CFC-based refrigerants for systems using large chillers.*
- ✓ *Specify equipment that meets or exceeds the U.S. Department of Energy's "Energy Conservation Voluntary Performance Standards for New Buildings."*
- ✓ *Use ENERGY STAR-approved products.*
- ✓ *Consider recovery systems that pre-heat or pre-cool incoming ventilation air.*
- ✓ *Consider "economizer cycles" for small, packaged systems in mild climates.*
- ✓ *In hot, dry climates, consider indirect evaporative cooling.*
- ✓ *Investigate the potential for on-site cogeneration.*
- ✓ *Locate ducts in conditioned or semi-conditioned spaces.*

"Right-size" the system

- ✓ *Consider standard HVAC sizing safety factors as upper limits.*
- ✓ *Apply any safety factors to a reasonable base condition for the building: not the hottest or coldest day of the year with maximum attendance; not the most temperate day of the year with the school half full.*
- ✓ *Select systems that operate well under part-load conditions.*
- ✓ *Monitor existing local systems to size future systems.*

Incorporate controls that boost system performance

- ✓ *Consider integrated building management systems that control HVAC, lighting, outside air ventilation, water heating, and building security.*
- ✓ *Consider individual HVAC controls for each classroom.*

Water Efficiency

Fresh water is an increasingly scarce resource. A high performance school should control and reduce water runoff from its site, consume fresh water as efficiently as possible and recover and reuse gray water to the extent feasible.

Basic efficiency measures can reduce a school's water use by 30% or more. These reductions help the environment, locally and regionally. They also lower a school's operating expenses. While the cost savings may be modest now, since water is relatively inexpensive in most areas of the country, there is a strong potential that these savings will rise over time, especially in areas where water is scarce and becoming more expensive.

A Closer Look – Roy Lee Walker Elementary School McKinney, TX, Independent School District

Rain is "harvested" from the roof of this 608-student, K-5 school 30 miles north of Dallas, and is used to water the grounds and flush the toilets year round. The water is stored in six above-ground cisterns designed as integral components of the overall architecture of the facility.

The system shows how incredibly efficient rainwater collection can be, even in relatively dry locations. According to architect Gary Keep, just using the roof, "…enough water can be collected in a one-year period to flush toilets and water the grounds for about six years."

The technologies and techniques used to conserve water — especially landscaping, water treatment, and recycling strategies — can be used to help instruct students about ecology and the environment. Guidelines covering issues such as efficient irrigation systems, water reclamation, and low-flow devices are featured in the Water Conservation chapter. The use of drought-resistant plants is discussed in the Site Design chapter. The following checklist summarizes the key issues related to water efficiency.

Water Efficiency Checklist

Design landscaping to use water efficiently

- ✓ *Reduce water use.*
- ✓ *Consider innovative wastewater treatment options.*
- ✓ *Specify hardy, native vegetation.*
- ✓ *Consider using an irrigation system for athletic fields only, not for plantings near buildings or in parking lots.*
- ✓ *Use high efficiency irrigation technology (e.g., drip irrigation in lieu of sprinklers).*
- ✓ *Use captured rain or recycled site water for irrigation.*
- ✓ *"Design in" cisterns for capturing rainwater.*

Set water use goals for the school

- ✓ *Recommended goal: 20% less than the baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.*

Specify water-conserving fixtures and equipment

- ✓ *Specify water-conserving plumbing fixtures that exceed Energy Policy Act of 1992 requirements.*
- ✓ *Specify high efficiency equipment (dishwashers, laundry, cooling towers).*
- ✓ *Consider single temperature fittings for student toilets/locker rooms.*
- ✓ *Consider automatic lavatory faucet shutoff controls.*
- ✓ *Consider low-flow showerheads with pause control.*

Consider using recycled or rainwater for non-potable uses

- ✓ *Decrease use of potable water for sewage conveyance by using gray and/or black water systems. Opportunities include toilet flushing, landscape irrigation, etc.*
- ✓ *Consider on-site wastewater treatment, including full or partial "solar aquatics" systems on large sites.*
- ✓ *Possible applications include HVAC and process make-up water.*

Material Efficiency

Material efficiency in this manual refers specifically to two overarching goals: 1) waste reduction — including construction and demolition (C&D) source reduction, reuse, and recycling; and 2) the use of building products that are manufactured in ways that conserve raw materials, including the use of recycled content products, that conserve energy and water, that are reused or salvaged, or that can be recycled or reused at the end of the building's service life. Addressing these goals provides significant environmental benefit. According to WorldWatch, buildings account for 40% of many processed materials used (such as stone, gravel, and steel) and 25% of virgin wood harvested. These withdrawals can cause landscape destruction, toxic runoff from mines, deforestation, biodiversity losses, air pollution, water pollution, siltation, and other problems.

> ***A Closer Look – Ocean Park School, Santa Monica, CA***
>
> *Certified sustainable yield lumber, formaldehyde-free particleboard and insulation, non-VOC sealants, and recycled plastic bathroom partitions were all incorporated into this 45,000 ft^2, K-8 school in Santa Monica.*
>
> *"It's not difficult to make our schools healthier and more environmentally responsible, but you have to start early in the process by 'designing in' high performance, non-toxic materials and products from the very beginning," says Betsey Dougherty, lead architect for the project.*

The checklist below summarizes key material efficiency strategies. When considering recycled content products or other materials-efficient products, be sure to consider their effect on acoustic, visual, and indoor air quality. Be aware that using certain recycled products may conflict with goals for long-term materials efficiency, since a product's recycled composite may be difficult to recycle. Avoid products that unnecessarily complicate operation and maintenance procedures, and be sure that the custodial staff receives training in proper upkeep of the products. Using these strategies can help teach students about the role of waste reduction in protecting the environment.

Material Efficiency Checklist

Design to facilitate recycling

- ✓ *"Design in" an area within the building dedicated to separating, collecting, storing, and transporting materials for recycling including paper, glass, plastics, and metals.*

Reduce the amount of construction waste going to landfills

- ✓ *Develop and implement a management plan for sorting and recycling construction waste.*
- ✓ *Consider a goal of recycling or salvaging 50% (by weight) of total construction, demolition, or land clearing waste.*

Specify salvaged or refurbished materials

- ✓ *Evaluate the potential impact of salvaged materials on overall performance, including energy and water efficiency and operation and maintenance procedures.*

Maximize recycled content of all new materials

- ✓ *Use EPA-designated recycled content products to the maximum extent practicable.*
- ✓ *Use materials and assemblies with the highest available percentage of post-consumer or post-industrial recycled content.*
- ✓ *Set a goal to achieve a minimum recycled content rate of 25%.*

Eliminate materials that may introduce indoor air pollutants

- ✓ *Use materials or assemblies with the lowest level of (VOCs).*
- ✓ *Evaluate the potential impact of specified materials on the indoor air quality of the school.*

COMMISSIONING, OPERATION, AND MAINTENANCE

Building commissioning is the process of ensuring that systems in schools are designed, installed, tested, and verified as being capable of operating according to the school's needs and the designer's intent. The term comes from shipbuilding where "commissioning a ship" means thoroughly testing it to ensure that it is seaworthy. For buildings, commissioning has a similar meaning, which is, testing the important building systems to ensure that they operate the way the designers expect and that they serve the needs of teachers, students, and school districts.

High performance schools can only be achieved with some level of commissioning. Higher test scores, increased average daily attendance, reduced operational costs, staff retention, and reduced liability may be compromised unless critical systems are commissioned to achieve proper performance. Because it anticipates problems, commissioning can avoid costly change orders, delays, and litigation. In addition to commissioning building systems, design professionals can commission high performance materials by making sure they are installed as specified and that proper documentation exists so the design intent is not compromised in the event of cleaning, repair, or replacement.

Studies show that building systems will not operate as expected unless they are commissioned. One study of 60 newly constructed nonresidential buildings showed that more than half had controls problems, 40% had malfunctioning HVAC equipment, and one-third had sensors that did not operate properly. In many of the buildings, equipment called for on the plans and specifications was actually missing. One-fourth of the buildings had energy management control systems, economizers, or variable-speed drives that did not run properly.[1]

Additional information on commissioning can be found in the Commissioning chapter at the end of this manual.

Systems that Require Commissioning

Commissioning can reduce these problems by systematically assuring that the critical systems are properly installed, calibrated, and working. Systems for which commissioning is essential include lighting sweep systems, photocell daylighting controls, energy management systems, variable-speed motor drives, building pressurization control, floating head pressure in refrigeration equipment, anti-condensate heaters in refrigeration systems, and capacity controls in central heating and cooling plants. A more comprehensive list of systems that might require commissioning include:

- HVAC plant
- Air and water delivery system
- Energy management system
- Electrical and lighting system
- Fire/life safety system
- Kitchen equipment and fume hoods
- Building envelope
- Renewable energy system
- Science lab gas delivery system
- Emergency power supply

[1] Piette, Mary Ann. 1994. Quantifying savings from commissioning: Preliminary results from the Northwest. Lawrence Berkeley National Laboratory.

- Data networks/communications
- Security system
- Plumbing
- Irrigation system.

The Commissioning Agent

The commissioning agent is responsible for coordinating and carrying out the commissioning process. For complex projects, the commissioning agent should be brought on as part of the design phase. However, for most schools, commissioning may not be needed until construction start-up, and knowledgeable in-house personnel may fill the role of the commissioning agent. Commissioning should continue well into start-up, and be integrated into the operation and maintenance plan.

The responsibilities of the commissioning agent include:

- Assisting with a clear statement of the design intent for each building system.
- Writing the commissioning specifications and incorporating them in the appropriate divisions of the construction specifications.
- Carrying out pre-functional and functional testing of all equipment and systems to be commissioned, using procedures designed in advance.
- Reviewing operation and maintenance documents to be provided by the contractor.
- Developing operation and maintenance training curricula and materials to ensure they meet needs of staff.
- Writing a final report including all commissioning documentation and recommendations for the district.

Cost of Commissioning

For schools, the cost of commissioning can range between \$0.10/ft^2 to \$0.60/ft^2 of building area. Studies show that commissioning can be very cost effective, with simple paybacks ranging between 4 and 20 months.[2]

Commissioning References

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1996. *The HVAC Commissioning Process, ASHRAE Guideline 1-1996*. Available on-line at: http://www.ashrae.org/.

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U.S. Department of Energy (DOE). 1998. *Model Commissioning Plan and Guide Specification*s. NTIS #DE97004564. Available on-line at: http://www.peci.org/.

U.S. Green Building Council. *LEED 2.0 Reference Guide* (for commercial buildings). Available at http://www.usgbc.org/.

[2] Gregerson, Joan. 1997. Cost effectiveness of commissioning 44 existing buildings.

MATERIAL SELECTION AND RESEARCH

In a high performance school, materials are selected for several characteristics beyond the traditional issues of performance, price, availability, and aesthetics. Designers should look for environmentally preferable materials that are:

- **Durable.** Offers (proven) longer service life compared to other options in a given product category.
- **"Healthy."** Does not introduce toxic or polluting emissions into the building.
- **Made with recycled content.** Includes materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process (pre-consumer), or after consumer use (post-consumer).
- **Salvaged or reused.** Includes materials that are refurbished and used for a similar purpose; not processed or remanufactured for another use.
- **Recyclable.** Can be collected, separated, or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product.
- **Responsibly produced.** Extracted, harvested, or manufactured in an environmentally friendly manner (includes certified wood products).
- **Environmentally benign.** Includes or introduces no, or low amounts of, known pollutants to the natural ecosystem (includes non ozone-depleting or toxic materials).
- **Low in embodied energy.** Does not require significant amounts of energy to produce or transport the material (includes locally manufactured or extracted options in a given product category).
- **Produced from rapidly renewable material.** Includes material that is grown or cultivated and can be replaced in a relatively short amount of time (defined by the type of material).
- **Made with industrial byproducts**. Includes material that is created as a result of an industrial process (flyash, for example).
- **Marketed in an environmentally responsible manner.** Includes products available with minimal packaging.

For the high performance label to be meaningful, it's important for designers to ensure that a significant number of materials used for the project meet one or more of the above attributes. This will require research and documentation. Many sources of information are available to help with this process.

Product Suppliers

Some building material suppliers are making significant efforts to incorporate resource-efficient goals in their processes and operations and in their products. Companies serious about this commitment will provide detailed information about their product's performance. When investigating products, it is always recommended that the design team consult with the manufacturer's technical rather than sales staff.

Material Safety Data Sheets

Material Safety Data Sheets (MSDS), which must be prepared by product manufacturers, can provide some information and in particular can help "red flag" problem ingredients that may be toxic or emit significant VOCs. For example, the Health Hazard Rating (zero is low, five is high) found on an MSDS provides some indication of whether a product is appropriate for indoor school environments. MSDSs are often incomplete, however. Generally they do not include information about environmental attributes other than toxicity of regulated ingredients. MSDS's are primarily useful for eliminating building materials that may cause serious environmental problems.

Product Certification

Product certification programs can help identify environmentally preferable products. Many product suppliers have increased the credibility of their environmental claims by obtaining industry or independent certifications of their products' environmental attributes. Independent programs provide the most objective documentation and include:

- *ENERGY STAR.* A program of the federal government, manufacturers are allowed to use the ENERGY STAR label only if the product meets certain energy efficiency levels set by either the U.S. EPA or U.S. Department of Energy. Tel: (888) STAR-YES. Web site: http://www.energystar.gov/.
- *Green Seal.* Green Seal standards are based on environmental protection. They focus on reduced air and water pollution, reduced consumption of energy and other resources, protection of wildlife and habitats, reduced packaging, quality, and performance. Tel: (202) 588-8400. Web site: http://www.greenseal.org/.
- *Scientific Certification Systems (SCS).* SCS is a nonprofit organization that assesses products based on a life-cycle or "cradle to grave" evaluation. Their Environmental Report Card gives detailed information about the environmental burdens associated with the production, use and disposal of the product. Tel: 800-ECO-FACTS. Web site: http://www.scs1.com/.
- *Forest Stewardship Council.* A product bearing the Forest Stewardship Council (FSC) trademark is made with wood certified to have come from a forest that is well managed according to strict environmental, social, and economic standards. Look for FSC-certification as opposed to self-certification of forest management practices. FSC is an international nonprofit association working in partnership with industry and other groups to improve forest management worldwide. Tel: (802) 244-6257. Web site: http://www.fscoax.org/. Also see Smart Wood, a U.S.-based program of the Rainforest Alliance, accredited by the FSC for the certification of forest management. Tel: (802) 434-5491. Web site: http://www.smartwood.org/.

Environmentally Preferable Product Directories

There are several good directories that identify environmentally preferable product options. Some focus on a product category (for example, recycled content products), while others cross categories.

- Architects/Designers/Planners for Social Responsibility (ADPSR). *Architectural Resource Guide*. Organized by CSI, this guide lists environmentally friendly, less polluting, local, and recycled building products as well as related information and a recommended reading list. Available as hard copy or CD. Web site: http://www.adspr.org/.
- U.S. EPA's *Preliminary Guidelines for Recycled Content*. Web site: http://www.epa/gov/epaoswer/non-hw/procure/products.htm.
- *Guide to Resource Efficient Building Elements (GREBE).* 1998. Edited by T. Mumma. Contact: Center for Resourceful Building Technology, Box 100, Missoula, MT 59806. Tel: (406) 549-7678. Web site: http://www.montana.com/crbt. Resource book on resource-efficient building systems. Updated regularly.
- *GreenSpec: The Environmental Building News Product Directory and Guidelines Specifications.* 1999. Published by E Build, Inc., Brattleboro, VT. Tel: (802) 257-7300. Web site: http://www.buildinggreen.com/. *GreenSpec* is organized in standard CSI divisions.
- California Integrated Waste Management Board's web site provides a "Recycled Content Product Procurement List" at http://www.ciwmb.ca.gov/RCP/. The database is searchable by CSI section number and provides links to manufacturers. The CIWMB also sponsors many Buy Recycled programs. Information on these programs can be found at http://www.ciwmb.ca.gov/BuyRecycled/.
- Sustainable Products Purchasers Coalition (SPPC). Web site: http://www.sppcoalition.org/.
- U.S. EPA's *Comprehensive Procurement Guidelines (CPG).* The CPG program promotes the use of materials recovered from solid waste. Web site: http://www.epa.gov/epaoswer/non-hw/procure/index.htm. The products page, http://www.epa.gov/epaoswer/non-hw/procure/products.htm, provides an online list of construction, landscaping, and other categories of products. The web site briefly describes each of the listed products. You also can view EPA's recommended recycled content ranges and a list of manufacturers, vendors, and suppliers for each item. Also see the *Database for Environmentally Preferred Products*: http://www.notes.erg.com (this is an EPA contractor's web site).

Environmentally Preferable Product Evaluation Tools

The following resources provide methodologies or suggestions for evaluating products:

- BEES (Building for Environmental and Economic Sustainability) software helps analyze the environmental and economic performance of some building products. The software is downloadable at http://www.bfrl.nist.gov/oae/software/bees.html.
- *Environmental Resource Guide*. 1996. Edited by Joseph A. Demkin. Offers a methodology for preparing life-cycle assessments of building materials, materials comparisons, and case study information about how high performance buildings have worked in practice. Tel: (800) 346-0104.
- *Environmental Building News* (EBN). Brattleboro, VT. Tel: (802) 257-7300. Web site: http://www.buildinggreen.com/. The leading green building professional journal. Offers excellent articles, product reviews, book reviews, and resources. Online EBN product reviews available. Two pertinent articles are: "What Makes a Product Green?" (Vol. 9, No. 1: January 2000), which offers a simple methodology for evaluating a product; and "Material Selection Tools, Resources and Techniques for Choosing Green," (Vol. 6, No. 1: January 1997), which offers a survey of analytical tools and references for evaluating environmentally preferable materials.

- *Proceedings from the LAUSD Workshop on Sustainable Schools*. February 16, 2000. See the Breakout Session section on “Green” Materials and Systems, and other related sections. Available online at http://www.eley.com/lausd.

GENERAL PURPOSE DESIGN AND EVALUATION TOOLS

Appropriate design tools are discussed in the overview of each technical chapter and within each guideline. Some general design and analysis tools are addressed here because they are common to many of the technical chapters that follow. More information on design tools can be found at http://www.eren.doe.gov/buildings/energy_tools/.

Conceptual Design Tools

Energy-10 is an educational tool that provides an overview of the performance interactions between different design strategies during conceptual design. For more information, visit the National Renewable Energy Laboratory’s (NREL) Energy-10 web site at http://www.nrel.gov/buildings/energy10/ or the Sustainable Buildings Industry Council (SBIC) web site at http://www.sbicouncil.org.

Green Building Advisor™ (GBA) is a CD-ROM-based software tool that can be used as a “first cut” to help designers identify building design strategies that can be incorporated into specific projects. Based on inputs provided by the user, GBA generates a list of prioritized strategies organized by categories. The software provides information on relative cost as well as case studies where the strategy has been implemented. Registered users get a user’s manual and free technical support. For more information, call (802) 257-7300 or visit http://www.buildinggreen.com/.

Energy Analysis Tools

These are computer programs designed to predict the annual energy consumed by a building. They can be used to evaluate the energy impacts of various design alternatives and, in particular, to compare specific low-energy strategies (for example, higher insulation levels, better glazing, increased thermal mass) in terms of their impacts on overall building performance. Combined with accurate cost estimates, they can help create a high performance school that is optimized in terms of its overall energy performance, which can save money on initial construction costs as well as on long-term operating expenses.

For example, a school that combines daylighting strategies and highly efficient electric lighting in its classrooms will require less electricity to illuminate those classrooms, providing a long-term operating savings. In addition, the rooms, because they take advantage of daylight and use high efficiency lamps, may need fewer light fixtures overall to achieve a high quality visual environment, providing an upfront savings on initial costs. Finally, highly efficient lighting — and, potentially, fewer light fixtures — will result in less waste heat in each classroom. This, in turn, will allow the cooling system for the classrooms to be smaller, generating additional upfront savings.

A wide number of energy analysis tools are currently available, some appropriate for the early stages of a project, some for the later phases. A sampling of these tools is provided below. Energy performance analyses using one or a combination of these tools should be conducted during each of the following design phases: programming, schematic design, design development, construction documents, and bidding and negotiation.

Architectural Design Tools

These are used primarily during a project's programming, schematic design, and design development phases.

- *Building Design Advisor.* Contact: Lawrence Berkeley National Laboratory. Web site: http://www.lbl.gov/.
- *Energy Scheming.* Contact: Iris Communications. Web site: http://www.oikos.com/esb/37/scheming.html.
- *VisualDOE.* Contact: Eley Associates. Web site: http://www.greendesigntools.com.

Load Calculation and HVAC Sizing

These are used primarily during a project's design development and construction documents phases.

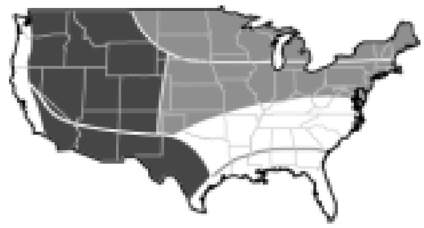
- *EnergyPlus.* This computer program, which is being developed by the U.S. Department of Energy, is considered to be the successor to both DOE-2 and BLAST. It combines features from both programs and includes modules for the thermal analysis of windows, radiant transfer within spaces and other features. Contact: Lawrence Berkeley National Laboratory. Web site: http://www.lbl.gov/.
- *DOE-2.* This widely used program for analyzing the energy efficiency of buildings uses an hourly weather file and simulates energy performance during a typical year. Contact: Lawrence Berkeley National Laboratory. Web site: http://www.lbl.gov/. There are several Windows user interfaces that make it easier to use DOE-2, including VisualDOE, PowerDOE, and EnergyPro.
- *BLAST.* Contact: University of Illinois. Web site: http://www.bso.uiuc.edu/.

ANATOMY OF A GUIDELINE

Each guideline in this manual follows the format outlined below. Information relevant to multiple guidelines is typically discussed in the Overview for that chapter.

- **Recommendation:** A brief description of how to apply the high performance design concept to the building feature.
- **Description:** More detailed information on the technology or design strategy.
- **Applicability chart:** Indicates the applicability of the guideline to particular spaces, climate zones, and design process steps. (See the end of this section for more information on the climate zones covered in this manual.) In the example below, the black areas indicate the guideline's strong applicability and the gray areas represent limited applicability. Unshaded areas indicate that the guideline is not applicable.

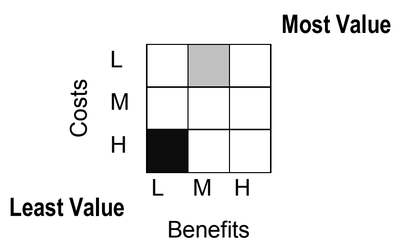
Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	□
Gym	□
Corridors	□
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■

- **Integrated Design Implications:** Describes the implications that the design strategy or technology might have on other building systems (e.g., if cooling load is significantly reduced by high performance fenestration, the HVAC system might be made smaller and natural ventilation might become more viable). Discusses the phase of design when the strategy or technology might best be implemented.
- **Cost Effectiveness:** Describes the benefits and costs of the strategy/technology on both a system basis and an overall project basis. The chart below shows construction costs on the vertical scale, ranging from low to medium to high. The horizontal scale represents benefits, also categorized from low to medium to high. A black mark shows the overall project impact and a gray mark represents the system impact. In the diagram below, the system benefits are medium and the system costs low, while the overall cost is high and benefits are low.



For ranking the *system* benefits and costs:

- Low represents an increase in costs or benefits of 0% to 20% over the basecase system.
- Medium is a cost or benefit increase of 20% to 50% over the basecase system.
- High is an increase in costs or benefits of more than 50% over the basecase system.

For ranking the *overall* benefits and costs:

- Low represents an increase in costs or benefits of 0% to 2% over the basecase system.
- Medium is a cost or benefit increase of 2% to 8% over the basecase system.
- High is an increase in costs or benefits of more than 8% over the basecase system.

The cost scale refers only to the initial construction cost, which is a significant issue for schools and their architects. On an overall basis, low means that the incremental construction cost is small or even negligible and that the district should be able to afford the strategy/technology with the normal school construction budget. Medium cost means that the strategy/technology will cost a little more and the school construction budget will need to be supplemented or will need to realize savings from other systems (e.g., HVAC downsizing).

This section also presents general information on construction costs on a $/ft² or $/classroom basis, when possible. It identifies and quantifies operation and maintenance costs if applicable and/or possible. The section describes environmental costs or externalities that cannot be given a dollar value.

- **Benefits:** Outlines the benefits expected from the implementation of the measure including energy savings, improvements in indoor environmental quality, productivity benefits, and possible impact on average daily attendance.
- **Design Tools:** Lists any applicable design tools, including software that can be used to optimize the design, quantify the benefits, or estimate construction costs. In some cases, the section will describe a technique for using a general-purpose tool such as DOE-2 to evaluate and analyze the design.
- **Design Details:** Contains more thorough details on the design, such as rules of thumb, specific recommendations, sample specifications, or schematic diagrams.
- **Operation and Maintenance Issues:** Outlines potential operation and maintenance concerns and requirements for keeping the strategy/technology operating at optimal performance.
- **Commissioning:** Discusses the need for calibration, functional tests, static tests, commissioning plan requirements, statement of design intent, post-occupancy tests, and other issues and requirements related to ensuring that the strategy/technology was implemented as the designer intended.
- **References / Additional Information:** Provides a sampling of documents, websites, etc. where additional information about the strategy/technology can be found.

CLIMATES

The guidelines have been tailored for the seven U.S. climate regions shown at the beginning of this manual.

Table 2 – Climate Zone Details

Climate	Model City	Location	Summers	Winters
Hot and Humid	Orlando	Gulf Coast	Hot and humid, long	Mild, short
Temperate and Humid	Atlanta	Southeast	Hot and humid	Cold
Cool and Humid	Boston	Northeast, Mid-West, Southern Plains	Warm and humid	Cold snowy
Cold and Humid	Minneapolis	Northern Plains	Short in duration, but warm and humid	Long in duration, very cold
Hot and Dry	Phoenix	Southwest Desert	Hot and dry	Clear and mild
Cool and Dry	Denver	Western states	Warm and clear	Clear and cold
Temperate and Mixed	Seattle	Pacific Coast	Clear mild	Long, overcast and mild

One city in each climate served as the model city for that zone. Many of the recommendations vary depending on the climate where the school is constructed. In these cases, the recommendations, and their applicable climate zones, will be indicated in both the guideline text and the applicability chart described in the previous section.

SITE DESIGN

This chapter provides guidelines for:

Optimum Building Orientation (Guideline SD1)

Landscaping to Provide Shade to HVAC Equipment, Buildings, and Paved Areas (Guideline SD2)

Landscape Design and Management (Guideline SD3)

Impervious Surfaces (Guideline SD4)

Native and Drought-Tolerant Plants (Guideline SD5)

Landscaping Soil, Amendments, and Mulch (Guideline SD6)

Integrated Weed, Disease, and Pest Management (Guideline SD7)

Environmentally Responsible Job-Site Management (Guideline SD8)

Indoor Air Quality During Construction (Guideline SD9)

Site Protection During Construction (Guideline SD10)

OVERVIEW

Objectives regarding the protection and retention of existing landscaping as well as the site's natural contours and features should be established early during the programming phase. NREL/PIX 11341

Site design is a fundamentally important aspect of high performance design. The choices made during site selection and site planning reverberate throughout the entire school. All aspects of high performance design — from energy and water efficiency, to acoustic comfort and environmental impacts — are affected. Furthermore, every site and district will face unique constraints. Some districts have the luxury of choosing between several options while other districts have known for years the precise site that must be used. It is important to remember that regardless of what site is chosen, and whether it is in an urban or rural landscape, the site can be developed wisely to incorporate ideas that support the high performance goals of the entire project.

Open spaces at schools typically fall into two categories: hard surfaces and lawn. Districts can and should move beyond this approach to create more vibrant and environmentally responsive site designs. Even if the opportunities for a particular site seem modest, there are better ways to pave a parking lot, water a soccer field, and manage stormwater than are typically practiced.

Site selection and design can either support or detract from the overall performance of the building. Table 1 summarizes some of the benefits associated with wise site planning.

Table 1 – Site Design Considerations

Goal	Site Design Considerations
Energy Efficiency	Energy efficiency is improved with effective building location, orientation and massing, and the placement of vegetation for shade or wind protection.
Water Efficiency	Standard irrigation practices typically waste significant amounts of water. Using native plants and water-efficient irrigation technologies are two straightforward methods of reducing demand. More resource-efficient water management might include captured water, green roofs, and natural stormwater management strategies like vegetated swales and ponds. (See the Water Conservation chapter for more information on irrigation and stormwater management.)
Protection of the Natural Ecosystem	The majority of site planning decisions will directly affect the overall level of impact to the natural environment: water conservation, treatment of surface water, building orientation, preservation and restoration of natural habitats, use of native plants and appropriate landscaping materials, etc.
Material Efficiency	The site should incorporate salvaged landscaping materials or those made from recycled materials. Vegetation waste should be composted.
Acoustic, Thermal, and Visual Comfort	Comfort is heavily dependent upon orientation and building envelope. Glazing type, size, and orientation are particularly important. The relationship of buildings, especially classrooms, to sources of exterior noise such as roadways must be taken into account to achieve adequate background noise levels. Double glazed windows will reduce excessive exterior noise. Conversely, the relationship of HVAC equipment, recreation areas, and other noise producers will impact the surrounding neighborhood. Reducing the “heat island effect” decreases air conditioning loads during the summer by minimizing hard surfaces and using trees or shade structures.
Health and Indoor Air Quality	Sites cannot contain hazardous chemicals or airborne pollutants that endanger student health. Well-designed sites improve opportunities for natural ventilation and reduce carbon dioxide levels.
Security and Safety	Building placement, landscaping, protected courtyards, and well-situated access and circulation points all heavily impact safety and security.
Connection to Neighborhood and Surrounding Community	Consider community gardens, school parks, meeting rooms, multi-use facilities such as day care, laundry, café, etc, to connect the school to the community. Joint-use partnerships with local nonprofit organizations are an excellent way to fund and share facilities or park space and improve security.
Learning	Use nature as a teaching tool for science, math, history, art, and health programs; use gardens to connect students to natural concepts. Consider the potential opportunities for real-life lessons in business and economics through on-site programs involving growing and selling or trading products.
Playing	Install creative play areas utilizing a wide variety of natural elements. Consider a schoolyard landscape rich with soil, water, and “critters,” rather than simply formal, planted hedges and groomed turf.

Resource-Efficient Site Design Process

Resource-efficient site planning is adaptable to all school sites. It balances ecological, social, and economic needs and emphasizes long-term, cost-effective strategies over immediate short-term results. It should be an open process and include the input of the school staff and local community.

Site selection is crucial in the resource efficiency of school design, and districts must balance cost, student demographics, and environmental concerns during the site selection process. In some cases, school sites have been determined years in advance, eliminating some options for districts and designers when the school is being built. However, when the district can select sites, being conscious of ecosystem protection, careful building orientation, and a design that controls urban heat islands can significantly lower the school’s environmental impact.

When selecting a site, maintaining the health of students should be the first concern. Sites must not contain toxins, pollutants, or safety hazards that will impact student health, such as:

Once a site is selected, address areas of the site targeted for conservation, development, or natural enhancement. NREL/PIX 11333

- Hazardous agents, including industrial, agricultural, and naturally occurring pollutants such as asbestos and heavy metals.
- Nearby facilities that might emit hazardous air emissions or handle hazardous or acutely hazardous materials.
- Other objects that are potentially harmful near a school, such as hazardous pipelines, high voltage power-line easements, railroad tracks, adverse levels of traffic noise, and airports.

The district should also address issues of land use and open space, including:

- Developing sites that are centrally located for the student population. Both schools and parents spend significant time, energy, and money transporting students to and from school. Cars driven by parents, guardians, or the students themselves are the largest resource users and producers of transportation-related pollution. Centrally located sites mean that cars do not have to travel as far and encourage more students to walk or bike to school.
- Develop joint-use agreements with community organizations to share parts of the school buildings, parks, or recreation space. As part of a growing trend, schools are being integrated with a variety of organizations, from laundromats and coffee shops, to police stations and park districts. Benefits include better campus security, improved community relationships, and reduced site acquisition and construction costs.
- Avoiding development on prime farmland, public parkland, flood zones, and on habitats for threatened or endangered species.
- Preserve undeveloped lands. By not developing on greenfields, which are sites that have not been previously developed, or have been restored to park or farm use, urban redevelopment can reduce environmental impacts.
- Promoting alternative transportation, by locating the school close to public transportation and creating bike facilities. (See the Transportation chapter for additional information.)

Once a site is selected, use educational specifications and the schematic design to address areas of the site targeted for conservation, development, or natural enhancement. Select and specify environmentally preferable site materials — building products that use raw materials efficiently and do not introduce pollutants or degradation to the project site or atmosphere, and building systems that conserve water and energy. (For additional information about materials, see the Resource-Efficient Building Products chapter.) All stakeholders should meet to review the baseline data and discuss the opportunities and constraints based upon the initial site analysis and program. These stakeholders help define the project's "vision," which guides development of the plan. Their involvement is essential throughout the planning and design process. The plan, developed by the design team and approved by the community, might include many, or all, of these principles:

- Identify and protect existing natural features and ecosystems.
- Repair and restore damaged natural areas and create habitat to promote biodiversity.
- Respect and incorporate historic, cultural, and artistic resources.
- Use stormwater management to reduce pollution and the load on local infrastructure.
- Create healthy landscapes that evolve over time and survive intensive use.
- Develop a responsible maintenance and management program that incorporates an objective monitoring and evaluation strategy.
- Provide a strong link to the surrounding neighborhood and become an active part of the community.

Design Goals and Guidelines

Site design activities for a high performance school seek to achieve one or more of the following three primary goals:

1. Protect and/or restore the site.
2. Incorporate the site's natural features to achieve high performance.
3. Select environmentally preferable products.

Protect and Restore the Site

During construction, literally hundreds of opportunities exist to work toward fulfilling the environmental goals of a high performance school or, alternatively, to compromise them. To ensure the construction process is consistent with these goals, contractors should be made aware of them up front, as part of the bidding process. Ideally, the selected contractor should have experience with some of the practices recommended in this Best Practices Manual. At a minimum, they should be aware of, and responsive to, the goals set for the project. The clearer the expectation that contractors will play an important role in achieving these goals, the more likely the construction process will go smoothly in this regard.

In practice, requiring the contractor to produce and implement a job-site operations plan has proven to be the most effective way to ensure that environmental goals will be given equal treatment along with other project goals. In addition, including a requirement to produce and implement a job-site operations plan in bid documents and in the contract language of specifications, levels the bidding playing field.

Environmentally responsible job-site operational costs are generally minimal, and cost benefits can be significant. Planning helps minimize costs and liabilities, including expensive delays, stoppages, and callbacks due to mistakes made during construction. Savings resulting from job-site waste reduction practices are well documented. Contractors familiar with environmentally responsible job-site operations will know the benefits and understand that these are not complicated practices. Contractors unfamiliar with them, however, will assume they cost more and bid accordingly. Bid packages should contain references to existing resources to help contractors familiarize themselves with these types of plans as well as provide tools to estimate costs and benefits more accurately.

An environmentally friendly job-site operation will use a combination of contract language, signage, weekly job-site meetings, and incentives/rewards to educate and motivate field personnel to ensure everyone works towards this goal. Brief presentations, signage that both informs and motivates by reporting progress on environmental goals, and contractor's field guides can be helpful communication aids. On most construction sites, signage and other printed instructions will need to be written so individuals for whom English is a second language can easily understand.

In addition, the most successful contractors identify an individual (often the safety officer) who can enforce the job-site operations plan on a day-to-day basis. With many recommended job-site practices, it is difficult to determine whether they actually occur without regular monitoring. Ideally, the same individual monitoring compliance would take an active role in training and other on-site educational efforts.

The natural functions of a site (hydrologic, geologic, and micro-climatic) can also be seriously disrupted by the operation of a building. The design of a high performance school will consider ways that natural site features can be protected — perhaps even restored — through the design, development, and construction processes. For example, preserving natural vegetation reduces overall disturbance to the site. Soil amendments help restore the health of disturbed soils. And designing to reduce impervious surfaces mitigates stormwater runoff caused by construction and protects the hydrologic functions of the site.

Site protection and restoration objectives include:

- Minimizing disturbance to the site.
- Mimicking (or restoring) natural processes in disturbed areas.
- Protecting water quality.

Incorporate the Site's Natural Features to Achieve High Performance

A high performance school responds to the site. Building placement, orientation, massing, and layout decisions made early in the school design process can profoundly affect the energy impacts of the building. These decisions also bear on the resulting indoor environment since they either capture or lose opportunities for daylighting and natural ventilation. Other implications include acoustic comfort, safety, and visual quality. The design of a high performance school incorporates the site's natural advantages and features to achieve the school's high performance goals.

Site design can create opportunities for outdoor classrooms and environmental learning projects. NREL/PIX 02682

In addition, the high performance school site and building should "teach" environmental protection concepts. Site design will take into consideration opportunities for outdoor classrooms and environmental learning projects. With careful planning and coordination with school staff, such projects can be identified and then facilitated during construction. For example, stream restoration by students and staff can take place more easily if a culvert has been removed during construction. Or a wetland graded during construction can be planted as part of lessons about the natural ecosystems.

Site planning objectives that fall into this category include:

- Reducing the demand for water
- Reducing energy demand
- Selecting environmentally preferable materials.

A steadily increasing number and variety of environmentally preferable products are available for sitework and landscaping. Salvaged materials, originating from both on-site and off-site, should also be used where possible. These products include landscaping accessories made with post-consumer and post-industrial recycled materials (parking stops, bike racks, tree cuffs, grates, landscaping ties, planters, outdoor furniture, and lighting and sign posts), recycled concrete asphalt aggregate for fill or road base, concrete made with flyash, and recycled content soil amendments.

Specific examples include:

- Synthetic surfacing for exterior sports surfaces, playgrounds, and other surfaces. Made from 84% to 98% post-consumer rubber from used tires.
- Fencing made with recycled plastic or salvaged wood or metal.
- Running track surfaces made with 100% recycled rubber/tires.

While maintenance will vary by product, in most cases maintenance needs are reduced compared to conventional products. For example, plastic lumber is more durable and requires less ongoing maintenance than wood.

In addition, the selection of environmentally preferable materials has an added benefit as a teaching tool. Prominent interpretive signage can inform students, staff, parents, and the community about environmentally preferable materials and their attributes.

Table 2 summarizes the site design goals and objectives described above, and shows the correspondence of these objectives to the guidelines provided in this chapter.

Table 2 – Site Planning Goals and Relationship to Guidelines

	SD1: Optimum Building Orientation	SD2: Landscaping to Provide Shade to HVAC Equipment, Buildings, and Paved Areas	SD3: Landscape Design and Management	SD4: Impervious Surfaces	SD5: Native and Drought-Tolerant Plants	SD6: Landscaping Soil Amendment and Mulch	SD7: Integrated Weed, Disease, and Pest Management	SD8: Environmentally Responsible Job-Site Management	SD9: Indoor Air Quality During Construction	SD10: Site Protection During Construction
Goals										
Protect and Restore the Site										
Minimize disturbance to the site					●			●		●
Mimic natural process				●		●				
Protect water quality						●	●			
Incorporate the Site's Natural Features to Achieve High Performance										
Reduce water demand			●		●	●	●			
Reduce energy demand	●	●								
Select Environmentally Preferable Materials			●	●		●			●	

Resources

Architects, Designers and Planners for Social Responsibility (ADPSR) West Coast. 1998. *Architectural Resource Guide.* Contact: ADPSR, PO Box 9126, Berkeley CA. Tel: (510) 273-2428. Resources and information on green and healthy buildings, including many sources for materials.

Barnett, D.L. 1995. *A Primer on Sustainable Building.* Snowmass, CO: Rocky Mountain Institute. An excellent overview of issues and benefits of sustainable building. http://www.rmi.org.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. http://www.sustainable.doe.gov.

Crowther, R.L. 1992. *Ecological Architecture*. Boston: Butterworth Architecture. Primer on ecological design, emphasizing the importance of holistic building design and its integration with natural systems. Includes design guidelines for design, landscaping, and planning.

King County, Washington. *Construction and Landscaping Materials Specifications*. http://www.metrokc.gov/procure/green/const.htm.

Los Angeles, City of. *Sustainable Building Reference Manual.* Contact: Nady Maechling. Tel: (213) 473-8226. Contains local information and resources.

Lyle, J.T. 1994. *Regenerative Design for Sustainable Development*. New York: John Wiley & Sons. One of the seminal books on the theory, design, and construction of regenerative systems and the practical application of ecological design.

Marsh, W. M. 1991. *Landscape Planning: Environmental Applications.* New York: John Wiley & Sons. A definitive reference for landscape architects, planners, and designers on the definition and application of environmental design principles to landscape and site planning.

Maryland State Department of Education. *Conserving and Enhancing the Natural Environment, A Guide for Planning, Design, Construction, and Maintenance on New & Existing School Sites* and *Building Ecology and School Design*. 1999. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097

Mason, Gary et al. *An Ecosystem-based Approach to Planning Communities: An Ecosystem Manager's Workbook*, USDA Forest Service, Center for Urban Forestry, 1994, 1996, 1998.

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Rocky Mountain Institute.1998. *Green Development: Integrating Ecology and Real Estate.* New York: John Wiley & Sons.

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Sorvig, K. 1996. *Sustainable Building Technical Manual*. Washington DC: Public Technologies Inc. Chapter 7, Site Materials and Equipment, offers a concise, valuable overview that highlights design considerations for soil amendments, plant materials and management, paving materials, and materials for site construction and furnishings.

Spurgeon, Richard. 1988. *Ecology: A Practical Introduction with Projects & Activities.* Osborne Publishing Ltd.

For additional information about environmentally preferable materials, see the Material Selection and Research section in the Introduction to this manual.

Acknowledgments

The following resources were particularly useful for developing this chapter on site planning:

BUILT GREEN™ Handbook. 1999. BUILT GREEN is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County, Washington, and Snohomish County, Washington. http://www.builtgreen.net/.

Partnership for Resource-Efficient Schools. 1998. *Recommended Best Management Practices Promoting Energy Efficiency, Resource Conservation, and Environmental Quality.* A publication of the Seattle Public Schools Building Excellence Program and the City of Seattle (Solid Waste Utility, Water Department and Seattle City Light). The following web site provides information about the Partnership for Resource-Efficient Schools project and a link to download the Best Management Practices manual: http://www.cityofseattle.net/util/rescons/susbuild/partnership.htm

Santa Monica, City of. 1999. *Santa Monica Green Building Design and Construction Guidelines.* Available on-line at http://greenbuildings.santa-monica.org/main.htm.

Sustainable Building Task Force. The Sustainable Building Task Force was formed by a number of California agencies to institutionalize resource-efficient building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing resource-efficient building practices in all future and current state buildings, including those leased by the State.
See http://www.ciwmb.ca.gov/GreenBuilding/TaskForce/ for more information and links to member agencies.

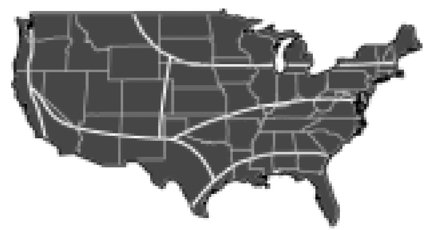
GUIDELINE SD1: OPTIMUM BUILDING ORIENTATION

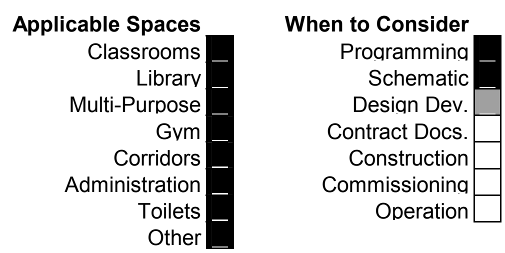
Recommendation

When site conditions permit, orient buildings so that major windows face either north or south. Position classrooms so that light and air can be introduced from two sides. Solar orientation should guide the placement of building and site features. Reduce the impact of exterior noise sources by locating noise sensitive areas, such as classrooms, away from noise producers, like roadways, train tracks, etc.

Orientation plays a key role in the landscaping and daylighting design. NREL/PIX09704

Applicable Climates





Description

Space heating and cooling accounts for nearly 20% of all energy consumption in the U.S. Optimal orientation of the building creates opportunities to utilize the potential contributions of the sun, topography, and existing vegetation for increased energy efficiency by maximizing heat gain (or minimizing heat loss) in winter and minimizing heat gain in summer. In the case of existing buildings, arrangement of interior spaces, strategic landscaping, and modifications to the building envelope can mitigate unfavorable orientation.

Applicability

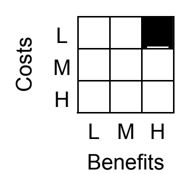
All climates. Primarily for new buildings and site planning, with some applicability to retrofitting existing buildings for greater efficiency.

Integrated Design Implications

Knowledge of the existing site soils, vegetation, and microclimate are critical to understanding how to best arrange site elements to create the least disruption to the site and orient structures and spaces appropriately. Integrate existing site features; proposed landscape design; orientation, height, and finish of walls; architectural design; impervious surfaces; location of heating and cooling equipment. Refer to guideline: SD2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas and TR2: Safe and Energy-Efficient Transportation.

Cost Effectiveness

Cost implications exist mainly in the design phase. Resulting cost savings will be demonstrated during building operation with lowered heating and cooling requirements.



Benefits

Reduced energy consumption will result in cost savings for year-round heating and cooling. The arrangement of interior and outdoor spaces with thoughtful solar orientation allows optimal natural lighting and user-friendly spaces. Studies have shown that students in classrooms with the most daylighting have a 21% improvement in learning rates over students in classrooms with poor natural light.[1] See the Daylighting and Windows chapter for more information on this research.

Design Tools

Many utilities offer the use of heliodons for accurate modeling of daylighting effects. A physical model is mounted on the heliodon and a simulated sun shows shadows and solar exposure for different times of the day and the year. Most are coupled with a video camera for recording the test.

A sun angle calculator is a handy tool for studying sun position for different times of the day and year. It can be used to determine the required distance between buildings needed for adequate solar exposure and for determining the effect of shading obstructions such as adjacent buildings.

Design Details

Consider east-west orientation to maximize north-south daylighting opportunities. Single-story designs offer toplighting daylight strategies for all spaces. Keep width of building to less than 60 ft to increase daylight and ventilation opportunities.

Timesaver Standards for Landscape Architects presents the following site planning and building orientation information:

- Plan site clearing and planting to take advantage of solar access. Solar orientation, cloud cover, and topography create unique site attributes. A site’s latitude determines the sun’s altitude and associated azimuth for a given time or day. Orient the building to take advantage of solar energy for passive and active solar systems. The building should take advantage of shade and airflows to maximize summer cooling and to optimize passive solar energy for heating and wind protection during winter months. Orient solar collectors for maximum sun exposure.
- Orient building entrances and outdoor gathering spaces to maximize safety, ease of access, and protection from elements.

Solar angles, soils, and topography determine plant species and distribution, as well as vulnerability of the land to erosion by runoff. The extent of disruption to the site during construction can be minimized with careful orientation of buildings and site elements. Align long buildings and parking areas parallel to landscape contours.

Building orientation can have a significant impact on the acoustical performance of a building. Locating noise producers away from noise sensitive areas is the primary goal. Barriers of solid walls or berms of earth, which break the line-of-site between the noise source and the receiver (e.g. classroom), can be effective in reducing sound intrusion. A single row of trees or shrubs will be ineffective in reducing unwanted sound. Since windows are frequently the “weakest link” acoustically in a building structure, double glazed windows are often the only alternative to controlling exterior noise. Normal therma-pane double paned windows with ¼ in. or ½ in. airspace are not effective acoustically. The small airspace, and the two panes of similar glass severely limit its acoustical performance. To be effective acoustically, at least the outer pane should be laminated glass. Additional airspace between the two panes of glass is also very important. It is not uncommon to require 2 in. to 4 in. airspace and thicker laminated glass to control exterior traffic and/or aircraft noise, which contain substantial low frequency energy.

Operation and Maintenance Issues

None.

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[1] Heschong Mahone Group and New Building Institute. “Re-Analysis Summary: Daylighting in Schools, Additional Analysis.” On behalf of the California Energy Commission Public Interest Energy Research (PIER) Program, Feburary 2002.

Commissioning

None.

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American Institute of Architects Research Corporation. *Solar Dwelling Design Concepts.* Washington, DC: U.S. Department of Housing and Urban Development, 1976.

Balcomb, John Douglas. "Using Energy-10 to Design Low Energy Buildings." National Renewable Energy Laboratory, 1999. A summary report that describes Energy-10 and presents a detailed worked example carrying a particular building from pre-design through preliminary design. http://www.nrel.gov/buildings/energy10/resources.html.

Buffo, John, et al. "Direct Solar Radiation on Various Slopes from 0 to 60 Degrees North Latitude." U.S. Department of Agriculture Forest Service Research Paper PNW-142, 1972, 74pp.

DeChiara, Joseph. *Site Planning Standards.* McGraw-Hill, Inc. 1978.

Durant Road Middle School, Wake County, NC, utilized many recommendations from this guideline.

Harris, Charles. *Timesaver Standard for Landscape Architecture: Design and Construction Data.* McGraw-Hill, Inc. 1998.

Land Design/Research, Inc. *Energy Conserving Site Design Case Study*, Burke Center, Virginia. Washington, DC: U.S. Department of Energy, 1979, 60pp.

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Marsh, William M., and Dozier, Jeff. *"The Radiation Balance." Landscape: An Introduction to Physical Geography*. Reading, MA: Addison-Wesley, 1981, pp. 21-35.

Sizemore and Associates. *Methodology for Energy Management Plans for Small Communities.* Washington, DC: U.S. Department of Energy, 1978.

Sterling, Raymond, et al. *Earth Sheltered Community Design.* New York: Van Nostrand Reinhold, 1981, 270 pp.

Guideline SD2: Landscaping to Provide Shade to HVAC Equipment, Buildings, and Paved Areas

Recommendation

Shade HVAC equipment from direct sun. Ensure landscaping does not block air circulation to or from the building. Use landscaping to shade windows on the east- and west-facing building facades. Use landscaping or shade structures to shade paved areas to reduce the heat island effect.

Description

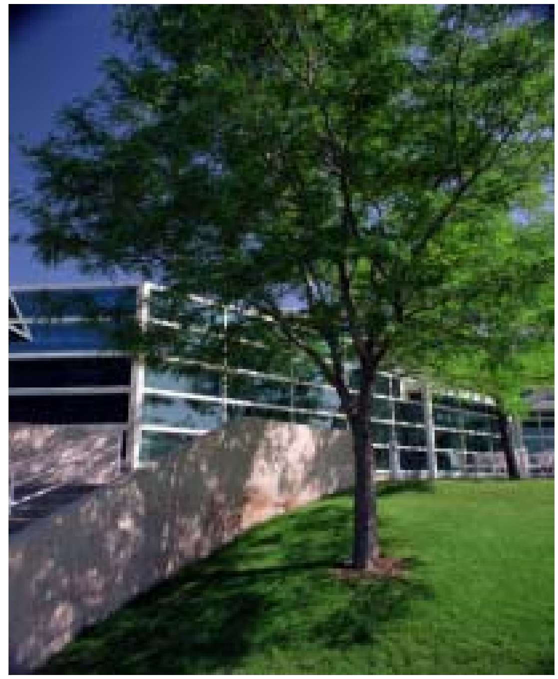
Shading HVAC equipment from direct sunlight can significantly lower the cooling demand. Landscaping can greatly reduce the impacts of heavy radiation loads on the roof, and east and west exposure in summer. In temperate regions, site planning and design should seek to promote shade and evaporative cooling in warm periods, and block winds and promote heat gain in cool periods, without disrupting favorable summer wind patterns. In hot, arid regions, plan to balance daily temperature extremes by storing energy, increasing humidity, and diverting desiccating winds.

Applicability

All climates.

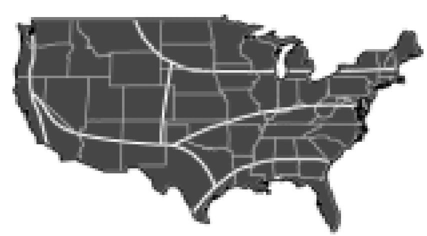
Integrated Design Implications

Integrate landscaping, HVAC design, parking lot design, lighting design, irrigation, and preservation of existing plants with building design and orientation. Wind and moisture patterns should be considered during site planning in conjunction with goals to provide building shade. Design coordination will be needed so that trees and lighting are placed without conflicting with the shade or footcandle requirements. Refer to guideline SD1: Optimum Building Orientation; TR1: Transportation and Site Design; SD4: Impervious Surfaces; Mechanical and Ventilation Systems guidelines; as well as guidelines in the Energy-Efficient Building Shell chapter.



Landscaping and trees help minimize heat gain to the building and surrounding concrete. NREL/PIX03779

Applicable Climates

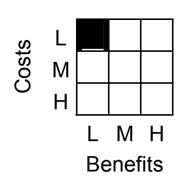


Applicable Spaces	
Classrooms	
Library	
Multi-Purpose	
Gym	
Corridors	
Administration	
Toilets	
Other	■

When to Consider	
Programming	■
Schematic	■
Design Dev.	▒
Contract Docs.	
Construction	
Commissioning	
Operation	

Cost Effectiveness

Costs will vary depending on the type and extent of vegetation or shading structures used. Costs are minimal for HVAC shading, particularly if incorporated into overall HVAC system and landscaping design. Consult with a qualified HVAC engineer regarding opportunities for downsizing systems due to decreased system load.



Benefits

Lower energy costs from reduced solar loads on building. Shading HVAC equipment lowers demand for electricity and reduces heat islands.

Design Tools

Charts illustrating distance required between buildings or landscaping to avoid shadows and minimum spacing required to assure adequate light penetration. Solar path, latitude, and altitude charts should also be utilized.

Design Details

Building orientation should be closely integrated with landscape design. Planting deciduous trees on the southeast, southwest, and west side of the building will reduce solar gain in summer during the morning and afternoon. Deciduous vines on arbor structures will provide shade, particularly when used adjacent to the building on the south or west face, sheltering the interior from summer midday sun while allowing solar penetration in winter. Plant low branching deciduous trees on the west side to keep low afternoon sun off west and north walls in summer.

Consider the use of vines against south- and west-facing walls to reduce reflected and absorbed heat and light. This can reduce the temperatures in courtyards and outdoor spaces as well as adjacent buildings and interior spaces.

In urban environments, the site context may include solar windows (gaps between buildings) and shadow corridors (elongated zones which block the sun), which should be considered during site design to maintain sunlight to structures.

Parking lots and paved areas can reflect sunlight and absorb heat that raises temperatures. Shading with trees, shade structures or structures with vines can help lower temperatures.

Locate HVAC equipment so that it is shaded from afternoon sun during the cooling season. Plant trees so that at maturity their canopies shade the unit and the adjacent area during the entire cooling season.

Operation and Maintenance Issues

Design criteria and maintenance guidelines will be needed so that trees shading parking lots and other paved areas can grow to full maturity without excessive pruning. However, care must be taken to avoid contaminating HVAC equipment with leaves or other organic debris. Maintenance must keep plantings from growing too dense and preventing the proper circulation of air around the unit.

Commissioning

None.

References/Additional Information

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Marsh, W.M. *Landscape Planning: Environmental Applications.* John Wiley & Sons, New York. 1991.

Parker, D.S. “Measured Impacts of Air Conditioner Condensor Shading.” The Tenth Symposium on Improving Building Systems in Hot and Humid Climates. Fort Worth, TX, 1996. Archived at http://www.fsec.ucf.edu/~bdac/pubs/PF302/PF302.htm, 12/15/2000.

Parker, J.H. "The Impact of Vegetation on Air Conditioning Consumption." Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, CA, pp. 45-52, 1989.

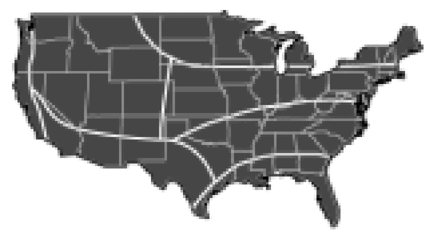
GUIDELINE SD3: LANDSCAPE DESIGN AND MANAGEMENT

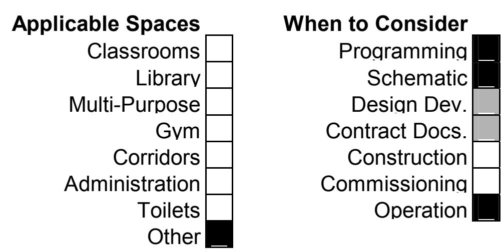
Recommendation

Develop a landscape plan based on an ecological approach, emphasizing plant diversity, natural lawn care, and resource conservation. Use this plan to guide site preparation, site design, and ongoing care of the site. Include objective plans, tasks, standards, and requirements that provide information about how to create a healthy and attractive landscape.

High performance landscape design emphasizes plant diversity, natural lawn care, and resource conservation. NREL/PIX 11335

Applicable Climates





Description

Every site has an ecological dynamism that involves all the physical elements of the landscape. A high performance approach to landscape design and management should be guided by four basic principles that respect this dynamism: resource conservation, diversity, connectivity, and environmental responsibility.

- *Resource Conservation.* Identify, use, and recycle available natural and physical resources that do not degrade the ecosystem. This principle should also be applied to site and landscape accessories.
- *Diversity.* Maintain a healthy natural system that gives primary consideration to habitat, species, and genetic diversity.
- *Connectivity.* Maintain networks of natural resources and interconnecting habitats to maximize healthy ecological functions.
- *Environmental Responsibility.* Protect, restore, and manage resources to maintain a healthy ecosystem in perpetuity.

To apply these principles to landscape care, it's important to understand the difference between landscape *maintenance* and landscape *management*. Maintaining a landscape implies that the landscape deteriorates and needs to be returned to a "correct" condition by the maintenance crew. This static vision belies the natural dynamism of the landscape. Seeking to simply maintain landscapes works against the dynamic tendencies of nature, resulting in great expense of time, energy, and money.

Management, on the other hand, acknowledges the constant change of nature. To manage a landscape is to work with the basic tendency of nature to change. Management based on ecological principles does not try to always return the landscape to a single, static state. Management — as opposed to maintenance — recognizes the dynamic qualities of landscapes and takes advantage of interconnected elements such as water, soil, and pests.

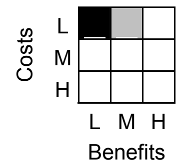
Applicability

All climate regions.

Integrated Design Implications

Planning for landscape management should be integrated and coordinated with Guideline SD5: Native and Drought-Tolerant Plants; Guideline SD6: Landscaping Soil, Amendments, and Mulch; and Guideline SD7: Integrated Weed, Disease, and Pest Management. All landscape planning should also take into account irrigation system parameters to help maximize water efficiency (see Guideline WC1: Water-Efficient Irrigation Systems).

Cost Effectiveness



Costs will vary depending on the extent of the site and scope of management plan. Native grasses save money on maintenance with reduced or eliminated mowing schedules. Recycled-content landscaping products are comparable in cost to conventional options.

Benefits

High performance landscape design and management, which seeks to bring the designed landscape into a closer adherence with the region's natural systems, provides a high level of benefit. A well-designed and implemented landscape management plan results in water conservation; soil improvement; the use of less intensive practices to manage plants; and the preservation, enhancement, or creation of habitat. The use of recycled content products helps alleviate waste disposal problems and reduces energy use and consumption of natural resources during manufacturing.

Landscape management, including natural lawn care practices, can help make the school grounds healthier for students and staff; protect beneficial soil organisms; and protect the environment through reduced use of water, pesticides, fertilizers, and pollution-producing mowers and maintenance equipment.

Properly designed earth berms can shield the school from nearby roadways, train tracks, etc. However, landscaping, trees, and shrubs cannot be used to reduce the level of exterior noise at the building façade.

Design Tools

To identify high performance landscape and site planning strategies, consider consulting with a landscape professional that has expertise in ecological approaches to vegetation management.

Design Details

Key Elements of a Landscape Management Plan

A landscape management plan needs to take into account three different functions: managing the vegetation, including lawn care; managing the site's infrastructure; and managing those responsible for its care. A landscape management plan should contain the following components:

- *Management vs. Maintenance*: Briefly discuss the basis of an ecological approach, the concept of maintenance vs. management, and the principles of ecosystem-based management.
- *Vegetation Types and Locations*: Discuss the concept of vegetation types, including diversity of vegetation. Also describe the landscape management zones, and list and describe the types of vegetation to be included in each zone. Provide standards that describe the desired condition of each vegetation type. Vegetation types include trees (young, street, native, ornamental, naturalized, riparian); shrubs (ornamental, naturalized, riparian, native); perennials; vegetables; meadow; lawn; groundcover; vines; and weeds and undesirable plants.
- *Infrastructure Standards*: Discuss standards for infrastructure care to achieve the desired condition.
- *Designating Responsibility*: Discuss who is responsible for each aspect of the landscape management, and delineate responsibility on a site map.

- *Sustaining the Landscape*: Describe the general tasks necessary to implement the landscape management specifications, including a yearly calendar of tasks as well as monthly task checklists to monitor the work and the health of the landscape.

Establishing Landscape Management Zones
A high performance design should divide a landscape into management zones based on each zone's differing design intents and maintenance requirements. In general, three landscape management zones exist:

- *Ornamental Zone*: The more traditional landscape areas next to buildings, parking areas, streets, and other public use facilities. This zone creates strong identity and focus for the schools. The landscape in this zone is typically designed to be organized, attractive, and lush. This zone requires the highest level of management to maintain a visually pleasing and healthy appearance.
- *Natural or Native Zone*: Existing natural areas on, or adjacent to, the site that are to be preserved, enhanced, or expanded.
- *Buffer Zone*: The interface areas between the other two zones. The management goal is to provide a visually pleasing landscape that bridges the ornamental zone and the native, or more natural, areas.

Natural Lawn Care
Lawns are typically the most intensively managed type of vegetation on a school site. A high performance approach to lawn care starts with lawn placement at the site. Lawn can be divided into different zones, based on how it will be used and how it needs to be cared for. Typically, three standards of care should be considered:

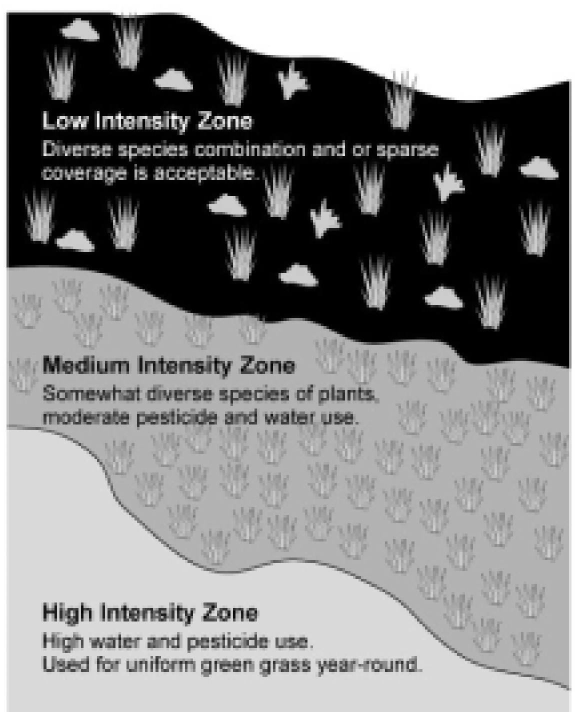


Figure 1 – Landscape Management Zones

- *High Intensity*: Requires uniform species composition, high irrigation demands, high synthetic fertilizer use, and regular pesticide and herbicide use. Used when primarily concerned with having uniform green grass year round with no weed, pest, or soil organisms.

- *Medium Intensity*: Allows for more diverse species composition, less demanding irrigation, moderate organic fertilizer use, and integrated pest management approach. Green is important, but not essential year round. Building soil structure over time is an important goal.
- *Low Intensity*: Diverse species composition and/or sparse coverage is tolerable. Alternatives to lawn are considered, with other vegetation taking precedence over lawn.

Plants depend on soil organisms to recycle nutrients, protect them from disease, and build loose fertile soil. Overusing soluble fertilizers and pesticides can disrupt this ecosystem and contribute to landscape and lawn problems like thatch buildup and soil compaction. Ecological approaches to landscape management and natural lawn care practices can help make lawns healthier for students and staff, protect beneficial soil organisms, and protect the environment.

A natural approach to lawn care produces lawns that stay healthy and are easier on the environment. Strategies include soil preparation/amendment, choosing groundcovers or no-mow lawn varieties, minimizing turf areas, "grass cycling" (leaving clippings to decompose quickly, releasing valuable nutrients back into the soil), mowing at the proper height, minimal use of pesticides, applying smaller amounts of fertilizers at regular intervals, appropriate watering, and accepting an appropriate threshold for some weeds.

Operation and Maintenance Issues

Consider a variety of alternatives to traditional school staff for maintenance. For example, Conservation Corps or job training programs for restoration and habitat areas.

Landscape management is a different approach from conventional landscape maintenance. Planning, education, and training are key to a program's success. Each school district should develop and implement a written landscape management policy and program.

Commissioning

None.

References/Additional Information.

Clean Air Lawn Care, South Coast Air Quality Management District. Available on-line at http://www.aqmd.gov/monthly/garden.html.

Cook, Tom and Roy L. Goss. *Construction and Maintenance of Natural Grass Athletic Fields*. Washington State University Cooperative Extension, Publication PNW0240. This bulletin provides the basis for developing and maintaining high quality fields for different purposes under different conditions. Explains construction, establishment, drainage, irrigation, maintenance, and some troubleshooting. Rev. 1992. 28 pages. To order, call (800) 723-1763.

Craul, Phillip J. *Urban Soil in Landscape Design.* John Wiley & Sons, Inc. 1992.

Hunter, Charles D. *Suppliers of Beneficial Organisms in North America.* California Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch. 1997.

Los Angeles County Department of Public Works. *The Natural Approach to Lawn Care.* Available on-line at http://www.smartgardening.com/grassrecycling.htm.

Olkowski, William et al. *Common Sense Pest Control.* The Taunton Press. 1991.

People's Park Landscape Management: Vegetation and Infrastructure Program. A program developed for the University of California, City of Berkeley, and the Park/Community Advisory Group. This program uses an ecological approach to the renovation and care of the landscape. Information available from Wolfe Mason Associates at http://www.wolfemason.com.

Profiles: A Special Report on Grounds Care. A report of grounds maintenance challenges at Georgetown University, Washington, DC, the University of Texas Southwestern Medical Center in Dallas, and the Orange County Public School District in Orlando, Florida. Available on-line at http://www.facilitiesnet.com/fn/NS/NS3m9li.html.

GUIDELINE SD4: IMPERVIOUS SURFACES

Recommendation

Minimize impervious surface areas to reduce stormwater runoff. Use material-efficient products for installed pervious and impervious surfaces.

Description

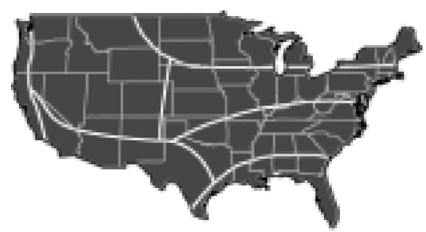
Impervious areas, such as roofs, driveways, sidewalks, and streets, increase stormwater runoff by preventing the infiltration of surface water into the ground. This increased stormwater runoff results in increased erosion, higher flow rates, higher ambient temperatures, and incdreased sediment in nearby waterways. Additionally, as stormwater flows over buildings, parking lots, and play fields, it collects pollutants, such as oil, litter, and dirt. These waterborne pollutants often discharge directly into waterways. Conversely, permeable surfaces reduce peak stormwater runoff and treat stormwater pollutants. In addition, impervious surfaces create higher ambient temperatures on the site compared to permeable or vegetated alternatives.

Strategies to limit impervious surfaces on the building site include:

- Using permeable (or porous) pavement systems in lieu of impervious asphalt or concrete. Examples:
  - Porous asphalt, paver blocks, or large aggregate concrete for parking and high use bicycle and pedestrian areas.
  - Lattice blocks that permit grass growth for fire lanes and overflow parking.
  - Crushed stone or brick for lightly used pedestrian paths.
- Minimizing the amount of paving by designing for multiple uses. Uses can include access, parking, pathways, meeting places, and game courts. Surfacing materials can vary depending on intensity of use, e.g., access roads paved and parking gravel, turf block for emergency access, and decomposed granite for secondary paths. All surfacing materials can utilize porous paving techniques.
- Retaining or substituting vegetation in lieu of hard surfaces.
- Designing to distribute runoff from impervious surfaces over large vegetated areas prior to reaching a stormwater conveyance system. This reduces the flow velocity, removes pollutants, and promotes groundwater infiltration.
- Installing a vegetated roof.

Minimizing impervious surfaces maximizes the area available for soils and vegetation to receive and treat surface water. NREL/PIX 11414

Applicable Climates



Applicable Spaces	
Classrooms	□
Library	□
Multi-Purpose	□
Gym	□
Corridors	□
Administration	□
Toilets	□
Other	■

When to Consider	
Programming	■
Schematic	■
Design Dev.	■
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

- Using natural or constructed wetlands to provide on-site retention and treatment of stormwater.
- Minimizing the building footprint through design. (Note: Minimizing building footprint usually means building "up" rather than "out." For schools, this may not be desirable because of conflicts with higher priority goals, such as daylighting and natural ventilation.)

Where impervious surfaces are necessary, use resource-efficient materials. Examples include:

- Rubber modified asphalt or recycled concrete asphalt.
- Recycled aggregate for base course of new parking lots and roadways.
- Concrete made using flyash, a byproduct of coal combustion, to replace a portion of the Portland cement, a high-embodied energy material.

Applicability

All climates.

Integrated Design Implications

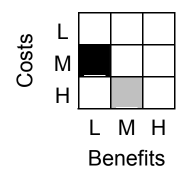
Strategies to minimize impervious surfaces should be integrated with decisions about landscaping design; shading of the building, site, and heat rejection equipment; building orientation and design (footprint); roofing selection; stormwater management; parking lot and paving design; building layout; vegetated roof design; and parking lot design.

Note: One limitation of porous pavement is its tendency to clog if improperly maintained. Once it is clogged, it is difficult and costly to rehabilitate and often must be completely replaced. Clogging can be prevented most easily by not installing it in areas where erosion is a concern and by waiting until all other phases of construction are complete and vegetation is stabilized to install the pavement. Other concerns include the lack of expertise of pavement engineers and pavement contractors. Also, some studies indicate that porous systems have slightly higher deformation in porous pavement compared to conventional.

A vegetated roof reduces the amount of rainwater runoff while simultaneously minimizing heat build-up and providing insulation.
NREL/PIX 11411

Cost Effectiveness

Minimizing paved areas means less paving material overall, which translates into lower initial cost.



The cost of permeable paving systems will vary depending on the system used. For example, porous (no fines) concrete may be comparable to conventional pavement. (This material requires a contractor familiar with the process, however.) Grid types, pavers, and brick systems have a cost premium. Cost is offset by its dual purpose as a stormwater system. Less land is needed for this type of system, because an area for detention, retention, or infiltration is not necessary.

Benefits

Minimizing impervious surfaces helps preserve the hydrological and geological functions of a developed site by maximizing the area available for soils and vegetation to receive and treat surface water and facilitates groundwater recharge. The flow, velocity, and quantity of surface water is decreased overall, reducing the sediment and pollutant load on local waterways as well as the burden on municipal water management systems.

Ancillary benefits include reduced heat, local heat build-up (heat islands) from the shading and cooling effects of vegetation, vegetated roofing, and whitetopping. These translate into reduced cooling loads and energy consumption. Several permeable pavement systems are manufactured with recycled content, making them material efficient. Impervious paving that uses recycled concrete aggregate for base or flyash in concrete is also material efficient.

Design Tools

Applicable state and local stormwater and surface water management design manuals.

Permeable Paving

Specifications, if any, for porous pavement will vary from state to state. As an example of the types of guidelines states can provide, the documents listed below are used in Washington State:

Interim Guidelines for the Construction of Portland Cement Pervious Pavement or "No Fines" Concrete, a working document of the Washington State Aggregates and Concrete Association, soon to be updated.

BMP T3.40, Porous Pavement, from the *Final Draft, Stormwater Management Manual for Western Washington, Volume V*, *Runoff Treatment BMPs*. Washington State Department of Ecology, Water Division. August 1999, revised August 2000. This document can be downloaded at http://www.ecy.wa.gov/biblio/9915.html or call (360) 407-6614.

Whitetopping

American Concrete Paving Association (ACPA), Whitetopping, State of the Practice. Publication EB210P. This engineering bulletin covers of all aspects of concrete overlays on existing asphalt pavement. Its five chapters include: Introduction (uses and benefits), History and Performance, Design Practices (conventional whitetopping), Construction Practices, and Ultra-Thin Whitetopping (UTW). The last chapter presents the interim procedure for determining the load-carrying capacity of UTW based on research and performance surveys. 1998. Order from the ACPA, http://www.pavement.com/.

Design Details

Effective surfaces are those, pervious or impervious, that are connected via sheet flow (shallow or concentrated surface flow) or discrete conveyance (such as drainage ditch) to a drainage system. *Effective impervious surface* is a measure of the performance of the lot with respect to stormwater flows, which provides a way of monitoring impact due to construction. Methods to minimize runoff can be expressed: (1) prescriptively, such as using pervious surfaces, or (2) performance-based, such as providing zero effective impervious surface (no net increase in runoff). Specific strategies will depend upon the specific site and local requirements.

Concrete manufactured with flyash can be used for paving. NREL/PIX04358

Where impervious pavement must be used, specify the use of recycled asphalt, concrete manufactured with flyash for paving, and/or rubberized asphalt pavement. In hot climates, look for opportunities to whitetop asphalt surfaces with heat-reflecting white concrete.

For concrete work, use reusable steel forms, expansion joint filler with recycled content, and least toxic release methods.

When using porous paving or on-site bio-filtration swales, it is critical that sub-base soils are tested so that designs are sufficient to process the stormwater flow.

Utilize surface stormwater flow wherever possible. Introduce oil/water separators at catch basins.

Note that design considerations should assume a minor loss in porosity in the first four to six years.

Avoid compaction of site soils in adjacent areas during construction to retain infiltration and water holding capacity of existing soils.

Operation and Maintenance Issues

For bio-swales and constructed wetlands, the design intent is to create a self-sustaining system that requires little maintenance. Monitoring and maintenance as the landscape matures provide educational opportunities. As bio-swales and constructed wetlands provide wildlife habitat, mowing and thinning plants should be minimal unless soils testing shows that impurities from runoff are high. In that case, mowing and thinning will help remove toxins that may accumulate in the vegetation.

In parking areas, prune plants as needed to maintain sight lines and the desired aesthetic. If storm drains are used, clear as needed to prevent blockages. Avoid soil compaction in vegetated areas.

For porous asphalt and concrete, vacuum with a hydrovac to maintain or restore porosity by removing sediment from the paving surface. If areas become deformed by traffic, drill compacted areas to restore porosity. Keep underdrains, overflow drains, and edge drains clear.

Grassed paving systems need to be mowed. Tall grasses create a less-permeable surface. If this type of system is perceived as unmaintained, it may discourage potential users. The durability of the system depends on soil type and climate; however, maintenance is decreased with the use of appropriate groundcover plants in lieu of lawn. Some groundcovers can take foot traffic but lawn, in turf block or grids, is best used where there is auto traffic.

Unit pavers on a permeable subgrade settle after the initial installation, and therefore require that a joint-filler material be swept in. Permeability decreases over time as the joints become compacted.

The systems mentioned above are conducive to “spot fixes” should replacement of small areas be required due to damage. It should also be noted that maintenance is reduced where snow removal is significant, as snow melts faster on permeable surfaces.

Longevity of the system depends on the type of system used, the amount of use it receives, and the appropriate match of system to site.

Commissioning

None.

References/Additional Information

California Integrated Waste Management Board. *Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction*. See Chapter 8, “Strategies to Reuse Materials and Reduce Material Use in Construction,” *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding. Chapter 8 is in Part D. Revised July 2000.

International Erosion Control Association. Provides technical assistance and an annual Erosion Control Products and Services Directory. (800) 455-4322. http://www.ieca.org/.

Stormwater and Urban Runoff Seminars — Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, (800) 368-5242 x538 or http://www.nahb.com/.

Stockdale, E.C. *Freshwater Wetlands, Urban Stormwater, and Nonpoint Pollution Control: A Literature Review and Annotated Bibliography*. 2nd Ed. WA Dept. of Ecology, Olympia, WA. 1991.

Strecker, E.W., J.M. Kersnar, E.D. Driscoll & R.R. Horner. *The Use of Wetlands for Controlling Stormwater Pollution*. The Terrene Institute, Washington, DC. April 1992.

U.S. Environmental Protection Agency. *Natural Wetlands and Urban Stormwater: Potential Impacts and Management*. EPA843-R-001. Office of Wetlands, Oceans and Watersheds, Washington, DC. February 1993.

U.S. Environmental Protection Agency. *Stormwater Management For Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance*. EPA#833-R-92-001, Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. October 1992. (800) 245-6510, (202) 260-7786 or http://www.epa.gov/owm/sw/construction/.

GUIDELINE SD5: NATIVE AND DROUGHT-TOLERANT PLANTS

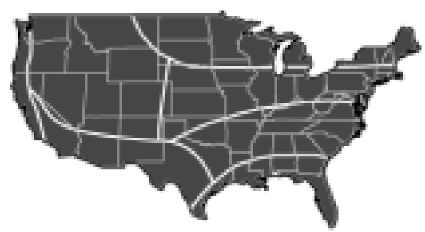
Recommendation

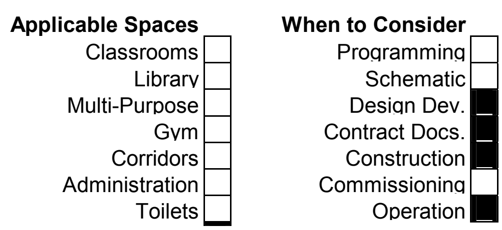
Use vegetation that is drought-tolerant and native to the school's climate area. Preserve existing vegetation, especially groups of plants or significant specimens wherever possible. Design for plant survival since many landscape areas in schools can be destroyed by intensive use. Design landscapes with a minimal water-use budget, using low-flow irrigation systems.

Water needs for irrigation can be minimized by protecting existing vegetation and using native planting.

NREL/PIX 11340

Applicable Climates





Description

Native vegetation is adapted to regional climate conditions. They are easy to establish, are drought-tolerant (require little or no irrigation once established), and are naturally disease-resistant and pest-resistant. Planting for minimal water use is also referred to as "xeriscaping" or "drought-tolerant" landscaping.Existing vegetation is the easiest and most cost-effective way to landscape the site. It also provides historical connection to the surrounding neighborhood.

Plant survival can be increased by using tough plants that can take foot traffic such as plants grown from corms or bulbs. Good examples include *Dietes vegeta, Acanthus mollis, Phorium sp.,* and many of the grasses, reeds and sedges. These tough plants should anchor corners and edges of planted areas. Also raised beds, curbs, and temporary but artistic barriers can help protect plants into maturity. Preparing designs and management programs that layer plant types, use a mixture of sizes at initial plantings, and plan for plant succession will also help.

Applicability

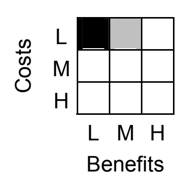
This guideline applies to all climates

Integrated Design Implications

Drought-tolerant landscaping should be integrated/coordinated with Guideline SD2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas; Guideline SD3: Landscape Design and Management; and Guideline SD7: Integrated Weed, Disease, and Pest Management. All landscape planning should also take into account irrigation system parameters to assist in the goal of maximum efficiency. See Guideline WC1: Water-Efficient Irrigation Systems.

Cost Effectiveness

Costs are competitive with, or only slightly higher than, conventional landscape design. Additional cost benefit occurs if reusing existing vegetation.



Benefits

The use of drought-tolerant, native species conserves water (thereby reducing water costs), provides lots of attractive planting options, presents minimal disease and pest problems, thrives with little fertilization, requires low pruning and maintenance, provides wildlife habitat, and saves valuable landfill space. If retaining native vegetation in a landscape (rather than removing them and then replanting), added benefits include excellent erosion, sediment, dust, and pollution control.

Design Tools

Landscaping for minimal irrigation also requires careful planning of plant groupings, the "right plant, right place" concept, soil considerations, and other landscape design practices. The use of a landscape professional with expertise in native and drought-tolerant vegetation for the school's climate region is recommended.

Landscape Auditors certified by the Irrigation Association (703) 536-7080, Web site: http://www.irrigation.org/.

Design Details

Add language into construction specs to protect existing plants, especially trees and root systems.

Soils are often disturbed during construction activities, and native vegetation may not thrive in degraded soils. Unless soil amendments are used to restore disturbed soil, it may be more appropriate to use water-efficient, non-native vegetation. See Guideline SD6 for using soil amendments.

Clearly define planting zones by intended use, e.g., lawns for play, tree groves for shade and habitat, shrub masses for buffering and screening.

Introduce plants to increase habitat, e.g., butterflies and hummingbirds.

Create a diversity of landscape areas, e.g., ponds, meadows and groves; community gardens; vines and perennials.

Operation and Maintenance Issues

Native, drought-tolerant plants are usually hardier and more pest-resistant, requiring less fertilizer and pesticide use. Use organic, slow release fertilizers and integrated pest management for pest control. See Guideline SD7 on integrated pest management.

Recommend that the landscape contractor specify in the maintenance contract that new landscaped areas be maintained for a two to three year plant establishment period. Monthly findings on plant establishment should be reported to the owner.

Commissioning

None.

References/Additional Information

Arizona Native Plant Society, http://www.aznps.org/.

Arkansas Native Plant Society, http://www.anps.org/

Carnegie Library of Pittsburgh, http://www.trfn.clpgh.org/Lifestyle/Gardening/nativeplants.html. The Native Plants page has links to Pennsylvania resources, as well as national information.

City of Fort Collins. (March 1999). Xeriscape: a New Kind of Landscaping. A summary of environmentally responsive landscaping resources, including a list of very low, low, and moderate water consumption.

http://www.ci.fort-collins.co.us/utilities/water/conserv/xeriscap.htm.

Connecticut Botanical Society, http://www.ct-botanical-society.org/

Florida Native Plant Society, http://www.fnps.org/.

Gardening to Preserve Maine's Native Landscape, University of Maine Cooperative Extension Bulletin #2500, http://www.nps.gov/plants/pubs/gardenME/

Georgia Native Plant Society, http://www.gnps.org/.

Idaho Native Plant Society, http://www.idahonativeplants.org/Index2.html.

Illinois Native Plant Society, http://www.inhs.uiuc.edu/inps/

Indiana Native Plant and Wildflower Society, http://www.inpaws.org/

Marsh, W. M. 1991. *Landscape Planning: Environmental Applications.* John Wiley & Sons, New York. A definitive reference for landscape architects, planners, and designers on the definition and application of environmental design principles to landscape and site planning.

Maryland Native Plant Society, http://www.mdflora.org/

Minnesota Native Plant Society, http://www.stolaf.edu/depts/biology/mnps/

Missouri Native Plant Society, http://www.missouri.edu/~umo_herb/monps/

Montana Native Plant Society, http://www.umt.edu/mnps/

Nevada Native Plant Society, http://www.state.nv.us/nvnhp/nnnps.htm

Texas Native Plant Database. Run by Texas A&M University and the Dallas Arboretum, this site features a searchable database with photos of native Texas trees and plants. http://www.dallas.tamu.edu/native

The Lady Bird Johnson Wildflower Center. Links page has contact information for native plant organizations for most states. http://www.wildflower.org/links.html.

U.S. Environmental Protection Agency, Great Lakes Region. This site is a thorough resource for native landscaping in the Great Lakes area. http://www.epa.gov/greenacres/

Utah Native Plant Society, http://www.unps.org/.

Virginia Native Plant Society, http://www.vnps.org/.

WaterWiser — a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. The web site provides information and resources including links for all aspects of outdoor and indoor water conservation, recycled water collection and reuse, irrigation, landscaping, and efficient fixtures and appliances. AWWA number is (202) 628-8303. http://www.waterwiser.org/.

Washington State University Cooperative Extension. This site contains a database with detailed information on plants native to the Pacific Northwest. http://www.gardening.wsu.edu/nwnative/

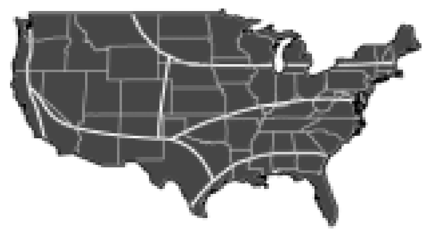
GUIDELINE SD6: LANDSCAPING SOIL, AMENDMENTS, AND MULCH

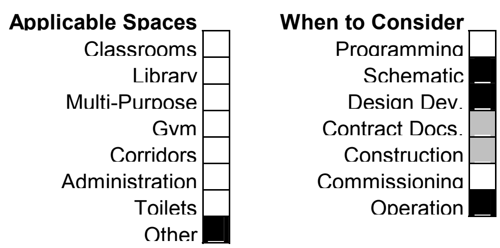
Recommendation

Use organic soil amendments to help restore the health of disturbed soils. Where feasible and appropriate, use soil amendments and mulch with recycled content.

Amendments protect the health of soil. NREL/PIX01791

Applicable Climates





Description

The appropriate use of organic soil amendment will offset degradation in soil health due to construction activities, reduce runoff, help treat stormwater pollutants, and help ensure establishment of vegetation. Where feasible, use soil amendments from composted green waste and mulch from shredded bark, which adheres better to the soil.

Applicability

All climates.

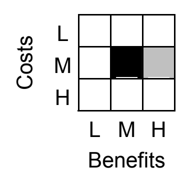
Integrated Design Implications

Soil amending should be integrated/coordinated with Guideline SD2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas; Guideline SD3: Landscape Design and Management; and Guideline SD5: Native and Drought-Tolerant Plants.

Cost Effectiveness

Medium.

Benefits



Research at the University of Washington has shown that, compared to traditional lawn installations, landscape grown on composted-amended soils:

- Uses less water for irrigation.
- Requires less fertilizer and pesticide.
- Covers and "greens up" more quickly.
- Has improved appearance.
- Reduces stormwater runoff.

Design Tools

Appropriate use of soil amendments requires site soil testing and analysis to determine type and amount of amendment.

Design Details

Key steps in creating and maintaining healthy soil and amendments include:

- Minimize disturbance of existing soil.
- Test the horticultural suitability of existing soil.
- Strip and save suitable existing soil for re-use in landscape areas.
- All existing soil in areas to be planted that have been degraded and compacted from building construction must be scarified before planting. In general, and depending on soil type, planting soils can not be compacted more than 80% so that air and water can percolate through the soil cross section.
- Incorporate organic soil amendments from composted green waste to help restore the health of disturbed soils.
- Use a minimum 3 in. to 4 in. layer of mulch at all planting areas to help retain soil moisture and discourage weed growth. Some types of mulch can also take foot traffic.

Urban development often involves clearing, removing topsoil, cuts, and fills. Once the work is done, the remaining soil is often much less healthy than the original, native soil.

Table 3 – Characteristics of Healthy vs. Disturbed Urban Soil

Healthy Native Soil	Disturbed Urban Soil
• Stores water and nutrients — Contains a rich, diverse makeup of organisms, organic matter, and pores. Healthy soil acts like a giant sponge, storing and slowly releasing water, oxygen, and nutrients to plants as needed. • Regulates water flow — Maintains the natural water cycle by slowly discharging to streams and lakes and recharging aquifers. • Neutralizes pollutants — Soil rich in organic matter contains microorganisms that can immobilize or degrade pollutants.	• Compacted — The removal of topsoil exposes subsoil that is often compacted. Heavy construction equipment can further compact soils. These dense layers resist plant root penetration and lack pores needed for adequate aeration. As a result, the soil is less able to absorb, retain, and filter (purify) groundwater. • Reduced storage capacity — Because subsoil is less able to retain water, more stormwater ends up as runoff, disrupting the natural water cycle and degrading the health of nearby streams and waterways. • Poorer quality — The subsoil layer generally contains less organic matter and fewer nutrients than rich topsoil. This soil is less able to immobilize or degrade pollutants.

The result is increased erosion and stormwater runoff, as well as higher flow rates, higher temperatures, and increased sediment in nearby streams from disturbed urban soil. In addition, developed sites with poor soil typically require more irrigation, pesticides, and fertilizers to establish and maintain landscaping. Increased water usage as well as pesticide/fertilizer runoff causes further habitat damage.

Operation and Maintenance Issues

Vegetation grown on amended soils establishes more quickly and requires less ongoing maintenance compared to vegetation grown on un-amended, disturbed urban soil.

Commissioning

None.

References/Additional Information.

U.S. Composting Council. This non-profit organization is involved in research, public education, composting, and compost standards. Their website has links to composting resources throughout the country. Web site: http://www.compostingcouncil.org/

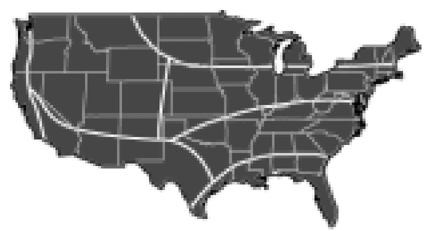
GUIDELINE SD7: INTEGRATED WEED, DISEASE, AND PEST MANAGEMENT

Recommendation

Control and manage weeds, disease, and pests within tolerable limits to maintain the landscape in a manner that achieves attractive and healthy growth for plants, animals, and people while conserving energy and water.

Outdoor learning areas like this must be kept free of harmful chemical pesticides and herbicides. NREL/PIX10675

Applicable Climates



Applicable Spaces		**When to Consider**	
Classrooms	☐	Programming	☐
Library	☐	Schematic	☐
Multi-Purpose	☐	Design Dev.	■
Gym	☐	Contract Docs.	■
Corridors	☐	Construction	■
Administration	☐	Commissioning	☐
Toilets	☐	Operation	■
Other	■		

Description

The most effective weed, pest, and disease control measure is to keep plants healthy. When a problem is caused by an adverse environmental condition, chemically treating the problem will not prevent its recurrence, but will only treat the symptoms. Control of disease and pests includes, but is not limited to, rust, scale, aphids, mealy bugs, pine shoot moths, snails, and rodents.

Once viewed as safe and effective for insect control, chemical pesticides and herbicides are now recognized poisons that can contaminate the soil and harm wildlife and humans — especially children. Some of this poison finds its way into lakes, streams, and groundwater supplies, where it disrupts the balance of life. Reducing the use of pesticides protects lakes and contributes to a healthier environment for fish, wildlife, and people.

Integrated pest management (IPM) is a horticultural practice that stresses the application of biological and cultural pest control techniques with selective pesticides, when necessary, to achieve acceptable control levels with the least possible harm to human health and safety, non-target organisms, and the environment.

IPM encompasses various environmentally sound strategies, including:

- Use of appropriate, adapted plant varieties
- Installation of a compatible, supportive landscape/site design (such as incorporating concrete mow strips near fencing to eliminate the need for herbicide use in these areas)
- Providing the necessary nutrients and moisture
- Following through with good maintenance practices.

Applicability

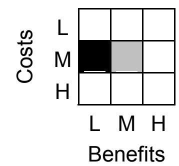
All climates.

Integrated Design Implications

Planning for IPM should be integrated/coordinated with Guideline SD2: Landscaping to Provide Shade to HVAC Systems, Buildings, and Paved Areas; Guideline SD3: Landscape Design and Management; Guideline SD5: Native and Drought-Tolerant Plants; and Guideline SD6: Landscaping Soil, Amendments, and Mulch.

Landscape design that employs IPM will help limit the release of potential stormwater pollutants.

Cost Effectiveness



Medium. IPM may have a higher initial cost than pesticide programs, but it is cost effective over the life of the building and produces safer school grounds, healthier vegetation, and lower spraying costs. Frequent pesticide use can result in a chemical dependent situation, where an insect comes back stronger than it was before. Increasing doses and frequency of application are then needed for attempted control of the pest. For example, pesticides that kill aphids also kill aphid predators. Since aphids reproduce more quickly than their predators, when they return to the plant, their natural enemies will be gone, and they may also become resistant to the pesticide. IPM means less pesticide/herbicide use, but may entail additional ongoing labor for maintenance as well as additional training, documentation, and policy development costs.

Benefits

Decreased pesticide use means less health risk to students and staff, and lower maintenance costs associated with the purchase of pesticides.

Design Tools

None.

Design Details

There are four key issues for weeds, disease, and pests:

- Planting appropriate species and maintaining them in a healthy condition since most weeds and pests are more attracted to weak or over-fertilized plants than to those in good health.
- Determining what really is a weed or pest. A plant is a weed only if it is in an undesirable location or is out-competing more desired species. Many ”bugs” are essential to plant propagation and are beneficial to the health of plant.
- Maintaining weeds and pests on vegetation (grass, groundcover and shrubs, grasses and turf, gardens and perennials) within tolerable levels using the IPM approach.
- Controlling damage from water fowl, gophers, and other rodents by replacing inappropriate plants with those that are less susceptible, and by adding mechanical protection devices (cages, mesh, etc.) during the early growth period of the new plants, as needed.

Consult a landscape professional with expertise in IPM to identify landscape and site design strategies that will support ongoing IPM. Select plant species less prone to disease.

Perform weed control by hand, pulling and hoeing whenever possible. It is important to do this frequently enough so that weeds to not have a chance to go to seed. Remove weeds from pavement and all vegetative areas. If there is a persistent problem, a pre-emergent herbicide may be considered for the large or particularly troublesome areas *only* after review and approval.

IPM requires a proactive management program with a good system of monitoring and record keeping as the first line of defense. Contractors’ monthly reports shall include all weed, pest, or disease observations and actions taken for review by the management team. Mechanical and biological control measures, such as hand picking, water jets, safer soap, barriers (e.g., organic pastes or poly mesh), biological controls (e.g., *Bacillus thurengiensis*), and less toxic sprays (e.g., dormant/summer oil, sulfur fungicides, pyrethrum, or rotenone) are first considered for use, often in combination. Less toxic chemicals will be considered before stronger chemicals.

Controlling pests is the subject of several research projects, particularly in grass areas. Herbicides and sprays used to eliminate broadleaf weeds or fungus have caused numerous injuries, studies, and debates. If grass areas are properly located and receive proper care, weeds and disease should not be a major problem. If problems do arise, they are to be reviewed with the consulting architect, and physical or biological solutions explored before chemicals are requested. Broadleaf weeds are to be kept to a minimum but multiple grass varieties are acceptable. The use of green dyes in particularly noticeable brown spots is an option.

Operation and Maintenance Issues

IPM is a different approach and requires planning, education, and training to succeed. Each school district should develop and implement a written pest management policy.

Commissioning

None.

References/Additional Information

Overview of Pest Management Policies, Programs, and Practices in Selected California Public School Districts. This is a report of a study conducted by the Environmental Monitoring and Pest Management Branch of the Department of Pesticide Regulation (DPR) of pest management programs in California's public school districts. The study was conducted in cooperation with the California Department of Education (CDE) to: (1) obtain an overview of district pest management policies, programs, and practices, (2) identify policy and program constraints, and (3) identify ways that DPR can work cooperatively with CDE to assist school districts in implementing pest management programs based on the principles of IPM. The report is available on-line at http://www.cdpr.ca.gov/docs/dprdocs/schools/schools.htm.

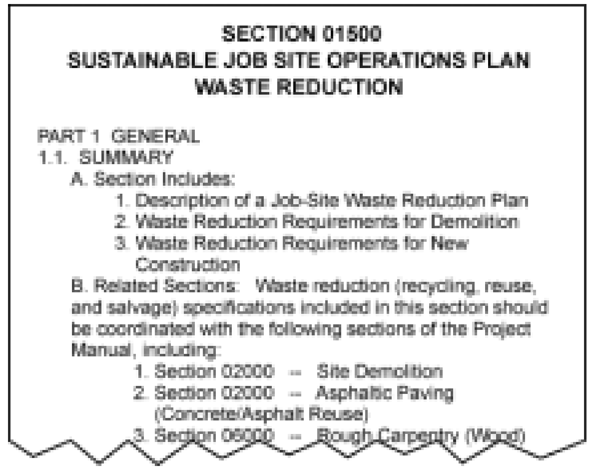
Reducing Pesticides in Schools: How Two Elementary Schools Control Common Pests Using Integrated Pest Management Strategies. The Pesticides Reduction in Schools (PRI-School) Project explored the potential for reducing risks associated with unnecessary pesticide use by implementing IPM programs in schools throughout Santa Barbara County. The main goals of the project were to identify the local administrative, technical and social barriers to implementing effective IPM programs and to explore ways to overcome these barriers. Funding for the PRI-School Project was provided by the U.S. Environmental Protection Agency and the Santa Barbara Foundation. The project was managed jointly by the Community Environmental Council and Organic Consulting Services, both from Santa Barbara. The report is available on-line at http://www.grc.org/cec/pubs/IPM_report2.html.

University of California's Statewide Integrated Pest Management Project, web site: http://www.ipm.ucdavis.edu/default.html.

GUIDELINE SD8: ENVIRONMENTALLY RESPONSIBLE JOB-SITE OPERATIONS PLAN

Recommendation

Require a job-site operations plan that includes protocols for Job-Site Waste Reduction (Guideline RS3), IAQ (Guideline SD9), and Site Protection (Guideline SD10).



SECTION 01500
SUSTAINABLE JOB SITE OPERATIONS PLAN
WASTE REDUCTION

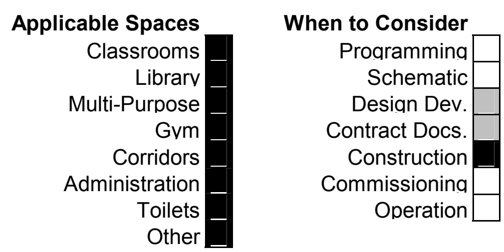
PART 1 GENERAL
1.1. SUMMARY
A. Section Includes:
1. Description of a Job-Site Waste Reduction Plan
2. Waste Reduction Requirements for Demolition
3. Waste Reduction Requirements for New Construction
B. Related Sections: Waste reduction (recycling, reuse, and salvage) specifications included in this section should be coordinated with the following sections of the Project Manual, including:
1. Section 02000 -- Site Demolition
2. Section 02000 -- Asphaltic Paving (Concrete/Asphalt Reuse)
3. Section 06000 -- Rough Carpentry (Wood)

Sample job site operations plan.

Description

A job-site operations plan will describe goals, construction practices to achieve those goals, methods to train or otherwise communicate these goals to field personnel, and methods to track and assess progress towards those goals. For each component of the plan (waste reduction, IAQ, and site protection), these elements will be specified. In addition, the plan will specify the method of documenting compliance with these goals, including in the case of product substitutions.

Applicable Climates



Applicability

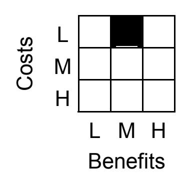
Job-site management is applicable to all spaces in schools and to all climates. While it is carried out in the construction phase, the contract documents must clearly specify the expectations of the general contractor.

Integrated Design Implications

An environmentally responsible job-site operations plan protects the integrity of design goals to reduce waste, improve air quality, and protect the site and surrounding waterways from degradation.

Cost Effectiveness

Costs for implementing the plan will include labor for overseeing and documenting compliance and should not be significant.



Benefits

Having a plan in place helps minimize costs and liabilities, including delays, stoppages, and residual problems in the completed school building. Proper planning is always more cost-effective than cleaning up after a mistake.

Design Tools

None.

Design Details

The requirement for an environmentally responsible job-site operations plan would appear in the "Temporary Controls" section(s) of specifications. The more clearly a plan allocates responsibilities and expectations, the less likely the project will generate unpleasant surprises during and after construction. Ideally, the plan should specify a time requirement for when a plan must be submitted, such as within 14 days of Notice of Award and prior to applicable construction activities. In addition, it can include sample forms, references, or other resources for the contractor to help facilitate development of an effective plan.

Operation and Maintenance Issues

The plan should specify a method of providing documentation for products substituted in the field, so that information is available to custodial staff should a replacement or repair be required. In addition, when dealing with non-conventional or innovative materials, information about how a product behaves during installation and pre-occupancy maintenance (such as during cleanup), as well as other "lessons learned" noted in a field log can be helpful.

Commissioning

None.

References/Additional Information

See the References listed for individual components of the plan in the following guidelines: RS3, SD9, SD10.

GUIDELINE SD9: INDOOR AIR QUALITY DURING CONSTRUCTION

Recommendation

Require indoor air quality (IAQ) planning and preventive job-site practices.

Description

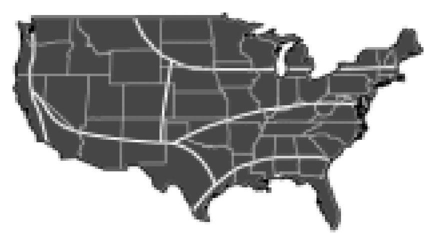
Preventive job-site practices can reduce residual problems with IAQ in the completed building and eliminate undue health risks for workers. "Healthy" job-site planning will adequately address problem substances, including construction dust, chemical fumes, off-gassing materials, and moisture. It will make sure these problems are not introduced during construction, or, if they must be, eliminates or reduces their impact. Areas of planning will include product substitutions and materials storage, safe installation, proper sequencing, regular monitoring, as well as safe and thorough cleanup.

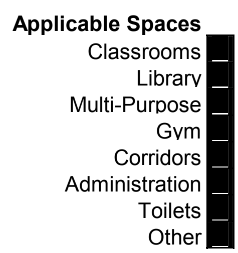
Healthy job site signage.
NREL/PIX 11408

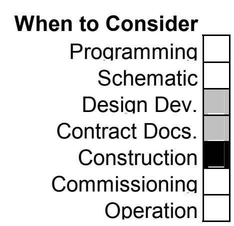
Applicability

Maintaining healthy job-site conditions is important for all spaces and all climates. The activity is carried out in the construction phase, but must be planned in the design development and contract documents phases.

Applicable Climates



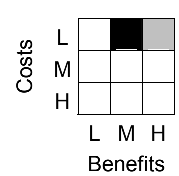




Integrated Design Implications

When identifying "healthy" materials for use in buildings, the focus is generally on preventing problems during occupancy. This guideline implies that some responsibility for air quality occurs during installation, which may impact the choice of material and/or the method of installation. Also, since substitutions may happen in the field, it is important to outline the approval process for these substitutions clearly. For materials with off-gassing potential, require specific ingredient information about the product itself (as well as any adhesives, solvents, or other products that might be used during installation or maintenance). Designing to use mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents can reduce potential problems with IAQ during construction.

Cost Effectiveness



Implementing this guideline should not necessarily add cost to the project. The one area where it might add cost is in potential delays due to sequencing and ventilation requirements. However, this cost can be avoided by proper planning.

Risk managers will be reluctant to take on the added responsibility of requiring IAQ planning and preventive job-site practices. However, school districts and project architects across the country have experienced litigation related to poor IAQ resulting from construction activities. Addressing these issues before and during construction will reduce exposure of the district and designers to potentially expensive litigation in the future.

Benefits

The costs of poor IAQ are difficult to quantify, but considerable. They include the sum of illness and decreased student productivity paid by students and teachers, along with the district's cost of equipment replacement, workers' compensation claims, and in the most severe cases, potential litigation. Unfortunately, serious health complaints have resulted from careless acts during construction projects, such as failure to clean up spilled adhesives or neglecting to properly ventilate during and after applying sealants in an occupied building. These mistakes have led to school closures, unpleasant headlines, and costly lawsuits. Good IAQ strategies during construction will help eliminate these potential liabilities.

Design Tools

The U.S. Environmental Protection Agency has an online checklist available for IAQ issues at all stages and aspects of construction. Visit http://www.epa.gov/iaq/schools/tools4s2.html.

Design Details

IAQ goals (as with all other resource-efficient building goals) should be outlined in the Instructions to Bidders as part of the Project Summary addition. IAQ specifications should be included in the Temporary Controls sections of General Conditions.

The specifications should describe what is included in an IAQ construction plan, outline submittal requirements, and reference the SMACNA IAQ Guidelines for Occupied Buildings Under Construction 1995, with the goals of:

- Protect the ventilation system components from contamination, or provide cleaning of the ventilation components exposed to contamination during construction prior to occupancy.
- Provide a minimum continuous ventilation rate of one air change per hour during construction, or conduct a building flush-out with new filtration media at 100% outside air after construction ends (following issuance of Occupancy Certificate) and prior to occupancy for seven days (one week). Provide a minimum of 85% filtration (as determined by ASHRAE Standard 52.1-1992) on any return air systems operational during construction, and replace filtration media prior to occupancy. Note that seven days is considered a minimum. IAQ specialists recommend flushing the building with 100% outside air for 30 days prior to substantial completion.

If the contractor is required by the specification to be responsible for protecting IAQ during construction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative for contractors to include a list of proven air quality protection strategies, such as:

- Use supplemental (temporary) ventilation when installing carpet, paints, furnishings, and other VOC-emitting products, for at least 72 hours after work is completed. Preferred HVAC system operation uses supply air fans and ducts only, with windows providing exhaust. Use exhaust fans to pull air from deep interior locations. Stair towers and other paths to the exterior can be useful during this process.
- Perform regular inspection and maintenance of IAQ measures, including ventilation system protection and ventilation rate.
- Provide VOC-safe masks for workers installing VOC-emitting products (interior and exterior), which are defined as products that emit 150 grams per liter (gpl) or more. If local jurisdiction's requirements are stricter, the strictest requirement should be followed for using VOC-safe masks.
- Provide low-toxic cleaning supplies for surfaces, equipment, and worker's personal use. Options include several soybean-based solvents and cleaning options and citrus-based cleaners.

- Wet sand gypsum board assemblies. Exceptions should be clearly defined and include full isolation of space undergoing finishing or closure of all air system devices and ductwork. Additional conditions can be set.
- Use safety meetings, signage, and subcontractor agreements to communicate the goals of the construction IAQ plan.

The IAQ construction plan is also a good opportunity to proscribe unacceptable behaviors that represent a potentially negative impact on long term IAQ such as smoking, using chew tobacco, or wearing contaminated work clothes.

Operation and Maintenance Issues

Contractors should be required to provide information on product substitutions sufficient to enable operation and maintenance staff to properly maintain and repair low-emitting or otherwise "healthy" materials.

Commissioning

None.

References/Additional Information

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org. Also see Carpet and Rug Institute (CRI) guidelines for carpet installation. The Painting Contractors Union (New York City local) has reportedly developed guidelines for ventilation during painting.

U.S. Environmental Protection Agency. www.epa.gov/iaq/schools/tfs/renovate.html. A checklist for IAQ issues at all stages of construction.

GUIDELINE SD10: SITE PROTECTION DURING CONSTRUCTION

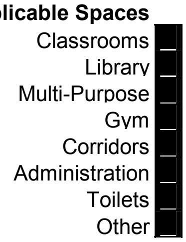
Recommendation

Require best management practices for site protection during construction.

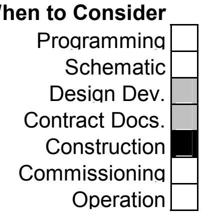
Silt fencing helps to avoid construction delays and work stoppages due to erosion. NREL/PIX 11409

Applicable Climates

Applicable Spaces



When to Consider



Description

An effective job-site protection plan will describe construction practices that eliminate unnecessary site disturbance, minimize impact on the site's natural (soil and water) functions, and eliminate water pollution and water quality degradation.

Primarily it will include protocols for:

- Construction equipment operation and parking
- Topsoil and vegetation protection and reuse
- Hazardous materials management
- Installation and maintenance of erosion control and stormwater management measures.

Applicability

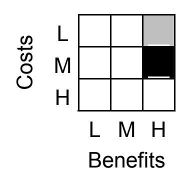
This guideline applies to all climates and spaces.

Integrated Design Implications

The plan should be integrated with stormwater management and erosion control measures. In addition, a requirement to submit ingredient information about in-field product substitutions to avoid degradation of water quality on the site is important.

Cost Effectiveness

This guideline recommends going beyond typical site practices. The project architect needs to evaluate the risk of erosion problems to determine whether redundant erosion control measures are cost effective. Least-toxic pest and weed control is quite cost effective, as it can provide savings and an increased level of safety for students who will be using the school grounds.



Benefits

Construction delays and work stoppages due to erosion control failure are avoided. Water quality in surrounding waterways and groundwater supplies are protected. Health risks to students due to residual toxicity on the site can be reduced.

Design Tools

None.

Design Details

Site protection (as with all other resource-efficient building goals) should be referenced in the Instructions to Bidders as part of the Project Summary. In addition, site protection specifications should be included in the Temporary Controls sections of General Conditions. The specifications should describe what is included in a site protection plan, outline submittal requirements, and recommend strategies, including:

- Regular inspection and maintenance of site protection measures. At a minimum, inspection of all erosion and sedimentation measures after a heavy rainfall, which is defined as 0.5 in. in less than 24 hours.
- Redundant mechanisms for site protection of any critical or sensitive areas, as identified in the site plan. Silt fencing fabric and other temporary site protection measures should be selected to last for the life of the project.
- Measures to ensure that detergent does not get into soil and sediment separators.
- Posted protocol for construction vehicles regarding parking and access on the site.
- Rocked heavy construction vehicle entrance and tire wash.
- Posted clean-up procedures for spills to prevent illicit discharges.
- Measures to minimize risk of the toxic release of hazardous wastes, including paints and other finish products, solvents, adhesives, and oils as follows:
  - Avoid overstocking.
  - Adopt a first-in, first-out policy.
  - Label containers properly.
  - Control access to storage areas and routinely inspect containers.
  - Inspect all containers upon receipt. Reject leaking or damaged containers.
- Topsoil preparation, planting, and maintenance using Integrated Pest Management (least-toxic) protocol. Least-toxic products for controlling pests and insects in detention ponds and for soil prep. No chemical weed eradication.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the site protection plan.

Operation and Maintenance Issues

Operation and maintenance staff should be informed so that least-toxic products have been used for soil preparation and for controlling pests and insects in detention ponds. Also, contractors should be required to provide information on product substitutions sufficient to enable operation and maintenance staff to properly maintain site protection measures.

Commissioning

None.

References/Additional Information

Ross Middle School. Ross School District, CA. Completed in 1999. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org. Also see the Environmental Protection Agency (EPA) publication: *Stormwater Management for Construction Activities, Chapter 3*

DAYLIGHTING AND WINDOWS

Gentle, diffuse daylight permeates a classroom with both sidelight and toplight. Note that all surfaces are painted white to distribute light more efficiently and reduce contrast glare. NREL/PIX 11392

Daylighting forms the cornerstone of resource efficient, high performance design for schools. Affecting individuals on both conscious and subconscious levels, it provides light to see the work environment, a natural rhythm that determines the cycles of days and seasons, and biological stimulation for hormones that regulate body systems and moods. In addition, it offers opportunities for natural ventilation and, if properly integrated with the electric lighting system, can provide tremendous energy savings. The advantages of daylighting translate to higher performance in schools. Research has shown that children achieve significantly higher test scores in classrooms that are daylit than in those that are not,[1] making daylighting one of the best building-related investments for the learning environment.

This chapter provides an overview of daylighting and fenestration design. It also presents eight daylighting guidelines for specific sidelighting and toplighting schemes.

- View Windows (Guideline DL1)
- High Sidelighting—Clerestory (Guideline DL2)
- High Sidelighting—Clerestory with Light Shelf or Louvers (Guideline DL3)
- Classroom Daylighting—Wall Wash Toplighting (Guideline DL4)
- Central Toplighting (Guideline DL5)
- Patterned Toplighting (Guideline DL6)
- Linear Toplighting (Guideline DL7)
- Tubular Skylights (Guideline DL8)

To fully daylight most spaces, the guidelines should be combined with each other or repeated as a pattern across the space. For example, Wall Wash Toplighting (Guideline DL4) on an interior wall could be combined with High Clerestory Sidelighting (Guideline DL2) and View Windows (Guideline DL1) on an

1 Heschong Mahone Group, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance," prepared for Pacific Gas & Electric Company and funded by California utility customers, 1999. Heschong Mahone Group and New Buildings Institute, "Re-Analysis Summary: Daylighting in Schools, Additional Analysis." February 2002.

exterior wall to fully daylight a classroom. Since daylight is additive, the total amount of daylight in the space is the sum of the daylight available from each individual pattern. Each guideline represents a daylight delivery system with inherent advantages and disadvantages, which are summarized below in Table 1.

Table 1 – Selection Criteria for Daylighting Strategies

Design Criteria	**View Windows** (DL1)	**High Sidelight w/ Light Shelf** (DL2 & DL3)	**Wall Wash Toplighting** (DL4)	**Central & Patterned Toplighting** (DL5 & DL6)	**Linear Toplighting** (DL7)	**Tubular Skylights** (DL8)
Uniform Light Distribution	○○	●/○	●	●●	◉	◉
Low Glare	○	●	●	●	●	●/○
Reduced Energy Costs	○	●	●	●●	●	●
Cost Effectiveness	●	●	●	●	●	●●
Safety/Security Concerns	○	●/○	●	●	●	●●
Low Maintenance	○	●	●	●	●	●

●● Extremely good application ● Good application ○ Poor application ○○ Extremely poor application ◉ Depends on space layout and number and distribution of daylight apertures ●/○ Mixed benefits

OVERVIEW

Guideline DL5: Central Toplighting from a sawtooth monitor with sun baffles is combined with DL1: View Windows to provide balanced illumination in a classroom. NREL/PIX 11406

Daylight can be provided via windows and glazed doors, as well as via skylights and other forms of toplighting. These glazed openings are collectively referred to as "fenestration." The placement, design, and selection of materials for fenestration are extremely important and can tip the balance between a high performance and low performance building. Fenestration impacts building energy efficiency by affecting cooling loads, heating loads, and lighting loads. Visual comfort is strongly affected by the window location, shading, and glazing materials. Well-designed windows can be a visual delight. But poorly designed windows can create a major source of glare. Thermal comfort can also be compromised by poor fenestration design. Poorly insulated windows add to a winter chill or summer sweat, while windows with low U-values keep glass surface temperatures closer to the interior air temperature, improving thermal comfort. In addition, east-west windows and unshaded south windows can cause excessive cooling loads. And although windows and skylights provide opportunities for natural ventilation, they must be designed to ensure a safe, secure, and easily maintained facility.

Benefits of Daylighting

There are several advantages to the use of daylight in schools.

Academic Performance

Studies indicate that well-designed daylighting is associated with enhanced student performance, evidenced by 13% to 26% higher scores on standardized tests, while poor daylighting design has been shown to correlate with reduced student performance.[2] It makes sense that students and teachers perform better in stimulating, well-lit environments. Daylighting can provide high quality light, stimulating views, and an important communication link between the classroom and adjacent spaces.

Energy Savings

Daylighting can save energy and reduce peak electricity demand if electric lights are turned off or dimmed when daylight is abundant. Nationally, K-12 schools spend more than $6 billion a year on energy. For most school buildings, electric lights are the largest energy consumer. For instance, in California, about 40% of school building energy use is attributable to just electric lighting. Daylighting per se, however, saves no energy unless the electric lighting system is appropriately controlled. To be effective, daylighting must be thoughtfully designed, avoiding glare and overheating, and must include dimming or switching of the electric lighting system, preferably with automatic photocell control. Designing systems for supplementary electric lighting and controls is addressed in the chapter on electric lighting.

Better Light

Daylight provides the highest quality light source for visual tasks. It enhances the color and visual appearance of objects, and helps students to see small details better.

Connection to Nature

Daylight provides a connection to the natural world by supplying information on time of day, season, and weather conditions. In doing so, it enriches the learning environment and may also help to make lessons more memorable. The constant variety in the quality and quantity of daylight also helps keep students and staff more alert.

Improved Health

Views provided by windows contribute to eye health by providing frequent changes in focal distance, which helps to relax eye muscles. Daylight, whether associated with a view or not, may also reduce stress for both students and teachers. Research in Sweden showed that work in classrooms without daylight “may upset the basic hormone pattern, and this in turn may influence the children’s ability to concentrate or co-operate, and also eventually have an impact on annual body growth and sick leave.”[3]

Environmental Education

Windows and solar gain through windows can present opportunities to teach how the sun moves through the sky and how daylight can be controlled by carefully designed overhangs and other shading devices. These observations can form part of an experiential learning unit for environmental education as students plot the movement of the sun on a sundial or across a schoolyard wall

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[2] Ibid.

[3] Kuller and Lindsten. 1992. *Journal of Environmental Psychology* 12:305-317.

Basic Daylighting Principles

The following six principles, described in more detail below, provide fundamental guidance in designing daylit schools.

1. Prevent direct sunlight penetration into glare-sensitive teaching spaces.
2. Provide gentle, uniform light throughout space.
3. Avoid creating sources of glare.
4. Allow teachers to control the daylight with operable louvers or blinds.
5. Design the electric lighting system to complement the daylighting design, and encourage maximum energy savings through the use of lighting controls.
6. Plan the layout of interior spaces to take advantage of daylight conditions.

A skylit library provides a stimulating yet peaceful environment. Colorful banners enliven the space while blocking glare from the skylights and helping to diffuse the daylight. NREL/PIX 11393

1. Prevent Direct Sunlight Penetration

One of the delights of daylight is that it changes in quality throughout the day and with each season. The daily and seasonal path of the sun is the prime determinate of sunlight availability, while the presence of clouds and moisture in the air affect the quality and intensity of light from the sky. It is essential that designers understand the basic principles of solar orientation, climate conditions, and shading systems to design successful daylit buildings.

Sunlight Versus Daylight

Direct beam *sunlight* is an extremely strong source of light, providing up to 10,000 footcandles of illumination. It is so bright, and so hot, that it can create great visual and thermal discomfort. *Daylight*, on the other hand, which comes from the blue sky, from clouds, or from diffused or reflected sunlight, is much more gentle and can efficiently provide excellent illumination without the negative impacts of direct sunlight. Good daylighting design typically relies on maximizing the use of gentle, diffuse daylight, and minimizing the penetration of direct beam sunlight. In general, sunlight should only be allowed to enter a space in small quantities, as dappled light, and only in areas where people are not required to do work.

The best daylighting designs are initiated early in the design process of new buildings. The first step in good daylighting design is the thoughtful orientation of the buildings on the site and orientation of the fenestration openings. A carefully oriented building design will allow maximum daylight while minimizing unwanted solar gains. It is easiest to provide excellent daylight conditions using north-facing windows, since the sun only strikes a north-facing window in early morning and late evening during midsummer. South-facing windows are the next best option because the high angle of the south sun can be easily shaded with a horizontal overhang. East- and west-facing windows are more problematic because when the sun is low in the sky, overhangs or other fixed shading devices are of limited utility. Any window orientation more than 15° off of true north or south requires careful assessment to avoid unwanted sun penetration.

For sidelighting, carefully designed shading devices both inside and outside the building can limit direct sun penetration while allowing diffuse daylight. For toplighting, avoid direct sun by using glazing that diffuses the sunlight, or by reflecting it off baffles, louvers, or light well walls. The sections on Sidelighting and Toplighting below give strategies for designing shading devices for optimum performance.

North versus south windows-south windows are shaded from direct sun-but receive daylight reflected off of concrete walk and white painted overhangs. North windows are large and unshaded.

NREL/PIX 11394

2. Provide Gentle, Uniform Illumination

Daylight is most successful when it provides gentle, even illumination throughout a space. Evenly diffused daylight will provide the most energy savings and the best visual quality. Achieving this balanced diffuse daylight throughout a space is one of the greatest achievements of a good daylight designer.

It is easiest to achieve uniform daylight illumination from toplighting strategies that distribute light evenly across a large area. The next best approach is to provide daylight from two sides of a space with a combination of view windows and high windows, preferably no more than 30 ft to 50 ft apart. Combinations of sidelighting with toplighting can also be successful in providing uniform illumination levels. The most challenging condition is a room with windows on only one side. There, daylight illumination levels will be very high right next to the window and drop off quickly. Various strategies to distribute light deeper into the space are available, but require more design skill and construction cost.

Daylight can most easily be used to provide a base level of illumination throughout a space, referred to as the ambient illumination, which is often on the order of 20 to 30 footcandles. Individual work areas can then be highlighted with electric task lights to bring the illumination levels in specific areas to higher task level requirements, such as 50 or 75 footcandles. Alternatively, if the daylighting fenestration area is increased to provide the higher task illumination for most of the day, the electric lighting energy savings will be maximized while heating and cooling costs may increase. The best daylighting designs balance these energy costs with the desired lighting quality.

Walls, Ceilings, And Other Reflective Surfaces

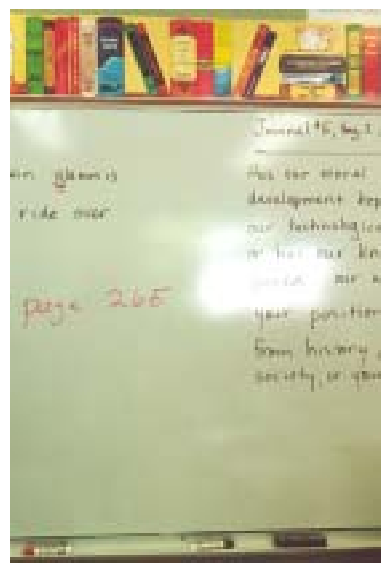
The arrangement of reflective surfaces that help to distribute the light are just as important as the arrangement of daylight openings for providing gentle, uniform illumination. Whenever possible, place daylight apertures next to a sloped or perpendicular surface so the daylight washes either a ceiling or a wall plane, and is reflected deeper into the space. It is essential to recognize that walls and ceilings are part of the daylighting design. For greatest efficiency and visual comfort, they should be painted white, or a very light color. Even pastel-colored paint absorbs 50% of the light that strikes it, correspondingly reducing daylight levels. Saturated colors should be used only in small areas, for accents or special effects.

Advanced daylighting designs take advantage of additional exterior and interior reflecting surfaces to shape the distribution of daylight in the space. Light-colored walkways and overhangs can help reflect daylight. Light shelves can be used to bounce daylight deeper in the space (see Guideline DL3), or a series of reflective or refractive surfaces built into the glazing itself can redirect sunlight onto the space's ceiling. These approaches are integral to the architecture of the building and are designed differently for each cardinal orientation. For example, classrooms may have light shelves on the south side of the building, but none on the north. In this way, the design is "fine tuned" to optimize the daylight delivery for each orientation.

Deeply coffered ceiling helps to diffuse light from four skylights. There are no electric lights on in this photo. NREL/PIX 11470

3. Avoid Glare

Excessively high contrast causes glare. Direct glare is the presence of a bright surface relative to the surroundings (for example, a bright diffusing glazing or direct view of the sun) in the field of view that causes discomfort or loss in visual performance. This glare can have negative effects on student and staff performance. A recent study showed that skylights admitting direct sun (and presumably glare) into classrooms correlated with a *decrease* in student performance on standardized tests.[4] Eliminate glare by obscuring the view of bright sources and surfaces with blinds, louvers, overhangs, reflectors, and similar devices.



Glare from windows or light fixtures reflecting off of shiny surfaces, such as computer screens or whiteboards, can reduce student performance.

NREL/PIX 11395

Placing daylight apertures next to reflective surfaces reduces glare and distributes the daylight more evenly. It brightens interior surfaces to reduce their contrast with the bright glazing surface. If washing a wall with daylight is not possible, some glare reduction can be achieved by splaying window reveals and skylight wells. Blinds or drapes can also reduce contrast by controlling the amount of brightness at the windows, and diffusing the light. Punched windows (simple holes in the middle of a wall) represent the worst scenario for glare and are not recommended.

Glare can also occur when daylight strikes a reflective surface, like a computer screen or a whiteboard, and produces shiny reflections that make it difficult or impossible to see. You can

[4] Heschong Mahone Group, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance," prepared for Pacific Gas & Electric Company and funded by California utility customers, 1999. Heschong Mahone Group and New Buildings Institute, "Re-Analysis Summary: Daylighting in Schools, Additional Analysis." February 2002.

predict when these reflections will be a problem by placing an imaginary (or real) mirror on the screen or whiteboard and seeing if any bright light sources or surfaces are visible in the mirror. If they are visible, reorient the screen/whiteboard or redesign the apertures to eliminate their reflection in the surface.

Automatic photosensor controls turn off first bank of lights next to skylight well. The light fixtures are arranged parallel to skylights to left and windows (out of picture) to right, while whiteboard is located perpendicular to windows and skylights.

NREL/PIX 11398

VDT Screens

When video display terminals (VDTs) are located in daylit spaces, the designer must take great care to minimize daylight reflections from the VDT screen. This problem is especially acute when the computer screen is oriented so that the screen is facing the daylighting aperture (that is, the student's back is to the window or skylight). Under these conditions, reflected glare may completely wash out the screen, making work impossible without completely closing window blinds or drapes. If the VDT screen is located so that the screen viewing orientation is parallel to or 45° to the windows (see figure on left), reflected glare poses less of a problem and, if present, can usually be reduced by using polarizing filters or meshes attached directly to the screen. Flat screen monitors have fewer glare problems.

4. Provide Control of Daylight

Daylight is highly variable throughout the day and the year, requiring careful design to provide adequate illumination for the maximum number of hours while contributing the least amount possible to the cooling load. The ideal daylighting design would have variable apertures that respond to changes in the availability of daylight. The apertures would become smaller when daylighting is abundant and larger on cloudy days or at times when daylight is less available. While electrochromic glazing may permit variable daylighting apertures in the future, with today's technology the size of the aperture and its transmission are fixed. The principal means of

Horizontal blinds allow control of brightness from lower view windows. Note that high clerestory windows have no blinds so that daylight can reach deep into classroom. Most classrooms do not need complete black out capability for viewing of modern video equipment.

NREL/PIX 11396

Reflections of luminaires in computer screens can cause veiling glare. Careful lighting and daylighting design avoids these problems.

NREL/PIX 11397

control is through the use of shades or blinds located inside or outside the window.

Teachers should have easy access to controls for these shades or blinds to adjust light levels as needed throughout the day. These systems should be reliable, as well as easy and economical to clean and repair. Manually operated controls are slightly less convenient but also less expensive and less likely to need repair. They may, however, be used less by teachers due to their awkward functionality for many skylights at significant heights above the floor. Avoid the use of moveable exterior shades; they are exposed to weather conditions that may degrade their performance. Ensure that fixed exterior shading devices are sloped slightly so they drain water.

5. Integrate with Electric Lighting Design

The daylight and the electric light systems must be designed together so they complement each other to create high quality lighting and produce energy savings. This requires an understanding of how both systems deliver light to the space. For example, if daylight lights the two sidewalls, electric light may be used to highlight the teaching wall. The Design and Analysis Tools section later in this chapter discusses tools to help visualize the overall light distribution in the space.

Color

Daylight is a "bluer" light source than most electric lighting. Fluorescent lights that are designed to match the color of incandescent light will appear yellow in comparison with daylight. The color temperature of a light source is a number that describes its relative blueness or yellowness. When mixing daylight and electric light, most designers choose fluorescent lamps in the blues range, with a color temperature of 3500ºK to 4100ºK or even higher.

Controls

Daylighting is also more thermally efficient than electric lighting, meaning that the cooling load created by daylighting illumination is much lower than that created by electric lighting providing the same light level. Since electric lighting is a major contributor to the cooling load in schools, substituting daylight for electric lighting reduces cooling costs as well as lighting costs. But these energy savings will only be achieved if the electric lights are turned off or dimmed in response to the daylight.

The electric lighting should be circuited and controlled to coincide with the patterns of daylight in the space, so that the lights can be turned off in areas where daylight is abundant and left on where it is deficient. Controls can either be manual or automatic. Automatic controls use a small photosensor that monitors light levels in the space. Manual controls are substantially less expensive, but need to be convenient and well labeled to ensure their use. Automatic controls guarantee savings, but are more expensive and must have overrides so the teacher can darken the room for audio/visual use. Lighting controls are discussed in more detail in the chapter on Electric Lighting and Controls.

6. Plan the Layout of Interior Spaces

Successful daylighting designs must include careful consideration of interior space planning. Since daylighting illuminance can vary considerably within the space, especially with sidelighting, it is important to locate work areas where appropriate daylighting exists. Perhaps more importantly, visual tasks (especially the teaching wall) should be located to reduce the probability of discomfort or disabling glare. In general, work areas should be oriented so that daylighting is available from the side or from above. Facing a window may introduce direct glare into the visual field, while facing away from a window may produce shadows or reflected glare.

Sidelighting vs. Toplighting

Toplighting reduces the glare and allows for a more even distribution of daylight within a space. NREL/PIX08834

The location, orientation, and size of the daylighting apertures are of paramount importance, as is the selection of the glazing materials used and how they are shaded from direct sun. When possible, it is always better to locate daylighting apertures in the ceiling plane — a strategy known as toplighting. This reduces the likelihood of glare and allows for a more even distribution of daylight within the space. Toplighting, of course, can only be provided for one-story buildings or for the top floor of multi-story buildings. The other basic strategy, sidelighting, allows daylight to enter through windows in vertical walls. With windows, uniform illuminance is more difficult to provide, as there is always more light next to the window. Glare is also more difficult to control. But there are design techniques that can substantially reduce problems associated with sidelighting.

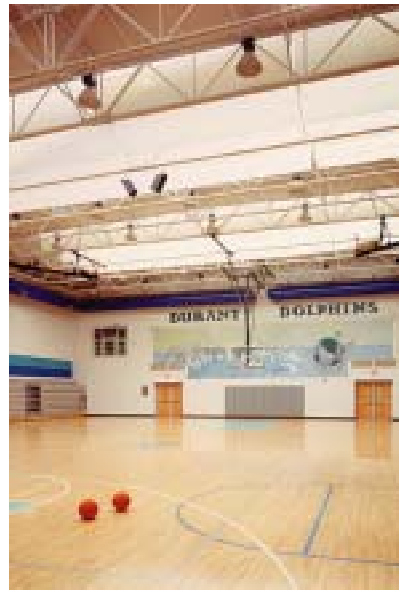
The basic sidelighting pattern provides windows on one or more walls of the space. The depth of daylighting penetration from vertical windows is largely dependent on the height of the window head (that is, the top of the window). For a simple sidelighting scheme, a rough rule of thumb is that useable daylight will be available about 1.5 times the window head height. So for good daylight delivery, sidelighting windows should be located as high as possible in the wall. However, to provide exterior views, windows need to be at eye level. Since these requirements clearly conflict, advanced daylighting designs differentiate between the functions of view and task daylighting, frequently providing separate windows for each of these.

The orientation of a sidelighting aperture strongly affects the quantity, quality, and distribution of daylight. For sidelighting and no shading, north-facing windows provide the most even illuminance. The quantity of light is diminished, but a larger aperture will compensate, providing adequate and more even illumination.

Exterior Shading Strategies

Shading devices for sidelighting strategies minimize solar gains and glare, and can also be designed to increase illumination levels. Shading devices — both overhangs and fins — can be either opaque or translucent, and solid or louvered. It is best to place shading devices outside the glazing to stop solar gains before they hit the window and to reduce potential glare from bright window views.

Exterior overhangs should be deep enough to minimize direct sun on the window for the hottest hours of the day during the cooling season. For south-facing windows in sunny (clear sky) climates with very high air conditioning loads, a good rule of thumb is to design the overhang with a shading cutoff angle about equal to 90° minus the site latitude. This provides full shading between March 21 and September 21. Many areas are likely to experience their hottest weather in September, and still need full shading that time of year. Overhangs for climates with lower air conditioning loads and/or more summer overcast can increase this angle by 5° to 15°. Overhangs or fins for windows facing east or west do not lend themselves to simple rules of thumb and should be carefully designed for the specific site, climate, and space. North-facing windows usually do not need exterior overhangs or fins, but may occasionally require interior blinds or louvers to control glare.



Monitors provide diffuse light into gymnasiums. NREL/PIX 11338

Interior Shading Strategies
Interior shading devices for windows reduce solar heat gain somewhat (by reflecting solar gain back out through the glazing) but are most effective at controlling glare. The most common interior glare control devices are horizontal mini-blinds, vertical blinds, shade screens, and curtains. Mini-blinds positioned between the panes of glass in double-glazed fenestration do not have to be cleaned and may have the lowest maintenance costs, but their initial cost is substantially higher. They can also pose replacement problems if a window is broken. Interior shading devices can also be used for security purposes to obscure the view of room contents when a space is unoccupied. Many school spaces will also require blackout shades. All these operable devices should have robust, reliable controls that are easily accessible to the teacher. However, operable louvers, blinds, and drapes are frequently left in a non-optimal daylighting setting —either fully closed or fully open. Systems that have fixed louvers or settings for the daylight glazing and operable glare control for view glazing will be more likely to deliver dependable daylight throughout the year.

Landscaping
Daylight is also affected by obstructions on the site, such as trees and other buildings. Landscaping can serve an important shading and sun control function if it is strategically placed or incorporated into a trellis device. Deciduous trees and vines positioned to the south of a window are extremely useful for providing shade during overheated summer months while admitting more sun in areas with cold or overcast winters. Evergreens provide shade year-round in consistently overheated climates. They are also useful for blocking low east and west sun.

Toplighting
Providing daylight from above, generically referred to as "toplighting," can generally provide the most uniform illumination throughout a space. Examples of toplighting strategies include roof monitors, unit skylights, and tubular skylights. The vast majority of schools are one or two stories, and so a large proportion of school spaces can easily be lit from above. Toplighting schemes have many other advantages, including freeing up walls for tack space or storage, and increasing security by reducing access to fenestration.

Toplighting schemes can provide much more useful illumination from smaller apertures than sidelighting when they capture and diffuse sunlight. Sunlight is roughly 10 times brighter than light from the sky or clouds. If the sunlight is diffused through the use of lenses, baffles, or reflecting surfaces, it can be diffused and spread over a large area. Thus, one ft^2 of a diffusing skylight can provide illumination to about 10 times the area of one ft^2 of equivalent window glazing.

As with any lighting design, it is important to strive for good lighting quality with toplighting, which is best done in two ways. First, design openings so that they maximize illumination on vertical surfaces. Skylights or roof monitors should be placed preferentially adjacent to important walls that should be highlighted. Be careful that ceiling returns or structural members do not create shadows on important vertical surfaces. Secondly, design for uniform illumination by using many openings spread out uniformly across the space. The higher the daylight aperture, the more broadly the light will diffuse in the space. Thus, it is easier to successfully toplight spaces with high ceilings. As a rule of thumb, skylights should be spaced apart no more than one-and-a-half times the ceiling height. (When the skylight well is broadly splayed, the vertical distance can be measured to the top of the splay.) This means that spaces with low ceilings will require more small skylights spaced closer together than the spaces with the same floor area but a higher ceiling. Some software tools feature a calculator that helps to figure out appropriate skylight spacing relative to ceiling heights and structural grids.

Glare is also an issue with skylights. Diffuse glazing, such as fiberglass or white acrylic, can become extremely bright in direct sunlight, and should be kept out of direct view of the occupants. Recessing skylight diffusers behind other elements, such as structural members, banners, or splayed wells, all help prevent glare. Lensed glazing can also help to break sunlight up into smaller bits, reducing glare potential. The designer should assess glare potential of any toplighting product and design in direct sunlight conditions.

Horizontal vs. Vertical Glazing

Toplighting designs can have either horizontal or vertical glazing. Because the sun is higher in the sky during the summer than in the winter, toplighting schemes with horizontal glazing receive more direct sun in the summer (when it is generally not needed) and less in the winter (when it is needed). The opposite is true with south-facing vertical glazing schemes. So in terms of optimizing yearly heating and cooling balance, south-facing vertical glazing tends to be most efficient. North facing glazing will receive much lower and more uniform levels of diffuse daylight, and thus need to be sized significantly larger than south-facing apertures to achieve equivalent illumination levels. East and west orientations show large variations in light levels throughout the day and the greatest solar gains in the summertime, and therefore are not recommended.

However, horizontal glazing or skylights have several other advantages. First of all, skylights' energy performance on a flat roof is fairly independent of orientation, allowing more architectural freedom on other issues. Skylights actually deliver more daylight into a space over the course of a year than comparable vertically oriented glazing. Pyramid, bubble, or arched-shaped diffusing skylights are effective at collecting daylight during the very low sun angles of early morning or late afternoon when it is most needed. And during overcast days, the sky is brightest straight up, so horizontal glazing will deliver the most light under these conditions. Solar heat gains in skylights tend to be less than expected due to stratification of heated air in the skylight wells. The advantages of skylights in collecting daylight throughout the year allow them to have a smaller aperture than vertical glazing for the same amount of illumination delivered, which also reduces relative heat loss and heat gain.

Another consideration in the decision between vertical versus horizontal glazing is cost. Prefabricated skylights, which are inserted into a roofing system, can be much less expensive than custom-built roof monitors requiring extensive structural modifications and flashing. Integration of the toplighting scheme with the HVAC, ceiling, and lighting systems is also an important concern. The final decision for horizontal or vertical glazing is a balance of these concerns for the specific building and climate, as well as the ability to integrate into the architecture.

Linear skylight in multipurpose room includes electrically operated louvers to reduce brightness when needed.

NREL/PIX 11399

Toplighting Shading Strategies

Shading for monitors may not be needed if the light well design prevents direct sun from entering the space. Exterior shading devices for skylights are available, but are not recommended due to maintenance problems. Rooftop devices are usually exposed to more severe weather, dust, and debris but have less maintenance supervision than windows. Sturdy, dependable performance is an essential criterion. Thus, it is a good idea to protect any shading or operable equipment for skylights below at least the first layer of skylight glazing. Some skylight manufactures offer fixed or operable louver options for sun and daylight control, to reduce solar gain and excessive daylight. Others offer movable insulation devices that can be operated, either manually or automatically, to reduce both solar gain and nighttime heat losses. Recent advances allow some blinds within the glazing system to be manual or automatic and also reduce maintenance and cleaning issues. One foreseeable issue for these devices is that internal systems may require complete removal of the glazing system if shading devices break down and require replacement.

Structural Considerations

All toplighting schemes represent penetrations through the roof diaphragm, which is often a critical part of the building's structural system, designed to stiffen the building and resist forces that tend to twist the structural frame. This structural diaphragm can have various numbers and sizes of holes in it and still continue to function. But at some point, additional holes will weaken its strength, limiting the size and location of toplighting apertures. However, if more toplighting apertures are desired than allowed by the structural system, the project's structural engineer may be able to devise ways to strengthen the diaphragm to allow additional penetrations.

The light well connecting the toplighting aperture with the space below may also intersect HVAC ducting, electric lighting layouts, and fire sprinkler systems. Careful coordination of the structural and mechanical designs will ensure compatibility among these systems.

Fenestration Products

Pyramid skylights on experimental portable classroom design integrate skylights into a high efficiency modular design. NREL/PIX 11400

High performance fenestration features include double and triple glazing, low-emissivity coatings, and blue/green tints. These have become a very important means of energy conservation in modern construction to reduce both thermal losses and solar gains, while maintaining light transmittance. Fenestration has three principal energy performance characteristics, which have been identified by the National Fenestration Rating Council (NFRC) to be tested and labeled on manufactured windows: Visible light transmittance, solar heat gain coefficient, and U-factor. Site-built windows and skylights may or may not have such tested information available.

- *Visible light transmittance (VLT)* is the fraction of light that is transmitted through the glazing. Light is that portion of solar radiation that is visible, meaning it has a wavelength between about 380 and 780 nanometers. Single clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05. The quantity of daylight that enters a window or skylight is directly proportional to the VLT. In general, VLT should be as high as possible, provided it does not create glare or other visibility problems.
- *Solar heat gain coefficient (SHGC)* measures the solar heat gain through a window. A window that has no solar gain would have a SHGC value of zero, while a perfectly transmissive glazing would have a SHGC of 1.0. These extremes are both theoretical concepts that are not possible in the real world. Except in passive solar applications where solar heat gain is desired, everything else being equal, glazing materials should be selected with the lowest possible SHGC. However, glazing materials with a low SHGC (like dark gray and bronze tints) may also have a low VLT, so the challenge is to identify specialized “selective” low-e products and blue/green tints that combine the lowest SHGC with the highest VLT.
- *U-factor* measures the heat flow through a window assembly due to the temperature difference between the inside and outside. The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. Everything else being equal, the U-factor should be as low as possible. The fenestration frame and glazing edge spacers degrade the U-factor of an insulated glass assembly. So two U-factors are frequently specified: the center of glass (COG) value, which is the U-factor measured at the center of the assembly, and the whole-window value, which is the overall U-factor of the glazing plus the spacer and frame system. (The whole-unit value will be higher than the COG value.) Single pane windows typically have a U-factor in the range of 1.0 to 1.2 COG; double pane windows range from 0.65 to 0.45 COG. With low-e coatings, inert gas fills, and multiple glazings, the U-factor can be as low as 0.1 COG.

Other glazing considerations include diffusion, transparency, and durability:

- *Diffusion and Transparency.* Transparent glazing materials provide views, but diffuse materials can spread daylight better in the space. Diffusion is one of the most important characteristics in selecting a skylight. Good diffusing glazings maximize the spread of light in the space and minimize “hot spots” and glare. Diffusion may be accomplished by using a white pigment, a prismatic surface, or embedded fibers. Unfortunately, specifications on diffusion properties are rarely available for fenestration products. Thus, samples of diffusing glazing materials should be visually evaluated to see how well they diffuse direct sunlight. A simple test is to place the product in the sun and see if it allows your hand to cast a shadow. A fully diffusing material will blur the shadow beyond recognition and will not concentrate the sunlight into local hot spots. Note that diffusing glazing placed in direct sunlight can be glaringly bright if it is within the field of view. It should be placed above the direct line of sight or be obscured by baffles.

- *Durability.* Characteristics such as UV degradation (yellowing and other aging effects), structural strength, scratch resistance, breaking and fire resistance, along with replacement cost and availability, should be considered in selecting a glazing material.

