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Comfort and electricity use in remote Australian buildings

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Australian Government
Department of Industry and Science

Business
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The CRC-REP produces two series of reports: working papers and research reports. Working papers describe work in progress for the purposes of reporting back to stakeholders and for generating discussion. Research reports describe the final results of completed research projects.

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Comfort and electricity use in remote Australian buildings

The thermal and electrical efficiency of eight buildings used by four art centres and a corporation in remote Australia

Peter Osman, Lisa Havas, Michael Ambrose and Geoff Clark



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Executive summary

Overview

This study is aimed at improving the safety, comfort, productivity and energy efficiency of enterprise buildings in remote communities. Two building types, besser block and steel frame, were investigated in both hot arid and hot humid climate zones of northern Australia.

Adaptation to climate change and the increasing cost of electricity are key drivers for improving the thermal efficiency of the built environment. The need is particularly acute in remote regions of Australia where temperatures and energy costs are rising. Additionally, building construction for new enterprises is largely reliant on building energy efficiency codes developed in the major cities where the climates are temperate or cool.¹ Remote community buildings in Far North Queensland (FNQ) and Central Australia (CA) have unique requirements. Electricity and transport are expensive, incomes are relatively low and maintenance services are almost non-existent. At the same time, enterprise buildings have to provide an environment that is safe and productive while coping with climate extremes that are rarely encountered in Australian cities.

The case studies reported here quantify the impact of climate extremes on enterprise buildings in remote Australia. The report will describe the current usage and performance of eight buildings, including their design, function, electricity consumption and thermal response to climate variables. It will provide assessments of the thermal and energy efficiencies of these buildings using AccuRate, a standard tool used throughout Australia to assess the thermal efficiency of buildings. The assessments are intended to inform guidelines for designing remote community enterprise buildings for improved comfort and energy efficiency. They will also demonstrate how the standard building energy efficiency model AccuRate can be adapted for use in remote Australia.

Method

Selection of buildings

In selecting buildings for this study, it became clear that the most readily accessible were of old construction and were not purpose built. The art centres and corporation we studied provided a range of buildings in four distinctly different construction types, including high thermal mass besser block buildings and low thermal mass steel or wood frame buildings. Both types included examples that were well ventilated or with quite restricted ventilation. The besser block buildings all had air conditioning, as did half of the steel and wood frame buildings.

Data acquisition and volunteer confidentiality

The data acquired included architectural drawings and photographs, temperature measurements, infrared photography and switchboard sub-circuit electricity consumption measurements. About 100 temperature sensors were monitored at between ten-minute and hourly intervals; likewise, 104 sub-circuits were monitored at one-minute intervals. Brief interviews were also conducted with each art centre manager and the corporation building manager. The personal information of the manager and occupants is not made available in this report. The consent agreement allows the use of measured data and dissemination of

¹ Ambrose MD, James M, Law A, Osman P, White S. 2013. *The evaluation of the 5-Star Energy Efficiency Standard for Residential Buildings*. CSIRO, Australia.
<https://industry.gov.au/Energy/Documents/Evaluation5StarEnergyEfficiencyStandardResidentialBuildings.pdf>

results. In return for assisting the study, the building management was given the energy monitoring system at the end of the study and provided with support to keep it running for two years. The management of each research site will also receive a report with recommendations on energy-saving strategies focused specifically on their site buildings.

Data analysis

Three analyses were carried out: i) an assessment of the overall building design and thermal efficiency using the energy efficiency rating tool AccuRate, ii) a comparison of temperatures outside the building and in the main air conditioned rooms inside the building, iii) an analysis of the electricity consumed by appliances distributed throughout these rooms.

Data analysis was based on comparisons against a standard model, AccuRate, used by government authorities, builders and architects throughout Australia to assess building thermal energy efficiency ratings for the Nationwide House Energy Rating Scheme (NatHERS).² NatHERS uses AccuRate to produce a star rating that is adapted for each state. AccuRate was also used to predict temperatures in buildings and to help estimate how much electricity or gas is needed to heat and cool a building. It can model buildings with or without air conditioning. AccuRate can produce a star score from 0 to 10 stars, where a 6-star rating indicates good, but not outstanding, thermal performance.

AccuRate simulations of temperature distribution and energy consumption were carried out on all eight buildings and the predictions compared against measured readings.

Key outcomes and recommendations

1. Electricity consumption savings of up to 40% are achievable if out-of-hours consumption is reduced by:
 - assessing if appliances and equipment need to run or operate in standby mode 24 hours a day
 - use of automated controllers to switch off appliances when and where appropriate.
2. Electricity can be saved and comfort improved in buildings with air conditioning by upgrading building design so that air conditioners do not need to run 24 hours a day. Upgrades include:
 - insulating the walls and ceilings and reducing uncontrolled draughts.
 - using controlled forced ventilation at night in buildings with high thermal mass.
3. The buildings without air conditioning were typically unoccupied for most of the day from late spring to early autumn due to excessive heat. The temperature can be reduced by as much as 5–10 °C and the number of available working days increased by upgrading building design using:
 - low thermal emissivity foil insulation on the underside of roofs
 - trees and shrubs to provide shade and transpiration cooling
 - replacing uninsulated skylights with high insulation translucent honeycomb units
 - forced ventilation.
4. Evaporative coolers, although very efficient, are too hazardous for use in remote locations due to lack of maintenance resources. The key risks are scaling blockages in sprinklers, leading to fires, and health issues associated with warm stagnant water.
5. The house energy efficiency design and NatHERS rating tool AccuRate could be made suitable for designing thermally efficient enterprise buildings in remote Australia by allowing:

² Website available at <http://www.nathers.gov.au/>.

- users to input thermal load parameters to account for occupancy and equipment
- users to input external environment temperature
- calculation of the benefit of low thermal emissivity foil insulation
- calculation of the benefit of forced ventilation at different times of day.

1. Introduction

A high proportion of electricity is used to power air conditioners and supply fresh water to maintain liveability in central and northern Australia. Yet the increasing cost of conventional sources of energy (e.g. commonly, diesel-fuelled mini-grids supply the electricity in remote communities of 200–800 people) and the warming climate suggest that current approaches to maintaining liveability are unlikely to be sustainable. Improved electricity consumption management by households and community-based enterprises will be vital if the liveability of remote central and northern Australia is to be maintained. Management of energy consumption encompasses:

- quality and scale of infrastructure (e.g. building design and immediate vicinity)
- extent, quality and usage of appliances (e.g. cooling and heating)
- human behaviour (as individuals and social norms, institutional arrangements).

Facilitating enduring change to energy consumption at the local level requires careful analysis and integrated management of all three components. For example, improving the energy star rating of a building may not alter the energy footprint of the building if it is not accompanied by complementary change in the other components (e.g. there is risk of a rebound effect in energy use). Conversely, an energy efficient building design may show a marked reduction in a building's energy consumption when combined with the occupant's improved understanding of how to use the building (e.g. using natural ventilation to cool it and vegetation to provide shade from the afternoon summer sun) – reflecting the strong interdependence of behaviour and building design.

Recent research by the CRC-REP indicates that household adoption of energy efficiency measures (EEMs) is weakly correlated with potential cost savings from reduced energy consumption as discussed in *Power to Change: Analysis of household participation in a renewable energy and energy efficiency program in Central Australia*³ and *Energising households: a financial analysis of incentivised energy efficiency measures in remote Australia*⁴. The research analysed responses to the Alice Solar City program, which offered a range of financial incentives for households to adopt EEMs that would not meet the cost payback period within the expected life of the product. The findings from the research show that government policies seeking a shift in energy consumption by households and enterprises in remote Australia are unlikely to be effective if they are framed around an economic behaviour rationale without taking into account building design and appliance efficiency. The goal of this research is to inform the shift to improved electricity consumption management by enterprises and households in central and northern Australia.

This study provides an evidence base for clear policy recommendations and advice to communities in remote Australia to enhance the thermal performance of enterprise buildings and to reduce the electricity consumption in those buildings without compromising their amenity. The findings are based on thermal efficiency and energy consumption assessments for five research sites in four community enterprises and one corporation over a nine-month period to determine the potential for cost effective interventions to reduce energy costs and improve liveability. The research sites are as follows:

³ Havas L, Ballweg J, Penna C and Race D. 2015. Power to Change: Analysis of household participation in a renewable energy and energy efficiency program in Central Australia. *Energy Policy*. 87, pp. 325-33. <http://dx.doi.org/10.1016/j.enpol.2015.09.017>.

⁴ Havas L, Ballweg J, Penna C and Race D. 2015. Energising households: a financial analysis of incentivised energy efficiency measures in remote Australia. *Energy Efficiency*. 8, 5, pp. 951-62. <http://dx.doi.org/10.1007/s12053-015-9326-6>.

Table 1: Research sites

Research site	Proposed name	Rooms
FNQ1	Art centre main building	First floor office/showroom
		Ground floor workspace
		Attached studio
	External studio	External studio (discussed as whole)
	Residence	Residence (discussed as whole)
FNQ2	Art centre building	Keeping place/offices/reception
		Studio/kitchen/computer room
FNQ3	Corporation building	First floor boardroom/offices/bedrooms
		Ground floor offices/kitchen/reception
CA1	Art centre main building	Office/showroom
		Studio/kitchen/stores/workshops
	External studio	External studio
CA2	Art centre building	Office/showroom
		Studio
Sites: 5	Buildings: 8	Rooms/spaces: 34

2. Consolidated findings for communities and policymakers

2.1 Overview

This section presents those findings that were commonly observed in the eight buildings studied across the four art centres and the corporation research sites. They are based on comparisons made between the electricity consumption and thermal efficiencies of high and low thermal mass buildings and buildings that are well or poorly ventilated. The section initially discusses the comfort, convenience and safety of each research site and then focuses on cooling amenity, the minimisation of electricity consumption and a brief discussion of an important issue observed with use of evaporative cooling. Recommendations are given for improving building comfort, safety and thermal efficiency, reducing electricity consumption and for adapting AccuRate for use on enterprise buildings in remote Australia. The components of the study include:

- initial engagement with stakeholders and preliminary research
- a thermal efficiency analysis of the enterprise buildings
- installation of research site energy monitoring infrastructure and training for local maintenance personnel and site managers in its use
- integration of key findings and recommendations to enhance policies, practices and institutional arrangements.

The findings are presented as individual case studies and then consolidated to provide conclusions and recommendations of relevance to remote communities and policymakers. This includes:

- policy recommendations for the management and retrofitting of existing housing/building stock in central and northern Australia
- recommendations for households and community-based enterprises to enhance their short- and medium-term electricity consumption management
- advice on building designs suited to central and northern Australia.

The findings address the following key areas for assuring the greatest saving of electricity for the lowest investment:

- the use of night-time ventilation and insulation in high thermal mass buildings
- the impact of low emissivity foil for roof insulation in structures that have no air conditioning
- the use of electricity out of hours
- potential hazards for evaporative coolers in remote communities
- upgrades required so the nationally used rating tool AccuRate can be used in the design of remote enterprise buildings in northern Australia.

2.2 Comfort, convenience and safety

At least 40% of electricity consumed in the research sites is for air conditioning, and typically 30–40% is used for appliances such as computers and telecommunication equipment. Electricity supply, the thermal comfort and wellbeing of building occupants and the safe operation of equipment are therefore key indices when assessing the efficacy of electricity consumption. This section covers the thermal comfort of people

working in the research sites, the electricity and telecommunication supply reliability and the risk of fires and a potential biological hazard associated with evaporative coolers.

2.2.1 Thermal comfort

An analysis was carried out to determine the average diurnal⁵ operating temperatures for principal rooms in each building and their associated heat and discomfort indices (Figure 1). In FNQ, five of the eight rooms are air conditioned and were assessed to have average temperatures of 29 °C, which at a typical 65% relative humidity provides an apparent⁶ temperature of 32 °C. Likewise, four of the five rooms in CA had reverse cycle air conditioning and had average temperatures of 31 °C at 50% relative humidity and also an apparent temperature of 32 °C. These temperatures imply a frugal use of air conditioning. A heat index chart would typically report them as slightly uncomfortable, with fatigue possible on prolonged exposure.

Most of the unconditioned rooms were found to be operating at temperatures in summer that would require significant caution and restricted working hours. The general practice and experience of people working in these buildings seemed to be aligned with the necessary caution, but this did mean that several rooms or buildings were unsuitable for occupancy for significant parts of the day in summer. Two of the buildings were unusable from midday from late spring to early autumn. One of these appeared to be occupied in the late evening rather than the afternoon, which, as the lightweight buildings cooled quickly, was an effective use of the resource. Improving the thermal comfort of such buildings by following recommendations in this report would increase the number of days in a year that they could be used.

2.2.2 Electricity supply power failures and power cards

The electricity supply was monitored at one-minute intervals for power failures, as there had been a history of intermittent supply in the communities visited. Research site managers all reported either that they had no problems at all or that power interruptions had reduced to a level that was of no consequence. This was borne out by the measurements, which detected only two or three general power failures across the five research sites. However, there were several protracted failures that could last days to weeks caused by power cards running out of credit or the absence of the building occupant; in one building, a failure was caused by studio equipment overloading a power supply. In two centres we found and repaired electrical wiring that had been installed incorrectly and without appropriate overload protection.

2.2.3 Telecommunication failures

While measuring the electricity supply, we found many telecommunication failures associated with data transmission. These appeared to be due to spurious code signals being transmitted by the telecommunication provider and to congestion on the internet rather than to low signal strength. The data-logging equipment automatically recovers from such failures, and future work might include a statistical analysis of their frequency and impact. This may be of interest to research site managers, as internet communication is problematic in the five research sites visited. Examples of the negative impacts of low internet capacity included art centre managers describing the difficulty of working on payrolls or modifying web pages that advertised artworks or events, and a school teacher described the impossibility of providing school educational services via the internet.

⁵ ‘Diurnal’ here means a set of measurements taken throughout the 24-hour day. It may include subsets of data that are during working hours or outside working hours.

⁶ Apparent temperature is the perceived temperature when relative humidity is taken into account.

2.2.4 Fires and biological considerations in evaporative coolers

Evaporative coolers use approximately a third of the energy that reverse cycle air conditioners use for the same level of cooling and are frequently recommended in remote arid communities to save energy. This is a hazardous recommendation due to the lack of adequate maintenance services. We were notified of three small smouldering fires requiring evacuation of the occupants in one of the art centres, and we investigated the cause. The issue is that bore water with a high dissolved mineral content is being used in the sprinklers, which become blocked by scale and fail to supply water. Consequently, the wood chips in the filter dry out and may catch fire when a fan produces an electrical spark. Additionally, reservoir tanks may become blocked and hold warm stagnant water, or they may overflow and create pools of stagnant water. We could find no recorded instances where the failure of a sprinkler system in a remote community has led to a *Legionella* infection, but the risk of this happening should be considered. Preliminary recommendations are:

- not to install evaporative coolers in regions where maintenance services are inadequate
- shut down evaporative coolers and empty their water tanks if the sprinklers fail
- if an evaporative cooler is to be used, then i) appropriate water treatment should be applied or demineralised water used, and ii) filter material should be fireproof.

2.3 Building design

When we selected buildings for this study, it became clear that the most readily accessible were of old construction and not purpose built. This section therefore deals with aspects of the building design that can be readily upgraded. However, in one respect this study does contribute to the design tools for construction of new buildings and that is through its focus on AccuRate, the assessment tool underpinning the NatHERS. One of the goals of the study was to determine in what areas AccuRate needs to be adjusted for use in designing buildings for remote communities.

The research sites we studied provided a range of buildings in four distinctly different construction types, including high thermal mass besser block buildings and low thermal mass steel or wood frame buildings. Both types included examples that were well ventilated or had quite restricted ventilation. The besser block buildings all had air conditioning, as did half of the steel and wood frame buildings.

The low thermal mass, lighter constructed buildings were harder to air condition efficiently because they were large and sometimes had considerable capacity for natural ventilation. They were all poorly insulated, with little or no management to control solar heating of the roof and subsequent heat radiation into the building. Under these circumstances, roof temperatures can readily rise to greater than 60 °C between late spring and early autumn. Figure 2 illustrates the issue. While ambient air temperature outside the building may be no more than 32 °C, the interior of such a building can typically be 10 °C higher. In Chapter 5 we demonstrate that application of low emissivity foil reduced the roof temperature by 15 °C. With careful application, it should be possible to bring the roof temperature down to external ambient air temperatures.

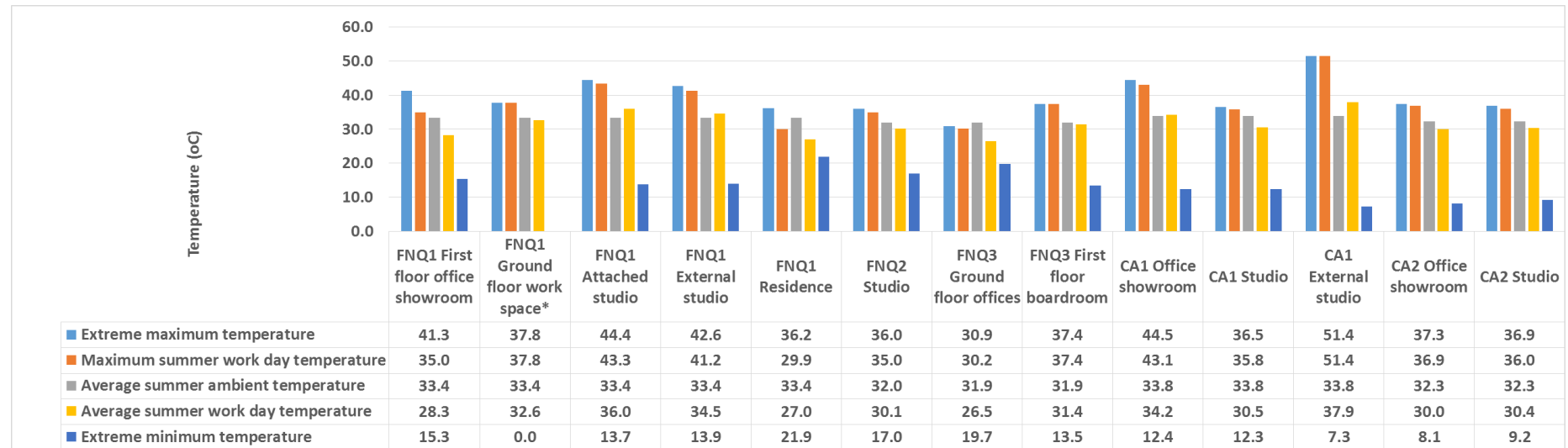


Figure 1: Research sites – working hours temperature profiles for high occupancy rooms

* Note: Sensor lost in FNQ1 ground floor workspace, hence no minimum recorded

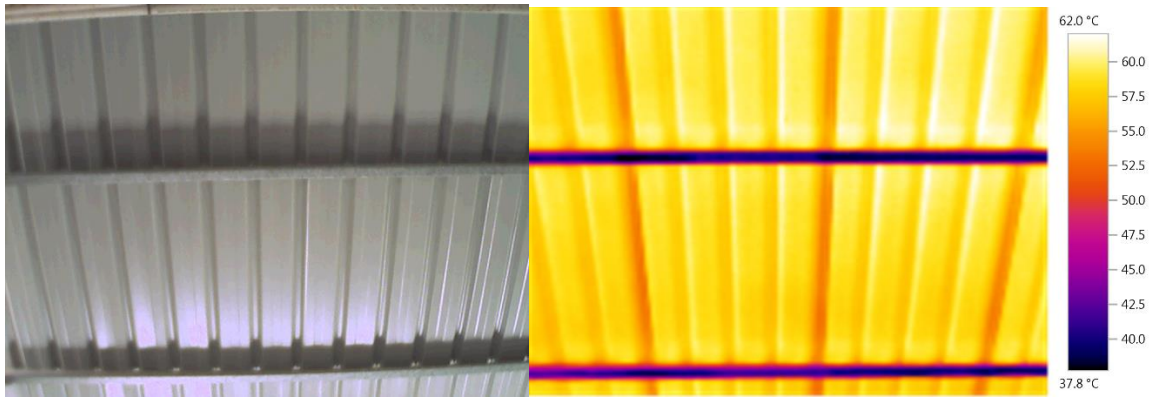


Figure 2: Visible light and infrared images of a 60 °C roof

Where air conditioning is unavailable, lightweight buildings have distinct advantages. If they are well ventilated, they can rapidly dissipate heat generated inside the building. A fundamental limit with such buildings is the ambient air temperature, which typically ranges from 29 °C to 32 °C during daylight working hours in northern Australia. This temperature limit could be reduced by growing shade trees and shrubs around the building to provide both shade and transpiration cooling.

The high thermal mass buildings usually had some form of insulation and frequently included low emissivity insulation in their roof space. They responded reasonably well to air conditioning. However, air conditioning works best when the space is sealed from ventilation, and this means that the buildings stored the heat generated by people, appliances and windows, particularly if the buildings were heavily insulated or contained appliances with a high electricity consumption. Consequently, unless air conditioning was run all night, the building temperature was invariably higher than the ambient temperature at night. Controlled forced ventilation should work very well after the air conditioners are switched off and the outside air temperature has cooled, allowing air conditioned high thermal mass buildings to be cooled in winter or at night. Figure 3 demonstrates the temperature reduction that could be achieved. It is based on the difference between the summer average diurnal minimum temperature and the night-time ambient temperature in the buildings studied; it does not include rooms that are conditioned overnight.

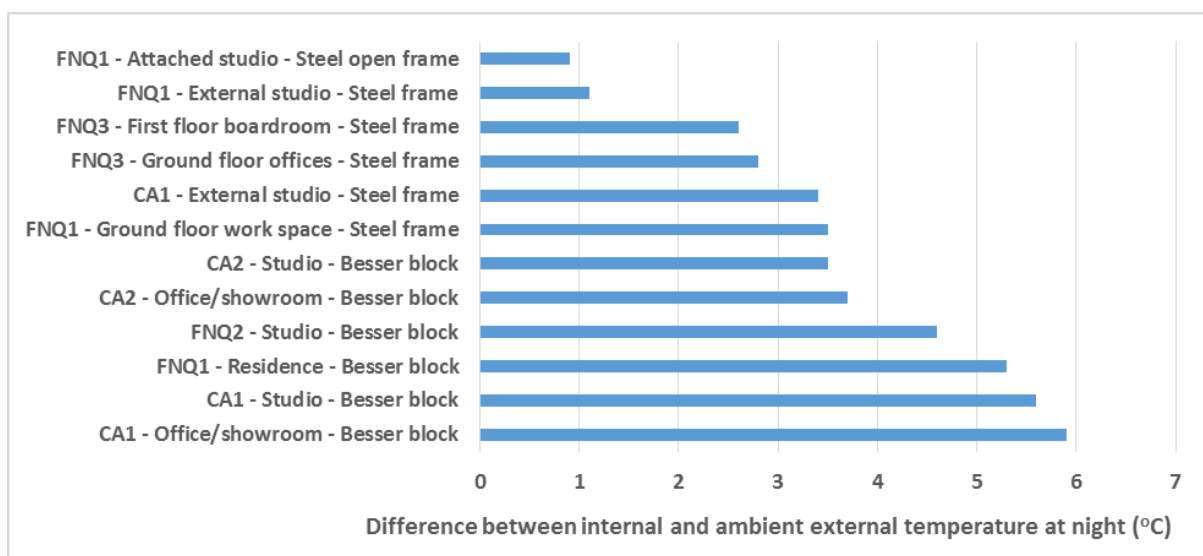


Figure 3: Research sites – summer night ventilation cooling potential for each building construction type (for rooms that are not air conditioned overnight)

2.3.1 Location of heat-generating appliances

In all the research sites, the offices, showrooms or keeping places⁷ contained a variety of computer and telecommunication equipment. The telecommunication equipment appeared to be left on all night, and in some offices the computers may have been on standby as well. This contributed to a higher than expected cooling energy consumption as well as office temperatures that were higher than in the studios. Controlling out-of-hours electricity consumption has the potential for direct savings, if such appliances can be switched off, and for additional indirect savings from the reduced load on air conditioning. It may be worth, if possible, completely switching off such equipment at night or siting it in a dedicated room, cupboard or annexe, with specific cooling to maintain the equipment's required operating temperature. This should be a consideration in the design of new buildings as well as when new equipment is installed.

2.3.2 Role of AccuRate

All eight buildings studied were simulated by AccuRate. The temperature measurements were compared with the external ambient temperatures assumed by AccuRate and with the temperatures it predicted for rooms in the buildings. AccuRate was also used to compare the measured and predicted heating and cooling electricity consumptions to assess the difference that building improvements might make to the building thermal efficiency.

AccuRate can make assessments with or without an air conditioner, termed 'rating mode' and 'free running' respectively. In rating mode, AccuRate produces a star score from 0 to 10 stars, where 6 stars represents a building that is regarded as good at keeping places cool in summer and warm in winter for the minimum energy consumption that readily available technology allows.

While AccuRate was a useful tool for this work, it is designed for residential buildings and for less extreme environments. The following are some key suggestions to enable AccuRate to more capably model the energy efficiency of buildings designed for remote communities in FNQ and CA:

- The assumed values for ambient temperature around the outside of the building were too low. This may be due to the paucity of Bureau of Meteorology (BoM) stations in the regions we visited, or the temperature gradient between a building and the open isolated space that is considered ideal for BoM stations. This led to predictions that significantly underestimated the cooling capacity needed for a building.
- There is no capability for assessing the impact of using low emissivity foil to reduce the radiation temperature of solar-heated roofs. This is a key requirement where buildings have no ceiling and is even more important if they have no air conditioning.
- There is no capability for assessing the impact of intermittent controlled forced ventilation for cooling high thermal mass buildings at night.
- The occupancy and heat load assumptions are too low, particularly for office areas.

2.4 Saving electricity

The electricity consumption was monitored on each sub-circuit of each of the eight buildings minute by minute for nine months. There were two or three interruptions in two buildings that lasted for several weeks when power cards ran out of credit. No adjustment was made for these interruptions, as they were considered to be normal usage. Data interpolations were made for interruptions that lasted several weeks in

⁷ A keeping place is where repatriated cultural material can be kept; it can hold objects of ongoing spiritual and cultural importance and so is more than a simple storage area.

one building due to a local building power failure and for three data-logging equipment failures lasting one or two weeks each. The key observations from these measurements included:

- All the research sites were frugal in their use of electricity, so savings were more likely to be found in the way equipment was operating than in an examination of occupant behaviour.
- 40–50% of the electricity consumption was used for air conditioning and 30–40% was used in appliances running from general power outlets (GPOs).
- In FNQ, 40% of the electricity consumed was being used outside the working hours of 9 am to 5 pm, and it appears that most of this electricity consumption is unnecessary.
- Electricity consumption in FNQ was three to four times greater than in CA.
- Electricity consumption for cooling in FNQ was twice as great as the equivalent usage in CA.

2.4.1 Distribution of electricity consumption

The distribution of electricity consumption between remote art centre sites is shown in Figure 4.

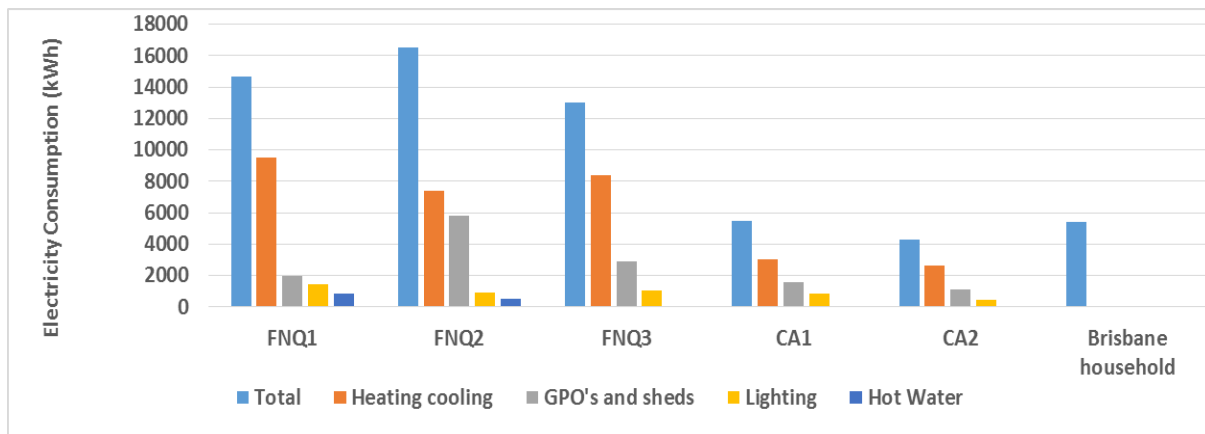


Figure 4: Art centres – comparison of distribution of electricity consumption

At all sites, space heating and cooling is the dominant consumer of cooling energy. The CA1 and CA2 sites use the least electricity for cooling; however, CA2 is the only site to use evaporative coolers that produce approximately three times as much cooling per kilowatt hour (kWh) as the reverse cycle air conditioners used in the other sites. Evaporative cooling is not practical in FNQ because of the high humidity. On this basis, the FNQ sites are using two to three times as much electricity for cooling as the equivalent CA sites.

FNQ1 and FNQ2 are the only sites that run an air conditioner for 24 hours a day in their showroom or keeping place. FNQ1 has an exceptionally high consumption by its only functional air conditioner, which is running 24 hours a day in a room that has a very high thermal leakage with a star rating of 0.

Appliances run from GPOs are the other major consumer of electricity. The differences here in electricity consumption relate to the after-hours operation of these appliances, which is much higher in FNQ than in CA. This may be a side effect of their multiple buildings and the consequent difficulty of ensuring that everything is switched off before leaving.

2.4.2 Electricity consumption outside working hours

Electricity may be used after hours because it is required, for example, to run emergency lighting. It may also have been inadvertently left switched on, or the appliance may not have been switched off at the GPO but only at the appliance or by using a remote. It is obvious that leaving an appliance switched on from 5 pm to 9 am is going to consume a great deal of electricity; it is less well known that switching it off at the appliance while leaving it switched on at the GPO can also consume significant quantities of electricity. Of the total energy consumed, it was typical that 40% of it was the out-of-hours consumption for the appliances in this study.

2.4.3 Equipment left on or running in standby

Standby power is the power that remains switched on if an appliance is turned off using only the appliance on/off switch or a hand control. Over a year, equipment left in standby can typically consume from 10 kWh to 1 MWh, enough to run a small heater continuously for a month. To turn an appliance completely off, including the standby power, it is a useful precaution to switch off first at the appliance and then at the GPO. Switching on should follow the reverse sequence, first on at the GPO then on at the appliance. Using this sequence sometimes extends appliance life and ensures that appliances start up in a controlled manner and without a power surge.

2.4.4 Reducing electricity consumption outside working hours in air conditioners

Air conditioners can use standby power in two ways: i) maintaining timers, clocks and sensors for temperature and humidity control, and ii) some larger, older design units will also run heaters on standby to stop refrigerant from pooling. If an air conditioner is consuming excessive electricity on standby, then it would be worth contacting the supplier and asking if the unit can be safely switched off at the GPO. Alternatively, it is now possible to buy air conditioners with very low standby electricity consumption and which can be switched completely off. This could be worth planning for when the present high consumption unit reaches the end of its life.

2.4.5 Reducing electricity consumption outside working hours in other appliances

Whereas air conditioners dissipate most of their waste heat outside the building, non-conditioning equipment that is switched on will heat the building: 100 kWh of standby electricity is equivalent to 100 kWh of heating. This is particularly a problem in high thermal mass buildings, such as those built with besser block, where the heat cannot quickly leak away.

Whether telecommunication equipment can be switched off depends on the need for continuity of service, either for the user or the service provider. As with air conditioners, the equipment manufacturer and service provider should be asked if their telecommunication equipment can be switched off outside working hours.

Computer equipment seldom runs at full power when it is not being used and has several levels of standby if left to shut down by itself that can be programmed by the user. However, the most certain way to avoid wasting electricity is to switch the computer off at the GPO.

2.4.6 Automatic rather than manual shutdown

It can be very inconvenient in a large complex of buildings to switch off equipment at a GPO. This is made easier by setting up clusters of appliances that can be switched off with one automatic timer. Where rooms such as keeping places may be sensitive to temperature or humidity, the timer should incorporate humidity and temperature sensors. These are not readily available commercially, but given the significant cost

savings, and that commercial and residential buildings in general could benefit from such controllers, a program to produce custom-built controllers may be worth considering.

Out-of-hours electricity consumption ranks with building design as having the greatest impact on saving electricity in the research sites studied. Table 2 demonstrates the seriousness of this problem, showing the out-of-hours load and its percentage of the full load for the air conditioners, the GPOs and the total. Air conditioners and GPOs are the greatest contributors to out-of-hours electricity consumption, with very minor contributions from other loads. Managing the issue could save up to 20% of the electricity consumed at the CA sites and up to 50% for the three research sites in FNQ.

Table 2: Research sites – comparison of out-of-hours electricity consumption of electrical services

Location	Total load (OH)	Heating and cooling (OH)	GPOs (OH)
FNQ1	7.2 MWh (50%)	5.1 MWh (54%)	1.0 MWh (45%)
FNQ2	7.2 MWh (46%)	2.2 MWh (30%)	3.7 MWh (64%)
FNQ3	5.5 MWh (42%)	2.8 MWh (39%)	2.1 MWh (49%)
CA1	0.9 MWh (16%)	0.7 MWh (23%)	0.2 MWh (60%)
CA2	0.7 MWh (17%)	0.2 MWh (9%)	0.4 MWh (40%)

2.5 Key observations and recommendations

The recommendations are targeted towards four stakeholder groups:

1. the managers of the five research sites
2. the local community
3. state/territory governments
4. industry building standards organisations.

Only key recommendations that can be generalised across all research sites are given here. Reports to individual centres will be more comprehensive and specific.

2.5.1 Improving thermal comfort in buildings, especially those without air conditioning

The research sites in both FNQ and in CA had average apparent temperatures during the day of 32 °C in their air conditioned spaces. These temperatures imply a frugal use of air conditioning. Only one site had work rooms that were not air conditioned, and these were unusable due to thermal stress from late spring to early autumn during a significant proportion of the working day. The users of these spaces seemed aware of the issue and occupied the buildings accordingly, including using one or two of the buildings in the relatively cool late evening.

