CHAPTER 1

HEATING, COOLING, AND LIGHTING AS FORM-GIVERS IN ARCHITECTURE

Two essential qualities of architecture [commodity and delight], handed down from Vitruvius, can be attained more fully when they are seen as continuous, rather than separated, virtues.

. . . In general, however, this creative melding of qualities [commodity and delight] is most likely to occur when the architect is not preoccupied either with form-making or with problem-solving, but can view the experience of the building as an integrated whole. . . .

John Morris Dixon,
Editor of* Progressive Architecture*, 1990

All design projects should engage the environment in a way that dramatically reduces or eliminates the need for fossil fuel.

The 2010 Imperative,
Edward Mazria, AIA,
Founder of Architecture 2030

1.1 INTRODUCTION

Architecture has been called journalism in stone, since it reflects the culture, climate, and resources of the time and place. During the Renaissance, for example, the main influence was the rediscovery of the classical world. What is the agent of change today?

The story that is now shaping the future of architecture is sustainability. There are few people left today who are not in favor of creating a sustainable world or who would claim that we are living in a sustainable world. Since building impacts the environment more than any other human activity, architects have both the responsibility and the opportunity to lead humankind to a sustainable future.

Sustainable architecture can be achieved by using "the best of the old and the best of the new." A new architecture is being created by using modern science, technology, and ideas of aesthetics combined with traditional ideas that responded to human needs, regionalism, and climate. Such architecture will be more varied than contemporary architecture, which gives no clue to where a building is located. Much contemporary architecture looks the same in New York, Paris, New Delhi, or Tokyo. Furthermore, this de facto "international" architecture is equally inappropriate wherever it is built since it is not sustainable for any climate.

Sustainability covers many issues, but none is as important as energy consumption. More than any other factor, the energy consumption of buildings is destroying the planet as we know it. Buildings use about 48 percent of all the energy consumed, with 40 percent for their operation and 8 percent for their construction (Fig. 1.1a). This energy is mostly derived from fossil sources that produce the carbon dioxide that is the main cause of global warming. We must replace these polluting sources with clean, renewable energy sources such as wind, solar energy, and biomass, or we must increase the efficiency of our building stock so that it uses less energy. Of course, we need to do both, but decreasing the energy consumption of buildings is both quicker and less expensive. Furthermore, the design of energy-responsive buildings will yield a new aesthetic that can replace both the blandness of most modern buildings and the inappropriate copying of previous styles.

Is it really possible for architecture to seriously address the problem of global warming? The answer is an unambiguous yes, both because present buildings are so wasteful of energy and because we know how to design and construct buildings that use 80 percent less energy than the standard new building. Presently, there are architects around the world designing "zero-energy buildings," which are designed to use as little energy as possible, with the small remaining load being met mostly by on-site renewable energy such as photovoltaics (Fig. 1.1b). We have the know-how (see Sidebox 1.1); all we need is the will.

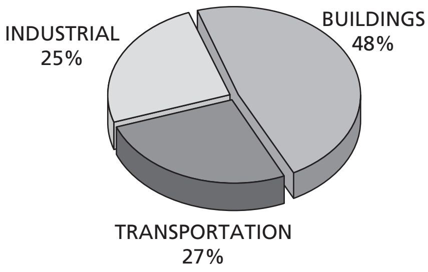


Figure 1.1a Buildings are the main cause of global warming because they use about 48 percent of all energy. Of that 48 percent, about 40 percent is for operating the buildings (heating, cooling, lighting, computers, etc.) and about 8 percent is for their construction (creating materials, transportation, and erection). (Courtesy of Architecture 2030.)

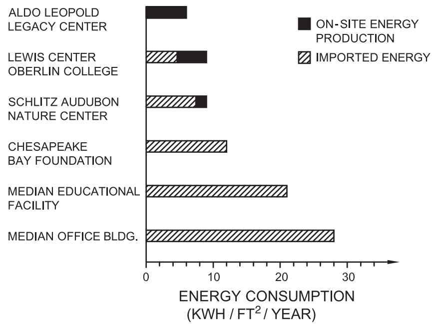


Figure 1.1b The good news is that buildings do not have to use climate-changing fossil fuels. Over the years, we have learned how to design buildings so energy efficient that we can now build zero-energy buildings. The small amount of energy that they still need can be supplied by renewable sources such as photovoltaics on the roof.