The fenestration frame holds the glazing material in place and forms the structural link with the building envelope. The frame and the spacer between the glazing panes in multiple glazed units form a thermal short circuit in the insulating value of the fenestration. This degradation of the U-factor at the fenestration perimeter can be minimized with high performance frame and spacer technologies now available. This is important both for energy conservation and the potential for condensation on the frame.

Frames are available in metal, wood, vinyl, composite, and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Insulated vinyl and fiberglass frames have the lowest U-factor. The NFRC has established a rating system to evaluate the whole window performance including the frame, spacer, and glazing. More information can be found at their website, http://www.nfrc.org. The whole-window U-factor, VLT, and SHGC is shown on a label attached to all rated windows. Rated windows should be purchased for all school projects and frame/spacer performance should be compared based on these overall ratings. Site-built windows and skylights will not have these ratings available.

Design and Analysis Tools

There are three general categories of tools for evaluating daylighting and fenestration: physical models, lighting computer simulation programs, and whole-building energy simulation programs.

Physical Models

Physical scale models are probably the easiest and most intuitive way to understand daylighting design options. Scale models can be easily built that quickly and accurately illustrate the daylighting conditions created by any given design. They also help non-professionals, such as teachers and parents, to see lighting quality issues directly, and understand why one design might work better than another. Photographs of the interior of scale models are an easy way to record the impacts of various design options. Many daylighting textbooks include a chapter on the construction and testing of daylight models. An excellent training video — Daylight Models, available from the Lighting Design Lab in Seattle — also describes how to build and test these models. (See the References section below for more information.)

Daylighting models can also be used for numerical analysis. The models may be tested either outside under real sky conditions or in artificially constructed overcast sky and direct sun simulators. Small light measuring devices (photocells) can be used to record light levels within the model. Sun simulators (heliodons) can be set to represent the correct sun angle for the site latitude and hour of day and are used to visualize the movement of light during a typical day. Measurements in a simulated sun or sky are more reproducible than in the real sky, which is constantly changing. Several universities and electric utilities have sun and overcast sky simulators, associated video equipment, and photocell arrays.

Lighting and Daylighting Computer Simulations

Electric lighting and daylighting computer simulations give information about the distribution of lighting in spaces with contributions from windows and skylights as well as electric lighting systems. Unlike the energy simulation programs described below, these programs produce results for a single instant in time. Multiple calculations are needed to study varying sky and solar conditions. These computer-based tools give light level values and gradients for both daylight and electric light across the space. Some of these tools also produce realistic renderings of lighting within the space, which may be linked to generate an automated “walkthrough” of the space for a particular day and time or to simulate the daylight variations through the hours of the day. The programs that are easiest to use may be constrained by the complexity of shapes they can simulate. The more complex programs can simulate almost any room shape or material, but require significantly more expertise and modeling time.

Whole Building Energy Simulations

Whole building energy simulation tools, such as DOE-2, EnergyPlus, BLAST, and spreadsheet estimating programs consider all aspects of the fenestration’s impact on building energy use, including solar gains, impact on HVAC equipment sizes, and reduction of electric lighting energy. Many of the energy simulation programs have user-friendly interfaces to make it easier to construct models and evaluate results. Most of these tools have simplified daylighting simulation algorithms that may not accurately represent daylight levels from complex designs (like light shelves). For these designs, daylight predictions from one of the computer simulations mentioned above may need to be input to the energy program to accurately predict daylight’s potential to save energy by turning off or dimming electric lights.

Resource Efficiency

In terms of energy performance, windows and skylights are two of the most important considerations in building design. They also provide an opportunity to address other environmental objectives, including material efficiency, indoor air quality (IAQ), and pollution prevention during manufacturing.

To achieve material efficiency, windows are now being manufactured with durable alternatives to wood frames and sashes, including options made with post-industrial waste. Unfortunately, many of these products can contribute to pollution during manufacture, and possibly even to IAQ problems. For now, the best environmental performance strategy is to select durable frame and sash options that enhance energy performance as well as meet programming and daylighting needs. Table 2 lists currently available options that are environmentally preferable from a material efficiency perspective.

Table 2 – Strategies for Constructing Resource Efficient Fenestration Systems

Window Frame and Sash	Strategies	Environmental Benefits & Considerations
Wood	Select windows produced with wood certified by Forest Stewardship Council (FSC), Scientific Certification Service (SCS).	Prevents degradation to forest and wildlife habitat; wood can be high maintenance. Good energy performance.
	Specify factory-applied finish.	Typically more durable than field-applied. More controlled finishing environment prevents pollution.
Wood and Plastic Composite	Durable options combine wood fiber and post-consumer waste plastic and combine recycled PVC scrap, virgin PVC, and fiber from recycled wood scrap.	Utilizes industrial waste, stretching the wood supply. Very durable and low maintenance. Manufacture of PVC can contribute to pollution, however. Good energy performance
Vinyl	Vinyl frames include foamed PVC insulating core.	Low maintenance. Needs no paint. Manufacture of PVC can contribute to pollution, however, and high coefficient of thermal expansion can lead to premature failure of seal. Excellent energy performance.
ABS Plastic		Low maintenance. Needs no paint. Manufacture can contribute to pollution, however, and high coefficient of thermal expansion can lead to premature failure of seal. Moderately good energy performance.
PVC Plastic		Low maintenance. Manufacture can contribute to pollution, however, and high coefficient of thermal expansion can lead to premature failure of seal.
Fiberglass	Pultruded fiberglass frame members have a hollow profile usually insulated with fiberglass or polyurethane foam.	Promotes durability. However, difficult to recycle. Emissions contribute to IAQ problems and manufacture contributes to air pollution. Moderately good energy performance.
Metal	Specify durable, factory-applied finishes, anodized, polyvinlidene fluoride, and siliconized polyester.	Promotes durability and reduces potential pollution on site. Energy-intensive production however. Not the best energy performance. Do not use metal frames that lack thermal break.

Source: GreenSpec: The Environmental Building News Product Directory and Guideline Specifications.

For specific product recommendations, see GreenSpec: The Environmental Building News Product Directory and Guideline Specifications, http://www.buildinggreen.com and OIKOS's Redi Guide (Resources for Environmental Design Index). Iris Communications, 800-346-0104, http://www.oikos.com.

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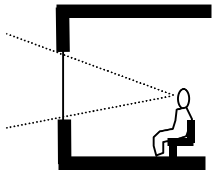
GUIDELINE DL1: VIEW WINDOWS



Recommendation

Provide access to exterior views through view windows for all interior spaces where students or staff will be working for extended periods of time.

Description

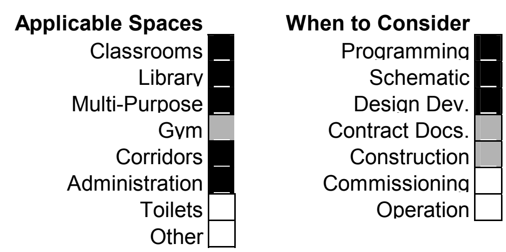
A view window is vertical glazing at eye level, which provides a view to the exterior or interior adjacent spaces.

Applicability

View windows are essential in all school spaces (except spaces requiring visual privacy) to provide relaxing views and information about exterior natural conditions and to allow people outside of a space to view and connect with activities inside. They are applicable to all climate regions and should be planned in the schematic design phase.

View windows at Camaron Library expand the space outward and connect the reading area with the natural landscape. NREL/PIX 11401

Applicable Climates



Integrated Design Implications

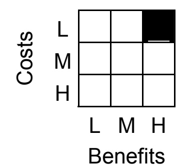
- **Balance with other program needs.** View windows serve a broad range of important functions for view, social communication, egress, ventilation, and energy conservation (see Benefits below). However, view windows are often inefficient at supplying working daylight to the space. The square footage of view windows will reduce the allowable area for windows and skylights placed higher in the wall and ceiling that can be designed to deliver more useful daylight across the space. However, areas where many buildings will be multi-story, sidelighting is the only option for lower floor spaces and should be designed to provide as much useful daylight as possible with the least problematic glare. View windows also decrease valuable classroom wall space and pose potential acoustic and vandalism problems. A balance should be achieved among these conflicting needs.
- **Integration with mechanical ventilation.** Operable view windows should be used to naturally ventilate the space and reduce mechanical ventilation needs. Evaluate prevailing wind conditions to assess the feasibility. A statistical analysis of 650 schools by the Florida Solar Energy Center found a strong correlation between the presence of operable windows and a decrease in indoor air quality complaints.[5]

[5] M. Callahan et. al. Energy Efficiency for Florida Educational Facilities: 1996 Energy Survey of Florida Schools Final Report. Report # FSEC-CR-951-97. Florida Solar Energy Center. Submitted to Florida department of Education, July 1997.

- **Integration with HVAC.** View windows should decrease overall seasonal heating and cooling loads on the building if they are oriented, glazed, and shaded correctly. This can reduce the initial size of the HVAC system and annual energy costs. The analysis of Florida schools noted above also found that the presence of windows strongly correlated with an overall reduction in total building energy use.
- **Thermal Comfort.** Window surfaces that are considerably above or below the mean radiant temperature of other room surfaces will be uncomfortable for occupants adjacent to them. Shade the windows, use high performance glazing, and design HVAC to minimize radiant thermal discomfort.
- **Space Planning**. View windows should be oriented relative to the location of stationary tasks, such as desks, teaching wall, computer locations, and reading areas. Avoid reflected glare from windows in computer screens or on whiteboard surfaces. The best classroom location for view windows is perpendicular to the teaching wall.
- **Design Phase.** To function well, view windows must be at eye level, glare-free, oriented toward views that will not distract occupants, and designed to reduce building energy loads. A requirement for view windows should be identified in the building program; their location and design objectives should be determined in the early phases of schematic design.

Cost Effectiveness

Costs for view windows are typically low. View windows are (or should be!) standard practice for classrooms. The incremental cost of energy-efficient glazing ranges from \$0.75/ft^2 to \$2.50/ft^2 of glass. Daylight energy savings from view windows are negligible because the shading elements required to minimize glare usually render them unreliable for reducing electric light consumption.



Benefits

View windows provide numerous benefits, serving a broad range of important functions for view, social communication, egress, ventilation, and energy conservation

The outward views they provide are essential for mental stimulation and relaxation for eye muscles. Optometrists recommend access to long views for any sedentary workers (such as students) for frequent shifting of eye focal length, which promotes eye health and good vision. This may be especially important for young children while their eyes are still developing.

View windows provide occupants a connection with nature, weather, cardinal orientation, and some natural light (though not evenly distributed across the space). Occupant productivity and connection with place may increase through the associated views. Studies have shown that the primary reason people prefer having a window is view, preferably a view of nature. Research suggests that natural views elicit positive feelings, hold interest, and reduce fear and stress.[6] Teachers have reported a reduction in stress levels when they have access to a relaxing view from their classroom.[7]

View windows, especially on the first floor of school buildings, also provide an important social communication function, allowing teachers, administrators, and parents to quickly assess what is going on inside a classroom. When installed with clear glass, they are often used to display art work and current student projects, contributing to both pride and awareness of other's efforts.

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[6] Norris and Tillett. 1997. "Daylight and productivity: Is there a causal link?" Glass Processing Days Conference, Tampere, Finland (September).

[7] Heschong Mahone Group, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance." Prepared for Pacific Gas & Electric Company and funded by California utility customers, 1999.

Operable view windows provide emergency egress and natural ventilation. A recent study has shown that natural ventilation in classrooms correlates with higher student test scores.[8]

Well-designed view windows can reduce the overall building heating and cooling loads and north-facing view windows can also deliver enough dependable daylight to reduce electric lighting loads with manual or photocontrols. Other orientations, however, often have blinds or curtains drawn. Thus, unless a view window faces north or has a head height over 8 ft, and separate glare control for at least 2 ft of the top glazed area, it should not be counted on to provide sufficient daylight to merit the installation of automatic photocontrols and reap predictable savings from reduced electric lighting use.

View windows are separated from the daylight feature overhead and use lower transmission glass to reduce glare.

NREL/PIX 11402

Design Tools

The physical models and daylight simulation tools noted in the Overview can be used to evaluate potential daylight levels, and energy programs can be used to understand building energy implications.

For critical view areas, access to views and view angles from various positions in the space can be evaluated graphically with scaled drawings or with the use of a scale physical model. For a physical model analysis, it is helpful to have a "lipstick" video camera head, which can be moved around inside the model to record the views available at each location. Alternatively, view ports for standard cameras can be built into several walls of a model for various views.

Design Details

- **Orientation.** Orient view windows toward the north or south to avoid low angle east/west sun. Up to 15° variance from true north or south is acceptable, but will reduce performance.
- **Shading devices.** Because view windows are within the occupants' normal field of view, the contrast between the bright window view and other interior surfaces is an important glare consideration. Use exterior shading devices (overhangs, fins, etc.) or landscaping to eliminate direct sun and reduce brightness. If this is not possible, use a lower transmission glazing adjusted for the window orientation (about 40% transmission for south windows, 30% for east/west windows and 60% to 85% for north windows). On south, east, and west orientations, add an interior shade (shade screen, blinds, or drapes) so the teacher can adjust brightness and sun penetration as needed. In general, visible transmission of view glazing should not be reduced below 30% in clear sky climates or below 50% in heavily overcast climates. If tinted glazing is used, evaluate its effect on distortion of colors (for example, the graying of greens and blues in the landscape) in both overcast and clear skies. Provide blackout capability for view windows as needed.

View windows promote communication between interior and exterior spaces. NREL/PIX 11403

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[8] Ibid.

- **Reflectance.** Deep splayed walls or mullions will also reduce glare and contrast. Paint all surfaces near windows white or off-white to further reduce contrast between the brightness of the window and its surrounding wall. The adjacent spaces that are daylit will not reduce the light level at the window, but will provide a transitional element providing physical separation between the bright window area and less bright interior surfaces. The eye is more comfortable with this stepped down light level effect. Place view windows adjacent to a perpendicular surface to reflect daylight onto adjacent surfaces. Placing view windows adjacent to walls is best. Avoid punched holes in walls, as they create the worst glare conditions.
- **Outside reflective surfaces.** Be aware of bright reflective surfaces outside the view window that may create glare when they are in sunlight. Reflected sun off a car windshield can be especially troublesome. However, when glare is less of a concern (for instance, in a more overcast area), light-colored ground surfaces outside the windows may also be used as a giant light shelf to bounce light through the view windows onto the ceiling. Light-colored walls or glass walls within view can also create glare sources when they are in direct sun. Plant hedges or trees to reduce the glare potential from these exterior sources.
- **Thermal comfort.** Window surfaces that are considerably above or below the mean radiant temperature of other room surfaces will feel uncomfortably cold or hot for occupants sitting next to them. In very cold or hot climates use double glazing with a low-e coating to maximize comfort and energy efficiency. In cold climates, use a minimum of double glazing with a low-e coating to provide comfort and energy efficiency. Provide additional layers of films or triple glazing, gas filling, warm glazing edges, improved thermal breaks in window frames, etc., to maximize thermal comfort near windows.
- **Views.** In classrooms, orient views toward “passive” nature scenes. In administration areas, views may be oriented toward the school entry or other security concerns.
- **Teaching surface.** In classrooms, the teaching wall should be perpendicular to the window wall for best illumination.
- **Computer screen location.** Orient computers at a 45° angle from view windows to avoid glare from reflections of the window in the VDT screen. Flat screen computers and adjustable-angle LED screens also help to reduce glare.
- **Security.** Provide operable interior shades and/or laminated glass for security in ground level rooms that contain computers or other valuables.
- **Durability and accessibility.** Use sturdy mechanisms for all operable ventilation and shading devices. Make them easily accessible to the teacher and easily repairable.
- **Noise transmission.** Because windows are frequently the “weakest link” acoustically in a building structure, double glazed windows are often the only alternative to controlling exterior noise. Normal therma-pane double-paned windows with ¼ in. or ½ in. airspace are not acoustically effective. For better acoustic performance, windows should have laminated glass on at least one pane, as well as significant airspace between the two panes. In high noise areas (from exterior traffic and/or aircraft), it is not uncommon to require thicker laminated glass and 2 in. to 4 in. of airspace between the panes.
- **Balancing with electric light.** If view windows are the only daylight apertures in the room, and they appear on only one wall of the space, balance their brightness in the room by washing other interior walls with electric light.

Operation and Maintenance Issues

View windows should be washed on a schedule. Elements provided to reduce glare and allow blackout conditions (blinds, drapes, blackout shades, etc.) need to be cleaned and replaced over time. Give consideration to the robustness of operable shade mechanisms that are accessible to students. Coordinate selection of glazing materials with the maintenance staff to ensure ease of cleaning and replacement. Districts may have district-wide standards to ensure quick replacement of broken glass, but ensure that it is replaced with the same type of glass.

Design ventilation devices to prevent physical entry as well as any rain or maintenance water penetration.

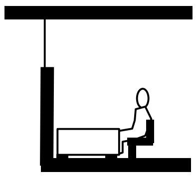
Commissioning

None.

References/Additional Information

See this chapter's Overview.

GUIDELINE DL2: HIGH SIDELIGHTING—CLERESTORY



Clerestory windows provide a more uniform distribution of daylight across the space. NREL/PIX 11404

Recommendation

Use high clerestories in perimeter walls to increase daylight delivery deeper in classrooms, offices, libraries, multipurpose rooms, gymnasiums, and administrative areas.

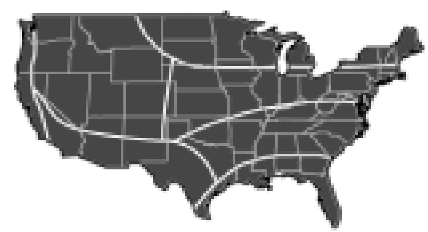
Description

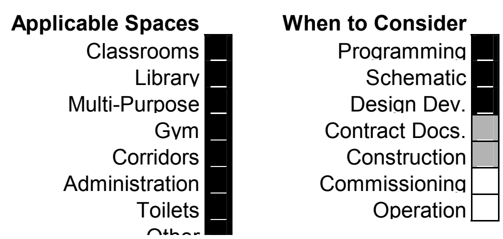
High sidelighting clerestories are vertical glazing in an exterior wall above eye level (usually above 7 ft). Because the penetration of daylight from vertical glazing is about two times the window head height, moving the window higher in the wall increases daylight penetration in the space.

Applicability

High clerestory windows can be used in all school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

Applicable climates:





Integrated Design Implications

- **Design phase.** High sidelighting requires high ceilings and perimeter walls. North and (shaded) south orientations are preferable, although east, and west orientations can be acceptable if diffusing glazing is used, or if low-angle sun penetration will not be bothersome in the space. High sidelighting is most appropriate for open plan interior layouts that allow unobstructed daylight penetration. It should be considered in the early schematic design phase.
- **Balance with other daylight needs.** Applied to one wall, this approach creates a decreasing gradient of useable daylight about two times the clerestory head height into the space. Spaces of 20 ft to 40 ft in width (classrooms, etc.) can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. View windows should also be provided. The total glazing area should be apportioned among these needs.

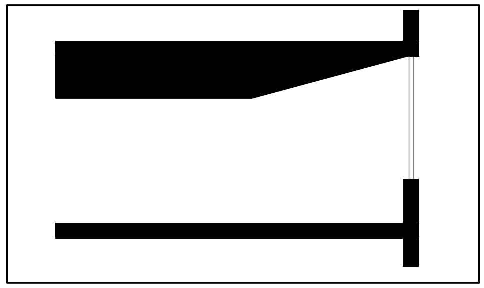


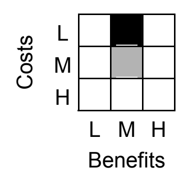
Figure 1 – Sloped Ceiling

Sloped ceiling at perimeter increases window head height by reducing plenum space.

- **Reduced plenum space.** Clerestory sidelighting requires ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by careful integration of the structural system, HVAC ducts, and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter (see figure) — essentially reducing the plenum space there — can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.
- **Natural ventilation.** High windows can be especially beneficial for natural ventilation, by allowing heated air to escape out near the ceiling. The ideal location for high operable windows is on the leeward side of a building
- **Integration with HVAC.** High sidelighting glazing impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, glazing materials, shading, and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs.
- **Duct work.** Keep ductwork away from high windows to avoid blocking daylight.
- **Integration with electric lighting.** High sidelighting creates linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight.

Cost Effectiveness

Costs for high sidelighting are low to moderate. Windows are standard practice for classrooms. A balance of view and clerestory windows can be provided for each classroom with minimal increase to the overall glazed area. The incremental cost of energy efficient glazing ranges from $0.75/ft^2 to $2.50/ ft^2.



Benefits

High sidelighting provides a moderate level of benefits. The general energy saving, productivity, and visual comfort benefits of daylighting are discussed in the Overview section to this chapter. Clerestory sidelighting both saves energy and improves lighting quality. Energy savings come from reduced electric lighting energy use. Lighting quality is improved by a more uniform distribution of daylight across the space.

Design Tools

Computer simulation programs and scale models as outlined in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions and check direct sun penetration through the clerestory glazing for the lowest expected sun angles. Even occasional penetration of low sun angles can be extremely bothersome to occupants and may lead to blocking a window.

Energy savings from minimized HVAC loads and control of electric lighting in response to daylight can be estimated with the DOE-2, EnergyPlus, and Energy-10 programs available.

Design Details

- **Ceiling height.** High sidelighting glazing works best in spaces with high ceilings. A minimum perimeter ceiling height of 9.5 ft is recommended. Generally, the higher the ceiling height, the better.
- **Balancing with view windows.** Lower view windows are frequently coupled with high sidelighting schemes, but they do not have to coincide for the whole perimeter. The high glazing should be continuous along the whole area to be daylit. View windows can be selectively spaced beneath these high windows as needed. This balance between high clerestories and view windows can leave lower perimeter wall space available for other uses.
- **Shading devices.** Design high sidelighting clerestories with exterior shading, diffusing glazing, operable blinds, or light shelves to eliminate direct sun penetration. Horizontal blinds are better for bouncing light deeper into a room, especially when facing south. Vertical blinds may be more appropriate to catch low angle east and west sunlight and bounce it into the room, while allowing south-facing light to enter directly.Mini-blinds positioned between the panes of glass in a double glazed window accomplish this with minimal maintenance. (A light shelf or louver system may also be used; see Guideline DL3.) Dedicated blinds or shades for the upper clerestory glazing can allow lower view windows to be controlled separately for glare. Blackout shades may need to be provided.
- **Glazing materials.** New glazing materials (prismatic, lensed, holographic, or laser cut acrylic) may be available to redirect daylight to the ceiling from the clerestory. These can deliver daylight deeper in the space but may cause very bright glazed areas and should be tested to see if they produce glare.
- **Orientation.** Clerestories are most effective on south and north orientations, but should be carefully evaluated on east and west orientations to assure that low sun angle penetration and direct solar gain into the space is minimized. Shade exterior glazing with an overhang on east-, west-, and south-facing glazing to minimize solar gain or use a selective low-e coating (SHGC less than .45).
- **Visible transmission.** Use high transmission, clear glazing (visible transmission 60% to 90%) on the upper window to admit the maximum daylight to the space
- **Stepped ceiling.** Clerestories may create a comparatively dark area along the wall directly beneath them. An interior stepped ceiling in a multi-story building can create a clerestory that reflects daylight back onto the wall to brighten it and deliver reflected daylight to the space. Alternatively, this space may be used for purposes where relatively lower light levels are appropriate, such as for computer stations.

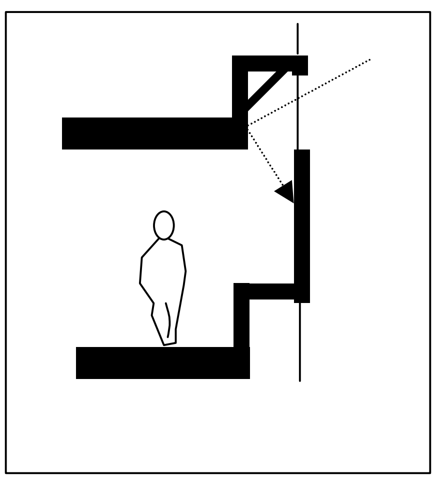


Figure 2 – Clerestories in Multistory Buildings

Clerestories in multistory buildings can redirect daylight onto the perimeter wall to brighten it.

- **Reflectance.** Paint all surfaces near the clerestories white or off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>70%) white or off-white surface to help diffuse a maximum amount of daylight into the space. Use specially designed “high reflectance” ceiling tiles (>83%) if the budget allows.
- **Teaching surface.** In classrooms, the teaching surface should be perpendicular to the window wall for best illumination. Avoid orientations that will put students’ or teachers’ faces in silhouette or cause reflected glare on whiteboards or computer screens.

Operation and Maintenance Issues

For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle.

For shades or blinds that are operated by teachers, ensure that their control mechanisms are accessible, robust, and easily repaired.

Clerestory windows should be washed on a regular schedule.

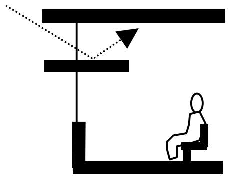
Commissioning

Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

References/Additional Information

See this chapter’s Overview.

GUIDELINE DL3: HIGH SIDELIGHTING—CLERESTORY WITH LIGHT SHELF OR LOUVERS



Exterior lightshelves reflect sunlight onto classroom ceilings. NREL/PIX 11435

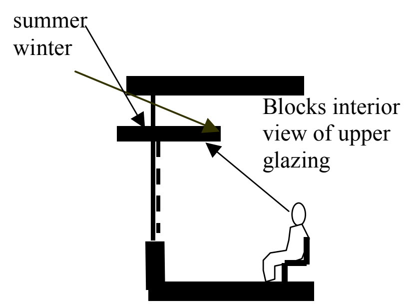
Recommendation

Use light shelves or louvers with high clerestory glazing to improve daylight distribution; block direct sun penetration; and minimize glare in classrooms, offices, libraries, multipurpose rooms, gymnasiums, and administrative areas.

Description

A light shelf is a horizontal panel placed below high clerestory glazing (with a view window generally below it) to bounce daylight deeper into the space. Light distribution is improved as daylight reflects off the top surface of the light shelf or louver onto the ceiling. There is a common misconception that light shelves increase light levels deep within the room. However, light levels are instead reduced near the windows, while being maintained deep in the room, keeping the contrast significantly lower within the room, as well as reducing glare near the windows.

A series of smaller horizontal louvers (6 in. to 24 in. wide) can replace a single large light shelf with a slight sacrifice in performance. The larger the louver, the deeper it will deliver daylight into the space. Light shelves and louvers can be located on the exterior, interior, or both. Exterior shelves shade the lower window from solar heat gain and reflect high angle summer sun into the room. Interior shelves reflect lower angle winter sun while blocking the penetration of direct sun and reducing glare from the upper glazing.

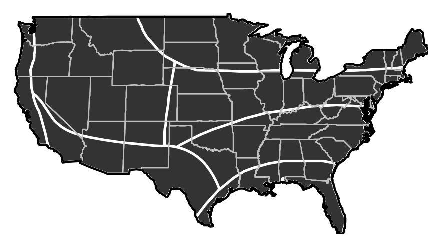


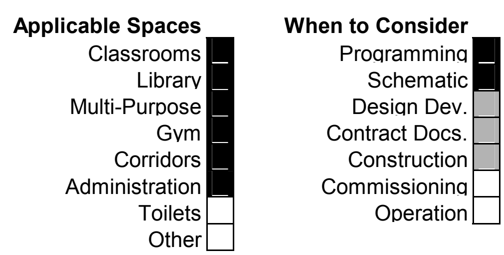
Exterior light shelves shade lower window and reflect summer sun into room. Interior shelves reflect winter sun while reducing glare.

Applicability

High clerestory windows can be used in most school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

Applicable Climates



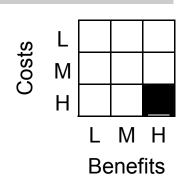


Integrated Design Implications

- **Design Phase.** Clerestories with light shelves require perimeter access to south-facing (+/- 15°) sidelighting and impact many aspects of building massing. They also benefit from open plan interior layouts that allow unobstructed daylight penetration. They should be considered in the early schematic design phase. Calculating the size and cutoff angles of the light shelf or louver system is critical In some climates, depending on the hours of air conditioning use, interior light shelves may be more appropriate than exterior only shelves because they bounce the light deeper into the room and reduce glare, but only after allowing the passive solar gain to enter the school. Additionally, interior light shelves allow a more traditional aesthetic for the outside of schools, allowing them to be used in retrofits and new schools where more traditional aesthetics might not allow exterior light shelves.
- **Balance with Other Daylight Needs.** Applied to one wall, this approach creates a decreasing gradient of useable daylight about 2.5 times the clerestory head height into the space. Spaces of 20 ft to 50 ft in width (such as classrooms) can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. Lower view windows are frequently coupled with light shelf schemes, but they do not have to coincide for the whole length of the light shelf. The high glazing with light shelf should be continuous along the whole area to be daylit. View windows can be selectively spaced beneath the light shelf as needed. This balance between high sidelighting and view windows leaves some lower perimeter wall space available for other uses. Total glazing area should be apportioned among these needs.
- **Integration with Ceiling Plenum.** Clerestories with light shelves require ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by carefully integrating the structural system, HVAC ducts, and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter — essentially reducing the plenum space there — can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.
- **Integration with HVAC.** Glazing above a light shelf impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, performance, shading, and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs. Light shelves also must be designed so as not to interfere with circulation of air from the HVAC system. It is typically desirable in climates with cold winters to wash exterior glazing with heat to avoid drafts on the room occupants. If window systems with extremely high U-values (over .12, for example) have not been used, the light shelf should be designed to allow this heat wash over the windows. If fin tube radiation occurs below the windows, this is not a problem but if ceiling diffused air is used, there may be eddies of cool air below the light shelf if other modifications are not made.
- **Integration with Electric Lighting.** Clerestories with light shelves create linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight. Light shelves and louvers deliver daylight indirectly to the space; they work well when coupled with direct/indirect pendant electric lighting. Sometimes the first row of electric lighting is incorporated into the light shelf itself. Design electric lighting to provide adequate daylighting and/or electric light under the light shelf on the wall and work surfaces directly adjacent to the wall, especially for evening use or where view windows are not located under interior light shelves.
- **Integration with Other Mechanical Systems.** Design light shelves so they do not interfere with the operation of a fire sprinkler system.

Cost Effectiveness

Clerestories with light shelves or louvers are relatively expensive, but downsizing cooling systems may offset some cost (if electric lights are automatically switched or dimmed in response to daylight). Energy savings from reduced lighting and cooling energy are adequate to recover the initial investment in about 8 to 12 years.



Benefits

Clerestories with light shelves or louvers produce a high level of benefits. The general energy saving, productivity, and visual comfort benefits of daylighting are discussed in the Overview section to this chapter. Clerestories with light shelves or louvers both save energy and improve lighting quality. Energy savings come from reduced solar gains (when an exterior light shelf shades lower glazing) and reduced lighting energy use.

Lighting quality is improved because daylight is delivered deeper in the space, creating a more even distribution. Interior light shelves and louvers restrict the view of the bright upper glazing and eliminate the direct sunlight hitting the desk level, which minimizes glare.

Design Tools

Computer simulation programs and scale models as outlined in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions, and check direct sun penetration through the upper glazing for the lowest expected sun angles.

Most whole-building energy simulation programs (like DOE-2 and EnergyPlus) do not accurately represent the increased daylight distribution from a light shelf or louver system. For more accurate simulations of electric lighting energy savings, the daylight distribution should be simulated with a physical scale model or daylight simulation program and then input to the energy program.

Design Details

- **Ceiling height.** Provide a minimum perimeter ceiling height of 9.5 ft (the higher, the better). Position the light shelf at 7 ft or more above the floor. Coordinate shelf position and design with pendant electric lighting, door headers, shelving, fire sprinklers, and other interior features.
- **Orientation.** Light shelves are most effective on south orientations and occasionally on the north (to reduce glare from the upper glazing). They should be avoided on east and west orientations.

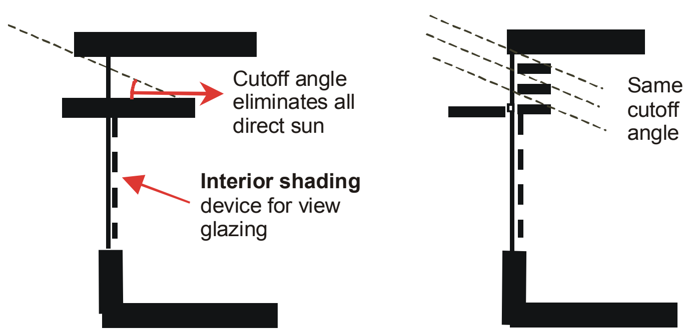


Figure 3 – Cutoff Angle of Light Shelves

Set the cutoff angle of light shelves or louvers to eliminate direct sun penetration during normal school hours.

- **Cutoff angle.** Set the cutoff angle of the light shelf or louvers (see the figure above) to eliminate direct sun penetration during normal school hours. Cutoff angle can be increased by 10° if there are operable shades on the upper glazing, and increased by 20° if operable louvers will be seasonally adjusted.
- **Visible transmission.** Use high transmission, clear glazing (visible transmission 60% to 90%) on the upper window to admit the maximum daylight to the space.
- **Reflectance.** The top surface of the light shelf or louvers should be highly reflective (greater than 80% reflectance and with a diffuse, not mirrored, surface). Paint all surfaces near the clerestories white or

off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>70%) white or off-white surface to help diffuse a maximum amount of daylight into the space. Use specially designed “high reflectance” ceiling tiles if the budget allows.

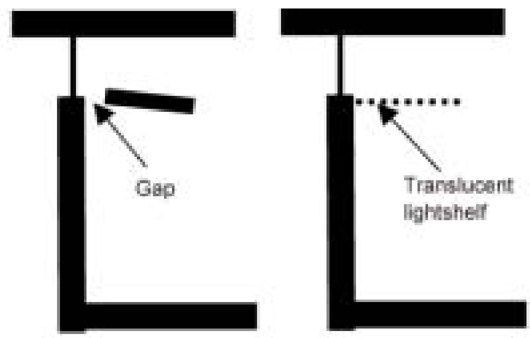


Figure 4 – Creating a Wall Wash

If opaque light shelves aren’t coupled with view windows, consider leaving a gap between the light shelf and the wall to create a wall wash. Translucent shelves provide a soft light under them.

- **Materials.** Light shelves and louvers may be opaque or translucent and constructed of wood, metal panels, glass fiber-reinforced concrete (GFRC), plastic, fabric, or acoustic ceiling materials. Material choice should include consideration of reflectivity, structural strength, cost, ease of maintenance, and durability. Some curtain wall or window manufacturers can assist in developing details for light shelves and offer add-on products as part of their service. Fabric “shelves” can be suspended from the ceiling at their interior edge.
- **Top surface.** The top surface of a row of lockers or casework that lines a perimeter wall can also be used as a light shelf if its reflectivity and dimensions are appropriate. Slope the top surface so it will not be used for storage.
- **Opaque vs. translucent shelves.** Opaque shelves may create a dark space along the wall directly under them if they are not coupled with a view window. Leave a gap between the light shelf and the wall to create a wall wash or use electric lighting to brighten this wall. Translucent shelves provide a soft light under them but must be carefully evaluated so the direct view of the under side does not create glare. See Figure 4 above.
- **Dirt accumulation.** To reduce accumulation of dirt, exterior shelves should be sloped at least .25 in./ft so that rain can help keep it clean and not pool on the shelf. Also slope interior shelves so they are not used for storage. Fabric construction is another way of preventing this.
- **Accessibility.** Both exterior and interior light shelves can be an “attractive nuisance” in school buildings, inviting students to climb or hang on them. Minimize access to the shelf or use a series of louvers instead.
- **Access for cleaning.** Detail the light shelf or louver system so it is easy to clean the glass above it, both inside and out. Large light shelves may need to be moved away from the window by six inches to allow for window cleaning equipment to be inserted from below the shelf. Light shelves without access space should be structured to carry the weight of cleaning staff.
- **Teaching surface. I**n classrooms, the teaching surface should be perpendicular to the window wall for best illumination.

Operation and Maintenance Issues

The glazing and light shelf/louver system forms a light delivery system that must be kept clean to ensure maximum delivery of daylight to the space. The top surface of the shelf or louvers should be cleaned each time the windows are washed. Make sure light shelves or louvers are detailed correctly to allow easy window cleaning. For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle. Interior light shelves must be designated by design, signage, or through staff education to not be used as a storage shelf.

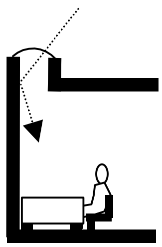
Commissioning

Unless the light shelf or louvers are moveable, commissioning should not be necessary. Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

References/Additional Information

See this chapter's Overview.

GUIDELINE DL4: CLASSROOM DAYLIGHTING—WALL WASH TOPLIGHTING



Recommendation

Use wall wash toplighting for interior classroom walls to balance daylight from window walls, brighten interior classrooms, and make them seem more spacious.

Description

Wall wash toplighting provides daylight from above through a linear skylight or monitor to wash an interior wall. The glazing is obscured from direct view by the skylight or monitor well. Daylight is diffused with diffusing glazing, baffles, or reflections off of matte reflective light well and interior walls.

Applicability

A toplighting scheme applies to single-story buildings or the top floor only of a multistory building. Appropriate spaces for wall wash toplighting may include classrooms, libraries, multipurpose spaces, gyms, corridors, and administration offices. It is applicable to all climate regions and must be planned for in schematic design.

Integrated Design Implications

- **Balance with other daylight.** Applied to one wall, this approach creates even daylight across a classroom that is roughly 1.5 times the height of the daylit wall. It should be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire classroom. View windows should also be provided. The total glazing area should be apportioned among these needs.
- **Skylights vs. vertical glazing.** The glazing for this wall wash toplighting scheme may be either horizontal or vertical (facing north, east, south, or west). Skylights can offer an advantage of lower construction costs.

Skylit wall wash delivers daylight across two-thirds of this classroom.

NREL/PIX 11405

Applicable Climates

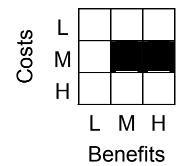
Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

- **Integration with HVAC.** Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs. If it is oriented, glazed, shaded, and integrated with electric lighting controls, toplighting should decrease overall seasonal heating and cooling loads on the building. This can reduce the initial size of the HVAC system and annual energy costs.
- **Integration with mechanical ventilation.** Operable rooftop fenestration can be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Integration with structural system.** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity
- **Safety and security**. Toplighting scenarios on relatively flat roofs have liabilities for both safety and security.

Cost Effectiveness

Costs for wall wash toplighting are moderate to high, depending on design. Commercial, single glazed skylights are usually the least expensive approach.



Benefits

Wall wash toplighting provides a moderate to high level of benefits. This approach washes a wall with light, and bounces glare-free daylight into the classroom. It will make the space appear larger and brighter. The uniform light from this approach can easily light the inner two-thirds of a classroom. It is excellent when combined with another wall wash or a sidelighting technique that increases daylight on the opposite side of the room (for example, a perimeter window) to create even, balanced daylight across the whole room.

This approach saves electric lighting energy if the first row or two of lights adjacent to the wall wash are switched off or dimmed in response to the daylight. Savings for controlled fixtures may be 40% to 80% during daylight hours.

If this scheme is used to provide natural ventilation, it may increase student performance. Natural ventilation has been correlated with higher student scores on standardized tests and lower overall building energy use.In climates where natural ventilation will only be a viable option for a much smaller portion of the year, it is assumed the improvement in student performance would be more muted.

Design Tools

The computer simulation programs and scale models described in this chapter's Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can handle this situation.

Design Details

General

- **Orientation.** Optimize the toplighting design for the climate, orientation, and budget. A skylight will perform better in a predominantly overcast sky condition and for non-north/south orientations. A well-designed monitor with north- or south-facing glazing will be more expensive, but may perform better than a skylight in sunny climates with high air conditioning loads.
- **Diffusion.** Diffuse the daylight before it washes the wall. Eliminate direct sun patches with diffusing glazing, baffles, or a deep well. For skylights, use a high performance diffusing material, such as prismatic acrylic, to maximize light transmission while minimizing hot spots. For clear glazed, baffled systems, design fixed baffles to cut off all expected sun angles or provide adjustable baffles.

- **Visible transmittance.** Use glazing with the highest ratio of visible transmittance to thermal resistance to bring in the most daylight relative to the glazed area while minimizing energy loss. For vertical glass, use a low-e coating to minimize heat loss; use a selective low-e coating to minimize solar gain on solar orientations.Review energy performance based on proposed building scheduled use and percentage of air conditioning use.
- **Light wells.** A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Diffusely reflecting light wells should be less than 8 ft deep; mirrored reflecting wells can be used for deeper wells when necessary.
- **Surface colors.** The top of the wall that is washed should be light in color (>70% reflectance) so it can reflect daylight into the space. It should not have protrusions that will cast objectionable shadows.
- **Balancing daylight.** Combine wall wash toplighting approach with another linear approach on the opposite wall to balance daylight in the space.
- **Insulation.** Insulate light well walls to minimize thermal losses and reduce condensation.
- **Task and accent lighting.** In addition to ambient lighting, this approach can be used for task lighting on the wall (lighting lockers) or accent lighting (lighting artwork). It is excellent for corridors and other circulation spaces.
- **Blackout capability.** The aperture will need blackout capability for most classrooms.
- **Integrating with electric light.** Consider an electric lighting wall wash luminaire to illuminate the wall at night, or during heavily overcast conditions. Photoswitch this light in response to daylight levels.
- **Safety and security.** Operable mechanisms should prevent any physical entry. A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles may also serve this function.) Make sure this grating does not create a shadow pattern on the wall.
- **Leakage.** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer. Any operable opening should prevent rain penetration.

Monitors

Monitors with glazing oriented north/south (elongated east/west, or a double-sided, monitor-oriented east/west (elongated north/south), will exhibit the least variation of daylight levels throughout the day and will be easiest to design for good energy performance. South-facing vertical glazing should have an overhang, or spectrally selective low-e coating (SHGC less than .45) to reduce solar gains during the cooling season, combined with baffles or diffusing glazing to eliminate direct sun. Monitors with glazing oriented east or west are more likely to show variations in light level and quality from morning to afternoon unless it is provided with glazing in both directions. This allows the classroom below to enjoy the benefits of daylight as well as the energizing effects of changing light directions with the natural movement of the sun throughout the day. If the east-west orientation is required, a skylight may perform better than a monitor.

Operation and Maintenance Issues

- Educate teachers about how wall wash toplighting delivers daylight to the space; discourage them from placing dark colored artwork and posters high on the washed wall.
- Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.
- The mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor, and easily repaired.

- The janitorial service should check all operable windows or skylights for closure daily.

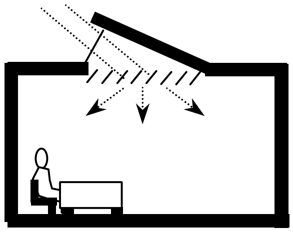
Commissioning

Check to ascertain that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See this chapter's Overview.

GUIDELINE DL5: CENTRAL TOPLIGHTING



Central sawtooth monitor provides even illumination across desktops in this classroom. NREL/PIX 11406

Recommendation

Use central toplighting in single-story classrooms to provide high levels of even, balanced daylight across the entire room.

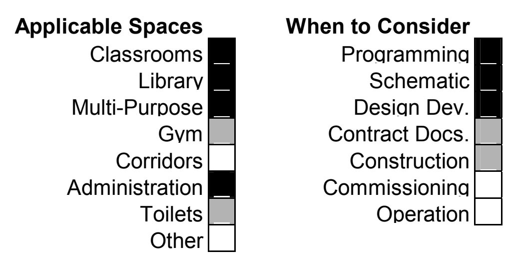
Description

Central toplighting uses a central monitor or skylight (or cluster of skylights) to distribute daylight evenly across the room. Daylight is diffused with diffusing glazing or baffles that can be fixed or operable. Daylight levels are highest directly under the aperture and gradually reduce toward the perimeter of the space.

Applicable Climates

Applicability

Central toplighting is applicable in single-story or top floor spaces including classrooms, libraries, multipurpose spaces, and administrative offices. It is appropriate for all climate regions and should be considered during the programmatic, schematic, and design development phases of a school building project.



Integrated Design Implications

- **Integration with site plan.** This toplighting scheme applies to single-story buildings or the top floor only of a multi-story building. It must be planned for in the schematic design.
- **Skylight vs. vertical glazing.** The glazing for a central toplighting scheme may be either horizontal or vertical (facing north, east, south, or west). In climates where a high percentage of solar gain from skylights is desirable due to the long heating season, it is often more energy efficient to provide skylights than monitors. Schools that are in operation later in the day as well as throughout the summer when peak cooling loads are highest, will see greater energy advantages to monitors than schools with less cooling hours.
- **Balance with other daylight.** This scheme may be combined with view windows in perimeter walls. Since the toplighting aperture provides most of the ambient daylight, smaller windows can be judiciously spaced in exterior walls to optimize views and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.
- **Integration with HVAC.** Placement of skylights and monitors, and their associated light wells, must be coordinated with the location of rooftop HVAC equipment and interior ducts.

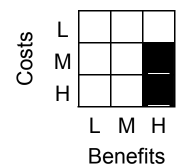
- **Integration with structural system.** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity.
- **Integration with electric lighting.** Central daylighting schemes often fail to provide bright illumination on interior walls. Electric lighting wall wash fixtures may be needed to supplement the daylight.
- **Integration with mechanical ventilation.** If the toplighting fenestration is operable, it can be used to naturally ventilate the space. Evaluate the percentage of the year this would be functional based on the climate, then considerthe thermal stratification of air in the space and the prevailing wind conditions to assess the feasibility.

Toplighting reduces glare and allows for a more even distribution of daylight within a space. NREL/PIX 08834

- **Safety and security.** Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered.

Cost Effectiveness

Costs for central toplighting are medium to high, depending on design. Commercial, double glazed skylights or a diffusing, double wall panel system with a sheetrocked well will be the least expensive. Site-built monitors with vertical or sloped glazing will cost more.



Benefits

Central toplighting provides a high level of benefits. With good diffusion, this approach creates even, balanced daylight across the classroom, which has been correlated with higher standardized test scores. (However, uncontrolled direct sun toplighting in classrooms has been associated with lower standardized test scores. See this chapter’s Overview for details.)

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40% to 80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different classroom activities.

Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, having been positively correlated with higher student scores on standardized tests. In climates where natural ventilation will only be a viable option for a much smaller portion of the year, it is assumed the improvement in student performance would be more muted.

Design Tools

The computer simulation programs and scale models described in this chapter’s Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check that the simulation program can handle this.

Design Details

General

- **Visible transmittance.** Use high visible transmission glazing materials (greater than 60%) to maximize daylight, use glazing with the highest affordable visible transmission to thermal resistance ratio, while minimizing the size of the glazed area with its relatively low U-factor. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. Relatively new double wall polycarbonate glazing materials are now available with electronically controlled, built-in shading devices that automatically close down as lumen levels increase within the space, reducing unwanted solar heat gain. Additionally, these automatic devices close at night, reducing radiation losses to the cold night sky. The balance between visible transmittance and insulation levels, as well as automatic shading, is best studied with an hourly climate simulation software tool.
- **Orientation.** Optimize the toplighting design for the climate and budget. A skylight will perform better in a predominantly overcast sky condition, or non-optimum orientation. A well-designed, north- or south-facing monitor will be more expensive, but may perform better than a skylight for sunny climates with high air conditioning loads. A two-sided monitor with glazing facing both east and west will also be more expensive but is another way to use monitors even in non-optimal orientations while still providing even light levels throughout the day.
- **Reflective materials.** A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white, flat paint works best. Diffusely reflecting light wells should be less than 8 ft deep; specular reflecting wells can be used for deeper wells when necessary.
- **Diffusion.** Diffuse the daylight with diffusing glazing or baffles. Design baffles to cut off all expected sun angles or to be adjustable. Avoid placing diffusing glazing within the normal field of view, as it will cause excessive glare.
- **Splayed light wells.** Splay light well walls to spread the daylight more effectively in the space and reduce glare. A 45° to 60° angle works best.
- **Insulation.** Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.
- **Blackout capability.** Add blackout capability, as needed, and louvers to modulate the daylight levels.
- **Integration with electric lighting.** If the light well is visible (not obscured by baffles), provide some electric light so it does not become a “dark hole” at night. Pendant uplight fixtures work well. Photoswitch these lights in response to daylight levels. See the Lighting and Electrical Systems chapter for information about controlling electric lights in response to available daylight.
- **Safety and security.** A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall.
- **Leakage.** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.
- **Reflectors.** A reflecting device may be placed below the light well to redirect daylight onto the ceiling or walls of the space. This ceiling/wall wash will make the space appear larger and brighter, even though horizontal footcandles measured at desk height may be reduced. The reflector may consist of flat or curved mirrored or matte reflective surfaces. It may also be partially translucent (fabric, plastic, or perforated metal). This device will require extra floor to ceiling height and should be studied with a physical scale model to evaluate daylight distribution.

Skylights

Use a glazed area of about 3% to 12% of the floor area. Use the lower end of this range for spaces with high air conditioning or heating loads, and the higher end for temperate climates with more overcast skies. In cold climates, consider south-facing clerestories instead of skylights.

Monitors

A sawtooth monitor with glazing oriented north will exhibit the least variation of daylight levels throughout the day and will have better energy performance than east or west glazing. South-facing vertical glazing should have an overhang or spectrally selective low-e (SHGC less than .45) to reduce solar gains during the cooling season. Avoid sawtooth monitors with glazing oriented east or west; they will show large variations in light level and quality from morning to afternoon and will have poor thermal performance. Double-sided monitors with glazing facing both east and west will provide more even lighting but will also cost more.

Operation and Maintenance

Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

Mechanisms for operable louvers and blackout shades should be robust, accessible to the teacher, and easily repaired.

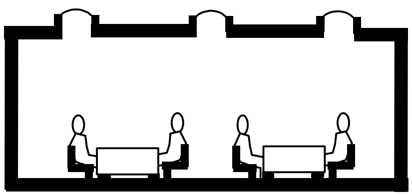
Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See this chapter's Overview.

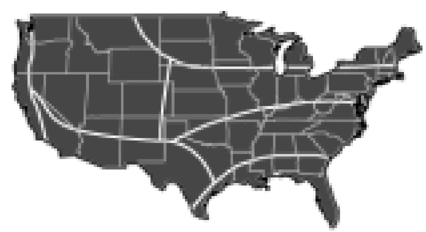
GUIDELINE DL6: PATTERNED TOPLIGHTING

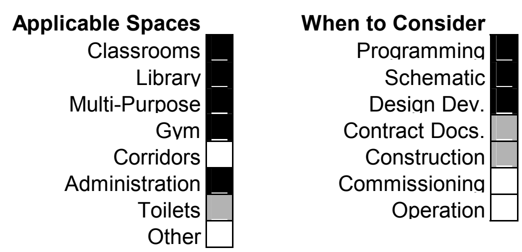


Grid of skylights provide even illumination across the space.

NREL/PIX 11434

Applicable Climates





Recommendation

Use patterned toplighting in interior spaces that need even, low-glare illumination across a large area.

Description

Patterned toplighting provides daylight through a two-dimensional grid of skylights or rows of linear monitors (sawtooth or square). It provides even, glare-free daylight across large areas. Spacing of the pattern is largely a function of the ceiling height.

Applicability

This daylighting pattern is useful for any large area that needs even daylight levels. It is especially good for gymnasium, library, multipurpose, or cafeteria spaces. For gymnasium ball courts, add baffles or high light well cutoff angles to minimize direct views of bright glazing surfaces during ball games (See Design Details below). Patterned toplighting is appropriate for all climate regions and should be considered during the programmatic, schematic, and design development phases.

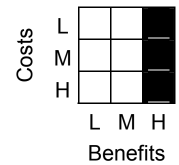
Integrated Design Implications

- **Integration with site plan.** This toplighting scheme applies to single-story buildings or the top floor only of a multi-story building. It must be planned for in the schematic design.
- **Skylight vs. vertical glazing.** The glazing for these patterned toplighting schemes may be either horizontal or vertical (preferably facing north or south).
- **Balance with other daylight.** This scheme may be combined with view windows in perimeter walls. Since the toplighting aperture provides most of the ambient daylight, smaller windows can be judiciously spaced in exterior walls to optimize views, and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.
- **Integration with HVAC.** Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs.
- **Integration with mechanical ventilation.** If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate the percentage of the year this would be functional based on

climate, and then consider the thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.

- **Integration with structural system.** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity
- **Safety and security.** Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered.

Cost Effectiveness



Costs for patterned toplighting range from low to high, depending on design. A grid of skylights with unfinished wells will be the least expensive; monitors with reflecting devices will be much more expensive. Costs include the expense of the skylight or monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.

Benefits

Patterned toplighting provides a high level of benefits. This approach creates even, balanced, low-glare daylight across the space. This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40% to 80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, having been positively correlated with higher student scores on standardized tests. In climates where natural ventilation will only be a viable option for a much smaller portion of the year, it is assumed the improvement in student performance would be more muted.

Design Tools

The computer simulation programs and scale models described in this chapter’s Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this.

Design Details

General

- **Optimize for climate and budget:** A grid of skylights will perform better in a predominantly overcast sky condition where air conditioning loads are low. A series of well-designed monitors will be more expensive, but will perform better than a skylight for sunny climates with high air conditioning loads.
- **Visible transmittance:** Use high visible transmission glazing materials (greater than 60%) to maximize daylight and glazing with the highest affordable visible transmission to the thermal resistance ratio,while minimizing the size of the glazed area with its relatively low U-factor.
- **Diffusion:** Diffuse the daylight with diffusing glazing or baffles. Design baffles to cut off all expected sun angles or to be adjustable. Avoid placing vertical diffusing glazing within the normal field of view.
- **Splayed light wells:** For deeper, narrow light wells, splay the light well walls to spread the daylight more effectively in the space and reduce glare. A 45° to 60° angle works best.
- **Reflectance:** A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white flat paint works best. Diffusely

reflecting light wells should be a maximum of 6 to 8 ft deep; specular reflecting wells can be used for deeper wells when necessary.

- **Insulation:** Insulate light well walls to minimize thermal losses and reduce condensation. Use an R-value at least equivalent to the code requirement for wall insulation.
- **Blackout capability:** Add blackout capability, as needed, and louvers to modulate the daylight levels.
- **Safety and security:** A safety/security grating can be placed in light wells under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.)
- **Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

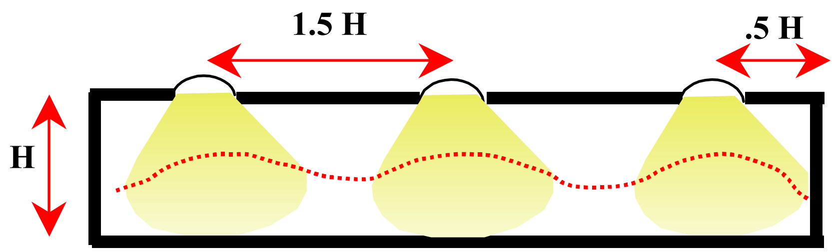


Figure 5 – Skylight Grid Spacing

Skylight Grid

As a rough rule of thumb, skylights should be spaced about one-and-a-half times the floor-to-ceiling height (H in Figure 5 above). Their glazing should be about 3% to 12% of the floor area to be lighted.

Series of Monitors

Sawtooth monitors with glazing oriented north will exhibit the least variation of daylight levels throughout the day and will have better energy performance than east or west glazing. South-facing vertical glazing should be smaller and should have an overhang or spectrally selective low-e coating (SHGC less than .45) to reduce solar gains during the cooling season. Avoid sawtooth monitors with glazing oriented east or west; they will show large variations in light level and quality from morning to afternoon and poor energy performance.

Operation and Maintenance

Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

Mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor, and easily repaired.

Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See this chapter's Overview.

GUIDELINE DL7: LINEAR TOPLIGHTING

Recommendation

Use linear toplighting as a single downlighting element in a long, linear space (such as a corridor) to direct movement or establish a visual orientation. Use it on two sides of a space to define separate functions or activities, to define edges in a larger space, and/or to downlight the space from two directions.

Description

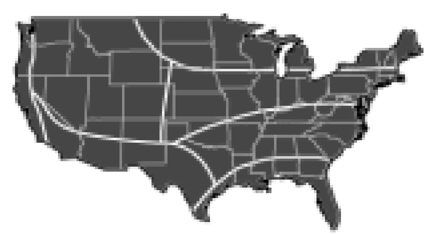
Linear toplighting is a downlighting scheme that provides a line of high intensity daylight directly under it, which diminishes as an individual moves perpendicularly away from it. It establishes a strong longitudinal orientation in the space and is best coupled with a corresponding circulation pattern or linear visual cue. Used bilaterally (from two sides), it can frame a larger space.

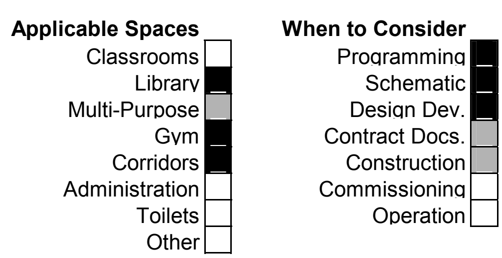
Applicability

This daylighting pattern is useful for enclosed hallways and linear walkways within a larger space, or for use bilaterally to frame centrally focused areas like gymnasiums, libraries, and multipurpose areas. Linear toplighting may also be used in covered exterior walkways to minimize their shadow, especially in covered walkways adjacent to rooms with sidelighting.

Libraries with skylights create bright welcoming corridors. Photo by Peter Vanderwalker, courtesy of HMFH Architects.

Applicable Climates





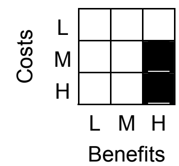
Integrated Design Implications

- **Design Phase.** This toplighting scheme applies to single-story buildings or the top floor only of a multistory building. It must be integrated with the site plan and building massing and should be planned for in the schematic design phase.
- **Balance with other daylight.** Since overall glazing area is limited, the amount of glazing in a linear toplighting scheme must be balanced with the need for view windows and other apertures in the space.
- **Integration with electric lighting.** Electric lighting should be aligned with the toplighting without blocking it and causing shadows on the floor.
- **Integration with structural system.** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity

- **Integration with HVAC.** Placement of the linear toplight and its associated light well must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Interruptions in the linear run of this toplight may be required to accommodate these other needs. The interruptions should be sequenced in a regular manner to prevent a random pattern of light and dark.
- **Integration with mechanical ventilation.** If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate percentage of the year this would be functional based on climate, and then consider thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Safety and security.** Toplighting scenarios on relatively flat roofs have both safety and security issues that should be considered.

Cost Effectiveness

Costs for linear toplighting range from moderate to high, depending on design. A linear row of skylights will be the least expensive; monitors with reflecting devices will be more expensive. Costs include the expense of the skylight or monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.



Benefits

Linear toplighting provides a high level of benefits. This approach creates bright, welcoming corridors that link important functions in the building. It can provide a strong visual cue for circulation that guarantees daytime egress lighting independent of electric power. In a bilateral scenario, it can provide balanced daylighting that graduates from high at the perimeter to moderate between the two linear toplights

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40% to 80% during daylight hours.

Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance, having been positively correlated with higher student scores on standardized tests. In climates where natural ventilation will only be a viable option for a much smaller portion of the year, it is assumed the improvement in student performance would be more muted.

Design Tools

The computer simulation programs and scale models described in this chapter’s Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this.

Design Details

- **Visible transmittance.** Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. The balance between visible transmittance and insulation levels is best studied with an hourly climate simulation software tool.
- **Glazing area vs. floor area.** Use a glazed area of about 3% to 12% of the floor area. Use the lower end of this range for spaces with high air conditioning or heating loads, and the higher end for temperate climates with more overcast weather.
- **Circulation.** When applicable, coordinate linear toplighting with major circulation areas in the school. Increase light levels at major intersections and at hallway ends to draw students in that direction.
- **Diffusion.** Either diffuse daylight or direct sun may be used in circulation and transition areas. Daylight diffused with translucent glazing or baffles will spread the daylight evenly in the space, making the

most effective use of the light. Occasional patches of direct sun can create a vibrant splash of light to emphasize major intersections and circulation spines. Some designs have successfully combined patterns of diffusing glazing with smaller areas of transparent glazing to animate a circulation space. It is pleasant to see the blue sky, as well as the daylight in spaces where some glare will not impede the performance of the space.

- **Shared daylighting.** Consider sharing diffuse corridor daylight with adjacent spaces by glazing the upper portion of the wall. Avoid this in areas where acoustic separation is important. In multistory buildings, consider sharing daylight from the top floor corridor with the lower floor by periodically cutting light wells to the lower level.
- **Splayed light wells.** For diffusing skylights with deeper, narrow light wells, splay the light well walls to spread the daylight more effectively in the space and reduce glare. A 45° to 60° angle works best.
- **Insulation.** Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.
- **Safety and security.** A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall.
- **Leakage.** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

Operation and Maintenance

Clean glazing on a schedule. Horizontal glazing (and clear glazing) needs more frequent cleaning in climates with low rainfall.

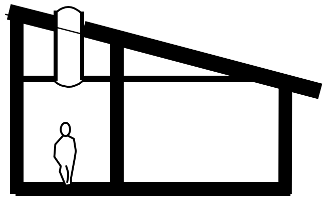
Commissioning

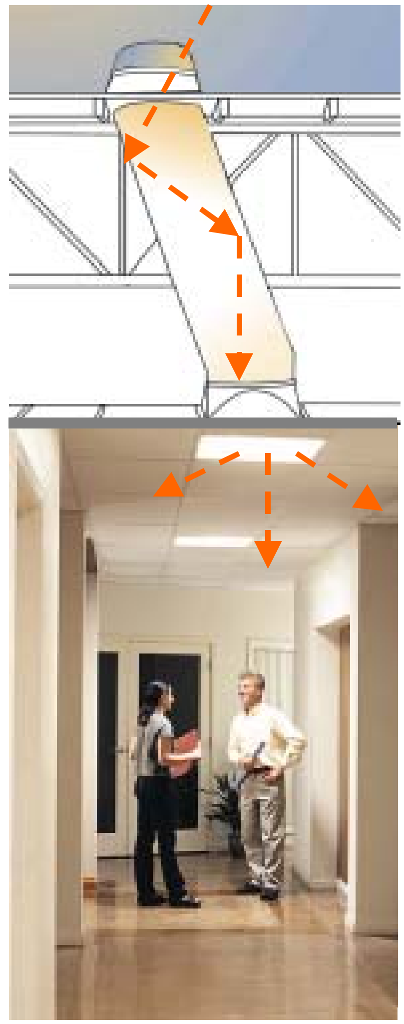
Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

References/Additional Information

See this chapter's Overview.

GUIDELINE DL8: TUBULAR SKYLIGHTS





Tubular skylights work well for small spaces, such as toilet rooms, locker rooms, kitchens, and interior corridors. NREL/PIX 11430

Recommendation

Use tubular skylights for toplighting in areas with relatively deep roof cavities and for low-cost retrofits to existing spaces.

Description

Tubular skylights are small clear-domed skylights with mirrored reflective ducts connecting them to the ceiling plane of the space. They have an interior diffuser at the ceiling plane to spread daylight in the space. They may have electric lighting within the duct or diffuser that is switched or dimmed in response to the available daylight. Since they depend on multiple reflections to deliver daylight to the space, they perform better under direct sun than overcast sky conditions.

Applicability

Tubular skylights are especially good for small spaces, such as toilet rooms, locker rooms, kitchens, interior corridors, enclosed staff work areas, and other interior spaces that are sporadically occupied and would benefit from a low-cost toplighting solution. They are also good for retrofit into any existing school space that needs extra daylight or needs to balance an existing asymmetric daylight distribution.

These units will work significantly better in clear sky climates than in overcast climates. As the duct gets longer, less daylight is delivered; so they are limited to spaces with roof cavities of 8 ft or less.

Integrated Design Implications

- **Integration with site plan.** This toplighting scheme applies to single-story buildings or the top floor only of a multistory building. It must be planned for in schematic design.
- **Balance with other daylight.** This scheme may be combined with view windows in perimeter walls. Since the toplighting aperture provides most of the ambient daylight, smaller windows can be judiciously spaced in exterior walls to optimize views and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.

- **Integration with HVAC.** Placement of tubular skylights must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Although the reflective ducts can jog to avoid barriers in the ceiling plenum space (within reason), efficiency of daylight delivery is reduced with each change in direction.
- **Integration with structural system.** Skylights interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity. The small diameter of these units reduces their impact on the structural system relative to larger framed skylights.
- **Integration with electric lighting.** Some tubular skylights come equipped with compact fluorescent (or incandescent) electric lights within the duct or ceiling plane diffuser that can be switched or dimmed in response to daylight. Ascertain that any included electric light not block the daylight delivered through the device.
- **Safety and security.** Unless these skylights are larger than 16 in.^{2}, they should not pose a safety or security liability.

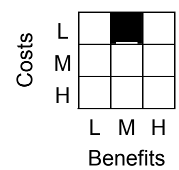
Applicable Climates

Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Cost Effectiveness

Costs for tubular skylights are low. For smaller spaces like hallways and offices, 10 in. and 14 in. tubular skylights cost approximately $300 and $400 (not including installation costs), respectively.



Benefits

Tubular skylights provide a moderate level of benefits. This approach provides daylight “fixtures” that deliver daylight through a ceiling plenum to an interior space. Arranged in a grid, they can provide even, balanced daylight across the space, though daylight levels will fluctuate widely between direct sun and overcast sky conditions. Daylight in classrooms has been correlated with higher standardized test scores. See this chapter’s Overview for details.

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 20% to 60% during daylight hours

Design Tools

The specular reflective tube makes it difficult to simulate the performance of these skylights with physical scale models and computer tools. Local case studies, test installations, and estimating tools from the manufacturers are the best tools for evaluating performance. Designers should take note that many manufacturers of tubular skylights have made exaggerated claims about both daylight delivery and R-value of their products.

Energy performance of these skylights is also handicapped by the lack of U-factor and SHGC data. As this information becomes available, hourly building energy evaluation programs like DOE-2, EnergyPlus, and Energy-10 can be used to evaluate the energy impacts.

Design Details

- **Length and bends.** Minimize the overall length and minimize bends in the reflective duct running from the skylight to the ceiling plane.

- **Reflective ducts.** Use a product with a highly reflective cylindrical duct. Do not use a corrugated duct; the corrugations trap light.
- **Half dome vs. full dome.** In predominantly sunny climates, use a tubular skylight with a south-facing, reflective half-dome under the skylight "bubble" to increase the reflection of low angle winter sun into the skylight (see Figure 6 below). In predominantly overcast climates, use a full clear dome. Special lenses or geometric shapes can also help to catch low angle sun and direct it downward.

Tubular skylights in interior administrative office provide high lighting levels even when electric lights are off. Skylight diffuser panel fits into a standard suspended ceiling system.

NREL/PIX 11427

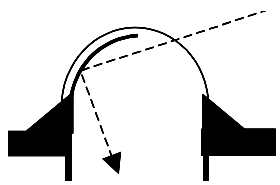


Figure 6 – Section of Reflective Half Dome *NREL/PIX 11432*

- **Diffusers.** Some products have a flat bottom diffuser that fits into a standard 2 ft x 2 ft or 2 ft x 4 ft dropped ceiling grid. These may incorporate the electric lighting in them or may alternate in a grid with recessed fluorescent electric lighting fixtures.
- **Insulation.** For ducts installed in uninsulated ceiling or attic spaces, insulate the duct to an R-level at least equivalent to the code requirement for air ducts to minimize thermal losses and reduce condensation.
- **Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

Operation and Maintenance

Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

Commissioning

None.

References/Additional Information

See this chapter's Overview.

ENERGY-EFFICIENT BUILDING SHELL

Designing the school building enclosure — or envelope — entails many considerations. The materials — both indoors and out — must be durable, resistant to water damage and vandalism, easy to clean, and inexpensive. They must be strong enough to meet seismic codes, yet appear inviting. Add energy efficiency and resource-efficiency to this list and the design team's job is even more complex.

This chapter provides technical guidelines for the school building enclosure, including:

Fenestration (windows and skylights) is addressed in the chapter on Daylighting and Fenestration Design.

The construction of the building enclosure, especially its air and vapor permeability,color, levels of insulation, resistance to unplanned air leakage, and thermal mass, has a significant effect both on energy efficiency and occupant comfort. The building enclosure also affects acoustic comfort as it can attenuate site and traffic noise. Selecting materials for the construction of the building enclosure affects school resource efficiency, including transport energy, the volume and type of raw materials that must be extracted from the earth, the energy required for manufacturing, and packaging. Building shell construction also affects thermal comfort. Even when heating and cooling systems are large enough to make up for poorly insulated components, the building's surface temperature may be cold or hot (depending on season), and this affects the radiant temperature of the space and the comfort of the occupant.

OVERVIEW

Heat Transfer through the Building Enclosure

Heat transfer through envelope components is quite complex and dynamic. The direction and magnitude of heat flow is affected by solar gains from the sun, outdoor temperature, and indoor temperature. Building envelope components have four important characteristics that affect their performance: their U-factor or thermal resistance (R-value); their air and vapor permeability; their thermal mass or ability to store heat, measured as heat capacity (HC); and their exterior surface condition/finish (for example, are they light in color to reflect the sun or dark to absorb solar heat?).

These concepts are explained in greater detail below. Also discussed below is the use of radiant barriers to reduce heat transfer in certain situations.

U-factor

The U-factor is the rate of steady-state heat flow. It is the amount of heat in British thermal units (Btu) that flows each hour through 1 ft^2 of surface area when there is a 1°F temperature difference between the inside and outside air. Heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. Insulation and most other building materials affect heat flow equally in both directions, but some construction elements, such as radiant barriers, may reduce heat flow entering the building, but have little impact on heat leaving the building.

Steady-state heat flow assumes that temperatures on both sides of the building envelope element (while different) are held constant for a sufficient period so that heat leaving one side of the assembly is equal to heat entering the opposite side. The concept of steady-state heat flow is a simplification, because in the real world, temperatures change constantly. However, U-factor can predict average heat flow rates over time and is commonly used to explain the thermal performance of construction assemblies. Because they are easy to understand and use, the terms for steady-state heat flow (R-values and U-factors) are part of the basic vocabulary of building energy performance.

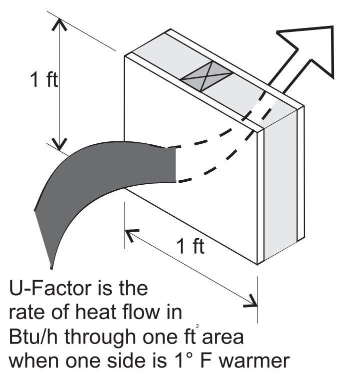


Figure 1 – Concept of U-factor

With metal framing, thermal bridges significantly impact the performance of the overall assembly, sometimes reducing the insulation effectiveness to less than half. The U-factor accounts for thermal bridges and the conductance of every element of the construction assembly, including the air film conductances on the interior and exterior surfaces. The air film conductances quantify the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment. This conductance depends on the orientation and roughness of the surface and the wind speed across the surface.

For light frame walls, U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant temperature conditions. The dynamic heat storage properties of concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow (see discussion of Heat Capacity below).

R-values

R-values are also used to describe steady-state heat flow but in a slightly different way. The R-value is a material property that is proportional to resistance to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R-value. The opposite is true with U-factors, that is, the lower the better.

R-values are widely recognized in the building industry and are used to describe insulation effectiveness. The insulation R-value does not describe the overall performance of the complete assembly, however. It only describes the thermal resistance of the insulation material and does not take into account the impact of air leakage in the wall or roof assembly. The performance of the entire wall assembly can be significantly lower when metal framing, steel beams, metal window casements, or other elements penetrate the insulation.

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value and conduct heat more readily than the insulated areas. Framing members must be considered when calculating the U-factor of a wall, roof, or floor assembly. See the Design and Analysis Tools section below for more details.

Thermal Mass

Thermal mass is another important characteristic that affects the thermal performance of construction assemblies. Heavy walls, roofs, and floors have more thermal mass than light ones. Thermal mass both delays and dampens heat transfer (see Figure 2). The time lag between peak outdoor temperature and interior heat transfer is between 4 and 12 hours depending on the thickness and the heat capacity of the construction and other characteristics. For buildings like schools that are often not heated or cooled at night, delaying heat transfer can be just as effective as reducing it, so long as the outside air cools down at night. However, in humid climates, there is a small diurnal temperature swing on hot days, so this effect is not as significant as it is in climates such as desert areas, where the diurnal temperature swing can be 30ºF or more.

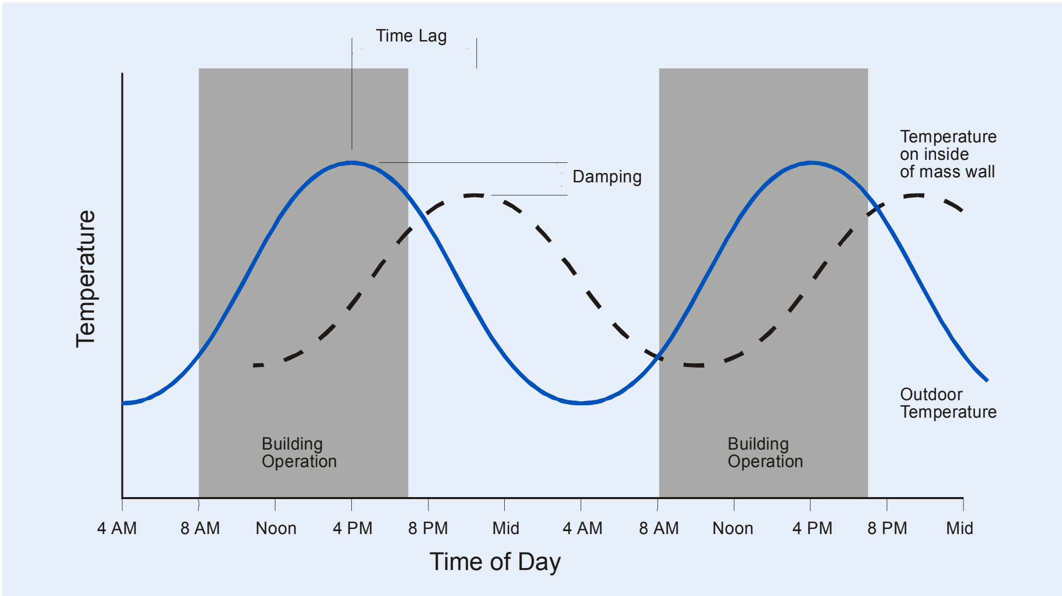


Figure 2 – Temperature Swing

Thermal mass that is exposed to interior air has other benefits as well. If the mass is allowed to cool at night, it will absorb heat during the morning and reduce the cooling load. If the interior thermal mass is exposed to sunlight, it will warm during the day and release the heat at night. Thermal mass used this way is a basic principal of passive solar design and may be appropriate in the Cool and Humid, Cold and Humid, and Cool and Dry climates.

Figure 3 shows examples of mass walls commonly used in school construction.

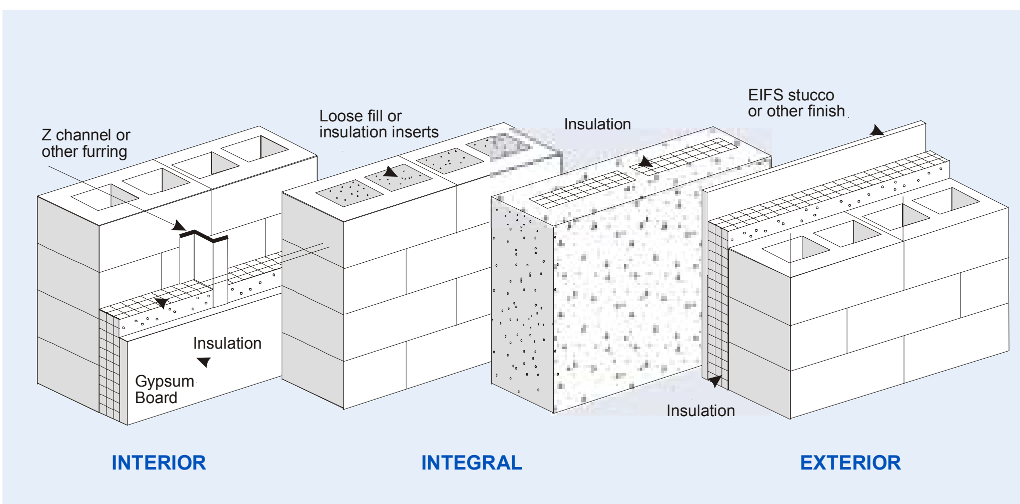


Figure 3 – Mass Wall Constructions

Heat Capacity

Heat capacity (HC) is the metric used to quantify thermal mass. HC is the amount of heat in Btu that must be added to 1 ft^2 of surface area to uniformly elevate the temperature of the construction by 1°F. The units are Btu/ft^2·°F. HC is the sum of the heat capacity of each individual layer in the wall. The heat capacity of each layer is the density of the material times its thickness times its specific heat (all in consistent units). HC can be approximated by multiplying the weight of a ft^2 of wall, roof, or floor by 0.2. For example, a wall with a weight of 100 lb/ft^2 has an HC of approximately 20 $Btu/ft^2 \cdot °F$.

Many energy standards consider HC as a factor in the overall performance of a building envelope component. ASHRAE/IESNA Standard 90.1-1999, for instance, has a mass wall class of construction with separate thermal performance criteria.

Concrete is not a very good insulating material. However, some varieties are better than others. There is a class of materials called aerated concrete that has air bubbles entrained in the concrete, which makes the concrete lighter and also improves its insulating ability. Low-density aggregates such as perlite or vermiculite can be used to produce lightweight concrete. The moisture transport characteristics of the materials must also be considered.

Cool Roofs

Heat transfer is also affected by the exterior surface. This is especially important for roofs. In fact, the term "cool roof" is used to describe those with favorable surface characteristics. Cool roofs have two key features. First, they have a high solar reflectance, which usually means that they are light in color. The high reflectance means that solar radiation is reflected rather than absorbed by the roof surface, keeping the surface temperature lower and reducing heat gain, which will reduce the need for air conditioning and significantly reduce the amount of heat that a rooftop ventilation unit will pick up while providing economizer cooling or bringing in outside air ventilation. This will extend the amount of time that outdoor air without mechanical cooling will be able to keep a classroom from overheating. Second, cool roofs have a high or normal emittance. Emittance is a little harder to understand than reflectance, but it can be just as important to energy performance. Emittance is that percentage of energy that would be radiated to the sky from a surface. Galvanized metal and other metallic finishes have a low emittance, which means that when they warm up, they cannot easily release their heat by radiating it back to the sky. Keeping the roof cool reduces cooling loads but also reduces expansion and contraction of the roofing materials, which dramatically increases the life of the system. Cool roofs also decrease the heat island effect of buildings, an especially important factor in dense urban areas.

Radiant Barriers

One last feature of construction assemblies that deserves some discussion is radiant barriers. Many construction assemblies have a large cavity. An attic, for instance, is a cavity separating the roof from the ceiling. Radiant barriers are not typically installed in walls. In construction assemblies that have a cavity, much of the heat transfer from the warmer surface to the colder surface is due to radiation. A radiant barrier can reduce this component of heat transfer. A radiant barrier is a shiny metallic surface on one or more sides of the cavity that has a low emittance. Radiant barriers are commonly installed in attics.

Applicable Codes

Many states have energy efficiency standards that establish minimum insulation levels in schools. Adopted standards vary from state to state, but the standards in many states are based on ASHRAE/IESNA Standard 90.1-2001 (referenced in this section as Standard 90.1). Standard 90.1 has both prescriptive criteria expressed as minimum R-values (see Table 1) and component performance criteria expressed as maximum U-factors (see Table 2). The Standard 90.1 recommendations are minimum requirements. For most schools, it will be cost effective to exceed these requirements. Specific recommendations are contained in the guidelines that follow.

Table 1 – Minimum R-values from ASHRAE/IESNA Standard 90.1-2001

This table shows the prescriptive building envelope criteria from Standard 90.1, expressed as minimum R-values. The columns show the criteria for each of the seven climate zones (and representative cities) covered by the National Best Practices Manual. The rows show the criteria for various classes of construction. The designation "ci" means that the insulation must be installed in a continuous manner so that framing members do not interrupt it. Table 2 shows the same criteria, but expressed as maximum U-factors.

	Climate Region						
	Hot and Dry	**Hot and Humid**	**Temperate and Humid**	**Temperate Mixed**	**Cool and Humid**	**Cool and Dry**	**Cold and Humid**
	(Phoenix)	**(Orlando)**	**(Atlanta)**	**(Seattle)**	**(Boston)**	**(Denver)**	**(Minneapolis)**
Roofs							
Insulation Entirely above Deck	R-15 ci	R-15 ci	R-15 ci	R-15 ci	R-15 ci	R-15 ci	R-15 ci
Attic and Other	R-30	R-30	R-30	R-30	R-30	R-30	R-38
Walls, Above Grade							
Mass	NR	NR	R-5.7 ci	R-5.7 ci	R-7.6 ci	R-7.6 ci	R-9.5 ci
Steel Framed	R-13	R-13	R-13	R-13	R-13+3.8 ci	R-13+3.8 ci	R-13+3.8 ci
Wood Framed and Other	R-13	R-13	R-13	R-13	R-13	R-13	R-13
Wall, Below Grade							
Below Grade Wall	NR	NR	NR	NR	NR	NR	NR
Floors							
Mass	R-4.2 ci	R-4.2 ci	R-6.3 ci	R-6.3 ci	R-8.3 ci	R-8.3 ci	R-8.3 ci
Steel Joist	R-19	R-19	R-19	R-19	R-19	R-19	R-30
Wood Framed and Other	R-19	R-19	R-19	R-19	R-30	R-30	R-30
Slab-On-Grade Floors							
Unheated	NR	NR	NR	NR	NR	NR	NR
Heated	R-7.5@12 in.	R-7.5@12 in.	R-7.5@12 in.	R-7.5@24 in.	R-10@36 in.	R-10@36 in.	R-10@36 in.
Note: "ci" means continuous insulation. "NR" means no requirement.							

Table 2 – Maximum U-factors from ASHRAE/IESNA Standard 90.1-2001

This table shows the component performance building envelope criteria from Standard 90.1, expressed as maximum U-factors. The columns show the criteria for each of the seven climate zones (and representative cities) covered by the National Best Practices Manual. The rows show the criteria for various classes of construction. The designation "ci" means that the insulation must be installed in a continuous manner so that framing members do not interrupt it. Table 1 shows the same criteria, but expressed as minimum R-values.

	Climate Region						
	Hot and Dry	**Hot and Humid**	**Temperate and Humid**	**Temperate Mixed**	**Cool and Humid**	**Cool and Dry**	**Cold and Humid**
	(Phoenix)	**(Orlando)**	**(Atlanta)**	**(Seattle)**	**(Boston)**	**(Denver)**	**(Minneapolis)**
Roofs							
Insulation Entirely above Deck	0.063	0.063	0.063	0.063	0.063	0.063	0.063
Attic and Other	0.034	0.034	0.034	0.034	0.034	0.034	0.027
Walls, Above Grade							
Mass	NR	NR	0.151	0.151	0.123	0.123	0.104
Steel Framed	0.124	0.124	0.124	0.124	0.084	0.084	0.084
Wood Framed and Other	0.089	0.089	0.089	0.089	0.089	0.089	0.089
Wall, Below Grade							
Below Grade Wall	NR	NR	NR	NR	NR	NR	NR
Floors							
Mass	0.137	0.137	0.107	0.107	0.087	0.087	0.087
Steel Joist	0.052	0.052	0.052	0.052	0.052	0.052	0.038
Wood Framed and Other	0.051	0.051	0.051	0.051	0.033	0.033	0.033
Slab-On-Grade Floors (F-factor)							
Unheated	NR	NR	NR	NR	NR	NR	NR
Heated	1.020	1.020	1.020	0.950	0.840	0.840	0.840

Note: "ci" means continuous insulation "NR" means no requirement.

The requirements of Standard 90.1 are code minimums. The cost effective level of insulation for schools exceeds these values and are shown in Table 3 and Table 4. These recommendations are based on:

Table 3 – Recommended Minimum R-values for Schools

This table shows the recommended minimum R-values for building envelope components in schools. The columns show the criteria for each of the seven climate zones (and representative cities) covered by the National Best Practices Manual. The rows show the criteria for various classes of construction. The designation "ci" means that the insulation must be installed in a continuous manner so that framing members do not interrupt it. Table 4 shows the same recommendations, but expressed as maximum U-factors.

	Climate Region						
	Hot and Dry	**Hot and Humid**	**Temperate and Humid**	**Temperate Mixed**	**Cool and Humid**	**Cool and Dry**	**Cold and Humid**
	(Phoenix)	**(Orlando)**	**(Atlanta)**	**(Seattle)**	**(Boston)**	**(Denver)**	**(Minneapolis)**
Roofs							
Insulation Entirely above Deck	R-20 ci	R-20 ci	R-20 ci	R-20 ci	R-20 ci	R-20 ci	R-20 ci
Attic and Other	R-38	R-38	R-38	R-38	R-38	R-38	R-60
Walls, Above Grade							
Mass	R-7.6 ci	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-13.3 ci	R-15.2 ci
Steel Framed	R-13+3.8 ci	R-13+3.8 ci	R-13+7.5 ci	R-13+7.5 ci	R-13+7.5 ci	R-13+7.5 ci	R-13+7.5 ci
Wood Framed and Other	R-13	R-13	R-13	R-13	R-13+7.5 ci	R-13+7.5 ci	R-13+7.5 ci
Wall, Below Grade							
Below Grade Wall	NR	NR	NR	R-7.5 ci	R-7.5 ci	R-7.5 ci	R-7.5 ci
Floors							
Mass	R-8.3 ci	R-8.3 ci	R-8.3 ci	R-10.4 ci	R-12.5 ci	R-12.5 ci	R-14.6 ci
Steel Joist	R-30	R-30	R-30	R-30	R-30	R-30	R-38
Wood Framed and Other	R-30	R-30	R-30	R-30	R-30	R-30	R-30
Slab-On-Grade Floors							
Unheated	NR	NR	NR	NR	R-10@24 in.	R-10@24 in.	R-15@24 in.
Heated	R-7.5@12 in.	R-7.5@12 in.	R-10@36 in.	R-10@36 in.	R-10	R-10	R-15

Note: "ci" means continuous insulation. "NR" means no requirement.

Table 4 – Recommended Maximum U-factors for Schools

This table shows the recommended maximum U-factors for building envelope components in schools. The columns show the criteria for each of the seven climate zones (and representative cities) covered by the National Best Practices Manual. The rows show the criteria for various classes of construction. The designation "ci" means that the insulation must be installed in a continuous manner so that framing members do not interrupt it. Table 3 shows the same recommendations, but expressed as minimum R-values.

	Climate Region						
	Hot and Dry	**Hot and Humid**	**Temperate and Humid**	**Temperate Mixed**	**Cool and Humid**	**Cool and Dry**	**Cold and Humid**
	(Phoenix)	**(Orlando)**	**(Atlanta)**	**(Seattle)**	**(Boston)**	**(Denver)**	**(Minneapolis)**
Roofs							
Insulation Entirely above Deck	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Attic and Other	0.027	0.027	0.027	0.027	0.027	0.027	0.017
Walls, Above Grade							
Mass	0.123	0.123	0.104	0.090	0.080	0.080	0.071
Steel Framed	0.084	0.084	0.064	0.064	0.064	0.064	0.064
Wood Framed and Other	0.089	0.089	0.089	0.089	0.051	0.051	0.051
Wall, Below Grade (C-factor)							
Below Grade Wall	C-1.140	C-1.140	C-1.140	C-0.119	C-0.119	C-0.119	C-0.119
Floors							
Mass	0.087	0.087	0.087	0.074	0.064	0.064	0.057
Steel Joist	0.038	0.038	0.038	0.038	0.038	0.038	0.032
Wood Framed and Other	0.033	0.033	0.033	0.033	0.033	0.033	0.033
Slab-On-Grade Floors (F-factor)							
Unheated	F-0.730	F-0.730	F-0.730	F-0.730	F-0.540	F-0.540	F-0.520
Heated	F-1.020	F-1.020	F-0.840	F-0.840	F-0.550	F-0.550	F-0.440
Note: "ci" means continuous insulation							

Design Tools

The thermal performance of construction assemblies can be calculated in many ways. The appropriate method depends on the type and complexity of construction. The basic calculation methods include:

- *Series Calculation Method.* This is the easiest way of calculating U-factor, but its use is limited to constructions that have no framing and are made of homogenous materials.
- *Parallel Path Calculation Method.* This simple extension of the series calculation method can be used for wood-framed assemblies.
- *Effective R-value (Isothermal Planes).* This method uses principles similar to the series and parallel path calculation methods, and is appropriate for construction assemblies such as concrete masonry and metal-framed walls/roofs where highly conductive materials are used in conjunction with insulated or hollow cavities.
- *Two-Dimensional Calculation Method.* Two-dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer.
- *Testing.* This is the most accurate way to determine the U-factor for all types of construction, except slabs-on-grade. But it is costly and time consuming, and because a large variety of possible construction assemblies exist, it is impractical to test them all. Calculation methods are usually more cost-effective.

Table 5 provides guidelines on which method can be used with different types of construction assemblies.

Table 5 – Procedures for Determining U-factors for Opaque Assemblies

	Series Calculation Method	Parallel Path Calculation Method	Effective R-value (Isothermal Planes)	Two-dimensional Calculation Method	Testing
Roofs					
Insulation above Deck	✓			✓	✓
Attic (wood joists)		✓		✓	✓
Attic (steel joists)			✓	✓	✓
Other				✓	✓
Walls					
Mass			✓	✓	✓
Wood Framed		✓		✓	✓
Steel Framed			✓	✓	✓
Other				✓	✓
Below-Grade Walls					
Mass			✓	✓	✓
Other				✓	✓
Floors					
Mass	✓		✓	✓	✓
Steel Joist			✓	✓	✓
Wood Framed		✓	✓	✓	✓
Other				✓	✓

Computer Programs

The calculation methods described above are implemented several design tools and computer programs.

- The Therm program available from Lawrence Berkeley National Laboratory is designed primarily to analyze window frames, but can be used for any type of two-dimensional heat transfer analysis. This program can be downloaded from http://windows.lbl.gov/software/therm/therm_getacopy.htm.
- General-purpose energy simulation programs such as DOE-2 and EnergyPlus can be used to calculate the energy savings of various construction assemblies. With these programs, the dynamics of heat transfer are modeled. In fact, EnergyPlus models the temperature gradient in constructions. DOE-2, on the other hand, uses a more simple response factor method. Energy-10, available from SBIC, is a simple energy-modeling program that architects can use. It is very limited in capabilities but can provide quick relative analysis for simple buildings.

Pre-calculated Data

The U-factor of common constructions has been calculated and values are published in several sources.

- Appendix A of ASHRAE/IESNA Standard 90.1-1999 has published values in both inch-pound and metric (SI) units. Constructions include walls, roofs, floors, slabs, and below-grade walls. These values are also contained in the EnvStd 4.0 computer program, which can be downloaded from http://www.eley.com.

Indoor Air Quality and Moisture

It is extremely important to provide an exterior weather barrier with drainage plane to prevent moisture from entering construction cavities. It is also very important to design a wall, roof, and foundations system, so that if water enters, it can dry out. Wet or damp construction cavities, attics, and plenums are a major source of mold and can contribute significantly to IAQ problems. In addition, moisture can damage the structure and degrade the performance of insulation, increasing energy and operating costs. Many IAQ complaints received by local schools are related to leaky roofs that have resulted in the growth of mold in a plenum, wall system, attic space, or in part of a foundation space such as a crawl space or utility trench.

Water vapor can also enter construction cavities through a process of moisture migration. Moisture migrates from the warm and humid side of the construction assembly to the cold dry side of the construction assembly. The vapor cools as it moves through the wall and, as it reaches dewpoint conditions, may condense into water molecules that can accumulate to cause damage and create mold. Moisture also follows air leakage through a construction assembly.To prevent water vapor migration, framed walls, floors, and roofs should have a vapor barrier on the warm moist side. For non-humid climates, this means that the vapor barrier should be on the interior side, with the opposite being true for humid areas. Vapor barriers also are available as part of most insulation products and consist of an asphalt-impregnated paper or metal foil. Care should be taken during construction to ensure that this vapor barrier is continuous, tightly secured at the framing members, and not damaged. Special care should be taken in lockers, showers, food preparation areas, and other spaces that are likely to have high humidity.

In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation to dry spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum one-inch clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates. An infiltration barrier should be installed under slabs with ventilated gravel in areas with soil gas contaminants like radon or methane.

Air Infiltration

Controlling infiltration is very important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semi-heated spaces. In climates with moist outdoor conditions during the day or night, it is also a major source of latent heat. Latent heat must be removed by the air conditioning system at considerable expense. Many state building codes require air barriers in walls and roofs to control air leakage. These barriers must be durable or maintainable. They also must be capable of withstanding both positive and negative pressure as well as transferring loads to the structure, which means they must permanently adhere to a durable substrate or be sandwiched between materials like gypsum sheathing and rigid insulation. The barriers must be continuous with all adjacent envelope parts and tie continuously to the foundation, the roof air barrier, and across all control, construction, and expansion joints.

Insulation Protection

Insulation should be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish, and often a drainage plane is required behind most EFIS systems to allow wind-driven rain to escape. In cold climates, mechanical or other equipment should not be installed in attics, since it can generate heat and cause uneven snow melting and ice dams. For moderate climates, access to equipment installed in attic spaces should be provided in a way that will not cause compression or damage to the insulation, which may mean using walking boards, access panels, and other techniques.

In situations where insulation is left exposed (including return air plenums), fiberglass insulation products should be encapsulated in a manner that prevents fibers from becoming airborne. To maintain a continuous vapor barrier, all seams should be sealed with tape or mastic. In this application, simply stapling the insulation is not adequate.

Material Efficiency and Other Environmental Considerations

One of the most effective ways to achieve material efficiency in a building is to reuse all or part of an existing building enclosure. This reduces solid waste produced by a project and avoids the environmental burdens associated with production and delivery of materials for a new building enclosure. Saving the building enclosure, however, may not be appropriate if the existing structure is not energy efficient and cannot be adequately upgraded to meet high performance objectives.

When designing a new building enclosure, material efficiency can be achieved by:

- Using panelized, pre-cut, and engineered construction products.
- Designing with standard dimensions to reduce on-site waste.
- Designing a compact building (this also reduces impervious surface on the site, but may conflict with daylighting objectives).
- Planning for future adaptability to extend the life of the building.
- Choosing durable materials and systems.

In addition, building enclosure and insulation materials exist that are recyclable, include recycled or resource-efficient content, or have other environmentally preferred characteristics. The materials may, for example, avoid introducing toxics into the building or natural environment, or they may be produced using environmentally friendly methods. In addition to the design strategies above, refer to Table 6 below for some easily achievable strategies that will improve the resource efficiency of the building enclosure and insulation.

Table 6 – Strategies for Constructing Resource-Efficient Building Enclosures

Building Component	Strategies	Environmental Benefits & Considerations
Foundation and Concrete Work	For concrete materials, specify flyash as replacement, not addition. 10%–25% replacement is commonly specified, but higher percentages are possible, depending on application.	Formerly landfilled as industrial waste, flyash is now used to replace energy-intensive Portland cement in concrete mix. Flyash adds workability and strength.
	Use autoclaved and/or aerated concrete for appropriate concrete applications.	Aerated concrete is lighter and has better insulating properties than standard concrete.
	Prohibit dumping concrete waste anywhere intended to be pervious.	Prevents degradation of the site and permits infiltration.
	Use steel rather than wood forms.	Although energy intensive, steel is reusable, contains recycled content and can be recycled at the end of service life.
	If wood forms are used, reuse wood in framing and sheathing.	Reduces resources used. Reduces waste.
	Use low and non-toxic form releases. Bio-based products are available.	Prevents soil contamination, and reduces human health risk. Promotes worker safety. Water-based products should be protected from freezing during storage.
	Use expansion joint fillers with recycled content.	Appropriate use of recycled, relatively low-strength materials, such as waste cellulose from recycled newspapers.
	Use rebar supports with recycled content. DOT-approved products are available with 100% recycled content, including engineered plastics and fiberglass.	Rebar supports in concrete form-work have minimal structural requirements; appropriate use of recycled waste plastic.
	If using ICFs, use options with ozone-friendly foam ingredients. (ICFs are permanent forms with integral insulation that are not disassembled after the concrete is cured. Note: not all ICFs are alike; field R-values can differ significantly so rely on results from completed projects.)	ICFs can provide significant improvements in energy efficiency and can reduce the use of energy-intensive Portland cement. Using ozone-friendly options (with EPS foam) eliminates a source of global warming.
	Use sill sealers to limit infiltration at the foundation.	Increases energy efficiency.
	Use sub-slab ventilation in areas with radon or potential soil gas submissions.	Improves indoor air quality.

Table 6 – Strategies for Constructing Resource Efficient Building Enclosures (Continued)

Building Component	Strategies	Environmental Benefits & Considerations
Masonry Walls	Use mortar dropping control product to prevent blocking of weep holes. Product available with 100% recycled polyethylene.	Maintains air flow and allows moisture migration from behind masonry veneer facades. Improves building durability.
	For concrete masonry units (CMUs): maximize recycled content. Typically available with 10% recycled content.	Reduces resources used to produce new CMU material. No difference in product performance or application. Products are high strength, highly fire resistant, and highly durable.
	For CMUs: use CMUs containing flyash.	Formerly landfilled as industrial waste, flyash is now used to replace energy-intensive Portland cement in concrete mix. Flyash adds workability and strength.
	For CMUs: consider using lightweight CMUs.	Reduces transportation-related impacts.
	For CMUs: pull watermark line down below window framing to eliminate finishing details.	Reduces maintenance over the life of the building.
	For CMUs: do not paint, order with color.	Avoids resources used to produce paint. Avoids use of VOC-emitting paints generally used to finish CMUs. The pigments typically used in colored CMU are nontoxic and contain none of the solvents associated with painting and re-painting. Products are low maintenance.
Steel Framing	Use systems with highest level of recycled content. Although steel may have as little as 25% recycled content, most structural steel framing has as much as 90% or more. Many load-bearing stud systems include up to 60% recycled content.	High recycled-content steel uses less embodied energy, and minimizes mining waste and pollution associated with virgin steel production. Also generally reduces job site waste, as waste steel is highly recyclable. Transportation of steel uses less energy and creates less pollution compared to dimensional lumber due to weight. Steel conducts heat efficiently. When using light-gauge steel, ensure that insulation is adequate to prevent thermal bridging and heat loss.
	Use fireproofing available with recycled EPS foam and recycled newsprint.	Traditionally, products contained fiberglass and asbestos for this use. More benign products that make efficient use of recycled materials are preferable.
Wood Framing	Use advanced or intermediate framing systems where applicable and accounting for seismic requirements for building site. Example framing elements include 24 in. on-center framing, insulated headers, two stud corners with drywall clips, ladder partitions. References: *Builder's Guide* – Building Science Corporation, and *Efficient Wood Use in Residential Construction* – Natural Resources Defense Council.	This both allows for more insulation, less "cold" spots, and increased wood efficiency, thus improving both energy and materials efficiency.
	Use engineered wood products in place of dimensional lumber such as floor joists and roof joists.	Engineered wood products are lighter weight and use fewer resources for the same function as dimensional timbers.
	Use wood certified with FSC or SCS. A variety of certified dimensional and engineered wood products are available.	Prevents degradation to forest and wildlife habitat.

Table 6 – Strategies for Constructing Resource Efficient Building Enclosures (Continued)

Building Component	Strategies	Environmental Benefits & Considerations
Siding	Use fiber cement siding. Most available factory primed; suggest back priming. Proper painting is important for the siding's long-term durability.	Reduces virgin wood use and can be a durable option.
Roofing	Use metal roofing.	Includes recycled content, is durable, and can be recycled at the end of service life.
	Use non-PVC options for membrane roofing.	Avoids the environmental impacts of PVC manufacturing.
	Consider a green or vegetated roof system for low-slope roofs. These roofs contain plants in a lightweight soil to absorb and slow runoff that would otherwise pour from rooftops. These roof systems typically consist of drainage, soil, and vegetation layers. Be sure to use native plants and grasses in green roof systems.	Can absorb and slow rainwater runoff to reduce peak loads on sewer systems. Helps reduce building heat gain and prevents urban heat islands. Plantings also absorb carbon dioxide. Helps conserve energy in the winter by insulating rooftops. Green roofs, however, require structural steel to support their weight. Because steel has high-embodied energy, this may offset some of the environmental benefits of using green roofs.
Moisture and Waterproofing	Sealants and repellants: Limit use of sealants through proper detailing. Use least-toxic options. Avoid products containing methylene chloride, chlorinated hydrocarbons, aromatic and aliphatic solvents, styrene butadiene, or products containing bactericides and fungicides classified as phenol mercury acetates, phenol phenates, or phenol formaldehyde.	Combining good detailing and low toxicity will prevent air quality problems while promoting long service life of the building.
	Do not rely on caulking for waterproofing. Proper flashing will prevent water from entering the building.	In addition to adding durability to shell, proper flashing prevents mold and mildew build up, reducing health risk.
	If using a vapor retarder, select film available with up to 100% LDPE (plastic).	Utilizes plastic waste that would otherwise be landfilled. Reduces resources required to produce virgin-based material.
Insulation	Use fiberglass insulation with up to 30% verified (SCS) recycled content. Formaldehyde-free fiberglass option also available (price premium).	Uses glass collected at curbside recycling programs. Formaldehyde-free option promotes good indoor air quality and promotes worker safety.
	Use cellulose insulation produced with 100% recycled newsprint.	Utilizes paper waste that would otherwise be put in landfills.
	If using rigid insulation with polyisocyanurate foam, use ozone-friendly option.	Prevents further degradation of the earth's atmosphere through global warming.
Exterior Doors (for window recommendations, see Daylighting chapter)	Use doors produced with reclaimed lumber.	Reduces pressure on timber supply, as well as degradation of forest habitat.

Source: Adapted from *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications*

Guideline EB1: Wall Insulation

Recommendation

Wood-Framed Walls. Install a minimum of R-13 cavity insulation in all climates. In the Cool and Humid, Cold and Humid, and Cool and Dry climates, also install R-7.5 insulating sheathing. See Table 4 for equivalent U-factor recommendations.

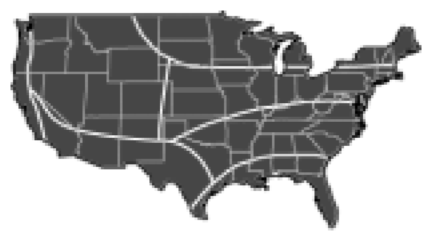
Metal-Framed Walls. Install a minimum of R-13 cavity insulation in all climates. In the Hot and Humid and Hot and Dry climates, also install R-3.8 continuous insulating sheathing. In the other climates, use R-7.5 continuous insulating sheathing.

Mass Walls. Install R-7.6 continuous insulation in the Hot and Dry and Hot and Humid climates. Upgrade this to R-9.5 in the Temperate and Humid climate, to R-13.3 in the Cool and Humid and Cool and Dry climates, and to R-15.2 in the Cold and Humid climate. Higher levels of insulation may be appropriate depending on local climate.

Note: Even though R-13 is recommended for both wood-framed and metal-framed walls, the U-factor, or overall thermal performance, will be better for wood-framed walls since the metal studs are more conductive.

Well-insulated and sealed walls can result in smaller HVAC equipment and reduced costs. NREL/PIX 11418

Applicable Climates



Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Description

The construction of exterior walls affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by size and height of a building, budget, requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates and less in more temperate climates.

Concepts of thermal heat transfer are presented in this chapter's Overview and should be reviewed, since they apply to walls as well as other building enclosure components.

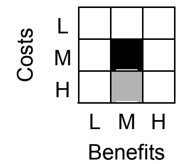
Applicability

These recommendations apply to all exterior walls in all spaces that are heated or cooled. Design decisions that affect wall thickness must be considered in the schematic design phase of the project.

Integrated Design Implications

Well-insulated and sealed walls with a continuous air barrier sealed to all adjacent materials can reduce moisture intrusion from wind-driven rain, cold drafts, and thermal loads in buildings, which can result in smaller HVAC equipment and reduced costs.

Cost Effectiveness



The cost of insulating the cavity of wood- and steel-framed walls is low, but the value of this insulation is also low because of the thermal compromising of the system by the studs, especially with metal framing. Continuous insulation is required by the building code and is most cost effective outboard of the framing. Once a significant layer of continuous insulation has been provided, the actual R-value of the insulation between the studs is significantly improved because the temperature gradient from one side of the studs to the other is much smaller.

However, insulating mass walls is more difficult and expensive. Insulating the cavity of mass walls is not very effective because of thermal bridges across the concrete webs, and seismic safety requires that most of the hollow cells be grouted and reinforced. The most effective way to insulate mass walls is to use an Exterior Insulation Finish System (EIFS), which costs $7/ft² for 1-in. insulation and $8/ft² for 2-in. insulation. If budget permits, this is the preferred method, since the benefits of the thermal mass are maximized. As an alternative, steel or wood furring can be used on the interior of the wall, batt insulation can be placed in the cavities between the furring strips, and gypsum board can be used as the interior finish.

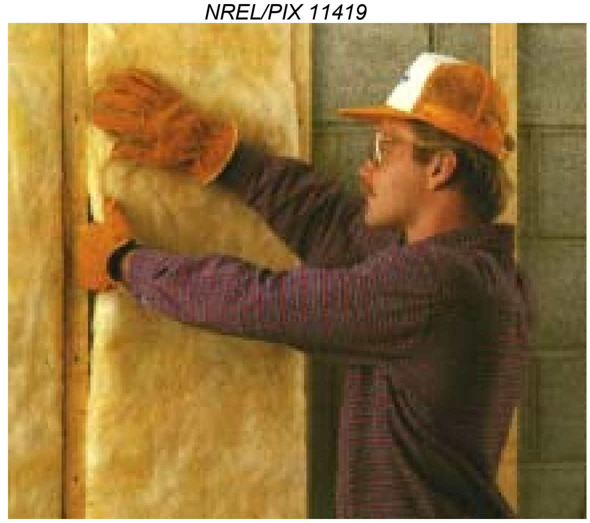
Rigid Insulation is the most effective way to insulate metal studs.

NREL/PIX 11419

Benefits

Insulating walls and reducing air infiltration has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Indoor air quality is improved by reduced mold and mildew.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Greater acoustic separation is provided from the outdoors.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.



Masonry walls can be insulated on the interior, but the benefits of thermal mass are mostly lost.

NREL/PIX 11420

Design Tools

The Overview section of this chapter discusses methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass walls, because of the time delays and dynamic effects inherent with this type of construction.

Design Details

- For framed walls in cold climates, provide a continuous vapor barrier on the inside surface of walls. However, for hot, humid climates and air-conditioned buildings, the vapor barrier should be placed on the exterior. If the vapor barrier that comes with batt insulation is used, then the paper or foil should be stapled to the face of the studs, not the inside. This will provide a more secure and continuous vapor barrier and will reduce compression of insulation.
- Provide a continuous air barrier that is durable or maintainable. Provide details that demonstrate how it is tied to the foundation, windows, and doors; between different wall systems; to the roof; across construction, control, and expansion joints; and to wall, floor, and roof utility, pipe, and duct penetrations.
- For wood framing in the Hot and Dry, Cool and Humid, and Cool and Dry climates, use 2x6 framing. The studs should be spaced at 24 in. on center (o.c.), the headers over doors and windows should be insulated with rigid insulation, and minimum wood framing should be used at corners, wall intersections, and openings.
- EIFS systems used with mass walls should be installed according to manufacturers' instructions. Make sure that the exterior finish is durable and weather resistant. Include a drainage plane to prevent moisture from being trapped in the wall.
- Electrical and mechanical equipment should be minimized for exterior walls. Equipment such as electrical outlets and other recessed equipment can create thermal bridges and increase infiltration. If insulation is used in stud cavities, exterior wall outlet boxes should be provided with air-tight back boxes that are sealed both around wires and to the gypsum wall board. Outlets can also often be located on wing and interior walls.
- For wood-framed walls, use wood products that are produced through environmentally friendly forest practices. Require that framing members be certified by the Forest Stewardship Council.
- For metal-framed walls, specify that the steel used for manufacturing have 30% recycled content.
- Seal drywall at the top and bottom of the walls to ensure a continuous air barrier.

Operation and Maintenance Issues

Exterior and interior wall finishes must be maintained. The interior finish should be maintained for aesthetic reasons, but also light colors should be maintained to enhance the performance of the electric lighting and daylighting systems. Exterior surfaces should be maintained to be waterproof or water resistant and secure. This is important to prevent water from entering construction cavities, which can cause the growth of mold, damage the structure, and deteriorate the performance of thermal insulation. Mold can be a major source of indoor air quality problems and needs to be avoided. All wall systems must be designed to let moisture that may enter from the wind-driven rain to escape back out.

Commissioning

No commissioning of exterior walls is needed other than normal construction administration.

References/Additional Information

See this chapter's Overview.

GUIDELINE EB2: ROOF INSULATION

Recommendations

Insulation Entirely Above Deck. Install R-20 insulation above the structural deck. The thickness of the insulation will depend on the type of insulation that is used.

Attic and Other Construction. Install R-38 insulation in all climates except the Cold and Humid climate, where R-60 insulation should be used.

Description

The construction of roof assemblies affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood-framed, steel-framed, or mass) is usually determined by the size and height of the building, requirements for fire separation between spaces, durability, or other issues. The recommended insulation levels for these classes are based on life-cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates, with less in more temperate climates.

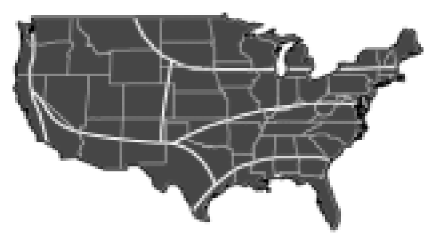
Concepts of thermal heat transfer are presented in the Overview to this chapter and should be reviewed, since they apply to roofs as well as other building enclosure components.

Applicability

This roof insulation guideline is applicable for all spaces in schools that are heated or cooled. The class of construction is usually determined in schematic design, but the insulation level can be set in design development or even contract documents.

Well-insulated roofs and roof cavities can reduce drafts and thermal loads in buildings. NREL/PIX 11421

Applicable Climates



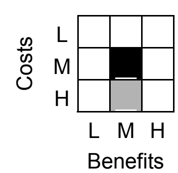
Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Integrated Design Implications

Well-insulated roofs and roof cavities can reduce drafts and thermal loads in buildings. HVAC ducts located in ceiling cavities can be leaky and can be a significant component of thermal loads. These losses are far less significant when ducts are located in sealed and insulated ceiling cavities. Reduced loads can result in smaller HVAC equipment and reduced costs.

Cost Effectiveness



The cost of roof insulation varies with the class of construction. Insulating attics and the cavity of wood- and steel-framed roof assemblies is low since labor is minimal and the roof cavity is readily accessible during construction. Rigid insulation installed over structural decks is more expensive because of construction details and the added cost of rigid insulation.

Benefits

Insulating roofs and ceilings has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

Design Tools

This chapter's Overview discusses methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass roofs.

Design Details

- For attics with sloped roofs, make sure that the insulation over the ceiling has full depth all the way to the edge. This may mean installing a raised heel truss or other special construction techniques. There are two reasons for this. The first is to provide a continuous and effective thermal barrier, but another equally important reason is to assure that the temperature of the roof is constant. If the insulation is thinner near the edge, then more heat escapes at the eave. This can cause snow to melt near the eave, only to freeze again as an ice dam. This can cause water leakage as well as structural damage to the roof and building.
- Do not locate heat-producing equipment such as furnaces, water heaters, or air handlers in attics because these can cause uneven roof temperatures that could result in ice dams (see above).
- Insulation should not be installed in exposed applications or in return air plenums. If no other location is possible, it should be either encapsulated or otherwise sealed from contact with moving air. It should never be left exposed.
- Make sure that insulation is dry before walls or other cavities are enclosed. Moisture in building cavities can be a source of mold, which can cause building damage and indoor air contamination.
- Do not install insulation over suspended ceilings, because the insulation's continuity is likely to be disturbed by maintenance workers. Also, a suspended ceiling is a poor barrier to infiltration. If the insulation is located at the ceiling, many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior. If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be worsened.
- Use type IC light fixtures in insulated gypsum board ceilings.
- Consider recycled insulation materials for attics and other places where loose-fill insulation is used. If cellulose (recycled paper) is used, make sure that the chemicals used as a fire retardant contain no VOCs and are not a possible source of pollution.

Operation and Maintenance Issues

The roof membrane must be maintained to prevent moisture from entering. Moisture in ceiling/roof constructions is a source of mildew, which causes serious indoor air quality problems. Insulation materials themselves require no maintenance. Roof drainage systems must be maintained on low-pitch roofs.

Commissioning

No commissioning is needed for roof insulation systems.

References/Additional Information

See this chapter's Overview.

GUIDELINE EB3: COOL ROOFS

Recommendation

In air-conditioned buildings, use a roof surface that is light in color (high reflectance), yet has a non-metallic finish (high emissivity). Asphalt roofs with a cap sheet and modified bitumen roofs should be coated with a material having an initial reflectance greater than 0.7 and an emittance[1] greater than 0.8. Single-ply roofing material should be selected with the same surface properties.

Description

Solar gain on roofs is a significant component of heat gain, and using materials that have a high reflectance and a high emittance can significantly reduce the load. The high reflectance keeps much of the sun's energy from being absorbed. The high emittance allows radiation to the sky. Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single-ply and liquid-applied. Examples of single-ply products include:

- White PVC (polyvinyl chloride)
- White CPE (chlorinated polyethylene)
- White CPSE (chlorosulfonated polyethylene, e.g. Hypalon)
- White TPO (thermoplastic polyolefin).

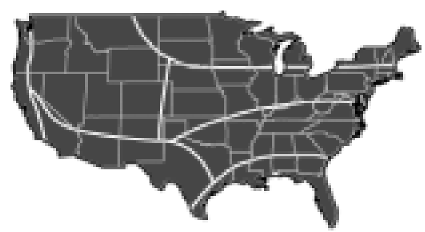
Liquid-applied products may be used to coat asphalt cap sheets, modified bitumen, and other substrates. Products include:

- White elastomeric coatings
- White polyurethane coatings
- White acrylic coatings
- White paint (on metal or concrete).

Cool roofs are becoming available in different colors. Table 7 shows reflectance and emittance for some typical roofing products.

Because solar gain on roofs is a significant component of heat gain, using materials that have a high reflectance can significantly reduce the load. NREL/PIX 03510

Applicable Climates



Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

[1] Heat radiated from a roof surface is proportional to the 4th power of the absolute temperature and depends on emittance. Emittance is the ratio of radiant heat flux emitted by a specimen to that emitted by a black body at the same temperature and under the same conditions.

Table 7 – Solar Reflectance and Emittance of Different Roofing Materials.

Source: Berdahl and Bretz 1995, Akbari 1990, Parker et al. 1993, LBNL Cool Roofing Materials Database

	Material	**Total Solar Reflectance**	**Emittance**
Reflective Coatings	Elastomeric coating over asphalt shingle	0.71	0.91
	Aged elastomeric on plywood	0.73	0.86
	Elastomeric coating on shingle	0.65	0.89
	Aluminum pigmented roof coating	0.30 - 0.55	0.42 - 0.67
	Lo-mit on asphalt shingle	0.54	0.42
White Metal Roofing	Siliconized white	0.59	0.85
Single-Ply Roof Membrane	Black EPDM	0.06	0.86
	Grey EPDM	0.23	0.87
	White EPDM	0.69	0.87
	White T-EPDM	0.81	0.92
Paint	White	0.85	0.96
	Aluminum paint	0.80	0.40
Asphalt Shingles	Black	0.03 - 0.05	0.91
	Dark brown	0.08 - 0.10	0.91
	Medium brown	0.12	0.91
	Light brown	0.19 - 0.20	0.91
	Green	0.16 - 0.19	0.91
	Grey	0.08 - 0.12	0.91
	Light grey	0.18 - 0.22	0.91
	White	0.21 - 0.31	0.91

Note: Shaded products all have a reflectivity greater than 0.70 and an emittance greater than 0.80.

Applicability

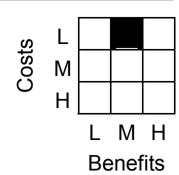
Cool roofs are applicable to all spaces in schools and to most climates. The benefits are less, however, in the Cool and Humid and Cold and Humid regions. To take advantage of equipment downsizing, cool roofs should be considered in the schematic design phase.

Integrated Design Implications

Cool roofs can significantly reduce cooling loads, resulting in smaller air conditioning equipment or, in some cases, eliminating air conditioning entirely in favor of natural ventilation. Like all roofing systems, skylights and other roof penetrations, as well as the rooftop equipment mounts, should be considered when designing the roof. Equipment access should be provided in a manner that does not create undue wear or damage to the roof membrane.

Cost Effectiveness

The additional cost for coating an asphalt cap sheet or modified bitumen roof is about \$1/ft² to \$2/ft². The cost premium between a conventional single-ply roof membrane and one with a high reflectance (all have high emittance) is negligible.



Benefits

Cool roofs can save demand charges and energy charges. They are highly cost effective, especially in the Hot and Dry climate. However, there are other benefits as well. Since solar radiation (especially ultraviolet light) is a major cause of roof deterioration, cool roof coatings can significantly increase the life of the roof membrane. Cool roofs also can help make the whole community cooler by reducing the “heat island” effect.

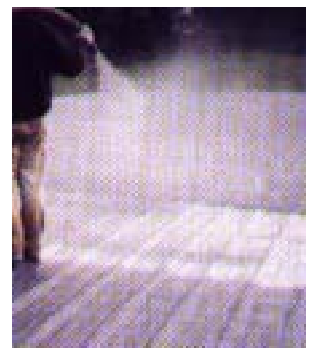
Design Tools

Cool roofs are effective for several complex reasons. They reflect heat from the sun, and assessing this benefit requires a model that accounts for the position and intensity of the sun. Sun that is absorbed by the roof (that which is not reflected) increases the surface temperature of the roof and induces heat gain in addition to that driven by temperature differences. At night and at other times, hot roof surfaces radiate heat to the cool night sky. This is a valuable benefit that requires knowledge of the roof surface temperature and the sky temperature. Because of the complexity of heat transfer related to cool roofs, energy simulation programs are necessary to accurately assess their benefits and must be tailored for the scheduled use of this particular school to accurately reflect energy savings.

Oak Ridge National Laboratory's Radiation Control Calculator can be used to estimate energy savings. See http://www.ornl.gov/roofs+walls.

Design Details

- The performance of cool roofs is affected by the accumulation of dirt. Dirt accumulation can be reduced if roof surfaces slope at least 0.25 in./ft.
- When liquid-applied coatings are used, carefully select coatings that are compatible with the underlying substrate.
- Liquid-applied cool roof coatings should comply with ASTM Standard 6083-97 for durability and elongation and have a minimum thickness of 20 mils.



Elastomeric or other coating can be field applied to many roof substrates.

NREL/PIX 11472

Operation and Maintenance Issues

To assure continued performance of cool roofs, they will need to be cleaned each year with a high-pressure water spray. (Verify that doing this does not void the product warranty.) Liquid-applied coatings may need to be refinished every five years or so.

Commissioning

No commissioning is needed.

References/Additional Information

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Simpson, J. R. and E. G. McPherson. 1997. "The Effects of Roof Albedo Modification on Cooling Loads of Scale Model Residences in Tucson, Arizona." *Energy and Buildings*, Berkeley, CA. Vol. 25, pp. 127 - 137.

Taha, H. 1997. "Urban Climates and Heat Islands: Albedo, Evapo-transpiration, and Anthropogenic Heat." *Energy and Buildings*, Berkeley, CA. Vol. 25, pp. 99 - 103.

U.S. Environmental Protection Agency. 1998. Roof Products MOU - Version 1.0.

GUIDELINE EB4: RADIANT BARRIERS

Recommendation

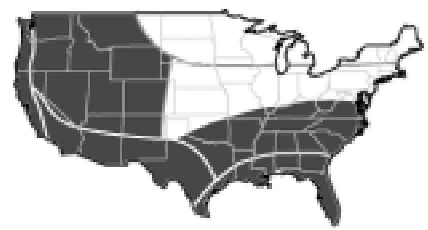
Use a radiant barrier in conjunction with attic construction in schools in all climates except for the Cool and Humid and Cold and Humid climates.

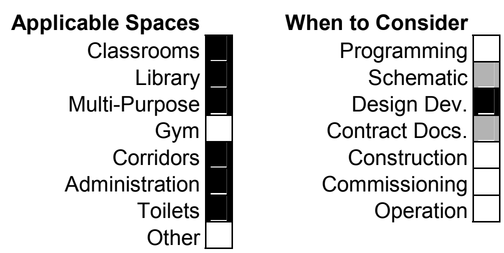
Description

A radiant barrier is a surface with a low emittance that is installed at the ceiling of attics. The radiant barrier surface is usually aluminum foil or another shiny metallic finish that has a low emittance. A couple of installation methods exist. The least costly method is to use plywood or composition board with a film that is pre-applied to the board. An alternate, but more effective method, is to drape foil over the rafters before the sheathing is installed (see photo).

Radiant barriers are recommended for hot and coastal climates, over spaces cooled by air conditioners or natural ventilation. NREL/PIX 11331

Applicable Climates





Radiant barriers are effective because they reduce one of the major components of heat gain, which is radiation from the hot attic ceiling to the cooler attic floor. The amount of heat that is radiated from the attic ceiling to the floor is directly proportional to the emissivity of the surfaces. Uncoated plywood and most other conventional building materials have an emittance of about 0.8, while the surface of a radiant barrier has an emittance of around 0.1. The radiation component of heat transfer can, therefore, be as much as eight times lower than without a radiant barrier.

Radiant barriers are effective in reducing cooling loads, but not heating loads. Radiant barriers can also improve the system efficiency of HVAC air distribution ducts that are located in attics. Duct losses during cooling mode are proportional to the temperature difference between air inside the duct and the temperature of the attic. Radiant barriers reduce the temperature of the attic during cooling conditions, and therefore, duct system efficiency is improved.

Applicability

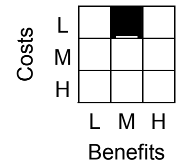
Radiant barriers are highly recommended in the hot climates. They can also be effective in coastal climates. They are recommended for attics over any spaces that are cooled by air conditioners or natural ventilation. Radiant barriers should be considered no later than the design development phase so that the HVAC equipment may be appropriately downsized.

Integrated Design Implications

Radiant barriers directly reduce cooling loads, which can result in smaller air conditioners. HVAC air duct efficiency is also improved when air distribution ducts are located in attics.

Cost Effectiveness

When applied to sheathing, the cost premium for radiant barriers is on the order of \$0.10/ft² to \$0.15/ft². Cost is a little higher for draped installation, mainly because additional labor is required.



Benefits

Radiant barriers reduce cooling loads and energy costs. They can also result in smaller air conditioners, which can more than compensate for the added cost of the radiant barrier. Attics where radiant barriers are installed have a lower temperature, which results in improved HVAC duct efficiency and other benefits.

Design Tools

Estimating the benefits of radiant barriers can be approximated by making an adjustment to the U-factor of the ceiling/roof construction. The problem with this approach is that radiant barriers only have a benefit in reducing cooling loads. In fact, they can have a slightly negative effect on heating loads, since solar gains are reduced, which might be useful when schools are in a heating mode. The most accurate way to evaluate radiant barriers in attics is to use an hourly simulation model where the attic itself is modeled as a separate, unconditioned thermal zone, and where radiation transfer can be explicitly modeled. The only models with these capabilities are for research purposes and are difficult for practitioners to use. However, the U.S. Department of Energy released a tool called EnergyPlus, which has these capabilities. Version 1.0 was released in April 2001.

Design Details

- Choose radiant barrier surfaces that have an emittance less than 0.1, when tested in accordance with ASTM E408. When comparing products, select a product with the lowest emittance. Some have an emittance as low as 0.05.
- Install radiant barriers so that the shiny surface faces down to prevent dirt from accumulating on the surface. Dirt can depreciate performance.
- When using radiant barriers that are pre-applied to sheathing, make sure that care is taken to not damage the surface during shipping and installation.
- When using the draped method of installation, let the radiant barrier sag about an inch from the sheathing, creating an additional air gap. This accounts for the improved performance of the draped installation method.

Operation and Maintenance Issues

Radiant barriers rarely require any maintenance, unless they are damaged while other maintenance work is being performed in an attic.

Commissioning

No commissioning is necessary.

References/Additional Information

Ross Middle School, Ross, CA. Architect: Esherick Homsey Dodge & Davis.

U.S. Department of Energy, Radiant Barrier Fact Sheet, June 1991. Prepared by Oak Ridge National Laboratory.

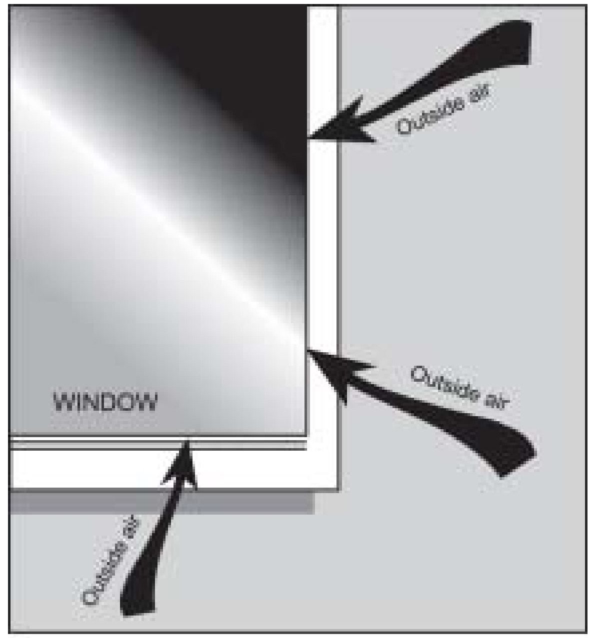
GUIDELINE EB5: AIR BARRIERS AND OTHER METHODS TO REDUCE INFILTRATION

Recommendation

Design and construct the building envelope to limit the uncontrolled entry of outside air into the building. This is achieved through building envelope sealing (caulking and weather stripping), specifying windows and doors that have been tested to have low rates of infiltration, and by using air lock entries in cold climates.

Recommendation

Design and construct the building envelope to limit the uncontrolled entry of outside air into the building. This is achieved by providing a continuous air barrier on roof and walls, tied to all adjacent materials including windows, doors, and penetrating pipes or ducts. Specify windows and doors that have tested, low rates of infiltration and are appropriately weather sealed. Install airlock vestibules at all major entries.

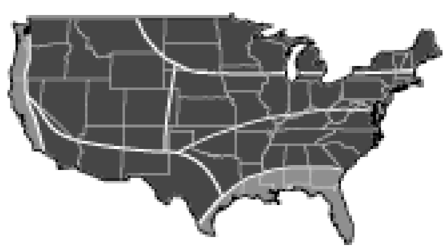


Reducing entry of outside air into a building can be beneficial in preventing energy loss.

Description

Controlling infiltration is very important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semi-heated spaces. In the winter, it also causes buildings to become very dry. In climates with moist outdoor conditions during the day or night, it is also a major source of latent heat. Latent heat must be removed by the air-conditioning system at considerable expense. The ASHRAE 90.1-2001 Standard has requirements for sealing building envelope elements, infiltration through doors and windows, air seals at loading dock doors, and vestibules to limit infiltration at main entrance doors to buildings.

Applicable Climates



Applicable Spaces
Classrooms
Library
Mulit-Purpose / Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Applicability

Schools in all climates should be sealed to reduce infiltration, but it is especially important in the more harsh climates such as the Cool and Humid, Cold and Humid, Cool and Dry, and Hot and Dry climates. The recommendations apply to all spaces in schools. Sealing and infiltration control should be first considered in the design development phase, but details should be specified in the contract documents. Tight construction is mainly a matter of care during construction and should be verified during construction as well as during the commissioning phase.

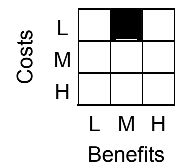
Integrated Design Implications

Poorly sealed buildings can cause problems for maintaining comfort conditions when additional infiltration loads exceed the HVAC design assumptions.

Integrated Design Implications

Uncontrolled air infiltration carrying untempered air as well as high moisture levels is the main source of water condensation in walls leading to mold and mildew. Poorly sealed buildings also waste energy and can compromise the ability of building systems to maintain comfortable conditions when additional infiltration loads exceed the HVAC design assumptions.

Cost Effectiveness



The cost of controlling infiltration is minimal. Mainly it is a standard of care that must be exercised during the construction phase.

Benefits

Controlling infiltration makes it easier to balance and maintain HVAC systems. Energy costs are also reduced in a cost-effective manner.

Benefits

Controlling air infiltration saves energy and improves indoor environmental quality. Uncontrolled air infiltration carrying untempered air, as well as high moisture levels, is the main source of water condensation in walls leading to mold and mildew. Poorly sealed buildings also waste energy and can compromise the ability of building systems to maintain comfortable conditions when additional infiltration loads exceed the HVAC design assumptions.

Design Tools

All energy calculation methods are capable of accounting for infiltration in some manner. Some use an air-changes-per-hour method, while others are based on the concept of an effective leakage area. Many hourly simulation methods are capable of modeling infiltration using either calculation method.

At the start of the air barrier construction process, the Air Barrier Association of America (ABAA) recommends a review of design intent between designers and contractors. A mockup or in-place sample of construction should be visually and quantitatively tested for air leakage in accordance with ASTM standards, and bond adhesion tests should be performed on air-barrier membrane systems.

During construction, air leaks can be detected and repaired through pressurization tests, often called blower door tests. With this procedure, a building or space is pressurized with a large fan that is usually mounted in the door (thus, blower door). The space is pressurized to about 50 Pascals of pressure and leakage is measured. The location of leaks can be identified using smoke sticks. These tests are difficult on typical large schools facilities that may be well over 100,000 ft^2 and require many zones for testing and the installation of temporary infiltration barriers between zones. For this reason, the ABAA recommends the smaller in-place sample testing which makes greater improvements at a lower cost at a time when improvements are practical, even though it does not measure total performance.

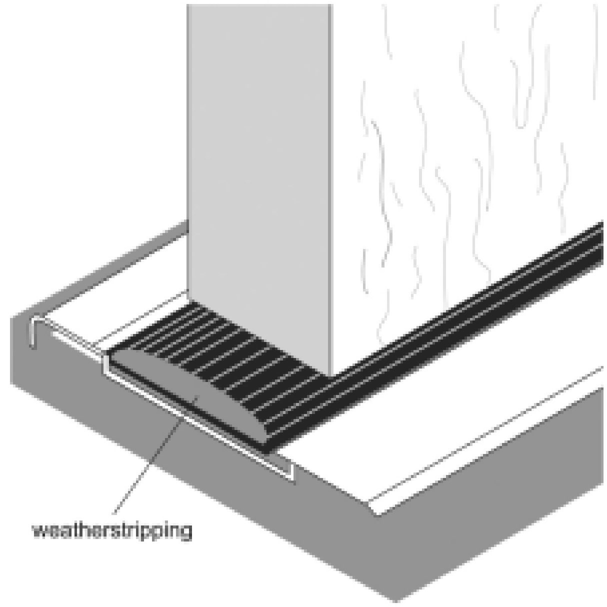
Design Details

Air barriers must:

- Be continuous with airtight joints
- Be capable of withstanding positive and negative pressure without damage or displacement (polyethylene sheets flapping in the breeze are no longer acceptable)
- Transfer all loads to the structure
- Be durable or maintainable
- Be joined in an airtight and flexible manner to all adjacent materials
- Use material with an air permeability not to exceed 0.004 cfm/ft^2 under a pressure of 1.57 psf.

ABAA recommends the installed and tested system not exceed five times the allowable air leakage rate of .004 cfm/ft^2 at 1.57 psf.

Doors and access openings leading to shafts, stairwells, and elevator lobbies need to be equipped with weatherseals.



Door weatherstripping is one method for reducing infiltration.

Operable dampers that penetrate the air barrier, such as at mechanical equipment air intakes or elevator shaft louvers, are required to be airtight.

Recessed light fixtures installed in the building envelope are required to be insulation cover-rated and to meet air infiltration standards.

Building Envelope Sealing

Exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed. The construction drawings and specifications should require the sealing, but special attention is needed in the construction administration phase to assure proper workmanship. A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Special attention should be paid to several areas of the building envelope including:

- Joints around fenestration and door frames
- Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels
- Openings at penetrations of utility services through roofs, walls, and floors
- Site-built fenestration and doors
- Building assemblies used as ducts or plenums
- Joints, seams, and penetrations of vapor retarders
- All other openings in the building envelope.

Standard 90.1 also has requirements for limiting infiltration through mechanical air intakes and exhausts. These requirements are addressed in the mechanical section (§ 6) of the Standard, not in the building envelope section.

Fenestration and Doors

Fenestration products, including doors, can significantly contribute to infiltration. Most fenestration products should have an infiltration rate less than 0.4 cfm/ft². For glazed entrance doors that open with a swinging mechanism and for revolving doors, the infiltration should be limited to 1.0 cfm/ft². Infiltration rates should be verified with NFRC 400. A laboratory accredited by the NFRC or other nationally recognized accreditation organizations must perform the ratings.

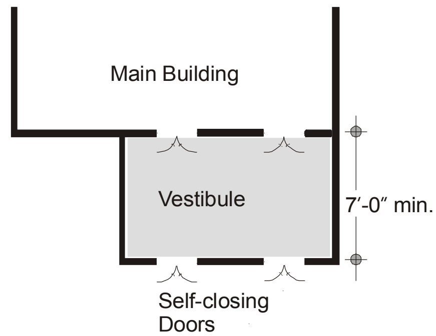


Figure 4 – Vestibule Diagram

Vestibules

In cold climates, vestibules should be created at the main entrance to schools. All the doors entering and leaving the vestibule must be equipped with self-closing devices and the distance between the doors should be at least 7 ft.

Operation and Maintenance Issues

Weatherstripping around doors and other openings must be maintained and replaced every 5 to 10 years. Caulking in exposed locations will need to be replaced or touched up each time the exterior of the school is painted.

Air barriers are to be durable or maintainable, according to MSBC. Since most air barriers are permanently installed within the interior of a wall or roof system where maintenance is not possible, they should be durable for the expected life of the building and not require any maintenance.

Commissioning

See the Design Tools section above for construction-phase quality assurance procedures. It is critical to complete the majority of quality assurance work before construction ends. If commissioning work, such as blower door testing, is completed too late in the project, it is often too late to correct any issues, beyond ripping walls down and rebuilding them. The commissioning agent should verify that weather stripping, expanding foam sealants, spray foam sealants, contractors sealing tape, and caulking is properly installed. Fenestration products should be labeled by NFRC to enable easy field verification of the specified infiltration requirements.

References/Additional Information

See this chapter's Overview.

GUIDELINE EB6: CONCRETE MASONRY

Recommendation

Specify colored concrete masonry for concrete masonry unit (CMU) wall applications.

Description

CMU construction is high-strength, fire-resistant, durable, and economical. Improvements in manufacturing and quality control of colored concrete masonry assure greater CMU uniformity and color consistency, reduced porosity, and reduced shrinkage. In addition, high-performance water repellents can be applied to walls or added to the concrete and mortar mixes so that it is unnecessary to paint or coat the units with block-filler to avoid water penetration.

Applicability

All climates.

Integrated Design Implications

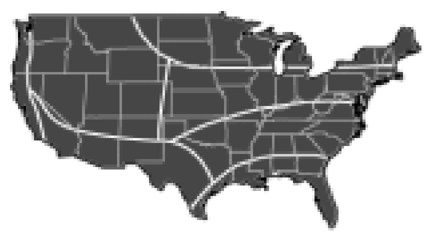
Recycle waste CMUs, if possible, and require the supplier/subcontractor to take them back for recycling.

Cost Effectiveness

The first cost of masonry walls is considerably more than for traditional, framed walls. In cold climates, masonry walls exposed to the exterior must be insulated, entailing additional cost in materials and labor. However, not having to paint or coat a colored CMU wall saves time and money during construction, and additional savings accrue throughout the lifetime of the building since colored concrete is a permanent material that requires little or no maintenance.

The concrete masonry unit used at this market had considerably lower first costs than would traditional, framed walls. NREL/PIX 11412

Applicable Climates

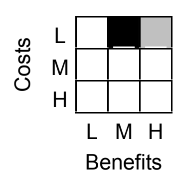


Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	□

Benefits

Masonry is a material-efficient, high-strength, durable material with high fire resistance and low maintenance requirements. The integral color pigments typically used in colored CMU are non-toxic and contain none of the solvents associated with painting and re-painting.



Design Tools

See Design Tools listed in this chapter's Overview and:

American Concrete Institute ACI 530.1, *Specifications for Masonry Structures*

ASTM C90, *Specification for Loadbearing Concrete Masonry Units*

ASTM C270, *Specification for Mortar for Unit Masonry*

ASTM C979, *Pigments for Integrally Colored Concrete.*

Design Details

In general, colored CMU is specified and installed in the same way as other high-quality masonry construction.

To assure uniform colors, all CMU used on a particular project should be produced with consistent manufacturing and curing techniques and with cement and aggregates from a single source. Pigments should comply with ASTM C979 Pigments for Integrally Colored Concrete, which establishes criteria for the pigment's resistance to weather and light and its compatibility with concrete. Mortar can be tinted with the same pigments used in the CMU to match or complement the hue of the masonry units. Some variation in appearance is a normal design feature of CMU and mortar, whether colored or not. Mortar lightens as it cures; allow up to 28 days for this process.

Specify the submittal of samples showing the range of each CMU to be used on the job. On jobs with critical appearance tolerances or unique requirements, specify a mock-up to demonstrate that the materials and workmanship to be used will produce the desired results.

Efflorescence, a white crystalline deposit that can form on concrete surfaces, can be especially visible on colored CMU surfaces. To minimize the potential for efflorescence, detail and build the wall to avoid penetration of water into the masonry, and keep the top of the wall covered when work is stopped.

Efflorescence is easiest to remove if it is cleaned promptly after it appears. A water-repellent or clear glaze coating also can help reduce water penetration; test any surface-applied treatment or coating before proceeding with the application to determine the effect on masonry appearance. Caulking materials used to seal joints can be specified in colors to match the masonry.

Operation and Maintenance Issues

Colored concrete is a permanent material that normally requires little or no maintenance. Sandblasting will remove graffiti.

Commissioning

None.

References/Additional Information

American Concrete Institute (ACI), PO Box 9094, Farmington Hills, MI 48333-9094. Tel: (248) 848-3800. Fax: (248) 848-3801. Web site: http://www.aci-int.org/.

National Concrete Masonry Association (NCMA). 2302 Horse Pen Road, Herndon, VA 20171-3499. Tel: (703) 713-1900. Fax: (703) 713-1910. Web site: http://www.ncma.org/. The web site provides a list of certified masonry consultants.

LIGHTING AND ELECTRICAL SYSTEMS

Electric lighting is one of the major energy consumers in schools. Enormous energy savings are possible using efficient equipment, effective controls, and careful design. Using less electric lighting reduces heat gain, thus saving air-conditioning energy, increasing the potential for natural ventilation, and reducing the space's radiant temperature (improving thermal comfort). In cold, predominately heating climates, reducing electric lighting use does decrease heat gain from lights, which in turn, increases conventional energy use for space heating during the winter. However, this increase in heating energy is more than made up for in electrical savings. Electric lighting design also strongly affects visual performance and visual comfort by aiming to maintain adequate, appropriate illumination while controlling reflectance and glare. Finally, visual and accessible light and power meters can educate students and faculty about how lighting systems and energy controls work.

This chapter provides guidelines for:

OVERVIEW

This section outlines lighting quality, lighting technology, lighting energy use, and other important lighting issues such as design criteria, maintenance, and commissioning. These factors all affect the design, installation, and maintenance of lighting systems in different school building spaces.

Visual Tasks in Schools

Common Visual Tasks

School visual tasks vary in terms of size, contrast, viewing angle, and distance. Many of these activities require close attention for prolonged periods of time. Critical visual tasks common to all school environments include:

- Writing
- Reading printed material
- Reading material on visual display terminals (VDTs)
- Reading from blackboards, whiteboards, overhead and video projections, and bulletin boards.

Additional School Tasks

In addition to the reading and writing visual tasks common to all school environments, several more specialized activities may occur in specific circumstances, which require specialized lighting equipment and design. Examples include:

- Drawing, painting, and other artwork
- Laboratory work
- Food preparation
- Performance activities, such as dramatic productions and debates
- Sports
- Home economics activities, including sewing and cooking
- Industrial education activities, such as metal shop and wood shop.

One notable difference between schools and other environments is that students must constantly adapt their vision between “heads-up” and “heads-down” reading conditions. Copying a homework assignment from the blackboard into a notebook, for instance, requires the eyes to adjust for differences in visual target size, distance, contrast, and viewing angle. To create comfortable and productive spaces, the lighting design must address the quality of the entire visual environment instead of merely accounting for horizontal illuminance, as is too often the case.

Lighting Quality Issues

Lighting in schools should provide a visual environment that enhances the learning process for both students and teachers, allowing them to perform their visual tasks quickly and comfortably. Several lighting quality issues important in school lighting are outlined below. Table 1 provides information about the relative importance of various lighting quality issues for specific school spaces.

