energy design resources

design brief

DESIGN FOR YOUR CLIMATE

By understanding climatic conditions that are specific to a project's location, design teams are able to develop climate-responsive building designs. The result is a building that utilizes less energy and provides a high quality and comfortable environment for the occupants.

Summary

Sun, land, and water interact in complicated ways throughout each day and throughout the year, and the result is what we commonly refer to as weather. These interactions produce daily as well as seasonal temperature, humidity, and wind patterns that can vary substantially between locations in close geographic proximity. California, in particular, has many diverse climate characteristics that occur across the state. Yet, many architects and engineers develop their design strategies for new buildings without full consideration of the impact of regional and site-specific climate conditions.

Climate-responsive design is a strategy that seeks to take advantage of the positive climate attributes of a particular location, while minimizing the effects of attributes that may impair comfort or increase energy requirements. Designers who strive to develop comfortable, low-energy buildings can enjoy the benefits of climate-responsive design by considering five basic points in the course of designing new commercial buildings.

1. Understand climate zones and microclimates
2. Understand the basic physiology of human thermal comfort
3. Control the sun to reduce loads and enhance visual comfort
4. Use thermal mass to improve comfort and efficiency
5. Select space-conditioning strategies that are climate responsive

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Introduction

In California's commercial new construction market, emphasis is placed on minimizing the time and effort required for new buildings to be built and occupied. As a result, many owners and developers favor simple building shapes along with construction methods and materials that facilitate an "assembly line" approach to building. Unfortunately, the efficiency of this approach is usually achieved at the expense of other important building characteristics—namely, comfort and energy efficiency. Stated another way, owners and developers are producing buildings that are designed independent of climatic conditions, instead of designing for their particular climate.

According to the California Energy Commission (CEC), the state is officially divided into sixteen climate zones. The climatic characteristics of a building's particular location—temperature, humidity, wind, and sun—can either help or hinder the designer's efforts to provide comfort for building occupants. A building with a climate-responsive design includes design features and building systems that allow it to take advantage of all that its climate has to offer—be it a cool, coastal breeze or a hot, dry summer. A building that has been designed in the context of its prevailing climatic conditions will usually have lower operating costs yet achieve higher occupant satisfaction than buildings where such considerations have not been made.

"What is Climate-Responsive Design?"

If the old adage, "If life gives you lemons, make lemonade," were modified to express the underlying philosophy of climate-responsive design it would read as follows.

"If your climate gives you scorching daytime temperatures, low relative humidity, and wide daily temperature swings, thoughtfully design your building with evaporative cooling, nighttime ventilation and high thermal mass."

What is Climate-Responsive Design?

Climate-responsive design seeks to create inherently comfortable buildings that require minimum energy input. Such buildings take advantage of regional climatic characteristics that can help with comfort and efficiency, while minimizing the impact of any characteristics that may impair performance. Climate-responsive design may be thought of as the ultimate expression of building efficiency—achieving what we desire (a comfortable building) with the lowest possible energy input.

To gain a better understanding of this concept, it is worthwhile to understand some of the events that influenced current architectural and urban design practices. In the era before refrigerated air conditioning was available, climate-responsiveness was an essential building feature because there was no other reasonable way to maintain acceptable temperatures within the building. Architects and engineers employed imaginative schemes to bring daylight and ventilation into all parts of a building in order to provide a comfortable working environment. In those times, it was essential to create inherently comfortable buildings (**Figure 1**).

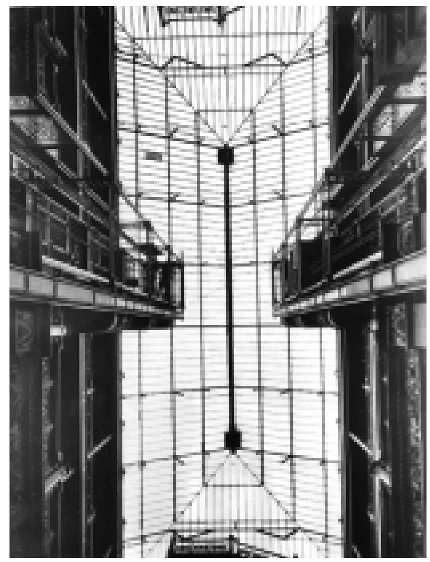
That all changed in 1906, when a young employee at Buffalo Forge Company by the name of Willis Carrier obtained a patent for his "Apparatus for Treating Air" that he designed several years before to regulate environmental conditions at a Brooklyn printing plant. This printing plant was encountering problems because changes in temperature and humidity caused the dimensions of their printing paper to change, resulting in misalignment of printed text. It took nearly 20 more years for the idea of keeping people cool and dry (and not just rolls of paper) to catch on, when the J.L. Hudson Department Store in Detroit, Michigan installed three centrifugal chillers and shoppers began to flock to the "air-conditioned" store. Though the Great Depression and World War II slowed the growth of air conditioning for non-industrial purposes, the inward and outward appearance of buildings was irrevocably altered in the post-war era as the building community wholeheartedly embraced this new technology.

With the advent of air conditioning, it was no longer essential to provide natural ventilation and daylight in building designs – the ability to extract heat from all parts of a building allowed architects and engineers to use as much glass and electrical lighting as they pleased. In addition, building shapes that were once favored because they provided access to natural light and ventilation were dropped in favor of shapes that maximized

Figure 1: Climatically responsive building

Designed by Architect George H. Wyman in 1893 about 30 years before the advent of air conditioning for human comfort, the Bradbury Building in downtown Los Angeles provides excellent natural lighting and ventilation to occupants utilizing a large enclosed atrium.

Taken on the floor of the atrium, the photo is looking straight up at the glazed roof.



Source: Regional History Center, University of Southern California (1961).

usable square footage. As a result, many new buildings resembled immense glass boxes, utterly devoid of exterior fins, overhangs, or form articulation to provide shade from the sun. At that time, the penalty for energy-unconscious design was minimal because energy prices were low, and represented an insignificant portion of a building's operating budget. The Arab oil embargo in the early 1970's put conservation on the nation's front burner, leading many designers to rediscover the means and methods of creating a building that exists in concert with, rather than in opposition to, its environment.

Five Basic Concepts for Climate-Responsive Design in California

Though there are a great number of nuances and details associated with designing a truly climate-responsive building, architects and engineers involved in commercial new construction may reap some of its benefits by considering the following five basic concepts:

- Understand climate zones and microclimates
- Understand the basic physiology of human thermal comfort
- Control the sun to reduce loads and enhance visual comfort
- Use thermal mass to improve comfort and efficiency
- Select space-conditioning strategies that are climate responsive

It must be pointed out that most climate-responsive design strategies rely on close coordination and cooperation between a project's various design team disciplines. For example, a building that features climate-responsive architectural features such as high thermal mass and abundant daylighting apertures will not enjoy all the benefits these features afford unless the electrical and mechanical engineers provide building systems that work in conjunction with them.

Understand Climate Zones and Microclimates

What we think of as climate and weather patterns results from interaction between the sun, land, and water. As the Earth rotates about its axis once per day and orbits the sun once per year, landmasses and oceans absorb and radiate the sun's energy differently according to their different heat absorption characteristics (**Figure 2**), thus creating temperature and pressure differentials that produce wind. Wind, in turn, cools or warms the land and water lying in its path, and carries along moisture that is ultimately transformed under certain conditions into rain and snow. Mountains and valleys redirect the wind in a variety of directions, producing an array of regional climates and microclimates. Just as solar gain varies throughout the day, wind flow direction can change throughout the day as well—especially where land meets water (**Figure 3,** page 6).

