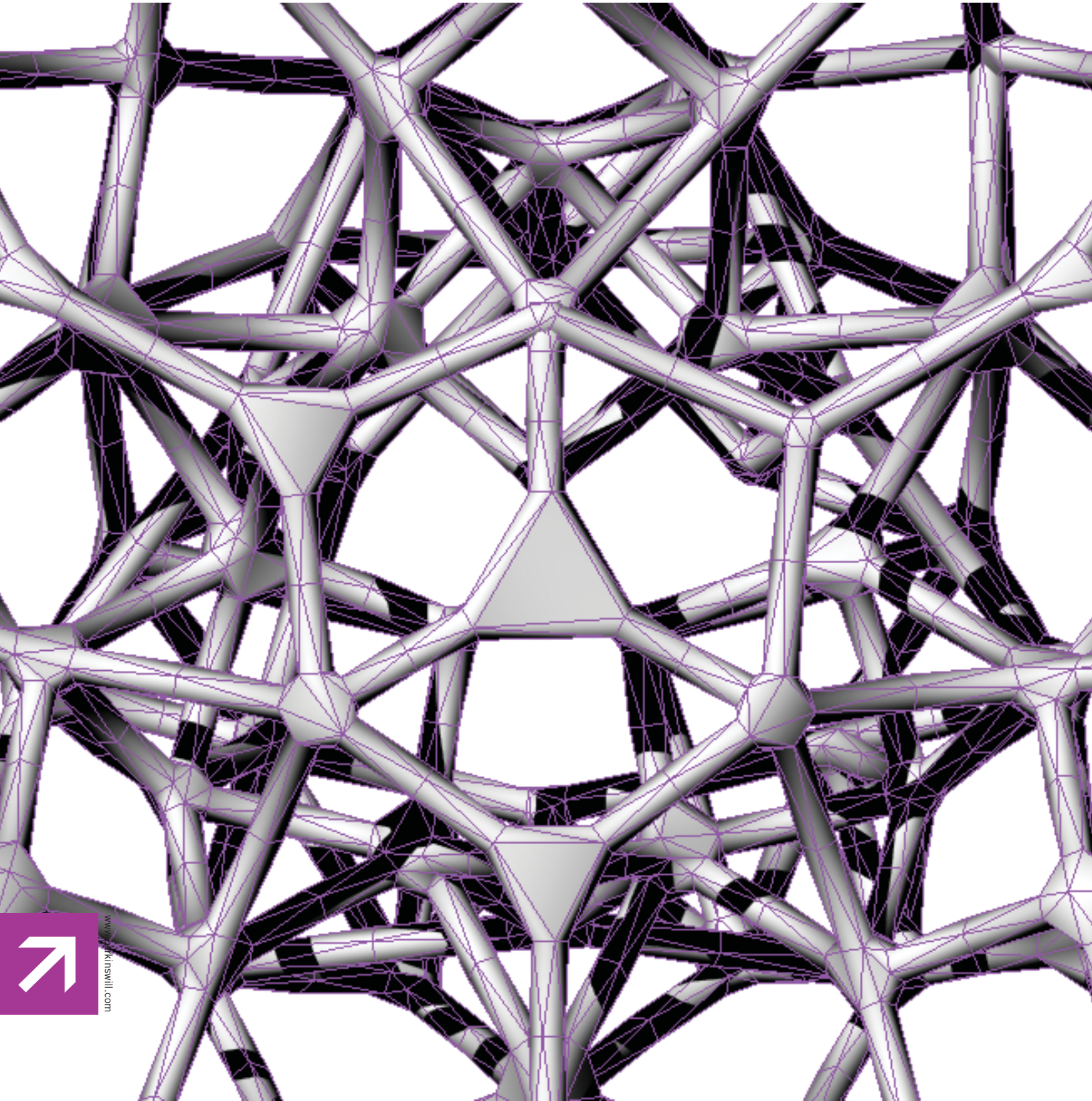


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**04.****CLIMATE CHANGE AND PERFORMANCE OF FACADE SYSTEMS:**

*Analysis of Thermal Behavior and Energy Consumption in Different Climate Types*

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**ABSTRACT**

The facade is one of the most significant contributors to the energy budget and the comfort parameters of any building. Control of 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. The purpose of this research was to analyze thermal behavior and energy performance of different facade types, as well as impacts of climate change on facade performance. The study was conducted by modelling conductive heat transfer in seven different exterior wall types, considering conventional and thermally improved opaque and glazed systems. Conventional facade systems included brick cavity wall, rainscreen facade with terracotta cladding, rainscreen facade with glass-fiber reinforced concrete cladding and a conventional curtain wall, while thermally improved systems included rainscreen facade with thermal spaces, rainscreen facade with thermal isolators and a curtain wall with thermally broken framing. Heat transfer and thermal gradients through these systems for four exterior environmental conditions were simulated, considering outside temperatures of 90°F, 60°F, 30°F and 0°F. Also, heat transfer coefficients (U-values) were calculated and 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 percent, 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 the energy usage is increased for all investigated wall types and in almost all climates.

**KEYWORDS:** high-performance facades, simulations, heat transfer, energy modeling, energy efficiency, climate change

**1.0 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<sup>1</sup>. An increase in average global temperatures infers more numerous and extreme heat events. For most buildings, the facade af-

fects the building's energy budget and the comfort of its occupants more than any other system, especially the glazed facade types<sup>2</sup>. Climate-specific guidelines must be considered during the design process of high-performing building enclosures<sup>3,4</sup>. 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<sup>5</sup>.

There are essentially two types of facades, opaque and glazed. Opaque facades are primarily constructed of layers of solid materials, such as masonry, stone, pre-cast concrete panels, metal cladding, insulation and framing, and may include windows. Glazed facades, such as curtain walls or storefront facades, primarily consist of transparent or translucent glazing materials and metal framing components. Physical behaviors of these two types of facade differ, since their components, materials, and construction methods are different. Opaque facades typically have more mass, greater insulation levels, and better heat retention than glazed facades. On the other hand, glazed facades usually allow more daylight to the interiors and provide better views for occupants. They also impose less dead load on the building structure than opaque facades.

The rate of conductive and convective heat transfer through the building skin depends on the difference between the interior and exterior temperatures, and the capacity of the facade to control heat flow<sup>6</sup>. Factors that influence heat flow within the facade include the overall thermal resistance, material properties and air leakage<sup>7</sup>. Design strategies for controlling heat flow include use of a continuous thermal barrier (insulation layer), filling air gaps between material layers to prevent conduction, providing a continuous air barrier to prevent heat loss through air leakage, and avoiding thermal bridging.

Improving thermal performance and minimizing thermal bridging are extremely important design strategies for high-performance facades. Thermal bridging within a wall occurs where a highly conductive material, such as a metal support, penetrates the facade's insulation layer. This can significantly affect the thermal performance of the wall, and decrease its effective thermal resistance<sup>8</sup>. Thermal bridging can occur in all types of facades, and significantly impacts thermal performance, energy consumption and thermal comfort of building occupants. Thermally improved facades limit thermal bridging, and can improve thermal performance by using materials that reduce heat transfer between different components.

The purpose of this research was to investigate heat transfer in several exterior wall types, methods for minimizing thermal bridging and improving thermal performance, and the effects of climate change on energy consumption. These following research questions were addressed:

- How do different types of opaque and glazed facades transfer heat under the same environmental conditions?

- What is the relative performance ranking of different facade systems in terms of their ability to resist heat transfer and U-value?
- How can thermal bridging be minimized?
- What is the effect of different facade configurations on energy consumption of commercial spaces in different climates?
- What is the effect of facade orientation and window-to-wall ratio on energy consumption of commercial spaces in different climates?
- What is the impact of climate change on energy consumption of commercial spaces for different facade configurations?

## 2.0 RESEARCH METHODS

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

- Type 1: Brick cavity wall with metal framing
- Type 2: Rainscreen facade with terracotta cladding and metal framing
- Type 3: Rainscreen facade with glass-fiber reinforced concrete (GFRC) cladding and metal framing
- Type 4: Curtain wall with aluminum framing
- Type 5: Curtain wall with thermally broken aluminum framing
- Type 6: Rainscreen facade with terracotta cladding and thermal spacers
- Type 7: 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. Four exterior temperatures of 90°F, 60°F, 30°F and 0°F were used as boundary conditions to represent different climate types, while interior temperature was set at 72°F. U-values were also calculated for each facade system. The restrictions of the software is that it calculates heat transfer in two-dimensions and ignores the third dimension. There are existing studies that analyzed three-dimensional heat transfer in building envelopes<sup>9</sup>. However, THERM software is one of the few software programs approved by the National Fenestration Rating Council (NFRC) for calculating properties of glazed facades and framing, and thus was chosen for this study.

The energy performance of the seven facade types was studied using whole year energy simulations, which were performed using EnergyPlus (version 8.3) software 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 gen-

erator that takes into account impacts of climate change on weather patterns<sup>10</sup>.

### 2.1 Thermal Modeling and Heat Transfer Analysis

The properties of different facade materials are listed in Table 1. These values were used for the simulations and were constant throughout the study. The components of different facade types are discussed in more detail below.

Table 1: Material properties.

Material/component	Conductivity (Btu/h-ft-°F)	U-value (Btu/h-ft <sup>2</sup> -°F)	Solar Heat Gain Coefficient	Visual Transmittance
Air	0.01	-	-	-
Aluminum	137	-	-	-
Batt insulation in framing cavity	0.03	-	-	-
Brick	6.0	-	-	-
Exterior gypsum sheathing	1.8	-	-	-
Fiberglass spacer	0.17	-	-	-
GFRC	18.0	-	-	-
Glass	-	0.29	0.38	70%
Interior gypsum sheathing	1.8	-	-	-
Rigid insulation	0.03	-	-	-
Terracotta cladding	1.2	-	-	-
Thermal break for curtain wall framing	0.13	-	-	-
Thermal isolator	0.17	-	-	-

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

- Brick: 4 in
- Air cavity: 2 in
- Rigid insulation: 2 in
- Brick ties
- Air/vapor barrier
- Exterior gypsum sheathing: 5/8 in
- Framing cavity with batt insulation: 6 in
- Interior gypsum sheathing: 5/8 in.

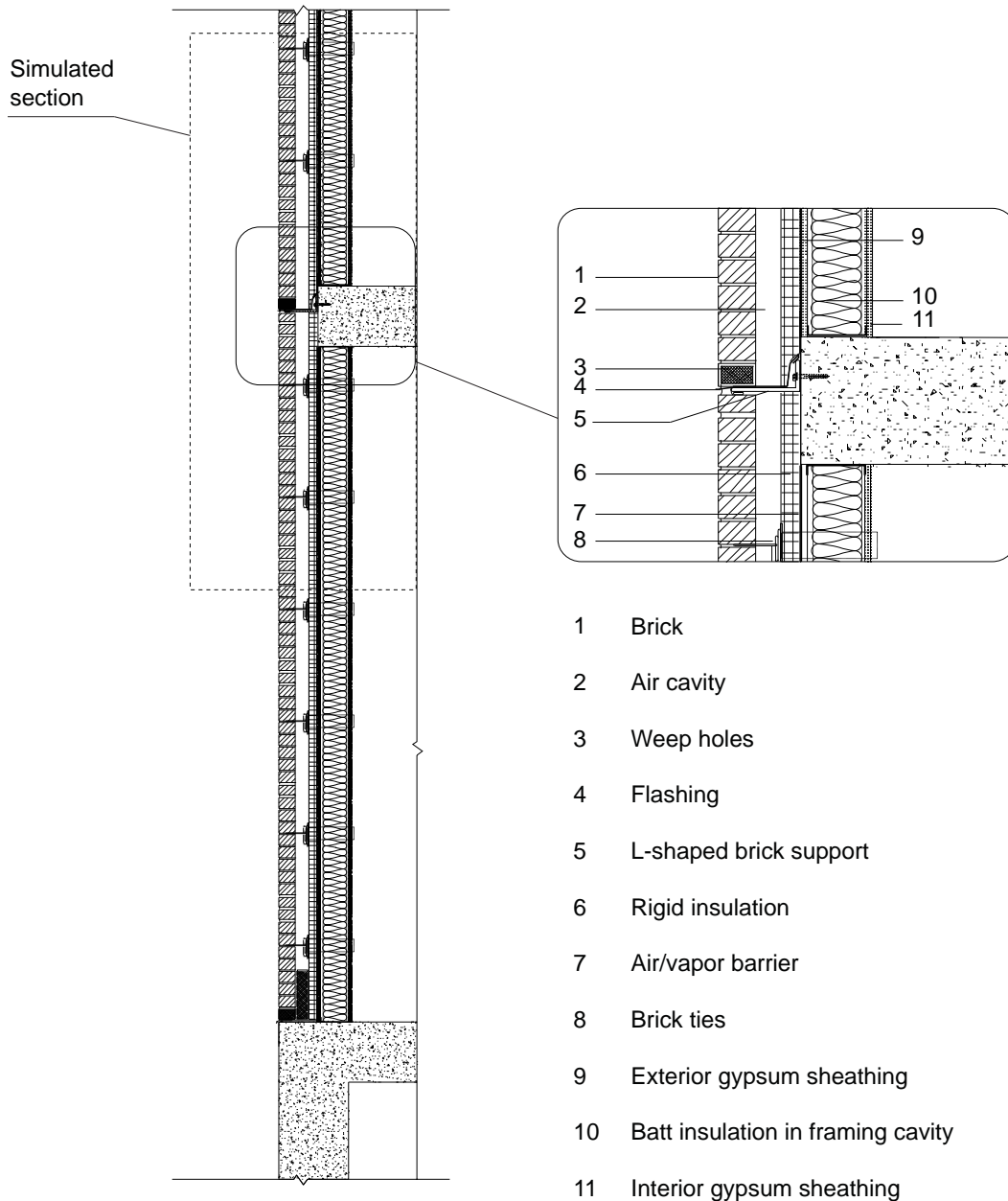


Figure 1: Components of the brick cavity wall.

