## Face Time the emergence of the facade as the integrative factor in holistic building design

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### **IMPACT OF CLIMATE CHANGE**

# Thermal and energy performance of facade types in different climates



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#### ABSTRACT

The facade is one of the most significant contributor to the energy budget and the comfort parameters of any building. Control of physical environmental factors must be considered during the design process. High-performance facades need to block adverse external environmental effects and maintain internal comfort conditions with minimum energy consumption. This research was conducted by modelling conductive heat transfer in five different exterior wall types (brick cavity wall, rainscreen facade with terracotta cladding, rainscreen facade with glass-fiber reinforced concrete cladding, curtain wall, and a curtain wall with thermally broken framing), where U-values were compared to determine thermal performance. Impacts on energy use were also investigated, where energy usage was modeled for an office space enclosed with the analyzed facade types for all U.S. climate zones and 12 orientations, and for window-to-wall ratio of 20% and 40%, using historical weather data. The results show relative performance of analyzed exterior wall types, in terms of thermal performance and energy usage. Then, future climate conditions were considered, where the impacts of climate change on changing weather patterns were investigated. Specifically, predicated climate change weather files for the years 2050 and 2080 were used to model energy usage for the office space enclosed with analyzed exterior wall types. The results show the impacts of climate change on the energy performance, and show that typically the energy usage is increased.

#### **KEYWORDS**

heat transfer, energy modeling, climate change, terra cotta, GFRC, thermal break, curtainwall

#### INTRODUCTION

Increases in average global temperatures are expected to be within the range of 0.5°F to 8.6°F by 2100, with a likely increase of at least 2.7°F due to climate change, with some regions projected to see larger temperature increases than the global average which infers more numerous and extreme heat events. (Melillo 2014). For most buildings, the facade affects the building's energy budget and the comfort of its occupants more than any other system, especially the glazed facade types (Huizenga et al. 2006). Climate-specific guidelines must be considered during the design process of high-performing building enclosures (Lee et al. 2002; Oral et al. 2004). Design strategies need to consider the temperature, humidity, wind, precipitation, solar radiation and other characteristics of the climate zone to minimize the impacts of external environmental conditions and reduce energy consumption (Aksamija 2013).

The purpose of this research was to investigate heat transfer in several exterior wall types and the effects of climate change on energy consumption. These following research questions were addressed:

- What is the relative performance ranking of different facade systems in terms of their ability to resist heat transfer and U-value?
- What is the effect of façade orientation and climate change for different facade configurations on energy

#### consumption of commercial office spaces in different climates?

#### **RESEARCH METHODS**

The study consisted of two parts-thermal modeling and energy modeling. The analyzed facade systems included:

- Brick cavity wall with metal framing
- Rainscreen facade with terracotta cladding and metal framing
- · Rainscreen facade with glass-fiber reinforced concrete (GFRC) cladding and metal framing
- Curtain wall with aluminum framing
- Curtain wall with thermally broken aluminum framing
- Rainscreen facade with terracotta cladding and thermal spacers
- Rainscreen facade with terracotta cladding and thermal isolators.

Thermal modeling was performed using two-dimensional steady-state heat transfer simulation software THERM (version 6.3), developed by Lawrence Berkeley National Laboratory. Individual material layers and their properties were modeled in detail, as well as the boundary conditions for exterior and interior temperatures. U-values were calculated for each facade system.

The energy use of the seven facade types was studied using whole year energy simulations and were performed using EnergyPlus (version 8.3) for a typical office space. The total yearly energy values included heating, cooling, lighting and fans. Simulations were conducted for 15 cities in the U. S., representing different climate zones for three time periods; present day, the year 2050 and the year 2080. Weather files for 2050 and 2080 were created using a weather file generator (Jentsh, 2012).

#### THERMAL MODELING AND HEAT TRANSFER ANALYSIS

#### PROPERTIES OF ANALYZED FACADE SYSTEMS

The properties of different materials are listed in Table 1. These values were used for the simulations and were constant throughout the study.