Table 1 – Lighting Quality Issues for Sample School Building Spaces

	General Classroom	Computer Classroom	Multipurpose Classroom	Corridor
Control of Direct and Reflected Glare	Important	Very Important	Important	Somewhat Important
Light on Walls and Ceiling	Very Important	Very Important	Very Important	Important
Fixture Location Related to People	Important	Very Important	Important	Somewhat Important
Light Patterns – Uniformity vs. Shadows	Important	Very Important	Important	Somewhat Important
Daylight	Important	Somewhat Important	Important	Important
Color Rendering and Color Temperature	Important	Important	Important	Important
Lighting Controls, Flexibility	Very Important	Important	Very Important	Somewhat Important

● Very Important ◉ Important ○ Somewhat Important

Quantity of Light

In design, the quantity of light is measured in footcandles, taken in the horizontal plane at the task. IESNA publishes illumination level recommendations. With the ninth edition of the *IESNA Lighting Handbook (2000)*, IESNA revised its recommended lighting design procedure and issued the latest recommendations for horizontal illuminance. For most typical classroom and office reading tasks, the current recommended light level is 30 footcandles, as shown in Table 2. However, because some classroom tasks may justify up to 50 footcandles, choosing a level between 30 and 50 is an excellent compromise. Exceptions include art classrooms, shops, laboratories, and other spaces where tasks may require light levels as high as 70 to 100 footcandles.

Even if designing electric light levels for 30 to 50 footcandles of electric illumination, higher light levels – up to about 150 to 200 footcandles under peak solar conditions – can be provided by properly designed daylighting systems in most classrooms. (Computer labs and similar spaces are the exception – high daylight levels cause visual difficulties, so daylight, if introduced at all, should be done carefully and at very low light levels.) To take advantage of natural light, electric lighting systems should be dimmed or extinguished to fully harvest the energy and maintenance savings.

Previously, many published school lighting design guides recommended much higher levels, but the combination of better visual materials and other media, such as video and computer, permit current light level standards. Designers taking advantage of the latest light level recommendations can specify lighting systems that use less energy and require less maintenance than designs performed to older standards.

Note that lower lighting levels (15 to 30 footcandles) are suggested for computer classrooms. Moreover, providing a low ambient light level (5 to 10 footcandles) and task lighting is often preferred for computer spaces.

Table 2 – IESNA Recommended Illuminance Levels

Category	Description	Recommended Illuminance (fc)
Orientation and Simple Visits	Public spaces	3 fc
	Simple orientation for short visits	5 fc
	Working spaces where simple visual tasks are performed	10 fc
Common Visual Tasks	Performance of visual tasks of high contrast and large size	30 fc
	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	50 fc
	Performance of visual tasks of low contrast and small size	100 fc
	Performance of visual tasks near threshold	300 – 1,000 fc

Source: *IESNA Lighting Handbook, 9th ed. (2000), p. 10-13*

Lighting Quality

IESNA's current lighting design procedure consists of a six-step process that emphasizes the relative importance of numerous design issues for specific applications. In addition to issues such as color appearance, daylighting integration and control, luminances of room surfaces, and many others, topics addressed include vertical illumination, glare control, uniformity, and color rendering.

Vertical Illumination. Vertical illumination is one of the more critical design issues in school lighting. With the exception of desktop reading, many school visual tasks are "heads-up" type activities, requiring proper vertical illumination of chalkboards and other displays. In addition, the perception of what comprises lighting quality is strongly influenced by vertical illumination. For example, wall illumination is a critical factor in the sense of brightness and cheerfulness of a room. In nighttime environments, vertical illumination that promotes facial recognition is important in creating a sense of safety and security. Appealing vertical illumination promotes the important school activity of social communication.

Glare Control. Light sources that are too bright create uncomfortable glare. In extreme cases, direct or reflected glare can also impair visual performance by reducing task visibility. In such a case, fatigue results from the eye having to work much harder to perform. All sources of light, including daylight, must be carefully controlled to avoid causing discomfort or disabling glare. Common glare problems in classrooms include uncomfortable overhead glare from direct distribution luminaires, reflected luminaire imaging on VDTs and whiteboards, and direct glare from uncontrolled windows or skylights. Very bright sources, such as T-5 straight, twin tube, and T-5HO straight lamps, should only be used in high spaces like gyms, or in cove lighting and indirect luminaires in ordinary classrooms and other spaces. Indirect and direct/indirect lighting systems tend to provide superior glare control as compared to more conventional, direct lighting systems.

Uniformity. For the most part, building spaces should be as uniformly illuminated as possible, avoiding shadows or sharp patterns of light and dark. For classrooms, luminance contrast ratios between the visual task and its immediate surround should not exceed 3:1, and contrast between the brightest surfaces in the visual field and the visual task should not exceed 10:1. Higher ratios contribute to fatigue because the eye is constantly adapting to differing light levels. Recessed or surface-mounted parabolic fixtures should be avoided in most spaces, because they block light from reaching the upper portion of the wall and create a shadowy, cave-like environment. Exceptions might include lighting systems for theaters and social spaces in the school, where a downlighting system might be used to create a dramatic atmosphere.

Maximize overall lighting uniformity by following guidelines for maximum spacing of luminaires. The best method of maximizing uniformity is to make a concerted effort to light vertical surfaces, as well as the ceiling (using indirect or indirect/direct luminaires) whenever possible. Using light-colored, diffuse surface materials also optimizes lighting uniformity.

Color Rendering. Light sources that render color well enhance the visual environment. Light sources should have a minimum color-rendering index (CRI) of 80 for most interior spaces. Ceramic metal halide lamps, the latest “second generation” T-8 lamps, T-5 lamps, and most compact fluorescent lamps have a CRI in the range of 82 to 86.

Lighting Control Flexibility

Lighting controls should be designed for flexibility to accommodate the varying nature of many school spaces. In addition to saving energy, bi-level or multiple-level switching enables different light levels to respond to changing requirements. Separate circuiting of luminaires in daylit zones also enhances space flexibility and energy savings. Control flexibility improves lighting energy performance by encouraging the use of lights that are only needed for the activity at hand.

Control flexibility is especially important in classrooms, which typically must be responsive to varying illumination schemes due to a wide variety of conditions and activities that occur. It is critical that teachers have the ability to override any automatic dimming and/or occupancy sensor controls, so that they can switch the lights off manually when necessary.

In multi-purpose spaces, several different lighting control schemes may need to be designed to account for all the different activities. In these cases, it may make sense to specify a preset dimming or switching system, allowing one-button scene changing.

Lighting control systems must also be easy to understand and operate. Non-intuitive control interfaces are likely to be ignored at best, and disabled in more extreme cases.

Integration with Daylight

Properly controlled daylight promotes comfort and productivity. To achieve energy savings, electric lights must be turned off (either manually or automatically) when sufficient daylight is available. Many teachers and students are quite conscientious in manually turning off the lights when not needed, but automatic systems tend to result in greater energy savings over the long run.

The first and most important step in integrating electric lighting with daylighting is to make sure that the electric lights are circuited so they can be logically switched off or dimmed in proportion to the presence of daylight in the room. This generally means that the electric lights should be circuited in lines parallel to the daylighting contours in the space. The areas of the room with the most daylight, the space adjacent to windows or skylights for example, should be turned off or dimmed first. A good rule of thumb for daylighting integration: control electric lights with a minimum of three separate circuits in daylighted spaces.

The electric lighting should be designed to provide balanced and sufficient illumination under nighttime conditions, but it should also be circuited to supplement partial daylight when needed on dark days. The electric lighting designer should thoroughly understand the patterns of daylight illumination expected during different times of the day and year, so that the electric lighting design can supplement the daylight, filling in darker areas of the room or highlighting a wall when needed.

The choices of switching versus dimming, and manual versus automatic photosensor controls, are partly cost issues, and partly operational issues. The pros and cons of each are discussed in Guideline EL4: Lighting Controls for Classrooms. Issues of daylighting design are discussed in the following chapter.

Light Sources

A wide variety of light sources are available for schools. Light source selection critically affects building space appearance, visual performance, and comfort. This section outlines the different types of sources available to the designer

Incandescent and Halogen Lamps

Incandescent lamps represent the oldest of electric lighting technologies. Advantages of incandescent technology include point source control, high color performance, instant starting, and easy and inexpensive dimming. Disadvantages range from low efficacy and short lamp life to high maintenance costs.

Incandescent sources should not be used in new schools except in very limited and special accent lighting circumstances. Examples might include dimming applications where color performance, beam control, and/or dramatic effect is critical, such as teleconferencing rooms, theaters, and the highlighting of artwork. In most of these cases, halogen sources, which offer longer life, better point source control, and crisper color performance, are superior to standard incandescent lamps. The most efficient halogen technology is “infrared reflecting” or “IR,” which should be used whenever possible. T-5 or compact fluorescent lamps can also be considered for many accent lighting applications.

Fluorescent Lamps

Fluorescent lamps can and should be used to light nearly all types of school building spaces. They offer long life, high efficacy, good color performance, and low operating and maintenance costs. Fluorescent lamps are typically straight or bent tubes, which limit their use somewhat. Dimming fluorescent lamps require special electronic ballasts that cost more than standard high frequency ballasts.

Several different types of fluorescent lamps are worth noting, as described in Table 3.

Table 3 – Summary of Fluorescent Lamp Technology

Type of Lamp	Advantages/Disadvantages	Applications
T-12	Antiquated technology. Relatively low efficacy. Supplanted by newer technologies such as T-8 and T-5.	Should not be used in new school construction.
Standard T-8 (7xx and 8xx color)	Smaller diameter standard lamps now in general use throughout the world. Offer 10% to 20% higher energy efficiency than T-12 lamps and other performance improvements when used with electronic ballasts. Low-cost lamps and ballasts.	Most general lighting applications in schools, including classrooms, offices, multipurpose rooms, and libraries.
Premium and Super T-8 (8xx color only)	So-called "super" and other "premium" T-8 lamps offer higher color rendition, higher maintained lumens, and a 20% to 50% increase in lamp life over standard T-8s. Energy efficiency can be 10% to 20% greater than standard T-8 lamps depending on brand and type.	Same.
T-5	Similar performance to "super" T-8 lamps, but a more compact lamp envelope (5/8 in. vs. 1 in. diameter). T-5 luminaires should be well-shielded to minimize glare. More expensive than the T-8 lamp and ballast system.	Smaller profile luminaires. Especially effective in indirect luminaires, cove lighting systems, and wall washers.
T-5 High Output (T-5HO)	Light generation per unit length is the highest. Very good energy efficiency, long lamp life, and high optical efficiency. Currently more expensive than T-8 lamp and ballast system.	Smaller profile suspended luminaires for offices and classrooms. Also, for direct "high bay" applications such as gyms.

For schools, the best choices are T-8 premium and super lamps, T-5, and T-5HO lamps. If taken into account during design, the added energy efficiency and longer life of these slightly more expensive lamps more than pay for the initial cost difference.

Fluorescent Ballasts

All fluorescent lamps require a ballast, which is an electric device that starts and regulates power to the lamp. Electronic high frequency ballasts are now standard equipment for most fluorescent sources. In addition to their efficiency advantages, electronic ballasts have minimal flicker and ambient noise, and are available in a variety of *ballast factor* configurations, allowing the designer to "tune" light levels based on the ballast specification.

Consider the following recommendations for fluorescent ballasts.

There are four different ballast types:

- Instant start ballasts, which have high energy efficiency but may reduce lamp life. A standard T-8 lamp operated for more than three hours per start on an instant-start ballast will last about 15,000 hours. However, if the lamp is operated a short time each start (such as when controlled by a motion sensor), lamp life can drop to less than 5,000 hours. Choose instant-start ballasts for locations with constant light operation.
- Rapid-start ballasts, which are increasingly rare because they are less energy efficient and offer no significant lamp life advantages.
- Program start ballasts, which are both energy efficient and significantly reduce the effect of controls and operating cycle. A standard T-8 lamp operated on a program start ballast will last 24,000 hours at three hours per start, and premium or "super" lamps can last as long as 30,000 hours at three hours per start. Equally important, a "super" lamp operated on a motion sensor will still last over 20,000 hours. Note that all T-5 ballasts are program start. Choose program start for all applications, especially those with short-cycle lamp operation.
- Dimming ballasts will be discussed later.
- The "ballast factor" of the ballast, which describes the percentage of rated lamp lumens generated and power used, is variable and can be used to tune lighting systems, especially T-8 lighting systems.

- The standard or “normal light output” (NLO) system produces 87% of the rated light output of the lamp. This is the most common ballast system and it is normally furnished unless otherwise requested.
- In renovation projects, use reduced light output (RLO) electronic ballasts in building spaces lighted with fluorescent lamps where slightly lower light levels will suffice. RLO ballasts produce approximately 75% of rated light output and use 12% to 20% less power than standard NLO ballasts. Applicable spaces might include corridors, rest rooms, and storage areas. In new construction, simply specifying lower wattage fixtures or increasing fixture spacing would result in greater initial construction cost savings as well as energy savings.
- Use high light output (HLO) electronic ballasts where a modest increase in light output is required. A typical HLO ballast produces 115% to 120% of the lamp’s rated light output for a 15% to 20% increase in power, but does not materially affect lamp life. Clever designs can sometimes employ two lamps and an HLO ballast rather than three lamps and an NLO or RLO ballast, permitting the use of a smaller luminaire or simply fewer lamps.

Table 4 – Fluorescent Lamp/Ballast Power and Light Level (Based on Mean Lamp Lumens) Using Generic T-8 Lamp and Ballast as the Reference

For the numbers in parentheses following the lamp name, the first digit represents the Color Rendering Index (CRI) and the final two digits indicate the color temperature.
** Lamps rated 3000 initial lumens and high lumen maintenance*
*** Lamps rated 3200 initial lumens and high lumen maintenance*

Lamps	Type of Ballast	Relative Light	Relative Power
Standard T-8 (735)	NLO instant start	100%	100%
Standard T-8 (735)	RLO instant start	89%	87%
Standard T-8 (735)	HLO instant start	135%	134%
Standard T-8 (835)	NLO instant start	106%	100%
Standard T-8 (835)	RLO instant start	94%	87%
Standard T-8 (835)	HLO instant start	141%	134%
Premium* T-8 (835)	NLO instant start	111%	100%
Premium* T-8 (835)	RLO instant start	99%	87%
Premium* T-8 (835)	HL) instant start	149%	134%
Super** T-8 (835)	NLO instant start	119%	100%
Super** T-8 (835)	RLO instant start	106%	87%
Super** T-8 (835)	HLO instant start	158%	134%
Super** T-8 (835)	RLO program start	100%	80%
T-5 (835)	Program start	125%	100%
T-5HO (835)	Program start	214%	200%

Dimming ballasts for fluorescent lamps require an additional investment, but increase lighting system performance by optimizing space appearance, occupant satisfaction, system flexibility, and energy efficiency. Dimming fluorescent ballasts should be considered in all cases requiring maximum energy performance and light level flexibility. They are particularly effective in daylit classrooms, computer classrooms, audio video rooms, and similar spaces.

Compact Fluorescent Lamps

Compact fluorescent lamps (CFLs) can be used in nearly all applications that traditionally have employed incandescent sources. CFLs offer excellent color rendition, rapid starting, and dimmability. A large palette of different lamp configurations enhances design flexibility. Principal advantages of CFLs over incandescent sources include higher efficacy and longer lamp life. They can be dimmed, though dimming CFL ballasts are expensive. In colder outdoor environments, CFLs can be slow to start and to achieve full light output.

Compact fluorescent lamps can be used in nearly all applications. NREL/PIX06244

Use CFL lamps extensively in task and accent lighting applications, including wall washing, supplementary lighting for visual tasks requiring additional task illumination above ambient levels, and portable task lighting in computer environments. They are also valuable for medium-to-low level general illumination in spaces such as lobbies, corridors, restrooms, storage rooms, and closets. In climates where the temperature does not often drop below 20°F, they are quite suitable for outdoor corridors, step lighting, and lighting over doorways. High wattage BIAX-type CFLs can be used for general space illumination in recessed lay-in troffers (see Luminaires section below), as well as in more decorative direct/indirect luminaires for office lobbies, libraries, and other spaces requiring a more “high-end” look.

High Intensity Discharge (HID) Lamps

HID lamps provide the highest light levels of any commercially available light source and come in a wide variety of lamp wattages and configurations. In addition, they offer medium-to-high efficacy and relatively long lamp life. The principal disadvantage to HID sources is that they start slowly and take time to warm up before coming to full brilliance, making them difficult to use in many automatic lighting control scenarios without expensive two-level switching systems. As a result, these lamps may not work well in daylit interior spaces where lights may be turned on and off. In some applications, such as warehouses and vehicle maintenance areas, this may be cost effective when evaluated from a life-cycle cost perspective, but be prepared for reduced color performance and lamp life if used with metal halide lamps. Dimming HID lamps are expensive and unreliable and are not recommended.

Low Mercury Lamps

Rising concern over mercury disposal has increased the importance of using low mercury content lamps. Low mercury versions of all fluorescent and compact fluorescent lamps, as well as some HID lamps, are available from most manufacturers and should be used. Initial lamp costs may be slightly higher, but when disposed of, these lamps will no longer be treated as hazardous waste with those associated high costs. See the section below on Mercury and Lamp Recycling.

Light Emitting Diodes (LEDs)

LEDs are semiconductor devices that generate an intensely directional, monochromatic light. Research today is directed at producing a commercially viable white LED source. Because selection is mainly limited to red, blue, or green products at this time, using LED as a light source in schools is generally limited to exit and other signs. The principal advantage of LEDs over other sources is their extremely long life. In addition, a two-sided LED exit sign can usually be illuminated with less than 5W.

LEDs are highly recommended for use in school exit signs. They offer high efficacy and very low maintenance costs when compared with either incandescent or fluorescent products, and are available in most of the popular exit sign configurations.

Energy Efficient Choices

Lamps convert electricity (Watts) to light energy (lumens), and most modern lamps require a ballast to regulate the power flow into the lamp. The efficacy of the conversion is measured in lumens of light output divided by Watts of electric power input. The input Watts includes both the lamp and the ballast. **In general, it is best to use the system with the highest possible efficacy that is suited for the project.**

Some electric lamps emit less light as they age, called *lumen depreciation*. Significant improvements in certain lamps make lumen depreciation a very important consideration. Lamps are now rated in *mean lumens per Watt (MLPW),* which better represents the efficacy of the lamp over its life.

Table 5 gives the MLPW for a variety of lamp/ballast systems and may be used to select light sources. Follow it closely to get the best efficacy. For instance, “premium” T-8 lamps are the best overall choice for most applications, and you can use 835 (neutral color), 830 (warm color) or 841 lamps (cool color) and get the same efficacy. But by substituting 735 color (which is cheaper), the MLPW drops to less than 80.

Table 5 – Lamp Application Guidelines

MLPW*	Lamp Type	CRI	Ballast	Good Applications	Limitations
93	T-8 “super” lamps (F32T8/835)	86	Electronic program start	General lighting. The most energy-efficient lighting and longest life system available for most uses.	Not for general exterior lighting; not for very high spaces (20 feet or above).
92	T-5 standard 4’ lamps (F28T5/835)	86	Electronic program start	Specialty lighting such as valences, undercabinet, coves, and wallwash.	Not for troffers; produce a limited amount of light.
90	T-8 premium 4’ lamps (F32T8/835)	86	Electronic instant start (IS)	General lighting. The lowest cost and most efficient system available. Dimmable.	Not for general exterior lighting; not for very high spaces.
87	T-8 premium 8’ lamps (F96T8/835)	86	Electronic IS	General commercial and institutional lighting. Dimmable.	8’ long lamps generally best in large spaces only.
81	T-5HO high output 4’ lamps (F54T5/835)	86	Electronic program start	Indirect office lighting; high ceiling industrial lighting and specialty applications such as coves and wallwash. Gyms. Dimmable.	Very bright lamps should not be used in open fixtures unless mounted very high.
80	Metal halide lamps, pulse start, M141 (1000 watt class)	65	Magnetic CWA	Very high bay spaces such as sports arenas, stadiums, and other locations above 30’.	Very long warm up and restrike times prevent rapid switching and dimming.
79	T-8 premium “U”-bent lamps (F32T8/U/835)	86	Electronic IS	Recessed commercial lighting. Dimmable.	More expensive than straight lamps.
78	T-5 twin tube (“biax”) 40-50 watt (FT40T5/835)	82	Electronic IS	General commercial and institutional lighting; track mounted wallwash and display lighting. Dimmable.	More expensive than straight lamps – can be too bright in open fixtures.
78	Metal halide lamps, pulse start, 450 watt class	65	Magnetic CWA	General high bay lighting for gyms, stores, and other applications to about 30’; parking lots.	Very long warm up and restrike times prevent rapid switching and dimming.
76	Standard T-8 generic lamps (F32T8/735)	75	Electronic IS	General commercial lighting. Dimmable.	Not for general exterior lighting; not for very high spaces.
75	T-8 premium 2’ lamps (F17T8/835)	86	Electronic IS	General commercial lighting. Dimmable.	Not for general exterior lighting; not for very high spaces.
67	Metal halide lamps, pulse start, M137 (175 watt class)	65	Magnetic CWA	Parking lots and site roadway lighting.	Very long warm up and restrike times prevent rapid switching and dimming.
64	Metal halide lamps, pulse start, M142 (150 watt class) compact T-6 high CRI	85	Electronic (CWA magnetic <60 MLPW)	Track and recessed mounted display lighting.	May not be suitable for general illumination due to lamp cost; very long warm up and restrike times prevent rapid switching and dimming.
63	Metal halide lamps, pulse start, ED-17 M140 (100 watt class) high CRI	85	Electronic or magnetic HX or CWA	Recessed and track mounted display lighting.	May not be suitable for general illumination due to lamp cost; very long warm up and restrike times prevent rapid switching and dimming.
62	Compact fluorescent 18-42 watt triple	82	Electronic	Downlights, sconces, wallwashers, pendants and other compact lamp locations; can also be used outdoors in most climates. Dimmable.	Modest efficacy is still far better than incandescent.
30	Halogen infrared reflecting lamps in PAR-30, PAR-38, MR16 and T-3 shapes	100	None required	Localized accent lighting and where full range, color consistent dimming is absolutely required such as fine restaurants, hotels, high end retail, etc	Cost effective technology must be used in limited amounts.

*Mean lumens per watt vary depending on specific ballast. Values given are optimum lamp-ballast combinations, and other combinations may be lower.

Luminaires

Luminaires (light fixtures) generally consist of lamps, lamp holders or sockets, ballasts or transformers (where applicable), reflectors to direct light into the task area, and/or shielding or diffusing media to reduce glare and distribute the light uniformly. An enormous variety of luminaire configurations exist. This section briefly outlines some of the more important types for school lighting design.

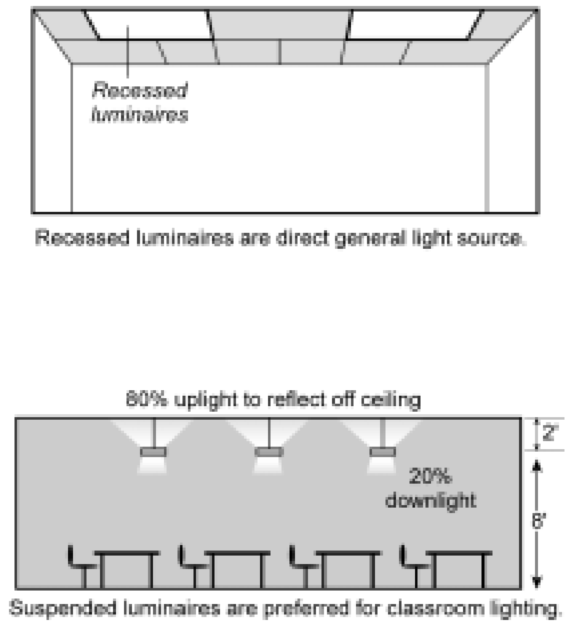


Figure 1 – Recessed vs. Suspended Luminaires

Recessed Luminaires

Recessed luminaires represent a large segment of the overall luminaire market. There are two basic variations, lay-in troffers and downlights. The primary use of lay-in troffers is as a direct general light source. Downlights are relatively compact luminaires used for wall washing, accent lighting, supplemental general or task illumination, as well as for lower levels of ambient illumination.

A relatively new type of recessed luminaire is the indirect troffer. It is meant to soften the distribution pattern of a direct distribution luminaire without losing lighting uniformity. However, in many cases the surface brightness of the exposed reflector is actually higher than that of a standard troffer. Use them with caution, and do not use them in larger building spaces such as classrooms and open offices.

Suspended Classroom Luminaires

Suspended indirect or direct/indirect luminaires are the preferred luminaires for lighting classrooms. They are also appropriate for offices, administrative areas, library reading areas, and other spaces. Typically these luminaires employ T-8, T-5, or T-5HO lamps, and mount in continuous row configurations. See Guideline EL1: Pendant-Mounted Lighting.

Suspended High Ceiling Luminaires

Both fluorescent and HID suspended luminaires are useful for illuminating building spaces such as gymnasiums and other high-ceilinged spaces. HID luminaires can be classified as either high bay (>25 ft mounting height) or low bay, depending on the configuration. Compact fluorescent, high bay luminaires are also available to light high ceiling spaces. They employ up to eight compact fluorescent lamps to approximate the light output of an HID luminaire, while allowing for additional control flexibility. See Guideline EL5: Gym Lighting for more information. Linear hooded industrial fluorescent luminaires can be extremely effective at lighting high ceiling spaces.

Surface-Mounted Luminaires

Surface-mounted fluorescent, compact fluorescent, and HID luminaires are valuable for wall and ceiling mounting situations, particularly when ceiling access is a problem.

Specialty Luminaires

Several specialty luminaires are available for specific school lighting applications, including specialty wall wash luminaires to illuminate blackboards, task lighting luminaires to supplement general illumination, wet location luminaires for exterior areas open to the elements, and high-abuse luminaires designed to withstand vandalism in school and other institutional environments.

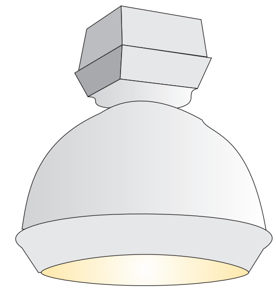


Figure 2 – Low-bay HID Luminaire

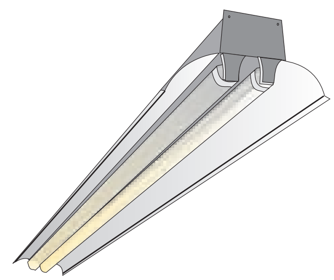


Figure 3 – Hooded Industrial Fluorescent Luminaire

Compact fluorescent lighting fixture. NREL/PIX 09211

Exit Signs

Numerous exit sign configurations are available for schools. LED exit signs offer the best alternatives for minimizing energy use and maintenance. Avoid self-luminous atomic exit signs because they are difficult to dispose of and may not provide adequate surface luminance.

Lighting Controls

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques ranges from simple to extremely sophisticated. Lighting control strategies are most successful when people can easily understand their operating characteristics. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent. Finally, regularly scheduled maintenance of control equipment will improve the long-term success of the system. Poorly designed, commissioned, or maintained automatic lighting controls can actually increase lighting energy use and cause user dissatisfaction.

This section provides a brief overview of lighting control hardware available for school applications.

Switches

Manual switches are the simplest form of user-accessible lighting control. Minimal compliance with most codes requires individual manual switching for each separate building

ASHRAE 90.1-2001 mandates that buildings larger than 5,000 ft^2 have an automatic control device that can turn off lighting in all spaces without occupant intervention. This automatic control can be based on a time schedule or occupancy sensor. Manual switches are especially valuable in daylit building spaces because they allow people to turn off electric lights when daylight is adequate. Manual switches should also be installed in spaces with occupancy sensors to increase the energy savings by allowing people to turn off the lights when they are not needed.

Occupancy Sensors

Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Some sensors employ both passive infrared and either ultrasonic or microphonic detection. Mounting configurations include simple wall box sensors appropriate for small spaces such as private offices, and ceiling- or wall-mounted sensors that provide detection of areas up to 2,000 ft^2.

Figure 4 – Occupancy Sensor

Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied. The best school applications include classrooms, private offices, restrooms, and storage areas. Use occupancy sensors in combination with manual overrides whenever possible to maximize energy savings, space flexibility, and occupant satisfaction. Including manual off override to the control scheme allows the teacher to turn the lights off for video presentations or other situations requiring the lights to be off. See Guideline EL4: Lighting Controls for Classrooms.

Timing and sensitivity for occupancy sensors should be carefully reviewed for the optimum compromise between energy savings and appropriate function. It has been found that if lights often automatically shut off when students and teachers sit still for several minutes during tests, the sensors will require re-adjustment or simply be disconnected. If staff is driven to disconnect occupancy sensors, the school incurs the increased initial construction costs but loses any energy savings. This type of dissatisfaction also makes it more difficult to include these energy saving features in the next project.

Time Controls

Time controls save energy by reducing lighting time of use through preprogrammed scheduling. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones.

Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable. Candidate building spaces include classrooms, offices, library stacks (local digital time switches), auditoriums, and exteriors.

Energy Management Systems (EMS)

Typically an EMS controls lighting via a time clock. However, many building operators take advantage of the built-in EMS functions to monitor lighting usage on a space-by-space basis. EMS control of lighting systems may also allow building operators to dim or turn off lights to shed non-essential lighting loads during peak demand periods.

Manual Dimmers

Next to standard wall switches, manual dimmers are the simplest of lighting control devices. Manual dimmers serve two important functions. First, dimming lights reduces lighting demand and energy usage. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.

Consider manual dimmers (combined with dimming ballasts, where applicable) for many school building spaces, including classrooms, computer classrooms, and office spaces. Audio/visual rooms *require* manual dimming to function properly.

Photosensor controls

Photosensor control systems are used to control electric illumination levels in daylit spaces. A photosensor detects the daylight illumination level and sends a signal to a logic controller to switch off or dim the electric lights in response. In *open-loop* systems, the sensor is placed so that it “sees” a representative daylight level, such as looking up into a skylight or out a window. In a *closed-loop* system, the sensor is placed so that it “sees” both the daylight and electric illumination level combined. Closed-loop systems tend to be more difficult to calibrate since they are partially responding to the light source that they are also controlling. Different photosensors are designed to be used as open- or closed-loop systems, and should be selected specifically by their intended use and location. Compatibility between photosensor, logic controller, and ballasts should also be carefully reviewed. Finally, calibration is important and should be done after the space is painted and furnished with carpets, blinds, and furniture, so that illumination levels are as the occupants will experience them.

Occupant Education

It is extremely helpful to educate the building occupants in how lighting controls work, so that they are less likely to be surprised or annoyed by their operation. A brief tutorial for teachers on occupancy, a one-page explanation taped to the light switch, or best yet, some type of permanent explanation affixed to the classroom wall will greatly aid in the acceptance and appropriate use of the controls. Even manual switches benefit from some education, as teachers often do not realize they have control of more than one light level in their rooms.

Analysis and Design Tools

Several high-quality analysis tools can help professionals design lighting systems. The simplest of these programs provide rudimentary zonal cavity calculations to predict average horizontal footcandles, while the most sophisticated tools can handle extensive calculations and produce realistic renderings.

Many of the major luminaire manufacturers offer standard computational software that can predict the performance of their (or other's) luminaires in typical lighting designs. Typically, these programs can calculate horizontal and vertical illuminance for a number of points within the space. Some can produce rudimentary renderings as well. Most can export output to CAD software.

Companies that specialize in lighting software offer the most sophisticated lighting software packages. These products are typically much more robust than the manufacturer-provided packages, and can handle more complex problems, such as surface luminances, daylight effects, irregularly shaped rooms, and high resolution rendering.

However, minimally acceptable results may be obtained using the lumen or Watts/ft^2 methods.

Applicable Codes

Several codes or standards affect the design and installation of lighting equipment. Some of the relevant considerations are outlined below.

ASHRAE/IESNA Standard 90.1-2001

Many states and local governments have adopted energy efficiency standards that apply to the design of new schools and major renovations. While these are quite varied, many are based on ASHRAE/IESNA Standard 90.1-2001, a consensus standard approved by the IESNA. Standard 90.1 has requirements on minimum lighting controls and maximum lighting power in spaces.

Americans with Disabilities Act (ADA)

The ADA affects the selection and installation of lighting equipment. For the most part, ADA only affects wall-mounted luminaires, which cannot protrude more than 4 in. when mounted less than 80 in. above the finished floor.

Egress and Emergency Lighting

Emergency egress and exit lighting requirements are mandated in the Universal Building Code (UBC), National Electric Code (NEC), and National Fire Prevention Association (NFPA) codes. Lighting design must address the minimum lighting levels for egress, as well as include the necessary exit signage. Most counties and municipalities require at least minimal compliance with NEC, and some may require additional measures.

UL Listing

According to the NEC, all luminaires used in construction must be listed by an approved testing agency, such as Underwriters Laboratory (UL). The designer must be sure that all luminaires specified are properly listed by a testing agency recognized by the local electrical inspector. In addition, there are distinctions that must be made for special applications, such as damp, wet, and hazardous locations.

Resource Efficiency

The overall value of energy-efficient lighting systems is reduced energy use and cost, less air pollution, lower maintenance costs, and reduced material requirements. Properly designed lighting systems minimize lighting demand and energy use. In addition, effective use of lighting controls can extend the service life of lighting equipment, reducing maintenance costs and replacement equipment inventories.

Although lighting's environmental impacts primarily relate to energy performance and enhanced indoor environmental quality, other environmental considerations include materials efficiency and pollution prevention during manufacturing:

- *Materials efficiency:* Metal components of lighting fixtures can be recycled, and whole fixtures can be salvaged during building deconstruction. These fixtures can be refurbished and reused. The metal components of fixtures may include recycled content, although data is not readily available as to the amount.
- *Pollution prevention:* Powder finishes on luminaires may pose a problem during manufacture, but information about these finishes is not readily available.

Mercury and Lamp Recycling

Mercury in fluorescent lamps is a serious issue that has been documented and is being addressed by the lighting industry. Mercury is a toxic element and there are significant concerns about mercury being emitted into the atmosphere or released into groundwater when fluorescent lamps are discarded.

Fluorescent lamps use electricity to excite mercury gas so that it emits ultraviolet light, which in turn causes the phosphor coating to fluoresce and emit light. According to a 1999 National Electrical Manufacturers Association (NEMA) study, the average new fluorescent lamp contained approximately 12 milligrams (mg) of mercury per 4-ft lamp in 1999. Recent developments in lamp coating technology have resulted in lower mercury lamps that contain between 3 and 9 mg of mercury per 4-ft lamp. Three-mg lamps are available with up to 90% efficiency over the life of the lamp, while 9- to10-mg lamps can be specified with up to 94% efficiency.Environmental concerns are complicated by the fact that mercury is also sent into the atmosphere during the combustion of coal, oil, or gas burning at power plants in the production of electricity. Because of the high percentage of mercury from power production, less mercury may actually be produced from using the 9-mg mercury lamps with 94% efficiency than using the 3- to 4-mg lamps with lower efficiencies because of the former's reduced energy consumption. Lamps with less than 3.8 mg mercury pass California's TTLC test. Lamps with less than 9 mg mercury pass the TCLP test by using additives. Another way to reduce mercury use is to specify lamps with higher-rated life hours. Lamps with 30,000 average rated life hours will last 50% longer than standard lamps and will therefore reduce mercury in the environment. The U.S. Environmental Protection Agency (EPA) has declared that lamps containing mercury are hazardous materials requiring special handling. This mandate applies to most fluorescent lamps, and in some cases may also be defined to include HID lamps. Spent lamps may be disposed of in special landfills; however, it is much more ecologically responsible to recycle them. Most lamps used in schools can be completely recycled by a number of different recycling companies. Current costs for recycling lamps average about $0.06/lin ft. When preparing a maintenance plan for a lighting system, include a lamp recycling procedure.

School districts should be good environmental stewards and engage in recycling programs for fluorescent lamps. For demolition and renovation projects, recycling lamps should be required where local recycling options are available.

Maintenance

Maintaining lighting systems is critical to the performance, lighting quality, and energy efficiency of lighting systems. Establishing proper maintenance procedures is as much a responsibility of the designer as it is of the custodian who changes lamps. A good lighting maintenance plan should be included within the building specifications.

Luminaire Cleaning and Troubleshooting

Luminaires need to be cleaned at regular intervals. Consistent maintenance ensures that the lighting system will continue to perform as designed, thereby maximizing lighting quality and space appearance. When cleaning luminaires, maintenance personnel should also check for and replace any broken or malfunctioning equipment, such as lenses, louvers, and ballasts.

Group Relamping

Lighting systems perform best when they are maintained at regular intervals. Group relamping is a maintenance strategy aimed at maximizing lighting system performance and maintenance economy by changing out all lamps at regular intervals, as opposed to relamping only when lamps have burned out. In the long run, group relamping reduces the cost of maintaining lighting systems through simple economy of scale. Furthermore, relamping luminaires at regular intervals maintains light levels and lighting quality according to design intent and establishes good lighting maintenance procedures. For cost effectiveness, group relamping should be combined with luminaire cleaning and troubleshooting. Lamps using with dimming ballasts should be properly seasoned prior to being dimmed. See discussion under Commissioning below.

Specifications

Designers of school lighting systems have several specification tools available to promote proper maintenance and reduce maintenance costs. For example:

- Specify premium or super T-8 lamps whenever possible to extend lamp life by 20% (lamps rated 24,000 hours) or up to 30,000 hours with specific program start ballasts.
- Try to limit the number of different lamp types specified, which will simplify maintenance and allow for reduced lamp backup stocks.
- Include specification language that requires the contractor to supply the school district with manuals for occupancy sensors and other automatic control hardware.
- Include a maintenance manual in the lighting specification (see below).

Maintenance Manual

Include a detailed maintenance package with the building specifications. At a minimum, the package should contain the following:

- As-built plans showing the installed lighting systems
- Luminaire schedule that includes detailed lamp and ballast information
- Luminaire cut sheets
- Lamp inventory list, including recommended stocking quantities
- Manufacturer data for all lighting controls, including operating documentation and tuning procedures

- Procedures for maintaining lighting controls
- Luminaire cleaning and troubleshooting procedures
- Group relamping procedure
- Lamp recycling plan and contacts.

Commissioning

All automatic lighting control systems must be tuned after installation to ensure optimal performance and energy efficiency. Malfunctioning automatic control systems waste energy and will disturb students, teachers, and staff. Building specifications should include a commissioning plan that identifies the commissioning agent and details the required procedures. The commissioning plan should include the following items:

Dimmed Fluorescent Lamps. Manufacturers recommend that fluorescent lamps be fully seasoned prior to being dimmed. Dimming the lamps without this “burn-in” period can result in unstable light output and/or shorter lamp life. Recommendations vary from 10 to 100 hours, depending on the manufacturer. Eventually this requirement may become unnecessary by the use of “smart” ballasts that can sense a lamp’s status. Until such ballasts are available, both new and replacement lamps should be seasoned before dimming.

Occupancy Sensor Sensitivity/Time Delay. Motion sensors must be adjusted to ensure that they only sense motion in the controlled space. Motion in adjoining spaces can cause false triggering or cause the lights to remain on needlessly, thereby wasting energy. Similarly, sensor sensitivity should be set to a high level so that the sensors do not turn lights off when spaces are occupied but students or teachers are not moving much. An additional adjustment to the sensors can control the time delay period between last detection and lights off. In most cases, this period can be set to 10 minutes for good results.

Photosensors. Photosensors designed for use in open-loop daylighting control systems must be mounted so that they cannot detect the lights they control. This may require some tweaking or relocation of the unit after installation. Consult the manufacturer’s recommendations for proper commissioning procedures for photosensor devices.

Dimming Controllers: Dimming controllers for lighting systems should be tuned so that illuminance at the high dimming range will not exceed design parameters. Only a simple adjustment is required on most dimming boards. Similarly, the commissioning agent can also set the minimum light level.

Stepped or Relay Controllers. If a stepped lighting control system is employed for daylight harvesting, it is important to adjust the deadband between the on and off switching thresholds so that the system does not cycle on cloudy days. Continuous on-off cycling is annoying to building occupants and reduces lamp life.

References/Additional Information

Advanced Lighting Guidelines: 2001 Edition, New Buildings Institute. http://www.newbuildings.org/.

IESNA Lighting Handbook. Illuminating Engineering Society of North America. http://www.iesna.org/.

IESNA RP-3-00: Lighting for Educational Facilities. Illuminating Engineering Society of North America. http://www.iesna.org/.

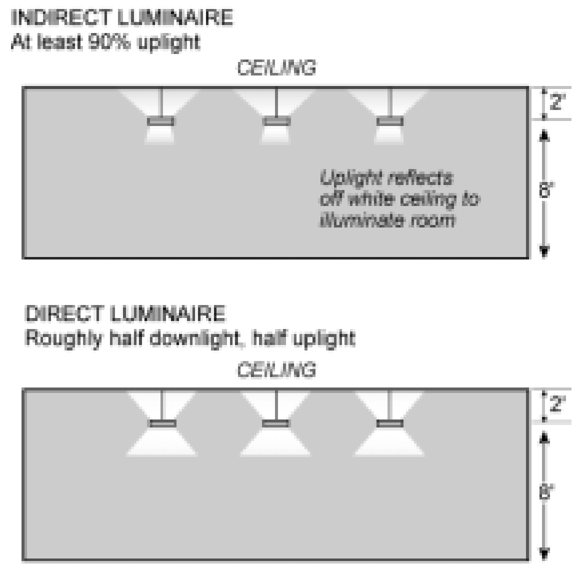
GUIDELINE EL1: PENDANT-MOUNTED LIGHTING

Recommendation

Classrooms should have ceilings at least 10 ft above the finished floor, which permits the use of either:

- Luminaires with a semi-indirect or indirect distribution and at least 85% luminaire efficiency, using T-5HO, T-5 or T-8 premium lamps, and electronic ballasts; or
- Luminaires with direct/indirect distribution and at least 75% luminaire efficiency, using T-8 premium lamps and electronic ballasts.

In either case, the design should usually operate at between 0.9 W/ft^2 and 1.1 W/ft^2, and it will generate 40 to 50 footcandles, maintained throughout the student desk area.



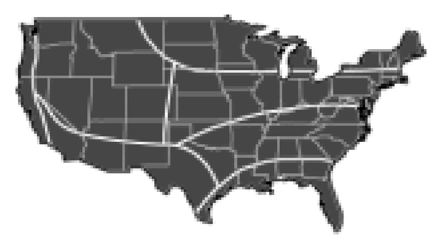
The two primary types of suspended fluorescent luminaires.

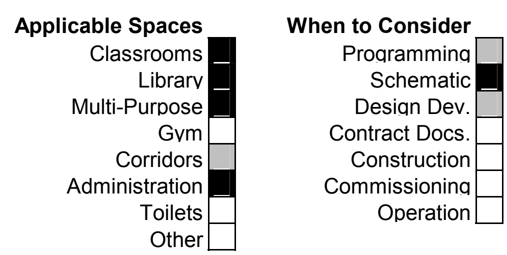
Description

There are two primary, appropriate types of suspended fluorescent luminaires, which are classified according to the fraction of uplight and downlight.

- Direct/indirect luminaires designed for general classroom use. Ceiling, walls, and floor are all illuminated relatively evenly.
- Indirect and semi-indirect luminaires originally designed for office lighting. The ceiling and upper walls are brightest, reflecting light downward onto tasks.

Applicable Climates





Most direct/indirect luminaires are rated according to the percentages of uplight and downlight. In a direct/indirect luminaire, the amount of uplight and downlight is roughly the same. The type of luminaire shown here is 60% uplight and 40% downlight. While a light colored ceiling is preferred to take advantage of the uplight, a direct/indirect lighting system can be used with light colored wood or other materials. Darker colored ceilings reduce the efficiency of the lighting system. The suspension length of direct/indirect lighting is less critical than for indirect lighting.

In an indirect luminaire, the amount of uplight is at least 90%. If there is any downlight from the luminaire, it is only intended to create a sense of brilliance. Most of the illumination in the room is caused by reflected light from the ceiling. Indirect lighting requires a white ceiling and a minimum suspension length of 18 in., with 21 in. or greater strongly preferred. A semi-indirect luminaire has between 10% and 40% downlight, and suspension length is less critical.

In all cases, affordable luminaires are made of steel bodies, and steel or plastic louvers. More sophisticated luminaires employ extruded aluminum housings, but this generally incurs significant cost increases.

Applicability

Pendant mounted lighting is appropriate for all classrooms, libraries, multi-purpose spaces, and administration spaces.

Integrated Design Implications

Suspended lighting systems can work well with almost all ceiling systems that are at least 9 ft-6 in. high. However, ceilings with dark stained wood or dark colored paint must be avoided. For direct/indirect luminaires, ceilings should be light colored; for indirect fixtures, ceilings must be white or off-white, as should upper walls. A direct/indirect luminaire with a greater percentage of downlight (50% or more) should be used for rooms with extremely high ceilings, such as above 14 ft. Note that for maximum efficiency with indirect and semi-indirect lighting systems, it is best to employ ceiling systems with very high reflectivity. Modern white paints and certain ceiling tiles with reflectance of 90% or greater can dramatically increase system performance.

Pendant indirect or direct/indirect lighting systems are particularly well suited for integration with daylight systems, since both approaches require higher ceilings and the use of secondary reflective surfaces. In daylit rooms, pendant systems should be run parallel to the primary windows or daylight source, so that they can be switched or dimmed in response to daylight gradients. In a classroom, three rows of pendants will allow a more gradual response to daylight than just two rows. Daylight controls can then switch or dim each row separately.

Cost Effectiveness

Suspended lighting systems costs are shown in Table 6. Suspended lighting systems provide a high degree of cost effectiveness in most applications. Non-dimming, indirect steel luminaires are the lowest cost, but optimum solutions are generally steel luminaires with steel or plastic louvers providing 35% to 50% downlight.

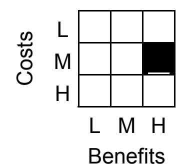


Table 6 – Indirect/Direct Lighting Costs

Lighting System Type	Cost per Lineal Foot, Installed*
Steel Indirect Luminaires, 90%+ Uplight, T-8 Lamps, Non-dimming	$35
Steel Direct/Indirect Luminaires, Plastic Louvers, 65% Uplight, T-8 Lamps, Non-dimming	$40
Steel Direct/Indirect Luminaires, Steel Louvers, 50% Uplight, T-8 Lamps, Non-dimming	$45
Extruded Aluminum Luminaires, Parabolic Louvers, 75% Uplight, T-8 Lamps, Non-dimming	$50
Add for Dimming Ballasts Using Standard 0-10 volt type	$12-15

*Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting, including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

Benefits

Direct/indirect lighting systems generally offer an optimum combination of efficiency and visual comfort, and make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 0.9 W/ft² to 1.0 W/ft² will generate between 40 and 50 footcandles on average, with excellent uniformity. Indirect lighting systems are generally less efficient, requiring 1.0 W/ft² to 1.1 W/ft² to achieve 40 to 50 footcandles.

Design Tools

See this chapter's Overview.

Design Details

This type of lighting provides good, general lighting throughout the room and is suitable for most types of classroom work. Some types of direct/indirect lighting are optimized for computer CRT work, although they tend to be expensive. It may be necessary to provide separate chalkboard illumination, especially if the suspended lighting system is manually dimmed. Be certain to employ premium T-8 lamps with 835 or 841 color, rated 24,000 hours. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 4 and specify ballasts accordingly.

A typical classroom is shown in the figure below with three rows of two lamp suspended luminaires. Not including daylight contribution, most of the room is between 40 and 60 footcandles at 0.9 W/ft². A slight increase in power will result in a proportional increase in light level; at 1.1 W/ft^2, the light levels will range between 49 and 73 footcandles.

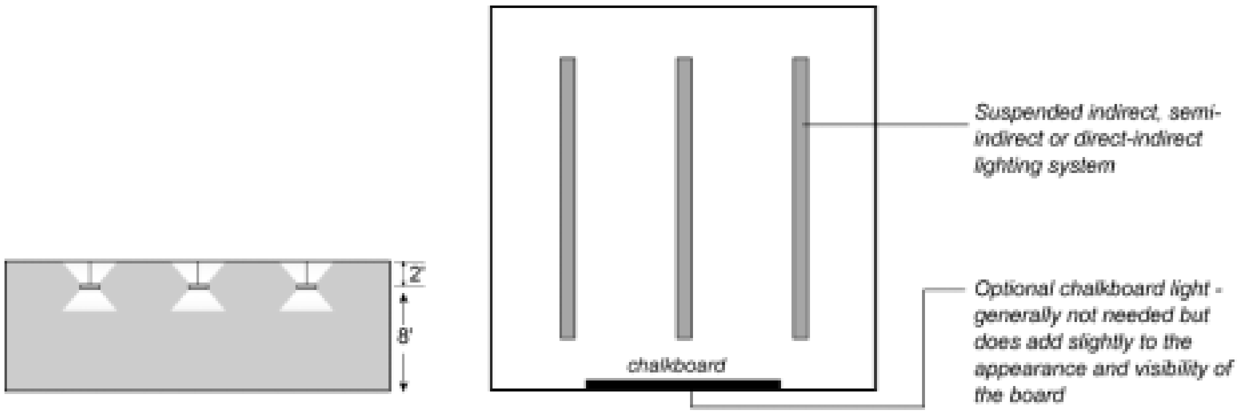


Figure 5 – Classroom Pendant-Mounted Lighting Design

This classroom design uses three rows of suspended fluorescent luminaires.
An optional blackboard light can be mounted at the teaching wall.

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which, with normal school use, could be as seldom as every six years. (Using certain lamps and ballasts can extend this period to 20,000 to 22,000 hours). Luminaires should be cleaned annually. Open louvered luminaires, especially those using plastic louvers, require less cleaning and are the most tolerant of poor maintenance and abuse. Indirect fixtures require more regular cleaning and dusting.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

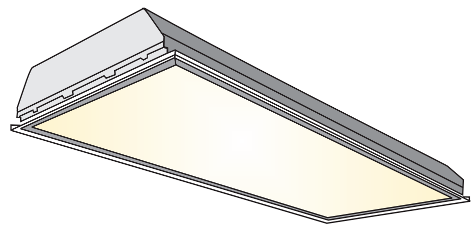
References/Additional Information

See this chapter's Overview.

GUIDELINE EL2: TROFFER LIGHTING

Recommendation

This recommendation is **only** for spaces having no ceiling or a low ceiling (less than 9 ft-6 in.) where pendant mounted lighting is inappropriate. In these cases, use surface or recessed fluorescent troffers having at least 78% luminaire efficiency, T-8 premium lamps and electronic ballasts, and a connected lighting power of 0.9 W/ft^2 to 1.1 W/ft^2.



Modern lens recessed troffer (above); surface troffer (below)

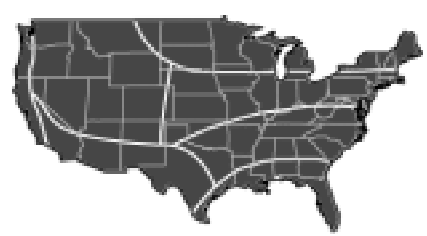
Description

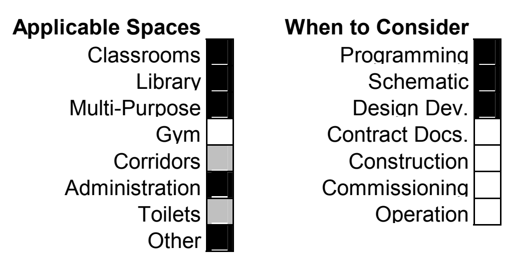
Fluorescent troffers are designed to replace an acoustical tile in grid tee-bar ceiling systems. The most common and cost effective size is 2 ft x 4 ft; less common sizes include 2 ft x 2 ft and 1 ft x 4 ft. Two (or more) T-8 lamps are inside.

The three common troffer types are:

- *Lens troffers,* in which the down-facing side of the luminaire is covered with a plastic lens.
- *Parabolic troffers*, in which the down-facing side of the luminaire is enclosed by a metal louver having aluminum blades.
- *Basket troffers*, in which the down-facing side of the luminaire is partially covered by a perforated basket to hide the lamps.

Applicable Climates





While parabolic troffers and basket troffers may be used in schools, lens troffers generally should be chosen because of their specific light distribution and economy. Parabolics tend to create a cave-like appearance that may be suitable for some types of spaces, but typically should be avoided for general use in schools. They do decrease glare, which is important in low-ceiling work areas and office spaces. Basket luminaires are relatively expensive and have poor light distribution qualities for classrooms, although they might be used in other spaces, especially corridors.

In a modern lens troffer, the interior reflector should be either high-reflectance white paint or highly-polished ("specular") silvered coating or aluminum. Silvered coating increases the cost considerably but also increases efficiency to over 85%. The lens should be an industry standard "Pattern 12" prismatic acrylic lens, with a minimum lens thickness of 0.125 in. for durability and appearance.

The luminaires can be laid out in rows or in a grid pattern, although many architects prefer a doughnut configuration for classrooms. See the examples, below.

Applicability

Lens troffers have a distinctly inexpensive and institutional appearance. Also, the light quality is marginal. Nonetheless, under correct circumstances, troffer lighting is appropriate for classrooms, libraries, multipurpose spaces, administration spaces, and corridors.

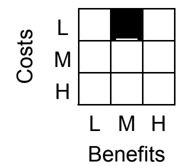
Integrated Design Implications

This type of lighting should only be used in flat acoustic tile ceilings, and then only when ceiling height and/or budget prevents consideration of other options.

In daylit classrooms, three circuits for switching or dimming are recommended. The troffers should be circuited into zones that respond to the daylight gradients in the space, such as defining an outer zone along a window wall, a central zone, and an inner wall zone.

Cost Effectiveness

Recessed lighting systems cost about $120 per luminaire[1] for basic, white interior luminaires with 0.125 in. lens, two premium T-8 lamps, and electronic ballast. A dimming ballast will add about $40 to $50 to each luminaire. Although lens troffer lighting systems are extremely low cost, their inexpensive appearance can be a drawback.



Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1 W/ft^2 will generate between 50 and 60 footcandles maintained average, with very good uniformity.

Design Tools

See Overview section of this chapter.

Design Details

There are a number of troffer variations. These include:

- *Quality or price class*. A “specification grade” troffer is generally deeper, heavier gauge metal and costs more. A basic troffer works just as well, but is flimsier.
- *Door type*. A flat steel door with butt joints costs the least; a regressed aluminum door with mitered corners costs quite a bit more, but looks better.
- *Lens*. In addition to the industry standard “Pattern 12” lens, there are other lens designs that can provide increased efficiency and other benefits, but at greater cost.
- *Air Handling*. “Static” troffers are enclosed boxes that do not interface with HVAC equipment. “Heat extraction” troffers serve as a return path for HVAC systems using the ceiling plenum for return, and they cool lamps in the process (not necessary with two-lamp systems). “Air handling” troffers are connected to special HVAC supply or return devices. The cost of HVAC attachments is high, and they do not fully eliminate the need for conventional HVAC diffusers and grilles.

While this type of lighting is suitable for most types of classroom work, lens troffers are not recommended for computer workspaces. Separate chalkboard illumination is usually not required. It is best to employ premium or super T-8 lamps with 835 or 841 color. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 4 and specify ballasts accordingly.

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[1] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting, including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

Luminaires need to be restrained in case of an earthquake or other natural disaster. In general, this means that each luminaire must be hung from the structure with hanger wires independent of the ceiling system.

There are two common designs:

- A typical classroom with a "modified doughnut" pattern of two lamp troffers (see Figure 6 below). By orienting luminaires parallel to all walls, superior upper wall lighting occurs, although this pattern may cause slightly more glare than by simply using a grid layout.
- A conventional layout of troffers in a simple grid. Upper wall illumination of the end walls is not as good, but the lighting system will produce less glare.

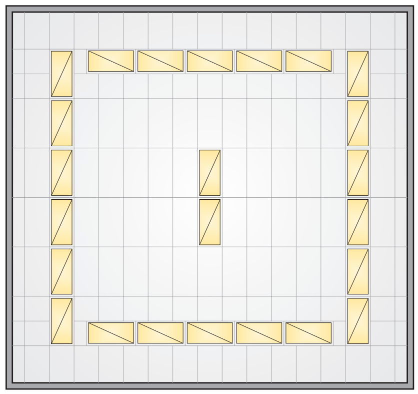


Figure 6 – "Modified Doughnut" Classroom Recessed Lighting Design

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which, with normal school use, could be as seldom as every six years (consider premium lamps and specific lamp/ballast systems for even longer life and less maintenance). Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively inexpensive.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

References/Additional Information

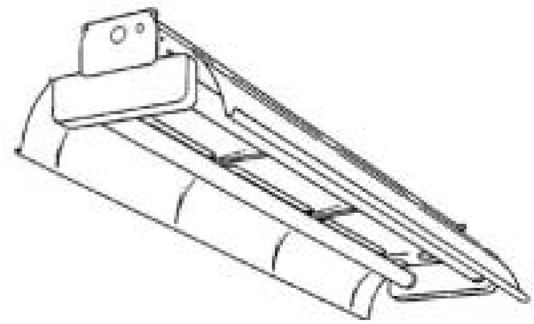
See this chapter's Overview.

GUIDELINE EL3: INDUSTRIAL-STYLE CLASSROOMS

Recommendation

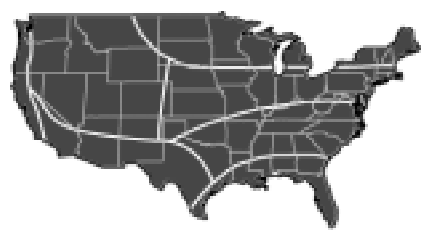
This recommendation applies to rooms without a finished ceiling and to classroom and office spaces designed to have an industrial, exposed construction style.

Use direct or semi-direct fluorescent industrial luminaries that have T-5HO or T-8 premium lamps and electronic ballasts and have at least 70% efficiency. Lighting power should be approximately 1 W/ft^2 to 1.4 W/ft^2.



Industrial fluorescent with uplight

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	□
Multi-Purpose	□
Gym	□
Corridors	□
Administration	■
Toilets	□
Other	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	□
Commissioning	□
Operation	□

Description

In rooms without finished ceilings, some creativity may be needed to implement a lighting solution that is both attractive and performs as well as those designed for more finished spaces. This system may also be appropriate in shop areas where tops of uplights would slowly get caked with sawdust. Depending on budget and architectural requirements, designs may employ strip lights with reflectors, true industrial-style fluorescent luminaires, or styled industrial-like luminaires.

In general, the following strategies should be employed:

- Use either direct lighting systems (up to 10% uplight), or semi-direct lighting systems (up to 40% uplight). The majority of the light needs to be directed downward since the ceiling of the space, often a metal deck or other unfinished surface, can not be relied on to efficiently reflect light.
- Include some form of glare shielding for the downlight component, although this can often be ignored if the lighting systems are mounted relatively high in the space.
- Have an uplight component to produce balancing luminance and comfortable light, but without being wasteful. The uplight component may be omitted in dusty environments.
- Use simple ideas to make the luminaires visually appealing.

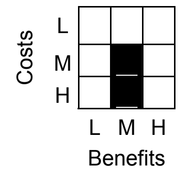
Applicability

This type of lighting should only be used in very specific applications, such as high-bay industrial spaces like industrial arts rooms and art studios. Rooms with unusual architecture, especially if the school is within an existing building or structure, may also benefit from this type of lighting system. This type of lighting system has gained wider acceptance recently as architects explore more “industrial” and constructed forms of design. However, it is best reserved for spaces where it truly suits the aesthetic.

Integrated Design Implications

Designing spaces with unfinished ceilings should be carefully contemplated, since light colored and reflective ceilings tend to improve the efficiency of light utilization.

Cost Effectiveness[2]



An industrial lighting system can be very cost effective, even in unusually high open spaces. Industrial-style lighting systems will cost about $35/ft to $75/ft of luminaire depending on the quality and style aspects of the chosen product. To minimize costs, consider using HLO ballasts or T-5HO lamps to increase the power of each luminaire and reduce the number of lights required. If the space is sufficiently high, mounting luminaires in continuous rows reduces mounting and wiring costs.

Benefits

Industrial lighting systems generally offer excellent efficiency, but with varying degrees of visual comfort. For instance, the strip light, the most basic industrial lighting system, is very efficient but also produces glare. Industrial luminaires make excellent use of the low-cost, widely used 4-ft T-8 lamp system, as well as the less common but equally efficient 8-ft lamp system. For most situations, installations operating at less than 1.5 W/ft^2 will generate appropriate lighting with very good uniformity.

Power use will be affected by the system's mounting height. The efficiency of a luminaire decreases as the mounting height increases. Many spaces without finished ceilings may have a roof structure 20 ft or more in the air, but the luminaires may be suspended as low as 12 ft above floor. In general, power use will range from 1 W/ft^2 to 1.2 W/ft^2 with luminaires at 12 ft, and between 1.2 W/ft^2 to 1.4 W/ft^2 at 16 ft.

Design Tools

See this chapter's Overview.

Design Details

- A reflector directing the light downward is necessary, which means strip lights without reflectors are probably not an acceptable choice. Determining the amount of uplight needed is a balance between comfort (more uplight) and efficiency (less uplight). The reflectivity of the ceiling cavity affects this decision a little; the more reflective (such as white painted roof deck), the more benefit will be gained from uplighting.
- Contemplate shielding. Most ordinary industrial lighting systems are open, exposing the lamps to view. However, shielding with louvers or lenses decreases overall efficiency. As a rule of thumb, the need for shielding tends to decrease with ceiling height.
- Choose luminaires with an appropriate distribution of light. As the luminaire is mounted higher, the distribution pattern should become narrower and the spacing to mounting height (S/MH) of the luminaire should become smaller. At lower mounting heights, luminaires rated 1.2 S/MH or more are generally acceptable, but at 15 ft or more, a fluorescent luminaire with S/MH of 1 or less may be the best choice. Avoid wide throw luminaires such as wraparounds.
- Evaluate lamp and ballast options. If the lighting system can be mounted above 12 ft, the use of high light output ballasts on T-8 lamps (up to 1,025 initial lumens per lamp-foot), or even T-5HO lamps (up to 1,250 initial lumens per lamp-foot), can reduce the number of lamps – and luminaires – needed to light the space, which saves costs and complexity. Use Table 4 in this chapter's Overview and specify ballasts accordingly.
- Fluorescent luminaires are strongly encouraged over HID sources due to superior color rendering, energy efficiency, immediate starting and restarting, long lamp life, low flicker, and other qualities. Fluorescent luminaires designed specifically for high-bay spaces like gyms can also be used in high-bay industrial spaces, such as industrial arts and shops. In some extreme situations, metal halide

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[2] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

high-bay or low-bay luminaires may be used, although fluorescent solutions should always be considered first.

- Some spaces, such as precision industrial arts and art studios, may benefit from higher light levels. Provide up to 1.6 W/ft^2 in these spaces.
- Consider using 8 ft lamps if enough space exists to warrant the introduction of this less-common lamp type.
- If luminaires are mounted sufficiently high in the space, they may be best installed in rows (see Figure 7 below), which in turn permits luminaires to be wired end-to-end, minimizing electrical construction and reducing the number of points where structural support or seismic bracing are required. Luminaires may be suspended on aircraft cables, chains, rigid stems, or may be attached to the surface of the roof or structure above. The lighting system should be mounted to maintain clearances for equipment, overhead doors, etc.
- See Guidelines EL1 and EL2 for examples on using indirect, semi-indirect, and direct luminaires in classrooms with ceilings. These lighting systems can often be applied to spaces with relatively high ceilings as well.

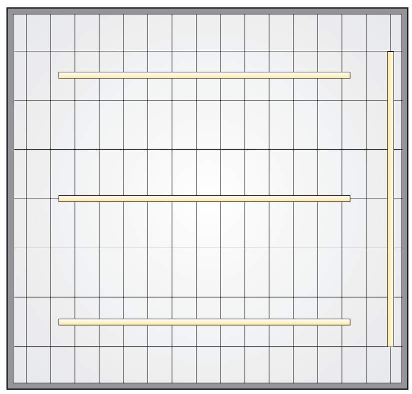


Figure 7 – Industrial Classroom Suspended Lighting Design

Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation (longer with certain lamps and lamp ballast systems), which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Open luminaires tend to require less maintenance.

Commissioning

No commissioning is needed.

References/Additional Information

See this chapter's Overview.

GUIDELINE EL4: LIGHTING CONTROLS FOR CLASSROOMS

Recommendation

All lighting systems in spaces with daylight should be circuited so that lighting can be turned off to respond to daylighting availability. Depending on daylight availability and the audio/visual needs of the classroom (including extensive computer work), the following recommendations should be followed:

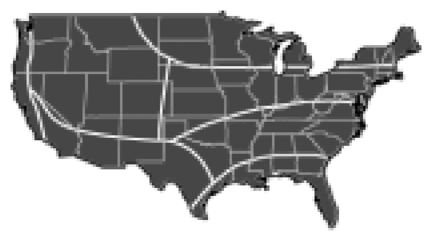
Daylit classroom: To meet the classroom's audio/visual needs, the lighting system should include dimming ballasts, automatic daylight sensing, manual dimming, and manual override. If the classroom has no special audio/visual needs, dimming ballasts and automatic daylight sensing should still be included, as well as motion sensing with manual override.

Classroom with minimum daylighting: If the classroom has audio/visual needs, the lighting system should include dimming ballasts, automatic daylight sensing, manual dimming, and manual override. If the room has no special audio/visual requirements, a motion sensing system with manual override should be used.

Light sensors, like the one being tested here, can dramatically affect both energy use and usability.

NREL/PIX 05171

Applicable Climates



Description

Lighting controls can dramatically affect both the energy use of a lighting system and the usability of the lighting when the classroom is being used for audio/visual or computer education.

As a minimum, all classrooms should employ motion sensors, preferably in conjunction with a switch that can turn lights off regardless of sensor "state." Most sensors are passive infrared and respond to the movement of warm bodies. Upper wall and corner sensors are the best choice, and dual mode sensors employing ultrasonic, microphonic, or another form of backup sensing are strongly recommended. These types of sensors generally require a power pack (transformer-relay) that actually switches the circuit.

Wallbox sensors that replace wall switches are not a good choice for classrooms. For maximum flexibility, manual switches should be wired in series with the motion sensor relay so that lights can be turned off manually, regardless of whether there is motion in the room.

The falling cost of dimming ballasts for T-8 lamps makes dimming possible for many projects. Dimming ballasts permit both manual dimming, allowing the teacher to adjust lighting levels, and automatic dimming, especially to respond to daylight. Ballasts should be specified in conjunction with an overall dimming system to ensure compatibility.

Spaces with audio/visual needs that require manual dimming should use a wall-mounted dimmer controller.

Applicability

These lighting control strategies are appropriate for classrooms and some areas in administration spaces and libraries.

Integrated Design Implications

Controls are essential in achieving the overall goal of reduced energy consumption. The mechanical engineer should be informed of expected changes in the lighting system's pattern of operation due to automatic controls. Reduction in the operating hours or the power of the lighting system will lower the internal heat gain in the space, changing the needs for supplemental heating, cooling, and ventilation.

For spaces with daylight, automatic daylight sensors are recommended for lights near the window wall or underneath skylights. Lighting control circuits should be designed to parallel daylight contours. Two switches should be located close to the room entrance, one enabling the lighting fixtures near the window and the other controlling the lighting fixtures away from the window. The lighting circuit next to the window should also be controlled by an "open loop" photosensor. "Open loop" sensors that are not affected by room light are strongly recommended since they are more reliable and easier to calibrate. A third "energy management" switch is recommended to toggle the central row of fixtures so that they can be grouped either on the photosensor circuit or the non-daylighted circuit, depending on the season of the year and other factors that affect daylight availability. See Figure 8 below.

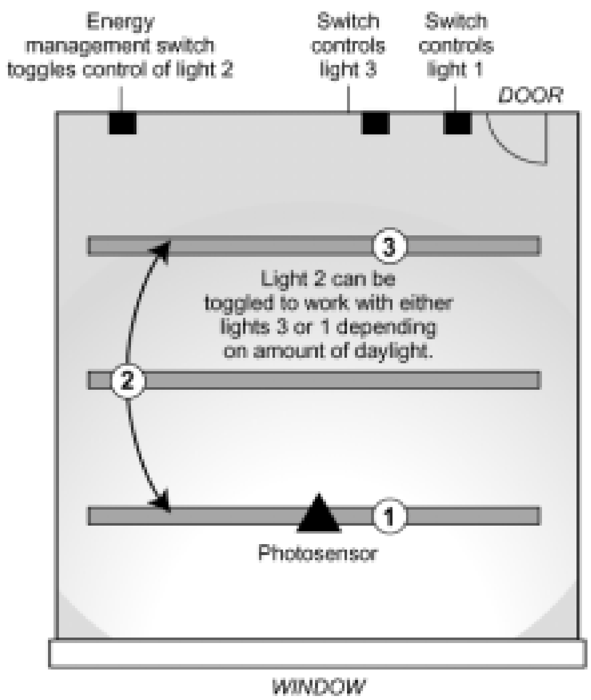
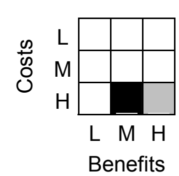


Figure 8 – Simple Windowed Classroom Control

Cost Effectiveness



For motion sensing, cost effectiveness varies depending on the overall energy management skills of teachers and staff. People who are personally careful with energy outperform motion sensors, but for less well managed spaces, motion sensors are worthwhile.

Daylight sensors and dimming ballasts are worthwhile if the daylighting is designed correctly. Systems employing manual dimming, daylighting, and motion sensing are presently only cost effective if audio/visual or computer requirements of the building use need to be met.

Controls are an evolving area of lighting technology for buildings. While cost effectiveness is good at present, costs remain relatively high.

A pair of motion sensors and one power pack adds about $200 per classroom. Dimming ballasts add approximately $40 to $50 per ballast, or up to $1,200 per classroom. Automatic daylighting control without manual dimming adds about $200 per classroom, in addition to the costs of ballasts.

A control system that permits manual dimming in conjunction with motion sensing and daylighting will cost about $1,000 per classroom,[3] in addition to the costs of the dimming ballasts.

Benefits

Each added control element saves energy. Depending on the school's operating months, the quality of daylight, the climatic zone, whether the building is air conditioned or not, and other factors, energy cost savings can vary from good to dramatic.

Design Tools

Very few useful design tools exist for this evolving field. The best information is usually obtained from controls manufacturers and their representatives.

Design Details

- Use two dual-technology motion sensors, set in the corners of the classroom opposite the door. Wire the power for the lights in series with the sensors' transformer-relay and wall switches. Use one switch if automatic daylight controls are being used, and two switches if not. Multiple circuit switching allows teachers flexibility in providing lower light levels for various activities such as nap times or watching a video.
- Use 0-10 volt dimming ballasts unless employing a complete manufacturer-integrated system of control. 0-10 volt controls are the most universal at present and there is more competition in the market.
- Use "open loop" daylight sensors located within 5 ft of the window.

Operation and Maintenance Issues

In operation, a properly commissioned system needs only periodic maintenance to ensure optimum performance. Refer to the manufacturer's recommended recalibration and cleaning cycle for sensors.

Commissioning

Commissioning of motion sensor systems and daylighting controls is critical to their success. Systems that work properly will be left alone; systems that have false tripping and other unwanted behavior will be disconnected or bypassed by occupants.

Good rules of thumb:

- The sensitivity of motion sensors should be set according to the manufacturer's instructions. A proper setting will minimize false tripping and unwanted cycling. Because sensors are both physically and electronically adjustable, care should be taken to ensure the sensors are working as intended.
- The time-out setting of motion sensors is also critical. A setting too short may cause false tripping; a setting too long fails to save energy as well. A preliminary time-out setting of 10 to 15 minutes is usually the right balance.

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[3] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

- Daylight sensor settings should be made and checked several times. Use a good light meter (Minolta TL-1 or better).

References/Additional Information

See this chapter's Overview, and:

Controls: Patterns for Design. Electric Power Research Institute. http://www.epri.com/.

GUIDELINE EL5: GYM LIGHTING

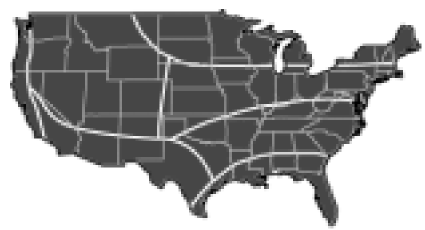
Recommendation

Over basketball courts, volleyball areas, gymnastics areas, and other portions of the gymnasium with a high ceiling and structure, three choices for lighting exist:

1. **T-5HO High-Bay Fluorescent.** Use industrial high-bay luminaires with T-5HO or T-8 lamps. Each luminaire should have symmetric reflectors for downlight distribution, and a wire cage or lens should be used to protect the lamps from flying balls. Four-ft luminaires with four or six lamps and two-lamp ballasts produce similar results as a like number of metal halide luminaires, but with fewer watts and greater versatility.

Metal halide luminaires are one option for general lighting in gymnasiums. NREL/PIX 11437

Applicable Climates



Applicable Spaces: Classrooms ☐, Library ☐, Multi-Purpose ☐, Gym ■, Corridors ☐, Administration ☐, Toilets ☐, Other ☐

When to Consider: Programming ■, Schematic ■, Design Dev. ■, Contract Docs. ■, Construction ■, Commissioning ☐, Operation ☐

2. **Compact Fluorescents**. Employ industrial-style luminaires having multiple compact fluorescent lamps in a single housing. Each luminaire should use eight 32-W or 42-W compact fluorescent triple-tube lamps, with electronic ballasts. The fixture should not have a lens, but consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.

3. **Metal Halide.** Use metal halide industrial-style “high bay” luminaires. The metal halide luminaires should employ 320-W to 450-W “pulse-start” lamps and 277-volt reactor ballasts, if possible. They will provide at least 50 footcandles of general lighting. Use a protected lamp suitable for open luminaries, not a lensed or enclosed lamp. Slightly higher light levels may be provided for the main basketball court in middle schools and high schools. Consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.

Whichever system is used, it will probably be necessary to design at about 1 W/ft^2 to meet modern expectations for gym lighting. Gyms where significant television broadcasts occur may also employ a separate television lighting system.

It will also be necessary to provide an *emergency lighting system*. In addition to self-illuminated exit signs, provide either:

- Some luminaires powered by batteries or a generator in a high-bay fluorescent system or compact fluorescent system.
- Use quartz auxiliary lamps powered from batteries or an emergency generator in a metal halide system.

Also consider providing a separate halogen downlight system for “house” lighting during dramatic and social uses of the gym. This system may also be powered in full or in part from an emergency generator or battery backup power source. As a basic design, use suspended cylinder downlights with halogen IR

PAR-38 flood lamps. Design the system to provide at least two footcandles of illumination with normal power and one footcandle from an emergency source. This system provides both egress lighting and serves other uses (see below). It must be controlled to prevent concurrent operation with the general lighting system.

Description

The height of the gym space's ceiling plays a major role in choosing gym lighting systems. This can be partly assessed by examining the coefficient of utilization (CU) at Room Cavity Ratio (RCR) = 2.5 of candidate systems. It is also useful to examine their spacing to mounting height (S/MH) as well.

Fluorescent systems using multiple T-5HO or T-8 lamps are preferred for ordinary gyms and other high ceiling spaces. Superior color, elimination of flicker, and the ability to turn lights on and off as needed are major advantages over HID systems. The added cost of the fluorescent system is offset by much lower energy use, estimated to be as much as 50% less if the multiple light level capability of a fluorescent system is utilized. Systems using multiple compact fluorescent lamps also provide these benefits, although without the high efficacy of the linear fluorescent lamps.

In general, metal halide high-bay lighting systems tend to be more appropriate when ceilings are especially tall, such as in a field house. Long lamp life and a minimum number of luminaires keep costs down. The color of metal halide is suitable for television as well as everyday use. The long warm-up and restrike periods of metal halide lighting are a drawback since switching lights off regularly is not recommended for these systems. Be certain to use pulse-start lamps. These systems are, however, compatible with daylit gyms if they have switched lighting levels.

Multiple compact fluorescent "high bay" lights are a distant third choice. These systems are less energy efficient and require more costly and frequent maintenance than the other choices.

A separate downlight system using halogen lamps is highly recommended for two reasons:

- It is an instant-on, instant-off system that can be dimmed inexpensively. This feature is especially important if metal halide lights are accidentally extinguished, as they will require a five to 10 minute cool-off and restrike delay.
- A dimmable tungsten downlighting system can make the gym more appealing for social events, and can also serve as a "house" lighting system for many of the gym's performance and entertainment uses.

Lighting quality is a crucial issue in gym spaces. Avoiding direct view of an extra bright light source, such as a metal halide lamp, high output lamp, or skylight, can be especially critical in a gymnasium where athletes must scan for the ball and react quickly. Even though a luminaire may normally be out of the line of sight, it can still create a devastating glare source to a volleyball or basketball player.

Applicability

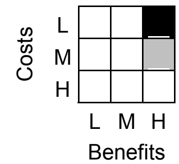
This guideline can be used in most schools, including colleges and universities, public K-12, private, and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Integrated Design Implications

High bay luminaires are easily attached to most structures. It is recommended that the luminaires be suspended within the "truss space" or, in other words, with the bottom of the luminaire not lower than the lowest beam or truss member. In the rare instance where the gym has a finished ceiling, recessed lighting should be considered.

Daylighting design is especially well suited to the high ceilings and large open space of gymnasiums. Gentle diffuse systems, which avoid creating excessive bright spots within the athletes' critical viewing directions, are especially appropriate. For example, side lighting should be placed perpendicular to the primary basketball walls. Wall wash top lighting or high sidelighting with light shelves or louvers can be effective techniques for gyms, since both involve secondary reflections on room surfaces that prevent direct view of the window or skylight. Direct sun penetration into gyms should be prevented at all times.

Cost Effectiveness[4]



Each metal halide luminaire costs about $325, or about 79 mean lumens/dollar. A multiple compact fluorescent luminaire costs about $425, or about 52 mean lumens/ dollar. A T-5HO 6-lamp luminaire costs about $375, or about 76 mean lumens/dollar. Each PAR38 downlight costs about $150. Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

The best solution for a particular gym depends on hours of use and other variables.

- A metal halide lighting system has the lowest first cost. There is no less expensive way to provide the necessary quantity of light from this mounting height. The use of high Watt metal halide lamps minimizes the number of luminaires (first costs) and the number of lamps (maintenance costs).
- A system employing multiple T-5HO or T-8 lamps offers the least energy use and longest life lamps (lowest maintenance costs). Multiple light level capability saves additional energy and extends maintenance periods.
- A system using multiple compact fluorescent lamps combines the flexibility of fluorescent systems with the appearance of HID. While most costly to build and to operate, this approach results in a flexible design that can be energy effective if multiple light levels are used, and the system looks like a metal halide system.

Design Tools

See this chapter's Overview.

Design Details

- Fluorescent high-bay lighting is a relatively new solution. Consider both T-8 and T-5HO systems. This choice requires specific considerations for reflector shape, photometry, and lamp protection. Products are available from some major fluorescent manufacturers and several specialty fluorescent makers. Careful study to ensure proper lighting levels is recommended.
- Any fluorescent choice permits the use of multiple level switching, including automatic daylight control. Take advantage of this feature in gyms with skylights and clerestories.
- Metal halide "high bay" luminaires are commonly available in a number of reflector types including aluminum, ribbed acrylic, and ribbed glass. Among these, ribbed acrylic offers the best combination of efficiency and uplight, and is sufficiently durable for the application.
- It is critical to specify the 320-W to 450-W, pulse-start, 277-volt reactor ballast system. If 277-volt (three-phase) power is not available, then use a 120-volt CWA ballast, although it is less energy efficient. Do not use the standard (probe-start) 400-W metal halide system, as it produces less maintained light than the 320 pulse-start system.
- In gyms with skylights (highly recommended), using a two-level controller for the metal halide lamps should be considered. A photoelectric switch, sensing when adequate daylight is present to turn lights down to the low setting, should control the action.

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[4] Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

- Switches for metal halide lamps should NOT be readily accessible. They should be in a controlled location such as an electric room, press box, teacher/coach's office, or other location where inadvertent operation of the lights will not occur. This adds support to the concept of a separate halogen system in which the switch is quite accessible. It would be a good idea to interlock the two systems so that the halogen system cannot operate once the metal halides are at, or near, full light.

Operations and Maintenance

This design should be easy to operate and manage. Dimming on the halogen system (if used) will extend lamp life, and a metal halide system will require relamping every 12,000 to 14,000 hours (depending on hours of operation, this could be three to five years). System cleaning should be simple. Linear fluorescent systems require relamping every 15,000 to 20,000 hours, but compact fluorescent systems require relamping every 8,000 to 10,000 hours. However, if both fluorescent lamp systems rotate lamp operation at reduced light levels, relamping cycles can be very long.

The control system should be designed for easy use. Automatic time-of-day control with manual override is an acceptable means to control the metal halide lamps, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time-of-day controller, are properly set up.

References/Additional Information

See this chapter's Overview.

GUIDELINE EL6: CORRIDOR LIGHTING

Recommendation

There are two principal choices for illuminating corridors in schools:

- Use recessed fluorescent luminaires that have a means to both protect the lamp and create relatively high angle light perpendicular to the corridor axis.
- Use surface-mounted corridor “wrap-around” fluorescent luminaires designed for rough service applications.
- In either case, luminaires should use T-5 or T-8 lamps and electronic ballasts. Caution should be employed to ensure that the luminaires are not overly “institutional” in appearance. Align luminaires parallel to corridor walls to provide good quality of light and to make light useful for lockers.

Outdoor corridors and corridors with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be powered from an emergency generator or battery backup power source.

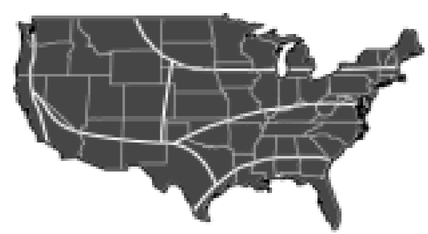
Corridor lighting that emits light to the sides allows for more illumination of the walls and minimizes downlighting.
NREL/PIX 11438

Description

It is important to minimize downlighting so that the walls of the corridor will be better illuminated. Lights that emit very well to the sides should be chosen. Choose from among the following types of products:

- Interior corridors may employ “recessed indirect” luminaires. Luminaires should be oriented with the lamp’s long axis along the corridor long axis. This design is suited for all ceiling types.
- As an alternative, especially for schools where vandalism is a concern, use surface ceiling wrap-around luminaires, preferably vandal-resistant or high abuse types.
- Exterior corridors should employ surface-mounted wrap-arounds or ceiling-mounted, high abuse luminaires. In some cases, wall-mounted, high abuse luminaires may be acceptable.

Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	☐	Programming	■
Library	☐	Schematic	■
Multi-Purpose / Gym	☐	Design Dev.	■
Corridors	■	Contract Docs.	■
Administration	☐	Construction	■
Toilets	☐	Commissioning	☐
Other	☐	Operation	☐

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private, and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

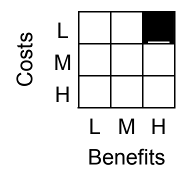
Integrated Design Implications

Given the luminaire choices that are available, it should be possible to find an attractive solution that is suitable for any type of corridor ceiling construction, including indoor and outdoor corridors, acoustical tile or wallboard ceilings, etc.

Corridors are generally excellent spaces for daylighting. Furthermore, daylight in corridors provides an important safety feature of guaranteed lighting during any daytime emergencies. For single story or top floor corridors, linear toplighting is especially appropriate. For corridors not directly under a roof or adjacent to an exterior wall, pools of light from intermittent sidelighting or toplighting borrowed from the floor above can create important social spaces, with higher levels of illumination than that provided by the electric lighting system. Daylight introduced at the end of a long corridor can have a glaring effect, making the corridor feel more like a tunnel. Daylight introduced from the side or above is generally more effective with less glare. As with electric lighting, illuminating the corridor walls should be the primary objective.

Corridor daylighting may be less costly than classroom daylighting because glare control is not as critical as in a learning environment. For this reason, glare-control sun shades or overhangs may be value-engineered out of the corridor portion of a project without creating significant learning rate issues. However, corridor daylighting may also not enhance the accelerated learning rates provided by daylighting in teaching spaces.

Cost Effectiveness



The corridor lighting systems recommended here are very cost effective. Each corridor luminaire costs about $200.[5] Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

Fluorescent corridor lighting systems provide solid results for a modest investment. Long product life will result from carefully choosing a rough service grade luminaire.

Design Tools

See this chapter's Overview.

Design Details

The following are typical lighting layouts for corridors:

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[5] *Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.*

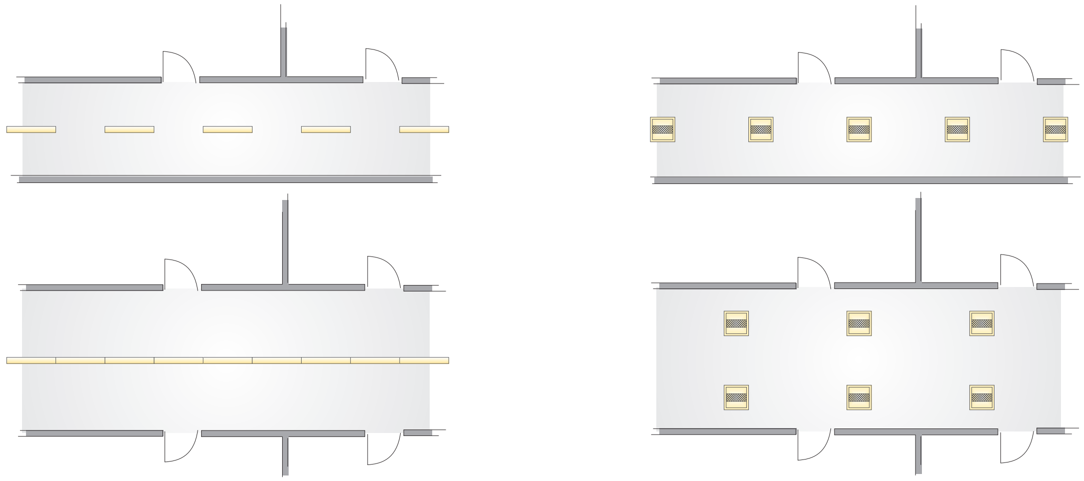


Figure 9 – Corridor Lighting Designs

- If required by the application, choose one of many modern “rough-service” luminaires that are attractive as well as durable.
- In general, recessed downlights generally have insufficient vertical illumination to provide good service in corridors. However, recessed downlights using compact fluorescent lamps may be preferred for lobbies and similar applications where a dressier appearance is desired.
- Switching of the lighting system should NOT be readily accessible. In general, switching should utilize an automatic time of day control system with motion sensor override during normally “off” hours.
- In addition, provide automatic daylighting controls, including dimming or switching off lights in corridors having windows, skylights, or other forms of natural lighting.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, relamping every 12,000 to 14,000 hours is recommended. Ballast life extends 10 years or more. System cleaning should be simple.

The control system should be designed for easy management. Automatic time-of-day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time-of-day controller, are properly set up.

References/Additional Information

See this chapter’s Overview.

GUIDELINE EL7: LIGHTING FOR A MULTI-PURPOSE ROOM

Recommendation

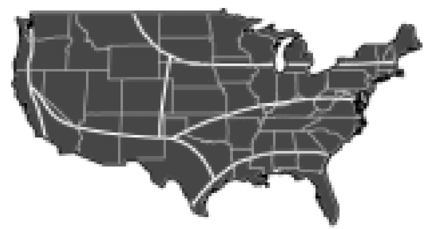
As a minimum, a multi-purpose room should have at least two independent lighting systems:

- A general lighting system providing 20 to 30 footcandles of uniform illumination using standard T-8 lamps or other high efficiency lighting; and
- A dimmable "house lighting" system supporting audio/visual and social uses of the room, producing no more than 5 footcandles.

In addition, theatrical lighting may be added to illuminate specific stage or performance locations.

A multi-purpose room should have at least two independent lighting systems for flexibility of use. NREL/PIX 11436

Applicable Climates



Applicable Spaces
- [ ] Classrooms
- [ ] Library
- [x] Multi-Purpose
- [ ] Gym
- [ ] Corridors
- [ ] Administration
- [ ] Toilets
- [ ] Other

When to Consider
- [x] Programming
- [x] Schematic
- [x] Design Dev.
- [x] Contract Docs.
- [x] Construction
- [ ] Commissioning
- [ ] Operation

Description

The general lighting system should probably be one of the types previously suggested for classroom lighting in Guidelines EL1 through EL3. If suspended luminaires are chosen, be careful to locate luminaries so as not to interfere with audio/visual and other uses of the room. If the room's uses include any sports or games, all lighting systems should be recessed or otherwise protected from damage similar to Guideline EL5: Gym Lighting.

The house lighting system should probably employ recessed or surface downlights. Narrow beam downlights should be chosen, and halogen lighting is recommended due to its superior color, inexpensive dimming, and good light control. Luminaires should use standard IR halogen PAR lamps. Black baffles or black alzak cone trims are recommended for audio/visual applications. The house lighting system should be laid-out to prevent light from striking walls or screens. Note that some general lighting systems might also serve as the house lighting system if properly laid out and equipped with electronic dimming ballasts, but most general lighting systems generate too much diffuse light, even when dimmed, for audio/visual use.

As with corridors and other common spaces, a control system that activates the general lighting system according to a calendar program and employs motion sensing for "off" hours should be used. Rooms with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day. A manual override switch should be provided. Manual dimming of the house lighting system should be provided along with an interlock switch preventing simultaneous operation of both general and house lighting.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be powered from an emergency generator or battery backup power source.

Applicability

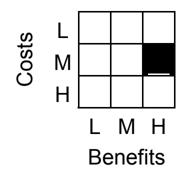
This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Integrated Design Implications

Because multi-purpose rooms often serve as a cafeteria, study hall, social gathering spot, special event space, community meeting hall, and audio/visual facility, it is extremely important to ensure that the lighting and controls provide proper operation for every intended use of the room. Moreover, this room may benefit from greater architectural design than other spaces, and lighting designers should be prepared to creatively provide the functions of the lighting described here, but use other types of equipment better suited to the specific architecture.

Multipurpose rooms can be successfully daylit, either from high clerestories or toplighting approaches. However, near-blackout capability for the daylight system is probably most important in this type of space, so operable louvers or blinds are highly recommended. If the daylight system can be reduced to a minimum of one to three footcandles, most reduced light functions, including stage performances, can operate effectively. A small amount of sunlight can be a cheerful presence in multipurpose rooms used as a cafeteria, as long as it can be blocked when needed.

Cost Effectiveness[6]



In general, two separate lighting systems, with one being a dimmed halogen system, is the most cost effective. A single fluorescent lighting system with dimming system is usually more costly and less flexible.

Each downlight costs about $175 (see the other guidelines in this chapter for general lighting costs). Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

This “two component” lighting design approach, when combined with effective controls, permits a wide range of uses of the multipurpose room, exactly what these rooms are designed for.

Design Tools

See this chapter’s Overview.

Design Details

The figure below shows a typical multipurpose room with two lighting schemes. The left side uses pendant-mounted luminaires, and the right side shows recessed troffers.

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6 Approximate cost to owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

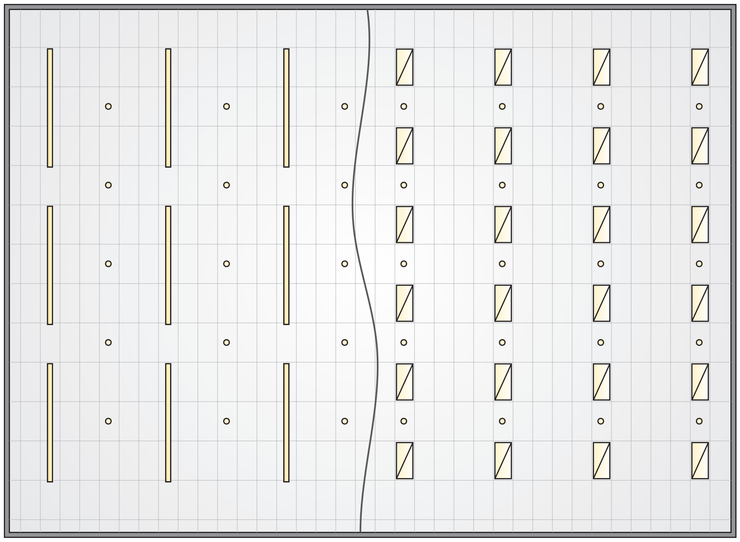


Figure 10 – Multipurpose Lighting Designs

This figure shows two approaches to lighting multipurpose rooms. Both schemes have a separate system of downlights to serve as "house" lights for social and A/V use.

- In this room, self-contained emergency ballast/battery units should be avoided unless specially designed to employ an external voltage sense connection. Leaving any general lighting luminaire operating in the dimmed mode is usually not acceptable.
- Consider placing the lighting in zones that have individual manual override switches to permit de-activating a zone when not occupied.
- Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.
- Consider a modern preset dimming or control system, especially if touch-screen control and other modern audio/video interfaces are planned.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000 to14,000 hours. Ballast life should cover 10 years or more. Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

The control system should be designed for easy management. Automatic time of day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time-of-day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are pre-seasoned, i.e., operated at full light for 100 hours prior to dimming them.

References/Additional Information

See this chapter's Overview.

GUIDELINE EL8: LIGHTING FOR A LIBRARY OR MEDIA CENTER

Recommendation

Provide lighting for a library as follows:

- A lighting system providing 20 to 50 footcandles of general illumination in casual reading, circulation, and seating areas using standard T-8 lamps.
- Overhead task lighting at locations such as conventional card files, circulation desks, etc.
- Task lighting at carrels and other obvious task locations, using compact fluorescent or T-8 lamps.
- Stack lights using T-8 or T-5 lamps in areas where stack locations are fixed, and general overhead lighting in areas employing high density stack systems.
- Special lighting for media rooms, as required.

This library uses a combination of daylighting for ambient light and task lighting above desks and card files. NREL/PIX 11439

Applicable Climates

Applicable Spaces	
Classrooms	□
Library	■
Multi-Purpose	□
Gym	□
Corridors	□
Administration	□
Toilets	□
Other	□

When to Consider	
Programming	■
Schematic	■
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	■
Operation	□

Description

The general lighting system may be one of the types previously suggested for classroom lighting (Guidelines EL 1-3 and EL9). As long as adequate ceiling height is present, suspended lighting systems are preferable. Overhead lighting systems for task locations should also be selected from among choices suitable for classrooms or offices.

Task lighting at carrels and other spots should be selected according to architecture and finish details. Two common options include:

- Under-shelf task lights using T-8 or modern T-5 lamps (e.g., F14T5/8xx, F21T5/8xx, or F28T5/8xx).
- Table or floor lamp equipped with a compact fluorescent lamp up to 40 W.

Stack lighting should utilize luminaires specifically designed for lighting stacks. A number of choices exist, but generally, a single continuous T-8 or T-5 lamp system will provide adequate illumination.

Media rooms, such as video monitoring and editing, sound monitoring and editing, distance learning, and video teleconferencing all have special requirements. It is important that lighting be designed to meet those specific needs and that lighting controls be provided to enable room use. No specific recommendations for those spaces are made here, but depending on the room, professional lighting design services may be needed to assist the standard design team.

A control system that activates the general lighting system according to a calendar program and employs motion sensing for “off” hours should be used. In areas with plentiful daylight, employ automatic daylight switching or dimming to reduce electric lighting by day. In addition, in areas of the library that are less frequently used, such as reference stacks, consider providing individual motion sensors or digital time switches for stack aisles that are connected to dimming ballasts, producing low light levels (but not completely off) until the aisle is occupied. Individual reading and study rooms should employ motion sensors, with “personal” motion sensors and plug strips used at study carrels, especially those with fixed computers.

It will be necessary to provide emergency lighting with this system. Some of the general lighting luminaires must be powered from an emergency generator or backup battery power source.

Applicability

This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities containing libraries, such as churches and private institutions.

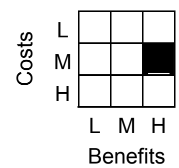
Integrated Design Implications

Libraries are often more highly designed than other spaces. In some designs, other lighting systems that integrate better with the architecture should be considered.

Daylight is an excellent choice for providing basic ambient light in a library. Reading areas and storytelling niches especially benefit from the presence of gentle daylight and view windows. With thoughtful daylight design, only the task lighting at checkout desks or stack areas needs to be on during the day. And these can be connected to occupancy sensors to reduce their hours of operation.

If the library has computers for research or card catalog searches, special care should be taken to avoid glare sources on the computer monitors from light fixtures or windows.

Cost Effectiveness



Library spaces will tend to be among the most expensive to light. These recommendations provide a good balance between cost, energy efficiency, and good lighting practice.

A 4-ft-long stack light is approximately $200. A 3-ft-long undercabinet task light costs about $175. A high-quality compact fluorescent desk lamp falls in the $300 price range. Dimming, switching, and emergency power costs vary and are in addition to the luminaire costs.

Benefits

These recommendations provide proper light for a library and media center. Task light levels are provided only at task locations, while ambient and general light levels are lower to ensure energy efficient operation.

Design Tools

See this chapter’s Overview.

Design Details

Below is a lighting design for a typical library:

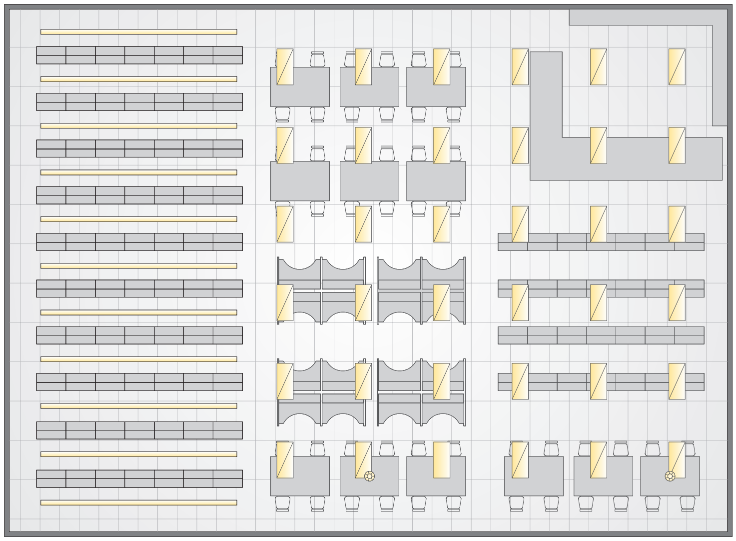


Figure 11 – Library Lighting Design

This design illustrates general lighting using troffers, table lights for study desks, task lights at kiosks, and stack lights. Using high ballast factor 2-lamp troffers, this design works at an overall power density of 1.27 W/ft^2. Increasing stack lights to high ballast factor increases overall connected power to 1.38 W/ft^2. Note that the stacks to the right on the plan are half height.

- The general lighting system can be designed to become more “dense” in task areas such as circulation desks, thus minimizing the number of different lighting types.
- Undercabinet task lights should be specified carefully. Avoid traditional “inch light” systems with magnetic ballasts that use twin tube compact fluorescent lamps and old-style linear lamps like the F6T5 (9 in.), F8T5 (12 in.), and F13T5 (21in.). Use tasks lights employing modern F14T5 (22 in.), F21T5 (34 in.), F28T5 (46 in.), F17T8, F25T8, or F32T8 lamps. Always use electronic ballasts, and consider dimming for all task lights.
- Desk lamps and table lamps with compact fluorescent hardwired lamps should be used. Relatively few products exist. Medium-based screw-in compact fluorescent lamps are not a good choice for new projects.
- Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.
- In media rooms, consider a modern preset dimming or control system, especially if touch-screen control and other modern audio/video interfaces are planned.

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000 to 14,000 hours. Ballast life lasts 10 years or more. Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time-of-day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are pre-seasoned (i.e., operated at full light for 100 hours prior to dimming them).

References/Additional Information

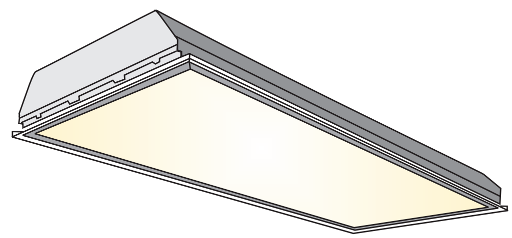
See this chapter’s Overview.

GUIDELINE EL9: LIGHTING FOR OFFICES AND TEACHER SUPPORT ROOMS

Recommendation

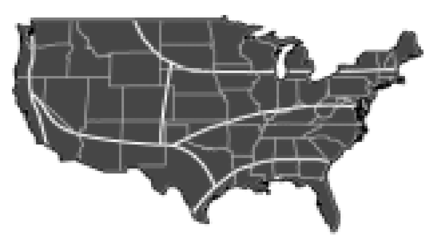
This recommendation is for offices and teacher support rooms having a ceiling no more than 12 ft high and a flat suspended acoustical tile ceiling. There are three choices:

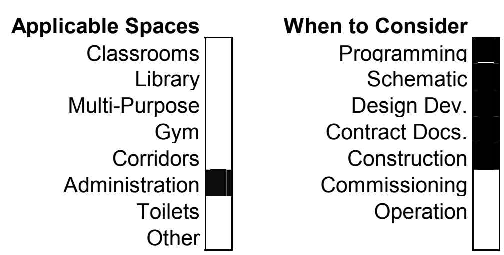
1. Use recessed fluorescent lens troffers having at least 78% luminaire efficiency, using T-8 premium lamps and electronic ballasts. The connected lighting power should be 0.9 W/ft^2 to 1.1 W/ft^2.
2. Use recessed fluorescent troffers with parabolic reflectors in low ceiling offices where glare or institutional feel of lensed troffers are unacceptable.
3. Use suspended indirect lighting to produce an ambient level of 15 to 20 footcandles (about 0.6 W/ft^2) and task lighting where required.



Recessed fluorescent lens troffer.

Applicable Climates





Description

See Guidelines EL1 and 2.

Applicability

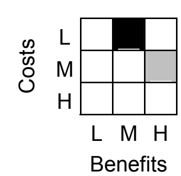
This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Integrated Design Implications

This type of lighting should only be used in flat acoustic tile ceilings and then only when ceiling height and/or budget prevents consideration of other options.

Cost Effectiveness

Lens troffer lighting systems are low in cost, but their inexpensive appearance can be a drawback. Suspended lighting systems provide a high degree of cost effectiveness and improved appearance in most applications.



Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. Troffers with parabolic reflectors provide improved visual comfort but have poorer cut off angles so the walls tend to be darker near the ceiling than with lensed fixtures. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1 W/ft^2 will generate between 50 and 60 footcandles maintained average, with very good uniformity. Separate task and ambient systems may create a more comfortable atmosphere.

Design Tools

See this chapter's Overview.

Design Details

See Guidelines EL1 and 2.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 4 in this chapter's Overview and specify ballasts accordingly.

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to16,000 hours of operation, which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively inexpensive.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

References/Additional Information

See this chapter's Overview.

GUIDELINE EL10: LIGHTING FOR LOCKER AND TOILET ROOMS

Recommendation

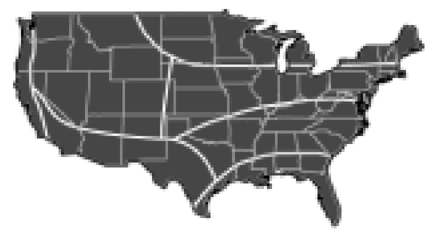
Over mirrors and vanities, employ rough-service-grade fluorescent wall-mounted lights. Over stalls and locker areas, use recessed or surface-mounted, rough-service-area fluorescent lights. In showers, employ ceiling-mounted, watertight, rough-service-grade fluorescent lights.

In general, choose luminaires that are attractively styled to prevent an overly institutional appearance.

Rough service grade fluorescent lights, like the ones over these mirrors, last long, continue to look good, and do not suffer from cracks and other signs of abuse.

NREL/PIX 11471

Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	☐	Programming	■
Library	☐	Schematic	■
Multi-Purpose	☐	Design Dev.	■
Gym	(shaded)	Contract Docs.	■
Corridors	☐	Construction	☐
Administration	☐	Commissioning	☐
Toilets	■	Operation	☐
Other	☐		

Description

This guideline generally recommends fluorescent luminaires using standard T-8 or compact fluorescent lamps. These luminaires are part of a relatively new generation of “vandal-resistant” or “rough-service” lights that are considerably more attractive than previous products. These luminaires should be specified with UV-stabilized, prismatic polycarbonate lenses for maximum efficiency and resistance to abuse. The use of tamper-resistant hardware is also recommended.

Wall-mounted rough-service lights include:

- Linear lights using T-8 lamps and electronic ballasts.
- Rectangular, oval, and round lights that can be equipped with compact fluorescent lamps (low Watt HID lamps can also be used in these luminaries, but are not recommended).

Recessed ceiling lights are generally troffers (see Guideline EL2) that employ the polycarbonate lens and tamper-resistant hardware, as well as more robust components. These luminaires are available in 1 ft x 4 ft, 2 ft x 2 ft, and 2 ft x 4 ft versions with standard T-8 lamps and electronic ballasts.

For showers, employ either surface or recessed luminaires designed for compact fluorescent lights. Due to the long warm-up and restrike times, HID lamps should not be used. In either case, luminaires should be listed for wet applications.

Applicability

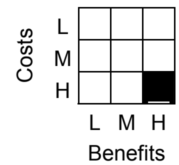
This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Integrated Design Implications

These types of spaces are historically the most abused interior portions of school buildings. Durable lighting is unfortunately less attractive and less integrated than other lighting types.

Daylight is a welcome addition to any locker or toilet room. The high light levels from daylight promote good maintenance and sunlight can actually help sanitize the spaces by killing bacteria. For privacy and security reasons, daylight is often best provided in these spaces via diffusing skylights. Often these spaces can be designed to need no additional electric light during the day.

Cost Effectiveness



The investment in rough-service equipment is paid back over time. In high schools and colleges, the payback can be rapid, especially if the students are particularly rough or abusive.

Rough-service lighting systems will cost about $200 to $300 per luminaire for the types listed above, with compact fluorescent or T-8 lamps and an electronic ballast.

Benefits

Rough-service lighting will last longer in these applications while continuing to look good and not suffer from cracks and other signs of abuse.

Design Tools

See this chapter’s Overview.

Design Details

Be certain to employ premium T-8 lamps with 835 or 841 color, rated at 24,000 hours. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 4 in this chapter’s Overview and specify ballasts accordingly.

Controls should perform in one of the following ways:

- Continuously on during normal school hours, with a night/emergency light on all the time; or
- Continuously on during normal school hours, with both a night/emergency light on at all times and a motion sensor override for full lighting during “off” hours.

Operation and Maintenance Issues

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000 to 16,000 hours of operation, which with normal school use could be as seldom as every six years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap.

Commissioning

No commissioning is needed, other than pre-seasoning of lamps in dimming applications.

References/Additional Information

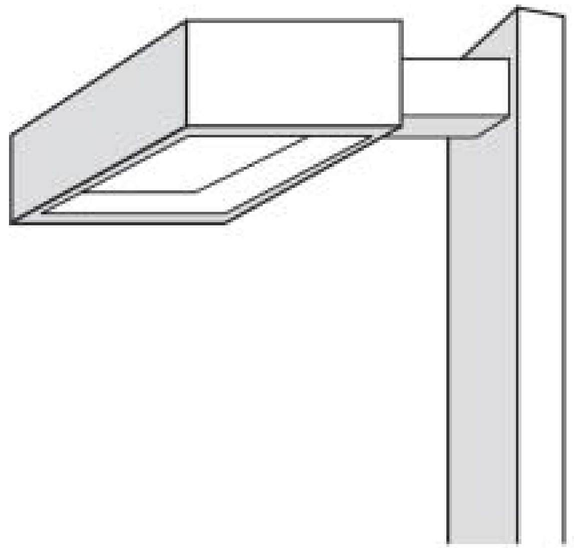
See this chapter’s Overview.

GUIDELINE EL11: OUTDOOR LIGHTING

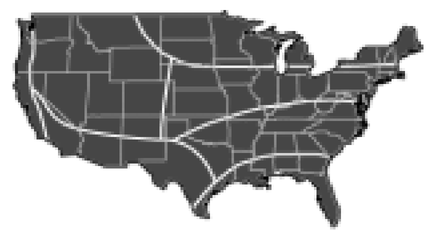
Recommendation

As a minimum, provide the following exterior lighting systems:

- At every door, place canopy or wall-mounted lights to illuminate the general area.
- For parking lots, use pole-mounted, full cut-off lights to illuminate the lot as well as surrounding walks and other areas.
- For driveways intended for night use, have pole-mounted, full cut-off lights for the drive and associated sidewalks.
- For walkways intended for night use, use suitable walkway lighting systems, such as pedestrian light poles or bollards.
- Other lighting as called for by the site or local requirements.



Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	☐	Programming	■
Library	☐	Schematic	■
Multi-Purpose	☐	Design Dev.	■
Gym	☐	Contract Docs.	■
Corridors	☐	Construction	■
Administration	☐	Commissioning	☐
Toilets	☐	Operation	☐
Other	■		

Description

Lights under canopies or mounted to walls should be attractive, rough-service, semi-recessed, or surface luminaires with lens. The lens should be a UV-stabilized polycarbonate prismatic lens. If mounted to walls, use designs that direct light downward and minimize light trespass and light pollution.

Parking lots and driveways should be illuminated using pole-mounted full-cutoff luminaires. Luminaires should be at least 17 ft above grade; actual pole height depends on the type of pole and base. Direct burial, color-impregnated composition or fiberglass poles are recommended if soil and other site conditions are acceptable; if used in the center of a large parking area, however, consider steel or aluminum poles that are anchor-bolt mounted to foundations. Typically, luminaires will employ 150-W or 175-W pulse start metal halide lamps, and in parking lots, two luminaires may be mounted to a single pole.

Lower level lights may be used for walkways, especially if located away from buildings and parking lots. Choose between short poles (8 ft to 12 ft) using compact fluorescent or low Watt HID lamps, or bollards using compact fluorescent lamps.

A control system that activates the exterior lighting system according to an astronomic clock, instead of a photocell, should be used. The system should permit activation at sunset and deactivation at a programmable time, allowing the school to be “dark” and save energy as much of the night as possible. Separate “off” times programmed for parking lot, driveway, and building lighting are highly desirable. This system should be located where accessible to administration personnel; it must be easy to set and permit manual override.

In many suburban or rural locations, a “dark” school after hours is highly desirable. Carefully located motion sensors can be used to activate low-cost compact fluorescent or quartz lights that serve as both safety lighting and as a deterrent against vandalism.

It may be necessary to provide emergency lighting with this system. Some of these luminaires must be powered from an emergency generator or battery backup power source.

All lights should be chosen with consideration of the weather conditions under which they will operate. In most cases, the primary consideration is lamp-starting temperature, which is a function of both lamp and ballast.

Photovoltaic-powered lights should be considered for locations where grid power is not easily available.

Applicability

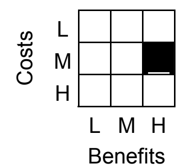
This guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs, and private institutions.

Integrated Design Implications

Exterior lights should be chosen with the architectural impact to the building’s exterior in mind. Select the proper color, shape, and style to reinforce architectural themes of the building.

Cost Effectiveness

The cost of exterior lighting tends to be relatively high. However, compromising on costs, such as using lower quality products, will result in needing to replace the lighting system sooner, thus making it a poor choice when considering life-cycle cost.



- A typical pole luminaire, 17 ft high, 175 W, type III distribution, with steel pole and anchor base, costs approximately $1,500.
- A bollard, contemporary, with 42-W compact fluorescent and concrete anchor base costs $600.
- A canopy-mounted, rough-service luminaire, with two 32-W compact fluorescent, contemporary style costs $300.
- A high quality motion sensor floodlight, 350-W quartz, costs $250.

Switching and emergency power costs vary and are in addition to the luminaire costs.

Benefits

Properly designed exterior lighting systems permit the extended use of the facility, promoting increased personal safety and security and reduced vandalism.

Design Tools

See this chapter’s Overview.

Design Details

- Pole lights should use a variation of the classic “shoebox” full cutoff lights. Avoid traditional lights or contemporary lights that do not produce full shielding to help prevent light trespass and light pollution.
- Many choices in wall lights exist, and this is one situation where aesthetics may be critical. Be certain to choose die-cast aluminum bodies, rough-service polycarbonate lenses or diffusers, and/or other heavy-duty construction. Several look-alike products made of lightweight and inferior materials are on the market, so be especially wary of imitations and substitutes.
- If choosing a “dark” school approach to security, use of motion sensors and quartz floodlights may be warranted. Either separate or integrated units may be used. Quality is especially important in choosing

exterior motion sensors because a faulty sensor will give false indications and activate lights (and concerned neighbors) needlessly.

- Lighting layouts for parking lots and the direct pedestrian access should be performed using an outdoor lighting analysis computer program. Design criteria should be at least 0.5 footcandle in parking lots, with an average light level of 2.0 footcandles and average minimum uniformity of 4:1 or better.
- Consider zoning exterior lighting so that the parking lot zone nearest the building can be activated separately from the majority of the lot.
- Manual override switching of the lighting system should NOT be readily accessible. Locate controls in a supervised location. Use a digital controller, not a mechanical “time clock.”

Operation and Maintenance Issues

This design should be easy to operate and manage. As with most HID and compact fluorescent lighting systems, the lighting system should be group relamped every 8,000 hours, or about every two years. Ballast life should cover 10 years or more. Spot relamping is recommended to ensure security and safety. The design should make system cleaning simple.

Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that the lighting controls are properly set.

References/Additional Information

See this chapter’s Overview.

MECHANICAL AND VENTILATION SYSTEMS

This chapter presents guidelines for mechanical ventilation, heating, and cooling systems. This chapter also presents strategies that can enhance the effectiveness of natural ventilation when the outdoor temperature and humidity is suitable to provide improved thermal comfort during the spring and fall. Presented together in one chapter, the organization emphasizes the interrelationship between these systems. Guidelines are provided for the following technologies and design strategies:

Cross Ventilation (Guideline MV1)	Water-Loop Heat Pumps (Guideline MV15)
Stack Ventilation (Guideline MV2)	Evaporatively Precooled Condenser (Guideline MV16)
Ceiling Fans (Guideline MV3)	Dedicated Outside Air System (Guideline MV17)
Gas/Electric Split System (Guideline MV4)	Economizers (Guideline MV18)
Packaged Rooftop System (Guideline MV5)	Air Distribution Design Guidelines (Guideline MV19)
Displacement Ventilation System (Guideline MV6)	Duct Sealing and Insulation (Guideline MV20)
Hydronic Ceiling Panel System (Guideline MV7)	Hydronic Distribution (Guideline MV21)
Unit Ventilator System (Guideline MV8)	Chilled Water Plants (Guideline MV22)
Ductless Split System (Guideline MV9)	Boilers (Guideline MV23)
Evaporative Cooling System (Guideline MV10)	Adjustable Thermostats (Guideline MV24)
VAV Reheat System (Guideline MV11)	EMS/DDC (Guideline MV25)
Radiant Slab System (Guideline MV12)	Demand Controlled Ventilation (Guideline MV26)
Baseboard Heating System (Guideline MV13)	CO Sensors for Garage Exhaust Fans (Guideline MV27)
Gas-Fired Radiant Heating System (Guideline MV14)	Timers for Recirculating Hot Water Systems (Guideline MV28)

OVERVIEW

The main purposes of HVAC systems are to provide thermal comfort and to maintain good IAQ. These conditions are essential for a quality, high performance learning environment. HVAC systems are also one of the largest energy consumers in schools, and relatively small improvements in design or equipment selection can mean large long-term savings in energy expenditures over the life cycle of the system.

The choice and design of HVAC systems can affect many other high performance goals as well. Water-cooled air conditioning equipment is generally more efficient than air-cooled equipment, but increases water consumption and maintenance. HVAC systems are the major source of outside air ventilation in schools, making their operation and maintenance mission critical for IAQ. The acoustic environment of classrooms, libraries, and other school spaces can be adversely affected by noise created by the movement of air through ducts and air diffusers and from the operation of HVAC equipment. Properly designed, installed, and operated HVAC systems and controls minimize these issues as well as provide a key component of the "buildings that teach" theme.

Integrated Design

To achieve a high performance design, it is very important to integrate the HVAC systems with the building envelope and lighting system. Integrated design creates opportunities for greater comfort, lower first costs, easier equipment maintenance, and lower operating costs. Some of the ways in which high performance can be achieved through integrated design are:

- Careful attention to shading, the locations of windows and glazing types, roof colors, building thermal mass, and enhanced natural ventilation may reduce, or even eliminate, the need for cooling in many locations, and can reduce cooling loads in all climates.
- Natural ventilation can eliminate the need for ductwork in some climates, allowing higher ceilings and more opportunities for daylighting savings.
- Under-floor air distribution allows access for future power and communication needs. The system can also be designed to work in harmony with natural ventilation.
- Attention to the radiant temperature of surfaces through careful envelope design reduces heating and cooling energy requirements. This is especially true of windows.
- Using a central heating and chilled water plant can allow for future installation of a thermal solar or geo-exchange source for heating or cooling energy, or for the use of a thermal energy storage system or other peak electric demand-reducing measures.
- Integrating HVAC, multiple light switches, and lighting occupancy sensor controls can reduce operating costs for both systems.

Thermal Comfort

Thermal comfort is affected by air temperature, humidity, air velocity, and mean radiant temperature (MRT).[1] Non-environmental factors such as clothing, gender,[2] age,[3] and metabolic activity also affect thermal comfort.

- Air temperature is measured with a normal thermometer, and most people are comfortable between about 70ºF and 76ºF. However, an individual's preferred temperature is higher in the summer and lower in the winter, mostly because of differences between summer and winter wardrobes.

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1 MRT is the temperature of an imaginary enclosure where the radiant heat transfer from a human body equals the radiant heat transfer to the actual non-uniform temperature surfaces of an enclosure.

2 Women generally prefer temperatures about 1° warmer.

3 Persons over 40 generally prefer temperatures about 1° warmer.

- The relative humidity range for human comfort is between about 20% in the winter and 60% in the summer. The moisture content of air can also be expressed as the wetbulb temperature, humidity ratio, or dew point temperature.
- Ceiling fans, circulation fans, or operable windows can provide air movement, and such air movement increases the upper temperature limit of comfort by about two degrees.
- The temperature of the surfaces surrounding a person (walls, ceiling, floor, and especially windows) affects the mean radiant temperature (MRT) especially during hot and cold days. Caves have a low MRT, which makes them comfortable even when the air temperature is high. Likewise, rooms with heated floors are comfortable, although the air temperature may be cooler.

The most accepted definition of thermal comfort is ASHRAE Standard 55, but recent research is resulting in a reevaluation of this definition. Standard 55 currently defines comfort in terms of operative temperature and humidity, and represents the range of thermal conditions when 80% of sedentary, or slightly active, people find the environment thermally acceptable (see Figure 1). Operative temperature is the average of the mean radiant and ambient air temperatures, weighted by their respective heat transfer coefficients. The Standard 55 definition of comfort does not consider air movement or velocity. Most occupants do not feel comfortable when it is drafty and cold.

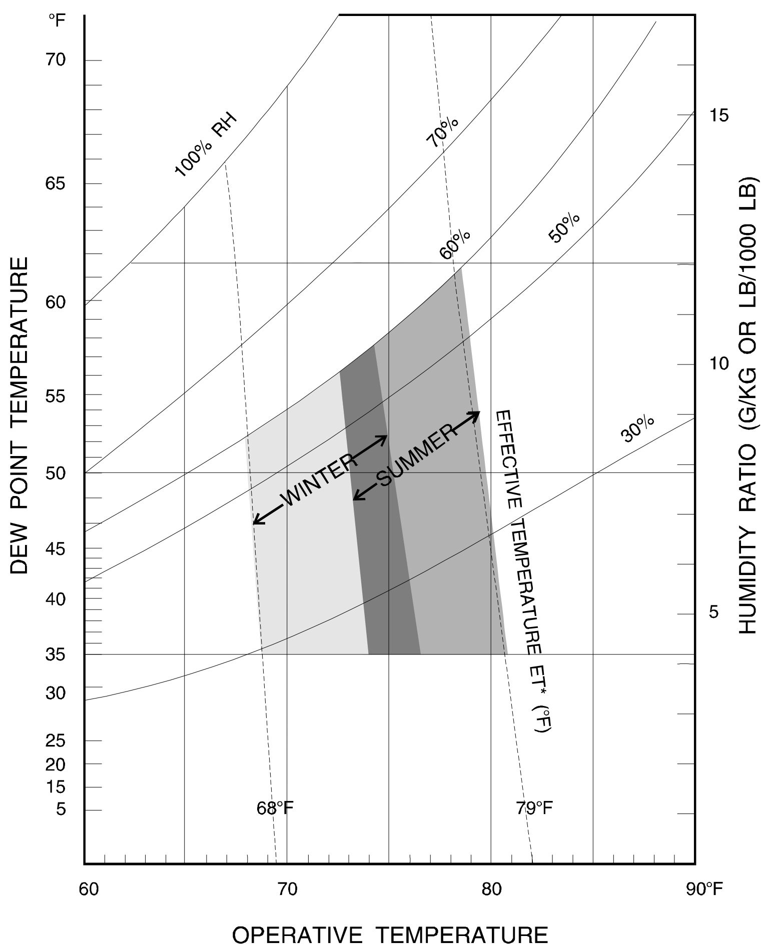


Figure 1 – ASHRAE Standard 55 Comfort Envelope

Source: 2001 ASHRAE Handbook – Fundamentals. This figure shows the temperature and humidity ranges within which about 80% of the population will be comfortable while wearing typical summer and winter clothing and being in a sedentary or slightly active state.

Much of the research on thermal comfort is based on asking people if they are hot or cold, and correlating their response to measurements of air temperature, humidity, air velocity, and MRT. The ASHRAE thermal sensation scale is commonly used for such surveys (see Table 1). Some of this research has been conducted in test environments where temperature and humidity can be tightly controlled. Other research has been conducted in workplaces.

Table 1 – ASHRAE Thermal Sensation Scale

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+3

Since thermal comfort is not an absolute condition but varies with each individual, statistical measures of thermal comfort are sometimes used. One statistical measure is the Predicted Mean Vote (PMV). PMV predicts the mean response of a large population on the ASHRAE thermal sensation scale (see Table 1). A PMV of +1 means that, on average, people are slightly warm. PMV can be calculated if information is known about the metabolic rate, typical clothing, and environmental conditions such as temperature and humidity. Once PMV is known, it can be translated to another statistical factor called percent of population dissatisfied (PPD).

Air movement also affects comfort. Operable windows, ceiling fans or circulation fans create or enable air movement. Too much air movement is uncomfortable, especially when it is cold. When it is hot, air velocities up to about 200 ft/minute are pleasant and enable most occupants to be equally comfortable at 2ºF higher temperatures. Air speeds higher than about 200 ft/minute should be avoided because they can create drafts and be annoying (see Table 2).

Table 2 – Effect of Air Movement on Occupants

Source: Victor Olgyay, Design with Climate, Princeton University Press, 1963

Air Velocity	Probable Impact
Up to 50 ft/minute	Unnoticed
50 to 100 ft/minute	Pleasant
100 to 200 ft/minute	Generally pleasant, but causes a constant awareness of air movement
200 to 300 ft/minute	From slightly drafty to annoyingly drafty
Above 300 ft/minute	Requires corrective measures if work and health are to be kept in high efficiency

Research by Gail Brager and others at the University of California, Berkeley, shows that students and teachers in naturally ventilated schools are comfortable in a wider range of thermal conditions than in schools that have continuous mechanical cooling. Occupants of air-conditioned schools develop high expectations for even and cool temperatures and are quickly critical if thermal conditions drift from these expectations. Occupants in naturally ventilated schools adapt to seasonal changes in mean outdoor temperature and are comfortable in a wider range of conditions. They even prefer a broader range of thermal conditions. The comfort range for naturally ventilated buildings is considerably larger than the common definition of comfort published in ASHRAE Standard 55-1992.

Research shows that part of the difference in comfort expectations is due to behavioral adaptations: occupants in naturally ventilated schools wear appropriate clothing and open windows to adjust air speeds. However, some of the difference is due to physiological factors. The human body's thermal expectations actually change through the course of a year, possibly because of a combination of higher levels of perceived control (occupants can open and close windows) and a greater diversity of thermal experiences in the building.

Using an adaptive model of thermal comfort, instead of ASHRAE Standard 55, allows schools to be designed and operated to both optimize thermal comfort and reduce energy use. In many climates, maintaining a narrowly defined, constant temperature range is unnecessary and expensive. Brager's research is the foundation of changes currently being considered to ASHRAE Standard 55.

Potential for Natural Ventilation

Natural ventilation is an effective and energy-efficient way to provide outside air for ventilation and to provide cooling in many climates during certain times of the spring and fall. In the winter, the challenge is to temper the cold ventilation air as it is brought into the classroom. Humidity is the challenge in the warm portions of the season. Schools that are operated throughout the year should have some means of dehumidification or air conditioning. Historically, schools have not been air conditioned and natural ventilation (cooling with outside air) has been the only means of cooling. Prior to the widespread availability of mechanical cooling, the classic classroom had high, large operable windows to provide both natural ventilation and daylighting.

In most climates, natural ventilation is a useful strategy only during the spring and fall. When any significant number of operable windows are utilized, the building as a system must be carefully designed to minimize glare and heat gain from the sun shining in through the glass, and to maintain a safe and secure facility while still allowing air to enter and escape. Use of ventilation in the off-hours must be approached very carefully as the humidity load from damp nighttime air can lead to moisture problems in some climates. This is especially important if some areas of the facility are mechanically cooled or have any cold surfaces that might be below the dew point of the damp nighttime air.

Figure 2 through Figure 8 contain weather data and analysis of the seven national climates. The figures include data from a typical school year: Monday through Friday, from 7 am to 3 pm, September through June. These figures show drybulb temperature on the vertical axis and relative humidity on the horizontal axis. The figures in the cells are the number of hours during the year when a particular combination of relative humidity and drybulb temperatures exist. The preferred humidity and temperature ranges (30% to 55% and 68°F to 77°F) are shaded gray. The overlapping area indicates when outdoor temperature and humidity are within the ASHRAE 55 Comfort Zone.

Natural ventilation is an effective and energy-efficient way to provide outside air for ventilation and to provide cooling in many climates. However, in climates with extreme cold and/or humid weather, the challenge is to temper the cold ventilation air as it is brought into the classroom during the winter months. Humidity is the challenge in the warm portions of the season. Historically, schools have not been air conditioned and natural ventilation has been the only means of cooling. The classic classroom has high windows to provide both natural ventilation and daylighting.

Seattle, WA
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100 %	Total
98-102	1																	1
93-97	2																	2
88-92		1	2															3
83-87				7	2													9
78-82		1	1		3	1	1	1										8
73-77		2	1	7	4	3	5	6										28
68-72		1	5	5	11	15	12	11	6	2								68
63-67		2	4	6	14	6	19	17	30	12	8	2						120
58-62		4	2	2	12	28	30	28	31	38	24	21	10	19	1			250
53-57			2	5	5	10	20	35	19	15	16	37	56	30	23	2	3	278
48-52		4	1	3	5	4	11	15	23	32	27	17	29	41	39	6	3	260
43-47		1	2	7	10	8	13	15	27	21	71	66	19	52	42	8	3	365
38-42	2	3	1	5	8	6	12	10	14	23	3	52	79		34	7	12	271
33-37	1				3		5	2	8	6	7		21		10	18	7	88
28-32						3		1		2		9		3		4	4	26
23-27												3		1			3	7
Total	6	19	21	47	77	84	128	141	158	151	156	207	214	146	149	45	35	1784

Relative Humidity

Total Hours
ASHRAE 55 Comfort Zone 68

Figure 2 – Climate Analysis, Temperate and Mixed (Seattle)

Denver, CO
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	<15 %	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	100 %	>100 %	Total
88-92	22	1																		23
83-87	22	9	3	1																35
78-82	49	16	5	4																74
73-77	58	21	12	11	7	5			1											115
68-72	34	14	22	12	15	19	4	4	1	3	1									129
63-67	21	30	12	8	10	8	9	14	5	5	5	1								128
58-62	37	28	12	18	17	6	1	7	8	13	10	5	3		1	1				167
53-57	46	34	18	14	21	14	6	10	6	4	3	9	4	5	1		1			196
48-52	25	27	18	20	23	12	8	8	5	4	10	8	1	1	2	3	1			176
43-47	21	13	23	10	12	16	10	7	6	7	6	1	6	12		2	1		2	155
38-42	5	7	9	17	18	15	12	9	10	9	7	10	1	5	6		2			142
33-37	4	7	11	6	14	11	18	17	10	5	13	8	7		7		5		1	144
28-32	2	1	9	1	8	4	5	8	6	16		17		14		16		3	3	113
23-27		1	1	1	3	16	1	3	11	2	15		4	4		19		2	3	86
18-22		1			1	1	6		4	8		8	14		1	2			2	48
13-17											6	5			5					16
<13			1		2	2	1	2	5	2	4		4	13					1	37
Total	346	210	156	123	151	129	81	89	78	78	80	72	44	54	23	43	10	5	12	1784

Relative Humidity

Total Hours
ASHRAE 55 Comfort Zone 56

Figure 3 – Climate Analysis, Cool and Dry (Denver)

Phoenix, AZ
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	<15 %	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	>100 %	Total
108-113	10																		10
103-107	28	15	2																45
98-102	37	13	14	2															66
93-97	36	20	12	7	7	2	1												85
88-92	66	40	18	11	12	8	3	2											160
83-87	65	45	39	19	11	5	7	5	6	1									203
78-82	44	47	23	27	13	7	2	2	3		7								175
73-77	25	28	49	24	25	14	7		6		2	2	2						184
68-72	15	28	35	29	15	22	9	5	3	1		1	1	1	2	2			169
63-67	6	12	24	24	33	12	11	12	5	5	2	2	2		1				151
58-62	4	8	17	22	15	38	19	11	11	2	3	4	2		2	3			161
53-57	3	10	8	6	12	14	18	21	12	8	6	4	4	6	3	5	2		142
48-52	1	2	6	6	13	7	7	8	10	9	16	11	4	2	2	2	6		112
43-47		4	5	5	3	3	3	5	4	9	6	3	8	5		4	3		70
38-42			2	2	2	2	3	1	4		2	7	1	7			3	1	37
33-37				1	2			1	1	1		1	2		2				11
28-32						1				1									2
23-27									1										1
Total	340	272	254	185	163	135	90	73	66	37	44	35	26	21	12	16	14	1	1784

Relative Humidity

	Total Hours
ASHRAE 55 Comfort Zone	**106**

Figure 4 – Climate Analysis, Hot and Dry (Phoenix)

Minneapolis, MN
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100 %	Total
93-97			1															1
88-92				3	1	2	4	4										14
83-87	2	1		1	7	4	2	3	3	1								24
78-82	3	5	6	5	10	9	6	9	3	5	1							62
73-77	3	3	2	9	9	6	19	11	10	6	3	2	1	1				85
68-72	1	1	3	12	7	17	7	7	12	5	8	5	2	4	1			92
63-67			3	5	6	13	16	11	8	12	21	11	16	15	2			139
58-62		2	9	12	11	14	14	19	9	8	5	12	5	14	2			136
53-57		4	5	10	8	14	13	27	3	8	5	7	5	3	5			117
48-52		10	9	8	15	15	7	16	17	13	6	2	3	6	11			138
43-47		3	6	3	6	5	10	15	7	2	15	8	1	3	2	2		88
38-42			1	1	4	3	17	17	8	19	4	14	15		18	1	1	123
33-37					1	8	15	10	14	10	26		30		18	10	15	157
28-32					1	6		18		28		36		18		6	2	115
23-27						3	7	3	23		32	15		18		3	5	109
18-22				2	8		11	10		22	29		21	13		3	3	122
13-17					5	8	4		29	19			24			1	3	93
<13		1	1	7	10	23	21	21	16	24	18	18				6	3	169
Total	9	30	46	78	109	150	173	201	162	182	173	130	123	95	59	32	32	1784

Relative Humidity

Total Hours
ASHRAE 55 Comfort Zone **91**

Figure 5 – Climate Analysis, Cold and Humid (Minneapolis)

Boston, MA
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100 %	Total
88-92					4	2	1												7
83-87				2	2	7	6	7	4										28
78-82		1	1	12	7	5	3	7	13	5	1								55
73-77		1	3	4	4	3	10	9	14	6	12	8	5	1					80
68-72			1	4	6	14	12	10	8	11	6	8	15	7	15	2	1		120
63-67				3	10	10	15	17	14	6	11	21	13	6	8	8		1	143
58-62			1	6	12	6	15	8	13	10	6	10	12	15	21	10	1	1	147
53-57	1	2	8	13	7	13	12	11	8	11	5	4	1	10	13	24			143
48-52		2	2	7	11	11	14	11	11	13	10	12	1	5	29	26	3	2	170
43-47		3	12	10	11	19	19	22	18	14	2	10	28	4	16	23	3	5	219
38-42			2	13	12	14	11	20	12	4	10	1	12	18		7		4	140
33-37			8	16	20	19	15	18	15	10	10	18		26		20	3	5	203
28-32		1	3	16	16	17	33	4	28		23		14		6		3	1	165
23-27	2	1	5	3	14	7	11	11	4	11		3	6					2	80
18-22			5	5	13	11		7	9										50
13-17			3	4		6	3	4		2									22
<13				1	1	4	3	2	1										12
Total	3	11	54	119	150	168	183	168	172	103	96	95	107	92	108	120	14	21	1784

Relative Humidity

	Total Hours
ASHRAE 55 Comfort Zone	**76**

Figure 6 – Climate Analysis, Cool and Humid (Boston)

Atlanta, GA
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	10%-15%	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100 %	Total
93-97						1														1
88-92						2	9	3												14
83-87				1	4	6	8	14	23	10	4									70
78-82			2	4	9	5	10	16	15	26	25	20	6	6						144
73-77			3	1	8	10	13	16	17	15	8	28	32	13	6	5	2			177
68-72	3	1	1	3	5	11	12	24	10	14	12	8	13	20	14	24	13	14	1	203
63-67		7	5	10	11	16	9	19	11	13	9	9	20	14	20	32	25	1		231
58-62	1	3	6	6	7	14	9	16	17	9	6	12	5	9	15	19	31	2	7	194
53-57		1	7	8	9	14	10	7	8	11	12	8	7	13	10	16	19	6	2	168
48-52			5	6	9	10	7	8	4	8	13	11	10	8	9	8	16	3	2	137
43-47		3	2	3	5	5	9	3	8	7	11	3	17	7	4	18	21	9	7	142
38-42		1	4	10	8	6	6	12	7	3	4	9	3	5	2		8	6	7	101
33-37		3	1	4	5	9	9	10	7	3	4	4	15		7		11	13	4	109
28-32		1	2	1	4	2	3	7	1	7		3		2		12		3		48
23-27		1	2	1	5	1	1	1	7	1	5			1		1				27
18-22				1	2	2			1	2			1		1	1				11
13-17								1	2		2	1								6
<13										1										1
Total	4	21	40	59	91	114	115	157	138	130	115	116	129	98	88	136	146	57	30	1784

Relative Humidity

Total Hours
ASHRAE 55 Comfort Zone 126

Figure 7 – Climate Analysis, Temperate and Humid (Atlanta)

Orlando, FL
September - June
7 am - 3 pm, weekdays

Dry Bulb Temp	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100 %	Total
93-97				2	3	1	4												10
88-92			1	7	6	23	14	26	25	2									104
83-87				2	7	26	44	57	44	66	48	28	3	1					326
78-82			5	2	9	21	34	37	22	39	51	30	67	30	2	1			350
73-77		2	7	6	13	13	27	31	34	22	31	31	25	26	31	15	4		318
68-72		2	13	3	10	12	15	28	21	26	10	15	19	7	20	15	16		232
63-67	1	1	3	7	5	6	12	17	10	10	9	13	12	22	13	18	4	4	167
58-62		2	4	1	4	4	5	6	8	6	12	12	20	20	15	13	1	1	134
53-57		4	1	1		4	3	5	4	5	5	2	8	5	11	7	1	1	67
48-52			1	1	1	1	5		8	5	3	2	2	1	7	5			42
43-47				1	1	1	1	5	4		1	4	2						20
38-42						1		4	2	3	1		1						12
33-37							1							1					2
Total	1	11	35	33	59	113	165	216	182	184	171	137	159	113	99	74	26	6	1784

Relative Humidity

Total Hours
ASHRAE 55 Comfort Zone 158

Figure 8 – Climate Analysis, Hot and Humid (Orlando)

Outside Air Ventilation

Classrooms and other school spaces must be ventilated to remove carbon dioxide and other pollutants from breathing, odors, and other pollutants. The national consensus standard for outside air ventilation is ASHRAE Standard 62.

If outside air is provided through natural ventilation, then all spaces within the room must be within 20 ft of a window, door, or other ventilation opening, and the total area of ventilation openings must be greater than 5% of the floor area. For a typical 960-ft² (30 ft x 32 ft) classroom, the minimum free ventilation area must be at least 48 ft². The 20-ft rule would also require that ventilation openings be provided on two sides of the room; otherwise some portions of the classroom would be further than 20 ft from a window.

If outside air is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside air must be provided for each occupant. A typical classroom with 30 people requires a minimum of 15 x 30 or 450 cfm per occupant. Other spaces in schools require differing levels of outside air ventilation, based on the expected occupant density of the space and the recommended ventilation rate of 15 cfm/occupant.

The number of occupants is highly variable in some school spaces such as gyms, auditoriums, and multi-purpose rooms. Many codes require systems to vary the quantity of outside air ventilation in these spaces based on the number of occupants. One technique for addressing this issue is to install carbon dioxide (CO_2) sensors that measure concentrations and vary the volume of outside air accordingly. If an auditorium fills up for a school assembly, CO_2 concentrations will increase, the HVAC system will be signaled, and outside air volumes will be increased accordingly. This type of control can both save energy and significantly improve IAQ.

Systems must also be designed to provide at least three air changes per hour, or the required ventilation rate indicated above for the hour prior to normal occupancy of the building. This requirement ensures building-related contaminants that may have built up overnight while the system was shut down are flushed out.

The location of ventilation air intakes and exhausts is a critical aspect of integrated building design and sometimes difficult to coordinate or optimize. Outside air intake dampers must be carefully located to avoid pollution from sources such as parking lots, loading docks, adjacent roadways, sewer vents, or boiler exhaust fumes. Patterns of air movement around buildings can be quite complex and dynamic. Designers are advised to consult ASHRAE Fundamentals Chapter 15 airflow analysis models for exhaust stack reentrainment modeling. If major sources of industrial pollution exist nearby, more sophisticated models are often used for predicting downwind concentrations of pollutants. In the extreme case of urban settings with multiple building heights, designers should consider building scale models for testing in wind tunnels.

IAQ is also affected by the selection of interior finishes and materials. These issues are discussed in the Resource-Efficient Building Products chapter. The design of air distribution ducts and fan systems can also have a significant effect on IAQ. Exposed fiberglass and other porous or flaking materials should never be used on the interior of ducts, unless they are encapsulated with a surface finish that is robust, will not break down from atmospheric ozone exposure (smog), and can be cleaned with a mechanical brush without releasing particles.

Load Calculations

Properly sizing HVAC systems in schools is critical to both energy efficiency and cost effectiveness. The compressors in oversized packaged air conditioners or heat pumps cycle frequently and overall efficiency drops with each cycle. Frequent cycling also reduces the efficiency of boilers, furnaces, and many other types of equipment. Properly sized equipment, with multiple firing rates and stages of cooling, reduces cycling and helps maintain efficient operation, but smaller, properly sized equipment that is matched to the building load is also often less expensive and can reduce initial construction costs.

Many computer programs and calculation methodologies can be used for load calculations. The assumptions used about infiltration rates, lighting levels, equipment, and occupant loads are often more important than the actual software that is used in the calculations. Engineers should take care to make assumptions that are consistent with the energy-efficient recommendations made in other chapters of the Best Practices Manual. An efficient building shell and lighting system should result in significant HVAC equipment size reductions and reduce cost.

Environmental Considerations

In terms of environmental performance, the HVAC system primarily affects energy usage, acoustic comfort, the life of building materials, and indoor environmental quality. Other environmental considerations are relevant, such as using materials efficiently, employing energy recovery devices for heating or cooling, conserving water, using materials that can be readily recycled, and avoiding ozone-depleting refrigerants. The following specific measures can be used to reduce the environmental impact of HVAC systems.

- A well-designed building with integrated building systems will significantly reduce the requirements for heat and cooled air distribution. In addition to energy savings, significantly less equipment, or smaller equipment, is needed.
- A well-designed HVAC system always provides easy access for cleaning and repair, enhancing long-term ability to provide good IAQ and thermal comfort.
- Selection of equipment and materials play a part as well. Strategies and considerations include:
    - Specifying low-toxic (water-based) mastic to seal ducts, or in cases where round ducts are used, specify internal gasketed duct joint systems so that duct sealants are not needed.
    - Selecting durable long-life equipment with hinged access doors that allow for equipment service and that can be easily refurbished.
    - Limiting the use of equipment that uses CFC or HCFC refrigerants.
    - Consider alternatives to cooling towers, which use significant amounts of water.
    - Metal components of HVAC systems can be recycled. Suggest recycling equipment at the end of its life cycle. In addition, metal components of HVAC equipment typically include recycled content, although data is not readily available as to the amount.
    - Energy recovery equipment should always be considered for the ventilation system since heating and cooling the ventilation air accounts for the majority of the load that is placed on the systems in a well-designed facility. Payback periods for energy recovery are often 10 years; however the school systems are designed to last 30 to 50 years.
    - Consideration needs to be given to renewable energy heating and cooling sources such as geothermal standing column wells.

Commissioning

Commissioning is the process of ensuring that the intent of the project program is properly reflected in the design and that the design intent is properly executed during construction and operation. Commissioning tasks start at the very beginning and continue throughout the project, even into the occupancy period. Experience has shown that most energy-efficient designs do not achieve intended savings without the oversight and testing provided by a commissioning process.