It should be possible to significantly increase the available working hours for the unconditioned buildings using controlled ventilation, wall insulation, low emissivity foil insulation for roofs, and plants for improved shade and transpiration cooling. The low thermal emissivity foil could be usefully fitted into all the buildings that had exposed roofs (i.e. no ceilings). Temperatures on the underside of these roofs were measured as high as 62 °C using infrared photography. Such high roof temperatures can raise interior temperatures significantly where there is no air conditioning and increase energy consumption where there is air conditioning. Likewise, controlled ventilation to take advantage of cool night air could be useful for the high thermal mass better block buildings. Such ventilation would ensure that heat build-up during the

day was removed and allow insulation to be used to reduce air conditioner electricity consumption. Several buildings had no insulation in the ceilings, and none had comprehensive wall insulation.

2.5.1.1 Specific recommendations

- Use low emissivity foil with a suitable spacing/insulating element on the underside of all roofs without ceilings. This could reduce the temperature in a room by 5–10 °C in summer. If it is not possible to install foil, instead use a white surface covering such as sarking to give a partial improvement or, alternatively, paint the roof white.
- Plant shade trees and shrubs around the building, but do not obstruct breezeways.
- Replace skylights with commercial high R-value translucent honeycomb skylights.
- Use the building, landform and fans to control breezeways. Utilise natural breezeways (mountains, corridors, sea breezes) and locate the coolest air around a building for night ventilation. This may require installing a security mesh on doors and windows to secure against intruders or insects, while still allowing the passage of air.
- If heating is likely to be a problem in winter in CA, include insulation in ceilings and walls and seal off uncontrolled air leaks but ensure there is ample controlled ventilation for use in summer months. Include north- and west-facing windows or skylights with external controllable blinds or shading angled to block the summer sun but let in the winter sun to heat areas of high thermal mass, typically a cement floor that is raised or insulated from the ground.
- If the building is too large and open to be economically air conditioned, for example a large, highly ventilated shed, consider constructing a relatively small thermally insulated air conditioned office or workspace inside the building for use by occupants who need to work for long periods in summer.

2.5.2 Saving electricity

Electricity was used frugally in the FNQ and CA research sites. However, there was a very significant level of inadvertent out-of-hours electricity consumption from appliances such as computers and telecommunication equipment, and it is likely that the 24-hour operation of air conditioners in artwork storage areas was also unnecessary. Out-of-hours electricity consumption accounted for 40% of electricity consumption in the FNQ research sites either because equipment needs to be left running, equipment has been left on inadvertently or equipment is running on standby electricity. This is where most savings can be made in electricity consumption.

In two cases, air conditioners were being run 24 hours a day to safely store valuable artworks. In one of these cases, a single air conditioner was using 70% of the centre's electricity in an effort to cool a low thermal efficiency art storage area. In both cases, controlled night ventilation may have been sufficient to maintain the temperature. Humidity, which is a key issue for storing artworks, could be managed using a humidity control on the ventilation fan.

The two art centres in CA consumed relatively little electricity, possibly because the low humidity made safe storage of artworks less energy-dependent, and the smaller building complexes would have meant that switching off appliances outside working hours was easier to manage. Nevertheless, there were opportunities to save electricity by reducing the out-of-hours operation of computer and telecommunication equipment.

2.5.2.1 Specific recommendations

- Determine if equipment really needs to be switched on at the mains outside working hours and either switch off or replace equipment that consumes a high level of standby electricity. Managing this is the single most cost-effective energy-saving measure that can be carried out in the research sites visited.
- Reconsider the practice of leaving fans running in a building when absent. This is a valid practice to avoid mould during periods of high humidity but may not be needed 24 hours a day all year round. Use timers or controllers with timing and temperature/humidity sensors.
- If buildings have air conditioning, insulate the ceiling and, if possible, the walls. Also ensure that high thermal mass buildings are ventilated at night when the air conditioning is switched off and the outside air is significantly cooler than inside the building. Use timers to control the ventilation. If the building contents are sensitive to temperature and humidity, use controllers with timing and temperature/humidity sensors.
- Locate electricity-intensive appliances away from offices and studios and preferably with a localised source of cooling specifically for the equipment.
- When lights are due for replacement, substitute existing with LED lights.
- One CA site now has PV and both CA sites have solar hot water. Consider installing solar hot water and solar PV at the remaining CA and FNQ sites.

2.5.3 Reducing hazards in evaporative coolers

Evaporative coolers require low to moderate humidity environments to work properly and are commonly used in Central Australia, where they are often recommended for use in remote communities. They use approximately three times less electricity than reverse cycle air conditioners. However, they are unsafe in remote communities when not appropriately serviced, because they become fire hazards and compromise biological safety if they are not properly maintained.

2.5.3.1 Specific recommendations

- Use reverse cycle air conditioners rather than evaporative coolers if adequate maintenance is not available.
- If evaporative coolers are to be used, ensure they are fitted with non-flammable filter material.
- Consider chemical water treatment or demineralisation filters to reduce scale build-up.
- Carry out regular (monthly) inspections of water tanks, pumps and sprinklers.
- Shut down and drain the tanks of any evaporative coolers where the sprinklers or pump have failed.
- Set up drainage or irrigation processes to manage water run-off from evaporative cooling systems to avoid algae spread.

3. Methodology

3.1 Objectives and scope

The methodology is designed to provide an information base to reduce energy costs and improve liveability of buildings in remote northern Australia. The findings are to be delivered to multiple stakeholders:

- enterprise building managers
- local communities
- state and territory governments
- industry building standards organisations
- architects, builders, appliance manufacturers and building energy efficiency researchers.

The findings draw on case studies of the energy efficiency of steel frame and besser block enterprise buildings in arid and tropical climate zones in FNQ and CA. The study focuses on physical measurements and makes no attempt to directly assess occupant behaviour.

The scope of the study comprises architectural, thermal and electrical measurements and analyses of eight buildings. Four structural types have been selected, including buildings of high and low thermal mass, both of which have examples that are highly ventilated or with restricted ventilation. The buildings are located in two climate zones: Building Code of Australia (BCA) Climate zone 1 – High humidity summer, warm winter; and BCA Climate zone 3 – Hot dry summer, warm winter.

3.2 Research schedule

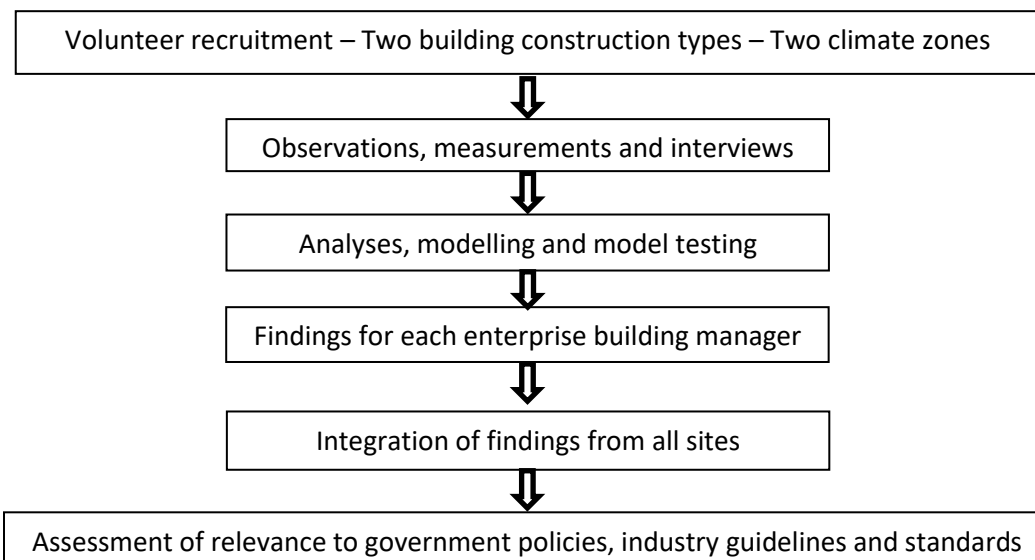


Figure 5: Outline of the process for acquiring, analysing and applying the study's data

3.3 Recruitment

A minimum of four buildings were required to represent the two types of construction in the two climate zones and in order to manage the inevitable contingencies expected when working in isolated communities. Eight buildings/structures were selected.

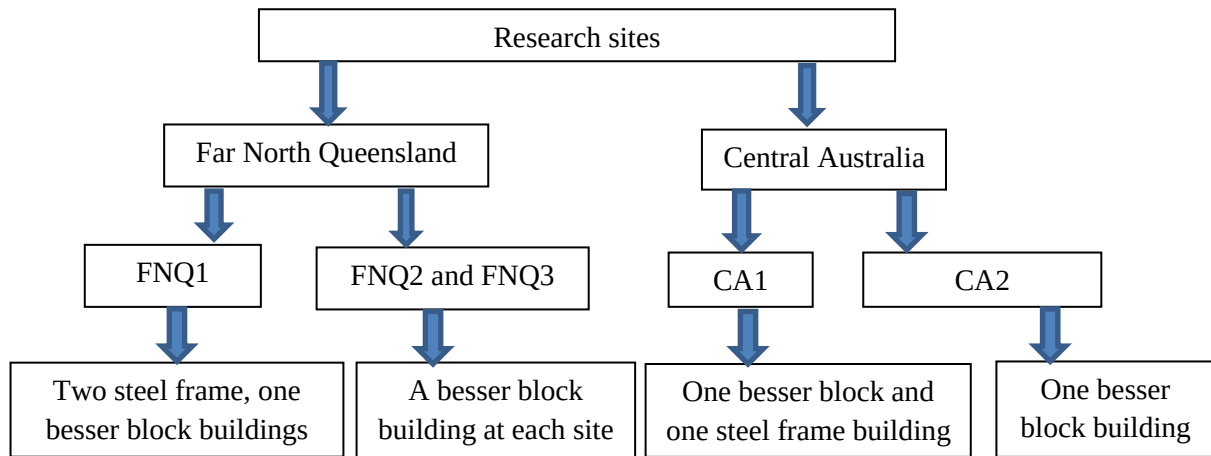


Figure 6: Research sites – geographic distribution of building construction types

Four art centres were selected for the study, as they included a range of enterprise building types, were expected to have similar electricity requirements within each climate zone and were likely to have long periods occupied and unoccupied so that the buildings could be studied in both active and passive states, that is, with both low and high thermal and electrical loads. A residential building used as an Aboriginal Corporation office became available as a fifth research site and was included to supplement the analysis of office equipment thermal loads and standby operation.

Confidentiality extends to the personal information of the building managers and occupants but allows freedom to use the measured data and disseminate the results. In return for assisting the study, the building management was given the energy monitoring system at the end of the study and provided with support to keep it running for two years. The management of each research site will also receive a report with recommendations on energy-saving strategies focused specifically on their research site's buildings. This research received ethics approval from the CSIRO Ethics committee operating under a reciprocal agreement with the Central Australian Human Research Ethics Committee ref 2009.10.C12.4.

3.4 Safety issues

Appropriate practices were implemented and three safety issues dealt with as follows:

- Two residential buildings were removed from the study because of fall hazards associated with excessively slippery roofs and inaccessible wiring.
- Hazardous wiring and overloading were encountered in two sites, and these were rectified as per normal trade practices. Advice on improved distribution of loads was provided.
- During the study, a number of small smouldering fires occurred in evaporative coolers. Improved maintenance procedures were recommended, and the faulty equipment was closed down. This could be a widespread problem and is further discussed in the general recommendations.

- One building was labelled as having asbestos present, so appropriate precautions were taken. Indirect assessment and infrared measurements were used to characterise sealed wall or roof insulation instead of drilling to take samples or make viewing ports.

3.5 Observations, measurements and interviews

All buildings were surveyed, their construction materials noted and schema drawn up to describe building and room dimensions, window and door dimensions, skylights, wall and roof materials, insulation, lighting, the location of heating and cooling appliances and the location of temperature and humidity sensors.

Infrared photography was used to assess the temperatures of broad or inaccessible areas, such as roofs, and optical photography was used to describe particular features of the building as well as identify the location of temperature and humidity sensors.

Major appliances were identified, their power rating noted and, where practical, direct measures of their electricity consumption were taken and recorded.

Temperatures were logged at approximately 100 locations across all of the buildings from 1 June 2015 to 29 February 2016. The sensors were located to record ambient values within the principal rooms of the buildings at ten-minute intervals and temperature differentials across windows and walls at hourly intervals. External shaded and unshaded temperatures were measured at hourly intervals. Humidity levels were logged at two or three locations inside each building, and readings were obtained from the nearest BoM weather station.

Data loggers were set up to monitor the voltage, current and power factor of each switchboard sub-circuit. From 12 to 38 sub-circuits were monitored in each building, sampling each circuit once a minute. Backup power supplies and automatic resetting modems were used to ensure the equipment could recover from any power or communication service failures. Electricity consumption data was stored locally at the data-logger site and downloaded each day to a central secure data bank. Temperature and humidity data were downloaded manually each season during site visits.

Informal and formal interviews were carried out with each building manager and, where possible, with a few builders, architects and maintenance personnel associated with the buildings.

3.6 Analysis and modelling

The aim of the analysis was to identify and prioritise actions needed to improve the building thermal environment so that occupants can carry out their work more effectively and comfortably. The methodology was derived from techniques used in *The evaluation of the 5-star energy efficiency standard for residential buildings*⁸. The two principal areas addressed were building thermal efficiency and electricity consumption.

3.6.1 Building thermal efficiency

The temperature methodology was an important basis for analysing the AccuRate star ratings and the accuracy of the model's temperature and energy-use predictions. At each site, the sensors for best

⁸ Ambrose MD, James M, Law A, Osman P, White S. 2013. *The evaluation of the 5-star energy efficiency standard for residential buildings*. CSIRO, Australia. Available from <http://www.industry.gov.au/Energy/Documents/Evaluation5StarEnergyEfficiencyStandardResidentialBuildings.pdf>.

measuring the outside temperatures, both shaded and unshaded, were identified. These sensors values were compared to each other and averaged to create a full nine-month record of estimated local outside building temperatures at all sites but FNQ1, due to the loss of a sensor. These values were compared against the closest appropriate BoM weather station, in some cases a few kilometres away and in others several hundred kilometres away. These values were also compared against the assumed outside values that AccuRate uses. Where possible, working hour calculations used sensors that were closest to the building being investigated.

Building thermal efficiency was assessed using methods adapted from AccuRate. While we report a star rating, our recommendations are based on the energy efficiency values derived from AccuRate and qualified by direct measurements of temperature and energy consumption. Discrepancies between AccuRate and the measured results were analysed to compare:

- temperature measurements from the project sensors and from the nearest BoM station with the values that AccuRate assumes or predicts for buildings in the region being measured. These were measured under both passive and active heating and cooling regimes, that is, with and without air conditioning
- measured heating and cooling energy consumptions vs. the values calculated by AccuRate.

This approach serves two purposes. It provides a baseline model of nationally accepted building thermal efficiency against which the building's thermal characteristics and potential improvements can be measured. However, it also provides the opportunity to evaluate whether significant discrepancies are due to a deficit in the building design and construction or whether the NatHERS model AccuRate could usefully be adapted to the conditions and usage of remote enterprise buildings.

3.6.2 Electricity consumption

Electricity consumption was assessed at the switchboard sub-circuit level in each building. Details of the equipment used for these measurements are given in a separate appendix.⁹ The analysis of these consumptions focuses on identifying excessive, ineffective and faulty appliance usage and on whether the standby energy consumed when an appliance is apparently switched off has a useful purpose. A secondary focus was the waste heat that all appliances produce as a by-product of doing useful work. This is considered as an additional load on air conditioners and evaporative coolers and as a negative load when heaters are occasionally used in winter. The cost of electricity was determined from whatever electricity bills could be made available by the building manager.

Figure 7 is an example of the average diurnal consumption for GPOs left switched on in this study. It shows there are appliances consuming electricity outside working hours, but it does not indicate if the electricity is due to standby consumption or an appliance that has been left running.

⁹ Enquiries should be addressed to Peter Osman, peter.osman@csiro.au.

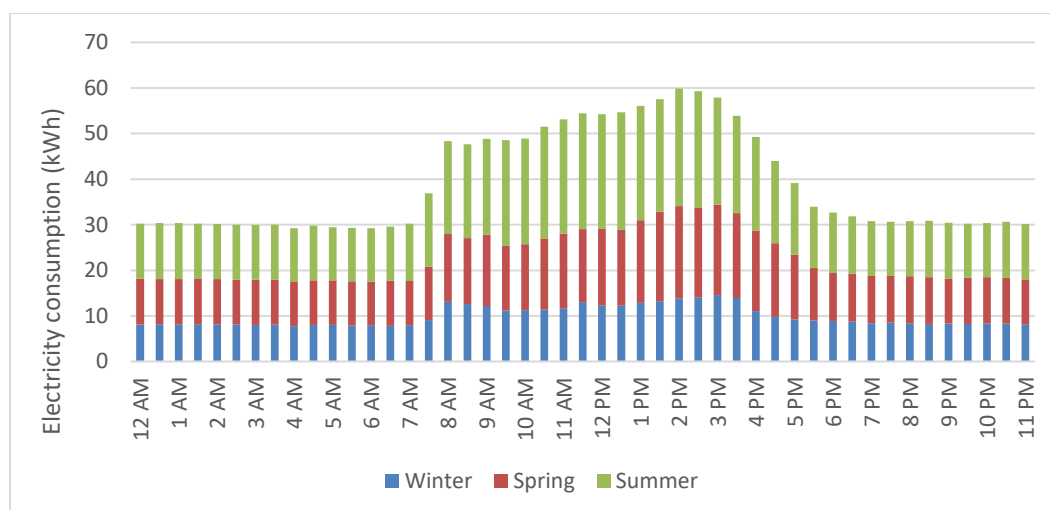


Figure 7: Example of diurnal electricity consumption from general power outlets for winter, spring and summer

Each power and lighting sub-circuit supplied a number of different fixtures and appliances, including space heating equipment, whereas air conditioners and evaporative coolers tended to have dedicated power circuits. A new method that evaluated the energy and duration of consumption associated with different operating power levels was used to identify appliances in sub-circuits that supplied a number of GPOs. It also enabled us to discriminate between standby and operation of appliances on dedicated sub-circuits. Figure 8 shows plots for an appliance that over the nine-month period of the study: i) runs 24 hours a day, ii) runs through the day and is left on standby outside working hours, and iii) is left completely switched off outside working hours.

When the hours (red line and right-hand y-axis) are close to zero at zero power and if the blue bars (energy consumed) are high at high power, then the appliance is running most of the time.

If the hours (red line and right-hand y-axis) are close to zero at zero power and are high at low power, then the appliance is running most of the time on standby and is making a significant contribution to the total energy consumed.

If the hours (red line and right-hand y-axis) are very high at zero power, then the appliance must be switched off outside working hours.

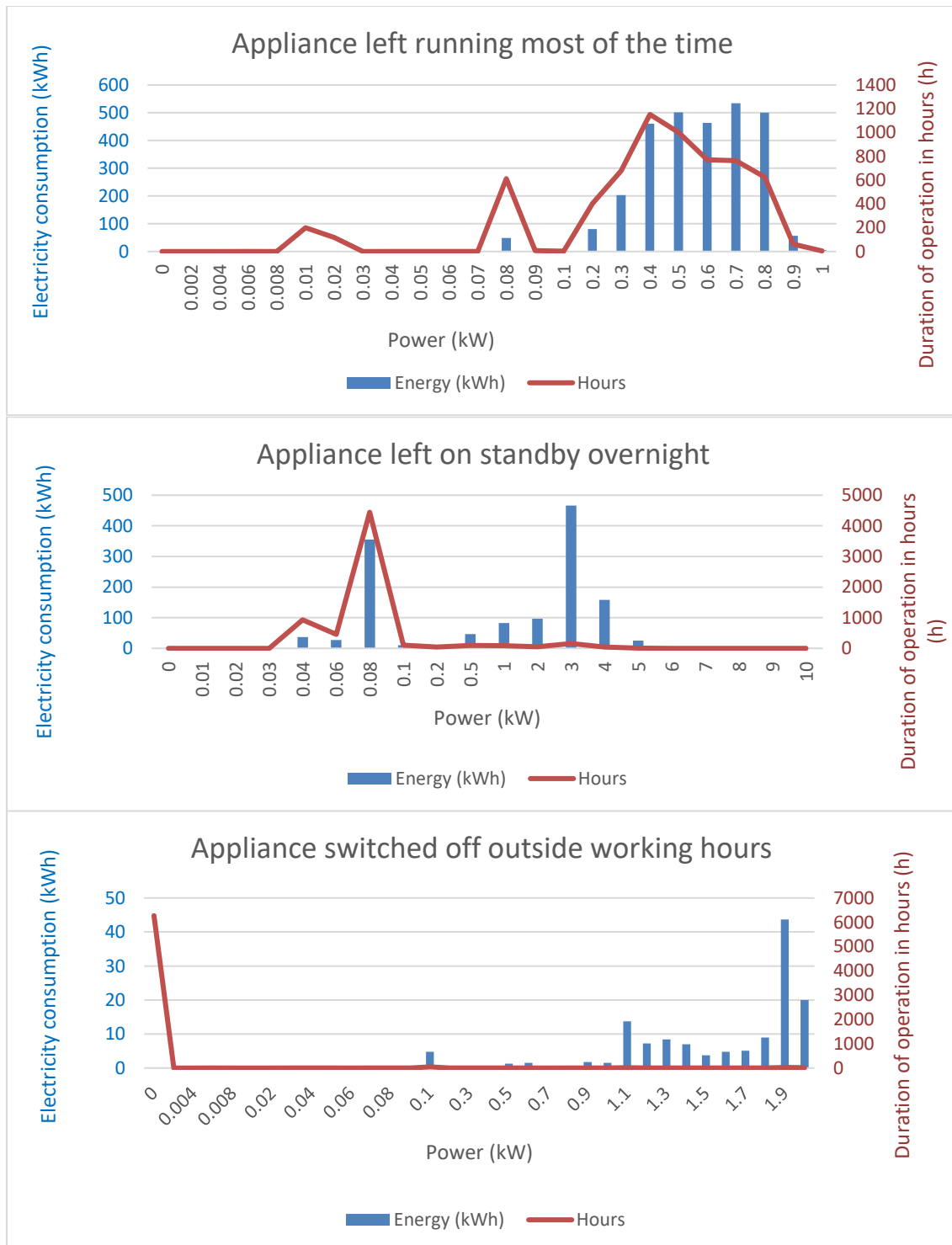


Figure 8: Discriminating between appliances left running, left on standby or switched off

3.7 Development of recommendations

The next five sections contain assessments for each of the eight buildings. Each assessment is in three parts:

- a building thermal efficiency assessment using an AccuRate model to determine changes to the building that would improve its thermal efficiency
- an assessment of the temperatures measured in the building and surrounding environment and a comparison of the measured temperatures with those predicted by AccuRate
- the potential for reducing electricity consumption.

The recommendations derived from these assessments focus on the following:

3.7.1 Building upgrades

- the applicability of natural or forced ventilation
- shading strategies and low emissivity foil insulation for roofs
- wall and ceiling insulation for summer and winter, conditional on first removing internally generated unwanted waste heat
- sealing to prevent uncontrolled air circulation from draining away cooled or heated air

3.7.2 Reduction of electricity consumption without loss of amenity

- automatic or manual shutdown of appliances that are not supplying useful work
- assessment of value or otherwise of standby energy in specific appliances
- management of waste heat where a significant number of appliances are being used

3.7.3 Improved safety and comfort

- reducing excessive heat and humidity for safety and to enable work to be carried out more effectively and comfortably
- removal of specific hazards identified during the study

The recommendations are being provided to art centre and corporation building managers in two stages: first a draft recommendations report for their comment and then a final recommendations report for their reference. The comments from building managers about these reports will then be combined with those recommendations that are of general relevance. These will be checked against local and state building recommendations and discussed, where possible, with architects, builders, appliance manufacturers and service providers working in the regions prior to releasing advisory material for communities and policymakers.

4. FNQ1 Art centre

4.1 Background

FNQ1 art centre is based in West Cape York. It has about 30 members, with seven or eight of the artists regularly working at the centre, producing artwork that is sold internationally to private collectors, museums and art galleries. The centre has three buildings: the art centre, which holds the main office and showroom, a work space for sketching and wood sculpting and an attached shed studio; a separate studio used for training, painting and craft work; and the manager's residence. The centre has a total floor area of 630 square metres, excluding the manager's residence.

The art centre is a two-storey wood frame building. The main office and display area is on the first floor, which has the only working air conditioner. Access to the first floor is from an internal staircase leading from the ground floor. The ground floor (workspace) has two storage areas and is normally open along one of the side walls via a set of roller doors. Its front door is usually open, with fans running to maintain a tolerable temperature. Artists tend to work in this area intermittently. The attached studio shed is accessed by a covered walkway of four or five metres length. It is a steel frame structure open on three sides and is used for the preparation of wood sculptures. It also has an enclosed row of toilets and a storeroom adjacent to the wall. For clarity, the analysis focuses on three rooms: the main room on each of the floors: first floor (office/showroom), ground floor (workspace); and the attached studio. The attached studio is included in the analysis but is not modelled by AccuRate, as it was unsuitable for air conditioning and relied principally on forced ventilation for its cooling, with low emissivity roof insulation being the major upgrade required. Forced ventilation and roof emissivity are not yet included in AccuRate's modelling capability.

The external studio is completely separate from the main arts centre building. It is a large, very recently constructed steel frame structure with fibreboard panels and a corrugated steel roof. A side wall and the front entrance can be completely opened using roller doors. At the back of the main building are two annexes. One is a storage area adapted from a shipping container; the second is a washroom. Great care has been taken with natural ventilation in the building, with screened openings along the junctions of the walls and roof. There is no air conditioning and no insulation in the roof. The studio is the biggest room with the greatest occupancy; for clarity, the analysis that follows references just this room.

The art centre manager's residence is a besser block building with a steel roof and besser block internal walls. Each bedroom and the main living area have air conditioning. During the period of the study there were three art centre managers who used the residence intermittently. This allowed us to carry out measurements of both the active and passive heating and cooling states of the house.

4.2 Art centre main building

4.2.1 Building assessment and modelling

4.2.1.1 *Star rating assessments*

The art centre main building was rated 0 stars under the NatHERS energy rating scheme, which is well below the 2 stars typical for buildings of this age.

The building itself is a simple barn-like design and predominantly has steel cladding for the external walls and roof. It is unknown whether insulation has been installed in the walls or ceiling spaces. Given the age of the building it is unlikely that wall insulation is present, so for rating purposes it has been assumed that

the exterior walls and roof are uninsulated. Consequently, the model has also been run with insulation added.

4.2.1.2 Improved star rating – potential upgrades

The main modification scenarios that were modelled through the AccuRate software were:

- painting exterior white
- insulating external walls (unpainted and painted exterior)
- insulating roof (unpainted and painted exterior)
- insulating all (unpainted and painted exterior).

The simulation results from the various modifications are shown in Table 3. The results show that the current building rating of 0 stars can be increased to 2.4 stars by simply painting the exterior white. The style of the building means that the exterior is almost entirely steel cladding; consequently, painting this cladding is a fairly simple solution.

It has been assumed that no insulation is present in the building, but again the style of the building means that adding insulation is a feasible option. Adding insulation only to the external walls increases the star rating to 1.7 stars. Insulating only the roof increases the star rating significantly to 4.1 stars. Insulating both the walls and the roof results in a massive improvement in star rating from zero to 7.4 stars. If, in addition to adding the insulation, the exterior is painted white, the results are 4.3, 5.7 and 7.8 stars for insulating the walls, roof and both respectively.

Table 3: FNQ1 art centre main building – AccuRate star rating scenario results

	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	Accurate Star Rating
Modification	MJ/m²				
Current building	0.1	698.1	154.3	852.5	0.0
Exterior painted white	0.2	445.9	123.1	569.2	2.4
Insulated walls	0.0	509.1	141.6	650.7	1.7
Insulated roof	0.0	317.1	119.6	436.7	4.1
Insulated all	0.0	143.4	99.5	242.9	7.4
Insulated walls (white)	0.1	310.9	112.9	423.9	4.3
Insulated roof (white)	0.0	234.9	108.9	343.8	5.7
Insulated all (white)	0.0	126.0	94.7	220.7	7.8

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software was used to model actual energy consumption verses the theoretical energy consumption. The modelling assumed that conditioned air was required from 8 am to 6 pm each day, and that it was provided by reverse cycle systems with a coefficient of performance (COP) of 3. Only the upstairs areas were considered to be conditioned, with the large downstairs studio space being left unconditioned.

In FNQ1 the ambient temperature varies over a small temperature range throughout the year. The relative humidity is more variable. During the wet season (November–March) it is often in the 90th percentile, while during the dry season (May–August) relative humidity is close to 50%. Consequently, cooling and

dehumidifying the air to make it comfortable is the primary objective, and thus the wet season sees the highest air conditioning loads. Heating is never required. Figure 9 shows the modelling results for the current building.

The simple act of painting the exterior white predicts an 8% energy saving during the high demand period. For the different insulation scenarios it has been assumed that the exterior has been painted white, thus also insulating the roof reduces consumption by around 50%, while fully insulating the building sees a reduction in energy of around 70% during the wet season cooling period.

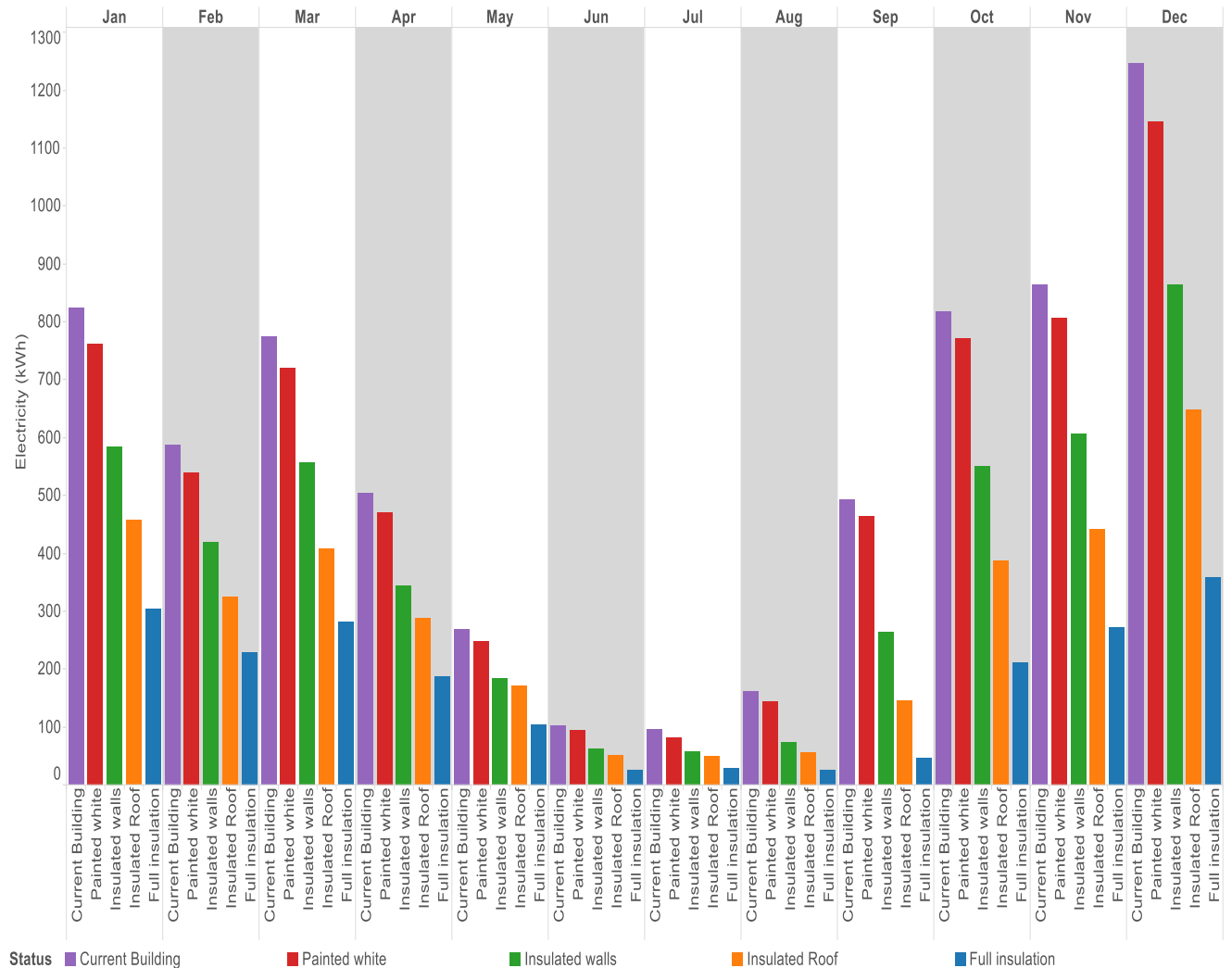


Figure 9: FNQ1 art centre main building – monthly air conditioner electricity consumption for different energy-saving scenarios

Figure 10 predicts the typical hourly use profile during the wet season for each scenario. It can be seen that the peak consumption occurs in the afternoon at around 2 pm for all scenarios modelled. Again, the 50% reduction in energy is seen for the insulated roof and painted exterior scenario. The fully insulated scenario shows a different consumption pattern to the other scenarios with the cooling system cycling on and off during the day to maintain interior comfort, but consuming up to 70% less energy than the current building modelling results.