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

- Terracotta cladding: 1 3/16 in
- Aluminum clips
- Air cavity: 1 in

- Vertical aluminum support extrusions
- Rigid insulation: 3 in
- Horizontal L brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 5/8 in
- Framing cavity with batt insulation: 6 in
- Interior gypsum sheathing: 5/8 in.

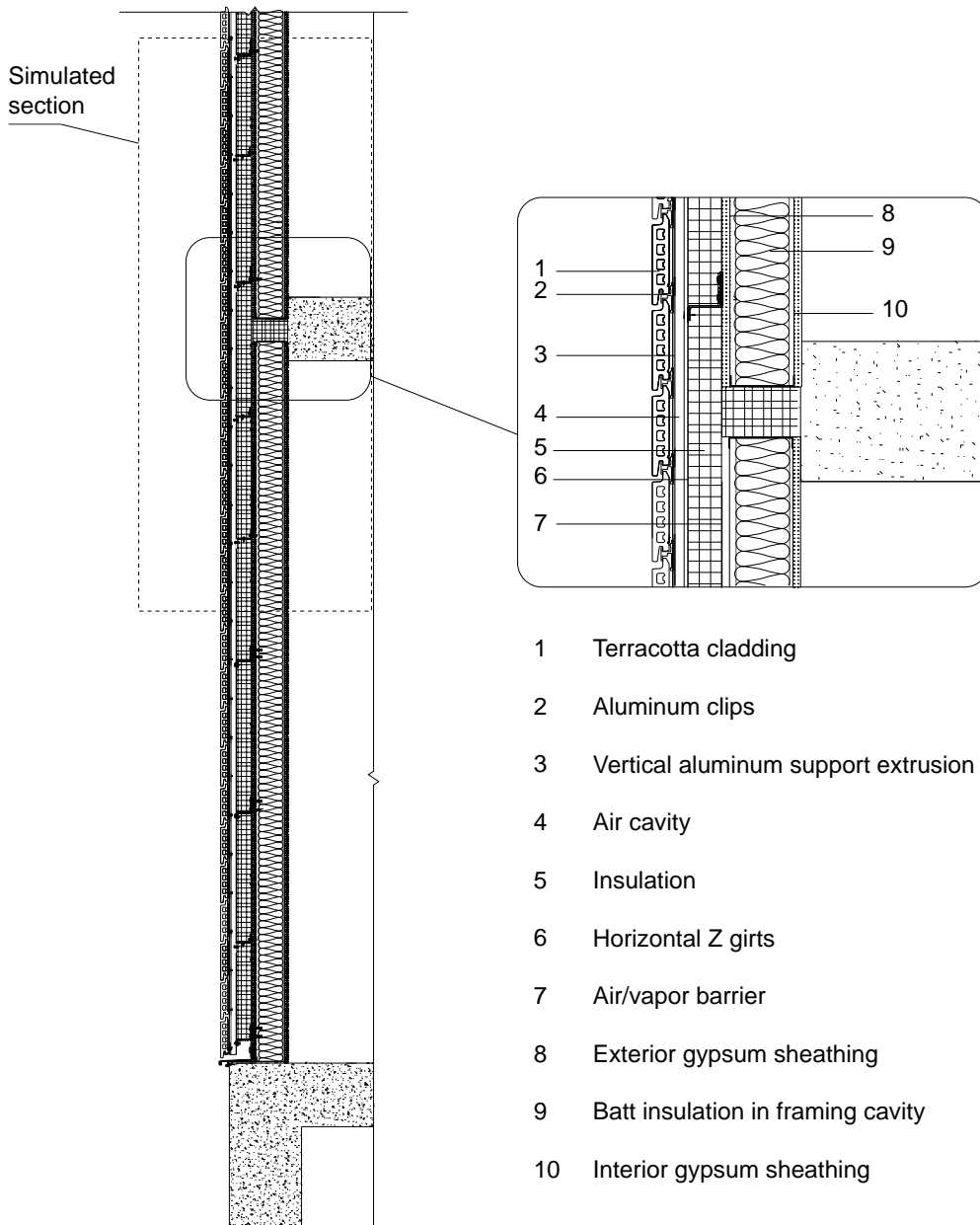


Figure 2: Components of the rainscreen facade with terracotta cladding.

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

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

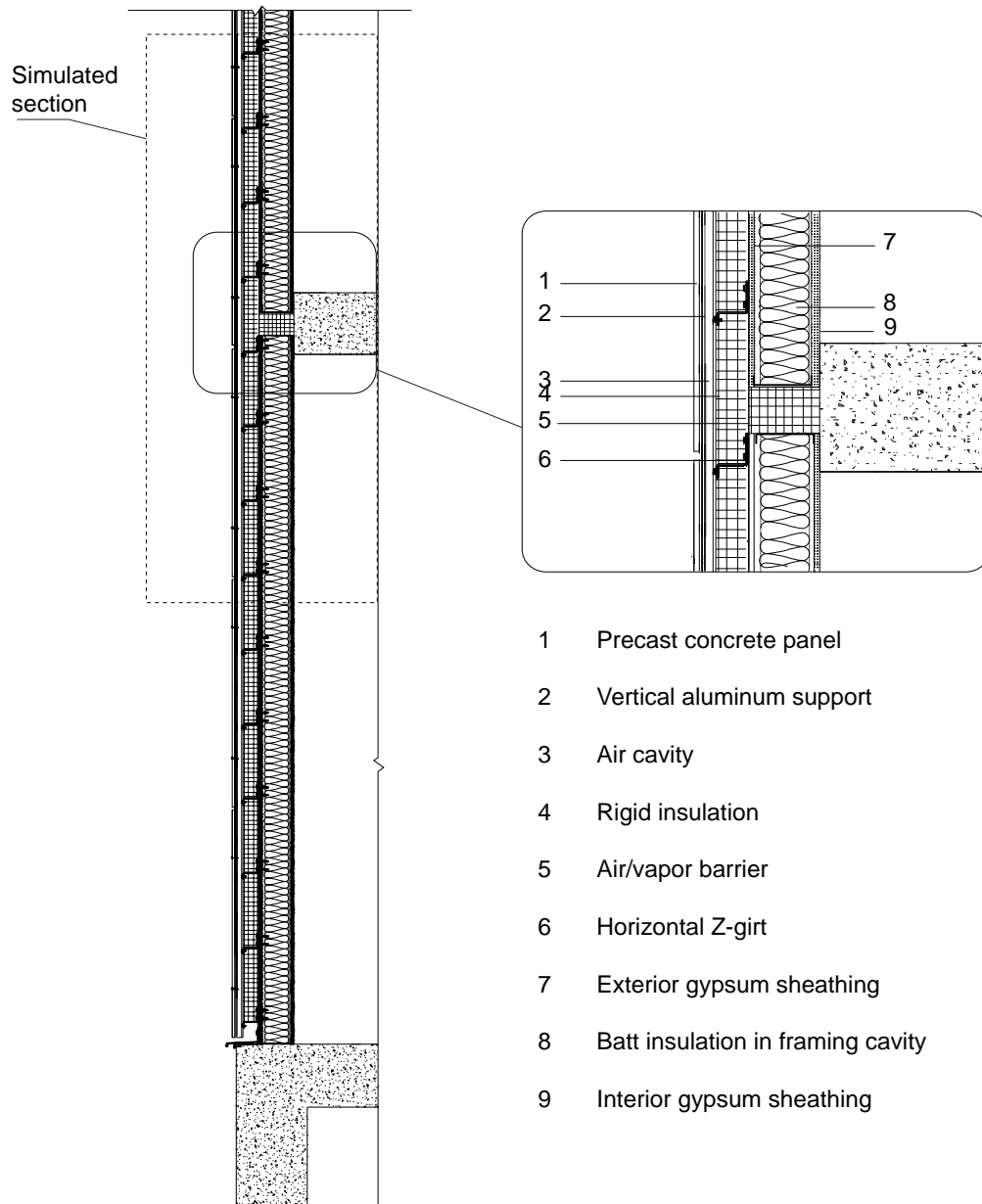


Figure 3: Components of the rainscreen facade with GFRC cladding.

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

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

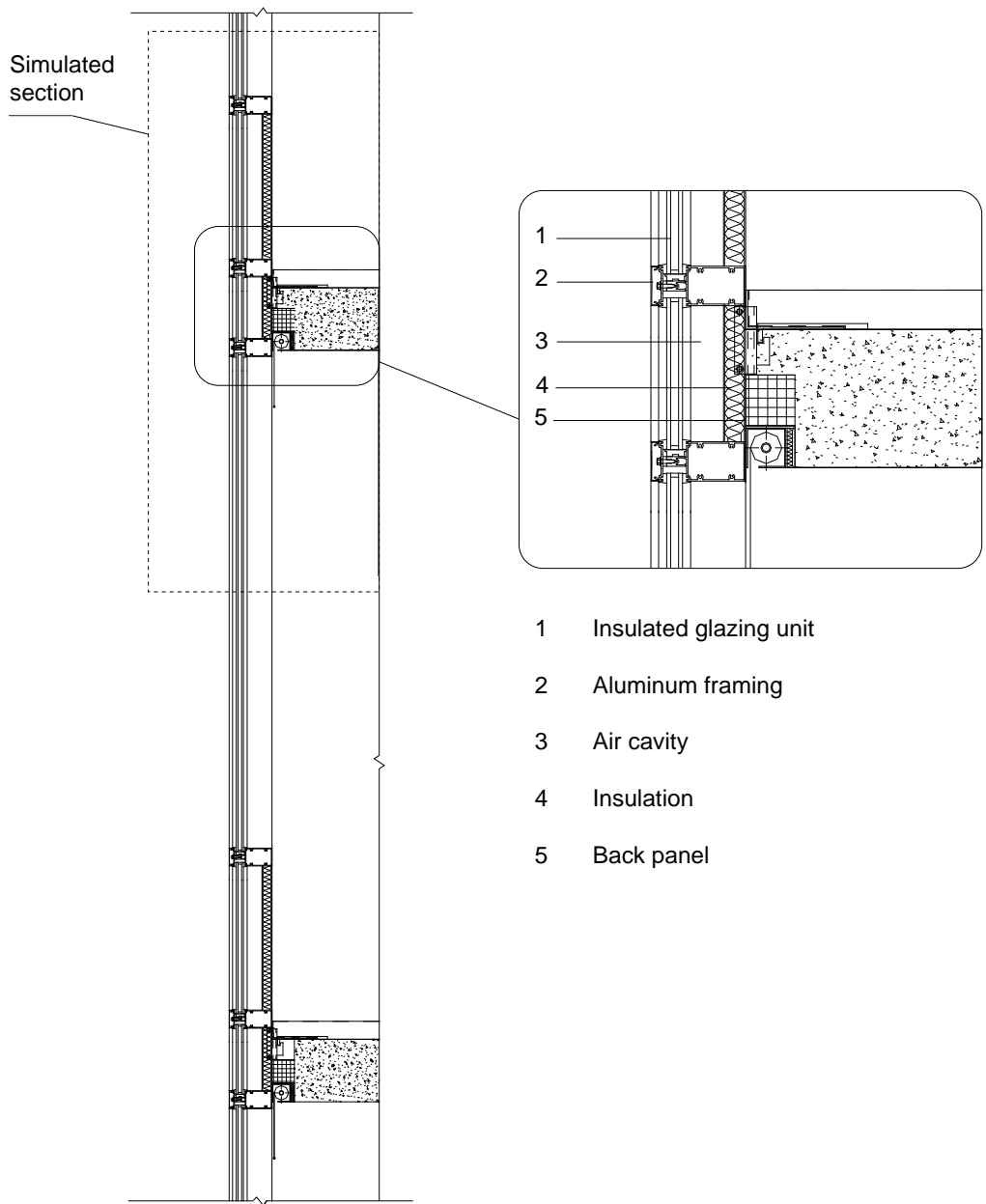


Figure 4: Components of the curtain wall.



The fifth case (Type 5) considered thermally improved curtain wall, shown in Figure 5. The analyzed curtain wall consisted of vision glazing 8 1/2 ft vertically, spandrel area of 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, 3 in air cavity, 2 in insulation and aluminum back pan
- Aluminum framing members with thermal breaks.