Finally, the sun's intensity varies according to altitude. Many mountainous regions are known for intense sun because there is less airborne matter at high elevations—atmospheric air, clouds, moisture, and pollution—that filters, reflects, and diffuses solar energy. Locations at lower elevations usually receive less intense and more diffused sun because of the filtering effect of the atmosphere.

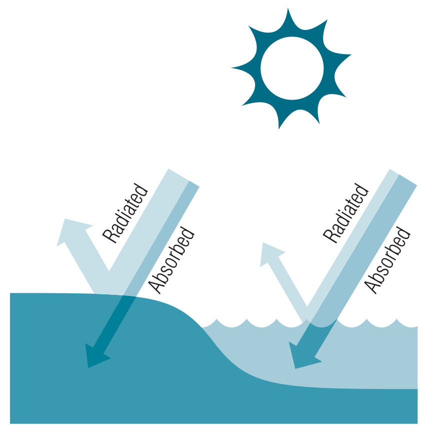
The result of these interactions is a wide variety of climatic conditions that are experienced around the world. Cities located close to the ocean have weather patterns that are greatly influenced by the nearby presence of an immense volume of water, and the result is typically mild temperatures with night and morning low clouds. On the other hand, desert locales are subject to the vast amount of solar energy absorbed by the land, and tend to be hot and windy for much of the year.

As mentioned, the CEC divides California into 16 unique climate zones (**Figure 4**, page 7), based upon a combination of temperature and humidity patterns as well as geographic considerations. Yet despite this seemingly detailed parceling of on of the largest states in the union, there are often pockets of

Figure 2: Sun, land and water = weather

Land and water absorb and reflect solar energy differently due to their differing specific heat and reflectance characteristics. It takes far more energy to raise the temperature of a pound of water by one degree than a pound of earth.

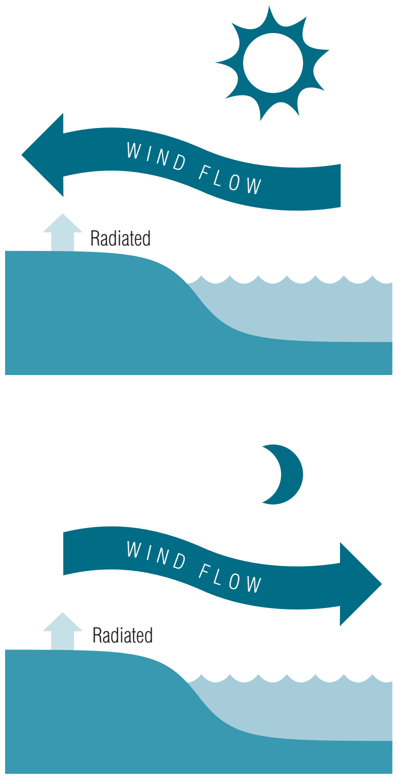
Landmasses typically reflect more of the sun's energy while bodies of water tend to absorb more. This is illustrated by the fact that 12 to 30 percent reflectance is typical for meadows and fields, compared to 3 to 10 percent reflectance for water surfaces. The resulting temperature differentials ultimately lead to wind, clouds, and rain.



Source: CTG Energetics

Figure 3: Wind effect

Wind flow direction changes between night and day where land meets water: Land heats up during the day more quickly than water, causing warmer and more buoyant air to rise. Cooler air over the water begins to push inland creating a breeze. The rising warm air over the land cools and moves over the ocean to replace the cold air that moved inland.



Source: CTG Energetics

significant climatic variation within each zone. Understanding specific climates and "microclimates"—and how they affect energy use and comfort in buildings—is the first and most important step in climate-responsive design.

For example, the San Diego region officially falls into the CEC's Climate Zone 7. Included in this single climate zone, however, are beach communities such as Del Mar (mild summer and winter), coastal valleys such as San Luis Rey (mild summer, cooler winter), and inland cities such as La Mesa (hot summer, cold winter). Despite the fact that California's Title 24 Energy Efficiency Standards specify one set of energy efficiency requirements for all commercial new construction within Climate Zone 7, it should be clear that each microclimate is diverse and requires different design solutions. An air economizer for the heating, ventilation, and air conditioning (HVAC) system, for example, may be very effective in the coastal regions but less effective in the inland regions. Night and morning low clouds in the coastal regions might also impact the location of windows and external-shading devices versus a building located further inland.

In addition, there may be site-specific conditions that further modify the climate and microclimate. To illustrate, windy conditions may be prevalent if a project is built on a hilltop rather than in a valley. The impact of wind direction and intensity may affect everything from the location of entryways to the location of the outside air intakes and plumbing vents. Other examples of site-specific factors include shading or solar reflection from adjacent buildings and urban heat island effects.[1]

To properly begin climate-responsive design endeavors, designers should keep the following points in mind.

- *Look beyond California's "official" climate zones.* Take time to gain an understanding of climate and microclimate conditions that may exist at a particular project site. Also, consider site-specific conditions due to local geography or adjacent structures that may impact the project. For any preliminary energy building simulation that will be performed, obtain two hourly weather files: the California Climate Zone file that will be used for Title 24 compliance calculations, and a weather file for the specific city in which a project will be located.[2] You may be surprised at the different results—cooling loads and annual energy use, for example—that may be achieved when using the different weather data.

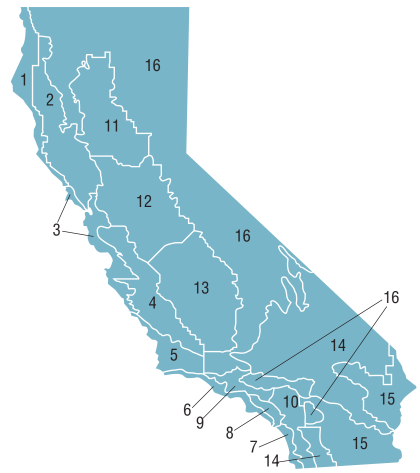
- *Tally a climate's beneficial (and detrimental) characteristics*. Early in the conceptual design phases for a project, review climate data in order to identify potentially effective energy design strategies. Evaluate solar data (intensity and solar angles throughout the year), windrose data (**Figure 5**, page 8), rainfall data, and temperature and humidity data. This is also the time to identify any climate conditions that may be detrimental to comfort or efficiency, such as high humidity, specific solar gain problems during certain times of the day, or wind patterns that may lead to drafty conditions.

- *Design for peak conditions, but optimize for average conditions*. Although HVAC systems should be sized to provide comfort during the hottest and coldest conditions that are expected for a particular location, systems should be designed and optimized to provide their most efficient performance during frequently encountered or average weather conditions. For example, many parts of Southern California experience "Santa Ana" winds—hot, dry winds that blow in from the deserts to the east—during the late summer and early fall. During Santa Ana conditions, even typically cool and breezy coastal regions may become decidedly desert-like. However, HVAC strategies that excel in desert climates such as evaporative cooling should not be installed in coastal climates to provide comfort during the Santa Ana winds, because they would be ineffective for the majority of the year.