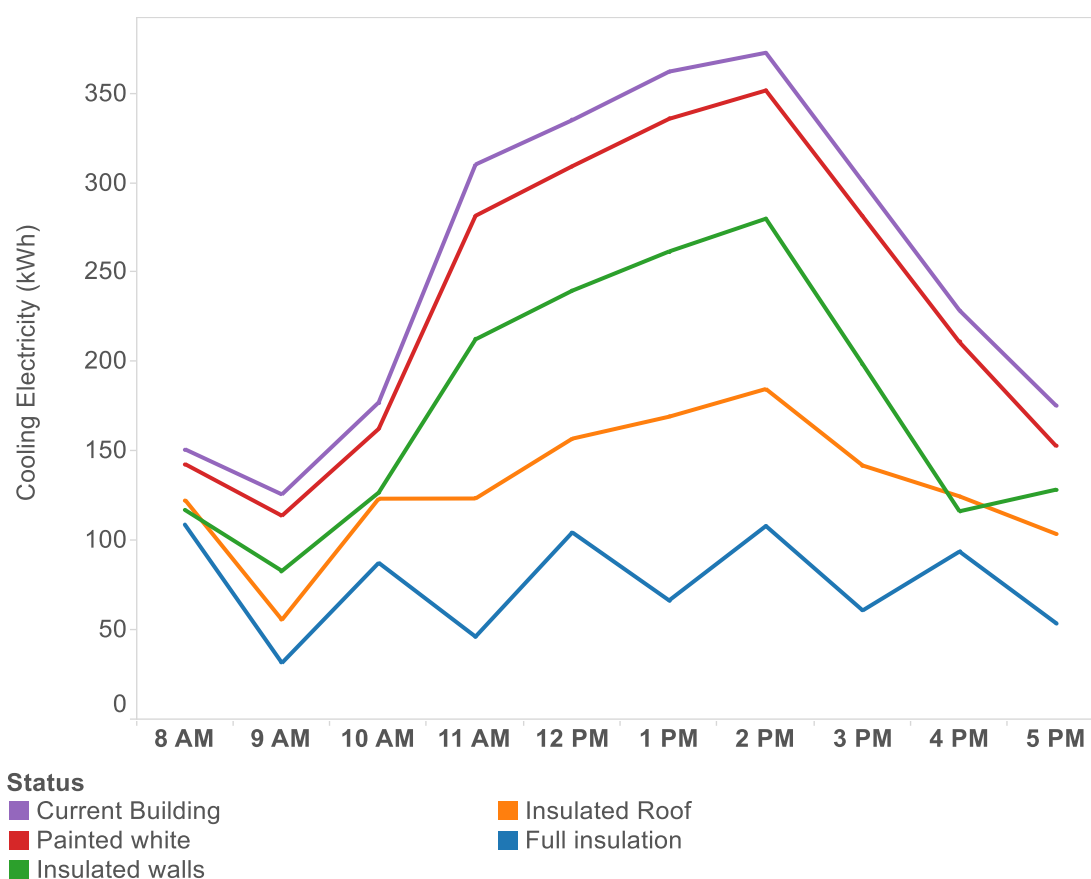


Figure 10: FNQ1 art centre main building – summer diurnal electricity consumption predictions for different energy-saving scenarios

4.2.1.3 Summary observations

The simple act of painting the exterior white results in good energy savings. However, insulating the building as well will deliver energy savings of up to 70%. The upper floor area is the main conditioned space and is suitable for retrofitting insulation, with the roof area likely to deliver the greatest reduction in electricity consumption.

4.2.2 Climate control

4.2.2.1 Outside the building – comparison of BoM, AccuRate and measured temperature values

The maximum and minimum BoM temperatures for winter and summer are close to the measured values in the shade at the FNQ1 art centre.

Table 4 compares the AccuRate assumed outdoor temperatures against the measured values throughout the 24-hour day. In winter, the assumed and measured values are similar. In summer, the assumed values are close to the measured values outside working hours but 4–5 °C lower during working hours.

Table 4: FNQ1 – measured and predicted winter and summer temperatures outside the buildings

Average diurnal external shaded temperatures (°C)	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	18.7	31.2	29.1	24.7	35.5	33.4
AccuRate	19.5	29.9	28.5	24.7	30.5	29.8

4.2.2.2 Inside the office/showroom – measured vs. AccuRate temperature values

The first floor office/showroom air conditioner provides cooling 24 hours a day when the art centre is occupied. Table 5 compares the AccuRate predictions of conditioned air with the measured temperature values. On average, the predictions during working hours were close to the measured values in winter and 2.0 °C below the measured values in summer. This suggests that either the air conditioner had insufficient capacity or its temperature was set high, as the office air temperatures during working hours would be considered high in summer. This is addressed later when discussing air conditioner energy consumption.

Table 5: FNQ1 art centre main building, first floor office/showroom – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): First floor office/showroom	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	18.6	27.4	25.2	20.6	31.1	28.3
AccuRate air conditioned	20.5	27.8	26.5	25.0	27.1	26.3
AccuRate non-conditioned	20.5	28.7	27.3	25.4	35.8	33.6

4.2.2.3 Extreme temperatures

Over the nine-month monitoring period, the extreme values measured in the office showroom when the air conditioner was not running were a maximum of 41 °C and a minimum of 15 °C. In the ground floor workplace there was a maximum of 38 °C, but the minimum was not read as the sensor was lost.

4.2.2.4 Ground floor workspace

On the ground floor, the artists' workspace is not air conditioned but is sheltered by the floor above. It is well ventilated and has very little equipment that produces waste heat. Nevertheless, in summer it is uncomfortably hot and humid and is only tolerable for short periods of time. While the pattern of AccuRate temperature predictions is reasonable, in this space they are biased 3.4 °C lower than the measured values because of AccuRate's assumed outdoor temperatures (Table 6).

Table 6: FNQ1 art centre main building, ground floor workspace – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): Ground floor workspace	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	-	-	-	28.2	34.1	32.6
AccuRate	22.0	27.2	25.7	26.1	31.3	29.2

4.2.2.5 Attached studio

This is essentially a shelter with one wall. Storerooms and toilets are attached to the wall. The roof has no insulation or low emissivity foil, and infrared measurements showed the roof temperature rising to at least 62 °C during the site visits. Figure 11 shows an example of a roof radiating heat into the area under the roof. Table 7 shows the average diurnal temperatures for summer and winter, which were up to 3–4°C above ambient. This could be reduced to near ambient temperatures by reducing the roof temperature using low emissivity foil. AccuRate was not used to assess the attached studio/shed as it has no capability yet for measuring the impact of low emissivity foil and is not intended for assessing open structures (shelters).

Table 7: FNQ1 art centre main building, attached studio – measured winter and summer temperatures inside

Average diurnal temperatures (°C): Attached studio	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	19.0	34.3	31.5	25.6	39.3	36.0

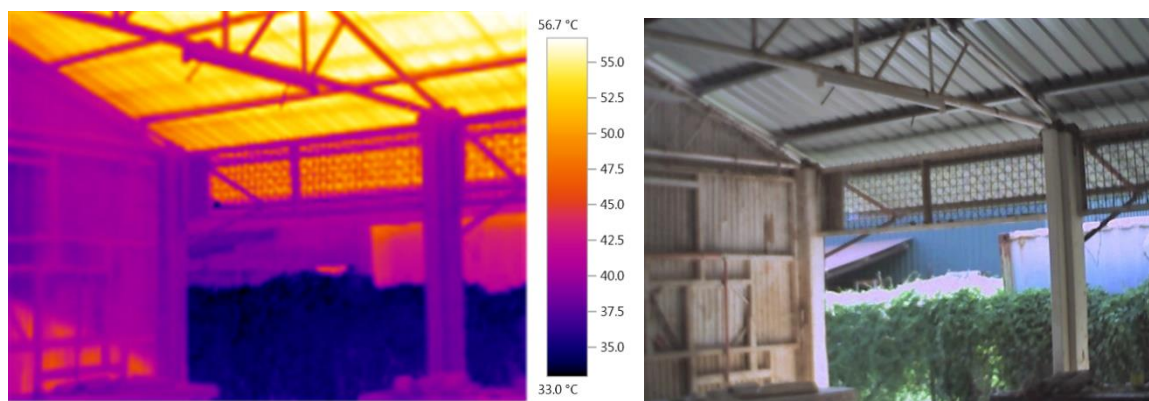


Figure 11: FNQ1 art centre main building, attached studio – visible and infrared images of the roof

4.2.2.6 Summary observations

In summer, the rooms in the art centre buildings rise to temperatures and humidities that are not appropriate for work activity. However, the occupants of these buildings use appropriate judgement and work in these environments only when the temperature and humidity allow. Water and informal rest areas are available. In practice the buildings are usable in mid to late autumn, winter and early spring, but become increasingly unusable in summer.

4.2.3 Electricity consumption management

4.2.3.1 Total electricity consumption

Electricity from the community diesel generator is the principal source of energy. The electricity is supplied via a switchboard managed by the local council. Power shutdowns of longer than two minutes caused by generator failures were very rare. Local partial shutdowns lasted several weeks in the external studio and the residence until power cards were replaced. Figure 12 shows the total consumption for the art centre main building and the external studio. The residence electricity consumption is not included, as it is a private dwelling; it is analysed separately (section 4.4). Total consumption for the art centre, attached shed and external shed is 14,686 kWh. The attached studio accounts for 3% and the external studio for 6%

of electricity consumption. Air conditioning consumes 65%, and this is used in one air conditioner that runs 24 hours a day in the office showroom area when the art centre is occupied. The remaining 26% is divided between lighting, hot water and GPOs that supply office equipment such as computers, printers, modems and general equipment, including standard lights, fans and wood cutters.

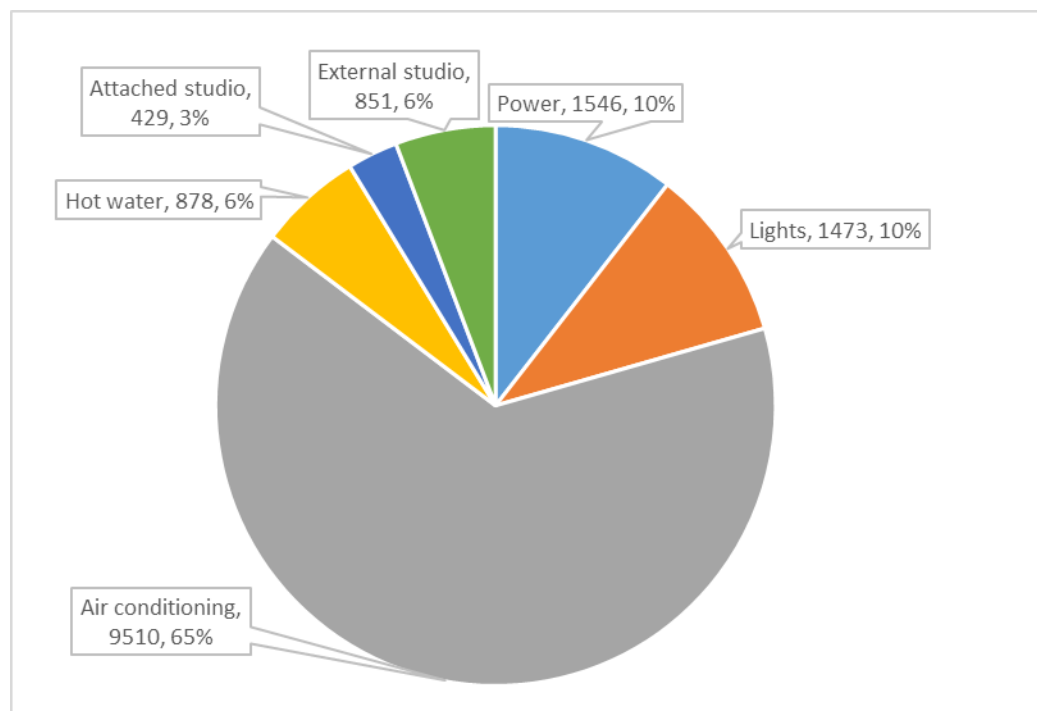


Figure 12: FNQ1 art centre – distribution of electricity consumption in kWh

4.2.3.2 Art centre main building electricity consumption

The electricity consumption for the art centre main building, including the attached studio, is assessed here; the external studio is separately assessed (section 4.3).

The total art centre main building electricity consumption over the nine months was 14.7 MWh, of which 50% (7.3 MWh) was used outside working hours. Table 8 shows which services are being used outside working hours, and the analysis that follows establishes how that energy is being used.

Table 8: FNQ1 art centre main building – hours of operation of building electrical services

Service	Consuming electricity all day nearly everyday	Only consuming electricity during working hours
Lights	✓	
Office general power outlets	✓	
Attached studio	✓	
Office air conditioner	✓	
Hot water	✓	

4.2.3.2.1 Air conditioning electricity consumption

A comparison of the AccuRate models with the measured heating and cooling consumption in the office (Figure 13) shows that the air conditioning electricity consumption is much greater than predicted, except

for December when the building is mostly unoccupied. Waste heat alone is not sufficient to explain this. Figure 14 compares an infrared with a visible light photograph of the office/showroom area. The high temperatures at the roof and the junction between the roof and the far wall suggest that poor roof and wall insulation is also contributing to the thermal load.

There are two air conditioners at the art centre main building. One is rarely, if ever, used and has a negligible consumption, whereas the office showroom air conditioner is used 24 hours a day when the art centre is occupied and is switched to standby with a very low standby consumption when the art centre is unoccupied. Over the nine-month study, the total air conditioner consumption was 9.5 MWh, which accounts for 62% of the art centre's main building electricity consumption. Half of this could be saved by switching off the air conditioner outside working hours. The poor insulation and low thermal capacity of the building suggest there would be very little, if any, comfort benefit in leaving the air conditioner running constantly; it would probably be sufficient to put the air conditioner on a timer that starts up at 7 am and shuts down at 5 pm or 6 pm.

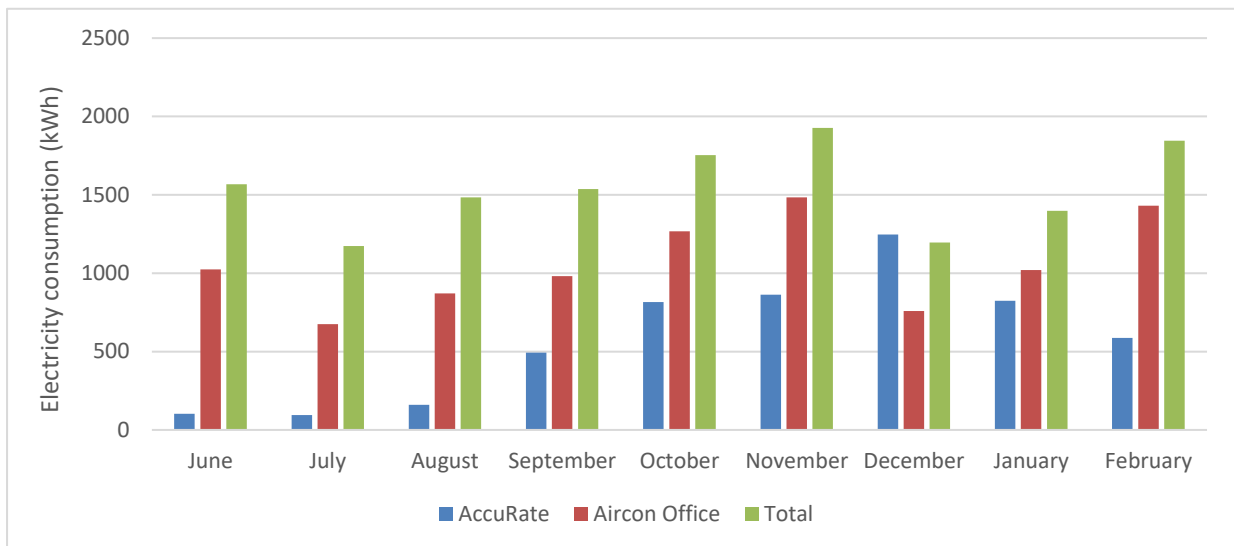


Figure 13: FNQ1 art centre main building – AccuRate vs. measured values for air conditioner and total electricity consumption

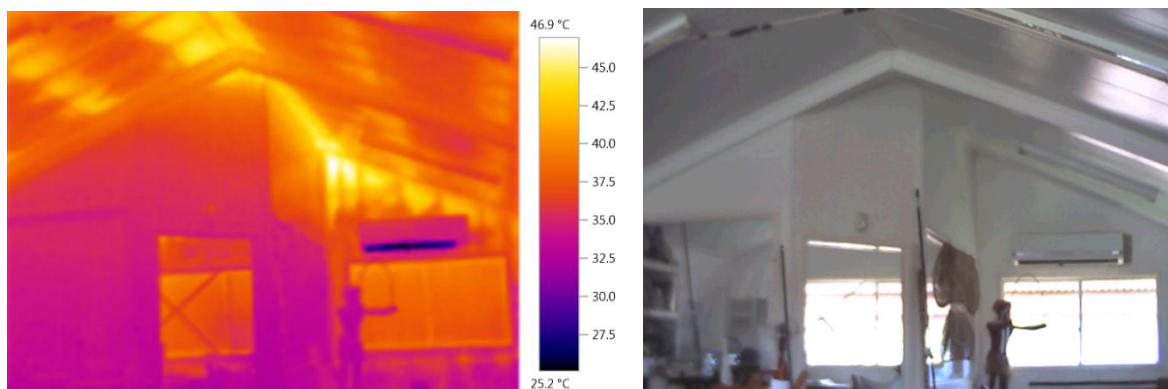


Figure 14: FNQ1 art centre first floor office/showroom – infrared images showing thermal leakage

4.2.3.2.2 General power outlets, lights and hot water

The electricity consumed each season by GPOs is 1546 kWh, with 50% of this being consumed outside working hours (Figure 15). This is probably due to office equipment not being switched off at the GPO. About half of the electricity consumed might be saved by switching off appliances after hours where possible.

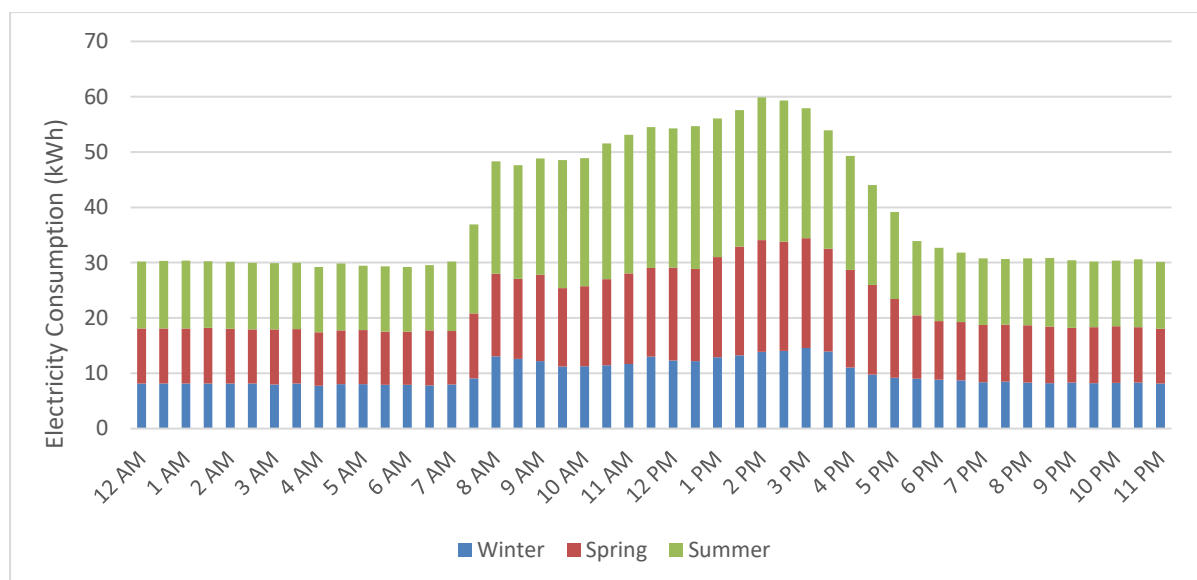


Figure 15: FNQ1 art centre main building – diurnal general power outlet electricity consumption for winter, spring and summer

4.2.4 Recommendations

1. Place the air conditioner on a timer so that it starts up one hour before the working day commences and finishes an hour after the end of the working day.
2. Make sure as many appliances as possible are switched off at the mains outside working hours. When doing this, it is advisable to first switch off at the appliance and then at the mains switch. This may mean initiating timer controls or setting up power boards where multiple appliances can be switched off with one switch.
3. Insulate the ceiling and walls in the office showroom area. An option to consider is using low emissivity foil insulation under the ceiling with the foil facing downwards and with an air or insulation gap between the foil and the roof.
4. Install low emissivity foil insulation under the roof of the attached studio, with the foil facing downwards and with an air or insulation gap between the foil and the roof.
5. Consider planting shade plants around the building.
6. Consider painting the outside roof white.

4.3 FNQ1 External studio

4.3.1 Climate control

The external studio is a completely separate steel frame building in which one side and the front can be opened up using roller doors. It has no air conditioning but can be well ventilated using a combination of fans and natural ventilation. The lowest temperature that can be achieved is defined by the outside air temperature in the shade. The roof has no insulation or low emissivity foil except for a white sarking material that reduces the radiation temperature from the roof by about 1 °C.

4.3.1.1 Winter

Table 9 demonstrates that overnight the air temperature inside the building approaches the ambient temperature. Likewise during the day, the internal temperature rises to an average daily maximum 1.6 °C higher than the external air temperature. The interior temperatures are approximately consistent with AccuRate values when the discrepancy in assumed values for outside temperature is accounted for.

4.3.1.2 Spring and summer

Table 9 demonstrates that overnight the temperatures inside the building approach the ambient temperature as they fall to a minimum. During the day, the internal temperature rises to an average daily maximum (Table 8) about 2 °C higher than the external air temperature (Table 3). AccuRate significantly underestimates the internal temperature by up to 5.3 °C, and this is consistent with AccuRate's assumption of outside temperatures that are 4–5 °C lower than measured during summer working hours.

Table 9: FNQ1 art centre external studio – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): External studio	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	19.3	32.8	29.4	25.8	37.7	34.5
AccuRate non-conditioned	20.0	29.6	28.2	25.1	32.4	31.2

The internal temperatures can reach more than 40 °C at 40% relative humidity. The building is not likely to be usable after midday from late spring to early autumn.

4.3.1.3 Extreme temperatures

Over the nine-month monitoring period, the extreme values measured were a maximum of 43 °C and a minimum of 14 °C.

4.3.1.4 Reducing roof temperature using sarking, foil or shade trees

Figure 16 shows how using a tree for shade and transpiration cooling has reduced the roof temperature inside the building. Likewise, installing low emissivity foil insulation will also reduce the roof temperature by up to 10 °C so that it is close to ambient air temperature during the day and possibly below ambient temperature during the night and early morning. This should reduce the room temperature by at least 3 °C and could be useful from late spring to early autumn.

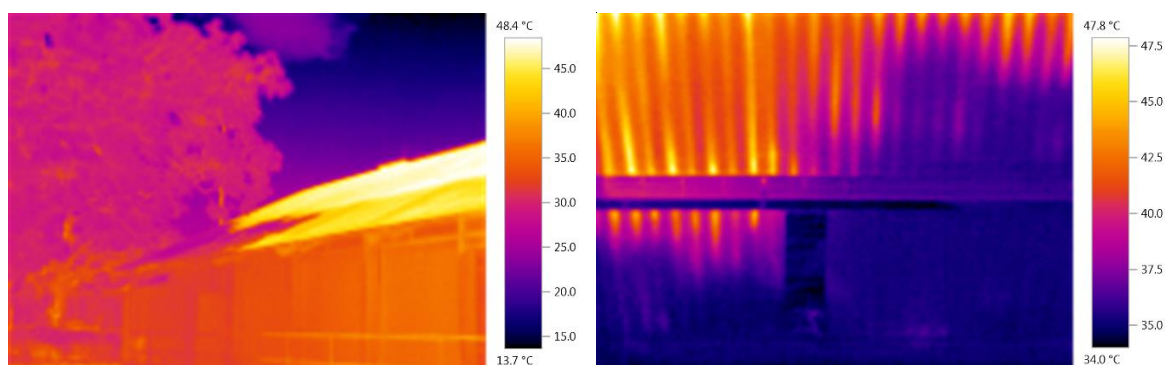


Figure 16: FNQ1 External studio – shade tree reduces the roof temperature from 45 °C to 35 °C inside the building

4.3.2 Electricity management

Electricity from the community diesel generator is the principal source of energy for the external studio. The electricity is supplied separately from that supplied to the main art centre and is controlled via its own switchboard and power card user interface. Power shutdowns of longer than two minutes caused by generator failures were infrequent. Local partial shutdowns due to power cards reaching their limit lasted several weeks to months until power cards were replaced. There is no air conditioning; most of the electricity is used for lighting, hot water and GPOs that supply studio equipment and a washroom (Figure 17). The total electricity consumption over the nine months was 851 kWh. Peak times for usage were between 8 am and midday and 7 pm to midnight (Table 10). The consumption from 5 pm to 9 am was 62% of the total consumption (527 kWh) but it is likely that this was not all standby use.

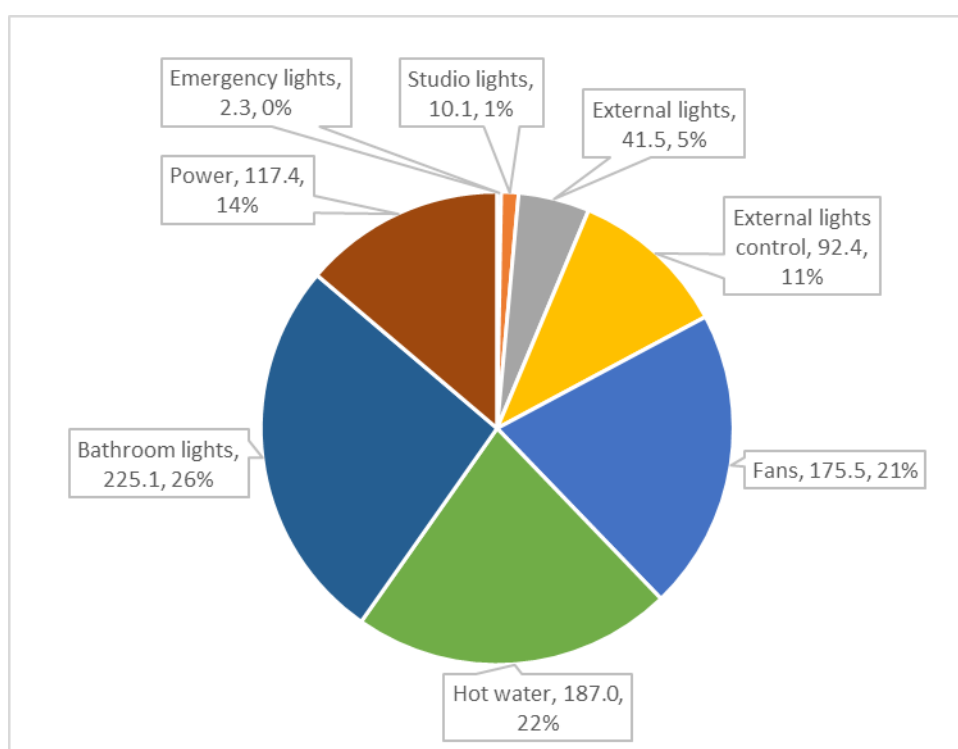


Figure 17: FNQ1 art centre external studio – distribution of electricity consumption in kWh

Table 10: FNQ1 art centre external studio – hours of operation of building electrical services

Service	Consuming electricity all day nearly everyday	Only consuming electricity during working hours
Lights	Some lights: 7 pm to 11.30 pm	
Office general power outlets		✓
Fans		✓
Hot water	✓	

4.3.3 Recommendations

1. Prepare the hot water plumbing for a changeover to solar hot water when it is time to replace the hot water tank.
2. Change lighting to LED lights when present lights need replacing.
3. Switch off as many GPOs as possible outside working hours. It may be worth considering a low power timer switch to do this automatically.
4. Consider fitting low emissivity foil insulation inside the roof with the foil facing down and with an air/insulation gap between the foil and the roof.
5. Consider planting shade plants around the building.
6. Consider painting the outside roof white.

4.4 FNQ1 Residence

4.4.1 Building assessment and modelling

4.4.1.1 Star rating assessments

The building was rated 6.4 stars under the NatHERS energy rating scheme, which is well above the typical value of 3–4 stars for buildings of this age. The building itself has a floor area of 135 square metres and is a simple besser block construction that is well shaded by extended eaves and verandahs. The combination of thermal mass and shading results in a building that performs well in this climate.

4.4.1.2 Improved star rating – potential upgrades

The main modification scenario that was modelled through the AccuRate software was insulating the ceiling space of the building. Inclusion of insulation in tropical climates is often considered unnecessary and sometimes even viewed as detrimental to the performance of the building. However, in conditioned buildings such as this one, the insulation can help reduce heat gain from the external environment and prevent cooled conditioned air escaping from the interior of the building. In cooler climates, increased insulation levels can deliver significant improvements, but often in tropical climates they offer only small improvements in performance. Two thicknesses of ceiling insulation were modelled for this building to see what level of additional improvement they offered:

- insulating ceiling batts with a thermal resistance of R2.5
- insulating ceiling batts with a thermal resistance of R6.0.

The simulation results from the various modifications are shown in

Table 11. The results show that the current building rates 6.4 stars, which is already an excellent result. It can be increased to 7.3 stars by adding R2.5 batts to the ceiling space, but increasing the thickness and consequently raising the R-value to 6.0 delivers minimal additional benefit and no further increase in the star rating.

Table 11: FNQ1 residence – AccuRate star rating scenario results

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star Rating
	MJ/m ²				
Current building	0.0	202.7	96.4	299.1	6.4
Ceiling insulation (R2.5)	0.0	161.8	89.7	251.5	7.3
Ceiling insulation (R6.0)	0.0	157.8	88.9	246.7	7.3

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software was used to model actual energy consumption verses the theoretical energy consumption that is modelled in the NatHERS rating mode. The modelling assumed that conditioned air was required all day and that it was provided by reverse cycle systems with a COP of 3.

Figure 18 shows the predicted total electricity consumption for cooling for each month for each of the different scenarios. Insulating the ceiling space results in a 20% energy saving during the highest demand period, but only an additional 2% improvement is gained through increasing the R-value of the insulation.

Figure 19 shows the typical hourly use profile during the wet season for each scenario. It can be seen that the peak consumption occurs in the afternoon at around 5 pm for all scenarios modelled. This peak is usually associated with the preparation of the evening meal, when ovens and stovetops will provide additional heat load to the building that then needs to be countered with increased air conditioner use.

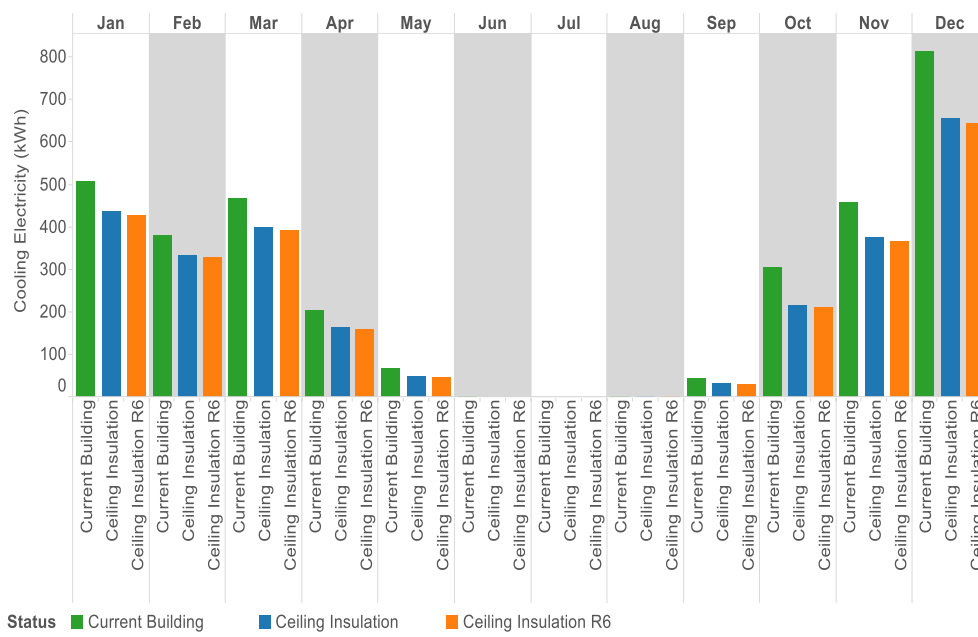


Figure 18: FNQ1 residence – predicted electricity consumption for summer cooling for different scenarios

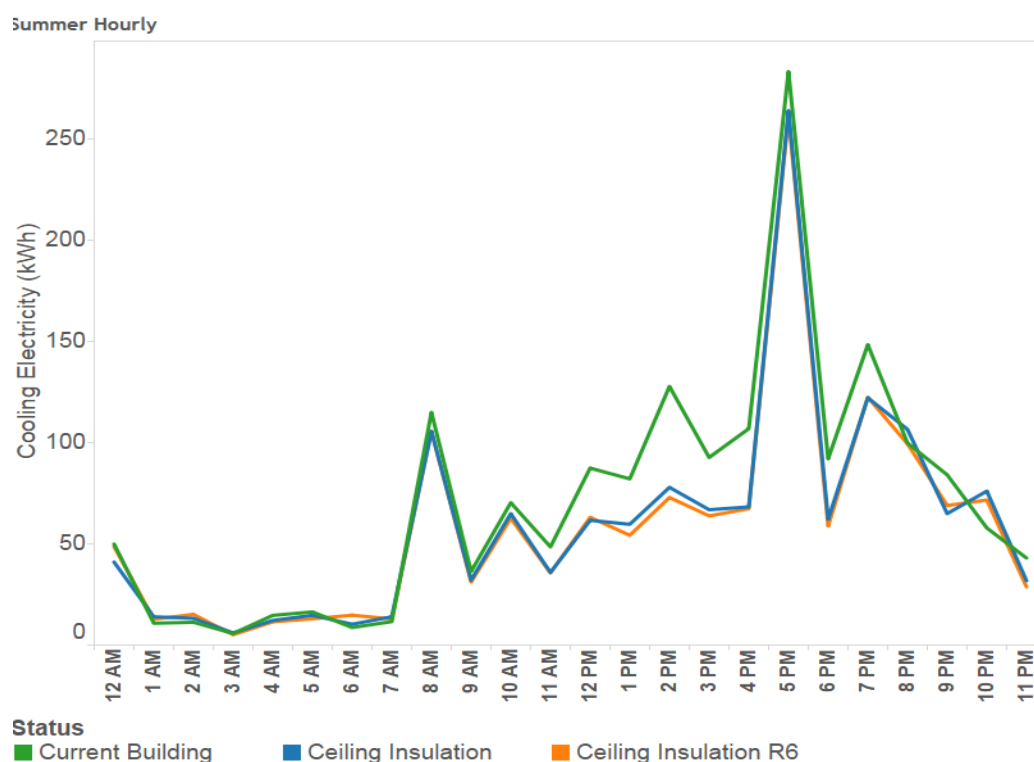


Figure 19: FNQ1 residence – monthly air conditioner electricity consumption for different energy-saving scenarios

4.4.1.3 Summary observations

Insulating the ceiling space provides good additional improvement to the building, which is already performing well. Only the low cost R2.5 batts are required to be installed, as the more expensive and thicker batts provide little, if any, additional benefit.