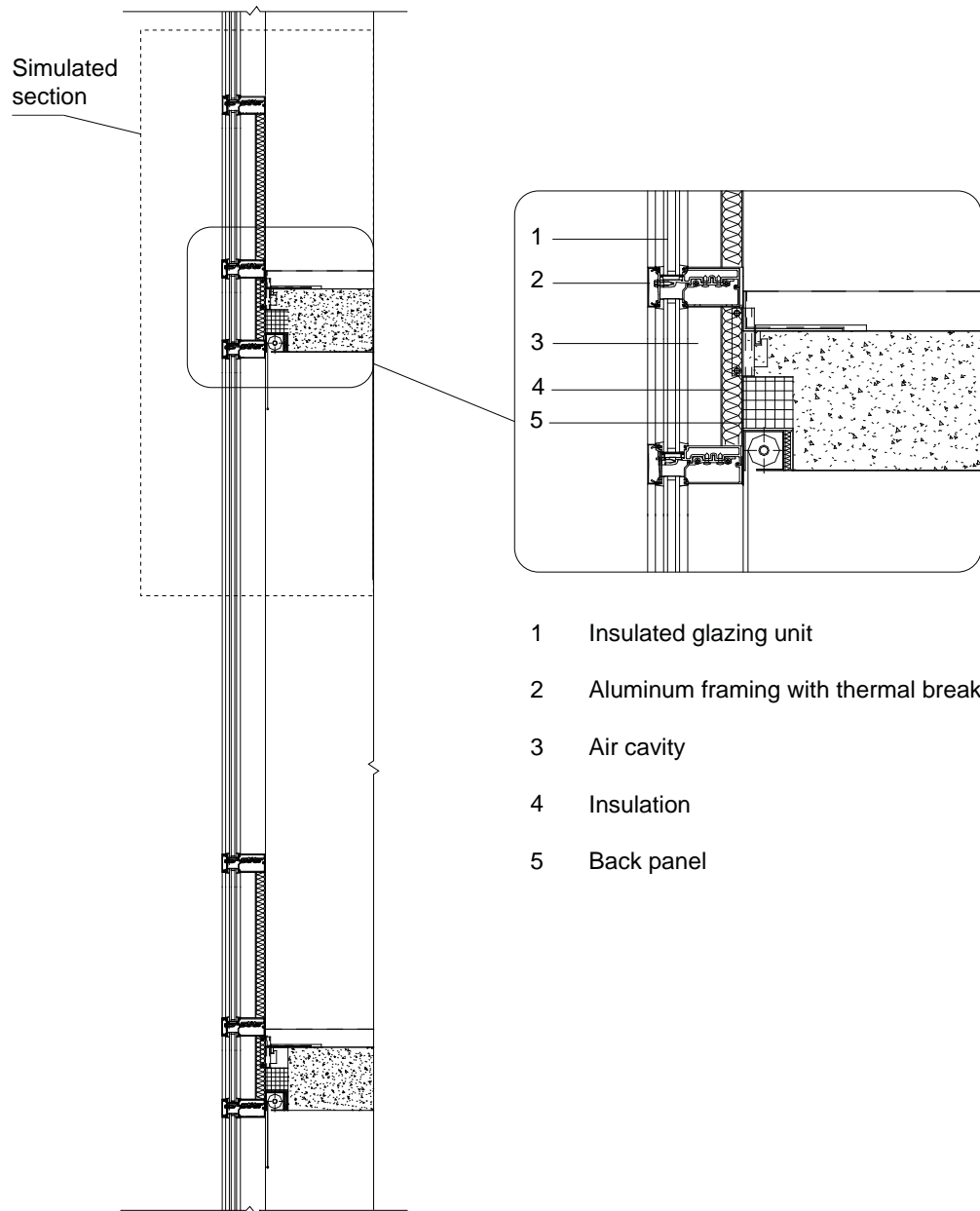


Figure 5: Components of the thermally broken curtain wall.

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 system, as demonstrated in Figure 6. The components of the analyzed assembly are:

- Terracotta cladding: 1 3/16 in
- Aluminum clips
- Air cavity: 1 in

- Vertical aluminum support extrusions
- Fiberglass spacers
- Rigid insulation: 3 in
- Horizontal L brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 5/8 in
- Framing cavity with batt insulation: 6 in
- Interior gypsum sheathing: 5/8 in.

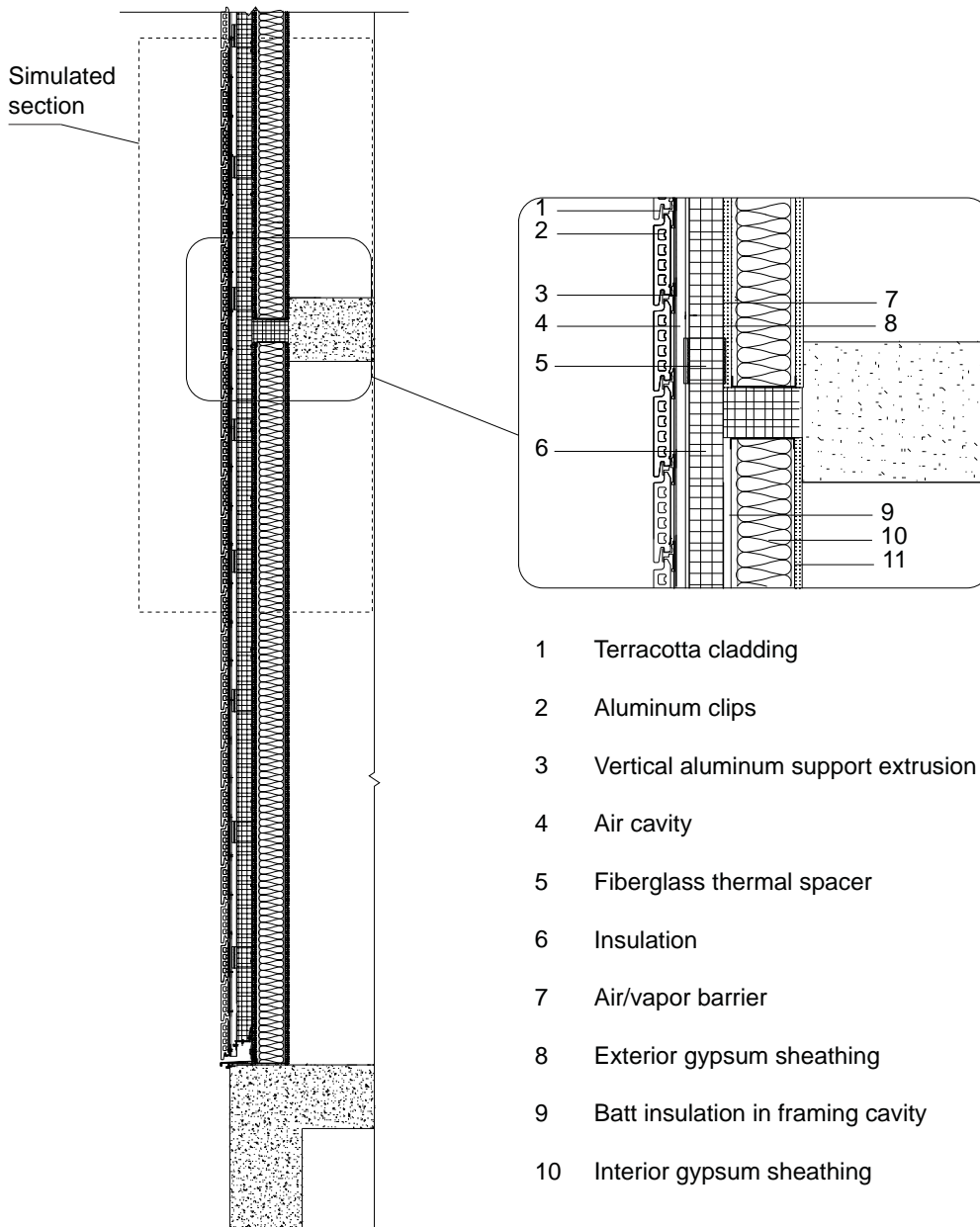


Figure 6: Components of the rainscreen facade with terracotta cladding and thermal spacers.

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

- Terracotta cladding: 1 3/16 in
- Aluminum clips
- Air cavity: 1 in
- Vertical aluminum support extrusions

- Rigid insulation: 3 in
- Horizontal L brackets with thermal isolators placed on the interior side of the brackets
- Air/vapor barrier
- Exterior gypsum sheathing: 5/8 in
- Framing cavity with batt insulation: 6 in
- Interior gypsum sheathing: 5/8 in.

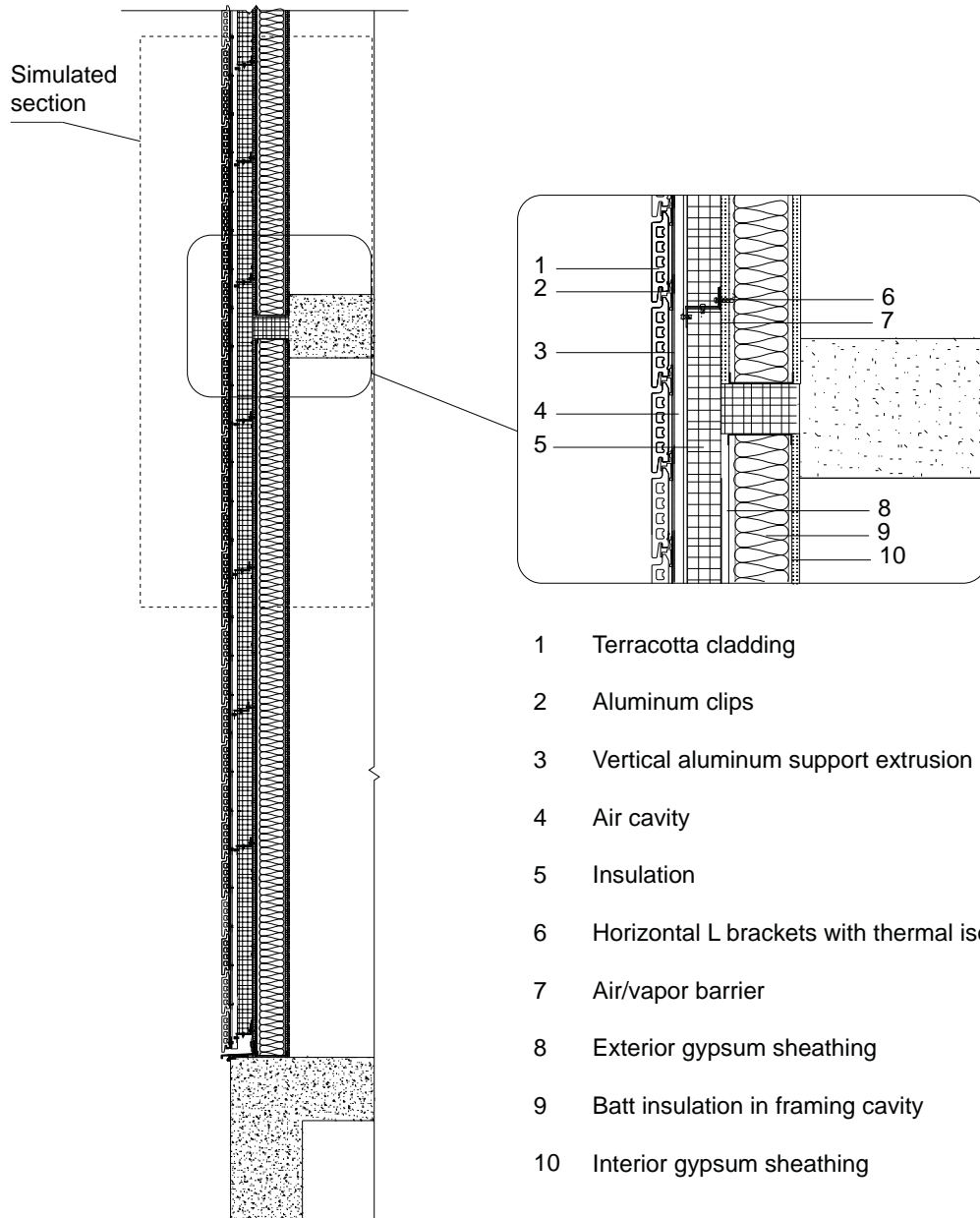


Figure 7: Components of the rainscreen facade with terracotta cladding and isolators.

## 2.2 Energy Modeling

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 percent for occupant views and daylighting, while glazed facades were modeled with 80 percent window to wall ratio.

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 13 ft high by 12 ft wide and 16 ft deep, as seen in Figure 8. The facade was 13 ft high by 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 modeled 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 70°F with 60°F setback during unoccupied hours, and cooled to 75°F with 80°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 0.5 W/ft<sup>2</sup> load density and continuous daylighting control<sup>11</sup>. Equipment load for the office was modeled at 0.7 W/ft<sup>2</sup>, 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 for three 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 3,780 simulations were run.

# Climate Change and Performance of Facade Systems

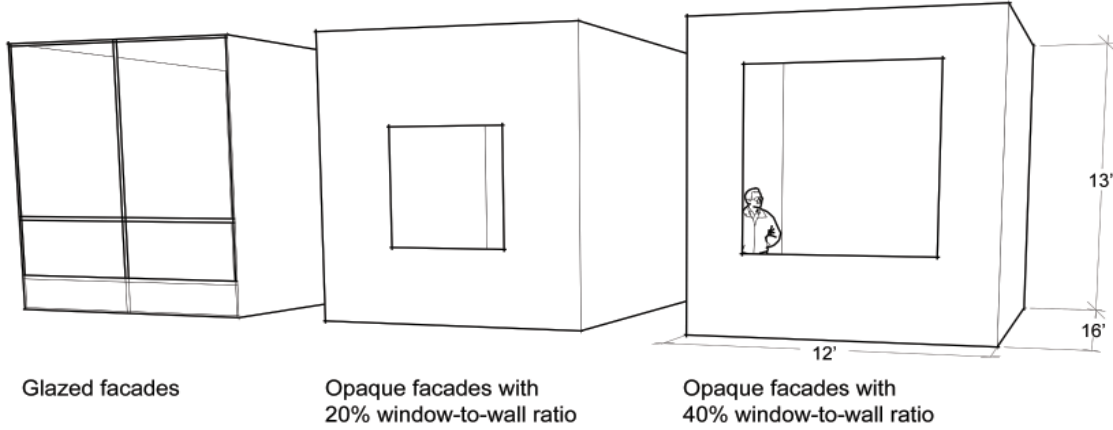


Figure 8: Diagram showing dimensions and components of the simulated office space.

Table 2: Climate zones and representative cities used for energy modeling.

	Climate Zone	City	Zone	Region
1	1A	Miami, FL	very hot	moist
2	2A	Houston, TX	hot	moist
3	2B	Phoenix, AZ	hot	dry
4	3A	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	

### 3.0 RESULTS

#### 3.1 Thermal Modeling Results

Four different thermal models were developed in THERM for each facade system, representing different exterior environmental conditions, where these conditions would be representative of different climate types and seasons. Interior conditions for all scenarios were kept constant at 72°F. The exterior temperatures of 90°F, 60°F, 30°F and 0°F were used to represent different climate types. This was conducted to understand behavior of these different exterior wall types under various conditions, and to determine thermal gradients since this information is useful for design decision-making process. Figures 9 to 12 show results for thermal gradients through all facade types.

