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CHAPTER 1

CLIMATE-BASED DESIGN APPROACH FOR FACADES

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Building facades perform two functions: first, they are the barriers that separate a building's interior from the external environment; and second, more than any other component, they create the image of the building. *High-performance sustainable facades* can be defined as exterior enclosures that use the least possible amount of energy to maintain a comfortable interior environment, which promotes the health and productivity of the building's occupants. This means that sustainable facades are not simply barriers between interior and exterior; rather, they are building systems that create comfortable spaces by actively responding to the building's external environment, and significantly reduce buildings' energy consumption.

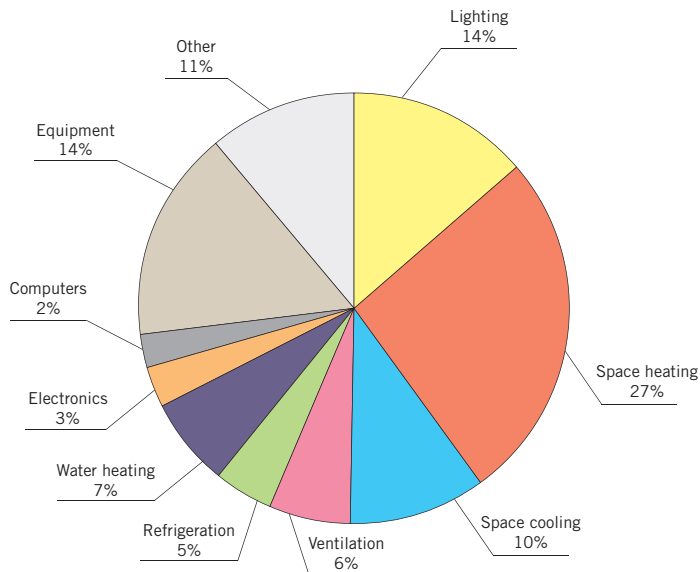


Figure 1-1 Energy use breakdown for commercial buildings (Adapted from DOE, 2012).

Average energy use for commercial buildings is shown in Figure 1-1. Heating, cooling, lighting, and ventilating interior spaces account for more than half of the energy use. The performance of the building facade can significantly affect the energy consumed by these building systems.

Designers of sustainable facades should use the specific characteristics of a building's location and climate, as well as its program requirements and site constraints, to create high-performance building envelopes that reduce the building's energy needs. Climate-specific guidelines must be considered during the design process. Strategies that work best in hot and arid climates are different from those that work in temperate or hot and humid regions.

In this chapter, we look at the different ways of classifying climates, and the characteristics of each climate zone. We also discuss some of the factors that must be considered when designing high-performance sustainable facades, based on climatic environmental characteristics.

CLIMATE CLASSIFICATIONS AND TYPES

Climate encompasses the sum of temperature, humidity, atmospheric pressure, wind, rainfall, atmospheric particles, and other meteorological characteristics over extended periods of time. Climate is affected, in varying degrees, by latitude, terrain, and altitude, as well as by nearby mountain ranges or bodies of water. In the United States, for example, the coastal regions of the Pacific Northwest are at the same latitudes as the northern Great Plains. However, due to the tempering effects of ocean currents, its coastal winters are mild compared to the harsh winters on the northern plains. The effects of the Gulf Stream, an ocean current in the northern hemisphere, are responsible for moderating the climate of western Europe. Therefore, countries such as the United Kingdom and France have relatively warm winters, although they are positioned along the same latitude as Canada.

The Koppen Climate Classification System was one of the first methods to categorize different climates. It consists of five major climate groups, each of which is further divided into one or more subgroups. The five primary groups are labeled by the letters A through E, and the subgroups by two- and three-letter codes to designate relative temperature, average precipitation, and (where relevant) native vegetation. The entire world can be classified using this system, as shown in Figure 1-2. Table 1-1 summarizes the basic characteristics of all Koppen climate groups and subgroups, and indicates representative locations.