Material/component	Conductivity W/m-K (Btu/h-ft-°F)	U-value W/m <sup>.</sup> -K (Btu/h-ft <sup>.</sup> -°F)	Solar Heat Gain Coefficient	Visual Transmittance
Air	0.02 (0.01)	-	-	-
Aluminum	237 (137)	-	-	-
Batt insulation in framing cavity	0.05 (0.03)	-	-	-
Brick	10.4 (6.0)	-	-	-
Exterior gypsum sheathing	3.1 (1.8)	-	-	-
Fiberglass spacer	0.3 (0.17)	-	-	-
GFRC	31.2 (18.0)	-	-	-
Glass	-	1.65 (0.29)	0.38	70%
Interior gypsum sheathing	3.1 (1.8)	-	-	-
Rigid insulation	0.05 (0.03)	-	-	-
Terracotta cladding	2.2 (1.2)	-	-	-
Thermal break for curtain wall framing	0.23 (0.13)	-	-	-
Thermal isolator	0.3 (0.17)	-	-	-

Table 1: Material Properties

The components of different facade types are listed below.

Brick Cavity Wall

The first case (Type 1) considered brick cavity wall with steel framing. The components of the analyzed assembly are:

- Brick: 100 mm (4 in)
- Air cavity: 50 mm (2 in)
- Rigid insulation: 50 mm (2 in)
- Brick ties
- Air/vapor barrier
- Exterior gypsum sheathing: 15 mm (5/8 in)
- Framing cavity with batt insulation: 150 mm (6 in)
- Interior gypsum sheathing: 15 mm (5/8 in).

Rainscreen Facade with Terracotta Cladding

The second case (Type 2) considered rainscreen system with terracotta cladding and metal framing. The components of the analyzed assembly are:

- Terracotta cladding: 30 mm (1 3/16 in)
- Aluminum clips
- Air cavity: 25 mm (1 in)
- Vertical aluminum support extrusions
- Rigid insulation: 75 mm (3 in)
- Horizontal L brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 15 mm (5/8 in)
- Framing cavity with batt insulation: 150 mm (6 in)
- Interior gypsum sheathing: 15 mm (5/8 in).

Rainscreen Facade with GFRC Cladding

The third case (Type 3) considered rainscreen system with GFRC cladding. The components of the analyzed assembly are:

- GFRC cladding: 20 mm (3/4 in)
- Air cavity: 25 mm (1 in)
- Vertical aluminum support extrusions
- Rigid insulation: 75 mm (3 in)
- Horizontal Z girts
- Air/vapor barrier
- Exterior gypsum sheathing: 15 mm (5/8 in)
- Framing cavity with batt insulation: 150 mm (6 in)
- Interior gypsum sheathing: 15 mm (5/8 in).

Curtain Wall with Aluminum Framing

The fourth case (Type 4) considered a standard curtain wall. The analyzed curtain wall consisted of vision glazing 2.6 m vertically (8 1/2 ft), as well as spandrel area of 1.4 m (4 1/2 ft). The components of the analyzed curtain wall are:

- Vision glass: double, air-insulated low-e glazing unit
- Spandrel: spandrel glass, air cavity 75 mm (3 in), insulation 50 mm (2 in), aluminum back pan
- Aluminum framing members.

Curtain Wall with Thermally Broken Aluminum Framing

The fifth case (Type 5) considered thermally improved curtain wall. The analyzed curtain wall consisted of vision glazing 2.6 m vertically (8 1/2 ft), spandrel area of 1.4 m (4 1/2 ft), and thermal breaks within the framing members to minimize thermal bridging. The components of the analyzed curtain wall are:

- Vision glass: double, air-insulated low-e glazing unit
- Spandrel: spandrel glass, air cavity 75 mm (3 in), insulation 50 mm (2 in), aluminum back pan
- Aluminum framing members with thermal breaks.

Rainscreen Facade with Terracotta Cladding and Thermal Spacers

The sixth case (Type 6) considered rainscreen system with terracotta cladding, and fiberglass spacers that are used to minimize thermal bridging through the vertical cladding support systems. The components of the analyzed assembly are:

- Terracotta cladding: 30 mm (1 3/16 in)
- Aluminum clips
- Air cavity: 25 mm (1 in)
- Vertical aluminum support extrusions
- Fiberglass spacers
- Rigid insulation: 75 mm (3 in)
- Horizontal L brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 15 mm (5/8 in).
- Framing cavity with batt insulation: 150 mm (6 in)
- Interior gypsum sheathing: 15 mm (5/8 in).