Heat transfer coefficients (U-values) were also calculated for all of the analyzed facade systems using THERM

software. Heat transfer through exterior walls depends on the following factors: 1) the difference between temperature between exterior and interior environment, 2) the materials of the wall and their thicknesses, and 3) the thermal conductivity of material layers. Total rate of heat transfer through an opaque wall assembly is calculated by area-weighted approach, where separate heat transfer contributions of different material layers are taken into account, based on the relative area that they occupy within the wall system. For glazed facades, area-weighted approach is also used to calculate heat transfer, where center-of-glass, edge-of-glass and frame U-values are taken into account. Standard exterior environmental conditions, prescribed by NFRC were used for the simulations, (outdoor temperature of 0°F and indoor temperature of 70°F)<sup>12</sup>. Therefore, a total of 35 thermal models were developed and simulated.

# Climate Change and Performance of Facade Systems

Exterior temperature: 90°F  
Interior temperature: 72°F

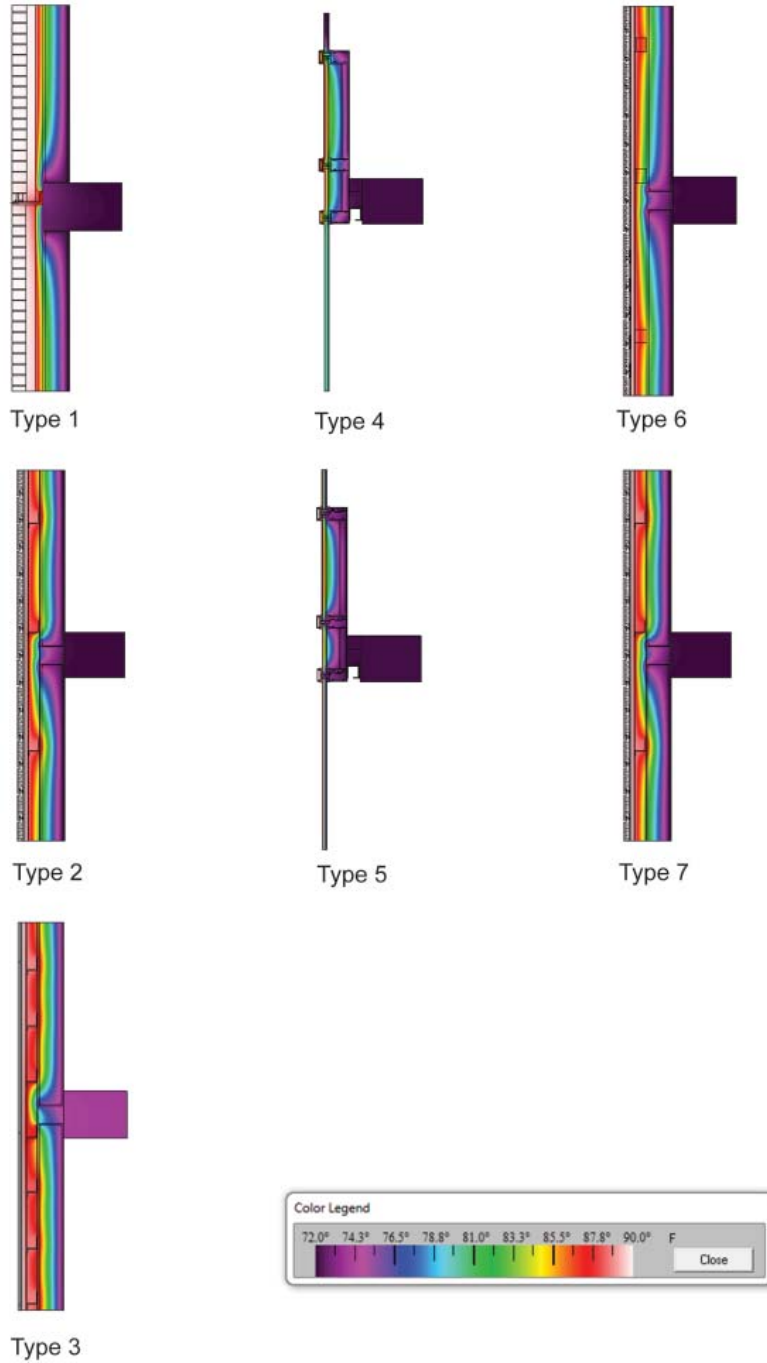


Figure 9: Results of thermal modeling, showing thermal gradient through the exterior wall assemblies, with exterior temperature of 90°F.

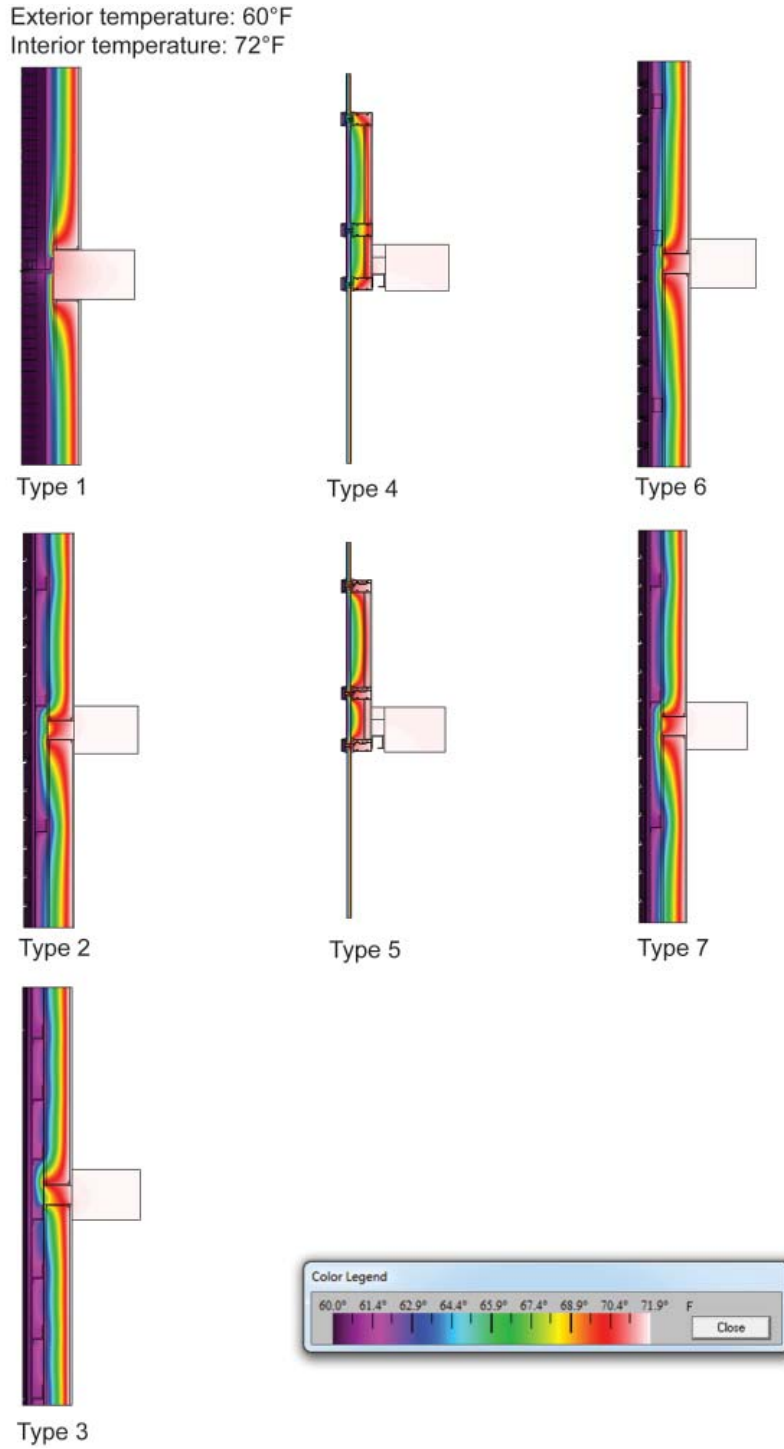


Figure 10: Results of thermal modeling, showing thermal gradient through the exterior wall assemblies, with exterior temperature of 60°F.



# Climate Change and Performance of Facade Systems

Exterior temperature: 30°F  
Interior temperature: 72°F

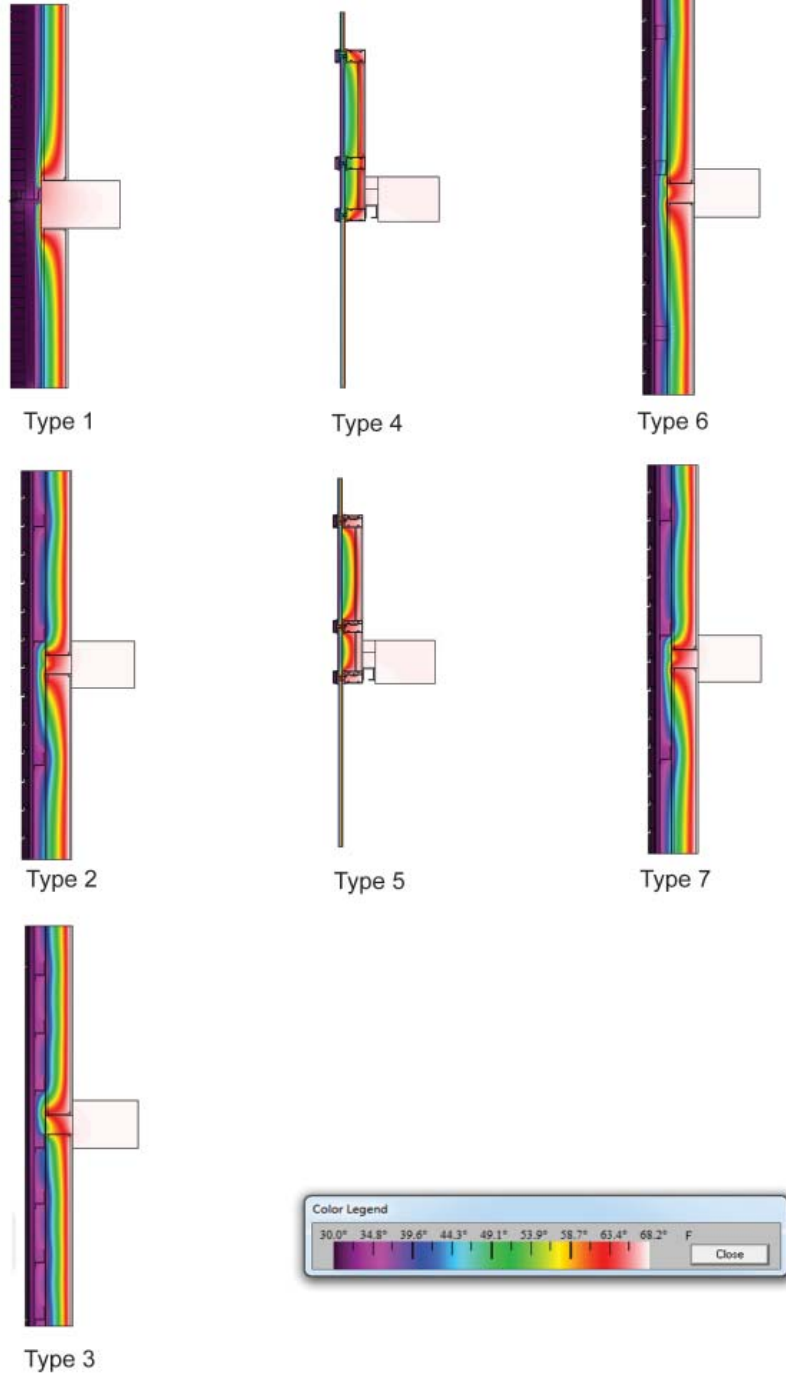


Figure 11: Results of thermal modeling, showing thermal gradient through the exterior wall assemblies, with exterior temperature of 30°F.