One effective way to gain understanding of the prevailing temperature conditions for a region is to consult bioclimatic charts for a specific project location. Though they can be

Figure 4: California climate zones for residential and nonresidential occupancies

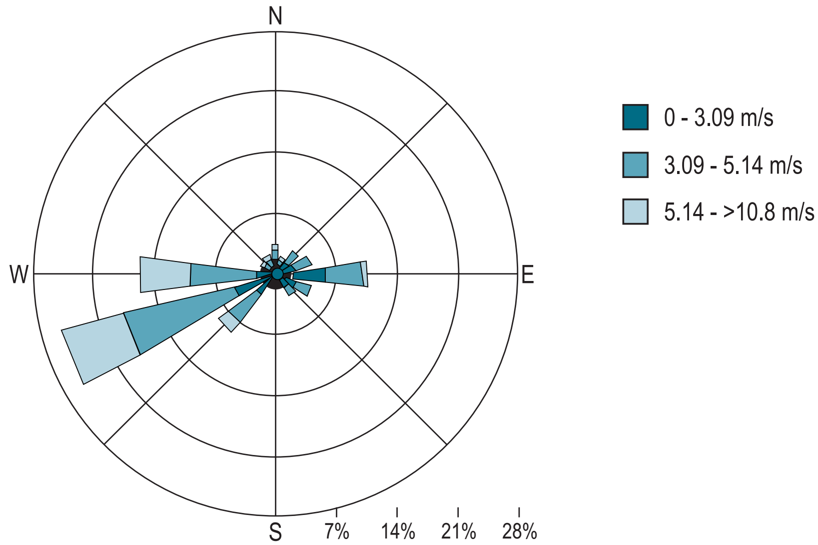
California's Title 24 Energy Efficiency Standards divide the state into 16 different climate zones.



Source: California Energy Commission

Figure 5: Windrose data

No, it's not a new variety of foliage. Windrose data is tabulated wind speed and direction data for specific locations. Designers use this data as a guide for selecting building orientation and potential cooling strategies. In the associated graph, windrose data for the Los Angeles area is shown from 1997.



Source: Breeze-Software.com

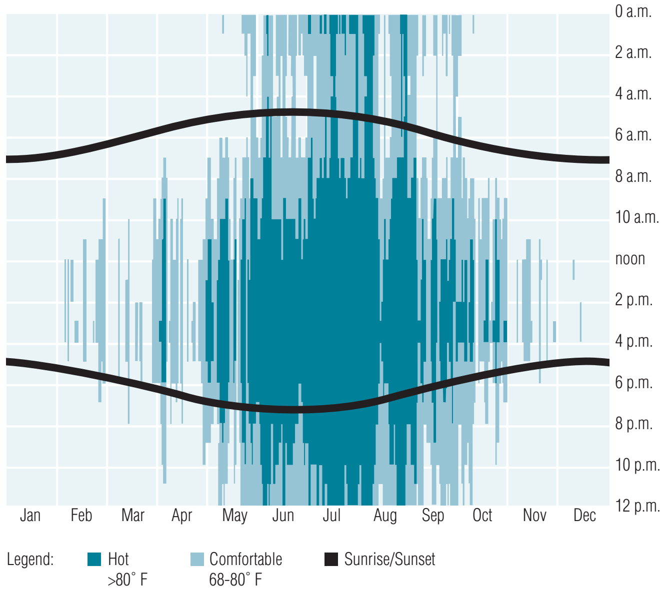
formatted in slightly different ways, such charts usually offer a graphic depiction of temperatures throughout the day and year. **Figures 6** and **7** show bioclimatic charts for two California cities: Bakersfield and San Francisco. It should be clear from the charts that the vastly different daytime temperatures have implications on climate-responsive design strategies.

Understand the Basic Physiology of Human Thermal Comfort

According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), human thermal comfort is defined as, "…that condition of mind that expresses satisfaction with the thermal environment." ASHRAE Standard 55, "Thermal Environmental Conditions for Human Comfort," specifies that thermal comfort is achieved when 80 percent of sedentary or slightly active persons find the environment thermally acceptable.

Figure 6: Bioclimatic chart for Bakersfield, California Climate Zone 13

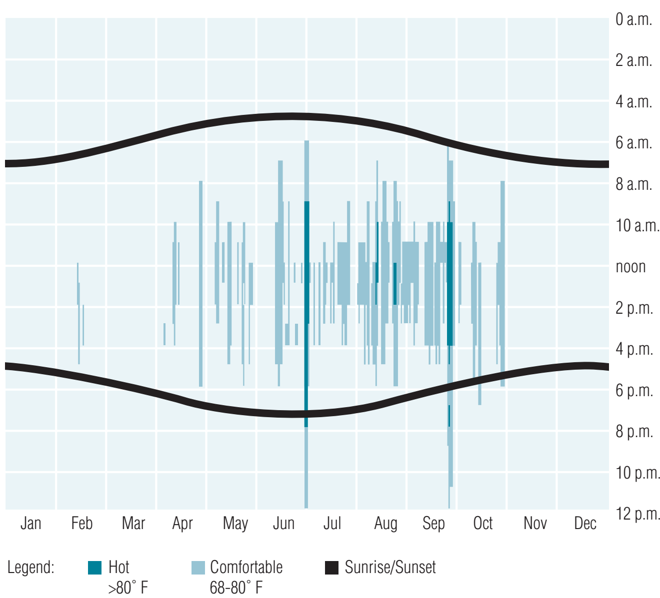
Cities in California's Central Valley typically have very hot summers and often require air conditioning long after the sun has set.



Source: CTG Energetics

Figure 7: Bioclimatic chart for San Francisco, California Climate Zone 3

This chart depicts why summer in San Francisco does not feel like a summer to most people. This region has few periods of very hot weather, and natural ventilation can provide comfort and efficiency during most of the year. The parameters of both charts were run to analyze for the cooling season only, depicting temperatures above 68°F.



Source: CTG Energetics

A Mathematical Approach to Predicting Thermal Sensation

ASHRAE has developed a thermal sensation scale that assigns a numerical representative for thermal sensations ranging from hot (+3) to neutral (0) to cold (-3) and all points in-between.[3]

Based on their research, ASHRAE has developed regression equations to predict thermal sensation for men, women, and men and women combined, in response to temperature, humidity, and duration of exposure.

For example, the following equation is to predict thermal sensation for a combination of men and women with an exposure period of 2.0 hours:[4]

$$Y = 0.140 * t + 1.65 * p - 11.339$$

Where Y = thermal sensation index (TSI)

T = dry-bulb temperature, °F

P = vapor pressure, psi[5]

For example, an 80°F drybulb temperature and 40 percent relative humidity (vapor pressure of 0.066 PSI) results in a TSI of –0.03, a neutral thermal environment.

Although such definitions suggest that comfort is primarily a qualitative topic, ASHRAE and others have conducted research seeking quantitative approaches to predicting when people are likely to experience thermal comfort (see **Sidebar**).

It stands to reason that architects and engineers must understand how humans perceive thermal comfort in order to provide it in buildings. The two most significant elements of thermal comfort —as exemplified in the equation contained in the **Sidebar**—are temperature and humidity. If temperature and humidity are regulated uniformly, then a thermal acceptability of 90 percent may be achieved, which exceeds the ASHRAE Standard 55 requirement of 80 percent.

The temperature within a space is the most conspicuous element of thermal comfort, and is the only element that occupants generally have control over in buildings via the thermostat. According to ASHRAE, an "average" person (wearing seasonally appropriate clothing and performing a primarily sedentary activity) is most comfortable when the drybulb temperature is between 69° and 81° Fahrenheit (F).

Relative Humidity (%RH) can be defined as the amount of moisture contained in the air relative to the total amount of moisture that the air could hold at fully saturated conditions. Relative humidity is a function of temperature; as air warms, it is capable of holding more moisture. Our body rejects heat through perspiration, and this critical system works most effectively when relative humidity levels are lower. Perspiration does not evaporate as readily at higher relative humidity levels, to the detriment of thermal comfort. Most people are comfortable when the relative humidity is between 30 and 60 percent, though once again there are seasonal variations.