For larger facilities, the project manager should consider including an independent commissioning agent in the early planning process. A commissioning plan should be developed during schematic design and updated at each project phase. Typical elements of a commissioning process include:

- Commissioning plan development
- Documentation of design intent
- Design review
- Submittals review
- Inspections and system functional testing
- Enhanced operating and maintenance documentation, including hands-on training of the staff operating and maintaining the equipment
- Post-occupancy testing and operation evaluation.

For small schools with relatively simple mechanical systems, a detailed commissioning process may not be feasible. However, some form of a testing of the equipment and controls is essential to ensure systems are operating properly and at peak efficiency before, or soon after, occupancy.

Specific commissioning issues are discussed in each of the guidelines below. A number of sample commissioning plans and guidelines are also available. A good source is the Portland Energy Conservation Inc. at http://www.peci.org/. Other resources include the U.S. Department of Energy at http://www.energy.gov/, the American Society of Heating, Refrigerating and Air-Conditioning Engineers at http://www.ashrae.org/, and the Sheet Metal and Air Conditioning Contractors' National Association at http://www.smacna.org/.

Design Tools

In addition to general energy simulation programs, many useful tools for optimizing mechanical design exist. Heating and cooling load calculation programs that are widely available from equipment manufacturers and commercial vendors are most commonly used. Other programs integrate with CAD software and aid the design of piping and duct systems. Many of these tools also have cost estimating capabilities, which are very helpful in design optimization and budget review.

Computational fluid dynamics (CFD) software can help in studies of natural and mechanical ventilation and is very useful in creatively integrating mechanical and architectural design. Historically, this type of analysis is expensive. Many manufacturers of air distribution equipment can now provide CFD graphic representation of the air distribution delivered by their products.

Controls

HVAC, lighting, water heating, signal/communication wiring, and other systems need to be operated and controlled efficiently and effectively. With integrated design, the effective control of one system may depend on how another system is being operated. Building management systems offer integrated control of HVAC, lighting, outside air ventilation, natural ventilation, building security, and water heating systems. Energy can be saved through efficient control that turns off or slows down systems when they are not needed. In general, slowing down most fans by 25% cuts the electric energy the fan uses by 50%. Building management systems can also provide information for students and faculty to understand how the building is working and how much energy it is using. Building management systems should always be equipped with easy-to-use graphic interfaces to facilitate their proper use.

System Selection

Figure 9 illustrates a few important questions that help narrow the choice of HVAC system for each space. This decision tree leads to one of several categories of system types. There are three main questions:

1. Can natural ventilation meet all reasonable cooling needs? For many locations this is possible, especially with careful attention to architectural design. If cooling is unnecessary, then several heating-only options exist.
2. Can outdoor air ventilation be provided naturally or is mechanical ventilation required? This affects the system choice regardless of whether it is heating only, or heating and cooling. If fans are not required for ventilation, the design should allow them to be off for much of the year, saving fan energy.
3. If cooling is required, can an efficient evaporative cooling system be used? If not, compressor cooling, either with a direct expansion or chilled water system is required.

There are, of course, many other considerations in system selection. This chapter provides guidelines for most of the common HVAC system types used in schools. Table 3 provides an overview of what systems are most applicable to each climate zone.The choice of optimal system type for a specific school is a complex decision based on many factors. Many tradeoffs are involved, especially price versus performance. Other important considerations are:

- Noise and vibration
- IAQ ventilation performance
- Thermal comfort performance
- Operating costs and energy efficiency
- Maintenance access, costs, and needs
- HVAC equipment space requirements (in the classroom, on the roof, in mechanical rooms)
- Durability and longevity
- The ability to provide individual control for classrooms and other spaces
- The type of refrigerant used and its currently understood ozone-depleting potential.

Table 4 compares system types using these criteria and others. More information regarding the applicability of each system type is discussed in the individual guidelines.

Phasing of construction projects also influences the decision between central systems and distributed systems. If a large facility is to be constructed in several phases, then it may be difficult to afford the upfront investment in the central plant option.

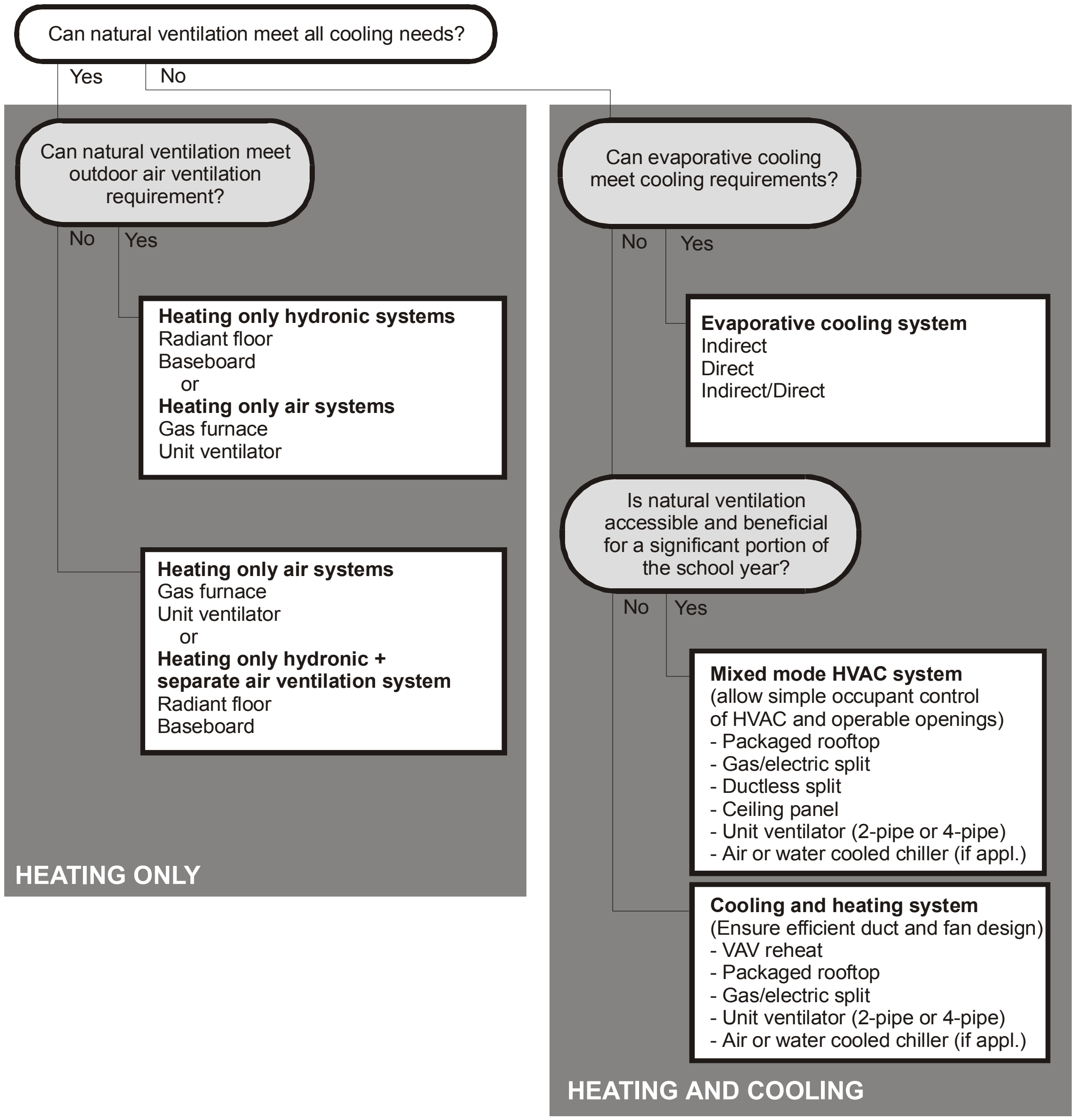


Figure 9 – HVAC System Selection Decision Tree

Table 3 – Climate Zone Applicability for HVAC Guidelines

Guideline	Temperate and Mixed	Cool and Dry	Hot and Dry	Cold and Humid	Cool and Humid	Temperate and Humid	Hot and Humid
MV1: Cross Ventilation	●	●	○	●	●	◉	○
MV2: Stack Ventilation	●	●	◉	●	●	◉	○
MV3: Ceiling Fans	●	◉	◉	●	●	◉	○
MV4: Gas/Electric Split System	○	◉	●	○	◉	●	●
MV5: Packaged Rooftop System	○	◉	●	○	◉	●	●
MV6: Displacement Ventilation System	◉	●	◉	○	●	●	◉
MV7: Hydronic Ceiling Panel System	◉	●	◉	◉	●	○	○
MV8: Unit Ventilator System	●	●	◉	●	◉	◉	◉
MV9: Ductless Split System	◉	●	◉	●	◉	◉	○
MV10: Evaporative Cooling System	○	●	●	◉	◉	○	○
MV11: VAV Reheat System	◉	◉	●	○	○	●	●
MV12: Radiant Slab System	●	●	○	●	●	◉	○
MV13: Baseboard Heating System	●	●	○	●	●	◉	○
MV14: Gas-Fired Radiant Heating System	●	●	◉	●	●	◉	◉
MV15: Water-Loop Heat Pumps	●	●	○	●	●	◉	○
MV16: Evaporatively Precooled Condenser	○	◉	●	○	◉	●	◉
MV17: Dedicated Outside Air Systems	◉	●	○	●	◉	◉	○
MV18: Economizers	●	●	●	●	●	●	◉
MV19: Air Distribution Design Guidelines	●	●	●	●	●	●	●
MV20: Duct Sealing and Insulation	●	●	●	●	●	●	●
MV21: Hydronic Distribution	◉	◉	●	◉	◉	●	●
MV22: Chilled Water Plants	◉	◉	●	◉	◉	●	●
MV23: Boilers	●	●	●	●	●	●	●
MV24: Adjustable Thermostats	●	●	●	●	●	●	●
MV25: EMS/DDC	●	●	●	●	●	●	●
MV26: Demand Controlled Ventilation	●	●	●	●	●	●	●
MV27: CO Sensors for Garage Exhaust Fans	●	●	●	●	●	●	●
MV28: Timers for Recirculating Hot Water Systems	●	●	●	●	●	●	●

Legend: ● Best Applicability ◉ Mid-Range Applicability ○ Worst Applicability

Table 4 – HVAC Selection Criteria

Selection Criteria		Gas/Electric Split System	Rooftop Packaged System	Displacement Ventilation	Ceiling Panels	Unit Ventilator (4-pipe)	Unit Ventilator (2-pipe)	Ductless Split System	Evaporative Cooler	VAV/Reheat.	Radiant Floor	Baseboards	Gas-Fired Radiant System for Gyms	Chiller – Water Cooled	Chiller – Air Cooled
First Cost		◉	●	○	○	○	◉	◉	◉	◉	○	◉	◉	○	◉
Maintenance Cost		◉	◉	◉	◉	◉	◉	◉	●	◉	◉	◉	◉	◉	◉
Cooling Effectiveness		◉	◉	●	●	◉	◉	○	◉	●	N/A	N/A	N/A	●	●
Heating Effectiveness		◉	◉	○	○	◉	○	○	N/A	◉	●	●	●	N/A	N/A
Energy Operating Cost		◉	◉	●	●	◉	◉	◉	●	◉	●	◉	●	●	◉
Durability		◉	◉	◉	●	◉	◉	◉	◉	●	●	●	◉	●	◉
Life-Cycle Cost		◉	○	●	◉	○	○	◉	●	◉	◉	◉	◉	●	◉
Noise (Acoustic Environment)		◉	◉	●	●	○	○	○	◉	◉	●	●	●	○	○
Roof Space Required		●	○	◉	●	●	●	●	○	○	●	●	●	N/A	N/A
Water Consumption		●	●	●	●	●	●	●	○	●	●	●	●	◉	●
Classroom Control		●	●	●	◉	●	●	●	●	●	◉	◉	●	N/A	N/A
Multi-Zone Capability		○	○	○	◉	○	○	○	○	●	◉	◉	◉	N/A	N/A
Ozone Depletion		○	○	◉	◉	◉	◉	○	●	◉	◉	◉	◉	◉	◉
Outside Air Ventilation		◉	◉	●	○	◉	◉	○	●	◉	○	○	○	N/A	N/A
Thermal Comfort		◉	◉	●	●	○	○	○	◉	●	●	◉	◉	N/A	N/A
Natural Ventilation (Mixed Mode Method)	Compatibility (poor/fair/good)	◉	◉	◉	●	◉	◉	◉	◉	○	●	◉	●	N/A	N/A
	Change-Over (yes/no)	●	●	●	○	●	●	●	●	●	○	○	○	N/A	N/A
	Concurrent (yes/no)	○	○	○	●	○	○	○	○	○	●	●	●	N/A	N/A
Indoor Air Quality		◉	◉	●	●	◉	◉	◉	◉	◉	●	●	●	N/A	N/A

Legend: ● Better than average (better performance or lower cost) ◉ Average ○ Worse than average (lower performance or higher cost)

Selection Criteria		**Gas/Electric Split System**	**Rooftop Packaged System**	**Displacement Ventilation**	**Ceiling Panels**	**Unit Ventilator (4-pipe)**	**Unit Ventilator (2-pipe)**	**Ductless Split System**	**Evaporative Cooler**	**VAV/Reheat.**	**Radiant Floor**	**Baseboards**	**Gas-Fired Radiant System for Gyms**
Spaces Applicability (black, gray or clear)	Classrooms	●	◉	●	●	◉	◉	○	◉	◉	●	◉	○
	Library	◉	◉	◉	○	○	○	○	◉	●	◉	◉	○
	Multi-purpose	◉	◉	◉	○	○	○	○	●	◉	◉	◉	●
	Gym	◉	◉	○	○	○	○	○	●	◉	◉	○	●
	Corridors	◉	◉	○	○	○	○	○	●	◉	◉	◉	○
	Admin	◉	◉	●	●	○	○	◉	●	●	◉	●	○
	Toilets	◉	◉	○	◉	○	○	◉	◉	◉	◉	◉	○
	Other	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉	◉
Possible Cooling Sources	DX	●	●	◉	○	◉	◉	●	○	●	N/A	N/A	N/A
	CHW	○	○	●	●	●	●	○	○	●	N/A	N/A	N/A
Possible Heating Sources	HP	○	●	●	○	◉	◉	●	○	○	○	○	○
	HW	○	◉	●	●	●	●	○	◉	●	●	●	○
	Furnace	●	●	●	○	○	○	○	◉	●	○	○	○
Optional Energy Efficient Features	Air Economizer	◉	●	●	○	●	●	◉	●	●	○	○	○
	Evaporative Precooler	●	●	●	○	○	○	●	○	●	○	○	○
	Variable Speed Fan	◉	◉	◉	○	◉	◉	◉	●	●	○	○	○
	High Efficiency Motors	●	●	●	●	●	●	●	●	●	●	●	○

Legend: ● Better than average (better performance or lower cost) ◉ Average ○ Worse than average (lower performance or higher cost)

GUIDELINE MV1: CROSS VENTILATION

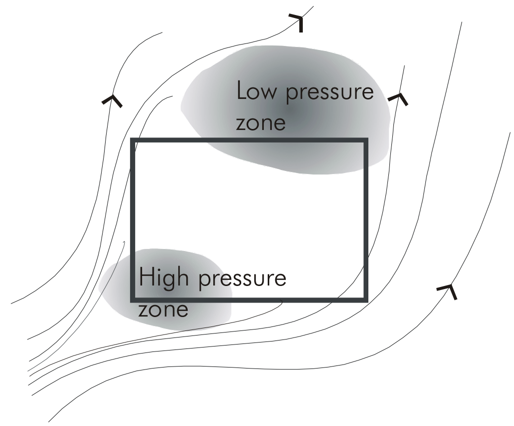
Recommendation

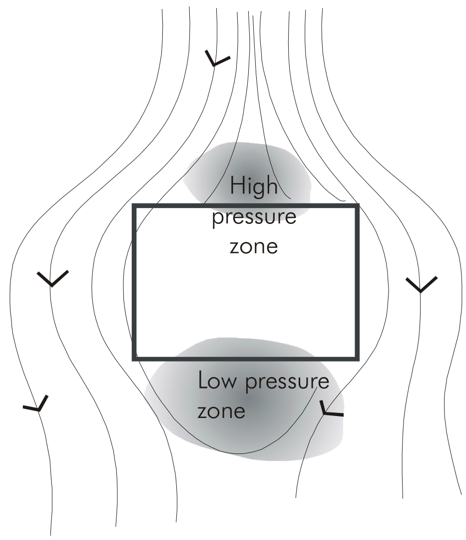
Provide equal area of operable openings on the windward and leeward side. Ensure that the windward side is well shaded to provide cool air intake. Locate the openings on the windward side at the occupied level.

Description

Wind-driven ventilation is one of two methods of providing natural ventilation. All natural ventilation strategies rely on the movement of air through space to equalize pressure. When wind blows against a barrier, it is deflected around and above the barrier (in this case, a building). The air pressure on the windward side rises above atmospheric pressure (called the pressure zone). The pressure on the leeward side drops (suction zone), creating pressure stratification across the building. To equalize pressure, outdoor air will enter through available openings on the windward side and eventually be exhausted through the leeward side.

Pressure is not uniformly distributed over the entire windward face, but diminishes outwards from the pressure zone. The pressure difference between any two points on the building envelope will determine the potential for ventilation if openings were provided at these two points. The airflow is directly proportional to the effective area of inlet openings, wind speed, and wind direction.

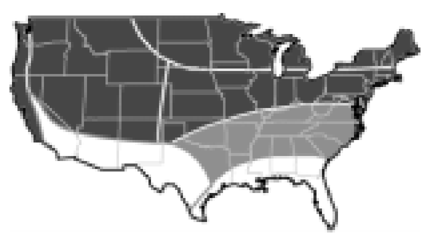


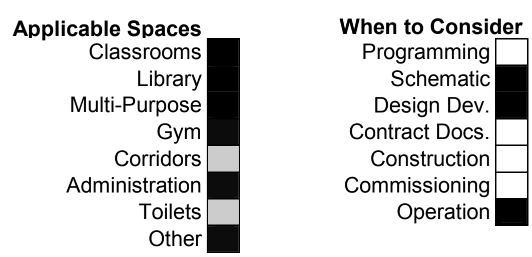


Applicability

Cross ventilation is a very effective strategy for removing heat and providing airflow in mild climates. In coastal climates, the need for a cooling system may be eliminated by a carefully designed natural ventilation system. In most other climates, it can alter interior conditions only modestly. Hybrid systems work best in such situations. In humid climates, natural ventilation cannot replace the moisture-removing capabilities of air conditioning (although desiccant systems that remove moisture from the space can be used for more effective natural ventilation). Introducing humid air (even if it is relatively cool) into a space will add a substantial load on the cooling system in hybrid systems. However, even extreme climates experience moderate conditions during spring and fall, and natural ventilation should be designed to take full advantage of these conditions.

Applicable Climates





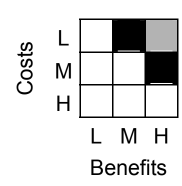
This strategy relies heavily on two parameters that may change continuously: wind availability and wind direction. Consequently, it is a somewhat unreliable source for thermal comfort. Spaces, like computer rooms and laboratories, that need strict maintenance of indoor temperature and humidity should definitely use hybrid systems for both cooling and ventilation. Introducing natural ventilation in a building may cause increased levels of dirt, dust, and noise, which could also be a serious limitation for certain types of spaces.

Cross ventilation has to be an integral part of the design schematic and design development phases. An effective natural ventilation design starts with limiting space sizes to facilitate inward flow of air from one face and outward flow from the other — architectural elements can be used to harness prevailing winds. This may alter building aesthetics and needs to be addressed early in the design phase.

Integrated Design Implications

- **Design Phase.** Cross ventilation can (or should) very strongly influence building aesthetics and site planning. Natural ventilation codes will dictate space widths and minimum opening sizes. To maximize the effectiveness of openings, the long façade of a building should be perpendicular to the prevailing wind direction. Narrow and woven plans with more surfaces exposed to the outside will work better than bulky plans with concentrated volumes. Singly loaded corridors will provide better air flow than doubly loaded ones. An open building plan with plenty of surface area exposed to the outside will work well for cross ventilation. Architectural elements like fins, wing walls, parapets, and balconies will enhance wind speeds and should be an integral part of cross ventilation design.
- **Thermal Mass.** Cross ventilation should be combined with thermal mass to take advantage of large diurnal temperature swings. Mass walls can act as heat reservoirs, absorbing heat through the day and dissipating it at night. At night, natural ventilation can be used to increase the quantum of dissipated heat as well as to accelerate the process of dissipation (see section on Energy-Efficient Building Shell for details). This will reduce the load on the cooling system by pre-cooling the building. A large diurnal temperature swing (as in desert areas) will ensure that the building is more effectively "flushed."
- **Integration with Daylighting and View Windows.** The apertures for cross ventilation will also serve as view windows and luminaires for side lighting. All architectural elements intended to enhance one strategy should also work for the other. Orientation that works for ventilation (openings on the windward side) may not be the ideal direction for bringing in daylight. West orientation for windows will increase heat gain and cause glare, but may be the best orientation for bringing in outside air in the coastal areas. Prioritize the needs of the space based on function and climate. For instance, benefits of daylighting in a cold climate outweigh those of cross ventilation, therefore orient the building based on daylighting considerations.
- **Integration with HVAC.** Natural ventilation may be intended to replace air conditioning entirely or, as is more often the case, to coexist with mechanical systems in a "hybrid mode." Also, natural ventilation may occur in "change-over" (windows are shut when mechanical system is on) or "concurrent" modes. Fewer systems are compatible with the concurrent mode. These factors need to be carefully considered before selecting a system (for more information on system selection see this chapter's Overview).

Cost Effectiveness



Low to moderate. Buildings that use natural ventilation may have higher initial costs, due to the higher cost of operable windows. Operable windows typically cost 5% to 10% more than fixed glazing. Based on average installed cost for metal frame, double-glazed, fixed windows of $\$20/ft^2$ to $\$30/ft^2$, the operable window should cost $48 to $72 more per classroom for buildings that meet their ventilation needs through natural ventilation only (based on code-prescribed minimum area of operable glazing per classroom). For "hybrid" buildings, the cost will be more modest because the operable window area can be less than the code prescribed minimum (5% of floor area). In buildings where natural ventilation is designed to occur concurrently, the initial costs may be higher due to limitations in system selection.

Benefits

Moderate to high. This varies significantly depending on climatic conditions and natural ventilation design.

- In a moderate climate, wind-driven ventilation can meet the cooling loads most of the time. In such climates, the simple payback period will vary between 8 to 12 years. At times, a good natural ventilation design may completely eliminate the need for a cooling system. This design will result in huge savings that offsets the cost of installing operable windows and lowers the simple payback period to one to four years.
- Buildings located in harsher climates will use “mixed-mode” systems. In such climates, natural ventilation may have limited application resulting in higher payback periods of 12 to 15 years.
- Cross ventilation alleviates odors and quickly exhausts contaminants from a space.
- Increased airflow in a space results in higher thermal comfort levels and increased productivity.
- Operable openings at the occupied level instill the occupants with a sense of individual control over the indoor environment.
- An intangible benefit of natural ventilation is the establishment of a connection with the outdoors (both visual and tactile), weather patterns, and seasonal changes. This results in higher tolerances for variations in temperature and humidity levels.
- Natural ventilation systems are simple to install and require little maintenance.

Design Tools

Opening areas may be derived using spreadsheet-based calculations. These estimates use approximation techniques but are good numbers to start with. The following algorithm shows the rate of wind-induced airflow through inlet openings:

$$Q = C_4 C_v A V$$

where,

Q = airflow rate, cfm

C_v = effectiveness of openings (C_v is assumed to be 0.5-0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds)

A = free area of inlet openings

V = wind speed, mph

C_4 = unit conversion factor= 88.0

The following algorithm calculates the required airflow rate for removal of a given amount of heat from a space (see section on Load Calculations for estimating the amount of heat to be removed):

$$Q = \frac{60q}{c_p \rho (t_i - t_o)} \qquad Q = \frac{\text{Btu/h}}{1.08 \Delta T}$$

where,

Q = airflow rate required to remove heat, cfm

q = rate of heat removal, Btu/h

C_p = specific heat of air Btu/lb°F (about 0.24)

ρ = air density, lb_m/cf (about 0.075)

t_i-t_o = indoor-outdoor temperature difference, °F

Many computer programs are available for predicting ventilation patterns. Some that use the “zonal” method may be used to predict ventilation rate (mechanical and natural), magnitude and direction of air flow through openings, air infiltration rates as a function of climate and building air leakage, pattern of air flow between zones, internal room pressures, pollutant concentration, and back drafting and cross-contamination risks. These models take the form of a flow network in which zones or rooms of differing pressure are interconnected by a set of flow paths. This network is approximated by a series of equations representing the flow characteristics of each opening and the forces driving the air flow process. Widely available codes include BREEZE and COMIS.

A computational fluid dynamics (CFD) program is a more accurate and complex tool for modeling airflow through a space based on pressure and temperature differentials. These programs can simulate and predict room airflow, airflow in large enclosures (atria, shopping malls, airports, exhibitions centers, etc.), air change efficiency, pollutant removal effectiveness, temperature distribution, air velocity distribution, turbulence distribution, pressure distribution, and airflow around buildings. FLUENT is a sophisticated analysis technique that can, among other things, model and/or predict fluid flow behavior, transfer of heat, and behavior of mass. This software is particularly geared towards ventilation calculations including natural and forced convection currents. It also accurately calculates air density as a function of temperature and predicts the resulting buoyancy forces that can give rise to important thermal stratification effects. Important outputs from FLOVENT are user variables, such as the comfort indices of predicted mean vote, percentage of people dissatisfied, mean radiant temperature, dry resultant temperature, and percentage saturation, including a visualization of their variation through space. A summary of minimum, maximum, mean, and standard deviation for all calculated variables is also available.

Design Details

- Orient the building to maximize surface exposure to prevailing winds.
- Provide the inlets on the windward side (pressure zone) and the outlets on the leeward side (suction zone). Use architectural features like wing walls and parapets to create positive and negative pressure areas to induce cross ventilation. Air speed inside a space varies significantly depending on the location of openings (see table below). As far as possible, provide openings on opposite walls. Using singly loaded corridors will facilitate provision of openings on opposite walls. Limit room widths to 15 ft to 20 ft if openings cannot be provided on two walls. Windows placed on adjacent walls also perform very well due to the wall-jet phenomenon wherein the inflowing air moves along the nearest wall surfaces. This positioning should be limited to smaller spaces (less than 15 ft x 15 ft).
- Air inlet and outlets should be designed to minimize noise transfer from the exterior to the interior and to adjacent occupied spaces.

Table 5 — Average Indoor Air Velocity as a Percentage of the Exterior Wind Velocity for Wind Direction Perpendicular to and 45° to the Opening

Window Height as a Fraction of Wall Height	1/3	1/3	1/3
Window Width as a Fraction of Wall Height	1/3	2/3	3/3
Single Opening	12%-14%	13%-17%	16%-23%
Two Openings on Same Wall	-	22%	23%
Two Openings in Adjacent Walls	37%-45%	-	-
Two Openings on Opposite Walls	35%-42%	37%-51%	46%-65%

Source: Givoni, Baruch; Man, Climate, and Architecture*, London: Applied Science, 1976.*

- A free ventilation area of 1.5% to 2% (of the floor area), which is the recommended minimum area for operable windows only, will meet the ventilation requirements. Daylighting considerations will require a larger window area. Also, if the space is solely dependent on natural ventilation then code requirements will set the minimum operable window area to 5% of the floor area. Although this area will meet the ventilation requirements of a space during mild climatic conditions, larger window areas should be provided for occupant cooling through increased air movement. For cooling purposes provide 5% to 8% of the floor area as free ventilation area. Equal inlet and outlet areas maximize airflow, whereas outlets that are 2% to 5% larger than inlets produce higher air velocities.The inlet location affects airflow patterns far more significantly than outlet location. Inlet location should be a higher priority (if faced with a choice), as a high inlet will direct air towards the ceiling and will almost bypass the occupied level. Locate inlets at a low or medium height.For natural ventilation to function properly, solar gains should be minimized. Direct sunlight penetrating into the space during periods of natural ventilation may make it difficult or impossible to achieve comfortable conditions with natural ventilation alone. Use shading devices such as overhangs, awnings, and fins to control solar gains.

- The incoming air may be cooled through good site planning, landscaping, and planting strategies. If a water body is planned for the site, place it on the windward side to pre-cool the incoming air through evaporative cooling. Planting tall deciduous trees on the windward side will lower the temperature of the inflow and shade the openings.
- Provide windows with shutters that can be opened or shut in increments. This allows the occupants to vary the inlet and outlet areas according to seasonal variations.
- Use features like overhangs, awning windows, eaves, and porches to protect the openings from rain and to minimize excess heat gain from direct sunlight. Awning windows work very well for cross ventilation because they provide more airflow than double-hung windows (for the same glazed area) and also provide protection from rain. Casement windows provide maximum airflow in both perpendicular and oblique wind conditions.
- Ensure that vents and windows are accessible and easy to use. Avoid blocking windows with exterior objects such as shrubs and fences, but do not eliminate shading.
- Provide inlets for cross ventilation openings at the occupied level. Stagger the outlet openings both vertically and horizontally by a few feet to achieve longer air paths. Concentrate ventilation openings in spaces most likely to require cooling.
- Use overhangs, porches, and eaves to protect windows and vents from rain to extend the amount of time that natural ventilation can be used.
- Ensure that openings can be tightly sealed in winter or when using air conditioning or dehumidification systems.
- HVAC systems should be designed to work in harmony with natural ventilation. The objective of a concurrent natural ventilation system is to meet the outside air requirement using the least possible opening area. The objective of a change-over natural ventilation system is to meet the outside air requirement as well as provide cooling. The HVAC and natural ventilation system are mutually dependent. See the Overview for a detailed discussion.

Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success. Automated operation may make sense for very large commercial buildings, but not for schools.

- Encourage students and teachers to open/close openings regularly.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Periodically clean windowsills, panes, fins, screens, and louvers to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings are shut during cold weather and the hours of operation of the mechanical system. Also ensure adequate opening area is available for nighttime ventilation in hot dry climates.

Commissioning

None.

References/Additional Information

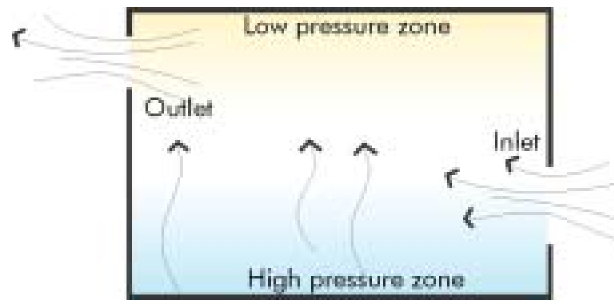
Cook, Jeffrey, Ed. *Passive Cooling*. Cambridge: MIT Press, 1989.

Brown, G.Z. *Sun, Wind, and Light*. New York: John Wiley & Sons, 1986.

GUIDELINE MV2: STACK VENTILATION

Recommendation

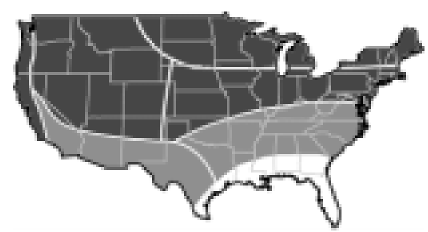
Use inlets and outlets of equal area and maximize the vertical distance between these two sets of apertures. Place inlets close to the floor or at the occupied level. Locate the outlets closer to the ceiling on the opposite wall. To facilitate varying summer and winter strategies, provide incrementally operable shutters.

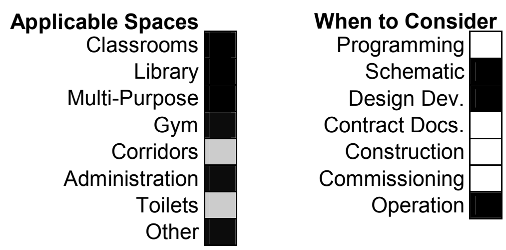


Description

Stack ventilation is one of two methods of providing natural ventilation. Stack ventilation utilizes the difference in air densities to provide air movement across a space. At least two ventilation apertures need to be provided; one closer to the floor and the other high in the space. Warmed by internal loads (people, lights, equipment), the indoor air rises. This creates a vertical pressure gradient within the enclosed space. If an aperture is available near the ceiling, the warmer air at the upper levels will escape as the lower aperture draws in the cool outside air. Higher indoor temperatures are essential for causing a pressure difference such that the upper openings act as the outlet and cool air intake is induced at the lower opening.

Applicable Climates





The airflow induced by thermal force is directly proportional to the inlet-outlet height differential, the effective area of the aperture, and the inside-outside temperature differential.

Applicability

Pressure-differential-driven natural ventilation is an effective strategy for meeting minimum airflow requirements, especially during winter, when the inside-outside temperature differential is at a maximum. It is also appropriate for providing cooling during mild weather conditions when direct outside air is still sufficiently cool to meet interior space cooling requirements.

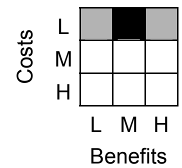
Integrated Design Implications

- **Design Phase.** Using the stack effect for ventilation requires an integrated design approach. Stack ventilation will affect building mass and aesthetics. Vertical airshafts for providing stack ventilation also need to be considered early in the design phase.
- **Thermal Mass.** Nighttime ventilation coupled with thermal mass is a very effective strategy for heat removal in hot, dry climates.
- **Integration with Daylighting and View Windows.** Apertures for stack ventilation need to be located close to the floor and ceiling for best results. The high apertures can couple as clerestories or side-lighting luminaires. Benefits of daylighting and natural ventilation need to be considered in conjunction with each other to arrive at the ideal location and size for openings.
- **Integration with HVAC.** Stack ventilation will be used for meeting the outside air requirement in most climates other than Hot and Dry (where stack ventilation will also be used for nighttime cooling).

Carefully integrating this strategy with HVAC system selection and operation will maximize its benefits. For details, see the Overview section.

Cost Effectiveness

Low to moderate.



Stack ventilation may not add to overall costs significantly if integrated with view windows, high side lighting, and other daylighting strategies. However, an additional cost of $2/ft^2 may be associated with ensuring that all openings are operable. Adjustable frame intake louvers may cost up to $25/ft^2 (this includes installation costs). Additional cost of installing windows high in the space will range from $15/ft^2 to $30/ft^2.

Benefits

Low to moderate.

The benefits depend largely on weather conditions (indoor-outdoor temperature differential) and the design of openings.

- In a moderate climate, a combination of wind-driven and stack ventilation strategies can meet the cooling loads most of the time. In more extreme climates (with a large diurnal range of temperature), stack ventilation can operate in “mixed-mode” systems and reduce the peak demand through nighttime flushing, resulting in lower utility bills and first costs. In such climates, the simple payback period will be 8 to 12 years. For most other climates, the simple payback period will be 10 to 14 years.
- Stack ventilation apertures can also double as side and high side lighting strategies.
- Stack ventilation effectively removes contaminants and pollutants from space.

Design Tools

The airflow (cfm) required can be reasonably estimated using spreadsheet-based calculations. The following algorithm defines the airflow as it varies with the area of openings, indoor temperature, outdoor temperature, and location of the inlet and outlet:

$$Q = 60 C_D A \sqrt{2g\Delta H_{NPL} (T_i - T_o) / T_i}$$

Q = airflow rate, cfm

C_D = discharge coefficient for opening

ΔH_{NPL} = height from mid-point of lower opening to Neutral Pressure Level (NPL) ft

T_i = indoor temperature, °F

T_o = outdoor temperature, °F

Use this algorithm to estimate the aperture area for a particular hour of a day (with Q equal to 15 cfm).

Several computer tools are available for simulating pressure driven airflow. Refer to Guideline MV1: Cross Ventilation for details.

Design Details

- Provide equal inlet and outlet areas to maximize airflow. Airflow will be dictated by the smaller of the inlet and outlet areas.
- The width to height ratio of openings should be more than one as far as possible (i.e., orient openings horizontally).
- The free ventilation area of the inlet and outlet should be at least 1% of the total floor area of the room (4.8 ft^2 each per classroom, based on 32 ft x 30 ft x 9 ft-6 in. classrooms). This is adequate to meet outdoor air requirements with perpendicular wind speeds as low as 2 mph and low temperature differentials that occur during summer months. Lowering the air intake of these openings during

winter or completely shutting some of these openings may avoid uncomfortable winter conditions. For extreme climates, all the available operable openings may remain open only for limited periods.

- Allow for at least a 5-ft center-to-center height difference between the inlet and the outlet. Increasing the height differential further will produce better airflow.
- Use stairwells or other continuous vertical elements as stack wells by providing adequate apertures. Such spaces may be used to ventilate adjacent spaces because of their ability to displace large volumes of air (because of greater stack height).
- Carefully control and minimize solar gains. For details see Guideline MV1: Cross Ventilation.
- Combine stack ventilation with cross ventilation elements. Set the inlet openings for cross ventilation lower in the wall so that they can double as inlets for stack ventilation.
- Use louvers on inlets to channel air intake. Use architectural features like wind towers and wind channels to effectively exhaust the hot indoor air.
- HVAC systems should be designed to work in harmony with stack ventilation (see the Overview section for a discussion).
- Air inlet and outlets should be located or designed to minimize noise transfer from the exterior to the interior and to adjacent occupied spaces.
- Large openings may require installing security grills to limit potential points of entry.

Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success:

- Openings should be appropriately operated according to indoor-outdoor temperature differentials.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Windowsills, fins, screens, and louvers should be periodically cleaned to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings remain shut during the mechanical system's hours of operation unless the ventilation is designed to work concurrently.
- Ensure that adequate opening area is available for nighttime ventilation in hot, dry climates.

Commissioning

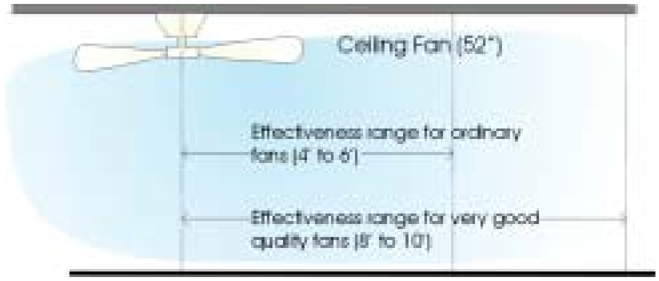
None.

References/Additional Information

Cook, Jeffrey. *Passive Cooling*. Cambridge: MIT Press, 1989.

Brown, G.Z. *Sun, Wind, and Light*. New York: John Wiley & Sons, 1986.

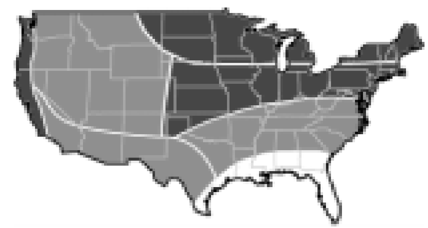
GUIDELINE MV3: CEILING FANS

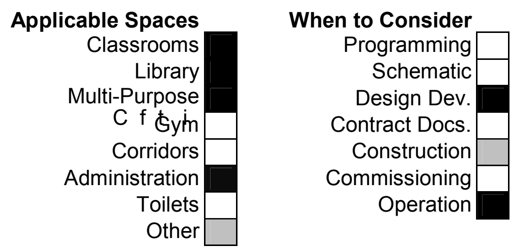


Recommendation

Use ceiling fans in classrooms to provide enhanced thermal comfort for occupants through higher air velocity. Use the ceiling fans instead of air conditioners in mild coastal climates. In more extreme climates, use ceiling fans as a supplement to cooling systems.

Applicable Climates





Description

A ceiling fan is a device for creating interior air motion. It is a permanent fixture operated by a switch or a pull string. Acceptable comfort levels can be maintained above the customary comfort zone for air speeds exceeding 50 fpm by using a ceiling fan. Generally, for speeds above 30 fpm, most people will perceive a 15 fpm increase in air to be equal to 1°F decrease in temperature. This phenomenon is commonly called "chill factor." Outside air can be introduced into a space through openings using a fan when outside air cannot enter the space on its own, because it is either too humid or too hot. A fan can also re-circulate air within a space. Fans also cool by increasing evaporation of moisture from the skin (skin moisture vaporizes using body heat to change phase).

In a high ceiling space, ceiling fans can help "destratify" the warm air layer, which collects near the ceiling, and distribute it to the lower part of the space for thermal comfort. As a result, heating thermostats need not be set as high.

The interior air motion caused by ceiling fans varies as a function of fan position, power, blade speed (measured in rpm), blade size, and the number of fans within the space. Moreover, air speeds within a space vary significantly at different distances from the fan.

The normal current draw will range from approximately 15 W at low speed to 115 W at high speed.

Applicability

Ceiling fans are appropriate for classrooms and administration areas. They may not be suitable for gyms because of the potential for rapid skin cooling (more skin moisture is secreted during intense physical activities). Nor are they appropriate for toilets as the space may be too small for a ceiling hung fan. Noise produced by ceiling fans may be an issue in auditoriums or classrooms if fans turn at too high a velocity.

Ceiling fans are suitable for most climates that require cooling. Combined with other passive strategies they may eliminate the need for air conditioning in the Temperate and Mixed region. They are not very useful in humid climates.

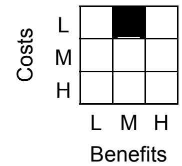
Ceiling fans should be considered in the design development stage due to electrical wiring and ceiling height issues, although adding fans to existing spaces is feasible too.

Integrated Design Implications

Using ceiling fans does not significantly impact other design decisions, except when a displacement airflow design is being considered.

- A minimum ceiling height of 9 ft must be provided to accommodate a fan such that its blades are at a distance of 8 ft from the floor and 1 ft from the ceiling.
- Ceiling fans should be combined with natural ventilation strategies for best results.

Cost Effectiveness



Ceiling fans cost between $75 and $200. The typical cost of a professionally installed fan is about $250. Fans with features such as light fixtures, reverse or multiple speed settings, and extended warranties may cost more. Some ceiling fans are very economical to operate as they consume very little energy. Others have very inefficient motors and add considerable heat to the room. Careful selection should be made.

Benefits

- Moving air extends the comfort range and allows occupants to feel comfortable at higher temperatures. It also helps occupants feel dry. Wind speed is one of the six factors that affect thermal comfort indices like the predicted mean vote (PMV). Increasing air speeds results in PMVs that fall in the comfort zone (for detailed discussion, see this chapter's Overview section).
- Temperature settings for mechanical cooling equipment can be higher and an energy savings greater than the energy consumption of the fans can be realized. According to the Texas Energy Extension Service, for a three-ton cooling system costing $550 per season, raising the thermostat from 75°F to 80°F can reduce the operating cost by $151. Operating a ceiling fan 10 or more hours a day may cost less than $3/month. For example, a typical fan operating at high speed uses approximately 100 W of power. Assuming that the fan is operated five hours/day with an energy cost of $0.08/kWh, the cost of operation will be $0.04/day. At lower speeds this operating cost will be even less. This low operating cost and the potential reduction in cooling and heating cost make the ceiling fan one of the better energy-saving devices on the market. As a rule of thumb — each degree rise in a thermostat setting (beyond 78°F) results in a 3% to 5% saving on cooling energy. If the ceiling fan is supplementing air conditioning, the thermostat of the air conditioning unit may be raised a full 4°F above the standard 78°F setting while still maintaining comfortable space conditions.
- In the heating season, ceiling fans can help bring the warmer air that stratifies near the ceiling down to where the occupants are located. A low speed that does not create a significant breeze is best for this heating season application. Again, the thermostat set point may be lowered by nearly 2°F.

Design Tools

Use the following charts to size ceiling fans according to largest room dimension and room area:

Table 6 — Fan Diameter Selection Based on Space Dimensions

Largest Dimension of Room	Minimum Fan Diameter
12 ft or less	36 in.
12 - 16 ft	48 in.
16 - 17.5 ft	52 in.
17.5 - 18.5 ft	56 in.
18.5 ft or more	2 fans needed

Table 7 — Fan Diameter Selection Based on Space Area

Room Area	Minimum Fan Diameter
100 ft^2	36 in.
150 ft^2	42 in.
225 ft^2	48 in.
375 ft^2	52 in.
400+ ft^2	2 fans needed

Sources: Consumer Guide to Home Energy Saving (1995) by the American Council for an Energy Efficient Economy.

Design Details

- Use ceiling fans in frequently occupied spaces.
- Use “Quiet Type” energy-efficient fan and motor assemblies.
- A larger fan provides a greater range of airflow settings and ventilates a larger area at lower velocities, with less noise, and only slightly more power than similar smaller units. Use two 48-in. fans in classrooms (based on 30 ft x 32 ft classrooms). These will move air most effectively in a 4 ft to 6 ft radius, and somewhat less effectively for another 3 ft to 4 ft radius. At the level of seated occupants, this will achieve air speeds ranging from 50 fpm to 200 fpm. Beyond 30 fpm, every additional 15 fpm results in a perceived 1°F drop in temperature. The more blade surface, the more air it will catch.
- Ceiling fans work best when the blades are 8 ft to 9 ft above the floor and 10 in. to 12 in. below the ceiling. Placing fans so the blades are closer than 8 in. to the ceiling can decrease the efficiency by 40%. Fans also require at least 18 in. of clearance between the blade tips and walls. Two types of mountings are available for ceiling fans — rod and hugger. In rod fans, the motor housing is suspended from the mounting bracket by a rod. With hugger fans, the motor housing is mounted directly to the ceiling box. Hugger fans are not as efficient as rod fans in the down motion, especially at higher speeds. The blades will starve themselves for air when they are too close to the ceiling.
- Use ceiling fans to supplement air movement in natural ventilation strategies.
- Select a fan with at least a two-speed control for better regulation of air movement. Variable-speed fans are preferable so that the lowest speed can be used in the heating season to accomplish destratification without causing excessive draft. If using a reversible fan, ensure that the fan has a setting low enough to circulate the air without creating too much of a breeze. These fans are best for rooms that tend to build up heat.
- Fans should be on only when the space is occupied; otherwise the movement of the motor is also introducing some heat in the room without any cooling benefits. Remember that ceiling fans cool people, not spaces. Consider using an occupancy sensor.

Operation and Maintenance Issues

- Ceiling fans should be operated only when the rooms are occupied. A motion sensor or a clear policy of operating ceiling fans only when using the room is needed. In the destratification mode, starting the fans several hours before occupancy would be beneficial for getting ceiling accumulated heat down.
- Ensure that all blades are screwed firmly into the blade holder and that all blade holders are tightly secured at the fan. This should be checked at least once a year.
- It is important to periodically clean the fan, as the blades tend to accumulate dust on the upper side. An anti-static agent can be used for cleaning, but do not use any cleaning agents that can damage the finish. Never saturate a cloth with water to clean the ceiling fan.
- For a fan to perform efficiently, it is very important that the blade be aerodynamically shaped to increase its efficiency, similar to an airplane propeller. "Balanced" blades; that is, blades that are electronically matched at the factory; are sold as balanced four- or five-blade sets, depending on the design of the fan. For this reason, never interchange blades between fans.

- Use durable fans with longer warranties. Use fans with metal motor housings — these may require annual lubrication while plastic motor housings will not.

AIRBASE (database of over 7,000 abstracts of international papers on infiltration and ventilation), Air Infiltration and Ventilation Centre, Sovereign Court, University of Warwick Science Park, Sir William Lyons Road, Coventry, CV4 7EZ, U.K. Tel: 44-203-692050, Fax: 44-203-416306.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE 62-Ventilation for Acceptable Indoor Air Quality.* 1791 Tullie Circle NE, Atlanta, GA, 30329-2305. Tel:(404) 636-8400; Fax:(404) 321-5478.

Bower, John. *Understanding Ventilation: How to Design, Select, and Install Residential Ventilation Systems.* The Healthy House Institute, 430 N. Sewell Rd., Bloomington, IN 47408.

The Home Ventilating Institute. *The Certified Home Ventilating Products Directory.* 30 West University Dr., Arlington Heights, IL 60004-1893. Tel:(708) 394-0150.

GUIDELINE MV4: GAS/ELECTRIC SPLIT SYSTEM

Recommendation

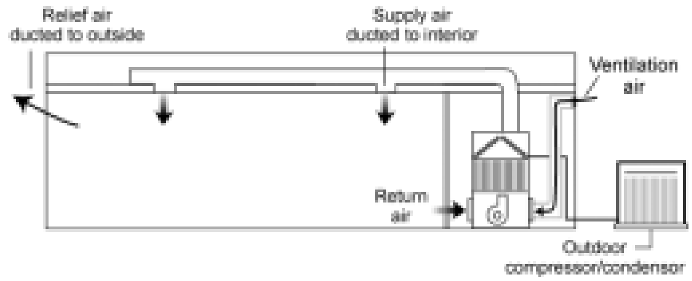
When specifying a gas/electric split system, consider an add-on economizer, two-speed blower/furnace/compressor, high-efficiency furnace (AFUE 90+), and high-efficiency cooling (SEER 14+).

Description

This system is similar to a typical residential heating and cooling system. The components include an indoor fan unit and outdoor compressor and condenser package. The indoor unit usually includes a cooling coil and furnace section, although the furnace can be omitted if the compressor is also used for heating in heat pump mode. The indoor and outdoor sections are connected via refrigerant tubing and control wires.

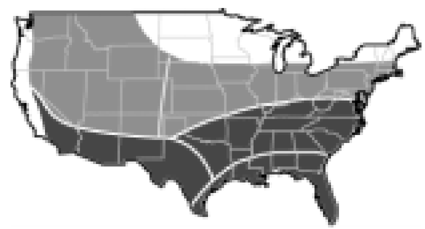
Supply air from the indoor unit is typically ducted to several supply diffusers in the ceiling. Return air may be ducted or returned directly to the unit through a grill.

While most residential systems recirculate indoor air only, an outside air duct is essential to supply ventilation air that is mixed with return air for schools.



Basic gas/electric split system.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	☐
Multi-Purpose	☐
Gym	☐
Corridors	☐
Administration	☐
Toilets	☐
Other	☐

When to Consider	
Programming	☐
Schematic	■
Design Dev.	☐
Contract Docs.	☐
Construction	☐
Commissioning	☐
Operation	☐

Variations and Options

An economizer is not standard with split systems but is available as an aftermarket option. The additional equipment includes a mixing box with outdoor and return air dampers and the associated controls. Check with split system manufacturer for control compatibility.

For climates where cooling is unnecessary, the system can be used for heating only, or for heating and ventilating. Eliminating the cooling coil and outdoor compressor unit reduces the cost significantly. An economizer may be installed to provide free cooling if the space design does not allow for convenient natural ventilation cooling (due to drafts, outdoor noise, dust, or similar problems).

Indoor units are available for either horizontal or vertical installation. Horizontal units are typically installed above the ceiling. Vertical units may be installed in a mechanical closet with flow direction either upwards or downwards.

A high-efficiency, condensing furnace is available as an option for most split systems. Annualized fuel utilization efficiency (AFUE) is 90% to 96%, compared to about 80% for standard units.

High-efficiency cooling is also an option provided by most manufacturers. Systems are available with efficiencies greater than seasonal energy efficiency ratio (SEER) 14, compared to typical units with SEER 10 to 11.

A two-speed blower and variable output furnace is an option that can provide significant fan energy savings and improve comfort through less on-off cycling.

Two-speed compressors are available that can be controlled together with a two-speed indoor fan for better comfort and humidity control.

Heat pump heating is an option for locations without convenient natural gas access. In cool climates, a supplementary electric resistance heating element may be necessary, especially to handle relatively high ventilation air requirements for classrooms.

Natural gas engine-driven heat pumps are available; however, they are more expensive. These units use a reciprocating natural gas engine rather than an electric motor to drive the compressor and provide heating and cooling.

Applicability

This system type is appropriate for classrooms or other single zone spaces up to about 2,500 ft^2. Minimum cooling efficiency is SEER 10.0 for split systems smaller than 65,000 Btu/h of cooling capacity. Minimum heating efficiency is 78% AFUE for gas furnaces smaller than 225,000 Btu/h. These efficiency requirements are federal regulations.

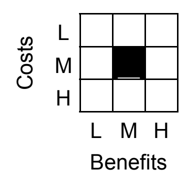
Integrated Design Implications

Location of the indoor and outdoor units needs to be considered early in the architectural design to ensure optimal performance. See Design Details below for important considerations. Similarly, the location of ducts and supply registers should be considered when making structural and lighting system decisions.

System controls should be specified so they integrate with natural ventilation design. Use automatic interlock controls to shutoff the system when windows are opened or allow manual fan shutoff. If the space is designed for good natural ventilation, then an economizer may not be necessary.

Try to place ducts within the conditioned envelope to minimize the impact of leakage and conduction losses, which can be very significant. Insulate under the roof deck rather than on top of a suspended ceiling. If possible, place the indoor unit within the conditioned envelope as well. Ensure, however, that combustion air is properly vented.

Cost Effectiveness



Overall system cost for a gas/electric split system ranges from $10/$ft^2$ to $12/$ft^2$.

A high-efficiency (condensing) furnace adds roughly $700, compared to a standard efficiency unit with a base installed cost of about $550. However, the extra cost may also cover multi-speed fan control and variable furnace output, in addition to better efficiency.

An efficient three-ton air conditioner with 13 SEER costs roughly $2,500, compared to $1,700 for a SEER 10. The incremental cost is roughly $800.

An outside air economizer adds about $300 to $500.

For a 960-ft^2 classroom, incremental cost for combined measures is about $2,000, or $2/$ft^2$ of floor area.

High-efficiency cooling is generally cost effective in warm regions. A high-efficiency, condensing furnace should be cost effective in cool climates, especially considering construction cost savings due to more flexibility in locating the low temperature flue vent.

Benefits

Advantages

- High heating and cooling efficiencies are available. (By contrast, efficient heating options are seldom available for packaged rooftop units.)
- Two-speed fan and compressor options improve partial load efficiency, comfort, and humidity control.

- Numerous system capacities are possible with combinations of furnace units, cooling coils, and compressors.
- An economizer can be added to take advantage of outdoor air for free cooling.
- Outdoor unit is relatively small.
- It is possible to keep all ducts within the insulated building shell to minimize impact of duct losses.
- Moderate initial cost.
- This can be installed as a heating-only system at a lower cost. A cooling coil and outdoor condensing unit can be added later if desired. However, their ductwork and air distribution system would need to be sized for greater cooling airflow requirements.

Disadvantages

- Space within the building shell is required for the indoor unit, either above the ceiling or in a closet.
- An indoor unit may create noise in the space if not carefully designed and installed.
- Air ducts are required, which can be leaky and inefficient if not installed properly.
- High-efficiency units have a significant cost premium.
- Limited multi-zone capability.
- Poor dehumidification control (better with two-speed compressor and fan).
- Higher maintenance cost for large facilities compared to central VAV system.

Design Details

Indoor unit location considerations:

- To reduce noise, isolate the unit from the occupied space, and provide appropriate noise control measures at the intake and discharge and adequately sized ducts and registers to avoid excessive air velocity.
- Make sure that filters and coils are easily accessible for maintenance.
- Provide easy access for the outdoor air inlet, minimizing length of ducts and eliminating turns from ductwork if possible.
- Allow access to outdoors for furnace combustion air and provide a vent for flue gas as recommended by the manufacturer.
- Minimize the number of duct turns necessary to reach supply diffusers and return grilles, and minimize duct length (second priority compared to number of turns). At the same time, however, ensure that noise transmission through the ducts is controlled.
- Consider that cooling coil condensate must drain to a proper receptacle and condensate pan overflow should drain to a visible location.
- Provide adequate vibration isolation. Manufacturer may provide standard vibration isolation package.
- See also MV19: Air Distribution Design Guidelines for information about choosing locations for supply and return registers to minimize noise and maximize performance.

Outdoor unit location considerations:

- Typically, the unit is placed on a concrete pad alongside the building. However, rooftop installation is possible as well.
- To reduce noise, keep the unit away from operable windows and doors.
- Remember that outdoor units face the potential for vandalism and design accordingly.
- Provide access for maintenance.

- Try to choose a shaded location with the lowest possible ambient air temperature to improve cooling efficiency. Be especially careful to avoid direct exposure to afternoon sun.
- Provide adequate clearance around the outdoor unit to prevent airflow obstructions.
- If the outdoor unit is mounted on the rooftop, then consider using a reflective white roof membrane to reduce temperature and improve system performance. Standard roofs exceed 150°F on a sunny day, while white roofs can be 50°F cooler.

Match the compressor and indoor fan units for proper performance. See manufacturers' literature for combinations and their efficiency ratings.

Be sure to allow for furnace condensate drainage for high efficiency units, and provide condensate drainage for cooling coils.

Design the air distribution system to minimize pressure drop and set blower fan motor to low or medium speed to reduce fan energy consumption and minimize noise (see MV19: Air Distribution Design Guidelines).

Do not oversize heating and cooling capacities (see the topic Load Calculations in this chapter's Overview section).

If choosing a system with a multiple-speed fan as well as variable heating and cooling capacity, then specify a thermostat with those control capabilities.

Operation and Maintenance Issues

Maintenance requirements for a gas/electric split system are very similar to other system types. However, all compressor cooling systems require additional maintenance skills and cost more to maintain compared to heating-only systems.

Recommended maintenance tasks include:

- Replacing filters regularly
- Cleaning indoor and outdoor coils regularly
- Checking refrigerant charge
- Cleaning the cooling coil condensate pan and drain
- Lubricating and adjusting the fan as recommended by manufacturer.

Commissioning

Measure total supply airflow with a flow hood or comparable measuring device. Make sure that airflow is within 10% of design value. If airflow is low, then check ducts for leaks and constrictions, and check that filters and coils are free of obstructions. Larger ducts, or shorter duct runs, may be necessary. Reduce the number of duct turns to a minimum. If airflow is high, then reduce fan speed if possible according to manufacturer's instructions.

If an economizer is installed, then verify proper operation (see MV18: Economizers).

References/Additional Information

MV18: Economizers; MV19: Air Distribution Design Guidelines.

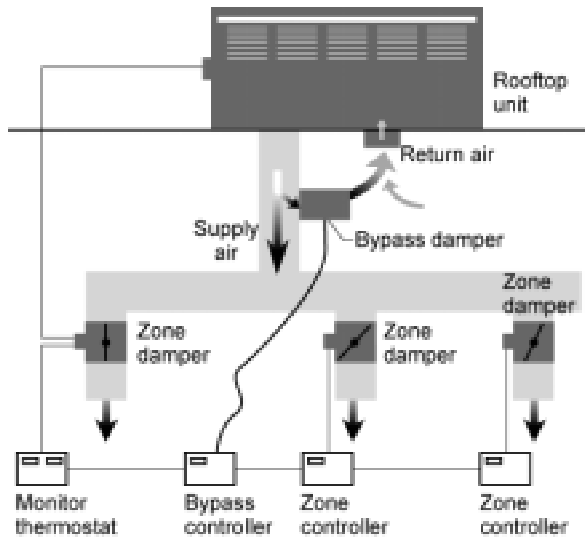
GUIDELINE MV5: PACKAGED ROOFTOP SYSTEM

Recommendation

If choosing a packaged rooftop system, specify a high-efficiency unit with an integrated economizer and design the duct system to allow proper airflow at low or medium fan speed.

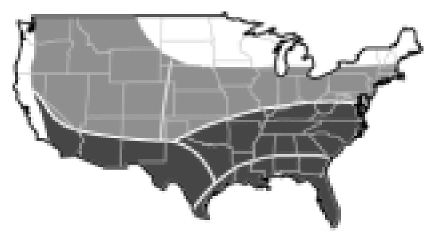
Description

A packaged rooftop system is fully self-contained, and most consist of a constant volume supply fan, direct expansion cooling coil, heating (when required) with gas furnace, filters, compressors, condenser coils, and condenser fans. Units are typically mounted on roof curbs but can also be mounted on structural supports or on grade. Packaged rooftop single-zone units are typically controlled from a single space thermostat with one unit provided for each zone. Supply air and return air ducts connect to the bottom (vertical discharge) or side (horizontal discharge) of the unit.



Packaged rooftop system.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider	
Programming	□
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Variations and Options

Economizers are often standard, cost-effective options for rooftop units (see MV18: Economizers).

High-efficiency cooling with seasonal energy efficiency ratios in the range of 12 to 13 is commonly available.

Units can be purchased as heat pumps for use in areas without convenient access to natural gas for heating.

An evaporative precooler can be added to the condenser to increase capacity and efficiency during hot weather.

A "single zone" rooftop unit can condition multiple zones when equipped with special controls and hardware. This type of system includes an automatic damper in the ductwork for each zone, which modulates to control temperature. If some zones require cooling while others need heating, then the controller switches the rooftop unit between both modes and the zone dampers will open or close as appropriate. This system also includes a bypass damper between the supply and return that is opened to maintain constant airflow through the rooftop unit when one or more zone dampers are closed.

Applicability

A packaged rooftop unit is applicable for spaces that require heating and cooling. However, due to their relatively low cost and expected short life (less than 30 years), they are sometimes installed where only heating is required.

Due to the constant-volume fan, this system is most applicable where loads and ventilation requirements are relatively constant, such as in classrooms, administration areas, and libraries. The system is less applicable for intermittent occupancies such as assembly areas.

Packaged rooftop units are available in capacities from 2 tons to more than 100 tons and can be used for single zones from 600 ft^2 to more than 30,000 ft^2.

Multiple zones where the zone loads are not too different can be handled with special controls. There is no theoretical limit to the number of zones possible, and commercially available controllers will serve 32 or more. However, in practice, these controls should be used for no more than a handful of zones. For larger systems, variable air volume (VAV) controls will be more effective and efficient.

See Table 8 for minimum cooling efficiency requirements. For units smaller than 65,000 Btu/h, these efficiency requirements are federal regulations.

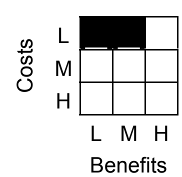
Integrated Design Implications

Rooftop units can have a significant visual impact and can create concern regarding noise level at adjacent properties. Their location should be considered early in the architectural design process to allow for efficient duct layout. In addition, location of ducts and supply registers should be considered when making lighting system decisions.

System controls should be specified so they integrate with natural ventilation design. Use automatic interlock controls to shut off the system when windows are opened or allow manual fan shutoff. If the space is designed for good natural ventilation, an economizer may not be necessary.

Try to place ducts within the conditioned envelope as much as possible to minimize the impact of leakage and conduction losses, which can be very significant. This is only recommended, however, where approximately the first 20 ft of duct runs above spaces that are not sensitive to noise. Insulate under the roof deck rather than on top of a suspended ceiling.

Cost Effectiveness



The overall cost for a packaged rooftop system can be as low as $15/$ft^2$ to $20/$ft^2$ (installed cost, including ductwork and controls).

The unit cost alone ranges from about $1,500 for a two-ton unit to around $2,000 for a five-ton unit. High-efficiency package units (when available) cost about 10% more than standard efficiency models and have paybacks of around three to four years in warm climates.

Packaged rooftop systems are often the lowest first-cost alternative when both heating and cooling are required. However, they are relatively costly to maintain, energy costs are higher than average, and life expectancy is less than 30 years.

Benefits

Advantages

- Low initial cost.
- No inside mechanical equipment space is used.
- An added economizer can take advantage of outdoor air for free cooling (see MV18: Economizers).
- Systems are widely available.

Disadvantages

- Fewer efficiency options exist compared to gas/electric split systems (e.g. condensing furnace, two-speed fan, high efficiency cooling).
- Systems are relatively large and require roof space.
- Air ducts, which can be leaky and inefficient if not installed properly, are required.

- Systems have limited multi-zone capability.
- Poor dehumidification control can occur compared to VAV systems (due to compressor cycling).
- Higher maintenance costs occur for large facilities compared to central VAV systems.
- Systems have typically shorter lifetimes than central VAV systems.

Design Details

Most packaged systems have several fan speed options that can be selected in the field when the unit is installed. Careful design of the air distribution system can reduce pressure drop and provide significant savings if the fan is wired for low or medium speed (see MV19: Air Distribution Design Guidelines).

The incremental equipment cost for packaged rooftop equipment is not too large to increase size from, say, two to four tons. Therefore, the temptation is strong to specify the larger unit for safety's sake. However, there are performance penalties for oversized systems. Bigger is not always better. Do not rely on rules of thumb to select airflow, cooling capacity, or heating capacity. See this chapter's Overview section for a discussion of load calculations and the impact of cooling capacity oversizing.

Table 8 lists recommended minimum efficiencies for packaged rooftop equipment.

Vibration isolation is often provided internally. Internal isolation should be reviewed for proper spring type and static deflection. If internal isolation is not provided, or is unacceptable, external spring isolators should be utilized. Refer to 1995 ASHRAE Handbook Chapter 43 for recommended vibration isolation. If external isolation is used, all internal spring isolators should not be released from their restraining bolt.

The unit should be located above unoccupied spaces (i.e. storage, stairwells, etc.).

Provide appropriate intake and discharge noise control consistent with meeting the Noise Criteria.

Table 8 – Recommended Minimum Efficiencies for Air-Cooled Packaged Rooftop Equipment

Capacity	Recommendation
< 65,000 Btuh	12.0 SEER
65,000 – 135,000 Btuh	11.0 EER
135,000 – 240,000 Btuh	10.5 EER
> 240,000 Btuh	10.0 EER

Operation and Maintenance Issues

Maintenance requirements for a packaged rooftop system are very similar to other system types. However, all compressor cooling systems require additional maintenance skills and cost more to maintain compared to heating-only systems.

Recommended maintenance tasks include:

- Replacing filters regularly
- Cleaning indoor and outdoor coils regularly
- Checking refrigerant charg.
- Cleaning and draining cooling coil condensate pan, and specify pans that are pitched to drain continuously under all operating conditions
- Pitch and properly trap drain pan and drain condensate to a roof drain, not over the side of a building
- Lubricating and adjusting fan as recommended by the manufacturer.

Commissioning

Measure total supply air flow with a flow hood or comparable measuring device. Make sure that airflow is within 10% of design value. If airflow is low, then check ducts for constrictions and check that filters and coils are free of obstructions. Larger ducts or shorter duct runs may be necessary. Reduce the number of duct turns to a minimum. If airflow is high, then reduce fan speed if possible, according to manufacturers' instructions.

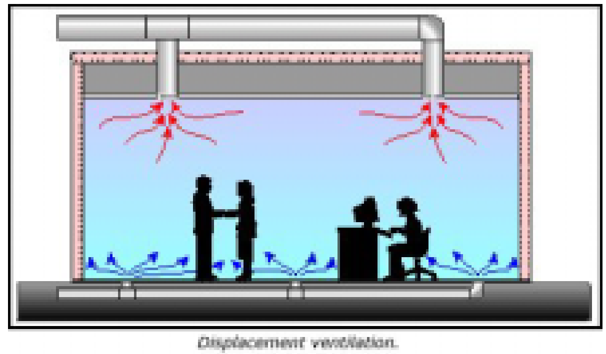
If an economizer is installed, then verify proper operation (see MV18: Economizers).

References/Additional Information

Guideline MV18: Economizers; Guideline MV19: Air Distribution Design Guidelines.

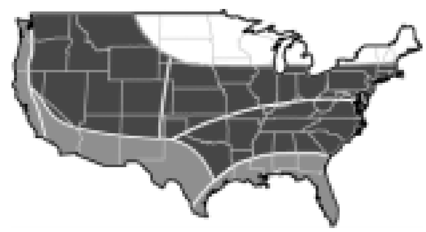
GUIDELINE MV6: DISPLACEMENT VENTILATION SYSTEM

Description



Ventilation system.
(source: http://www.advancedbuildings.org)

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	□
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	■
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Displacement ventilation systems are different from most other HVAC systems for schools and offer a number of advantages. With displacement systems, air is delivered near the floor, at a low velocity, and at a temperature from 63ºF to 65ºF (compared to around 55ºF for conventional air distribution cooling). The goal of displacement systems is not to cool the space, but to cool the occupants. Cool air flows along the floor until it finds warm bodies. As the air is warmed, it rises around occupants, bathing them in cool fresh air. Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone rather than being mixed in the space. Similarly, cooling loads decrease significantly because much of the heat generated by occupants, lights, and computer equipment rises directly out of the occupied zone and is exhausted from the space. This is especially true in classrooms designed for 100% outside air with total energy recovery.

Variations and Options

There are several supply air distribution options:

- Access floor.
- Low wall outlets.
- Infloor outlets.

The best cooling source for a displacement ventilation system is a chilled water coil. The control valve in a hydronic system allows supply of constant 63ºF to 65ºF air. A typical direct exchange (DX) system is designed to provide colder 50ºF to 55ºF air while the compressor is running and cycles on and off to meet space loads. This lower temperature and temperature fluctuations would create a comfort problem in displacement ventilation when it comes in contact with occupants. However, larger DX systems with several compressors and temperature reset capabilities can be used as an alternative to a chilled water system. For example, a packaged rooftop VAV system serving 10 or more classrooms should be able to provide the necessary supply air temperature control.

Evaporative cooling is also a potential source because it typically produces higher air temperature than a DX system.

Applicability

Displacement ventilation is most appropriate for spaces with ceiling height of at least 10 ft to permit stratification. Systems that utilize 100% outside air design with enthalpy energy recovery are very suitable for high occupant density areas like classrooms and auditoriums. This distribution type is also a great choice where raised access floors are desired for flexibility of power and communication wiring (although access floors are not required for displacement ventilation).

Integrated Design Implications

Supply air outlets must be coordinated with the location of furnishings and space usage. The outlets may be integrated with cabinets or seating.

There is an excellent opportunity to integrate electrical and communication wiring with the air distribution either under the floor or along the baseboard.

A displacement system can eliminate the need for a suspended ceiling and allow the ceiling to be clear of supply diffusers.

If the ceiling is high enough, displacement ventilation can be integrated into portable classroom design, where space for ducting exists in the crawlspace beneath the floor.

Slab floors may be designed with integral ducts or troughs for air distribution.

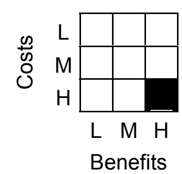
Consider using variable-speed heating and cooling sources to minimize the on-off cycling and variations in supply air temperature.

Ceiling fans are not recommended with displacement ventilation because they are designed to mix air in a space and will disrupt the stratification created by the displacement ventilation system.

Cost Effectiveness

There is not a great deal of experience with displacement ventilation in classrooms, but it is growing in popularity for new commercial buildings. For the near future, costs are likely to be higher than standard overhead air distribution.

A displacement ventilation system will probably not provide a short payback based on energy savings alone. However, the system provides additional comfort and air quality benefits.



Benefits

Advantages

- Significantly lower cooling loads (1/3 lower) result from thermal stratification.
- Significantly low system capacities will be needed if enthalpy energy recovery is used in combination with this vertical displacement approach.
- Air quality will improve per cfm moved compared to systems that mix space air.
- Can provide equal or better air quality with less outdoor air due to stratification.
- Lower fan energy with lower static pressure may result (depends on distribution type and outlet type).
- Ceiling remains clear of supply registers, except for exhaust/return grills.
- Raised access floor systems are typically made up of 1-in. to 1.5-in.-thick concrete sections. This provides advantages from the standpoint of controlling duct noise breakout and/or radiated noise from VAV or fan powered boxes.

Disadvantages

- Heating performance may be worse than systems providing air at greater velocities. Mixing (i.e., destratification) is desirable for heating.
- First cost may be higher with raised floor systems.
- Some floor area or low wall area is required for supply air outlets.

Design Tools

All manufacturers of sidewall displacement diffuser and floor systems offer design assistance and computational fluid dynamics (CFD)-generated graphics that depict air supply patterns with defined supply air temperatures and air flows.

CFD software that now runs on personal computers can help predict airflow patterns within a room, as well as help with the selection and location of supply outlets.

Design Details

Provide 20 cfm to 30 cfm per occupant (0.6 cfm/ft² to 0.9 cfm/ft²) for classrooms depending on cooling loads. At this relatively low airflow rate, 100% outside air may be necessary.

Deliver supply air at 63ºF to 65ºF.

Design for air velocity at supply outlets no greater than 25 ft/minute to 50 ft/minute. Therefore, displacement ventilation requires significantly larger supply outlets than an overhead distribution system. However, the system would be typically delivering close to half the airflow rate of a conventional mixed air system.

Try to place sidewall outlets at the corners of the room. Try to avoid situations where occupants are more than 15 ft from the nearest supply outlet.

Use barometric relief dampers to exhaust the 100% outside air.

Minimum ceiling height is about 10 ft for adequate stratification.

In choosing cooling capacity, consider that loads from lighting, computers, and occupants will be reduced by about one-third compared to a system type that mixes indoor air.

Higher air velocity is desirable in heating mode, so consider a design that reduces supply air outlet area (either manually or automatically) when the system provides heating, or that uses VAV in cooling and full airflow in heating. This is especially important in large halls, such as a gymnasium with sidewall supply. Consider demand control and variable frequency drive (VFD) in gyms, auditoriums, and cafeterias.

Operation and Maintenance Issues

Operating and maintenance requirements are similar to overhead air distribution systems.

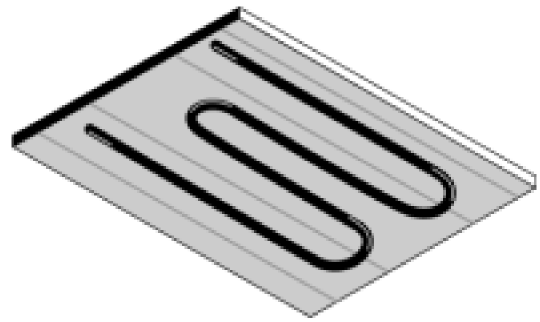
Commissioning

Check for proper supply air temperatures. Ensure that air velocity at supply outlets is not too high for comfort. Verify that total airflow meets design requirement. Verify proper control operation and temperature reset for heating or cooling. Verify VAV or VFD operation if demand control is incorporated into an area such as a gym.

References/Additional Information

Boscawen School, NH implemented this type of system. H. L. Turner Group, Architects.

GUIDELINE MV7: HYDRONIC CEILING PANEL SYSTEM



Recommendation

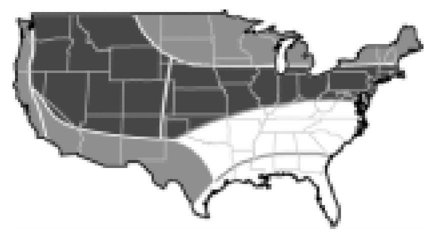
Install radiant cooling ceiling panels in arid areas needing significant cooling.

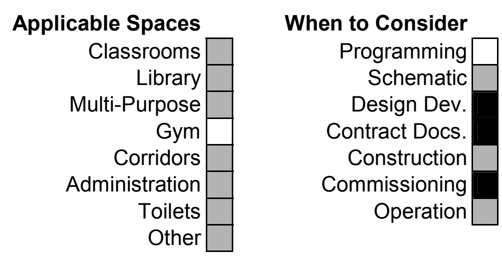
Description

A hydronic ceiling panel system provides thermal comfort predominately through radiation heat transfer with objects and occupants. Basic ceiling panel design consists of a metal sheet with copper tubing attached to the upper side and covered with insulation/acoustical inlay material. Applications can take the form of modular panels or wall-to-wall linear design. The system can be suspended, recessed, or placed in a grid configuration. A ceiling panel heating/cooling system involves the following:

- Ceiling panels
- Support system
- Control system
- Hydronic distribution system
- Hot/cold water source.

Applicable Climates





Applicability

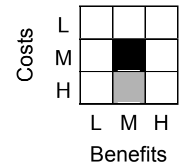
Most applicable in areas with low latent heat load, but can also work in more humid climates with a proper dehumidifying system. Panels can also be used for heating, generally as a substitution for radiators around building perimeter.

Integrated Design Implications

Extruded Aluminum Linear Panel. NREL/PIX 11422

- Hydronic ceiling panel systems provide no outside air ventilation so fresh air must be supplied with either operable windows or an air-handling system.
- Choosing any hydronic cooling system affects hot and chilled water decisions (solar thermal, chiller, boiler, etc.).
- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.
- Depending on regional weather characteristics and required panel water temperature, an air-conditioning system may be required to remove excess latent heat load and avoid condensation.
- Possibly integrate the system with building sprinkler systems to lower installation costs. Check with the fire marshal to ensure this does not violate fire code regulations.
- Use a heat pump or possibly a cooling tower to attain required temperatures.
- Acoustic properties of the panels need to be considered.
- If the system is to be used for both heating and cooling, a choice between a two-pipe and four-pipe system must be made. This decision will affect the hydronic distribution system.
- Use heavy-duty ceiling grid and provide space in plenum for hangar support.
- System can be integrated into a facility-wide hydronic heating and cooling system, including baseboards and radiant slabs.
- Effectiveness of panels relates to architectural and daylighting decisions regarding ceiling height. Performance of panel system degrades with increasing ceiling height.

Cost Effectiveness



Price for installed panels is roughly $\$18/\text{ft}^2$ of active ceiling area. This does not include costs for control system, hot/cold water supply, or hydronic distribution. Installed cost for modular and linear panels is roughly equal.

- Suppliers report that 10-year savings are substantial. Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air handling systems. The system is generally most cost effective when part of a facility-wide hydronic heating and cooling system.

Benefits

- Hydronic systems can decrease or eliminate the need for mechanical air-handling systems.
- The water pumping system does not create as much internal heat as air fans do.
- Aluminum panels present the possibility for high recycled-content material use.
- Added cooling comfort results from lower perceived temperature.
- The system's low noise makes it a good choice for classrooms.
- Energy demand is significantly lower than that for air systems due mostly to savings in fluid transport systems.
- Quick response time.

Design Tools

- RADCOOL is a software program developed by the Lawrence Berkeley National Laboratory for modeling buildings with radiant cooling systems.
- Design and sizing procedure is documented in Chapter 6 of the 2000 ASHRAE Systems and Equipment Handbook.
- Additional tools are available that provide AutoCAD-based programs for layout design and Microsoft Excel-based spreadsheets for sizing calculations. Other software programs cover design for floor, ceiling, and baseboard radiant systems.

Design Details

- If the panels are to be used for heating and cooling, a two- or four-pipe system can be used. A two-pipe system is less expensive and will work for applications with infrequent changeover from one mode of operation to another. If frequent changeovers occur, it is best to use a four-pipe system.
- Panel performance is dependent upon room air, panel water temperatures, and thermal resistance of the panel. Cooling performance for modular panels is generally around 27 Btu/h ft^2 with an 18°F temperature difference between room air temperature and mean water temperature. Extruded linear panels absorb from 40 Btu/h ft^2 to 50 Btu/h ft^2 with the same temperature difference. In either case, performance degrades with increasing ceiling height. Heating performance ranges from 40 Btu/h ft^2 to 200 Btu/h ft^2 for mean water temperatures of 120°F and 180°F and a 70°F room temperature.
- Cooling water temperatures are generally between 58°F and 65°F, depending on dewpoint.
- Heating water temperatures are usually between 120°F and 180°F.
- Panels located above occupants should not exceed a 95°F surface temperature for comfort reasons. Higher temperatures may be used for panels that do not extend more than 3 ft into the room. These high temperature panels can be used in lieu of baseboard radiators to heat glass surfaces and exterior walls to decrease downdrafts.
- Water temperature should be kept at least 1°F higher than the dewpoint temperature at all times.
- Temperature rise for cooling systems should be less than 5°F and temperature drop for heating systems less than 20°F.

- Be sure the water flow rate is in the proper range. Rates too high can cause noise and those too low can result in a significant decrease in heat transfer rate due to laminar flow.
- Panels can be perforated and installed with a special inlay material to improve acoustical properties.
- To avoid condensation, a control system must be used. The system can either use flow control or temperature control. A flow control system uses humidity sensors, temperature sensors, and control valves. It is an on-off system; as soon as the water temperature reaches the dew point temperature, the control valve closes. This system is cheap and simple, but can make the system useless for extended periods. A temperature control system uses similar sensors and a two- or three-way valve to adjust water temperature and avoid condensation. This system is more complex, but it allows for system operation when humid conditions exist.

Operation and Maintenance Issues

Normal hydronic operation and maintenance issues include checking pumps, valves, pipe leaks, chemical water treatment, and water quality/pipe fouling (important for sustaining maximum heat transfer and minimum pressure drop in open systems). Significant maintenance does not appear to be an issue. The ceiling panels have a life expectancy in excess of 30 years.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. The ceiling panel array(s) should be documented with an infrared camera during testing, adjusting, and balancing work to guarantee even cooling and/or heating.

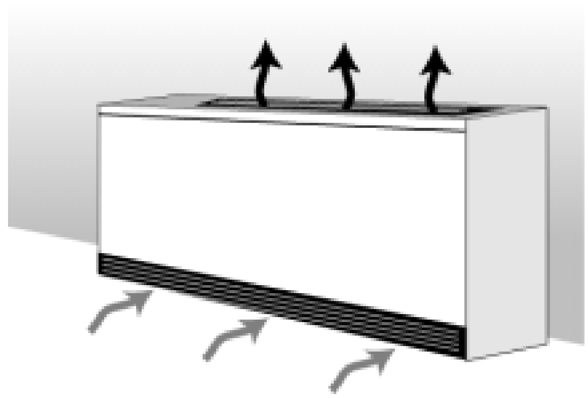
References/Additional Information

Preparation room in the Challenger Learning Center, Phoenix, AZ, uses 2 ft x 4 ft REDEC CBA-C modular panels for 15/16 in. T-Grid with micro perforation and sound absorbing mats.

GUIDELINE MV8: UNIT VENTILATOR SYSTEM

Recommendation

If choosing a unit ventilator system, specify units with multiple-speed fans, two-way control valves, and economizer controls. Also specify variable-flow chilled water and hot water distribution systems.



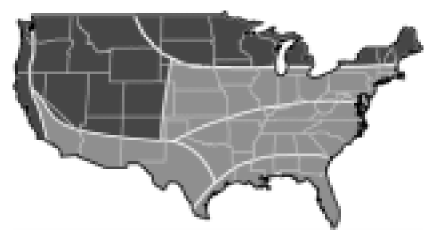
Unit Ventilator, aka Classroom Ventilator

Description

Unit ventilators, sometimes called classroom ventilators, provide heating, cooling, and ventilation for a single space. The units consist of constant volume fans, chilled water and hot water coils (typical), filters, and outdoor and return air dampers, all enclosed in a heavy gauge metal housing. Ventilation and/or economizer air is drawn from adjacent openings in the outside wall. Relief is either by gravity or powered exhaust remote from the unit.

A unit ventilator can be mounted in a vertical or horizontal position. A typical installation is a vertical discharge unit on the floor against an exterior wall. However, horizontal discharge units may be suspended from the ceiling or hidden above the ceiling.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	□
Gym	□
Corridors	□
Administration	□
Toilets	□
Other	□

When to Consider	
Programming	□
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Variations and Options

A unit ventilator may be part of a two-pipe or four-pipe hydronic distribution system.

A two-pipe system (i.e., one supply pipe and one return pipe) is also known as a changeover system, if it provides both heating and cooling. The same piping is used for both hot water and chilled water, and the central plant produces either one or the other. During mild weather periods, the system may be required to switch from heating to cooling as the day warms up. Therefore, two-pipe systems must be designed to account for the potential thermal shock to the equipment. Two-pipe systems likely need supplemental natural ventilation to accommodate swing seasons.

Four-pipe systems can circulate hot water and chilled water throughout the facility simultaneously. The advantage is better zone control because some zones may be heating while others are cooling. The main disadvantage is higher initial cost.

The control valve within a unit ventilator may be a two-way or three-way valve. In both cases, the valve modulates the flow of water through the coil. The difference is how the valve affects flow in the rest of the distribution system. A three-way valve provides a bypass so total flow through the unit ventilator is constant even though flow through the coil changes. A two-way valve modulates the total flow through the unit ventilator. A distribution system with two-way valves will have variable flow and potentially lower pumping energy consumption, especially if pumps are controlled with variable-speed drives.

Economizer controls are an option for some units. An actuator controls the integral outdoor air and return air dampers to take advantage of free cooling when it is available.

Direct expansion cooling may be an option in place of a chilled water-cooling coil.

Alternatives to hot water heating include steam coils and heat pumps.

Some unit ventilators offer a heat recovery option that uses exhaust air to either preheat or precool the outdoor ventilation air. Options for this heat recovery function include an air-to-air heat exchanger and a heat pipe.

Some manufacturers offer matched cabinetry to make the unit ventilator look like part of the furnishings.

Applicability

Systems are applicable for classrooms and other spaces with exterior wall access.

The systems should also be used in facilities with central chilled water and hot water distribution. These are typically large schools that are fairly centralized (to minimize length of chilled water and hot water distribution piping).

In spaces where ceiling height is restricted, these systems can be useful because ducts are unnecessary.

Integrated Design Implications

A unit ventilator requires more coordination with classroom space planning than most other system types. Casework systems are available to integrate the unit with classroom fixtures. An exterior wall with clean outdoor air must be available for unit ventilator installation.

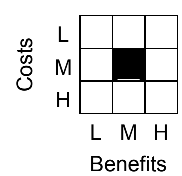
Hydronic distribution may free up space normally reserved for ducts, permitting lower floor-to-floor heights or enabling higher ceilings and better daylighting performance. Hydronic piping should not be run in floor trenches as they are impossible to clean and often grow mold, which can impact indoor air quality since the unit ventilator always pulls some air from the trench.

With unit ventilators as well as other hydronic system types, pay attention to site planning and building layout to minimize the length and complexity of piping between the central plant (chiller and/or boiler) and the terminal units.

As with other system types, controls should be designed to allow simple manual or automatic interlock with natural ventilation systems. In addition, economizer controls may be unnecessary if the space is designed to encourage occupants to use operable ventilation openings during mild weather.

Cost Effectiveness

A system consisting of unit ventilators, a chiller, boiler, and two-pipe distribution costs roughly $\$14/\text{ft}^2$ to $\$16/\text{ft}^2$ of floor area served. Cost for a four-pipe system is $\$17/\text{ft}^2$ to $\$18/\text{ft}^2$, similar to central-type systems with energy recovery.



A unit ventilator system may be cost effective in specific cases, but in most cases other system types will be either lower cost and/or higher performance.

Benefits

Advantages

- Fan energy savings increase, as duct friction losses are avoided.
- Cooling can be very efficient if water-cooled chillers and a well-designed pumping system are installed.
- Constant, or slowly varying, supply air temperature (through modulation of control valves).
- Multiple-speed fans are available in some units.
- Provides flexibility for heating or cooling different parts of the building.

Disadvantages

- Poor air distribution, subject to drafts.

- Noise, particularly for student sitting adjacent to unit.
- Vulnerable to student abuse.
- Subject to turning-off or blocking air output by teachers.
- Air intakes can gather pollutants from mowing, rain intrusion, and vehicle exhaust.
- Relatively high first cost.
- Relatively inefficient fans.
- Console units take up floor space within the room.
- Significant maintenance needed in each classroom.
- Typically limited to poor air filtration.
- Energy recovery difficult or expensive.
- Multiple controls and valves located in every classroom.

Design Details

Ensure that the outdoor air intake area is free from potential pollution sources. Assure that buses will not be staged in areas with unit ventilators. Do not plant shrubs at unit ventilator air intakes. Also make sure to locate the unit to minimize drafts indoors. Air from the units must not be discharged on the occupants, and seating should never be immediately adjacent to the unit. The top of the unit should not be used for storage.

Specify the lowest possible noise levels. If possible, specify a unit with multiple-speed fan control so that normal ventilation occurs at low fan speed. For chiller, boiler, and hydronic distribution system design details, see those individual guidelines. Specify two-way valves in all unit ventilators and variable-flow chilled water and hot water systems.

Load calculations are important, but oversizing of cooling and heating capacity, as long as it is not excessive, is less of a concern with unit ventilators (and with most other hydronic system terminal units) because control valves can modulate output rate. On/off cycling and partial load efficiency degradation is less of a concern, especially with variable-speed fan control. Note, however, that overall facility load calculations are still very important for central plant equipment sizing, where oversizing penalties do occur.

Two-pipe systems should be avoided in climates where heating and cooling may be needed on the same day (or even the same week). The switch from heating to cooling wastes energy and can take a long time. In some cases, the cooling tower and a heat exchanger are used at switchover to cool the loop. The chillers are engaged once the loop has dropped to a tolerable temperature.

Operation and Maintenance Issues

Unit ventilator maintenance is significant, and requires a high skill level for all the controls that are involved in keeping discharge temperatures correct. They are often difficult to access due to classroom arrangements. Furniture should not be pushed up against the unit. Chiller and boiler maintenance requires a relatively high skill level.

Maintenance tasks include:

- Cleaning cooling coil condensate pans to prevent mold growth
- Replacing filters at least three times a year
- Cleaning coils to prevent mold growth
- Cleaning outdoor air intake louvers
- Lubricating fans if required by manufacturers

- Lubricating and adjusting outdoor air and return air dampers.

Commissioning

Check fan speed setting and airflow. Check control valve operation and thermostat operation. Confirm staging of fan speed if applicable. Check coil connections for proper water flow direction. Check outdoor air supply, economizer operation, and economizer airflow. Make sure the outside air duct boot is sealed to the building shell and that water will not enter into it.

References/Additional Information

Guideline MV18: Economizers; Guideline MV21: Hydronic Distribution; Guideline MV22: Chilled Water Plants; Guideline MV23: Boilers.

GUIDELINE MV9: DUCTLESS SPLIT SYSTEM

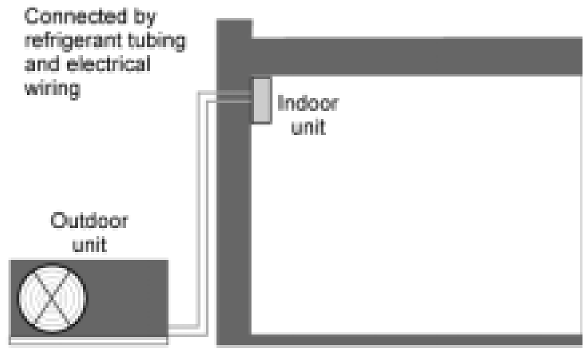
Recommendation

For ductless split systems, specify high efficiency, multiple fan speed, and low noise.

Description

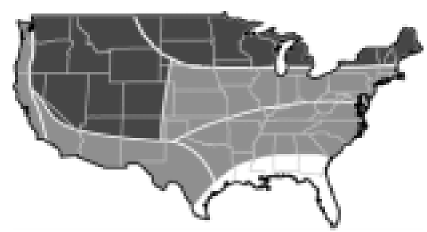
A ductless split system consists of two matched pieces of equipment: an indoor fan coil unit and an outdoor condenser and compressor unit connected by refrigerant tubing and control wiring run through the wall or roof. The indoor unit contains a cooling coil, fan, and filter. The outdoor unit includes compressor(s), condenser coil, and condenser fans.

In its simplest form, a ductless split system recycles 100% indoor air. However, on many units, ventilation air can be supplied with an optional duct attachment that passes through the wall.



Ductless split system.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	☐
Multi-Purpose	☐
Gym	☐
Corridors	☐
Administration	■
Toilets	☐
Other	☐

When to Consider	
Programming	☐
Schematic	■
Design Dev.	☐
Contract Docs.	☐
Construction	☐
Commissioning	☐
Operation	☐

Variations and Options

The indoor unit is available in several forms: high wall mount, ceiling mount, and above-ceiling mount. The high wall mount may be least costly but is usually limited in peak capacity to about two tons. Capacities up to five tons are available with suspended ceiling units. The above-ceiling units typically fit in a 2 x 2 suspended ceiling system and resemble a typical supply diffuser from below.

Many of these systems can be supplied with a heat pump option to provide heating as well as cooling. Alternatively, heating can be provided through a separate system such as a radiant floor.

Variable-speed fans are common and desirable to minimize cycling and reduce noise.

Economizers are typically not available for most ductless split systems.

Systems are available that allow two indoor units to be connected to a single outdoor unit, which can increase system capacity up to four tons.

Applicability

A ductless split system can serve spaces up to about 1,000 ft^2, or perhaps 2,000 ft^2 if multiple units are installed. They are most useful for buildings with indoor and/or outdoor space constraints, where rooftop space is unavailable or space for ducts is limited.

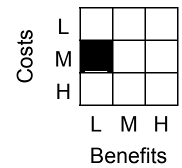
Ductless split systems are good choices when integrated with natural ventilation that can provide free cooling. For sealed spaces without operable openings, a split system is less desirable because it does not typically have capability to provide 100% outdoor air for free cooling.

This system is also applicable for retrofits where ducts do not currently exist.

Integrated Design Implications

A ductless split system is a good complement to radiant heating for spaces where cooling is also necessary but infrequent.

Cost Effectiveness



In North America, ductless split systems are usually more expensive than packaged rooftop systems due to higher equipment cost. The unit price for a typical two-ton unit is $4,000 to $5,000.

Due to the extra cost, a ductless split system will probably be cost effective only where space constraints prohibit the use of ducted system types.

Benefits

Advantages

- Systems can be utilized where outdoor space is limited.
- Equipment is compact.
- No duct losses.
- Simple installation.
- Multiple-speed fans are commonly available.

Disadvantages

- Does not provide good outside air ventilation.
- Relatively poor indoor air distribution and higher potential for drafts.
- Systems have limited capacity to handle ventilation air.
- Heating option is limited to heat pump.
- System use is less common in North America, where equipment cost is relatively high.

Design Details

Place the indoor unit on an external wall for ventilation air access and for minimum distance to the outdoor unit. Follow manufacturers' recommendations for positioning the indoor unit to provide maximum air distribution and avoid drafts.

Pay attention to security, noise, and ambient temperature when positioning the outdoor unit.

Specify high efficiency units if they are available. Specify low-noise units.

- Fan coils should be isolated from occupied spaces. Locate rooftop units above unoccupied spaces.
- Provide appropriate intake and discharge noise control consistent with meeting the Noise Criteria.

Outdoor units should be located away from noise sensitive areas and windows.

Be very careful not to oversize the unit to avoid excessive cycling, which reduces humidity control and irritates occupants. Manufacturers even recommend choosing a system slightly smaller than peak load for these reasons.

Insulate suction and liquid refrigerant lines separately during installation. Otherwise, one heats the other causing capacity and efficiency loss.

Water may condense on the indoor cooling coil. Therefore, a condensate pump may be required to remove water from the condensate drain pan to an approved receptacle. Overflow from the drain pan must be routed to a visible location.

Operation and Maintenance Issues

Maintenance requirements and operator skills are similar to gas/electric split systems and rooftop packaged systems.

Commissioning

Verify proper multiple-fan-speed control operation and thermostat operation.

References/Additional Information

None.

GUIDELINE MV10: EVAPORATIVE COOLING SYSTEM

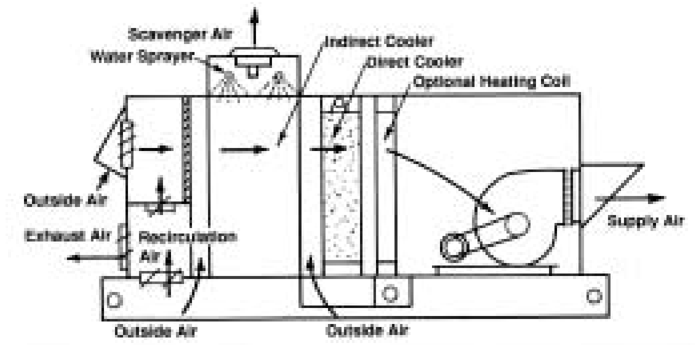
Recommendation

Consider evaporative cooling for spaces with high outside air ventilation requirements.

Description

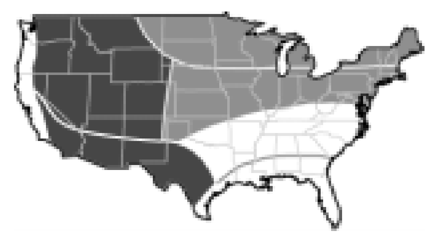
Evaporative cooling is an alternative way to provide air conditioning. Lower energy costs result because no compressor is needed, only a fan and pump.

Evaporative cooling can be "direct" or "indirect." In a direct evaporative cooling system, the water is exposed to the supply air stream. Usually the water flows over a special medium designed to maximize the surface area of water in contact with air, and the air is cooled by the evaporation. The effectiveness can reach 80% to 90%, meaning that the drybulb temperature drops by 80% to 90% of the difference between the drybulb and wetbulb temperature of the entering air. For example, if entering air temperature is 80°F drybulb and 50°F wetbulb, then the leaving air is cooled to 53°F to 76°F drybulb.



Evaporative Cooling System

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	□
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	■
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Indirect evaporative cooling is not as effective as direct evaporative cooling, but adds no moisture to the supply air. In some systems, the air passes through a heat exchanger that is wetted on the outside, where cooling takes place in a secondary air stream. In other systems, air passes through a cooling coil supplied with water from a remote cooling tower. Indirect evaporative cooling can be approximately 60% effective in reducing the dry bulb temperature of the entering air to its wet bulb temperature. While direct cooling provides 72°F to 74°F air in the example above, indirect cooling could provide 78°F air.

Combining indirect and direct evaporative cooling (as shown in the figure above) further reduces the supply air temperature. When air passes through the indirect cooler first, then drybulb and wetbulb temperature is reduced through sensible cooling. Due to the lower wetbulb temperature, the direct cooler can achieve even cooler temperature for the supply air.

Variations and Options

Packaged evaporative coolers are available in a wide range of sizes, approximately 3,000 cfm to 20,000 cfm. They are typically roof mounted to supply outside air for the indirect cooling stage.

Packaged air handlers are available that incorporate both indirect and direct evaporative cooling. The evaporative cooling system has an economizer that uses 100% outside airflow during cooling mode, and minimum outside airflow during heating mode. This allows the use of return air during the heating season to keep heating costs equivalent to a standard system. These package units can have hot water coils or duct furnaces installed to provide heating.

If evaporative cooling alone does not satisfy cooling loads, then it can be combined with packaged rooftop cooling by adding direct and/or indirect coolers onto the outside air intake of the packaged unit or it can be integrated directly into the mixed air stream (outside + return) of the packaged unit. Evaporative cooling reduces the load on the direct expansion (DX) cooling coil, allowing the compressor size to be reduced, and peak power to be reduced.

Alternatively, a combination of cooling tower and heat exchanger could be used with cooling coils and standard air handlers.

Some indirect evaporative cooling systems are designed to use exhaust air rather than outside air as the secondary air stream, providing heat recovery.

Other systems combine evaporative cooling with a desiccant wheel and/or enthalpy wheel as a method of precooling the outdoor air and increasing cooling capacity.

Applicability

Evaporative cooling is most effective in hot, dry climates but it can also be used to completely replace compressor cooling in cold and coastal areas. For areas with higher design wetbulb temperatures, such as Phoenix, AZ (100°F/70°F), evaporative cooling can produce most of the space cooling needs. However, if evaporative cooling is used exclusively, space temperatures may rise above 80°F during design conditions a few hours each year. Direct evaporative cooling is only marginally applicable in the Cool and Humid and Cold and Humid climates. Indirect evaporative cooling may be a better approach in these climate zones.

Evaporative cooling is especially appropriate for spaces with high outside air ventilation requirements such as showers, locker rooms, kitchens, or shops. Compressor cooling is often too expensive to operate for these applications.

Integrated Design Implications

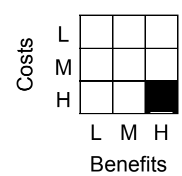
Evaporative cooling is a good match for displacement ventilation systems, which are designed for higher supply air temperature than a typical overhead air distribution system. However, the design will need to accommodate higher airflow that could disrupt stratification. Therefore, careful attention is necessary in locating and sizing supply outlets.

Larger ducts are required compared to a typical compressor cooling system, and duct size may be a consideration in the architectural and structural design.

Direct evaporative cooling may not be appropriate for spaces with materials such as wood floors that might be damaged by high humidity.

These systems require regular maintenance and are difficult to seal against air infiltration in cold climates.

Cost Effectiveness



Installed costs are typically greater than for typical packaged air-conditioning equipment.

Evaporative cooling is usually cost effective in warm and dry climates as long as somewhat higher indoor temperatures are acceptable during hot periods.

Benefits

Advantages

- Lower electricity consumption and lower peak electric demand result.
- Systems typically use 100% outside air in cooling mode, providing better air quality.
- Smaller electrical supply.

Disadvantages

- Regular maintenance is more critical than for compressor cooling systems.

- Higher airflow requirements lead to increased fan energy.
- Cooling unit requires water supply.
- On-site water consumption increases.
- Cooling requirements in some climates may not be completely satisfied.
- Direct evaporative cooling increases space humidity.
- First cost is higher.

Design Details

An evaporative cooling system requires higher airflow due to higher supply air temperature. Therefore, special attention to duct design and sizing is required to avoid high fan energy costs. The appropriate airflow depends on design conditions for the school's location.

A variable-speed or two-speed fan is a good idea to allow lower airflow in heating mode.

In warm climates, try to use exhaust air as the secondary air stream for indirect evaporative cooling systems.

Vibration isolation is often provided internally. Internal isolation should be reviewed for proper spring-type and static deflection. If internal isolation is not provided, or is unacceptable, external spring isolators should be utilized. Refer to 1995 ASHRAE Handbook Chapter 43 for recommended vibration isolation. If external isolation is used, all internal spring isolators should not be released from their restraining bolt.

- Locate rooftop units above unoccupied spaces.
- Provide appropriate intake and discharge noise control consistent with meeting the noise criteria.

Operation and Maintenance Issues

Evaporative coolers demand more maintenance than a typical compressor-based system, so they should be specified only for facilities with qualified maintenance staff or with a qualified outside service company.

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup (without causing excessive water consumption). Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

Commissioning

Check for correct airflow.

Check for correct water flow rate over the evaporative media.

Check the bleed-off rate of water from the evaporative system to ensure that it is adequate to prevent mineral buildup but not too large to cause excessive water consumption.

Verify all modes of operation.

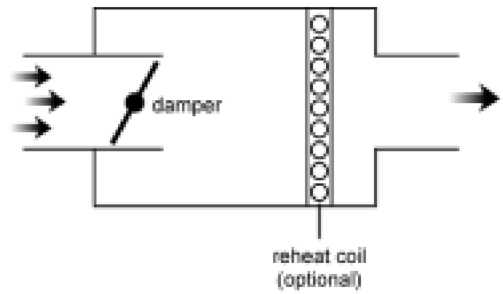
References/Additional Information

None.

GUIDELINE MV11: VAV REHEAT SYSTEM

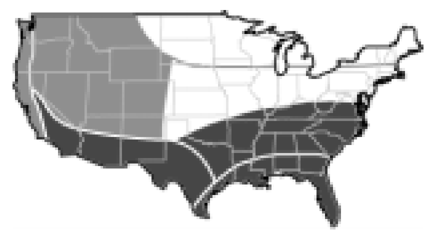
Recommendation

Choose a VAV reheat system for large administration or classroom facilities, especially multi-story buildings. Specify variable-speed fan control, low face velocity cooling coil, bypass damper, monitored/measured outdoor air supply, supply air temperature reset control and supply duct pressure reset control and graphic-displayed direct digital controls (DCC).



VAV Box

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	□
Corridors	□
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	■
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Description

VAV is a general term for a type of HVAC system that supplies only the amount of air needed to satisfy the load requirements of a building zone and can supply different volumes to different zones at the same time. The result is that the total supply of cool air changes over the course of the day, depending on the heat gains in different building areas at different times.

In a VAV system, a central supply fan sends air through medium-pressure ductwork to terminal units (VAV boxes) throughout the building. The airflow to each zone — a space or group of similar spaces — is controlled by the VAV box (a "smart damper"), which varies the airflow in response to the space temperature. As cooling loads in the zone drop, the damper continues to close until it reaches a minimum position. The minimum position provides the occupants of the zone with adequate ventilation air. Some VAV boxes, especially those in perimeter zones, contain a reheat coil for times when the minimum airflow provides too much cooling. The reheat coil — typically hot water — prevents zones from being overcooled. The reheat coil also provides winter heating, typically during a morning warm-up period prior to occupancy when the outdoor air dampers are closed.

A duct-mounted pressure sensor that decreases the fan output as the VAV box dampers close controls the main system fan.

Variations and Options

VAV air handlers may be purchased as factory-fabricated units or may be assembled from components in the field (built-up). In either case, cooling can be provided with a chilled water coil or a direct expansion refrigerant coil.

- A common choice for schools is the packaged rooftop VAV air-conditioning system. The self-contained unit consists of a variable-volume supply fan; direct-expansion cooling coil; heating (when required) with gas furnace, hot water, or steam; filters; compressors; condenser coils; and condenser fans.
- Facilities with a central chilled water plant often use factory-fabricated air handlers with chilled water coils. In this case, the unit includes a supply fan, cooling coil, filters, and perhaps a heating coil.

VAV systems usually include economizer controls. Several VAV box types are available and some can be combined within the same system:

- Most common for new buildings are pressure-independent boxes with DDC-controlled actuators.
- Fan-powered mixing boxes recirculate room or plenum air and are available in two types: series fan or parallel fan. The series fan box requires the fan to operate at all times. The parallel fan box fan activates only when reheat is required.
- Dual-duct VAV boxes contain two dampers controlling a cool duct inlet and a warm duct inlet. Typically, the warm duct damper is closed during cooling periods. When cooling load drops and the cool duct damper reaches its minimum position, then the warm duct damper begins to open to prevent overcooling in the space.

A dual-fan, dual-duct VAV system is an alternative to VAV reheat and requires less reheat energy. The warm duct recirculates indoor air and adds heat if necessary. The cool duct provides ventilation air and cooling. Rather than using a reheat coil to avoid overcooling at minimum ventilation position, the dual duct system mixes warm return air to offset cooling.

Applicability

VAV systems are appropriate for administration buildings or large classroom buildings with peak cooling load greater than 20 tons. The minimum size for a packaged VAV system is about 20 tons.

The overall efficiency of VAV systems depends on the diversity of zone heating and cooling loads. If a particular building has very similar zones and constant loads (such as classrooms with identical occupancy schedules in an extremely well-insulated building), the potential for savings from a VAV system are reduced.

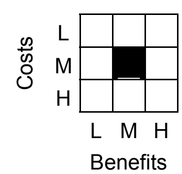
Integrated Design Implications

VAV systems require space for ductwork and should be considered early in the design process.

Requirements for fire separations can affect duct layout and architectural design. Fire separation is less of an issue with single-zone systems because all the ductwork is typically within a single fire zone.

Shaft space may be required in multi-story buildings to deliver air to the lower floors.

Cost Effectiveness



A typical VAV reheat system costs \$16/ft^2 to \$18/ft^2 of floor area. This cost is greater than packaged single-zone systems and roughly equal to a unit ventilator system, but offers far greater performance and control.

A VAV system is usually cost effective for larger buildings. It is the most common system type for new multi-story commercial facilities.

Benefits

Advantages

- Better comfort control results from steady supply air temperature (vs. single-zone systems that are constant volume and variable temperature).
- Moderate initial cost for buildings that require multiple zones.
- Better dehumidification control than packaged single zones.
- Energy efficiency of variable air volume.
- Larger and more efficient fans than single-zone systems.
- Centralized maintenance for coil cleaning and filter replacement.
- Relatively simple to add or rearrange zones.

Disadvantages

- Sometimes higher fan pressure occurs than with variable-speed, single-zone systems, depending on load matching of design. This may lead to higher energy consumption.
- Requires more sophisticated controls than single-zone systems.
- VAV box can generate noise that radiates out of the sheet metal walls (radiated noise), and travels down the supply duct (discharge noise).

Design Details

Although several methods are possible, a variable-speed fan is the recommended approach to controlling duct air pressure in a VAV system. Variable-speed drives are the most efficient and have the added advantage of limiting current inrush for startup of large motors (“soft-start” feature). Other, less effective, duct pressure-control devices are variable inlet vanes, inlet cones, sliding covers, and discharge air dampers.

For direct-expansion VAV systems, multiple-step unloading or variable-speed compressors should be specified, which prevents frosting of the evaporator coil at low cooling loads (particularly important for units equipped with economizers). Greater numbers of unloading steps also improves supply air temperature control by allowing a smaller throttling range.

Supply air temperature reset. Specify controls that will adjust the supply air temperature according to demand for cooling. As cooling demand drops, supply air temperature may be increased so that compressors operate more efficiently, and outside air can provide a larger fraction of cooling. However, more airflow is required with higher supply air temperature and, at some point, the extra fan energy exceeds the cooling energy savings. Carefully consider the characteristics of a specific building when choosing a supply air reset schedule. Computer simulations can help to determine optimal settings.

Supply air pressure reset. Consider controls that will also minimize the supply air pressure required to meet all zone loads. Typically, the supply fan is controlled to maintain a constant static pressure of around 1.5 inches water column in the duct upstream of the VAV boxes. However, lower pressure may satisfy airflow demands at many times of the year and can save fan energy. Automatic reset controls can monitor damper position in all VAV boxes and lower the supply duct pressure when all dampers are partially closed.

Ventilation air control can be tricky in a VAV system due to varying supply airflow. One option is to modulate the outdoor air damper based on measurement of outdoor airflow. This modulating damper method can also allow demand ventilation control to reduce airflow when spaces have low occupancy (see Guideline MV26: Demand Controlled Ventilation). Another option is a separate outdoor air fan that injects a constant volume of ventilation air into the supply air stream when the system is not in economizer mode.

To minimize reheat energy consumption, set the minimum flow on each VAV box as low as possible. In many cases, reheat would be unnecessary if the minimum flow were zero. However, the need for ventilation air usually requires some minimum damper position. In some systems, heating occurs at minimum airflow. Therefore, heating load can also be a constraint on the minimum flow. In these situations, reverse acting damper control is recommended. As heating load increases, the damper reopens.

The zone thermostats should have separate setpoints for heating and cooling with a deadband in between. This control also helps to minimize reheat energy.

Zone controls should also be tied to a central energy management and control system (EMCS). An EMCS reduces operation and maintenance cost by allowing remote monitoring and control.

To minimize air pressure drop across the cooling coils, limit the face velocity to 300 fpm, which requires a larger coil as well as larger equipment and floorspace. Also consider specifying a bypass damper that opens when the cooling coil is not needed, such as in economizer mode. Both measures help reduce fan energy consumption.

Rather than installing a return air fan, consider using a relief fan or barometric relief dampers to minimize fan energy.

Design duct systems to minimize pressure drop and leakage. For recommendations on duct design, see Guideline MV19: Air Distribution Design Guidelines.

VAV boxes should not be located over noise-sensitive areas (i.e., classrooms) when an acoustical tile ceiling system is being used. A gypsum board ceiling will do a better job of reducing VAV-radiated noise than a typical ceiling tile system. For this reason, most VAV boxes can be located above noise-sensitive areas where a gypsum board ceiling, which has all penetrations and joints well sealed, is installed.

Oversizing VAV boxes is one way to reduce radiated and discharge noise levels. This has to do with the velocity of air as it enters the box and passes by the damper.

Static pressure drop across the VAV box also has an impact on the amount of noise generated. Designing the system so that the damper does not produce more than 0.5 in. of static pressure drop will minimize noise.

Operation and Maintenance Issues

VAV system operation requires a skilled commissioning staff to ensure that controls operate efficiently. However, maintenance is relatively simple once the system is operating. Maintenance is centralized for boilers and chillers rather than being distributed to individual units. Many tasks are centralized and take less time than for a system with single-zone units.

VAV boxes typically have DDC interfaces allowing space conditions to be monitored from a central building management system. The information and remote control capability helps reduce maintenance costs.

Commissioning

Calibrate zone airflow sensors, and confirm minimum and maximum flow for each VAV box.

Calibrate all system temperature and pressure sensors. Confirm supply air temperature, reset supply pressure, and reset control operation.

Calibrate outside airflow measurement (if one is installed) and ensure that minimum ventilation airflow is provided under varying conditions.

Confirm proper functioning of all valves and dampers.

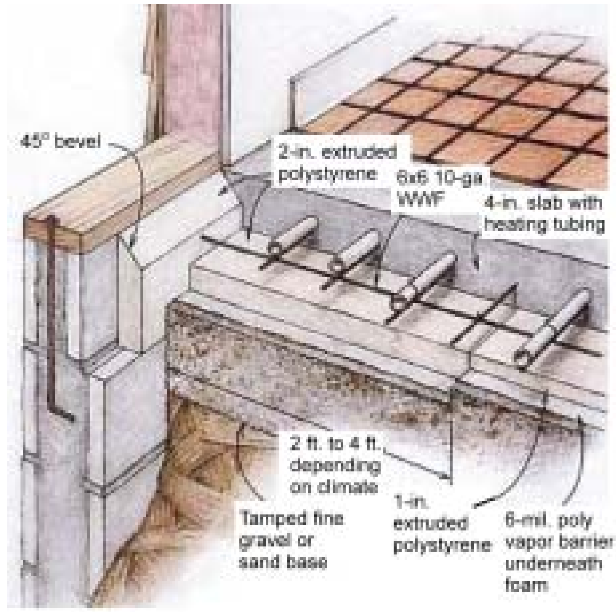
References/Additional Information

None.

GUIDELINE MV12: RADIANT SLAB SYSTEM

Recommendation

Install radiant slab-on-grade systems in rooms with heating demand. When conditions permit, use a solar thermal, geothermal system, and/or recovered thermal energy for the hot water supply.



Radiant slab

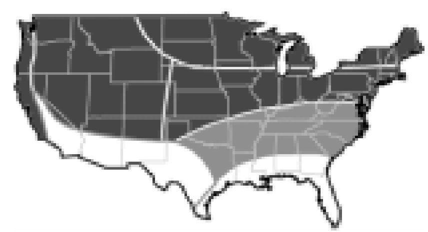
Description

A radiant slab heating system consists of the following:

- Hydronic distribution
- Hot water source (boiler, solar, geothermal heat pump, etc.)
- Control system.

Like all radiant heating systems, radiant slab systems provide thermal comfort to building occupants predominantly through radiation heat transfer. In other words, the system heats or cools room objects and occupants, rather than the surrounding air. Two basic configurations exist for hydronic radiant slab heating and/or cooling. The first option involves the placement of pipes in the foundation slab itself, referred to as slab-on-grade. The second, called thin-slab, consists of piping placed in a thinner slab layer that is situated on top of the foundation slab or on suspended floors. Each consists of a loop of tubing (normally cross-linking polyethylene, PEX) that is imbedded in concrete or a similar material, such as gyp-crete. Hot water is passed through the tubing, which heats the slab, and in turn, the room.

Applicable Climates



Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Applicability

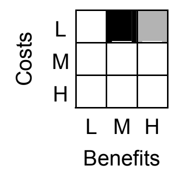
The use of radiant slabs for heating is applicable in all regions with a heating demand. However, due to condensation concerns, the use of radiant slabs for cooling should be limited to areas with a low latent cooling load.

Integrated Design Implications

- Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).
- All radiant hydronic systems provide an alternative to large-scale air-handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, and ducting, among other things.
- The slab system is a low-temperature application and is complemented well by alternative water heating methods including geothermal heat pumps and solar thermal systems. Typical hydronic heating systems, such as baseboard radiators, use water temperatures of 140°F to 200°F, whereas radiant floor heating uses temperatures between 90°F and 120°F.

- Consider framing strength when installing suspended-floor, thin-slab systems. It is much more cost effective to consider this during design rather than reinforcing the framing during construction.
- This system can be integrated into a facility-wide hydronic heating and cooling system including baseboards and ceiling panels.
- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

Cost Effectiveness



- The installed cost of the slab only ranges from \$2/ft^2 to \$20/ft^2 depending upon application. PEX tubing costs around \$0.65/lin ft retail.
- Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air-handling systems.
- The system is generally most cost effective when part of a facility-wide hydronic heating and cooling system.

Benefits

Advantages

- Hydronic systems can decrease or eliminate the need for mechanical air handling systems.
- Quiet operation.
- Better perceived comfort. Radiant slabs heat occupants from the bottom up and are purported to increase comfort. Allows for lower thermostat settings.
- Lower boiler temperatures of 90°F to 120°F compared to 140°F to 200°F for other heating systems. These temperatures can be accomplished by a geothermal heat pump or solar thermal system.
- Can provide fuel savings when compared to forced air systems.
- Aesthetically pleasing; no heat registers or visible radiators.

Disagvantages

- Hard to set back temperatures because of lag.
- Ground losses can reduce efficiency if insulation is not properly installed.

Design Tools

- Using a CAD-based program to design the layout of the tubing will save time, materials, and money.

Design Details

- Install edge insulation around radiant slab.
- Older installations used copper or other metal tubing, but these materials can react with the concrete and corrode if not properly treated. Copper has excellent heat transfer characteristics, but its short coil length and incomplete compatibility with concrete has caused a switch to polymer or synthetic rubber tubing. Most modern installations use cross-linked polyethylene (PEX) tubing. PEX tubing is usually layered with an oxygen diffusion barrier to extend the life of system components. Some installers use stainless steel components in lieu of the diffusion barrier. Another option is PEX-aluminum (PEX-Al-PEX) composite tubing, where the aluminum acts as a nearly perfect diffusion barrier. PEX-Al-PEX is also easier to bend than standard PEX.
- Any PEX tubing outside of the slab should be protected from sunlight to prevent corrosion.
- Tubing must be routed through the sub-soil or in a protective sleeve when passing through expansion joints.

- Before pouring the concrete, tubing should be laid out and pressurized to 100 psi for 24 hours to ensure no leakage. The tubing should remain pressurized throughout the pouring and curing process.
- Water should be delivered to the slab at a temperature that can maintain surface temperatures between 80°F and 85ºF. The required inlet water temperature is dependent upon the thermal resistance of the slab and any floor finishing material.
- Tubes should be spaced between 6 in. and 15 in. apart, depending on application.
- Use tighter spacing for slabs with wood floor finishing. Even temperatures are critical to avoiding varying levels of expansion and contraction in wood floors.
- Early planning, including an accurate estimate of the load requirements in the rooms to be heated and cooled, is key for these systems. Due to the nature of the system (in the foundation slab), the earlier the decision is made the better.
- High quality control systems should be used that monitor both indoor and outdoor temperatures. The slab is a large thermal mass and care must be taken to avoid under or over shooting the prescribed temperature.

Operation and Maintenance Issues

- The slab system consists of a large thermal mass and thus takes a significant amount of time to respond to changes in control settings. The response time of the system can be through proper operation and maintenance practices that serve to avoid severely over or under shooting the desired temperature.
- Modern radiant slab systems require little maintenance and do not have the leakage concerns of earlier systems.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. Proper installation and management of the control system for a radiant slab are particularly important. Be sure indoor and outdoor sensors are sited correctly and functioning properly.

References/Additional Information

None.

GUIDELINE MV13: BASEBOARD HEATING SYSTEM

Recommendation

Use baseboard heating in areas experiencing periods of at or below-freezing temperatures, especially under areas of glass.

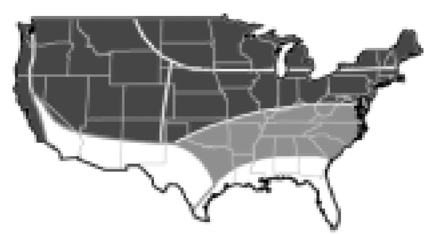
Description

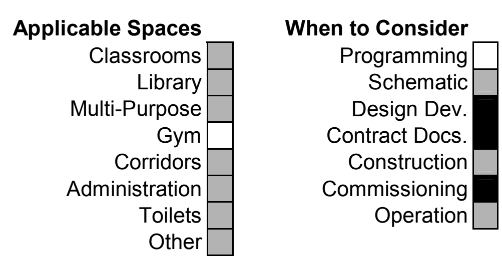
Hydronic radiant baseboard heating is a common application that has been used for over 50 years in the United States. The most common types are the finned-tube convector and radiant convector, both of which heat cold air at the floor of the room and induce an upward convective current. This is extremely effective in reducing downdrafts at cold facades and under windows. These models provide heat through a combination of convection and radiation. Another model is the panel, or flat pipe, radiator. Panel radiators are common in Europe and provide thermal comfort predominately through radiation heat transfer. A baseboard heating system requires the following:

- Baseboard heaters (convector or panel)
- Hydronic distribution system (piping, pumps, valves)
- Control system (sensors, thermostats)
- Hot water source (boiler, solar thermal, recovered thermal energy, geothermal heat pump)

Baseboard heaters such as this are commonly used as an effective way to reduce downdrafts experienced at cold facades and under windows. NREL/PIX 11423

Applicable Climates





Applicability

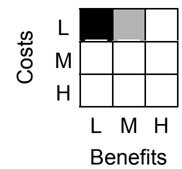
These systems are applicable in all areas experiencing extreme cold, and are especially effective in areas of significant heat loss, such as entryways or under windows.

Integrated Design Implications

- Baseboards are a good compliment for displacement ventilation systems. They can operate independently to maintain space temperature and to recover from night cool down.
- Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).
- All radiant hydronic systems provide an alternative to large-scale air-handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.
- The systems can be integrated into a facility-wide hydronic heating and cooling system including radiant slabs and ceiling panels.

- They can be the main heat source, or integrated with another system and used primarily to reduce downdrafts at cold walls or glass, and can provide off-hours heating without running fans.
- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

Cost Effectiveness



Baseboard heaters cost $10/lin ft to $25/lin ft.

- Operation and maintenance costs are low. Fuel costs and electric pumping costs in a well-designed system are lower due to increased efficiency compared to air-handling systems.
- The system is generally most cost effective when part of a facility-wide hydronic heating and cooling system.

Benefits

- Hydronic systems can decrease or eliminate the need for mechanical air-handling systems.
- These well-understood systems have been used for over 50 years.
- The systems are low maintenance.
- They can be more fuel efficient than air systems and use less power to move heat through the facility.
- Since they are quiet, these systems are good for classrooms.
- Cold downdrafts at outside walls and windows are stopped.
- Systems should be configured to allow for individual room control.

Design Tools

- The *Advanced Installation Guide for Hydronic Heating Systems*, available from the Hydronics Institute, includes a design and sizing procedure for baseboard heating.
- *Hydronics Design Toolkit* software is available from the Radiant Panel Association.

Design Details

- Baseboard systems can use zone control or individual room control. Zone control uses one thermostat to regulate several spaces in a single hydronic loop. This system is simple and cheap, but often involves large temperature drops and can be difficult to balance. Individual room control uses thermostatic radiator valves (TRV) to independently control baseboard elements in each space. The TRV allows educators to control the thermal environment of their own classroom.
- Flow rate must be controlled to ensure turbulent flow. If the flow rate is in the laminar regime, the heat transfer rate will be dramatically lower and more sensitive to flow rate changes causing difficulties in maintaining intended thermal conditions. Too high a flow rate can cause pipe noise.
- Proper water flow design is especially important if low temperature water will be used for heating, such as with a geothermal heat pump design.
- Increases in altitude can decrease the performance of finned-tube and radiant convectors.
- Painting panel radiators can affect performance. Aluminum and bronze paint can reduce total heat output by up to 10%.
- Make allowances for pipe expansion during installation to decrease audible disturbances.
- Water should be delivered to baseboard radiators between 140ºF and 200ºF.
- Care should be taken to ensure baseboard surface temperatures do not reach levels dangerous to young children.

- Output ranges from 300 Btu/hr/ft to 800 Btu/hr/ft depending on inlet/outlet temp and flow rate.
- Temperature drop across heater should not exceed 20ºF to insure uniform heating.
- Be sure not to inhibit convective flow patterns when arranging furniture near baseboard heating elements.
- “Quiet Type” baseboard heaters (ie., heaters designed to produce less operating noise) should be specified for occupied areas.

Operation and Maintenance Issues

Operation and maintenance issues for baseboard heating systems are minimal. Heat transfer surfaces should be kept clean and free of dust. If the system is open to the potable water supply, some internal cleaning may be necessary to avoid fouling. Pipe fouling can lower efficiency by decreasing the heat transfer rate and increasing the pressure drop.

Commissioning

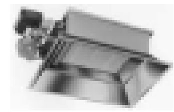
Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components.

References/Additional Information

"Advanced Installation Guide for Hydronic Heating Systems." Available from Hydronics Institute. Berkeley Heights, NJ 07922.

Radiant Panel Association, PO Box 717, Loveland, CO 80539-0717. Phone: (800) 660-7187 or (970) 613-0100. Fax: (970) 613-0098. Email: info@rpa-info.com.

GUIDELINE MV14: GAS-FIRED RADIANT HEATING SYSTEM



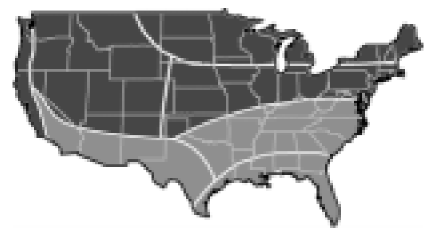
Recommendation

Consider gas-fired radiant heating for spaces with high ceilings and potentially high infiltration, or in large spaces with spot heating needs such as workshops or gymnasiums.

Description

This class of radiant heaters burns gas to heat a steel tube or a ceramic surface. The heated surface emits infrared radiation that is absorbed by occupants, furniture, floor, and elements of the building in view of the heating element. Those objects then heat the air in the space through convection. An advantage to this type of radiant heating in high traffic areas is that the objects in the space remain warm even if cool air is introduced.

Applicable Climates



Applicable Spaces	
Classrooms	
Library	
Multi-Purpose	■
Gym	■
Corridors	
Administration	
Toilets	
Other	■

When to Consider	
Programming	
Schematic	■
Design Dev.	
Contract Docs.	
Construction	
Commissioning	
Operation	

Variations and Options

- Several configurations of gas-fired radiant heaters are available. Some are linear units consisting of a long steel pipe with a reflector above. Another option is a smaller unit with heated ceramic surface design to cover a rectangular area of floor.

Applicability

Radiant heating is appropriate in spaces with high ceilings because it helps to overcome thermal stratification. Much of the heat is delivered directly to objects and occupants at floor level.

As mentioned earlier, radiant heating is also useful in areas with high traffic where infiltration can be a problem.

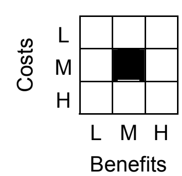
Appropriate spaces include gyms, shops, greenhouses, and high-traffic entrances or lobbies.

Radiant heaters can provide spot heating in large open spaces such as workshops or warehouses.

Integrated Design Implications

Consider the need for combustion air and flue gas venting when choosing the location for a gas-fired radiant heater. Also allow for adequate clearance around the unit, as recommended by the manufacturer.

Cost Effectiveness



Gas-fired radiant heaters are usually a cost-effective choice for spot heating in large open spaces. They may also be cost effective for general heating in spaces like gymnasiums when energy savings are considered.

Benefits

Advantages

- Equal comfort with lower indoor air temperatures results in lower heating energy consumption.
- Fan energy and/or pumping energy required for heating distribution is eliminated.

Disadvantages

Occupants may experience some discomfort due to warm heads and cool feet.

Design Tools

None.

Design Details

Provide protection for units installed in gymnasiums to prevent contact with sports equipment.

Follow the manufacturers guidelines for clearance above and to sides.

Provide an outdoor combustion air source and vent flue gas to outdoors.

“Quiet Type” unit should be specified.

Operation and Maintenance Issues

Gas-fired radiant heaters are relatively low maintenance systems.

Commissioning

None.

References/Additional Information

None.

GUIDELINE MV15: WATER-LOOP HEAT PUMPS

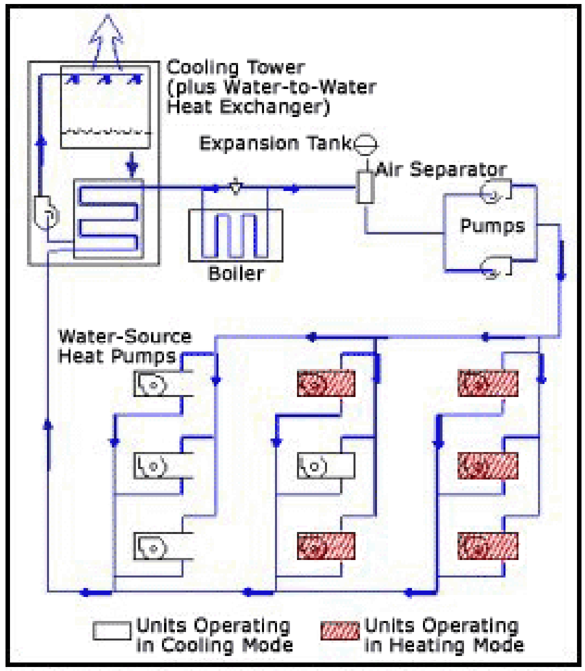
Recommendation

Consider using water-loop heat pumps if the building requires simultaneous heating and cooling, and has a minimum cooling capacity of 35 to 50 tons.

Description

A water-loop heat pump system provides space heating and cooling for individual building zones. Each building space contains a separate heat pump connected to a single circulating water loop. The piping system adds or removes heat to the circulating water. When most of the pumps are working to cool building spaces, heat must be removed from the loop via a cooling tower or other means. If most of the pumps are heating building zones, a boiler must generate added heat for the loop.

When heat is being removed from some zones (i.e. certain heat pumps are working in cooling mode and rejecting heat to the loop) as well as being delivered to other spaces (i.e. other heat pumps are working in heating mode and using heat from the loop), the water loop remains within the desired temperature range without the addition or removal of heat.



Typical commercial water source heat pump system

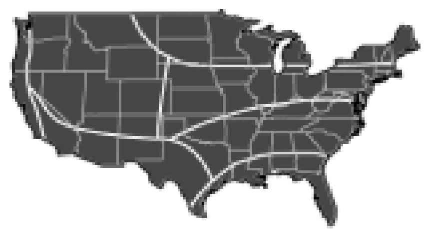
(Source: AdvancedBuildings.org)

Applicability

This system is applicable to all interior school spaces. It is most effective in schools where simultaneous heating and cooling is required in different areas of the building.

This system offers limited benefits where cooling loads are small or non-existent.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	▒

When to Consider	
Programming	□
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

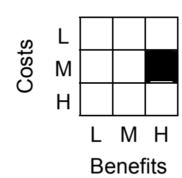
Integrated Design Implications

Water-loop heat pumps can be used as part of geothermal heat pump systems (See Guideline RE5).

Cost Effectiveness

The cost of a water-loop heat pump system is generally more than a two-pipe fan/coil system, but less than a four-pipe fan/coil system.

Benefits



Advantages

- Ability to use unwanted heat from one zone to heat another zone.
- Provides easy temperature control for building spaces. Units in areas not requiring heating or cooling can be turned off and bypassed.
- Provides high reliability for both heating and cooling modes.

- Do not require wall openings to reject heat from air-cooled condensers.
- Have a longer service life since they are not exposed to the weather.
- Failure of an individual water-source heat pump does not cause the entire system to fail.

Disadvantages

- Failure of a loop pump, heat rejection device, or secondary heater can affect system operation.
- Increases electrical load in the winter.
- Requires a central boiler and cooling tower.

Design Tools

See this chapter's Overview.

Design Details

Water in the loop needs to be kept within a temperature range of 60°F to 90°F.

Due to the limited operating range, insulation is not required on the water loop.

Changes to building spaces can generally be accommodated by adding or removing individual pumps.

Heat pumps must be specified for the proper operating temperature. Do not use electric boilers for the auxiliary heating.

Operation and Maintenance Issues

Typical life cycle for water-loop heat pumps is 15 to 20 years, depending on quality of maintenance. Regular cleanings of heat exchanger coils and regular air filter changes are required. This system can have higher maintenance costs because of the multiple compressors and fans.

Commissioning

Flushing the loops will ensure the system is in good operating order.

References/Additional Information

Advanced Buildings Technologies and Practices. http://www.advancedbuilding.org/.

Cooling System Alternatives. Tri-State Generation and Transmission Association. http://www.tristate.apogee.net/.

International Ground Source Heat Pump Association, Oklahoma State University, Stillwater, OK. http://www.igshpa.okstate.edu/.

Geothermal Heat Pump Consortium. http://www.geoexchange.org/.

GUIDELINE MV16: EVAPORATIVELY PRECOOLED CONDENSER

Recommendation

Specify an evaporatively precooled condenser for larger packaged units (10 tons or greater) in warm climates.

Description

An evaporative precooler is an option available for some packaged air conditioners that cools the air entering the unit's condenser coils. The precooler reduces the temperature at which the condenser operates and increases the efficiency and capacity of the packaged unit.

The evaporative precooler consists of an evaporative medium several inches thick that replaces the inlet grill that typically protects the condenser coils. The medium is wetted using a recirculating system or a "once-through" system. Air drawn over the medium by the condenser fan is evaporatively cooled to a point close to the wetbulb temperature of outside air.

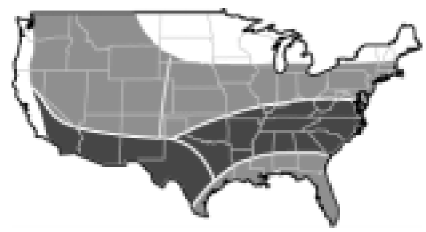
Precoolers are also available for outdoor units of some split systems.

Applicability

These condensers are applicable for larger units, especially those serving spaces used in summer. They should be used in facilities with skilled maintenance staff.

Evaporatively precooled condenser.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	□
Schematic	■
Design Dev.	■
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Integrated Design Implications

An evaporative precooler increases the capacity of air conditioners under hot conditions. Therefore, a smaller unit can be installed that will run more efficiently under normal partial load conditions. Water supply piping is required.

Cost Effectiveness

Evaporative precooled condensers add about 10% to the cost of the equipment and can pay for themselves in two to three years.

An evaporatively precooled condenser is generally cost effective for units over 10 tons.

Costs \ Benefits	L	M	H
L		■	
M			
H			

Benefits

Condensers increase capacity and efficiency of packaged direct exchange air conditioners. They can also reduce summer demand peaks.

Design Tools

None.

Design Details

Evaporative precoolers are typically controlled to operate only at higher outdoor air temperatures, approximately 80°F and above. At lower temperatures, less benefit occurs.

When sizing the packaged rooftop system, reduce the design outdoor drybulb temperature assuming that the evaporative precooler is about 50% effective. For example, in a climate with summer design conditions of 100°F drybulb and 70°F wetbulb, use an outdoor drybulb of 85°F for selecting the system capacity. This smaller system will run more efficiently at part load and have a smaller peak electric demand.

The addition of the evaporative precooler will reduce condenser airflow due to extra pressure drop. Check with the unit's manufacturer to make sure that airflow will be adequate.

Ensure that the precooler medium is properly designed and sized to prevent carry-over of water onto the condenser coils.

Operation and Maintenance Issues

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup (without causing excessive water consumption). Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

Specify periodic cleaning of evaporative medium and periodic inspections of water circulation rate and bleed-off rate.

Commissioning

Check that the precooler is activated when system runs and outdoor air exceeds the minimum setpoint (typically 80°F).

References/Additional Information

None.

GUIDELINE MV17: DEDICATED OUTSIDE AIR SYSTEMS

Recommendation

Install dedicated outside air ventilation systems to supplement or replace natural ventilation. Install systems to provide dehumidification of outdoor air supply with or without air conditioning.

Description

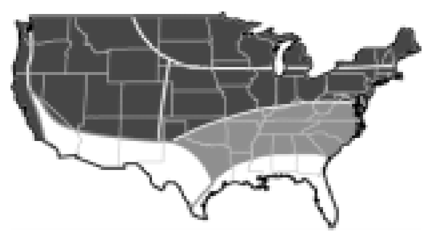
Dedicated outside air systems typically provide 100% outside air and deliver approximately 450 cfm to each classroom.

Outside air systems can be designed with ducted return or with relief dampers to outdoors. Systems with ducted return air can recover exhaust heat with an air-to-air heat exchanger. Systems without a heat exchanger usually need some means to temper the outside air, especially during winter.

Small systems are available that can serve individual rooms, while larger systems can serve an entire building. With larger centralized ventilation systems, evaporative cooling or waste heat recovery may be economical for tempering outdoor air.

Rooftop air-to-air heat exchangers are useful in systems with ducted return air for recovering exhaust heat. NREL/PIX 11424

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	☐
Administration	☐
Toilets	☐
Other	☐

When to Consider	
Programming	☐
Schematic	■
Design Dev.	☐
Contract Docs.	☐
Construction	☐
Commissioning	☐
Operation	☐

Applicability

This design strategy applies mainly to classrooms, or other areas with expected high occupant density, but can be used for spaces where hydronic heating systems and natural ventilation are appropriate. This design strategy is not as applicable for spaces that have conventional air conditioning, since outside air ventilation would be provided by the air-conditioning system.

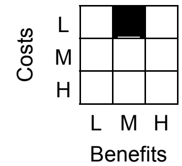
Dedicated outside air ventilation is especially appropriate in combination with baseboard or radiant heating systems, where a fan is not required for heating. However, even with forced-air heating systems, a separate ventilation system may be appropriate if access to clean outdoor air is difficult from each individual room. In these cases, a central air handler can supply tempered ventilation air to each room, while each space heater recirculates indoor air and runs only when there is a demand for heating. Alternately, a separate baseboard system can be used to provide well-controlled heating in each zone.

A dedicated ventilation system may also be appropriate where natural ventilation access is difficult because of noise, extreme temperatures, dust, security, or lack of physical access to the outdoors.

Integrated Design Implications

Special attention to controls is important to make sure that the ventilation system works together with the heating and/or cooling system. As with any ducted HVAC system, architectural coordination is important in locating relief dampers and routing ventilation ducts.

Cost Effectiveness



A dedicated outside air system may add cost to the overall HVAC system, but when combined with a well-designed displacement system in a coordinated building, it would be expected to be competitive with a well-designed, high-quality conventional HVAC system.

The U.S. EPA has created the School Advanced Ventilation Equipment Software (SAVES) that uses DOE-2 and code by the Florida Solar Energy Center and others to show that dedicated outdoor air supply systems with energy recovery ventilation components have a payback of under seven years in most areas (except the Hot and Dry and Temperate and Mixed climates).

Benefits

These systems, especially when combined with enthalphy energy recovery, will reduce energy costs in most regions. In addition, they ensure proper ventilation, improving air quality and occupant well being.

Design Tools

Most popular energy simulation programs, such as DOE-2, do not have the capability to directly model dedicated outside air distribution systems or 100% outdoor air systems with enthalpy energy recovery. However, there are some tricks that can give an approximation of the energy use, and some manufacturers of enthalpy energy recovery equipment can provide modeling.

Design Details

- In both hot and cold climates, consider using an enthalpy air-to-air heat exchanger to precondition outside air that is brought into the building. This will also reduce winter dryness.
- In hot climates, evaporation can be used to lower the temperature of air that is delivered to the space.
- Provide VAV dampers that can automatically minimize and shut off ventilation air to each classroom if it is not occupied. Consider using a motion sensor already installed for lighting as a control.
- Consider variable-speed controls for central ventilation fans, so that airflow can be reduced when some rooms are unoccupied.
- Use gravity type or automatic relief dampers in each classroom, unless exhaust air is ducted to a central unit for heat recovery.
- Size the system to provide at least 15 cfm per person in classrooms and other spaces. If a classroom is expected to have 30 students, 450 cfm should be delivered. If a classroom is expected to have 24 students, 360 cfm is appropriate.
- Use filters to remove dust and other particles from outside air.
- Isolate unit from occupied spaces. Provide appropriate intake and discharge noise control consistent with meeting the Noise Criteria. Locate rooftop units above unoccupied spaces and away from pollution sources on the roof.

Operation and Maintenance Issues

Replace filters on a regular basis.

Commissioning

Provide documentation regarding the design intent to contractors and building operators to ensure that the system gets implemented properly. Systems should be balanced and controls commissioned so that adequate air is delivered to each classroom.

References/Additional Information

None.

GUIDELINE MV18: ECONOMIZERS

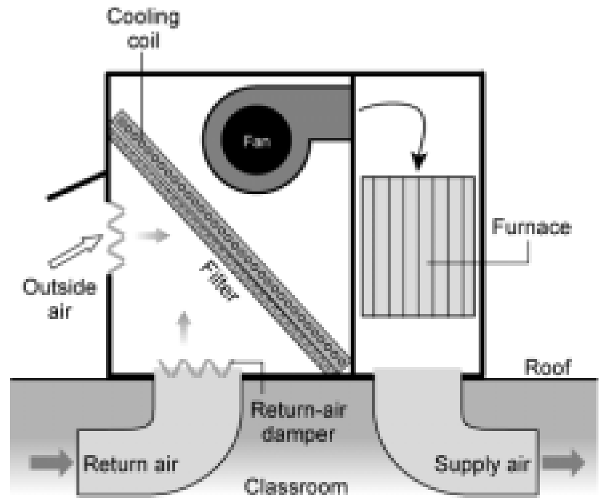
Recommendation

Incorporate integrated economizer dampers and controls on HVAC systems that utilize return air. For units under five tons, use non-integrated economizers with two-stage cooling controls

Description

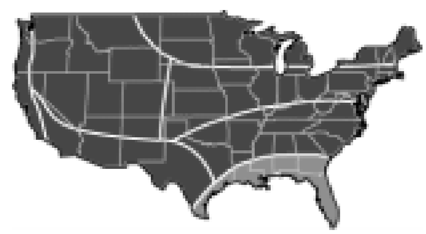
Economizers consist of three sets of dampers with interlinked controls: an exhaust damper that relieves space return air to offset ventilation air brought in; an outside air damper that controls the amount of ventilation air brought into the system; and a return damper that balances the return and outside air portions of the economizers. At low outside air temperature (below 65°F), the economizer dampers modulate to minimum ventilation position unless more outside air is needed for cooling. This minimizes the heating load and protects the cooling coils from frosting at low loads. At high outside air temperature (above about 75°F), the economizer dampers return to this low ventilation position. At these temperatures, the recirculated space air takes less energy to cool. Between these points, the economizer dampers modulate from minimum ventilation to 100% outside air, acting as a first stage of cooling in an attempt to maintain the desired supply air temperature.