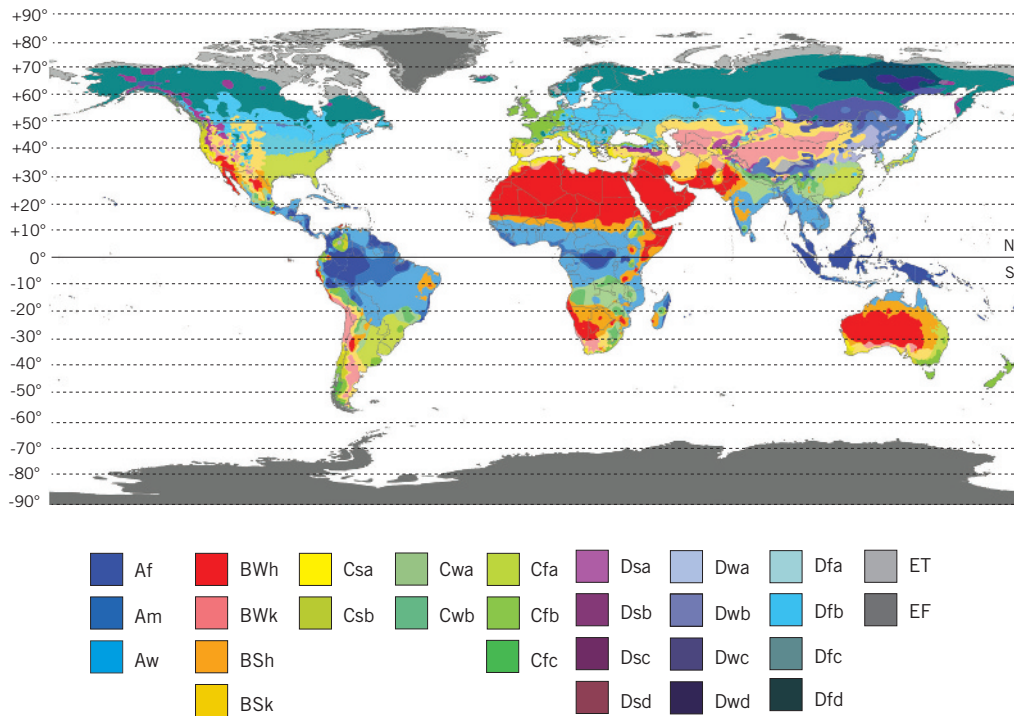


Figure 1-2 Koppen Climate Classification System (Adapted from Peel et al., 2007).

Table 1-1 Koppen Climate Classification System.

Group	Subgroups	Characteristics	Regions
A: Tropical climate Nonarid climate throughout the entire year Mean temperature of 64°F (18°C) Warm to hot, and moist, during the entire year Af: Tropical rainforest Am: Tropical monsoon Aw: Tropical wet and dry or savannah climate	Af: Tropical rainforest	No dry season, average annual rainfall at least 2.4 in. (60 mm)	Typically within 5°–10° latitude from the equator
	Am: Tropical monsoon	Short wet season and long dry season, annual precipitation less than 2.4 in. (60 mm)	Most common in southern Asia and West Africa
	Aw: Tropical wet and dry or savannah climate	Distinct dry season, annual rainfall less than 2.4 in. (60 mm)	Most common in central Africa
B: Dry climate (arid and semi-arid) Severe lack of precipitation Annual evaporation exceeds annual precipitation BS: Steppe climate BW: Desert climate	BSh: Hot steppe climate	Subtropical desert with average temperature greater than 64°F (18°C) Hot semi-arid climate with extremely hot summers and mild to warm winters	Low latitudes (0°–10°) of central Africa, north and east parts of Australia
	BSk: Cold semi-arid climate	Cool dry climate	Temperate zones and continental interiors in middle latitudes (10°–30°), away from large bodies of water
	BWh: Hot desert climate	Precipitation too low to sustain much vegetation; precipitation less than 10 in. (250 mm) per year Very high diurnal shifts in temperature	Central and northern Africa, parts of southwestern United States, central Australia
	BWk: Cold desert climate	Found in temperate zones, typically in the rain shadow of high mountains; hot summers and very cold and dry winters	Close to high mountain ranges, typically at high altitudes, such as southern parts of South America