Rainscreen Facade with Terracotta Cladding and Thermal Isolators

The seventh case (Type 7) considered rainscreen system with terracotta cladding, and thermal isolators placed on horizontal L brackets. The components of the analyzed assembly are:

- Terracotta cladding 30 mm (1 3/16 in)
- Aluminum clips
- Air cavity: 25 mm (1 in)
- Vertical aluminum support extrusions
- Rigid insulation: 75 mm (3 in)
- · Horizontal L brackets with thermal isolators placed on the interior side of the brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 15 mm (5/8 in)
- Framing cavity with batt insulation: 150 mm (6 in)
- Interior gypsum sheathing: 15 mm (5/8 in).

#### THERM RESULTS

Thermal performance of analyzed facade systems was compared based on calculated U-values and are listed from highest conductance (worst performing) to lowest conductance (best performing)(Table 2).

Façade Type	Name	Conductance
Туре 4	Curtain wall	3.98 W/m <sup>2</sup> -°K (0.70 Btu/h-ft <sup>2</sup> -°F)
Type 1	Brick cavity wall	3.43 W/m <sup>2</sup> -°K (0.60 Btu/h-ft <sup>2</sup> -°F)
Туре 5	Curtain wall with thermally broken framing	2.59 W/m <sup>2</sup> -°K (0.46 Btu/h-ft <sup>2</sup> -°F)
Туре 3	Rainscreen facade with GFRC cladding	1.06 W/m <sup>2</sup> -°K (0.19 Btu/h-ft <sup>2</sup> -°F)
Type 2	Rainscreen facade with terracotta cladding	0.41 W/m <sup>2</sup> -°K (0.07 Btu/h-ft <sup>2</sup> -°F)
Туре 6	Rainscreen facade with terracotta cladding and thermal spacers	0.33 W/m <sup>2</sup> -°K (0.06 Btu/h-ft <sup>2</sup> -°F)
Туре 7	Rainscreen facade with terracotta cladding and thermal isolators	0.33 W/m <sup>2</sup> -°K (0.06 Btu/h-ft <sup>2</sup> -°F)

Table 2: Thermal Performance

#### WHOLE YEAR TOTAL ENERGY USE

The energy modeling was performed in EnergyPlus, simulating whole year total energy use for an office space, enclosed by the seven different exterior wall types. The five opaque walls were modeled with a window to wall ratio of both 20% and 40% for occupant views and daylighting into the office space.

A single zone office space was chosen in order to highlight the thermal properties of the different wall types at different orientations. The dimensions of the office space were modeled at 4 m (13 ft) high by 3.75 m (12 ft) wide and 5 m (16 ft) deep. The facade was 4 m (13 ft) high by 3.75 m (12 ft) wide. The floor, ceiling and the three interior walls were modeled as adjacent

to other interior spaces with the same thermal conditions without heat transfer occurring, but they will retain and release heat due to their thermal mass. The interior walls were model as gypsum board over steel studs, the floor was carpet over a concrete slab and the ceiling was a drop ceiling of standard acoustical tiles.

The office space was heated to  $21^{\circ}$ C ( $70^{\circ}$ F) with  $15.6^{\circ}$ C ( $60^{\circ}$ F) setback during unoccupied hours and cooled to  $24^{\circ}$ C ( $75^{\circ}$ F) with  $26.7^{\circ}$ C ( $80^{\circ}$ F) setback using the Ideal Loads Air System component to maintain thermal comfort for the whole year. The Ideal Loads Air System component was used to study the performance of the office space without modeling a full HVAC system. Lighting was designed with a 5.6 W/m (0.5 W/ft) load density and continuous daylighting control (ASHRAE 2010). Equipment load for the office was modeled at 8.0 W/m (0.7 W/ft), and the occupancy load was one person.

The single office space with each type of exterior wall was modeled and rotated in 12 different orientations at 30° increments, and using climate data inthree time periods, present day, the year 2050 and the year 2080, for 15 different cities, representing all climate zones in the United States (Table 2). The zones are numbered from 1 (very hot) to 8 (subarctic). Some of the eight climate zones may also be subdivided into moist (A), dry (B), and marine (C) regions, giving a total of 15 different climate types in the U.S. Future predicted climate change weather files were created for the 15 climate zones for the years 2050 and 2080 using the climate change world weather file generator tool developed by Sustainable Energy Research Group, University of Southampton (CCWorldWeather-Gen version 1.2). These files were used to simulate and compare present day energy use with future energy use for each of the facade types. A total of 3780 simulations were run.