While the right combination of temperature and humidity may cause a person to feel thermally neutral (corresponding to a score of zero on the ASHRAE thermal sensation table or the bull's eye of the comfort dartboard), there are other conditions that may impair comfort, if not addressed. These include non-uniform conditions and local discomfort.

Thermal discomfort may result when humans are subjected to non-uniform (asymmetric) thermal radiation. A common example is when one sits next to a large window on a cold day and heat radiates from one side of the body to the nearby cold pane of glass. Heat radiates at a different rate from the other side of the body facing away from the window. Research indicates that occupants begin to feel discomfort when radiant temperature asymmetries are higher than about 18° F.[6]

A draft is an undesirable localized cooling effect caused by air movement. Conditions that make one part of our body uncomfortable lead to an overall lower level of thermal comfort. An example is a cold draft on one's feet. One study concluded that, in an otherwise thermally neutral environment, air velocity of more than 50 feet-per-minute negatively affected thermal acceptability to building occupants.[7]

From a comfort standpoint, temperature, humidity, non-uniformity, and drafts are interrelated, and changing one of them will necessitate changes in the others to maintain acceptable thermal comfort. To illustrate, a person who sits by a single-pane window on a cold day will usually require a warmer space temperature to offset the heat transferred from their body to the cold glass surface than an individual sitting in an interior office without any windows. The converse is true on hot days.

Various combinations of temperature and relative humidity that provide acceptable thermal comfort can be plotted on a standard psychrometric chart in order to define the human "comfort zone" (**Figure 8**, page 12). The implication is space conditions that fall within this zone are likely to provide acceptable thermal comfort for most people. However, it is important to note that each person's comfort zone will vary depending upon the individual's amount of clothing, metabolic activity, and other factors. Surprisingly, with the diverse range of climates, living conditions,

What is Thermal Radiation?

Objects within line-of-sight at different temperatures transfer thermal energy between one another via radiation.

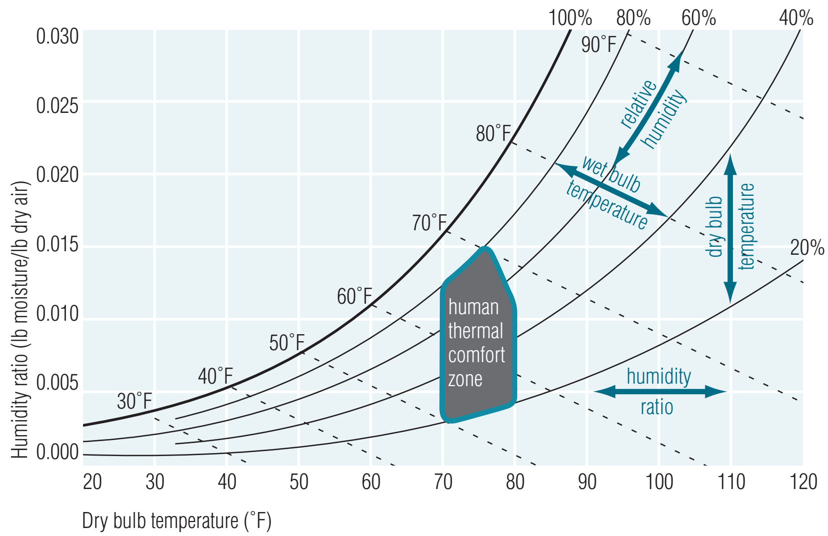
Just as the extremely high surface temperature of the sun is capable of warming planets that are separated from it by a vast, airless void, so too a cold surface will rob heat from our body.

Thermal radiation occurs regardless of the medium separating the two objects—be it air, water, or the vacuum of space. It is a function of the distance and temperature difference between the two objects.

Figure 8: The comfort zone

This chart shows the combinations of temperature and relative humidity that will provide thermal comfort for most people. Though not indicated on this chart, it is important to note that variations may result from different clothing worn during summer and winter.

For example, a dry-bulb temperature of 75° F with a relative humidity of 40 percent would provide a comfortable environment for occupants. However, a dry-bulb temperature of 75° F with 20 or 80 percent relative humidity levels would yield uncomfortable conditions.



Source: CTG Energetics

and cultures around the world, most people would choose to be within the same temperature range when clothed similarly and performing at the same level of activity.[8] However, regional adaptation does occur and should be considered.

In order to improve thermal comfort in commercial new construction projects, architects and engineers should consider the following strategies:

- *Understand a climate's barriers to comfort*. Buildings located in extreme climates will present greater challenges to thermal comfort than those in benign climates. Whether a climate features intense sun, high humidity, or chilly winter temperatures, all of these characteristics may lead to poor occupant comfort, if not addressed properly. The first step in evaluating comfort challenges for a particular project is to understand climatic characteristics that affect it.

- *Use well insulated glazing systems*. Dual-pane glazing provides a much higher resistance to heat flow than single-pane systems and can reduce comfort problems associated with asymmetric thermal radiation. Where a typical single-pane piece of glazing may have a U-Value of about 1 Btu/SF°F, today's multi-pane, low-e systems can achieve U-Values of 0.20 to 0.30. Thus, heat loss/gain through well-insulated glass may be reduced by 70 to 80 percent, and asymmetric radiation effects on occupants mitigated during heating and cooling seasons.

- *Use high-performance glazing*. High-performance glazing that admits visible light while rejecting much of the infrared spectrum can greatly reduce heat gain in a building. Thus, it can reduce the localized heating effect that direct beam sunlight may have on occupants sitting adjacent to a window while still providing ample daylight. Dual-pane, low-emissivity products that provide excellent thermal as well as visual performance are widely available.

- *Locate occupants away from drafts and asymmetric radiation sources*. Locating occupant workstations away from entrances that may receive lots of air from the outside can reduce the likelihood of uncomfortable drafts. In cold climates, if it is essential that occupants work in close proximity to a well-used entrance (for example, security guards or receptionists), consider including a vestibule to provide a thermal buffer that will reduce drafts.

  Also, workstations should not be located directly below HVAC diffusers. Despite engineers' best design intentions, diffusers often "dump" cold air onto occupants during the cooling season because low delivery volumes impair diffuser effectiveness.

  During the summer, it may be uncomfortable to sit below a poorly insulated roof—especially if there is not a suspended ceiling to provide a thermal buffer from the warm inside surface of the roof. ASHRAE research indicates that warm ceilings are the most problematic source of asymmetric radiation[9] from the standpoint of occupant thermal discomfort.

It is becoming increasingly common in the design of new commercial buildings to use the outermost (e.g. adjacent to the glass line) spaces of buildings as circulation spaces instead of permanent occupant locations. This practice may be beneficial to comfort because such spaces will be only intermittently occupied, thus reducing the likelihood of thermal discomfort as a result of asymmetric radiation. Keeping the perimeter open also encourages deeper daylight penetration into the building's interior.

- *Think "inside the box."* When reviewing the comfort zone chart, consider the impact of certain temperature and humidity combinations that may technically fall within the "box" defined as acceptable, but are on the fringe of being uncomfortable. For example, if you are considering designing a system to operate at the upper end of acceptable temperatures, it may be prudent to design for an overall lower humidity level. Summer and winter comfort zones are based upon an assumed amount of clothing and activity. Age, gender, and length of exposure also significantly impact comfort zone validity. Designers should treat the comfort zone as a useful guideline, but apply common sense as well.

- *Let occupants define their own comfort zone*. In an ideal HVAC system, each occupant would have his or her own thermostat. Unfortunately, it is more common for a single thermostat to be shared by ten or more occupants. Certain HVAC system types, such as underfloor air distribution systems, provide each occupant with their own manually adjustable air diffuser, allowing them to control temperature and airflow according to their own preferences. Operable windows accomplish this, as well.