4.4.2 Climate control

The average internal temperature in winter varies from 0 °C to 6 °C higher than the external air temperature throughout the day and night. In summer, the internal temperature varies from 3.5 °C lower to 4.5 °C higher than the external air temperature.

Table 12 gives average diurnal values for temperatures. Although the table suggests that the temperature is uncomfortably high, this may reflect the long periods during which the house was unoccupied. The AccuRate unconditioned air predicted values are slightly lower than the measured values, and this is consistent with its lower input values for summertime external ambient temperature.

Table 12: FNQ1 residence – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): Residence	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	25.1	28.2	27.1	29.9	32.6	27
AccuRate air conditioned	22.6	27.9	26.7	26.0	27.8	27.0
AccuRate non-conditioned	22.6	28.2	26.8	26.9	29.8	29.3

4.4.2.1 Extreme temperatures

Over the nine-month monitoring period, the extreme values measured when the air conditioner was not running were a maximum of 36 °C and a minimum of 22 °C.

4.4.3 Electricity management

4.4.3.1 Total electricity consumption

Electricity from the community diesel generator is the principal source of energy for the art centre manager's residence. The electricity is supplied separately from that supplied to the main art centre and is controlled via its own switchboard and power card user interface. Power shutdowns of longer than two minutes caused by generator failures were infrequent. However, the residence was unoccupied for long periods and the power was shut down several times for periods of a few weeks to months during periods of transition between art centre managers or during overseas travel to exhibitions. This provided a useful opportunity to compare passive and active thermal responses in the building.

The total electricity consumption over the nine months was 2715 kWh (Figure 20). The residence was unoccupied for much of the study. Most of the GPO supply is used for bedroom air conditioners and ceiling fans. The only other appliances are two televisions, a fridge-freezer and cooking facilities. The air conditioning consumption appears relatively low because only the main living area has an air conditioner with its own sub-circuit, and bedroom air conditioner use is incorporated in the GPO consumption; Figure 21 shows that the GPO consumption peaks in the evening during spring and summer, suggesting that there is an unmeasured and significant component of bedroom air conditioner use in addition to the air conditioner in the main room.

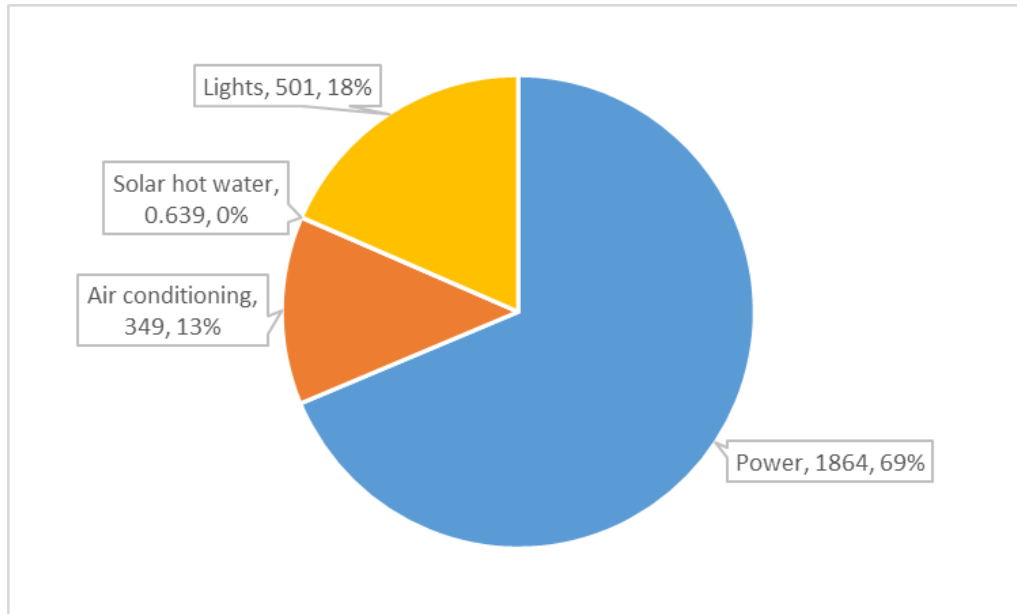


Figure 20: FNQ1 residence – distribution of electricity consumption in kWh

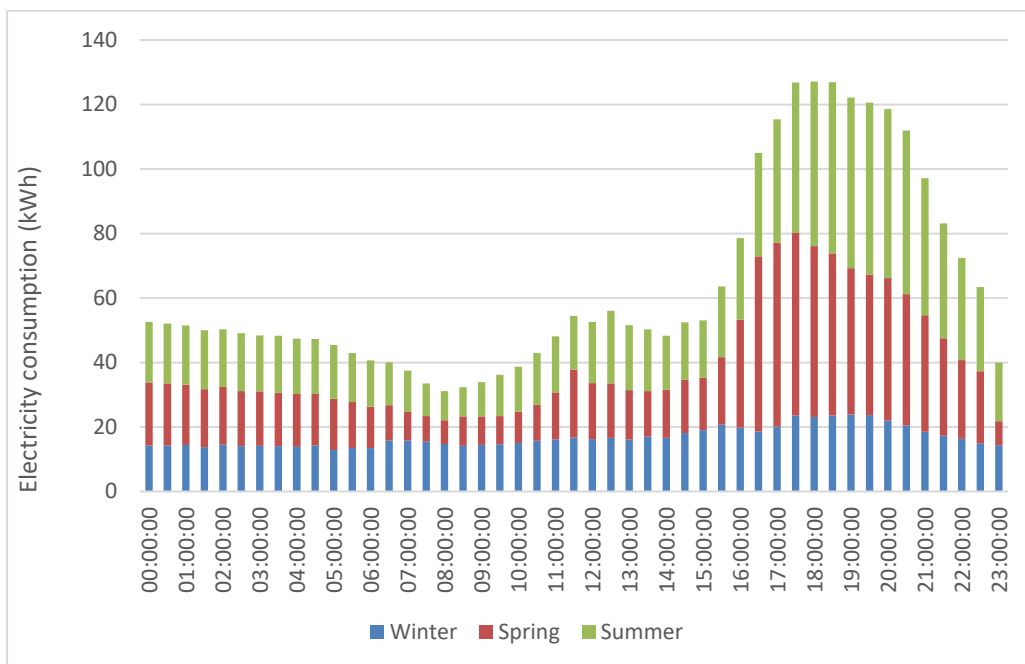


Figure 21: FNQ1 residence – diurnal total electricity consumption for winter, spring and summer

Table 13: FNQ1 residence – hours of operation for building electrical services

Service	Consuming electricity all day when the building was occupied	Only consuming electricity during the day
Lights	✓	
General power outlets (mainly fans, fridge and air conditioners)	✓	
Air conditioners (main room)		✓
Solar hot water		✓

4.4.4 Recommendations

- Change lighting to LED lights when present lights need replacing.
- The fans are frequently left running when the building is unoccupied to prevent mould and damp. A low power timer switch to cycle the fans automatically could save most of this electricity.
- Consider using ceiling insulation.
- Empty the fridge and switch it off when the house is unoccupied for long periods.
- Consider fitting controlled forced ventilation for night-time ventilation when air conditioners are not running.

5. FNQ2 Art centre

5.1 Background

The FNQ2 Aboriginal art centre is located in a coastal town in Far North Queensland. It provides studios, training and management services for artists from an area of about 25,000 square kilometres.

The building was originally used for training but has developed into a meeting place for an active group of artists and crafts-people. The group creates works of art for museums and exhibition centres worldwide, and artists from the centre travel widely to support this demand. Ten artists regularly use the studios, and occupancy can vary up to a peak of 40 at a time. The centre also hosts community meetings and is occasionally used to provide services such as health clinics.

The building is of better block construction with air conditioners in every room. It has a total floor area of 246 square metres, with a reception area for visitors, tourists and school groups; a keeping place for the storage and display of artworks and artefacts; two offices; a computer training room; a kitchen dining area; a large enclosed studio/workshop that can also be used for meetings; an external secure and sheltered studio area; three storage rooms; and two washrooms.

5.2 Building assessment and modelling

This assessment is aimed at reducing electricity consumption while retaining a safe and comfortable working environment. The building is well shaded and temperatures are considered comfortable, but its occupants are acutely aware of the potential for reducing electricity consumption. This is borne out by the measurements we have taken, which indicate that temperatures are close to those assumed by the AccuRate model but that electricity loads are comparatively high.

The building was rated 5.2 stars using AccuRate, which is a good result and demonstrates that the building utilises several features to reduce its overall energy consumption profile. In particular, the building utilises shading and thermal mass to its advantage.

The NatHERS results show that cooling energy is the dominant requirement, constituting 99.1% of the total heating/cooling energy requirements. Effectively, this means that heating is never required in the building at any time of the year, which is hardly surprising given its location. Consequently, building design should focus on keeping the building cool and reducing exterior heat gain. Because the building is conditioned, it is also important to ensure that the conditioned air is held within the building and not lost to the exterior environment.

The exterior and interior walls of the building are concrete block, and the floor is a concrete slab. This constitutes a large amount of thermal mass, which can be both beneficial and problematic when trying to maintain the interior temperatures within the comfort band. Thermal mass helps reduce the rate of rise of interior temperatures during the day. However, in doing so the thermal mass absorbs and stores heat and later transfers that heat to interior spaces. Consequently, shading exterior walls is essential to reduce the amount of direct solar exposure. The building utilises many shading devices, including wide eaves and verandahs that help protect the exterior walls and windows from direct sun exposure.

While shading of walls is critical to stop heat gain, much of the heat gain will come via the ceiling space. The building has a steel roof; although it has reflective sarking directly underneath it, the roof cavity still reaches high temperatures.



Figure 22: FNQ2 art centre building – roof with low thermal emissivity foil insulation and ceiling with no insulation

The NatHERS modelling estimates that the roof cavity will often reach 35 °C in the hot summer months during the middle of the day. This heat will transfer to the occupied spaces within the building if the ceiling is not insulated. Unfortunately, this is the case in this building, as it has no ceiling insulation. The lack of ceiling insulation also means that the cooled conditioned air can be lost by being transferred to the roof space through the ceiling, as little resistance is offered.

5.2.1 Improved star rating – potential upgrades

Several modification scenarios were modelled through the AccuRate software to determine which modifications would produce the highest impact:

- install ceiling insulation
- increase air tightness of building (improved sealing)
- decrease air tightness of building (increase natural ventilation)
- increase shading of exterior walls via trees
- increase shading of exterior walls via extended verandahs/shade sails.

The simulation results from the various modifications are shown in

Table 14. The results show that the current building rating of 5.2 stars can be increased by 1.5 stars to 6.7 stars by simply installing ceiling insulation with a bulk insulation thermal resistance of R2.5. Increasing the R-value of the insulation to R4.0 gains an additional 0.2 stars, to 6.9 stars.

Increasing air tightness of the building, through improved weather sealing, sees a 1.1-star improvement over the current building to 6.3 stars. However, decreasing air tightness and allowing more natural ventilation actually results in a reduction in the star rating to 3.5 stars. The main reason for the changes in performance due to the tightness of the building are because the building is conditioned. Increasing natural ventilation means that the conditioned air can more easily escape the building, and thus maintaining the building within the comfort bands requires increased conditioned air and consequently increased energy consumption. When the air conditioner is not running, increasing natural or forced ventilation could be beneficial.

Table 14: FNQ2 art centre building – AccuRate star rating scenario results

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star rating
	MJ/m ²				
Current building	1.3	85.4	61.0	147.7	5.2
Ceiling insulation (R2.5)	0.1	59.3	51.7	111.1	6.7
Ceiling insulation (R4.0)	0.1	57.6	50.8	108.4	6.9
Increase air tightness	1.2	72.7	47.6	121.5	6.3
Decrease air tightness	1.6	107.8	87.3	196.7	3.5
Sealing + insulation	0.1	48.3	40.9	89.3	7.7
Tree shading	1.4	83.2	59.3	143.9	5.4
Shade sail	1.3	82.9	59.9	144.1	5.3

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

Additional shading to the building along the north-east elevation was modelled using two different shading regimes. Firstly, a line of trees was added that were 5 metres high and 5 metres from the building. Most trees allow a certain percentage of sunlight through, so it was assumed that the shading was at 80% for the entire year. This resulted in a small improvement in the star rating of 0.2 stars. A second shading scheme was also modelled using extended horizontal shading. This could be via an extended verandah or shade cloth. It was assumed that this extended an additional 5 metres from the building and provided 100% shade cover. Again, this option only resulted in a small improvement in the star rating. Seeing only small improvements under both shading scenarios is probably due to the fact that the building is already well shaded; consequently, increasing the shading regime is only having minimal additional benefit.

The AccuRate software can be used to model the actual energy consumption verses the theoretical energy consumption obtained when it is in rating mode. This modelling assumed that conditioned air was required from 8 am to 6 pm each day, and that it was provided by reverse cycle systems with a COP of 3. Figure 23 shows the results of undertaking the improved insulation and sealing option as compared to the current building. The improved building shows significant reduction in the energy required. Also, conditioned air is only required during the warmer months, with virtually no conditioning required during winter. Thus adding ceiling insulation and improving the air tightness of the building gives the best overall result of 7.7 stars. This is an improvement of 2.5 stars over the current building rating, which is a significant improvement and sees a 40% reduction in the modelled energy requirement.

The need for conditioned air is at its greatest during the summer months (December–February), and during these periods it will peak in the afternoons during the hottest period of the day.

Figure 24 shows the modelling results for the hourly energy required for the summer period during the occupied hours for the building. Peak energy occurs at 2 pm for all the scenarios modelled. However, the scenario with ceiling insulation added used 30% less energy than the current building requirement; by improving sealing as well as insulation, the reduction is 40% over the base case. Over the course of a day, the insulated ceiling has an increasing impact on reducing the cooling energy load. This is because as the ceiling space increases in temperature, the insulation is reducing the transfer of heat to the occupied spaces below.

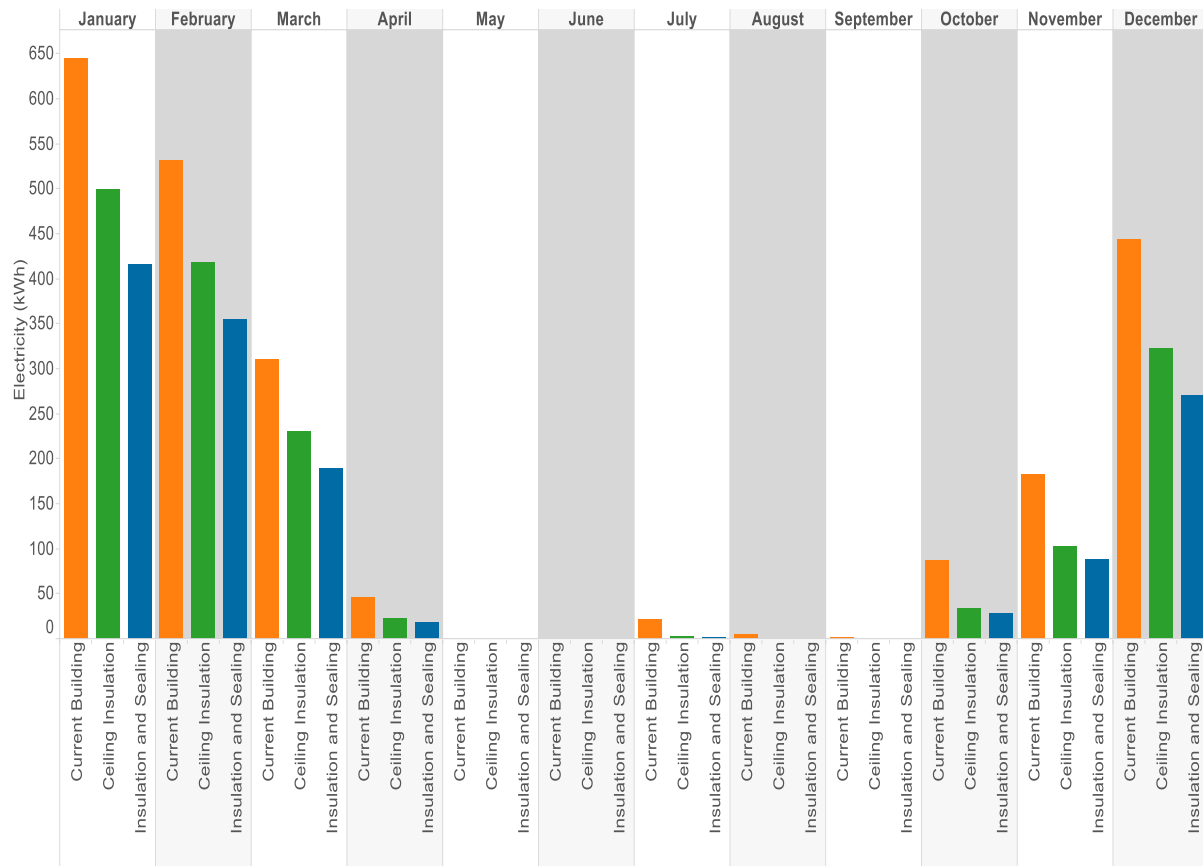


Figure 23: FNQ2 art centre building – monthly electricity consumption for insulation and draught exclusion scenarios

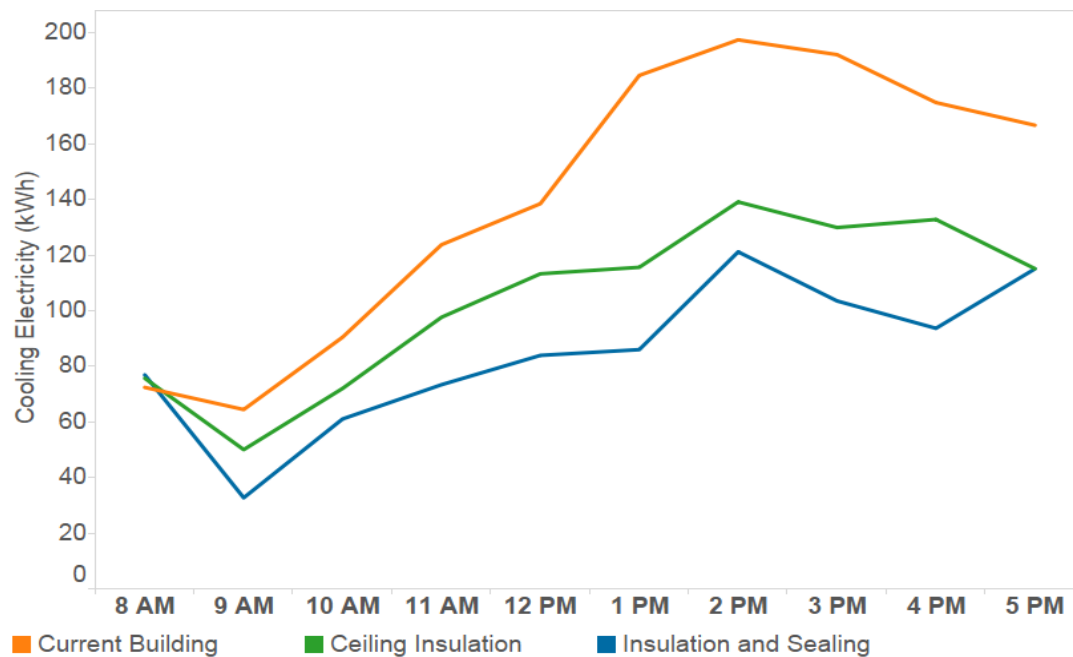


Figure 24: FNQ2 art centre building – summer diurnal electricity consumption predictions for improved insulation and sealing

5.2.2 Summary observations

Overall, it can be seen that simple upgrades such as the addition of ceiling insulation and improved sealing of the building can result in significant reductions in the cooling energy required to maintain the building within a comfortable temperature range. Both these improvements are easy to install and are relatively low cost solutions. Just adding ceiling insulation alone delivers a significant benefit; this would be recommended as an immediate improvement that could be undertaken. However, these recommendations are contingent on assumptions made for the use of energy within the building. In addition, they do not take into account the potential for forced ventilation to replace a proportion of the air conditioning load. These and associated issues are addressed in the following sections: Climate control and Electricity consumption management.

5.3 Climate control

5.3.1 Outside the building – comparison of BoM, AccuRate and measured temperature values

The measured outside temperatures differed from those recorded by BoM despite being within 1 kilometre of the BoM measuring station, which is located on an open grass verge between the road and the seashore. The maximum temperatures read by shaded north side building sensors were about 5 °C higher than those read by the BoM and by the south side building sensor temperatures during summer and about 2 °C higher in winter. The discrepancy between the BoM and the FNQ2 building sensors on the northern wall might be explained by the likely presence of an afternoon sea breeze during summer afternoons that would be cooler adjacent to the shore.

Table 15 compares the AccuRate assumed temperatures against the measured values. The minimum assumed and measured 24-hour values are comparable, but the maximum and in summer the average assumed values are 2–4 °C lower than the values measured on the north side of the building during working hours.

Table 15: FNQ2 – measured and predicted winter and summer temperatures outside the building

Average diurnal temperatures (°C): Outside the building	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	17.0	29.4	25.7	24.2	33.7	32.0
AccuRate	18.5	25.2	24.4	24.9	30.1	29.5

5.3.2 Inside the building measured vs. AccuRate temperature values

Table 16 compares the AccuRate predictions of conditioned air with the measured temperature values for the keeping place and studio respectively. The predicted and measured keeping place temperatures were comparable. However, the predicted temperatures for the studio are up to almost 5 °C lower than studio measured temperatures. This suggests either low usage or that the air conditioner had insufficient capacity to manage the summer thermal load or its thermostat was set high. This is clarified later when discussing air conditioner energy consumption.

Table 16: FNQ2 art centre building – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C):	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Keeping place						
Measured	21.9	24.4	23.4	24.2	26.4	24.7
AccuRate air conditioned	21.2	23.1	22.3	26.0	27.7	27.0
AccuRate non-conditioned	21.2	23.1	22.3	26.4	28.8	28.1
Studio						
Measured	22.1	27.4	25.6	28.8	32.6	30.5
AccuRate air conditioned	21.0	23.5	22.9	25.4	27.7	27.2
AccuRate non-conditioned	21.0	23.5	22.9	25.6	29.5	28.9

5.3.3 Extreme temperatures

Over the nine-month monitoring period, the extreme temperature values measured were a maximum of 30 °C and a minimum of 18 °C in the keeping place and a maximum of 36 °C and a minimum of 17 °C in the studio.

5.3.4 Summary observations

The extreme temperatures recorded were likely to have occurred only when the air conditioners were switched off. This should be verified with a more detailed analysis.

The air conditioners were not maintaining room temperatures within the usually accepted comfort band in the studio in summer. This may have been due to low usage, or the air conditioners being under capacity or because the temperature control was set high. This is analysed in more detail in section 5.4 below.

In summer, the indoor temperature is about 5 °C higher than outdoors from 10 pm to 7 am. This suggests the potential for controlled active ventilation overnight to remove warm air and heat that has built up during the day. However, care would be needed not to exceed the humidity constraints applying to preservation of artworks stored in the building. A fan should be run within controlled limits for time, temperature and relative humidity to prevent damage to artworks.

In winter, the measured outdoor temperature on the sheltered south side of the building ranges from 17.5 °C to 25 °C. Using fans or just opening windows to draw in air from the courtyard on the south side of the building may be all that is needed during daylight working hours in winter to maintain a comfortable temperature.

5.4 Electricity consumption management

5.4.1 Total electricity consumption

Grid electricity is the principal source of energy for FNQ2. Figure 25 shows that 45% of electricity consumption is used for air conditioning and 35% for GPOs, which include computers and a computer room, kitchen equipment (oven, instant hot water, refrigerator, water cooler) and audio video equipment. The total electricity consumption over the nine months was 16.5 MWh, of which 46% (~7.6 MWh) was

used outside working hours (Figure 26). This out-of-hours power consumption is the single greatest contributor to electricity overuse.

Table 17 indicates which services are being used outside working hours, and the analysis that follows establishes how that energy is being used. It focuses particularly on air conditioning and general power outlet electricity consumption.

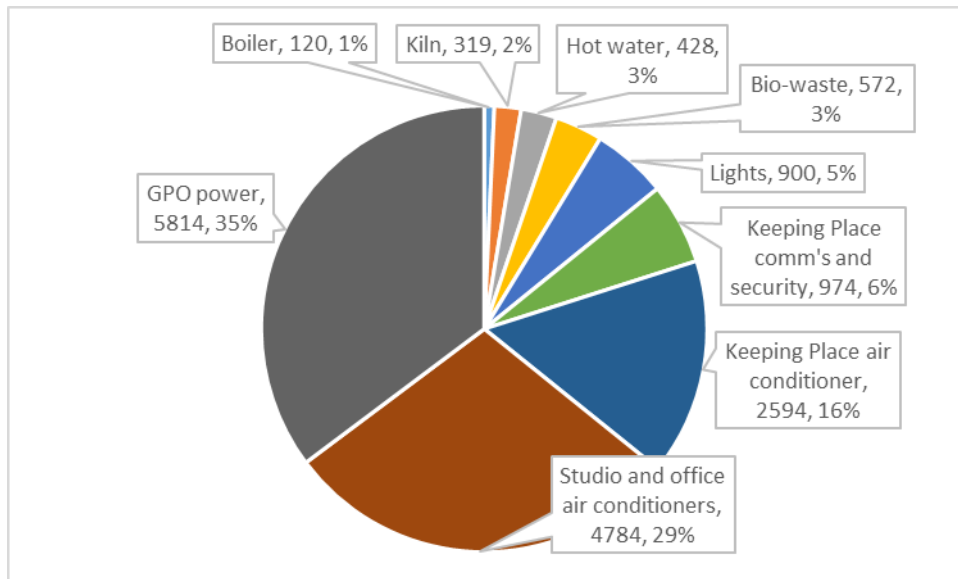


Figure 25: FNQ2 art centre building – distribution of electricity consumption in kWh

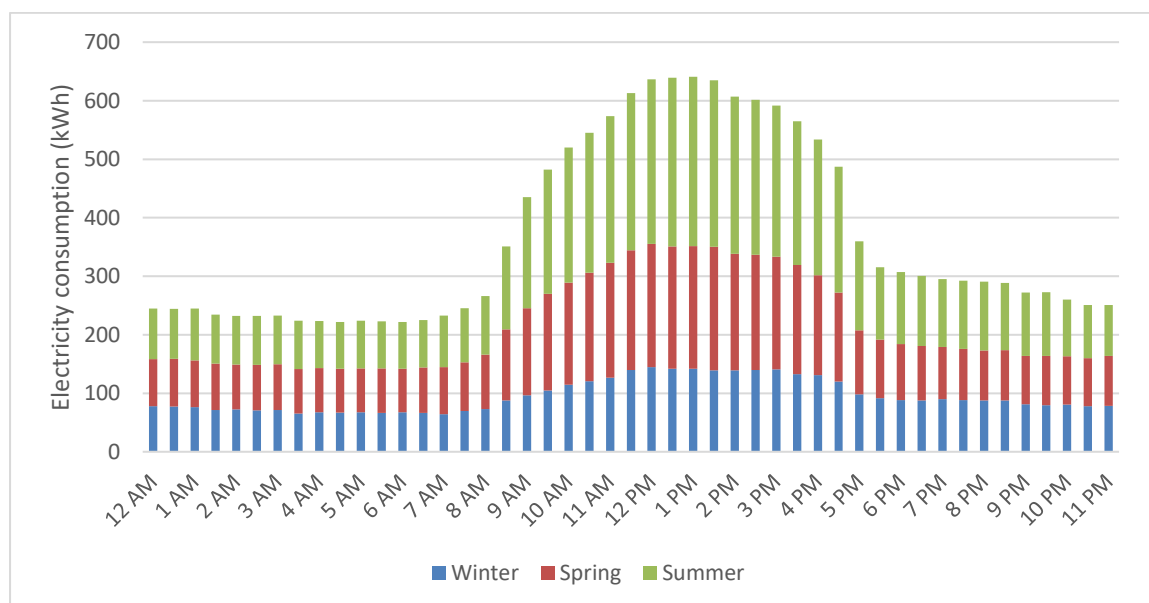


Figure 26: FNQ2 art centre building – diurnal total electricity consumption for winter, spring and summer

Table 17: FNQ2 art centre building – hours of operation for building electrical services

Service	Consuming electricity all day nearly everyday	Only consuming electricity during working hours
Lights		✓
General power outlets	✓	
Air conditioners		✓
Air conditioner keeping place	✓	
Bio-waste	✓	
Boiler	(on standby)	
Hot water		✓
Kiln		✓

The air conditioning consumption is much higher than AccuRate predicts (Figure 27). It varies from an average of 30 times more in winter to two to eight times as much in late spring and summer. Over the nine months, this amounts to a discrepancy of 5330 kWh if the keeping place air conditioning is included and 2736 kWh if it is excluded. Despite the high air conditioner usage, the measured temperatures,

Table 16, show that studio temperatures are about 3–5 °C higher than the AccuRate estimate when the air conditioner is running.

Figure 27 also shows that the total equipment electricity consumption has the potential to present a significant thermal load on the air conditioners. This could be why the air conditioners are consuming more electricity than AccuRate predicts while the cooling obtained is lower.

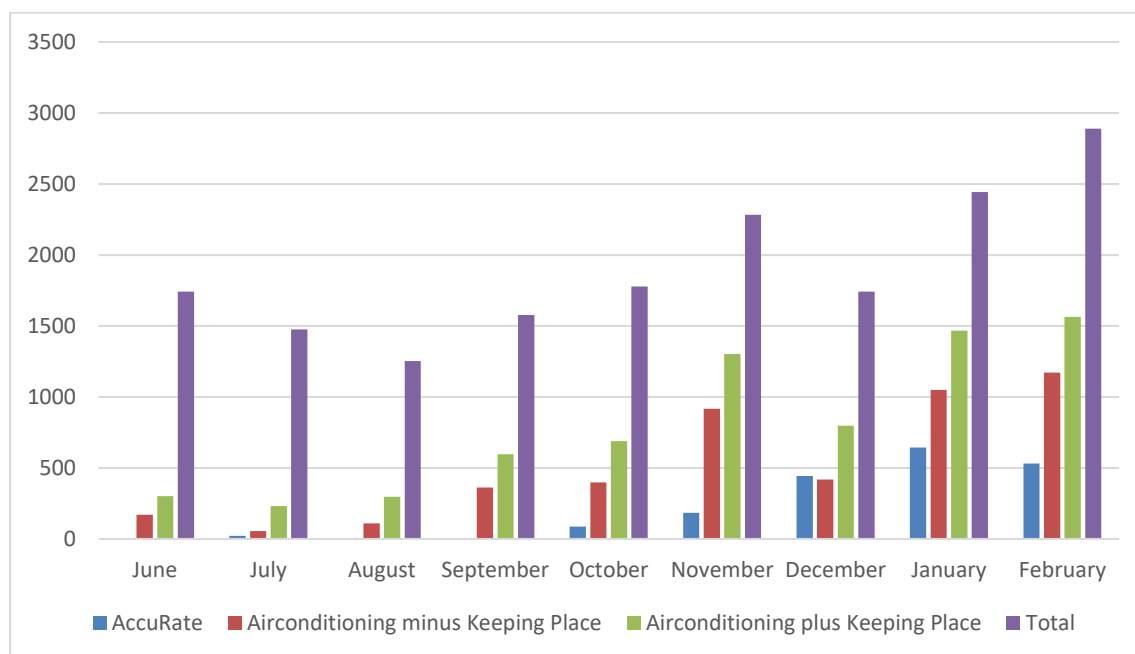


Figure 27: FNQ2 art centre building – AccuRate vs. measured values for air conditioner and total electricity consumption

The next section compares the electricity consumption of appliances and air conditioners and examines how their use might be adjusted to cool the building more effectively by reducing waste heat.

5.4.2 Consumption hot spots

5.4.2.1 Air conditioner electricity consumption

Figure 28 shows the air conditioning consumption over nine months for the principal rooms in the building. The keeping place had the highest consumption at 2.6 MWh, followed by the reception area at 1.7 MWh. The keeping place air conditioner runs 24 hours a day in spring and summer, consuming 34% (880 kWh) of its nine-month electricity consumption from 5 pm to 9 am (Figure 29); the remaining air conditioners are switched off from 5 pm to 9 am (Figure 30). None of the air conditioners were consuming excessive standby power.

The keeping place is a small, totally enclosed windowless room. According to the AccuRate building model, the air conditioner is somewhat over-capacity and overused. However, the room also contains several large items of telecommunication equipment, and the air conditioner may be required to keep this equipment cool.