Group	Subgroups	Characteristics	Regions
C: Temperate climate Cw: Temperate climate with dry winters Cs: Temperate climate with dry summers Cf: Temperate climate with significant precipitation	Csa/Csb: Dry summer subtropical climates	Warmest month average temperature above 72°F (22°C), with at least four months averaging above 50°F (10°C)	Western sides of continents between latitudes of 30° and 45° (such as southern California coastal regions in North America, Mediterranean regions)
	Cfa/Cwa: Humid subtropical climates	Humid summers, precipitation present during all seasons	Interiors or east coasts of continents, mainly between 30° and 45° latitudes (such as Florida in the United States)
	Cfb: Marine temperate climate	Changeable weather, cool summers and mild winters	Western sides of continents between 45° and 55° latitudes (such as the Pacific Northwest of North America)
	Cwb: Temperate climate with dry winters	Noticeably dry winters and rainy summers	Typically associated with highlands in the tropics
	Cfc: Maritime subarctic climate	Cold winters and very mild summers	Narrow coastal strips (such as southern Alaska coastal regions of North America)
D: Continental climate Dw: Continental climate with dry winters Ds: Continental climate with dry summer Df: Continental climate with significant precipitation during all seasons	Dfa/Dwa/Dsa: Hot summer continental climates	Warmest month temperatures greater than 71.6°F (22°C)	Interiors of continents and on eastern coasts, such as northeastern part of South America
	Dfb/Dwb/Dsb: Warm summer continental climates	Warmest month temperatures averaging below 71.6°F (22°C), but with at least four months averaging above 50°F (10°C)	Immediately north of hot summer continental climates (northern part of North America, northern Europe, parts of South America)
E: Polar climate ET: Tundra climate EF: Ice cap climate	ET: Tundra climate	Warmest temperatures below 50°F (10°C) during all seasons	Polar regions and high elevations
	EF: Ice cap climate	Temperature almost never exceeds 32°F (0°C); covered by permanent layer of ice	Antarctica and Greenland

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Although the Koppen Classification System can be used to classify climate and environmental conditions for any location in the world, its complexity makes it difficult for designers to use when relating local climate to energy-reduction design strategies. The International Energy Conservation Code (IECC), in conjunction with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), has developed a climate classification system for the United States that is easier for designers to use. The IECC climate map provides a simplified, consistent approach based on widely accepted descriptions of world climates, as well as the number of cooling and heating degree days for each location. This classification system divides the United States into eight temperature-based climate zones (labeled by numbers 1 to 8), and three subzones based on humidity levels (labeled by letters A, B, and C).

The eight climate zones are:

- Zone 1: very hot
- Zone 2: hot
- Zone 3: warm
- Zone 4: mixed
- Zone 5: cool
- Zone 6: cold
- Zone 7: very cold
- Zone 8: subarctic

The three subcategories based on the location's humidity are:

- A: humid
- B: dry
- C: marine

Every location in the United States has an associated IECC climate zone and humidity subcategory, as seen in Figure 1-3. The IECC and ASHRAE standards, and the energy codes that are based on them, use this classification system.

Although the IECC climate classification system is useful for designers, and is referred to frequently throughout this book, it has some limitations. The IECC system does not recognize local microclimates. For example, the entire Chicago metropolitan region falls within climate zone 5A. However, the microclimate within a mile of Lake Michigan is different from an inland location such as O'Hare International Airport (one of the

weather stations where Chicago weather data are collected). Another example is the city of Los Angeles, which is located in climate zone 3B. However, the microclimate near the Pacific Ocean shore is significantly different from the microclimate of the San Fernando Valley, which is 600 or more feet above sea level and entirely surrounded by hills. For buildings in urban areas, designers should research local microclimate conditions, which may vary from the IECC climate zone description.