Integrated economizers allow simultaneous economizer and mechanical cooling. Non-integrated economizers first attempt to cool with outside air; if that does not satisfy the load, the economizer dampers return to minimum position and mechanical cooling is initiated.



Components of an economizer.

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider	
Programming	□
Schematic	■
Design Dev.	■
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

There are three common control methods:

- **Fixed temperature setpoint** economizers close to minimum position when outdoor air exceeds a fixed temperature setpoint, typically 72° to 74°F.
- **Differential temperature** economizers will operate whenever the temperature of the outside air is below the temperature of the return air.
- **Differential enthalpy** economizers compare the enthalpy of the outside air and return air streams and operate whenever the outside air has less heat content. Enthalpy economizers are most important in humid climates.

For moderate climates, economizers can be a significant means of minimizing space-conditioning costs, because outside air will be within the comfort range for much of the school day throughout the year.

Applicability

Economizers make the most difference for systems serving spaces with low occupant density, such as libraries, administration, and other areas. In those spaces, the normal ventilator rate is fairly low and little free cooling occurs without an economizer. In classrooms and assembly areas, where high occupant density will dictate a large minimum position on the outside air damper (30% or above), economizer controls will have less impact. However, they will still be cost effective due to higher cooling loads in these spaces.

On many existing systems, economizers can be added as a retrofit.

Economizers will not be as useful for spaces designed to use natural ventilation for cooling. In those cases, the cooling system may run only during hot periods when an economizer would be at minimum position anyway.

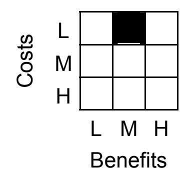
Economizers should not be installed in facilities that do not receive maintenance because a failure can increase energy consumption.

Integrated Design Implications

Economizers are especially valuable with displacement ventilation systems because the higher supply air temperature may allow an economizer to provide 100% of the cooling demand for a greater number of hours each year.

An economizer may be unnecessary in spaces with exterior walls and good natural ventilation design.

Cost Effectiveness



The cost premium is $200 to $500 to add an economizer to a small packaged rooftop system.

Economizers are very cost effective for spaces without natural ventilation.

Design Tools

None.

Design Details

Economizers should be factory-installed or specified to be factory-designed if they are to be field-assembled. Improper installation may cause coil and/or compressor damage.

Differential temperature control is recommended for most climate areas. However, in humid climates a differential temperature economizer could actually increase the system energy use by imposing a latent cooling load during economizer operation. A differential enthalpy economizer is ideal for humid areas, but enthalpy sensors require maintenance and can be unreliable. Therefore, a fixed temperature economizer with a setpoint around 72°F is a good choice for coastal areas where mild temperatures are accompanied by fairly high humidity.

For retrofit applications, care must be taken to protect the direct exchange coil and compressor from damage during low loads. With existing direct exchange systems, either non-integrated economizers should be installed or controls should be added to prevent compressor cycling and cutout on low evaporator temperatures. Economizer retrofits are likely to be cost effective only for larger systems (above 7.5 tons).

Operation and Maintenance Issues

Clean and lubricate dampers and control linkages. Maintenance is critical to ensure that economizers work properly for the lifetime of the system.

Commissioning

A functional test is critical to ensure that economizer controls are operating properly. With the system running during mild weather (outdoor cooler than indoor air), set the space thermostat to a low value to call for cooling and check that the outside air dampers are completely open. Then use a heat source, such as a hot-air gun, to warm the outside air temperature sensor and check that the outside air damper closes to its minimum position. Remove the heat source and check that the damper reopens (after the sensor has cooled).

For integrated economizers, also check that the outside air dampers remain completely open when the compressor is running and outdoor air is cool.

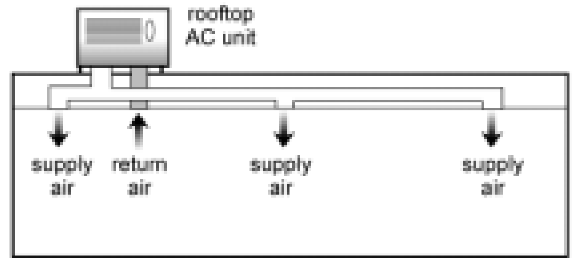
References/Additional Information

None.

GUIDELINE MV19: AIR DISTRIBUTION DESIGN GUIDELINES

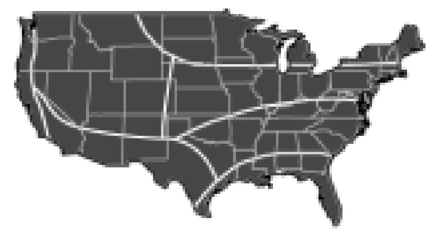
Recommendation

Design the air distribution system to minimize pressure drop and noise by increasing duct size, eliminating duct turns, and specifying low-loss duct transitions and plenums. Use lowest possible fan speed that maintains adequate airflow. Pay special attention to the longest or most restricted duct branch. (See Guideline MV11: VAV Reheat System for information on variable volume systems.)



Basic air distribution system.

Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	■	Programming	□
Library	■	Schematic	■
Multi-Purpose	■	Design Dev.	■
Gym	■	Contract Docs.	■
Corridors	■	Construction	■
Administration	■	Commissioning	■
Toilets	■	Operation	□
Other	■		

Description

Optimal air distribution system design is fairly complicated. An optimal design balances the need for comfort and low noise with overall HVAC system cost, energy cost, and long-term maintenance and replacement costs. Many factors affect performance: diffuser type, number of diffusers, diffuser size, duct size, duct material, plenum type and size, fitting types, length of ducts, number of turns, type of turns, location of duct system (e.g., unconditioned attic or within conditioned space), priority for heating performance vs. cooling performance, and fan characteristics (pressure vs. airflow).

Due to the complexity of design, a detailed analysis is common for small systems. Typically, designers and contractors rely on experience or rules of thumb in choosing system components. Even if design calculations are performed, however, decisions are not always the best, in terms of energy efficiency and acoustic performance.

This guideline addresses small, constant-volume duct systems that are common in schools. It covers design targets for air velocities and pressure loss that help ensure an efficient and quiet system.

Applicability

All ducted air systems.

Integrated Design Implications

Air distribution design options are closely tied to the architectural design. The choice of duct type is often limited by space availability, but acoustics should be considered. Round ducts with no internal glass fiber lining tend to keep noise inside and not let it be reduced as it travels away from the noise source (i.e., fan). Rectangular ducts with no internal glass fiber lining allow more sound to escape than circular ducts, but can be problematic if the noise level traveling through the sheet metal walls of the duct is too high.

Ducts may be located outside, in unconditioned space, or within the conditioned space. The most energy-efficient option is usually within conditioned space, but excessive noise may require that the first section of duct to be attenuated over unoccupied areas for a considerable distance. More expensive sheet metal ducts are usually required, but they need not be insulated. If ducts are located in an unconditioned attic, then the roof must be insulated and/or equipped with a radiant barrier to reduce heat gain to the ducts. Outdoor ducts should not be used unless no other option is feasible, as they almost always get wet and become mold sites.

Location of supply air outlets must be coordinated with lighting design (if located in ceiling) or space plan and furniture (for wall or floor outlets).

Cost Effectiveness

Sometimes extra costs for low-loss fittings or larger ducts are necessary to achieve a high performance design. However, these costs can often be offset by carefully sizing the heating and cooling system to reduce overall system size. In addition, many air distribution improvements have little or no extra cost, such as proper installation of flex duct that should be limited to the last 5 ft to 6 ft due to higher internal pressure drop.

Design Tools

Numerous duct-sizing computer programs are commercially available.

Design Details

These guidelines are intended to cover typical, small, single-zone systems. Additional criteria appropriate for multi-zone air distribution systems are not covered here.

Airflow

System cooling airflow. Total system airflow should generally fall between 350 cfm/ton and 450 cfm/ton for systems with cooling. If airflow is greater, condensation might blow off the cooling coil. If airflow is less than 350 cfm/ton, the cooling capacity and efficiency drop. The capacity loss due to low airflow is worst in dry climates where latent cooling loads are low.

System heating airflow. For heating-only systems, a good target is 25 cfm per kBtu/h of heating capacity, providing about 105°F supply air. Heating airflow should not be lower than 15 cfm per kBtu/h because supply air temperature will exceed 135°F. If the airflow is low, supply air will be too warm and air velocity too low, and poor mixing occurs in the room. Excessive airflow during heating creates more noise and can cause uncomfortable drafts.

Airflow adjustment. After system installation, airflow can be adjusted by either changing the fan speed or altering the duct system. To reduce airflow, lower the speed of the fan rather than install dampers. Try to use the lowest fan speed possible because fan energy consumption drops rapidly as fan speed decreases. If possible, specify a variable-speed or multiple-speed fan. To increase airflow, try to modify the duct system rather than increase the fan speed. Possible measures include replacing the most restrictive ducts with larger sizes, improving duct transitions to reduce pressure loss, and eliminating duct turns or constrictions (especially in flex duct).

Supply diffuser. Most diffusers also have a minimum velocity, both for proper mixing and to avoid dumping cool air on occupants. Refer to manufacturers’ guidelines for specific types of supply diffusers. When choosing diffusers based on Noise Criteria (NC), remember that manufacturers’ data are usually at ideal conditions (long, straight duct attached to diffuser) and actual noise level is likely to be higher. To account for this, diffusers should be selected for 5 to 10 NC points below the NC criteria of the room. Refer to Table 9 below for suggested air velocities.

Table 9 – Air Velocities for Supply Outlet and Return Inlet

	Design Criterion NC or RC(N)	Neck Air Velocity (fpm)
Supply Outlet	45	625
	40	560
	35	500
	30	425
	25	350
	20	300
Return Inlet	45	750
	40	675
	35	600
	30	500
	25	425
	20	375

(Source: 1999 ASHRAE APPLICATION HANDBOOK)

Return grille. The return air grille(s) must be larger than the total supply air diffuser area to avoid excessive noise. Refer to table above for suggested air velocities.

Duct. Air velocity should not exceed 700 fpm in flex ducts and 1,200 fpm in sheet metal ducts above occupied areas. Higher flow creates excessive turbulence and noise. There is usually a practical lower limit to duct air velocity, where the duct becomes too large and expensive.

Cooling coil. Air velocity through the cooling coils should be minimized to reduce pressure loss. A good target is 300 fpm. However, designers seldom have a choice of coil area in small packaged HVAC units, though it is possible to compare airflow and fan power data from different manufacturers to identify units with lower internal pressure loss.

Duct type

Flex duct. Flexible ducts are widely used. They offer several advantages when properly installed, but also have some disadvantages.

Flex ducts are most popular for their low cost and ease of installation. In addition, they attenuate noise much better than sheet metal ducts, but allow noise to escape into the ceiling plenum, which may not be acceptable if noise levels at the flex duct are excessive. Flex duct also offers lower air leakage, are usually pre-insulated, and provide some flexibility for future changes.

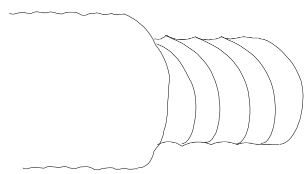
On the down side, pressure loss is greater in flex ducts, even when they are properly installed. They are also prone to kinking, sagging, and compression, which are problems that further reduce airflow and create noise. And since they are flexible, flex ducts are usually installed with more turns than sheet metal ducts. Actual performance of flex ducts in the field is often poor due to these installation problems. As a final disadvantage, flexible ducts are typically warranted for only about 10 years and will need replacement more often than a sheet metal equivalent.

If flex duct is used, several important points to consider are:

- The duct must be large enough for the desired airflow (see Table 10 below).
- The ducts must be properly suspended according to manufacturer guidelines without compressing or sagging.
- All ducts must be stretched to full length (see table notes below).
- Keep flexible duct bends as gentle as possible; allow no turns of more than 45°.
- Fasten all flex ducts securely to rigid sheet metal boots and seal with mastic (see Guideline MV20: Duct Sealing and Insulation).

- Limit duct lengths to no longer than about 5 to 10 ft to facilitate drop in ceiling designs (otherwise pressure loss may be too high).

Table 10 – Minimum and Maximum Airflow Values



Flex Duct Diameter (in.)	Minimum Airflow (cfm)	Maximum Airflow (cfm)
4	20	60
5	40	100
6	60	140
7	90	190
8	130	240
9	175	310
10	230	380
12	380	550

Table Notes:

- Maximum airflow limits correspond to velocity of 700 fpm. Higher flows create turbulence and noise in flex ducts.
- Minimum airflow corresponds to a design friction rate of 0.06 in./100 ft.
- The airflow values in the table assume that the flex duct is stretched to its full length. Airflow resistance increases dramatically if flex duct is compressed in length. Pressure loss doubles if the duct is compressed to 90% of its full length and triples if it is 80% compressed.

Sheet metal duct. The advantages to sheet metal ducts are lower pressure loss, longer life, greater durability, and the potential for reuse or recycling at the end of the system's life. They are the only option for long duct runs or medium- to-high-pressure duct systems. In addition, sheet metal ducts may remain exposed in conditioned spaces.

Disadvantages to sheet metal ducts are higher cost, higher sound transmission (sometimes they require noise attenuation measures that offset some of the pressure loss advantage), insulation requirement, and potentially greater leakage (though leakage is not an issue if they are properly sealed).

From a pressure loss standpoint, round sheet metal ducts are preferred over rectangular when adequate space is available. Round sheet metal ducts keep noise inside better than rectangular ducts. This may be preferred if the ducts are running over a noise sensitive space, and duct noise breakout is a concern. However, because round ducts do not allow noise to escape as easily as rectangular ducts, noise will not be reduced as quickly as the noise travels down the duct system. When ducts cannot be lined with internal glass fiber, rectangular ducts are preferred to allow low frequency noise to escape the duct before reaching the diffuser. Rectangular ducts are susceptible to noisy drumming at high airflow.

Reducing pressure loss

Several measures may be taken to reduce pressure loss and improve airflow. Knowledge of the following simple principles may help the designer improve airflow:

- **Air resists changing direction.** The pressure drop of a turn can be reduced dramatically by smoothing the inside and outside radius. When possible, avoid sharp turns in ducts and never allow kinks in flexible ducts. Turning vanes are another option to reduce the pressure drop in a sharp turn.

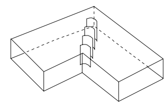
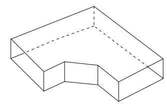
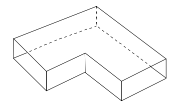
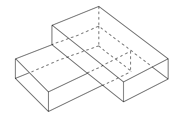
				
	BEST	**GOOD**	**FAIR**	**POOR**
Relative Pressure Loss	1.0	X 1.3	X 4.7	X 13.0

Figure 10 – Pressure Loss for Duct Turns

Note: Total pressure loss calculated at 800 fpm air velocity.

- **Airflow into branch ducts will be improved by using angled transitions (or conical taps) rather than typical straight connections.** The angled transition is especially useful for critical branches that are not getting enough air.

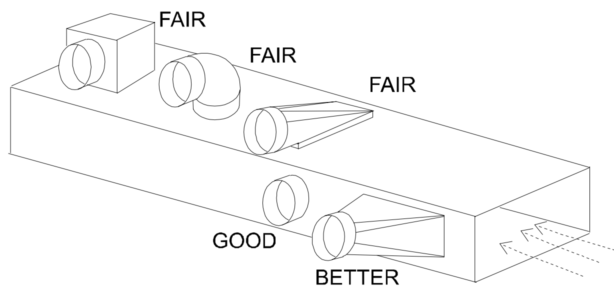


Figure 11 – Various Connections for Branch Ducts

From a pressure loss standpoint, the fewer turns the better. However, turns help reduce noise, particularly at high frequencies, as it travels through the duct system. For example, a side branch takeoff provides less flow resistance than a top branch takeoff because the top takeoff requires the air to turn twice.

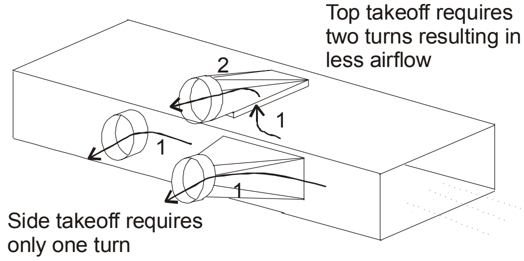


Figure 12 – Side Takeoff Vs. Top Takeoff

Reducing noise

Noise reaching the space via the duct system is either transmitted from the air-conditioning unit or generated by air turbulence within the air distribution system.

There are several measures available to reduce noise as it travels through the duct system, such as sound absorbing duct liner, flex duct, duct turns, and sound attenuators (silencers). Each of these elements has different noise reduction characteristics that need to be considered when analyzing the system for noise. Duct lining thickness and duct dimensions control the amount of noise reduction per linear foot of duct. Thicker glass fiber lining will reduce noise faster. Length and diameter controls the amount of noise reduction across flex duct. Duct dimensions and the way in which the duct turns (i.e., turning vanes, radiused elbow, etc.) impacts the amount of noise reduction. Please bear in mind that noise reduction is frequency dependant. Noise reducing elements (i.e., elbows, flex duct, etc.) may reduce noise effectively at high or low frequencies, but seldom have the same amount of noise reduction across the audible frequency range.

The first three measures mentioned above are the most feasible for small, single-zone systems because they are not prohibitively expensive and do not necessarily cause excessive pressure loss (small packaged systems usually do not have a lot of pressure to spare). Careful design is important to balance noise attenuation benefits vs. additional pressure loss.

Limiting air velocity as described earlier in this guideline controls noise generation with the ducts, or at grilles and diffusers.

Other Design Issues

Pay special attention to the duct branch with the greatest pressure drop, either the longest branch or the one with the most constricted turns. For longer branches, either larger duct size or low-loss duct transitions will be required to achieve proper airflow.

Do not place balancing dampers directly behind diffusers. If they are necessary, dampers should be located as close to the fan as possible to minimize noise and air leakage in the supply duct.

Connections to ceiling diffusers should have two diameters of straight duct leading into the diffuser. Otherwise noise and pressure drop can increase significantly.

Avoid placing ducts in a hot attic. The roof can reach 150°F on a sunny day and the radiant heat load on the duct is significant. If ducts are above the ceiling, insulation must be installed on or under the roof or a radiant barrier must be installed under the roof deck.

In many cases, if the pressure loss in the air distribution system can be reduced by as little as 0.15 in. SP, fan speed can be reduced and fan power decreases significantly. In the case of a three-ton rooftop packaged unit, energy savings can be $200 to $300 over a 10-year period. Manufacturer's data for a typical three-ton unit shows that the fan can supply 1,100 cfm at 0.8 in. w.c. external static pressure, if the fan is set to high speed. The fan can provide the same airflow at 0.65 in. w.c. at medium speed. Therefore, if the duct system is carefully designed and installed, it may be possible to run at medium speed. The fan power then drops from 590 W to 445 W. For typical operating hours and electricity rates, the savings are about $30/year.

Operation and Maintenance Issues

Filters must be replaced regularly to maintain airflow. Fans and drives must be lubricated to maintain proper operation.

Commissioning

Measure supply airflow and external static pressure to compare with design values. If airflow is low, take measures to reduce restrictions in duct system rather than increasing fan speed.

References/Additional Information

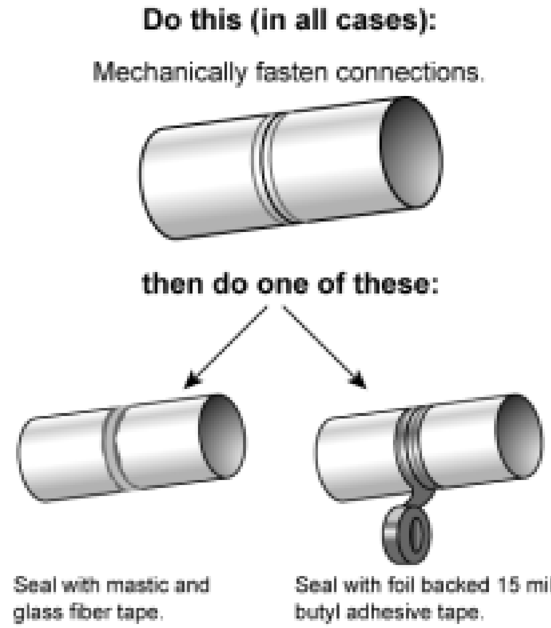
American Society of Heating, Refrigeration and Air Conditioning Engineers. *ASHRAE Handbook - 2001 Fundamentals*. Atlanta, GA.

Sheet Metal and Air Conditioning Contractors National Association. *HVAC Systems Duct Design*. Chantilly, VA.

GUIDELINE MV20: DUCT SEALING AND INSULATION

Recommendation

Create strong and long-lasting connections by mechanically fastening all duct connections and using mastic to seal connections and transverse joints (those perpendicular to airflow). If choosing pressure-sensitive tape as a sealant, then specify foil-backed tape with 15-mil butyl adhesive. Internal gasketing at joints is an excellent choice for round ducts.



Description

Duct leakage has a big impact on system efficiency and capacity. Studies of residential systems conducted by the Lawrence Berkeley National Laboratory show that 20% loss is common.[4] Similar problems exist in commercial duct systems.

Other studies have shown that some types of pressure-sensitive tape fail quickly in the field. Therefore, duct sealing systems must be specified carefully for longevity as well as strength and air-tightness.

Depending on duct location, insulation also plays a critical role in ensuring system efficiency and capacity.

Supply and return air plenums must be sealed as well. These are usually the areas of greatest pressure in the air distribution system, and small holes create significant leaks.

Applicable Climates

Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	□

Applicability

All ducted air systems.

Integrated Design Implications

Duct leakage problems can be avoided by placing ducts within the conditioned envelope or by eliminating them altogether (e.g., hydronic heating and cooling).

Cost Effectiveness

Using mastic for duct sealing may increase material costs, but many find that labor costs drop compared to sealing with tape. Therefore, good duct sealing should not have a significant cost impact.

Costs \ Benefits	L	M	H
L	□	□	■
M	□	□	□
H	□	□	□

Benefits

Careful duct sealing and insulation application will allow use of smaller cooling and heating equipment or at least allow the use of smaller safety margins in sizing calculations. Lower equipment cost may be a result.

[4] http://www.lbl.gov/Science-Articles/Research-Review/Highlights/1998/v3/EES_duct.html.

Lower cooling and heating costs result. Other benefits include improved system performance, potentially better comfort, and reduction in infiltration and potential moisture problems within envelope components.

Design Tools

None.

Design Details

Do not rely on sealants, such as tape or mastic, to provide a mechanical connection. Specify screws, draw bands, or other mechanical fastening devices as appropriate for the duct type.

As a first choice, use mastic to seal all connections and transverse joints. Mastic is a liquid applied sealant that can also be used together with a mesh or glass fiber tape to provide added strength or to span gaps of up to about ¼ in. Specify mastic in a water-based solvent with a base material of polyester/synthetic resins free of volatile organic content.

If choosing pressure-sensitive tape as a sealant, specify foil-backed tape with 15-mil butyl adhesive. Butyl tape has been found to have greater longevity in the field. Avoid using tape with rubber or acrylic adhesive.

Flexible ducts must be mechanically fastened with draw bands securing the inner and outer plastic layers to the terminal boot. Specify that the draw bands be tightened as recommended by the manufacturer using an adjustable tensioning tool.

Seal both supply and return ducts and plenums.

Commissioning

Inspect duct connections.

Test duct leakage with smoke testing or pressure testing.

References/Additional Information

None.

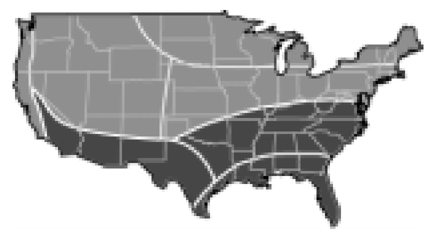
GUIDELINE MV21: HYDRONIC DISTRIBUTION

Recommendation

Consider using a variable flow system with variable-speed drive (VSD) pumps, but be careful to keep turbulent flow in the fintube during cold weather. Insulate exposed hydronic heating/cooling piping. Make early decisions regarding the placement of heating/cooling components (radiators, ceiling panels, slab floors, boilers, chillers). Use this information to create a system layout that minimizes piping material (pipes, bends) and head loss. When possible, use larger pipe diameters and smaller pumping equipment to conserve energy.

These loop water pumps and piping are part of a geothermal heat pump system being used by Nebraska schools to save money and energy on heating and cooling. NREL/PIX07415

Applicable Climates



Applicable Spaces	**When to Consider**
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Description

Significant amounts of energy must be used to distribute water for heating and cooling. Proper design can result in substantial economic and energy savings. Unfortunately, hydronic distribution design is often governed by *past* practices and not necessarily *best* practices. This factor makes the design process quick and easy, but not always the most economical or energy efficient. A hydronic distribution system consists of pipes, fittings, tanks, pumps, and valves.

Applicability

Applicable in all areas. However, the system is most applicable to the Hot and Dry, Hot and Humid, and Temperate and Humid regions.

Integrated Design Implications

Hydronic distribution is related to nearly all aspects of building design and construction. It is crucial that the HVAC piping contractor be involved throughout the design and construction process to maximize the efficiency and cost effectiveness of the hydronic distribution system. Simply laying out heating and cooling elements (baseboards, ceiling panels, chillers, boilers) in such a way that minimizes the required pipe material and maximizes straight-running pipe can save significant amounts of energy. Maximizing the amount of straight-running pipe also simplifies the insulating process.

Cost Effectiveness

Initial cost for hydronic distribution depends on the quantity, size, and type of piping, valves, and pumps. Initial cost can be minimized through proper planning, sizing, and placement of each.

When doing life-cycle cost analysis, compare incremental cost of increased pipe diameter to energy savings, and savings from decreased size and cost of pumping system.

Benefits

- A properly sized and installed system will provide quiet, efficient, and virtually maintenance-free operation at minimal cost.

- Properly insulating all exposed piping will save energy and money, which can be cost effective at levels beyond code requirements.
- Increasing piping diameter significantly decreases the pumping power required. Pressure head loss due to friction drops the fifth power with pipe diameter.
- Oversized piping allows for increases in load requirements from add-ons or renovations without complete system overhaul.

Design Tools

- Use a CAD-based program to design pumping layout.
- ASHRAE Handbook - Fundamentals outlines the process for determining pressure drop through piping layout.
- Pipe diameter selection involves balancing the following:
- Location of pipe in the system
- First costs of installed piping
- Pump costs (capital and energy)
- Erosion considerations
- Noise considerations
- Architectural constraints
- Budget constraints.

Design Details

Piping Circuits

There are four general types of piping circuits: series, diverting series, parallel direct-return, and parallel reverse-return. The series circuits are one-pipe circuits and are the simplest and lowest-cost design. Both the series and diverting series involve large temperature drops; however, only the latter allows for control of individual load elements.

The advantage of parallel piping circuits is that they supply the same temperature water to all loads. Direct-return networks are sometimes hard to balance due to sub-circuits of varying length. Reverse-return networks are designed with sub-circuits of nearly equal length. Parallel circuits are two-pipe systems.

Piping attached to vibration-isolated equipment (typically within the first 25 ft to 30 ft from the equipment) should be supported with vibration isolators, similar in type and static deflection to the vibration isolation being used for the associated equipment.

Fluid flow should be limited to 4 fps in 2-in. diameter pipes and below. For larger pipes a flow velocity of 6 fps is recommended.

Maintain a maximum of 50 psig water pressure at plumbing fixtures.

Valves

In general, either two-way or three-way control valves are used to manage flow to the load. A two-way valve controls flow rate to the load through throttling, which causes a variable flow load response. Three-way valves are used in conjunction with a bypass line to vary flow to the load. Because the water that does not go to the load simply passes through the bypass line, three-way valves provide a constant flow load response. Significant energy savings can be realized when two-way control valves are used in conjunction with VSD pumps.

It is recommended that ball valves or butterfly valves be used for all isolation and balancing valves. These valves are reliable and offer a low-pressure drop at a low cost.

Pumps
Centrifugal pumps are most commonly used in hydronic distribution systems. The use of VSD pumps can save significant amounts of energy and simplify the distribution system. Pump power falls at a cubed rate with speed; thus, a VSD pump can be extremely cost effective for systems with significant load variations. Also, variable flow networks with VSD pumps use a simple two-way valve and do not require balancing valves. For systems that use supply air temperature reset controls, specify a clamp on the speed of the pump to avoid excessive energy use during system startup.

Refer to 1995 ASHRAE Handbook Chapter 43 for recommended vibration isolation.

Dual-Temperature Systems
When a space requires both heating and cooling, either a two-pipe or four-pipe system can be used. In a two-pipe system, all the loads must be either heating or cooling congruently. Two-pipe systems cannot be used when some spaces on the piping network need cooling, while others need heating. Switching from one mode of operation to the other increases overall energy usage and can be a fairly time-consuming process. A four-pipe system is more complex, but it allows for heating and cooling on the same network and is more convenient than a two-pipe system when frequent changeovers are required.

Expansion Chamber
- Closed systems should have only one expansion chamber.
- Expansion tanks open to the atmosphere must be located above the highest point in the circuit.

Air Elimination
Measures such as manual vents and air elimination valves should be taken to purge any gases from the flow circuit. Failure to do so can lead to corrosion, noise, and reduced pumping capacity.

Insulation
The insulation process becomes significantly easier when the piping network is laid out properly. Install all valves with extended bonnets to allow for the full insulation thickness without interference with valve operators. It may be cost effective to insulate pipes beyond code requirements.

Water Treatment
Care should be taken to avoid scaling and biological growth within the distribution system. Significant fouling resulting from either source is detrimental to system performance. The degree to which scaling can occur is dependent upon temperature, pH level, and the amount of soluble material present in the water. Scale formation can be controlled through several means including filtration and chemical treatments.

Biological growth is generally a larger problem for cooling systems. Heating systems typically operate at temperatures high enough to prohibit substantial biological growth. Chemical treatments with biocides such as chlorine and bromine have traditionally been used to control this growth. Alternatives to these chemicals include ozone and UV radiation. Ozone itself is toxic; however it readily breaks down into non-toxic compounds in the environment. UV radiation is completely non-toxic, but is only effective when turbidity levels are low. Mechanical methods such as blow downs can also be utilized to control fouling and decrease chemical use, but these methods increase water usage.

Operation and Maintenance Issues
- Water quality should be checked on a regular basis to ensure fouling due to scaling or biological growth is not occurring.
- Periodically check piping insulation. Insulation adhesive can fail and expose piping.
- Check pressures, pumps, and valves on regular basis to ensure system is performing as intended.

Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. Water flow should be measured and adjusted accordingly. System head should be measured and compared to design system head.

References/Additional Information

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Handbook - HVAC Systems and Equipment*. 2000.

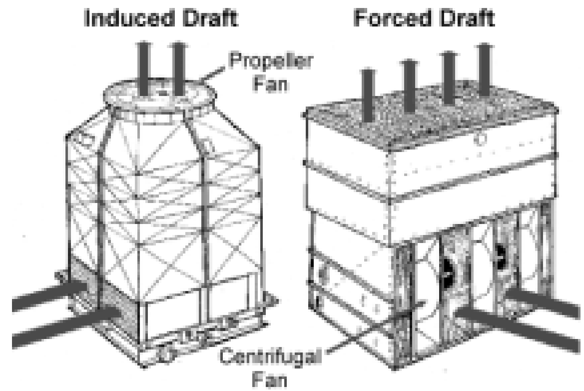
CoolTools: Chilled Water plant Design Guide. Available from Pacific Gas and Electric, P.O. Box 770000, B32. San Francisco, CA 94177.

Hydronics Institute, Berkeley Heights, NJ 07922. Phone: (908) 464-8200.

GUIDELINE MV22: CHILLED WATER PLANTS

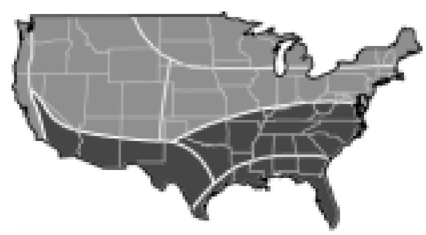
Recommendation

Use high-efficiency, water-cooled, variable-speed chillers. Use chiller heat recovery if there is a reliable hot water demand. Install oversized induced-draft cooling towers with axial propeller fans. Use low approach temperatures and variable-speed fan control.



Cooling Towers

Applicable Climates



Applicable Spaces

Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider

Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Description

Chillers

There are two basic chiller classifications, air-cooled and water-cooled. Water-cooled chillers cost more (when considering the cooling tower and condenser water loop), but are more energy efficient. Several chiller types exist within the classifications, including electric (centrifugal, reciprocating, screw or scroll), gas-fired (engine-driven or double effect absorption), and steam absorption.

Towers

A cooling tower provides heat rejection for a water-cooled chiller by exposing as much water surface area to air as possible to promote the evaporation of the water and thus cooling. Cooling towers come in a variety of shapes and configurations. A “direct” tower, also known as an “open” tower, is one in which the fluid being cooled is in direct contact with the air. An “indirect” tower, or “closed-circuit fluid cooler,” is one in which the fluid being cooled is contained within a heat exchanger or coil, and the evaporating water cascades over the outside of the tubes. The tower airflow can be driven by a fan (mechanical draft) or can be induced by a high-pressure water spray. The mechanical draft units can blow the air through the tower (forced draft) or can pull the air through the tower (induced draft). The water invariably flows vertically from the top down, but the air can be moved horizontally through the water (cross flow) or can be drawn vertically upward against the flow (counterblow).

Applicability

These towers are applicable for a small percentage of schools in areas needing significant amounts of chilled water and space cooling.

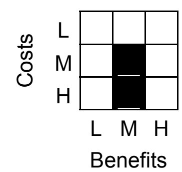
Equipment should perform in accordance with efficiency guidelines in ASHRAE 90.1-2001. The energy performance requirements set forth by ASHRAE 90.1-2001 state that heat rejection devices must supply ≥ 38.2 gpm/hp for axial fan towers and ≥ 20.0 gpm/hp for centrifugal fan towers. The U.S. Environmental Protection Agency codes chemicals (usually chlorine) used for cleaning. Methods using ozone for cleaning are also an option, but this can lead to increased corrosion of internal systems.

Integrated Design Implications

Chiller and tower decisions are related to many aspects of building design and construction including space considerations, cooling/heating choices, and the hydronic distribution system layout. Tower performance is related to facility layout and orientation. The tower should be sited properly to minimize recirculation of saturated air.

The placement of chilled water plant components affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

Cost Effectiveness



Installed estimates for chillers fall between $575/ton and $781/ton, depending on efficiency and drive choice. Installed tower cost estimates are between $133/ton and $178/ton.

As a general rule, air-cooled chillers are more cost effective if the chiller plant is less than 300 tons. Water-cooled are more cost effective above 300 tons. However, many factors affect operating costs for a chilled water plant, and the best choice of type, size, efficiency, and controls is difficult to generalize. First-cost premium, when improving from an efficiency of 0.7 kW/ton to 0.6 kW/ton, is $70/ton. This number increases to $136/ton for variable-speed chillers. Simple payback periods vary from 3 to 11 years.

Increasing the cooling tower's size and efficiency is generally cost effective with a four- to seven-year payback. Annual energy savings are between \$0.01/ft^2 and \$0.04/ft^2. Incremental costs are between \$0.08/ft^2 and \$0.12/ft^2, depending upon climate.

Design Tools

- CoolTools: Chilled Water Plant Design Guide available from Pacific Gas and Electric.
- The use of chillers with various efficiencies can be modeled using DOE-2 and VisualDOE.

Design Details

Vibration Isolation

Refer to 1995 ASHRAE Handbook Chapter 43 for recommended chiller and cooling tower vibration isolation.

Chiller Type

The best choice among electric, gas, and steam chillers (or some combination thereof) is largely site specific. If a reliable source of free or very low cost steam is available on site, then steam absorption makes the most sense.

Gas versus electric or hybrid gas/electric will depend on utility rates. Gas-fired chillers can cost two times more than electrically driven machines and will require a larger cooling tower and condenser water pump. Gas engine chillers are more energy efficient than absorption machines and have high temperature heat readily available for recovery; however, are more maintenance intensive than absorption machines.

Chiller type has a significant impact on the level and quality of noise produced. Historically, rotary screw compressors produce very high levels of noise, which typically contain an annoying tonal component. Centrifugal compressors are usually quieter than screw chillers and do not contain a tonal component. Scroll compressors are the most quiet of the three, but are usually air-cooled. The predominant source of noise from air-cooled scroll compressor chillers is generated by the cooling fans. VSDs can reduce the amount of noise being generated by slowing the flow of refrigerant through the compressor.

The most cost-effective type of electric chiller is primarily a function of chiller size. General decision guidelines are listed in Table 11.

Table 11 – Recommended Electric Chiller Types

Chiller Size	Recommendation
<= 100 tons	1st choice: reciprocating 2nd choice: scroll 3rd choice: screw
100 – 300 tons	1st choice: screw 2nd choice: scroll 3rd choice: centrifugal
> 300 tons	1st choice: centrifugal 2nd choice: screw

Number of Chillers

As a general rule:

- If the peak chilled water load is less than 300 tons, then a single chiller is usually most economical.
- If the load is greater than 300 tons, use two chillers. This offers better low-load capability and operating efficiency and offers some redundancy should one of the chillers fail.

Having one smaller or pony chiller (as opposed to two or more equally-sized chillers) can improve part-load efficiency of the plant. However, some operators prefer if all the machines are the same size due to familiarity and parts interchangeability.

Unloading Mechanism

Centrifugal chillers typically use inlet vanes to control the chiller output at part-load. Using hot gas bypass as a means to control the chiller at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties. Using a VSD instead of inlet vanes allows the compressor to run at lower speed at part-load conditions, thereby reducing the chiller kW/ton more than inlet vanes. The energy savings from a VSD chiller can be quite significant if the chiller operates many hours at low load. To capture the potential savings of VSD chillers, it is important that the condenser water temperature is reset when ambient conditions are below design conditions. This can be accomplished either by using a fixed setpoint (e.g., 70°F) that is below the design condenser water temperature (e.g., 85°F) or using wetbulb reset control, which produces the coldest condenser water the tower is capable of producing at a particular time. A gas engine chiller is also capable of unloading by decreasing engine speed.

Chiller Efficiency

The ratings in Table 12 should be considered as upper bounds. Lower efficiencies are available and are often the lowest lifecycle cost option.

Table 12 – Recommended Chiller Rated Efficiency

Condenser Type	Compressor Type	Min Tons	Max Tons	Recommended kW/Ton	Recommended IPLV	Recommended C.O.P.
Water-Cooled	Scroll	1	80	0.79	0.78	
Water-Cooled	Screw	1	150	0.76	0.70	
Water-Cooled	Screw	151	300	0.72	0.70	
Water-Cooled	Screw	301	& up	0.64	0.61	
Water-Cooled	Reciprocating	1	80	0.84	0.75	
Water-Cooled	Reciprocating	81	& up	0.82	0.75	
Water-Cooled	Gas Engine	501	2000			1.80
Water-Cooled	Absorption (SE)	150	1000			0.65
Water-Cooled	Absorption (DE)	150	1000			1.00
Water-Cooled	Centrifugal	1	150	0.62	0.62	
Water-Cooled	Centrifugal	151	300	0.60	0.61	
Water-Cooled	Centrifugal	301	& up	0.56	0.56	
Air-Cooled	Scroll	1	80	1.25	1.10	
Air-Cooled	Absorption (SE)	1	& up			0.60
Air-Cooled	Screw	1	& up	1.21	1.00	
Air-Cooled	Reciprocating	1	& up	1.15	1.15	
Air-Cooled	Centrifugal	1	& up	1.30	1.30	

Heat Recovery Chiller

Heat rejected from the condenser of a chiller can be recovered and used to drive a desiccant system or for preheating domestic hot water by routing the condenser water through a double-wall heat exchanger that is either an integral part of a storage tank or is remotely located with a circulation pump to the storage tank. Heat recovery chillers are typically used only for a portion of the total cooling load, because of the need to match hot water load and cooling load and because of the lower efficiency of heat recovery chillers. Heat recovery chillers are not typically piped in parallel with other chillers but rather are either piped for “preferential” loading or in series with other chillers, allowing the cooling load on the heat recovery chiller to be matched to the hot water load. Waste heat can also be recovered from the engine jacket and exhaust of gas engine-driven chillers.

The energy savings from chiller heat recovery are reduced when using economizers (air-side or water-side) because chillers are often not needed when the weather is mild or cold. Chiller heat recovery cannot eliminate the need for a DHW boiler but it can eliminate the need for some of the cooling towers at a site.

Chiller Staging

For a plant composed of single-speed chillers, control systems should be designed to operate no more chillers than required to meet the load. A plant composed of variable-speed chillers should attempt to keep as many chillers running as possible, provided they are all operating at above approximately 20% to 35% load. For example, for the typical variable-speed chiller plant, it is more efficient to run three chillers at 30% load than to run one chiller at 90% load. The use of hot gas bypass at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties.

Tower Fan Speed Control

Two-speed (1,800 rpm/900 rpm) or variable-speed fan control is always more cost effective than single-speed fan control. For plants with multiple towers or multiple cells, provide two- or variable-speed control on all cells, not just the “lead” cells. The towers are most efficient when all cells are running at low speed rather than some at full speed and some off. For instance, two cells operating at half speed will use about 15% of full power compared to 50% of full power when one cell is on and the other is off.

Tower Oversizing

The tower and fill can be oversized to reduce pressure drop, thereby allowing the fan to be slowed down, which reduces motor power and noise. Tower heat transfer area should be oversized to improve efficiency to at least 60 gpm/hp to 80 gpm/hp at CTI conditions.[5] The energy savings should outweigh the added cost to oversize the tower and to accommodate the larger tower footprint and weight.

A larger tower can also produce cooler water, allowing chillers to run more efficiently. Selecting towers for a 4% or 5% approach will generally be cost effective relative to a more typical 10%. Cooling towers are available with as low as 3% approach temperature, but the tower cost increases as the degree of approach drops. A life-cycle cost analysis should be performed to compare the extra cost to the energy impact on the tower, chiller, and pumps.

Tower Performance

The performance of a cooling tower is a function of the ambient wetbulb temperature, entering water temperature, airflow, and water flow. The drybulb temperature has an insignificant effect on the performance of a cooling tower. “Nominal” cooling tower tons are the capacity based on a 3 gpm flow, 95°F entering water temperature, 85°F leaving water temperature, and 78°F entering wetbulb temperature. For these conditions, the range is 10°F (95°F-85°F) and the approach is 7°F (85°F-78°F).

Table 13 – Cooling Tower Design Considerations

	Energy	**Noise**	**Height**	**Chiller Fouling**	**Cost**	**Application**
Packaged Induced Draft, Axial Fan	Lower	Higher	Higher	Higher	Medium	Best for most plants.
Field-Erected Induced Draft, Axial Fan	Lowest	Higher	Higher	Higher	Higher	Very large plants.
Forced Draft, Centrifugal Fan	Higher	Lower	Lower	Higher	Lower	Best if noise or height constrained or large external static pressure (e.g., tower located indoors).
Closed Circuit Evaporative Cooler, Axial Fan	Higher	Higher	Higher	Lower	Highest	Appropriate for heat pumps, not most chillers.
Closed Circuit Evaporative Cooler, Centrifugal Fan	Highest	Lower	Lower	Lower	Highest	Appropriate for heat pumps, not most chillers.
Spray Towers	Lowest	Lowest	Higher	Higher	Lowest	Seldom used due to high maintenance and variable condenser water flow.

Operation and Maintenance Issues

Periodic blow downs and scrubbing of cooling towers must be performed to avoid scaling of internal systems and biological growth. The condition of cooling tower fill is critical to performance. It should be inspected every year and the chemistry of the tower water should be maintained to minimize fouling.

Commissioning

For chillers to operate efficiently, they must be properly commissioned. Part of this process is making sure that sensors (such as chilled water flow, chilled water supply and return temperatures, and chiller electric

[5] Tower efficiency (as defined in ASHRAE Standard 90.1-1999) is the ratio of the maximum tower flow rate (gpm) to the fan motor horsepower (hp) at standard CTI rating conditions (95°F to 85°F at 78°F wetbulb). Standard efficiency is about 35 gpm/hp to 40 gpm/hp efficiency.

demand), are specified and properly calibrated. Sensor data should be permanently stored by the energy management system and easily visualized graphically. Not only is this data valuable for insuring that the design intent is met in the construction process, but also for maintaining energy efficiency over the life of the chiller. For example, by monitoring the approach temperatures in the condenser and evaporator heat exchangers (as the heat exchanger surface becomes fouled, the approach temperature increases), maintenance can be scheduled when needed, as opposed to too often, which wastes maintenance resources, or too infrequently, which wastes energy. A detailed account of commissioning issues specific to chilled water plants can be found in the CoolTools design guide (see the References section below).

References/Additional Information

CoolTools: Chilled Water Plant Design Guide. Available from Pacific Gas and Electric, P.O. Box 770000, B32, San Francisco, CA 94177.

STD-201 (November 1996) Certification Standard for Commercial Water Cooling Towers. Available from Cooling Tower Institute, Post Office Box 73383, Houston, Texas 77273. Phone: (281) 583-4087.

GUIDELINE MV23: BOILERS

Recommendation

Consider medium-to high-efficiency gas-fired boilers or medium efficiency oil-fired boilers for space heating and domestic hot water. If demand is large and variable, install several smaller modular boilers instead of one large unit.

Description

Boilers are pressure vessels that transfer heat to a fluid. They are constructed of cast-iron, steel, aluminum, or copper. There are two basic types, fire-tube and water-tube. Fire-tube configurations heat water by passing heated combustion gases through conduit that is submerged in the water. This system generally uses natural gas or oil as the combustion fuel. Water-tube configurations pass water in pipes through the heated combustion gases and can use natural gas, oil, coal, wood, or other biomass. The air needed for combustion can be supplied by either mechanical or natural means. Hot water boilers are generally classified as either low temperature (less than 250°F) or high temperature (250°F to 430°F), and are rated by their maximum working pressure. All boiler systems have the following components in common:

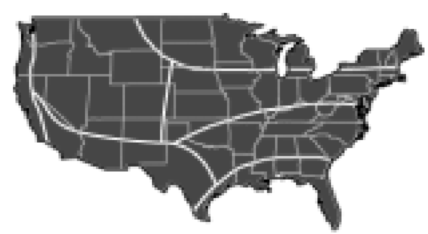
- **Fuel supply:** natural gas, oil, wood, or other biomass.
- **Burner:** The burner injects a fuel-air mixture in the combustion chamber.
- **Combustion chamber:** Location in boiler where combustion occurs.
- **Heat exchange tubes:** Tubes within the boiler that contain water for a water-tube model and combustion gases in a fire-tube unit.
- **Stack:** The stack is the chimney through which combustion gases pass into the atmosphere.
- **Hydronic distribution system:** Supplies feed water to the boiler and distributes hot water to the facility.

Applicability

Applicable in any situation where a significant amount of space heating and/or water heating are required.

This central, high-efficiency boiler supplies hot water to two insulated storage tanks, providing hot water to six baths and a radiant floor heating system. NREL/PIX07925

Applicable Climates



Applicable Spaces

- Classrooms
- Library
- Multi-Purpose
- Gym
- Corridors
- Administration
- Toilets
- Other

When to Consider

- Programming
- Schematic
- Design Dev.
- Contract Docs.
- Construction
- Commissioning
- Operation

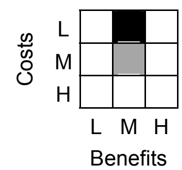
The boiler should comply with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. This includes codes regarding suggested maintenance. Stack placement should adhere to ASHRAE 62 standards. Stack emissions must conform to requirements set forth by the Clean Air Act under jurisdiction of the applicable air quality district. The stack will produce transmit vibration and noise if the stack is not decoupled from the building structure. Ensuring that the stack is isolated from the building structure is particularly important when the stack is close to occupied areas.

Integrated Design Implications

A certain amount of hot service water will always be needed for restroom facilities. Any additional need is dependent upon the choice of space heating system (air or hydronic) and whether or not the building design includes a swimming pool and/or commercial sanitation and food preparation equipment. The actual heating load is dependent upon climate and decisions regarding fenestration, hydronic distribution, building envelope, indoor equipment, and building orientation. The placement of boiler affects requirements of the hydronic distribution system. Try to make these decisions early to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

If a central cooling plant is being considered for the facility, the possibility of using recovered thermal energy should be considered. Using this technique could affect many aspects of design including chiller choice.

Cost Effectiveness



Total installed costs between $35/kBtuh and $52/kBtuh, depending on efficiency. Maintenance costs exists, but they will be less in comparison and can save huge future costs.

Condensing boilers cost from 30% to 60% more than standard units up to 500 kBtu/hr. Incremental costs for more efficient boilers range from $\$0.23/\text{ft}^2$ to $\$0.35/\text{ft}^2$depending on climate. The more efficient boilers realize a simple payback period of 5 to 10 years.

Benefits

- Longer life span than standard storage water heaters.
- Can be more efficient than a furnace, but not always.
- Gas boilers burn significantly cleaner than oil-, coal-, and wood-fired units.

Design Tools

The use of boilers with various efficiencies can be modeled using DOE-2 and VisualDOE.

Design Details

- Large systems between 75% and 85% efficient.
- New condensing gas-fired boilers are up to 96% efficient.

Boiler Energy saving add-ons:

- Economizers preheat feed water with energy from stack gases before it goes to the boiler.
- Air preheaters preheat the air that is mixed with the fuel for combustion leaving more energy to heat the water.
- Turbulators increase the convective heat transfer rates in fire-tube boilers by inducing higher levels of turbulence.
- Oxygen trim controls measure and adjust oxygen levels in the inlet air before combustion.
- Boiler reset controls automatically change the high-limit set point based on changes in outdoor temperatures.
- Since boilers are generally most efficient at their rated capacity it is better to have several smaller boilers rather than one large unit that is rarely used at its most efficient setting.

- Condensing boilers produce acidic condensate that is corrosive to some materials such as steel or iron. Make sure to account for proper condensate drainage and follow manufacturers specifications for exhaust flue design if specifying a condensing boiler.
- Refer to 1995 ASHRAE Handbook Chapter 43 for recommended boiler vibration isolation.

Operation and Maintenance Issues

Performing basic operating and maintenance practices on boilers is very important. Regular inspection of boiler system components ensures safe and efficient operation. Proper maintenance can lead to energy savings of 10% to 20%, reduce harmful emissions, and increase the lifespan of the system.

High efficiency boilers (<90% efficiency) need meticulous maintenance to keep them working correctly.

Fire-side maintenance:

- Minimize excess combustion air and monitor stack gas O_2 and CO_2 to ensure proper percentages. Too little air can cause increased CO and particulate emission, while too much can lower efficiency.
- Clean heat transfer surfaces.

Water-side maintenance:

- Perform regular 'blow downs" to reduce the level of total dissolved solids (TDS) in the system. High TDS levels cause pipe fouling that reduces the heat transfer rate and increases the pressure drop.
- Insulate boiler walls and piping.

Commissioning

Commissioning should be performed to ensure proper installation and operation. It is particularly important to properly train maintenance operators. The safety and efficiency of a boiler system is highly dependent upon the duties performed by boiler personnel.

References/Additional Information

American Society of Mechanical Engineers. *Boiler and Pressure Vessel Codes.* New York: ASME, 1998.

GUIDELINE MV24: ADJUSTABLE THERMOSTATS

Recommendation

Specify thermostats or temperature sensors that will allow classroom teachers control over comfort conditions in their classroom including temperature (within limits) and noise.

Description

Teachers find it helpful to have control over conditions in their classrooms because different conditions may be appropriate at different times. For example, cooler temperatures may be appropriate after recess or for a more active group. It may be appropriate to turn off mechanical ventilation for certain activities requiring acute hearing or when windows are open. Where an energy management system is not used for temperature control, programmable thermostats can allow implementation of energy-saving and comfort-enhancing measures, but only if programmed and maintained properly. Care should be taken to select a model that is very easy to program. Otherwise, it is likely to be overridden or set for continuous operation.

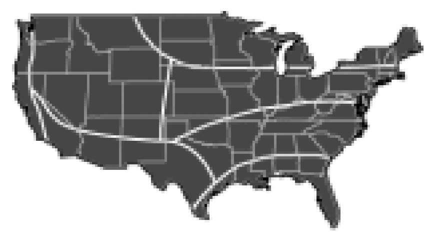
Cost Effectiveness

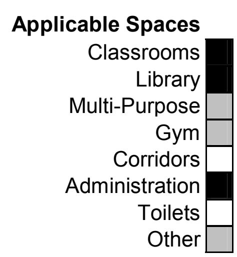
$50 to $200 premium for programmable thermostat.

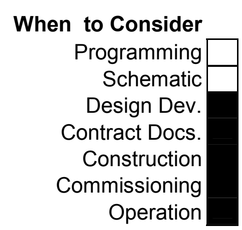
Programmable thermostats are highly cost effective. For a relatively small incremental increase over conventional thermostats, a carefully selected and programmed model will provide teachers with control over their classroom environment while combining time-of-day and override functions. DDC system sensors with adjustable set point have a greater incremental cost impact over plain sensors, but the benefits of giving teachers control should not be underestimated.

Adjustable thermostats allow the user to have control over the conditions of the room, which can improve overall comfort and create a better learning environment. NREL/PIX04899

Applicable Climates

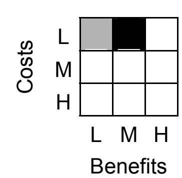






Benefits

Improved comfort and sense of control may foster a better attitude and teaching environment. Some energy savings may be realized due to stopping mechanical ventilation when windows are open. Service requests may be reduced compared to situations where teachers must request a set point change from operations and maintenance personnel. Programmable thermostats replace time clocks, eliminating associated first and maintenance costs.



Design Tools

None.

Design Details

- Specify programmable thermostats for control, adjustment, time clock, and override functions when no DDC system will be used for temperature control.

- Sensors with set point control and fan/unit on-off control should be specified for temperature control of classrooms using a DDC system. Also specify limits within which the set point may be varied and the time period after which an overridden value or state will revert to the standard “automatic” (default) value or state.
- If it is necessary to have thermostat covers that lock, provide a means for faculty access.
- Place the thermostat on an interior wall in a location out of direct sun and away from heat sources such as copiers or computers. A point close to the return air or exhaust air inlet is often a good choice.

Operation and Maintenance Issues

Faculty may require repeated training on programmable thermostat operation. Unlike DDC system temperature sensors with adjustable set point, which can be programmed to revert to standard operation after a specified period, programmable thermostats may allow the HVAC system to be switched off, rather than overridden. This can defeat morning warm-up, resulting in comfort problems and complaints. Specify that simplified one-page instructions be provided by the installing contractor and kept on file at school office with copies distributed to teachers for adjustable sensors or programmable thermostats. Programmable thermostats may require periodic replacement of back-up battery.

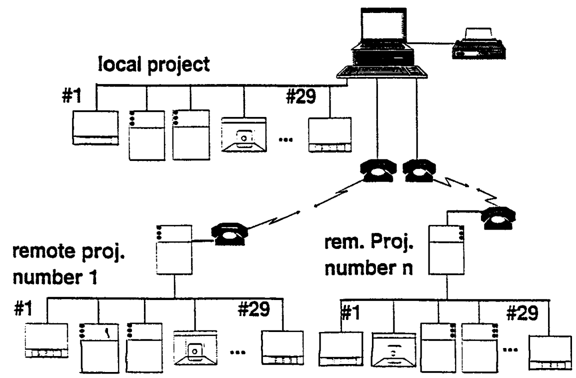
Commissioning

Proper functioning of any thermostat or temperature sensor must be verified prior to acceptance of the installation. Programmable thermostats and temperature sensors with adjustable set points necessitate a slightly more involved verification procedure.

References/Additional Information

None.

GUIDELINE MV25: EMS/DDC



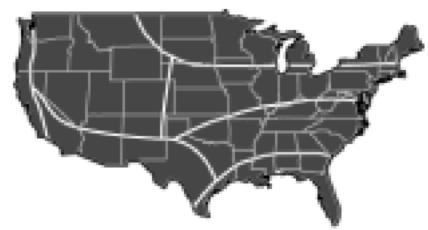
Recommendation

Use a graphic-interfaced, DDC system to integrate multiple components of HVAC and other building systems and manage them from a single (local and/or remote) location.

Description

Automatic control of multiple pieces of HVAC equipment and other systems may be integrated using computerized systems known variously as DDC, energy management systems (EMS), energy management and control systems (EMCS), building management systems (BMS), or building automation systems (BAS). The added expense and complexity may be justified by the equipment optimization and increased convenience of maintenance possible with such a system.

Applicable Climates



Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

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DDC systems generally perform three functions: equipment on/off control, space temperature control, and equipment status monitoring. A single system can control lighting, security, central plant equipment, and space conditioning equipment. Systems may be specified to allow local override and temperature adjustment at selected space temperature sensors. Graphical user interfaces may be custom configured with different levels of access to allow limited adjustment of schedules and other system parameters by various personnel. While a DDC system will permit the implementation of energy- and cost-saving measures not otherwise possible, the advantages will only be realized if the system is initially programmed correctly and checked periodically by adequately trained personnel.

DDC systems consist of individual controllers that communicate with one another over a network linked by two-conductor cable or other means. Each controller is wired directly to relays, valve and damper motors, and temperature sensors to control and monitor specific equipment. Controllers generally require line voltage power to control panels containing one or more controllers. All other wiring is generally low voltage. The systems may connect directly, via a local-area network (LAN) or modem to a desktop or laptop computer for monitoring and adjustment. A “user-friendly” graphical interface is desired. Systems may be programmed to retain and plot temperature and other status data for performance analysis over limited periods, but retention of historical data requires optional software and additional storage media.

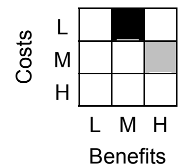
Applicability

DDC systems may not be appropriate for small schools with very simple HVAC systems. Their applicability increases with the size of the facility, the complexity of the HVAC system, and the size of the district.

Integrated Design Implications

Coordination between mechanical and electrical consultants is necessary for supplying power to a DDC system. If the system is to integrate control of lighting and other building systems, significantly greater coordination will be required. It may also be desirable to have the DDC system use the building (or district-wide, if available) LAN for communications between controllers and with users. These decisions must be made early in the design phase to allow for coordination throughout the design.

Cost Effectiveness



\$0.50//ft^2 to \$1.50/ft^2. \$300 to \$500 per input or output "point." Special operation and maintenance training is required to operate, maintain, and troubleshoot DDC systems. Periodic recalibration of sensors may be required for precise control. Software upgrades are periodically required, and life expectancy of major system components may be as low as 8 to 10 years due to the rapid pace of computer technology development.

Cost effectiveness can be very high, with simple paybacks commonly estimated at 4 to 15 years. However, benefits will only be realized when certain conditions are met: the system must be programmed carefully, checked out thoroughly, and maintained actively. If operation and maintenance personnel are not comfortable with the system, it is likely to be bypassed, so good training is critical. Many school districts find that the greatest benefit of a DDC system is as a maintenance tool, allowing remote adjustment and troubleshooting of equipment.

Benefits

Energy savings may be realized from a DDC system that is correctly installed and actively maintained. Additionally, comfort conditions may be more easily and consistently attainable, and improvements can be made in operation and maintenance resource utilization, through the use of the DDC system for fine tuning, analysis, and trouble shooting.

Peak electric demand savings are possible through load management controls. A DDC system can be programmed to shutoff or reduce power to specific loads during times of high peak demand charges. The savings can be significant, especially if implemented throughout a district.

Comfort improvements and energy savings may be achieved through such features as adaptive optimum start programs that learn when to start morning warm-up to achieve comfort at occupancy time for different operating conditions such as Monday mornings (when the building may have cooled off more than on other mornings).

DDC systems can also offer remote monitoring of system status from a central office and help reduce time spent on maintenance and trouble calls.

DDC systems have the added benefit of eliminating the air compressors required for pneumatic control systems, together with associated maintenance costs, failures, etc.

Design Tools

Control system manufacturers and their representatives are usually eager to assist with the design process (or take it over, if possible). This resource should be used with care, so as to not overlook the design engineer's responsibility to specify a well-engineered system. Close attention to the development of operation sequence is always worthwhile. Software is available, both commercially and from control manufacturers, to chart sequences of operation in block diagrams or flow charts.

Design Details

- Keep controls as simple as possible for a particular function. They will generally be operated (or bypassed) to the lowest level of understanding of any of the operation and maintenance personnel responsible for the HVAC system.
- Rooftop units are often available with optional factory-installed control modules that will interface with the DDC system as an independent "node," allowing a high level of monitoring and control.

- Discharge air temperature sensors are necessary for troubleshooting, even if not required for control.
- Specify temperature sensors with adjustable set point to give teachers control.
- Specify training. Because operation and maintenance personnel will “inherit” the system, and its performance will ultimately depend on them, involve them as much as possible in design decisions.
- Specify at least a one-year warranty, including all programming changes.
- By specifying the configuration of specific data trend logs (not just the capability to collect them) and their submittal for review and approval at system completion, some system commissioning may be accomplished by the design engineer and/or other owner’s representatives.
- Specify all software necessary for efficient system operation by operation and maintenance personnel to be provided as part of the system installation.
- Local DDC contractors will usually be willing to provide design assistance or even a “complete” design package. Great care should be taken in such collaboration, for it is unlikely that thorough engineering will be applied to the design. The control system should be carefully specified by the design engineer, and details left up to the installing contractor only after careful consideration.
- Control algorithms that may be specified to increase energy efficiency include: optimal start time calculation based on learned building behavior; operation of central equipment based on zone demand, including supply temperature or pressure reset; night purge ventilation to cool building interiors with cool nighttime air in hot climates; heating and cooling system lockouts based on current or predicted outside air temperature; or heating and cooling lockout when windows or doors are opened for natural ventilation (using security system sensor switches).
- Automatic alternation of redundant and lead/lag equipment based on runtime should be accomplished by the DDC system, with provision for operator override.

Operation and Maintenance Issues

Calibrating critical points is required annually or semi-annually. Alternating redundant or lead/lag equipment for even wear may be triggered automatically or manually. Operation and maintenance requires special training, particularly in the case of software, and consistency with existing systems may be desirable. Permanent software changes should be carefully limited. Periodic checkout is necessary.

Commissioning

Careful commissioning is critical for the success of DDC system installations, and proper control operation is necessary for proper equipment operation. Since DDC software may be somewhat esoteric, lack of commissioning may mean that this important aspect of the contractor’s work may never be inspected and may never be finished to the desired level. Therefore, it is a very good idea to provide for some commissioning of the control system by an independent party or organization representing the owner’s interests. Submittal and review of contractor’s input and output point verification test documentation should be required. Field calibration of any temperature sensors that must be accurate for proper control is necessary. (Factory calibration is adequate only for non-critical sensors, such as room temperatures with adjustable set points.) One minimal but effective commissioning method is to specify submittal of trend data logs, showing system operation in specified modes, for review by the design engineer. User interfaces including graphics (when specified) should also be reviewed.

References/Additional Information

None.

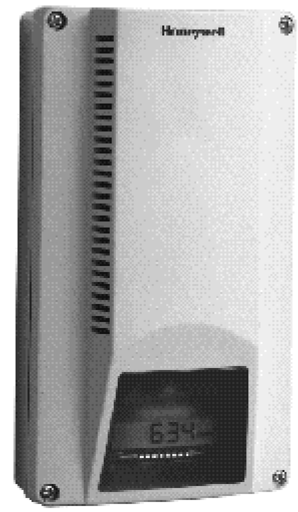
GUIDELINE MV26: DEMAND CONTROLLED VENTILATION

Recommendation

Specify controls to adjust ventilation rate for spaces with varying occupancy to prevent unnecessary cooling or heating of large quantities of outside air, and insure that adequate ventilation *is* provided when needed.

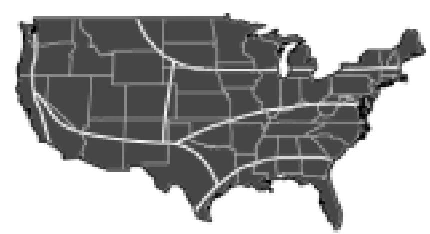
Description

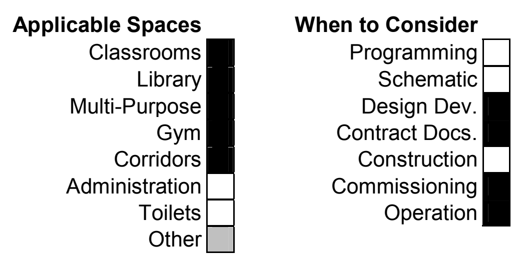
Many spaces in schools require high ventilation rates due to dense “design” occupancy, but experience this occupancy level sporadically or occasionally. The outdoor air required may represent a very large heating or cooling load, depending on the season and climate. Therefore, reducing the amount of ventilation during those times the space is partly occupied or unoccupied may save substantial amounts of energy and wear on equipment, but temperature needs to be maintained. This may be accomplished using occupancy sensors or air quality (CO_2 concentration) sensors to control the quantity of ventilation air. This may be done either in conjunction with a DDC system or by independent controls.



CO_2 sensors help indicate building occupancy levels, allowing for better control of the quantity of ventilation air needed. NREL/PIX 11425

Applicable Climates





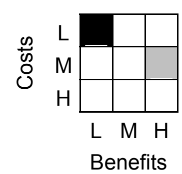
Applicability

For variable air volume, variable airflow with constant volume, multi-zone or small packaged unit zones, occupancy sensors may be applied but must be enabled/disabled to meet any pre-occupancy ventilation requirements. For larger intermittently occupied spaces such as multi-purpose rooms, auditoriums, cafeterias, and gyms, the energy savings may justify the added first cost, maintenance cost, and complexity of a CO_2-sensing system that modulates the outside air quantity down from the design level when interior air CO_2 levels indicate partial occupancy.

Cost Effectiveness

Each CO_2 sensor costs approximately $400.
Installation, testing, and adjustment ranges from $500 to $1,500 per system. A hand-held CO_2 sensor for calibration costs $500.

Generally, cost effectiveness for occupancy sensor-based controls will be very high for larger systems. For CO_2 sensor-based control, it will depend on the climate being “severe” enough, and the required ventilation rate being large enough, so that the heating and cooling load reduction saves enough energy costs to offset the first cost of the CO_2 sensing equipment.



Benefits

- Reduced energy consumption.
- Reduced wear on equipment.
- Confirmed/documented interior air quality.

Design Tools

None.

Design Details

- Demand-controlled ventilation responds to human occupancy only. Other sources of internal pollutants must be addressed with per-area baseline ventilation, targeted ventilation, etc. This should be considered very carefully before applying this type of control, especially to classrooms, where various odor sources may be used. Demand-controlled ventilation always results in worse interior air quality than a properly adjusted system constantly delivering ventilation for rated occupancy.
- CO_2 sensor-based ventilation control uses the measured CO_2 level as an indicator of the current occupancy level, so the ventilation rate may be adjusted accordingly. This is an important difference from using the CO_2 sensor as a direct indication of air quality.
- In areas where outdoor air CO_2 concentration is relatively constant, ventilation may be controlled by a single return air sensor to maintain a fixed CO_2 limit. Otherwise, outdoor and return air sensors should be used.
- The setpoint must be calculated based on occupancy and activity level. For example, the CO_2 concentration for an office space designed at 15 cfm per person (sedentary adult) can be calculated at 700 ppm above ambient.

Operation and Maintenance Issues

Calibration is required.

Commissioning

Review system operation under varying occupancy. Correlate with balance report data for minimum and maximum outdoor air damper positions. Verify acceptable levels of CO_2 concentration in space when occupied using hand-held sensor. Perform all testing in non-economizer mode.

References/Additional Information

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Journal*, April 1997. Interpretation of ventilation standard IC-62-1989-27.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 62-99*.

GUIDELINE MV27: CO SENSORS FOR GARAGE EXHAUST FANS

Recommendation

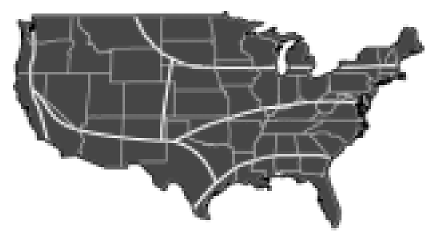
Use carbon monoxide (CO) sensors to prevent parking garage exhaust fans operating when they are not needed.

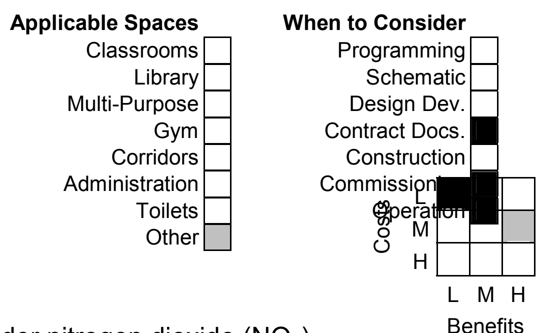
Description

Parking garage ventilation is often provided by an exhaust fan operated during normal occupancy hours. However, the high ventilation rate required when traffic is present need not be maintained most of the time, when no vehicles are operating. Substantial energy savings may be realized by limiting fan operation to only those periods during normal occupancy when CO concentration in the garage rises above acceptable levels. CO concentration-sensor technology has advanced substantially in recent years, reducing cost and improving reliability.

Control strategies, like CO sensors, help reduce energy loads by preventing equipment from operating when not necessary. NREL/PIX 11332

Applicable Climates





Applicability

School buildings with enclosed parking garages requiring mechanical ventilation.

Cost Effectiveness

$0.20/ft^2 to $0.40/ft^2 of garage. $1,000 to $2,000 per sensor installation.

Benefits

Benefits include energy savings, wear reduction, and noise reduction.

Design Tools

None.

Design Details

- Diesel exhaust does not contain high levels of CO. Consider nitrogen dioxide (NO_2) sensors if substantial traffic or idling of diesel vehicles is anticipated.
- Include time-of-day control in addition to CO concentration control.
- Sensor coverage area is limited, so multiple sensors may be required.
- Specify calibration tools provided to operation and maintenance personnel at time of training.

Operation and Maintenance Issues

- Annual calibration of sensors is required.

Commissioning

- Verify threshold adjustment and function. Also verify training of operation and maintenance personnel, including calibration.

References/Additional Information

None.

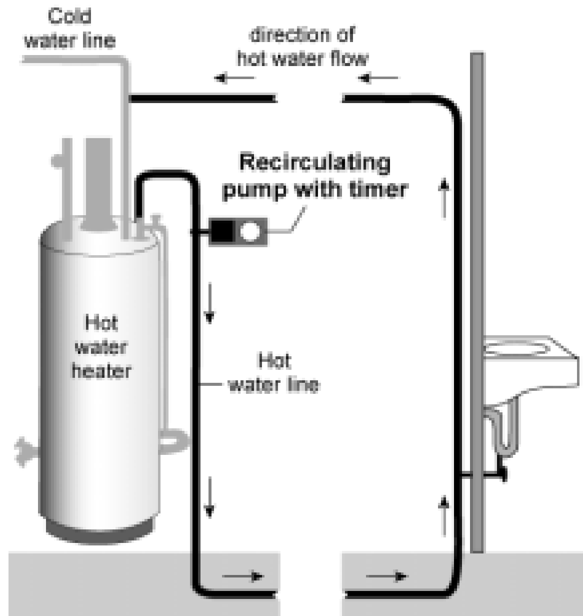
GUIDELINE MV28: TIMERS FOR RECIRCULATING HOT WATER SYSTEMS

Recommendation

Use recirculation timers to control circulation of hot water based on demand. Use separate hot water systems for areas with significantly different demand patterns.

Description

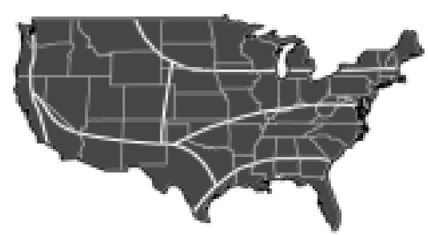
Recirculating hot water systems connect to the hot water pipe and constantly circulate hot water through the pipes, from the heater to the furthest fixture and then back to the heater, making warm water immediately available upon turning the tap. Large facilities use recirculating hot water systems, which result in heat losses through the distribution piping. Installing timers ensures that hot water circulates only during times of need, which greatly reduces the heat loss through the distribution piping as well as the daily pumping load.



Applicability

Timers are applicable for large facilities where hot water is recirculated. Timers will work effectively only when the hot water demand for a facility can be predicted accurately, as in the case of classrooms and school administrative areas.

Applicable Climates



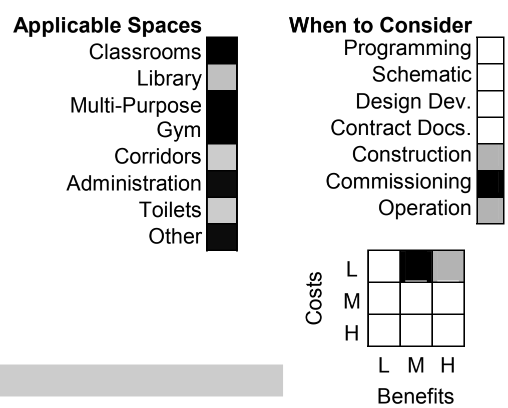
Cost Effectiveness

Timers are very cost effective and have a two- to five-year payback period.

Prices for recirculating system timers range between $40 and $50.

Benefits

Timers greatly reduce heat losses through distribution piping. Daily pumping loads are also reduced considerably.



Design Tools

None.

Design Details

Most schools are ideal candidates for using timers because of the predictability of classroom schedules. Set the system to operate only between classes, just before and after the school day, and during lunch periods.

Administrative areas, locker rooms, and other areas may have a demand schedule different from that of the classroom facility. Separate hot water systems or gas-powered, instantaneous water heaters can be used to accommodate these areas. Avoid using timers for areas with random and intermittent schedules.

Consider using thermostats connected in series with the timers. The thermostat turns off the pump when the water in the pipes reaches a certain temperature. Once the water in the pipe is hot, the pump turns off. If the timer and thermostatic controls are installed together in series, the circulator operates only at the preset clock times and only when the temperature conditions of the thermostat are met. That is, if either the timer control or the thermostatic control switch is open (off), the circulator will not operate, which results in additional savings.

Operation and Maintenance Issues

- Adjust the initial timer schedule based on observed or monitored demand data. Schedules may vary from school to school, and it is important to fine-tune the timer settings based on specific demand patterns.
- Check the hot water supply every six months to ensure that the timer is functioning as expected.
- Always set the timer switch to the actual time by turning the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.
- In a power outage, the timer will not keep time. After power has been restored, the correct time of day must be reset by rotating the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.

Commissioning

If installing a thermostat along with the timer, ensure that the two devices are installed in series.

After wiring is completed and checked, install the timer control unit onto the terminal box bracket of the pump and reinsert the terminal box screw. Be careful not to bind or leave any terminal box wires exposed.

References/Additional Information

http://www.eren.doe.gov/buildings/consumer_information/water/waterques.html#13.

RENEWABLE ENERGY SYSTEMS

This chapter provides guidelines for:

OVERVIEW

This chapter presents guidelines for using renewable energy systems for part of a school's required energy load. As demand on fossil fuel reserves and existing electricity grids increases, a growing number states are facing energy shortages and skyrocketing utility costs. The problem will continue to worsen as the nation's energy needs are expected to grow by 33% during the next 20 years.[1] Renewable energy can help fill the gap. Renewable energy sources not only release less pollutants into the environment than traditional energy sources, but they save school districts money in the long term while also serving as valuable teaching tools for students and faculty.

Environmentally Friendly Energy Resources

Renewable energy systems are those that use fuels from renewable resources, including the sun, wind, and the Earth's heat. Renewable energy technologies are often referred to as "clean" or "green" because they produce few, if any, pollutants. Burning fossil fuels, however, sends greenhouse gases into the atmosphere, trapping the sun's heat and contributing to global warming.

Unlike fossil fuels, renewable energy resources are abundant. Every day, more energy falls on the United States than is used in an entire year. The total amount of solar energy per year falling on the conterminous 48 states is 46,700 Quads/year. (A Quad is one quadrillion ($1.0*10^{15}$) British thermal units (Btus). Compare this to 94.2 Quad/year, the U.S. energy consumption rate in 1997.[2]

Wind power is an increasingly common renewable energy source. Good wind areas, which cover 6% of the contiguous U.S. land area, could supply more than 1.5 times the 1993 electricity consumption of the entire country. California now has the largest number of installed turbines. Many turbines are also being installed across the Great Plains, reaching from Montana east to Minnesota and south through

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[1] http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

[2] Ibid.

Texas, to take advantage of its vast wind resource. North Dakota alone has enough wind to supply 36% of the total 1990 electricity consumption of the lower 48 states. Hawaii, Iowa, Minnesota, Oregon, Texas, Washington, Wisconsin, and Wyoming are among states where wind energy use is rapidly increasing.[3]

Geothermal power may be one of the lesser known renewable energy sources, but more than 500 schools nationwide have installed geothermal heat pump systems to provide their heating and cooling needs.[4]

Cost-Efficiency

Over the past two decades, the cost of renewable energy systems has dropped dramatically. Improvements in analytical tools are making passive solar technologies cost effective as well; they can be implemented into schools with less than a two-year return on investment. Wind turbines can produce electricity at less than $0.04/kWh — a seven-fold reduction in energy cost. Concentrating solar thermal technologies and photovoltaics have dropped more than three-fold during the last 20 years. GSHPs can have a 20% to 50% energy cost savings over traditional heating and cooling systems.[5]

By reducing its dependency on traditional electricity sources, the school will not only save in utility costs, but faces less risk of losing valuable teaching time due to rolling blackouts and power outages.

Renewable Energy as a Teaching Tool

In addition to providing economic and environmental benefits, these renewable energy systems are an important "living laboratory" to teach students about energy technologies of the future. Input from teachers early in the design process ensures that energy features are incorporated in a way that optimizes the learning experience. Buildings that teach offer students an intriguing, interactive way to learn about relevant topics like renewable energy sources.

Resources

The Center for Energy Efficiency and Renewable Technologies. http://www.cleanpower.org/index.html

The Renewable Resource Data Center. http://www.rredc.nrel.gov/.

U.S. Department of Energy's Energy Information Administration. "U.S. Renewable Energy Consumption." *Renewable Energy Annual 2000*. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/chapter1.html.

U.S. Department of Energy's Energy Efficiency and Renewable Energy Network (EREN) "Renewable Energy: An Overview." Consumer Energy Information: Erec Fact Sheets. http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

U.S. Department of Energy's Energy Efficiency and Renewable Energy Network (EREN) "Geothermal Heat Pumps Score High Marks in Schools." Geothermal Energy Program. http://www.eren.doe.gov/geothermal/ghp_schools.html.

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[3] http://www.eren.doe.gov/erec/factsheets/renew_energy.html.

[4] http://www.eren.doe.gov/geothermal/ghp_schools.html.

[5] Ibid.

GUIDELINE RE1: PASSIVE HEATING AND COOLING

Recommendation

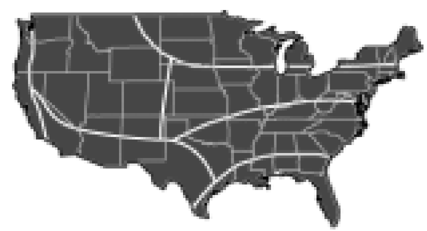
Increase energy efficiency and comfort in school buildings by incorporating passive solar design.

Description

Sunlight can provide heat, light, and shade and induce summertime ventilation into the well-designed school. Passive solar design has been used for centuries, but now designers have access to building materials, methods, and software that can improve the design and integration of solar design principles into modern buildings.

Passive solar features such as additional glazing, added thermal mass, and larger roof overhangs can pay for themselves. NREL/PIX 10684

Applicable Climates



Applicable Spaces	**When to Consider**
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Applicability

Passive solar design strategies vary by building location and regional climate, but the basic techniques remain the same: maximize solar heat gain in the winter and minimize it in summer. For commercial and school buildings, the first priority is to use passive solar design for light.

Reduce the window area on east- and west-facing walls. In northern states such as Montana, also reduce north-facing windows. In most climates, north-facing windows offer good, diffuse light. Daylighting should be mostly achieved through north and south windows. South-facing windows should have a high Solar Heat Gain Coefficient (SHGC) — usually 0.60 or higher — to maximize solar heat gain, a low U-factor (0.35 or less) to minimize thermal loss, and good light transfer. The south windows should also be shaded to avoid summer overheating.

Use more north-facing windows and shade south-facing windows. Shading from overhangs, landscaping, shutters, and solar window screens helps lower heat gain on windows that receive full sun, but window shading design should still maximize daylighting efforts. Cost effective windows for cooling climates have a U-factor below 0.4 and a SHGC below 0.55 (a lower SHGC cuts cooling costs).

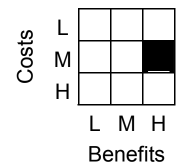
Integrated Design Implications

Passive solar design should be considered using the whole-building approach. Specific techniques include:

- Start by using energy-efficiency design strategies.
- Orient the building with the long axis running east/west.
- Select, orient, and size glass to optimize winter heat gain and minimize summer heat gain for the specific climate. Consider selecting different glazings for different sides of the building (exposures).
- Size south-facing overhangs to shade windows in summer and allow solar gain in winter.

- Direct solar gains may cause problems (hot spots, glare) that will make learning difficult. It may be better to optimize school design for daylighting instead of heating. Trombe walls should be looked at as an alternative to direct solar gains.
- Add thermal mass in walls or floors for heat storage.
- Use natural ventilation to reduce or eliminate cooling needs.
- Use daylighting to provide natural lighting.

Cost Effectiveness



Passive solar features such as additional glazing, added thermal mass, and larger roof overhangs, or other shading features can pay for themselves. Passive solar design often means less heating and cooling requirements; therefore savings can accrue from reduced HVAC unit size, installation, operation, and maintenance costs. Passive solar design techniques often require higher first costs but are less expensive over the life-cycle costs of the building.

Benefits

Passive solar design can reduce heating and cooling energy bills, increase spatial vitality, and increase comfort.

Design Tools

One of the best ways to design an energy-efficient building incorporating passive solar design techniques is to use a software simulation program. The U.S. Department of Energy sponsors a variety of appropriate software tools including its latest, EnergyPlus. Another tool, Energy-10 is a PC-based design tool that helps identify the best combination of energy-efficiency strategies including daylighting, passive solar heating, and high-efficiency mechanical systems. Another tool to optimize window size and aid in window selection is RESFEN.

Design Details

Passive solar design integrates several building features to reduce or eliminate the need for mechanical heating and cooling and artificial daylighting. Designers and engineers need to pay particular attention to the sun to reap passive heating, cooling, and daylighting benefits. The design does not need to be complex, but it requires knowledge of solar geometry, window technology, and local climate. Given the proper building site, virtually any architecture can incorporate passive solar design.

Passive solar heating techniques generally fall into one of three categories: direct gain, indirect gain, and isolated gain. *Direct gain* is solar radiation that directly penetrates and is stored in the building space. *Indirect gain* collects, stores, and distributes solar radiation using some storage material (e.g., Trombe wall). Conduction, radiation, or convection then transfers the energy indoors. *Isolated gain* systems (e.g., hallways and atriums) collect solar radiation in an area that can be selectively closed off or exposed to the rest of the building.

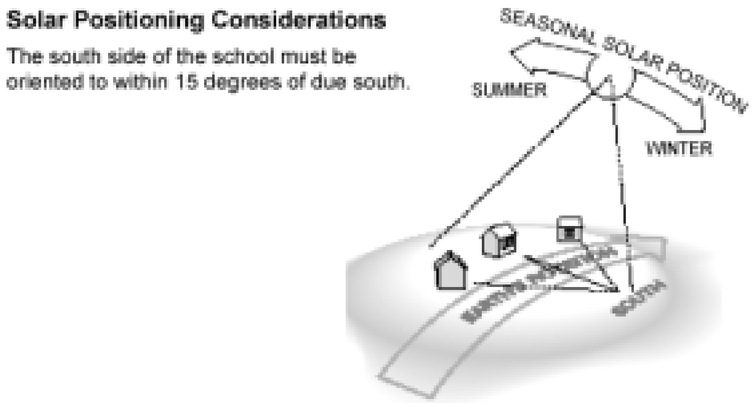


Figure 1 – Solar Positioning Considerations

For passive cooling, consider operable windows to provide an opportunity for natural ventilation in milder temperature months when interior loads on buildings exceed exterior temperatures. Night purging, letting cooler air into the building at night, can reduce HVAC startup loads the next morning. It is also necessary to optimize the building overhangs to reduce the cooling loads that result from unwanted solar gain.

Operation and Maintenance Issues

Passive solar design offers many benefits with minimal maintenance risks over the life of the building.

Commissioning

None.

U.S. Department of Energy-sponsored energy software tools including EnergyPlus, Energy-10, and RESFEN are available at http://www.eren.doe.gov/buildings/energy_tools.

Energy Efficiency and Renewable Energy Clearinghouse (EREC) 1-800-DOE-3732 or http://www.eren.doe.gov/.

Sustainable Buildings Industry Council, http://www.sbic.org/.

Efficient Window Collaborative website, http://www.efficientwindows.org/.

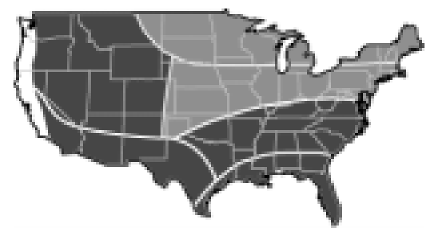
GUIDELINE RE2: SOLAR THERMAL HOT WATER SYSTEMS

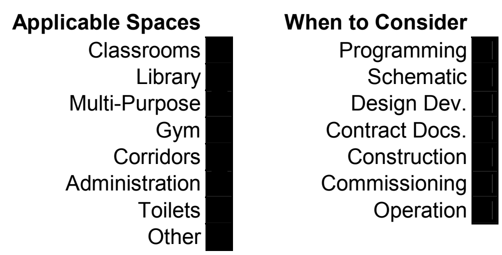
Recommendation

If conditions permit, augment high-efficiency, gas-fired boilers used for space heating and domestic hot water with a solar thermal system and/or recovered thermal energy.

Solar thermal hot water systems are applicable to any situation where a significant amount of space heating and/or water heating are required. NREL/PIX05183

Applicable Climates





Description

A solar thermal system can be either direct or indirect and classified as either active or passive. A direct system heats water directly in solar collectors. An indirect system uses a working fluid (usually a glycol-water mixture) in conjunction with a heat exchanger to increase the water temperature. Direct systems contain fewer elements and are less expensive, but they are prone to freezing and cannot be used in all climate zones without drain-back systems. Indirect systems use an antifreeze mixture and can be used in any climate zone. Active and passive refers to the method by which fluid reaches the collector. If the fluid moves through natural convection, the system is termed passive, and if pumps are used, it is active. Solar thermal systems consist of the following elements:

- **Solar radiation collector:** Collects solar radiation for heating.
- **Heat exchanger:** A heat exchanger is used in an indirect system to pass heat from the working fluid to the water supply.
- **Hydronic distribution system:** Supplies water to the collector for direct systems and to the facility for both direct and indirect systems.
- **Storage tank:** Stores heated water for facility use or for boiler feed water supply.

Applicability

Applicable in any situation where a significant amount of space heating and/or water heating are required. A solar thermal water heating system has the potential to be the main hot water source in some situations. For example, an elementary school in the desert could easily meet most of its hot water needs through solar energy utilization. In most areas it could at least augment the boiler system.

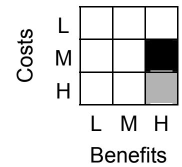
Integrated Design Implications

A radiant slab heating system works extremely well with solar thermal water heating. Solar thermal systems can generally achieve the low inlet temperatures (90°F to 120°F) required by a radiant slab system.

Because the performance of a solar thermal system is dependent upon the weather, it works best when used in conjunction with another heating system. Depending upon the situation, the solar system can be the primary heat source or can be used to augment and increase the efficiency of a boiler system. The increased efficiency is accomplished by preheating boiler feed water with solar thermal energy.

The use of a solar thermal system must be addressed early in the planning stages, as its viability is highly dependent upon available roof space and building orientation. It is also important to plan the placement of any other roof systems to avoid shading by packaged HVAC systems, stacks, walls, etc.

Cost Effectiveness



Initial costs are higher than that for a boiler system. Most systems cost between $30/ft^2 and $90/ft^2 of collector area. Maintenance costs are low and fuel expenses are zero.

The initial cost for solar thermal systems is somewhat more than boilers. However, the fuel is free and thus the system will eventually pay for itself. For a slab system, it may be the more cost-effective option since it is heating to its maximum while a boiler would need to be run at a lower, less efficient setting. The cost effectiveness of a solar system varies from site to site, as the payback period is dependent upon climate and available solar radiation. Solar thermal systems will be most cost effective in schools with substantial summer occupancy as this is the time of greatest available solar radiation.

Benefits

- Free fuel.
- No worry about changing fuel prices.
- Non-polluting. No fumes means healthier for students and teachers. No operational greenhouse gas emissions
- Great for teaching. The system itself can be a topic in science classes.

Design Tools

- The Transient System Simulation Program (TRNSYS), developed by the University of Wisconsin-Madison Solar Energy Laboratory is capable of modeling entire solar water heating systems.
- The National Renewable Energy Laboratory has extensive data regarding annual totals of solar radiation for different cities.
- *Solar Engineering of Thermal Processes* by John Duffie and William Beckman is a great resource for solar energy applications.

Design Details

System requires a differential thermostat to ensure heat is not being dumped to the collectors. The most important element of a solar thermal system is the solar collector. Solar collectors can be either fixed or track the sun. The latter is generally more expensive and is saved for high-temperature applications. Fixed collectors should be oriented facing south and tilted based on seasonal load. A good rule of thumb is to use the location's latitude as the tilt angle with respect to the horizontal.

- Flat-plate collectors consist of a metal frame box containing a layer of edge and backing insulation, an absorber plate with parallel piping, and glazing. The absorber plate is generally constructed of copper or aluminum with a high-absorbance coating. The glazing layer reduces convective and radiation heat loss and involves one or more sheets of glass. Solar thermal systems with flat-plate collectors are very common.
- Integral Collector Storage (ICS) systems use the storage tanks themselves as solar collectors. The tanks are painted black and are set on the roof alone or in insulating boxes with transparent covers angled south. ICS systems are applicable only in mild climates, as freezing and significant heat loss become issues in colder regions. This system is very simple and cost-effective.

- The evacuated tube collector is a long, thin version of a flat-plate collector where the box has been replaced by a glass tube and the insulation by a vacuum. These collectors are extremely efficient but are fragile and expensive.
- Concentrating collectors use a curved surface to reflect and concentrate the solar radiation onto a pipe containing fluid. These collectors are generally used for high-temperature applications and almost always configured to track the movement of the sun.

Operation and Maintenance Issues

- Collector glass should be cleaned regularly to ensure maximum efficiency.
- Direct systems must be drained when freezing conditions exist.
- Roof-integrated systems should be designed to allow easy removal when roof replacement is required.

Commissioning

Commissioning is important for solar thermal systems because the general contractor may not be familiar with them. Solar systems must be considered whenever rooftop decisions are made. The efficiency of the system is wholly dependent upon collector orientation and minimizing shading. It is important to have a solar expert on hand whenever the system is being considered, even for such things as storing collectors before installation. (Some collectors can be damaged if stored in the sun without fluid passing through them.)

References/Additional Information

ASHRAE Handbook: HVAC Applications, 2000.

ASHRAE Handbook: HVAC System and Equipment, 2000.

Beckman, J.A. and Beckman, W.A. *Solar Engineering of Thermal Processes.* New York: Wiley-Interscience, 1991.

Energy Efficiency and Renewable Energy Network. http://www.eren.doe.gov/.

Federal Energy Management Program. http://www.eren.doe.gov/femp/.

Solar Engineering Laboratory. University of Wisconsin-Madison, 1500 Engineering Drive, Madison, WI 53706. Phone: (608) 263-1589. Fax: (608) 262-8464. Email: trnsys@sel.me.wisc.edu. Web site: http://www.sel.me.wisc.edu/trnsys.

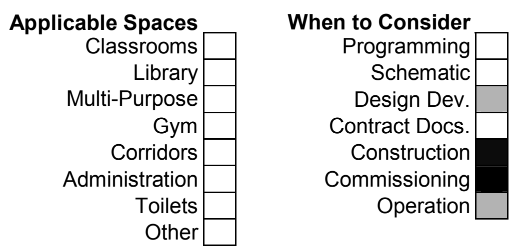
GUIDELINE RE3: SOLAR POOL HEATING

Recommendation

Use solar heaters for swimming pools as an environmentally friendly and cost-effective solution to pool heating requirements.

A solar heating system requires very little or no maintenance since it has no burners or moving parts. NREL/PIX08590

Applicable Climates



Description

Most solar pool heating systems consist of three basic components: a collector, a pump, and a controller. Unlike domestic solar water heating systems, which raise a small amount of water to a high temperature of about 140°F, pool heaters raise the temperature of several thousand gallons of water to about 80°F by circulating the water at a relatively fast rate through the collectors. This circulation allows most of the solar energy falling on the collectors to transfer to the pool water.

The collector consists of a large area of pipes that absorb solar energy in the form of heat. They are made from plastic or rubber compounds that can withstand continuous exposure to sunlight. The collector is positioned for maximum access to sunlight. The pump circulates water through the collector to continually absorb heat. The hot water is then pumped back into the pool. This pump may be separate (especially in retrofit situations) from the regular pool pump that circulates pool water through a filter. The pump is automatically switched off when the temperatures of the water in the pool and the collector approach each other. The controller regulates the flow of water within the collector based on the temperature of the outgoing water using a diverting valve, the only moving part in a solar pool heating system. This valve controls whether or not the water circulates through the collector loop. When the collector temperature is sufficiently greater than the pool temperature, the water is diverted from the filter systems through the collector loop. The water bypasses the solar collectors during nighttime or cloudy periods. Some smaller systems are operated manually or with timers, but larger systems may be operated through electronic sensors.

Strip, panel, and tube systems are the three major types of solar collectors available. All three perform to a more or less equal standard, although strip systems are the most commonly used type.

Applicability

Solar heating for swimming pools is feasible for all climate types, even those that experience sub-freezing temperatures. Waterways on strip systems can expand to accommodate the increased volume of frozen water.

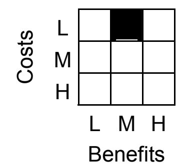
Most sloping roofs can be fitted with solar collectors. Relatively lightweight strip systems are suitable for sloping roofs. Strip collectors can be fitted to follow the roof contours and can be curved around obstructions, such as chimneys and skylights. Panel collectors are limited by their rigid sheet design and can be applied to flat or plane roofs only.

Integrated Design Implications

Although solar heated swimming pools can easily be accommodated later in the design or construction phases, the following issues should be considered beforehand:

- **Building aesthetics.** Installing solar collectors on rooftops may conflict with building aesthetics. Consider placement and orientation of the collectors early in the design phase to avoid this conflict.
- **Space availability.** Solar collectors may occupy an area equivalent to 75% of the pool's surface area. This roof area must be available near the location of the swimming pool for unobstructed access to sunlight (although it's possible to mount the collectors at ground level).

Cost Effectiveness



Collectors made of copper are more expensive than those made of plastic, although they last longer. Plastic collectors are less conductive than copper, but are inert to chemicals and have about a 10-year lifespan. On an average, solar heating systems for pools cost around $7.50/ft^2 to $10/ft^2 (installed). An unglazed solar heating system for an average 600-ft^2 pool, including separate pump and automatic controller, costs around $4,500 fully installed. The operating energy is practically free, as all the heating energy is solar.

Pool covers for an average size 600 ft^2-pool costs around $400 to $500 (not including the roller, which has a starting cost of around $300). Using the above figures for the cost of running a gas heater, heating the pool with solar energy can save from 3.8 tons to 5.1 tons of greenhouse gas emissions (CO_2) per year.

Benefits

- Since solar pool heating collectors operate just slightly above the ambient air temperature (80°F), such systems typically use inexpensive, unglazed, low-temperature collectors made from especially formulated plastic materials.
- The alternative system — a gas pool heater — has a starting price of around $2,000, plus additional heating costs varying from $600 to $900 per year. The solar heating system will therefore repay the extra cost in less than three to four years, and will have much lower running costs thereafter.
- A solar heating system requires very little or no maintenance since it has no burners or moving parts. A gas heater or heat pump requires far more maintenance and typically lasts only one-third the life span of a solar system.
- Solar heating systems' warranties are typically more inclusive and much longer (12 to 15 years) than warranties for gas heaters (five years) and heat pumps (typically 10 years).
- A good solar pool heating system can generally be expected to increase pool water temperature by 9°F to 18°F above the unheated water temperature from October through March. However, temperatures will vary depending on local climate conditions. The graphs below show the temperature differences claimed by one manufacturer in two climate extremes.
- Attic insulation gets saturated with radiant heat from roof decks that increases air conditioning bills. Collectors mounted on the roof will considerably lower air conditioning costs for that space.

Table 1 – Cost comparison for gas and solar pool heaters in a heating-dominated climate

Gas Pool Heater	Solar Pool Heater
Initial cost $2,400	Initial cost $3,495
Five year operating cost $6,000	Five year operating cost $0
Total five year cost $8,400	Total five year cost $3,495

Design Tools

Use the following simplified algorithm for arriving at the required collector area:

$$A = A_p \times O \times S \times Sol_{ins}$$

where,

A = Area of solar collector, ft^2

A_p = Effective area of pool (multiply the surface area of the pool with the shape multiplier from Table 2 below), ft^2

O = Orientation multiplier (from Table 3 below)

S = Shading multiplier (from Table 4 below)

Sol_{ins} = Solar insolation (from the figure below)

Table 2 – Shape Multiplier

Shape	Multiplier
Rectangle	1.00
Kidney/Freeform	0.85
Oval	0.90
Round	0.79

Table 3 – Orientation Multiplier

Orientation	Multiplier
South facing	1.00
East or west facing	1.25
Flat	1.10

Table 4 – Shading Multiplier

Shading (from 9 a.m. to 5 p.m.)	Multiplier
No shade	1.00
25% shade	1.10
50% shade	1.25
75% shade	1.50
100% shade	1.75

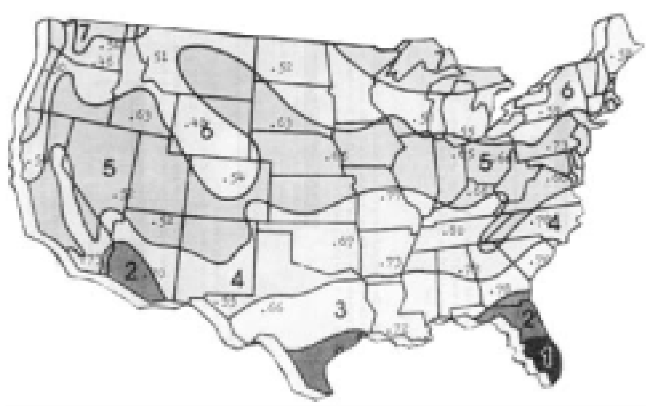


Figure 2 – Solar Insolation Levels in the United States

Free software is available from U.S. Department of Energy to analyze current energy consumption and project savings when implementing a variety of energy management systems from pool covers to solar systems. The *Energy Smart Pools* software uses hourly temperature and humidity data along with solar data to provide an accurate simulation of the heat losses and gains of a pool. Over 50 U.S. weather sites are currently available in the software. The program is intended to provide annualized simulation of annual energy costs, other costs, savings, and payback of adding a pool cover system, as well as costs, savings, and payback of adding a solar heating system.

Design Details

As in all solar heating, the primary factor in determining the effectiveness of the system is exposure to the sun. The size and the location of the collector, controller efficiency, local climate, wind protection, and roof orientation all influence the functioning of solar pool heating systems.

- Use a minimum collector area that is 60% of the pool's surface area. This applies only for ideal conditions (see the Design Tools section for simplified sizing). Whenever conditions are unfavorable, for example in colder climates, the size of the collector will need to be increased, with a minimum area of 80% recommended for such installations. Increase collector area to 75% of the pool surface area if collectors are laid flat or if collectors face west. Other orientations are not recommended. In general, for every 20% of the pool surface area that is installed as solar collector, a 3°F rise in water temperature can be expected (based on collector rating at 1,000 Btu/ft^2 of collector area).
- A south-facing roof is the best location for these systems. Use a west orientation or a flat roof if south orientation is unavailable.
- Ideally, tilt the south-facing collectors by 30° to 32°.
- Consider installing pool covers. They are the most cost effective measure for reducing heat loss, water evaporation, and chemical use.
- Manual operation or a simple timer may be substituted for expensive automatic controls.
- Indoor pools that are used year round require glazed flat plate collectors, which should slope between 35° and 45°.

Operation and Maintenance Issues

Ensure that pools are manually and seasonally drained. In areas subject to winter freezing, the collectors and plumbing should be installed to allow all water to drain when the system is off.

Paint all exposed PVC plumbing to protect it from damage due to solar energy.

Commissioning

Carefully check how long the manufacturer has been in business and what warranty services are available. Use the Florida Solar Energy Center rating system (see References for more information).

References/Additional Information

American Solar Energy Society, Inc. (ASES). 2400 Central Avenue, G-1, Boulder, CO 80301. Phone: (303) 443-3130; Fax: (303) 443-3212, Email: ases@ases.org. Web site: http://www.ases.org.

National Spa & Pool Institute (NSPI). Phone: (800) 323-3996. Web site: http://www.nspi.org/.

The Energy Efficiency and Renewable Energy Clearinghouse (EREC).. P.O. Box 3048, Merrifield, VA 22116. Phone: (800) DOE-EREC (800-363-3732). Email: doe.erec@nciinc.com. Florida Solar Energy Center. 1679 Clearlake Rd., Cocoa, FL 32922. Phone: (407) 638-1000, Fax: (407) 638-1010, Pamphlets available by mail - call for costs, Collector Thermal Performance Ratings (publication FSEC-GP-16), Design and Installation Manual (publication FSEC-IN-21-82), System Sizing (publication FSEC GP-13). Web site: http://www.eren.doe.gov/consumerinfo.

Solar Energy Industries Association (SEIA). 1616 H Street, NW, 8th Floor, Washington, DC 20006. Phone: (202) 628-7979, Fax: (202) 628-7779. http://www.seia.org/.

GUIDELINE RE4: WIND

Recommendation

Small wind electric systems may be an option to provide some of the required electrical load from renewable energy for some schools.

Reducing energy consumption at the school before selecting a small electric wind system will significantly lower energy bills and the size of system needed. NREL/PIX 09043

Description

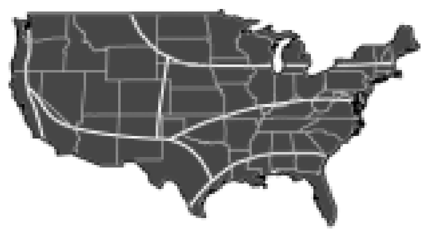
Wind is created by unequal heating of the Earth's surface by the sun. Wind turbines convert the kinetic energy in wind into mechanical energy that powers a generator to produce clean electricity. Turbine blades are aerodynamically designed to capture the maximum energy from the wind. The wind turns the blades, which then spin a shaft connected to a generator that makes electricity.

Applicability

A small wind electric system may be an appropriate technology to provide renewable power to a school if the following conditions are met:

- There is enough wind where the school is located (usually average wind speeds of 14 mph or greater are needed for cost effectiveness).
- Tall towers are allowed in the area.
- Enough space exists on the site.
- It makes financial sense for the school.

Applicable Climates



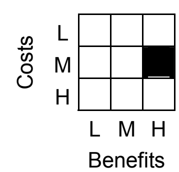
Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	▒

When to Consider	
Programming	□
Schematic	■
Design Dev.	□
Contract Docs.	□
Construction	□
Commissioning	□
Operation	□

Integrated Design Implications

Before selecting a small electric wind system for the school, first make the building as energy efficient as possible. Reducing energy consumption will significantly lower the school's energy bills and will reduce the size of the wind energy system needed.

Cost Effectiveness



A small wind turbine can cost anywhere from $3,000 to $35,000 installed, depending on size, application, and service agreements with the manufacturer. A general rule of thumb for estimating the size of a small wind system is $1,000/kW to $3,000/kW. Wind energy becomes more cost effective as the size of the turbine's rotor increases. Although smaller turbines cost less in initial outlay, they are proportionally more expensive.

Although wind energy systems involve a significant investment, they can be competitive with conventional energy sources when accounting for a lifetime of reduced or avoided utility costs. The length of the payback period depends on the system chosen, available wind resources, electricity costs, and how the wind system is utilized.

Benefits

Depending on the wind resource, a small wind electric system can lower electricity bills by 50% to 90%, prevent power interruptions, and is non-polluting. A wind energy system can also be a good teaching tool.

The economics are best when:

- There is a good wind resource (greater than 14 mph average annual wind speed at the hub).
- There is net billing with 50 kW cap or higher, preferably annual over monthly netting period.
- Electric rates are above average ($0.08/kWh or greater).
- Large kWh usage allows larger wind turbines, which improves payback due to economies of scale.

When Does Installing a Wind Turbine Make Sense?

- When adequate wind exists at school location.
- When the site has acceptable space.
- When the state has policies that encourage renewable energy:
    - A good net billing law
    - Loan funds
    - Income tax credits
    - Buy down program
    - Property tax abatement
- When electric rates are above average (typically $0.08/kWh or more).
- Single part rate is more favorable than two part rate (demand and energy charges).

Design Tools

The formula for calculating the power from a wind turbine is:

$$\text{Power} = C_p 1/2\ \rho A V^3$$

where :

C_p = Power coefficient, ranging from 0.2 – 0.4, dimensionless (theoretical max = 0.59)

ρ = air density, lb/ft^3

A = rotor swept area, or $\pi D^2/4$ (D is the rotor diameter in feet, π = 3.1416)

V = wind speed, mph.

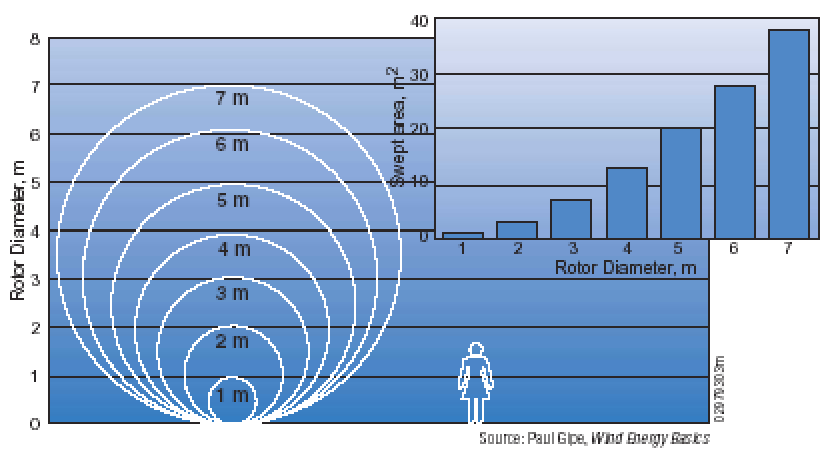


Figure 3 – Relative Size of Small Wind Turbines

The figure above shows the actual size of rotor diameters in relation to the size of an average person. This can help when examining the view of the turbine on a landscape.

The Wind Energy Design Payback Period Workbook, found at http://www.nrel.gov/wind under consumer information, is a spreadsheet tool that can help analyze the economics of small wind electric systems.

Design Details

Mounting turbines on rooftops is not recommended. All wind turbines vibrate and transmit the vibration to the structure on which they are mounted. This can lead to noise and structural problems with the building.

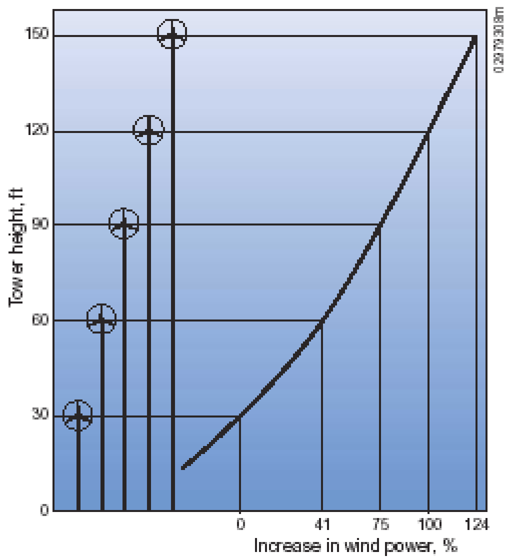


Figure 4 – Wind Speeds Increase with Height

Average wind speeds increase with height and may be 15% to 25% greater at a typical wind turbine hub height of 80 ft than at a typical airport anemometer height. As V^3 increases, power increases by approximately 60%.

Operation and Maintenance Issues

Although small wind turbines are sturdy machines, they do require some annual maintenance. Bolts and electrical connections should be checked and tightened. The machines should be checked for corrosion and the guy wires for proper tension. After 10 years, the blades or bearings may need to be replaced, but with proper installation and maintenance, the turbine should last 20 years or more.

Tilt-down towers provide easy maintenance for turbines.

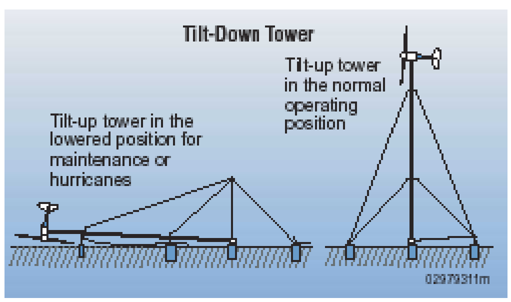


Figure 5 – Tilt-Down Towers

Commissioning

None.

References/Additional Information

Wind turbine manufacturers and dealers should be able to help size and install the system. A credible installer will provide many services, including permitting. State energy offices or local utilities can provide a list of local wind system installers.

More detailed wind resource information, including the *Wind Energy Resource Atlas of the United States,* published by the U.S. Department of Energy can be obtained at the National Wind Technology Center website at: http://www.nrel.gov/wind and the Windpowering America website at http://www.eren.doe.gov/windpoweringamerica. These sites also contain information on educational curriculum for teachers and students.

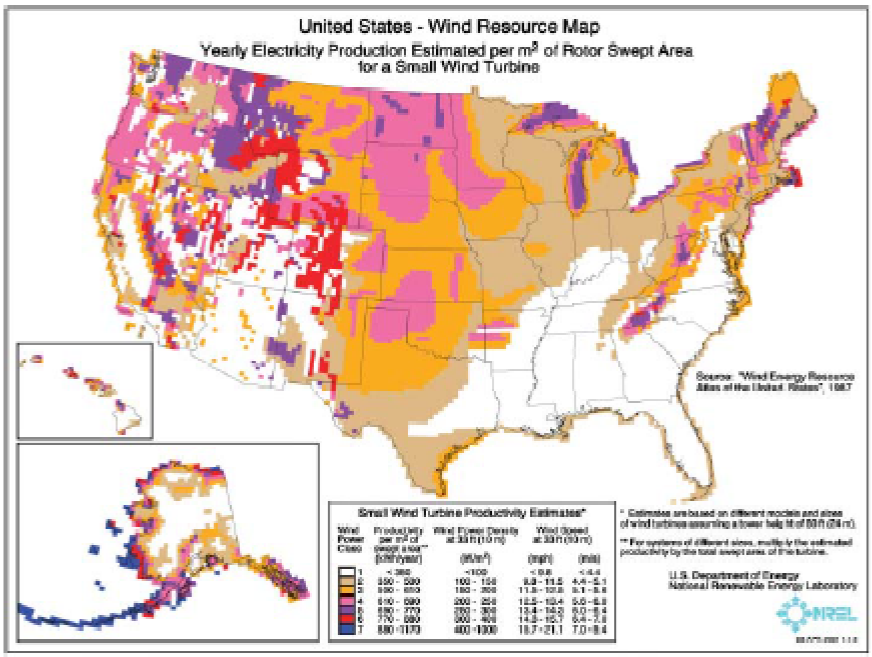


Figure 6 – Wind Resource Map

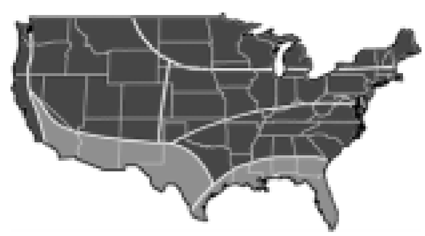
GUIDELINE RE5: GEOTHERMAL HEAT PUMPS

Recommendation

Consider ground source heat pump (GSHP) systems in locations with considerable heating and/or cooling loads, or when heating fuel is expensive.

Geothermal heat pump systems reduce peak energy demand and reduce the heat island effect, since waste heat is returned to the ground instead of the outside air. NREL/PIX 07191

Applicable Climates



Applicable Spaces
Classrooms
Library
Multi-Purpose / Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Description

GSHP systems are known by many names, including geothermal, earth-coupled, geoexchange, water-coupled, groundwater, ground-coupled, closed-loop, coiled, open- and water-source heat pump systems.

GSHP systems use a refrigeration cycle to extract and transfer heat. A ground source heat pump uses the earth as a source of heat in the winter and as a tool for heat removal from the building space in the summer.

GSHP systems can be grouped into two types: closed-loop and open systems, such as standing wells. The selection of the type of system depends on many factors, including the availability of groundwater and surface water, soil type, energy requirements, size of lot, and the experience of the designer and contractor.

An open-loop system takes water directly from a well, a lake, a stream, or other source, then filters it and passes it directly through the condenser loop of the heat pump system. When in a cooling mode, the water is warmed; and in a heating mode the water is cooled. The heated or cooled water is then released into another well or stream. Open systems are not permitted in most areas.

The closed-loop systems circulate a fluid (usually an antifreeze solution) through a subsurface loop of pipe to a heat pump. The system uses a subsurface loop and a refrigerant loop. The subsurface loop typically consists of polyethylene pipe, which is placed horizontally in a trench or vertically in a bore hole. This thin-walled pipe is a heat exchanger, transferring heat to and from the earth. Fluids inside the pipe circulate to the heat exchanger of an indoor heat pump where they exchange heat with the refrigerant. The refrigerant loop typically consists of copper pipes that contain a refrigerant.

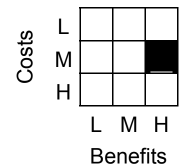
Applicability

These systems are applicable to all interior school spaces, including classrooms and administration facilities. The systems can also be used to heat water for the facility.

Integrated Design Implications

With a good design that includes elements like daylighting, thermal mass, and photovoltaic systems, GSHP systems can help a building become a “net-zero” facility, where all energy needs are supported on-site.

Cost Effectiveness



Large systems tend to have first costs that are similar, or slightly higher, to other high-quality HVAC systems with conventional energy sources. However, when compared to traditional HVAC systems, the energy savings offset the initial higher cost. GSHP systems can have 20% to 50% energy cost savings over conventional systems, with maintenance savings of approximately 30%.

Also, the payback period for the GSHP systems generally falls between 5 to 10 years. Some utilities offer incentives that make the systems more affordable.

Benefits

Energy use and fossil-fuel consumption in GSHP systems is reduced by 40% to 70% compared to systems that use air instead of the Earth to provide temperature control. Water consumption is also reduced since no cooling towers or water-cooled condensers are needed.

The systems reduce peak energy demand and reduce the heat island effect, since waste heat is returned to the ground, not the outside air.

The seasonal energy efficiency ratio (SEER) compares rejected heat to energy consumed to rate cooling efficiency. Higher numbers indicate more efficiency; values greater than eight are preferred. According to the Pennsylvania Ground Source Heat Pump Manual, advanced GSHPs are reaching SEER values of greater than 17.

Waste heat from the system can be used to heat water when the system is cooling the building.

Systems can be designed to use multiple heat pumps with dual-speed controls to improve part-load performance. Teachers can control the temperature in each classroom. Also, facilities staff can shut off unused zones during peak demand periods while allowing critical zones to operate normally without any decreased performance.

Since piping and pumps are buried or enclosed in the building, damage caused by inclement weather, insects, and vandalism can be greatly reduced.

Systems promote better aesthetics since no equipment needs to be placed on rooftops or outside the building envelope. They can be used with sloped roofs and work well with historic buildings, since the equipment is easily hidden from view.

Design Tools

Design tools available for GSHP systems include:

- HEATMAP© Geo, Washington State University Energy Program.
- GchpCalc Design Software for vertical ground-coupled heat pump systems design for commercial and institutional buildings, Version 3.1, Energy Information Services, Tuscaloosa, AL.
- Cycle Analysis Software Tool, National Renewable Energy Laboratory.
- Geocrack2D, Kansas State University.
- GEOCALC, Design Software, developed by Ferris State University, released by Thermal Works Software, Grand Rapids, Michigan.
- Wright Soft Geothermal Heat Pump Software, Lexington, MA.
- GL/GW-Source, Design Software, Kansas Electric Utilities Research Program.
- Geothermal Heat Pump Pipe and Fitting Program, Geothermal Heat Pump Consortium.
- Energy-Smart Choice for Schools, HVAC comparison tool, Geothermal Heat Pump Consortium.
- BuilderGuide, National Renewable Energy Laboratory, Golden, CO.

Design Details

In addition to the details below, it is recommended that the standards established by the International Ground Source Heat Pump Association (IGSHPA) for GSHP systems be followed.

Closed-loop systems
The heat transfer between the loop and the surrounding soil or rock depends on thermal conductivity, which is an important consideration when designing closed-loop systems. Consult a geological expert to evaluate the soil conditions at the site.

Non-toxic, biodegradable circulating fluids, such as food-grade propylene glycol or potassium acetate, are recommended for use in GSHP systems.

Loops should be at least 25 ft from any septic systems.

Configuration of subsurface loops can be almost any shape, including long trenches, parallel shorter trenches, radiating, coiled, and vertical borings.

Backfilling or grouting must be done at the end of the installation process to help provide good thermal contact and to protect the pipes.

Open ground systems
For standing column wells, the largest quantities of water will be produced during the coldest part of the winter, so the system must be sized to accommodate such a volume as well as handle extreme temperatures.

Selecting the appropriate groundwater pump size is important for open systems. The pump must be large enough to overcome the friction in the piping and to supply enough water for the heat pump and other uses. However, the pump must be small enough to be efficient in energy usage.

Subsurface disposal and recycling of water in a standing column well conserves groundwater and limits environmental problems.

At least 100 ft should separate wells from contamination sources such as septic tanks and livestock pens. Landfills should be separated by an even greater distance.

Acceptable drilling methods for wells include rotary, cable tool, and auger. The driller's method should be environmentally sound and prevent the introduction of any contamination.

Casing should be used when necessary to prevent collapse of the hole and the migration of surface pollutants into the drill hole.

Grout should be placed in the entire annular space between the surface casing and the drill hole.

Operation and Maintenance Issues

GSHP systems require little maintenance aside from regular cleanings of heat exchanger coils and strainers that filter the ground water, as well as regular air filter changes. These systems generally have an expected 25- to 30-year life cycle.

If a closed system is properly designed and installed, soil-freezing conditions do not create any system problems. At a soil temperature of 30°F, latent heat moisture in the soil adds considerably to the capacity of the system, allowing for very successful performance in northern climates.

However, aging, poorly installed, or improperly operated GSHP systems have a greater risk for system failure.

Commissioning

Closed loop

Flushing the loops will help to ensure the system is in good operating order. This process consists of debris flushing, air purging, pressure testing, and final charging of the system with antifreeze.

Also, the system "heat of extraction" and/or "heat of rejection" needs to be calculated, which can be done by non-technical staff using a probe thermometer and a probe pressure gauge. By measuring the temperature and pressure across the source heat exchanger and performing some basic calculations, the operating capacity of the system is determined. This capacity value is then compared with the manufacturer's printed capacity value.

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GUIDELINE RE6: PHOTOVOLTAICS

Recommendation

Install photovoltaic (PV) arrays to convert radiant energy from the sun to electricity. PV is ideal for isolated or stand-alone tasks, and can serve as an excellent teaching tool.

Description

PV converts radiant energy from the sun into direct current electricity, without any environmental costs (greenhouse or acid gas emissions) associated with other methods of electricity generation.

PV produces electricity from an abundant, reliable, and clean source. In fact, the amount of solar energy striking the earth is greater than the worldwide energy demand each year.

Photovoltaics are most cost effective in remote locations that are at a distance from an electrical grid, but they have zero environmental costs. NREL/PIX00006

Applicable Climates

Applicable Spaces		**When to Consider**	
Classrooms		Programming	
Library		Schematic	
Multi-Purpose		Design Dev.	
Gym		Contract Docs.	
Corridors		Construction	

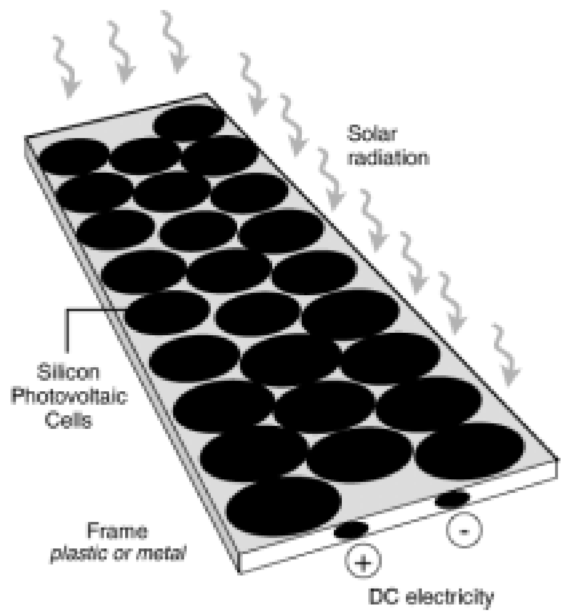


Figure 7 – Photovoltaic Module

The basic component of a PV system is a solar cell. Most solar cells are made of specially treated silicon semiconductor materials. Sunlight striking the cells generates a flow of electrons. This flow is directly proportional to the surface area of the cells and the intensity of the radiation (a cell of area 6.25 in.^{2} will produce 3.5 amperes in bright sunlight). Each solar cell produces approximately 0.5 volts. Higher voltages are obtained by connecting the solar cells in series. Solar cells are laminated; most have a tempered glass cover and a soft plastic backing sheet. This sealing protects the lodged electrical circuits from the outside elements and makes solar cells durable. Modules may be connected in series for higher voltages and in parallel for higher currents. The typical photovoltaic module uses 36 silicon solar cells, connected in series to provide enough voltage to charge a 12-volt battery. However, most schools do not require battery storage and can use grid-tied PV systems. A grid-tied system can provide electricity savings as well as provide additional shading or cooling benefit. Most schools can switch to a net metering rate schedule where utilities give credit for surplus electricity produced by PV systems.

Individual modules may be further combined into panels, sub arrays, and arrays. PV arrays with storage batteries are sources for uninterrupted power supply. Schools requiring emergency backup for communication systems in the case of an earthquake or rolling blackout can use this type of stand-alone system with batteries. Batteries store energy collected during the day for nighttime use. A battery charger controller may be included to avoid overcharging the battery. In addition, all systems include wire, connectors, switches, and electrical protective components. If the load requires alternating current (AC), an inverter is used to convert the direct current (DC) power to AC power. The energy collected during the day is stored for use during the night.

Applicability

- PV is very suitable for remote facilities that are more than one-third of a mile away from the electrical grid.
- PV is ideal for climates where plenty of sunlight is available. PV is also suitable for climates that may experience cloudy days periodically but have sunlight available on most other days. However, the availability of sunlight will influence the size and cost of the system. For example, a very small PV system designed to operate a 72-W load for eight hours/day would require a 120-W PV module in southern Arizona, as compared to a 240-W module in Wisconsin. This difference results from the fact that the daily solar insolation levels in southern Arizona are roughly twice the insolation levels in Wisconsin. Although applicable to a whole range of climates, including Hot and Dry and Cool and Dry, PV is more feasible in climates with high insolation levels. *The Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, published by the National Renewable Energy Laboratory, provides an accurate assessment of available insolation for 239 U.S. locations.
- PV is ideal for providing power to exterior and parking lot lighting, and for school zone flashers.

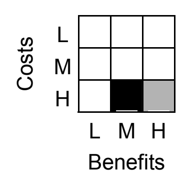
Integrated Design Implications

Building aesthetics. In the early design stage, consider mounting PV on rooftops for best results.

System integration. Since PV is most likely to be used in hybrid systems, the mechanical engineer needs to perform detailed planning in the early design stages.

Cost Effectiveness

PV panels typically cost anywhere between $3.50/W to $6/W for modules and $5/W to $20/W for the system, depending on the size and capacity of the installation (each W of PV array will produce 2 Wh to 6 Wh of energy depending on availability of sunlight). One-hundred-W installations will cost between $10/W to $12/W. Using typical borrowing costs and equipment life, the life-cycle cost of PV-generated energy generally ranges from $0.25/kWh to $1/kWh. The simple payback period for this system is 25 to 30 years.



Benefits

- PV is most cost effective in remote locations that are at a distance from an electrical grid. PV is typically three to six times more expensive than utility-supplied electricity. However, this figure does not take into account the “real” or environmental cost of utility-generated electricity or local rebates.
- PV is environmentally benign during use and does not produce any greenhouse gases or acid gas emissions associated with other methods of generating electricity. It has zero environmental costs.
- PV produces electricity from an abundant and reliable ”fuel” — sunlight. Coupled with storage batteries, PV is capable of supplying uninterrupted power.
- PV is available in modular building blocks; more arrays may be added as the demand for power increases.
- Wear and tear is minimized for PV, since it has no moving parts and produces power silently.
- Although PV may be combined with other power sources in hybrid systems to increase system reliability, PV itself requires no connection to an existing power source or fuel supply.

- For grid-tied PV systems, net metering allows schools to receive utility credits for the surplus electricity generated by PV systems.
- PV can withstand severe weather conditions including snow and ice.
- PV can be combined with other types of electric generators (wind, hydro, and diesel, for example) to charge batteries and provide power on demand.
- By putting power back into the electrical grid and shaving peak loads, PV can have far-reaching implications.

Design Tools

Most PV dealers will work with designers to engineer the best-customized system for the school. System requirements are determined by:

- Estimating the daily load demand.
- Determining the solar resource in the location.
- Calculating the battery size. (Note: A lead-acid battery is not a viable option.)
- Calculating the number of PV modules required.

For first estimates of the array size needed, consider the following variables that effect the production of power in an array:

- Outside air temperature. Use average annual temperatures.
- Amount of sunlight received, or Incident Solar Radiation, which depends on latitude, cloud cover, and angle of the array.
- Efficiency of the photovoltaic cells. This information should be available from the manufacturer and varies between 13% at unfavorable conditions to 30% under lab conditions.

$$P = (Sol_{ins} + \Delta t) \times A \times Eff$$

where,

P = Power generated, W

Sol_{ins} = Incident solar radiation, Wh/ft^2

Δt = Difference between the control and design temperatures (use zero if the design temperature is between 50°F and 60°F; for control temperature, use 50°F for colder weather and 60°F for warm weather)

A = Area of the array, ft^2

Eff = Efficiency of the system (multiply cell efficiency by efficiency of the storage unit)

A Macintosh software program is available for PV design and sizing, wherein designers can specify appliances and AC/DC loads, inverter efficiency, and site location. Based on these variables, the software recommends the number of solar modules and batteries. The software costs about $15.

PVWatts is another PV software program. Researchers at NREL developed PVWatts to allow non-experts to quickly obtain performance estimates for grid-connected PV systems at no cost.

Trnsys, a program developed at the University of Wisconsin, also helps size and locate PV systems. See the References section at the end of this guideline for more information.

Design Details

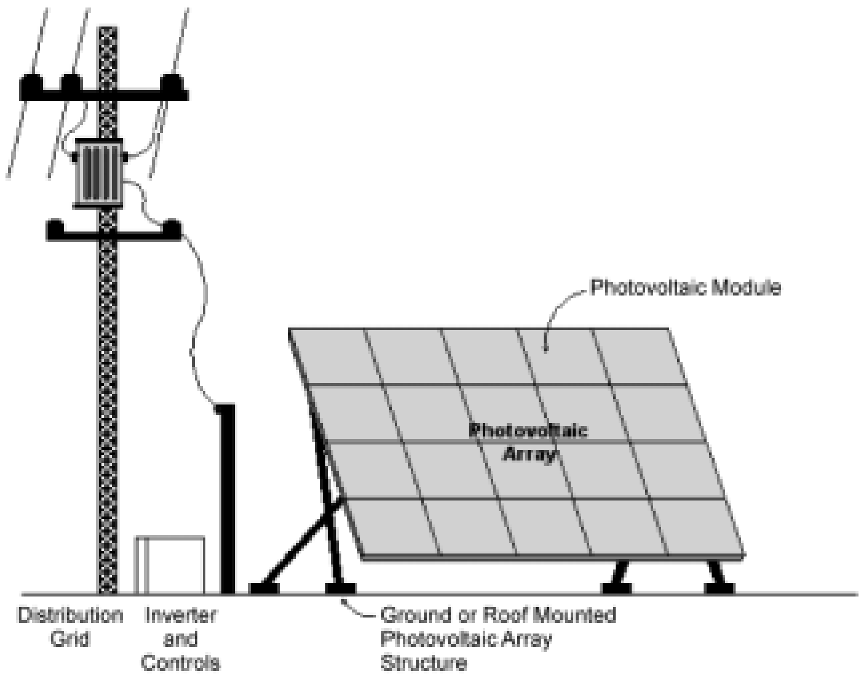


Figure 8 – PV Siting, Elevated

Source: Renewable Energy Project Analysis Software

- The most important aspect of installing PVs is siting. Shading can significantly reduce the output of solar cells. Mount PV arrays at an elevation or on roof tops. Consider both summer and winter sun paths and ensure that trees, neighboring buildings, or other obstructions do not shade any portion of the array between 10:00 AM and 3:00 PM.
- Mount the system for maximum southern exposure. The exact mounting angle will differ from site to site.
- Flat, grassy sites work better than steep, rocky sites.
- Use arrays as building components to economize to building materials and for unobtrusive design solutions. Arrays can be used as a finishing material on structures to create attractive roofs or skylights. Arrays can be used to break up and add interest to a large, uniform roof surface. They can double as shading devices, which not only block the sun but also capture it. Transparent arrays can be used as structural glazing instead of glass. Arrays can also be part of a curtain wall system.

Operation and Maintenance Issues

- PV systems require occasional cleaning to remove dust and debris. In cold, snowy climates, care must be taken to keep the array surface clear of snow.
- Some PV systems contain storage batteries that may require some watering and maintenance similar to that required by batteries in automobiles.
- PV modules are the longest living components of a PV system (20 to 30 years) and will likely outlive the batteries. Batteries may need replacement every six or seven years.
- No PV system is maintenance-free. Schedule regular inspections of the system to ensure that the wiring and contacts are free from corrosion, the modules are clear of debris, and the mounting

equipment has tight fasteners. Roof-integrated systems should be designed to facilitate regular inspection and maintenance.

- Monitor the power output of PV modules, the state-of-charge and electrolyte level of the batteries, and the actual amount of power that building loads use. Writing this information in a notebook helps to track the system's performance and determine whether the system is operating as designed. Monitoring will also help understand the relationships between the system's power production, storage capability, and load requirements.
- Roof-integrated systems should be designed to allow easy removal if roof replacement is required.

Commissioning

Do not compromise on the initial module cost of PV systems. Skimping on first costs results in having to pay later, in terms of higher operation ($/kWh) costs that amount to a much higher figure over the lifespan of a system.

Purchase PV systems from established and knowledgeable dealers who can help determine requirements specific to the site. Look for warranties of 20 years or more. Thoroughly check the rating system that the dealer/manufacturer is using for reliability.

Always engage a professional to design and install PV systems. A preliminary design is a necessity to determine the size, layout, and potential energy output of the PV modules. This design can be performed with computer simulation tools using estimated hourly weather, solar resource, and load data. The time required to prepare the preliminary design and detailed cost estimate typically falls between 30 and 60 hours, with fees ranging from $40/hour to $100/hour. Smaller scale projects with simple structural requirements fall at the low end of this time range. Larger scale projects requiring more difficult structural integration into existing buildings will be at the high end of this time range.

Fully commission panels and the entire array to confirm rated power is achieved.

References/Additional Information

U.S. Department of Energy, Energy Efficiency and Renewable Energy Network.

Maryland Solar Schools Program Plan. http://www.energy.state.md.us/executiv.htm.

Solar Engineering Laboratory, University of Wisconsin-Madison,1500 Engineering Drive, Madison, WI 53706, Phone: (608) 263-1589; Fax: (608) 262-8464, Email: trnsys@sel.me.wisc.edu, Web site: http://sel.me.wisc.edu/trnsys.

Solar Schoolhouse. Developed by the Rahus Institute, this web site contains information on PV systems, a database on schools using solar power, DSA approval checklists, lesson plans, etc. Site is expected to launch in June 2002. Web site: http://www.solarschoolhouse.org/.

Stand-Alone Photovoltaic Systems: Handbook of Recommended Design Practices, Sandia National Laboratory.

WATER CONSERVATION

This chapter provides guidelines for:

Water-Efficient Irrigation Systems (Guideline WC1)

Stormwater Management, Groundwater Management, and Drainage Materials (Guideline WC2)

Rainwater Collection Systems (Guideline WC3)

Gray Water Systems (Guideline WC4)

Waterless Urinals (Guideline WC5)

Efficient Terminal Devices (Guideline WC6)

OVERVIEW

Fresh water is an increasingly scarce resource throughout the United States. A high performance school should control and reduce water runoff from its site, consume fresh water as efficiently as possible, and recover and reuse gray water to the extent feasible.

Basic efficiency measures can reduce a school's water use by 30% or more. These reductions help the local and regional environment while decreasing operating expenses. While the cost savings may be modest now, since water is relatively inexpensive in most areas of the country, there is a strong potential that these savings will rise over time, especially in areas where water is scarce and becoming more expensive.

To achieve water conservation in high performance schools, designers should:

- Design landscaping to use water efficiently by reducing water use and specifying hardy, native vegetation.
- Use recycled water for non-potable purposes.
- Set water use goals for the school.

Water-Efficient Irrigation

Reducing the amount of irrigation on a school site can significantly affect a school's overall water use. Preserving existing vegetation in combination with a landscape design that features drought-resistant plants is a simple and effective way to decrease the amount of irrigation needed for the site. (See the Site Design chapter for more information on landscape design for high performance schools.)

Even though native, drought-resistant plants can reduce the amount of water needed for irrigation, an in-ground irrigation system may still be required. Consider using an irrigation system for athletic fields only, not for plantings near buildings or in parking lots. Use high-efficiency irrigation technology (e.g., drip irrigation in lieu of sprinklers). Sprinkler systems are notoriously wasteful, with up to 45% of the water used never reaching the vegetation at all. Drip systems are significantly more efficient, since delivering the water directly to the root area results in very little wasted water.

Recycled Water

Significant environmental and financial costs exist when streams, rivers, lakes, and groundwater resources are tapped to provide water for irrigation or non-potable indoor purposes such as flushing toilets. Rather than using scarce, high-quality potable water in these cases, reclaimed water is an effective alternative. Reclaimed water is highly treated wastewater that is safe for non-potable purposes. Extensive testing is performed to assure water quality standards are met. In the United States, for example, reclaimed water has been used safely for municipal, industrial, and agricultural purposes for more than four decades. Reclaimed water is available in many areas at low and sometimes no cost.

Recycled water can be provided by gray water systems. Gray water is “used” water from showers, bathroom sinks, and washing machines. These systems divert the gray water from the existing drain line to a surge tank where it is filtered, sterilized, and recycled for use in irrigation and toilets. Since this water is treated on-site, gray water systems reduce the load on local water agencies and treatment plants.

Rainwater collection is another source of recycled water for schools. If local climate allows, use captured rain or recycled site water for irrigation and “design in” cisterns for capturing rainwater. After passing through a filtration system to settle and disinfect the water, it can be used for showers, sinks, laundries, dishwashers, and toilets. Captured rainwater has excellent quality and in some cases, can be used for potable purposes.

Water Use Goals

A good starting point is using 20% less than the baseline calculated for the building after meeting the Energy Policy Act of 1992 fixture-performance requirements. This can be reached with a combination of water-conserving fixtures and equipment such as low-flow or waterless toilets and urinals, automatic lavatory faucet shut-off controls, low-flow showerheads, and high-efficiency dishwashers and laundry appliances. Low-flow devices can reduce water consumption by 15% to 20%. Low-flow toilets use only 1.6 gallons of water per flush, compared to the 3.5 gallons to 7 gallons used per flush by traditional toilets. Conventional faucets use between 3.5 gallons and 7 gallons per minute. Low-flow faucet aerators cut usage down to between 1.5 gallons to 2.5 gallons per minute.

Regular maintenance on this equipment can greatly reduce water use. Leaks are the biggest cause of wasted water in most buildings. A faucet drip or invisible leak in the toilet will add up to 15 gallons of water a day, or 105 gallons a week, which adds up to 5,475 gallons of wasted water a year.

Resources

American Water Works Association. http://www.awwa.org/.

U.S. Department of Energy. Energy Efficiency and Renewable Energy Network, http://www.eren.doe.gov/.

Water Environment Federation. http://www.wef.org/.

WaterWiser is a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. http://www.waterwiser.org/.

GUIDELINE WC1: WATER-EFFICIENT IRRIGATION SYSTEMS

Recommendation

Install drip or other low-volume, water-efficient irrigation and/or systems connected to humidity sensors, where appropriate.

Description

Supplemental irrigation accounts for most water use at schools during the summer and a significant amount during the spring and fall. Maximizing the water efficiency of irrigation systems supports healthy and attractive landscapes and sports fields.

Applicability

All climates.

Integrated Design Implications

Irrigation system design and installation should be closely coordinated with other landscape planning and water management activities. See Guideline SD3: Landscape Design and Management; Guideline SD5: Native and Drought-Tolerant Plants; Guideline SD6: Landscaping Soil, Amendments, and Mulch; Guideline SD7: Integrated Weed, Disease, and Pest Management; and Guideline WC3: Rainwater Collection Systems. Note: The soil should be amended and blended prior to installing the irrigation systems to avoid damage to the system.

Cost Effectiveness

Drip systems and micro-emitters have become very cost effective when evaluated against water restrictions and rising water costs.

Conventional spray heads deliver only 55% to 65% of the water to the ground – drip irrigation is up to 95% efficient.

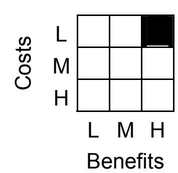
NREL/PIX 11426

Applicable Climates

Applicable Spaces	
Classrooms	
Library	
Multi-Purpose	
Gym	
Corridors	
Administration	
Toilets	
Other	■

When to Consider	
Programming	
Schematic	
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	
Operation	■

Benefits



Benefits include significantly reduced irrigation water consumption, reduced utility costs, and increased water conservation. Conventional spray heads deliver only 55% to 65% of the water to the ground; the rest is blown away or evaporates, depending on weather conditions. In contrast, drip irrigation is up to 95% efficient. Plants establish and thrive better with drip irrigation since water is delivered to the root zone, where it is needed. Water-efficient irrigation systems are also *waste*-efficient — water and fertilizer are used only where needed, preventing nutrient-consuming and waste-generating weed growth in other areas and reducing costs associated with managing and disposing of undesired plant growth.

Design Tools

None.

Design Details

- First, aim to eliminate the need for an irrigation system entirely. An effective stewardship program combined with drought-tolerant plants (Guideline SD5) might eliminate the need for an in-ground system.
- Where an in-ground system is required, the design and installation should be completed by a certified irrigation specialist and should conform to local ordinances. The ordinances include specifics about efficient irrigation.
- Systems should be installed to avoid runoff, low-head drainage, overspray, or other similar conditions where irrigation water flows onto adjacent property, non-irrigated areas, or impervious surfaces. Some irrigation systems can be connected to humidity sensors to keep from operating when humidity is high or when it is raining.
- Consider special problems posed by irrigation on slopes, in median strips, and in narrow hydrozones. Installation should provide easy access to sprinkler heads for inspection and maintenance.
- Use irrigation zones to group plants with similar water needs close to a water source, which limits the scope and impact of an in-ground irrigation system.
- Where possible, use the minimum amount of polyvinyl chloride (PVC) products. PVC is highly toxic during manufacture and disposal. Unfortunately the alternatives, such as copper or clay piping, tend to be more expensive. If substitution for virgin PVC is not an option, the system should be designed to use the minimum length of piping possible.
- Consider using irrigation systems made with recycled-content plastic, tire-derived rubber, and other recycled-content materials.
- Preserve established vegetation to minimize irrigation needs. Avoid killing existing vegetation with too much water from new irrigation systems.

Operation and Maintenance Issues

Requires regular monitoring to ensure system is operating properly. Develop a monthly schedule to visually inspect and monitor irrigation system(s) performance during irrigation season. Performance evaluation should be based upon original design intent, irrigation audit report, and water budget goals.

Commissioning

Work with the commissioning agent and certified irrigation auditor to ensure compliance with the design documents. In addition to checking for proper irrigation equipment and installation, check the system for adherence to specified performance criteria and operation parameters as designed. Verify that maintenance personnel are trained and proficient in the ongoing programming and adjustments for the irrigation system.

References/Additional Information

Drip Irrigation for Every Landscape and All Climates, Metamorphic Press, PO Box 1841, Santa Rosa, CA 95402.

Hawn, Joellyn. “Process Changes to Improve Commercial Landscape Viability.” *New England Real Estate Journal*, May 31-June 6, 1996.

Irrigation Association, various publications, including *Common Obstacles to Irrigation Efficiency* and *Drip Irrigation Technology*. Available on-line at http://www.igin.com/irrigation/irrigation.html.