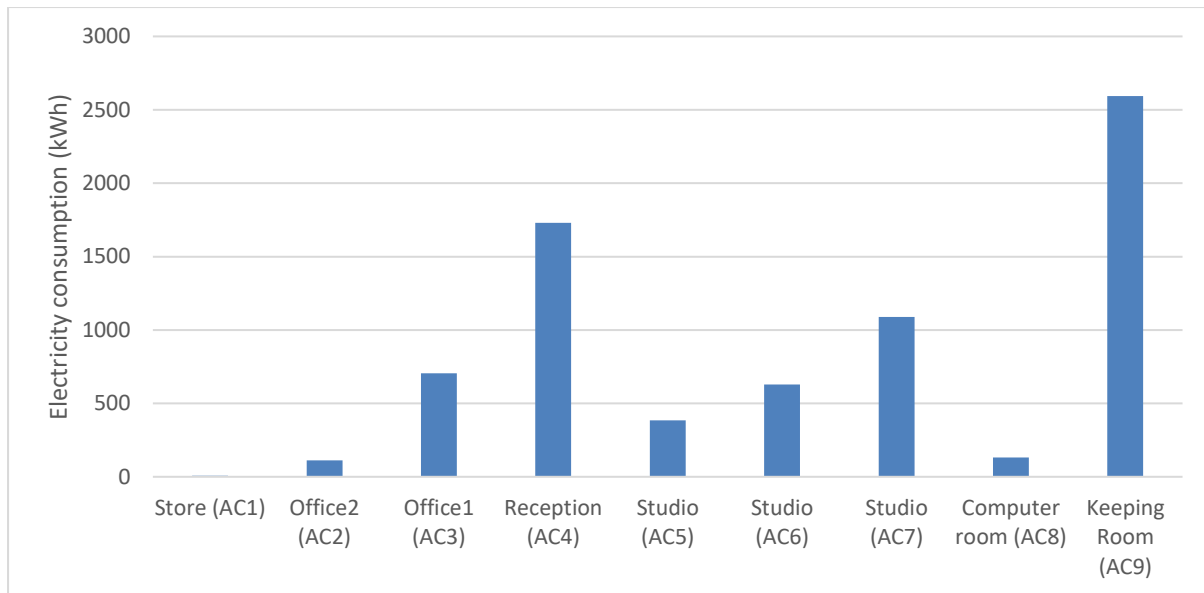


Figure 28: FNQ2 art centre building – air conditioner electricity consumption

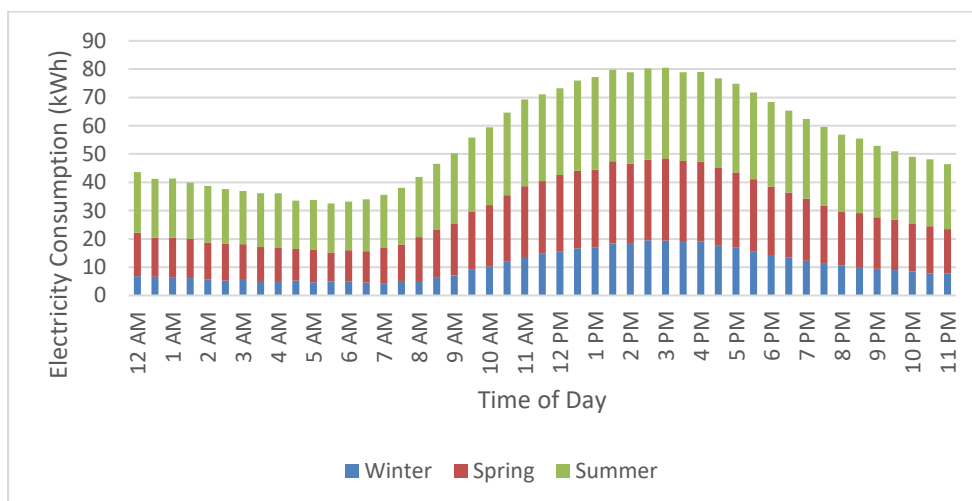


Figure 29: FNQ2 art centre building, keeping place – diurnal air conditioner electricity consumption for winter, spring and summer

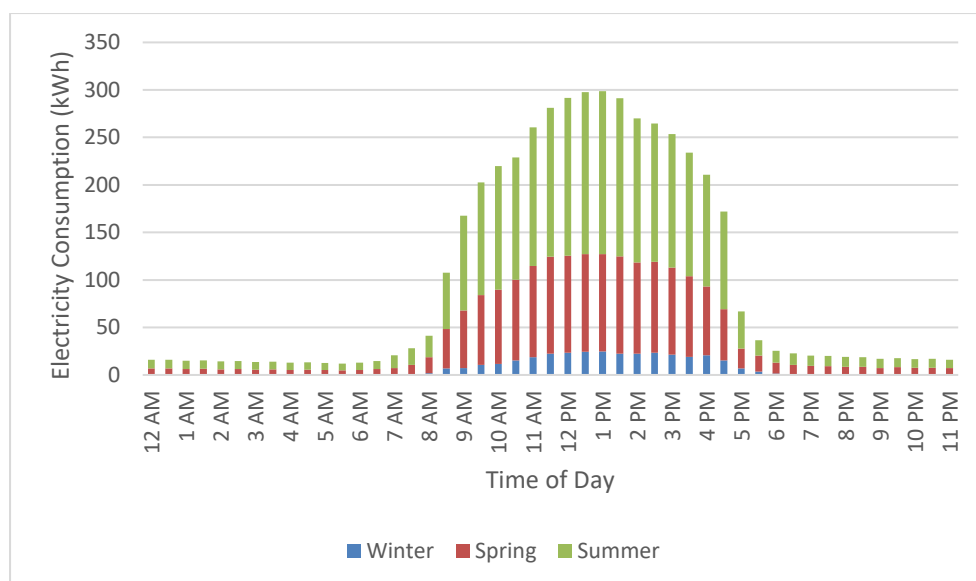


Figure 30: FNQ2 art centre building (excluding keeping place) – diurnal air conditioner electricity consumption for winter, spring and summer

Figure 31 shows an apparently decommissioned boiler consuming 110 kWh during the nine-month period. The power level is 20 W, confirming that the boiler is doing no useful work but is wasting a significant amount of energy by running on standby.

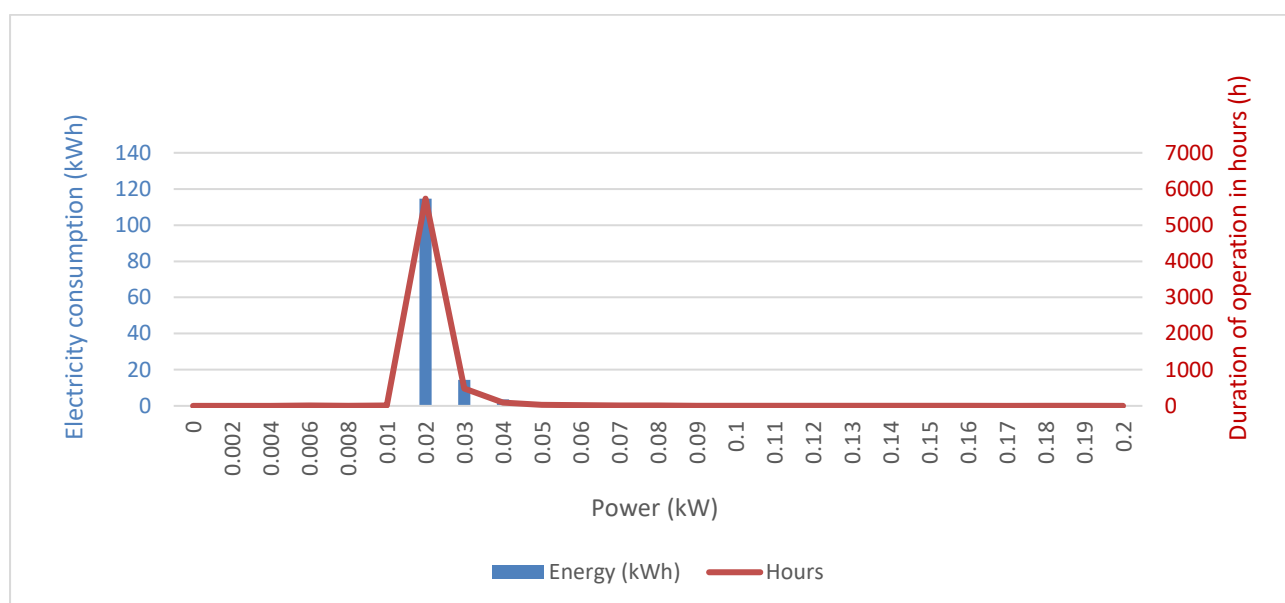


Figure 31: FNQ2 art centre building – unused boiler switched to standby

5.4.2.2 General power outlet electricity consumption

The general power outlet (GPO) use is unusually high, accounting for 42% of the art centre's electricity consumption with an almost constant 24-hour total consumption distributed across eight power outlets (Figure 32, Figure 33). The out-of-hours electricity consumption is 30% of the centre's total consumption. The total wasted electricity arising from unnecessary out-of-hours consumption can be divided into direct and indirect components. The direct component is the electricity drawn from these power outlets. The indirect component is the air conditioning needed to dissipate the waste heat from the equipment that is switched on unnecessarily. Air conditioners typically run with a COP of 3, which means that up to 1 kWh

of energy is consumed by an air conditioner to remove the heat generated by an appliance that consumed 3 kWh of electricity.

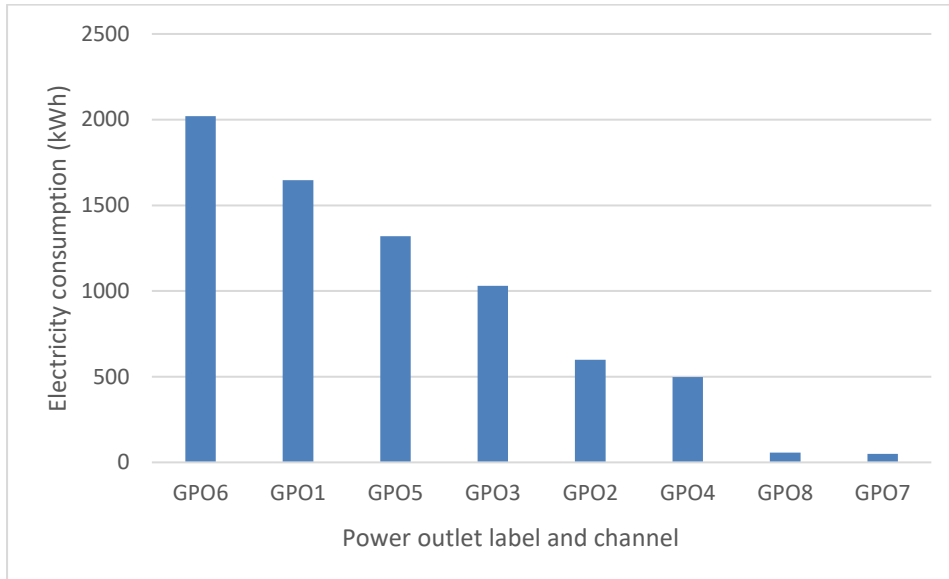


Figure 32: FNQ2 art centre building – distribution of electricity consumption across general power outlets

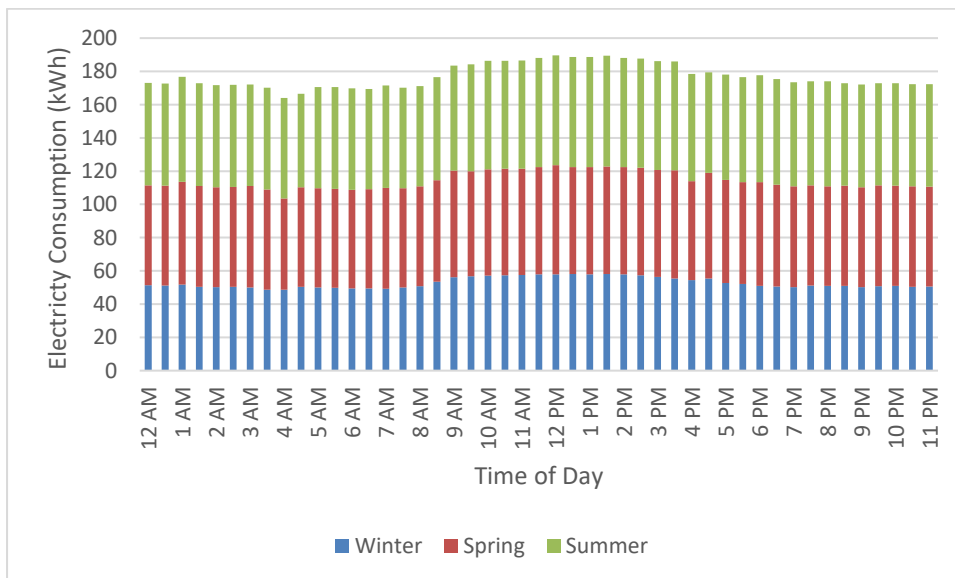


Figure 33: FNQ2 art centre building – diurnal general power outlet electricity consumption for winter, spring and summer

5.4.2.3 Indirect heating of the building

It was noted earlier that the air conditioning was consuming much more electricity than the AccuRate model suggested would be required to overcome natural warming of the building by the sun and environmental warm air. This can be accounted for by:

- air conditioner efficiency
- occupant metabolism
- waste heat from appliances.

We were not able to test appliance efficiency; however, most of them appeared to be relatively new, in reasonable condition and subject to occasional repair and maintenance.

The art centre has three permanent staff, and the art centre manager explained that there are 10 artists who regularly use the studios, with visitor numbers up to a peak of 40 at a time. Over the nine-month period we visited the premises five times. While there, we observed typically four or five people at any given time in the building, peaking to about 15 when a meeting or special activity was running. We have conservatively estimated occupancy as three staff in the building for 30% of the time, 10 regular users in the building for 20% of the time and an average of 15 visitors using the building once a month. Most activities were of necessity sedentary, so allowing a basal metabolic rate of 100 W per person would represent a heat load over nine months of approximately 1685 kWh.

The electrical energy that is consumed within the building in providing services to appliances is eventually converted to heat, which has to be removed by the air conditioners. This does not include air conditioning itself, as the air conditioner compressors that use most of the electrical power are located outside the building. This heat load is estimated as 8555 kWh.

The total heat load due to equipment and personnel is 10,240 kWh, requiring 3413 kWh of air conditioning electricity to offset.

5.5 Summary and recommendations

5.5.1 Electricity consumption – air conditioning and general power outlets

The electricity consumption in the art centre is dominated equally by air conditioning and the use of GPOs. Hot water, the kiln and lighting and biological waste management play a relatively minor role; however, an unused boiler was found to be wasting 110 kWh by running on standby over the nine-month period. The two principal loads account for more than 80% of the building's electricity consumption and are at quite high levels. The GPO loads operate 24 hours a day, seven days a week most of the year, running at a power level of about 1 kW. These loads may originate from the standby power associated with computers, audiovisual equipment and telecommunication equipment that is not switched off at the mains. Inadvertent electricity loss could be more than a quarter of the building's electricity use.

5.5.2 Waste heat from appliances and people

The higher values of the indoor measured temperatures compared with the modelled temperatures throughout the day and night, together with measured values of air conditioner electricity consumption that are much greater than those estimated in the AccuRate model, strongly suggest the presence of a heat source that is not accounted for by the model. An estimate of the heat from appliances and from human metabolism accounts for most of this discrepancy.

5.5.3 The benefit and risks of ceiling insulation and sealing

The AccuRate model strongly suggests that the air conditioning consumption could be reduced by 40% if the ceiling was insulated and a program of sealing against draughts was carried out on the building. However, this does not take into account the presence of the need to dissipate waste heat. Ceiling insulation and sealing against air leakage would trap this waste heat in the building and negate the benefit of the insulation. If the waste heat was removed overnight by appropriate ventilation, then the insulation and sealing measures would be more effective.

5.5.4 An optimal solution

As mentioned above in section 5.3, the night-time summer temperature indoors is about 5 °C higher than outdoors from 10 pm to 7 am. Controlled active ventilation overnight could remove the warm air and heat that has built up during the day, but care should be taken to control for time, temperature and relative humidity as required to safely store museum artefacts and artworks.

In winter, the sheltered south side of the building remains relatively cool. Fans or open windows drawing in air from that side of the building may maintain a comfortable temperature during the day.

Combining such ventilation with actions to reduce the wastage of electricity from GPOs and the use of ceiling insulation and draught sealing could reduce electricity consumption by up to 50%.

5.5.5 Recommendations

- Remove the unused air conditioner that is consuming standby electricity.
- Investigate why the unused boiler is running on standby and whether it can be shut down.
- Check all GPO circuits to determine if equipment is being left on either operating or in standby.
- Initiate a program of automatic control to reduce standby electricity and shut down appliances that are running unnecessarily.
- Shut down air conditioners in winter and instead use ventilation to draw in air from the southern courtyard side of the building.
- Implement ‘night flushing’ of conditioned spaces between the hours of 10 pm and 6 am. The fans used in this night flushing should have limits set for time, temperature and relative humidity so that they operate for predetermined periods, when the internal temperature is greater than the outside temperature, and within acceptable limits of internal relative humidity. This controller, while a straightforward device, is not likely to be available off the shelf and may need to be developed for this application. It is likely to be a building product of general applicability in tropical and sub-tropical regions of Australia.
- Once the above actions have been taken, monitor the building for a month or two in summer to check their efficacy. If the internal loads have been adequately managed, then install ceiling insulation and weather sealing.
- A small solar hot water service would reduce energy consumption by about 3% and might be worth considering when the hot water tank becomes due for replacement.
- Relocate the telecommunication equipment or replace with low energy equipment or after hours answering service.

6. FNQ3 Corporation

6.1 Background

FNQ3 is located in a coastal community in Far North Queensland. Its role is to promote Aboriginal culture and provide support for native title claims, land purchases and environmental management. FNQ3 also develops social and health care initiatives, provides employment and training programs and promotes good relationships with agencies and communities within the region.

FNQ3 offices are based in a steel frame, two-storey building that was originally residential. It has broad eaves and a second floor patio walkway on the north, south and west sides. The building has a total floor area of 278 square metres. The second floor has a small kitchen, two offices, two bedrooms and a large boardroom. Access to the second floor is via an outside staircase on the south-west corner of the building. The east side has a clear view to the coast and is largely constructed from glass doors and windows. The second floor windows can be opened for natural ventilation, but this is rarely used. The ground floor provides a reception area, kitchen and office space. This has been extended on the north side for offices that accommodate a geographic information system (GIS). Computer use and air conditioner use is intensive during working hours but shut down outside working hours. The occupant density is relatively high compared to the art centre buildings, with approximately nine staff using two floors of a compact building during working hours. Eight air conditioners are available, of which about half are usually operating during working hours. The analysis has focused on the major rooms on each floor: ground floor offices, which is the central large office space on the ground floor; and second floor boardroom, which opens onto an annexe and kitchen area.

6.2 Building assessment and modelling

The building is well shaded, and temperatures on the ground floor are considered comfortable by its occupants. The second floor boardroom can become excessively warm in summer, even with its small air conditioners running at capacity. The eastern windows on the second floor are well shaded and can access the afternoon sea breeze. However, they are not used as they take some effort to open and close, and excessive ventilation tends to blow papers around on the boardroom table. It is unknown if the roof space is insulated, so it has been assumed it is not for the base case modelling.

6.2.1 Star rating assessments

The building was rated 0.9 stars under the NatHERS energy rating scheme, which is a below the two-star rating typical for buildings of this age.

The NatHERS results show that cooling energy constitutes 99% of the total heating/cooling energy requirements. Consequently, building design should focus on keeping the building cool and reducing exterior heat gain. Because the building is air conditioned, it is important to ensure that the conditioned air is held within the building, not lost to the exterior environment.

The building itself is light-clad, and it is unknown whether insulation has been installed in walls and ceiling spaces. Given the age of the building it is unlikely that wall insulation is present, so it has been assumed that the exterior walls are uninsulated. It has been assumed for rating purposes that no insulation has been installed between the upper floor ceiling and the roof.

The building is well shaded by a combination of wide verandahs, eaves and vegetation. Consequently, additional shading was not deemed a priority.

Lighter coloured roofs increase the amount of sunlight that is reflected back and consequently reduce the heat load on the roof and the spaces under the roof. The current roof is a medium hue and is in some disrepair. Cleaning and repainting the roof white will increase the reflectivity of the roof and should improve the rating. However, if repairs are to be undertaken, then it would be worth ensuring that insulation is added, if it is not there already.

6.2.2 Improved star rating – potential upgrades

A few key modification scenarios were modelled through the AccuRate software to determine which would produce the highest impact:

- adding roof space insulation
- painting the roof white
- painting the roof white and adding roof space insulation.

The simulation results from the various modifications are shown in Table 18. The results show that the current building rating of 0.9 stars can be increased by 1.9 stars to 2.8 stars by insulating the roof space. Painting the roof white would increase the rating by 1.2 stars to 2.1 stars, while painting the roof and insulating sees a result of 3.1 stars, a 2.2-star improvement.

Table 18: FNQ3 corporation building – impact of energy-saving modifications on energy consumption

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star rating
	MJ/m ²				
Current building	4.5	231	71	306	0.9
Roof insulation	1.9	152	68	222	2.8
White roof (not insulated)	4.7	177	67	249	2.1
White roof (insulated)	1.9	143	67	212	3.1

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software can be used to model actual energy consumption verses the theoretical energy consumption that is modelled in the NatHERS rating mode. Figure 34 shows the results of undertaking the painting of the roof as compared to the current building and if the roof space is insulated. It can be seen that conditioned air is really only required during the warmer months and that during winter virtually no conditioning is required. Within each of the months that conditioned air is required, the options with the lighter roof show reductions in the energy required. This modelling assumed that conditioned air was required from 8 am to 6 pm each day and that it was provided by reverse cycle systems with a COP of 3.

If the ceiling is insulated, the additional benefits from having the roof painted white are small, around a 5% reduction in energy consumption. However, if the ceiling is not insulated, then the savings through painting the roof are more significant. Up to 17% saving in energy consumption would be possible under the no-insulation scenario through simply cleaning and painting the roof white.

It is difficult to model increased natural ventilation flows in AccuRate. However, the building does lend itself to take advantage of cooling breezes. The upper floor in particular could benefit, as this area is less likely to have air flow interrupted or blocked by surrounding buildings and vegetation. In addition, the style of windows installed in the building (sliding windows) means that significant openings can be created by simply opening windows. This is known as passive cooling and does not require any mechanical system

to operate. Of course, often there are other factors that prevent or restrict the amount of time windows can be left open, but often these can be addressed through other interventions.

The need for conditioned air is at its greatest during the summer months (December–February), and during these periods it will peak in the afternoons during the hottest period of the day.

Figure 35 shows the modelling results for the hourly energy required for the summer period during the occupied hours for the building. It can be seen that peak energy occurs at 2 pm for all the scenarios modelled. Ceiling insulation is the biggest improvement that can be made; it reduces energy loss by 27%. Painting the roof has its biggest impact in the middle of the day when the sun is at its highest point in the sky and solar loading is at its maximum.

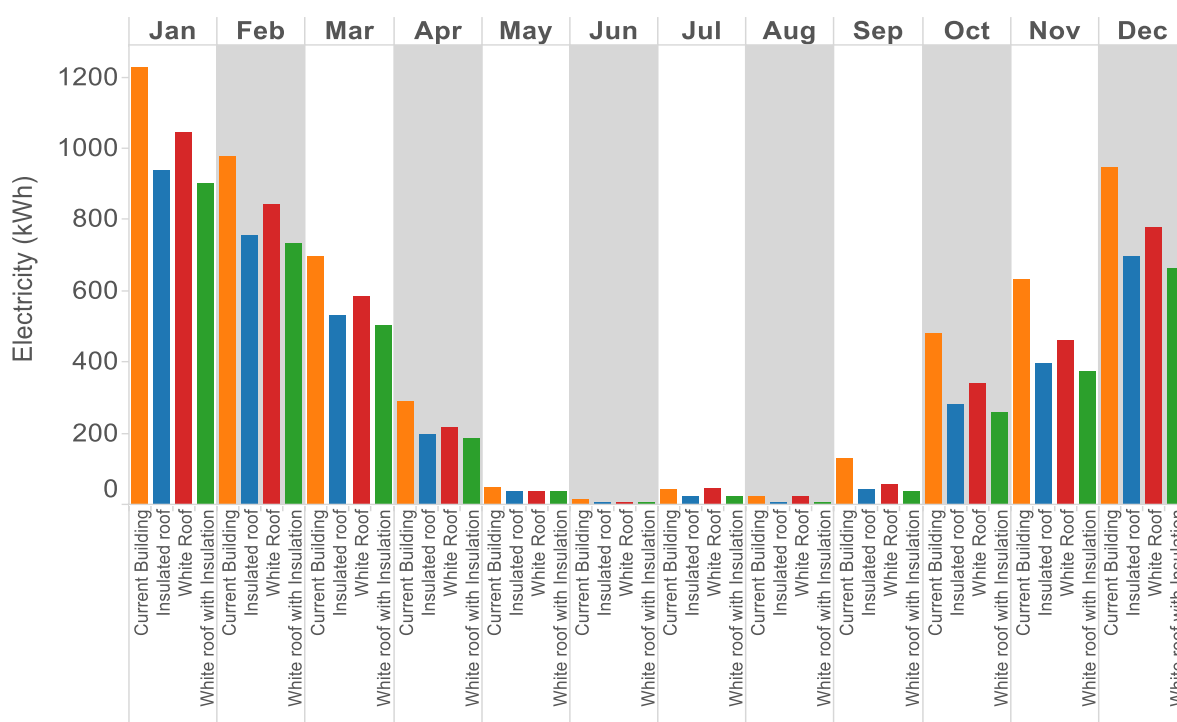


Figure 34: FNQ3 corporation building – monthly air conditioner electricity consumption for different energy-saving scenarios

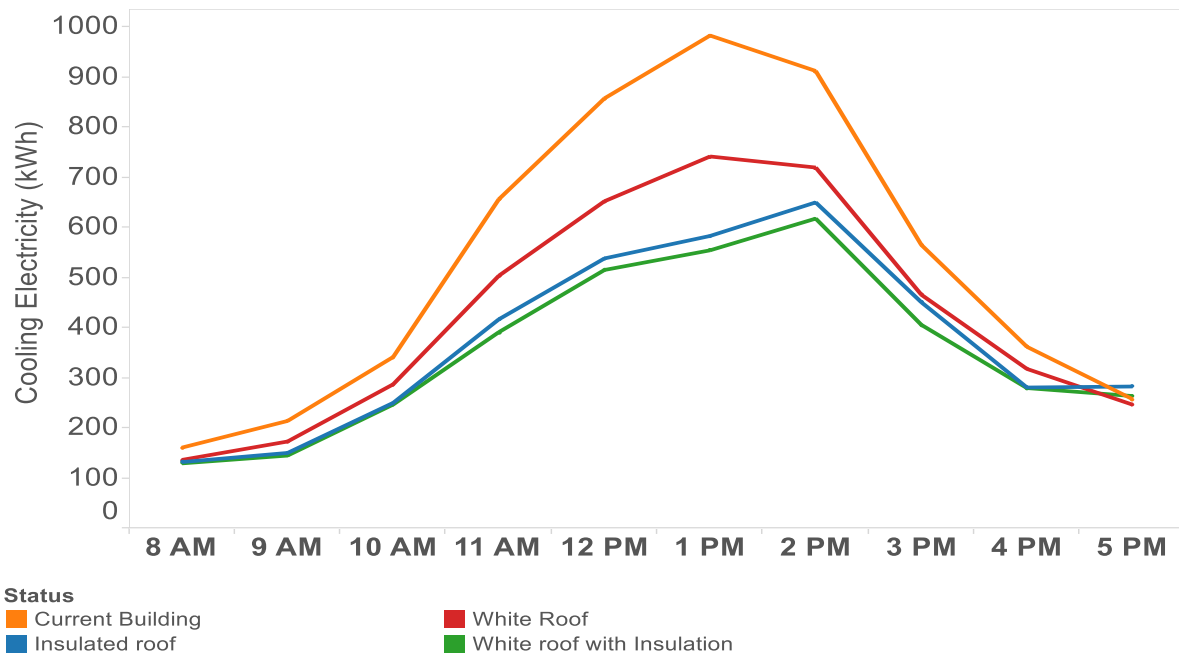


Figure 35: FNQ3 corporation building – summer diurnal electricity consumption predictions for different energy-saving scenarios

6.2.3 Summary observations

Ceiling insulation, if it is not already present, will make the biggest difference to energy saving, particularly in the first floor air conditioners. However, simply painting the roof a light colour can have a significant impact on the performance of the building. During the middle of the day when air conditioner use is likely to be at its highest, a white painted roof will reduce the energy load required by up to 17% if no ceiling insulation is present, but even if the ceiling is insulated savings of 5% are still possible.

6.3 Climate control

6.3.1 The building external environment temperature

The maximum external temperatures are about 4 °C higher than the AccuRate and BoM temperatures during summer and about 4 °C higher in winter.

The minimum temperatures were comparable to the BoM sensors, whereas the AccuRate values were frequently several degrees higher than the BoM or building sensors in mid to late winter and in summer.

Table 19: FNQ3 corporation building – measured and predicted winter and summer temperatures outside the building

Average diurnal external shaded temperatures (°C)	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	17.0	29.4	26.8	24.2	33.7	31.9
AccuRate	18.5	25.2	24.4	24.9	30.1	29.5

6.3.2 Ground floor offices

Table 20 shows that the measured and AccuRate values are similar during summer but that the AccuRate 24-hour minimum estimate is lower than measured by 2.1 degrees in winter.

Table 20: FNQ3 corporation building ground floor offices – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): Ground floor offices	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	23.8	24.8	24.3	27.0	28.4	26.5
AccuRate air conditioned	21.7	24.1	23.5	25.9	27.1	26.9
AccuRate non-conditioned	21.7	24.1	23.5	26.4	29.4	28.9

6.3.3 First floor boardroom

Table 21 shows that the AccuRate model, with air conditioning included, predicted a temperature that was 1 °C lower than the measured values during winter for both day and night and 1.7 °C lower during the summer nights and about 5.3 °C lower during the summer days. The summer discrepancy was consistent with low air conditioner usage.

Without air conditioning included, the model predicted a temperature that was 1 °C lower throughout the day and night. This could be accounted for by the lower external air temperatures assumed by AccuRate.

Table 21: FNQ3 corporation building first floor boardroom – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): First-floor boardroom	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	20.5	27.4	26.1	26.8	33.5	31.4
AccuRate air conditioned	19.5	25.9	25.0	25.1	28.2	27.0
AccuRate non-conditioned	19.5	25.9	25.0	25.2	31.8	30.8

6.3.4 Extreme temperature values

Over the nine-month monitoring period, the extreme values measured on the ground floor were a maximum of 30.9 °C and a minimum of 19.7 °C. On the first floor they were a maximum of 37.5 °C and a minimum of 13.5 °C.

6.3.5 Summary observations

On the ground floor, the AccuRate model predicted temperatures that were very close to the measured values, reflecting the high level of air conditioning control over temperatures. On the second floor, the temperatures were 1 °C higher than the modelled values, despite the relatively shaded environment of the

corporation buildings south of the art centre. This probably reflects the relatively low use of air conditioning and AccuRate's underestimate of external air temperatures.

The building has a lightweight construction, low thermal mass and consequently a rapid temperature response to outside temperatures. This suggests there is little benefit in keeping the building warm at night with equipment waste heat and, likewise, little benefit in ventilating it at night to cool it down. However, ventilation from the east and south windows could be useful during the day in place of air conditioning, particularly on the first floor.

6.4 Electricity consumption management

6.4.1 Total electricity consumption

Grid electricity is the principal source of energy for this building. Of the energy consumption, 54% is used for air conditioning and 42% for appliances supplied from GPOs. This includes geographic information survey (GIS) equipment as well as office computer and telecommunication equipment and two small kitchens. The total electricity consumption over the nine months was 12,997 kWh, of which 5492 kWh was used outside working hours (Figure 36, Figure 37). Table 22 shows which services are being used outside working hours, and the analysis that follows establishes how much energy was being used and how it might be managed.

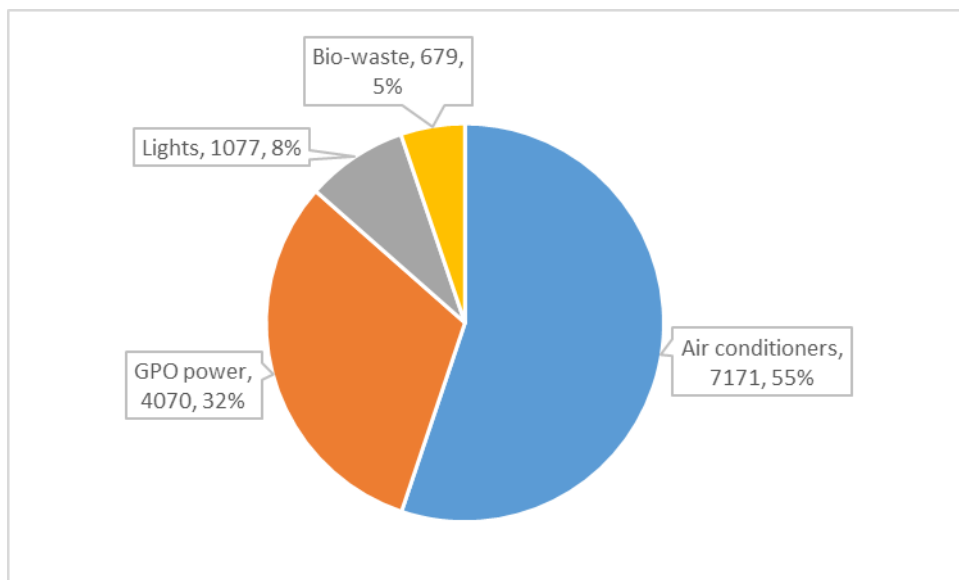


Figure 36: FNQ3 corporation building – distribution of electricity consumption in kWh

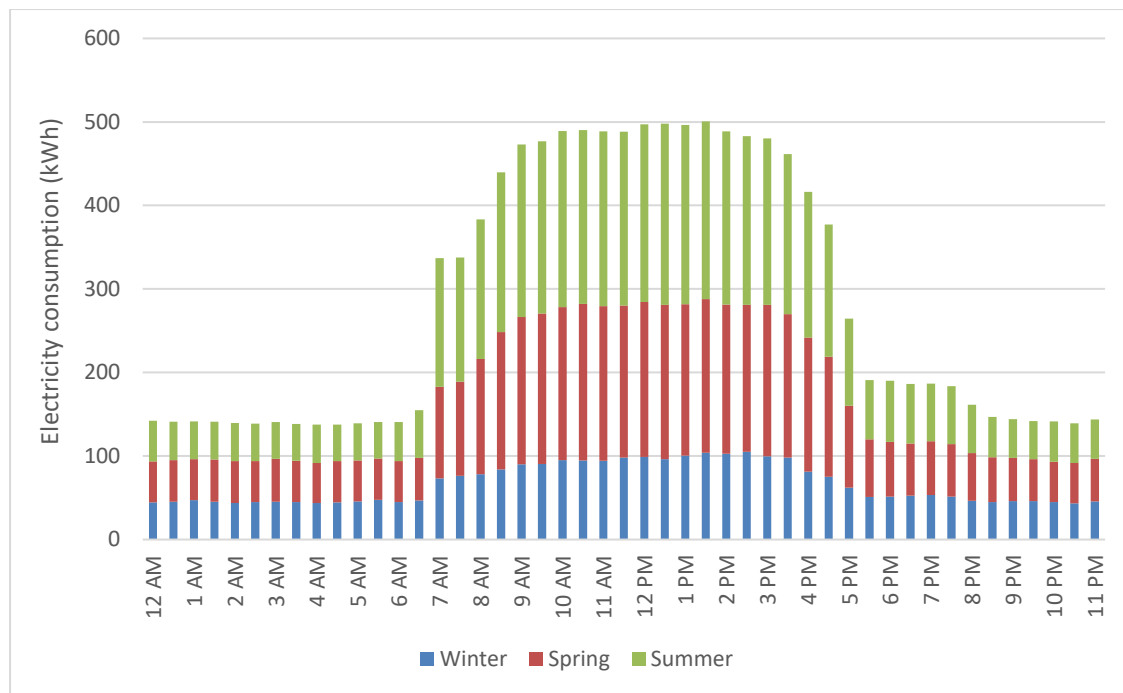


Figure 37: FNQ3 corporation building – diurnal total electricity consumption for winter, spring and summer

Table 22: FNQ3 corporation building – hours of operation for building electrical services

Service	Consuming electricity all day nearly everyday	Only consuming electricity during working hours
Lights		✓
General power outlets	✓	
Air conditioners: Email and 2x Acson	✓	
Air conditioners: Fujitsu, Panasonic, Lennox, Teco, N4		✓
Bio-waste	✓	

6.4.2 Air conditioning electricity consumption

Figure 38 shows that the measured air conditioning electricity consumption is significantly greater than the AccuRate simulated consumption in summer except for the holiday period in December and early January. Likewise, in winter the air conditioner consumption, although modest, is significant, while the AccuRate simulation suggests it should be near zero and near zero in spring. This suggests that the heat load from equipment and staff is contributing to the thermal load beyond the assumptions used by AccuRate.