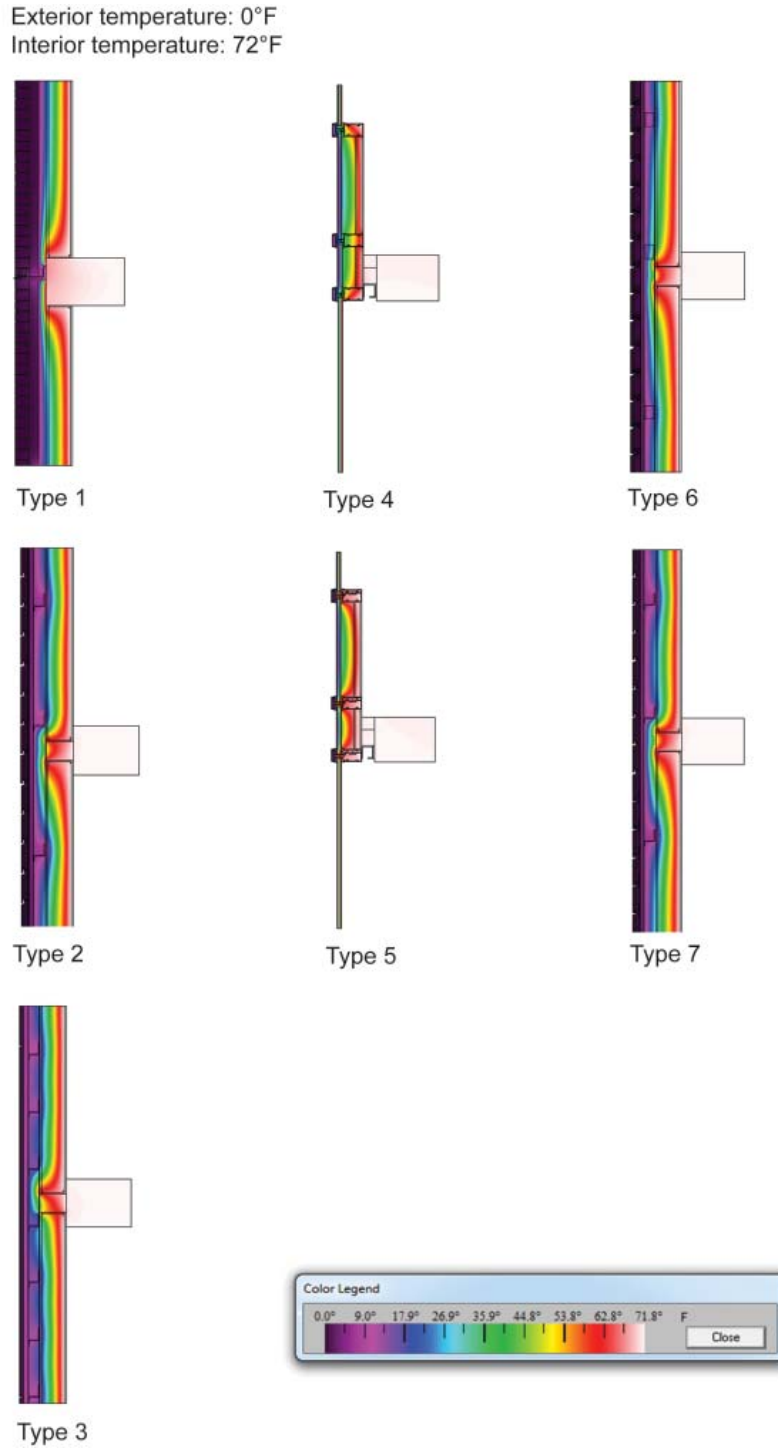


Figure 12: Results of thermal modeling, showing thermal gradient through the exterior wall assemblies, with exterior temperature of 0°F.

# Climate Change and Performance of Facade Systems

Results for U-values are shown in Figure 13. Thermal performance of analyzed facade systems was compared based on calculated U-values. Curtain wall is the worst performing assembly, followed by brick cavity wall. Curtain wall with thermally broken framing performs better than the analyzed brick cavity, but worse than all other types of opaque facades. Rainscreen facade with terracotta cladding has lower U-value coefficient than rainscreen facade with GFRC cladding, since it uses horizontal L brackets instead of Z girls to sup-

port exterior insulation layer and cladding, and spacing between them is larger. But, fiberglass spacers placed between the vertical cladding support system and framing improve U-value by 20 percent, since they minimize thermal bridging caused by metal components within the rainscreen assembly. Thermal isolators, placed on the interior side of L brackets, also reduce U-value by 20 percent, and are less expensive method for improving thermal performance.

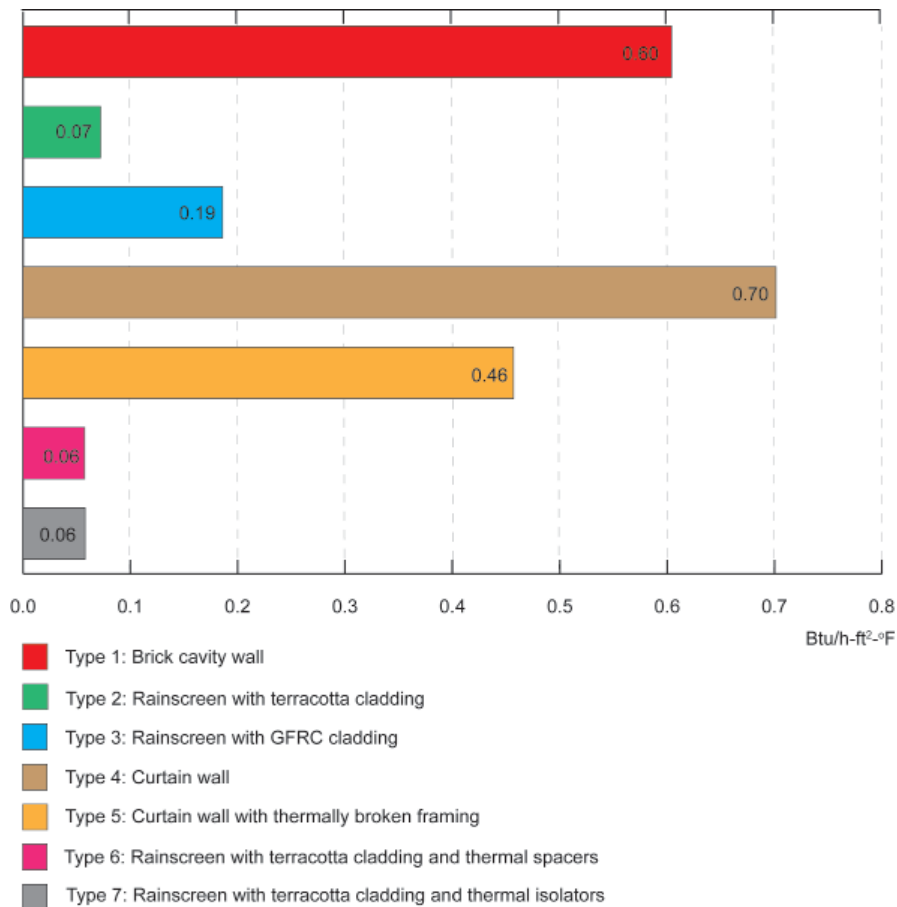


Figure 13: U-value comparison of all analyzed assemblies.

### 3.2 Energy Modeling Results

The plotted results, shown in Figure 14, indicate general patterns for each of the different wall types in the 15 climate zones, considering current climate data. Also, Tables 3 to 5 show detailed numeric results. 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. In general, the opaque facades all performed better than the transparent curtain walls, despite the energy reducing possibility of heat gain in winter and daylight harvesting.

The opaque walls also performed similarly for all orientations, with slightly better performance towards the north in warm climates and towards the south in cold climates. Orientation had a greater effect for the glazed walls, with east and west performing the worst. The south orientation performed the best in the coldest climates, but north facing performed the best for most of the other climate zones. In climate zones 1A through 3C, the north facing glazed facades performed nearly as well as the opaque facades.

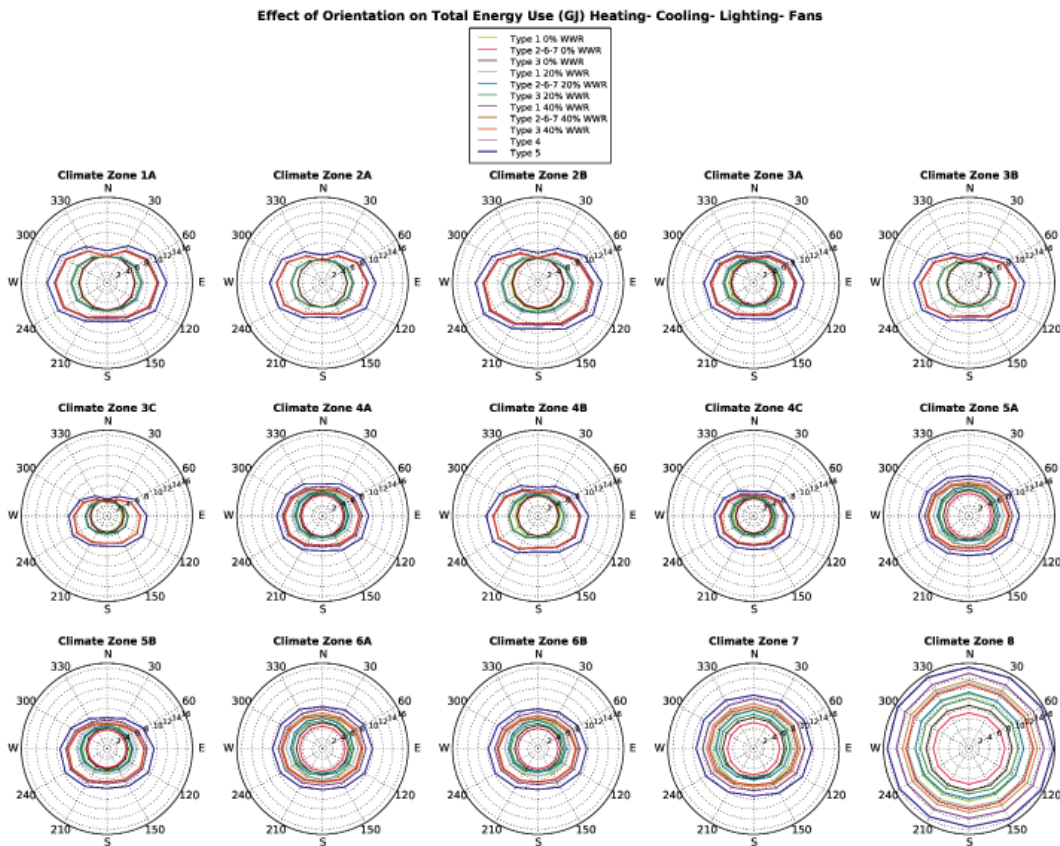


Figure 14: Total annual energy use for different wall types and orientations (current climate data).

# Climate Change and Performance of Facade Systems

Table 3: Total annual energy use for climate zones 1A-3C.