SIDEBOX 1.1

Characteristics of a Zero-Energy House

- Correct orientation
- Form as compact as appropriate for the climate and function
- Extensive use of white or very light colored surfaces
- Superinsulated walls, roof, and floor
- Airtight construction with a heat recovery unit for ventilation
- High-performance, properly oriented windows
- Windows fully shaded in summer
- Passive solar space heating
- Active solar domestic hot water
- High-efficiency appliances
- High-efficiency electric lighting
- High-efficiency heating and cooling equipment (e.g., earth-coupled heat pump)
- Photovoltaics on roof that produce the small amount of electricity still needed

There is a widespread belief that engineers design the heating, cooling, and lighting of buildings. The truth is that they only design the systems and equipment still needed after the architect designs the building to heat, cool, and light itself. Thus, the size of the mechanical and electrical equipment is an indicator of how successful the architect was. It is most important to realize that in designing a building to do most of the heating, cooling, and lighting, the architect is also designing the form and other aesthetics of a building.

This book was written to help the reader design sustainable buildings that use very little energy. It presents rules of thumb, guidelines, and examples that are drawn from the best of the old and the best of the new. Because traditional buildings used little energy, the methods they used to respond to their climate, locality, and culture can be a source of ideas and inspiration for modern architects.

1.2 INDIGENOUS AND VERNACULAR ARCHITECTURE

One of the main reasons for regional differences in architecture is the response to climate. This becomes apparent when looking at indigenous buildings, because they usually reflect the climate in which they were built.

In hot and dry climates, one usually finds massive walls and roofs used for their time-lag effect. Since the sun is very intense, small windows will adequately light the interiors. The windows are also small because during the daytime the hot outdoor air makes ventilation largely undesirable. The exterior surface colors are usually very light to minimize the absorption of solar radiation. Interior surfaces are also light to help diffuse the sunlight entering through the small windows (Fig. 1.2a).

Since there is usually little rain, roofs can be flat and are often used as additional living and sleeping areas during summer nights. Outdoor areas cool quickly after the sun sets because of the rapid radiation to the clear night sky. Thus, roofs are more comfortable than the interiors, which are still quite warm from the daytime heat stored in the massive construction.

Even community planning responds to climate. In hot and dry climates, buildings are often closely clustered for the shade they offer one another and the public spaces between them.

In hot and humid climates, we find a very different kind of building. Because water vapor blocks some solar radiation, air temperatures are lower than in hot and dry climates, but the high humidity still creates great discomfort. The main relief comes from shading and moving air across the skin to increase the rate of evaporative cooling. The typical antebellum house (see Fig. 1.2b) responds to the humid climate by its use of many large windows, large overhangs, shutters, light-colored walls, and high ceilings. The large windows maximize ventilation, while the overhangs and shutters protect from both solar radiation and rain. The light-colored walls minimize heat gain.

Since in humid climates nighttime temperatures are not much lower than daytime temperatures, massive construction is a disadvantage. Buildings are, therefore, usually made of lightweight wood construction. High ceilings permit larger windows and allow the air to stratify with people inhabiting the lower and cooler layers. Vertical ventilation through roof monitors or high windows not only increases ventilation but also exhausts the hottest air layers first. For this reason, high gabled roofs without ceilings (i.e., cathedral ceilings) are popular in many parts of the world that have hot and humid climates (Fig. 1.2c). Buildings are sited as far apart as possible for maximum access to the cooling breezes. In some humid regions of the Middle East, wind scoops are used to further increase the natural ventilation through the building (Fig. 1.2d).