	Climate			
No.	Zone	City	Zone	Region
1	1A	Miami, FL	very hot	moist
2	2A	Houston, TX	hot	moist
3	2B	Phoenix, AZ	hot	dry
4	ЗA	Memphis, TN	warm	moist
5	3B	El Paso, TX	warm	dry
6	3C	San Francisco, CA	warm	marine
7	4A	Baltimore, MD	mixed	moist
8	4B	Albuquerque, NM	mixed	dry
9	4C	Salem, OR	mixed	marine
10	5A	Chicago, IL	cool	moist
11	5B	Boise, ID	cool	dry
12	6A	Burlington, VT	cold	moist
13	6B	Helena, MT	cold	dry
14	7	Duluth, MN	very cold	
15	8	Fairbanks, AK	subarctic	

Table 3: Climate Zones

#### RESULTS

The results indicate energy usage and general patterns for each of the different wall types in the 15 climate zones. The results of the simulations typically show that the facades with a lower U-value have better energy performance for the whole year in all climates and orientations. Orientation had a greater effect for the glazed walls, with east and west performing the worst. The north facing facades performed the best for most of the climate zones due to lower cooling loads. All façade types showed the highest total energy use in the year 2080. The next highest was the year 2050 and the lowest total energy use was for present day weather files.

The results for Rainscreen Facade with Terracotta Cladding and Thermal Isolators (Type 7) and Curtain Wall with Thermally Broken Aluminum Framing (Type 5) were plotted and compared to represent typical results of all of the wall types. Type 7 had the lowest conductance in this test and Type 5 had the lowest conductance for a curtain wall in this test. Type 7 with 20 percent window to wall ratio had lower total energy use than Type 7 with 40 percent window to wall ratio (Fig. 1). Heating and cooling were compared for Type 7 with 20 percent window to wall ratio which shows that cooling loads dominate the energy use for the office space except in climate zone7 and 8. Cooling loads increase by a greater amount than the decrease in heating loads so net energy use is increased with climate change (Fig. 2). Similar results are seen for the curtain wall Type 2 (Fig. 3). A comparison of the total energy use between Type 7 with 20 percent window to wall ratio and curtain wall Type 5 shows the curtain wall performing worse and both wall types using greater amounts of energy in future simulated climate change weather files (Fig 4).



Figure 1: Type 7 total energy use



Figure 2: Type 7 20% WWR heating and cooling energy use.





Figure 3: Type 5 heating and cooling energy use.

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Figure 4: Type 7 20% WWR and Type 5 total energy use.

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#### CONCLUSION

Exterior walls significantly influence energy consumption and occupants' comfort for any building. High-performing facades need to minimize extreme exterior environmental conditions and maintain interior comfort conditions with minimum energy consumption. Climate-based design approaches are key elements in designing high-performance building facades, where specific climatic conditions need to be taken into account. Seven different exterior wall types were studied, where thermal performance, heat transfer and energy consumption were investigated, as well as their performance in 15 different climate zones and three different weather files simulated for climate change. The research was conducted by modeling heat transfer to calculate U-values for all seven exterior wall types. Results show that the curtain wall is the worst performing assembly and the best is the rainscreen facade with terracotta cladding.

Energy modeling was then conducted to analyze the effects of different exterior wall types on energy consumption of a commercial office space in various climate zones. Different different scenarios were modeled (a total of 12), two curtain walls and five opaque walls with 20 and 40 percent window to wall ratio, where a single zone enclosed with the analyzed exterior wall types was simulated, taking into account relative orientation of the facade, as well as specific climate data for three different time periods. Results show that the facades with a lower U-value have better energy performance. Orientation had a greater impact on the performance of glazed walls and curtain walls, where east and west oriented facades would have the highest energy use. Simulated climate change weather files for the year 2050 and the year 2080 increased the total energy use for all climates and façade types.

The next step in this research is to extend the study different types of facade materials (triple insulated glazing units for curtain walls, as well as some of the emerging materials, such as vacuum insulated glazing and phase change materials).

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