		Effect of Orientation on Total Energy Use (GJ) Heating- Cooling- Lighting- Fans												
Climate Zone	Wall Type	Orientation												
		0	30	60	90	120	150	180	210	240	270	300	330	
1A	Type 1, 0% WWR	5.46	5.52	5.61	5.67	5.69	5.66	5.63	5.64	5.64	5.56	5.50	5.50	5.49
1A	Type 2-6-7, 0% WWR	5.40	5.41	5.45	5.47	5.48	5.47	5.46	5.47	5.50	5.50	5.47	5.47	5.43
1A	Type 3, 0% WWR	5.45	5.47	5.53	5.56	5.58	5.57	5.56	5.59	5.61	5.61	5.56	5.56	5.51
1A	Type 1, 20% WWR	5.20	5.90	6.84	7.30	7.05	5.99	5.70	6.04	6.89	7.22	6.75	5.88	
1A	Type 2-6-7, 20% WWR	5.20	5.85	6.63	7.06	6.83	5.97	5.63	5.84	6.56	6.87	6.43	5.64	
1A	Type 3, 20% WWR	5.18	5.81	6.58	7.00	6.76	5.91	5.63	5.77	6.46	6.77	6.34	5.56	
1A	Type 1, 40% WWR	5.26	7.36	9.45	10.48	9.98	8.02	7.04	8.00	9.81	10.32	9.34	7.45	
1A	Type 2-6-7, 40% WWR	5.28	7.27	9.30	10.32	9.82	7.87	6.71	7.81	9.57	10.08	9.12	7.27	
1A	Type 3, 40% WWR	5.26	7.26	9.26	10.27	9.77	7.83	6.69	7.75	9.50	10.00	9.05	7.22	
1A	Type 4	6.40	8.33	10.70	11.91	11.12	8.76	7.62	8.80	11.11	11.89	10.81	8.49	
1A	Type 5	6.40	8.33	10.70	11.91	11.12	8.76	7.62	8.80	11.11	11.89	10.81	8.49	
2A	Type 1, 0% WWR	4.74	4.79	4.87	4.93	4.95	4.93	4.91	4.92	4.86	4.83	4.77	4.77	
2A	Type 2-6-7, 0% WWR	4.82	4.83	4.87	4.89	4.90	4.90	4.89	4.91	4.93	4.93	4.89	4.85	
2A	Type 3, 0% WWR	4.80	4.82	4.87	4.91	4.93	4.92	4.91	4.94	4.97	4.96	4.91	4.86	
2A	Type 1, 20% WWR	4.45	5.08	5.89	6.34	6.17	5.34	4.93	5.32	6.06	6.30	5.84	5.00	
2A	Type 2-6-7, 20% WWR	4.48	5.12	5.77	6.17	6.02	5.22	4.92	5.12	5.82	6.05	5.60	4.84	
2A	Type 3, 20% WWR	4.50	5.13	5.77	6.17	6.01	5.22	4.90	5.10	5.77	6.00	5.57	4.69	
2A	Type 1, 40% WWR	4.46	6.22	8.13	9.15	8.83	7.19	6.26	7.20	8.73	9.09	8.09	6.29	
2A	Type 2-6-7, 40% WWR	4.46	6.19	8.04	9.05	8.72	7.09	6.13	7.06	8.55	8.90	7.91	6.17	
2A	Type 3, 40% WWR	4.46	6.20	8.04	9.05	8.71	7.09	6.13	7.04	8.52	8.86	7.89	6.14	
2A	Type 4	5.48	7.15	9.31	10.50	9.96	7.98	6.83	8.06	10.03	10.60	9.44	7.26	
2A	Type 5	5.48	7.15	9.31	10.51	9.97	7.97	6.82	8.05	10.04	10.60	9.44	7.26	
2B	Type 1, 0% WWR	5.04	5.11	5.25	5.37	5.44	5.44	5.44	5.44	5.33	5.25	5.13	5.07	
2B	Type 2-6-7, 0% WWR	4.87	4.89	4.95	5.01	5.04	5.03	5.03	5.05	5.06	5.03	4.97	4.91	
2B	Type 3, 0% WWR	4.95	4.99	5.08	5.15	5.20	5.20	5.19	5.23	5.25	5.21	5.12	5.03	
2B	Type 1, 20% WWR	4.95	5.65	6.67	7.43	7.48	6.69	6.05	6.68	7.42	7.41	6.58	5.51	
2B	Type 2-6-7, 20% WWR	4.79	5.58	6.44	7.13	7.16	6.36	5.94	6.18	6.98	6.98	6.21	5.09	
2B	Type 3, 20% WWR	4.79	5.51	6.36	7.03	7.05	6.17	5.82	6.06	6.84	6.83	6.08	5.01	
2B	Type 1, 40% WWR	5.04	6.88	9.30	10.97	11.13	9.50	8.40	9.58	11.11	11.02	9.30	6.90	
2B	Type 2-6-7, 40% WWR	4.95	6.77	9.12	10.77	10.89	9.28	8.14	9.30	10.79	10.69	9.02	6.68	
2B	Type 3, 40% WWR	4.88	6.72	9.07	10.69	10.80	9.20	8.06	9.18	10.67	10.58	8.91	6.60	
2B	Type 4	5.99	7.80	10.52	12.46	12.45	10.48	9.11	10.66	12.66	12.73	10.71	7.85	
2B	Type 5	5.99	7.80	10.52	12.46	12.45	10.48	9.11	10.66	12.66	12.73	10.71	7.84	
3A	Type 1, 0% WWR	4.82	4.88	4.93	4.96	4.95	4.91	4.87	4.89	4.90	4.84	4.87	4.84	
3A	Type 2-6-7, 0% WWR	4.31	4.32	4.36	4.38	4.39	4.39	4.39	4.40	4.41	4.41	4.38	4.35	
3A	Type 3, 0% WWR	4.48	4.50	4.54	4.56	4.55	4.54	4.51	4.54	4.59	4.60	4.57	4.53	
3A	Type 1, 20% WWR	4.91	5.41	5.87	6.14	6.01	5.38	4.88	5.36	5.94	6.08	5.75	5.17	
3A	Type 2-6-7, 20% WWR	4.57	5.10	5.60	5.85	5.70	5.01	4.68	4.84	5.50	5.64	5.29	4.64	
3A	Type 3, 20% WWR	4.37	4.94	5.47	5.74	5.59	4.91	4.58	4.73	5.37	5.48	5.10	4.47	
3A	Type 1, 40% WWR	5.16	6.34	7.69	8.62	8.52	7.31	6.52	7.36	8.47	8.59	7.66	6.26	
3A	Type 2-6-7, 40% WWR	4.89	6.13	7.47	8.42	8.33	7.11	6.28	7.11	8.20	8.29	7.35	5.94	
3A	Type 3, 40% WWR	4.72	6.01	7.39	8.37	8.28	7.06	6.23	7.02	8.12	8.22	7.23	5.79	
3A	Type 4	5.90	7.26	8.77	9.86	9.64	8.15	7.21	8.29	9.80	10.03	8.90	7.16	
3A	Type 5	5.89	7.26	8.77	9.87	9.64	8.15	7.20	8.30	9.80	10.02	8.89	7.15	
3B	Type 1, 0% WWR	4.36	4.43	4.52	4.59	4.60	4.58	4.53	4.53	4.46	4.44	4.37	4.37	
3B	Type 2-6-7, 0% WWR	4.29	4.31	4.35	4.41	4.43	4.42	4.42	4.42	4.44	4.43	4.38	4.32	
3B	Type 3, 0% WWR	4.29	4.32	4.37	4.42	4.46	4.44	4.43	4.46	4.47	4.46	4.41	4.33	
3B	Type 1, 20% WWR	4.30	4.93	5.72	6.34	6.28	5.38	4.86	5.32	6.08	6.18	5.51	4.69	
3B	Type 2-6-7, 20% WWR	4.09	4.82	5.59	6.19	6.11	5.27	4.83	5.05	5.77	5.86	5.20	4.37	
3B	Type 3, 20% WWR	4.02	4.81	5.59	6.20	6.11	5.27	4.82	5.04	5.74	5.82	5.17	4.23	
3B	Type 1, 40% WWR	4.41	5.96	8.14	9.65	9.60	7.85	6.68	7.77	9.37	9.44	7.97	5.90	
3B	Type 2-6-7, 40% WWR	4.19	5.84	8.02	9.52	9.48	7.72	6.54	7.60	9.17	9.23	7.76	5.68	
3B	Type 3, 40% WWR	4.17	5.83	8.04	9.54	9.49	7.73	6.53	7.59	9.14	9.22	7.74	5.64	
3B	Type 4	5.14	6.85	9.29	11.01	10.79	8.69	7.27	8.70	10.81	11.05	9.32	6.81	
3B	Type 5	5.14	6.84	9.29	11.01	10.80	8.69	7.27	8.69	10.80	11.05	9.32	6.80	
3C	Type 1, 0% WWR	3.03	3.07	3.16	3.22	3.24	3.23	3.20	3.18	3.11	3.06	3.02	3.04	
3C	Type 2-6-7, 0% WWR	3.35	3.36	3.39	3.43	3.45	3.46	3.46	3.47	3.46	3.45	3.41	3.39	
3C	Type 3, 0% WWR	3.20	3.22	3.26	3.30	3.32	3.33	3.33	3.35	3.35	3.34	3.29	3.24	
3C	Type 1, 20% WWR	2.73	3.24	3.75	4.19	4.25	3.82	3.50	3.86	4.28	4.21	3.67	3.00	
3C	Type 2-6-7, 20% WWR	2.76	3.34	3.86	4.24	4.27	3.82	3.51	3.82	4.21	4.13	3.59	2.92	
3C	Type 3, 20% WWR	2.82	3.45	3.98	4.37	4.39	3.93	3.62	3.92	4.29	4.22	3.68	3.01	
3C	Type 1, 40% WWR	2.58	3.78	5.26	6.52	6.78	5.95	5.40	6.13	6.92	6.65	5.36	3.72	
3C	Type 2-6-7, 40% WWR	2.59	3.86	5.31	6.55	6.80	5.98	5.39	6.10	6.88	6.61	5.32	3.69	
3C	Type 3, 40% WWR	2.59	3.94	5.40	6.65	6.90	6.07	5.47	6.17	6.95	6.68	5.41	3.74	
3C	Type 4	3.28	4.55	6.20	7.61	7.80	6.72	6.04	6.98	8.13	7.94	6.46	4.47	
3C	Type 5	3.28	4.55	6.20	7.62	7.80	6.73	6.03	6.99	8.13	7.93	6.46	4.46	

Table 4: Total annual energy use for climate zones 4A-5B.

		Effect of Orientation on Total Energy Use (GJ) Heating- Cooling- Lighting- Fans											
Climate Zone	Wall Type	Orientation											
		0	30	60	90	120	150	180	210	240	270	300	330
4A	Type 1, 0% WWR	5.08	5.12	5.13	5.11	5.08	5.03	4.98	5.01	5.01	5.03	5.09	5.08
4A	Type 2-6-7, 0% WWR	4.13	4.14	4.16	4.17	4.17	4.16	4.16	4.17	4.19	4.20	4.18	4.15
4A	Type 3, 0% WWR	4.46	4.47	4.49	4.48	4.45	4.41	4.39	4.43	4.49	4.52	4.52	4.49
4A	Type 1, 20% WWR	5.40	5.66	5.88	5.94	5.75	5.21	4.85	5.19	5.67	5.88	5.77	5.44
4A	Type 2-6-7, 20% WWR	4.84	5.16	5.42	5.48	5.30	4.75	4.35	4.67	5.11	5.30	5.14	4.79
4A	Type 3, 20% WWR	4.53	4.87	5.18	5.30	5.11	4.57	4.18	4.49	4.90	5.06	4.86	4.50
4A	Type 1, 40% WWR	5.75	6.46	7.33	7.95	7.80	6.87	6.21	6.87	7.71	7.83	7.28	6.36
4A	Type 2-6-7, 40% WWR	5.35	6.10	6.99	7.66	7.55	6.60	5.93	6.56	7.37	7.45	6.86	5.91
4A	Type 3, 40% WWR	5.09	5.88	6.84	7.55	7.47	6.53	5.84	6.44	7.27	7.31	6.68	5.67
4A	Type 4	6.39	7.37	8.37	9.11	8.90	7.76	6.98	7.85	8.98	9.16	8.43	7.26
4A	Type 5	6.38	7.36	8.36	9.10	8.90	7.75	6.97	7.85	8.98	9.16	8.42	7.25
4B	Type 1, 0% WWR	4.54	4.60	4.62	4.62	4.58	4.51	4.45	4.46	4.44	4.47	4.48	4.54
4B	Type 2-6-7, 0% WWR	3.97	4.00	4.03	4.07	4.09	4.07	4.06	4.08	4.10	4.08	4.05	4.02
4B	Type 3, 0% WWR	4.13	4.16	4.20	4.20	4.17	4.12	4.08	4.12	4.18	4.22	4.22	4.17
4B	Type 1, 20% WWR	4.74	5.15	5.60	5.96	5.87	5.06	4.47	4.93	5.54	5.67	5.34	4.88
4B	Type 2-6-7, 20% WWR	4.30	4.80	5.32	5.71	5.64	4.84	4.40	4.54	5.17	5.24	4.84	4.31
4B	Type 3, 20% WWR	4.07	4.63	5.21	5.69	5.67	4.86	4.40	4.56	5.16	5.20	4.72	4.11
4B	Type 1, 40% WWR	5.02	6.04	7.62	8.98	9.09	7.59	6.44	7.33	8.56	8.50	7.33	5.93
4B	Type 2-6-7, 40% WWR	4.66	5.81	7.44	8.87	8.99	7.47	6.29	7.15	8.38	8.28	7.02	5.55
4B	Type 3, 40% WWR	4.46	5.69	7.41	8.90	9.02	7.51	6.30	7.17	8.39	8.28	6.95	5.40
4B	Type 4	5.60	6.93	8.74	10.31	10.31	8.49	7.11	8.33	9.99	10.05	8.60	6.79
4B	Type 5	5.59	6.93	8.73	10.33	10.32	8.50	7.13	8.34	9.99	10.05	8.59	6.77
4C	Type 1, 0% WWR	3.97	4.01	4.04	4.05	4.03	3.98	3.95	3.96	3.95	3.95	3.94	3.97
4C	Type 2-6-7, 0% WWR	3.39	3.40	3.43	3.45	3.46	3.47	3.47	3.49	3.49	3.48	3.45	3.42
4C	Type 3, 0% WWR	3.54	3.56	3.59	3.59	3.60	3.57	3.56	3.60	3.63	3.64	3.62	3.57
4C	Type 1, 20% WWR	4.13	4.38	4.68	4.86	4.82	4.49	4.25	4.53	4.86	4.86	4.56	4.16
4C	Type 2-6-7, 20% WWR	3.73	3.98	4.36	4.54	4.47	4.12	3.87	4.13	4.45	4.44	4.10	3.70
4C	Type 3, 20% WWR	3.50	3.81	4.23	4.43	4.38	4.03	3.76	4.02	4.32	4.29	3.94	3.50
4C	Type 1, 40% WWR	4.44	5.01	5.94	6.75	6.87	6.33	5.92	6.44	6.98	6.80	5.97	4.87
4C	Type 2-6-7, 40% WWR	4.10	4.75	5.71	6.56	6.69	6.13	5.69	6.21	6.72	6.53	5.68	4.53
4C	Type 3, 40% WWR	3.90	4.62	5.62	6.52	6.65	6.09	5.65	6.14	6.67	6.46	5.57	4.36
4C	Type 4	4.90	5.73	6.87	7.81	7.94	7.23	6.73	7.44	8.20	8.04	6.97	5.64
4C	Type 5	4.90	5.73	6.86	7.80	7.95	7.22	6.73	7.44	8.19	8.05	6.97	5.63
5A	Type 1, 0% WWR	6.11	6.15	6.15	6.13	6.07	6.00	5.95	5.99	6.03	6.04	6.11	6.11
5A	Type 2-6-7, 0% WWR	4.51	4.52	4.53	4.52	4.53	4.51	4.50	4.53	4.55	4.54	4.55	4.53
5A	Type 3, 0% WWR	5.12	5.12	5.14	5.12	5.08	5.02	4.99	5.03	5.09	5.13	5.16	5.14
5A	Type 1, 20% WWR	6.68	6.85	7.09	7.04	6.72	6.23	5.90	6.21	6.68	6.92	6.90	6.68
5A	Type 2-6-7, 20% WWR	5.88	6.07	6.33	6.32	6.00	5.49	5.05	5.42	5.85	6.05	6.01	5.76
5A	Type 3, 20% WWR	5.36	5.59	5.90	5.94	5.63	5.11	4.67	5.02	5.44	5.61	5.53	5.27
5A	Type 1, 40% WWR	7.31	7.80	8.47	8.85	8.55	7.64	7.05	7.68	8.48	8.69	8.36	7.65
5A	Type 2-6-7, 40% WWR	6.68	7.19	7.96	8.36	8.09	7.17	6.56	7.17	7.93	8.11	7.74	7.01
5A	Type 3, 40% WWR	6.29	6.83	7.67	8.12	7.86	6.96	6.34	6.92	7.67	7.83	7.41	6.64
5A	Type 4	7.93	8.74	9.59	10.03	9.68	8.59	7.91	8.71	9.74	10.01	9.52	8.61
5A	Type 5	7.92	8.73	9.57	10.01	9.66	8.58	7.90	8.70	9.73	9.99	9.51	8.59
5B	Type 1, 0% WWR	4.82	4.85	4.87	4.87	4.84	4.78	4.74	4.70	4.75	4.78	4.79	4.83
5B	Type 2-6-7, 0% WWR	3.78	3.79	3.82	3.84	3.85	3.83	3.83	3.84	3.86	3.86	3.83	3.80
5B	Type 3, 0% WWR	4.15	4.17	4.18	4.19	4.15	4.10	4.07	4.11	4.18	4.22	4.22	4.18
5B	Type 1, 20% WWR	5.23	5.37	5.69	5.94	5.86	5.41	5.03	5.33	5.74	5.85	5.61	5.23
5B	Type 2-6-7, 20% WWR	4.60	4.83	5.13	5.39	5.32	4.87	4.49	4.75	5.12	5.20	4.94	4.57
5B	Type 3, 20% WWR	4.24	4.52	4.85	5.14	5.11	4.69	4.31	4.56	4.91	4.93	4.62	4.23
5B	Type 1, 40% WWR	5.67	6.10	7.22	8.16	8.35	7.63	6.96	7.48	8.11	7.97	7.18	6.08
5B	Type 2-6-7, 40% WWR	5.16	5.68	6.84	7.81	8.02	7.31	6.63	7.12	7.74	7.55	6.72	5.60
5B	Type 3, 40% WWR	4.91	5.45	6.65	7.69	7.95	7.23	6.55	7.03	7.64	7.39	6.52	5.35
5B	Type 4	6.16	6.92	8.22	9.33	9.55	8.66	7.87	8.59	9.48	9.35	8.29	6.92
5B	Type 5	6.15	6.91	8.22	9.34	9.54	8.66	7.87	8.59	9.47	9.34	8.28	6.91

# Climate Change and Performance of Facade Systems

Table 5: Total annual energy use for climate zones 6A-8.