Control the Sun to Reduce Loads and Enhance Visual Comfort

In many respects, proper control of the sun's rays epitomizes climate-responsive design because the "best" design solutions will vary according to a project's specific location. Because the sun's apparent path varies according to latitude, its position in the sky will be different in San Francisco than in San Ysidro at the same time of the day. For this reason, particular design strategies that provide effective shading will differ according to latitude, and there is no "canned" strategy that works best in all locations.

Apparent seasonal changes in the sun's path occur because the earth is tilted at a 23.3° angle relative to the vertical plane, and as the earth orbits about its own axis once per day and around the sun once per year, the sun's position in the sky changes relative to the earth's surface. This tilt, along with earth's elliptical orbit around the sun, also places the surface of the earth closer to the sun during summer and further away during winter, which influences solar intensity.

While most people think that they have a good understanding of solar motion, their understanding is usually limited to their home latitude. Most North American inhabitants are thoroughly perplexed when their solar understanding is tested in Australia (where the sun travels through the northern sky and "summer" occurs during the "winter"), or Alaska (where the sun never sets during some summer days, opting instead to spin in a dizzying circle).

Other climatic characteristics for a particular location (temperature, humidity, wind, daily temperature swings) will impact our disposition towards solar gain, and the things we do to deal with it. In cold climates, designers may opt to use the winter sun as a means to provide passive heating for a building. In mild climates where some amount of cooling is required on a year-round basis, winter solar gain may be undesirable, and more extensive shading may be employed to reduce the amount of sun that enters the building.

Daylighting enhances productivity in schools and retail spaces

Research indicates that an additional benefit of daylight is that people may perform better in environments with ample daylight. One study showed that elementary school students performed significantly better on standardized tests when their classrooms were daylit than students in non-daylit spaces.

Another study indicated a substantial increase in retail sales for similar stores in the same region with skylighting versus stores without skylighting.

Source: Heschong Mahone Group

By properly introducing and controlling natural light in a building, it is possible to achieve efficient, low-glare illumination with excellent color rendering characteristics. Natural light also introduces less heat gain into a building than electric illumination sources (see **Table 1**). This characteristic makes direct sunlight an invaluable strategy for designers who want to lower cooling requirements due to lighting by introducing less heat gain into a workspace.

To understand how to control the sun, it is important to understand the sun's astronomical path in relation to earth. We all know that the sun rises in the east, travels through the sky, and sets in the west. During the winter, the sun's path is lower in the southern sky at locations north of the equator, resulting in the potential for increased heat gain and glare in south-facing offices. It is interesting to note that most south-facing spaces usually experience their greatest cooling loads in the month of December because of the intense heat gain that results from low solar angles striking the glass.

During the summer, the sun traverses a higher path through the sky (see **Figure 9**), resulting in longer days and increased solar gain on land and water surfaces. Though it is a commonly held belief that exterior solar treatment is not necessary on north façades because the north side does not receive direct sun, this is actually not the case. For example, at summer solstice, when the sun traverses its highest path through the sky, it actually sets about 26° to the north of due west at 36° N latitude (see **Figure 10**, page 18). The result is direct sunlight falling on north-facing walls and windows for California communities like Monterey and Santa Cruz.

The vast majority of new commercial buildings in California use little or no exterior shading to limit solar gain. Exterior fins, overhangs, light shelves, clerestories, and landscaping can all be employed by designers to appropriately control the sun on each façade of a building as well as provide interesting architectural form determinants.

Table 1: Efficacy of illumination sources

Virtually all light sources emit energy that is ultimately converted into heat within a building at the rate of 3.4 BTUs per watt. As indicated in the table, direct sunlight, when properly controlled, may provide greater efficacy than fluorescent and incandescent light sources; thus reducing cooling loads.

Light Source	Efficacy (lumens/watt)
Sun (altitude greater than 25 degrees)	117
Sky (clear)	150
Incandescent (150w)	16-40
Fluorescent (32w, T-8)	80-95
High Pressure Sodium	40-140

Source: Hopkinson et al., 1966 and I.E.S., 1981

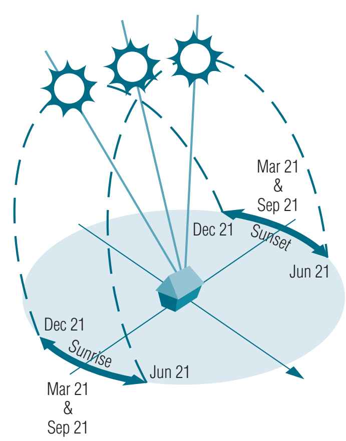
In order to make best use of the California sun, the following strategies and design considerations are recommended when evaluating building form, orientation, and glazing options.

- *Different façades require different exterior solar treatments*. A strong indicator that a building has not been designed with solar control in mind is when all four façades have the same outward appearance. The most egregious (and most common) example is a facility that is devoid of exterior fins or overhangs on any of its façades. In order to minimize the amount of direct sunlight that falls on glass areas, north, south, east, and west façades will require different design strategies. One must understand the interactions between window height, fin, and overhang depth and placement, as well as solar angles through the day and year to design effective solar solutions.

  East-facing windows receive intense morning sun that decreases as the sun climbs higher throughout the morning. Vertical fins and overhangs can effectively shade the glass during much of the year. However, it is important to recognize that there will always be two periods during the year when incoming sunlight is perpendicular to the glass, and neither will provide any shading effect.

Figure 9: Solar paths

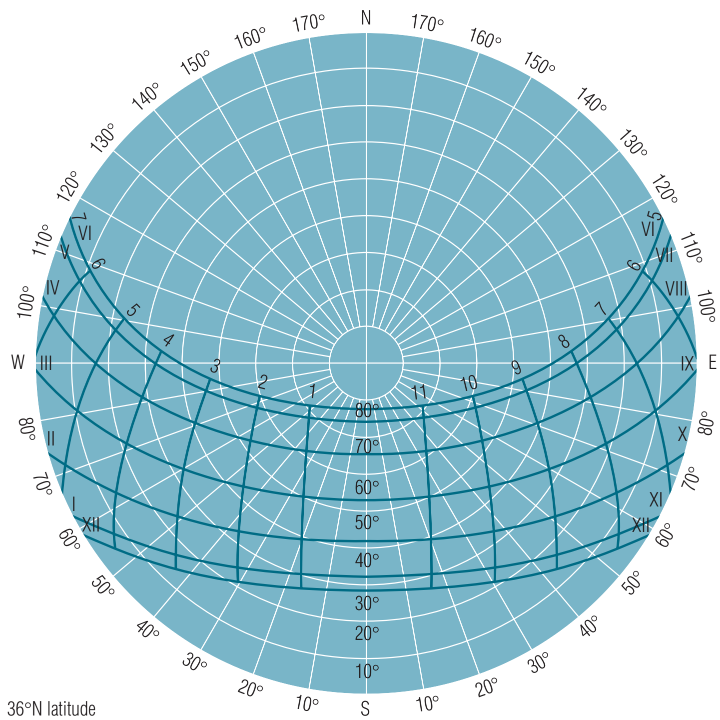
The sun is highest in the sky on the Summer Solstice (June 21), and lowest on the Winter Solstice (December 21). The apparent position at which the sun rises and sets changes seasonally.