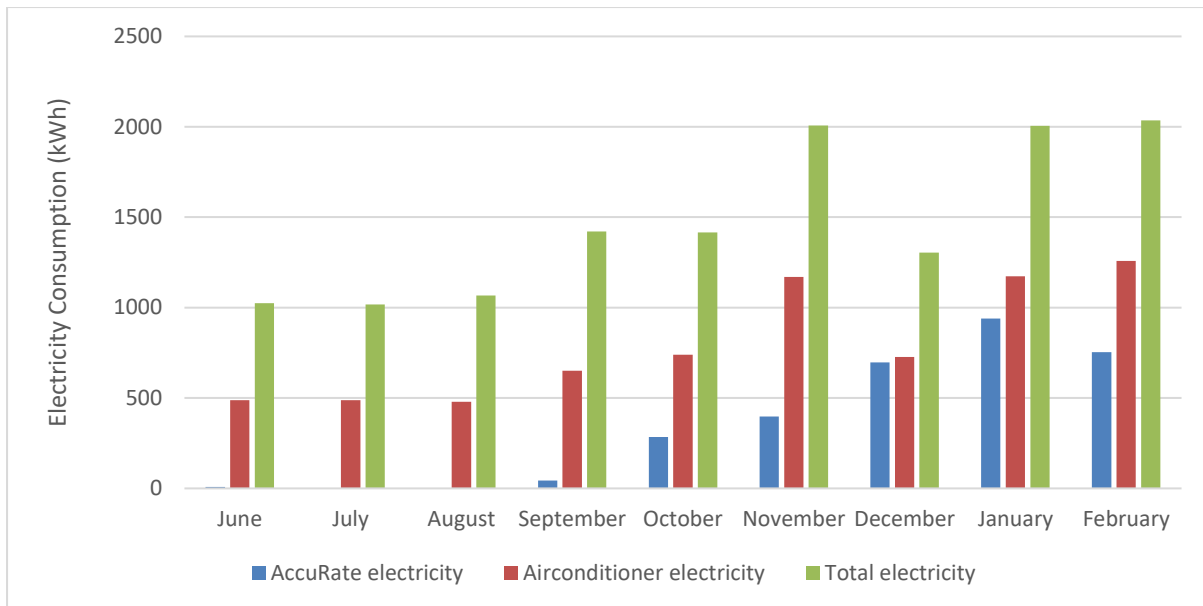


Figure 38: FNQ3 corporation building – AccuRate vs. measured values for air conditioner and total electricity consumption

6.4.3 Consumption hot spots

Figure 39 shows the air conditioning consumption in each area of the building. The ground floor offices have the most air conditioners and the highest consumption over nine months at 3.8 MWh, followed by the reception area at 1.4 MWh. This area may have the greatest occupancy as well as being located in an area with large windows.

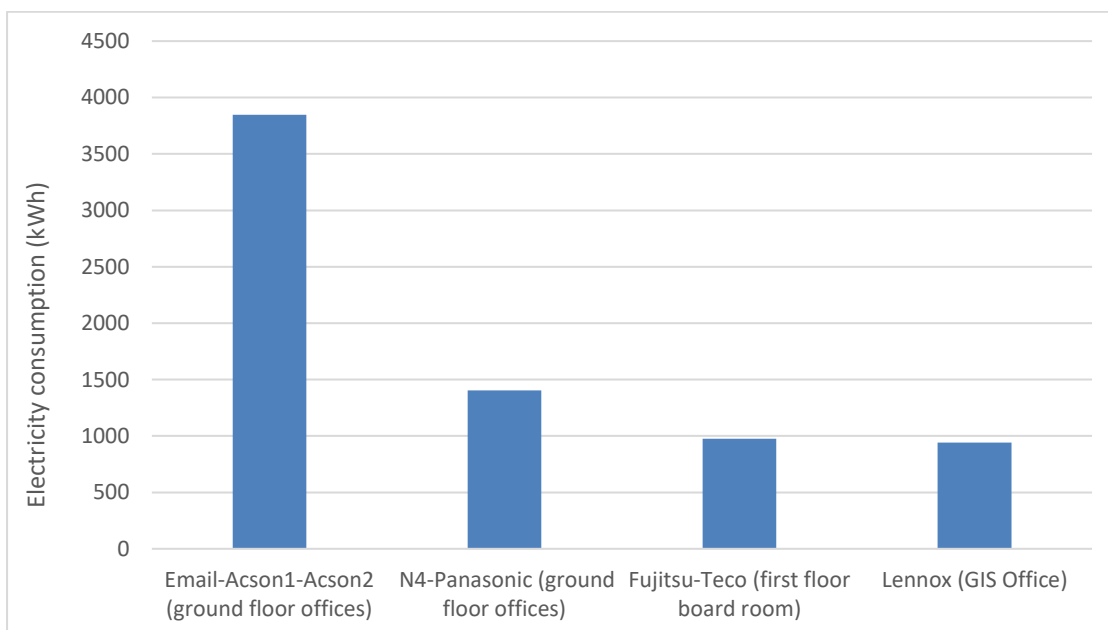


Figure 39: FNQ3 corporation building – air conditioner circuit consumption

6.4.3.1 Air conditioner electricity consumption outside working hours

Figure 40 shows the electricity consumption of all the air conditioners. All air conditioners are switched off using hand controllers when not in use but nevertheless show significant electricity consumption outside working hours throughout the year.

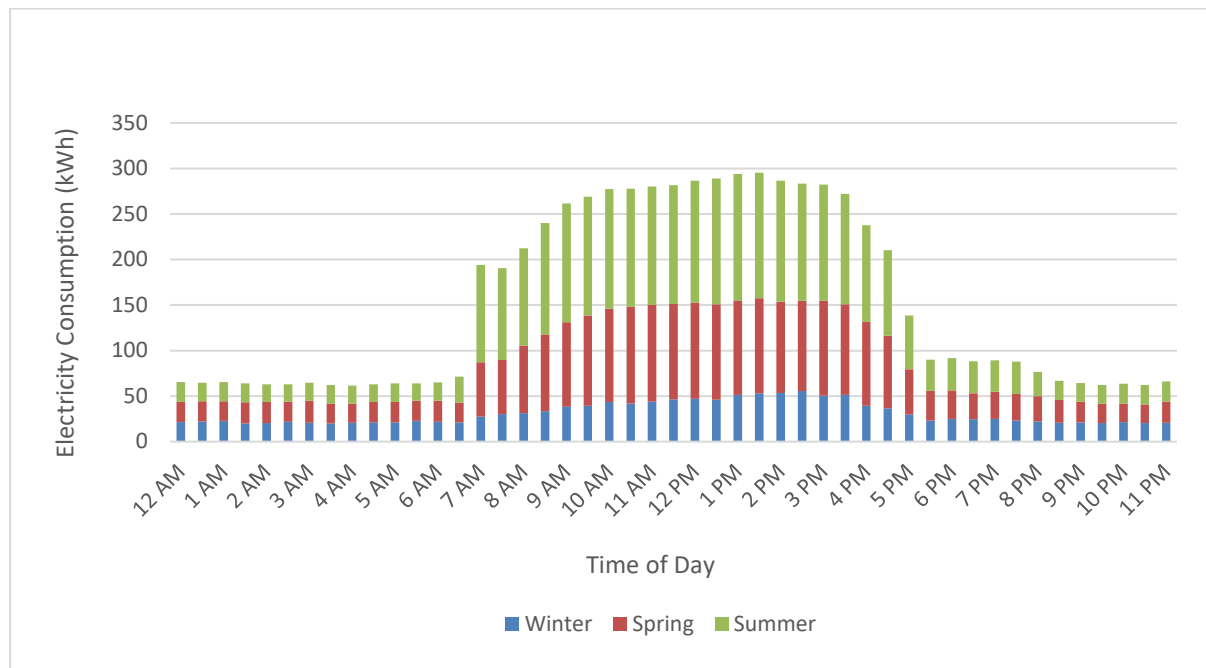


Figure 40: FNQ3 corporation building – diurnal air conditioner electricity consumption for winter, spring and summer

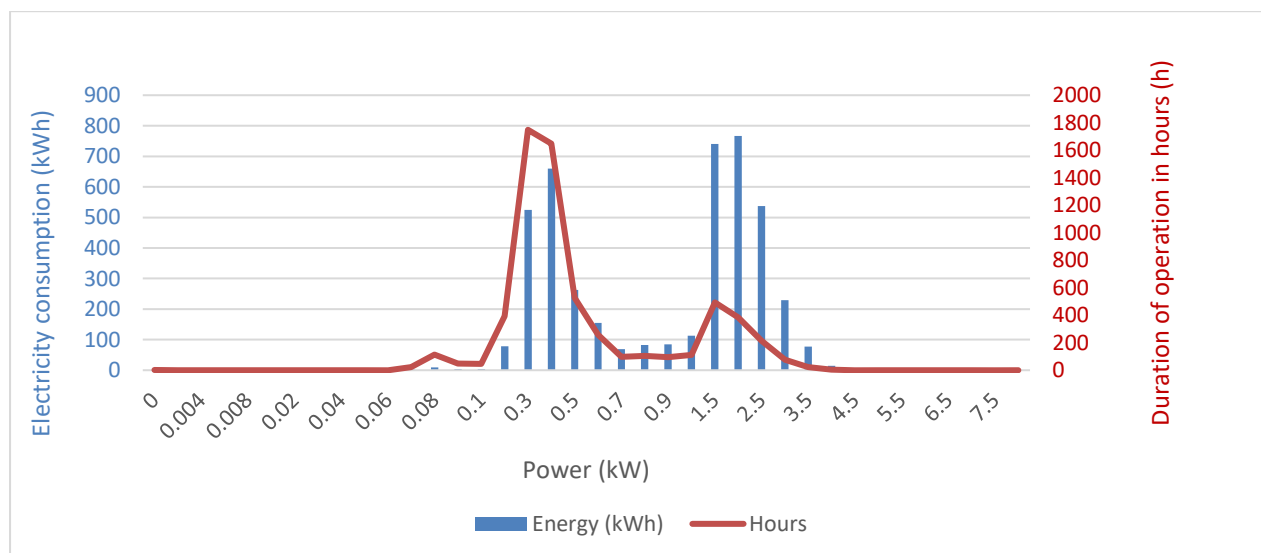


Figure 41: FNQ3 corporation building ground floor offices – hours and power levels of operation for the air conditioners

Figure 41 confirms that the Email, Acson1 and Acson2 units in the ground floor offices are never completely switched off. It can be seen that there is no time when the power is zero. There are two peaks of energy. The right hand peak shows a total consumption of 2565 kWh at a power level of about 2 kW and is associated with about 1500 hours of use. This is the air conditioner running in normal cooling mode

during working hours. The left hand peak shows a total consumption of about 1770 kWh at a mean power of 300 W and is associated with about 5000 hours of use. This represents air conditioners or other equipment running on standby, where the appliance is still drawing electricity because it has been switched off by the hand controller but not at the main GPO switch.

6.4.3.2 General power outlet electricity consumption

The GPO consumption during working hours is reasonable for the number of computers and pieces of office equipment in use. Nevertheless, it does account for a third of the building's electricity consumption. On the other hand, almost the same amount of electricity is consumed outside working hours; a review of what equipment can be switched off outside working hours is essential (Figure 42). When appliances are supplied from GPOs, it is harder say if their consumption is due to standby operation or because they are switched completely on outside working hours. However, Figure 43 does show that for most of the after-hours time, it is lower power devices that are consuming 1568 kWh of electricity, accounting for 40% of the GPO sub-circuit consumption. Reducing this out-of-hours consumption is an intrinsically worthwhile saving and could also save up to 700 kWh of waste heat load on the air conditioners.

6.4.3.3 Waste heat from appliances and people

In winter, the discrepancy between predicted and actual air conditioner consumption varies from 500 kWh per month in winter to as much as 900 kWh in the working months of spring and summer. Over the nine months this amounts to a discrepancy of 4046 kWh.

The higher values of the indoor measured temperatures compared with the modelled temperatures throughout the day and night, together with measured values of air conditioner electricity consumption that are much greater than those estimated in the AccuRate model, strongly suggest the presence of a heat source that is not accounted for by the model. An estimate of the waste heat needed to cope with the equipment and staff heat load is 5242 kWh over nine months. This accounts for the discrepancy in electricity consumption between the AccuRate model and the measured consumption. It suggests that reducing unnecessary out-of-hours electricity consumption would have a significant secondary benefit in reducing thermal load on the air conditioners. It also suggests that the air conditioners are likely to be operating at reasonable COP values of greater than 3.

Because the building is of lightweight construction, the heat is less likely to accumulate than if it were a better block or brick building. However, it may still be worth ventilating the building for one or two hours before it opens for business to remove waste heat that may have accumulated overnight.

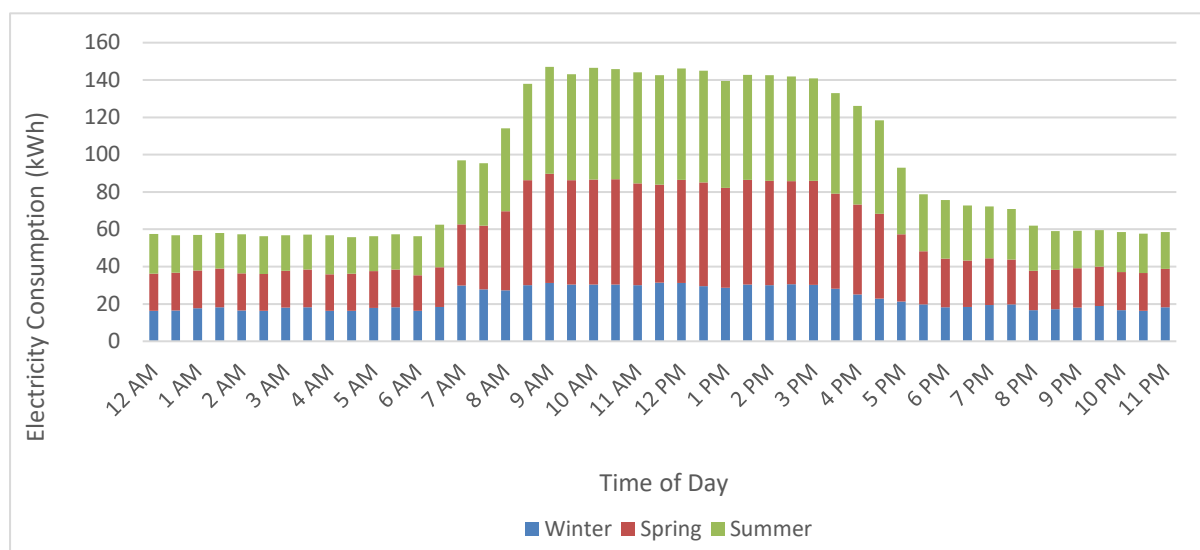


Figure 42: FNQ3 corporation building – diurnal general power outlet electricity consumption for winter, spring and summer

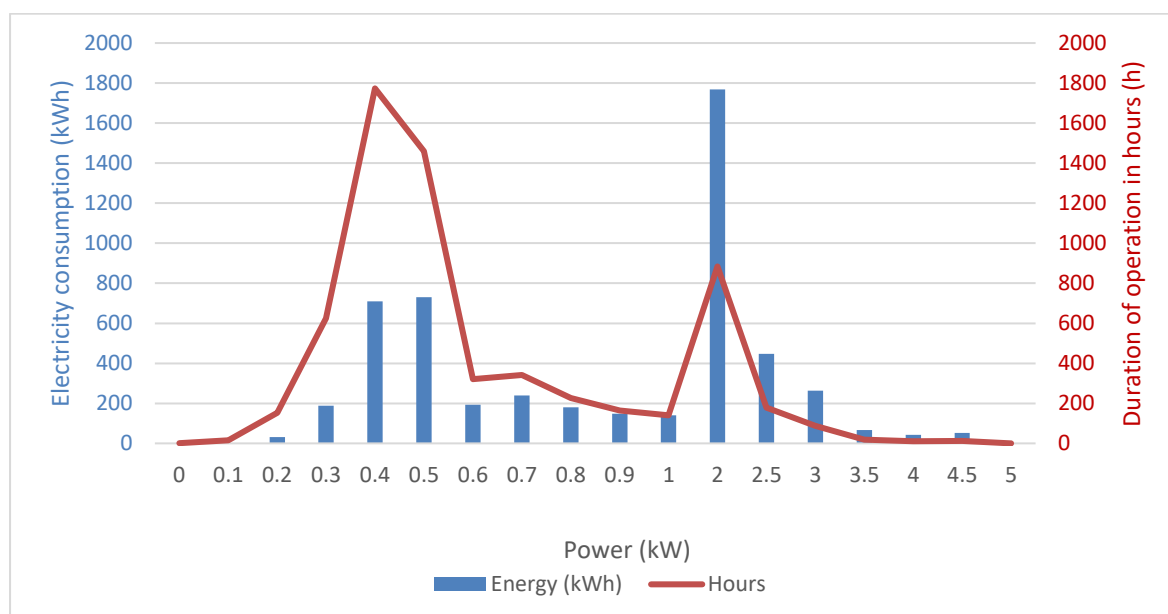


Figure 43: FNQ3 corporation building – hours and power levels of operation for general power outlets

6.5 Observations and recommendations

6.5.1 Electricity consumption – air conditioning and general power outlets

The electricity consumption in the building is dominated by air conditioning and the use of office equipment powered from GPOs. This amounts to 80% of the building's electricity consumption. Hot water, lighting and biological waste management play a relatively minor role. The GPO loads are moderate, operating 24 hours a day, seven days a week most of the year and running at an average power level of 500 W during the day and 200 W at night. The air conditioning consumption is also moderate, at an average power during the day of 1 kW and 200 W during the night. However, building temperature is

typically 2–4 °C higher than predicted by the AccuRate model of the building's thermal performance, despite air conditioner electricity consumption being twice as high. This is probably due to waste heat from equipment in the building being higher than that assumed by AccuRate. The principal opportunity for reducing electricity consumption is to ensure that appliances are turned off at night and that when new air conditioners are purchased they should be capable of being switched off at the wall rather than by simply using the controller. This may also be possible with the present air conditioners, though it would be wise to check with the contractor responsible for maintenance whether they can be switched off at the main supply without damaging the appliance.

6.5.2 Recommendations

1. Check with the maintenance contractor if air conditioners can be switched off at the mains. If so, ensure they are switched off at the mains outside working hours.
2. Consider shutting down air conditioners in winter and spring, just running them once a week for an hour to maintain the refrigerant seals in good condition. Then cool the building by using ventilation to draw in air from the eastern windows facing the main road and sea. Ideally, this would use automated vents.
3. When buying new air conditioners, make sure they can be switched off at the mains.
4. Make sure as many appliances as possible are switched off at the mains outside working hours. When doing this, it is advisable to first switch off at the appliance and then at the mains switch. This may mean initiating timer controls or setting up power boards where multiple appliances can be switched off with one switch.
5. Even without insulation in the ceiling, painting the roof white could save up to 17% of electricity. Alternatively, if ceiling/roof foil insulation is installed it could save a similar percentage of electricity.
6. On the second floor consider opening the windows, the back door and the fans instead of running the air conditioner. This could be effective in late winter and spring. In summer, the windows will need to be closed when people are working on the first floor; when no one is there, keeping the windows and door open should help to cool the building even in summer.

7. CA1 Art centre

7.1 Background

CA1 art centre is located in a community of about 150 people, a few hundred kilometres from Alice Springs. The art centre was established in 1992. It is now used by a community of artists that have developed an international reputation. The building occupancy fluctuates as artists and staff prepare and attend exhibitions worldwide.

The art centre has 52 registered artists with 10–15 regularly using the facilities each week. A typical day would see five or six artists painting, one manager working, and from May to September about three to five tourists a day, as well as relatives and other local visitors. The centre is closed for about three weeks a year during the Christmas period. Two buildings with a total floor area of 392 square metres support this activity. The main building has several rooms, including the main studio area, a separate office and display room, workshop and preparation areas and a small washroom. The main studio has two small annexes used as informal meeting rooms. They are made from steel wall and roof extensions to the main building. The other building is a studio comprising a single room/shed at the back of the centre away from the road. The office/showroom area was considered comfortable in winter but not in summer, while the reverse was true for the main studio area. The external shed studio was considered uncomfortable in both summer and winter. Improved comfort in the showroom area was needed to encourage tourists and to provide a congenial atmosphere for the appreciation and purchase of artworks. The studio manager had plans to incorporate gardens and improved facilities to this end, and during the period of the study significant progress had been made into developing the garden area. Towards the end of the nine-month project, the buildings underwent a major refurbishment organised by the manager and the Northern Territory Government, in which solar panels were installed together with LED lamps, improved ventilation and an upgraded air conditioner.

7.2 Art centre main building

7.2.1 Building assessment and modelling

7.2.1.1 Star rating assessments

The building was rated 1.9 stars using AccuRate, which is below the typical value of 3–4 stars typical for buildings of this age. It is located in Central Australia, and in winter the low overnight temperatures mean that during the morning it requires heating to be comfortable.

The building is predominantly besser block external walls, although there are several sections that are light clad. One of the besser block walls also has metal cladding on the outside. It is unknown whether insulation has been installed in the light-clad walls, but ceiling insulation is installed in the main studio area. The office showroom area has a raked ceiling and it is unknown if this is insulated. Given the age of the building it is unlikely that wall insulation is present, so it has been assumed that the exterior walls are uninsulated. It has also been assumed for rating purposes that no insulation has been installed in the raked ceiling.

7.2.1.2 Improved star rating – potential upgrades

Only two modification scenarios were modelled through the AccuRate software to determine which would produce the highest impact:

- insulation in the raked office/showroom ceiling
- insulation to the exterior light-clad walls as well as in the raked ceiling.

The simulation results from the various modifications are shown in Table 23. The results show that the current building rating of 1.9 stars can be increased by 0.7 stars to 2.6 stars by insulating the raked ceiling. If the light-clad external walls are also insulated, the rating increases to 3.2 stars.

Table 23: CA1 art centre main building – AccuRate star rating scenario results

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star rating
	MJ/m ²				
Current building	310.2	73.3	3.6	387.1	1.9
Insulation in office	258.3	54.1	3.1	315.5	2.6
Insulated walls	220.7	27.7	2.8	251.2	3.2

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software was used to model actual energy consumption verses the theoretical energy consumption that is modelled in the NatHERS rating mode. The modelling assumed that conditioned air was required from 8 am to 6 pm each day and that it was provided by reverse cycle air conditioners with a COP of 3. All areas were considered to be conditioned except the bathroom, the storeroom and the annexe on the north side of the building. Figure 44 shows the modelled results for the current building and clearly indicates the split in energy between the winter heating period and summer cooling; the line on the figure shows the average outdoor temperature experienced during each month. The monthly winter heating demand is up to five times more than the summer monthly cooling demand and is mostly driven by the very cold overnight temperatures. Over the winter months the average temperature is around 12 °C. The minimum temperatures predicted by the model (not shown on the chart) are often below zero in the winter months. These very cold temperatures mean that on winter mornings, indoor temperatures will be cold and heating will be required to bring the building up to a comfortable temperature. During the day the temperature does not rise significantly; consequently, heating is required throughout the day to maintain comfort.

Figure 45 predicts the total electricity consumption for heating and cooling for each month for each of the different scenarios. The mild autumn and spring seasons see little requirement for heating or cooling energy; winter is the dominant season. Insulating the raked ceiling reduces energy consumption over winter by around 14%. Also insulating the walls results in an energy saving of 25% over the winter period.

Figure 46 predicts the hourly energy consumption for each scenario for winter and summer. The summer performance shows that if the building is fully insulated, then energy demand is greatly improved and produces a much more even energy load across the day. Indeed, a 73% reduction in cooling energy is achieved during the peak afternoon compared to the current building performance.

The winter is markedly different to the summer performance. Maximum heating energy is required early in the morning to compensate for the cold night temperatures. Energy requirements then decrease during the day until the end of the working day and the system is shut down. Again, savings are achieved by insulating the whole building. A 27% saving is achieved during those initial heating hours if the building is fully insulated compared to the current building.

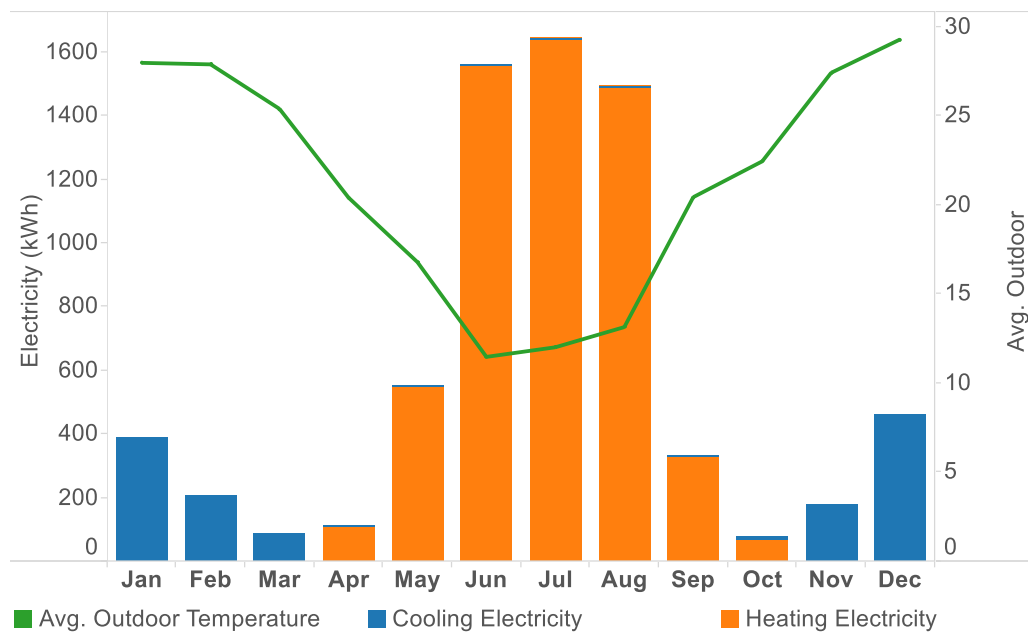


Figure 44: CA1 art centre main building, office/showroom: monthly air conditioner electricity consumption and average outdoor temperature

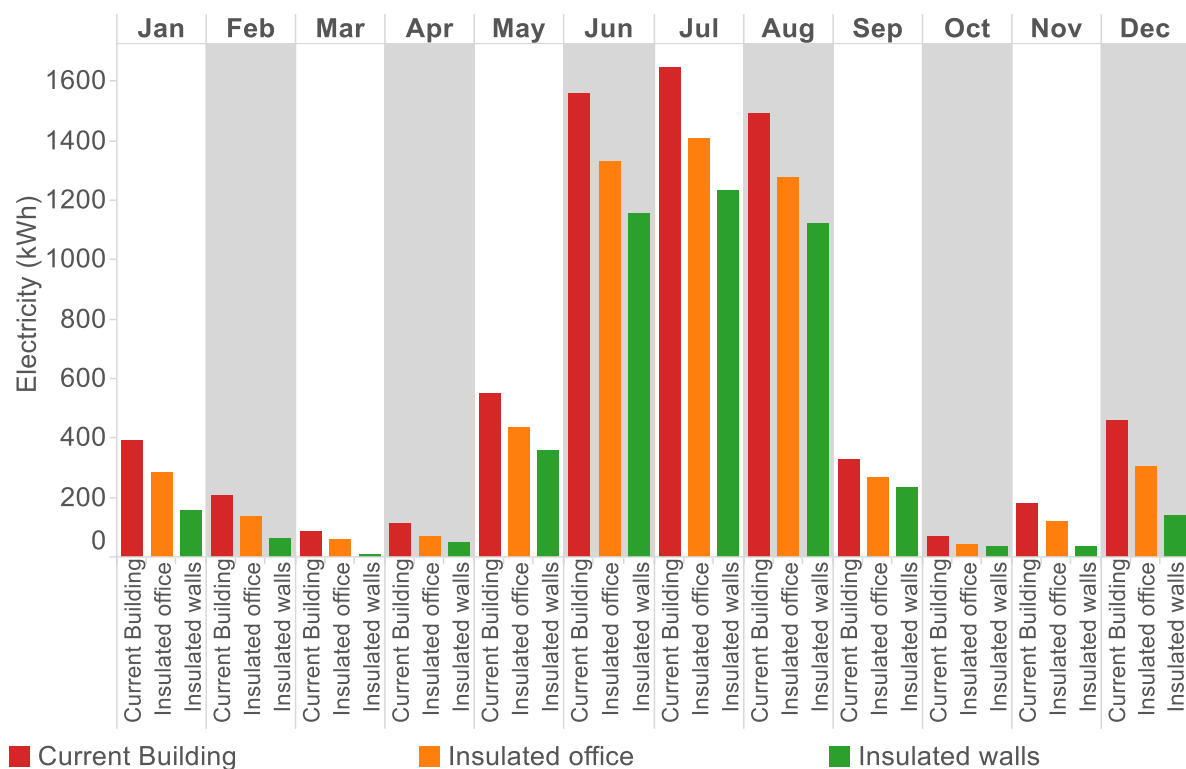


Figure 45: CA1 art centre main building – monthly air conditioner electricity consumption for different energy-saving scenarios

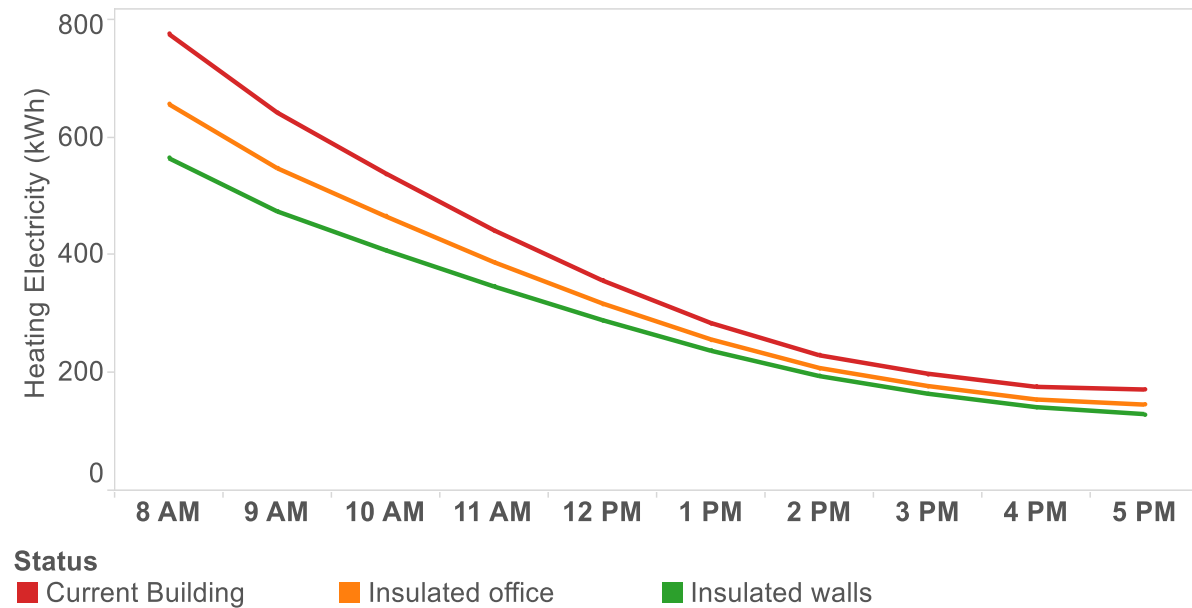
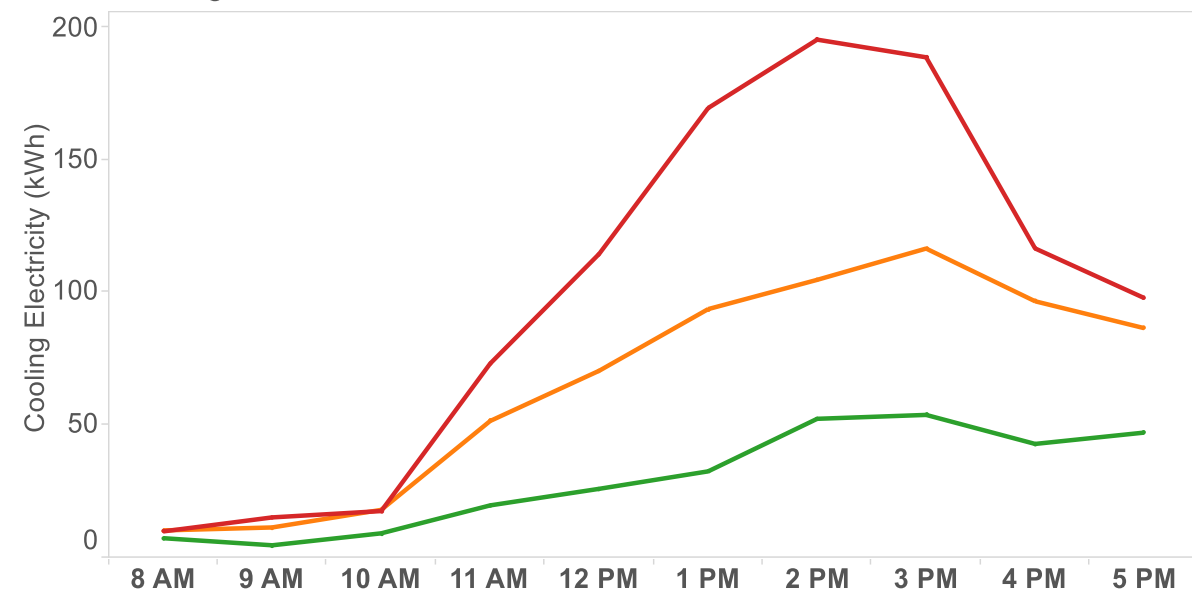
Winter Heating**Summer Cooling**

Figure 46: CA1 art centre main building – summer and winter diurnal electricity consumption predictions for different energy-saving scenarios

7.2.1.3 Summary observations

The energy profile of the building suggests that winter heating is the primary issue. Cold overnight winter temperatures mean the building begins a winter's day at a low temperature. Consequently, heating is required to bring the building's internal temperature up to a comfortable level. Improving insulation to the fabric of the building will help retain some heat overnight and will reduce the amount of heat escaping the building when the heating is operating. Insulation will also benefit the building during the summer periods when cooling is required. Significant savings in cooling energy can be achieved through insulating the building and creating a more even cooling load throughout the day.