Kourik, Robert. *Landscape Water Management Principles*, Version 1.01. Cal Poly ITRC, San Luis Obispo, CA, 1994.

WaterWiser is a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. Web site: http://www.waterwiser.org/. AWWA number is (202) 628-8303.

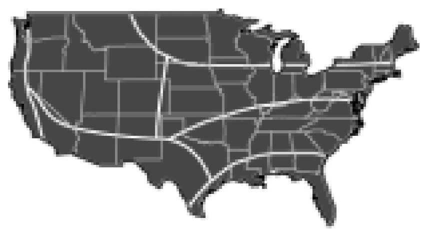
GUIDELINE WC2: STORMWATER MANAGEMENT, GROUNDWATER MANAGEMENT, AND DRAINAGE MATERIALS

Recommendation

Manage stormwater with systems that slow water velocity, maximize its use for irrigation, and filter pollutants. Use material-efficient options for on-site drainage systems. Groundwater should be managed separately from surface water.

Capturing and absorbing stormwater conserves water and can improve the health of on-site soils, vegetation, and habitat areas. NREL/PIX 11334

Applicable Climates



Applicable Spaces	
Classrooms	☐
Library	☐
Multi-Purpose	☐
Gym	☐
Corridors	☐
Administration	☐
Toilets	☐
Other	■

When to Consider	
Programming	☐
Schematic	☐
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	☐
Operation	■

Description

Stormwater management is vital to the safety and ecological health of a school site. Site planning and design should strive to balance water on the site and make effective use of the water for water supply and irrigation.

Water should always be absorbed and captured with the remainder moved slowly across the site into natural features wherever possible. Trying to move water quickly to gutters, downspouts, catch basins, and pipes increases water quantity and velocity, which requires the design of large and expensive drainage infrastructure. Options for material-efficient drainage include:

For fill

- Recycled concrete aggregate
- Crushed concrete
- Glass

For pipes

- EPS with recycled content

In areas where the water table is high, construction can cause groundwater to seep to the surface. In these cases, level spreaders should be used to pipe the discharge from curtain drains to trickle discharge onto fields or wetlands, in lieu of the stormwater system. It is important to manage groundwater separately from stormwater to prevent possible contaminants from destroying groundwater quality.

Applicability.

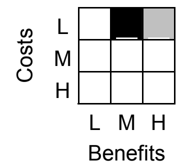
All climates.

Integrated Design Implications

Building design (especially roofs), site grading, erosion control, and bank stabilization need to be considered. Where applicable, the groundwater management system design should be integrated with the design of site-built stormwater system for greatest cost savings.

"Green" or living roofs present a possible alternative design strategy for managing site water that appears to exemplify the best principles of integrated design. Reducing the rate of runoff, developing natural habitat for birds and insects, increasing insulation levels, cooling roof temperatures, saving energy — all are touted as benefits of this type of system. One consideration is the requirement of manufacturers that the systems be irrigated to prevent wind erosion of the topsoil. Unless rainwater collection (see SP10) is employed, this represents an environmental liability of these systems.

Cost Effectiveness



On-site capture, absorption, and slowing of surface runoff usually has a lower first cost and ongoing maintenance expense than traditional underground retention structures and piping, which are very expensive and often fail. By managing groundwater separately from stormwater, the complexity and size of site-built stormwater systems can potentially be reduced, decreasing overall construction costs. Drainage material costs are comparable to, or less than, conventional materials. For example, recycled aggregate base is less expensive than virgin aggregate in the Los Angeles area. There also may be an economic advantage to crushing concrete, brick, and asphalt demolition debris on-site, where the material can be used as a base or sub-base. Analysis of these materials must be performed by a qualified soils and hazardous materials engineer to be sure that it is safe for such on-site re-use, in compliance with state and federal requirements. The economy of on-site crushing depends on several variables including the amount of rubble stockpiled, the capacity of the crushing equipment available (tons per hour), local tipping fees for the inert materials, the haul distance to local inert landfills, and the total cost of importing virgin or recycled aggregate base to the construction site.

Benefits

Capturing and absorbing stormwater is good water conservation. It also can improve the health of on-site soils, vegetation, and habitat areas. Using recycled-content products helps alleviate waste disposal problems, reduces energy use, and lowers consumption of natural resources during manufacturing.

Design Tools

None.

Design Details

Stormwater management should begin with capture in cisterns or ponds and absorption into groundwater aquifers, or landscape areas. Excess percolated water from green roofs and pervious paving should be filtered through vegetated areas or filters.

Any remaining runoff water should be slowed down and spread slowly over the entire surface of roofs and paved areas before entering bioswales and surface runoff channels, such as brooks and creeks.

If pipes and catch basins are used, use perforated pipe and filters wherever possible, in keeping with the intent of the system design.

Natural boulders can be effective as energy dissipaters or as checkdams, creating riffles and pools in the channels.

Use green roofs on buildings and incorporate bioswales in the site grading. Use site grading with bioengineered banks and channels, energy dissipaters, and check dams.

Operation and Maintenance Issues

Most traditional site maintenance programs at schools are limited to trash pickup and “mow and blow” cleanup. Local conservation corps, youth job training programs, experienced community gardeners, and neighborhood groups are good sources to help augment the school maintenance staff. They can help nurture a variety of landscapes, especially natural waterways and riparian corridors, ponds, meadows, and native planting beds.

If using level spreaders for groundwater management, they should be inspected after every runoff event to ensure proper functioning.

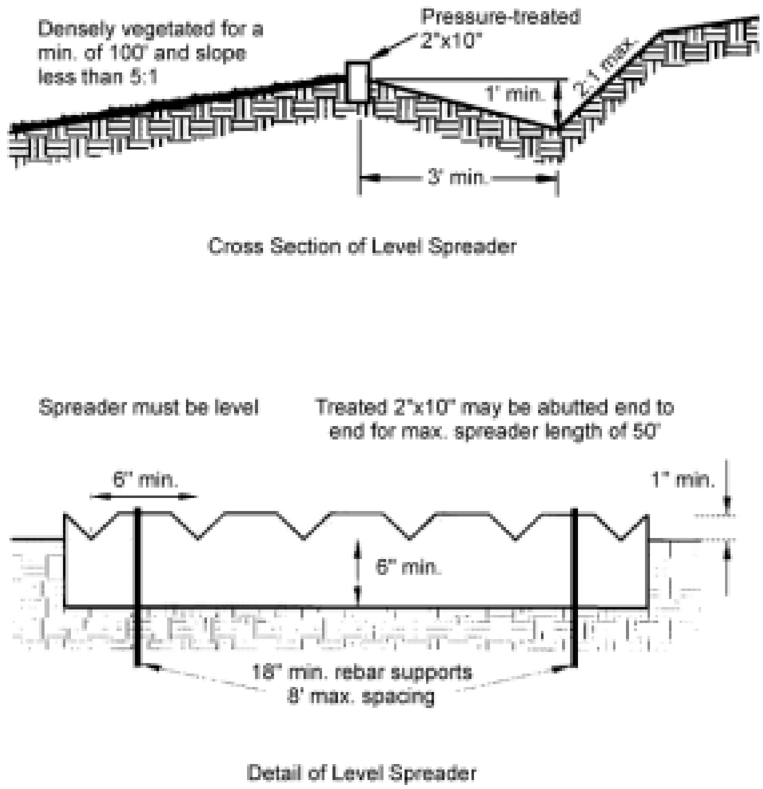


Figure 1 – Level Spreader, Cross Section & Detail

(Source: Washington State Department of Ecology, Stormwater Management Manual for Western Washington, Volume II, Construction Stormwater Pollution Prevention)

Commissioning

None.

References/Additional Information

California Integrated Waste Management Board. *Recycled Aggregate* Fact Sheet, CIWMB publication #431-95-052. Also available to download from: http://www.ciwmb.ca.gov/publications/condemo/43195052.doc.

International Erosion Control Association. Provides technical assistance and an annual Erosion Control Products and Services Directory. (800) 455-4322 or http://www.ieca.org/.

Kids in Creeks Program for School Teachers. Aquatic Outreach Institute, Richmond, CA.

Stream Corridor Restoration: Principles, Processes and Practices developed by 14 federal agencies. Available at http://www.usda.gov/streamrestoration/.

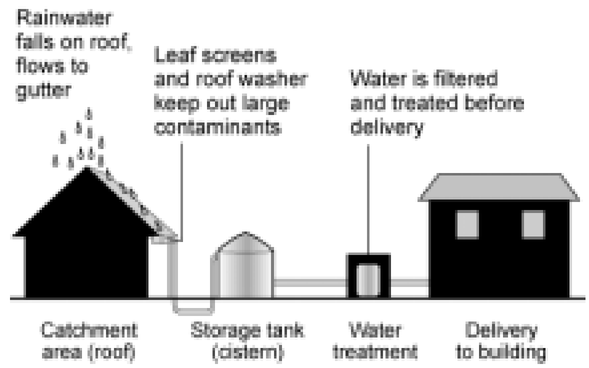
Stormwater and Urban Runoff Seminars — Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, (800) 368-5242 x538 or http://www.nahb.com/.

Stormwater Management For Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance. EPA#833-R-92-001, October 1992, U.S. Environmental Protection Agency Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. (800) 245-6510, (202) 260-7786 or http://www.epa.gov/owm/sw/construction/.

GUIDELINE WC3: RAINWATER COLLECTION SYSTEMS

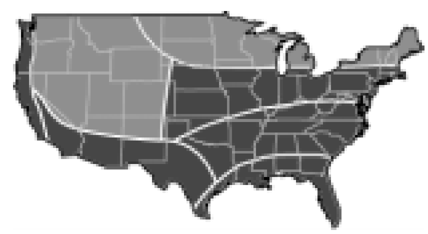
Recommendation

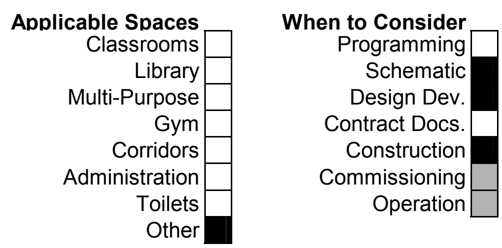
Use rainwater-harvesting systems for supplying year-round, dependable potable or non-potable water. Due to the expense of building freeze-protected cisterns, these systems are probably not applicable in colder climates, except in special or very limited application.



Schematic of a rainwater collection system.

Applicable Climates





Description

Drawing excessive water and paving all available open lands have considerably hindered natural ground water recharge. Rainwater harvesting is merely "putting back rain water into the soil." Rainwater is collected from roofs or ground-level surfaces and stored in a cistern. The water is then filtered and delivered to terminals through pumps. Rainwater is used for showers, sinks, laundries, dishwashers, and flushes. The components of a rain water system include:

- Catchment area/roof is the surface upon which the rain falls. Roofs are most commonly used as catchment areas although channeled gullies or other ground level features can serve the purpose equally well.
- Gutters and downspouts are the transport channels from catchment surface to storage. Water collected by the catchment area is delivered to the storage tank (or cistern) via gutters and downspouts. These need to be appropriately sized and sloped. Standard designs for these "transport systems" are readily available in the market.
- Leaf screens and roof washers remove contaminants and debris.
- Cisterns or storage tanks store the collected rainwater. Cisterns are the most expensive component of the rainwater system.
- The conveying or delivery system for the treated rainwater is accomplished through pumps or gravity. The water pressure for a gravity system depends on the difference in elevation between the storage tank and the faucet. Water gains 1 psi of pressure for every 2.31 ft of rise or lift. Many plumbing fixtures and appliances require 20 psi for proper operation, while standard municipal water supply pressures are typically in the 40 psi to 60 psi range. To achieve comparable pressure, a cistern would have to be 92.4 ft (2.31 ft X 40 psi = 92.4 ft) above the highest plumbing fixture of the facility. This means pumps are essential to convey the filtered water from cisterns to terminal devices.
- Water treatment, filters and equipment, and additives to settle, filter, and disinfect the collected water are important components of this system. It is essential that a professional decide the water treatment method to use for a given facility after conducting appropriate water tests in a laboratory to determine whether this water will be applicable to potable or non-potable uses. Types of treatment include filtration, disinfection, and buffering for pH control. Dirt, rust, scale, silt, and other suspended particles, bird and rodent feces, airborne bacteria, and cysts will inadvertently find their way into the cistern or storage tank even when design features such as roof washers, screens, and tight-fitting lids are

properly installed. Water can be unsatisfactory without being unsafe; therefore, filtration and some form of disinfection is the minimum recommended treatment if the water is to be used for human consumption.

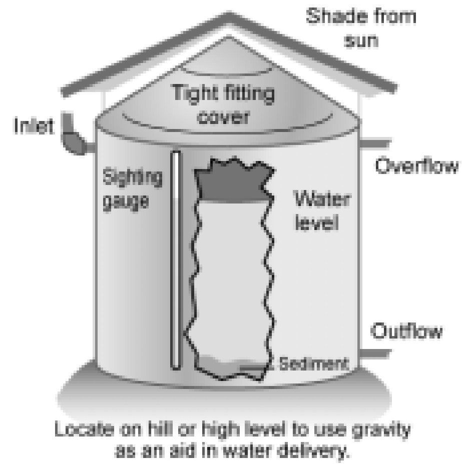


Figure 2 – Cistern for Rainwater Collection

The catchment area is the surface on which the rain that will be collected falls. While this guideline focuses on roofs as catchment areas, channeled gullies along driveways or yard swales can also serve as catchment areas, collecting and then directing the rain to a French drain or bermed detention area. Because composite asphalt, asbestos, chemically treated wood shingles, some membrane systems, and some painted roofs could leach toxic materials into the rainwater as it touches the roof surface, they are recommended only for non-potable water uses.

Gutters and downspouts are the components that catch the rain from the roof catchment surface and transport it to the cistern. Standard shapes and sizes are easily obtained and maintained, although custom fabricated profiles are also available to maximize the total amount of harvested rainfall. Gutters and downspouts must be properly sized, sloped, and installed to maximize the quantity of harvested rain. For various reasons, lead-coated copper should be avoided on school projects generally, but absolutely avoided in buildings with rainwater harvesting. If harvesting is planned for a renovation, special care should be taken to examine the existing roof and gutter system for hazardous materials, including lead and asbestos mastic.

Other than the roof, which is an assumed cost in most building projects, the storage tank represents the largest investment in a rainwater harvesting system. To maximize the system's efficiency, the building plan should reflect decisions about optimal placement, capacity, and material selection for the cistern.

Applicability

Rainwater systems are appropriate for most climates, although their application may be limited for severely cold climates. In dry climates, enough rainwater is available to meet 75% of the total water requirement of a facility.

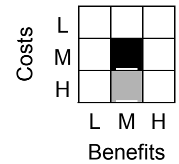
Rainwater harvesting should be considered early in the design phase for best (and safest) results.

Integrated Design Implications

Site planning is an important consideration in designing rainwater systems. Decisions regarding placing the cistern, creating natural slopes or gullies for channeling rainwater, and creating a pressure difference between the gutter spout and the cistern inlet should be made at the site-planning stage.

Building aesthetics will also be impacted depending on the choice of rainwater collecting element.

Cost Effectiveness



A rainwater harvesting system designed as an integrated component of a new construction project is generally more cost-effective than retrofitting a system onto an existing building. Many of the shared costs of roof and gutters can be designed to optimize system performance, and the investment can be amortized over time.

Generally rainwater systems cost about $1/gallon to $1.50/gallon of collection capacity although factors like design, topography, and climate can significantly alter these numbers.

City-supplied water is relatively inexpensive, although it must be added that municipal water cost is a simple number and does not include hidden environmental costs. Consequently, the pay back period for a full-service rainwater harvesting system where city water is available is rarely less than 30 years and can be as high as 90 years, assuming present values for municipal water and approximate construction costs of $1/gallon of collection capacity for a rainwater harvesting system.

Benefits

- It is an environmentally benign system.
- Rainwater quality is excellent.
- The concept is simple and easy to build. Operation and maintenance of systems are easy.
- Water and sewer costs are reduced.

Design Tools

For sizing catchment areas, it is reasonable to assume that 600 gallons is collected per inch of rain per 1,000 ft^2:

$$\text{Catchment Area (ft}^2\text{)} = \frac{\text{Average Rainfall (inches) x 600}}{1{,}000}$$

Several computer software programs are available for sizing purposes that simulate the performance of a rainwater collection system. For every month of the simulation, it subtracts the water that is used and adds in any rainwater that was collected. The amount of water remaining in the cistern at the end of the month is output to a graph. A total of 100 years' rainfall data may be added to certain programs. The following values are manipulated for simulation:

Basic Method Using Annual Data[1]

1. Calculate roof catchment area.

2. Multiply the collection area in ft^2 by 0.6 gallons/ft^2/in. of rain times the collection factor times the average annual rainfall and half of the average annual rainfall.

For example, if you have 2,500 ft^2 of collection area and live in Austin, where the average annual rainfall is 32 in. a year and the collection efficiency factor is 80%, the average amount of rain you can collect is:

2,500 X 0.6 X 32 = 38,400 gallons/year

3. Dividing this by 365 days a year, the supply would be 105 gallons/day.

4. Using the rule-of-thumb that half of the average rainfall will provide a close estimate of the low expected rainfall for the area, in an extremely severe drought year, approximately 19,700 gallons could be collected. This would result in a supply of only 53 gallons/day.

[1] Texas Rainwater Guide.

- Size of the collection area in ft^2.
- Number of gallons that will be used each month.
- Total size of storage capacity in gallons.
- Amount of water in storage at the beginning of the simulation, in gallons.
- Amount, if any, of water that will be put into storage if it is empty.

Companion programs calculate waste production and peak flow rate based on the collection area and peak design rainfall rates to be expected in this area once every 10 years. These programs are used to properly design the collection plumbing system to catch all rainfall flowing off the roof without losing any to system backup.

Design Details

- Collection area should be completely exposed and should not be shaded by trees. Rainwater yield and quality depends on the size and nature of the catchment area. Use smooth, impervious, and clean roofing for good quality yield. Textured roofing slows down water flow and is responsible for evaporative losses.
- Use pitched metal roofs to minimize losses. Metal roofs are also safe for potable water. Concrete or asphalt roofs increase losses to 10%. Further loss in volume could occur if built-up tar and gravel roofs are used. Clay and slate are also appropriate roofing choices for collecting potable water. Avoid roofing materials like asphalt, chemically treated wood, or asbestos for collecting potable water as they may introduce toxic matter in the rainwater.
- Surfaces like clay and slate should be treated with a special painted coating to discourage bacterial growth.
- Use aluminum copper or galvanized iron gutters and downspouts.
- Existing buildings should be fully examined for any lead or asbestos content in the planning stages of any rainwater collection project.
- Locate cisterns below ground to benefit from cooler year-round ground temperatures. However, this may involve extra excavation and maintenance costs. Above-ground cisterns also work well and may be installed if excavation costs are a major issue. Also, placing the cistern at the highest workable level will reduce pumping costs.
- Use durable cisterns (ferrocement or wood) with watertight exteriors. All joints should be sealed with a non-toxic joint sealant. The tank needs to be approved by the Food and Drug Administration if the water is intended for potable use. Use tight fitting covers to avoid losses due to evaporation and the entry of pollutants into the tanks.
- To maximize efficiency and minimize piping costs, locate cisterns close to both the rainwater collectors and the demand terminals.
- It is a good practice to shield cisterns from direct sunlight to prevent algae growth in the stored water.
- Site cisterns at least 50 ft away from sources of pollution like septic tanks.
- Cisterns should have vehicular access if the need to replenish the water through an auxiliary source arises.
- A settling compartment, which encourages any roof run-off sediment that may enter the tank to settle rather than be suspended in the tank, is an option that can be designed into the bottom of the cistern.

Cistern Types[2]		
Material	**Feature**	**Caution**
PLASTICS		
Garbage Cans (20-50 Gallon)	Commercially available, inexpensive.	Use only new cans.
Fiberglass	Commercially available, alterable, and moveable.	Degradable, requires interior coating.
Polyethylene/Polypropylene	Commercially available, alterable, and moveable.	Degradable, requires exterior coating.
METALS		
Steel Drums (55 gallon)	Commercially available, alterable, and moveable.	Verify prior use for toxics, corrodes and rusts, small capacity.
Galvanized Steel Tanks	Commercially available, alterable, and moveable.	Possible corrosion and rust.
CONCRETE AND MASONRY		
Ferrocement	Durable, immoveable.	Potential to crack and fail.
Stone, Concrete Block	Durable, immoveable.	Difficult to maintain.
Monolithic/Poured in Place	Durable, immoveable.	Potential to crack.
WOOD		
Redwood, Douglas Fir, Cypress	Attractive, durable.	Expensive.

Operation and Maintenance Issues

- All tanks intended for storing potable water should be continually shaded from sunlight.
- Tanks should be regularly inspected and cleaned. The roof terrace (or rainwater collection system) should be regularly and thoroughly cleaned. Filters attached to rainwater-conveying systems should be frequently cleaned to ensure maximum yield.
- Water from the first rains of the season should not be collected as it may contain atmospheric impurities and pollutants.

Commissioning

Buy durable cisterns with good warranties.

References/Additional Information

American Rainwater Catchment Systems Association, P.O.Box 685283, Austin, TX 78768-5283.

Center for Maximum Potential Building Systems, 8604 F.M. 969, Austin, TX 78724. (512) 928-4786.

American Water Works Association, 6666 West Quincy Avenue, Denver, CO, 80235.

Water Quality Association, 4151 Naperville Road, Lisle, IL 60532.

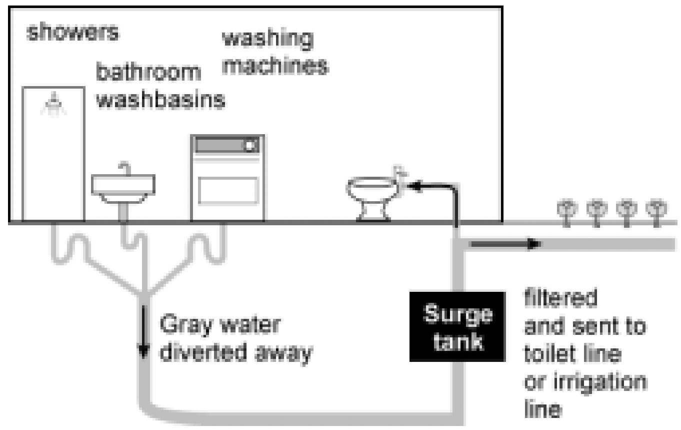
http://www.waterwiser.org/.

[2] Texas Rainwater Guide.

GUIDELINE WC4: GRAY WATER SYSTEMS

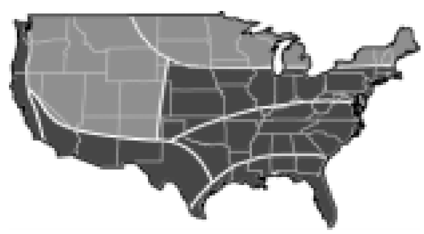
Recommendation

Use gray water systems for drought-resistant landscape irrigation and for flushing toilets.



Gray water systems can recycle up to 50% of the selected waste water from a school to use for irrigation and/or flushing toilets.

Applicable Climates



Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

Description

Gray water is untreated "used" water that is not contaminated by toilet waste. The California Gray Water Standards define it to include used water from showers, bathroom washbasins, and water from washing machines. It does not include wastewater from dishwashers, kitchen sinks, or laundry water from soiled diapers. Gray water systems filter, sterilize, deodorize, and recycle this used water for irrigating landscapes or flushing toilets.

Gray water systems have three major components: the drain-line plumbing, the surge tank and other equipment associated with it, and the delivery system. Surge tanks allow quicker inflow of water from the source than outflow to drainfields. The example schematic in Appendix J of the California Plumbing Code identifies the components of a gray water system where gray water is delivered to the landscape.

Plumbing work is required to divert the gray water from the existing drain lines. All drain lines from gray water sources should link to a common channel that connects to the surge tank. The surge tank contains filters, vents, valves, and pumps. Sand and settling (sedimentation) filters are most commonly used in large applications. Pumps deliver the gray water to toilets and the landscape (if drip irrigation is used).

Gray water composition varies depending on the water source, plumbing system, and user-specific variables (like cleaning products). At regular concentration levels, few components in gray water will damage trees and shrubs. Few detrimental soil changes will occur from well-managed gray water systems. Gray water contains high levels of grease, fibers, and particles (like dry skin), and is 5°F to 10°F warmer than non-gray water. Gray water does increase the number of soil organisms, but only slightly. Most harmful soil effects actually result from over-watering and prolonged saturation of the soil.

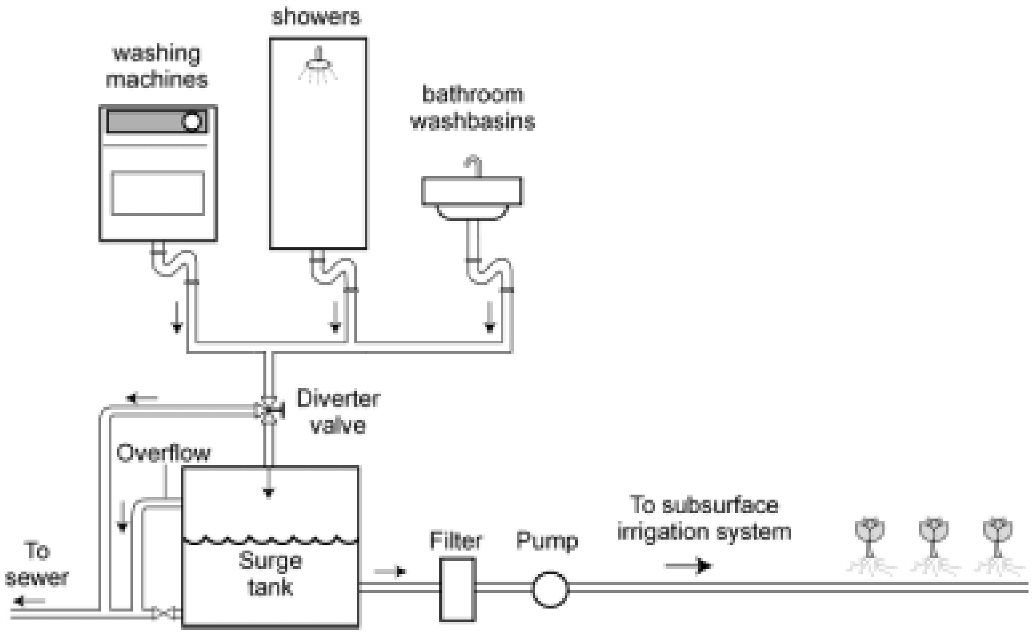


Figure 3 – Example Schematic of Gray Water System

Applicability

- They are appropriate wherever supplemental irrigation is normally required.
- They are applicable for all climate types, although their uses may be limited in severely cold climates. However, in colder weather conditions, graywater can be drained into leaching trenches that are deep enough to resist freezing, but shallow enough to keep the nutrients within the root zones of surface plants. Freezing can be prevented by applying a mulch over the subsurface leaching trenches. Drought-prone climates will especially benefit from a reliable, year-round source for irrigation.
- Do *not* use gray water for plants with limited root areas or on hydroponic plants. Acid-loving trees and shrubs (azaleas, begonias, and rhododendrons) may be affected because gray water is alkaline. Do *not* use gray water on edible plant parts.

Integrated Design Implications

Integrated gray water systems for new constructions are cost effective, although retrofitting is not a major issue either. Plumbing installation and surge tank location require consideration early in the design process.

Cost Effectiveness

Installation costs for gray water systems can range from several hundred dollars to more than $5,000 for small systems. Generally, systems will have an initial cost between $8/gallon to $15/gallon of stored gray water. The annual operating costs are between $0.15/gallon to $0.25/gallon of capacity.

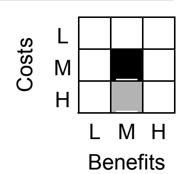


Table 1 – Types of Systems Currently Available

System Type	Source of Gray water	Features	Cost
Low-Tech Owner or Professional Installation	Washing machine only.	200 micron mesh filter. 55-gallon garbage can with locking lid.	$400-$800
Medium-Tech	Uses all gray water sources.	Sump pump to PVC tubing. Subsurface drip irrigation. 200-micron mesh filter. (2) 55-gallon storage tanks.	$1,000-$1,500
Fully Automated Professional Installation	Uses all gray water sources.	Automatically back-washed sand filter. 250-gallon storage tanks. Pumps at both source and tank/filter. Three-way valve, backflow preventers. Microprocessor controls all flows. Backed by potable water.	$2,500-$5,000

Benefits

- Promotes conservation and reduces water bills by reusing water from baths and sinks that would have otherwise gone down the drain. At least 30% of total "used" water is reutilized by such systems.
- Drought-proof landscaping. More than half the indoor water can be recycled, ensuring a constant source of water even during shortages. The nutrients in the gray water may also benefit plants. Valuable plant nutrients, such as phosphorous and potassium, are often found in gray water that can result in healthier plants and in the reduced application of fertilizers. By leaving the soil surface drier, it may also make for a healthier landscape by reducing disease and pests.
- Using gray water improves the efficiency of applied water because it is delivered to the plants underground, eliminating runoff, over spray, and evaporation.
- The community benefits from gray water use because it reduces the amount of wastewater that is discharged to the local treatment facility. This has the potential to reduce wastewater treatment costs, and may even postpone or avoid the need for flow-related expansions of the facility. Local water and wastewater agencies also experience reduced pumping costs.

Design Tools

One of the toughest challenges in designing the gray water system is laying out the irrigation system and determining the size of the area to be irrigated. The homeowner or designer must decide which plants can be irrigated with gray water. The size of the irrigated area is determined by the soil type, volume of gray water produced, and by the summer water requirements of the plants. A good rule of thumb is to expect 2 gallons to 2.5 gallons of water to effectively irrigate 1 ft^2/day. Estimate the total daily water requirement and assume that only 50% of this estimate will make it into the gray water storage.

Design Details

- Plumb "used" water from bathroom sinks, showers, and clothes washers separately from other wastewater. Kitchen sinks may be included if there are no in-sink garbage disposals. This water should drain by gravity into a surge tank.
- Surge tanks should have tightly fitted covers, vent stacks, and overflow drains attached. It should also have a one-way valve to prevent backflow. Install the tank such that the outflow can be gravity driven. If this is not possible, use pumps for delivering water for irrigation. Overflow pipes that redirect water to septic tanks or sewer lines are very important when the field gets saturated.
- The water in the surge tank should be filtered.
- Locate the distribution piping 9 in. below the soil surface to provide adequate decomposition and minimize health risks. Use dual pipes that consist of 1-in perforated pipes with 5/16-in holes at 6-in intervals lodged in pipes of larger diameters with slits at the bottom.
- Provide several independent drain areas with valves for alternate distribution.

- Use a check valve between the pump and outflow piping to restrict the gray water flow in one direction.
- It is a good practice to label and mark all piping, fixtures, and pumps that comprise a gray water system.

Operation and Maintenance Issues

The success of gray water systems is completely dependent on careful operation and periodic maintenance. The following guidelines should be strictly followed for health and safety reasons.

- Paint thinners, paints, or pesticides should never be washed down the drain, and substances such as ammonia and chlorine should find their way into gray water plumbing in very limited quantities only. Drains in schools must be clearly labeled with bilingual signs.
- While most detergents can be used with gray water systems, there are several important exceptions and several cautions. Products that contain boron should not be used. Boron has been shown to be very toxic to most plants. Use biodegradable soaps as much as possible.
- If salt buildup in the landscape is a concern (it should be in most cases), it is better to use liquid detergents than powdered detergents. Powdered detergents contain excessive amounts of sodium.
- Chlorine is extremely toxic to plants, but it has not generally been a problem in gray water irrigation. This may be because chlorine breaks down fairly rapidly and its effects may also be dissipated or diluted in the soil. Having some residual chlorine present in the surge tank to minimize bacteria buildup also appears to be a benefit. Chlorine bleach may damage plants if it touches the foliage.
- Gray water should not be sprayed, allowed to puddle, or run off property.
- Gray water should be rotated with fresh water to leach out any harmful build-up. Biodegradable soaps appear to have the least harmful effects.

Commissioning

For safety reasons, involve a soil engineer (or other experts) to assess available soil and the feasibility of the system based on soil quality. All purchased equipment should be accompanied by detailed installation information and all equipment should be professionally installed.

References/Additional Information

National Park Service. *Guiding Principles of Sustainable Design* (Chapter 8). http://www.nps.gov/dsc/dsgncnstr/gpsd.

U. S. Environmental Protection Agency, Office of Water, http://www.epa.gov/OW.

Water Alliance for Voluntary Efficiency (WAVE), http://www.epa.gov/owm/water-efficiency/faq.pdf

WaterWiser — The Water Efficiency Clearinghouse. http://www.waterwiser.org/

GUIDELINE WC5: WATERLESS URINALS

Recommendation

Install waterless urinals wherever applicable.

Description

Waterless urinal systems have been used in schools since 1993, and have some innovative features that distinguish the product from the conventional urinal systems available today. The products look, feel, and work like a conventional urinal system except for one difference: they do not require water to operate.

The system has three main components: a polypropylene trap insert, a sealant liquid, and a reinforced fiberglass urinal body.

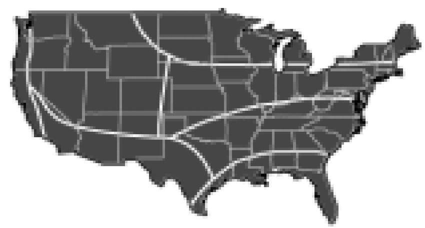
The primary component of the product is the trap cartridge. This cartridge "traps" the 99% biodegradable sealant liquid, which is lighter than other liquids. It floats on and seals the contents from the atmosphere. This special liquid allows urine to sink through its layer, creating a pleasant and odor-free environment. Since urine is 90% water, it readily flows down and falls through the trap. This trap design allows immersed urine to be discharged into the drain without using any mechanical parts.

The system requires only about three ounces of sealant liquid per charge to operate and will last for about 1,500 sanitary uses. Then, the liquid is simply replenished. The trap needs to be replaced three to four times a year, depending on frequency of use.

Waterless urinals are becoming more accepted as people begin to understand that these systems are not unsanitary compared to traditional urinals.

Waterless urinals have no moving parts, resulting in easy maintenance and low operating costs. NREL/PIX 11413

Applicable Climates



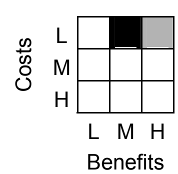
Applicable Spaces
- [ ] Classrooms
- [ ] Library
- [ ] Multi-Purpose
- [ ] Gym
- [ ] Corridors
- [ ] Administration
- [x] Toilets
- [ ] Other

When to Consider
- [ ] Programming
- [ ] Schematic
- [ ] Design Dev.
- [ ] Contract Docs.
- [x] Construction
- [ ] Commissioning
- [ ] Operation

Applicability

Waterless urinals are applicable to all restroom modernizations and new construction.

Cost Effectiveness



Costs for waterless urinals are comparable to regular manual flushed urinals, but are less than automatic-sensor flushed urinals.

The payback period for the system is one to four years. Savings due to waterless urinals are estimated between $150/urinal/year and $330/urinal/year depending on factors like number of users, cost of water, cost of sewer, volume of water use, and maintenance.

Benefits

Some benefits of waterless urinals include:

- Easy maintenance since it has durable, break-resistant fiberglass construction with no moving parts. This reduces operating costs by eliminating the problem of broken flush valves. However, more frequent washing may be required, as the inside of the urinals are not flushed out with water.
- Flushometer and valve replacements are common problems for flush urinals. Such repairs are not an issue for waterless urinals.
- Waterless urinals are simple to install and use. Replacing existing conventional urinals with waterless products is also relatively simple to accomplish, since they easily adapt to existing 2-in plumbing waste lines.
- They have a short payback period of one to four years.
- Fresh water supply will be preserved and can be applied in a more effective and meaningful way. In addition to saving water, they reduce the amount of water needing to be treated. Less water released into the treatment process lowers pollution and benefits the environment.
- Waterless urinals significantly reduce clogging and prevent overflows.

Design Tools

None.

Design Details

None.

Operation and Maintenance Issues

The smooth, simple design of the waterless system is easy to clean and maintain. Also, there are no costly repairs usually associated with the mechanical components of flush valves.

The trap cartridge should be replaced two or four times per year, depending on the frequency of use.

The sealant liquid is biodegradable and the trap cartridge should be recycled.

Commissioning

The drain line should be clear before installation, which may require snaking the drain line.

References/Additional Information

None.

GUIDELINE WC6: EFFICIENT TERMINAL DEVICES

Recommendation

Use low-flow toilets and low-flow devices on all terminals like faucets and showerheads. Use automatic faucets for controlling wastage of clean water.

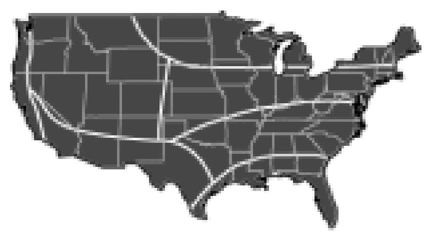
Description

Installing low-flow devices is simple and cost effective. In 1995, the National Energy Policy Act mandated the use of toilets that use no more than 1.6 gallons of water per flush (gpf), reduced from 3.5 gpf. Low-flow toilets use various technologies like large drain passages, redesigned bowls, and tanks for increased functionality and easier wash-downs.

Older showerheads typically deliver 4 to 5 gallons per minute (gpm) of water. Newer showerheads are more efficient and follow the National Energy Policy Act of 1992 that allows a maximum water flow rate of 2.5 gpm (at standard water pressure of 80 lb/in^2). Showerheads should use aerator technology and multiple flow settings to save water. Conventional bathroom faucets use 3 gpm to 7 gpm. New faucets, designed to meet federal codes, use a maximum of 2.5 gpm (at 80 psi), although some are being designed to use 1.5 gpm or less.

Low-flow devices will reduce water consumption by 15% to 20%, resulting in lower environmental costs and reduced load on wastewater treatment plants. NREL/PIX00653

Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	☐	Programming	☐
Library	☐	Schematic	☐
Multi-Purpose	■	Design Dev.	☐
Gym	☐	Contract Docs.	☐
Corridors	☐	Construction	■
Administration	☐	Commissioning	☐
Toilets	■	Operation	☐
Other	■		

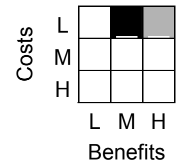
The new low-flow faucets essentially operate in one of two ways: aeration or laminar flow. In laminar flow faucets, the water travels in parallel streams, producing a clear flow of water without being mixed with air (as in aeration), which produces superior wetting ability over aerating faucets. Laminar flow faucets are somewhat more expensive than aerating types. Conventional faucet aerators do not compensate for changes in inlet pressure, so with greater water pressure, more water is used. New technology compensates for this occurrence and provides the same flow regardless of pressure. Aerators are also available that allow water to be turned off at the aerator itself.

Some low-flow faucets are the metered-valve type; they deliver a fixed quantity of water and then shut off automatically. Other automatic faucets include sensored and self-closing. Sensored faucets, either infrared or ultrasonic, are designed to turn on when a user's hands are placed under the faucet, and turn off when the hands are removed.

Applicability

Low-flow technology is applicable to all terminal devices that deliver water.

Cost Effectiveness



A good quality, low-flow showerhead will cost $10 to $20. Low-flow faucet aerators cost $4.50 to $8. A sensored faucet is expensive and may cost up to $160 per fixture more than the regular faucets.

Benefits

A low-flow device will pay for itself in energy saved within four to eight months.

Installing low-flow showerheads and faucet aerators can save significant amounts of hot water. Low-flow showerheads can reduce hot-water consumption for bathing by 30% while still providing a strong, invigorating spray.

Water consumption is reduced by 15% to 20%, resulting in lower environmental costs and reduced load on wastewater plants. Easy installation procedures make low-flow plumbing fixtures feasible for retrofitting. It is estimated that low-flow toilets alone could save up to 2,000 gallons of water per person.

Design Tools

None.

Design Details

Use aerators that deliver 0.5 gpm to 1 gpm of water for bathroom faucets.

Use aerators with higher flow rates (2 gpm to 3 gpm) for sink faucets that will be used for intensive washing purposes.

Operation and Maintenance Issues

Faucets should be periodically checked for leaks and repaired as needed. Leaky faucets can waste enormous amounts of water (up to tens of gallons in a single day).

Faucet aerators need to be checked periodically for clogging, some models clog more easily than others and may need to be cleaned too often to be effective. Some aerators may cause unacceptable performance or the perception of poor performance, resulting in an increase in water use.

Commissioning

Installation of low-flow plumbing fixtures is similar to that of conventional fixtures. Most of these fixtures require no special connections or fittings. Low quality showerheads may simply restrict water flow, which often results in poor performance.

References/Additional Information

American Water Works Association. 1401 New York Ave. NW, Suite 640, Washington, DC 20005. Phone: (202) 628-8303. Web site: http://www.awwa.org.

Plumbing Manufacturers Institute (PMI). 800 Roosevelt Road, Building C, Suite 20, Glen Ellyn, IL 60137. Phone: (708) 858-9172. Web site: http://www.pmihome.org.

RECYCLING SYSTEMS AND WASTE MANAGEMENT

This chapter provides guidelines for:

Paper, Plastics, Glass, and Aluminum Recycling (Guideline RS1)

Composting (Guideline RS2)

Construction and Demolition (C&D) Waste Management (Guideline RS3)

OVERVIEW

This section gives guidance on recycling systems and waste management at schools. Neither recycling systems nor waste management systems, such as composting, require extensive design accommodations. However, consideration of these issues during the design process, rather than after, can minimize waste streams and lower disposal costs, conserve natural resources, and provide an educational opportunity for students as well as teachers and administrators. Often, once site and building accommodations have been made for these systems, students can design and manage the programs as part of science or math curriculum.

The following guidelines cover recycling design requirements for paper, plastics, glass, and aluminum, as well as requirements for composting. For both, a comprehensive recycling and waste reduction plan is recommended.

However, recycling and waste management should begin long before the building is occupied. Environmental goals should not be compromised during high performance school construction. Construction and demolition (C&D) debris includes concrete, asphalt, wood, drywall, metals, and many miscellaneous and composite materials. Land clearing debris, such as stumps, rocks, and dirt, are also included in some state definitions of C&D debris. C&D work generates significant waste, with current estimates at 28% of the total waste tonnage.[1] A C&D waste management plan should either be part of an overall resource-efficient job-site operations plan (See Site Design chapter) or developed as a separate document.

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[1] http://www.ciwmb.ca.gov/ConDemo/factsheets/RecyProg.htm.

GUIDELINE RS1: PAPER, PLASTICS, GLASS, AND ALUMINUM RECYCLING

Recommendation

Require a comprehensive recycling and waste reduction plan. Develop a system for minimizing waste by recycling paper, plastics, glass, and aluminum products. Incorporate space for recycling receptacles in the design and construction of the school.

A well-coordinated school recycling plan requires minimal costs and can be more than offset by a reduction in waste pickup costs. NREL/PIX 11337

Description

An effective waste reduction plan will incorporate an organized system for recycling paper, plastics, glass, and aluminum, and will designate space to do so.

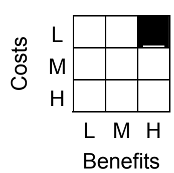
Applicability

Recycling is applicable in all climate zones and in all types of school spaces. While carried out during the operations phase, the recycling plan for a school should be considered throughout the design and construction process, ensuring that adequate space is designated for receptacles.

Applicable Climates

Applicable Spaces	
Classrooms	■
Library	■
Multipurpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	□
Construction	■
Commissioning	□
Operation	■



Integrated Design Implications

Space needed for waste disposal will be minimized with designation of space for recycling receptacles. Plans for recycling and garbage pickup service must be coordinated.

Cost Effectiveness

Implementing a well-coordinated school recycling plan is cost effective. If the school is also used as a recycling drop-off point for the community, it can be a cost-effective measure for the community as well. Minimal costs are involved, including the purchase or rental of recycling bins, possible pick-up costs, and possible labor costs associated with implementing and operating the recycling plan. The costs of a recycling program can be more than offset by the savings that result from reduced weekly trash pickups. Several cases indicate that a recycling program can result in a 40% to 60% reduction in number of weekly trash pickups. Recycling pickup should be coordinated with the garbage pickup service.

Benefits

A recycling program reduces the amount of waste produced, thereby reducing waste disposal costs. Recycling helps to ensure an adequate supply of raw materials for manufacturing recycled products. Environmental benefits include the conservation of energy, natural resources, and landfill capacity.

Design Tools

None.

Design Details

In several existing schools, space is an issue when it comes to recycling. School facility directors have commented on an inadequate amount of space, both indoors and outdoors, needed to accommodate the containment of recyclables. However, by keeping a recycling plan in mind during the design phase, recycling can become more convenient than disposal.

Collection points should be accessible throughout the school building and grounds. Recycling bins should be placed next to, or near, trash bins to make the choice to recycle easier.

Recommended collection points include:

- Classrooms (white and mixed paper)
- Break areas (aluminum cans, glass, and plastic bottles)
- Cafeterias (milk cartons, cardboard, aluminum and steel cans, glass, plastics)
- Supply or storage rooms (cardboard)
- Offices (white and mixed paper, cardboard)
- Near copiers and printers (paper)
- Machine shop areas (metals, wood, paper)
- Libraries (white paper, newspaper, magazines)
- Next to trash bins on the grounds of the facility.

In multi-floor areas of the school, chutes may be used to channel recyclables to central collection points. Glass, however, is not recommended for use in chutes, as potential for breakage increases with drop height.

The size of recycling bins should correlate with the amount of recyclables generated in particular areas. Smaller bins or containers (12 gallons to 18 gallons) can be used for collecting paper in classrooms or offices. Larger containers (30 gallons to 60 gallons) may be better suited near copy machines, in cafeterias, or in break rooms.

Space must be allocated on the school grounds for placing dumpsters for recycling and garbage pickup. At a minimum, allow space for one dumpster for cardboard, another for garbage, and one for glass/metal/plastic food and beverage containers. Depending on local sorting requirements for recyclables, glass, metals, and plastics may or may not need to be separated into their own receptacles. Accommodations for newspaper and white office paper recycling are also recommended.

In existing schools, conduct a waste audit to determine the amount of waste and recyclables generated on a monthly basis. Allocate space accordingly. The school's custodial staff can help design dedicated areas for recycling bins, recycling chutes, and other required elements.

For new school construction, determine the number of occupants who will be using the school. Contact existing schools of similar size who have conducted waste audits (or arrange to have one done for them) to estimate the typical amount of waste/recyclables generated and the subsequent space needed to accommodate them.

A typical elementary school cafeteria can distribute more than 1,000 milk cartons every week. Determine whether the local jurisdiction accepts this type of paper product for recycling. If so, allocate space and appropriately sized bins to accommodate milk cartons in cafeterias.

Operation and Maintenance Issues

A comprehensive recycling program must involve a coordinated effort with parties involved in waste disposal and composting.

Commissioning

None.

References/Additional Information

Connecticut Department of Environmental Protection. "Designing for Recycling in Schools: A Fact Sheet for Architects and Engineers," at http://www.dep.state.ct.us/wst/recycle/schplan.htm.

Los Angeles Department of Public Works, Elementary School Environmental Education Program. "Organizing Cafeteria Recycling Programs in Elementary Schools," at http://ladpw.org/epd/envdef/Teacher-PrincipalPacket.pdf.

U.S. Environmental Protection Agency. Office of Solid Waste. "How to Start or Expand a Recycling Collection Program," at http://www.epa.gov/epaoswer/non-hw/reduce/wstewise/pubs/howtopdf.pdf. January 1994.

U.S. Environmental Protection Agency. Office of Solid Waste. *The Consumer's Handbook for Reducing Solid Waste* at http://www.epa.gov/epaoswer/non-hw/reduce/catbook/. August 1992.

U.S. Environmental Protection Agency. Office of Solid Waste. "WasteWi$e Tip Sheet: Recycling Collection," at http://www.epa.gov/wastewise/pubs/collpdf.pdf. January 1994.

GUIDELINE RS2: COMPOSTING

Composting is applicable in all climates and reduces school waste streams. NREL/PIX 11336

Applicable Climates

Applicable Spaces	
Classrooms	■
Library	□
Multipurpose	■
Gym	□
Corridors	□
Administration	□
Toilets	□
Other	■

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	□
Construction	□
Commissioning	□
Operation	■

Recommendation

Incorporate composting into the recycling and waste management plan for the school. Recover food discards (meal preparation scraps and students' leftovers) and yard trimmings/gardening clippings for use as compost.

Description

Several methods exist for composting food discards and grass/yard clippings:

- Unaerated static pile composting
- In-vessel composting
- Vermicomposting
- Aerated windrow/pile composting.

Unaerated static pile composting is best suited for small operations like most schools; organic discards are piled and mixed with a bulking material. Unaerated static piles can be used in schools (and are cheaper than other composting methods as they do not require purchasing any vessels), though it is recommended that these be placed away from operable windows to reduce potential odor problems.

In-vessel composting can process larger quantities of material in a relatively small area more quickly than windrow composting and can accommodate animal products. Odors are not as great a concern since the process is enclosed and temperature and moisture are controlled. For these reasons, in-vessel composting is recommended for schools. Vessels come in a variety of sizes and have some type of mechanical mixing or aerating system.

Vermicomposting, which uses worms to break down organic materials into nutrient-rich soil amendment, is a tried-and-true composting method and can be a valuable teaching tool in the classroom. This method is faster than windrow or in-vessel composting and produces high quality composts. However, it cannot accommodate animal products or grease. Odors can be minimized by using the appropriate composting materials (see Design Details below).

Aerated windrow/pile composting may be better suited for larger operations than schools, but can accommodate large quantities of organics — organics are formed in rows or long piles and aerated either passively or mechanically.

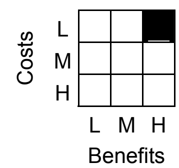
Applicability

Composting is applicable in all climates and in the following spaces: cafeterias, landscaping, and classrooms. Consider a composting strategy during the design development and operation phases.

Integrated Design Implications

A comprehensive composting strategy that recycles food scraps and yard trimmings can significantly reduce the amount of solid waste produced at a school facility, and, therefore, may reduce the need for conventional waste bins. Bins targeted specifically for collecting composting materials should be used instead. Aside from small vermicomposting projects in the classroom, composting areas should be located away from operable windows to reduce potential odor problems.

Cost Effectiveness



Composting can be quite cost effective. Materials costs are minimal and creating compost to use as a soil amendment saves on purchase costs for new soil amendments. Compost can even be sold to consumers, with some schools having sold their compost as a fundraiser. Incorporating the composting process into the school curriculum not only provides a powerful teaching tool for students, but also cuts down on operating costs.

Benefits

The benefits and applications of composting are numerous. Compost can be used for bioremediation and pollution prevention, disease control for plants and animals, erosion control and landscaping, treating contaminated soils, reforestation, wetlands restoration, and habitat revitalization. Economic benefits include avoided costs from reducing or eliminating the need for soil amendment purchases, as well as reduced or avoided landfill or combustor tipping fees. Where applicable, there may be an added benefit of revenue from selling the finished product or recyclable.

Environmental benefits of composting include extended landfill longevity. Compost-enriched soil can help suppress diseases and ward off pests, thereby reducing dependence on pesticides. It can also be used to reduce erosion and nutrient runoff and can alleviate soil compaction. Allowing students to play an active role in their school’s composting program can be a valuable teaching tool.

Design Tools

None.

Design Details

Outdoor composting bins should be kept away from direct sunlight, which may dry out the pile, and from strong winds that may also dry and cool the pile. Locate bins close to a water source in case they become too dry. Ensure that the pile has good drainage, as this will avoid standing water and the build-up of anaerobic conditions. Compost piles should be kept at a distance from wooden structures or trees to avoid causing decay. Allocate space for temporary storage of organic wastes.

Composting inside the classroom can be carried out in containers as small as soda bottles or as large as garbage cans. They must be carefully designed to provide the proper aerobic, heat-producing conditions necessary for composting to occur. For different types of composting methods suitable for the classroom, consult Cornell University’s “Composting in Schools” web site (listed in the References/Additional Information section below).

Yard Trimmings

Leave grass clippings on lawns to reduce the amount of waste that must be collected. Grass clippings increase the soil’s organic content, and also help the soil to retain moisture and nutrients, resist erosion, and maintain cooler temperatures in summer. Yard wastes such as leaves, grass, prunings, weeds, and remains of garden plants can all be used as compost, unless they have been chemically treated with pesticides or herbicides. Clip, saw down, or shred woody yard wastes to speed the composting process.

Other Compostable Materials
Other materials that can be composted include vacuum cleaner lint, wool and cotton rags, sawdust, shredded newspaper, and fireplace ashes. All of these compostable materials can be stored and composted together. Food discards should be kept in separate bins. For details on setting up and operating a compost system for yard trimmings, consult the links in the References/Additional Information section below.

Vermicomposting with Food Discards
Composting with worms is a method for recycling food waste into a rich, dark soil conditioner. It can be done indoors or outdoors, allowing for year-round composting. Use food scraps such as raw fruit and vegetable scraps, pulverized eggshells, tea bags, and coffee grounds. According to a U.S. General Accounting Office (GAO) report, on average, 30% of raw vegetables/salad and 22% of fresh fruit are wasted in school cafeterias. A breakdown of typical food portion wasted by food type in schools can be noted in the following graph from this GAO report.

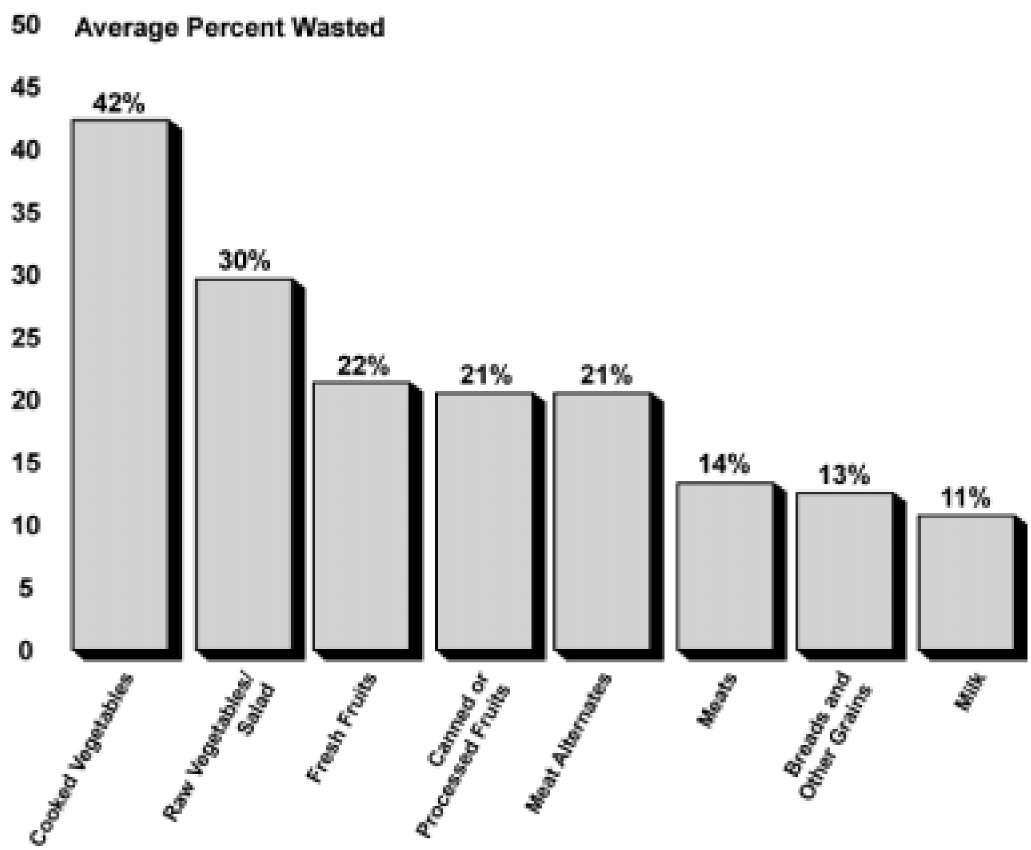


Table 1 – Amount of Food Portion Wasted by Food Type

The following figure from the same GAO report shows the percentage of foods wasted by school level (elementary, middle, high school).

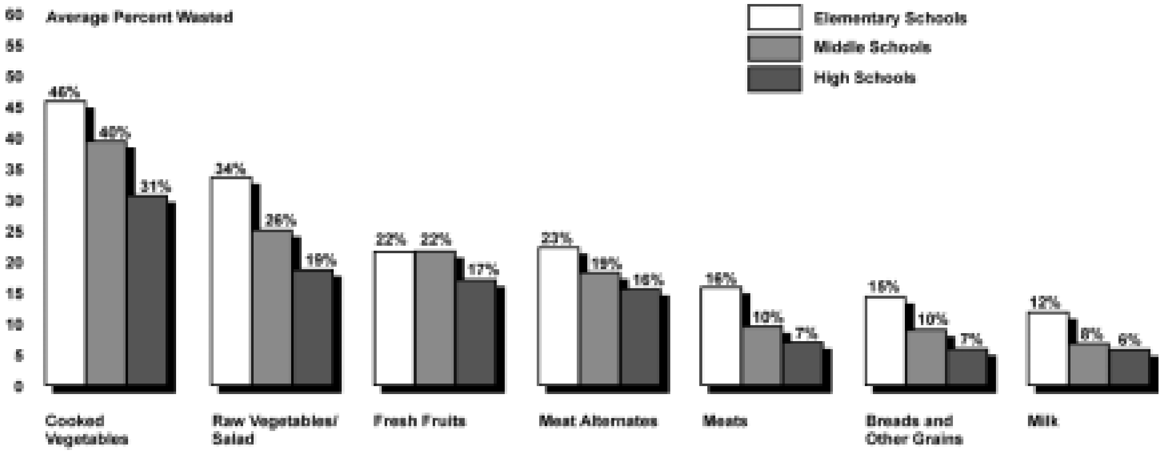


Figure 2 – Variation in Amount of Waste by School Level for Seven Food Types

Avoid foods such as orange rinds and other citrus fruits, which are too acidic and can attract fruit flies. Also try to avoid onions and broccoli because of their strong odor. Otherwise, the more vegetable matter, the better. Other foods that are not advisable for composting are oily foods, meats, dairy products, and grains — they take longer to break down which may attract pests and cause odor problems.

To set up the worm bin, use a box (provide 1 ft^2 of surface area/lb of food scraps), moist newspaper strips, and red or red wiggler worms (*Eisenia foetidia* or *Lumbricus rubellus*), which can be ordered from a worm farm and mailed to the school. For every 1 lb of food waste, use 2 lbs of worms (roughly 2,000 worms). Temperatures for worm bins should be 40°F to 80°F. In colder weather, the bins should be well-insulated. For more details on setting up and operating a worm-composting bin, consult the links below.

Operation and Maintenance Issues

A comprehensive composting program must involve a coordinated effort among all parties involved in waste disposal and recycling. In cases where composting is used as a teaching tool either in or out of the classroom, students can be responsible for maintaining the compost piles/bins with some guidance.

Commissioning

None.

References/Additional Information

Cornell University. *Cornell Composting: Composting in Schools.* Web site at http://www.cfe.cornell.edu/compost. The Cornell University Resource Center (resctr@cornell.edu) also has several resources available, both written and audio-visual.

City Farmer, Canada’s Office of Urban Agriculture. “Composting With Red Wiggler Worms.” http://www.cityfarmer.org/wormcom61.html. 1995.

New Hampshire Department of Environmental Services and New Hampshire Governor’s Recyling Program. *Composting at New Hampshire Schools: a “How to” Guide.* http://www.state.nh.us/recycle/guide.pdf. Spring 1997.

U.S. Environmental Protection Agency. Office of Solid Waste. *Composting Yard Trimmings and Municipal Solid Waste.* http://www.epa.gov/epaoswer/non-hw/compost/cytmsw.pdf. May 1994.

U.S. Environmental Protection Agency. Office of Solid Waste. “Don’t Throw Away That Food: Strategies for Record-Setting Waste Reduction.” http://www.epa.gov/epaoswer/non-hw/reduce/food/food.htm.

U.S. Environmental Protection Agency. Office of Solid Waste Environmental Fact Sheet, “Recycling Grass Clippings.” http://www.epa.gov/epaoswer/non-hw/recycle/grass.pdf. July 1992.

U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response Environmental Fact Sheet, “Yard Waste Composting.” May 1991.

U.S. General Accounting Office Report: RCED-96-191: “School Lunch Program…views on food wasted.” http://www.gao.gov/. July 1996.

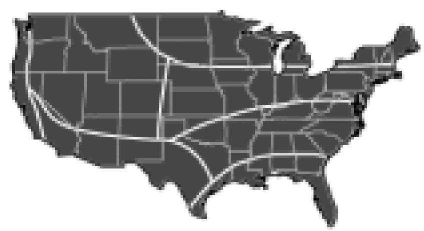
GUIDELINE RS3: CONSTRUCTION AND DEMOLITION (C&D) WASTE MANAGEMENT

Recommendation

Require waste reduction planning and job-site practices. These guidelines recommend that an environmentally friendly job-site operations plan (Guideline SD8) be developed that incorporates a job-site waste reduction component. An alternative is to develop a stand-alone Construction and Demolition (C&D) Waste Management Plan.

A construction site waste audit can help reduce waste generated and divert materials through processes from disposal through reuse and recycling. NREL/PIX 11407

Applicable Climates



Applicable Spaces	When to Consider
Classrooms	Programming
Library	Schematic
Multi-Purpose	Design Dev.
Gym	Contract Docs.
Corridors	Construction
Administration	Commissioning
Toilets	Operation
Other	

Description

Effective job-site waste management will reduce the amount of C&D waste generated, as well as divert materials generated through C&D processes from disposal through reuse (salvage) and recycling. This effort can be combined with a concerted use of salvaged or recycled-content building materials throughout the building project; specific materials would be called out in appropriate sections of project specifications.

C&D waste management will include developing a waste reduction plan, identifying personnel responsible for implementing and monitoring the plan, and outlining the consequences for non-compliance. Waste management should reflect the prioritized hierarchy of “Reduce, Reuse, and Recycle” with recycling efforts occurring in concert with *source reduction* and applying only to materials that *cannot be reused*. The concept of source reduction eliminates or reduces potential waste prior to generation. By reducing waste and using materials efficiently, money will be saved on purchasing and avoided disposal costs. If materials are not generated in the first place, recycling efforts should only apply to materials that cannot first be reused.

Applicability

Construction waste management is applicable in all climates and in all types of school spaces. While carried out during the construction phase, the contract documents must clearly lay out the responsibilities of the general contractor.

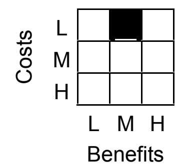
Integrated Design Implications

Some waste reduction can be designed into the building project, such as standardized dimensioning, modular or panelized building units, and layout of openings (see the Energy-Efficient Building Shell chapter). Specifying the use of mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents will allow components to be easily disassembled and reused.

It is important to make the intent of these design details clear to avoid in-the-field decisions that waste materials. Contractors are excellent problem solvers and should be encouraged to find cost-effective substitutes that they know will meet or exceed the environmental goals.

Improper materials handling on the job site can add to the construction waste. Materials contaminated by mildew and mold due to moisture exposure have to be discarded and replaced.

Cost Effectiveness



Costs include labor for overseeing and implementing the C&D waste reduction (or waste management) plan, rental for additional bins or other containers used for recycling or salvage, and transportation. Research indicates labor costs decrease significantly as contractors become more familiar with job-site waste reduction techniques. Some contractors keep costs down by utilizing temporary lay down areas with plywood barriers to hold recyclables, rather than renting bins or containers. Alternatively, planning ahead and ordering bins only when needed can keep down costs, since C&D materials are typically generated at predictable phases of the project.

Waste disposal/management is generally budgeted as a very small portion of overall job costs. However, the cost of purchasing materials to replace materials that are wasted is rarely taken into account. The tendency is to assume that effective waste reduction takes more time and results in higher costs, but case studies show that, if labor crews are adequately trained and a good plan is in place, costs do not increase.

Benefits

In general, C&D waste reduction should also reduce overall construction costs, especially as the practice becomes a part of every job and the C&D recycling/reuse infrastructure matures. If revenues from waste reduction, reuse/salvage, and recycling are allocated to the contractor, the responsibility (and the incentive) for waste reduction clearly lies in the contractor’s domain. Most contractors report that having a good waste reduction program in place results in a cleaner, safer site, resulting in less lost time and delay.

Environmentally, less waste means better use of limited raw materials and of the energy required to produce, transport, and dispose of building products used in the project. Also, recycling provides “stock” for new materials to be manufactured.

Design Tools

See the sample specifications included in *Green Spec: The Environmental Building News Product Directory and Guideline Specifications*.

Design Details

Scheduling should permit salvaging and deconstruction activities, as appropriate.

Waste reduction goals (as with all other resource-efficient building goals) should be outlined in the Instructions to Bidders section of the Project Summary. In addition, waste reduction specifications should be included in the Temporary Controls sections of General Conditions.

As part of identifying those materials that should be targeted for recycling or reuse in a particular project, contact the local waste authority for information about building materials that can be cost-effectively recycled or salvaged in the project area. These materials, an example being gypsum drywall, should be called out for recycling in the General Conditions specifications section pertaining to waste reduction and in other pertinent sections.

Waste reduction specifications should reflect local jurisdictional requirements, but should be organized using typical CSI convention. The specifications should describe what is included in the job-site waste reduction plan, outline submittal and documentation requirements; indicate ownership of revenues resulting from waste reduction efforts; and include performance goals like minimum levels of waste reduction. The specifications should also outline remedies in the event those levels cannot be met.

If the contractor is required by ordinance or specification to be responsible for achieving waste reduction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative to contractors to include a list of proven waste reduction strategies, such as:

- A pre-C&D waste management meeting to discuss procedures, schedules, coordination, and special requirements for materials.
- A waste-reduction provision in supply agreements specifying a preference for reduced, U-turn, and/or recyclable packaging.
- Detailed take-offs that identify location and use in the structure to reduce risk of unplanned and potentially wasteful cuts.
- Proper storage for materials to avoid water or other damage as well as outdating. Materials that become wet or damp due to improper storage shall be replaced at contractor's expense.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the waste reduction plan. Signage should be clear and easy to understand for multiple languages (use graphic symbols).
- On-site instruction regarding appropriate separation, handling, recycling, salvage, reuse, and return methods to be used to achieve waste reduction goals.
- Discussion of C&D waste management during regular job meetings and safety meetings.
- Contamination protection for materials to be recycled.

Operation and Maintenance Issues

Contractors should be required to provide sufficient information on product substitutions to enable the operation and maintenance staff to properly maintain, repair, and replace all products.

Commissioning

None.

References/Additional Information

California Integrated Waste Management Board web site. In particular, see "Job Site Source Separation," a fact sheet located at http://www.ciwmb.ca.gov/ConDemo/factsheets/JobSite.htm. Also see the Clean Washington Center's *Recycling Plus Manual* at http://www.ciwmb.ca.gov/ConDemo/Links.htm. Use this resource to produce a step-by-step construction waste management and recovery plan. *Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction*. Chapter 9, Managing Job-Site Waste, addresses C&D waste and is located at http://www.ciwmb.ca.gov/ConDemo/Pubs.htm.

U.S. Environmental Protection Agency, *Characterization of Building-Related Construction and Demolition Debris in the United States*, June 1998, at http://www.epa.gov/epaoswer/hazwaste/sqg/demol.htm. Provides national data that a builder may find helpful to estimate and characterize his own waste generation.

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org.

TRANSPORTATION

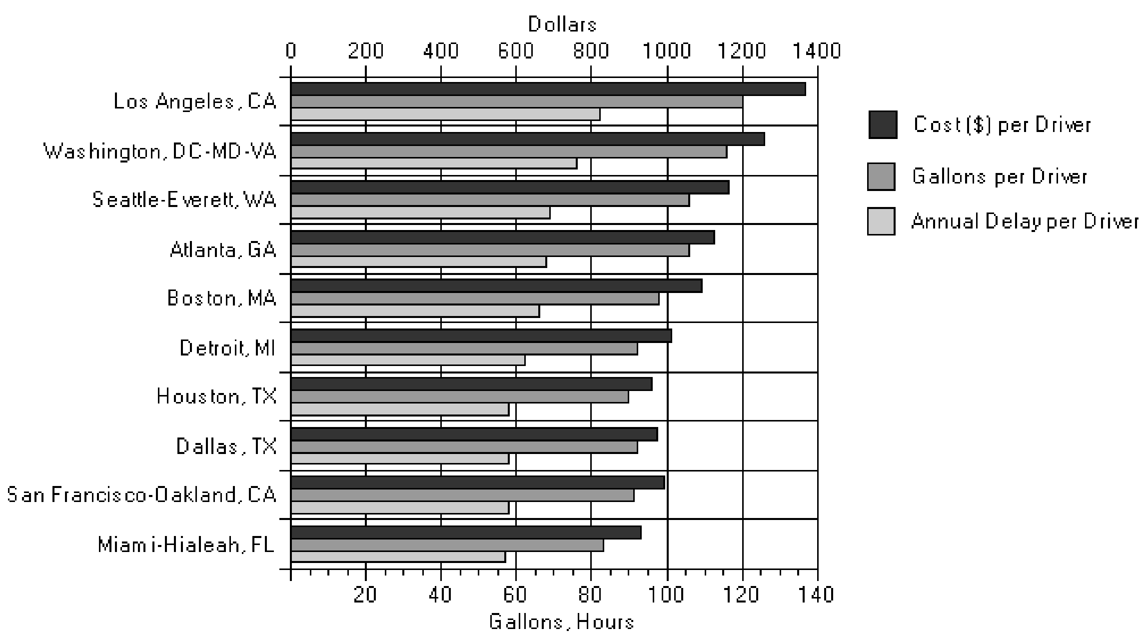
This chapter provides guidelines for:

Transportation and Site Design (Guideline TR1)

Alternative Fuel Vehicles (Guideline TR2)

OVERVIEW

In many school districts across the country, more energy dollars are spent by the school system in transporting students to and from school than in meeting the energy needs of their school buildings. Careful site planning can help promote alternative transportation. Locating the site close to public transportation and offering bus service will help reduce the automobile-related congestion and pollution. Up to 40% of morning traffic congestion at schools is a result of parents driving children to school. Even if the school location has already been selected, the site design can include features to encourage students, staff, and parents to leave their cars at home. Incorporating a network of safe walkways, bike paths, and carpool and vanpool locations into a school design can reduce local traffic congestion, minimize busing costs, and reduce air pollution. The figure below shows the cost per driver, gallons of fuel used per driver, and annual delay per driver in 10 major cities across the country.



Source: Texas Transportation Institute, 1999 Urban Mobility Study, *November 1999*

Figure 1 – Comparison of Costs for Drivers in 10 U.S. Cities

ALTERNATIVE FUELS

Incorporating natural gas, biodiesel, methanol, or electric vehicles into a district's existing vehicle fleet can help to reduce fuel costs, reliance on foreign oil, and harmful emissions — contributing to reduced operating and maintenance costs. The reduced cost of fuel will largely depend on individual state incentives and regional pricing of fuels.

Today, nearly 60% of all school buses run on diesel, a highly-polluting transportation fuel that poses considerable health risks.[1] Due to particulate emissions, the use of diesel fuel is increasingly becoming associated with increased asthma rates and other lung-related diseases. Alternative fuel buses and school fleet vehicles can be used to provide environmentally friendly alternatives to high-polluting vehicles. Options for alternative fuel buses include electric, hybrid electric, compressed natural gas, ethanol, methanol, and biodiesel — all of which are available on the market for a variety of vehicle types. In addition to long-term energy savings, these vehicles serve as great educational tools for the students and the community.

Table 1 – Varieties of Alternative Fuels

	Compressed Natural Gas (CNG)	**Ethanol (E85)**	**Methanol (M85)**
Chemical Structure	CH4	CH3CH2OH	CH3OH
Primary Components	Methane	Denatured ethanol and gasoline	Methanol and gasoline
Main Fuel Source	Underground Reserves	Corn, grain, or agricultural waste	Natural gas, coal, or woody biomass
Energy Content Lower Heating Value	20,550 Btu/lb	80,460 Btu/gallon	65,350 Btu/gallon
Energy Ratio Compared to Gasoline*	3.0 to 1 at 3600 psi	1.42 to 1	1.75 to 1
Liquid or Gas	Gas	Liquid	Liquid

*****Ratio tells how much space is needed to store the same amount of energy.
Source: http://www.afdc.doe.gov/questions.html, 2/13/02.

Electric Vehicles

Although a school bus can be powered by pure electricity, only a few electric school bus options are currently available due to the shorter driving range provided by electric power. However, small maintenance carts and other vehicles that are used by school officials and staff are available using electricity as a fuel. Electric vehicles typically have limited ranges based on the type of battery, so they can be great for short trips and stop-and-go driving. Electric vehicles reduce local pollution, and using a renewable energy source limits regional pollution.

[1] Alternative Fuels Data Center website: http://www.afdc.doe.gov/questions.html. 2/13/02.

Different types of batteries for electric vehicles are available, two of which are lead acid and nickel metal hydride.

Lead Acid

This is the most commonly used and least expensive battery technology. Generally, the vehicles have a range of less than 100 miles/charge, and the life of the battery is about three years. Chrysler, Ford, GM, and Toyota vehicles use this battery technology.

Nickel Metal Hydride (NiMH)

NiMH offers a range of about 100 miles/charge, but is more expensive. The life expectancy of the battery is about 100,000 miles. Chrysler, Ford (California only), GM, Honda, and Toyota offer vehicles with NiMH technology.

To ensure availability of “fuel,” the school or school system should provide a charging station for electric vehicles. These charging areas can be viewable by students to assist with teaching about renewable energy and can include displays to indicate the environmental benefits that the station is providing.

Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle to result in twice the fuel economy of conventional vehicles. This combination offers the extended range and rapid refueling that consumers expect from a conventional vehicle, with a significant portion of the energy and environmental benefits of an electric vehicle. HEVs can be fueled by conventional and alternative fuels. Propane- and natural gas-fueled hybrid electric buses are currently in service at several U.S. transit agencies. HEVs fueled by petroleum are not technically alternative fuel vehicles but they do help reduce petroleum use and produce fewer emissions than conventional gas and diesel vehicles. The practical benefits of HEVs include improved fuel economy and lower emissions compared to conventional vehicles. The flexibility of HEVs allow them to be used in a wide range of applications, from personal transportation to commercial hauling.

HEVs often have the same power as conventional vehicles, but do not have the reduced driving range that electric vehicles have. There are several options for HEV buses available today, and there are currently two HEV automobiles that can be used as school fleet vehicles. HEVs can be produced in a variety of ways, but typically the battery pack helps supplement the vehicles’ power when accelerating and hill climbing. During stop-and-go driving, both the internal combustion engine and batteries work together. For extended highway driving, the engine does most of the work because it operates most efficiently under those conditions. These vehicles provide much better gas mileage than conventional vehicles and are a valuable teaching tool to students.

The HEVs, in particular light-duty vehicles, available for sale are very cost competitive with similar conventional vehicles. Overall fuel savings and state and federal incentives can offset any financial premium that may be associated with HEVs.[2]

Ethanol

Ethanol is typically produced from domestic-grown, plant-based materials such as corn or other grains. For school districts using ethanol fuel, several vehicle choices are available. Ethanol fuel can be found at fueling stations across the country; however, some areas have more stations than others. Vehicles using ethanol perform as well as typical conventional vehicles. Under current conditions, the use of ethanol-blended fuels such as E85 (85% ethanol and 15% gasoline) can reduce the net emissions of greenhouse gases by as much as 37%.

Compressed Natural Gas Vehicles

Compressed natural gas (CNG) vehicles operate just like any other conventional vehicles — drivers cannot tell the difference in performance. Compressed natural gas buses are being used by many school districts across the nation. Compressed natural gas is recommended for schools because the vehicles are readily available and the fuel is considerably less expensive than gasoline. The San Marcos Unified School District in Northern San Diego County, CA, recently added six CNG buses to their fleet and report the cost per mile for CNG is $0.12 compared to $0.32 for diesel.[3] Several compressed natural gas sedans and trucks are also produced by auto manufacturers and would be good options for use in school fleets. Exhaust emissions of nitrogen oxides and particulates from natural gas vehicles are significantly lower than those from diesel powered vehicles.[4]

References/Additional information

Alternative Fuels Data Center website: http://www.afdc.doe.gov/questions.html.
Office of Transportation Technology: http://www.ott.doe.gov/vehicle_purchasing.shtml.
Clean Cities Program website: http://www.ccities.doe.gov/success/government.shtml - school_buses.

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[2] For a list of state/federal incentives, go to the Office of Transportation Technology: http://www.ott.doe.gov/vehicle_purchasing.shtml.

[3] For success stories go to the Clean Cities Program website: http://www.ccities.doe.gov/success/government.shtml#school_buses

[4] Ibid.

Guideline TR1: Transportation and Site Design

Recommendation

Locate schools and design school sites to encourage car/vanpooling and pedestrian modes of transportation, rather than single-use automobile transportation.

Incorporate safe and effective parking and storage for bicycles, skateboards, roller blades, scooters, etc.

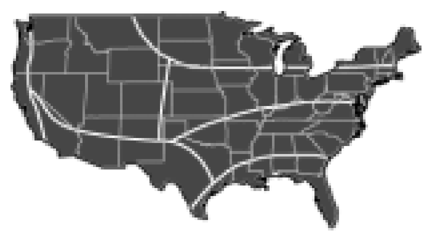
Use site design to connect the school to the community.

Designing bike and pedestrian paths and facilities for shared vehicle transportation helps to reduce morning traffic congestion at schools. NREL/PIX 09075

Description

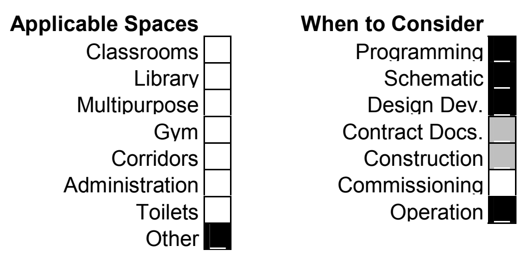
Up to 40% of morning traffic congestion at schools is a result of parents driving children to school. To reduce this congestion, schools should implement strategies encouraging the use of energy-efficient transportation alternatives including providing bike and pedestrian paths and providing facilities for shared vehicle transportation (car/vanpools, mass transit).

Applicable Climates



Applicability

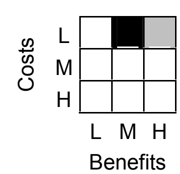
All climates.



Integrated Design Implications

This guideline should be addressed in the site selection and site planning stage. Also incorporate these strategies into the building and site design stages, especially when looking at access, circulation, and parking lot design. Be sure to locate parking lots and other sources of pollution away from fresh air intake ducts to preserve indoor air quality. Give adequate space for sidewalks, keeping the parking lot further from the school buildings.

Cost Effectiveness



Costs will vary with the strategies selected. In most cases, additional costs are minimized when integrated early into site/building design. Added costs will be offset by reduction in parking lot size.

The cost premium for providing for energy-efficient and environmentally safe transportation may be offset by grants offered by various agencies.

Benefits

Benefits include reduced automobile use, reduced traffic congestion, improved urban air quality, improved sense of community, and more efficient use of site (if parking lot size is reduced).

Design Tools

IESNA. 1980. RP-8 Roadway Lighting, Chapter 4, Pedestrian Walkway and Bikeway Lighting Design, Illuminating Engineering Society of North America (IESNA), New York. This document contains guidelines for designing fixed lighting for roadways, bikeways, and pedestrian paths.

Design Details

- Provide good access to public transit.
- Require pedestrian- and bike-friendly features including pedestrian paths and walkways, bike paths, safe and accessible bike storage, and showers/changing facilities. Although cyclists and joggers can change in washrooms and store a change of clothes in the workplace, dedicated facilities are more likely to encourage regular human-powered commuting. Provide changing rooms, lockers, and showers for employees. Connect changing room, shower, and locker facilities with bicycle storage, washroom facilities, or pools. Provide sufficient showers to avoid wait at peak times, and to accommodate growing use. Provide separate change/shower rooms for males and females, if possible. Facilities must be accessible to building occupants, but not to the general public or visitors.
- Building design can encourage carpooling and vanpooling by giving priority to shared transportation and by making waiting areas convenient.
- Ensure commuter safety with building lobbies that view waiting, pick-up, and drop-off areas, occupied windows that overlook them, good lighting, and, if necessary, prominent surveillance cameras. Eliminate potential hiding places for criminals. Ensure that sheltered areas are visible from the street and/or parking areas, sidewalk, and school building. Heavy and massive arcades and other features can obscure visibility and affect pedestrian safety.
- Locate carpool and vanpool parking spaces closer to the building entrance than other single-use automobile parking. Post prominent signage to identify the location of carpool and vanpool parking and pick-up areas. Provide comfortable waiting areas to encourage carpool and vanpool commuters. Consider amenities such as sunshades, rain canopies, seating, and bulletin boards.
- Design the school so that the athletic fields, gymnasium, media center, and classrooms are accessible and can be shared at appropriate times with the community.

Operation and Maintenance Issues

None. The work is done in designing stage.

Commissioning

Discuss the layout of school in relation to the community. Closely examine the plans with a whole-community view to make sure all inter-related components work well together.

References/Additional Information

Bicycle Federation of America. Internet Resource Center. Comprehensive coverage of a host of guidelines supporting bicycle use. http://www.bikefed.org/. April 1999.

Cox, E. *Long Term Bike Parking*. Useful overview of design considerations for long-term bicycle storage offering essential and optional features for caged facilities, bike rooms, bike lockers, and shower and clothes locker rooms. http://www.jps.net/cbc/longbikepark.html. April 1999.

Woodhull, J. 1992. *How Alternative Forms of Development Can Reduce Traffic Congestion.* Sustainable Cities; Concepts and Strategies for Eco-City Development, Ed. Bob Walter et al. Los Angeles: Eco-Home Media. Offers alternative approaches to traffic planning, concentrating on "access" rather than mobility. Covers densification, parking, and development patterns and offers solutions for pedestrian-friendly, transit-oriented development.

U.S. Department of Energy, Clean Cities Program. Program promotes building infrastructure to encourage smart transportation decisions. http://www.ccities.doe.gov/.

GUIDELINE TR2: ALTERNATIVE FUEL VEHICLES

Recommendation

Using alternative fuel vehicles can reduce criteria pollutants and greenhouse gas emissions as well as help educate students about greener alternatives for transportation. Alternative fuel vehicles are low-emission, high-efficiency vehicles that lower costs in the long-term, improve local air quality, and reduce reliance on petroleum.

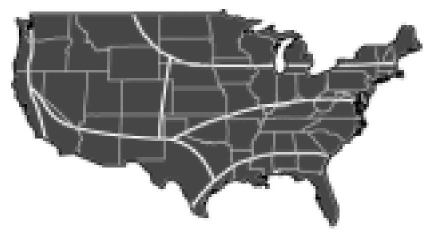
Alternative fuel vehicles have been shown to reduce operation and maintenance costs.

NREL/PIX 01552.

Description

The alternative fuel vehicles that currently exist on the market include electric, hybrid, ethanol, compressed natural gas, and biodiesel. Many of these vehicles are available as buses, but some are only available as cars or vans, in which case they can be used for transporting smaller groups or for within-town errands.

Applicable Climates



Applicable Spaces	
Classrooms	☐
Library	☐
Multipurpose	☐
Gym	☐
Corridors	☐
Administration	☐
Toilets	☐
Other	■

When to Consider	
Programming	☐
Schematic	☐
Design Dev.	■
Contract Docs.	☐
Construction	☐
Commissioning	☐
Operation	■

Applicability

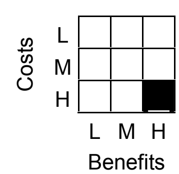
All climates.

Integrated Design Implications

Fueling stations for compressed natural gas and ethanol-fueled vehicles will need to be provided or be locally accessible.

Education on alternative fuels can be promoted by including prominent signage.

Cost Effectiveness



Compressed gas vehicles are very cost effective. Antelope Valley Schools Transportation Agency reports compressed natural gas buses with John Deere engines have maintenance costs of $0.13/mile, versus $0.24 for their standard diesel buses and $0.21 for advanced diesel buses.

Biodiesel is an inexpensive and quick way to change fleets and reduce emissions. Biodiesel (B20) costs $0.13 to $0.22 more per gallon than diesel, but it uses existing infrastructure and vehicles with little or no modifications to the engine.

Benefits

Alternative fuel vehicles have been shown to reduce operation and maintenance costs.

Propane and compressed natural gas cost less on an equivalent-gallon basis than gasoline or diesel, and natural gas results in reduced soot formation, less fouling of engine oil, and significantly less carbon deposits in these engines.

Alternative fuel fleets also achieve improved emissions. Diesel engines emit, on the average, 58% more smog-forming NOx and 89% more particulate matter (PM10) than a natural gas engine, both certified within the same year. Biodiesel cuts exhaust emissions, minimizing black smoke, odor, greenhouse gas emissions, air toxics, and particulates. Biodiesel also does not contribute to sulfur dioxide emissions that result in acid rain.

Design Tools

Alternative Fuel Bus Utility Software Version 1.01 (01/2001). Provided by the U.S. Department of Energy, Clean Cities Program.

Design Details

None.

Operation and Maintenance Issues

In general, alternative fuel vehicles require less maintenance than conventional vehicles. The operators should be made aware of the type of vehicle that they are driving and know the best way to get the most from that machine. The savings in maintenance can be used to educate the operators.

Commissioning

None.

References/Additional Information

Center for Transportation Technologies and Systems: a division of the National Renewable Energy Laboratory that strives to develop alternative fuel and advanced vehicle technologies. http://www.ctts.nrel.gov/.

U.S. Department of Energy, Clean Cities Program. Program promotes building infrastructure to encourage smart transportation decisions, including alternative fuel vehicles. Web site: http://www.ccities.doe.gov/.

U.S. Department of Energy, Clean Cities Program. “Making the Grade: Alternative Fuel School Buses.” January 2001. Call 1-800-DOE-EREC for more information.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. “Biodiesel Offers Fleets a Better Alternative to Petroleum Diesel.” Technical Assistance Fact Sheet. Clean Cities Alternative Fuel Information Series, May 2001.

U.S. Department of Energy. Office of Transportation Technologies, the Department of Energy’s alternative fuel technology research center. http://www.ott.doe.gov/.

RESOURCE-EFFICIENT BUILDING PRODUCTS

This chapter provides guidelines for:

Guideline
Carpeting (Guideline BP1)
Resilient Flooring (Guideline BP2)
Ceramic Tile/Terrazzo (Guideline BP3)
Concrete Flooring (Guideline BP4)
Wood Flooring (Guideline BP5)
Bamboo Flooring (Guideline BP6)
Gypsum Board (Guideline BP7)
Acoustical Wall Panels and Ceilings (Guideline BP8)
Paints and Coatings (Guideline BP9)
Casework and Trim (Guideline BP10)
Interior Doors (Guideline BP11)
Toilet Partitions (Guideline BP12)

OVERVIEW

The guidelines in this chapter provide advice on selecting flooring, wall and ceiling finishes, other interior surfaces, and their associated coatings and adhesives. When selecting interior surfaces for high performance schools, designers should consider two questions:

- Does this product introduce chemical compounds into the space that will affect IAQ?
- Is this a material-efficient product?

While many other characteristics, including acoustical performance and visual appearance, factor into product decisions, selecting material-efficient products that do not degrade IAQ are the main goals addressed in these guidelines. Evaluating resource efficiency and VOC emissions is an emerging science with many uncertainties. No material or product is going to be optimum with regard to all the criteria. Choosing materials and products requires some professional judgment as to which of the criteria should be given the greatest weight.

Indoor Air Quality

Since most school occupants are children or adolescents with still-developing respiratory systems, the importance of IAQ is heightened. The metabolic rates of children are significantly greater than adults, causing them to breathe more air and, as a result, absorb and retain more toxins. In addition, children's immune systems are less effective.

The U.S. EPA documents that Americans spend more than 90% of their lives indoors, and that pollutant concentrations inside buildings are two to five times greater than those outdoors. News reports and scientific inquiries have brought increased attention to the symptoms and causes of poor IAQ. Symptoms range from mild discomfort (sick building syndrome) to more severe illness and permanent injury (building-related illnesses and multiple chemical sensitivity). Health effects include headaches, fatigue, memory problems, eye irritation, and coughs.

Providing improved IAQ over the life of the building is a fundamental goal when designing high performance schools.

There are four principles in designing good IAQ and they all need to be implemented as a whole:

1. Source control: Reduce and/or eliminate the source of contaminants in buildings.
2. Ventilation control: Provide adequate ventilation to dissipate the contaminants in buildings. Contaminants emanate from the building contents, equipment, occupants, and outside air.
3. Building commissioning: Building commissioning is a process used during the design, construction, and post-occupancy phases of a project to ensure that the project is built and performs as designed, and that the systems and equipment function as intended.
4. Building maintenance: Buildings require regularly scheduled maintenance and cleaning to ensure that they perform throughout their life as they did when first constructed. Using environmentally friendly cleaning agents will reduce the opportunity for air contamination during the building's life.

Designers have a large impact on the selection of building materials, and therefore should seek to reduce or eliminate potential sources of indoor air pollution by selecting the lowest odor, least toxic, lowest emitting, most moisture resistant, and most durable materials that can be safely installed and maintained.

Indoor pollutants include VOCs, microbial volatile organic compounds (MVOCs), particulates, inorganic compounds (such as CO_2, CO, and ozone), and semi-volatile organic compounds (SVOCs), such as pesticides and fire retardants. Pollutant sources include the outside air, construction materials, furnishings, the building envelope, equipment, maintenance, and the occupants themselves. VOCs are of special concern because they can damage the natural environment during building material production and disposal, create hazards for installers and manufacturers, as well as cause health problems for building occupants.

VOCs are some of the most commonly discussed chemical emissions that affect IAQ. VOCs can occur in the air at normal environmental conditions and are emitted from interior materials such as paints, adhesives, sealants, sealers, carpets, resilient flooring, furniture, and ceiling panels. Materials and products emit ("off-gas") VOCs during and after installation, which can cause health problems for construction workers and building occupants.

Concentrations of several VOCs and formaldehyde are currently found in indoor air. In the indoor environment, formaldehyde can cause several health problems for occupants, including skin and eye irritation, upper respiratory system irritation, and symptoms of sick building syndrome. Formaldehyde is a known carcinogen so human exposure should be minimized, and indoor air concentrations should be kept as low as is reasonable to achieve.

In many cases, the best products, with the lowest VOC emissions, are made from water-based constituents. This said, it is also important to select materials that are easy to clean and maintain without the use of odorous, irritating, or toxic cleaning supplies.

Designers should also be aware that a product can be labeled as "low-VOC" or even zero-VOC and still emit VOCs that are odorous, toxic, or otherwise undesirable. Even small quantities of some chemicals can create problems indoors. The EPA VOC labeling requirements do not provide a straightforward way to compare VOC content since labels are required to only list chemicals classified as reactive, with the potential to create smog. Unlabeled non-reactive VOCs may react with oxidants to form odorous, irritating, or toxic chemicals in the indoor environment. While some VOC emissions may not cause an *air quality* problem for occupants, they may still be hazardous to installers and manufacturers.

VOC emissions are generally highest immediately after a new product is installed or a finish is applied, but emissions may continue for days, weeks, or months; and actual emission rates will be impacted by the ventilation conditions, indoor temperature, and humidity conditions. Even with low VOC-emitting materials, it is important to provide temporary ventilation during and after installation. However, the length of the required venting period depends on the amount of surface covered, as well as the volatility and toxicity of the finish. In addition, it is recommended that, prior to substantial completion, each school be flushed out with 100% outside air for about 15 calendar days, or as long as possible, to remove any remaining odor and VOCs.

Fleecy and absorbent surfaces such as carpets, wall coverings, window coverings, and ceiling tiles should be protected from exposure to the air during periods of high VOC emissions. Even better, construction work should be sequenced so that soft and/or porous materials are installed after VOC-emitting materials, finishes, or sealants have had a chance to "off-gas." Otherwise, emitted chemicals will be absorbed by porous surfaces, increasing the time required to clear the chemicals from the building.

Understanding chemical emissions adds to the complexity of reviewing contractor-initiated material and product substitution requests. Construction specifications should require that product ingredients and VOC emissions be reported, as well as information about any adhesives or solvents that are required during installation or maintenance. However, substitutions should be welcomed when contractors and subcontractors can provide information about new and improved product alternatives.

To assist in understanding and limiting indoor VOC emissions, it is recommended that designers refer to a model Special Environmental Requirements Specification (Section 01350), which establishes modeled indoor air concentration limits for 75 chemical compounds. It also provides testing protocols and reporting requirements for building materials.

In addition to product selection, the designer should also look for other ways to mitigate potential IAQ problems during construction. Dust and mold are two common construction by-products that can compromise IAQ. Construction activities such as wood sanding and drywall finishing generate large amounts of dust and debris, which can become an IAQ problem. Thoughtful work practices and thorough cleaning before occupancy will mitigate this potential problem.

Mold growth requires moisture and warmth and a material on which to grow. Excess humidity, caused by moisture intrusion or condensation, will promote the growth of mold and other biological contaminants within building materials that impact human health. Mold growth is commonly found on ceiling tiles, gypsum board, carpet, and other finishes. Special care should be taken during the delivery, storage, and handling of these materials to prevent moisture contamination on the construction site. If any moisture damage occurs, the materials must be removed and replaced as soon as reasonably possible.

In summary, objectives and strategies used to protect IAQ include selecting interior surfaces that are:

- Made with water-based coatings and adhesives
- Nontoxic and non-polluting during installation and use (low VOC emitting)
- Resistant to moisture or inhibit the growth of biological contaminants
- Easy to clean with non-polluting maintenance products.

Promoting Material Efficiency

Selecting material-efficient interior building products is another high performance goal. Product material efficiency can be evaluated using several different factors including recycled content, product recyclability and reusability, embodied energy, durability, and location of mining and manufacture. The material-efficiency calculations are complex and involve making professional decisions about the efficiency of one material versus another with a slightly different performance. For example, one type of flooring may be made from rapidly renewable resources, but is not very durable. Another flooring type is highly durable, but cannot be recycled. Which product is the better choice? Every product has tradeoffs. Weighing these product pros and cons can make it difficult to determine which products are most environmentally preferable. It is anticipated that, some time in the future, a life-cycle assessment tool will be developed to assist designers with this analysis.

Designers should evaluate the material-efficient product options available and select materials based on the environmental priorities of their project.

What Makes a Product Material Efficient?

To be considered material efficient, products should meet one or more of the following criteria.

- Durable.
- Reused, salvaged, and refurbished material or structure.
- Movable, refinishable, and reusable.
- Made with recycled content. Using recycled content materials (preferably post-consumer content rather than post-industrial content) helps address problems of solid waste disposal and the consumption of virgin resources.
- Recyclable.
- Made from or use resources that are renewable.
- Preferably manufactured within 500 miles of the project site to reduce transportation energy use.
- Packaged in minimal, recycled content or reusable containers.
- Purchased from a manufacturing source that embraces environmentally friendly corporate policy, which is reflected in the operation of the production plant.

Reduce, Reuse, Recycle

Interior finishes are important from a resource conservation perspective because they are used in large amounts and because they wear, requiring periodic maintenance or replacement. Material efficiency for building products should be approached in high performance school design according to the hierarchy of "Reduce, Reuse, Recycle."

Reduce. Techniques like dimensional planning, where the building is designed using common modular dimensions, help reduce waste through conservation. It is also important to select products that contain minimal packaging. Specifying products with high durability (which includes low maintenance requirements) can also reduce waste, since building materials that have been discarded after a short service life account for much of the content in landfills. Material reduction can also be achieved by not using materials if not needed. An example of this is the elimination of ceilings.

Reuse is defined as using a material over again in its current form without breaking it down into a raw material. Designs can promote the reuse of materials by specifying salvaged and refurbished materials and structures. Commonly salvaged materials include lumber, pipes, steel, fencing, wood flooring, doors, windows, stone flooring and wall panels, appliances, lighting fixtures, and decorative accessories.

Recycle. Since it can be quantified, recycled content is one of the most common indicators of material efficiency. However, it is important to understand the distinction between recycled-content products and those that are recyclable. The preferred products are those that both contain recycled content and are recyclable at the end of their service life. However, when choosing between specifying a product that contains recycled content and one that could be recycled, the recycled-content product should always take precedence. While a product's recyclability is important, it does not reduce the consumption of raw materials, nor does it promote completion of the cycle for existing materials that have already been diverted from the waste stream. The designer, in collaboration with the client, should set recycled-content goals for all building materials.

The term "recycled content" can refer to two types of recycled materials: post-consumer and secondary (also known as post-industrial). Post-consumer recycled content is "a finished material which would have been disposed of as a solid waste, having completed its life-cycle as a consumer item."[1] Secondary, or post-industrial, recycled content is defined as "fragments of finished products or finished products of a manufacturing process, which has converted a resource into a commodity of real economic value, but does not include excess virgin resources of the manufacturing process."[2]

When selecting products to meet the recycled-content goal, always maximize the amount of post-consumer recycled content. For instance, if the project has a recycled content goal of 50%, a product that contains 50% post-consumer recycled content and one with 30% post-consumer and 20% post-industrial content would both satisfy this goal, although the 50% recycled-content product would be the preferred choice.

Designers should set a minimum recycled-content goal of 25% for the project.

Material-Efficient Examples

Many building products that are material efficient in one or more ways are now available. Examples of material-efficient wood use include engineered lumber and composite wood products (FSC-certified), which can be used for casework and trim as well as for framing. Engineered lumber is manufactured by combining wood fibers with plastic resins to produce high quality, structural products such as I-joists, laminated veneer lumber (LVL), parallel strand lumber (PSL), and glue-laminated beams. Sheathing products manufactured in this manner, such as oriented strand board (OSB), wafer board, medium density fiberboard and particleboard, are made primarily of sawmill waste. While these products may be a potential source of indoor formaldehyde concentrations (see information below under Flooring), they promote source reduction. Likewise, finger-jointed lumber made from wood scraps uses material that would otherwise be wasted. And composite lumber composed of particleboard with a veneer of hardwood makes efficient use of fine hardwood for uses such as paneling and doors.

The design process also offers the opportunity to maximize material efficiency by using dimensional planning to reduce waste during construction. Toward this end, using modular systems such as carpet tile instead of carpet greatly minimizes this particular construction waste. Develop a Construction Waste Management Plan to target specific materials from construction that should be diverted from landfill to recycling facilities. A standard divergence goal is 75%, with an aim for 80% in the coming years.

Special Environmental Requirements (Section 01350) for the Construction Document Specifications

Reducing chemical emissions and providing for resource efficiency is relatively new to building design and construction. To assist owners, designers, and contractors, a model specification is available at http://www.chps.net/. This specification section, Special Environmental Requirements (Section 01350), has been used on several California state projects and is intended to be included in Division 1 of the Construction Document Specifications to lay out special environmental requirements related to IAQ, durability, recycled content and recyclability, wood from environmentally friendly sources, and product

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1 California Integrated Waste Management Board. "Manufacturer Identification of Recycled Content." http://www.ciwmb.ca.gov/publications/buyrecycled/43301018.doc.

2 Ibid.

packaging. The intent of providing this sample specification is to give designers throughout the country a base environmental specification from which to work. It is expected that each designer will customize this specification section for their specific project and coordinate with the other specification sections and the other parts of their project manual. Prior to use, the designer is expected to check the websites referenced in this specification section for the latest list of chemicals. Specification Section 01350 is intended to be placed into Division 1 of the project manual, so that it will govern all the other divisions (as is the case with submittal requirements and substitution requests, etc.).

Specification Section 01350 sets out environmental goals (specifically needed by the contractor if they are considering substitution requests), product emission testing methods, test protocols, sample procedures, and reporting requirements. The specification section also identifies the chronic reference exposure levels (REL)[3] for 75 hazardous airborne substances and uses these OEHHA RELs to establish acceptable modeled indoor VOC concentrations for these substances. In addition, recycled content and recyclability requirements for building materials are provided.

It is recommended that all interior materials that potentially emit VOCs (including adhesives, sealants, sealers, coatings, carpets, resilient flooring, ceiling materials, wall materials and coverings, architectural wood products, composites woods, and furniture) meet the emissions criteria outlined in Specification Section 01350. The emissions data and modeled chemical concentration information required by Specification Section 01350 should be provided by the manufacturers to the general contractor, who in turn submits it to the designer for review. For a product to be compliant with Specification Section 01350, the modeled VOC concentrations for its chemical components must be no greater than half the RELs provided on the OEHHA website, other than for formaldehyde. The formaldehyde concentration provided in the OEHHA list is not achievable in reality and a recommendation for this concentration is provided in the specification. These recommendations apply to all products, whether they are standard products used in school construction or environmentally preferable products made with recycled or rapidly renewable content.

However, chemical testing alone cannot fully evaluate the potential for *odor* from VOC emissions. Relying on experience, and even ad hoc experiments such as carefully controlled clean glass jar “sniff” tests to determine the odor acceptability of a product, may also be necessary if there is a concern regarding the VOC emissions.

Other Material-Efficiency Considerations

Embodied energy is the energy consumed during the entire life cycle of a product, including resource extraction, manufacturing, packaging, transportation, installation, use, maintenance, and when appropriate, even disposal. Products with low embodied energy are environmentally preferable. Since transportation is a component of embodied energy, give preference to products that are locally available.

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[3] According to California’s Office of Environmental Health Hazard Assessment website, “Chronic RELs are designed to protect the individuals who live or work in the vicinity of emissions of these substances. A chronic REL is an airborne level that would pose no significant health risk to individuals indefinitely exposed to that level. RELs are based solely on health considerations, and are developed from the best available data in the scientific literature.” http://www.oehha.org/air/chronic_rels/Jan2001ChREL.html.

Products produced in a way that protects the eco-system are also environmentally preferable. One example is certified wood products, which are produced from trees grown and harvested from Forest Stewardship Council (FSC)-certified forests. FSC is the accrediting agency for organizations such as Smart Wood and Scientific Certification Systems, which in turn oversee forestry practices and certify their environmentally friendly practices.

Other Considerations When Selecting Interior Surfaces

Acoustical benefits can also factor into product selection. For instance, consider carpet for areas when noise control is a concern. Also, be aware of how the acoustical properties of certain products can be impacted by other interior materials. For example, most ceiling tiles will lose their acoustical benefits if painted.

A product’s color can also influence the decision-making process. While color is always a factor for visual appeal, it can also have a functional impact. Consider light-colored paints and coatings to enhance daylighting.

In summary, when selecting materials, including interior building materials, for a high performance school, designers should look for cost-effective, durable, and material-efficient products that protect IAQ and provide the desired acoustical performance and aesthetic qualities. In addition, high performance school designers should attempt to minimize the impact on the natural environment by selecting locally produced materials, as well as those produced in an environmentally benign manner, preferably using suppliers and manufacturers that practice environmentally conscious management principles. Look for manufacturers that have a corporate policy incorporating these practices. The selection process should consider installation and maintenance requirements as well as how the material or furnishing performs during its service life.

Because of their high visibility, interior surfaces and furnishings provide an excellent opportunity to highlight the high performance approach. Environmentally preferable choices teach the importance of caring for the health of occupants, as well as the health of the natural environment.

Table 1 summarizes the interior surfaces goals and objectives and presents the predominant relationship between them and the guidelines that follow.

Table 1 – Interior Surfaces Goals and Relationship to Guidelines

	BP1: Carpeting	**BP2: Resilient Flooring**	**BP3: Ceramic Tile/Terrazzo**	**BP4: Concrete Flooring**	**BP5: Wood Flooring**	**BP6: Bamboo Flooring**	**BP7: Gypsum Board**	**BP8: Acoustical Wall Panels and Ceilings**	**BP9: Paints and Coatings**	**BP10: Casework and Trim**	**BP11: Interior Doors**	**BP12: Toilet Partitions**
Goals												
Protect Indoor Environmental Quality												
Use low VOC-emitting coatings and adhesives.	●	●	●	●	●	●	●	●	●	●	●	●
Use low VOC-emitting materials.	●	●	●	●	●	●	●	●	●	●	●	●
Use moisture-resistant materials.			●	●								
Use low VOC-emitting maintenance products	●	●	●	●	●	●				●		●
Use sound-absorbing materials	●							●				
Materials Efficiency												
Made from sustainable resources		●			●	●				●	●	
Made with recycled content	●	●	●	●			●	●				●
Recyclable	●	●	●	●	●		●	●		●		
Movable, refinishable, and reusable					●					●	●	●
Other Environmental Considerations												
Locally available	●	●	●*	●	●		●	●	●	●	●	●*
Durable	●	●	●	●	●	●	●					
Low in embodied energy					●							
Eco-system protective		●			●					●	●	

*Note: Verify that an in-state manufacturer exists.

The discussions below provide a summary of the specific considerations, advantages, and disadvantages of materials choices addressed in these guidelines.

The Vinyl Debate

Few building materials have generated more debate over material efficiency and the environment than those containing polyvinyl chloride (PVC). PVC is a highly versatile, stable compound used in numerous building products, including pipes, siding, wire and cable coatings, resilient flooring, carpets, wall coverings, and furniture. In fact, construction materials account for the largest percentage of PVC use.

Commonly referred to as "vinyl," PVC products are highly durable and require low maintenance, which have made them a popular choice in schools. For instance, vinyl composition tile (VCT) is the most commonly used flooring material for non-carpeted areas in schools due to its long life, low maintenance requirement, and moisture-resistant properties. First cost for PVC products appears to be low.

Much of the debate focuses on environmental concerns with the production of PVC. PVC is derived from petroleum, which is a non-renewable resource, and can be highly polluting during extraction, refinement, and manufacturing.[4] It should also be noted, however, that because many PVC products are manufactured in the United States, they can have lower embodied energy than other materials that are manufactured overseas.[5]

Vinyl chloride (VC), a colorless, flammable gas that serves as the building block for PVC, is a known human carcinogen. Studies of PVC factory workers have shown that long-term exposure (365 days or more) to VC can cause liver cancer, nerve damage, and immune system problems.[6] In response to these findings, the Occupational Safety and Health Administration in 1974 reduced the occupational exposure standard for VC gas in the air from 500 parts per million (ppm) to 1 ppm.[7] These tighter restrictions, in combination with a closed-loop polymerization process adopted by the industry in the United States, may have reduced the high-risk exposure for workers.[8] While most of the studies on VC exposure have focused on long-term exposure in factory workers, breathing high levels of VC gas for short periods of time can cause dizziness and unconsciousness, while breathing extremely high levels in a short period of time can cause death.[9] VC can be released into the air from plastics industries, landfills, and hazardous waste sites.[10]

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4 U.S. Environmental Protection Agency, Environmentally Preferable Purchasing Program. "Leading by Example: Two Case Studies Documenting How the Environmental Protection Agency Incorporated Environmental Features into New Buildings." December 1997. http://www.epa.gov/opptintr/epp/pdfs/grnbldg.pdf.

5 Ibid.

6 U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. "Vinyl Chloride Fact Sheet." September 1997, CAS #75-01-04. http://www.atsdr.cdc.gov/tfacts20.html.

7 Centers for Disease Control, Morbidity and Mortality Weekly Report. "Epidemiologic Notes and Reports: Angiosarcoma of the Liver Among Polyvinyl Chloride Workers – Kentucky." 1974, update 1997. http://www.cdc.gov/epo/mmwr/preview/mmwrhtml/00046136.htm.

8 Ibid.

9 U.S Department of Health and Human Services. "Vinyl Chloride Fact Sheet."

10 Ibid.

Concerns also exist surrounding the disposal of PVC products. Recycling options are currently limited, and most are not recycled, nor are they biodegradable. PVC can also be a problem in waste incineration[11] and building fires, because of dioxins emitted during combustion.

While serious concerns exist about its environmental impact, PVC also has some beneficial properties that have made it a widely used material in schools traditionally. CHPS has chosen to remain neutral on the use of vinyl products in schools. The guidelines in this chapter discuss the pros and cons of using PVC products for various building surfaces, but neither recommends nor discourages their use.

Flooring

Flooring should be durable to withstand heavy use without requiring frequent replacement, be easy to maintain, contain recycled content, be recyclable, contribute to a comfortable indoor environment, and not adversely affect human health. Based on life-cycle costs, highly durable materials are justified, especially for high-use areas.

Adhered carpet systems require maintenance, as do other flooring materials, and their need for more frequent replacement makes them materials- and energy-intensive over their lifetime. If selecting a carpet, select those carpets with a longer warranty to increase the service life and reduce the need for replacement. However, carpeting offers first cost, acoustical, and comfort benefits that are generally not available with other flooring choices. For these reasons, carpeting is often used in classrooms and administrative areas.

Floor choices include resilient flooring, concrete, tile, wood, and carpet. When selecting these surfaces, review the cleaning products that might be used throughout the life of the flooring. Hard surfaces are often selected for use in all areas except classrooms and administrative areas.

Walk-off mats are recommended for all school entrances to help minimize cross-contamination by pollutants brought into the building on occupants' shoes. Using walk-off mats to trap dirt, dust, grit, and moisture can also reduce maintenance costs, improve safety, and protect the life and appearance of the flooring.

Table 2 summarizes advantages and disadvantages of the flooring choices addressed in these guidelines.

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[11] U.S. Environmental Protection Agency, Environmentally Preferable Purchasing Program. "Leading by Example: Two Case Studies Documenting How the Environmental Protection Agency Incorporated Environmental Features into New Buildings." December 1997.

Table 2 – Environmental Criteria for Floors

Flooring Type	*Advantages*	*Disadvantages*
Carpet Guideline BP1	Material-efficient options available: minimum recycled content guideline of 50%, with at least 10% post-consumer recycled content Thermal comfort Physical comfort (cushion) Provides safety for small children Noise control Some recycling options are available	May emit some VOCs during and after installation. Can harbor dust and other allergy-causing particles. Requires regular maintenance. Requires frequent vacuuming, which stirs up dust. Can adsorb VOCs and re-emit (desorb) later. Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). Potentially need to allow time to air out carpet (precondition off site) before occupancy. Less durable and stains easier than other flooring options. Significant debris generated when it must be replaced. Can be a source of mold/mildew if placed in contact with moisture.
Resilient Flooring Guideline BP2	First cost can vary from low to high, depending on product, but due to its high durability, this flooring type tends to cost less per year of use than carpet. Easy to clean. High reflectivity can enhance daylighting.	Flooring adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options may be available). Most are not recyclable or biodegradable.
Ceramic Tile / Terrazzo Guideline BP3	Recycled content options available: minimum recycled content guideline of 55%–77%. Easy to clean and stain-resistant (some tile may need to be sealed first). Highly durable. High reflectivity can augment daylighting.	High cost. High embodied energy. Made from nonrenewable resources. Some ceramic tile is recycled as clean construction waste. When contaminated by bonding and setting agents, recycling is not feasible. Tile installation materials (mortar and grout) are sources of VOCs and toxic materials. (Portland cement-based mortar and grout appear to have less significant environmental impact than latex or solvent-based systems.) Terrazzo poses installation risks, depending upon type. (Cementitious type appears to have less significant environmental impacts than epoxy systems.) Hard finished surface can compromise physical comfort. Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).
Concrete Flooring Guideline BP4	Material efficient if manufactured with high fly ash content. Highly durable. Low maintenance and low cost.	Sealers and wax products can add to indoor pollution load (but low-toxic/low-VOC options are available).
Wood Flooring Guideline BP5	Renewable resource, if properly managed (FSC-certified forests). Low embodied energy. Wood flooring is recyclable and the market for recycled wood flooring is expanding. Biodegradable. Easy to clean. "Warm," comfortable surface. Durable and can be refinished to prolong its life. Good aesthetics.	High cost. Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). Requires special moisture-prevention care in handling and installation to prevent later IAQ problems. On-site sanding requires special measures.
Bamboo Flooring Guideline BP6	Material efficient. Durable and hard. Easy to clean. "Warm," comfortable surface.	High cost. Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).

Walls and Ceilings

Walls and ceilings should be durable, be easy to clean, contain recycled content, and be recyclable, as well as contribute to a healthy and comfortable indoor environment. Classrooms and other rooms require plenty of tackable wall space for teaching aids and displaying student projects. The type and color of surfaces on teaching walls should also be visually comfortable and not detract from teacher presentations.

Drywall is potentially recyclable and can be composted. Recycled content gypsum board core is available, but it is important to explicitly specify recycled content to ensure its use. Although they may not advertise it as recycled, many manufacturers already use post-industrial recycled content in their drywall product, and virtually all make the facing paper component from post-consumer recycled content paper. To protect IAQ, it is recommended that all drywall products meet the emissions requirements outlined in Specification Section 01350. See the discussion on Special Environmental Requirements (Section 01350) above.

When using wall coverings, use biodegradable papers that contain recycled paper or fiber content. Vinyl wall coverings are widely used but are manufactured from PVC, which was banned in some areas of Europe because of the creation of toxic byproducts during manufacture. (For further discussion of vinyl, see the Vinyl Debate section above.) Installation of wall coverings using traditional wallpaper paste is preferable to using self-stick wall coverings, due to the levels of VOC content in the adhesive.

Avoid using ceiling tile and sprayed-on ceiling finishes containing asbestos, formaldehyde, or crystalline silica, as these items are possible cancer and respiratory tract hazards. Table 3 summarizes advantages and disadvantages of the wall and ceiling choices addressed in these guidelines.

Table 3 – Environmental Criteria for Walls and Ceilings

Type	*Advantages*	*Disadvantages*
Gypsum Board Guideline BP7	Gypsum is highly recyclable if not contaminated (with paint, tape, compound, adhesives, or other coatings). Recycled content gypsum is readily available at no cost premium, and the paper facing is typically made with recycled paper. Durable, high-impact drywall contains up to 15% post-consumer recycled content. Recycled gypsum is more durable than conventional wallboard. Easy to repair. Low cost.	Dust generated during sanding (can specify "wet sanding" process). Gypsum surfaces are potent "sinks" for odors, which they can later re-release. Requires periodic painting. Paints and primers can add to indoor pollution load (but low-toxic/low-VOC options are available). Low durability compared to concrete block.
Ceramic Tile Guideline BP3	See Table 2, Ceramic Tile/Terrazzo Flooring.	See Table 2, Ceramic Tile/Terrazzo Flooring.
Acoustical Wall Panels and Ceilings Guideline BP8	Recycled-content materials readily available: minimum recycled content guidelines for ceiling tile is 79%–85%, for suspension system is 25%. Formaldehyde-free products available. Reclamation programs available (though limited). Easy installation. Acoustical ceiling tiles often cost less than wallboard ceilings. Do not require painting or other finish materials to complete the installation. Easy to reuse. Provides for easy relocation of fixtures, if required.	Tile collects dust and adsorbs odors. Tile and plenum requires periodic maintenance. Due to the grid organization, acoustical tile ceilings may not be as adaptable to renovations as a gypsum board ceiling. If the T-bar ceiling space has a return air plenum, as is common, this type of air handling design is difficult to clean. Many materials are used in the space above the T-bar ceiling. Material off-gassing, odors, and microorganisms in the plenum area can spread and be distributed to other areas. (Avoid this by installing return air systems using dedicated metal ductwork with access hatches for inspection and cleaning.)

Coatings

Paints and other coatings affect IAQ and may produce hazardous waste. Most conventional products off-gas VOCs, formaldehyde, and other chemicals that are added to enhance product performance and shelf life. These chemicals, especially in combination, may pose health concerns. Fortunately, high-quality, low-toxicity, and low-VOC substitutions are now available for all these products.

Adhesives and Sealants

Many conventional construction adhesives, sealants, caulking, grouts, and mortars used to bond structural components are solvent-based, toxic, and may off-gas large amounts of toxic VOCs (including solvents and aromatic hydrocarbons). Avoid using products that include butyls and urethanes indoors. Low-VOC, low-toxic, water-based, formulations are now available for many more applications.

Specify the least toxic/lowest VOC product suitable for the application and require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product.

Non-solvent adhesives have 99% less hazardous emissions than solvent adhesives, although their emissions may last much longer. When used to adhere dense floor coverings, emissions will be low, but prolonged. Yellow and white glues are recommended. When specifying sealants, consider using only silicone sealants in interior areas. However, some silicone sealants do contain acetic acid, which has an unpleasant odor that may be irritating. Other environmentally preferable alternatives include acrylics and siliconized acrylics. They are typically the safest to handle and have the lowest solvent content. All other sealant types, especially butyl sealants, emit VOCs and other toxic compounds, and emission test data should be requested and reviewed prior to including the product in a specification.

Applicable Codes

Applicable state and local school district design and materials standards.

Design Tools

Alevantis, Leon. 1996. *Reducing Occupant Exposure to Volatile Organic Compounds from Office Building Construction Materials: Non Binding Guidelines.* Published by the CA Department of Health Services. Available on-line at http://www.cal-iaq.org/VOC.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *ASHRAE Standard 62, Indoor Air Quality.* http://www.ashrae.org.

American Society for Testing and Materials (ASTM) Standard D5116-90, Small Scale Environmental Determination of Organic Emissions from Indoor Materials/Products.

King County, Washington. *Construction and Landscaping Materials Specifications*. Available on-line at http://www.metrokc.gov/procure/green/const.htm.

National Institute of Standards and Technology. Building for Environmental and Economic Sustainability (BEES) 2.0. BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach specified in ISO 14000 standards. Download the program at: http://www.bfrl.nist.gov/oae/software/bees.html

U.S. Environmental Protection Agency (EPA). *Tools for Schools Program and Tool Kit.* Available on-line at http://www.epa.gov/region01/eco/iaq/index.html.

U.S. Environmental Protection Agency (EPA). *Building Air Quality: A Guide for Building Owners and Facility Managers.* Ordering information: Tel: (800) 490-9198, order number EPA402F91102, or view at http://www.epa.gov/iedweb00/base/baqtoc.html.

References/Additional Information

Architects, Designers and Planners for Social Responsibility (ADPSR) West Coast. 1998. *Architectural Resource Guide.* Contact: ADPSR, P.O. Box 9126, Berkeley, CA. Tel: (510) 273-2428. Resources and information on green and healthy buildings, including many sources for materials in California.

Bernheim, Anthony. “Indoor Air Quality.” Sustainable Building Technical Manual, Green Design, Construction and Operations, Public Technology, Inc., DOE, USEPA, 1995.

Bernheim, Anthony. “Saving Resources.” Urban Land Institute, pp. 76-81, 94-95, June 2001.

Bernheim, Anthony. “Measure and Cost of Green Building.” AIA Convention 2000 Seminar S76. Download handout at http://www.aiaconvention2000.com/conted/schedule.asp?HandOut=1.

Building Ecology Research Group/Hal Levin & Associates. 1999. *Indoor Air Bulletin*. Contact: PO Box 8446, Santa Cruz, CA, 95061-8446. Tel: (831) 426-6624. A newsletter for architects and building professionals on indoor air quality.

California Integrated Waste Management Board (CIWMB) Database of Recycled Content Products. http://www.ciwmb.ca.gov/rcp.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. http://www.sustainable.doe.gov.

Maryland State Department of Education. *Building Ecology & School Design; Technical Bulletin: Carpet and Indoor Air Quality in Schools;* and *Interior Painting and Indoor Air Quality in Schools.* To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager, (410) 767-0097.

National Clearinghouse for Educational Facilities (NCEF). *Managing Indoor Air Quality in Schools.* Available on-line at http://www.edfacilities.org.

Spiegel, Ross and Dru Meadows. *Green Building Materials, A Guide to Product Selection and Specification.* New York: John Wiley & Sons, Inc., 1999. ISBN 0-471-29133-1.

Acknowledgments

The following resources were particularly useful for developing this chapter:

Sustainable Building Task Force. The Sustainable Building Task Force was formed by several state agencies to institutionalize sustainable building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing sustainable building practices in all future and current state buildings, including those leased by the State. Visit http://www.ciwmb.ca.gov/GreenBuilding/TaskForce/ for more information and links to member agencies.

Santa Monica, City of. 1999. *Santa Monica Green Building Design and Construction Guidelines*. Available on-line at http://greenbuildings.santa-monica.org/main.htm.

Partnership for Resource-Efficient Schools. 1998. *Recommended Best Management Practices Promoting: Energy Efficiency, Resource Conservation, and Environmental Quality*. A publication of the Seattle Public Schools Building Excellence Program and the City of Seattle (Solid Waste Utility, Water Department, and Seattle City Light). The following web site provides information about the Partnership for Resource-Efficient Schools project and a link to download the Best Management Practices manual: http://www.cityofseattle.net/util/rescons/susbuild/partnership.htm.

BUILT GREEN™ Handbook. 1999. BUILT GREEN™ is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County and Snohomish County, Washington. http://www.builtgreen.net/.

Maryland State Department of Education. *Building Ecology & School Design; Technical Bulletin: Carpet and Indoor Air Quality in Schools;* and *Interior Painting and Indoor Air Quality in Schools.* To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, (410) 767-0097.

GUIDELINE BP1: CARPETING

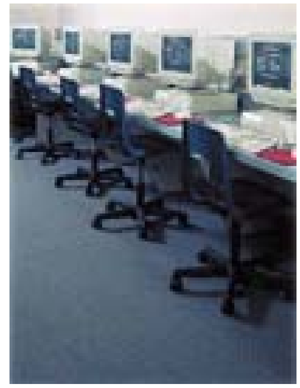
Recommendation

Select a carpet, carpet tile, cushion, pad, and adhesives that:

- Cause minimal pollution (low-volatile organic compound, or VOC, emissions).
- Are durable. Compare warranties.
- Are made with recycled-content.
- Can be easily cleaned and maintained.
- Are constructed so as to prevent liquids from penetrating the backing layer where moisture under the carpet can result in mold growth.
- Can be easily removed without the use of toxic chemicals.
- Can be easily replaced.
- Absorb sound.

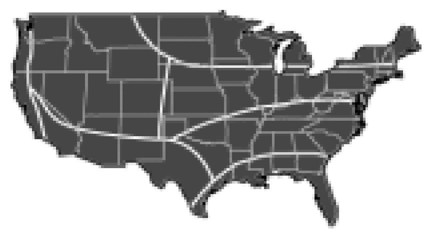
To reduce waste during construction and installation consider the use of carpet tile instead of broadloom carpet, if applicable.

Where practicable, select a carpet and pad that is recyclable at the end of its life. Even when made from recycled materials and/or with potential for recycling at the end of their useful lives, carpet service life is relatively short compared to other flooring -alternatives. Energy and other resources are consumed in the recycling process. Also, some carpet recycling does not re-use the material as carpet but rather in a lower form of carpet materials. Due to these factors, carpet should be used only when its performance characteristics outweigh its environmental costs.



Carpet, even recycled, should be used only when its performance characteristics outweigh its environmental costs. NREL/PIX 11415

Applicable Climates



Applicable Spaces	
Classrooms	■
Library	■
Multi-Purpose	□
Gym	□
Corridors	□
Administration	■
Toilets	□
Other	□

When to Consider	
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■

Follow recommendations from the Carpet & Rug Institute (CRI) for installation and maintenance.

Description

Because carpet systems off-gas when new, carpet is a potential source of indoor air pollution. (Typically, most VOCs are emitted from the backing, adhesive, and seam sealer rather than from the wear layer.) The specifications listed under the Design Details section below provide guidelines for procurement of low-emissions carpeting and adhesives.

Particles and debris accumulate on carpets, exposing occupants who regularly use the room. Easy and effective cleaning of carpets is critical to reduce long-term exposure to pollutants. Cleaning requirements include both vacuum use and wet-extraction processes.

Moisture trapped below a carpet can result in mold growth and the release of mold spores and mold metabolic products (microbial VOCs – MVOCs) into the air. Concrete must be sufficiently cured, dried, and sealed before carpet is installed over it.

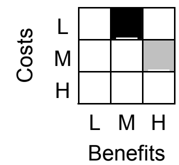
Applicability

Most suitable for classrooms, libraries, and administrative areas.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than most resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Recycle clean construction/installation waste carpet, if possible (require subcontractor to take back for recycling). Research carpet reclamation programs if the project involves disposing of an existing carpet. Flooring type also affects acoustics, noise control, safety, and maintenance. Complete all painting and other adhesive use prior to the installation of carpets to prevent VOC “sinks”.

Cost Effectiveness



A typical nylon carpet installation costs between $2.20/ft^2 and $3/ft^2. Recycled-content padding and carpeting are priced competitively, with a life expectancy between 10 and 15 years.

Benefits

Although not as materials-efficient as durable flooring, recycled content and recyclable flooring is material efficient. Carpeting provides acoustic benefits not available with other flooring types. Emissions specifications for carpeting in schools provides indoor air quality performance guidelines for school environments. Low-toxic adhesives minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See this chapter’s Overview.

Design Details

If regular, effective maintenance and cleaning cannot be assured (due to budget constraints, inadequately trained staff, or other reasons), carpeting should not be used. (See the Operations and Maintenance discussion below).

Emissions Criteria

The adhesives used to attach face fibers to backing materials and the adhesives used to install carpets usually contain volatile organic compounds (VOCs). These compounds may not be listed on the container or on manufacturer’s literature if they are considered exempt under the definition of VOCs in the Clean Air Act regulating reactive chemicals known to be precursors of photochemical smog. However, many of the exempt VOCs are of concern for indoor air quality. Depending on the strength, type, and duration of emissions from these chemicals, carpet can be a significant source of indoor air contamination.

The CRI has developed a program known as the CRI Indoor Air Quality Carpet Testing Program (CRI “Green Label”). This label identifies carpets that after 24 hours of testing, have VOC emissions below levels established by the CRI. At the time the CRI program was established, many carpets exceeded these emissions levels. Currently, almost all carpets qualify for the CRI Green Label. While the CRI label should be a bare minimum requirement for carpet selection, it is not a sufficient indicator of carpet emissions into indoor air. A Maryland State Department of Education Technical Bulletin, Carpet and Indoor Air Quality in Schools, cautions that CRI certification “does not provide information on comfort and health effects of specific VOC emissions, and should not be misunderstood to assure a safe product.”

It is recommended that all carpet products (virgin and recycled content) meet the emissions criteria outlined in Specification Section 01350 to ensure improved IAQ benefits required for a high performance school. Additionally, the specific criterion for 4-PC emissions applies to carpets.

- Under a test over a 96-hour time period after 10 days of conditioning (as described in Specification Section 01350), the carpet should emit less than 10 $\mu g/m^2$-hr of 4-PC.
- The proposed specifications should require that the contractor submit a compliance table, which documents the required performance criteria (as provided in the specifications) and actual test results.

School designers should also require manufacturers to submit the following information for each product making up the carpet system:

- The ingredients, including identification and quantified amounts of substances that are listed on either: (a) the International Agency for Research on Cancer List of Chemical Carcinogens; (b) the Carcinogen List of the National Toxicology Program; or (c) the Reproductive Toxin List of the Catalog of Teratogenic Agents.
- Emission factors for VOCs contained in the product, in milligrams per square meter per hour (mg/m^2-hr).
- Product TVOC emission factor (after 10 days of conditioning in clean air at 1 air change per hour then tested at 24, 48, and 96 hours (mg/m^2-hr).
- Emissions test protocol used.
- Organization evaluating the product.

Type of Carpet

When selecting carpet, space classification, desired design life, and desired aesthetics are the traditional considerations.

Look for low pile, dense loop, and needle-punch carpet types trap the least soil and show wear the least. One good choice for schools is a low nap, all-nylon carpet, which is less attractive to dust mites and mold.

Natural carpets are made from grasses, cotton and wool, with minimal treatment. However, natural carpet materials can harbor insects and support mold growth, as well as being more difficult to maintain. For these reasons, natural carpet is not recommended for schools.

Recycled Content

Select a carpet with a minimum of 50% total (yarn and backing) recycled content (minimum 10% post-consumer recycled content). The manufacturer’s warranty period should be reserved for such carpets, and those with a shorter life span should be used in low-traffic areas. Type One Commercial Carpet is available, either a tile or a broadloom, with backing made with post-consumer plastic (typically nylon, polypropylene or a mix of these two plastics). Some manufacturers offer product lines that contain 50% or more recycled content plastic by weight and above. Generally commercial carpet made from nylon 6 or 6,6 is the most durable type of carpet. At this writing, at least two manufacturers supply products made with 100% recycled nylon. Many manufacturers will offer a surface wear warranty of 15 years or more (e.g., 10% surface wear by weight). Some carpet manufacturers also offer reclamation programs to facilitate carpet recycling at the end of its useful life.

The life expectancy of recycled content carpet is between 10 and 15 years.

Carpet Tiles

Carpet tile systems save money and resources. They generate less waste during installation. They are also easily removed and replaced during renovation, and individual tiles can be easily replaced as needed, considerably extending the average service life of the carpet. A few disadvantages to carpet tiles are that they may be more subject to vandalism by students who discover the system is modular. Also, flooding or spills may cause moisture to infiltrate the joints, creating potential IAQ hazards.

Refurbished Carpet

At least one manufacturer refurbishes commercial carpet for reapplication as modular carpet tiles. The manufacturer super-cleans, re-textures and overprints new colors and patterns to previously used carpet. The end product has a warranty and costs about half of new. Refurbished carpet is considered a 100% post-consumer recycled content product. However, in some instances, manufacturers will add new backing to the refurbished product, which would reduce the amount of post-consumer recycled content.

Pad

Specify carpet pad with highest percentage of recycled content (and compatible with selected carpet product). Fibrous pad is also available in commercial grades made from recycled synthetic and natural fiber from textile mill waste.

Recyclability

Carpet recycling is a priority because of the large volumes being disposed and its resistance to decomposition. A national agreement for carpet stewardship called the Memorandum of Understanding for Carpet Stewardship (MOU) was signed on January 8, 2002. The MOU states that, “the amount of carpet that is reaching the end of its useful life and entering the waste stream is ever-increasing: estimated total discards for 2002 are **4.7 billion pounds**.” Fully recyclable carpets are just newly available. Many manufacturers now take the carpet and carpet tile at the end of its useful life and will recycle it back into new carpet backing (i.e., closed loop system).

Installation

Where new carpet odor is a concern, require suppliers to unroll and air-out carpets in a warehouse before bringing them into the building. Tests indicate that carpet emissions will decrease significantly within 48 to 72 hours with proper ventilation.

When installing carpet over concrete floors, ensure that the concrete is sufficiently dry prior to installation. If water vapor emissions from the concrete floor are greater than 5 lb/1,000 ft^2, a vapor emission control treatment should be applied to the floor until emissions meet the maximum levels allowed by the carpet manufacturer.

Specify the least toxic carpet adhesive system compatible with selected carpet products. Require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer’s performance specifications for that product. Alternately, specify tack-down carpet to eliminate gluing, while taking precautions to prevent potential mold and mildew growth under the carpet.

If covering a large surface area, carpet and other fabrics can act as "sinks" for the adsorption of VOCs from other sources (during application of paint and other finish coatings, for example) and re-emit them later. To minimize this “sink” effect and subsequent extended re-emitting of VOCs, install soft surfaces as late as possible and/or remove or cover all soft surfaces and use direct ventilation until the offensive coating dries.

Air out space(s) where carpet has been installed for a minimum of 72 hours. With a central HVAC system, the ventilation supply should be on, the return grille(s) sealed, and windows open.

In renovations, carpet installation should occur only when the school building is not in use. An exception would be for small installations in which the space can be exhausted directly to the outdoors, causing the room to be under negative pressure relative to adjacent spaces in the building. Extra ventilation should continue for a minimum of 72 hours after installation.

To reduce the risk of mold growth on carpet, do not install carpet near water fountains, sinks, showers, pools, or other locations where it may get wet.

Operation and Maintenance Issues

Carpeting acts as a highly effective reservoir for allergens such as dirt, pollen, mold spores, pesticides and other toxins, which are everywhere present outdoors and often introduced into the indoor environment in dirt from occupants' shoes. Old carpeting may pose more health risks to its occupants than new. Microbial contamination resulting from water infiltration or inadequate cleaning procedures is a potential problem. The presence of fungi and dust mites can exacerbate allergies. To help ensure longer life, maintain appearance, and help protect indoor air quality, carpet requires regular vacuuming with a well-functioning vacuum cleaner equipped with strong suction and a high-performance filtration bag. Walk-off mats should also be provided at all entrances.

Spills must be cleaned up immediately and thoroughly. If carpet becomes saturated and water is not quickly removed (less than 24 hours), experience suggests that carpeting will have to be discarded.

Commissioning

Airing out the space during and after carpet installation is essential and is recommended by the CRI, the U.S. Environmental Protection Agency, and the U.S. Consumer Product Safety Commission. The typical recommendation is to continuously operate the building ventilation system at normal temperature and maximum outdoor air during installation and for 72 hours after installation is completed. A longer flush-out of the entire building should also be considered. The CRI *Standard for Installation of Commercial Textile Floor Covering Materials* (CRI 104) addresses the topic of airing and other installation procedures.

References/Additional Information

California Integrated Waste Management Board (CIWMB) Database of Recycled Content Products: http://www.ciwmb.ca.gov/rcp.

Carpet and Indoor Air Quality in Schools. Published by the School Facility Branch of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, phone for Capital Projects Assistant Manager, (410)-767-0097.

Carpet & Rug Institute (CRI) website, http://www.carpet-rug.com. Provides information on selection, installation, and maintenance.

Comprehensive Procurement Guidelines. The recommended recovered material content for polyester face carpet fiber is listed as 25-100% PET resin (recycled plastic soda bottles). Envirotech (Image) and Envirolon (Talisman) lines meet this standard. EPA is expanding it's definition of environmentally preferred carpet by including nylon fiber with recycled-content backing (i.e., Collins and Aikman, Shaw, Interface). These new standards will soon be reflected in the CPGs. For more information on carpet manufacturers and suppliers and a GSA link, visit EPA's web site: http://www.epa.gov/epaoswer/non-hw/procure/products/carpet.htm.

Environmentally Responsible Carpet Choices, Sustainable Practices and Opportunities Plan, a project of the Department of Interior, National Park Services. http://www.nps.gov/sustain/spop/carpet.htm

The LaGrange Academy in LaGrange, GA. Several projects installed at this K–12 campus, including a multi-purpose building.

Standard for Installation of Commercial Carpet, CRI 104. An industry minimum commercial installation standard published by the Carpet and Rug Institute (CRI). Contains detailed outlines of technique, procedure, and terminology used in specification writing, planning, layout, and installation. Includes accepted tools and materials, floor preparation, installation in special areas, diagrams and charts. 25 pages, 8 ½" x 11" $6.00 each. ISBN #0-89275-010-3. To order, call CRI at 800-882--8846.

The Woodward Academy in Atlanta, GA, the largest private K–12 in the country. Five projects have now been installed on campus. Earth Square is now a standard for use based on environmental and economical reasons.

GUIDELINE BP2: RESILIENT FLOORING

Recommendation

Select resilient flooring and adhesives that are materials-efficient and non-polluting.

Description

Vinyl composition tile (VCT) has been the finish of choice for uncarpeted areas in schools, due to its durability and low maintenance. However, VCT is made of non-renewable resources and there is concern about environmental degradation associated with its production.

Linoleum, often the choice of environmentally conscious designers, is durable as well and is produced from minimally processed, renewable materials. However, it also poses some risks, including offensive odor during its early months and, sometimes, much longer.

Chlorine-free resilient flooring and recycled content rubber (tire-derived) tile/sheet flooring can also be environmentally preferable options. Vinyl-free products are also becoming available.

With respect to materials efficiency and air quality, there are important distinctions between material types, installation methods, and maintenance requirements. Final selection will depend upon the application and cost constraints.

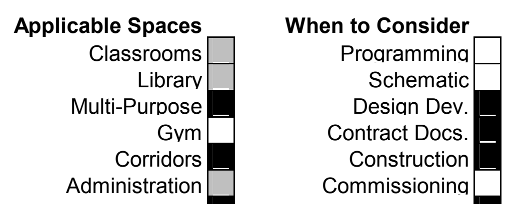
Applicability

Most suitable for high traffic areas not requiring the acoustic benefits of carpet, such as hallways, kitchens, cafeterias, art rooms, toilets or anywhere that liquid spills are likely.

All resilient flooring products meet emissions criteria since they all produce some air pollutant emissions.

NREL/PIX 03050

Applicable Climates

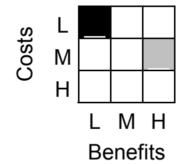


Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting reduces heat loss slightly more than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Resilient flooring does not generally provide the acoustic benefits of carpeting. Teacher preferences should also be considered, if feasible. Resilient flooring is more easily cleaned than carpeting and may last considerably longer. Some resilient flooring requires application of sealants and waxes, which result in periodic increases in occupant exposure to the chemicals emitted from these products. Recycle waste flooring, if possible (require subcontractor to take back for recycling).

While often considered environmentally preferable, linoleum contains linseed oil, which does off-gas. The oxidation products when the emissions occur are odorous compounds that may affect the acceptability of linoleum as a floor covering. It is recommended that designers obtain emissions test data from the producers of linoleum and other resilient floor products prior to specifying such products. Comparisons of emissions should be done prior to selection.

Cost Effectiveness



Costs will vary with type of product chosen. Some newer environmentally friendly products are on the market and the designer should obtain cost data.

Other alternatives, including cork and newer resilient flooring products (vinyl-free, chlorine-free) may be more expensive.

Benefits

Resilient flooring is highly durable.

Use of alternatives to VCT flooring is ecosystem-protective, avoiding environmental degradation attributed to the mining of limestone and production of PVC, which are both used in the manufacture of VCT.

Recycled content flooring and recyclable flooring are material efficient.

True linoleum is made with renewable materials (linseed oil, cork, wood dust and jute), does not contain the petrochemicals and chlorine found in vinyl and VCT flooring, or the plasticizers found in vinyl sheet flooring. Its known ingredients are minimally processed, commonly available, and biodegradable. Linoleum is durable. Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See this chapter's Overview.

Design Details

All resilient flooring products produce some air pollutant emissions; so do their setting and maintenance products. It is recommended that all resilient flooring products meet the emissions criteria outlined in Specification Section 01350.

Natural linoleum is another chlorine-free, product, made out of nearly all-natural ingredients. At present, linoleum is produced only in Europe at only three companies. Linoleum emits a fairly strong smell when the flooring is newly installed. The smell comes from linseed oil's oxidation products, which are primarily fatty acids – compounds that react with oxidants to produce new chemicals that have a strong smell even at very low concentrations. Emissions of odors have been measured and observed on aged linoleum as well.

Resilient textile flooring is a newly formulated product that comes in 1-m^2 (39 in. x 39 in.) tiles, comprising a sandwich of very different materials that is designed to come apart for recycling. Developed as part of the specific manufacturer's corporate sustainability policy and initiative, resilient textile flooring is recyclable, durable and manufactured using renewable energy. Acoustically it performs like carpet, according to the company. The manufacturer has targeted schools and hospitals as its primary markets, because both environments benefit from the comfort and acoustic qualities of carpet but struggle with the maintenance and cleanliness issues.

Cork is a natural material and harvested from trees in a resource-efficient manner. Cork flooring is durable, fairly easy to clean, thermally insulating, and naturally moisture-, mold-, and rot-resistant. Drawbacks are its high cost and high-embodied energy (because it is imported and is energy-intensive to ship to North America). Also, some flooring manufacturers use hazardous materials as binders and in installation. It is recommended that binders, adhesives, and coatings meet Specification Section 01350 specifications. If Specification Section 01350 cannot be used in these cases, request and carefully review the MSDS and ATSM emissions test data for these materials. Emissions tests of cork flooring have shown that some of the binder elements are emitted. Some chemicals emitted from cork flooring are toxic at elevated concentrations.

Recycled rubber tile and sheet goods made with waste tires are also available. These are materials efficient choices for heavy traffic and utility areas, but may be strong VOC emitters and odor sources.

Specifications should require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product. (In some applications, interlocked rubber tiles and heavy linoleum can be laid without adhesive).

When installing resilient flooring over concrete floors, ensure that the concrete is sufficiently dry prior to installation. If water vapor emissions from the concrete floor are greater than 3 lb/1,000 ft^2, a vapor emission control treatment should be applied to the floor until emissions meet the maximum levels allowed by the flooring manufacturer.

Specify adequate ventilation during installation and flush out the building for a minimum of 72 hours after installation.

Operation and Maintenance Issues

Maintenance products are also significant pollution sources. Flooring with sealed "low maintenance" surfaces should be preferred, both for reducing maintenance costs and the use of cleaners and waxes. It may be possible to require manufacturers to provide cleaning and maintenance product specifications and application procedures. In these cases, the chemicals in these products should be evaluated along with the emissions from the flooring itself.

Low VOC cleaners and sealers are available. Be sure to consult with the manufacturer when specifying sealers and other maintenance products. Use of the wrong products can cause problems, especially with natural linoleum. To help ensure longer life, maintain appearance, and help protect indoor air quality, resilient flooring requires cleaning/vacuuming. Walk-off mats should also be provided at all entrances.

Commissioning

None.

References/Additional Information

See this chapter's Overview.

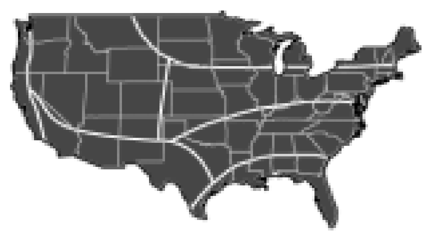
GUIDELINE BP3: CERAMIC TILE / TERRAZZO

Recommendation

Select locally available, recycled content ceramic or clay tile. If installing terrazzo, avoid the epoxy type; substitute cementitious terrazzo where appropriate. Specify low-toxic adhesives, grouts, caulks, sealants, and setting materials.