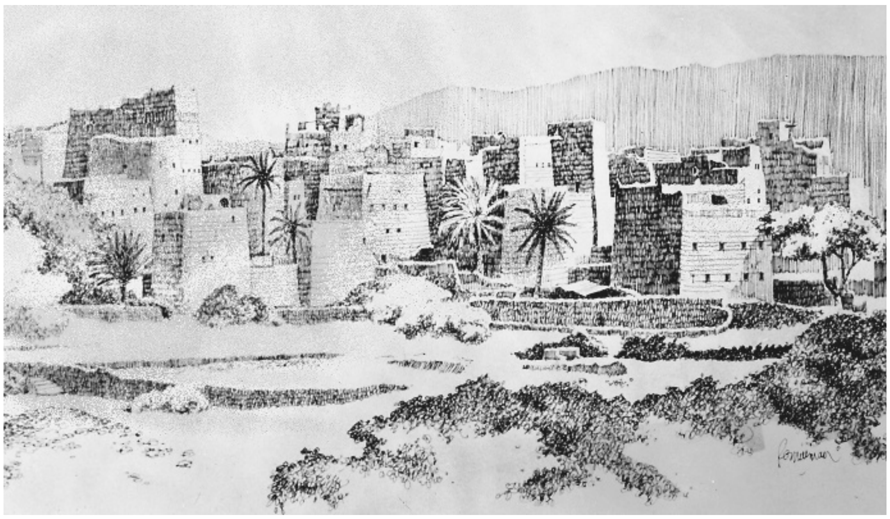


Figure 1.2a Massive construction, small windows, and light colors are typical in hot and dry climates, as in this Yemeni village. It is also common, in such climates, to find flat roofs and buildings huddled together for mutual shading. (Drawing by Richard Millman.)

Figure 1.2b In hot and humid climates, natural ventilation from shaded windows is the key to thermal comfort. This Charleston, South Carolina, house uses covered porches and balconies to shade both windows and walls, as well as to create cool outdoor living spaces. The white color and roof monitor are also important in minimizing summer overheating.

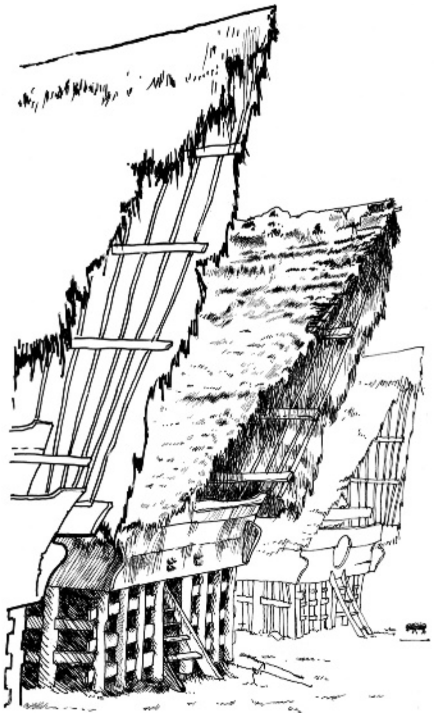


Figure 1.2c In hot and humid climates such as in Sumatra, Indonesia, native buildings are often raised on stilts and have high roofs with open gables to maximize natural ventilation.

Figure 1.2d When additional ventilation is desired, wind scoops can be used, as on this reconstructed historical dwelling in Dubai. Also note the open weave of the walls to further increase natural ventilation. Although this is a desert area, lightweight construction is appropriate because the region along the Persian Gulf is humid. (Photograph by Richard Millman.)

Figure 1.2e Bay windows are used to capture as much light as possible in a mild but very overcast climate such as that found in Eureka, California.

Figure 1.2f In cold climates, compactness, thick wooden walls, and a severe limit on window area were the traditional ways to stay warm. In very cold climates, the fireplace was located either on the inside of the exterior wall or in the center of the building. The log cabin was introduced to America by early Swedish settlers.

In mild but very overcast climates, like the Pacific Northwest, buildings open up to capture all the daylight possible. In this kind of climate, the use of bay windows is quite common (Fig. 1.2e).