7.2.2 Climate control

7.2.2.1 Outside the buildings – comparison of BoM, AccuRate and measured temperature values

In winter, the maximum AccuRate assumed values for the CA1 art centre were close to the maximum BoM temperatures at Alice Springs. In summer, they were regularly as much as 10 °C lower than the corresponding BoM values. Table 24 compares the AccuRate predicted temperatures against the measured values adjacent to the building. In winter, they were on average 5 °C lower than the measured values. In summer, they were 1–4 °C lower.

Table 24: CA1 – measured and predicted winter and summer temperatures outside the buildings

Average diurnal shaded external temperatures (°C)	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	10.4	25.0	19.5	24.2	38.9	33.8
AccuRate	4.8	19.1	16.8	21.0	34.5	32.8

7.2.2.2 Inside the building measured vs. AccuRate temperature values

The office air conditioner provides cooling for most of the year during working hours. Table 25 compares the AccuRate predictions of conditioned air with the measured temperature values. On average, the predictions during working hours were 3 °C below the measured values in winter and 7 °C below the measured values in summer. The AccuRate estimates without air conditioning were approximately 7–8 °C below the measured day time values in winter and summer.

The summer discrepancies may have been due to the air conditioners being under capacity or because the temperature control was set high. The discrepancy without air conditioning included can be partly ascribed to AccuRate's use of lower than measured outside air temperatures. This may account for a difference of 2–3 °C. The remaining 4–5 °C suggests that waste heat from the telecommunication equipment and radiated heat from the roof were also contributing factors.

Table 25: CA1 art centre main building, office/showroom – inside measured and predicted winter and summer temperatures

Average diurnal temperatures (°C): Office/showroom	Winter daily minimum	Winter daily maximum	Winter working hour average	Summer daily minimum	Summer daily maximum	Summer working hour average
Measured	15.9	23.4	21.4	30.1	37.2	34.2
AccuRate air conditioned	15.8	20.0	19.1	26.5	29.1	27.8
AccuRate non-conditioned	12.5	14.6	13.5	26.8	29.6	28.3

The role of waste heat and radiated heat from the roof is further confirmed in Table 26, which gives measured and AccuRate predictions for temperatures that are much closer inside the main studio than for the office showroom. The studio holds very little electrical equipment and has an insulated ceiling so that the influence of radiated heat from the roof would be much less.

The 3–4 °C discrepancies in the conditioned air predictions are consistent with the air conditioners being under capacity or because the temperature control was set high. Likewise, AccuRate’s use of assumed outside air temperature values that are too low is sufficient to explain the 3–4°C discrepancy for the unconditioned air predictions.

Table 26: CA1 art centre main building, studio – inside measured and predicted winter and summer temperatures

Average diurnal temperatures (°C): Studio	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	15.8	19.3	17.9	29.8	32.2	30.5
AccuRate air conditioned	16.1	20.1	20.0	24.6	28.7	27.2
AccuRate non-conditioned	12.8	14.9	13.6	24.7	29.7	27.6

7.2.2.3 Extreme temperatures

Over the nine-month monitoring period, the extreme values measured when the air conditioner was not running were a maximum of 44.5 °C and a minimum of 12.3 °C in the office and a maximum of 36.5 °C and a minimum of 12.3 °C in the studio.

7.2.2.4 Summary observations

The temperatures in the office are much higher than predicted by AccuRate in summer and winter, so that it is comfortable in winter and too hot in summer. The studio temperatures are a little higher than predicted in summer and winter, so that the studio is too cold in winter and warm but tolerable for most of summer.

These observations are consistent with AccuRate’s use of assumed values for outside temperature that are too low, as well as the presence of significant thermal load from computer and telecommunication equipment installed in the office and radiated heat from a roof that has no low emissivity foil insulation.

7.2.3 Electricity consumption management

7.2.3.1 Total electricity consumption

Electricity from the community diesel generator is the principal source of energy for the art centre. Power shutdowns of longer than two minutes caused by generator failures were not detected. Local partial shutdowns lasted a week or two during holidays or overseas travel to exhibitions.

The results shown here provide a baseline prior to the considerable improvements that have been implemented within a month of the completion of this study. The improvements were initiated by the art centre manager with support from the NT Government. They include solar photovoltaic panels, LED lighting, improved ventilation and an upgraded air conditioner. Before these improvements, the total electricity consumption over the nine months was 5477 kWh (Figure 47) of which 16% (0.9 MWh) was consumed outside working hours.

Figure 48 is a comparison of the AccuRate predictions and the measured electrical consumption. There is a factor of three increase in electricity consumption in summer compared to winter. This is mainly due to air conditioner use in summer which consumes five times as much electricity as in winter. This is consistent with the observation that the office was too hot in summer and quite comfortable in winter. It is quite

opposite to the AccuRate prediction, which assumes a greater need for heating in winter than for cooling in summer (Figure 48). The following factors contribute to this discrepancy:

- AccuRate underestimates the external ambient air temperature by 3–6 °C.
- Telecommunication and computer equipment in the office are contributing to the thermal load.
- There is no low emissivity insulation under the office roof.

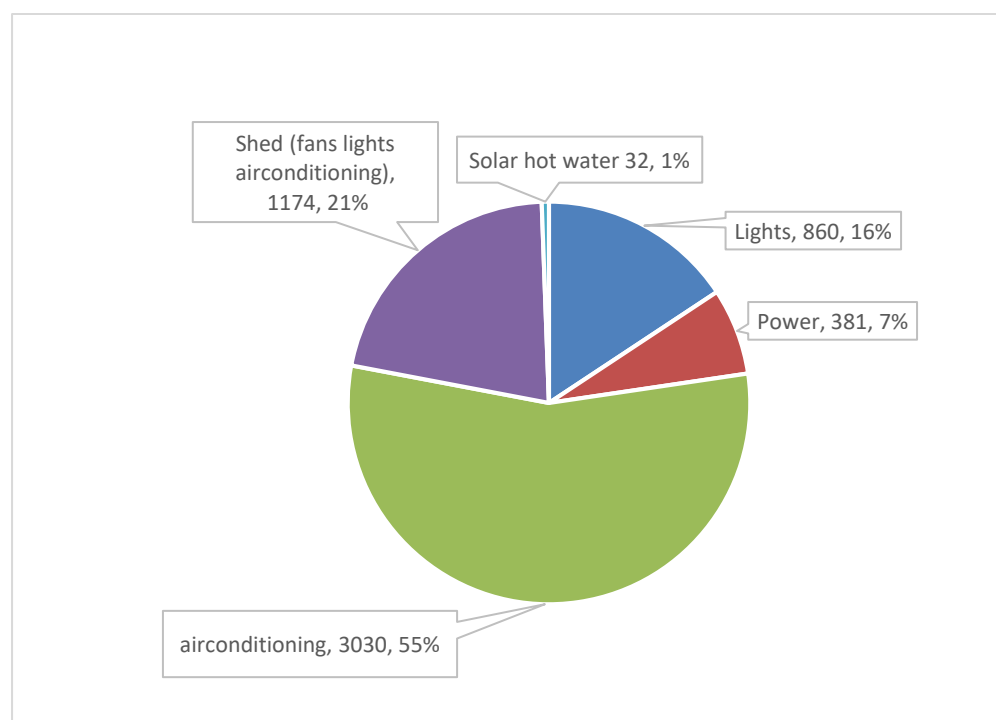


Figure 47: CA1 art centre – distribution of electricity consumption in kWh

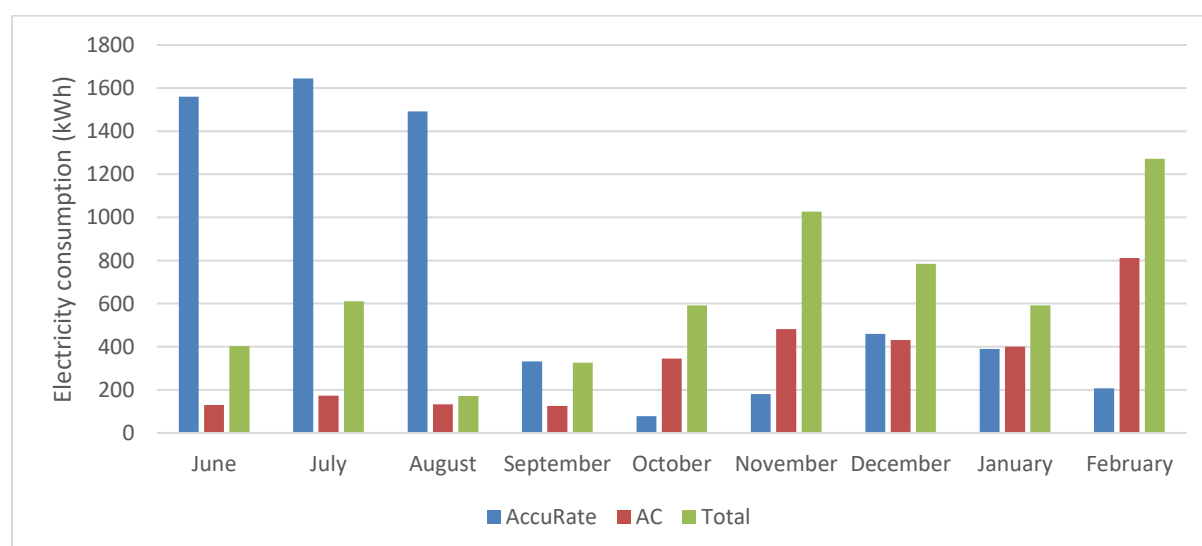


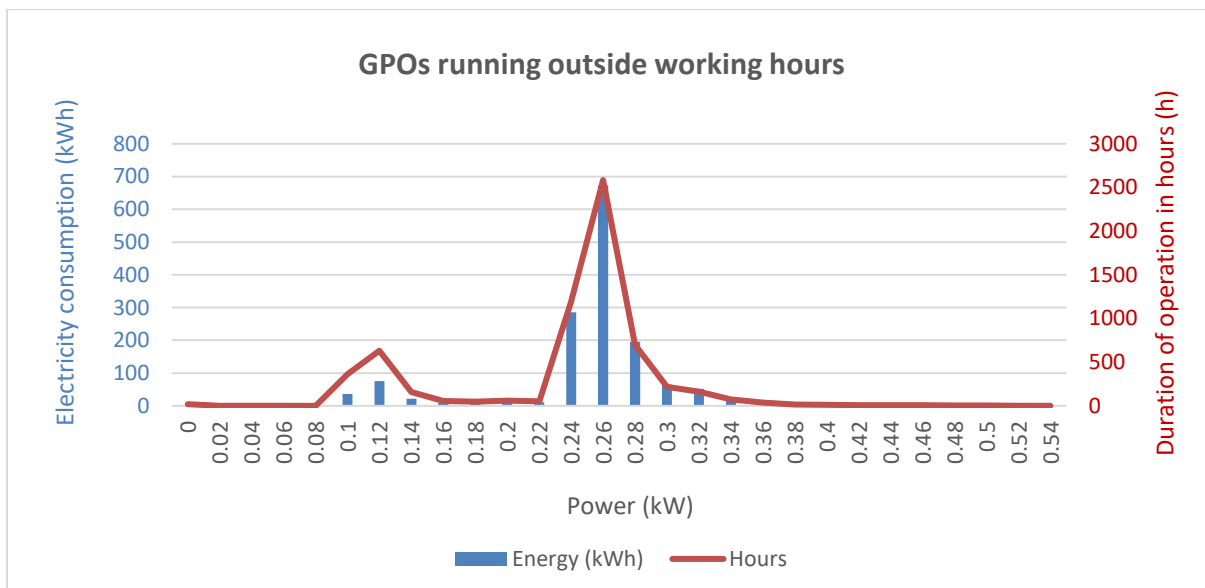
Figure 48: CA1 art centre – AccuRate vs. measured values for air conditioner and total electricity consumption

7.2.3.2 Out-of-hours electricity consumption

The out-of-hours consumption over nine months was 877 kWh, which is quite low when compared with other art centres. Table 27 shows which areas are contributing to this load. Figure 49 shows that the contribution from air conditioners is due to their being left on standby, whereas the contribution from GPOs is from equipment being left running outside working hours. Figure 50 shows the contribution from each air conditioner. The GPOs' consumption, although relatively small, also contributes to the air conditioner thermal load. Air conditioner waste heat tends not to contribute to the thermal load because it is largely dissipated outside the building.

Table 27: CA1 art centre – hours of operation for the building electrical services

Service	Consuming electricity all day nearly every day the building is occupied	Only consuming electricity during working hours
Lights		✓
General power outlets (including air conditioners in the external studio)	✓	
Air conditioners – kitchen, studio, office	✓	
Air conditioners – annexe	Insignificant	✓
Solar hot water		✓



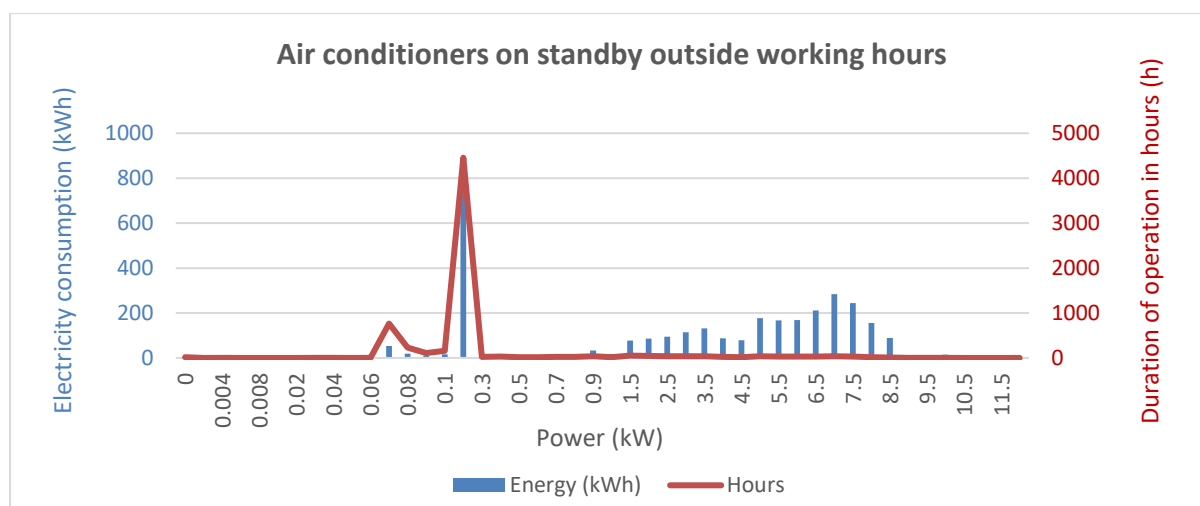


Figure 49: CA1 art centre – general power outlets' and air conditioners' electricity consumption outside working hours

7.2.3.3 Comparison of general power outlet active and passive use

The GPOs and external studio outlets consume 20% of their electricity (300 kWh) outside working hours and, as the computers are in standby during this time, it is likely that the satellite telecommunication equipment is mainly responsible for this consumption.

7.2.3.4 Comparison of air conditioner active and standby use

The air conditioners on average consumed 20% of their electricity (600 kWh) outside working hours, with the studio air conditioner consuming 30%.

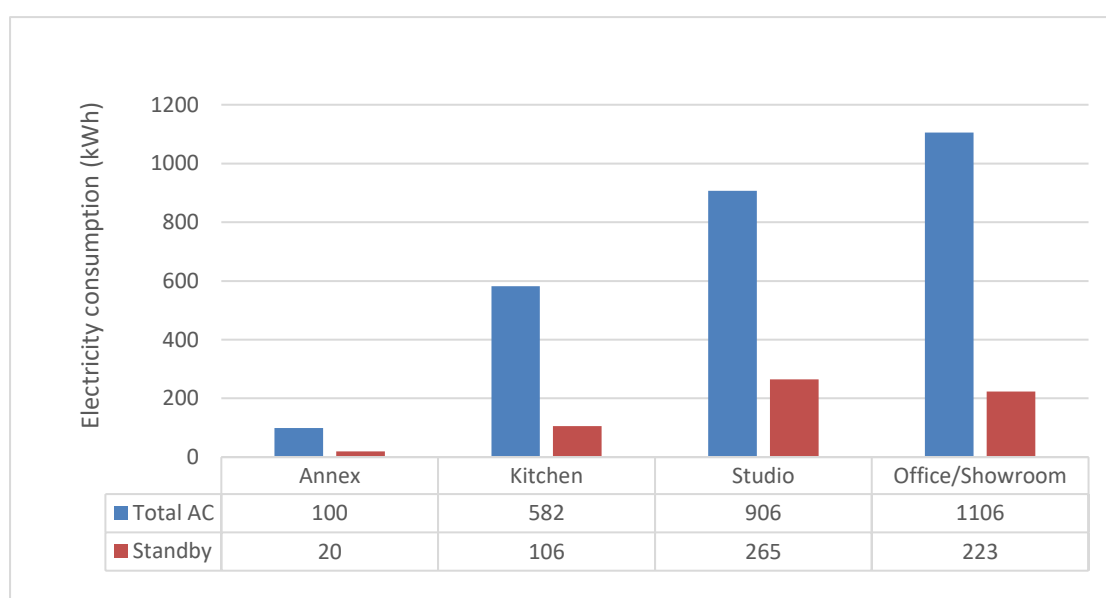


Figure 50: CA1 art centre main building – air conditioners' run and standby electricity consumptions

7.2.4 Recommendations

A great deal of work is already being carried out by the art centre manager to reduce energy consumption. The following actions may also be worth considering:

1. Check with the air conditioner manufacturers whether the units can be completely shut down rather than being left on standby. If so, place the air conditioners on a low power consumption timer that can be manually overridden, so that they are completely shut down outside working hours.
2. Relocate the telecommunication equipment to a protected environment, perhaps with a separate small air conditioner to maintain the appropriate operating environment.
3. Switch off computers by first shutting them down normally then switching them off at the mains. It may help to put the computer power supply on a timer or to arrange the supply from a power board so that all the equipment can be switched off at a single switch after the computer has been shut down.
4. Check with the telecommunication service if it is possible to shut down the telecommunication equipment after hours.
5. Consider a low emissivity insulation foil for the ceiling of the office or, alternatively, paint the outside roof over the office white.

7.3 CA1 external studio

7.3.1 Assessment and modelling

7.3.1.1 Star rating assessments

The building was rated 0 stars under the NatHERS energy rating scheme, which is not surprising given that the building is a simple metal-clad shed. These sheds usually have no insulation and no thermal mass (except the concrete slab). Consequently, their thermal performance is usually very poor. Despite the simplicity of the building, upgrades and improvements are possible. The modifications that were modelled were adding insulating rigid polystyrene panels to the roof and adding cellulose fibre insulation to the walls in addition to the roof insulation.

The simulation results from the various modifications are shown in Table 28. The results show that the current building rating of 0 stars can be increased to 1.9 stars by insulating the roof area. If the walls are then also insulated, the star rating increases to 2.6 stars, which is quite an acceptable performance level.

Table 28: CA1 external studio – AccuRate star rating scenario results

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star rating
	MJ/m²				
Current building	543.0	564.7	5.9	1113.6	0.0
Insulated roof	240.4	154.1	4.7	399.2	1.9
Insulated roof and walls	201.6	103.7	4.3	309.6	2.6

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software was used to model energy consumption. The modelling assumed that conditioned air was required from 8 am to 6 pm each day and that it was provided by reverse cycle systems with a COP of 3. The entire building is one space, so it was assumed that this was all conditioned. Figure 51 shows the results for the current building and shows high energy demand during summer and winter. Unlike the other buildings modelled in the same area, the summer cooling energy is higher than the winter heating energy, but both periods require a significant energy input to try and maintain comfort.

Figure 52 predicts the total electricity consumption for heating and cooling for each month for each of the different scenarios. Insulating the roof delivers significant energy savings in both summer and winter. A 70% saving in energy is achieved over the summer period, and a 50% saving is achieved during winter. A further 30% saving is achieved during summer if the walls are also insulated, while the additional saving in winter is around 15%.

Figure 53 predicts the hourly energy consumption for each scenario for winter and summer. The summer performance shows that if the roof is insulated, energy demand is greatly improved and produces a much more even energy load across the day. Again, a 70% reduction in cooling energy is achieved during the peak afternoon compared to the current building performance. Insulating the walls as well as the roof produces further reductions in energy.

As for other buildings modelled in the same area, the maximum heating energy is required early on winter mornings to compensate for the cold night temperatures. Savings are achieved by insulating the roof. A 50% saving is achieved during those initial heating hours.

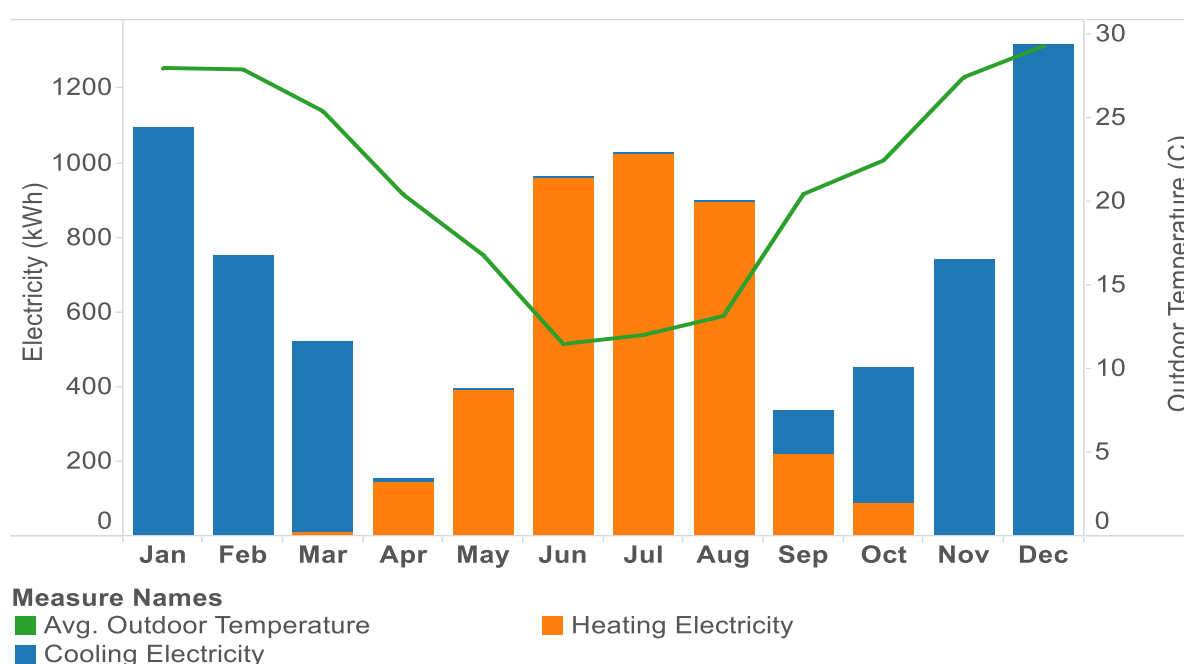


Figure 51: CA1 external studio – monthly air conditioner electricity consumption and average outdoor temperature

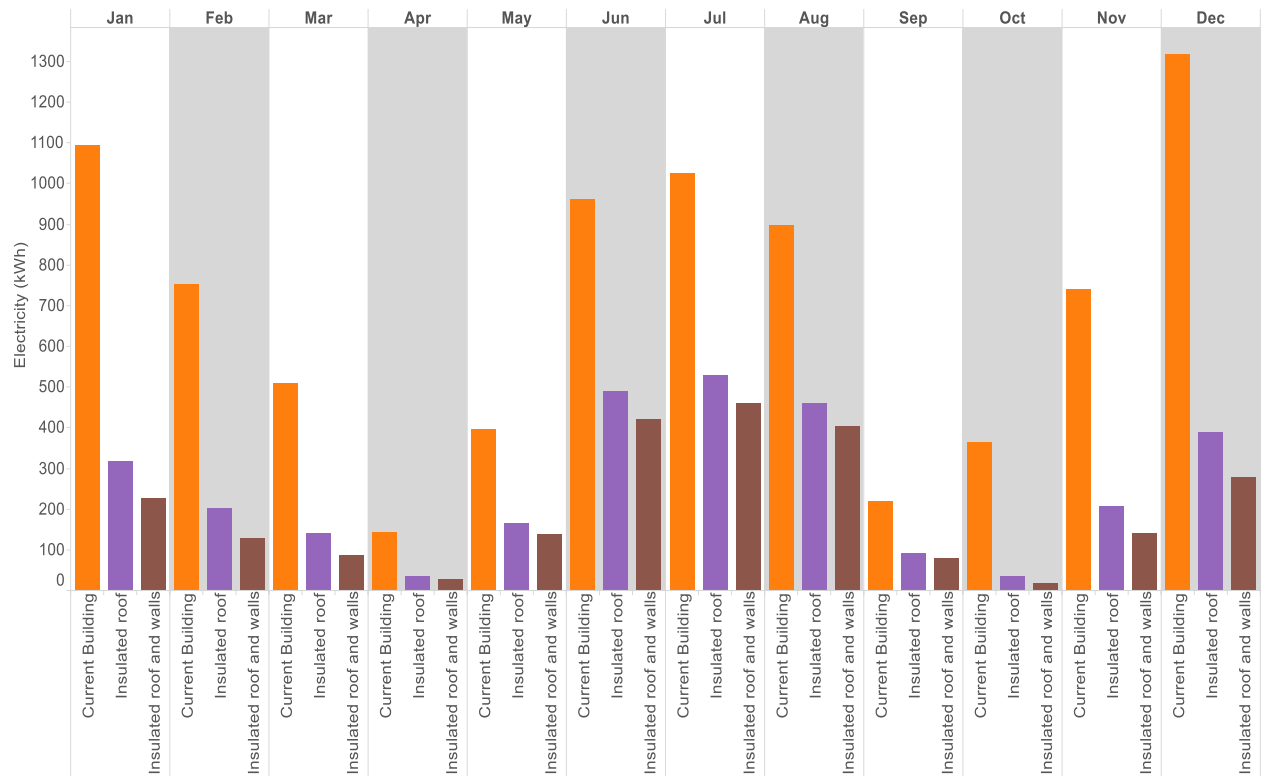
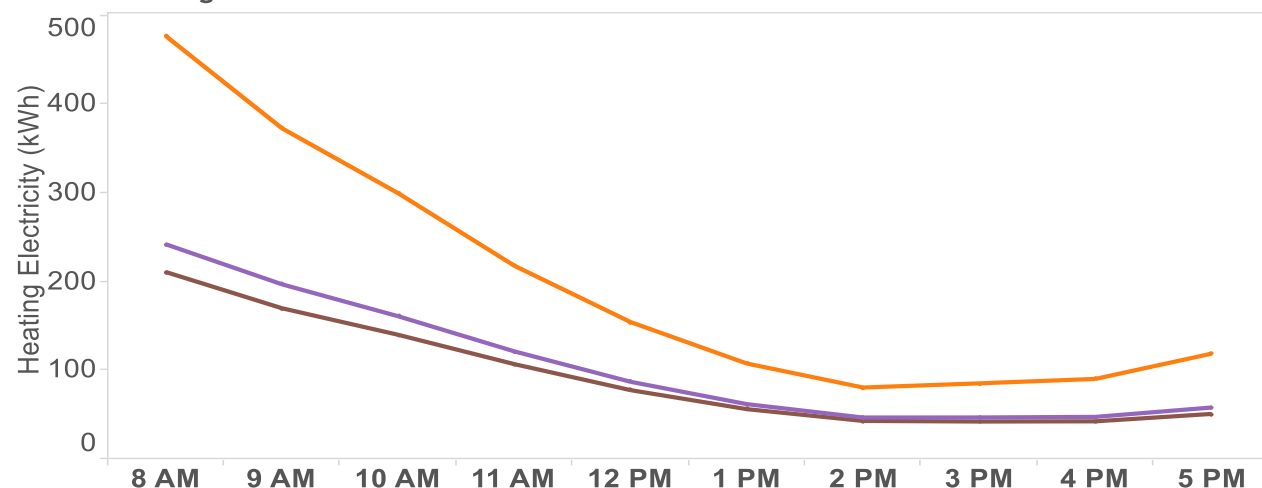


Figure 52: CA1 external studio – monthly air conditioner predicted electricity consumption for different energy-saving scenarios

Winter Heating**Status**

Current Building

Insulated roof

Insulated roof and walls

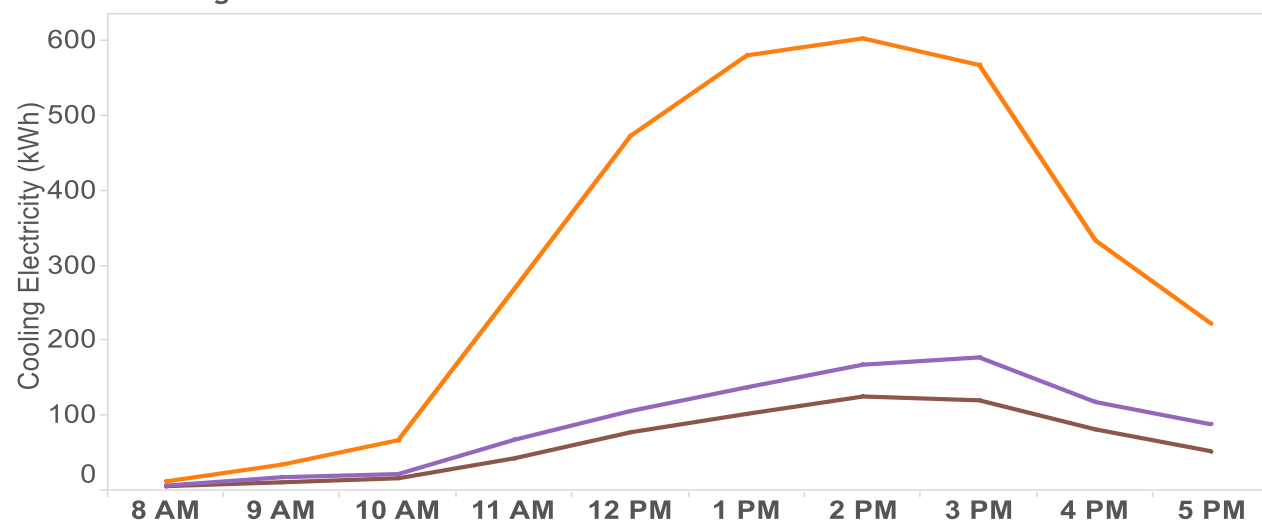
Summer Cooling

Figure 53: CA1 external studio – summer and winter diurnal electricity consumption predictions for different energy-saving scenarios

7.3.2 Climate control

7.3.2.1 Inside the building measured vs. AccuRate temperature values

Table 29 compares the AccuRate predictions of conditioned air with the measured temperature values. On average, the predictions during working hours were 2 °C lower than the measured values in winter but 11 °C below the measured values in summer. The unconditioned AccuRate predictions were close to the measured values in summer. This suggests that the external studio was used much more in winter than summer, with the implication that it was too hot to be usable most of the time in summer.

Table 29: CA1 external studio – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): External studio	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	12.4	29.2	24.2	27.6	42.5	37.9
AccuRate air conditioned	7.6	23.8	22.3	21.8	27.9	27.1
AccuRate non-conditioned	6.5	22.8	20.5	22.5	37.8	36.0

Figure 54 shows how the roof was constructed to use a large proportion of natural light from transparent panels. The figure indicates a temperature of up to 46 °C compared with 38 °C for the equivalent opaque roof section. This photograph was taken in July at 1 pm. It is likely that the summer temperatures would be much higher.