Use of locally or regionally manufactured ceramics reduces the high transportation costs associated with importing. *NREL/PIX 11433*

Applicable Climates



Applicable Spaces	
Classrooms	
Library	
Multi-Purpose	
Gym	
Corridors	■
Administration	
Toilets	■
Other	■

When to Consider	
Programming	
Schematic	
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	
Operation	■

Description

Recycled content ceramics, clay tiles, and terrazzo (made with cement and crushed stone) are durable and low emission interior finishes.

Terrazzo is a family of flooring materials that incorporates natural marble chips and other aggregates in a cementitious or epoxy mixture, which is usually applied wet and allowed to cure in place.

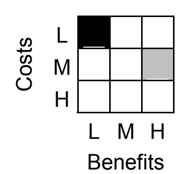
Applicability

Most suitable for traffic areas requiring high durability and low maintenance, but not requiring the acoustic benefits of carpet, such as entryways and toilets.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Tile/terrazzo flooring does not provide the acoustic benefits (tile flooring does not absorb sound and does not reduce impact noise transmission to spaces below) of carpeting, so this, along with teacher preferences, should be considered. As part of the C&D plan, recommend that the subcontractor take back waste tile for recycling.

Cost Effectiveness



Terrazzo costs between $5/ft^2$ and $10/ft^2$ to install, and will last the life of the building. Ceramic tile costs between $6/ft^2$ and $12/ft^2$ installed, and will last 40 to 80 years. Recycled-content tile can be higher priced than average tile products. Low-toxic adhesives used with tile and terrazzo are generally available locally and at competitive prices.

Though costly to purchase and install, the ceramic tile/terrazzo *life cycle* cost is among the lowest of all finishes for some applications, due to its long life and minimal maintenance. Ceramic tile with recycled content may cost 1.5 to 2 times more than conventional.

Benefits

Use of local or regionally manufactured ceramics reduces the high transportation consumption/cost associated importing with this heavy building material. Ceramics and terrazzo (made with cement and crushed stone) are durable and low emitting. Some tile is available with recycled content (up to 70%), such as scrap glass and feldspar waste from mining, which is material efficient, durable, and low- to non-emitting. Some manufacturers also have added heat recovery, water recovery, and clay mine restoration measures to their operations that exceed industry norms, which is ecosystem-protective.

Low toxic adhesives and coatings minimize the indoor pollution load and health risks to both installers and occupants.

Design Tools

See this chapter's Overview.

Design Details

Tile is a packaging-intensive product. Specify recyclable packaging. Check with the manufacturer to see if there is a collection program in place at no cost to owner or contractor.

Terrazzo

The two types of binders used in terrazzo flooring raise different environmental issues during installation. Cementitious terrazzo is composed of inert ingredients mixed with water. The primary installation hazard is dust during mixing and grinding. The installation of epoxy terrazzo, however, requires the use of OSHA-approved respirators, protective gloves, and safety glasses, as well as ventilation with 100% fresh air. The epoxy matrix contains a number of toxic materials. For these reasons, use of the epoxy type terrazzo should be avoided.

Tile

Avoid the use of imported tile. The glazing used on imported tiles can contain lead which is toxic and a potential health threat. Another disadvantage is that imported tiles have high-embodied energy.

Mortar, Adhesives, Caulking, and Sealants

Cement mortars, usually modified with acrylic additives, are the safest to handle for tile setting and offer the best performance for most applications. All plastic adhesives contain some solvents and will contribute to indoor air pollution. Where adhesives and caulking must be used, such as for cove bases and flexible joints, choose a low solvent-content product such as an acrylic. Cement-based, cellulose-based and acrylic-modified grouts are safe and have low emissions. Glazed tile and high-fired tile usually do not require sealers. If a porous tile is chosen, the safest sealers are the low-VOC, acrylic or water-based silicone types. Check with the tile manufacturer to select the lowest VOC, low toxic mortars, sealers, caulks, and adhesives that will provide the desired performance. Review MSDS and emission test data for sealers, caulks and other adhesives to understand their impact on indoor air quality.

Installation

Specify adequate ventilation during installation.

Tile is a non-porous surface and should be installed prior to porous, fleecy, and absorbent materials, which can act as "sinks", absorbing VOCs from other materials and later re-emitting them.

Require installer to use the smallest amount of adhesive and sealant necessary to fulfill the manufacturer's performance specifications for that product.

Perform building flush-out after floor installation.

Operation and Maintenance Issues

Terrazzo flooring should be sealed to prevent absorption of dirt and stains. Water-based sealers are available. Maintenance for ceramic tile varies with the type of surface and grout. Most unglazed tile is sealed after installation. Once floors are sealed, they may require re-sealing throughout their lives, in which the process may impact indoor air quality. Walk-off mats should also be provided at all entrances to help ensure longer life, maintain appearance, and help protect indoor air quality.

Commissioning

None.

References/Additional Information

See this chapter’s Overview.

GUIDELINE BP4: CONCRETE FLOORING

Recommendation

Select concrete flooring, made with fly ash. Use low toxic adhesives, sealers, and wax.

Concrete flooring is highly durable and low maintenance, which conserves materials and reduces potential indoor air quality problems. NREL/PIX 11416

Description

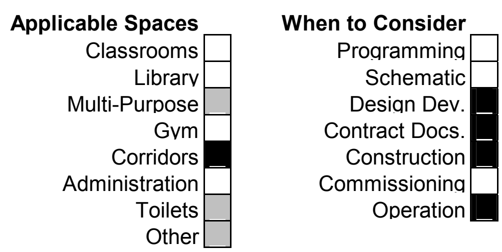
Finished concrete flooring is an integral system of slab and finish, produced by adding colorants and a sealer to the topping concrete (colorized cement) either before or after it cures. The concrete is often stamped with tile patterns and grid lines that also control cracking.

Applying a colorized stain to a cured concrete surface produces stained concrete flooring.

Both types of concrete flooring provide a durable and low maintenance finish. Saw-cut and other designs and colors can add interest and educational value.

Fly ash is a by-product of the coal burning industry.

Applicable Climates



Applicability

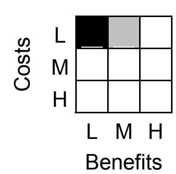
Especially suitable for high traffic areas, such as hallways, cafeterias, and gathering areas. Staining existing concrete flooring is generally appropriate for renovation. Finished concrete flooring with integral colorants is generally applicable to new installations. Concrete may be used for other building surfaces.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Concrete flooring adds thermal mass. Concrete floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness

Medium ($3.00/ft^2) to high first cost, depending upon complexity of the installation/design.



Benefits

Concrete flooring is highly durable and low maintenance, which conserves materials and reduces potential indoor air quality problems due to maintenance products. Concrete with fly ash is material efficient. Low-toxic coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See this chapter's Overview.

Design Details

Selection

Finished systems with integral color added to the entire topping layer are more resistant to damage, and less likely to require re-coloring than systems that are dyed after placing the concrete.

Ask supplier to recommend least toxic, VOC-compliant sealers and wax that will fulfill performance requirements.

Concrete staining is a technique often used in renovation of existing buildings with existing concrete sub-floors.

A variety of techniques are available to add designs – for example, cultural, school, community symbols – for use as teaching tools. Such artistic/educational amenities, however, will increase the cost.

Installation

Specify adequate ventilation during installation and flush out the building in accordance with project specifications.

Require installer to use the smallest amount of sealers and wax necessary to fulfill the manufacturer's performance specifications for that product.

Operation and Maintenance Issues

Proper sealing and re-waxing of stained concrete floors will ensure a long service life. Stained concrete flooring requires periodic re-waxing. Maintenance materials should be reviewed for low VOC emissions.

Walk-off mats should also be provided at all entrances to help ensure longer life, maintain floor appearance, and help protect IAQ.

Commissioning

None.

References/Additional Information

See this chapter's Overview.

GUIDELINE BP5: WOOD FLOORING

Recommendation

Select environmentally preferable products for wood flooring. Specify low-toxic adhesives, sealers, and finishes.

Description

Environmentally preferable wood flooring types include Forest Stewardship Council (FSC)-certified hardwood, salvaged wood, and laminated or veneered wood products. When permitted by the school district, other environmentally preferable choices include salvaged or reclaimed wood. Salvaged flooring is material efficient and considered a 100% post-consumer recycled content product.

If using hardwood, specify products certified by the FSC. FSC is the accrediting agency for organizations that certify forests as well managed. Other environmentally preferable alternatives to conventional hardwood flooring include a wide range of veneered and laminated products that have a hardwood surface with plywood, MDF, or other materials in the core.

FSC

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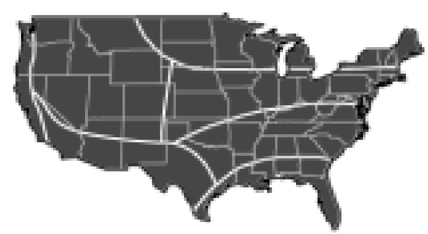
Applicable Climates



Applicable Spaces
Classrooms
Library
Multi-Purpose
Gym
Corridors
Administration
Toilets
Other

When to Consider
Programming
Schematic
Design Dev.
Contract Docs.
Construction
Commissioning
Operation

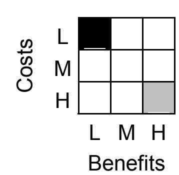
Applicability

Wood flooring is typically now specified for schools only where its performance characteristics make it uniquely desirable: gymnasiums, stages, and dance studios. However, some studies suggest that wood flooring from resource-efficient forests may be an appropriate flooring material for more functions, including classrooms, especially in regions where desirable species are native.

Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with higher reflectivity enhance daylighting). Wood floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness



Wood flooring costs between $6/ft^2$ and $10/ft^2$. The life expectancy averages 38 years. The cost premium for certified wood ranges from modest to significant, depending upon quantity, type, and current availability.

Benefits

FSC-certified wood is eco-system protective. Low toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. The factory pre-finished products have substantial air quality benefits because no sealer is applied, no sanding is performed, and no finishing is done on site.

Design Tools

See this chapter's Overview, and:

Certified Forest Products Database, Certified Forest Products Council. Web site: http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

Design Details

Selection

Several FSC-certified hardwood-flooring products are available. Look for woods grown in regional forests, which reduce the energy consumption involved in transportation.

Veneered and laminated products that have plywood, composite wood products, or MDF cores material efficient, but are less easily repaired than solid wood. These are usually pre-finished at the factory with a very durable, low-maintenance finish.

Low-toxic, clear sealers are also available to use as finishes for woodwork. Water-based varnishes, polyurethane, and other finishes for hardwood floors are very durable and much safer to handle than traditional products. Low-toxic solvents, water-based strippers, and all-natural thinners are also locally available.

A word of caution: not all water-based products are low-emitters and, in fact, some emissions continue far longer than those from traditional, oil based sealers. For example, acid cured lacquers can be strong emitters of formaldehyde while they are curing and for considerable time afterwards. Formaldehyde-free alternatives should be specified for schools. It is recommended that all veneered and laminated products should meet the emissions requirements outlined in Specification Section 01350.

Handling

Specify that woodwork be protected from water damage during transit, delivery, storage, and handling In addition to saving materials, this helps prevent future moisture/indoor air quality (IAQ) problems.

Installation

A steel track system using wedges to hold the flooring in place, or a "floating system," using edge gluing where necessary, makes wood floors easy to remove. A nail down system is also salvageable, but with some loss of material. Avoid parquet systems, which require a glue-down system and are therefore the least salvageable. Eliminating the use of adhesives reduces the impact on IAQ.

If sanding is done on the premises, the area must be carefully isolated, including sealing off the doors and HVAC system, and using temporary fans. Specify final cleanup with a HEPA filter-equipped vacuum.

Require installer to use the smallest amount of adhesive/coating necessary to fulfill the manufacturer's performance specifications for that product.

For finishing on site, use low-VOC emitting finishes. Hardening oils, varnishes and acid cured varnishes have prolonged emissions. If edge gluing is required, specify a low toxicity product such as white carpenters or woodworkers glue. If glue-down methods are required, such as for parquet, specify a low-VOC emitting flooring adhesive.

Specify adequate ventilation during installation and for 72 hours afterwards.

Woods naturally emit formaldehyde.

Operation and Maintenance Issues

After being finished with a synthetic topcoat, maintenance requirements for wood floors are similar to VCT and terrazzo. A typical hardwood floor might need re-sanding (which generates airborne dust) every eight to 10 years and can be re-sanded up to five times. Annual screening and re-coating maintains the protective wear layers. Wood flooring is easier to repair than most other materials.

Commissioning

None.

References/Additional Information

See this chapter's Overview, and:

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Tel: (503) 590-6600. Refer also to: http://fscus.org/html/index.html. Industry group provides information on distribution and other assistance.

Certified Forest Products Database, Certified Forest Products Council, http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

GUIDELINE BP6: BAMBOO FLOORING

Recommendation

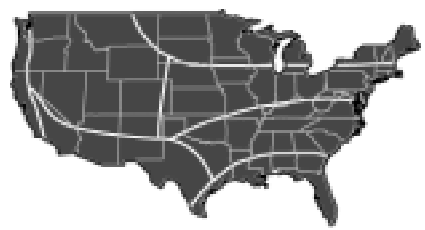
Specify domestically produced flooring made from rapidly renewable bamboo (it matures in less than five years). Install and finish with a low toxic, water-based sealer and wax.

Bamboo flooring is aesthetically pleasing, low emitting, durable, and produced from a renewable, harvested resource. NREL/PIX 11417

Description

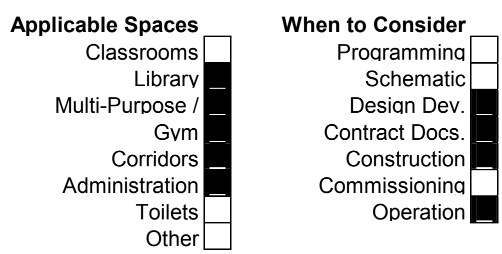
Bamboo is a natural material, technically a grass that can reach timber height of 100 ft. It is a renewable resource, requiring no pesticides, fertilizers or irrigation, so it is not labor intensive to farm. Some manufacturers source their bamboo from managed forests using a harvesting method done by hand. This reduces the impact on the local environment in terms of erosion and habitat destruction. Most bamboo used in flooring production is grown in, and imported from, China. Boric acid is sometimes added during the manufacturing process. Bamboo flooring is harder than most common wood flooring, very durable, fast-growing, and dimensionally stable.

Applicable Climates



Applicability

Suitable wherever wood flooring would be used. Bamboo may also be used as plywood, paneling, and veneer.

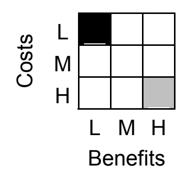


Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than other flooring does, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Bamboo floors do not absorb sound or reduce impact noise transmission to spaces below.

Cost Effectiveness

Costs range from $4/ft^2$ to $8/ft^2$, which is slightly more than domestic hardwoods. However, bamboo is more durable than wood (25% harder than oak, 12% harder by some tests than maple, and 2.5 times more dimensionally stable than maple).



Benefits

Bamboo flooring is aesthetically pleasing, low emitting, durable, and produced from a renewable, harvested resource. Low toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

Design Tools

See this chapter's Overview.

Design Details

Specify use of adequate ventilation during installation. Flooring is best applied by nailing, stapling, or gluing to a wood sub-floor, but can be glued to concrete at or above grade. If installing over concrete, moisture testing is recommended prior to installation.

Operation and Maintenance Issues

Place mats at entrances and exits to trap dirt from incoming traffic. Bamboo floors must be vacuumed or swept regularly with a nylon broom. Use non-alkaline cleaning solutions. Do not mop with water, since excess water can damage the floor.

Commissioning

None.

References/Additional Information

See this chapter's Overview, and:

The American Bamboo Society. Web site: http://www.bamboo.org/abs.

GUIDELINE BP7: GYPSUM BOARD

Recommendation

Specify gypsum wallboard with a minimum 100% recycled content paper facing. Recycled content gypsum (up to 10%) is available.

Gypsum used for recycling should be clean construction waste, uncontaminated by paint, tape, compounds, adhesives, or other coatings.

Description

Gypsum products are the most common interior panels used due to their fire retardant characteristics and low cost.

Applicability

Suitable for all spaces. High impact gypsum is appropriate for spaces requiring higher than normal durability.

Integrated Design Implications

Wallboard installation should be coordinated with the job-site waste reduction plan. Recycle clean waste drywall (require subcontractor to take back for recycling).

When recycling old gypsum board, check to see if the joint or topping compounds contained asbestos fibers. Sanding such material will result in the release of fibers into the air. State and federal laws regulate disposal of asbestos-containing materials.

Cost Effectiveness

Gypsum board is the lowest cost option for walls. However, for ceilings, it is competitively priced with drop-in ceiling.

Benefits

Gypsum is highly recyclable if not contaminated (with paint or adhesives) and the paper facing is generally made with recycled paper. Use of recycled-content gypsum is material efficient. High impact gypsum is more durable than conventional wallboard and has higher recycled content.

Design Tools

See this chapter's Overview.

Gypsum is highly recyclable if not contaminated with paint or adhesives and is more durable than conventional wallboard.
NREL/PIX 11410

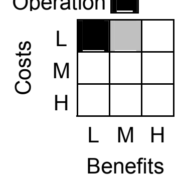
Applicable Climates

Applicable Spaces

Space	Applicable
Classrooms	■
Library	■
Multi-Purpose	■
Gym	■
Corridors	■
Administration	■
Toilets	■
Other	■

When to Consider

Phase	Consider
Programming	□
Schematic	□
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	□
Operation	■



Design Details

Selection

Specify a minimum 10% recycled content gypsum board core with recycled content facing paper. (Recycled content board must be specified, since recycled content is not automatically provided). It is recommended that all gypsum board products (virgin and recycled content) meet the emissions standards outlined in Specification Section 01350.

Consider gypsum produced by a recent innovation, the fibergypsum process. This board, now available in the U.S., has no paper facing but contains recycled wood, paper fiber, and perlite. It is very strong and scratch-resistant, and appropriate for high-wear areas such as schools.

Another environmentally preferable option is the use of gypsum board made with synthetic gypsum. Synthetic gypsum is produced with flue-gas desulfurization (FGD) gypsum, fluorogypsum, citrogypsum, and titanogypsum. This technology is not available in all areas, so embodied energy loads should be considered when selecting synthetic gypsum. Synthetic gypsum should also meet the emissions testing standards in Specification Section 01350. (Synthetic gypsum can have a negative environmental impact on agricultural land if it is used as a soil amendment, due to its heavy metal content.)

Installation

Special care should be taken during the delivery, storage, and handling of gypsum board to prevent to accumulation of moisture on the material or within its packaging. Exposure to moisture can cause mold growth in the gypsum paper facing. To prevent possible interior mold problems, any stored or installed gypsum board showing evidence of moisture damage, including moisture stains, mildew, and mold, should be immediately removed from the site and disposed of properly. Replace contaminated gypsum board with new, undamaged materials.

Specify wet sanding processes during finishing. An exception is that dry sanding may be allowed subject to full isolation of the affected space(s), installation of protective plastic sheeting to provide air sealing during the sanding; closure of all air system devices and ductwork, sequencing of construction to prevent contaminating other spaces with gypsum dust, use of proper worker protection, and owner approval of these measures. Using vacuums during dry sanding to reduce dust can also help protect the health of installers.

Unpainted gypsum surfaces are potent “sinks” — they absorb volatile organic compounds (VOCs) and then re-emit them. Require adequate ventilation during installation of adhesives and other materials that emit indoor pollutants. Where feasible, sequence work to avoid exposing applying VOC-containing materials in spaces with exposed, unpainted gypsum surfaces.

Operation and Maintenance Issues

Requires periodic painting for aesthetic purposes. Type of paint determines cleanability. Wallboard is easy to repair.

Commissioning

None.

References/Additional Information

See this chapter’s Overview.

GUIDELINE BP8: ACOUSTICAL WALL PANELS AND CEILINGS

Recommendation

Select formaldehyde-free acoustical ceiling and wall systems with recycled-content.

Description

Acoustical wall and ceiling systems are widely used in school for sound absorption. A variety of products are available including modular wall panels (textile and metal-covered), suspended ceiling tiles (t-bar ceilings), and surface mounted ceiling and wall panels.

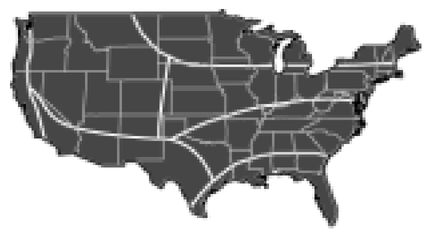
Ceiling tile (usually in a T-bar ceiling) is the most common ceiling finish in schools. Because of the large ceiling surface area, the likelihood of its being disturbed during modifications/renovations, and its contact with HVAC systems, it is an important product to consider for air quality and materials efficiency.

Types currently available include recycled content ceiling tiles made of recycled newspaper, mineral wool, perlite, glass fiber, and clay. Look for a minimum recycled content of 79%. (A recent informal survey conducted by the California Integrated Waste Management Board indicates that the recycled content of acoustical ceiling tiles varies between 18% and 82%). New products on the market can attain 85% recycled content, but with some diminished noise reduction value. Natural fiber acoustic ceiling panels are also available, for both walls and ceilings.

Formaldehyde-free acoustical panels with recycled content are considered a material efficient, low-volatile organic compound product, promoting healthy indoor air.

NREL/PIX 11441

Applicable Climates



Applicable Spaces		**When to Consider**	
Classrooms	■	Programming	□
Library	■	Schematic	□
Multi-Purpose	■	Design Dev.	■
Gym	■	Contract Docs.	■
Corridors	■	Construction	■
Administration	■	Commissioning	□
Toilets	■	Operation	■
Other	■		

Applicability

Use anywhere sound absorption and easy ceiling plenum access is desired.

Integrated Design Implications

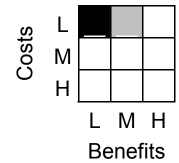
The T-bar ceiling system integrates with HVAC system ducting layout and operation. Do not use the space above the T-bar ceiling as a return air plenum because it is difficult to clean, and, if there is any off-gassing, odors, or microorganisms from any material in this area, contaminants can spread throughout the air space and be distributed to other areas. Instead, install return air systems using dedicated metal ductwork with access hatches for inspection and cleaning. Recycle construction waste (require subcontractor to take back for recycling).

Make sure insulation is not installed directly over drop-in ceilings. Lighting fixtures, diffusers, and other equipment interrupt the insulating barrier, leading to poor insulating performance. (Often the space above the ceiling is considered an attic space, requiring outside air ventilation.)

Make sure no fiberglass is exposed in the plenum.

Cost Effectiveness

Costs are low.



Benefits

Formaldehyde-free acoustical panels with recycled content are available. These panels are considered a material efficient, low-volatile organic compound (VOC) product that promotes healthy indoor environmental air quality

Acoustical products from wood fiber and other resource-efficient raw materials are highly durable.

Ceiling tile waste, either from construction or demolition, is nontoxic (as long as lead paint and asbestos were not used on older ceiling installations).

Design Tools

See this chapter’s Overview.

Design Details.

General

It is recommended that ceiling tiles meet the emissions standards outlined in Specification Section 01350. Emission test data and MSDSs for ceiling tile materials should also be obtained and reviewed.

Acoustical materials, including acoustical ceiling tiles, can act as "sinks" for the adsorption of odorous or irritating VOCs from other sources (during application of paint and other finish coatings, for example, or from occupant activities) and re-emit them later. Where feasible, sequence work to avoid exposing acoustical ceiling and wall systems while applying VOC-containing materials in spaces with exposed acoustical surfaces. Require adequate ventilation during installation of finish materials that emit pollutants.

Consult with the manufacturer before painting/coating any acoustical material. For example, with most ceiling tiles, the material loses its acoustical properties once it has been painted.

Sound absorbing materials such as acoustical wall panels and ceiling tiles should have their sound absorbing properties measured in a laboratory environment. Sound absorption is typically rated in terms of NRC (Noise Reduction Coefficient). The NRC scale ranges from 0.00 (totally reflective) to 1.00 (totally absorptive). Materials with “good” sound absorbing capabilities should have a minimum rating of NRC 0.65. Another acoustical parameter to be considered is the Ceiling Attenuation Class (CAC). Ceiling tiles typically range from CAC 25 to 40. Ceiling tiles with higher CAC ratings allow less sound to pass through and tend to absorb less sound than those with lower CAC ratings. In areas that have noise producing elements (i.e. Variable Air Volume (VAV) or Fan Powered Boxes (FPB)) in the ceiling space and also have a need for low background noise levels, a high CAC ceiling tile may want to be considered to help reduce background noise from terminal air devices or other noise sources. As always, a qualified acoustical consultant should review material selections before final decisions are made.

Acoustical Wall Panels

Low-density fiberboard is made from paper and wood fiber, and is available made from 100% recycled newsprint. Most processes use no glue. They are suitable for use as acoustic panels. Fiber-free foam panels are also available from some manufacturers.

Ceilings

Coordinate placement of lighting fixtures and other equipment in ceilings to provide clear access for inspection and servicing of HVAC system air filters and other components.

Where daylighting has been incorporated as a design strategy, consider using ceiling tiles with high light reflectance as specified in ASTM Standard E1477 (0.83lr).

Special care should be taken during the delivery, storage, and handling of ceiling tiles to prevent to accumulation of moisture on the material or within its packaging. To prevent possible interior mold problems, any stored or installed ceiling tiles showing evidence of moisture damage, including moisture stains, mildew, and mold, should be immediately removed from the site and disposed of properly. Replace contaminated tiles with new, undamaged materials.

Lights should be chosen to maximize the total area of the exposed acoustical ceiling.

Operation and Maintenance Issues

Ceiling tiles and other acoustical materials collect dust as well as adsorb and re-emit VOCs. Tile with mineral fiber content may also begin to shed hazardous fiber if disturbed or as it deteriorates. Both problems are a particular concern where the ceiling is used for a return plenum to carry air back to the HVAC air handlers. If this type of return system is used, the tile should be checked for damage and the plenum space occasionally cleaned with a high performance vacuum. If possible, in new and renovation design, HVAC returns should be ducted instead of risking contamination by debris in suspended ceilings (See Integrated Design discussion above.)

Commissioning

None.

References/Additional Information

See this chapter's Overview, and:

"Natural-fiber Acoustic Ceiling Panels," Environmental Building News, Volume 7, No. 4 (April 1998).

GUIDELINE BP9: PAINTS AND COATINGS

Recommendation

Specify the least toxic, low-formaldehyde, low- or zero-volatile organic compound (VOC) paint that meets durability and other performance requirements.

Description

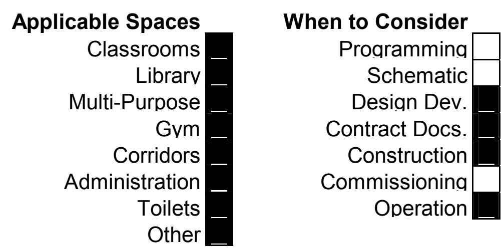
Emissions from paints and coatings are primarily from evaporating solvents, other VOCs and by-products released after oxidation. Water-based paints acrylic latex paints are lower in VOCs (<250 mg/L) than solvent-based paints. Low-VOC is generally accepted to mean paint with a VOC content less than 100 mg/L.

Low-VOC paints are usually those in the lighter color ranges. Tinting may increase VOC emissions.

Formaldehyde-free paint is not yet available, but several low-formaldehyde options exist. Select paint with the lowest formaldehyde concentrations possible.

While a variety of low-VOC and zero-VOC paints are now available to choose from, they vary in cost, potential toxicity, and performance. Therefore, paint selection should consider VOC content as well as overall composition and required performance characteristics, including cleanability, hideability (i.e., how well a product conceals a surface), and durability.

Applicable Climates



Recycled content paint that complies with Specification Section 01350 emissions standards is now available on the market, and may be considered for interior and exterior use.

Applicability

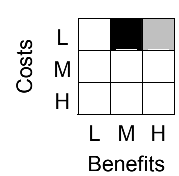
All interior painted surfaces.

Integrated Design Implications

Light colors enhance daylighting. Integrate with ventilation system installation/operation to provide proper ventilation during application, curing, and occupancy. Change out HVAC filters following application and before occupancy.

Cost Effectiveness

Costs vary widely with paint type and application. Low-VOC and zero-VOC paints have tended to cost 10% to 30% more than conventional paint, but prices are becoming more comparable as demand/production increases. Many low-VOC paints are now comparable in price to conventional paint.



Benefits

Zero-VOC or low-VOC paints minimize the indoor air pollution load, odors, and health risks to both workers and occupants. Water-based paints are generally safer to handle and can be cleaned up with water, reducing health risks to workers and minimizing/avoiding hazardous waste. Leftover latex paint may be recyclable, thus reducing waste.

Design Tools

See this chapter's Overview.

Design Details

Where practicable, leave surfaces of exposed structure unpainted.

A paint can be labeled low-VOC yet still contain odorous, irritating, toxic, or otherwise undesirable ingredients such as ammonia, formaldehyde, crystalline silica (a known carcinogen in dust form),[12] acetone, odor masking agents, glycols, and many other compounds, including fungicides and bactericides. Some of these may not be an *air quality* problem for occupants, but they may be hazardous to painters and those involved in manufacture of the paint. In addition, hazardous ingredients can degrade the natural environment during production and after disposal. Look for water-based paints that are low-formaldehyde, zero- or low-VOC, *and* low toxic. While information supplied on manufacturers' data sheets may make certain claims about VOC content or toxicity, speak with technical staff at the manufacturers' headquarters or manufacturing facility to obtain detailed information on product performance and environmental hazards. It is recommended that all paints meet the emissions testing standards outlined in Specification Section 01350.

Specify products containing no lead, mercury, hexavalent chromium or cadmium. Though regulations have eliminated many toxic components from consumer paint lines, industrial and commercial paints may still contain them. Check the MSDSs; all hazardous contents present at 1% of total weight and listed by (OSHA) as hazardous must be disclosed. Besides using Specification Section 01350 and the MSDS review, more detailed information can be obtained from the manufacturer and by reviewing emissions test results to determine the type of biocides used as well as the presence of other potentially hazardous ingredients.

High-traffic areas or areas vulnerable to graffiti may call for a more durable and smoother (enamel) finish. These paints typically have a higher VOC content. While there is little test data comparing "high-durability" and low-VOC paints, anecdotal information suggests that "high-durability" (usually alkyd paint) products would be expected to show roughly twice the performance of low-VOC paints.

If possible, the selection process should include a side-by-side paint comparison of the various products being considered, and should include comparison of abrasion resistance (durability), hideability, volume solids, odor, and overall appearance. Final paint selection should consider the following elements:

1. What is the allowable drying cycle for initial painting and subsequent maintenance cycles? Is the paint locally available? (An important consideration for future maintenance.)
2. What is the expected durability or life expectancy required? Requirements will likely vary with the space. For example, one manufacturer had specific and different recommendations for gymnasiums, cafeterias, restrooms, general classrooms, and hallways.
3. What is the method of application? Choices, such as in-house versus contractor and spray versus roller, have a bearing on paint choice.

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[12] Some low-VOC paints contain crystalline silica, a known carcinogen. This ingredient is not a hazard in the wet paint — it is an issue only when dried paint is sanded, and dust is generated.

4. What are the budget constraints, including first-time and maintenance? Budget analysis should consider not just cost per gallon, but also evaluate area coverage per gallon and projected time between re-painting, which can vary greatly with conditions of use.

Installation

Paint should be installed prior to soft surfaces such as carpeting to prevent absorption of VOCs. Specify isolation requirements (isolation of construction zones from completed zones to prevent cross-contamination; removal, coverage, or isolation of porous materials to avoid their adsorption and subsequent re-emission of solvents, maintaining negative pressure by exhaust ventilation in construction areas). Low-VOC paints may require a longer airing out time than other paints, so be certain to specify appropriate ventilation. When sanding dried paint, a dust mask should be worn.

Operation and Maintenance Issues

Review recommended duration between paint application and occupancy and review for compatibility with maintenance schedules/requirements. Ideally, work should be scheduled during unoccupied periods or periods of least occupancy. Large projects should be scheduled during the summer vacation months or other breaks. The maintenance schedule should also factor in manufacturer recommended air temperatures for application.

Caution

In jobs that require removal of old paint and may require chemical strippers, closely observe manufacturers recommendations for use, including ventilation and personal protective equipment per OSHA.

If performing renovation at a school constructed prior to 1980, do not begin work until testing paint samples for possible lead contamination. If lead-containing paint is present, observe appropriate abatement controls.

Where possible, perform painting and stripping off-site or select materials with factory-applied finishes. For on-site interior painting, cover surfaces, such as fabric-covered furnishings, to which VOCs may adsorb. Consider constructing barriers (for example, walls or curtains of plastic sheeting) to help isolate portions of larger areas and minimize the distribution of dust and other pollutants.

Wipe down all surfaces with a damp cloth as soon as practical after completing all dust-generating work typically associated with surface preparation.

Carefully observe manufacturers recommendation for cleanup, storage, and disposal, for paints, primers, and thinners. Some products are classified as “flammable liquids” under federal regulations and must be stored in a specifically constructed safety cabinet. Keep paint containers covered as much as possible during and following use to protect against VOC release. For excess paint, consider recycle/reuse options.

All paint containers with residual liquid must be disposed of as hazardous waste per U.S. Environmental Protection Agency regulations. Only dry containers can be placed in municipal landfills.

Commissioning

None.

References/Additional Information

See this chapter’s Overview, and:

*Interior Painting and Indoor Air Quality in Schools***.** Published by the School Facility Branch of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097.

GUIDELINE BP10: CASEWORK AND TRIM

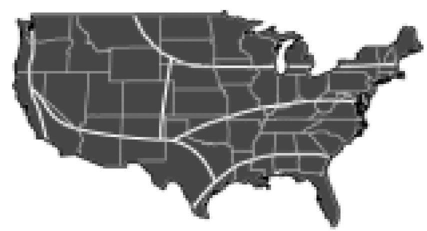
Recommendation

Specify casework and trim constructed from formaldehyde-free binders and other environmentally preferable materials. Design for easy future disassembly and reuse. Specify assembly off-site where major off-gassing can occur before products are brought into the building. Install with least hazardous, low- volatile organic compound (VOC) content adhesives and coatings.

Description

Conventional particleboard is made with bonding agents including urea-formaldehyde, which can off-gas for years after application. (Please refer to the discussion of formaldehyde-related indoor air quality problems in the Overview.) Authorities recommend fully covering all six sides of each surface with plastic laminate, or coating the particle board with a sealer to prevent off-gassing of formaldehyde and other volatiles (see Caution callout, below). However, unless a product's particleboard is fully-covered, it is recommended to use only products that use formaldehyde-free binders for interior use in high performance schools.

Applicable Climates



Applicable Spaces		When to Consider	
Classrooms	■	Programming	□
Library	■	Schematic	□
Multi-Purpose	■	Design Dev.	■
Gym	■	Contract Docs.	■
Corridors	■	Construction	■
Administration	■	Commissioning	□
Toilets	■	Operation	□
Other	■		

Environmentally preferable product alternatives for interior casework and/or trim include exterior grade plywood with phenolic formaldehyde resin, formaldehyde-free medium density fiberboard (MDF), oriented strand board (OSB), certified wood, salvaged lumber, bamboo, recycled plastic, metal, biocomposites (only for areas not subject to frequent wetting), and engineered wood. Certified MDF and plywoods also exist. Pre-assembled cabinets made with low-toxic materials and finishes, solid wood, engineered wood, and enameled metal are also available.

OSB, MDF, and other composite wood products can be strong sources of VOCs. Some of the emitted VOCs are terpenes which, when oxidized, form formaldehyde, higher molecular weight aldehydes, and acidic aerosols. Some of these oxidation products are more irritating or toxic than the chemicals emitted from the wood products. For instance, composite wood is the leading contributor to indoor formaldehyde levels, so reducing the amount of composite wood used is crucial to protecting indoor air quality. Some composite wood products manufactured with urban waste wood can contain wood preservatives, lead-containing paint, and other toxic compounds.

Acid-cured lacquers applied as finishes to wood products can be long-lasting sources of formaldehyde emissions.

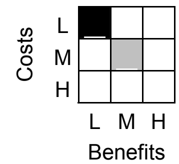
Applicability

All interior casework and trim.

Integrated Design Implications

None.

Cost Effectiveness



There is a cost premium for certified wood, ranging from modest to significant, depending upon quantity, type, and current availability. Engineered wood often costs less than virgin lumber. MDF made with formaldehyde-free binders may also cost more.

Benefits

Formaldehyde-free products and low toxic glues/adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. Certified wood is produced in a way that is ecosystem-protective. Products made from certified hardwoods are durable and reusable.

Engineered lumber makes use of wood waste that would otherwise be discarded. Products made with engineered wood have low moisture content and so are warp-resistant and shrink-resistant, adding to their durability. The products are strong, and their predictable qualities lead to less rework.

Bio-composites materials are made from natural, renewable resources including straw, recycled paper products, and a soy-based resin systems. These products have reduced emissions and are material efficient.

When plastic laminates are selected, look for options made from recycled laminating manufacturing wastes, which are material efficient and recyclable.

Design Tools

See this chapter’s Overview, and:

Certified Forest Products Database, Certified Forest Products Council, http://www.certifiedwood.org. 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. (503) 590-6600. Industry information on suppliers and standards.

Design Details

Design interior building components for future disassembly, reuse, and recycling.

> ***Caution***
>
> *Many of the engineered lumber products contain formaldehyde or other chemicals that are detrimental to the environment and to indoor air quality. Some types of particleboard are now being manufactured with resin binders that do not contain formaldehyde. If formaldehyde-free particleboard or plywood products are not available, select exterior grade plywood in lieu of interior grade products. Exterior grade contains phenol formaldehyde, which is less harmful than the urea formaldehyde in interior grade plywood.*
>
> *Note: Some practitioners recommend coating conventional particleboard with an impermeable sealant to prevent out-gassing of formaldehyde and other volatiles. However, others disagree that this is effective mitigation.*

Selection

Environmentally preferable alternatives include:

- Using certified hardboards with woods grown in regional forests, which reduces the energy consumption involved in transportation.
- For casework, consider urea formaldehyde-free MDF, or equal, exterior grade plywood (made with phenolic formaldehyde, which emits far less formaldehyde than the urea formaldehyde in traditional interior grade products).
- Consider veneered wood panels, such as OSB with hardwood facing, for cabinets and millwork. If installed for easy removal, they are reusable.
- Bamboo can be used for countertops. Also consider biocomposites for countertops in reception or other high profile (but not wet) areas.
- Low-density fiberboard is made from paper and wood fiber, available made from 100% recycled newsprint. Most processes use no glue. They are suitable for uses such as underlayment and tackboards.

- Recycled plastic panels made from consumer product waste are available for functional worktops. If installed for easy removal, they are reusable.
- Vegetable oil-based plastics are available in both flexible and rigid types. They can be colored and filled with minerals, metal shavings, or other plastic waste and wood fiber giving them a large range of texture and color possibilities. If installed for easy removal, these also have good reuse potential.
- Fiber reinforced cement boards made with recycled fiber are a durable, material efficient choice for use as substrates for tile and decorative finishes. If installed for easy removal, these also have good reuse potential.
- It is recommended that all casework assemblies and wood furnishes meet the emissions standards outlined in Specification Section 01350. It may also be beneficial to obtain and review MSDS and emission test data. Wood naturally emits formaldehyde, so test data should be carefully reviewed.

Installation

Dust from cutting and emissions from glues used for installation are indoor air quality issues during and after installation. Specify work to be performed in a shop off the premises where practicable. Require installer to use the smallest amount of adhesive/sealant necessary to fulfill the manufacturer's performance specifications for that product. Specify use of adequate ventilation and VOC-safe worker masks. Where appropriate, specify installation to permit easy removal and reuse, for example, screwed assembly instead of glued.

Operation and Maintenance Issues

Issues will vary with type of material selected, but are similar to requirements for traditional materials.

Commissioning

None.

References/Additional Information

See this chapter's Overview, and:

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Tel: (503) 590-6600. Industry group provides information on distribution and other assistance.

Certified Forest Products Database, Certified Forest Products Council. Web site: http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

The American Bamboo Society. Web site: http://www.bamboo.org/abs.

APA -The Engineered Wood Association. Tel: (206) 565-6600. Web site: http://www.apawood.org. Email: product.support@apawood.org.

American Institute of Timber Construction. Tel: (303) 792-9559. Fax: (303) 792-0669. Web site: http://www.aitc-glulam.org. Email: webmaster@aitc-glulam.org.

American Wood Council. Tel: (202) 463-2700. Web site: http://www.awc.org/. Email: AWCINFO@afandpa.ccmail.compuserve.com.

National Particleboard Association. Tel: (301) 670-0604. Web site: http://www.pbmdf.com. Email: info@pbmdf.com.

Western Wood Products Association. Tel: (503) 224-3930. Web site: http://www.wwpa.org. Email: info@wwpa.org.

GUIDELINE BP11: INTERIOR DOORS

Recommendation

Select formaldehyde-free interior doors constructed with recycled content or from certified wood. Avoid particleboard core board doors, which contain urea-formaldehyde and luan doors, which are made from wood harvested from rain forests. Select pre-finished products, if possible. If finishing on-site, select low toxic, low-VOC coatings.

Avoiding luan and solid wood doors helps protect limited forest resources and indoor air quality. NREL/PIX 11473

Description

Interior doors are usually wood, molded hardboard, or hollow core. Luan plywood is harvested from rain forests, so it should be avoided unless it has a Forest Stewardship Council (FSC) or other certification. Molded hardboard is often made with recycled material and pressed into shape, but some is made with urea-formaldehyde and should be avoided.

If using solid wood doors, select products with FSC or other certification (clear stock is becoming rare and if uncertified, often comes from old-growth forests.)

Applicability

All spaces.

Applicable Climates

Applicable Spaces	
Classrooms	☐
Library	☐
Multi-Purpose / Gym	☐
Corridors	☐
Administration	☐
Toilets	☐
Other	☐

When to Consider	
Programming	☐
Schematic	☐
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	☐
Operation	■

Integrated Design Implications

In areas where a high degree of speech privacy and/or sound isolation is required, doors should be solid core wood or hollow metal with acoustic fill. Full perimeter gaskets should also be included to reduce sound leaks around the edge of the door. Standard weather stripping with a door bottom sweep will minimize sound leaks, but wears down with use. Doors in areas that require a high degree of sound isolation should have heavy-duty adjustable sponge neoprene gaskets at the head and jamb. Automatic door bottoms with a neoprene element should also be used.

Cost Effectiveness

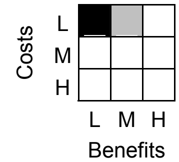
Costs are low.

Benefits

Avoiding luan and solid wood doors help protect limited forest resources. Formaldehyde-free materials protect indoor air quality and contribute to a more healthful environment. Low-toxic finish coatings minimize indoor air pollution load and health risks to both installers and occupants.

Design Tools

See this chapter's Overview.



Design Details

Review emissions data and MSDS prior to specification of a recycled content molded hardboard product to ensure that it is urea-formaldehyde-free. It is recommended that all hardboard products meet the emissions specifications outlined in Specification Section 01350.

Operation and Maintenance Issues

May require periodic re-coating for aesthetic purposes. Type of paint determines the ability to clean the surface.

Commissioning

None.

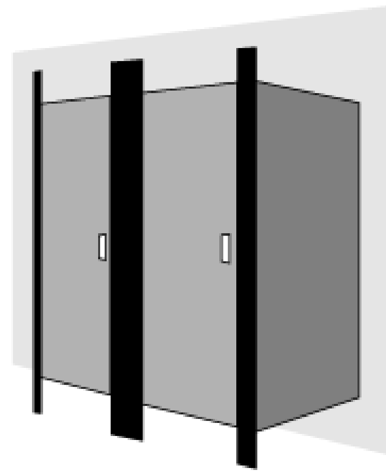
References/Additional Information

See this chapter's Overview.

GUIDELINE BP12: TOILET PARTITIONS

Recommendation

Select high durability, solid plastic toilet and shower partitions with recycled content.



High-density polyethylene (HDPE) restroom partitions are maintenance-friendly and durable.

Description

Several styles of toilet partitions are available, including baked enamel over metal, plastic laminate over particleboard, and solid plastic panel. Solid plastic toilet/shower partitions are the most durable type overall. Recycled content products are made with a post-consumer, high-density polyethylene (HDPE) content between 20% and 35%, depending on the manufacturer. In addition, some brands contain postindustrial plastic material. Look for purified HDPE, as it contains a predominant amount of post-consumer waste.

Applicable Climates

Applicable Spaces	
Classrooms	
Library	
Multi-Purpose	
Gym	
Corridors	
Administration	
Toilets	■
Other	■

When to Consider	
Programming	
Schematic	
Design Dev.	■
Contract Docs.	■
Construction	■
Commissioning	
Operation	■

Applicability

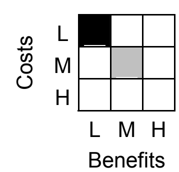
All toilet/shower partitions.

Integrated Design Implications

None.

Cost Effectiveness

Recycled content units cost 20% more than conventional units, but are more durable, require less maintenance, and can be reused. In addition, recycled content toilet partitions generally have a 15-year warranty verses the standard five-year warranty of other partition products.



Benefits

Recycled content partitions are material efficient, low maintenance, rot-resistant, and graffiti/vandal resistant.

Design Tools

See this chapter’s Overview.

Design Details

None.

Operation and Maintenance Issues

None.

Commissioning

None.

References/Additional Information

See this chapter’s Overview.

COMMISSIONING AND MAINTENANCE

INTRODUCTION

Building owners spend more on complex building systems than ever before, yet many find they are not getting the performance they expect. A 1994 study of 60 commercial buildings found that more than half suffered from control problems. In addition, 40% had problems with HVAC equipment and one-third had sensors that were not operating properly.[1] An astonishing 15% of the buildings studied were actually missing specified equipment. And approximately one-quarter of them had energy management control systems, economizers, and/or variable-speed drives that did not run properly. Problems also frequently occur on the envelope, structural, and electrical systems of many new buildings.

Schools are investments, and every new school is unique. In essence, each school design is a prototype expected to perform as if it were something that had been built before. Combining a new school design with modern technology, a tight construction schedule, and a fixed budget can lead to a building that does not perform as anticipated.

Building commissioning is one way to improve the outcome of a construction project. Neither the design team nor the district desires a poorly performing school. Unfortunately, school districts frequently are the ones left to deal with the resulting financial implications, including excessive repair and replacement costs, student absenteeism, indoor air quality problems, and construction team liability. Building commissioning can ensure that a new school begins its life cycle at optimal productivity and improves the likelihood that it will maintain this level of performance.

Commissioning is a quality-assurance process that increases the likelihood that a newly constructed building will meet district expectations. Commissioning can optimize the energy-efficient design features and improve overall building performance. Districts can use this proven, systematic approach to reduce change orders and liability exposure, and to ensure that they receive buildings that function according to their original project requirements (design intent).

WHAT EXACTLY IS BUILDING COMMISSIONING?

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent, and the school's operational needs. Ideally, this is achieved by beginning in the pre-design phase with design

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[1] Piette, Mary Ann. "Quantifying Energy Savings from Commissioning: Preliminary Results from the Northwest," in *Proceedings of the National Conference on Building Commissioning*, 1996.

intent development and documentation, and continuing through design, construction, and the warranty period with actual verification through review, testing, and performance documentation. The commissioning process integrates and enhances the traditionally separate functions of design peer review, equipment startup, control system calibration, testing, adjusting and balancing, equipment documentation, and facility staff training, as well as adds the activities of documented functional testing and verification.

Commissioning is occasionally confused with testing, adjusting, and balancing. Testing, adjusting, and balancing measures building air and water flows, but commissioning encompasses a much broader scope of work. Commissioning typically involves four distinct "phases" in which specific tasks are performed by the various team members throughout the construction process. The four phases are pre-design, design, construction, and warranty. As part of the construction phase, commissioning involves functional testing to determine how well mechanical and electrical systems meet the operational goals established during the design process. Although commissioning can begin during the construction phase, districts receive the most cost-effective benefits when the process begins during the pre-design phase at the time the project team is assembled.

A properly commissioned school can result in fewer change orders during the construction process, fewer callbacks, long-term occupant satisfaction, lower energy bills, and avoided equipment-replacement costs. Commissioning also assures that the building's operational staff is properly trained, with correctly compiled operation and maintenance manuals delivered at project turn-over.

COMMISSIONING APPROACHES

In recent California focus group studies, building owners and their representatives repeatedly stressed the lack of communication between the design team and construction team as a major problem. This lack of communication means that the original design intent of a project is unlikely to be carried through to project completion. (Documenting design intent — the expectations for building performance — is a critical component of commissioning and is discussed in more detail later.) Commissioning provides a means of linking the traditionally fragmented phases of the design and construction process, because it encourages the project team to view the process holistically. The commissioning process encourages parties to communicate and solve problems earlier in the construction process. Beginning proper commissioning during the design phase can help identify and solve problems that later may turn into performance problems, occupant comfort complaints, indoor air quality issues, and decreased equipment life.

Although commissioning works best when it begins during design, projects already under construction can still benefit from commissioning. Bringing a commissioning provider into a project during the construction phase can be invaluable in helping solve start-up problems that have stumped both designers and contractors. The commissioning provider can also document the start-up and functional testing results, thereby reducing future liability exposure for the designers and district. The provider also oversees operation/maintenance staff members training, thus improving the operating procedures of the facility.

BENEFITS OF COMMISSIONING

Until recently, the most frequently mentioned benefit of commissioning was its energy-related value: building commissioning ensures that the energy savings expected from the design intent are implemented correctly. While these benefits are significant, the non-energy-related benefits of commissioning far outweigh them. Examples include:

- Proper and efficient equipment operation
- Improved coordination between design, construction, and occupancy
- Improved indoor air quality, occupant comfort, and productivity
- Decreased potential for liability related to indoor air quality, or other HVAC problems
- Reduced operation and maintenance costs.

Proper and Efficient Equipment Operation

Commissioning verifies that equipment is installed and operating properly. Equipment that operates as intended lasts longer, works more reliably, and needs fewer repairs during its lifetime. By promoting equipment reliability, commissioning can reduce service, energy, and maintenance costs. Equipment that operates properly tends to use less energy, require fewer service calls and replacement parts, and demands less “crisis maintenance” from onsite staff (or expensive outside contractors), allowing them to concentrate on their normal duties.

Improved Coordination Between Design, Construction, and Occupancy

Commissioning can result in greater cooperation among the professionals involved in the project and provides a platform for cross-checking the performance of a building’s equipment and combined systems, which ultimately leads to fewer callbacks and litigation problems.

A good design includes systems that are sized correctly, rather than the oversized mechanical systems found in many commercial buildings.[2] On many projects, a lack of understanding and coordination between the design, installation, and/or operational team members can lead to systems that function inefficiently. Commissioning allows for a broad perspective and consistent focus throughout the design and construction process on whether the building will function as intended and identifies the best long-term solutions for problems that arise during the project. Commissioning can facilitate improved integration and communication among team members throughout these phases and can also ensure that correctly sized systems function as intended and specified.

Many districts mistakenly believe that adding commissioning quality assurance procedures to their design process will delay the project’s schedule and increase costs. Many who have

[2] York, Dan. “Commissioning Green Buildings,” in *Proceedings of the National Conference on Building Commissioning*, 1998.

incorporated commissioning into the design phase of their projects have discovered that commissioning can significantly reduce change orders,[3] which in turn reduces the requests for project delays and decreases the use of contingency funds for change orders. Thus, beginning commissioning during design can actually contribute to the on-time and on-budget completion of projects. It should be noted that these benefits will not be realized if the commissioning process begins during the equipment start-up phase of a project.

Improved Indoor Air Quality, Comfort, and Productivity

The benefits of high performance schools are all dependent on how well the building performs.

Surveys indicate that comfort problems are common in many U.S. buildings. A recent OSHA report noted that 20% to 30% of commercial buildings suffer from IAQ problems. Building occupants complain of symptoms ranging from headaches and fatigue to severe allergic reactions. In the most severe cases, occupants have developed Legionnaire’s disease, a potentially fatal bacterial illness. The National Institute of Occupational Safety and Health surveyed 350 buildings with deficient IAQ and found that more than half of the complaints stemmed from HVAC systems that were not operating properly.

Building commissioning is a tool districts can use to avoid the expenses and productivity losses associated with poor IAQ and student/teacher discomfort. Because commissioning assures that HVAC and other building systems are installed and operating properly, commissioned buildings tend to have fewer comfort-related problems.

Liability Related to Indoor Air Quality

Building commissioning protects schools in more than one way. First, it provides documented verification of a building’s performance and operation. Ventilation rates are a good example of a primary factor that affects indoor air quality. HVAC commissioning typically includes testing these flow rates under varying load conditions to assure that the ventilation systems are operating properly. If a school has deficiencies, the commissioning provider documents the original condition and records the repairs made. Commissioning should be repeated throughout the life of the school, and performance documentation should be updated regularly. This documentation provides districts with a record of building performance that can be used as evidence in the event of a lawsuit.

Commissioning also helps prevent many IAQ problems through its focus on training the teachers and staff in the proper maintenance of building systems. Properly run and maintained HVAC systems, with clean coils and air intakes as well as regularly changed filters, are less likely to contribute to IAQ problems. In addition, trained school staff can spot potential air quality and ventilation problems before they develop.

Both local and state government agencies have begun using commissioning as a tool to ensure that indoor air quality standards are being met when a building is constructed.

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[3] Savage, Jerry. “Commissioning a Materials Research Laboratory,” in *Proceedings of the National Conference on Building Commissioning*, 2000.

Reduced Operation, Maintenance, and Equipment Replacement Costs

Operation, maintenance, and equipment replacement costs will always consume a portion of building budgets. However, more operation and maintenance departments are realizing that they can minimize life-cycle costs by changing their practices. That is, proper operation and maintenance can actually save money compared to poor practices, and many businesses are reinvesting their operation and maintenance savings in more efficient building systems. The commissioning process establishes sound building operation and maintenance practices, and trains operators in carrying out these practices. (Some of these practices are discussed in more detail in the Operation and Maintenance for Persistence section of this chapter.)

The Bottom Line

Commissioning improves a building's value. Properly functioning buildings with reliable equipment kept in good condition are worth more than their non-commissioned counterparts. Commissioned systems and equipment retain their value longer. Additionally, an ongoing demand exists for comfortable, healthy working space. Finally, systems that function properly use less energy, experience less down time, and require less maintenance, thereby saving money for districts.

COSTS OF BUILDING COMMISSIONING

Currently, no standard method of reporting the costs and savings associated with commissioning exists. For many projects, commissioning costs are not separated from other project costs. For projects where these costs have been tracked separately, various methods have been used to report both the costs and associated benefits. The table below lists some of the most common cost-estimation methods. No matter which estimation method is used, however, commissioning accounts for only a very small portion of overall construction and retrofit budgets.

Table 1 — Estimated Commissioning Costs for New Equipment [4]

Commissioning Scope	Estimated Cost Range
Whole building (controls, electrical, mechanical) Commissioning from design through warranty	0.5% to 3% of total construction cost
HVAC and automated controls system only	1.5% to 2.5% of mechanical contract
Electrical system only	1% to 1.5% of electrical contract

SAVINGS FROM BUILDING COMMISSIONING

Districts and their servicing utilities are interested in the energy (kWh) savings achieved from commissioning energy systems and equipment. Additionally, they are also interested in how much the commissioning will save them in operation and maintenance costs. Just as commissioning costs can vary from project to project, so do commissioning savings. Savings

[4] Estimated costs adopted from PECI Data and Ron Wilkinson's article "Establishing Commissioning Fees," ASHRAE Journal-February, 2000.

will depend on the scope of the commissioning. Table 2 shows the reported savings for three different types of commercial buildings commissioned during the past few years. When commissioning is done properly, the savings can be quite substantial for schools as well.

Table 2 – The Savings from Commissioning New Equipment (Mechanical Systems)[5]

Building Type	Annual $ Savings	Annual Energy Savings
110,000-ft^2 Office	$22,320	279,000 kWh
22,000-ft^2 Office	$13,080	130,800 kWh
60,000-ft^2 High Tech Manufacturer	$26,880	336,000 kWh

Many districts question how they can pay for commissioning with a limited design and construction budget. Because commissioning can identify potential problems earlier in the design or construction process, the result is a lower overall construction budget, fewer contractor callbacks, and lower operating costs during the first year of operation. By transferring those potential savings to the design and commissioning team budgets, the total project costs can be equivalent to a project that is not commissioned, as illustrated in Figure 1 below.

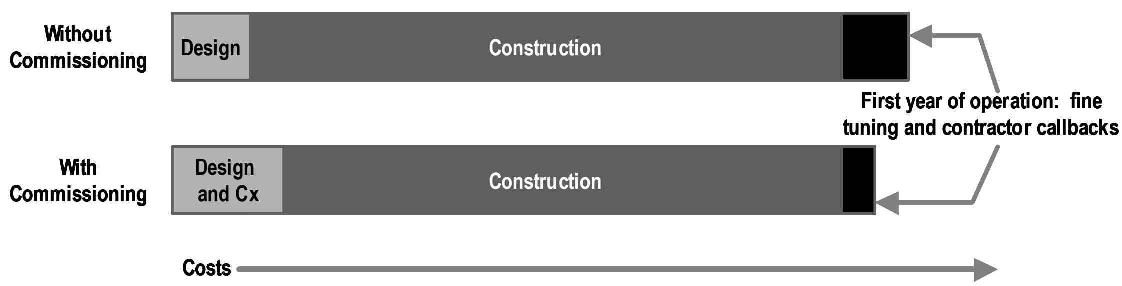

Figure 1 – How to Pay for Commissioning-One Option

Shift 2% of total project costs to the commissioning provider and 3% to the design team.[6]

SELECTING A COMMISSIONING PROVIDER

One of the most important commissioning decisions is selecting the commissioning provider and determining who will hold the commissioning provider's contract. Two primary methods exist for selecting a commissioning provider: competitive bid and selection by qualification. The Building Commissioning Association (BCA) can provide a list of commissioning providers. Contact information for the BCA can be found in the resources section at the end of this chapter. In the Request for Qualifications, be sure to ask for details on previous, relevant commissioning experience, including the depth of commissioning experience (what some call

[5] Annual energy savings calculated from three Northwestern United States commissioning projects. Cost savings estimates based on a blended 2000 California kWh rate of $0.10 for smaller office buildings and $0.08 for larger offices and industrial facilities.

[6] The Farnsworth Group, as presented in "How to Achieve Top Performance in Your Building: Commissioning Benefits, Process and Performance," a workshop series by the Association of State Energy Research and Technical Transfer Institutes, 1998.

commissioning is no more than traditional equipment startup).[7] Make sure that the provider's definition of commissioning corresponds to the one at the beginning of this chapter. Recommended commissioning provider qualifications are discussed in more detail in the following pages. Based on the responses, develop a list of firms to receive a Request for Proposal that details exactly what services the construction project will need to be properly commissioned. Districts can also select a commissioning provider based on qualifications and rate schedules, rather than by competitive bid. This process warrants careful interviewing and contact with the providers' current or past clients.

Any of the following parties can be selected to manage the commissioning provider's contract:

- Project Manager
- Architect/Design Engineer
- Contractor.

Each option has its advantages and disadvantages. The final choice will depend on the complexity and the specific needs of the particular project. As building commissioning has evolved and more practitioners with different ideas have entered the field, a group of interested parties worked to form the BCA, a professional association, in 1998. According to the BCA website (http://www.bcxa.org/), "The BCA's goal is to achieve high professional standards, while allowing for diverse and creative approaches to building commissioning that benefit our profession and its clients. For this reason, their focus is on identifying critical commissioning attributes and elements, rather than attempting to dictate a rigid commissioning process". The association believes that "the basic purpose of building commissioning is to provide documented confirmation that building systems function in compliance with criteria set forth in the project documents to satisfy the owner's operational needs." Paramount to this is the understanding that if the commissioning provider is not an independent party under contract directly with the district/owner then he or she must develop a formal plan for managing the potential conflict of interest. One method that has been used successfully to manage, but not eliminate, these potential conflicts of interest is parallel and simultaneous reporting of all findings to the district's representative and contract manager for the commissioning services.

Independent Third Party Under Contract to the District/Owner

Many districts/owners who have commissioned their buildings recommend using an independent third party as the commissioning provider. An independent commissioning provider can play an objective role and ensure that the district will truly get the building performance expected. For large and/or complex projects, especially in buildings with highly integrated, sophisticated systems, future savings from commissioning outweigh the slightly higher costs with an additional contract. Independent third party commissioning providers bring a fresh perspective to the project as they collaborate with the design team. By joining the project team during the design, the commissioning provider can identify more opportunities for

[7] " Start up" refers to the process of starting up equipment to determine whether it operates. Commissioning goes beyond start up to ensure that new equipment performs in conformance with design expectations in all modes and conditions of operation.

improvements and savings early on when changes can be made on paper. This approach is preferable to waiting to fix the problems through the change-order process as the building is being constructed.

Independent commissioning providers, who are often trained as design engineers, should have the qualifications listed under “Commissioning Provider Qualifications,” plus they should be able to write commissioning specifications for bid documents. Hands-on experience with building systems is especially critical. It is important to involve the independent authority as early in the project as possible. This allows the authority the opportunity to review the design intent for the project, begin scheduling commissioning activities, and begin writing commissioning specifications into bid documents for other contractors.

Architect or Engineer Overseeing the Commissioning Process

If commissioning requirements in the project specifications are rigorous and detailed, districts may consider having the architect manage the contract of a commissioning provider. When the architect or the mechanical designer has qualified field engineers on staff and those engineers do not have responsibility for the design of the project, the architect or engineer may be considered for directly overseeing the commissioning process. One advantage of using the architect or mechanical designer is that he or she is already familiar with the design intent of the project. Districts considering this option should bear in mind that commissioning is not included in a design professional’s basic fees. Districts should require that all findings of the commissioning process be directly reported to both the designer and to the district as they occur to manage the potential conflict of interest created by having the commissioning services under the designer. Districts must also recognize that even if this option is not chosen and an independent third party is used, designers might increase their fees slightly to offset the additional time requirements to coordinate their work with the commissioning provider.

Contractor

It used to be standard practice for many contracting firms to conduct performance tests and systematic checkout procedures for equipment they installed. As construction budgets became tighter, this service was dropped from most projects. Although contractors may have the knowledge and capability to test the equipment they install, they may not be skilled at testing or diagnosing system integration problems. In addition, some contend that it is difficult for contractors to objectively test and assess their own work, especially since repairing deficiencies found through commissioning may increase their costs. For districts that only wish to have the commissioning process begin during the construction phase, it may be appropriate to use the installing contractor as the commissioning provider in cases where:

- The building size is less than 20,000 ft^2.
- The project specifications clearly detail the commissioning requirements.
- The district has skilled staff that can review the contractor’s commissioning work.

Another option for districts that have a good relationship with the general contractor is to require that the general contractor hire a test engineer to commission the equipment. This scenario can work well when specifications and contract documents clearly detail the commissioning requirements and when the district has technical staff that is qualified to oversee the test engineer. Still, many general contractors welcome the opportunity to work with an independent commissioning provider, because of the objectivity they bring and because they assist in ensuring that the subcontractors perform their work properly, improving client satisfaction and ultimately reducing callbacks.

Commissioning Provider Qualifications

Currently, there is no broadly recognized and approved certification or licensing process for commissioning providers. Therefore, it is up to each district to determine the commissioning provider's qualifications appropriate for a given project. See the sidebar for guidelines on selecting a qualified commissioning provider.

Regardless of who is chosen to act as the commissioning provider, there are certain minimum qualifications any commissioning provider ought to have, and the following list is by no means all-inclusive. Certain projects may require more or less experience, depending on size, complexity, and specific building characteristics. Direct the commissioning provider to subcontract work in which he or she lacks sufficient experience.

Commissioning Provider Qualifications Checklist

In general, for complex projects, a commissioning provider who will personally develop the commissioning test plans and directly supervise the commissioning work should meet these qualifications. These qualifications are focused on HVAC and control systems. Where electrical and other systems will be commissioned, the firm's experience in these areas should also be considered. However, often the prime commissioning provider will team with other subconsultants to provide a team that can expertly address all the systems being commissioned. In such cases, the management skill of the prime commissioning provider is also important.

Recommended Minimum Qualifications

Experience in design, specification, or installation of commercial building mechanical and control systems, as well as other systems being commissioned.

Experience commissioning projects within the last three years with similar size building systems.

History of responsiveness and proper references.

Meet district's liability requirements.

Experience working with project teams, project management, conducting scoping meetings, and good communication skills.

At least two projects involving commissioning of buildings of similar size and equipment to the current project. This experience includes writing functional performance test plans.

Optional Qualifications

Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs.

Experience in design installation and/or troubleshooting of direct digital controls and energy management systems, if applicable.

Demonstrated familiarity with metering and monitoring procedures.

Knowledge and familiarity with air/water testing and balancing.

Experience in planning and delivering operation and maintenance training.

Building contracting background.

Overall understanding by the commissioning team of all building systems including building envelope, structural, and fire/life safety components.

THE COMMISSIONING TEAM

Members of a design-construction project team, like components of integrated building systems, need to interact in order to perform their tasks successfully. Commissioning actually facilitates this interaction, because it sets clear performance expectations and requires communication among all team members.

Any project involving commissioning should begin with a commissioning scoping meeting, which all team members are required to attend. At this meeting, the roles of each team member are outlined, and the commissioning process and schedule are described.

Commissioning team members most often include the district representative or project manager, commissioning provider, design professionals, installing contractors, and manufacturer's representatives. The team may also include facility staff and possibly testing or diagnostic specialists and utility representatives. The commissioning team does not manage the design and construction of the project. Its purpose is to promote communication among team members and to identify and resolve problems early in the process. To that end, the design professional and district representative are key members of the commissioning team.

Of course, few situations are ideal. Budget considerations and special project characteristics may expand or minimize the commissioning roles and responsibilities described below. Districts should consult with their commissioning providers about potentially combining some of the following roles. The commissioning provider can review the scope of commissioning and advise the district on how to consolidate roles and tasks to best fit the size and complexity of the project.

District Representative

The district's most significant responsibility is to clearly communicate expectations about the project outcome. The district's expectations are used by the designer to establish the design intent of the project and by the commissioning provider to evaluate whether this intent is met. Other responsibilities of the district representative include:

- Determining the objectives and focus of the project.
- Hiring the commissioning provider (if using an independent third party) and other members of the project team.
- Determining the project's budget, schedule, and operating requirements.
- Working with the commissioning provider to determine commissioning goals.
- Facilitating communication between the commissioning provider and other project team members.
- Approving start-up and functional test completion (or delegating this task to a construction or project manager).
- Attending building training sessions when appropriate.

Commissioning Provider

The commissioning provider's primary tasks include:

- Ensuring the completion of adequate design intent documentation.
- Providing input on design features that facilitate commissioning and future operation and maintenance.
- Assisting in developing commissioning specifications for the bid documents.
- Developing a commissioning plan that includes equipment and systems to be commissioned.
- Ensuring that team members understand their specified commissioning responsibilities; work to promote a positive, solutions-based team approach; and facilitate bringing a quality project to completion.
- Developing diagnostic and/or test plans for systems to be commissioned.
- Writing construction, functional, and performance tests.

- Submitting regular reports to the district representative.
- Witnessing selected contractor start-up tests, air and water testing and balancing, and duct pressure testing.
- Overseeing all functional and performance testing of systems.
- Reviewing and commenting on technical considerations from design through installation, to facilitate sound operation and maintenance of the building.
- Reviewing contractor and manufacturer training plans prior to delivery to facility staff.
- Reviewing operation and maintenance manuals documentation for completeness.
- Writing a final commissioning report documenting the final evaluation of the systems' capabilities to meet design intent and district needs.
- Developing a systems concepts and operations manual that details the most important operation parameters and equipment instructions.

Design Professionals

The responsibilities of the design professionals will vary with the interests of the designers and the needs of the project. The primary commissioning-related responsibilities of design professionals are to document the design intent for all systems, if this was not completed in pre-design; to write system descriptions and record design basis information; answer questions and issues brought up by the commissioning provider during design; and to make sure that commissioning is included in the bid specifications. If the design professional is hiring the commissioning provider, he or she should do so as early in the design process as possible. During construction, the designers are tasked with clarifying design issues related to system operation and design intent and to assist in resolving construction and operational deficiencies illuminated by the commissioning process. For complex projects, the designer may review commissioning plans, functional performance test plans, and may witness select functional testing. If this is the case, the design professional's proposal should include funds to cover these activities. As mentioned before, the design firm may be responsible for hiring and overseeing the commissioning provider.

Installing Contractors and Manufacturer Representatives

Contractors and manufacturer representatives are responsible for performing commissioning functions described in the specifications. These may include assisting with developing the commissioning schedule, conducting performance tests (under the supervision of the commissioning provider or facilities staff) of the systems they install, adjusting systems when commissioning indicates this is needed, and documenting system startup. Contractors and manufacturer representatives are also responsible for training building staff in the proper operation and maintenance of systems, and providing operation and maintenance manuals on the equipment they install.

Facility Manager/Building Operator

The building operator should assist with (or at least observe) as much of the functional testing as possible. To achieve even greater impact on the commissioning process as early as possible, the district should try to hire its new operator or assign an existing operator who will be responsible for this building to become closely involved with the construction commissioning team. The insights of an operator in the final phases of design can be quite beneficial. Often times there are details of the design that can be adjusted and modified at no cost yet will provide significant benefits to the ongoing operation of the building. Specific examples might include point-naming conventions, alarm messages, and graphic layouts of the energy management system. The operator can also help in interfacing any existing facilities management software, district standards, and equipment preferences into the project. As this employee observes the commissioning tests, the operator's understanding of the equipment and control strategies will improve. It also trains the employee to be able to retest systems periodically as part of ongoing operation and maintenance. The operator should also attend training sessions provided by manufacturer's representatives and/or contractors.

Testing Specialists

If the complexity of the project requires special testing, the specialists performing these tests should also be involved in commissioning. Test results and recommendations from these specialists should be submitted to the commissioning provider for review. They may also be required to review documentation relating to the systems they test and to train operators on the proper use of this equipment.[8]

COMMISSIONING PHASES

The commissioning process helps facilitate and connect each step of the construction process. Commissioning enhances communication among project team members and ensures that they all understand the project goals. This allows the project team to identify problems early, before they can affect later phases of the project and cause delays.

Predesign Phase

The predesign phase is the ideal time for the district to select a commissioning provider. Early selection allows the commissioning provider to play an advisory role during the conceptual process, suggesting ways to make the overall building more energy efficient and identifying key design strategies that can facilitate operation and maintenance. Involving the provider early can also increase buy-in for commissioning from other team members because the provider is involved from the beginning. Otherwise, the team may view the commissioning provider as an outsider who does not really understand the project. During this phase, the commissioning provider may assist in developing the district's goals or, at minimum, ensuring that these goals are clearly documented and distilled into a design intent narrative.

The design intent narrative, typically developed by the district, is an explanation of the ideas, concepts, and criteria that are important. It should generally describe the project both physically and functionally, and it should set the performance requirements for the design, construction, and operation. The level of detail will vary with the project's size and complexity,

[8] Dunn, Wayne. "Roles and Responsibilities," in *Proceedings of the National Conference on Building Commissioning*, 1995.

the district demands, and the design team's experience. The design intent should describe how the project will be used and operated, and should present known goals and objectives as measurable metrics when possible. It may also state specific contractual performance requirements or energy consumption targets, if the district establishes them. The design intent sets the criteria for all subsequent design decisions.

> ***Expected Deliverables***
>
> *Districts who decide to commission their buildings should expect to receive the following written deliverables:*
>
> *Commissioning plan and schedule detailing each step of the commissioning process and each team member's role and responsibilities.*
>
> *A diagnostic and functional test plan detailing the objective of each test, how each test will be accomplished, and noting expected performance parameters.*
>
> *A list of findings and potential improvements identified by the commissioning provider for design phase and construction phase activities.*
>
> *A training plan recommending specific topics and training schedules.*
>
> *At the completion of the project, a final commissioning report detailing all of the commissioning provider's findings and recommendations, including copies of all functional performance testing data.*
>
> *A systems concepts and operations manual which gives a description of each system with specific information about how to optimally operate and control the system during all modes of operation such as during fire, power outage, shutdown; etc., including special instructions for energy-efficient operation and recommissioning.*
>
> *Energy savings and implementation cost estimates for recommendations developed in the process are also deliverables in retro-commissioning projects.*

Design Phase

The goal of commissioning during the design phase is to ensure that the efficiency and operational concepts for building systems that were developed during programming are included in the final design. The main commissioning tasks during this phase are compiling and reviewing design intent documents if not already developed, incorporating commissioning into bid specifications, and reviewing bid documents. During the beginning of design, the designer develops the design concepts that he or she proposes to use to meet the district's program and intent. The designer also documents the assumptions (design basis) used in the design for sizing and selecting systems (i.e., codes followed, temperature parameters, and occupancy loads). The design concepts and design basis are compiled into a design narrative document that the commissioning provider reviews for clarity, completeness, and compliance with the design intent. As the design progresses, the design narrative is updated and compared against the design intent.

The bid specifications developed during the design phase include commissioning requirements for the contractors. Specifications should include any special equipment or instrumentation that must be installed for obtaining measurements during performance testing. They should also describe the responsibility that contractors will have for preparing operation and maintenance manuals and for training facility staff. The commissioning provider reviews these bid documents, updated design narratives, and all other design intent and contract documents.

The optimum time to hold the commissioning scoping meeting is during the design phase. At this meeting, the commissioning provider outlines the roles and responsibilities of the project team members with respect to commissioning and reviews the commissioning plan outline and schedule. Team members provide comment on the plan and schedule, and the commissioning provider uses these suggestions to complete the final commissioning plan. The final plan will include:

- The scope or level of commissioning
- Commissioning schedule
- Team member responsibilities
- Communication, reporting, and management protocols
- Documentation requirements of each team member
- Detailed scope of testing
- Detailed scope of monitoring
- Recommended training format.

The commissioning provider attends selected design team meetings and formally reviews and comments on the design at various stages of development. They note potential system performance problems, and may provide input on energy efficiency, indoor environmental quality, maintainability, commissionability, sustainability, and life-cycle cost, depending on the skills of the commissioning provider and design team and interests of the district. Making these changes during the design phase, rather than after construction begins, reduces costly change orders, which saves money in the long run. It is important for the district to understand that the commissioning provider does not approve the design. He or she makes recommendations to facilitate commissioning and improve building performance in a collegial manner in concert with the designated design team.

During this phase, the commissioning provider can also play a significant role in developing a building's operation and maintenance program or suggesting improvements for a program already in place. The provider interviews the facility manager to determine operating staff ability and availability to operate and maintain building equipment and systems. Careful consideration is given to whether the proper level of staffing resources is available to fully implement a successful long-term operation and maintenance system to ensure continued building performance. The commissioning provider also reviews the design documents and drawings to ensure that equipment is accessible for maintenance.

Construction Phase

During this phase, the commissioning provider reviews contractor submittals of commissioned equipment and the operation and maintenance manuals and may write test plans for each system and piece of equipment to be commissioned. The provider also visits the construction site periodically and notes any conditions that might affect system performance or operation.

During the construction phase, construction checklists — sometimes referred to as "pre-functional tests" and usually completed by the contractors — are used to ensure that equipment is properly installed and ready for functional testing. The commissioning provider approves and may oversee start-up and the use of construction checklists, as well as making sure that any deficiencies are remedied before functional testing begins.

The commissioning provider should involve the building operation staff in the construction checklist procedures and functional testing as much as possible. Doing so improves staff understanding of the proper operation of equipment and systems. It also provides operators with valuable hands-on training in running and troubleshooting the equipment they will manage.

The commissioning provider may write various progress reports during construction that document testing progress as well as deficiencies that may affect future building performance. These reports may be submitted to the district, design engineer, project manager, or contractors, depending on the contract arrangements for the project. (Establishing a clear process prior to the construction phase for delivering correction orders to the responsible contractors and tracking their responses is critical to the success of commissioning.)

The commissioning provider uses the functional tests to document and verify the proper operation of equipment and systems according to the building specification plans and change orders, as well as the architect's instructions. Most often, the commissioning provider directs the tests, but the subcontractors, particularly the controls contractor, perform the actual equipment operation during the tests. If corrective measures are required, the commissioning provider ensures they meet the district's criteria and the design intent, involving the owner and architect to resolve responsibility or strategy when necessary. Acceptable performance is reached when equipment or systems meet specified design parameters under full-load and part-load conditions during all modes of operation, as outlined in the commissioning test plan.

After completing functional testing, the provider writes a final commissioning report and submits it to the district for review. In addition to the final report, some commissioning projects include a more comprehensive documentation package to assist the district in understanding, operating, and maintaining their systems. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) calls this package a systems manual and recommends that it include:[9]

- Index of all commissioning documents with notations as to their storage locations
- Commissioning report
- Initial and final design intent documents
- As-built documents
- Description of systems, including capabilities and limitations
- Operating procedures for all normal, abnormal, and emergency operation modes
- Sequence of operation as actually implemented, with control systems data including all set points and calibration data
- Location of all control sensors and test ports
- Seasonal start-up and shutdown procedures

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[9] ASHRAE Guideline 1-1996-*American Society of Heating Refrigerating and Air-Conditioning Engineers*, Atlanta GA, 1996.

- Control schematics and computer graphics
- Complete terminal interface procedures and capabilities of the Direct Digital Control (DDC) system
- A list of recommended operation record-keeping procedures, including sample forms and trend logs
- Maintenance procedures.

The construction phase is complete when the facility has moved from the static construction state to the dynamic operating state essentially free of deficiencies. Control of the building may have been transferred from the design/construction team to the district and building operators prior to completing this phase. Part of this transfer involves training building operators how to operate and maintain the equipment and systems. Preferably, this training begins during the construction/installation phase, as discussed above.

The commissioning provider is responsible for interviewing the project manager and operation and maintenance staff to determine their training needs. With the district representative, the provider then selects the appropriate topics, level of detail, sequence of training, and training methods. Training may include both classroom sessions and hands-on site demonstrations of proper equipment operation and maintenance.

In addition, the commissioning provider oversees training sessions as specified in the bid documents that installing contractors, designers, and manufacturers' representatives will conduct. The provider also verifies that operation and maintenance manuals are complete and available for use during the training sessions. The commissioning provider may arrange for videotaping of the training and coordinate this videotaping with vendors. Videotaping training sessions often provides an extra incentive for vendors to ensure the quality of the sessions.

Warranty Phase

Upon turnover, the building is in the hands of the owner and operators. Even though the project is considered complete, some commissioning tasks from the initial commissioning contract continue throughout the typical one-year warranty period to ensure that full operation of building systems is achieved.

Any testing that was delayed because of site or equipment conditions or inclement weather, will be completed during warranty. Although some testing of heating and cooling systems can be performed under simulated conditions during the off-season, natural conditions usually provide more reliable results. Seasonal testing is conducted to verify proper operation during, at minimum, both winter and summer.

When performing testing during post-occupancy, the commissioning provider or test engineer must be careful not to void any equipment warranties. The district should require that contractors provide the commissioning provider with a full set of warranty conditions for each piece of equipment to be commissioned. Some warranty provisions may require that the installing contractor actually perform the testing, under the supervision of the commissioning provider.

The commissioning provider may also be tasked with returning a few months prior to the expiration of the contractor's one-year warranty to review system operation and interview facility staff. Acting as the district's technical resource, he or she assists the facility staff in addressing any performance problems or warranty issues.

It is a good idea for districts to consider recommissioning their facilities periodically to ensure that equipment performance levels continue to meet design intent. If school staff has been involved in the original commissioning effort, and if they received training that included the components listed in the Suggested Training Topics sidebar, they may be able to conduct the recommissioning process themselves.

When Does Commissioning End?

Commissioning ensures that a building is performing as intended at the time that commissioning occurs. This means that to maintain this level of performance, commissioning, in a sense, never ends. Certainly no one could reasonably expect building operation staff to perform functional tests on equipment and systems daily. However, operation and management staff should be encouraged to recommission selected building systems on a regular basis, perhaps every two to three years depending on building usage, equipment complexity, and operating experience. The commissioning provider can recommend an appropriate interval for the building and systems. In the meantime, implementing regular, sound operation and maintenance practices ensures that the savings from commissioning last.

OPERATION AND MAINTENANCE FOR PERSISTENCE

Sound operation and maintenance practices can help keep the school operating at commissioning levels. Some of these practices include:

- Establishing and implementing a preventive maintenance program for all building equipment and systems.
- Using commissioning documentation such as commissioning checklists and functional tests as a basis for periodic equipment testing.
- Reviewing monthly utility bills for unexpected changes in building energy use.
- Using energy accounting software to track building energy use.
- Tracking all maintenance, scheduled or unscheduled, for each piece of equipment. Periodic reviews of these documents will often indicate whether certain pieces of equipment require tuning up.
- Updating building documentation to reflect current building usage and any equipment change-outs.
- Establishing an indoor air quality program for the building.
- Assessing operator training needs annually.

Good Operation and Maintenance Begins During Design

Like commissioning, successful operation and maintenance begins in the design phase of a project. Soliciting input from operation and maintenance staff during the early stages of building design can facilitate good operation and maintenance practices. The more convenient it is for staff to perform regular checks and maintenance on building systems, the better building performance needs can be met and costly maintenance can be avoided. In addition, the installing contractor's responsibilities concerning operation and maintenance should be clearly detailed in the project contract specifications during the design stage, so that the contractor can adjust the bid price accordingly. For instance, specifications should explicitly state that contractors will be required to provide information needed to facilitate the commissioning process and to coordinate activities with the commissioning provider as needed. The specifications should also require the contractor to provide comprehensive operation and maintenance manuals for equipment and provide training for staff.

Operation and Maintenance Manuals

The contractor prepares operation and maintenance manuals for each piece of equipment. The commissioning provider reviews each manual for compliance with the specifications as part of the commissioning process. Operation and maintenance manuals should contain:

- Name, address, and telephone number of installing contractor
- Product data
- Test data
- Performance curves (for pumps, fans, chillers, etc.)
- Installation instructions
- Operation requirements
- Preventive maintenance requirements
- Parts lists
- Troubleshooting procedures specific to the equipment design and application.

If the provider believes it would be beneficial, additional information, already gathered during the commissioning process, can also be included in the operation and maintenance manuals. This information may include equipment submittals, design intent documents including control strategies and sequence of operations (normal and emergency), and copies of the commissioning tests (pre-functional checklists and functional performance test forms).

Operation and maintenance manuals are useful reference tools for current facilities staff and can also be used as a training resource for new staff members. The operation and maintenance manuals should be placed in three-ring binders. Contractors should be required to provide at least three copies of each manual to the district. Typically, one copy becomes the master copy, and remains in the facility manager's office. "Hard binding" the master copy so that pages cannot be removed and misplaced is recommended. The second copy functions as a field copy, and selected pages from it may be removed for use during site work. The third copy resides at district offices. If building equipment will be maintained and operated by an outside firm, a fourth copy should be requested and provided to them as a reference. Because manuals lose their usefulness if they are not kept up to date, any pages added to them, such as checklists or preventive maintenance work orders, must be included in each copy.

Training

Perhaps the most essential component of operation and maintenance is training. Unless building operators and managers are given the skills to perform quality operation and maintenance practices, there is no hope that a building will continue to perform optimally.

As with all training, instruction should be structured to meet the needs of building operator staff. Training session topics should ideally be specified in the bid documents.

By videotaping each training session, including the hands-on start-up and shutdown procedures for equipment, building operation staff gains a permanent and inexpensive onsite training aid. When new staff is hired, they can view the videos as part of their training.

For buildings where a facility manager without a technical background provides maintenance, the commissioning provider can still coordinate with contractors to ensure that the manager is educated about the capabilities, intended function, and required maintenance of the building systems. This education should enable the facility manager to respond to occupant complaints in a manner that does not circumvent the systems' design intent. It is important to provide a list of resources for the manager to call for maintenance assistance when necessary.

Once a building is operating and occupied, problems occasionally develop that were not apparent during the commissioning process. These problems often occur during the first year of operation after construction or renovation. Sometimes the service contractor or operating staff can effectively troubleshoot and solve the problem. However, if a problem becomes chronic (for example, repeated comfort complaints), or if operating staff is unable to solve a problem in a reasonable amount of time, the district should request expert troubleshooting assistance.

Suggested Training Topics

Descriptions of equipment and systems installed and their warranties or guarantees.

Equipment start-up and shutdown procedures, operation in normal and emergency modes, seasonal changeover, and manual/automatic control.

Requirements and schedules for maintenance on all operation and maintenance-sensitive equipment.

Indoor air quality, health, visual comfort, acoustic comfort, and safety issues.

Recommendations for special tools and spare parts inventory.

Emergency procedures.

Operation and adjustment of dampers, valves, and controls.

Hands-on operation of equipment and systems.

Common troubleshooting problems, their causes, and corrective actions.

Review of operation and maintenance manuals, and their location onsite.

Building walk-through.

Review of related design intent documents.

Energy management control system operation and programming.

Control sequences and strategies.

Thermostat programming.

Relevant commissioning reports and documents.

When and how to recommission building systems.

The maintenance work order management system.

Sound energy management practices.

Because the commissioning provider and design engineer are very familiar with the building systems, the district may want to consider contracting with one and/or both of them for the first year of operation to provide troubleshooting assistance on an as-needed basis. In traditional construction projects, the mechanical engineer is only responsible to help correct problems if their contract stipulates a warranty period and the problems are "design" related. The district may find that it is more cost-effective to purchase troubleshooting services from the commissioning provider or engineer, because their knowledge of the building systems and design saves them time in diagnosing problems. This contract could be written in a "fee-for-service" or an "amount-not-to-exceed" manner.

In the long run, districts may also find it beneficial to train operation and maintenance staff in energy accounting. In addition to tracking the building's energy use, energy accounting can also indicate problems or potential problems with equipment operation.

Preventive Maintenance

Another important operation and maintenance practice is preventive maintenance. Preventive maintenance can save school districts time and money by:

- Maintaining facility operation
- Extending equipment life
- Identifying equipment degradation

▪ Preventing losses of equipment, time, productivity, and resulting revenue.

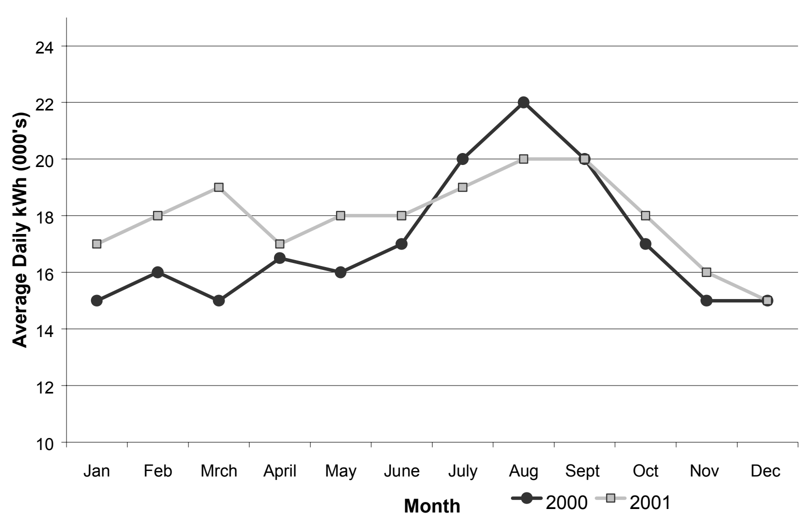
Effective maintenance and operations procedures are fundamentally important to sustaining the performance of all building systems. Student health and productivity can be affected when building systems fail to operate as designed. Sub-standard maintenance or incorrect operation of building systems usually results from a combination of factors. First, maintenance budgets are often the first to be reduced or eliminated when money becomes tight. Second, designers and contractors typically provide the building staff minimal or no training about how the building systems are supposed to operate or be maintained. Finally, schools eventually lose their institutional knowledge of the building systems because of staff turnover and lack of communication.

When estimating service life, manufacturers usually assume regular preventive maintenance of the equipment and system components. Many preventive maintenance procedures recommended by manufacturers are intended to extend the life of the component and the system as a whole. Lack of preventive maintenance reduces equipment life.

Identifying degradation of the system's components is another benefit of preventive maintenance. A proper facility operation and maintenance system that includes reporting and documentation reduces the incidence of failure. For example, if a component of the system is identified as potentially failing to operate as intended, a work order for replacement parts can

Energy Accounting

Energy accounting is a method of tracking a facility's energy use over time. Many facility managers seeking peak performance in their building have found that energy accounting software gives them a better understanding of their utility expenditures. Each month's usage and expenditures are input into a software program. The software then tracks the usage while normalizing for temperature changes over the period being analyzed. The energy "accountant" can then watch and see whether the facility performs as expected or uses more energy than expected over time. If higher than expected usage occurs, further investigation can identify the occupancy and/or usage changes, equipment problems, or other unknown problems that have increased the energy bills.



be set up immediately and work scheduled during unoccupied hours. Preventive maintenance can reduce the number and cost of emergency corrective maintenance bills.

Performing regular preventive maintenance can result in energy and cost savings. For example, simply replacing worn fan belts on a regular basis can save 2% to 4% of the energy used to run the fans. Cleaning air filters and cooling coils regularly can save 1% to 3% of the building's energy use for cooling. These basic activities cost very little to perform, but can add up to dramatic savings.

Preventive maintenance also makes buildings safer and can reduce potential district liability. Increasingly, building ventilation systems function as part of an engineered smoke-control system and, therefore, proper maintenance can decrease liability.

Developing a Preventive Maintenance Plan

The commissioning provider can help the district or facility manager develop a preventive maintenance plan for a building's HVAC and electrical systems. Most of the information required for developing a preventive maintenance plan is gathered as part of the commissioning process or can be obtained from the operation and maintenance manuals.

> ***Preventive Maintenance Software Modules***
>
> *Many major controls contractors also offer preventive maintenance modules for their software that will track and automatically advise operation and maintenance staff when equipment maintenance needs to occur. These systems can offer good value because the controls system already knows a lot about many of the building systems. To set these systems up properly to be operational when the building is first occupied, the district should allow some extra budget for a facilities operator to assist in set-up during construction. This will also allow the operator to become familiar with the system and maximize its benefits once the building is occupied.*

A preventive maintenance plan consists of a checklist of tasks that are performed at manufacturer-recommended intervals (usually measured in hours of equipment run time). This checklist is usually kept in the form of a log and is updated manually when tasks are performed. In buildings that use computerized maintenance management systems, the equipment that requires preventive maintenance should be entered into the system. If the computerized system is used for generating preventive maintenance work orders, update the system when work is performed and keep hard copies of completed work orders in a file or notebook. Another low-cost measure to consider is programming the energy management system to track and archive equipment run times. This option is easy and inexpensive if done when the initial system programming takes place, and it should be outlined in the original equipment specification in the contract.

The preventive maintenance plan for each piece of equipment should include the following fundamental information, gathered during the commissioning process:

- Unique equipment identification number
- Name plate information
- Manufacturer's name
- Vendor's name and telephone number
- Equipment location

- Date installed
- Expected equipment life
- Expected annual energy use.

Preventive maintenance should be performed according to manufacturer requirements. Consult the manufacturer's operation and maintenance manual for each piece of equipment for requirements such as frequency, chemical treatments, proper lubricants, special tools, etc. This information should also become a part of the preventive maintenance plan.

The preventive maintenance work order form or task list for each piece of equipment should have a verification section with at least two signature lines: one for the technician performing the preventive maintenance and one for the supervisor verifying that the maintenance was performed.

Outsourcing Preventive Maintenance

If a new piece of equipment does not require frequent maintenance, and current staff time is committed, a contract for outside help may be less costly than hiring and training full-time staff. If a sophisticated new piece of equipment is purchased, compare the cost of training in-house staff to the cost of hiring a trained outside contractor to perform maintenance on the equipment to determine the best option.

In buildings where operating staff is not available or trained to perform the required preventive equipment maintenance, districts may obtain a service contract from the vendor, installing contractor, or a maintenance service contractor. Ensure that the service contract covers all of the manufacturer's recommended preventive maintenance procedures as described in the operation and maintenance manuals. After each site visit, require the contractor to provide an invoice or preventive maintenance form stating clearly which preventive maintenance activities or repairs were performed. Keep these forms onsite in a file or three-ring binder for future reference. Regardless of who actually performs the preventive maintenance, the district is responsible for making sure that the preventive maintenance plans are complete.

Maintenance contracts tend to be site-specific, but in general, there are two basic types of services.

- **Preventive maintenance contract.** Normally, this type of contract does not cover the cost of replacement parts, but does include labor and supplies. The equipment owner is responsible for parts replacement. The duration of a preventive maintenance contract is usually one year. Frequency of site visits may depend on the equipment being serviced. Corrective maintenance may or may not be included.
- **Guaranteed service and repair contract.** Large maintenance contractors usually offer this type of contract. Under this arrangement, the contracting firm not only maintains but also replaces failed components. It is essentially an insurance policy with a low deductible, and typically is a multi-year contract. The cost for this type of contract is comparatively high.

Regardless of the type of contract used, it is important to carefully evaluate the cost for the service, quality of service, and the existing contractor's familiarization with the facility's equipment and operating procedures when the contract is up for renewal. Because any new contractor will face a learning curve when taking over a facility, it might not be a wise decision to choose a new contractor just because they offer a lower price. Careful consideration of the quality service already received and successful renegotiations with the existing service contractor might provide better long-term value.

LIST OF COMMISSIONING REFERENCES AND RESOURCES

Procedural Guidelines, Specifications and Functional Tests Last Updated: 10/25/01
*Denotes documents available on electronic disk.
Legend: ● Comprehensive Information ◉ Average Information/Partial Information ○ No Information

Source	Design		Construction		Sample Tests
	Guidelines	Specs	Guidelines	Specs	
Appendix VII Idaho New Building Commissioning Guidelines, State of Idaho, 2000. Available at: http://www2.state.id.us/adm/pubworks/archengr/app7nbcg.pdf	○	○	○	○	○
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Procedural Standards for Building Systems Commissioning, National Environmental Balancing Bureau (NEBB), 1999. (301) 977-3698.	◉	◉	◉	◉	◉
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The HVAC Commissioning Process, ASHRAE Guideline 1-1996, 1996. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329. (404) 636-8400. http://www.ashrae.org.	◉	◉	●	◉	○
Functional Test Protocol Library, Pacific Gas & Electric Company, 2001. Available on the EDR Commissioning Resources CD-ROM. For ordering information, call 925-866-5329.	○	○	○	○	●
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Engineering and Design Systems Commissioning Procedures, U.S. Army Corps of Engineers, 1995 (ER 1110-345-723). Dept. of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000.	◉	◉	◉	◉	○
Commissioning Specifications, C-2000 Program, Canada, 1995. C-2000 Program, Energy Mines & Resources, Energy Efficiency Division, 7th Floor, 580 Booth St., Ottawa, Ontario, Canada K1A 0E4.	○	○	○	*●	○
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Commissioning Guidelines, Instructions for Architects & Engineers, State of WA., 1995. Dept. of General Admin., Div. of Engin. & Arch., (360) 902-7272.	◉	○	◉	○	○
Commissioning of HVAC Systems, seminar/workshop training materials, Univ. of Wisconsin, Madison, 1994. (800) 462-0876 or (608) 262-2061.	○	○	◉	◉	◉

Source	Design		Construction		Sample Tests
	Guidelines	Specs	Guidelines	Specs	
Laboratory HVAC Systems: Design, Validation and Commissioning, ASHRAE collection of 11 papers, 1994. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329. (404) 636-8400. http://www.ashrae.org/	○	○	●	○	○
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Commissioning Guide, Public Works Canada, Western Region, 1993. (403) 497-3770.	◉	◉	◉	●	○
Guide Specification for Military Construction—Commissioning of HVAC Systems, Dept. of the Army, U.S. Army Corps of Engineers, 1993. Washington, DC 20314-1000.	○	○	○	*●	*●
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HVAC Functional Inspection and Testing Guide, U.S. Dept. of Commerce and the General Services Administration, 1992. NTIS: (800) 553-6847.	○	○	○	○	●
AABC Master Specification, Associated Air Balance Council. (Primarily for how the TAB fits into the commissioning process) AABC National Hdqrs, (202) 737-0202.	○	*◉	○	●	○

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Commissioning retrofits and existing buildings: overview, process, and case studies. Dedicated solely to retro-commissioning. 68 pgs. (800) 363-3736.

Beyond Lighting DSM: Life After Green Lights, Urban Consortium Energy Task Force of Public Technologies, Submitted by Montgomery County Government, MD, Div. of Facilities and Services, 1998. Existing building commissioning case study with sample process and detailed procedures. 70 pgs. (301) 217-6000.

Commissioning For Better Buildings in Oregon. Oregon Office of Energy/PECI, 1997.

New construction overview, benefits, process, and case studies. Contains some data on recommisioning. 44pgs. (503) 378-4040 or download at: http://www.energy.state.or.us/bus/comm/bldgcx.htm

What Can Commissioning Do For Your Building? PECI, 1997.

Commissioning overview and report of 175 building case studies. Contains some data on recommisioning. 12pgs. (503) 248-4636.

Commissioning Four New Science Laboratory Buildings (U. of WA). Bonneville Power Admin./Phoebe Caner, 1997. Commissioning case studies with detailed "lessons learned" information in all sections. ~70 pgs. (503) 230-7334.

Commissioning the Physics/Astronomy Building Control System (U. of WA). Bonneville Power/Phoebe Caner, 1996. Commissioning case study and report with lessons learned. ~110 pgs. (503) 230-7334.

A web site dedicated to providing access to documents dealing with the Guidelines for Total Building Commissioning is being developed under the auspices of the National Institute of

Building Sciences. The site is maintained by the Florida Design Initiative and is organized around the individual technical guidelines that will comprise the complete set of Guidelines for Total Building Commissioning. http://www.sustainable.state.fl.us/fdi/edesign/resource/totalbcx.

Implement Building Commissioning, published by U.S. Department of Energy, Rebuild America, EnergySmart Schools program (Washington, DC, 2000); available at: http://www.eren.doe.gov/energysmartschools/om_implement.html. Defines building commissioning; discusses the selection of a commissioning agent; the benefits, approaches, and components of commissioning; and lists resources.

Sustainable Building Technical Manual: Green Building Design, Construction, and Operations, produced by Public Technology, Inc., U.S. Green Building Council (USGBC), and U.S. Department of Energy, with support from EPA, 1996. See Chapter 15, “Building Commissioning.” Available from USGBC, San Francisco, CA; Phone: (415) 445-9500 or download at: http://www.sustainable.doe.gov/pdf/sbt

Four case studies. Seattle City Light. http://www.ci.seattle.wa.us/seattle/light/conserve/business/bdgcoma/cv6_bcam.html.

Web Sites Containing Commissioning Documents

Building Commissioning Association	http://www.bcxa.org/
Florida Design Initiative	http://www.state.fl.us/fdi/index.html. Ongoing articles & forum.
National Institute of Health Model Commissioning Guide	http://www.des.od.nih.gov/farhad2/Commissioning/nih_cx_guide/ComGuideTitle.htm
NEBB	http://www.nebb.org/. Certification program and manuals.
Oregon Office of Energy	http://www.energy.state.or.us/bus/comm/bldgcx.htm Benefits of Cx, case study, the full text of *Commissioning for Better Buildings in Oregon*. Contains some data on recommissioning.
PECI	http://www.peci.org/ NCBC information, downloadable *Model Cx Plan and Guide Specifications*, Cx and O&M resources.
Seattle City Light	http://www.ci.seattle.wa.us/seattle/light/conserve/business/bdgcoma/cv6_bcam.htm Standardized test procedures and case studies.
Texas A&M Energy Systems Lab	http://www-esl.tamu.edu/. Retrocommissioning process and software, for purchase. Dedicated solely to retrocommissioning.
University of Washington	http://www.depts.washington.edu/fsesweb/fdi2001/15_mech/doc/19-15t.doc. University Cx guide specs distributed throughout the specs. Vols 1-4.
USDOE / FEMP	http://www.eren.doe.gov/femp/techassist/bldgcomgd.html. Full text of GSA/USDOE *Building Commissioning Guide;* early version of *Model Cx Plan and Guide Specifications*.
USDOE	http://www.eren.doe.gov/. Links to commissioning documents. Search on “commissioning.”
Whole Building Design Guide (NIBS)	http://www.wbdg.org/. National Institute of Building Sciences. Find commissioning information by searching on “commissioning.”

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Rebuild America Schools
U.S. Department of Energy

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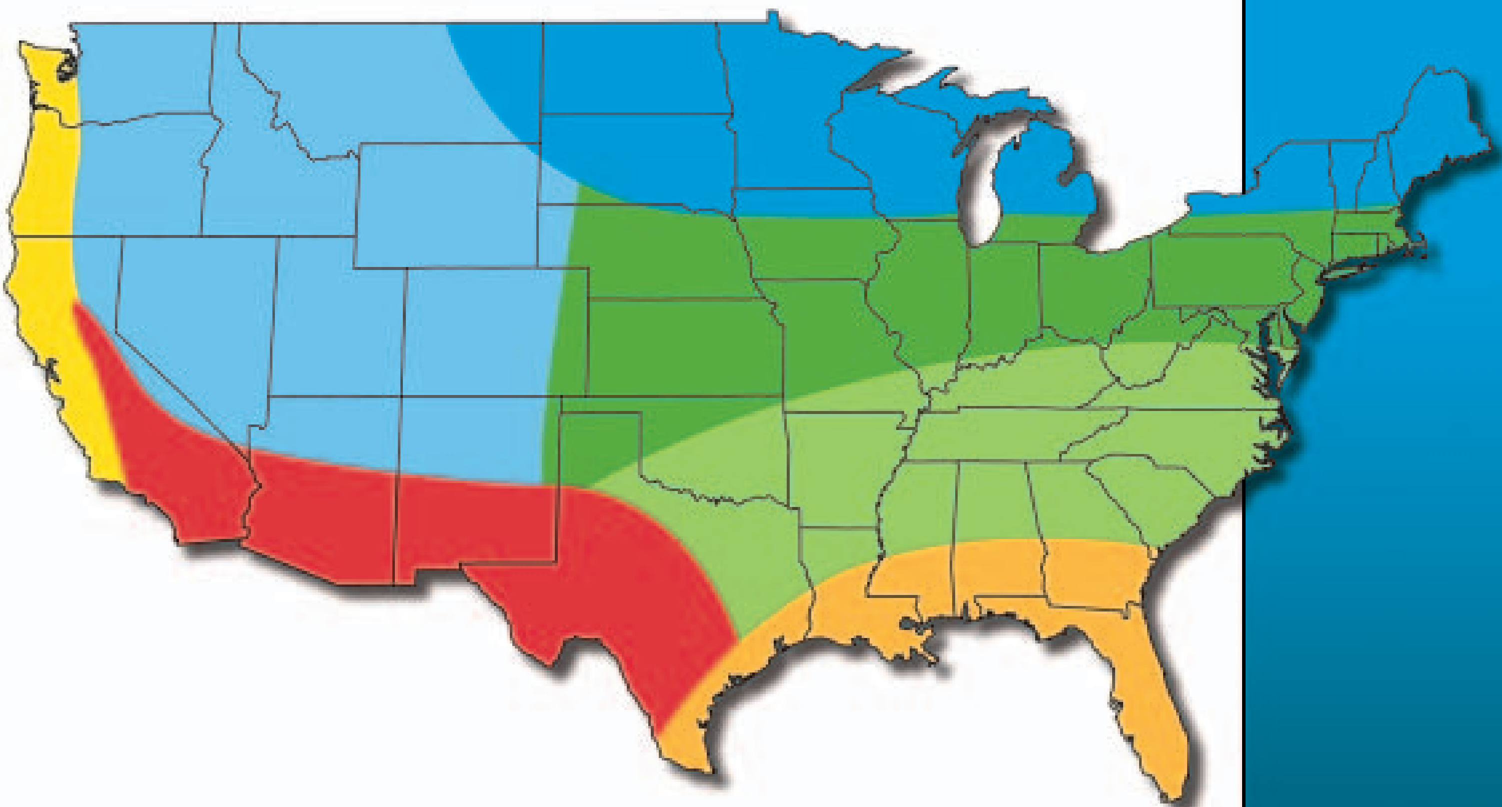
Cold and Humid Climates



Energy Design Guidelines
for High Performance Schools

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Creating High Performance Schools

School districts around the country are finding that smart energy choices can help them save money and provide healthier, more effective learning environments. By incorporating energy improvements into their construction or renovation plans, schools can significantly reduce energy consumption and costs. These savings can then be redirected to educational needs such as additional teachers, instructional materials, or new computers.

The US Department of Energy's (US DOE's) EnergySmart Schools provides school boards, administrators, and design staff with guidance to help them make informed decisions about energy and environmental issues important to school systems and communities. These design guidelines outline high performance principles for the new or retrofit design of your K-12 school. By incorporating these principles, you can create an exemplary building that is both energy- and resource-efficient — a school that is a teaching tool in and of itself.

"Good teachers never teach anything. What they do is create conditions under which learning takes place."
— S.I. Hayakawa

By implementing the high performance practices included within these guidelines, you will be taking a significant step forward in creating the physical conditions in which the learning process can thrive.

The Importance of Connecting Energy and Environmental Issues

Across our country we are again seeing signs that the supply of energy is not keeping up with rising demand. Brownouts are becoming more commonplace. The price of natural gas is twice what it was in the 1990s. We are moving from a period of less expensive energy and seemingly plentiful resources to a time in which building-related decisions will be more strongly influenced by energy and water availability. There is a growing concern about the environmental and societal implications of energy. Today, energy costs over the life of a school will far exceed the initial cost of the building. As prices rise, it will become even more critical to comprehensively address this issue.

This guide was developed to promote long-term thinking and to build our schools in ways that reflect values supportive of our planet. Our schools can make a strong statement that saving energy and resources, while protecting our environment, is important. The message that we give to future generations should be embodied in the buildings we use to teach them.

For more information, visit the EnergySmart Schools Web site:

www.energysmartschools.gov

Rebuild America Schools
U.S. Department of Energy

Help Your School Earn the ENERGY STAR Label

The ENERGY STAR label on a school building wall tells an important story. The label not only identifies a school building whose energy performance is among the nation's top 25% — but it also lets taxpayers know you're using money wisely, spending the resources on education instead of high energy bills. The label tells students that their school cares about the environment, that you're doing your part to reduce energy-related pollution. And it indicates that your school has the great lighting, comfortable temperatures, and high-quality air that go hand in hand with smart energy use.

ENERGY STAR, a registered trademark of the US Environmental Protection Agency (US EPA) and the US DOE, is the mark of excellence in energy performance. It is a trusted national brand symbolizing superior energy performance in more than 30 categories of consumer electronics and appliances, as well as office buildings, schools, supermarkets, hospitals, and homes. The ENERGY STAR benchmarking tool is a powerful way to manage building energy performance and to earn recognition for excellence in building energy performance. The rating system measures the energy performance of each building on a scale of 1 to 100 and shows how a building compares with other buildings in your portfolio or nationwide. The rating system provides useful baseline information to help organizations set energy performance targets and plan energy-efficiency improvements. Buildings whose energy performance places them in the top 25% among similar buildings nationwide, and that meet industry standards for indoor environment, are eligible to apply for the ENERGY STAR label, a large bronze plaque that can be displayed on the building.

Determining if your buildings qualify for this label is easy. All you need is data about your school's energy use over the past 12 months, the square footage of your buildings, and the number of students enrolled. You can then establish an account for your school district and enter your energy data into the ENERGY STAR computer analysis tool available on the Internet. Each school building that scores 75 or higher, while maintaining indoor air quality that meets industry standards, can apply for the ENERGY STAR label.

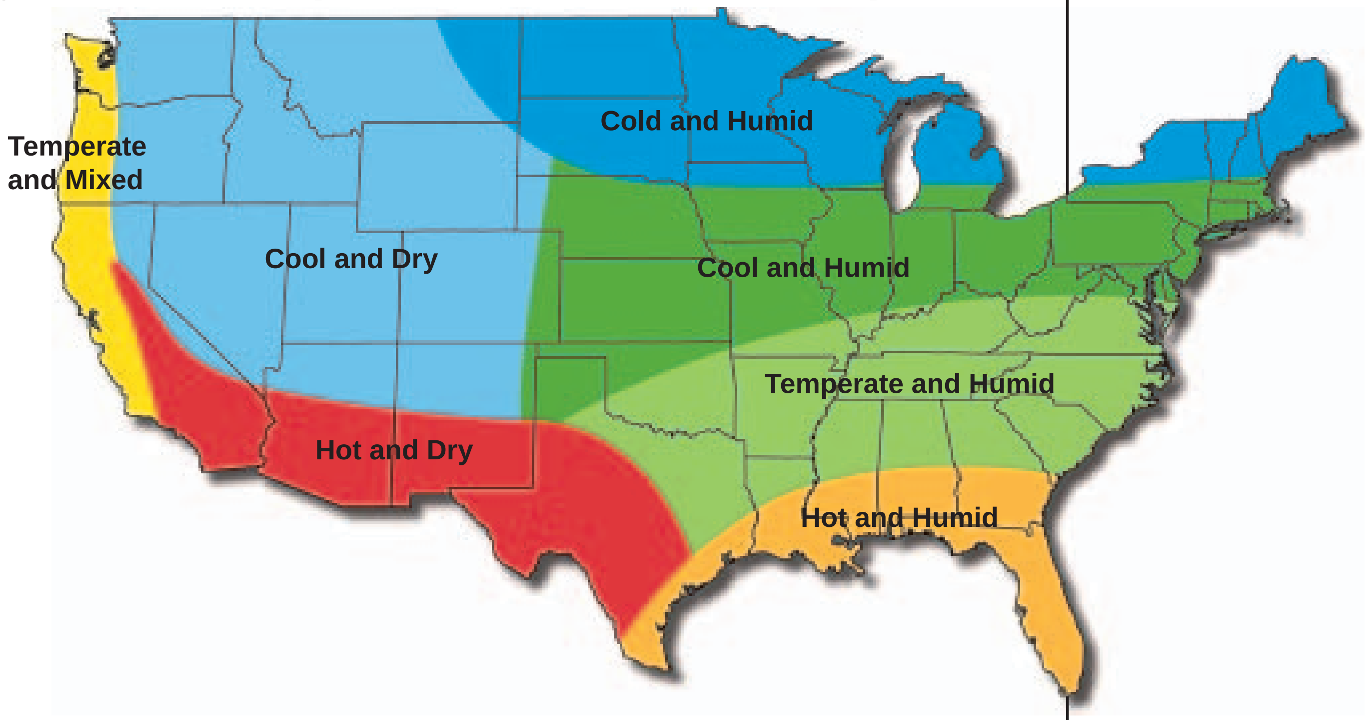
By incorporating the energy design guidelines detailed in this document into your school's construction or renovation plans, you can take the first essential steps toward earning the ENERGY STAR label for your school.

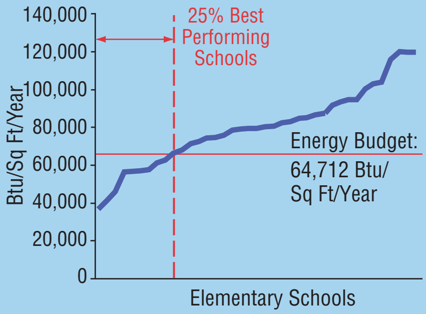
An Introduction to the Energy Design Guidelines

This document presents recommended design elements in 10 sections, each representing a key interrelated component of high performance school design. To effectively integrate energy-saving strategies, these options must be evaluated together from a whole-building perspective early in the design process. A "high performance checklist" for designers is located at the end of the document. The checklist is a quick reference for key architectural and engineering considerations. Case studies can also be found at the end of the document.

Climate Zones for Energy Design Guidelines

These guidelines contain recommendations generally appropriate for cold and humid climates, for which Minneapolis-St. Paul, Minnesota, served as a model city. Other guidelines have been developed for the other climate zones, shown on the map below.

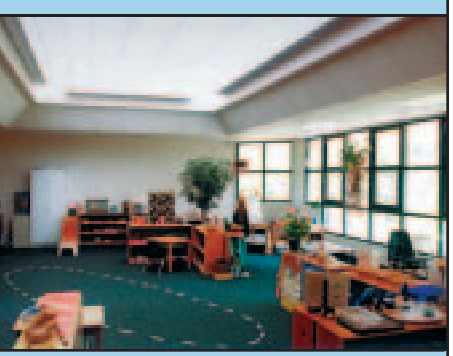




St. Paul Elementary Schools Annual Energy Consumption

Energy Budgets

The horizontal red line indicates a level of energy consumption achieved by the best 25% of the existing schools.



A 1999 study conducted by the Heschong Mahone Group shows that students with the best daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those with the worst daylighting.

Establishing High Performance Goals

Cost-effective energy- and resource-efficient schools start with good planning. Working closely with the school's design and planning staff, the architects and engineers should develop objectives that reflect local conditions and priorities, balance short-term needs and long-term savings, and address environmental issues. Goals can include reducing operating costs; designing buildings that teach; improving academic performance; protecting the environment; increasing health, safety, and comfort; supporting community values; and considering emerging solutions.

Reducing Operating Costs

To ensure that your school is water- and energy-efficient, you must first work with the school system to establish clear consumption goals. Given your climatic region and building type, this "energy budget" must be realistic, and it must be based on the potential of current, proven energy-saving technologies.

The graphic profile to the left depicts one simple procedure for establishing a realistic energy budget. The graph plots the range, from best to worst, of the current annual energy consumption (British thermal units per square foot) for all the existing elementary schools within the St. Paul School District, located in Minnesota. An energy budget can be established by simply setting the goal at a level equal to that achieved by the best 25% of the schools in the district. Many energy- and resource-saving options have very good financial value. Some of these solutions do not add anything to installation costs.

Designing Buildings that Teach

When designing the school, consider the importance of incorporating high performance features that can be used for educational purposes. Some high performance features may be harder to rationalize financially but from an educational standpoint are still important to consider. Solar electric systems (photovoltaics), for example, may have a longer return on investment but, if installed properly, can be a very powerful educational tool.

Improving Academic Performance

During the past decade, remarkable studies have indicated a correlation between the way schools are designed and student performance. You can maximize student performance by setting air quality objectives that:

- Define a level of indoor air quality desired during occupied times
- Place limitations on the use of materials, products, or systems that create indoor air quality problems
- Require monitoring equipment.

Establishing daylighting objectives will also improve classroom conditions and can help improve performance if you:

- Include controlled daylighting in all classrooms, administrative areas, the gymnasium, and other significantly occupied spaces
- Develop intentional visual connections between the indoor and outdoor environments.

Protecting Our Environment

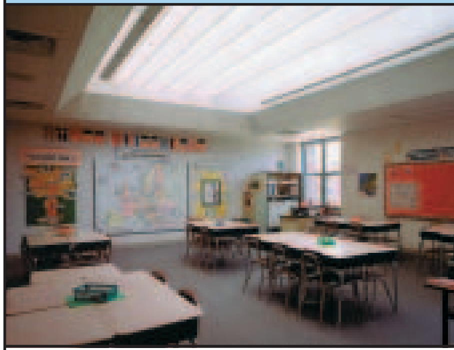
High performance school design takes into consideration not only the economic and academic impacts of design but also environmental impacts. Environmentally sound design elements are those that:

- Use renewable energy systems and energy-efficient technologies
- Incorporate resource-efficient building products and systems
- Promote water-conserving strategies
- Use less polluting transportation alternatives
- Establish recycling systems
- Incorporate environmentally sound site design.

Designing for Health, Safety, and Comfort

You cannot design a high performance school without including design strategies that address health, safety, and comfort issues. Goals should include objectives that:

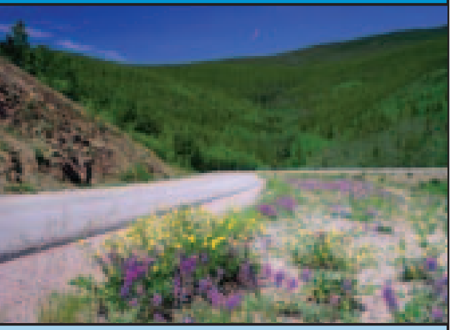
- Implement daylighting and indoor air quality solutions to make the school a healthier place to teach and learn
- Address acoustical and thermal comfort.



Supporting Community Values

Incorporating high performance strategies in your school's design results in a win-win situation for the community and the school. Through the implementation of energy-savings strategies, the school saves money and taxpayers benefit. Additionally, the energy dollars saved don't leave the immediate region but stay within the community and help to build a stronger local economy.

Building to high performance standards implies the purchase of locally manufactured products and the use of local services. This approach is effective because much of the environmental impact associated with materials, products, and equipment purchased for construction involves transportation. The more transportation, the more pollution. Specifying local products benefits the community in the same way that retaining energy dollars helps: it strengthens the local economy. Implementing energy-efficient, environmentally sound practices also has a direct impact on the local air and water quality. By establishing goals to positively address these issues, you are taking the first step toward creating a better community in which to live.



"We will insist on protecting and enhancing the environment, showing consideration for air and natural lands and watersheds of our country."

National Energy Policy, 2001

"Whole Building" Energy Analysis

Determining the relative merits of one energy strategy versus another can only be accurately determined by analyzing the specific measure in the context of the "whole building." Each component or system is continually impacted by changing climatic conditions and occupancy demands. Each component has an effect on another.

When evaluating energy options, it is essential that the design team use computer energy analysis programs that can simulate the impact the specific measure has on the overall energy consumption and peak load. The program must be able to provide hourly, daily, monthly, and yearly energy profiles and be able to accurately account for the benefits associated with daylighting. The US DOE has two programs to assist with this analysis: DOE-2 and Energy Plus. More information can be found on these programs in the resources section at the end of this document.

Considering Emerging Solutions

The recommendations listed within this document reflect proven technologies that have been successfully incorporated into school applications in this climate zone and across the country. However, every year, new solutions are developed that will be able to make your facilities more energy-efficient and environmentally sound. As these new systems, materials, and products become commercially available, designers should exercise care in selecting those that are viable but should not be discouraged from implementing technologies just because they are not commonplace.

Because of their dynamic nature, these emerging solutions will be addressed on the Web site, which provides cost information and examples of current projects where the solution is already in use.

Site Design

By orienting your school building effectively, you can maximize solar access and boost the effectiveness of daylighting strategies, reducing the need for electrical lighting as well as heating and cooling loads. Designing the site to reduce or eliminate vehicular travel to the school helps to reduce fuel usage and emissions, improving the air quality in and around the school. And water requirements can be reduced by incorporating vegetation native to the local ecosystem in the site design.

Decisions made early in the design can often have a significant impact on many other aspects of the design. Orienting the building linearly on an east-west axis is one important example. By maximizing well-controlled, south-facing glass and minimizing east- and west-facing glass, energy performance is greatly enhanced, comfort conditions are improved, and initial costs associated with cooling are reduced.

The educational potential of high performance design can also be greatly emphasized by integrating effective indoor-outdoor relationships between the building, the site, and the design of outdoor spaces as educational resources and venues.

When considering the location for a school site, it is critical not only to consider your initial cost but also to evaluate environmental implications, how health and safety are influenced, and how well the school design is integrated into the fabric of the community.

Photo: Roy Beaty

Retaining ecosystems and wildlife habitat surrounding schools and incorporating them into outdoor learning activities enhances student interest in the environment.

Students enjoy the outdoor teaching courtyards and "eco-gardens" that allow them to plant native vegetation, view natural habitat and wildlife, and better understand eco-cycles.

Before — Photo: Davis, Carter, Scott

The rehabilitation of a vacant commercial building into the new $1.8-million, 24,000-square-foot Arlington Mill School and Community Center in Virginia was the solution adopted by Arlington Public Schools to meet its urgent need for a new high school facility.

After — Photo: Estate of Doug Brown

Guidelines for Site Design

Selecting a Site

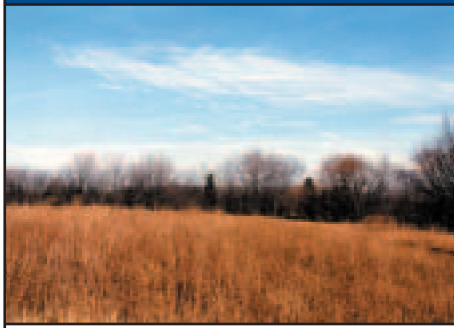
When selecting a school site, the highest priority should be given to appropriately located sites that enable the school to be built cost effectively and in a resource-efficient manner.

- **Cost**
  - Consider the rehabilitation of an existing site or an urban in-fill area before choosing an undeveloped site.
  - Select a site that can maximize solar access for daylighting and other solar systems and minimize east and west glass.
  - Consider the wind resources at the site and the potential for implementing wind energy systems.
  - Consider the availability and cost of utilities at the site.
  - Analyze mass transit and pedestrian accessibility as well as potential bus routes.
- **Environment**
  - Avoid selecting sensitive ecosystems, such as wildlife habitats.
  - Consider geological, micro-ecological, and micro-climatic conditions.
  - Evaluate the potential implications of erosion control and rainwater management.
  - Determine the presence of historic landmarks or archeological features on the site.
  - Conduct an assessment of the impact the school will have on the local environment.
  - Consider the ability to protect and retain existing landscaping.
- **Health/Safety**
  - Determine the existing and projected air, soil, and water quality.
  - Evaluate the physical relationships to industries or utilities that may pollute the air.
  - Evaluate noise levels typically experienced at the site.
- **Community**
  - Determine the ease with which the school could be linked into local communities through safe pedestrian walkways.
  - Evaluate the potential for recycling with the city or county.
  - Consider sites where local developers are interested in working together to integrate the school into the overall community design.

Protecting Local Ecosystems

The protection of local ecosystems is critical to an environmentally sensitive site design.

- Protect or restore ecosystems and wildlife habitats on the site.
- Develop a landscaping design that is compatible with existing plants and that uses native plants.
- Protect areas for viewing natural habitat.
- Develop interpretive nature trails through preserved wildlife habitats and ecosystems.
- Use explanatory signage for different plants and trees.
- Consult with local universities, cooperative extension offices, and master gardeners about local ecosystems, how to protect them, and ways to maximize their educational value.



Employing native xeriscape principles minimizes the need for irrigation.

Water-Conserving Strategies

The implementation of these commonsense ideas will help to drastically reduce school water use and conserve water in the community.

- Use native planting materials and xeriscape principles to minimize the need for site irrigation.
- Employ a rainwater catchment system for irrigation and toilet flushing.
- Use graywater from sinks and water fountains for site irrigation.
- Use soaker hoses and drip irrigation techniques that minimize evaporative losses and concentrate water on the plants' roots.
- Use timers on irrigation systems to water at night.

In cold and humid climates, water needs for irrigation can be minimized by protecting the existing natural vegetation and using native planting.

Erosion Control and Off-Site Impacts

Developing on-site erosion control and stormwater management strategies will better ensure that off-site impacts can be minimized.

- Employ site contours and natural drainage strategies.
- Minimize surfaces impervious to water.
- Determine the key pollutants that are impacting your watershed, and develop strategies to reduce the likelihood that the pollutants will reach the watershed.

The cost effectiveness of the daylighting strategies implemented at East Clayton Elementary School in Clayton, NC, is greatly enhanced by the elongation of the school on an east-west axis. This layout increases the potential for capturing winter gain while reducing unwanted summer sun that more often strikes on east-west surfaces.

Building Orientation

To minimize energy use, maximize your potential by siting the school correctly.

- Establish the building on an east-west axis.
- Develop a floor plan that minimizes east- and west-facing glass.
- Emphasizing one-story designs to maximize daylighting increases the foundation perimeter and roof area. Both of these are significant contributors to heat losses and therefore detrimental to low energy use in heating-dominated climates. Larger building footprints increase site impacts and consume more scarce buildable land, especially in urban areas.
- In multiple-story schools, minimize the depth of the rooms to maximize the daylighting contribution.
- Consider seasonal variations in wind speed and direction.

Renewable Energy

When evaluating site design issues, it is essential to investigate renewable systems early in the process. Solar systems need to have solar access, and wind systems require proper placement to be maximized.

- Consider climatic conditions at the site.
- To improve safety and save energy, consider non-grid-connected photovoltaic systems for:
  - crossing and caution lights
  - lighting at walkways and parking areas
  - telephone call boxes for emergencies.
- Consider installing building-integrated solar thermal systems for domestic hot water, space heating, and absorption cooling.
- Consider building-integrated photovoltaic systems for electricity production.
- Ensure that solar systems are not shaded and that they are positioned to be visible to the students, teachers, and parents.

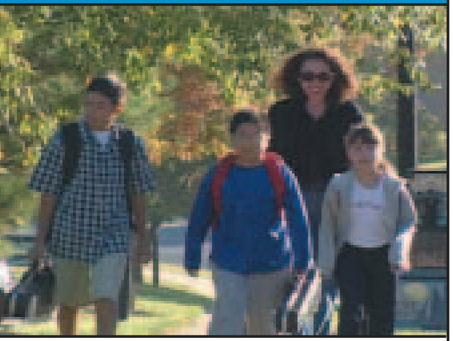
- Consider wind energy systems for electricity or well water.
- Consider geothermal heat pumps.

Maximize the Potential of the Site

Understanding and using the ground conditions at the site will determine, to a great degree, both the economic and environmental success of the design.

- Establish floor grades that least impact site grading.
- Use existing site contours to minimize grading and, where appropriate, to create berming opportunities to earth-temper walls.
- Consider existing and new landscaping as a means of providing shading in the warmer months.
- Stockpile appropriate rock from site development for later use as ground cover.

Durant Road Middle School in Raleigh, NC, is oriented on an east-west axis to maximize solar access.



Safe walkways connecting the school to the surrounding neighborhoods help reduce air pollution from cars and buses, avoid air pollution and traffic congestion, and decrease the cost of operating buses, creating a cleaner local environment.

Connecting the School to the Community

One of the measures of success of a school is the degree to which the school is a vital part of the community. If addressed early in the site selection and design phase, a school can be planned to serve not just the students but also the entire community.

- Consider designing the school so that the athletic fields, gymnasium, media center, cafeteria, and classrooms can be shared at appropriate times with the community.
- Provide for optimum access to public transit.
- Through good site design, link the school to the surrounding communities through safe bicycle routes and pedestrian pathways.
- Incorporate convenient bicycle parking at the school to encourage bicycle traffic.

Objectives regarding the protection and retention of existing landscaping as well as the site's natural contours and features have to be established early during the programming phase.

Daylighting and Windows

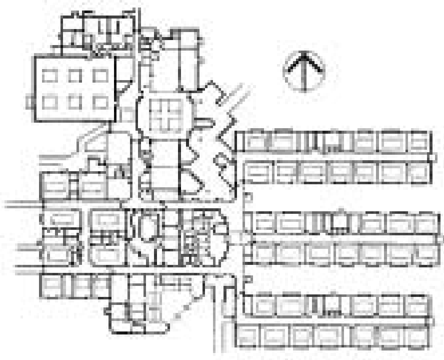
Of all the high performance design features typically considered, none will have a greater impact on your school than daylighting. Not only can optimum daylighting design drastically reduce energy consumption, but it also creates healthier learning environments that may result in increased attendance and improved grades. When properly designed, windows, clerestories, and roof monitors can provide a large portion of lighting needs without undesirable heat gain or glare.

Electric lights actually produce more waste heat energy than daylighting for the equivalent lighting effect. This heat must be removed in warmer months through ventilation or air conditioning. Sunlight, on the other hand, is a cooler light. Reductions in cooling loads due to daylighting strategies often enable designers to downsize air conditioning systems, reducing the initial cost of equipment. High performance windows also help to minimize heat gain in warmer months and heat loss in colder months. Although windows can create glare and skylights may cause overheating, properly designed daylighting strategies can reduce both lighting and cooling energy and control glare.

Photo: Robert Flynn

Effective daylighting strategies reduce both lighting and cooling loads.

This classroom, at Roy Lee Walker Elementary School in McKinney, TX, is daylit two-thirds of the time the school is occupied. The daylighting strategy selected consists of roof monitors, lightshelves, and light-colored interior finishes.



To optimize solar access, develop a floor plan along an east-west axis.

Lighting Efficacy

Lighting Source	Efficacy (lumens/watt)
Beam Sunlight/ Diffuse Skylight	110–130
High-Intensity Discharge (high pressure sodium, metal halide)	32–124
Fluorescent	55–90
Compact Fluorescent	50–60
Incandescent	10–20

Source: Lawrence Berkeley National Laboratory Lighting Market Source Book for the United States

Sunlight provides more lumens per watt than electrical lamps.

Design Guidelines for Daylighting and Windows

Building Orientation and Solar Access

By elongating the school design on an east-west axis, the potential for cost-effective daylighting is maximized.

- Consider daylighting strategies that primarily use south-facing glass and secondarily incorporate north-facing glass. An elongated building that has its major axis running east-west will increase the potential for capturing winter solar gain through south glass as well as reducing unwanted summer sun that more often strikes on the east and west surfaces. Exposed, eastern- and western-facing glass should be avoided wherever possible because it will cause excessive summer cooling loads. South glass should incorporate properly sized overhangs that limit radiation in warmer months.

- Verify that other exterior design elements or existing site features do not negatively affect the daylighting design.
  - Make sure other building elements do not unintentionally shade glazing areas that are designed as daylighting elements.
  - Consider the reflectance of the materials in front of the glazing areas. The use of lighter roofing colors can reduce the glass area needed for roof monitors, while a light-colored walkway in front of a lower window may cause unwanted reflections and glare inside the classroom.

Daylighting Strategies

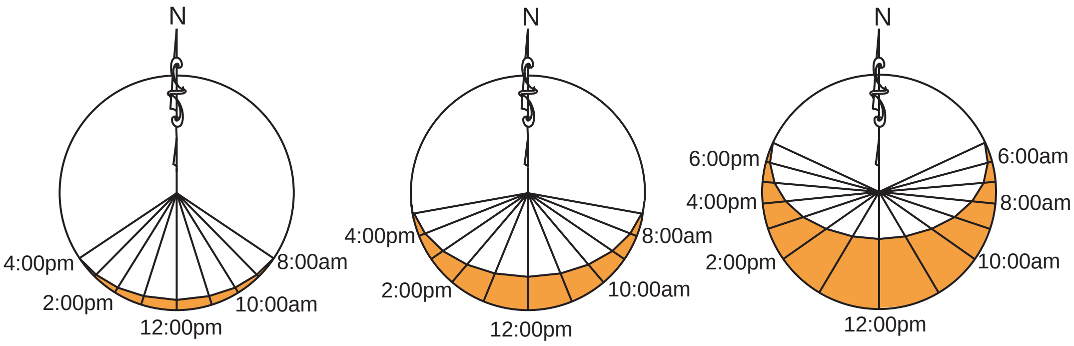
Because lighting is a significant component of a school's energy consumption, efforts to use daylighting should be given a high priority. Properly designed daylighting reduces the need for electric lighting and helps to create a more pleasant environment.

- Good daylighting design can reduce the electricity needed for both lighting and cooling a school. The reason is simple: daylight provides a higher ratio of light to heat than electrical sources. This ratio, known as lighting efficacy, means that daylight provides more light and less heat, which can greatly reduce cooling loads. The chart to the left compares the efficacy (measured in lumens per watt) of various light sources.

- In cold and humid climates, it is important to consider how passive heating can provide benefits without negatively impacting summer cooling. Properly designed south-facing monitors or windows with lightshelves can accomplish both. By facing the glass south and providing overhangs that maximize winter gain and block the majority of direct solar gain during summer peak cooling times, an optimum solution is possible. Because cooling loads are a great concern, it is very important to size the glass area so that during times of peak cooling no more solar gain is allowed to enter into the space than is necessary to provide the required lighting levels. If designed correctly, this sunlight will generate less heat for the same amount of light. This means that, in addition to the lights being off, the peak cooling mechanical load will be reduced.

- Consider daylighting apertures to limit the amount of beam radiation entering during the hottest part of the day in the cooling season. East- and west-facing glass should be minimized. In cold and humid climates, south-facing vertical glazing is typically better because roof overhangs can be designed to effectively admit low-angle winter radiation for daylighting and exclude excessive higher-angle sunlight in the warmer months. North glazing is second best because it doesn't create overheating problems during the cooling seasons, but it also doesn't provide any passive heating benefits. For example, the charts below indicate seasonal sun angles for Minneapolis.

For more information on sun angles, see the resource section in this report.



21st of January
Winter Sun Angles

21st of March/October
Spring/Fall Sun Angles

21st of June
Summer Sun Angles

Sun Angles for Minneapolis, MN

Sun angle charts indicate the location (azimuth) of the sun at various times of the year.

- Use a well-designed overhang to mitigate the potential drawbacks of summertime solar gains through south-facing glazing. An oversized overhang on the south is not recommended on daylighting apertures since it can block significant amounts of diffuse radiation in addition to the direct beam.

- Develop a daylighting design with primary emphasis on south- (typically best) or north-facing roof monitors and a secondary emphasis on lightshelves. Lightshelves can significantly enhance the natural lighting uniformity within a space and also provide good lighting in narrow rooms (less than 16 feet to 20 feet). Lightshelves may also be the only option on multiple-story schools.

South-facing roof monitors and windows provide natural light in the classrooms.

Properly designed daylighting strategies can provide superior light in classrooms more than two-thirds of the time.

Clear double glazing has to be used to optimize solar access. Overhangs block excessive radiation in the warmer months.

Translucent baffles block direct beam radiation and diffuse the sunlight throughout the space.

Roof Monitors and Clerestories

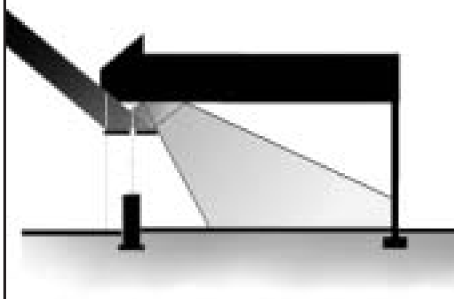
Roof monitors and clerestories perform two critical functions: they provide uniform light within the room, and they eliminate glare.

- Design daylighting strategies to meet the different lighting needs of each major space, accounting for:
  - differing lighting level requirements by time of day
  - the ability to darken particular spaces for limited periods of time.
- If south-facing roof monitors are employed, they should:
  - employ baffles within the light wells to totally block direct beam radiation from striking people, reflective surfaces, or computers
  - block high summer sun with exterior overhangs
  - reduce contrast between very bright surfaces and less bright areas.
- Optimize the design of roof monitors to enhance their benefits.
  - Minimize the size and maximize the transmission of glass to reduce conductive losses and gains.
  - Develop an overall building structural design that integrates the daylighting strategies and minimizes redundant structural elements.
  - For south-facing monitor glass, select clear double glazing or clear double glazing with argon. Do not use low-e or tinted glass in these windows because it has lower visible light transmission qualities. This adversely affects the daylighting and requires more glass area to achieve the same results.
  - Choose light-colored roofing materials in front of roof monitors to reflect additional light into the glazing.
  - In roof monitor/lightwell assemblies, incorporate white (or very light-colored) baffles that run parallel to the glass and are spaced to ensure that no direct beams can enter into the space. These baffles should be fire-retardant and UV-resistant. Use light-colored translucent baffles because, in addition to reflecting the sunlight into the space, they eliminate contrast from one side of the baffle to the other.
  - At the bottom of the lightwell, provide a transition between the vertical plane surface and the horizontal by either introducing a 45° transition or, if possible, a curved section. This will decrease the contrast between the higher light level inside the lightwell and the horizontal ceiling.
  - Ensure that the walls and ceiling of the roof monitor are well insulated and incorporate appropriate infiltration and moisture barriers.

Lightshelves

A south-facing window can be easily transformed into a well-controlled lighting source by adding a lightshelf a couple of feet below the top of the window. The lightshelf, made of a highly reflective material, will bounce the sunlight that strikes the top of the surface deep into the building. The reflected sunlight will hit the ceiling and, in turn, provide light for the room. This is an effective strategy for rooms up to 20 feet deep and can be employed in multi-story schools or where roof monitors are not possible. The lightshelf also serves the vital role of shading the window below.

- Select durable materials for both interior and exterior lightshelves, and design them to be capable of carrying the weight of a person.
- Specify aluminum exterior lightshelves as a good compromise among good reflectance, little or no maintenance, and cost.
- Incorporate white painted gypsum board on top of interior lightshelves. However, aluminized, acrylic sheets applied to the top of a shelf allows light to bounce farther back into spaces and can improve performance in deeper rooms without top lighting.
- Use blinds as a strategy to enhance performance. Even with a combination of interior and exterior lightshelves, direct beam light can, at times, enter into the space, creating unwanted glare. If the lightshelves are located close to perpendicular interior walls and are not deep enough to eliminate this problem (which is the typical case), vertical blinds can provide an excellent option. By using vertical blinds for the window section above the lightshelf, the light can be directed toward the walls, thus eliminating glare and enhancing the bouncing of light deep into the space. White blinds are preferred to increase reflectance. If the lightshelf windows are located near the middle of the space and farther away from perpendicular walls, horizontal blinds (flat or curved but turned upside-down) would allow the light to be reflected up toward the ceiling and deep into the space.
- Control the windows located above and below the lightshelves independently. On the south facade, daylighting can be enhanced by:
  - Incorporating vertical blinds that can focus radiation to the perimeter walls within a space and away from people within the space
  - Using horizontal blinds that can be installed to reflect the light up toward the ceiling, thus reflecting it back farther into the space.
- Don't use lightshelves on northern exposures. They are not cost-effective or necessary. However, it is still advisable to use clear double glass or clear double glass with argon (if possible) on high non-view windows on the north.
- When calculating daylighting contribution, don't consider the low north and south windows (view glass) in your calculation, as these windows are often closed or covered.



Using lightshelves on south-facing windows allows natural light to bounce deep into the room.

Lightshelves can also shade the lower window glass.

Light-colored interior finishes help the uniform distribution of natural light in the classroom.

Lighting Controls

Lighting controls can ensure that students and teachers always have adequate light and that energy efficiency is maintained.

- Enhance the economic benefits and provide for smoother transition between varying light conditions by using multi-staged or dimmable lighting controls. The success of these controls relies on:
  - having the sensors mounted in a location that closely simulates the light level (or can be set by being proportional to the light level) at the work plane
  - implementing a fixture layout and control wiring plan that complements the daylighting strategy
  - providing means to override daylighting controls in spaces that are intentionally darkened to use overhead projectors or slides.

Interior Finishes

The color of interior finishes will have a dramatic impact on the lighting requirements within each space.

- Use white (or very light-colored) paint inside the lightwell area. Colors inside the room can be slightly darker, but the lighter colors will help the light to reflect deeper into the space. Accent colors (with the majority still white) and beige colors are acceptable inside typical rooms. The tables included within the "Energy-Efficient Building Shell" section of this document provide additional information on the recommended reflectance ranges for different interior finishes.
- Apply carpet or other floor coverings that are as light as is practical for maintenance. This will greatly enhance reflectance and require less glazing to produce the same light levels. If the floor finish is dark, more glass is required to effectively daylight the space.
- If there are television monitors, computers, or whiteboards in the classrooms, locate them so as to minimize glare.
- Enhance the daylighting by placing south-facing windows with lightshelves close to perpendicular interior north-south walls. The color of the walls immediately inside the window should be light to enhance this reflectance. See page 22 for reflectance values of interior paint and wood.

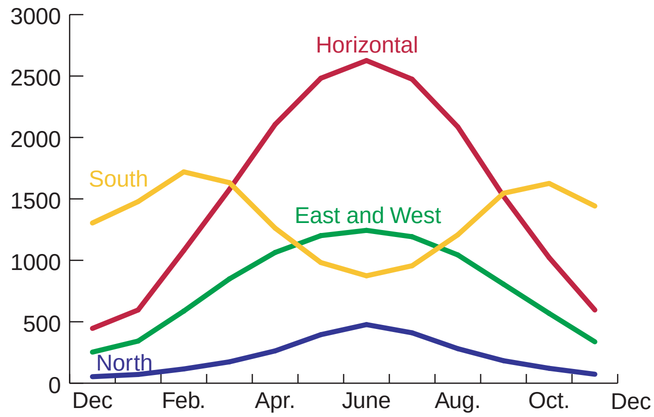
Skylights

Consider skylights if they can be specifically designed to avoid overheating during the warmer months and perform well with minimum maintenance.

- If skylights are used, specify those that incorporate:
  - motorized, louvered systems that seasonally and hourly adjust to allow the optimum amount of radiation to enter the glazing
  - a means to reduce glare and diffuse the radiation once inside the space.

Windows

Windows will have a significant impact on energy consumption. The characteristics of the windows and their location, design, and purpose will determine, to a great degree, the level of energy efficiency the school achieves.



Comparison of Window Orientations — 48° Latitude

The amount of solar radiation striking windows varies with the surface orientation.

Appropriate Choice

In all cases, windows should be made of high-quality construction, incorporate thermal breaks, and include the appropriate glazing for the particular application. Windows should be designed to meet the overall objective and not be oversized. To determine the optimum glazing for each application, the designer should conduct computer simulations that compare options. The US Department of Energy's DOE-2 program is one of the better analytical tools available for this purpose. More information on the DOE-2 program can be found in the resource section at the end of this document.

- Analyze and select the right glazing for each orientation, location, and purpose. For example, if windows are:
  - oriented east and west and not externally shaded, the best choice is to use a tinted glazing with low-e or low-e with argon
  - well-shaded by building elements (e.g., overhangs) or north-facing, tinting would not be advised since it restricts the transmission of diffuse radiation
  - located close to the floor, comfort becomes a more critical issue, and low-e or low-e windows with argon glazing is appropriate
  - designed as daylighting components above lightshelves or in roof monitors, the best option is typically clear double glazing or clear double glazing with argon.

Window Selection Considerations

Application	Exposure	Type
View Glass (Non-Daylighting Apertures)	South	Clear Double, Low-e with Argon
	North	Clear Double, Low-e with Argon
	East/West, Unshaded	Tinted Double, Low-e with Argon
	East/West, Shaded	Clear Double, Low-e with Argon
Windows Above Lightshelves	South	Clear Double or Clear Double with Argon
High Windows Above View Glass	North	Clear Double or Clear Double with Argon
Roof Monitors	South	Clear Double or Clear Double with Argon

The intended application and exposure determines appropriate window selection.