Climate Zone		Effect of Orientation on Total Energy Use (GJ) Heating- Cooling- Lighting- Fans											
		Orientation											
Wall Type	0	30	0	90	120	150	180	210	240	270	300	330	
6A	Type 1, 0% WWR	6.40	6.41	6.39	6.34	6.27	6.19	6.15	6.19	6.22	6.28	6.36	6.38
6A	Type 2-6-7, 0% WWR	4.53	4.54	4.55	4.54	4.53	4.52	4.51	4.53	4.55	4.56	4.56	4.54
6A	Type 3, 0% WWR	5.21	5.22	5.22	5.20	5.16	5.11	5.08	5.12	5.18	5.23	5.25	5.24
6A	Type 1, 20% WWR	7.12	7.18	7.27	7.16	6.87	6.41	6.13	6.41	6.83	7.08	7.13	7.02
6A	Type 2-6-7, 20% WWR	6.16	6.26	6.41	6.37	6.07	5.62	5.29	5.54	5.94	6.14	6.15	6.00
6A	Type 3, 20% WWR	5.58	5.70	5.92	5.93	5.65	5.20	4.87	5.10	5.47	5.65	5.61	5.42
6A	Type 1, 40% WWR	7.86	8.06	8.53	8.80	8.55	7.79	7.29	7.80	8.49	8.68	8.46	7.95
6A	Type 2-6-7, 40% WWR	7.12	7.40	7.94	8.26	8.02	7.27	6.76	7.24	7.88	8.05	7.77	7.22
6A	Type 3, 40% WWR	6.66	6.99	7.59	7.96	7.76	7.02	6.50	6.97	7.60	7.73	7.40	6.79
6A	Type 4	8.42	9.04	9.60	9.92	9.64	8.75	8.16	8.81	9.69	9.95	9.58	8.92
6A	Type 5	8.40	9.03	9.58	9.91	9.62	8.74	8.14	8.81	9.68	9.95	9.57	8.90
6B	Type 1, 0% WWR	5.86	5.88	5.83	5.74	5.63	5.52	5.45	5.47	5.56	5.67	5.77	5.85
6B	Type 2-6-7, 0% WWR	4.08	4.09	4.11	4.11	4.10	4.07	4.05	4.06	4.10	4.12	4.11	4.10
6B	Type 3, 0% WWR	4.69	4.70	4.71	4.67	4.60	4.52	4.47	4.51	4.60	4.68	4.72	4.72
6B	Type 1, 20% WWR	6.61	6.66	6.72	6.67	6.41	5.87	5.44	5.71	6.17	6.46	6.55	6.46
6B	Type 2-6-7, 20% WWR	5.65	5.74	5.88	5.88	5.65	5.11	4.71	4.94	5.37	5.58	5.58	5.47
6B	Type 3, 20% WWR	5.06	5.22	5.44	5.50	5.31	4.79	4.41	4.63	5.02	5.17	5.08	4.91
6B	Type 1, 40% WWR	7.36	7.52	8.15	8.64	8.54	7.77	7.13	7.61	8.24	8.31	7.97	7.40
6B	Type 2-6-7, 40% WWR	6.63	6.86	7.56	8.13	8.08	7.33	6.69	7.13	7.74	7.75	7.31	6.68
6B	Type 3, 40% WWR	6.17	6.49	7.26	7.90	7.91	7.20	6.55	6.98	7.55	7.50	6.99	6.26
6B	Type 4	7.94	8.54	9.28	9.90	9.80	8.89	8.12	8.81	9.63	9.72	9.16	8.40
6B	Type 5	7.92	8.52	9.26	9.89	9.80	8.89	8.11	8.80	9.63	9.71	9.14	8.38
7	Type 1, 0% WWR	7.84	7.86	7.81	7.73	7.63	7.54	7.49	7.55	7.60	7.69	7.78	7.84
7	Type 2-6-7, 0% WWR	5.23	5.24	5.23	5.22	5.21	5.19	5.18	5.20	5.22	5.24	5.25	5.25
7	Type 3, 0% WWR	6.21	6.21	6.20	6.15	6.08	6.01	5.99	6.03	6.11	6.18	6.23	6.22
7	Type 1, 20% WWR	8.96	8.88	8.84	8.55	8.13	7.60	7.30	7.66	8.17	8.56	8.77	8.76
7	Type 2-6-7, 20% WWR	7.66	7.63	7.66	7.44	7.02	6.50	6.18	6.50	6.98	7.32	7.47	7.44
7	Type 3, 20% WWR	6.84	6.86	6.96	6.79	6.38	5.89	5.56	5.87	6.33	6.63	6.73	6.65
7	Type 1, 40% WWR	9.95	9.94	10.15	10.14	9.66	8.83	8.33	8.97	9.78	10.19	10.19	9.84
7	Type 2-6-7, 40% WWR	8.97	9.01	9.31	9.35	8.92	8.09	7.58	8.19	8.95	9.32	9.26	8.87
7	Type 3, 40% WWR	8.35	8.44	8.81	8.90	8.53	7.72	7.21	7.81	8.54	8.86	8.75	8.30
7	Type 4	10.68	11.11	11.42	11.43	10.95	9.97	9.38	10.20	11.19	11.65	11.50	11.03
7	Type 5	10.65	11.08	11.41	11.41	10.93	9.95	9.37	10.19	11.17	11.63	11.48	11.00
8	Type 1, 0% WWR	10.93	10.94	10.88	10.76	10.60	10.47	10.47	10.54	10.70	10.82	10.89	10.91
8	Type 2-6-7, 0% WWR	7.13	7.14	7.12	7.10	7.06	7.04	7.05	7.07	7.12	7.15	7.16	7.15
8	Type 3, 0% WWR	8.61	8.61	8.58	8.52	8.44	8.37	8.36	8.42	8.52	8.58	8.62	8.61
8	Type 1, 20% WWR	13.07	12.87	12.71	12.37	11.98	11.64	11.57	11.91	12.33	12.63	12.77	12.77
8	Type 2-6-7, 20% WWR	11.22	11.07	10.98	10.71	10.33	10.03	9.94	10.24	10.62	10.87	10.96	10.96
8	Type 3, 20% WWR	10.06	9.94	9.90	9.67	9.33	9.05	8.96	9.22	9.56	9.78	9.83	9.79
8	Type 1, 40% WWR	15.02	14.68	14.67	14.50	14.18	13.88	13.82	14.21	14.68	14.91	14.80	14.61
8	Type 2-6-7, 40% WWR	13.62	13.36	13.39	13.27	13.02	12.73	12.66	12.99	13.42	13.60	13.48	13.23
8	Type 3, 40% WWR	12.73	12.54	12.61	12.55	12.34	12.07	11.99	12.29	12.68	12.84	12.67	12.37
8	Type 4	16.23	16.42	16.48	16.31	15.99	15.64	15.57	16.02	16.55	16.80	16.63	16.32
8	Type 5	16.19	16.38	16.44	16.29	15.96	15.61	15.53	15.99	16.51	16.76	16.59	16.28

In terms of heating energy demand, curtain walls performed better than the brick cavity wall (Type 1) in climate zones 4A through climate zone 7 for southern orientations (90° to 270°). For all other cases, curtain walls are the worst performing types, with highest heating energy demand in all climate zones compared to other exterior wall types. Differences between the standard and thermally improved curtain walls were negligible, and north-facing curtain walls would significantly increase heating energy demand compared to other orientations. Thermally improved rainscreen facades would have the lowest heating energy demand, due to very high thermal resistance. In terms of cooling energy demand, curtain walls were the worst performing as well. However, east and west facing curtain walls typically have higher cool-

ing energy demand than south orientated curtain walls for very hot (zone 1), hot (zone 2), warm (zone 3) and mixed climates (zone 4). In colder climates (zones 5 and 6), south oriented curtain wall would have higher cooling energy demand than other orientations. Opaque exterior wall types would have comparable effect on cooling energy demand, with only negligible differences for different wall types and orientations.

Figures 15 to 18 compare impacts of climate change on energy performance, considering current climate data, year 2050 and year 2080 for the best performing opaque and glazed exterior wall assemblies (Type 7 and Type 5).

**Effect of Orientation on Total Energy Use (GJ) Heating- Cooling- Lighting- Fans  
(Type 7 wall)**

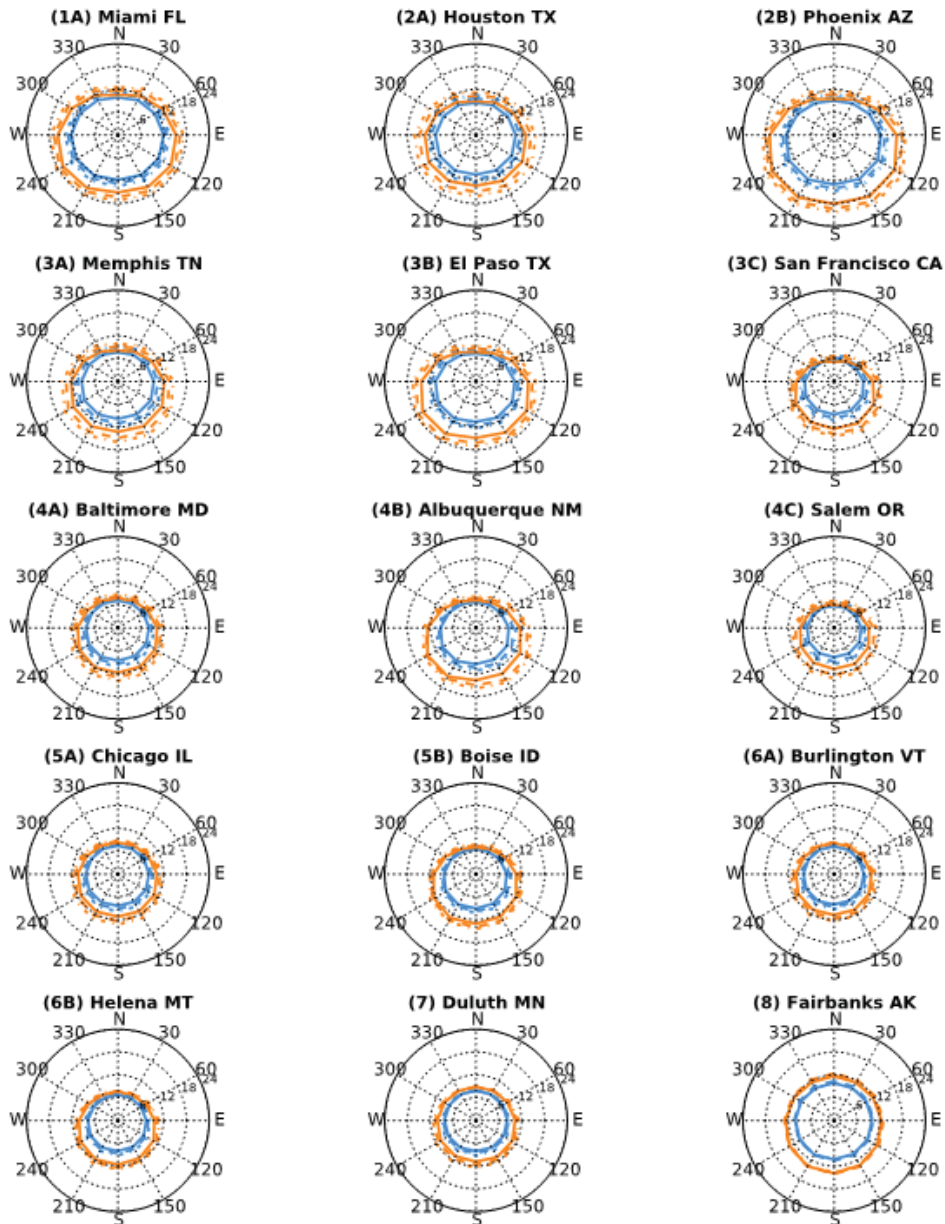
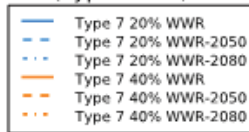


Figure 15: Total annual energy use for Type 7 exterior wall (current climate data).