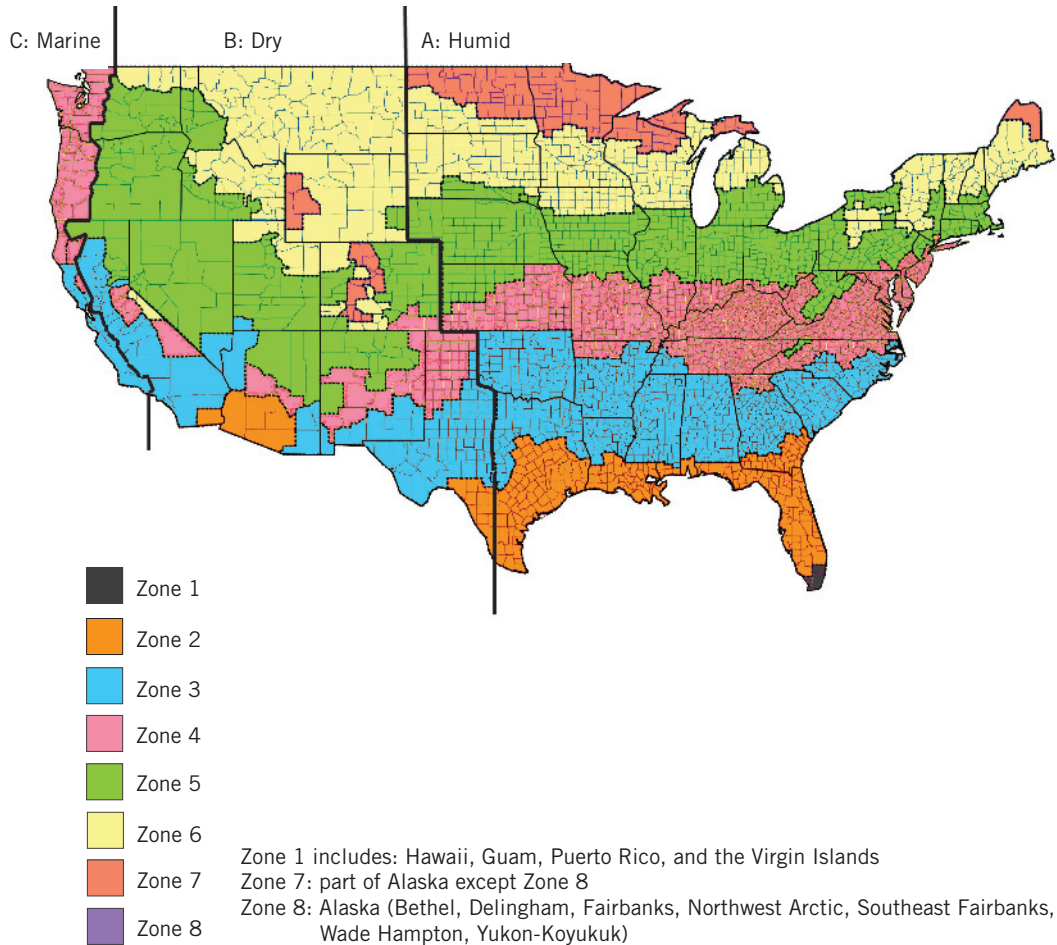


Figure 1-3 Climate classification for the United States.

Energy performance modeling for buildings is typically based on historical weather data, which are collected over a specific time period, such as thirty years. Temperature, relative humidity, wind speeds, precipitation, and solar radiation data are collected and statistically analyzed to identify typical weather patterns that can be used to predict heating and cooling loads when used in performance modeling. In addition to historic weather data, predictive climate models are currently being developed, which can be used to predict future conditions for a specific location (Lawrence and Chase, 2010). Predictive climate models account for climate changes, impacts of existing and projected greenhouse gas emissions, and slight increases in temperatures. Predicted weather data can be used instead of historical data for modeling a building's energy consumption, thus taking into account these future changes in climate and their effects on energy consumption.

CLIMATE-SPECIFIC DESIGN GUIDELINES FOR FACADES

Environmental Considerations and Design Criteria

For most buildings, the facade affects the building's energy budget and the comfort of its occupants more than any other system. To provide occupants with a comfortable and safe environment, a facade must fulfill many functions, such as providing views to the outside, resisting wind loads, supporting its own dead-load weight, allowing daylight to interior spaces, blocking unwanted solar heat gain, protecting occupants from outside noise and temperature extremes, and resisting air and water penetration (Aksamija, 2009).

Designers need to consider the external environment, building orientation, space dimensions, and occupants' comfort expectations. Table 1-2 shows how air temperature, solar radiation, humidity, wind velocity, noise, ground reflectivity, and dimension and location of external obstacles (e.g., buildings, topography, or plantings) can affect thermal, visual, and acoustic comfort. The relative importance of these criteria will affect design decisions, such as the properties of opaque materials (thickness, density, conduction, reflectivity) and transparent (glazing) materials (thickness, number of layers, heat transmission, light absorption, reflection).

Table 1-2 Environmental conditions and properties of facade elements that affect thermal, visual, and acoustic comfort.