Source: CTG Energetics

Figure 10: Solar path data for 36° N latitude

Solar path charts can be used to determine many useful solar characteristics for a project site. The chart displays the position (altitude and azimuth) of the sun at any time of day during a specific month at a particular latitude. Such charts can be used to determine when the sun will rise and set, its position during the warmest parts of the day (which can be used to optimize shading strategies), and its position during colder periods (which can be used to design building envelope features that admit winter sun).[10]



Source: CTG Energetics

Because morning sun can provide a passive warm-up on chilly mornings, glazing and shading devices must be selected carefully, if this effect is desirable. If passive heating is not desired, minimize the amount of east-facing glass in order to reduce glare and thermal comfort problems.

West-facing windows can be quite challenging from a solar control standpoint, particularly in California's coastal regions where it is desirable to maximize coastal views and therefore the amount of west-facing glass. Similar to east-facing glass, vertical fins and overhangs can provide shading during some (but not all) of the year. It is also possible to employ planter boxes and trellises to provide shade on west façades while still preserving the view. If view is not a priority, minimizing use of west-facing windows will reduce heat gain problems that are deleterious to comfort.

South-facing windows see the most complicated solar paths, as the sun climbs higher in the sky throughout the day but also traverses from east to west. As a result, a combination of fins and overhangs may be employed to deal with each component of the solar path. Vertical fins provide shading through the sun's horizontal motion from east to west. Overhangs can be employed to shade the glass from higher sun angles in the summer, while still allowing lower sun angles in the winter to hit the glass (**Figure 12**, page 20). Depending on project latitude, it may be necessary to use very deep overhangs to provide proper shading; for example, projects located farther to the north will require deeper overhangs to provide adequate shade.

In cooler climates, south-facing overhangs may be selected to shade the glass during warm summer months, while letting the winter sun in for passive heating (**Figure 12**).

North-facing windows do not receive direct sun for most of the year, and as a result are often given no special solar treatment. As previously noted, during mid-summer such windows actually will receive direct sun early and late in the day. Shallow vertical fins may be used to provide shade from this late afternoon surprise.

- *True north, or Plan north?* Most design drawings designate "plan north" in relation to the façade that points most nearly to the north. However, it is essential that solar control devices be designed to respond to the sun's motion relative to true north, as this is the proper reference point for solar paths. Some project locations may be particularly confusing in this regard. For example, downtown Los Angeles is laid out on a grid that runs at about a 45° angle relative to the cardinal directions, so basing solar control upon plan north would result in solutions that are ineffective.

Figure 11: Building 850 at Port Hueneme, California

The design team for Port Hueneme used orientation and form to optimize daylighting and natural ventilation strategies for this project.

Specific climate responsive measures include: underfloor supply air plenum, clerestory windows, heating and ventilation ductwork that doubles as a light shelf, high thermal performing building materials, and an integrated natural ventilation/mechanical HVAC system.

Source: CTG Energetics

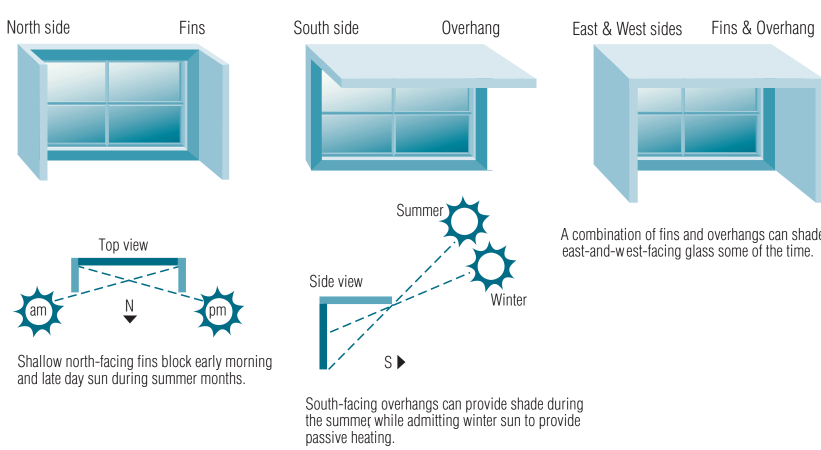
- *Consider solar gain when selecting building form and orientation*. Different building shapes will respond to the sun in different ways. A cube-shaped building, for example, will usually be less affected by the sun than a long, narrow building of the same volume. This is because the cube has a much lower surface-to-volume ratio, and therefore less glass and its attendant solar gain. In one recent project, about a dozen alternative building forms were evaluated using building simulation models for a new 600,000 SF commercial office building. The models indicated as much as a six-percent difference in energy use between building shapes based on how much and when solar gain occurs.

  The orientation of a particular building shape may also impact energy use and comfort. If site conditions allow, it may be possible to reduce energy use and improve comfort by changing the orientation of the building. Typically, orienting the longer exposures to face north and south and the shorter exposures to face east and west will reduce solar gain problems, while providing useful daylight.

- *Eschew rules of thumb in favor of real solar data*. Even though the generic design strategies described above for each

Figure 12: Shading strategies

Different shading strategies for different façades.



Source: CTG Energetics

building façade are useful starting points, they are not a substitute for site-specific solar data. Project latitude, for example, will determine the position of the sun in the southern sky. Because solar angles are well understood and solar data are readily available, it is possible to calculate effective dimensions for fins and overhangs for a specific latitude, thus creating a design solution that will be successful. For example, **Figure 10**, page 18, presents solar angle data for 36° N latitude.

Use Thermal Mass to Improve Comfort and Efficiency

Thermal mass describes a building material's ability to store thermal energy and delay heat transfer through a building component (**Figure 13**, page 22). Examples of building materials that are thermally massive include concrete panels, filled concrete masonry units, and bricks. Conversely, typical framed constructions using wood or metal framing members and lightweight outer finishes may be considered to be low-mass building materials. Properly applied, thermal mass may improve building comfort by moderating indoor temperature swings, reducing energy consumption, and reducing peak demand requirements.[11]

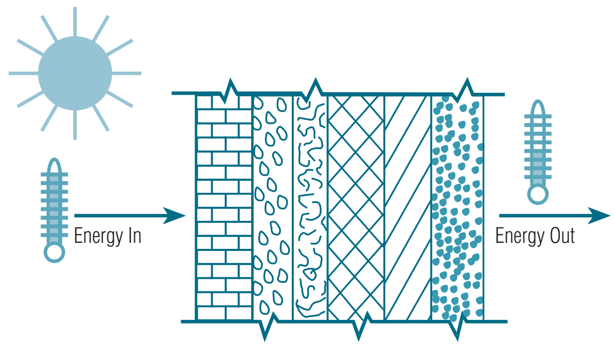
By storing thermal energy from the outdoors during the hottest periods of the day and delaying its transfer indoors, thermal mass reduces the daily temperature swing inside a building. This has the effect of reducing the peak cooling load, which may result in reduced HVAC equipment sizes—or may eliminate the need for mechanical cooling altogether for certain types of facilities that have less stringent environmental control requirements (storage and warehouse facilities, for example).

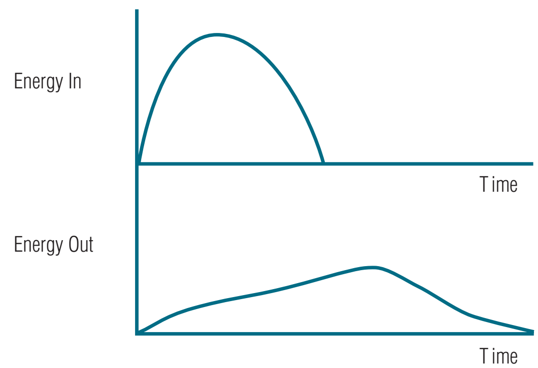
Another benefit is that a building in a very hot or cold climate using thermal mass will usually have lower energy consumption for HVAC versus a building using low-mass building materials. This is largely the result of delaying heat gains or losses to times when they may be less objectionable or even desirable. In regions that

Figure 13: Thermal mass delays heat gain

Thermal mass can be used to delay heat gain through walls. This illustration represents a generic wall cross section.