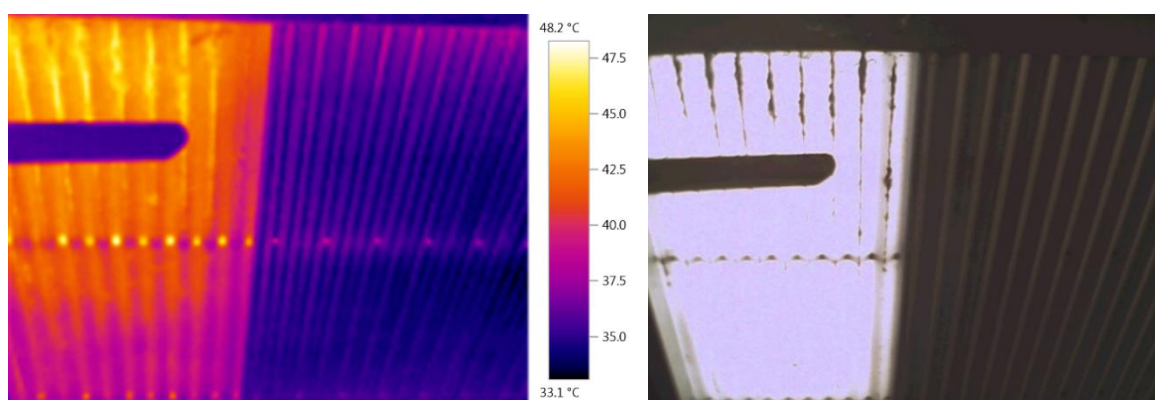


Figure 54: CA1 external studio – impact of uninsulated skylight on roof temperature

7.3.2.2 Extreme temperatures

Over the nine-month monitoring period, the extreme values measured when the air conditioner was not running were a maximum of 51.4 °C and a minimum of 7.3 °C.

7.3.3 Electricity consumption management

Over the nine-month period, the external studio consumed 1174 kWh, of which 20% (251 kWh) was out of hours. The load included fans, lights and two air conditioners. The installed air conditioner power was significantly under capacity to manage the external studio's heating and cooling requirements in summer. It was noted that AccuRate assumed external temperatures were lower than measured and estimated too low a cooling power for use in summer. This, combined with the lack of thermal insulation in the roof or walls and the poor condition of one of the air conditioners, accounts for the discrepancy between the AccuRate predictions and the measured energy consumption.

7.3.4 Recommendations

1. Insulate the shed walls and ceiling, including using low emissivity foil insulation.
2. Replace the skylight panels with honeycomb air-insulated skylights.
3. Replace the faulty air conditioner, which is consuming electricity for no useful cooling.
4. Provide external shrubs for shade and transpiration cooling.

8. CA2 Art centre

8.1 Background

CA2 is a community of about 400 people located about 200 kilometres west-north-west of Alice Springs. The art centre is set in a besser block building with a steel roof; the building was originally used for vehicle maintenance. The large openings that once allowed vehicular access have mostly been replaced with board and steel cladding that covers the door space and besser block walls at the front of the building. The building is now used by the CA2 community of artists who have an international reputation. This means that the building has significant periods throughout the year when it is closed down while artists travel to international events. About 100 artists use this building, which has a total floor area of 396 square metres and includes a studio, display room, office, washroom and storage and preparation areas. A typical day would see five or six artists painting, one or two managers working, and about five or six visits by locals and tourists. Monday is the busiest day, with 10–30 people using the building.

8.2 Building assessment and modelling

Electricity consumption in this building is already very low. It is well shaded, and temperatures on the ground floor are considered to be warm in summer but cool compared to most other buildings in the community. In winter, it is considered very cold; the occupants wear gloves and beanies. Maintenance is a significant issue, as the community is small and remote.

8.2.1 Star rating assessments

The building was rated 0.9 stars under the NatHERS energy rating scheme, which is well below the typical value of 2 stars typical for buildings of this age. This building is located in Central Australia, and the low overnight winter temperatures mean that it requires heating in winter mornings to achieve a comfortable temperature.

The building itself is very simple in design and predominantly has besser block external walls, although there are several sections that are light clad. Some of the besser block walls also have a metal (steel) clad on the outside. It is unknown whether insulation has been installed in the light-clad walls or ceiling spaces. Given the age of the building it is unlikely that wall insulation is present, so it has been assumed that the exterior walls are uninsulated. It has been assumed for rating purposes that insulation has also not been installed between the upper floor ceiling and the roof.

The building has a skillion roof with a wide eave on the western side, and there is a large tree at the south-west corner. The eastern side has a large shaded outdoor area that also shades around a third of the building on this side.

8.2.2 Improved star rating – potential upgrades

Two modification scenarios were modelled through the AccuRate software to determine which would produce the highest impact:

- adding ceiling insulation
- full insulation to ceiling and walls (where possible).

The simulation results are given in Table 30. They show that the current building rating of 0.9 stars can be increased by 1.5 stars to 2.4 stars by insulating the roof. Insulating the external walls where possible as well as the roof space increases the star rating to 3.0 stars. External walls that can be insulated include the light-clad fibre cement walls and the besser block walls that have the steel cladding.

Table 30: CA2 art centre building – AccuRate star rating scenario results

Modification	Heating	Cooling (Sensible*)	Cooling (Latent†)	Total	AccuRate star rating
	MJ/m ²				
Current building	430.2	154.3	7.5	592.0	0.9
Roof insulation	265.0	55.3	5.5	325.8	2.4
Full insulation	221.4	41.1	4.6	267.1	3.0

* Cooling (sensible) refers to the cooling energy required to change air temperature

† Cooling (latent) refers to the cooling energy required to remove moisture from the air

The AccuRate software was used to model energy consumption. The modelling assumed that conditioned air was required from 8 am to 6 pm each day, and that it was provided by reverse cycle air conditioners with a COP of 3. Only the office, storage and display rooms were considered to be conditioned with the large studio space being left unconditioned.

Figure 55 shows the results for the current building and clearly indicates the split in energy between the winter heating period and summer cooling. The monthly winter heating demand is up to five times more than the summer monthly cooling demand. This high winter heating demand is mostly driven by the very cold overnight temperatures. The line on Figure 55 shows the average outdoor temperature experienced during each month. Over the winter months, the average temperature is around 12 °C and the minimum temperature often below zero. These very cold temperatures, combined with a building that has little insulation, means that on winter mornings indoor temperatures will be cold and heating will be required to bring the building up to a comfortable temperature. During the day, the temperature does not rise significantly; consequently, heating is required throughout the day to maintain comfort.

Figure 56 shows the total electricity consumption for heating and cooling for each month for each of the different scenarios. The mild autumn and spring seasons see little requirement for heating or cooling energy; winter is the dominant season. If the building contains no insulation, then insulating both the roof space and the external walls that can be insulated will see a 40% reduction in energy use in the winter months. Even if the roof space is insulated, insulating the walls will improve energy consumption by around 15%. Significant savings are also achieved during summer, with an 80% reduction in energy consumption in December from a totally uninsulated building to a fully insulated building.

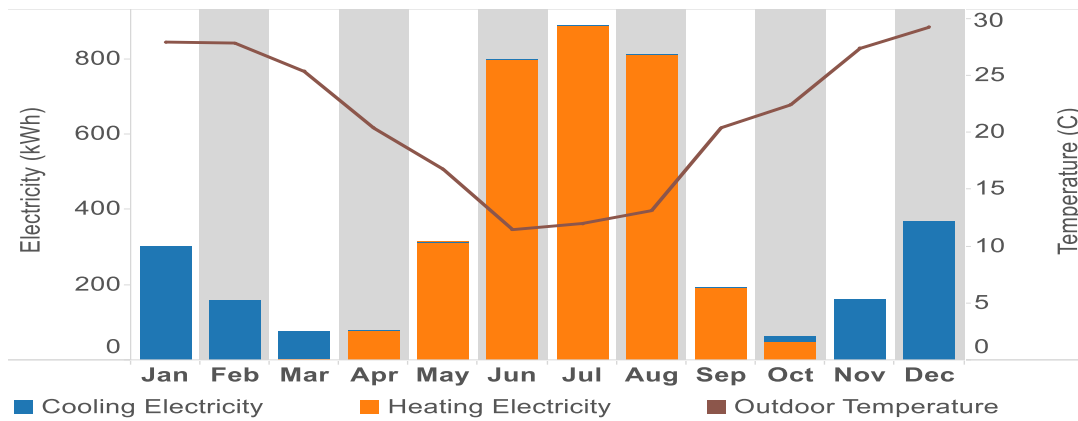


Figure 55: CA2 art centre building – monthly air conditioner electricity consumption and average outdoor temperature

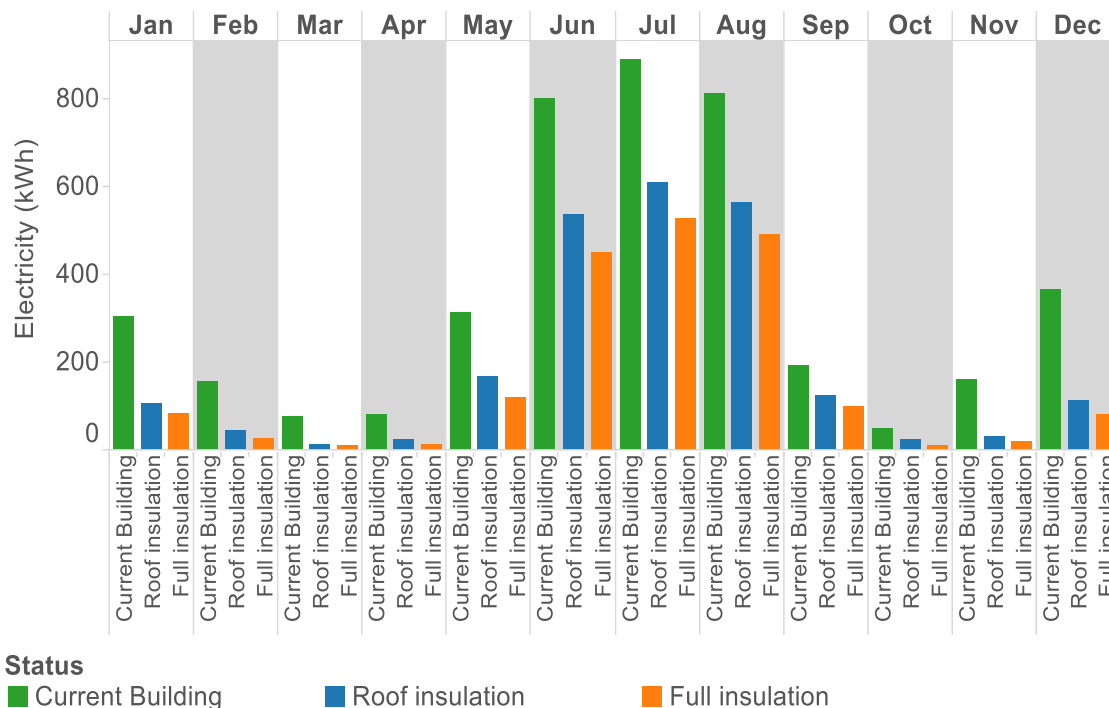


Figure 56: CA2 art centre building – monthly air conditioner electricity consumption for different energy-saving scenarios

If the building is uninsulated, then insulating the roof space will result in significant improvements. Indeed, a 70% reduction in cooling energy is achieved during the peak hour of 3 pm. Insulating the walls in addition to the roof space results in a further improvement of 30%. It is interesting to note that according to the model, cooling energy is usually not required until mid to late morning.

Figure 57 shows that the winter performance is markedly different from the summer performance. Maximum heating energy is required early in the morning to compensate for the cold night temperatures. Energy requirements then decrease during the day until the end of the working day and the system is shut down. Again, significant savings are achieved by insulating the whole building. A 42% saving is achieved during those initial heating hours if the building was fully insulated compared to no insulation being present.

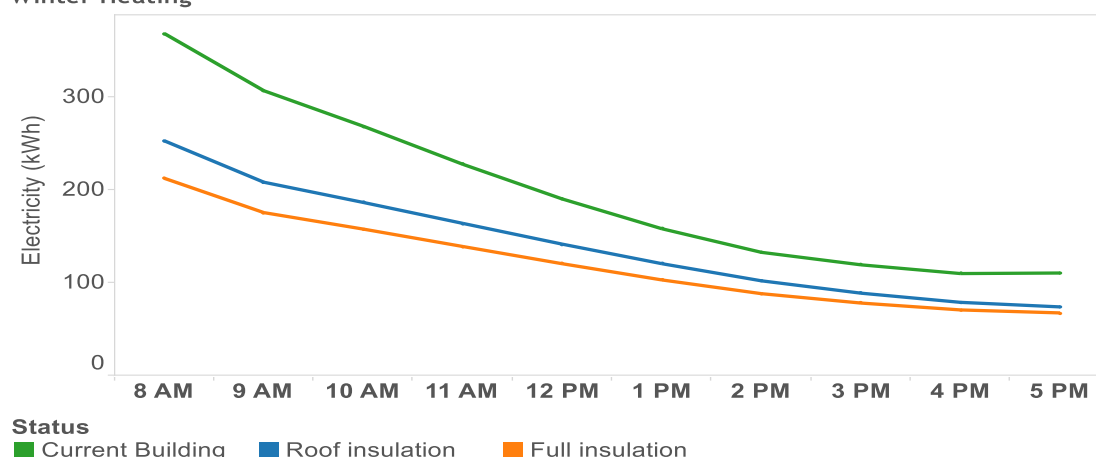
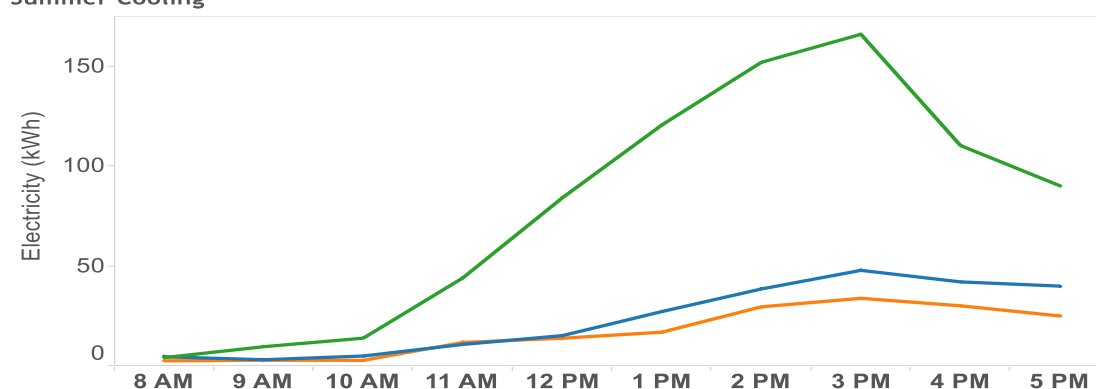
Winter Heating**Summer Cooling**

Figure 57: CA2 art centre building – summer and winter diurnal electricity consumption predictions for different energy-saving scenarios

8.2.3 Summary observations

The energy profile of the building suggests that winter heating is the primary issue. Cold overnight winter temperatures and lack of insulation mean the building begins a winter's day at a low temperature. Consequently, heating is required to bring the building's internal temperature up to a comfortable level. Improving insulation to the fabric of the building will help it retain some heat overnight and will reduce the amount of heat escaping the building when the heating is operating. With the present evaporative cooling, insulation will make little difference in summer. If reverse cycle air conditioners are ever used, insulation will also benefit the building during the summer periods when cooling is required by helping to reduce the escape of cooled conditioned air and reducing the impact of heat gain from the outside. In the event that insulation is used, a facility for night-time removal of heat in summer using automated fans could usefully be included.

8.3 Climate control

8.3.1 Outside the building – measured vs. BoM

The minimum BoM temperatures at Alice Springs were 1–2 °C higher than the values measured during winter and spring and approximately the same as measured values in the shade during summer. The maximum BoM and measured values were very similar throughout the year.

8.3.2 Outside the building – measured vs. AccuRate

Table 31 compares the AccuRate predicted temperatures against the measured values. In winter the AccuRate values were on average 2.0 °C lower than the measured values. In summer, the discrepancy varied throughout the day up to 5.8 °C lower.

Table 31: CA2 art centre building – measured and predicted winter and summer temperatures outside the building

Average diurnal external shaded temperatures (°C)	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	5.2	29.0	18.9	20.2	40.8	32.3
AccuRate	5.0	19.0	16.9	21.0	35.0	33.1

8.3.3 Air conditioned office/showroom

Table 32 shows that the AccuRate values were 1–3 °C lower than the measured values except for the winter daily minimum values. The summer discrepancies may have been due to the air conditioners being under capacity or because the temperature control was set high.

Table 32: CA2 art centre building, office – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): Office/showroom	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	14.0	21.5	20.1	28.2	32.0	30.0
AccuRate air conditioned	16.0	18.5	16.9	25.0	31.0	28.7
AccuRate non-conditioned	12.5	16.0	14.1	25.0	29.5	29.1

8.3.4 Studio

During summer, the AccuRate predicted temperatures for a conditioned space were 2–3 °C lower than the measured values (Table 33). The studio is probably incompatible with AccuRate modelling, as it is highly ventilated during summer and uses evaporative cooling.

Table 33: CA2 art centre building, studio – measured and predicted winter and summer temperatures inside

Average diurnal temperatures (°C): Studio	Winter 24-hour minimum	Winter 24-hour maximum	Winter working hour average	Summer 24-hour minimum	Summer 24-hour maximum	Summer working hour average
Measured	15.0	22.0	19.1	28.0	33.0	30.4
AccuRate air conditioned	15.0	20.0	20.1	24.5	29.5	28.0
AccuRate non-conditioned	13.0	16.5	14.8	24.5	31.0	28.9

8.3.5 Extreme values

Over the nine-month monitoring period, the extreme values measured when the air conditioner was not running were a maximum of 37 °C and a minimum of 8 °C in the office and a maximum of 36 °C and a minimum of 9 °C in the studio.

8.3.6 Summary

In summer, measured temperatures for the office are higher than predicted despite the fact that AccuRate appears to overestimate summertime external air temperature. This may be caused by the inclusion of periods when the building is unoccupied. It may also be due to the air conditioners being under capacity for the building thermal load or because the temperature control was set high.

AccuRate is not suitable as a model for the studio and showroom because of its inability to model highly ventilated spaces and evaporative cooling. Again, the modelled and measured temperatures suggest that the installed capacity is inadequate to provide temperatures that would normally be considered comfortable or else that the temperature is set high.

8.4 Electricity consumption management

8.4.1 Total electricity consumption

Electricity from the community diesel generator is the principal source of energy for the CA2 art centre building. Power shutdowns of longer than two minutes caused by generator failures were infrequent. Local partial shutdowns due to sub-circuit overloading could last several weeks until the loads were rebalanced. This occasionally affected the data logging and the values given use interpolation for these data logger down time periods. The total electricity consumption over the nine months was approximately 4278 kWh, and this is about half of what a reasonably energy efficient home might consume in a major city.

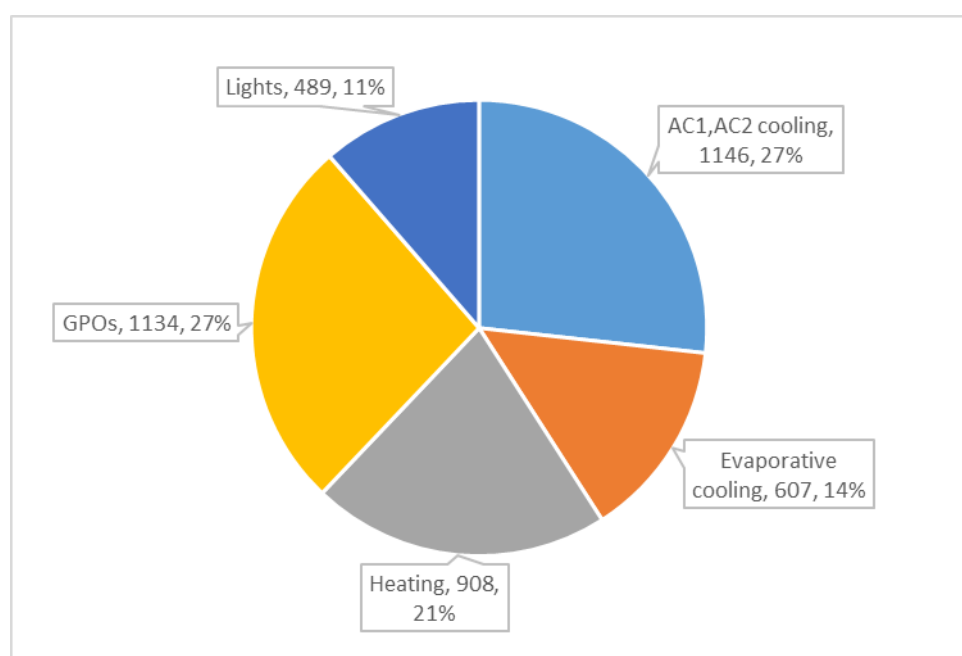


Figure 58: CA2 art centre building – distribution of electricity consumption in kWh

Two-thirds of the electricity consumption is used for reverse cycle air conditioners in the office and for evaporative coolers and radiant heaters in the studio to cool and heat the building. A quarter is used for

GPOs that supply office equipment such as computers, printers, modems and studio equipment, including standard lights, heaters and fans. The remainder is used for lighting (Figure 58). The heating energy could not be measured directly, as it was distributed among sub-circuits supplying both heaters and appliances. We estimated heater consumption by comparing the GPO load and its time dependency in summer, when heaters would not have been in use, from the load in winter when both heaters and appliances would have been used. Figure 59 demonstrates the substantial difference in load between summer and winter. The use of electricity was effective and frugal. The only substantial areas for savings were to reduce electricity used inadvertently from 5 pm to 9 am and to fit insulation to the building to reduce thermal leakage.

8.4.2 Electricity consumption outside working hours

Forty per cent of electricity (449 kWh) was consumed from 5 pm to 9 am (Figure 59). Table 34 shows which services are being used outside working hours. Of the 40%, 100 kWh was due to the air conditioning running while work was carried out in the early morning or evening, and another 100 kWh was due to standby electricity in the office air conditioner. The remaining GPO load was likely to include standby operation of a second office air conditioner, safety lights, computers not switched off at the GPO and therefore on standby, or telecommunication equipment that may have needed to be kept running.

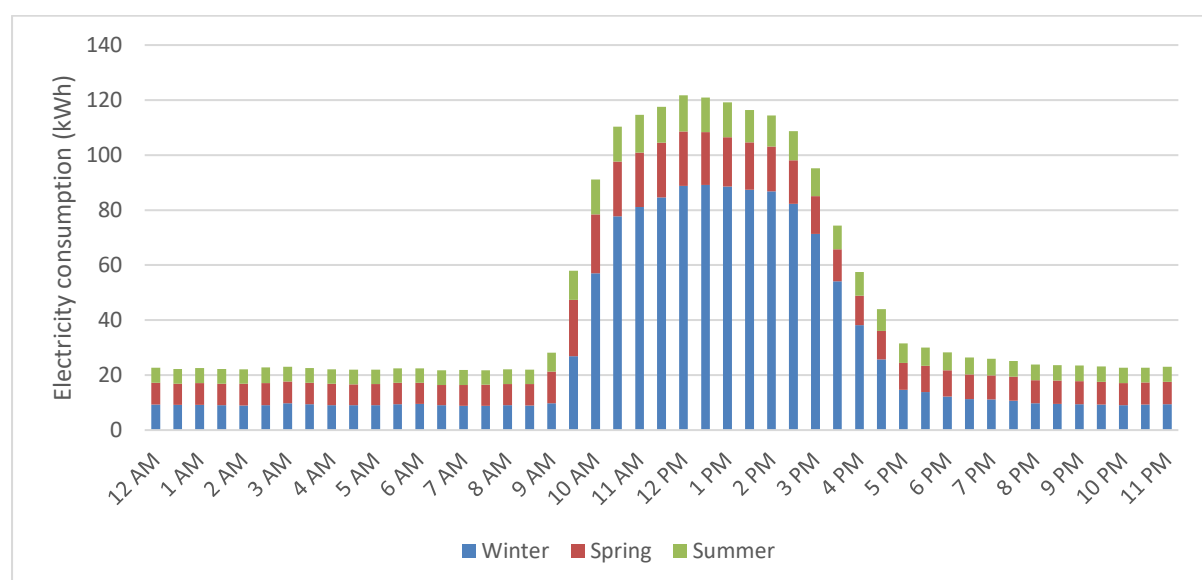


Figure 59: CA2 art centre building – diurnal electricity consumption for the principal GPO sub-circuit for winter, spring and summer

Table 34: CA2 art centre building – hours of operation for building electrical services

Service	Consuming electricity all day nearly everyday	Only consuming electricity during working hours
Lights		✓
Office general power outlets		✓
Studio general power outlets	✓	
Office air conditioner x1	✓	
Office air conditioner x1 (normally off)		✓
Evaporative coolers		✓
Hot water (normally off)		✓

8.4.3 Air conditioning electricity consumption

A comparison of the AccuRate models with the measured heating and cooling consumption in the office space (Figure 60) is consistent with the roof having thermal insulation. It also suggests that waste heat from office equipment is contributing significantly to keeping the office space warm, as in winter the reverse cycle air conditioning electricity consumption is much less than AccuRate predicts, whereas from September to February it is much greater than predicted, except for January when the building is mostly unoccupied.

No comparison has been made of the AccuRate models with the measured heating and cooling consumption in the studios, as cooling required the use of evaporators, some of which were faulty, and heating in winter used radiant heaters that did not have their own sub-circuit and so have not been directly measured. Heating in winter was derived by subtracting the sub-circuit power in summer from the sub-circuit power in winter.

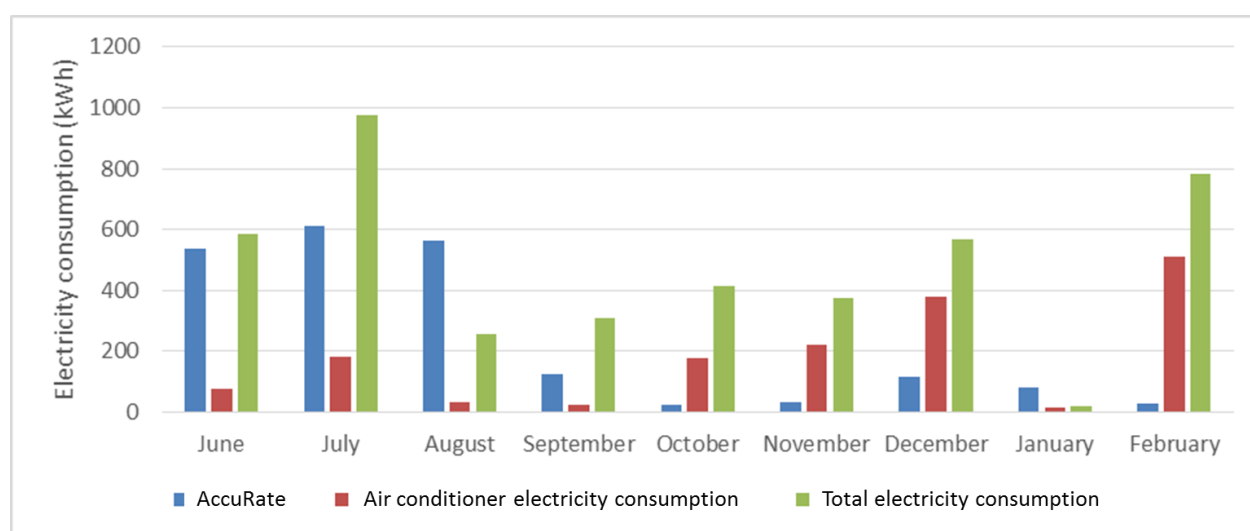


Figure 60: CA2 art centre building – AccuRate vs. measured values for air conditioner and total electricity consumption

8.5 Evaporative coolers or reverse cycle air conditioners – safety issues

A fire hazard and a potential biological hazard in the evaporative coolers were investigated at the request of the art centre manager and discussed with maintenance staff locally and nationally. Three incidents were reported during the nine-month study in which the art centre was evacuated because of smoke produced from small fires in the evaporative cooler. This safety risk may apply to other communities in remote Australia where evaporative cooling is used with flammable filter media and without access to adequate maintenance.

Two of the three evaporative coolers were cooling the studio space effectively. However, all three had defective sprinkler systems. The coolers each had six wood chip evaporator filter pads, four of which were readily accessible via the side panels; the other two were adjacent to the building wall. The first cooler was functioning quite well, but the spray on one side was excessive and the top water channel was overflowing. On the second cooler, only two of the four filters were being kept wet. On the third, only one filter of the four was wetted. The impact of the faulty sprinklers on cooling with an inlet temperature of 32 °C and a relative humidity of 15% was:

- cooler 1 was cooling by about 7.5 °C below the inlet temperature
- cooler 2 was cooling by about 5 °C
- cooler 3 was cooling by about 2 °C

In addition to the efficiency loss of 40% and 70% in coolers 2 and 3 respectively, there were associated health and safety issues:

- a risk of disease from ventilation air passing over warm stagnant water
- a fire hazard due to electrical arcing in the fan in the presence of tinder-dry wood chip filters.

The maintenance available has been both expensive and inadequate to keep these coolers operating properly. Possible solutions include:

- an on-site maintenance program for all evaporative coolers in the community
- a water purification or treatment system to reduce scaling on sprinklers
- replacement of the evaporative cooler with reverse cycle air conditioners.

The water purification system, if implemented appropriately and on a community-wide scale, may have health benefits beyond reducing the risk of Legionnaires disease. Alternatively, the reverse cycle air conditioner approach would reduce the drain on bore water and provide more efficient heating during winter.

8.6 Observations and recommendations

8.6.1 Electricity consumption – Air conditioning and general power outlets

Waste heat from office equipment is responsible for the discrepancies between AccuRate simulations and measured values of electricity consumption. This waste heat increases load on air conditioners in summer and reduces load in winter. The principal opportunity for reducing electricity consumption is to ensure that appliances are turned off at night and that newly purchased air conditioners can be switched off using a low power consumption timer (less than 1 W), rather than being switched to standby using a hand control. In winter, the timer should be programmed to come on an hour or two before the office opens and it should not come on during the weekends or holidays. This may also be possible with the present air conditioners, though it would be wise to check with the contractor responsible for maintenance whether these air conditioners can be switched off at the main supply without damaging the appliance.

8.6.2 Recommendations

8.6.2.1 Reducing electricity consumption

1. Check with the maintenance contractor if air conditioners can be switched off at the mains. If so, ensure they are switched off at the mains outside working hours in summer and from two hours before the working day until the end of the working day in winter.
2. Switch off appliances at night unless there is a good reason not to. This may require timers and power boards where multiple appliances can be switched off with one switch. Switch off first at the appliance and then at the mains; switch on first at the mains and then at the appliance.

3. Insulate all the walls and the ceilings and apply low emissivity foil insulation to roofs without ceilings.
Ensure there is forced ventilation to allow heat to be removed at night.
4. Replace incandescent with LED lighting.

8.6.2.2 Improved health and safety – in priority order

1. Set up an on-site maintenance program for all evaporative coolers in the community.
2. Install a water purification or treatment system to prevent calcification of sprinklers.
3. Replace the evaporative coolers with reverse cycle air conditioners.

9. Conclusion

This project covered a range of buildings, in diverse geographical conditions of remote Australia. Despite the differences between the research sites and the small number of buildings investigated, strong themes became evident through the project:

- The building managers were highly motivated to minimise and reduce electricity use. This was particularly evidenced by their conservative and frugal use of air conditioning, even when its use was warranted. This care for energy minimisation could be much better exploited by making other changes highlighted in Key outcomes and recommendations section of the Executive summary.
- There was significant potential to make better use of electricity consumption for heating and cooling buildings and for reducing inadvertent electricity waste, particularly by reducing out-of-working-hours electricity consumption and making low cost upgrades to building thermal properties. Reducing electricity use and improving building use in remote locations has material environmental and financial benefits.
- There were opportunities to improve building thermal efficiency whether air conditioning was available or not, and these could be highlighted by adding two capabilities to the building energy efficiency rating tool AccuRate: i) ability to assess the impact of low thermal emissivity foil insulation on roof and ceiling temperatures, ii) ability to assess the impact of overnight forced ventilation on high thermal mass buildings
- It was hypothesised that electricity security was going to be an issue for these remote locations. However, there was no evidence of power failures in either the electrical observations or interviews. There were some cases of lost power due to lack of funding but not due to grid instability. Interestingly the project showed that reliable telecommunication and internet availability were much more pressing concerns.
- In Central Australia, it was evident that lack of access to maintenance services and expertise in the most effective use of energy was impeding the manager's efforts to reduce electricity consumption. Reliable and effective services that would be taken for granted by enterprises in cities were close to impossible to source and very highly priced. The challenge is to either provide equipment that is robust and designed to operate for years without the need for maintenance or to provide remote Central Australia with access to the skills and expertise to effectively manage and minimise energy. On the other hand, the three sites in Queensland had access to very effective maintenance resources.

9.1 Some suggested future work

- Reports for managers of buildings on managing their electricity consumption and describing potential building upgrades. The reports will be specific to each volunteer research site.
- One-page decision chart and one-page rule-of-thumb design guides for high and low thermal mass buildings to be used with or without air conditioning in remote northern Australia – this targets building designers and policymakers.
- Brochures and information pamphlets for remote northern communities on i) managing electricity consumption, ii) specifying new buildings, and iii) specifying upgrades to old buildings.

- A proposed specification for the AccuRate tool to upgrade it for use in enterprise buildings in remote regions of the Northern Territory, Western Australia and Queensland. This targets building standards stakeholders and policymakers.
- Papers on building design for thermal efficiency in remote enterprise buildings and temperature and humidity limits to occupancy for high and low thermal mass buildings used with or without air conditioning in remote Australia.

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