Environmental conditions	Thermal comfort	Visual comfort	Acoustic comfort
Outdoor design criteria	Sun and wind obstructions	View and daylight obstructions	Noise obstructions
	Building dimensions	Building dimensions	Building dimensions
	Air temperature range	Latitude and location	Exterior noise level
	Relative humidity range	Time of day	Exterior noise source
	Wind velocity	External horizontal illuminance	
	Solar radiation	Ground reflectivity	

Environmental conditions	Thermal comfort	Visual comfort	Acoustic comfort
Indoor design criteria	Space dimensions User's activity level User's clothing insulation	Space dimensions Colors of surfaces Working plane location	Space dimensions Absorption coefficients of interior surfaces
Indoor comfort criteria	Air temperature Relative humidity Air velocity Mean radiant temperature	Illuminance level and distribution Glare index	Acceptable interior noise levels
Opaque facades	Material properties of cladding Amount of insulation Effective heat resistance properties (R-value)	Window-to-wall ratio	Material selection and properties
Glazing	Orientation Number of glass layers Layer thicknesses Heat transfer coefficient (U-value) Visual transmittance Solar heat gain coefficient (SHGC)	Orientation Window properties, size, location, and shape Glass thickness and color Visual transmittance Reflectance	Number of layers Layer thicknesses Layer density
Frames and supporting structure for glazed facades	Thermal properties of the frames		Material types

Design Strategies and Climate

Different design strategies are required for different climatic zones. Basic methods for designing high-performance building facades include:

- Orienting and developing geometry and massing of the building to respond to solar position
- Providing solar shading to control cooling loads and improve thermal comfort
- Using natural ventilation to reduce cooling loads and enhance air quality
- Minimizing energy used for artificial lighting and mechanical cooling and heating by optimizing exterior wall insulation and the use of daylighting

In choosing design strategies, we need to consider the conditions of the climate zone to minimize their impacts and reduce energy consumption. In Table 1-3, we see how design strategies are affected by climate types (Aksamija, 2010). Heating-dominated climates (zones 5 through 8) benefit from collection of solar radiation, passive heating, heat storage, improved insulation to reduce heating demand, and the use of daylighting to reduce lighting demand. In cooling-dominated climates (zones 1 through 3), protection from sun and direct solar radiation becomes more important. In mixed climates (zone 4), combined strategies that balance solar exposure and access to daylight should be implemented. In some cases, localized climate conditions, or microclimates, may be different from the generalized conditions of that climate zone. Designers need to respond to the specific characteristics of a building site.

Table 1-3 Facade design strategies for different climate zones.

Climate type	Design strategies for sustainable facades
Heating-dominated climates Zones 5, 6, 7, 8	<p><i>Solar collection and passive heating:</i> collection of solar heat through the building envelope</p> <p><i>Heat storage:</i> storage of heat in the mass of the walls</p> <p><i>Heat conservation:</i> preservation of heat within the building through improved insulation</p> <p><i>Daylight:</i> use of natural light sources and increased glazed areas of the facade, use of high-performance glass, and use of light shelves to redirect light into interior spaces</p>
Cooling-dominated climates Zones 1, 2, 3	<p><i>Solar control:</i> protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices</p> <p><i>Reduction of external heat gains:</i> protection from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices)</p> <p><i>Cooling:</i> use of natural ventilation where environmental characteristics and building function permit</p> <p><i>Daylight:</i> use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves</p>
Mixed climates Zone 4	<p><i>Solar control:</i> protection of facade from direct solar radiation (shading) during warm seasons</p> <p><i>Solar collection and passive heating:</i> solar collection during cold seasons</p> <p><i>Daylight:</i> use of natural light sources and increased glazed areas of the facade with shading devices</p>

Many energy codes reference ASHRAE 90.1, *Energy Standard for Buildings except Low-Rise Residential Buildings*, which provides recommendations for building envelopes (ASHRAE, 2007). ASHRAE 90.1 is periodically updated based on increasing expectations of building performance. These recommendations are based on building location and climate zone, using the IECC climate classification system of eight

zones and three subzones (Figure 1-3). If ASHRAE 90.1 has been adopted as part of the state energy or building code, then the ASHRAE recommendations become the required metrics of building performance. ASHRAE's requirements are categorized based on the basic building function and occupancy, including: (1) nonresidential conditioned space (daytime use, higher internal loads), (2) residential conditioned space (24-hour occupancy, building envelope-dominated due to lower internal loads), and (3) nonresidential and residential semiheated space.