By properly selecting building materials, the thermal energy absorbed by the outdoor side of this wall can be slowly released into the building over time, decreasing the need for mechanical space cooling and space heating.





Source: Architectural Energy Corporation

have large daily temperature swings—deserts, for example—it is often the case that air conditioning is needed during the daytime, yet heating is required overnight. In such climates, thermal mass has the two-fold benefit of decreasing the amount of cooling used during the day and heating required at night. During the day, high thermal mass delays heat gain through the walls and roof. At night, when temperatures drop and heating is required, thermal mass heat is released into the building interior to reduce or eliminate the need for space heating. Alternatively, nighttime ventilation of workspaces in order to remove unwanted heat or absorb cold into interior thermal mass materials (ie. concrete floors) can be a very effective strategy for reducing energy costs during the cooling season.

Thermal mass may also be used to reduce peak energy demands by shifting the operation of cooling equipment to off-peak periods when energy prices may be lower. An example would be to cool a building, using either natural or mechanical cooling systems, overnight during non-peak energy periods in order to reduce the temperature of thermally massive walls and roofs. During the daytime, the coolness stored in the building mass is emitted and helps offset heat gains from people, lights, equipment, as well as the outdoor weather. The result is reduced need for mechanical cooling during peak energy times.

To make the best use of thermal mass in a particular project, the following strategies should be considered.

- *Will thermal mass pay off for your project?* In general, thermal mass provides the most significant benefits when daily temperature swings are large, such as in desert regions, and when nighttime temperatures fall below desired indoor temperatures. If a project is to be built in a mild coastal climate, there is likely little or no benefit to specifying high thermal mass materials. Similarly, thermal mass will provide little benefit during periods of persistent hot weather, when the outdoor temperature is always above the desired indoor temperature.

  Using a building simulation computer program to model different wall assemblies is an effective way to assess benefits for a particular climate – and once the commitment has been made to use thermal mass, such models are essential to selecting the right type and thickness of mass materials.

- *Leave interior mass walls bare to maximize performance*. Much of the benefit of high-mass walls, roofs, and slabs is lost when they are covered with gypsum board, acoustic ceiling tiles, or carpet. When possible, leave interior mass surfaces untreated in order to better couple the interior space with the thermal mass. Designers should also consider stone tile floors as an option to carpet in order to tap into the thermal mass benefits of the slab and the earth below.

- *Insulation or "outsulation?"* Though it is possible to place supplemental insulation on the exterior or interior of the mass wall, studies find that external insulation is most effective for moderating indoor temperatures. Particularly in very hot climates with large daily temperature swings, high R-value "outsulation" greatly reduces indoor temperature swings.[12]

- *Let space temperatures "float" for greater savings*. If possible, the ability to let space temperatures "float" in high thermal mass structures is recommended for greater savings. Larger acceptable ranges of interior space temperature improve the effectiveness of thermal mass. For example, if the space temperature is allowed to float between 68°F and 78°F without using the HVAC system, the mass can charge itself with thermal energy during warmer indoor temperatures and can discharge thermal energy during cooler temperatures. Facilities that require narrow ranges of acceptable indoor temperature, such as laboratories, greatly limit the effectiveness of this strategy.[13]

- *Embrace the earth in extreme climates*. Despite wide variations in air temperature from night-to-day and season-to-season, the temperature of the earth is relatively constant just a few feet below its surface. This steady 60-or-so degree mass may provide an endless heat source or heat sink that can warm the building during winter and keep it cool during the summer. Single-story buildings make the best use of earth coupling because they have more coupled surface relative to total floor area. Earth-coupled design is a specialty unto itself, so it may be worthwhile to consult with experts when considering it for a project.

Select Space-Conditioning Strategies That Are Climate-Responsive

Even though California encompasses a wide range of temperature and humidity conditions, most HVAC systems are designed to provide comfort in essentially the same way—through mechanical cooling. While this traditional approach to cooling can provide acceptable comfort, it does not always do so in the most healthy, climate-responsive, or energy-efficient way.

After the design team works through the various issues of climate, human comfort, shading, and thermal mass, selecting space-conditioning strategies is the final consideration. The decision of what type of space-conditioning system to use can transform a good building into a great building, or turn an otherwise climate-responsive design into a building that is expensive to heat and cool.

While some mechanical system designers might consider the following suggestions as non-traditional, many others regularly utilize these strategies to enhance energy efficiency and comfort by taking advantage of a climate's predominant characteristics. It is worth noting that most of these strategies trace their lineage back to the era before mechanical cooling was commonly employed in commercial buildings.

- *Is cooling really necessary?* Even though many commercial building developers, owners, and occupants have a mindset to the contrary, air conditioning may often be eliminated in mild climates if the right combination of climate-responsive design features is implemented. Effective solar control, appropriate building materials, and internal load minimization (e.g., efficient lights, Energy Star office equipment) can reduce or altogether eliminate the need for mechanical cooling. Especially in coastal regions, the use of operable windows in perimeter spaces along with forced ventilation at 100 percent outside air in core spaces can keep conditions well within acceptable ranges of temperature and humidity for most of the year.

  Eliminating traditional mechanical cooling systems has numerous benefits, including reduced construction cost (which may allow enhancements to other building features in a cost-neutral manner), lower maintenance requirements, less noise, and significantly lower energy costs.

Newport Coast Elementary School

Designers for the Newport Mesa Unified School District in Newport, California, incorporated operable windows, cross-ventilation, and natural air stratification to provide natural cooling, where appropriate, to the classrooms.

Additionally, the campus includes high efficiency heat pumps and solar hot water collectors.

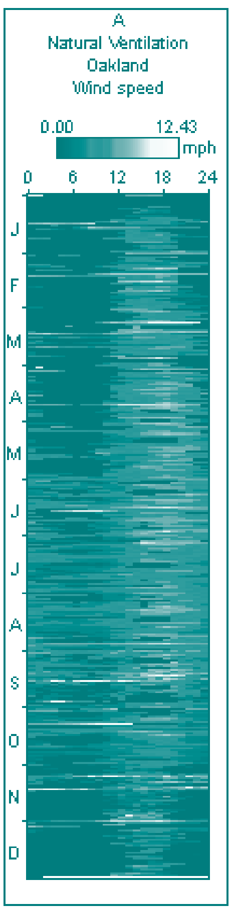
Source: Southern California Edison

Figure 14: Wind resources for natural ventilation strategies

The plot shown below is a three dimensional representation of wind resources for natural ventilation in Oakland.

Hours of the day are displayed horizontally and days of the year are displayed vertically. Wind speed in mph is represented as color. The wind data have been filtered to eliminate hours when the outdoor temperature is less than 55° F or greater than 75° F.

The dark areas indicate either calm conditions, or temperatures outside of the range of 55° F to 75° F. As indicated, there are many hours of favorable wind conditions for natural ventilation during both day and night in Oakland.



Source: Architectural Energy Corporation

The challenge in proposing to forego mechanical cooling is to demonstrate the level of comfort (indoor air temperature, humidity, and air movement) that may be expected under worst-case and average conditions to project stakeholders. Energy simulation programs may be used to develop realistic predictions of indoor conditions under a variety of weather scenarios. Other tools are also available to evaluate the wind resources that may be available in a particular geographic location (see **Figure 14**).