**Effect of Orientation on Heating and Cooling Energy Use (GJ per Year)**  
(Type 7 20% Window to Wall Ratio)

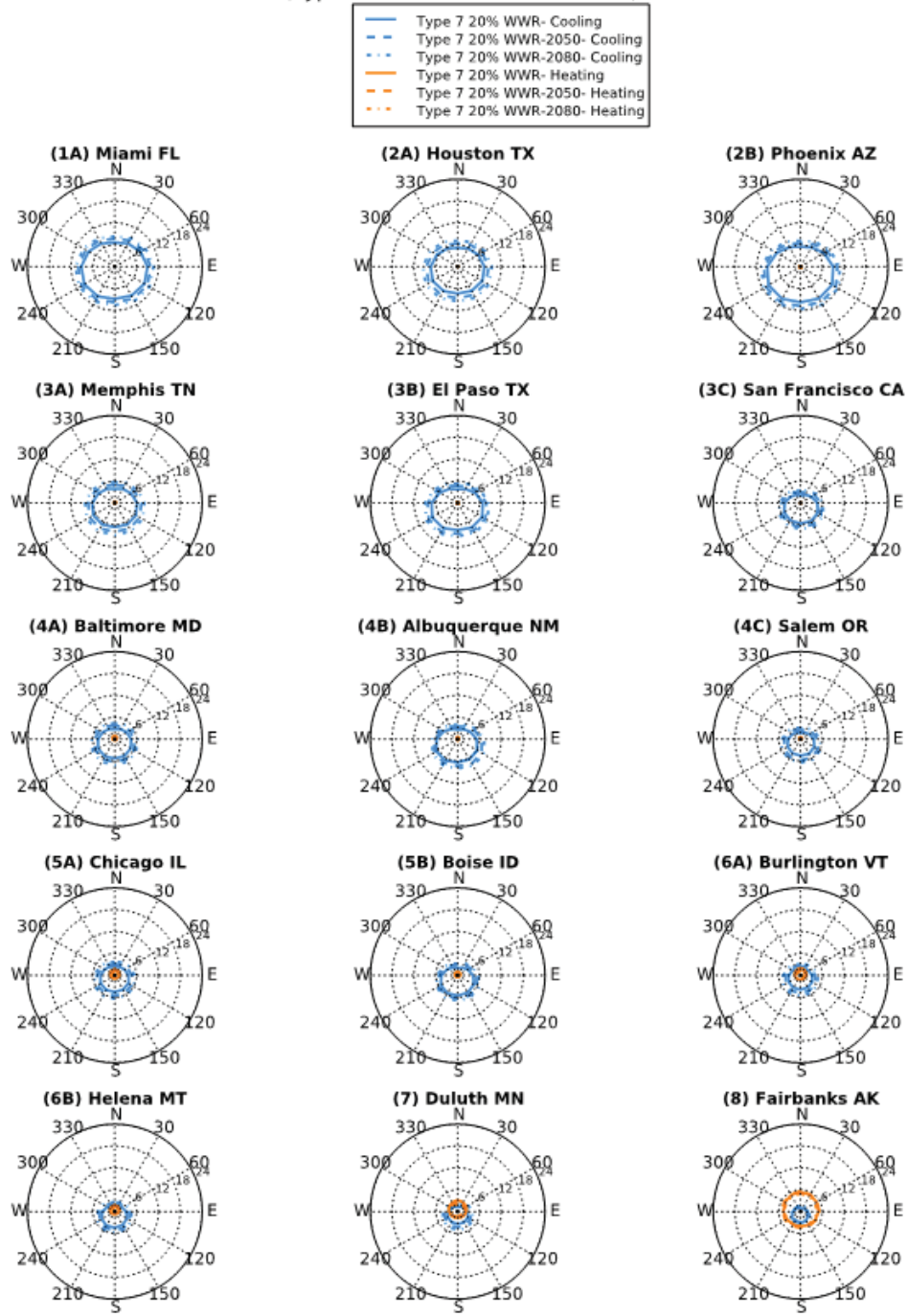


Figure 16: Comparison of heating and cooling energy use for Type 7 exterior wall (current climate data, year 2050 and year 2080).

**Effect of Orientation on Heating and Cooling Energy Use (GJ per Year)**  
(Type 5)

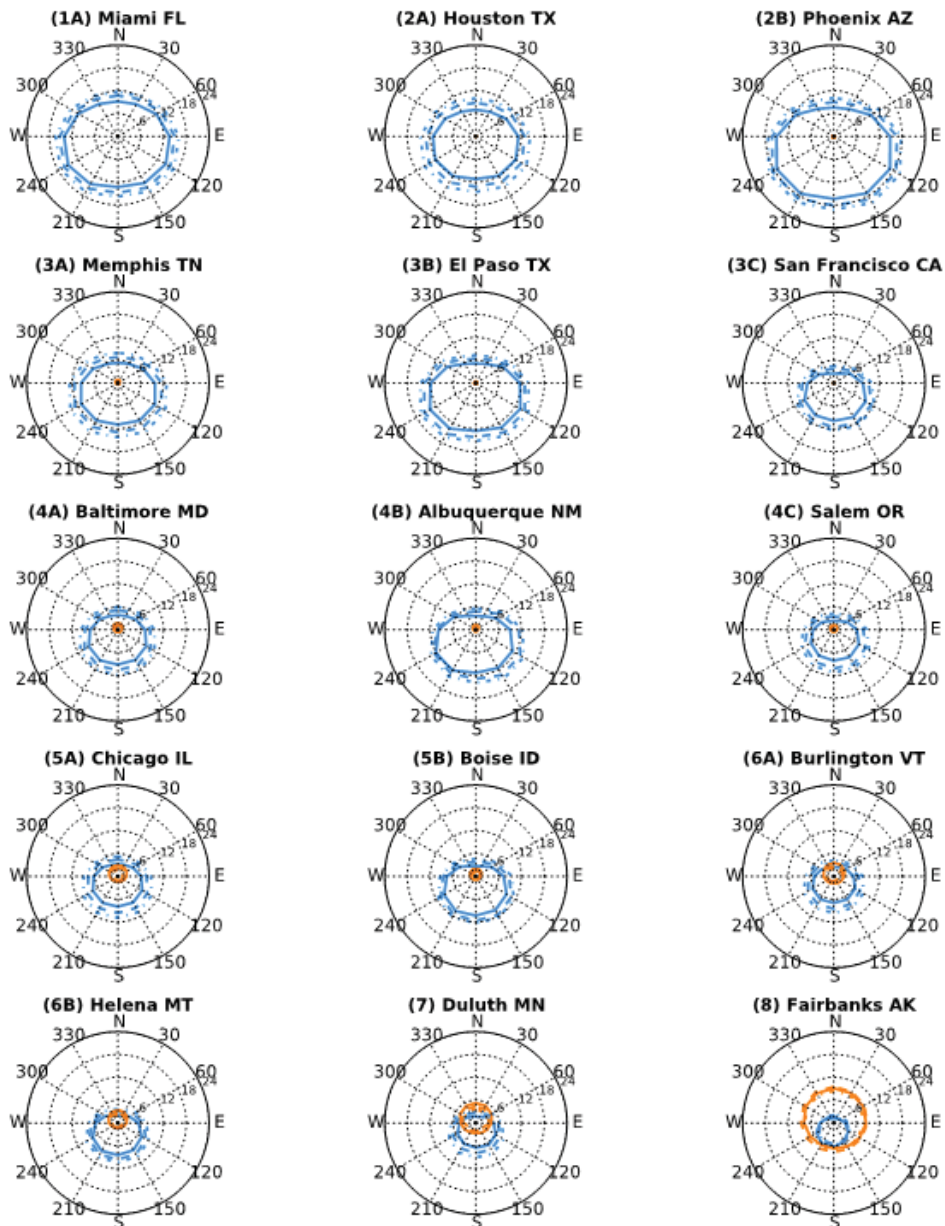
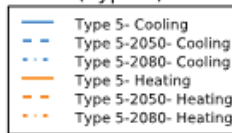


Figure 17: Comparison of heating and cooling energy use for Type 5 exterior wall (current climate data, year 2050 and year 2080).

**Effect of Orientation on Total Energy Use (GJ) Heating- Cooling- Lighting- Fans**  
 (Type 7 20% window to wall ratio and Type 5 glazed facade)

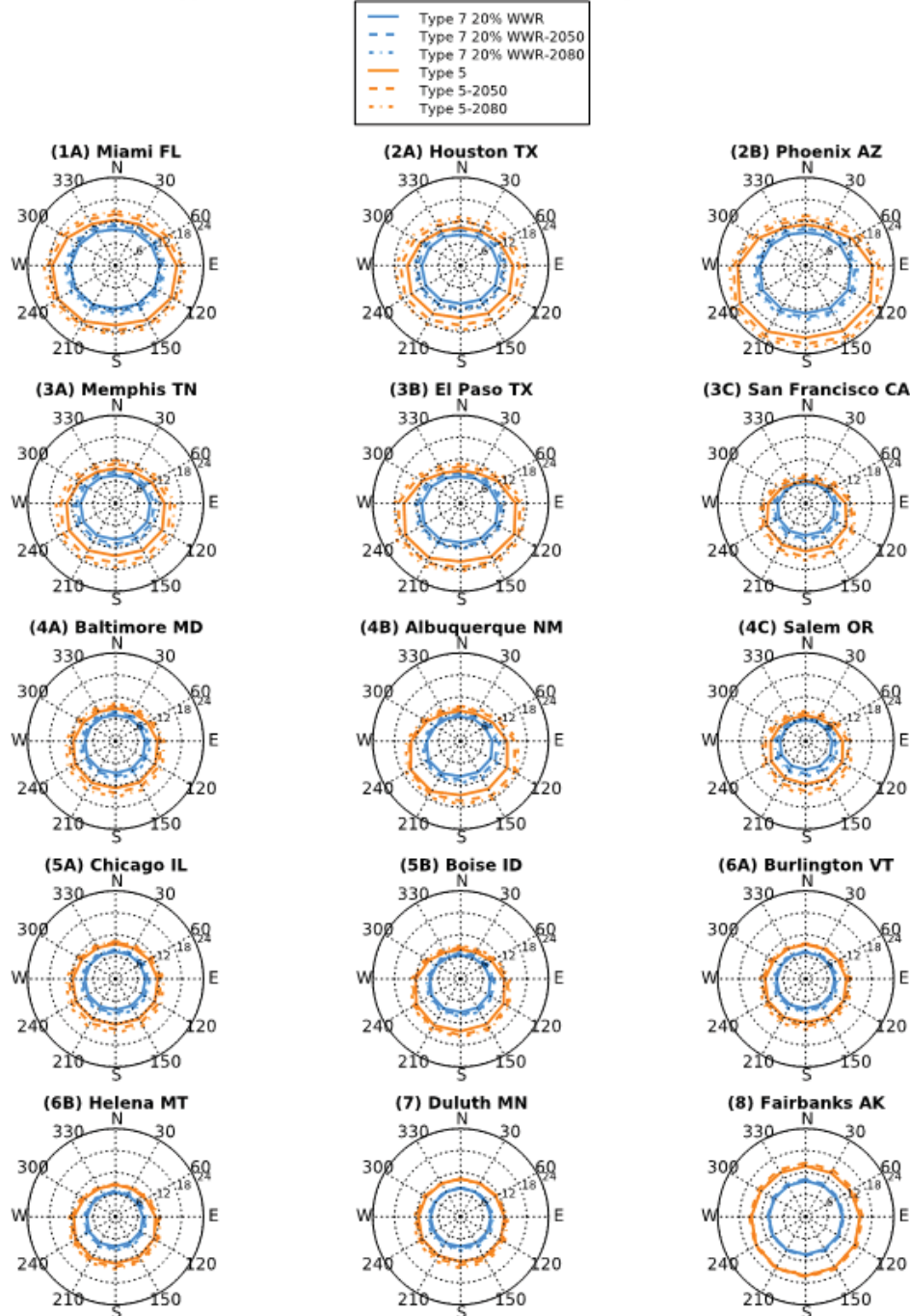


Figure 18: Comparison of total energy use for Type 7 (20% WTW) and Type 5 exterior walls (current climate data, year 2050 and year 2080).

The north facing facades performed the best for most of the climate zones due to lower cooling loads. All facade 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 study for the opaque assembly, and Type 5 had the lowest conductance for a glazed facade. Type 7 with 20 percent window to wall ratio had lower total energy use than Type 7 with 40 percent window to wall ratio (Figure 15). Heating and cooling loads 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 zones 7 and 8. Cooling loads increase by a greater amount than the decrease in heating loads, therefore net energy use is increased with climate change (Figure 16). Similar results are seen in Figure 17 for the curtain wall. 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 (Figure 18).

#### 4.0 CONCLUSION

Exterior walls significantly influence energy consumption and occupants' comfort for any building. High-performing facades need to block 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.

This research article discussed comparative study of seven different exterior wall types, where thermal performance, heat transfer and energy consumption were investigated, as well as their performance in different climate zones. Moreover, the impacts of climate change on energy consumption was investigated, where impacts of future predicted weather patterns for years 2050 and 2080 were studied. The research was conducted by initially modeling heat transfer in seven different exterior wall types, including conventional and thermally improved assemblies. Conventional systems included brick cavity wall with metal framing, rainscreen facade with terracotta cladding, rainscreen facade with glass-fiber reinforced concrete cladding, and a standard curtain wall. Thermally improved systems included a

curtain wall with thermally broken framing, rainscreen facade with thermal spacers and a rainscreen facade with thermal isolators. Four different exterior environmental conditions were chosen, which would represent different climates. Thermal gradients through the exterior walls were modeled, and U-values were calculated for all seven exterior wall types. Results show that the curtain wall is the worst performing assembly, followed by a brick cavity wall. The best performing scenario is the rainscreen facade with terracotta cladding and thermal isolators, since the framing support for the insulation and cladding would exhibit lower thermal bridging compared to other analyzed opaque facades. Also, thermal bridging would be minimized by including thermal isolators, which would lower the effective U-value by 20 percent compared to conventional rainscreen facade.

Following the heat transfer analysis, energy modeling was conducted to analyze the effects of different exterior wall types on energy consumption of a commercial office space in various climate zones. The effects of orientation, as well as different window to wall ratio (20 and 40 percent) were investigated. A single office zone was simulated, enclosed with the analyzed exterior wall types, 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 facade types.

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