ASHRAE identifies four types of exterior walls:

- Mass walls, generally constructed of masonry or concrete materials
- Metal building walls, consisting of metal members spanning between steel structural members (not including spandrel glass or metal panels in curtain walls)
- Steel-framed walls, with cavities whose exterior surfaces are separated by steel framing members (including typical steel stud walls and curtain walls)
- Wood-framed and other walls

ASHRAE requirements are prescribed in three ways for all climate zones:

- Minimum allowable thermal resistance (R-value) for the different exterior walls
- Maximum allowable heat transfer coefficients (U-value) for the facade assembly (including the thermal bridging effects of framing members)
- Maximum allowable solar heat gain coefficient (SHGC) for the glazed portions of a facade assembly

Thermal resistance (R-value) is an assembly's or a material's resistance to heat transfer, and is expressed in $\text{h}\cdot\text{ft}^2\cdot^\circ\text{F}/\text{Btu}$ or $\text{m}^2\cdot^\circ\text{K}/\text{W}$. Individual materials have specific R-values, usually listed as R-value per inch (see Chapter 2). The overall R-value of a facade assembly is calculated by adding the R-values of individual material layers. R-values are typically used to define the thermal performance of opaque areas of facades built up from multiple layers of materials.

Heat transfer coefficient (U-value) is the inverse of R-value. It measures the heat transmission through a material or a facade assembly. U-values are expressed in $\text{Btu}/\text{hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ or $\text{W}/\text{m}^2\cdot^\circ\text{K}$, and are usually used to define thermal performance of glazed parts of facade assemblies.

The *solar heat gain coefficient (SHGC)* quantifies the amount of solar radiation admitted into a building's interior through glass, and is expressed as a number between 0 and 1, with 0 meaning that no radiation is admitted and 1 meaning that no radiation is blocked.

Figure 1-4 shows ASHRAE recommendations for minimum R-values for nonresidential conditioned spaces, for each climate zone and four types of wall construction. R-values for mass walls are highly dependent on the climate, and increase from warmer to colder climates. Recommended minimum R-values for metal building walls are virtually identical for all climate types. The exception is for very cold and arctic climates, which demand significantly higher insulation. Recommended minimum R-values for steel-framed walls

are the same for mixed and colder climates. Recommended minimum R-values for wood-framed walls vary depending on climate zone. In general, steel-framed and wood-framed walls require higher levels of insulation than the other wall types.