Solar Transmission Values for Typical Glass Types

Glazing Type	Solar Transmission	Equivalent U-Value
Clear, Single	75%–89%	1.11
Clear, Double	68%–75%	0.49
Low-e, Double, Clear	45%–55%	0.38
Low-e, Tinted, Gray	30%–45%	0.38
Low-e, Argon	45%–55%	0.3

Considering the transmission values of glass by orientation can greatly reduce cooling loads.

Typically, low-e glass is not recommended because the glass, as well as the complementary components of the daylighting system (e.g., lightshelves, baffles, roof monitors, etc.), all have to increase to account for the reduced transmissions.

Light Transmission Values

0.9	Standard Double Glazing
0.5–0.9	Internal Venetian Blinds — Drawn
0.4–0.8	Internal Curtains — Drawn
0.4–0.8	Internal Roller Blinds — Drawn
0.7	Heat-Absorbing Glass
0.6	Tree Providing Light Shade
0.5	Internal Blind — Reflective Backing
0.4	Solar Control Glass
0.2	External Blinds — Drawn
0.2	External Shutters — Closed

Transmission of light is greatly impacted by the type of window treatments used.

- Select spectrally selective, low solar gain, low-e glazing for non-daylighting apertures.
- Consider the possibilities of implementing natural ventilation strategies that use operable windows.

Exterior Window Treatments

The most efficient means of appropriately restricting unwanted solar gain from entering glass areas is to block the radiation before it gets to the glazing.

- Properly size fixed overhangs on south-facing roof monitors and lightshelf glazing to block a large portion of the midday summer sun while still allowing the lower winter sun to reach the glass.
- Incorporate overhangs or other design elements above east- and west-facing glazing so that they effectively block the morning and afternoon sun.
- Consider the advantages of using seasonally adjustable or stationary awnings, solar screens, shutters, or vertical louvers when fixed overhangs are not possible or are impractical.

Clear glass for south-facing roof monitors and low-e glass for view windows are two daylighting and energy-efficient features.

Interior Window Treatments

If exterior window treatments cannot effectively control the seasonal and daily variations in radiation (and resulting glare), or if it is desirable to be able to darken the particular space, blinds or shades provide better control.

If blinds or rolling type dark-out shades are employed, install types that are either motorized or easily accessible and made of durable construction materials and components.

Energy-Efficient Building Shell

Because the building shell is typically responsible for 10%–20% of the total energy consumed in a school, focusing on this area of design can help you reduce energy consumption in your school buildings. Increased insulation in the walls and ceiling helps to reduce heat loss and improve comfort. Light-colored exterior walls and white roofs help to reduce cooling loads. These factors also contribute to reducing the size and cost of the HVAC system you will need. The useful life of building materials, systems, and equipment incorporated in schools can vary considerably, so the building shell decisions you make as a designer will impact the first cost of the school as well as the long-term costs associated with operation, maintenance, and replacement.

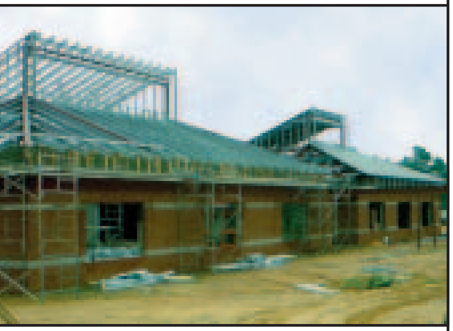
Wall insulation should be selected based on the likelihood that it will never be replaced. When selecting your wall and roof systems, it is critical that you choose what is best for the life of the facility. Specify interior and exterior finishes that are durable and as maintenance free as possible, and integrate insulation levels that are appropriate for the life of the facility. Also, incorporate durable strategies that address air infiltration.

If specified correctly, energy-efficient building shell elements can be effective in reducing our impact on the environment, and they will never need to be replaced.

Photo: Robert Flynn

High-mass exterior walls, light-colored roof finishes, and window treatments including lightshelves and low-e glazing for view windows are among the energy-efficient building shell elements.

Design Guidelines for an Energy-Efficient Building Shell

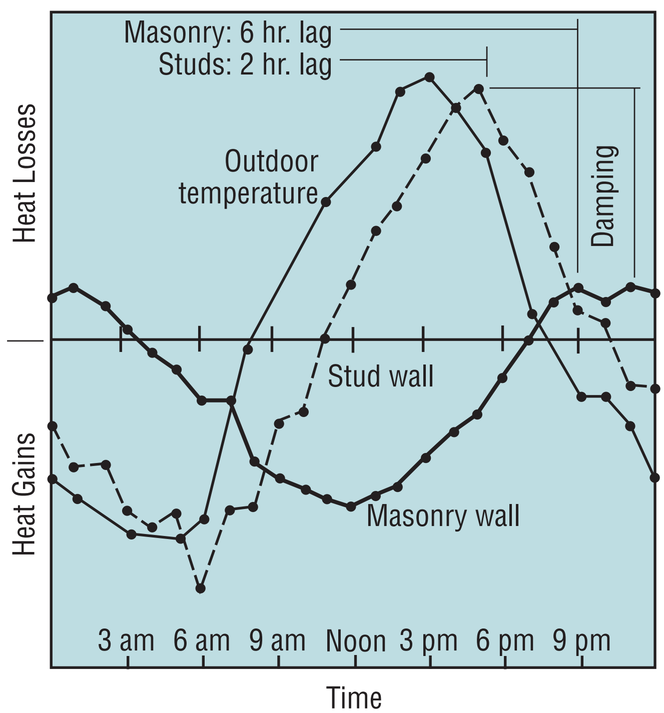


High-mass construction techniques, incorporating a brick-block cavity wall, lag the heat gain experienced during the daytime well into the evening.

Massive Wall Construction

In cold and humid climates, high-mass construction techniques are primarily used to store thermal energy in passive solar systems. But they can also be used to moderate the heat gain experienced during the hot days, delaying the impact until the nighttime when ventilation strategies could cool the interior spaces. If adequate mass is incorporated, these cooling strategies are particularly effective since schools are typically not occupied during evening hours.

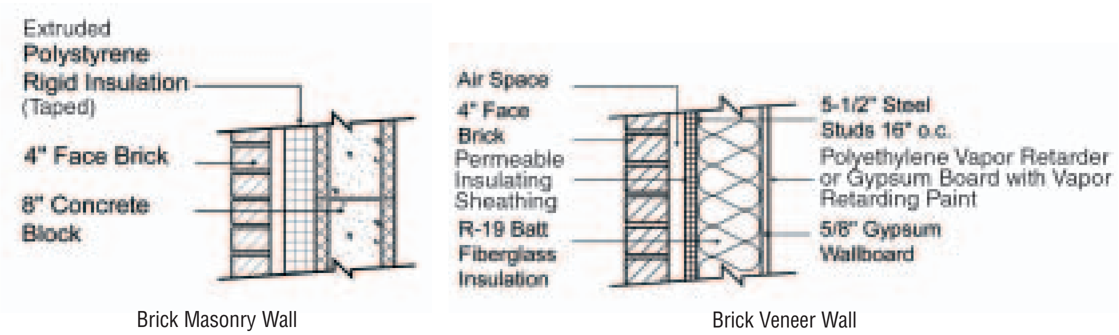
- By incorporating well-insulated masonry wall systems that are designed so that the mass is inside the insulation and exposed, the mass can be utilized to save thermal energy from passive heating strategies incorporated in the school.
- Employing high-mass wall construction techniques to lag the heat gains. Although not as abundant as in warmer climates, these techniques still provide a moderating effect in the warmer months.



Heat Gain Lags in High-Mass Walls

Using high-mass wall construction techniques can delay thermal gains by up to 12 hours.

- Newer wall systems using insulated concrete forms or tilt-up insulated concrete panels have also proved effective.



Brick Masonry Wall

Brick Veneer Wall

High-Mass Wall Sections

Passive solar energy can be stored if mass is exposed inside.

Moisture and Infiltration Strategies

Controlling air flow and moisture penetration are critical elements in reducing energy consumption, maintaining structural integrity, and ensuring a healthy indoor environment.

- Because designers in cold and humid climates need to primarily address a heating load, vapor barriers should be placed on the inside of the wall assembly's insulation to prevent moisture from entering the wall cavity.
- Permeable exterior sheathing materials will keep moisture from being trapped in the wall.
- Since air leakage can carry significant amounts of moisture into the building envelope, caulk and seal any building shell penetrations. Consider the use of a continuous air infiltration barrier.

Insulation Strategies

Energy-efficient building design starts with implementing optimum insulation levels. Evaluating the cost-effectiveness of varying insulation R-values allows you to maximize long-term benefits. High levels of wall and ceiling insulation are particullarly important in cold and humid climates.

- When selecting insulation levels, refer to ASHRAE Standard 90.1. R-values required by local building codes should be considered a minimum.
- When determining the choice of insulation, you should consider not only energy efficiency and initial cost but also long-term performance. Carefully research insulation products for stability of R-value over time, and make comparisons based on the average performance over the service life.

An energy-efficient building shell requires that the designer view the wall assembly as a system within the "whole building."

Light-colored finishes will significantly reduce lighting demands within interior spaces.

Interior Finishes

By properly selecting interior finishes, lighting energy demands can be reduced and visual comfort can be improved for no additional cost.

- Select light colors for interior walls and ceilings to increase light reflectance and reduce lighting and daylighting requirements.
- Consider the color and finish of interior walls and ceilings. When placed incorrectly, light-colored, glossy finishes can create glare problems that negatively impact visual comfort.

Reflectance Table: Paints

Color	Reflectance
Semi-Gloss White	70%
Light Green*	53%
Kelly Green*	49%
Medium Blue*	49%
Medium Yellow*	47%
Medium Orange*	42%
Medium Green*	41%
Medium Red*	20%
Medium Brown*	16%
Dark Blue-Gray*	16%
Dark Brown*	12%

Reflectance Table: Woods

Type	Reflectance
Maple	54%
Poplar	52%
White Pine	51%
Red Pine	49%
Oregon Pine	38%
Birch	35%
Beech	26%
Oak	23%
Cherry	20%

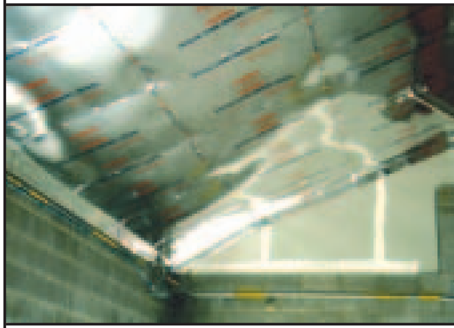
* These values are estimated for flat paints. For gloss paints, add 5%–10%. Source: SBIC, Passive Solar Design Strategies

Careful consideration of interior finishes based on reflectance values can reduce lighting demands.

Stopping Radiant Heat Gains

In cold and humid climates, creating a building shell that is massive and well-insulated can effectively address conduction gains and losses, but it is also beneficial to take into account radiant solar gains. In the warmer months, up to 90% of the cooling load coming from the roof area can be attributed to radiant heat gain. By addressing this problem, you can decrease your cooling load significantly.

- Incorporate radiant barriers in the roof assemblies to reduce up to 95% of radiant heat gain. When solar radiation strikes a roof, a certain percentage of radiation is reflected away, and the balance is absorbed. When this occurs, it heats up that material, and the material reradiates downward. The low-emissivity properties of the aluminum in the radiant barrier stop this radiant process, allowing only 5% of the radiation to pass through. Radiant barriers that have coatings to protect against oxidation help ensure long-term performance. These types of radiant barriers are superior to reflective roofing strategies that tend to lose their reflective qualities over time. Dust accumulation on radiant barriers reduces their performance. When possible, they should be suspended from the joists or rafters to reduce dust accumulation.
- To reflect solar gain away before it can create negative radiant impacts within the spaces below, incorporate highly reflective roofing systems. This strategy is important, particularly in areas where radiant barriers cannot practically be installed.
- Select a light color for the exterior finish to reflect solar radiation.
- Shade exterior walls with architectural elements (or landscaping) to enhance performance.



Radiant heat gain can be responsible for 90% of the heat entering through the roof. The use of a radiant barrier can block up to 95% of this gain.

Reflectance Values for Exterior Surfaces

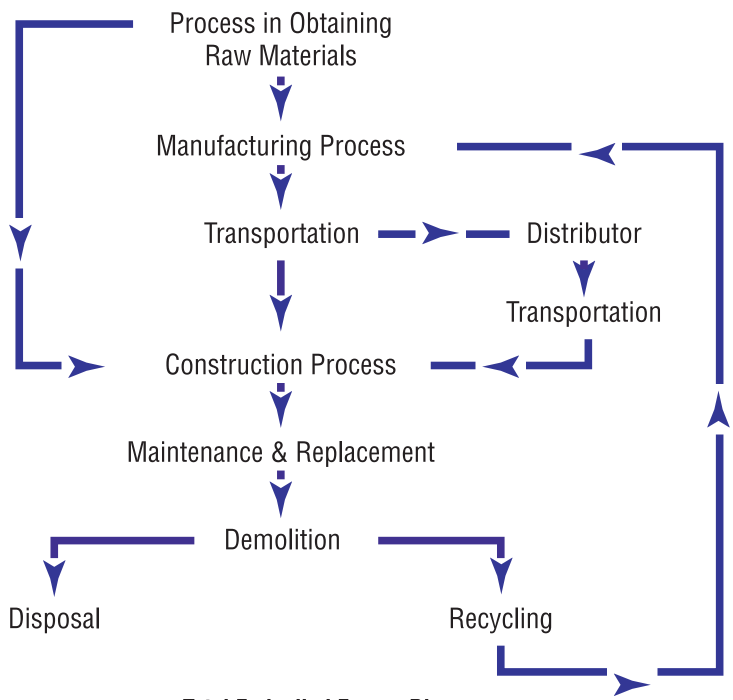
This chart indicates the reflectance of various typical roofing materials when first installed. Materials that maintain their reflective characteristics should be preferred.

		% Reflected	% Absorbed
Roofing Material (1)			
Single-Ply Roof Membrane	Black EPDM	6%	94%
	Gray EPDM	23%	77%
	White EPDM	69%	31%
Asphalt Shingles	Black	5%	95%
	Medium Brown	12%	88%
	Green	19%	81%
	Gray	22%	78%
	White	25%	75%
Metal Roof	Aluminum	61%	39%
	Metal White	67%	33%
Exterior Wall Material (2)			
Brick	Light Buff	45%	55%
	Dark Buff	40%	60%
	Dark Red	30%	70%
Concrete	Light	55%	45%
	Medium	20%	80%
	Dark	15%	85%

(1) Source: Berdahl 2000. "Cool Roofing Material Database," LBNL
(2) Source: 1981 IES Lighting Handbook

Embodied Energy

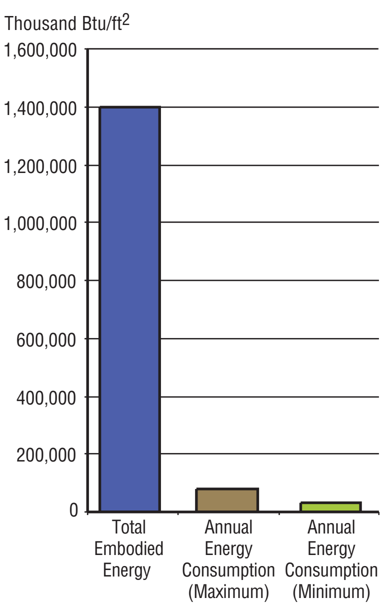
When selecting the building materials, consider that, in many cases, the amount of energy embodied in constructing the school is equal to more than two decades of a school's energy consumption. To seriously address the overall impacts of energy consumption, consider the energy involved in making each product, transporting the product to the site, and implementing the component into the school.



Total Embodied Energy Diagram

Products, materials, equipment, and processes incorporated into construction

- Because often half or more of the embodied energy involved in constructing a school is related to transportation, select locally made products and construction materials.
- Consider the energy intensity of the manufacturing process involved in making materials and products incorporated in the school.
- Encourage the use of recycled products.
- Evaluate the recyclability of products once the building has passed its useful life.
- If existing structures on the school site are to be demolished, consider how the typically wasted materials could be used in the new construction.



Total Embodied Energy per Square Foot for Educational Buildings

The embodied energy of a school building exceeds the annual energy consumption of the school.

Lighting and Electrical Systems

The design of your school's lighting system has direct bearing on the performance of your students and teachers. The ability to read comfortably and perform visual tasks is strongly impacted by the type and quality of the lighting systems implemented. Lighting strategies that reduce glare while still producing the required lumen levels are essential components of a high performance school.

Lighting represents 25%–40% of a typical school's energy costs. An energy-efficient lighting system can save thousands of dollars annually in just one school because improving the efficiency of the overall lighting system reduces the energy requirements for both lighting and air conditioning. Controls in daylit spaces can automatically reduce or increase light levels as needed, and occupancy sensors can automatically turn off lights in unoccupied spaces.

Your design team can create an energy-efficient, high-quality lighting system by following three strategies. First, select efficient lamps, ballasts, lenses, and fixtures that address the needs of each space and achieve the highest output of lumens per input of energy. Second, provide occupancy sensors, time clocks, and other controls that limit the time the lights are on to only hours when the space is occupied and the light is needed. And third, provide automated daylighting controls that dim the electrical lighting when sufficient natural light is present.

Photo: NREL/PIX03045

Indirect lighting can provide excellent uniform artificial lighting in a classroom, eliminating glare and contrast between bright and dark areas.

Design Guidelines for Lighting and Electrical Systems

Lighting Strategies

In naturally lit spaces, the artificial lighting design should be compatible with the objectives of the daylighting. In non-daylit spaces, the objective should be to implement the most energy-efficient system possible that minimizes glare while providing the proper level and quality of light.

- Maximize the illumination by considering the geometry and reflectance of finishes in each space.
- Implement indirect lighting strategies as a means to complement daylighting.
- Select fixtures that are designed to minimize glare, particularly in rooms with computers.
- Verify the lighting requirements for each space function.
- Consider the option of providing low-level ambient lighting supplemented by task lighting.
- Prefer photovoltaic lighting systems for remote exterior applications such as parking areas or walkways. It is often more cost effective to use a localized photovoltaic system with its own battery storage than to provide underground electrical service.
- In non-daylit spaces, incorporate lamps with high color rendering.
- Design switching circuits to allow spaces that are not commonly used to be switched off.

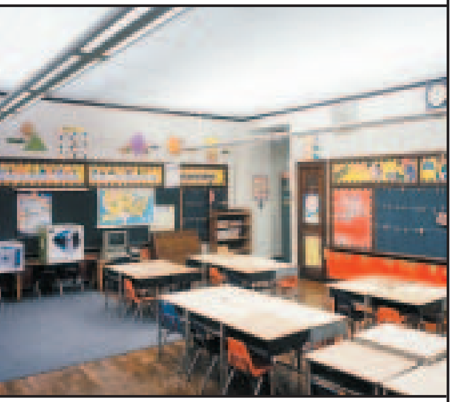


Photo: NREL/PIX03047

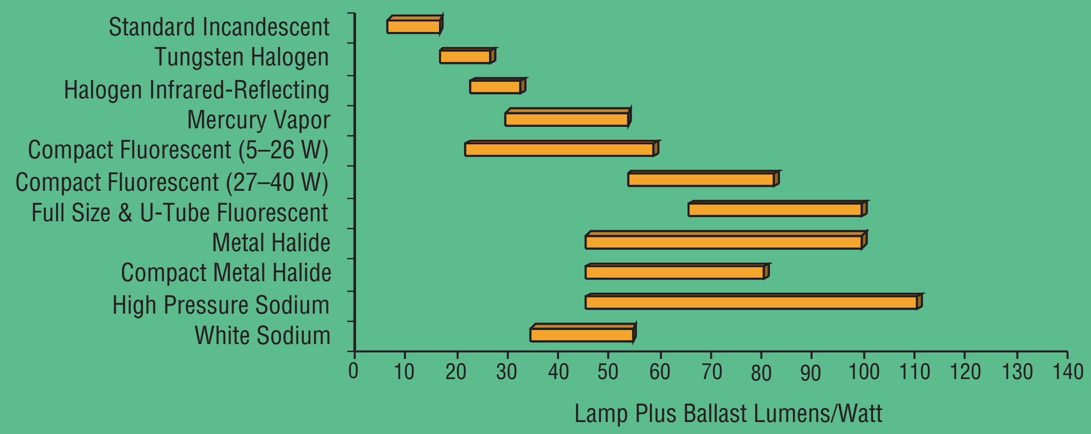
Indirect lighting systems provide high-quality artificial lighting in classrooms.

High-Efficacy Lamps

Efficacy is an important measure for energy efficiency in light output per unit of energy used. High-efficacy lamps can provide the same illumination and color rendition as standard lamps but at two to six times the efficiency.

High-efficacy lamps produce a high light output per unit of electric input.

Comparison of Lamp Efficencies



- Minimize the use of incandescent fixtures.
- When selecting lamps, consider the maintenance and lamp replacement costs.
- Select the lamps with the highest lumens of output per watt of input that address the specific need.

Fluorescent Lamp Technologies — Efficacy Comparisons

Lamp Type	Lamp Life (hours)	Lumen/ Watt	C.R.I.*	Lumen Maint.**	Ballast Factor	Description and Comments
T-5 Fluorescent (28 W/4 Ft)	20,000	104	85	0.95	1	5/8" dia. tube; high lamp and ballast efficiency, high CRI, similar output to T-8 with a 12% reduction in power usage
T-5 HO Fluorescent (54 W/4 Ft)	20,000	93	85	0.95	1	5/8" dia. tube; high lumen output, high CRI; 88% higher lumens than standard 4 ft T-8
T-8 Fluorescent (32 W/4 Ft)	20,000	92	82	0.92	0.9	1" dia; standard for efficient fluorescent lamps; 23% efficiency improvement over T-12
T-12 Fluorescent (34 W/4 Ft)	20,000	69	72	0.89	0.88	1 1/2" dia. tube, still being used where efficiency is not being considered

Developed by Padia Consulting from manufacturers' literature (Philips, Osram Sylvania, General Electric)

* Color Rendering Index
** The lumen maintenance percentage of a lamp is based on measured light output at 40% of that lamp's rated average life. For T-5, after 8,000 hours of lifetime, the lumens/watt will be 98.8 lumen/watt (104x0.95).

Fluorescent lamp selection should be based on the illumination needs of the area and lamp replacement frequency and cost.

Compact Fluorescent Lamps

- Consider compact fluorescent lamps that are energy-efficient and long-lasting. A 13-watt compact fluorescent lamp (about 15 watts with an electric ballast) provides the same illumination as a 60-watt incandescent lamp and lasts up to 10 times longer. Additionally, they have excellent color rendering.
- In larger daylit spaces like gymnasiums, provide ganged compact fluorescents as a practical means of addressing the need to implement dimmable lamps.
- Select fixtures with effective reflector design.

Fluorescent Lamps

- Choose the smaller diameter T-8 and T-5 fluorescent tubes over the traditional T-12s because they have a higher efficacy. The T-8 system produces 92 lumens per watt as compared with 69 lumens per watt for the T-12 system. The T-5 system produces 33% more lumens per watt than the T-12 system.
- Specify fixtures that are designed to enhance the efficacy of the T-8 and T-5 lamps by incorporating better optics in the luminaire design.

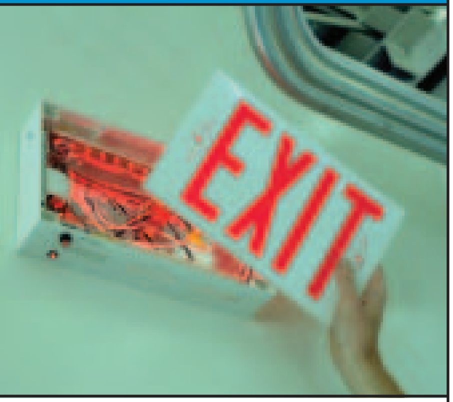


Photo: NREL/PIX07071

LED exit signs last 10–50 times longer than fluorescent and use less energy.

Metal Halide and High-Pressure Sodium Lamps

- Consider metal halide and high-pressure sodium lamps for exterior lighting applications.
- Use metal halide and high-pressure sodium lamps only in areas where the long warm up and restrike time after a power outage will not affect the safety of students, visitors, and staff.

LED Exit Lights

- Select light-emitting diode (LED) exit lights. Exit signs operate 24 hours a day, 365 days a year. LED exit signs offer energy savings between 80 kilowatt-hours/year and 330 kilowatt-hours/year per fixture with little maintenance. LED exit lights have a projected life ranging from 700,000 hours to more than 5 million hours, and the standby battery requires replacement about every 80,000 hours. Typical fluorescent lamps will last only 15,000 hours.

High-Efficiency Reflectors

High-efficiency fixtures employ two main strategies to minimize the blockage or trapping of light within the fixture housing: high-efficiency lensed troffers and fixtures with parabolic reflectors.

- Incorporate well-designed troffers that use the shape and finish of the inner housing to minimize inter-reflections and maximize the lumens per watt. A high-efficiency troffer with two or three lamps can produce the same illumination as a standard four-lamp fixture.
- Select fixtures with parabolic reflectors as an alternative means to improve the optics and increase the performance of the light fixtures.

Ballasts

Solid state electronic ballasts are available in both rapid-start and instant-start models. The instant-start ballasts have a very high efficiency but should be avoided in applications where sensors are used.

While selecting a dimmable ballast, take into consideration the fact that magnetic ballasts will only dim to about 40% of full power before the flicker becomes problematic, whereas electronic ballasts may be dimmed to near zero output with no perceptible flicker. Electronic ballasts also have a higher lumen output at reduced power levels than magnetic ballasts.

- Select high-efficiency electronic ballasts because they save energy, have a low propensity to attract dust, incorporate a minimum of hazardous materials, and operate at a cooler temperature.
- Select electronic ballasts because they minimize the characteristic humming from fluorescent lamps.

- Consider that conventional ballasts cycle at 60 hertz and create a perceptible flicker, whereas electronic ballasts cycle faster, reducing eye strain.
- In areas where daylighting strategies are being implemented, employ electronic ballasts designed specifically for dimming and controlled by photosensors.

Lumen Maintenance

The output of a fluorescent lamp decreases over its rated life. The strategy used for maintained light level calculations is the initial light output of the luminaires multiplied by factors for lamp depreciation, luminaire depreciation, and room surface dirt depreciation. This will drop the calculated output by 25%–30% or even more.

The better strategy is to measure the light output at the work surface using a light sensor in an "open loop" control. This will save power initially, extend the life of the lamps, and compensate for dirt on luminaires and room surfaces. It is important to establish a program of group lamp replacement. This will ensure that overall lighting levels are even, and maintenance labor costs are reduced by 88% over "spot" replacement.

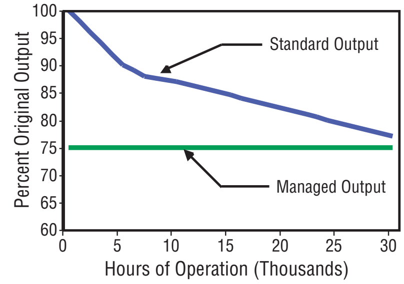


Chart: Padia Consulting

Typical Degradation of Fluorescent Lamp Output Over Time

Lamp output degradation should be managed to maintain constant lighting levels.

Lighting Controls

Because of changing use patterns in schools, occupancy sensors and photosensors can save considerable energy by simply turning off the lights when not needed. There are two commonly used occupancy sensors: infrared and ultrasonic. Infrared sensors detect occupants by sensing changes in heat as occupants move, while ultrasonic sensors detect movement of solid objects. Sensors that combine both technologies are available. It is also important to implement photosensor controls for outdoor lights to ensure that the lights are only on at night.

- Incorporate infrared, ultrasonic, or a combination of infrared and ultrasonic motion detectors in all major spaces to turn off the lights when the space is not occupied.
- In daylit spaces, incorporate staged or dimmable (preferred) lighting controls tied to photocells located within each space and capable of reading light levels at the work surface.
- Incorporate override switches for automatic daylight dimming controls only where the need to manually control lighting levels is necessary to the function of the space.
- Provide photocells on outdoor lights to ensure that they are off during daytime hours.

Daylight sensors combined with occupancy sensors are used as an energy-saving measure to turn the lights off if the natural light level is sufficient or if the space is unoccupied.

Electrical Systems

An inefficient electrical distribution system in a school can result in degraded power quality, the introduction of wasteful harmonics, and line losses up to 3% or 4%.

- Evaluate the merits of a high-voltage distribution system, taking into consideration the initial cost and operational savings due to reduced line losses. Analyze the costs of delivering power at 208/120 volts versus 480/277 volts.

- Correctly size transformers to fit the load, keep losses to a minimum, and optimize transformer efficiency. The correct sizing of a transformer depends on the economic value and size of load losses versus no-load losses, and consideration of expected transformer life.
- Consider more efficient transformers that operate at lower temperatures. Most transformers range in efficiency between 93% and 98%. Transformer efficiency is improved by reducing the losses in the transformer. Transformer efficiency standards exist in some states, and efficient transformers are required by code in others. Check with your state energy office.
- Consider using K-rated transformers to serve non-linear equipment. K factor is a constant developed to take into account the effect of harmonics on transformer loading and losses. A K-rated transformer may initially cost more, and may be less efficient, but it should result in a longer transformer life.
- Evaluate the distribution system to determine if power factor correction is justified. Utilities usually charge users for operating at power factors below a specified level. In addition to causing unnecessary line losses, low power factors create the need for a larger energy source. If power factor correction is necessary, a common method is to place power-factor-corrective capacitors or three-phase synchronous capacitors (motors) in the system, close to the load.
- In some situations, disconnecting the primary side of transformers not serving active loads can save energy. Disconnecting the primary side of transformers is safe provided that critical equipment such as fire alarms and heating control circuits are not affected.
- Where possible, minimize long runs of wire from power distribution panels to electrical equipment. Where equipment would be likely to operate at a low voltage due to distance from the distribution panel, install larger wire to reduce voltage drop.

Because appliances, motors, fans, and other electrical equipment are responsible for a high percentage of building electrical consumption, it is important to select equipment that is properly sized, energy-efficient, and environmentally sound.

- Don't oversize the equipment. It will add to the peak electrical loads, and oversized equipment often does not operate as well at part-load conditions.
- Use high-efficiency motors and, where appropriate, variable frequency drives. Compare motors using No. 112, Method B, developed by the Institute of Electrical and Electronic Engineers (IEEE).
- Select fans and pumps for the highest operating efficiency at the predominant operating conditions.
- Set temperatures on water heaters based on use requirements.
- Use timers to limit the duty cycle of heaters when they are not in full use.
- Select energy-efficient food-service appliances.
- Specify ENERGY STAR-rated appliances.

ESTABLISH ENERGY PERFORMANCE GOALS

For new school design (K-12), the US EPA recommends setting a design target and monitoring progress throughout the design process.

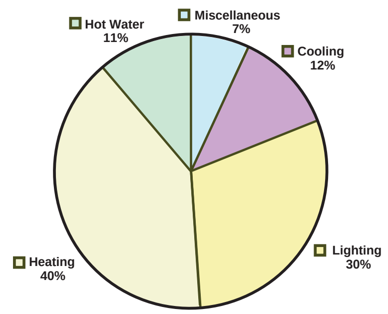
The ENERGY STAR label can also be used to identify energy-efficient office equipment, exit signs, water coolers, and other products. By choosing these products, your school can save energy and money.

Mechanical and Ventilation Systems

In cold and humid climates, heating, ventilation, and air conditioning (HVAC) systems are typically responsible for 50%–60% of the energy consumed in schools. By using the "whole-building" approach — looking at how all the building's design elements work together — your design team can factor in energy-saving choices that reduce heating and cooling loads and downsize the HVAC system needed. By not over-designing the HVAC system, you can reduce initial equipment costs as well as long-term operating costs.

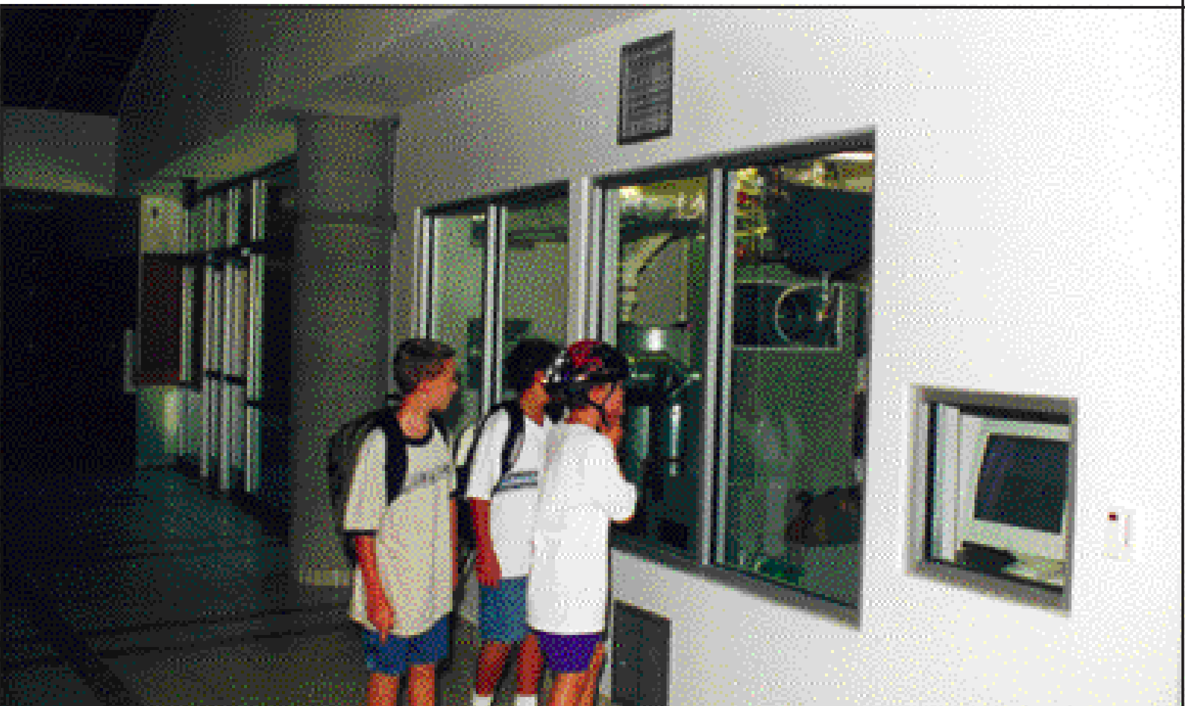
More importantly, HVAC systems have a significant effect on the health, comfort, productivity, and academic performance of students and teachers. A study by the US General Accounting Office found that half of the more than 90,000 public schools in the country are facing noise control problems, lack of adequate ventilation, physical security issues, poor indoor air quality, comfort issues, and below-standard lighting conditions. A 1999 US Department of Education study found that 26% of the country's schools had unsatisfactory levels of fresh air. Most of these issues are directly or indirectly linked to HVAC system design and operation and can be corrected by improved mechanical and ventilation systems.

The best HVAC design considers all the interrelated building systems while addressing indoor air quality, energy consumption, and environmental benefit. Optimizing the design and benefits requires that your mechanical system designer and your architect address these issues early in the schematic design phase and continually revise subsequent decisions throughout the remaining design process. It is also essential that you implement well-thought-out commissioning processes and routine preventative maintenance programs.



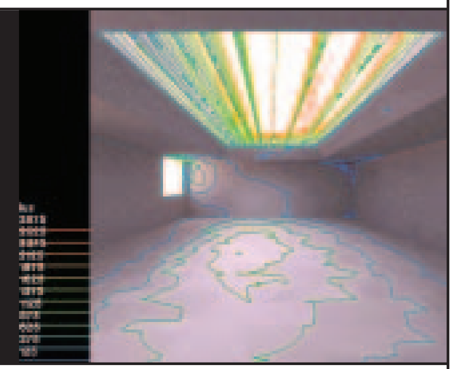
School Energy Use Distribution

In typical schools, energy is primarily used for heating and lighting.



At Roy Lee Walker Elementary School, McKinney, TX, the energy-efficient mechanical system is exposed to serve as an educational tool for energy conservation.

EnergyPlus is a new-generation building energy simulation program designed for modeling buildings with associated heating, cooling, lighting, and ventilation flows. EnergyPlus builds on the most popular features and capabilities of BLAST and DOE-2 and includes many advanced and innovative simulation capabilities.



Computer simulations of daylighting are essential to achieving a clear understanding of how this energy strategy impacts mechanical loads and the "whole building" performance.

Design Guidelines for Mechanical and Ventilation Systems

Energy Analysis

To optimize the selection of efficient, cost-effective mechanical and ventilation systems, perform an energy analysis early in the process, during the schematic design phase. System optimization also improves indoor air quality, allows better humidity control, and potentially lowers construction costs due to a reduction in size of mechanical and electrical systems. Several available computer programs can provide building simulations on an hourly basis to predict the energy behavior of the school's structure, air conditioning system, and central equipment plant.

An energy analysis considers the school's key components — the building walls and roof, insulation, glazing, the lighting and daylighting systems, as well as the HVAC systems and equipment. The analysis program can simultaneously assess and predict the results of choices associated with each component. For buildings in the design phase, computer models are generally useful for comparing alternatives and predicting trends.

Energy analysis computer programs that simulate hourly performance should include a companion economic simulation to calculate energy costs based on computed energy use. This model can estimate monthly and annual energy usage and costs. Some models allow the user to input estimated capital equipment and operating costs so that the life-cycle economics of the design can be evaluated and compared.

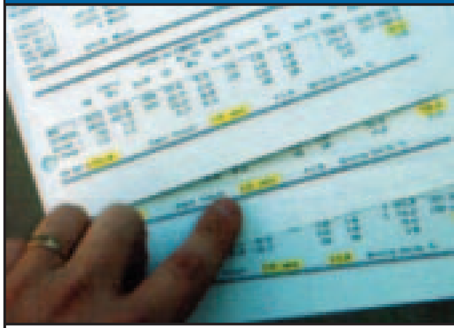
- Prior to starting work on the design, establish an "energy budget" for the project that exceeds the minimum building code standards. One consideration is to set an energy budget that would potentially qualify the school for an Energy Star buildings label. An Energy Star designation places the school in the top 25% of energy performance.
- Develop a clear understanding of how the school system wants to balance initial cost versus life-cycle cost, and point out the long-term advantages of investing in more energy-efficient, and environmentally friendly approaches.
- When evaluating life-cycle costs, take into account:

Communication among members of the school system, architects, and engineers early in the predesign process is critical for establishing the most energy-efficient "whole-building" strategy.

- – the initial cost of equipment
- – anticipated maintenance expenses
- – projected annual energy costs
- – projected energy and labor cost escalation rates
- – replacement costs.

- Optimize the mechanical system as a complete entity to allow for interactions between system components.
- In the schematic design phase, determine the mechanical system implications of all related site, building shell, daylighting, and lighting elements.

When energy use and operating expenditures are considered at the outset of the design process, energy- and resource-efficient strategies can be integrated at the lowest possible cost.

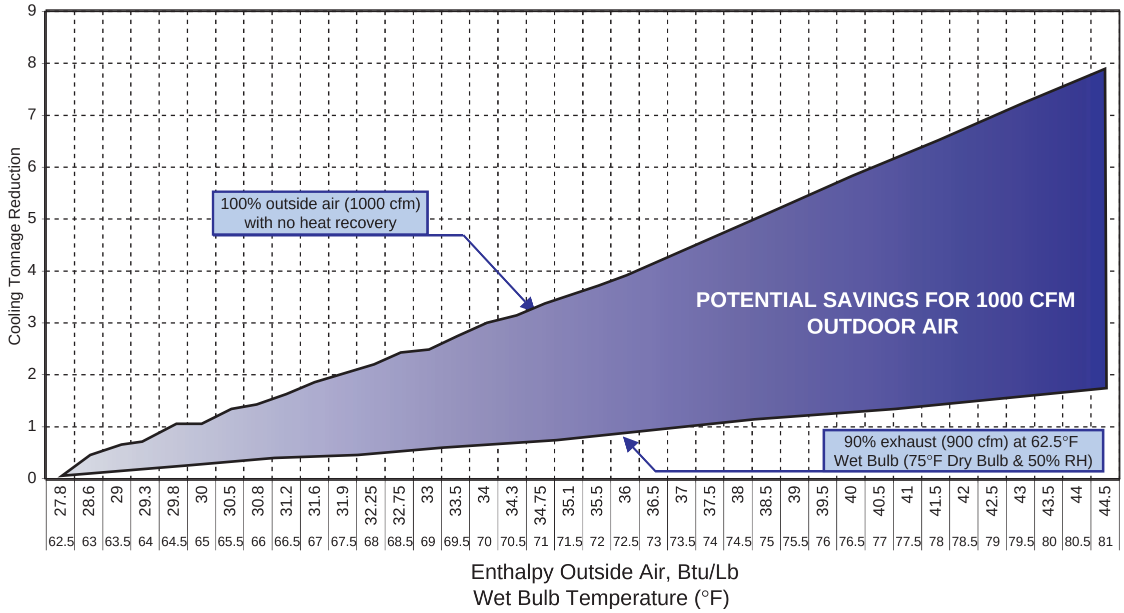


The energy budget and goals should be established prior to the start of the schematic design phase.

Cooling Systems

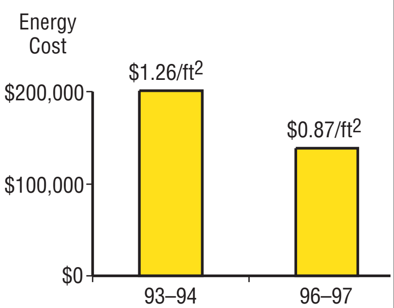
Consider cooling systems appropriate for cold and humid climates that match the building loads and are not over-designed.

- Evaluate various cooling equipment sizes and models to select the unit that best matches the demand requirements. To accomplish this, use an hourly computer simulation tool to generate energy consumption profiles and the incidence of coincidental peak cooling loads. Select equipment that achieves a high efficiency at the predominant load but also remains efficient over the range of operating conditions.
- For cold and humid climates, consider the use of desiccant dehumification (enthalpy heat exchangers), which can reduce the need for mechanical cooling to remove moisture. The requirements for proper maintenance of these systems should also be evaluated.
- Consider natural gas and/or solar-driven absorption cooling as a method of reducing peak electricity consumption.
- A form of free cooling is nighttime ventilation. Use nighttime ventilation strategies to cool interior mass and flush out stale air prior to morning occupancy. This purging cycle can be effective during low nighttime temperatures.
- To reduce upper atmospheric ozone depletion, reduce the use of CFC and HCFC refrigerants.
- Consider thermal (ice or water) storage in situations where peak load avoidance is critical. Thermal storage is a cost-saving technique that takes advantage of off-peak utility rate schedules where applicable. Some electric utilities promote thermal storage by offering an incentive for power usage that can be displaced from peak to off-peak time.



An outside air-handling unit equipped with an enthalpy heat exchanger results in a sizable reduction in cooling load and maintains a humidity level required for space comfort conditions.

Source: PADIA Consulting



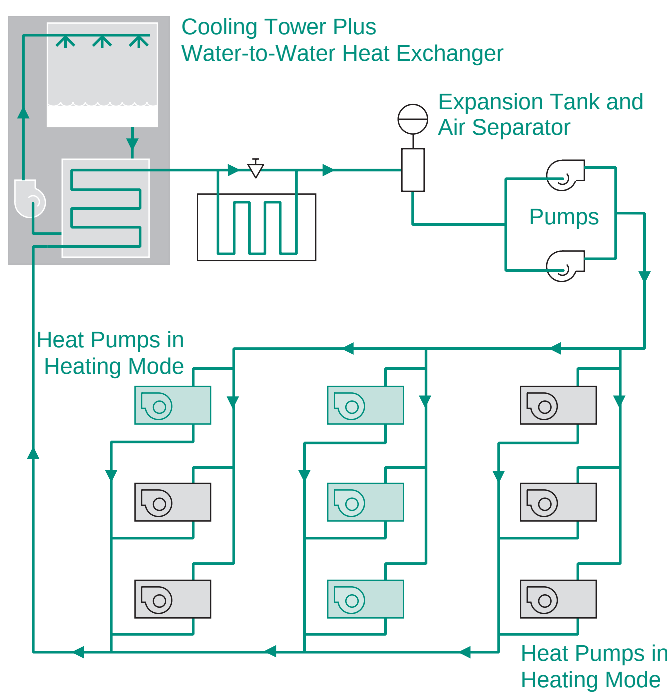
Energy Savings

Built in 1971, the 160,000-square-foot Daniel Boone High School, in Gray, TN, was heated by electricity and cooled by a two-pipe chilled water system. After analysis of other two-pipe retrofit options, a new geothermal heat pump system was installed in 1995–96. Costing an additional $197,000 and saving $33,000 versus the next best two-pipe system considered, the geothermal system saved Washington County Schools $62,000 the first complete year of operation.

Water-Source Heat Pumps

A water-source heat pump system is well suited to transfer heat from an interior zone, where cooling may be desired, to the perimeter, where heating may be needed. Buildings with simultaneous heating and cooling needs and a use for recovered heat (hot water) are ideal candidates for water-source heat pumps.

- Consider water-source heat pumps when it is necessary to subdivide the school building into many small conditioned zones to provide better comfort control.
- Consider the benefits of the heat pumps equipped with a hot gas reheating (free heating energy) in cold and humid climate regions.
- Evaluate the higher maintenance costs associated with multiple compressions and fans.
- Provide dedicated make-up air units to introduce fresh conditioned outdoor air for ventilation.



Water-Source Heat Pumps

Water-source heat pumps can provide significant savings in cold and humid climates.

Boilers

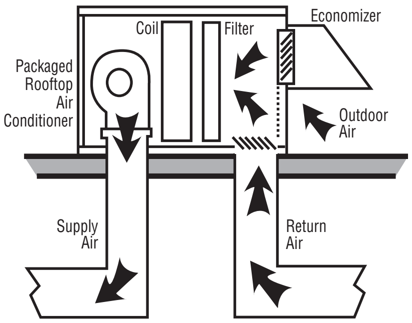
When considering centralized systems, choose the most efficient heating for the particular need.

- Consider condensing boilers. They are typically 10% more efficient than conventional boilers.
- Consider multiple, modular boilers that are more efficient at partial load.
- Employ draft control devices that reduce off-cycle losses.
- Design a water reset control that is keyed to the outside air temperature.
- Incorporate burner flame controls.
- For small renovation projects, install time clocks to control night and weekend set-back.

Ventilation and Indoor Air Quality Strategies

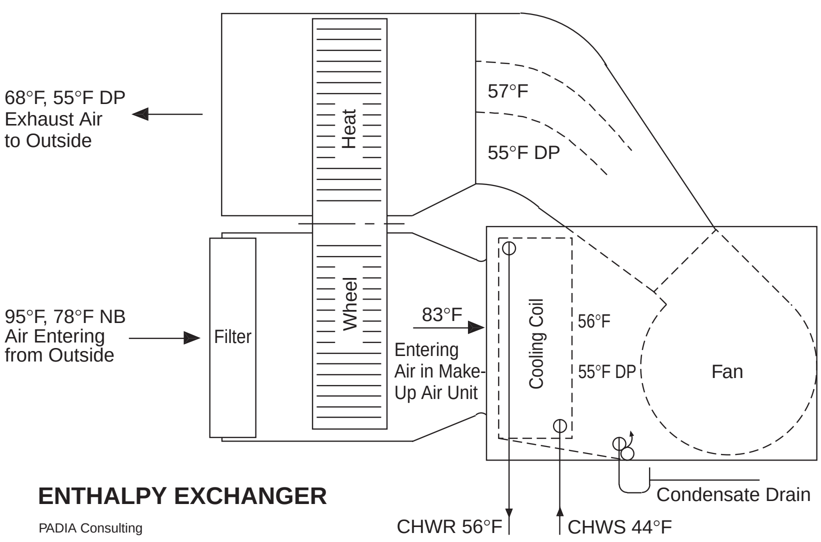
ASHRAE Standard 62 addresses the criteria necessary to meet ventilation and indoor air quality requirements. The outside air requirements for proper ventilation of an occupied school are considerable and have a substantial impact on HVAC system energy consumption and operating costs. The strategy employed to achieve proper ventilation must be carefully considered.

- Implement ventilation strategies that will ensure outside air by complying with ASHRAE Standard 62-1999.
- Consider a dedicated ventilation system such that the quantity of air can be regulated and measured, providing a greater certainty that proper ventilation is maintained. Such a dedicated system can also improve overall energy efficiency.
- Consider the use of a heat recovery system, like an air-to-air heat exchanger, that will transfer the heat between air supplied to and air exhausted from the building.
- Separate and ventilate highly polluting spaces. Provide separate exhaust from kitchens, toilets, custodial closets, chemical storage rooms, and dedicated copy rooms to the outdoors, with no recirculation through the HVAC system.
- Consider an enthalpy recovery system.



Economizer Cycle Diagram

An air economizer cycle based on enthalpy control can lower energy consumption by using as much as 100% outside air.



Enthalpy Recovery System

An enthalpy recovery system is used to reduce energy consumption by capturing the energy that would normally be lost in the exhaust airstream.

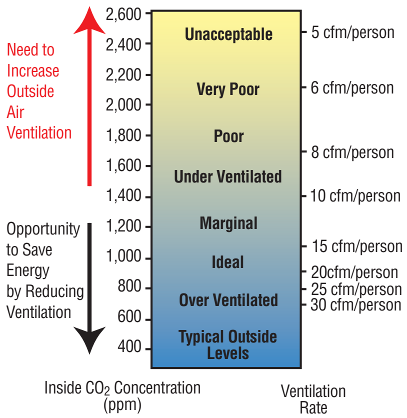
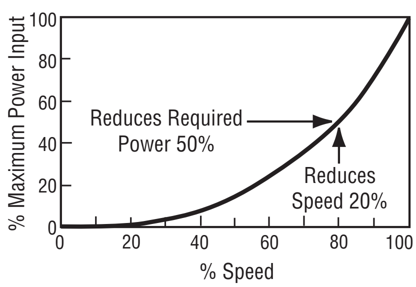


Diagram: TelAir, Goleta, CA

Conditions of Indoor Air Quality

Carbon dioxide concentration is a factor in determining adequate indoor air quality.



Graphic: Padia Consulting

VAV Fan Speed vs Input Power

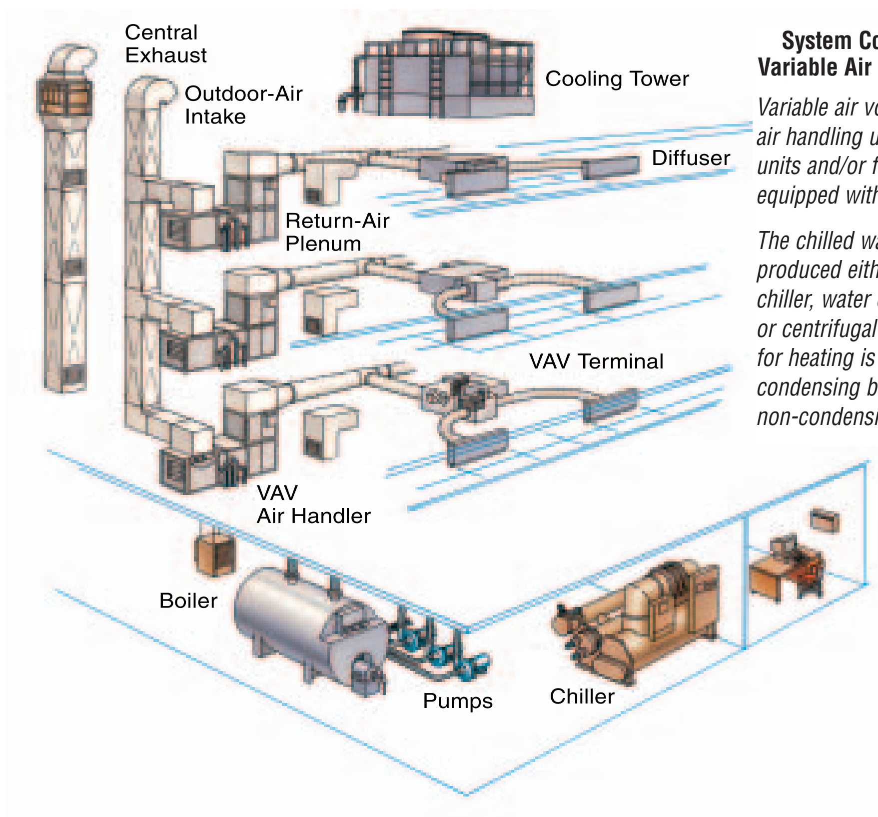
Controlling motor speed to control air flow is the more energy-efficient strategy. Variable frequency drive control offers a distinct advantage over other forms of air volume control in variable air volume systems.

- Evaluate the use of an outdoor air economizer cycle that will allow up to 100% outdoor air to be introduced into the distribution system to provide space cooling.
- Locate outdoor air intakes a minimum of 7 feet vertically and 25 feet horizontally from polluted and/or overheated exhaust (e.g., cooling towers, loading docks, fume hoods, and chemical storage areas). Consider other potential sources of contaminants, such as lawn maintenance. Separate vehicle traffic and parking a minimum of 50 feet from outdoor air inlets or spaces employing natural ventilation strategies. Create landscaping buffers between high traffic areas and building intakes or natural ventilation openings.
- Locate exhaust outlets at a minimum of 10 feet above ground level and away from doors, occupied areas, and operable windows. The preferred location for exhaust outlets is at roof level projecting upward or horizontally away from outdoor intakes.
- Provide filters capable of 60% or greater dust spot efficiency, and install them in a location capable of intercepting all make-up and return air. In dusty areas, use a higher efficiency filtration system (80%–85% by ASHRAE standards with 30% efficient pre-filters).

Distribution Systems

Design an air distribution system that is energy-efficient and protects against poor indoor air quality.

- Where individual room control is desired or diverse loads are present, employ variable air volume systems (versus constant air systems) to capitalize on reduced fan loads during times of reduced demand.



System Control Schematic — Variable Air Volume (VAV) System

Variable air volume (VAV) central air handling units with VAV terminal units and/or fan powered boxes equipped with hot water reheat coil.

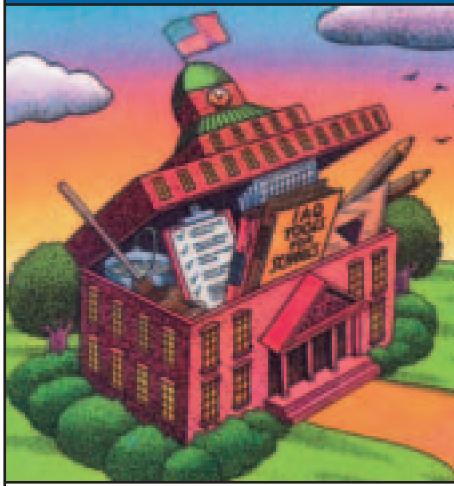
The chilled water for cooling is produced either by an air cooled chiller, water cooled screw chiller, or centrifugal chiller. The hot water for heating is provided either by a condensing boiler or a conventional non-condensing boiler.

- Use constant volume systems when the load is uniform and predictable (e.g., kitchen).
- If a particular mechanical system serves more than one space, ensure that each space served has the same orientation and fulfills a similar function. Consider independent mechanical rooms and systems on separate floors to reduce ductwork and enhance the balance of air delivered.
- Consider a design that supplies air at lower temperatures to reduce airflow requirements and fan energy.
- Specify ductwork that has smooth interior surfaces and transitions to minimize the collection of microbial growth. Design ductwork and plenums to minimize the accumulation of dirt and moisture and to provide access areas in key locations for inspection, maintenance, and cleaning. Use mastic to seal metal ductwork. Where possible, locate ductwork in conditioned or semi-conditioned spaces.
- Specify duct leakage tests.
- Make sure that air handling units and filters are easy to access and maintain.
- Reduce duct pressures to minimize the amount of fan energy used to distribute the air. Use low-velocity coils and filters.
- To minimize energy consumption, select fans for the highest operating efficiency at predominant operating conditions, and use lower fan speeds to reduce noise levels. Consider direct-drive fans for their improved efficiency.
- Use filters that meet a minimum of 60% ASHRAE Dust Spot Method Standards.

Controls

To ensure proper, energy-efficient operation, implement a control strategy that is tied to key energy systems. Include system optimization, dynamic system control, integrated lighting, and HVAC control.

- Use direct digital control systems for greater accuracy, performance, and energy savings.
- Set up the HVAC control system to operate according to need. Limit electrical demand during peak hours by turning off (or rotating) non-essential equipment.
- Establish temperature and humidity set points based on occupancy patterns, scheduling, and outside climatic conditions.
- Install occupancy sensors to reduce ventilation air requirements for unoccupied spaces.
- Make owners aware that they should periodically verify the accuracy of the sensors and control functions and calibrate if necessary.
- Notify owners of the need to periodically audit all computer-controlled HVAC systems to verify performance and calibration.



Indoor Air Quality: Tools for Schools

This program is designed to give schools the information and skills they need to manage air quality in a low-cost, practical manner. The kit is published by the US EPA and co-sponsored by the American Lung Association.

Control strategies like occupancy and pollutant sensors are essential to improve efficiency in the school's energy system management.

Photo: NREL/PIX09214

An energy management system optimizes mechanical and lighting system operation.

- Install sensors for relative humidity and temperature as close to occupants as possible. Carbon dioxide concentration sensors may be a helpful addition to a properly designed and maintained ventilation system.
- If using VAV systems, set supply-air temperature reset controls based on occupancy of space. Specify VAV controls to ensure that the proper amount of outdoor air is maintained, even when the total air supply is decreased.
- Control strategies for chilled water plant operation should address:
  - variable speed drives
  - the selection of modular chillers or chillers with multiple compressors
  - a chilled water reset
  - variable flow through the chillers
  - a condenser water reset
  - chiller sequencing
  - the soft-starting of chiller motors
  - demand control.
- In small schools, consider time clocks with night and weekend setbacks.
- Work with the school system to establish a means to monitor and document the performance of the energy management control system and provide training of future maintenance staff.

Hot and Chilled Water Distribution

- Carefully select heat exchangers with a low approach temperature and reduced pressure drops.
- In large systems with multiple heat exchangers, designate a separate pump for each heat exchanger to maintain high efficiency at part-load operating conditions.
- Consider primary pumping systems with variable-speed drives because of their effects on a part-load energy use.

Water Heating

- Consider heat pump water heaters or tankless (instantaneous) water heaters.
- Consider localized versus centralized hot water equipment by evaluating the types of loads served. A remote location may be best served by localized equipment.
- Consider a solar-assisted hot water system.
- Consider heat recovery systems.
- Use tankless water heaters in areas that are remote and require small hot water amounts.
- Minimize the standby heat losses from hot water distribution piping and hot water storage tanks by increasing insulation levels, using anti-convection valves, and using heat traps.

Renewable Energy Systems

There is no shortage of renewable energy. And renewable energy can contribute to reduced energy costs and reduced air pollution. More importantly, the renewable energy systems that you design into your school will demonstrate to the students the technologies that will fuel the 21st century.

Over the past two decades, the cost of renewable energy systems has dropped dramatically. Wind turbines can now produce electricity at less than 4 cents per kilowatt-hour — a seven-fold reduction in energy cost. Concentrating solar technologies and photovoltaics have dropped more than three-fold during the past 20 years. And, with improvements in analytical tools, passive solar and daylighting technologies can be implemented into schools with less than a two-year return on investment.

Incorporating renewable energy options into your school design helps students learn firsthand about these cost-effective and energy-efficient options. Input from teachers early in the design process helps to ensure that energy features are incorporated in a way that optimizes the learning experience. Buildings that teach offer students an intriguing, interactive way to learn about relevant topics like energy and the environment.

Photo: Glen Bair, by State of Texas Energy Conservation Office

Photovoltaic-powered school zone warning signals can be used as an alternative to traditional electric traffic signals.

Photo: NREL/PIX06461

Nantucket Elementary School, in Nantucket Island, MA, features a roof-mounted photovoltaic array that saves energy and serves as a teaching tool.

Photo: American Wind Energy Association

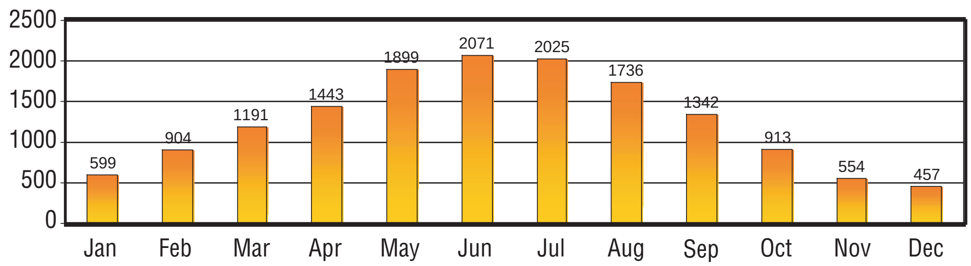
The wind turbine at Spirit Lake Elementary, in Spirit Lake, IA, saves the school $25,000 annually.

Design Guidelines for Renewable Energy Systems

Available Renewable Energy Resources

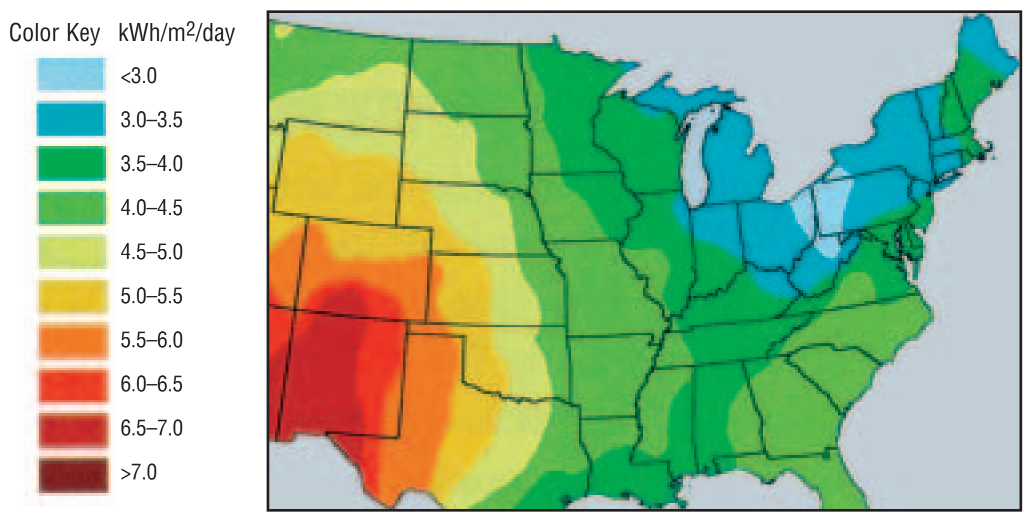
When evaluating potential renewable systems, use the best available historic climatic data, closest to the school site.

- Even though the radiation levels in cold and humid climates are lower than in most parts of the country, you should still evaluate the potential for solar systems. The following data show that the region's solar resource is good, but state specific information can be obtained from the State Energy Alternatives Web site.



Average Incident Solar Radiation in Minneapolis (Btus/Square Foot/Day)

NOTE: Watts/Square Meter x .317 = Btus/Square Foot

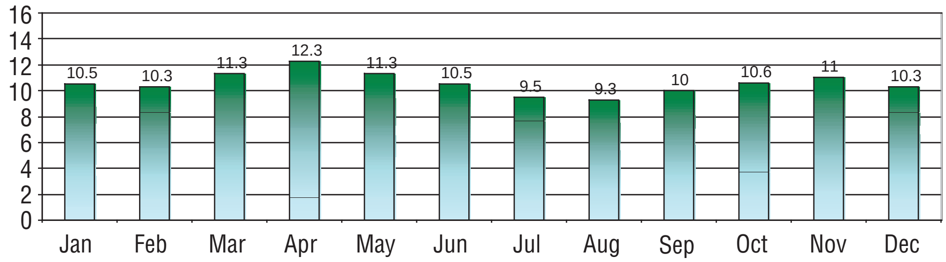


Average Direct Normal Radiation (kWh/Square Meter/Day)

- Wind generation becomes cost-effective in most areas when the average wind speed exceeds 10 miles per hour. In locations where the wind is marginally below this amount, wind systems should still be considered for their educational values.

Like in Minneapolis, wind in much of this region annually exceeds 10 miles per hour and is very good for wind applications.

Check the US DOE's State Energy Alternatives Web site (see the resources section at the end of this document) to determine the wind resources in your location.



Annual Mean Wind Speed (MPH)

Photo: NREL/PIX08884

This building-integrated photovoltaic system covers the roof of this school's cafeteria.

Building Orientation and Solar Access

Employing renewable energy strategies cost effectively requires the school to be sited to maximize the locally available natural resources.

- Establish the building on an east-west axis that maximizes southern exposure for daylighting and other solar systems. In Minneapolis, true north is 1°42' east of magnetic north (magnetic north is the direction a compass points).
- Ensure that adjacent buildings or trees do not block the intended solar access.

Building-Integrated Approaches

To maximize cost effectiveness and improve aesthetics, consider integrating solar thermal and photovoltaic systems into the building shell.

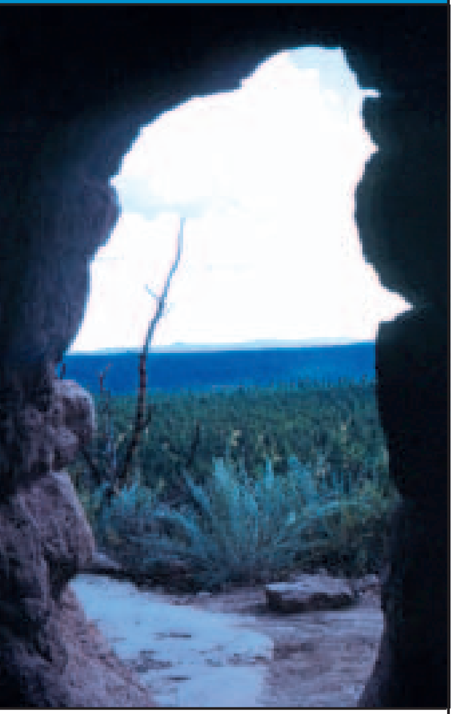
- Integrate solar systems into the overall design to allow the system to serve multiple purposes (e.g, a photovoltaic array that can also serve as a covered walkway).
- Eliminate the additional costs associated with a typical solar system's structure by designing the building's roof assembly to also support the solar components.
- Minimize redundant materials by using the glazing of the solar collector as the waterproofing skin of the building.
- Incorporate building-integrated approaches as a strategy to save valuable land.

Renewable Energy Applications for Schools

A variety of renewable energy applications are effective in cold and humid climates. Daylighting, passive cooling, solar hot water and space heating, photovoltaics, and wind should all be considered as energy-saving strategies that also help to teach students about energy technologies.

Daylighting

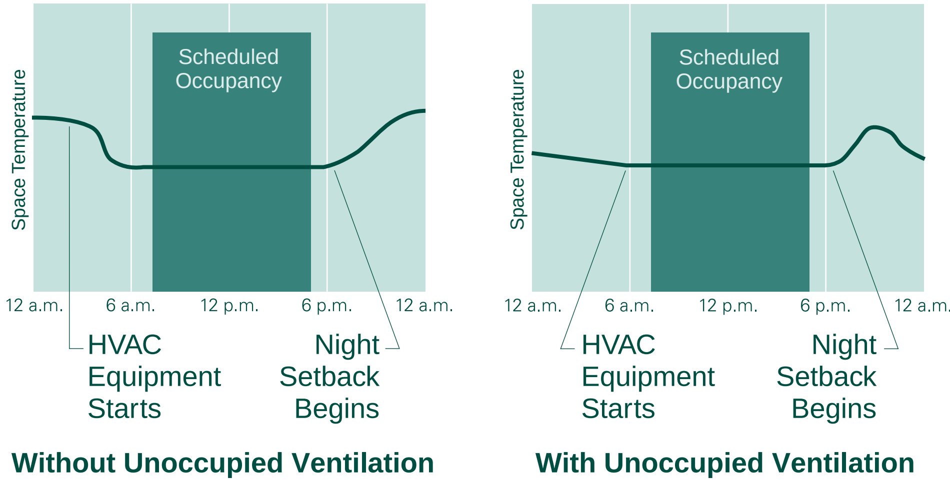
Because of the unique potential of this renewable energy option to provide multiple benefits, daylighting is discussed in a separate section within these guidelines. See the Daylighting and Windows section.



Massive walls have long been used to minimize the impact of midday sun.

Passive Cooling

- Natural ventilation should be viewed as a practical strategy for many of the warmer months of the year. Consider operable windows to provide the opportunity for natural ventilation when interior building loads dominate and the humidity is in acceptable ranges.



The Effect of Night Purging

Using night purging brings cool, outside nighttime air into the building to reduce HVAC startup loads.

- Incorporate night purging as a technique to improve performance. Using either natural, mechanical, or hybrid approaches to purge the air within a school can provide energy and indoor air quality benefits. When the ambient temperature during the nighttime drops several degrees or more below the set temperature, bringing outside air into the building and purging the warmer air can greatly reduce the cooling load on the building the next morning.

- Install massive wall construction to both reduce and stabilize cooling loads by including:
  - high-mass walls to increase the lag time of temperature flows
  - mass located inside the wall insulation to stabilize internal temperature fluctuation
  - light-colored exterior finishes to reflect solar radiation striking walls.

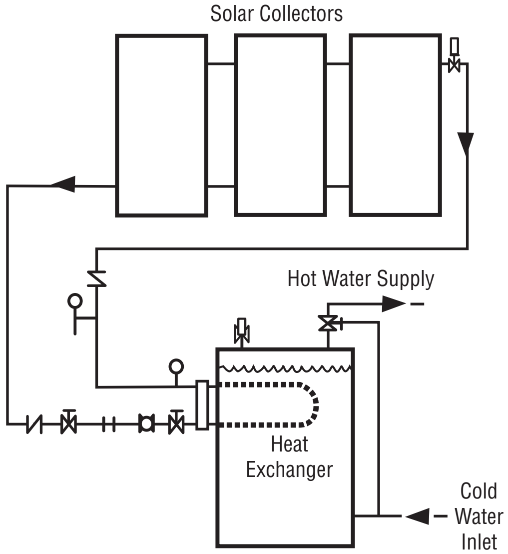
Solar Hot Water

Because of the high hot water demands associated with cafeterias, solar heating systems are often viewed as important strategies in reducing energy bills. In middle schools and high schools, with showers for gym classes and sports programs, it is even more beneficial to address this significant load.

Closed-Loop Systems

- Select a closed-loop, freeze-resistant solar system.

In closed-loop systems, a small pump circulates antifreeze-protected fluids through the collection loop when there is adequate solar radiation and the differential between the collector fluid temperature and the tank temperature justifies the collection mode continuing.



Closed-Loop Solar Hot Water System Diagram

Closed-loop systems use a controller to shut the system down when the temperature differential becomes too small or when the tank reaches a set peak temperature.

This solar domestic water system was added to the school's kitchen roof area and provides the majority of hot water required by the cafeteria.

Wind

Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used directly (e.g., water pumping), or it can be converted into electricity.

- Consider wind electric generators as a cost-effective application in areas where the sustained wind speed exceeds 10 miles per hour.
- Consider wind systems for well water pumping.
- Address potential noise problems by properly siting wind installations.
- Consider the educational benefits of installing a windmill or a wind generator on the school site.

Geothermal Heat Pumps

Geothermal heat pumps work differently than conventional air source heat pumps in that geothermal systems use the more moderately tempered ground as a heat source and heat sink. The result is that geothermal systems are more efficient and more comfortable.

- Use closed-loop systems in areas where well water is not present or adequate.
- Use open-loop systems in regions where sub-surface water can be extracted and reinjected into the ground, through wells, in an environmentally sound manner.
- Conduct a detailed site survey, and thoroughly analyze the heat gain and loss to avoid oversizing.
- Specify high-efficiency heat pumps.
- Avoid using excessive amounts of antifreeze.
- Specify thermally-fused, high-density polyethene (HDPE) for all in-ground piping.

Photovoltaics

Photovoltaic modules, which convert sunlight into electricity, have numerous school applications and can be designed as "stand-alone" applications or for utility "grid-connected" applications.

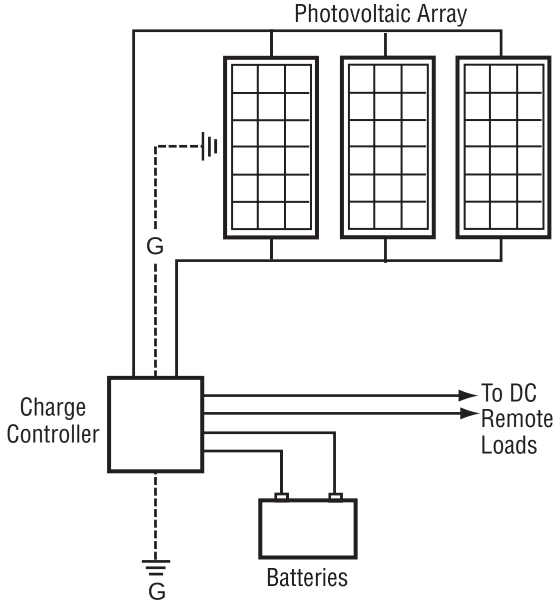
Photo: Advanced Energy

Geothermal systems have the added advantage of no outdoor condensing unit or cooling tower.

Stand-Alone Systems

- Select stand-alone photovoltaic systems to address small, remotely-located loads. They tend to be more cost-effective than the conventional approach requiring extensive underground wiring. Some of the more appropriate applications include parking and walkway lighting, caution lights at street crossings, security lights, emergency telephone call boxes, and remote signage.

Because these systems are not connected into the utility grid, battery storage is typically required. Depending upon the device being powered, a DC to AC inverter may or may not be installed.



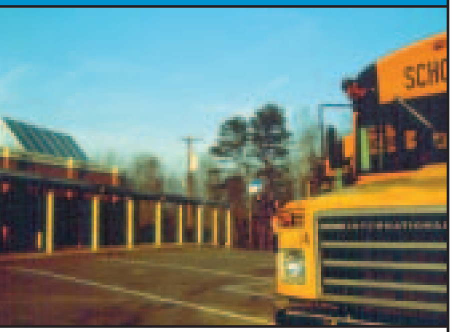
Stand-Alone Photovoltaic System

Stand-alone systems are ideal for remote loads located away from electrical lines.

These stand-alone photovoltaic systems power parking lights.

Photo: Bluffsview Middle School

Photovoltaic systems can be great teaching tools as well as energy savers.

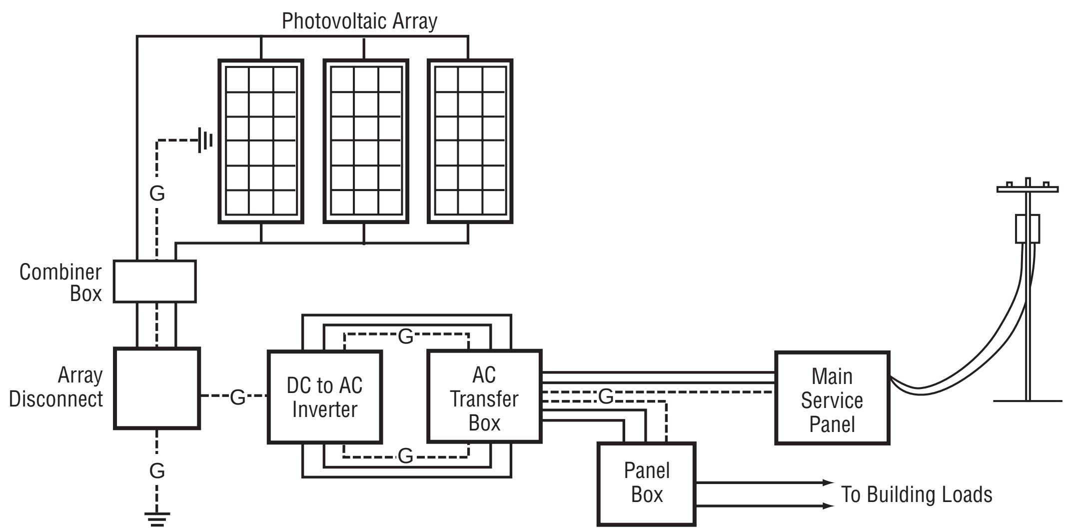


Photovoltaic systems in schools provide substantial energy savings and are educational tools for sustainability.

Grid-Connected Systems

- Choose grid-connected systems in large applications where peak load pricing is high or where first cost is an issue. Because these systems typically rely on the utility to provide power when the sun isn't shining, battery cost is eliminated and long-term maintenance is reduced greatly. This strategy is typically advantageous to both the utility and the school because peak demand will be occurring when the sun is shining.

In these applications, a DC to AC inverter is required. Additionally, in the event of a utility power failure, protection must be provided to ensure that the system does not feed back into the utility grid.



Grid-Connected Photovoltaic System Diagram

Grid-connected systems work well for large loads located near existing electrical service.

Water Conservation

Every day the United States withdraws 340 billion gallons of fresh water from streams, reservoirs, and wells — an amount equal to 1,000 gallons per person per day. And as the population grows, so does that demand for water. Combine the impacts of rising population with the demographic shift in people to more arid regions, and the pressure of providing clean water becomes more critical every year.

Water rationing is becoming commonplace in thousands of communities across the country, and the price of water is escalating at unprecedented rates. You can make a considerable difference at your school in reducing community water use. By using water-conserving fixtures, implementing graywater or rainwater catchment systems, and using xeriscape practices, schools can easily reduce their municipal water consumption 25%–75%. By saving half of the 1 million to 3 million gallons that each of the 90,000 public schools consume every year, more than 200 million gallons of treated water could be saved each day.

Many areas of the United States have resorted to piping or developing canals to move water from one region to another.

Photo: NREL/PIX00653

This water-conserving sink uses infrared sensors.

The Roy Lee Walker School, in McKinney, TX, collects 700,000 gallons of rainwater each year for toilet flushing and site irrigation.

A water gauge that measures the rainwater collection tank level helps demonstrate the value of water to students.

Design Guidelines for Conserving Water

Water-Conserving Landscaping Strategies

The demand for water will be greatly impacted by the amount of site irrigation required. By limiting new landscaped areas and considering the type of plants and vegetation installed, water needs will be reduced.

- Minimize disruption to the existing site conditions, and retain as much existing vegetation as is practical.
- Incorporate native and drought-resistant plants and xeriscape principles to minimize irrigation requirements.
- Use soaker hoses and drip irrigation technologies to minimize evaporative losses and concentrate water on plants.
- Provide timers on watering systems to ensure that irrigation occurs during the night.

Water needs for irrigation can be minimized by using native planting.

Conservation of Water During Construction

By including specifications addressing water during construction, you can save a considerable amount of water during your construction projects.

- Include disincentives in specifications to the general contractor for excessive water use and incentives for reducing consumption during construction.
- Specify that the general contractor is responsible for water cost during construction.
- Minimize watering requirements by specifying appropriate times of year when new landscaping efforts should occur.
- At pre-bid meetings, stress to the general contractor and sub-contractors the importance of water conservation.

Water-Conserving Fixtures

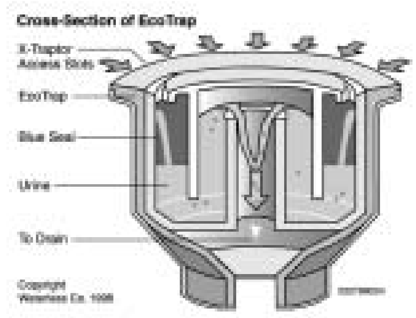
One of the most effective means to limit demand for water is to reduce the requirements associated with necessary plumbing fixtures.

- Consider the standards of the 1992 Energy Policy Act as a minimum. Specify low-flow toilets that use less than 1.6 gallons per flush.
- Consider showerheads that require less than 2.5 gallons per minute and incorporate levers for reducing flow between 2.1 and 1.5 gallons per minute.
- Use aerators to reduce flow in lavatory faucets to as low as 1 gallon per minute.
- Specify self-closing, slow-closing, or electronic faucets where it is likely that faucets may be left running in student bathrooms.
- Consider waterless urinals or 1-gallon-per-flush urinals.

Projected Water Savings by Installing Waterless Urinals in Schools

	School with Regular Urinals	School with Waterless Urinals
Number of Males	300	300
Number of Urinals	10	10
Use/Day/Male	2	2
Gallon/Flush	3	0
School Days/Year	185	185
Water Saved/Year		222,000 Gallons

Waterless urinals are one way to reduce water usage in your school.



Waterless Urinals

With waterless urinals, the traditional water-filled trap drain is eliminated, and the unit does not need to be flushed.

Photo: Darrow School

At the Samson Environmental Center of Darrow School, New Lebanon, NY, the Living Machine is used to teach students about on-site biological wastewater treatment systems. This garden uses large tropical plants to create a refuge for the microorganisms that break down nutrients and chemicals in the water and releases water that is treated to tertiary or, if desired, drinking water quality.

Biological wastewater treatment systems, like this living machine, can transform "waste" into a resource that can be used to improve soil conditions on the site, save water, reduce the need for municipal treatment infrastructure, and address problems directly associated with septic system technologies.

Roy Lee Walker Elementary School, in McKinney, TX, collects 700,000 gallons of rainwater each year.

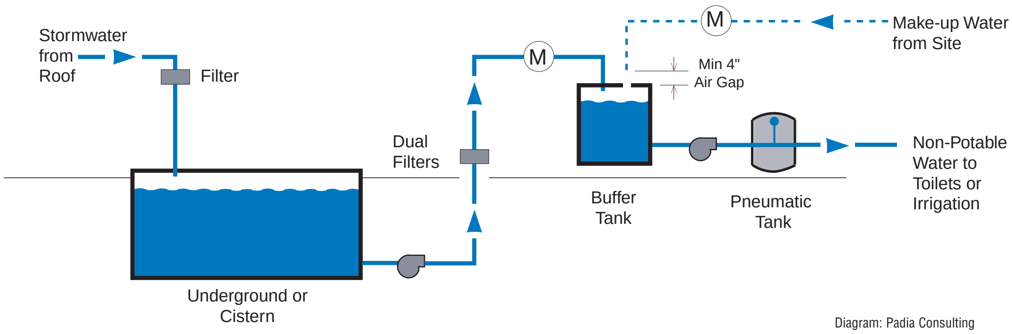
Rainwater Management

Rainwater captured off the roof of your school can be harvested and stored in cisterns for non-potable use. In most rainwater catchment systems, the water runs off the roof into gutters and downspouts, which carry the water to a storage device for future use.

- Consider the savings made possible by a reduced need for retention ponds.
- When cost-effective, implement a rainwater collection system to provide water for toilet flushing and irrigation through separate plumbing lines.
- Use a durable storage container, and locate it away from direct sunlight and septic tanks.
- Design systems so that potable water can be safely added to storage tanks, and guarantee an uninterruptible supply to toilets and irrigation systems.
- Determine the necessary water treatment and filters for your area.
- Install a storage tank underground to minimize freeze problems.

Rainwater Catchment Diagram

The initial water collected off the roof is intentionally "dumped" in order to reduce filtration of large particles. A low flow pump and chlorinator are used to stop algae growth. Make-up water, from your typical potable supply, is added to the tank when rainfall is insufficient.



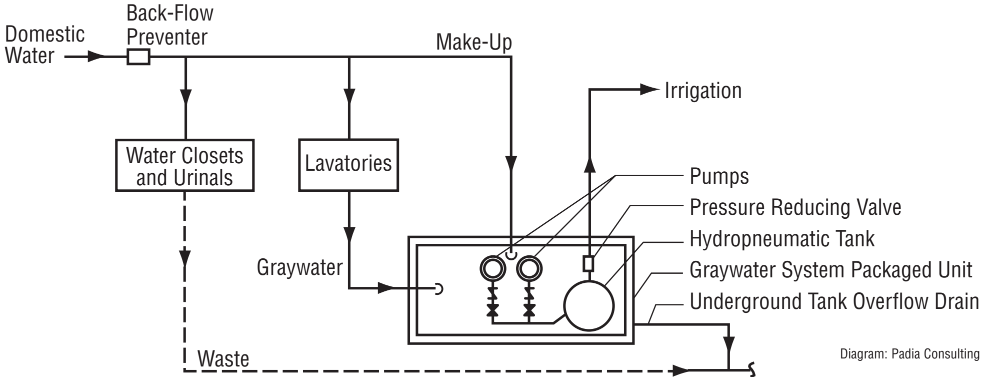
Graywater Systems

Relatively uncontaminated waste can be easily captured, stored, and used to fulfill non-potable needs.

- Use graywater from lavatories and water fountains for underground site irrigation. Design the system, meeting local regulations, to:
  - get the graywater into the soil as soon as possible instead of storing it
  - irrigate below the surface of the ground only
  - deliver the graywater to biologically activate the soil where organic matter will quickly be broken down.

Graywater System Diagram

Graywater collects through a separate plumbing system and is treated and stored in an underground tank. The graywater is then pumped into a second hydropneumatic tank that maintains the proper system pressure. When necessary, additional fresh water is brought into the graywater storage tank to maintain the minimum level needed for the circulation pumps.



Recycling Systems and Waste Management

Public schools across the country are producing billions of pounds of municipal solid waste each year. You can help reduce much of this waste by recycling or composting at your schools. In a compilation of studies of waste generation in Washington State and New York City schools reported by the US EPA, paper was found to account for up to half of waste in schools, organic (compostable) materials up to a third, plastic about 10%, and glass and metals about 7%. To the extent that school buildings can be made more recycling and composting friendly, very high percentages of this waste material can be kept out of the waste stream. In fact, if every school system implemented aggressive recycling efforts, landfills would have 1.5 billion pounds less solid waste each year.

By creating schools in which comprehensive waste recycling can be carried out, your design team has an opportunity to instill the practice of recycling in your school's children. Hundreds of schools throughout the country have embarked on exciting and highly successful hands-on programs to encourage recycling. Often, the students themselves design and manage these programs — and see the fruits of their labors as waste reduction or recycling is quantified. The most successful recycling and waste management programs are integrated into classes, with students making use of mathematical, investigative, and communication skills in implementing these programs.

For efficient recycling collection, the recycling bins must be labeled and located in areas easily accessible by students and staff.

Photo: Chittenden Solid Waste District

Michael Kellogg, waste reduction specialist for the Chittenden Solid Waste District, VT, educates students from the Calliope House of Allen Brook School in Williston about the system used to code types of plastics.

Photo: Huntsville High School East

Signage can encourage students and staff to actively recycle major waste materials in the school.

Photo: Mount Baker School District

In Deming, WA, the Mount Baker School District's recycling effort is in its eighth year and is now saving $25,000 annually. Successful because of its outstanding student participation, the award-winning program has a long list of recyclable or reusable materials. The program is totally self-supporting, and last year the students saved $18,000 through recycling and reuse and an additional $7,000 from avoided disposal fees. In 1999, through the school's efforts, 89,700 pounds of materials were recycled or reused and not put into a landfill.

Design Guidelines for Implementing Recycling Systems and Waste Management

Paper, Plastics, Glass, and Aluminum Recycling

Students are able and eager to participate in recycling programs. Successful recycling programs teach students recycling skills and save money through reuse of materials and avoided disposal fees.

Paper represents one of the largest components of a school's waste stream. In addition to glass, aluminum, plastic bottles, and cans, even styrofoam can now be recycled.

- Allocate space within each classroom, the main administrative areas, and the cafeteria for white and mixed paper waste.
- Provide central collection points for paper and cardboard that are convenient to custodial staff as well as collection agencies or companies.
- Place the receptacles for all recyclables where the waste is generated. The best places are in the cafeteria and administrative areas. Receptacles should be made available in public spaces, gymnasiums, and hallways for plastic and aluminum in schools with soda machines.
- Locate convenient bins for other materials being recycled.

In implementing a comprehensive approach to recycling, consider all the aspects needed to make recycling easier and more educational.

- Integrate containers into cabinetry, or have free-standing stations that do not disrupt other functions in the spaces.
- Design bins to be easily dumped into a cart that will be taken by custodial staff to a central collection point.
- Incorporate chutes to accommodate recycling in multi-story facilities.
- Establish a color coding system, and use clearly labeled dispersed containers and centralized bins to distinguish the recycled material.
- Use dispersed receptacles and centralized bins that are easy to clean and maintain.
- Coordinate with a local recycling agency or waste hauler to obtain important information regarding its trucks and how it prefers to access the recycling bins.

Safe Disposal of Hazardous Waste

- Provide a secure space within the school to temporarily store hazardous materials (e.g., batteries, fluorescent lights, medical waste) until they can be taken to a recycling center or safe disposal site.

Composting

About a third of the average school's waste stream is food and other organic materials. Composting is one environmentally friendly way of handling this waste.

- Design a conveniently located composting bin.
- Use vermicompost bins in classrooms as educational tools. The bins use worms to dramatically speed up the decomposition of food.

Composted kitchen scraps can be used to fertilize gardens at the school.

Photo: Chittenden Solid Waste District

Michael Kellogg, waste reduction specialist for the Chittenden Solid Waste District, VT, teaches students from Calliope House of Allen Brook School in Williston how worms can compost their food scraps.

Photo: NREL/PIX05289

Recycling by the contractor during construction should be encouraged to decrease the amount of waste sent to landfills.

Construction Waste Recycling and Waste Management

Recycling efforts should begin during the construction of the school and engage the general contractor and all sub-contractors.

- Specify the specific job-site wastes that will be recycled during construction (corrugated cardboard, all metals, clean wood waste, gypsum board, beverage containers, and clean fill material).
- Require that the contractor have a waste management plan that involves everyone on the site.
- Stockpile appropriate existing topsoil and rock for future ground cover.
- Monitor the contractor and sub-contractor's recycling efforts during construction.

To minimize the impacts from any hazardous materials or waste used in construction, require that the contractor use safe handling, storage, and control procedures, and specify that the procedures minimize waste.

Photo: Craig Miller Productions and DOE/PIX03494

Construction waste materials, including corrugated cardboard, metals, clean wood waste, gypsum board, and clean fill material like concrete or brick can be recycled or reused.

Transportation

In many school districts across the country, more energy dollars are spent by the school system in transporting students to and from school than in meeting the energy needs of their school buildings. Up to 40% of morning traffic congestion at schools is a result of parents driving children to school.

Incorporating a network of safe walkways and bike paths that connect into the community's sidewalks and greenways can reduce local traffic congestion, minimize busing costs, and reduce air pollution. And, by incorporating natural gas, biodiesel, methanol, or solar electric buses into a district's existing vehicle fleet, you can help to reduce fuel costs and harmful emissions — lowering fuel costs and contributing to reduced operating and maintenance costs.

Today, nearly 60% of all school buses run on diesel, a highly polluting transportation fuel that poses considerable health risks. Due to particulate emissions, the use of diesel fuel is increasingly becoming associated with asthma and other lung-related diseases. Alternative fuel buses and school fleet vehicles can be used to provide environmentally friendly alternatives to high-polluting vehicles. Options for alternative fuel buses include electric, hybrid electric, compressed natural gas, ethanol, and biodiesel — all of which are available today. In addition to long-term energy savings, these vehicles serve as great educational tools for the students and the community. The US DOE's Clean Cities Program can help you determine the best alternative fuel vehicles for your fleet.

Driving students one at a time to school each day is responsible for 0.5–3.3 tons of carbon dioxide per student being emitted into the air each year. Providing safe pedestrian walkways throughout the surrounding neighborhood allows students who attend a school in their community to walk, reducing busing and single car traffic.

The design team, developers, and local planning departments must work in close collaboration to maximize the pedestrian access to the school site from the community.

Design Guidelines for Integrating Transportation Considerations into School Design

Connecting the School to the Community

One of the measures of success of a school is the degree to which the school is a vital part of the community. If addressed early in the site selection and design phase, a school can be planned to serve not just the students but also the entire community.

- Design the school so that the athletic fields, gymnasium, media center, and classrooms are accessible and can be shared at appropriate times with the community.
- Provide good access to public transit.
- Through good site design, link the school to the surrounding communities through safe bicycle routes, pedestrian pathways, and greenways.
- Incorporate convenient bicycle parking at the school to discourage single car traffic.

In areas of the country experiencing growth, more schools are being built in conjunction with the construction of large subdivisions by local developers. This situation offers the school system and the community an excellent opportunity to coordinate with developers in making the school a more integral part of the community.

- Work with the developer to implement new, safe walkways and bike paths that link the neighborhood to the school.
- Develop a master plan with the community so that the main pedestrian ways to the site do not cross over busy roads. Or, if that cannot be avoided, provide safe and handicap-accessible pedestrian overpasses or underpasses.
- Develop recreational facilities that can be shared with the school.

Photo: Northwest Landing

With the tremendous amount of fuel currently consumed in transporting students, and the resulting pollution, it is critical to locate schools in a manner that minimizes vehicular transportation and maximizes the potential for pedestrian access. This master plan encourages walking instead of driving. Homes are, on average, a 10–15 minute walk from schools. Connecting school sites into the community's walkway system greatly decreases busing and car drop-offs and, in turn, reduces localized air pollution.

Walkways and Bike Paths

Safe walkways and bike paths that link the school to the sidewalks and greenways of the surrounding communities offer an easy solution to many of the school's budgetary problems and the community's air pollution and traffic problems. During the early planning of the school, the design team should work with the adjacent developers and local planning officials in implementing strategies to enhance safe pedestrian paths connecting the school and the community.

- If sidewalks provide the main pedestrian access to the school, encourage the developer and/or local planning department to separate them a safe distance from the road.
- Use walkway surfacing materials that are appropriate for handicap access.
- Provide separate bike paths.
- Incorporate caution lights throughout the community to warn drivers of the likelihood of student pedestrian travel.
- Provide controllable crossing lights at the intersections of student pedestrian paths and roadways.
- Provide underpasses or overpasses at the intersection of high-traffic roads and main pedestrian paths.
- On school property, minimize potential conflicts by separating students and vehicular pathways.

High-Efficiency and Low-Emission Vehicles

In addition to incorporating safe and traffic-reducing elements into your site design, consider the use of high-efficiency and low-emission vehicles in your fleet. Electric vehicles, hybrid electric vehicles, and vehicles using alternative fuels like ethanol and compressed natural gas are cost-effective and proven options.

Electric Vehicles

Although a school bus can be powered by pure electricity, only a few electric school bus options are available today. However, small maintenance carts and other vehicles that are used by school officials and staff can easily use electricity as a fuel. Electric vehicles typically have limited ranges, so they are great for short trips and stop-and-go driving. Electric vehicles reduce local pollution, but unless they are charged with renewable energy, they are still a source of regional pollution.

These charging areas can be viewable by students to assist with teaching about renewable energy and can include displays to indicate to students the contribution that the station is providing.

- To ensure availability, the school or school system should provide a charging station for electric vehicles.

CLEAN CITIES PROGRAM

The Clean Cities Program, sponsored by the US DOE, supports public-private partnerships that help get alternative fuel vehicles into the market and build supporting infrastructure.

Unlike traditional command and control programs, the Clean Cities Program takes a unique, voluntary approach to alternative fuel vehicle development, working with coalitions of local stakeholders to help develop the industry and integrate this development into larger planning processes.

Currently there are 80 Clean Cities coalitions dedicated to getting alternative fuel vehicles on the road. The Clean Cities Program helps educate fleets across the country on which AFVs and fuel types are right for each fleet. Coalitions also assist fleets with understanding incentives and legislation related to AFVs. More information on the Clean Cities Program can be found in the resources section at the end of this document.

Photo: Medford Township Board of Education

Medford Township Schools, in Medford, NJ, converted 22 of their school buses to run on a fuel consisting of 20% soy bean-derived biodiesel. According to Joe Biluck, director of operations for the school system, their goal of reducing pollution has been achieved. Particulate emissions have been reduced by 35%–40%.

Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) have the same power as conventional vehicles and do not have the reduced driving range that electric vehicles have. There are several options for HEV buses available today, and there are two HEV automobiles that can be used as school fleet vehicles. HEVs can be produced in a variety of ways, but typically the battery pack helps supplement the vehicle's power when accelerating and hill climbing. During stop-and-go driving, both the traditional gasoline engine and batteries work together. For extended highway driving, the engine does most of the work because that is when it is operating most efficiently.

Ethanol

Ethanol is typically produced from domestic-grown, plant-based materials such as corn or other grains. Ethanol buses and vehicles are good options for school districts because several vehicle choices are available. Ethanol fuel can be found at fueling stations across the country; however, some areas have more stations than others. Vehicles using ethanol as a fuel perform as well as typical conventional vehicles. Under current conditions, the use of ethanol-blended fuels such as E85 (85% ethanol and 15% gasoline) can reduce the net emissions of greenhouse gases by as much as 37%.

- To ensure availability, the school or school system should provide a storage tank for ethanol fuel.

Compressed Natural Gas Vehicles

Compressed natural gas (CNG) vehicles operate like any conventional vehicles. Drivers can't tell the difference in performance. CNG buses are being used by many schools districts across the nation. CNG is a great option for schools because the vehicles are readily available and the fuel is considerably less expensive than gasoline. There are also several CNG sedans and trucks that are produced by auto manufacturers and that would be good options for use in school fleets. Exhaust emissions from NGVs are much lower than those from gasoline powered vehicles.

- To ensure availability, the school system should provide a CNG fueling station.

Photo: NREL/PIX04152

This school bus looks and operates like a standard diesel bus but runs on compressed natural gas.

Resource-Efficient Building Products

A school, like any building, is only as good as the sum of the materials and products from which it is made. To create a high performance school, your design team must choose the most appropriate materials and components and combine these components effectively through good design and construction practices.

Typically, architects and engineers primarily consider the performance of materials and components in terms of how they serve their intended function in the building. While it is appropriate that material function be a top consideration, your design team should also consider the materials from a broader environmental perspective. For example, indoor air quality can be improved by eliminating or minimizing volatile organic compounds in paints, carpet, and adhesives and by minimizing formaldehyde in plywood, particleboard, composite doors, and cabinets.

The best resource-efficient products and systems not only contribute to improving the indoor air quality, energy efficiency, and durability of a school, but they also help reduce harm to the natural environment by minimizing use of limited resources and promoting reuse and recycling.

Photo: NREL/PIX03049

Photo: NREL/PIX03050

True linoleum, unlike vinyl flooring, is made from wood flour, cork, and linseed oil. It gets harder over time, and makes for an attractive, durable surface.

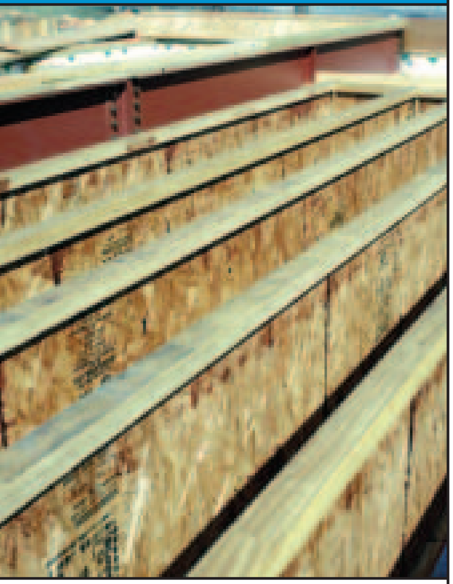
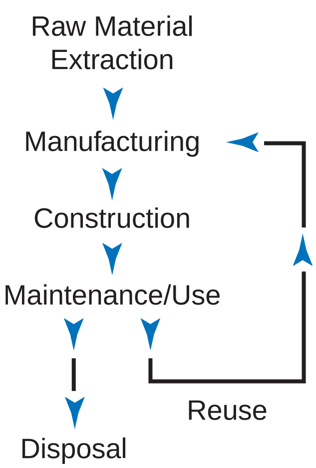


Photo: NREL/PIX02213

These ceiling beams are made from recycled wood products.



Life-Cycle Analysis

The life cycle of a building product can have significant environmental implications.

Design Guidelines for Resource-Efficient Building Products

The Life-Cycle Approach

To select environmentally preferable products, it is necessary to consider environmental impacts from all phases in the product's life cycle. This approach is called life-cycle analysis. A product's life cycle can be divided into the following phases:

– raw material extraction

– manufacturing

– construction

– maintenance/use

– reuse or disposal.

Environmentally important impacts associated with the transportation of raw materials and finished products are included with each of these phases.

Unlike many consumer products, in which the "use" phase is very short (a soft-drink bottle, for example), building materials are typically in place for a relatively long time. As a result, if there are ongoing environmental impacts associated with the use phase, these often outweigh those from other phases.

The following is a list of key issues to consider at each phase of the life cycle and some examples of products that have environmental advantages.

Phase 1: Raw Material Extraction

Building materials are all made from resources that are either mined from the earth or harvested from its surface. The most common materials are sand and stone to make concrete, clay for bricks, trees for wood products, and petroleum for plastics and other petrochemical-based products.

- Eliminate component materials from rare or endangered resources.
- Determine if there are significant ecological impacts from the process of mining or harvesting the raw materials.
- Specify that wood products must be harvested from well-managed forests. Require that suppliers show proof of credible third-party verification of environmentally sound harvesting methods.
- Determine the origin of the primary raw materials, and select options closer to the site, requiring less shipping.

Photo: NREL/PIX03048

Cork is harvested from the cork oak. The bark can be removed from the tree about every 9 years without adversely affecting the tree. Cork is used to make cork and linoleum flooring.

Photo: NREL/PIX03041

This environmentally sound, no-VOC carpet line is leased and maintained by the manufacturer, which reduces waste by recycling and reusing the carpet tiles. The up-front and maintenance costs are lower, and the environmental and health benefits are substantial.

Photo: NREL/PIX03043

Choose carpet backings with low or no formaldehyde to avoid indoor air contamination.

Phase 2: Manufacturing

Manufacturing operations can vary considerably in their impact on the environment. The manufacturer of one product may rely on numerous out-sourcing operations at separate locations or obtain raw materials from another country. Another, less energy-intensive product may be produced in a single, well-integrated operation at one site with raw materials and components coming from nearby locations. Likewise, a particular manufacturer may use a process that relies on toxic chemicals while a competing manufacturer may incorporate environmentally friendly technologies to accomplish the same end.

- Determine if the manufacturing process results in significant toxic or hazardous intermediaries or byproducts. Most petrochemical-based processes involve some hazardous ingredients, so plastics should be used only when they offer significant performance advantages.
- Specify products that are made from recycled materials.
- Select products that are made from low-intensity energy processes. The manufacture of some materials, such as aluminum and plastics, requires a lot of energy while the "embodied energy" to make other materials is considerably less.
- Select products manufactured at facilities that use renewable energy.
- Consider the quantity of waste generated in the manufacturing process and the amount that is not readily usable for other purposes.

Phase 3: Construction

To a great degree, the energy and environmental impacts of products and materials are determined by the way they are implemented.

- Avoid products containing pollutants by:
  - excluding high volatile organic compound paints (VOC), carpets, and adhesives
  - not incorporating products with excessive formaldehyde
  - using the least toxic termite and insect control.
- When pesticide treatments are required, bait-type systems should always be preferred over widespread chemical spraying and soil treatments.
- Separate materials that out-gas toxins (e.g., plywood with formaldehyde) or emit particulates (e.g., fiberglass insulation) with careful placement, encapsulation, or creating barriers.

Photo: BuildingGreen Inc.

Cement manufacturing is very energy intensive. The cement kiln is the largest piece of moving industrial machinery in common use, and temperatures inside it reach 2,700°F.

Photo: Barry Halkin Photography

Recycled tiles installed in school hallways and cafeterias require very low maintenance.

- Require the contractor to recycle construction materials.
- Ensure that unconventional products are installed properly.
- Require proper handling and storage of toxic materials at the job site.
- Require that the packaging of products, materials, and equipment delivered to the site be made of recyclable or reusable materials, and discourage unnecessary packaging.
- Ensure that product and material substitutions occurring during construction contain the same energy and environmental benefits.
- Avoid materials that are likely to adversely affect occupant health. Interior furnishings and finishes and mechanical systems all have the potential to affect the indoor air quality for better or worse. Material Safety Data Sheets (MSDS) can be a good source of information on the contents of various products.

Phase 4: Maintenance/Use

How easily building components can be maintained — as well as their impact on long-term energy, environmental, and health issues — is directly linked to the quality of the materials, products, and installation.

- Select materials, products, and equipment for their durability and maintenance characteristics. Particular attention should be paid to selecting roofing systems, wall surfaces, flooring, and sealants — components that will be subject to high wear-and-tear or exposure to the elements.
- Avoid products with short expected life spans (unless they are made from low-impact, renewable materials and are easily recycled) or products that require frequent maintenance procedures.
- Provide detailed guidance on any special maintenance or inspection requirements for unconventional materials or products.

Phase 5: Disposal or Reuse

Some surfaces in the school, such as carpets, may need to be replaced on a regular basis. The building as a whole will eventually be replaced or require a total renovation. To minimize the environmental impacts of these future activities, designers have to choose the right materials and use them wisely.

- Select materials that can be easily separated out for reuse or recycling after their useful life in the structure. Products that should be avoided include those that combine different materials (e.g., composites) or undergo fundamental chemical change during the manufacturing process.
- Avoid materials that become a toxic or hazardous waste problem at the end of their useful life. Preservative-treated wood, for example, contains highly toxic heavy metals that are contained within the wood for a time but will eventually be released when the wood decays or burns.

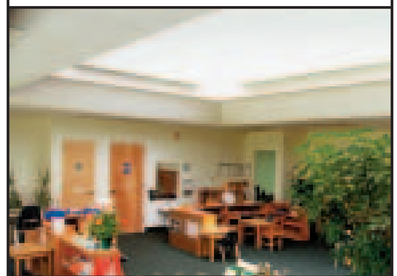
Checklist of Key Design Issues

The following checklist can be used by school designers, planners, and administrators when considering comprehensive high performance strategies for new and renovated schools.

The format follows each of the 10 design components and cross-references issues of critical importance for the school decisionmakers.

Legend

- ■ Critical Design Element
- □ Suggested Design Element



Checklist of Key Issues for Site Design

Site Design

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Take advantage of your site's natural resources by:						
– orienting the building to optimize solar access and daylighting	■		□	■	□	
– using vegetation and earth formations to your advantage.	■			■	□	
• Incorporate strategies to save water, such as the use of rainwater catchment systems and xeriscape landscaping principles.	■			■		■
• Retain and add site features that could become educational resources for teachers to incorporate into their instructional programs.		■	■	■		
• Include outdoor teaching and interpretive areas.		■	■	□		
• Provide diverse, natural environments for exploration.		■	■	□		
• Showcase local natural features.		■				
• Maximize the educational opportunities of the pedestrian pathways from residential areas to the school.		■	■			
• Provide the school with information on environmental design features.		■	■	□		
• Develop the site in a manner that protects the existing landscaping, ecosystems, and wildlife habitat.		□		□		□
• Employ energy-saving strategies, and use renewable energy to reduce air pollution.	■			■		■
• Create earth berms to provide sound barriers.			□		■	
• Develop on-site erosion control and stormwater management strategies.				■		■
• Connect the school's walkways and bike paths directly into greenways and sidewalks surrounding residential areas.	■			■	■	■
• Design the school as a part of the community by:						
– providing easy, safe pedestrian access to surrounding communities and mass transit	■			■		■
– allowing for shared recreational facilities.				■		■

Checklist of Key Issues for Daylighting and Windows

Daylighting and Windows

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Account for all the financial and environmental benefits associated with daylighting, including:						
– reduced electrical lighting and cooling	■			■	□	■
– decreased electrical service to the site	■			■		□
– less mechanical system maintenance	■			■		■
– fewer lamp replacements	■			■		■
– peak demand and equipment reductions caused by smaller lighting and cooling loads.	■			■		■
• Evaluate and avoid negative impacts associated with window treatments, placement, and types, including:						
– glare and direct beam radiation entering teaching and work spaces	□		■		■	
– excessive radiation in warmer months	■		■		■	
– comfort problems and unnecessary heat loss and gain due to the lack of thermal breaks, poorly insulated windows, and the choice of solar transmission values of glazing	■		■		■	
– maintenance.	■					
• Make daylighting strategies obvious to the students.	□	■		□		
• Create deliberate connections to the outside environment so that changes in weather conditions are apparent as well as stimulating to students.		■		□		
• Incorporate daylighting strategies that could be enhanced through student participation and understanding.	□	■	□	□		
• Recognize the importance of daylighting as a strategy to create superior learning environments that:						
– have a positive physiological impact on the students and teachers			■		■	■
– provide better quality light			■		■	
– increase the performance of students and teachers.			■			■
• Reduce building materials and cost by integrating daylighting into the overall structural design and roofing system.				■		
• Incorporate controlled daylighting strategies.			■		■	
• When climactic conditions allow, install operable windows to improve indoor air quality.			□		■	
• Use daylighting and high performance windows as strategies for reducing long-term energy costs, shifting more financial resources to critical educational needs, and keeping more of your energy dollars within the community.	■					■

Checklist of Key Issues for Energy-Efficient Building Shell

Energy-Efficient Building Shell

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Carefully evaluate building shell issues. Many of these components are likely to go unchanged during the life of the facility.	■					
• Consider the wide range of building systems that can improve energy consumption, reduce maintenance requirements, and improve comfort. These include:						
– light-colored exterior walls and high-reflectance roofing systems	■			■	□	■
– radiant barriers (in addition to insulation) in the roof/ceiling assemblies	■			■	□	■
– massive wall construction	■			■	□	■
– optimum wall and roofing insulation	■			■	□	■
– infiltration and weather-resistive barriers	■			□	■	■
– light-colored interior walls and ceilings.	■			■	■	□
• Incorporate artwork and graphics in the building that will help to educate students about energy and environmental issues.		■				
• Design energy-efficient building components to make their purpose and function obvious to the students.		■				
• Highlight different wall and glass treatments on each facade to emphasize the appropriateness of different design responses.		■				
• Consider building shell issues that directly impact comfort and health and indirectly affect the performance of students within the classroom.			■		■	
• Consider the embodied energy of optional building components and implementation strategies.				■		
• Consider the color and finish of interior surfaces in controlling glare and improving visual comfort.			■		■	
• Employ energy-saving strategies that will result in more energy dollars staying within the community.	■					■

Checklist of Key Issues for Lighting and Electrical Systems

Lighting and Electrical Systems	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Select high-efficiency lamps, ballasts, lenses, and lighting fixtures that address the specific task requirements.	■		■	■	■	■
• Specify high-efficiency appliances and equipment.	■			■		■
• Use long-life lamps to reduce maintenance.	■			■		■
• Develop the primary lighting strategy around a daylighting approach.	■	□	■	■	■	■
• Incorporate controls, occupancy sensors, and dimmable or staged lights to automatically reduce electric lighting during times of adequate daylighting.	■		□	■	■	
• Provide photocell controls on exterior lights to ensure lights are not operating during the day.	■			■		■
• Consider light-emitting diode (LED) exit lights.	■			■		■
• Minimize electrical line losses by installing a high-voltage distribution system.	■			■		■
• Conduct a commissioning process that verifies the proper operation of equipment and systems.	■			■		■
• Implement a regular maintenance schedule to ensure proper operation.	■			■		■
• Use ASHRAE Standard 9.01-1999 to establish lighting power densities (LPDs) for each space within the school.	■					
• Incorporate photovoltaic and solar thermal-electric systems where appropriate.	■	■		■	■	■
• Monitor total building energy use and renewable energy system contribution.	■	■	□	■		
• Design lighting to uniformly light each space, minimize glare, and reduce overheating from light fixtures.	■		■		■	
• Select lamps with minimal or no hazardous materials.				■	■	■
• Design site lighting in a manner that will minimize "light pollution" by:						
– using fixtures with cut-off angles that prevent light from going beyond the specific area to be lighted			■		■	■
– optimizing the height of luminaries for pathways to improve illumination and prevent light from straying onto adjacent properties	□			■	■	■
– limiting exterior lighting to critical areas only.	■			■	■	■

Checklist of Key Issues for Lighting and Electrical Systems

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Select ballasts that do not contain PCBs.				■	■	■
• Minimize glare and eye strain by:						
– incorporating indirect lighting, particularly in computer areas			■		■	
– using lenses that shield the lamp from direct view and help disperse light more evenly			■		■	
– evaluating the location of the lighting sources in relationship to the occupants and what the occupants will be viewing			■		■	
– avoiding reflected glare commonly experienced when viewing a computer screen and seeing the light fixtures			■		■	
– minimizing situations of "transient adaptation" in which the eye cannot properly adjust when going from one space to another with drastically different light levels.			□		■	
• Employ energy-efficient lighting and electrical systems that will result in more energy dollars staying within the community.	■					■
• Consider life-cycle costs to ensure that the best long-term solutions are implemented.	■					■

Checklist of Key Issues for Mechanical and Ventilation Systems

Mechanical and Ventilation Systems

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Implement the most energy-efficient mechanical and ventilation strategies to save energy.	■		□	■	■	■
• Consider the initial cost of equipment, anticipated maintenance expenses, and projected operating costs when evaluating the life-cycle benefits of system options.	■			■		■
• Use a computer energy analysis program that simulates hourly, daily, monthly, and yearly energy consumption and effectively accounts for daylighting benefits (i.e., reduced cooling).	■					
• Optimize the mechanical system as a complete entity to allow for the interaction of various building system components.	■					
• Employ the most energy-efficient mechanical systems by:						
– not oversizing equipment	■			■	□	■
– eliminating systems that first cool air and then reheat it or mix cool and hot air	■			■		■
– matching the air supply to the load, without adding a reheat penalty	■			■		■
– considering thermal storage systems	■			□		■
– zoning air handling units so that each unit serves spaces with similar orientation and use patterns.	■			■		■
• Implement a strategy that energy efficiently ensures adequate outside air by incorporating economizer cycles and heat recovery systems.	■		■		■	■
• Provide safe visual access to mechanical systems to explain how they work.		■	□			
• Use energy monitoring stations as teaching aids.		■	□			
• Improve student and teacher performance by ensuring adequate fresh air is provided by:						
– complying with ASHRAE ventilation standards	■		■		■	
– incorporating pollutant sensors	■		■		■	
– using nighttime ventilation strategies in the cooling season to flush out air prior to morning occupancy	■		■		■	
– installing ductwork that has smooth internal surfaces and transitions to minimize the collection of microbial growth	■		■		■	
– designing ductwork and plenums to minimize the accumulation of dirt and moisture and providing access areas in key locations for inspection, maintenance, and cleaning	■		■		■	

Checklist of Key Issues for Mechanical and Ventilation Systems

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
– locating outdoor-air intakes a safe distance from polluted and/or overheated exhaust grilles and away from parking or traffic.			■		■	
• Implement mechanical and ventilation strategies that control humidity and address all physical, biological, and chemical pollutants.			■		■	
• Incorporate renewable energy systems to provide for absorption cooling, space heating, hot water, and electricity.	■	□		■		■
• Address the impacts of CFCs and HCFCs when selecting refrigerants for cooling systems.				■		■
• Implement indoor air quality strategies that can provide for healthier learning environments.	■		■		■	
• Design the mechanical and ventilation systems to maximize the comfort of the students and teachers.			■		■	
• Employ energy-efficient mechanical and ventilation systems that will result in more energy dollars staying within the community.	■					■

Checklist of Key Issues for Renewable Energy Systems

Renewable Energy Systems

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Consider the wide range of renewable options, including:						
– daylighting	■		■	■	■	■
– passive cooling	■			■		■
– solar hot water and space heating	■			■		■
– photovoltaics	■			■		■
– wind.	■			■		■
• Consider daylighting your highest priority.	■		■	■	■	■
• Incorporate solar systems.	■			■		■
• Employ photovoltaic and wind systems as educational tools that demonstrate the opportunities for converting sunlight and wind into electricity.		■				
• Incorporate solar hot water, and provide a view that will illustrate how sunlight can be converted into thermal energy.		■				
• Use daylighting and passive ventilation strategies to show students the importance of working with, instead of against, nature.		■	□	■	■	
• Integrate displays showing total energy use at the school and the percentage of energy being provided by renewable energy sources.	□	■	■			
• Use renewable energy systems as stimulating, educational tools involving multiple subject areas.		■	■			
• Use on-site, renewable energy systems to help make the link between saving energy and helping our environment.		■	■	■		
• Use renewable energy systems in conjunction with battery storage to provide for emergency power.	□			□	■	■
• Use photovoltaic systems to reliably power:						
– parking and walkway lighting	■			■	■	■
– caution lights at street crossings and remote signage	■			□	■	■
– security lights	■			□	■	■
– emergency telephone call boxes	■			□	■	■
– electric charging stations.	■			■	■	■
• Employ renewable energy and energy-saving strategies that will result in more energy dollars staying within the community.	■					■
• Install renewable energy systems at schools to serve the community in times of natural disasters and utility outages.						■

Checklist of Key Issues for Water Conservation

Water Conservation

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Encourage the general contractor to conserve water during construction.	■			■		■
• Incorporate indigenous vegetation to minimize irrigation requirements.	■			■		■
• Install water-conserving fixtures.	■			■		■
• Incorporate graywater systems.	■			■		■
• Consider rainwater collection systems.	■			■		■
• Provide more localized hot water heaters, closer to the loads in the school, to avoid wasting water and energy.	■			■		■
• Use educational signage and graphics to help inform students and staff about the need to conserve water, and instruct them on what they can personally do to save water.	□	■	■	□		
• Install monitoring devices, sight glasses in storage tanks, and energy management systems that can be used by students to monitor school usage and see the benefits of using graywater.		■	■	□		
• Adequately insulate hot water supply piping.	■			■		■
• Ensure that the water is clean and lead-free.					■	
• Implement water-conserving strategies that will reduce the need to provide water from non-sustainable aquifers and water sources not within the immediate region.				■		■
• Consider installing an on-site biological wastewater treatment system.	■	■	□	■		■
• Check the condition of all existing plumbing lines and fixtures for sources of potential contamination, particularly lead.				□	■	
• Use only lead-free materials in the potable plumbing system to avoid lead-related impacts such as lower IQ levels, impaired hearing, reduced attention span, and poor student performance.				□	■	
• Verify the condition of the potable water supply.					■	
• Install separate plumbing lines that will allow the school to irrigate by using reclaimed water, avoiding the costs, chemicals, and energy associated with treating water to potable levels but still achieving health standards for discharging into streams.	■			■		■

Checklist of Key Issues for Recycling Systems and Waste Management

Recycling Systems and Waste Management

Recycling Systems and Waste Management	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Implement a comprehensive recycling strategy that involves all major recyclable waste materials in the school.	■	■		■		■
• Allocate space throughout the building for recycling receptacles to reduce waste hauling and disposal costs.	■			■		■
• Provide outdoor recycling bins accessible to collection agencies or companies.	■			■		□
• Allocate space for yard waste composting to further reduce landfill tipping costs.	■			■		■
• Ensure that recycling receptacles are designed and labeled so as not to be confused with trash receptacles.	■					
• Design recycling receptacles as attractive components, well-integrated into the overall design but still obvious to the students.		■				
• Incorporate recycling receptacles that are easily accessible to students and custodial staff and designed to be used by students.	■	■		■		
• Develop a recycling system that allows students to monitor their waste stream and that teaches them about waste reduction.		■	■	□		■
• Require a detailed waste management plan from the contractor to minimize the disposal of recyclable or reusable construction waste.	■			■		■
• Monitor construction waste management throughout the construction process to minimize the landfilling, incineration, or improper disposal of recyclable materials.				■		■
• Design recycling systems that will enable the school to recycle as much daily waste as possible.	■	■		■		■
• Consider incorporating a compost center that allows food waste to be used in gardens or landscaping.		■		■		
• Select recycling containers that are made of recycled materials.	■			■		
• Ensure that recycling receptacles are designed and installed so as not to create a physical hazard.					■	
• Design recycling receptacles for easy cleaning.					■	
• Provide documentation on cleaning procedures and maintenance requirements associated with the recycling receptacles.					■	
• Locate local companies or services that can benefit from the use of recycled materials or construction waste.				■		■

Checklist of Key Issues for Transportation

Transportation

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Work with developers and local planning departments to design easy, safe pedestrian access throughout the community to the school site.	■			■	■	■
• Use high-efficiency buses and service vehicles.	■			■		■
• Use graphics and signage to help educate students and the community about the environmental benefits of the energy-efficient and low-emission approaches to transportation implemented by the school.		■	■			
• Give high priority to the placement of bicycle racks, and use personalized nameplates for regular bikers.		■				
• Incorporate a highly visible solar electric and/or wind-powered charging station for electric buses and service vehicles.	■	■		■		■
• Design sidewalks and bike paths throughout the community and school site to help reduce air pollution associated with busing and single car drop-offs.	■			■	■	■
• Use low-emission methanol, biodiesel, natural gas, and solar electric buses and service vehicles to reduce air pollution.	■			■	■	■
• Stress safety when designing walkways and bike paths.					■	
• Use photovoltaic systems to reliably power:						
– parking and walkway lights	■			■	■	■
– caution lights and street crossings	■			□	■	■
– electric charging stations.	■			□	■	■
• Allow for handicap access.					■	■
• Encourage recreational activities by providing access to athletic facilities that can be shared with residents of the local community.						■
• Provide pedestrian ways to and a mass transit stop at the school site so that the school is more easily accessible to the community.	■					■
• Implement energy-efficient transportation options that keep energy dollars in the community, strengthening the local economy.	■					■
• Choose high-efficiency and low-emission vehicles as the best long-term solution to protect against future energy cost escalation.	■					■

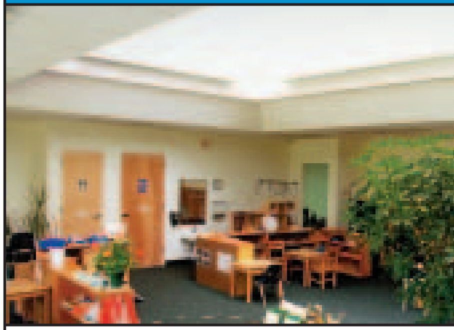
Checklist of Key Issues for Resource-Efficient Building Products

Resource-Efficient Building Materials

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Use products that are energy-efficient.	■			■		■
• Choose fixtures and equipment that conserve water.	■			■		■
• Specify building systems, components, and materials with low maintenance requirements.	■			■		■
• Incorporate less-polluting materials, the result being a reduced requirement for mechanically induced fresh air and better energy efficiency.	■		□	□	■	
• Incorporate pollutant sensors to reduce ventilation air exchange during non-occupied times.	■			■	■	■
• Design environmentally sound building components to make their purpose and function obvious to students.		■				
• Use products and systems that save water in explicit, visible ways.		■				
• Incorporate locally harvested or mined materials as prominent design elements.	■	■		■		■
• Avoid materials containing toxic or irritating compounds that negatively impact the indoor air quality.	□		■	■	■	
• Specify products, materials, and equipment that can be maintained in an environmentally friendly way.				■	■	
• Select products made from renewable energy and low-polluting processes.				■		■
• Specify products harvested from well-managed forests.				■		□
• Avoid products harvested or mined from environmentally sensitive areas.				■		□
• Select products that are made from recycled materials and/or are recyclable.				■		
• Specify products made with a minimum of process (embodied) energy.				■		
• Minimize the environmental impact of the building's operation by evaluating the environmental life-cycle impacts.				■	□	■
• Incorporate energy-efficiency and renewable energy systems.	■			■		■
• Use water-saving fixtures and appliances, and implement rainwater catchment and graywater systems.	■			■		■
• Avoid products that produce indoor air pollution.	■			■	■	

Checklist of Key Issues for Resource-Efficient Building Products

	Reducing Operating Costs	Designing Buildings that Teach	Improving Academic Performances	Protecting Our Environment	Designing for Health, Safety, & Comfort	Supporting Community Values
• Separate polluting materials from exposed surfaces.			□		■	
• Incorporate indoor planting strategies.			□		■	
• Avoid equipment that requires toxic or irritating maintenance procedures.			□		■	
• Provide detailed guidance on preferable maintenance procedures to minimize exposure of staff and students to toxic and irritating chemicals.			□		■	
• Work with the school system to develop an indoor pollutant source assessment and control plan.			□		■	■
• Choose products and materials that are locally produced or made from readily available materials.				■		■
• Choose products and building procedures that maximize local labor.						■
• Select indigenous materials, and implement designs that enhance the connection to "place."						■
• Select materials that can be reused or recycled, minimizing impacts on landfills.				■		■



Case Studies

The following case studies demonstrate successful applications of high performance solutions appropriate for cold and humid climates. Contact information is provided to allow you to gain firsthand knowledge from schools that have successfully implemented many of the high performance design strategies included in this guideline.

To find additional case studies around the country, log on to the EnergySmart Schools Web site:

www.energysmartschools.gov

or call the US DOE's energy clearinghouse:

1 (800) DOE-3732

Photo: Chris Barnes

Contact:
Bruce Cook, Principal
Brunswick High School
116 Maquoit Rd.
Brunswick, ME 04011
Phone: (207) 798-5500
Jack Despres, Head of Science Department
Phone: (207) 798-5500

Benefits:

- ✔ *Protection of local environment*
- ✔ *Water management strategies*
- ✔ *Environmental stewardship*

Brunswick High School, Brunswick, Maine

"We have found no dangerous readings indications of stress to the environment near the school. The retention ponds and water flow patterns around the school grounds appear to have functioned exactly as envisioned in both normal and abnormal weather events. Runoff from the parking lots and roofs is processed in the ponds, which are healthy and full of wildlife."

— *Jack Despres, head of science department, Brunswick High School*

Maquoit Bay near Brunswick, Maine, supports a productive shellfish industry. When a 50-acre site a mile from the bay was selected for the town's new high school, strong concerns were voiced by the community that pollutants from stormwater runoff would migrate to the bay, destroying fish. As a result, the town enacted one of the strictest environmental ordinances in the nation to protect the bay.

The design of the new high school and grounds, completed in July 1995, employs a system of man-made ponds, wetlands, and grassed swales that collect, divert, and slow the rate of stormwater runoff. Native sandy topsoil has been replaced with silty loam to promote quality turf for the playing fields and minimize leaching of nutrients into the ground water. Fifteen of the school's 50 acres have been preserved in their natural state. More than 75 species or varieties of native trees and shrubs are marked with identification tags, giving students a distinctive place for nature studies, which have been integrated into the curriculum.

The design of the school building itself minimizes energy consumption and its impact on the environment by incorporating local building materials, natural daylight, energy-efficient light fixtures, energy recovery equipment, and an energy usage monitoring system that is also used as a teaching tool.

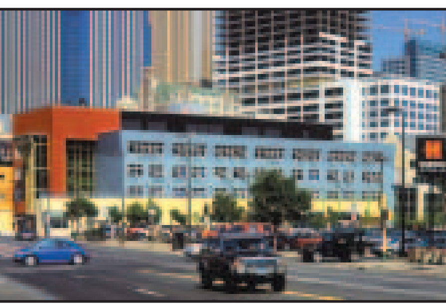


Photo: Peter Kerze

Contact:
Barbara Shin, Principal
Interdistrict Downtown School
10 South 10th St.
Minneapolis, MN 55403
Phone: (612) 752-7100

Benefits:

- ✔ *$5,600 savings per year*
- ✔ *Environmental impact*
- ✔ *Improved indoor environment quality*
- ✔ *Eco-education*

Interdistrict Downtown School, Minneapolis, Minnesota

The Interdistict Downtown School in Minneapolis, Minnesota is a multi-cultural magnet school for 520 students, kindergarten through twelfth grade. The school was completed in 1998 and incorporates a 2,115-square-foot solar wall heating system. The $50,000 active solar collector brings in outside air through perforations in the collector and is heated by the sun. The warm air is sent into the building's HVAC system. The collector, which was installed on the south penthouse wall, not only saves $5,600 per year in energy but also serves as an educational tool, introducing students to renewable energy principles. On a typical winter day, the solar collector is capable of preheating the air entering a building by 30°F.

Union 32 Community Building, Montpelier, Vermont

"The sunshine is always an added bonus.The building is an important part of the spirit of cooperation and collaboration at our school. I expect that we will continue to value it for years to come"

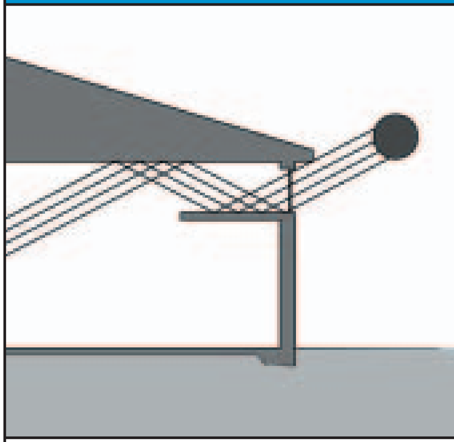
Dot Blake, principal, Union 32 High School

Faced with the prospect of severe overcrowding, the Union 32 High School in Montpelier, Vermont was preparing for the usual short-term fix — rent portable classrooms. When this news reached Andrew and Carolyn Shapiro, local residents with children in the school, they were not pleased. As an expert in energy efficiency and healthy buildings, Andrew knew that the portable classrooms would likely create poor air quality, bad lighting, and high heating bills. The Shapiros proposed an alternative: — why not have the community work together to build the needed classrooms and do it right?

Led by Andrew and Carolyn, more than 300 volunteers donated time and skills to have the building ready for occupancy by the next September. Many materials were supplied by local businesses at reduced cost. All the exterior siding and trim and interior trim came from stressed pine trees in a 100-acre woodland owned by the school, and framing lumber also came from a nearby source. The building was completed for a remarkable $30 per square foot — less than the cost of set-up and two years rent for two portable classrooms!

The building was designed for energy efficiency and is projected to consume half the energy of the portable classroom alternative. Contributing to the energy savings is the row of high windows on the southeast façade that bounce daylight off a wide interior lightshelf deep into the space. The walls are packed with 7 inches of cellulose insulation, the windows are low-e with argon gas, and an energy recovery ventilator provides fresh air and saves energy on heating and cooling.

Perhaps as an indication of how strongly the community feels about this building, they have chosen to move it to make room for the new addition rather than simply tear it down. In addition to a great building (now called the Community Building), the school gained a higher level of commitment and support from the community.



Owner:

Union 32 Community Schools
930 Gallison Hill Rd.
Montpelier, VT 05602

Contact:

Andrew M. Shapiro
Phone: (802) 229-5676

Benefits

✔ *Community values*

✔ *Better learning environment*

✔ *Energy savings*

Photo: Forest City Community Schools

Contacts:

Ron Kvale, Science Teacher
Forest City Community Schools
810 West K St.
Forest City, Iowa 50436
Phone: (515) 585-2323

Benefits:

✔ *Provide for 80%–90% of the school electrical needs*

✔ *Community values*

✔ *Eco-education*

✔ *Environmental impact*

Forest City Community Schools, Forest City, Iowa

"We will give our students firsthand experience in a technology that may be a big part of their energy future. We also want to share this data with other school districts and wind energy enthusiasts."

Dwight Pierson, superintendent, Forest City Community Schools

"We knew we were in a prime area of the state for using wind energy. When we found it would be to the school's advantage, we made a presentation to the school board."

Ron Kvale, teacher and member of the Wind Turbine Task Force

The wind turbine project began when Paul Smith, then a student at Forest City High School, presented a research paper on wind energy to the town's school board. Smith began researching the benefits of wind turbines for his science project.

The presentation generated a great deal of interest and resulted in the installation of the 600-kWh wind turbine. The turbine began producing electricity for the school system in January 1999. In addition to incorporating wind energy into the classroom curriculum, the school district maintains a Web site with a microprocessor-based connection to the turbine that displays electrical production and wind energy data. The turbine provides 80%–90% of the electrical needs of the community's entire school system.

Forest City Community Schools views renewable energy and energy efficiency as cost-effective ways to reduce electrical costs while being environmentally conscious and creating opportunities for students to study the benefits of renewable energy production in a hands-on manner. The city and its municipal utility have contracted with the school system to buy all excess power generated.

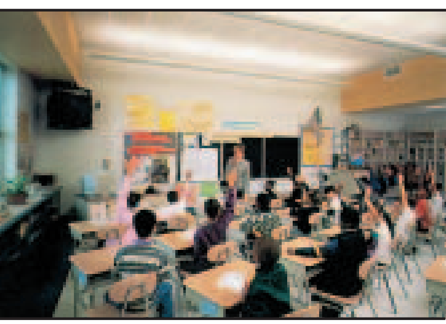


Photo: Jim Wilkes

Contacts:

Norma Bushorr, Principal
Mary McLeod Bethune
Elementary School
Phone: (716) 325-6945

Benefits:

✔ *Energy savings*

✔ *Increased visual comfort*

Mary McLeod Bethune Elementary School, Rochester, New York

Indirect lighting in schools can solve the problem of glare and visual discomfort for students and teachers. Lighting that is too bright or glaring on work surfaces or computers, creating high contrast between those surfaces and dark backgrounds, can give teachers and students headaches and eyestrain and can lead to absenteeism and poor performance.

The energy-efficient indirect lighting system at Mary McLeod Bethune Elementary School directs the light to the ceiling, where it is bounced into the classrooms and workspaces uniformly and without glare. This system is controlled by occupancy sensors and can be adjusted manually. In areas that need more direct task lighting, compact fluorescent lights are used to downlight specific workstations.

Mary McLeod Bethune Elementary also capitalizes on natural daylighting. Indirect lighting works well with daylighting, matching the light quality and complementing its energy saving attributes. The use of dimmable lights ensures that a constant and high quality light level is maintained in classrooms, work areas, the auditorium/ cafeteria, and the media center.

Spirit Lake Community Schools, Spirit Lake, Iowa

"The final payment for the loan on the first turbine was made during the 1998 fiscal year. Today, $25,000 per year in savings goes to the school's instructional programs. The development of wind energy is one of the most popular projects in the community. Everyone loves that we are helping to reduce our dependence on fossil fuels while educating our children about the importance of resource conservation."

Jim Tirevold, facilities manager, Spirit Lake Community Schools

"Education was the first priority. We need to teach preservation of the environment and, to do that, we have to model it. I've never been involved in something so accepted by so many."

Harold Overmann, superintendent, Spirit Lake Community Schools

On July 22, 1993, the wind turbine on the lawn of Spirit Lake Elementary School began producing electricity. By August 2000, seven years and two months later, the school's turbine had produced a total output of 2,068,803 kilowatt hours of electricity, which saved the district $176,445 in electricity costs. This corresponds to an average electrical output of 288,670 kilowatt hours per year and an average savings of $24,620 per year. Looking at the entire seven year, two-month period of operation, nearly all of the electrical needs of the elementary school have been met by the wind turbine.

The wind turbine system has made a significant contribution to the environment. The 2,068,803 kilowatt hours of electricity produced by the turbine in the first 86 months of operation is the energy equivalent of 3,641 barrels of oil or 1,034 tons of coal. It has eliminated 3,103,205 pounds of CO_2 emissions and 442,724 pounds of SO_2 emissions that would have been released to the atmosphere by conventional energy production.

In addition to its excellent financial success and its significant contribution to the environment, the school's wind turbine has been used in the curriculum as an educational tool for the students. The Spirit Lake Environmental Impact Calculator at the school district's wind energy Web site allows all the students in the district to monitor and study the environmental benefits of wind power generated at the school. They can choose interactive lessons from all areas of the curriculum. Wind production is entered into the environmental impact calculator to see the natural resources saved and emissions avoided by the wind-produced energy.

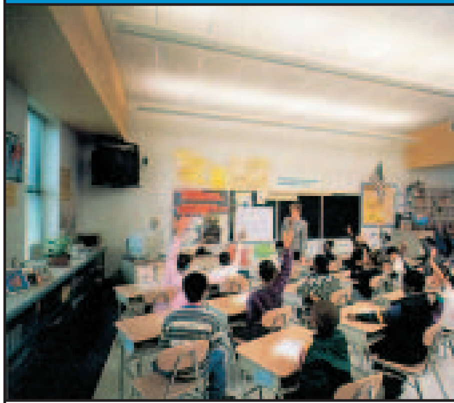


Photo: Jim Wilkes

Contact:

Jim Tirevold, Facility Manager
Spirit Lake Community Schools
900 20th St.
Spirit Lake, Iowa 51360
Phone: (712) 336-2820

Benefits:

✔ *Resource savings*

✔ *Environmental impact*

✔ *Eco-education*

EnergySmart Schools is part of the Rebuild America program, a national US DOE initiative to improve energy use in buildings. This means that if your school is part of a Rebuild America community partnership, you're ready to benefit from EnergySmart Schools.

Be sure to ask about energy improvements and educational materials for your bus fleet as well as your buildings. Rebuild America focuses on buildings, but its representatives can also direct you to resources for buses. After all, the goal of EnergySmart Schools is a comprehensive one: a nation of schools that are smart about energy in every way.

Web Resources for More Information

EnergySmart Schools Web Site: **www.energysmartschools.gov**

Comprehensive Sources

www.ase.org/greenschools/newconstruction.htm — Alliance to Save Energy's Green Schools Program

www.eren.doe.gov/EE/buildings.html — US DOE's Energy Efficiency and Renewable Energy Network buildings site

www.advancedbuildings.org/ — Advanced Buildings, Technologies, and Practices

www.edfacilities.org/rl/ — National Clearinghouse for Educational Facilities

www.epa.gov/building/schools — US EPA's ENERGY STAR for Schools

Introductory Section

www.rebuild.org — US DOE's Rebuild America program, with energy-efficient solutions for communities

www.eren.doe.gov/buildings/energy_tools/doe_tools.html — DOE energy simulation software

www.usgbc.org — US Green Building Council

Site Design

www.epa.gov/glnpo/greenacres/natvland.html — EPA's site on native landscaping

www.water.az.gov — Arizona Department of Water Resources

Daylighting and Windows

windows.lbl.gov/daylighting/designguide/designguide.html — Lawrence Berkeley National Laboratory's "Tips for Daylighting with Windows"

www.eren.doe.gov/erec/factsheets/windows.html — US DOE's "Advances in Glazing Materials for Windows"

www.nfrc.org — National Fenestration Rating Council

www.daylighting.org — Daylighting Collaborative

aa.usno.navy.mil/data/docs/AltAz.html — US Naval Observatory's sun or moon altitude/azimuth table

Energy Efficient Building Shell

www.nrel.gov/buildings_thermal/ — National Renewable Energy Laboratory's Center for Buildings and Thermal Systems

www.ornl.gov/roofs+walls/index.html — Oak Ridge National Laboratory's Building Thermal Envelope Systems and Materials Program

gundog.lbl.gov/dirsoft/d2whatis.html — Lawrence Berkeley National Laboratory's DOE-2 energy simulation software

Renewable Energy Systems

www.eren.doe.gov/state_energy/ — US DOE's State Energy Alternatives

www.eren.doe.gov/greenpower/ — US DOE's Green Power Network

www.nrel.gov — National Renewable Energy Laboratory

www.schoolsgoingsolar.org — The Interstate Renewable Energy Council Schools Going Solar program

Lighting and Electrical Systems

www.iaeel.org — International Association for Energy-Efficient Lighting

eetd.lbl.gov/btp/lsr/ — Lawrence Berkely National Laboratory's Lighting Systems Research Group

Mechanical and Ventilation Systems

www.epa.gov/iaq/schools/ — US EPA's Tools for Schools Indoor Air Quality program

www.eren.doe.gov/buildings/energy_tools/energyplus/ — US DOE's EnergyPlus energy simulation program

epb1.lbl.gov/EPB/thermal/ — Lawrence Berkeley National Laboratory's information on Resource Efficient Building Conditioning

Resource-Efficient Building Products

www.sustainable.doe.gov/buildings/rescon.shtml — US DOE's resource list of resource-efficient building products

www.ciwmb.ca.gov/GreenBuilding/Materials — California Integrated Waste Management Board's site on green building materials

www.ciwmb.ca.gov/ConDemo/Products/default.asp — California Integrated Waste Management Board's site of Recycled-Content Building Products Database

Water Conservation

www.epa.gov/ow/ — US EPA's Office of Water

www.water.az.gov — Arizona Department of Water Resources

www.amwua.org/conservation-school.htm — Arizona Municipal Water User Association's "Water in Our Desert Community," an instructional resource for middle school students

Recycling and Waste Management

www.epa.gov/globalwarming/actions/waste/warm.htm — US EPA's Waste Reduction Model to calculate greenhouse gas emissions

www.p2pays.org/ref/01/00626.htm — North Carolina Division of Pollution Prevention and Environmental Assistance's "Beyond Recycling: A Waste Reduction Manual for Schools"

Transportation

www.ccities.doe.gov — US DOE's Clean Cities Program

www.ott.doe.gov/ — US DOE's Office of Transportation Technologies

www.ctts.nrel.gov — National Renewable Energy Laboratory's Alternative Fuels Web site

This publication, and additional information, is available online at:

www.energysmartschools.gov

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For helpful resources or more information:

Call DOE's energy clearing house:
1 (800) DOE-3732

Ask a question about saving energy in your school or request information about the EnergySmart Schools campaign. You may want to inquire about the availability of the following EnergySmart Schools resources:

Publications and Videotapes

- Design Guidelines for New Schools and Major Renovations
- Portable Classroom Guidelines
- Decisionmaker Brochures
- Designing Smarter Schools, a 30-minute videotape that originally aired on the CNBC television network
- Educational CD-ROM featuring teaching and learning materials
- The High Performance Schools 30-minute video is also available by calling one of these three numbers: (303) 443-3130 Ext. 106, (202) 628-7400, or (202) 857-0666

Services

- Technical assistance
- Regional peer exchange forums
- State-based forums for school decisionmakers
- Financing workshops
- Technology workshops

Office of Building Technology, State and Community Programs
Energy Efficiency and Renewable Energy
US Department of Energy

EnergySmart Schools
Rebuild America Schools
U.S. Department of Energy

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