- *Natural ventilation expands the comfort envelope*. When asked to define indoor comfort, most mechanical engineers think of indoor temperatures between 72°F and 75°F. Recent studies have shown that occupants are tolerant of far greater temperature ranges, if they are provided with operable windows that allow them to regulate air temperature and movement to suit their own preferences. For buildings that are designed with both operable windows as well as traditional mechanical cooling (so-called "mixed mode" buildings), installing switches on the window sashes that shut off the HVAC for that space when the window is open expands the comfort envelope and minimizes potential energy waste.

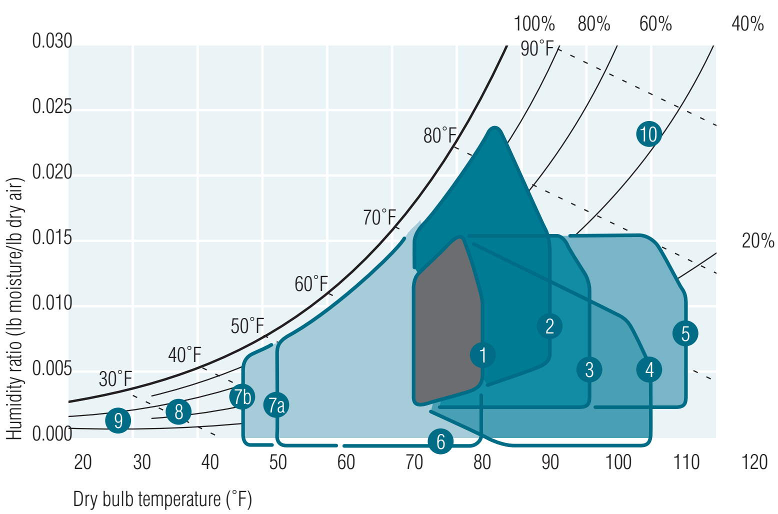
- *...but it's a dry heat*. In arid climates that have hot drybulb temperatures but low relative humidity, evaporative cooling can provide the two-fold benefit of reducing air temperature while increasing relative humidity to more comfortable levels—without using mechanical cooling. Evaporative cooling is an established, low-energy technology that adds water to incoming air in order to change its balance of sensible and latent heat content. The evaporative cooling process follows a line of constant enthalpy on the psychrometric chart. As the drybulb temperature drops and relative humidity increases, conditions move from hot and dry (lower right corner of the psychrometric chart, **Figure 8**, page 12) directly towards the comfort zone (upwards and to the left of the chart). Thus, this process takes uncomfortable conditions (hot/low humidity) and makes them comfortable (moderate temperature/ moderate humidity) with very low energy input.

- *Select design strategies that lead into the comfort zone.* The right combination of architectural approaches (passive solar heating, thermal mass) and mechanical system approaches (evaporative cooling, natural ventilation) can take almost any outdoor weather condition and shift it towards the comfort zone. This concept is demonstrated in **Figure 15**. While there are certainly climate conditions that require mechanical cooling or heating in order to maintain comfort, strategies such as the ones discussed in this design brief exist that can reduce or eliminate the heating or cooling requirements.

Figure 15: All roads lead to the comfort zone

This figure depicts various design strategies that can be used to provide thermal comfort with minimal energy input. Some of these strategies are mechanical system concepts, while others are architectural strategies that are discussed in this design brief.

The graph below indicates design strategies to consider when specific climatic conditions exist. For instance, when the dry-bulb temperature ranges from 70°F to 110° F and relative humidity is between zero and 60 percent, then evaporative cooling is a potential cooling option.



1. Human comfort zone
2. Natural or fan assisted ventilation
3. High thermal mass
4. High thermal mass with nighttime ventilation
5. Evaporative cooling
6. Humidification

7a Passive solar heating: 1300 Btu/sq. ft./day insolation ~48˚N latitude
7b Passive solar heating: 1700 Btu/sq. ft./day insolation ~32˚N latitude
8 Active solar heating
9 Conventional heating
10 Conventional cooling

Source: CTG Energetics

Conclusions

In many ways, architects and engineers who embrace climate-responsive design are merely getting back to the roots of their profession by striving to create buildings that are inherently comfortable. Just because lighting and HVAC technologies have afforded designers with artificial methods of providing comfort does not mean that weather patterns should be ignored. Often, the effort required for a climate-responsive design is not focused on technology so much as on initial consideration of a particular climate's challenges and opportunities, as well as methodical analysis of how different design strategies work in that climate's context.

Many examples of climate-responsive design (some presented in this design brief) are buildings that have elegantly simple mechanical and electrical systems. This simplicity when combined with climatic common sense allows buildings to work with—rather than against—the sun, wind, and temperature in that area. Artificial lighting, heating, and cooling are only used to supplement what nature already offers, thus providing a high quality and comfortable environment for building occupants with minimal energy requirements.

For More Information

National Climatic Data Center (NCDC)

NCDC is the world's largest active archive of weather data. NCDC produces numerous climate publications and responds to data requests from all over the world. It is a reliable source of hourly weather data for a variety of locations.

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001
Phone: (828) 271-4800
Fax: (828) 271-4876
www.ncdc.noaa.gov/

Sustainable Buildings Industry Council (SBIC)

SBIC is a nonprofit organization whose mission is to advance the design, affordability, energy performance, and environmental soundness of residential, institutional, and commercial buildings nationwide.
Energy simulation software is available.
1331 H Street, N.W., Suite 1000
Washington, DC 20005
Phone: (202) 628-7400
Fax: (202) 393-5043
www.sbicouncil.org

National Renewable Energy Laboratory (NREL)

Energy analysis and evaluation software is available.
1617 Cole Blvd.
Golden, CO 80401
Phone: (303) 275-3000
www.nrel.gov/buildings_thermal/buildings

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE)

ASHRAE 1997 Fundamentals Handbook.
1791 Tullie Circle, N.E.
Atlanta, GA 30329
Phone: (404) 636-8400
Fax: (404) 321-5478
www.ashrae.org

American National Standards Institute (ANSI)

ANSI/ASHRAE Standard 55,

Thermal Environmental Conditions for Human Occupancy

The purpose of ANSI/ASHRAE Standard 55 is to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80 percent or more of the occupants within a space.

1819 L Street, NW

Washington, DC 20036

Phone: (202) 293-8020

Fax: (202) 293-9287

www.ansi.org/

Notes

1 Thermographic studies show that many cities experience higher temperatures because of the vast quantities of dark asphalt and other heat-absorbing materials typically used in urban regions.

2 Hourly weather data for a variety of locations can be obtained for a modest fee from the National Climatic Data Center. Additionally, the National Renewable Energy Laboratory has a software program that will adjust regional weather data for specific locations. See the 'For More Information' section of this design brief for details.

3 1997 ASHRAE Handbook of Fundamentals, page 8.12.

4 1997 ASHRAE Handbook of Fundamentals, page 8.12, Table 9.

5 Vapor pressure is another way to express moisture content of air. Many psychrometric charts display a vapor pressure scale that makes it easy to obtain this information.

6 1997 ASHRAE Handbook of Fundamentals, page 8.13.

7 1997 ASHRAE Handbook of Fundamentals, page 8.13.

8 1997 ASHRAE Handbook of Fundamentals, page 8.1.

9 1997 ASHRAE Handbook of Fundamentals, page 8.13., Figure 5.

10 One source of solar path data is "Architectural Graphics Standards," Seventh Edition, 1981, published by John Wiley & Sons, Inc., New York, NY.

11 1997 ASHRAE Handbook of Fundamentals, page 39.12.

12 1997 ASHRAE Handbook of Fundamentals, page 39.12.

13 1996 ASHRAE Handbook of Fundamentals, page 39.12.

Pacific Gas and Electric Company

SDGE

A Sempra Energy company

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