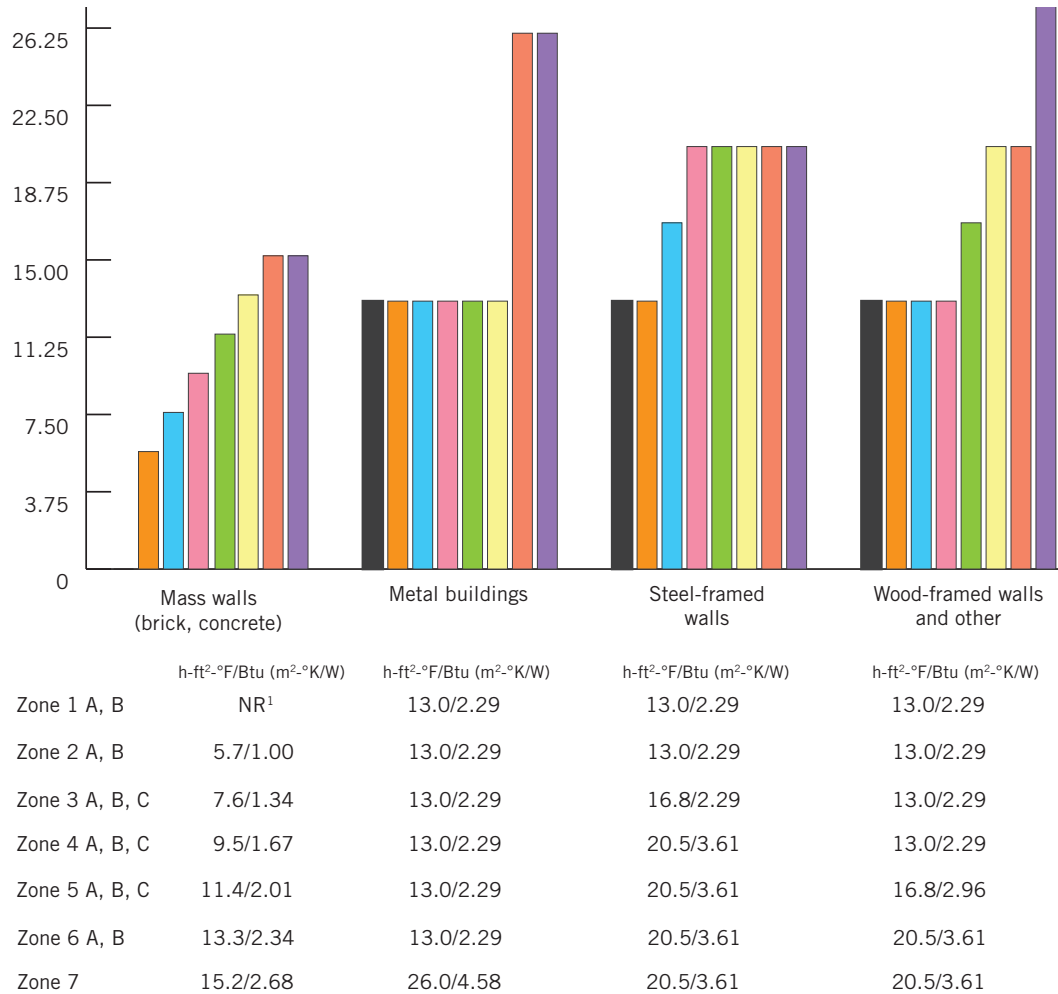


Figure 1-4 Minimum R-value recommended by ASHRAE 90.1-2007 based on wall construction type for all climate zones.

Figure 1-5 identifies maximum U-values recommended by ASHRAE for different facade assemblies (for nonresidential conditioned buildings); like Figure 1-4, it is based on four wall types and all climate zones. The recommendations are for entire wall assemblies, including glazed and opaque areas. All wall types in

colder climates require lower overall U-values. Requirements for masonry, steel-framed, and wood-framed facades tend to decrease as climates get colder. In contrast, required U-values for metal building walls fall into two clusters: very cold climates and all the others. Steel-framed walls require lower U-values than mass walls for all climate types, due to thermal bridging effects. Wood-framed walls require the lowest U-values for most climate types.

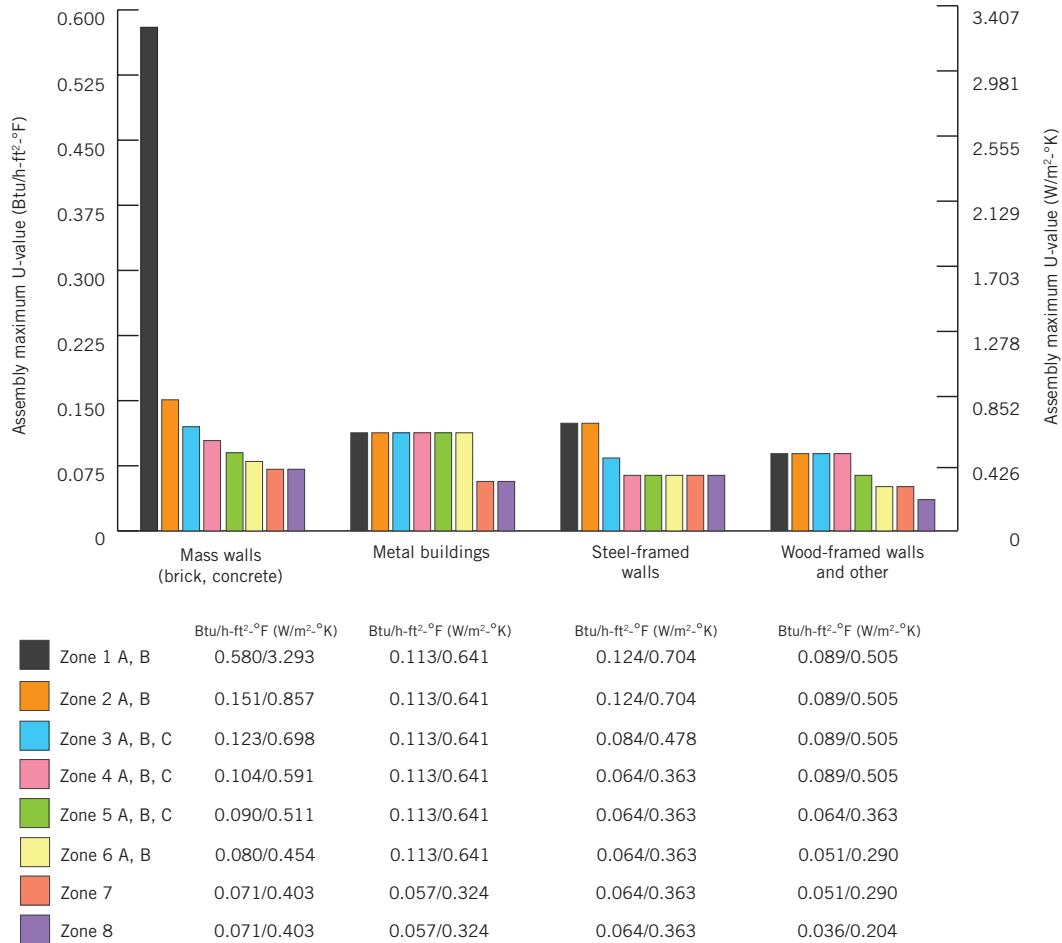


Figure 1-5 Maximum assembly U-values for exterior walls recommended by ASHRAE 90.1-2007 based on wall construction type for all climate zones.

Figure 1-6 shows ASHRAE recommendations for maximum SHGC for glazed areas of the facades. For warmer climates, lower SHGC, not exceeding 25%, is desirable, as excess solar radiation should be blocked. For colder climates, higher SHGCs can support passive solar heating, but should not exceed 45%.

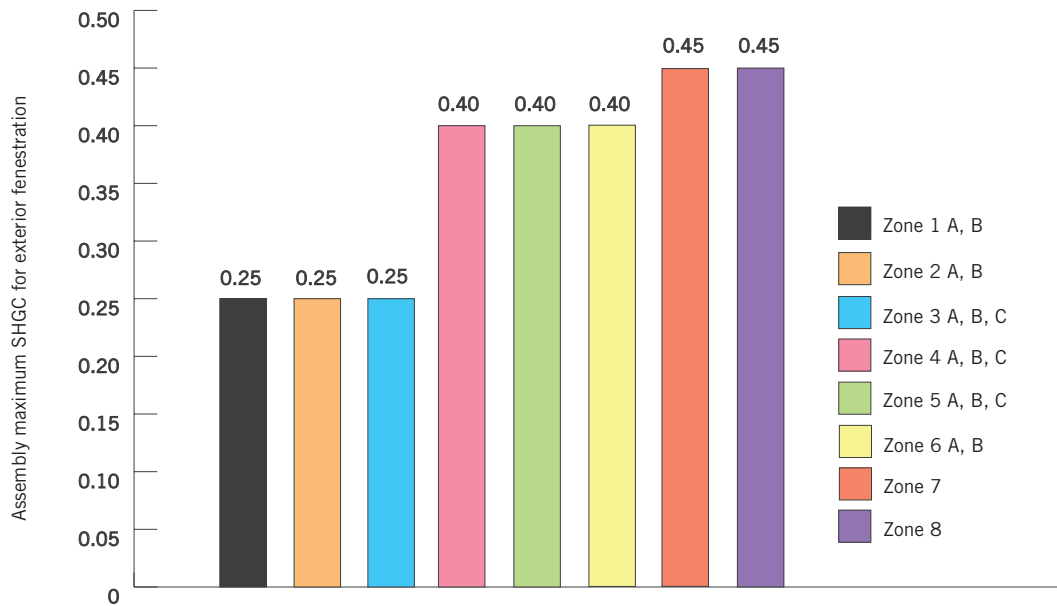


Figure 1-6 Maximum SHGCs for fenestration recommended by ASHRAE 90.1-2007 for all facade types and climate zones.

CHAPTER SUMMARY

This chapter discussed climate classification systems; climate-based design strategies for sustainable, high-performance facades; and energy code requirements for building envelopes. Standards prescribed by the energy codes, such as ASHRAE 90.1, only establish minimum requirements for improving energy efficiency of buildings. Sustainable facades, which use high-performance materials and glazing, and daylight harvesting strategies, shading devices, and control systems to monitor and adjust their performance, typically aim for better performance than those the energy codes prescribe. They also improve overall building envelope operation, thermal behavior, and occupants' thermal and visual comfort.

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