In a predominantly cold climate, we again see a very different kind of architecture. In such a climate, the emphasis is on heat retention. Buildings, like the local animals, tend to be very compact to minimize the surface-area-to-volume ratio. Windows are few because they are weak points in the thermal envelope. Since the thermal resistance of the walls is very important, wood rather than stone is usually used (Fig. 1.2f). Because hot air rises, ceilings are kept very low—often below 7 ft (2.2 m). Trees and landforms are used to protect against the cold winter winds. In spite of the desire for views and daylight, windows are often sacrificed for the overpowering need to conserve heat.

Despite the name, temperate climates are not mild. Instead, they are usually cold in the winter and hot in the summer. Consequently, temperate climates are difficult to design for.

1.3 FORMAL ARCHITECTURE

Throughout history, most master builders and architects have included environmental controls in their designs, just as their unschooled neighbors creating indigenous buildings did. After all, the Greek portico is simply a feature to protect against the rain and sun (Fig. 1.3a). The perennial popularity of classical architecture is based on not only aesthetic but also practical grounds. There is hardly a better way to shade windows, walls, and porches than with large overhangs supported by columns (Fig. 1.3b).

The Roman basilicas consisted of large high-ceilinged spaces that were very comfortable is hot climates during the summer. Clerestory windows were used to bring daylight into these central spaces. Both the trussed roof and groin-vaulted basilicas became prototypes for Christian churches (Fig. 1.3c).

One of the Gothic builders' main goals was to maximize the window area for a large, fire-resistant hall. By means of the inspired structural system of groin vaulting, they were able to

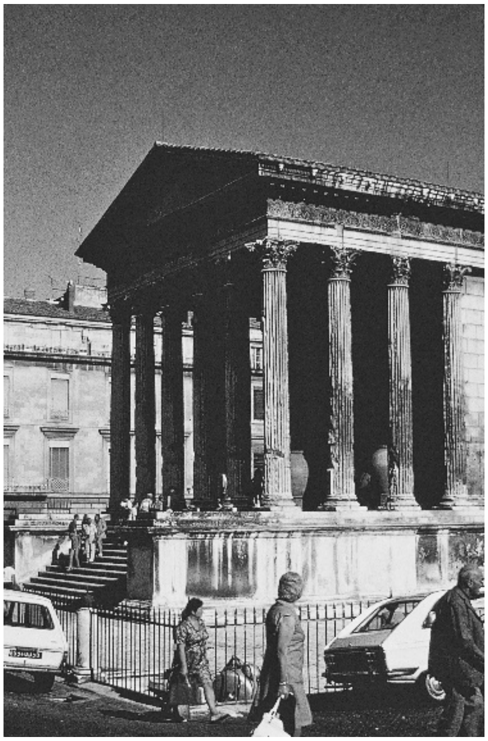


Figure 1.3a The classical portico has its functional roots in the sun- and rain-protected entrance of the early Greek megaron. Maison Carrée, Nîmes, France.

Figure 1.3b The classical revival style was especially popular in the South because it was suitable for hot climates.

Figure 1.3c Roman basilicas and the Christian churches based on them used clerestory windows to light the large interior spaces. The Thermae of Diocletian, Rome (A.D. 302), was converted by Michelangelo into the church of Santa Maria degli Angeli. (Photograph by Clark Lundell.)

send an abundance of daylight through stained glass windows (Fig. 1.3d).

The need for heating, cooling, and lighting had also affected the work of the twentieth-century masters such as Frank Lloyd Wright. The Marin County Civic Center emphasizes the importance of shading and daylighting. To give most offices access to daylight, the building consists of linear elements separated by a glass-covered atrium (Fig. 1.3e). The outside windows are shaded from the direct sun by an arcade-like overhang (Fig. 1.3f). Since the arches are not structural, Wright shows them hanging from the building.

Modern architecture prided itself on its foundation of logic. "Form follows function" was seen as much more sensible than "form follows some arbitrary historical style." However, "function" was usually interpreted as referring to structure or building circulation. Rarely did it refer to low energy usage, which was seen as a minor issue at best and usually was not considered at all. Although that belief was never logical, it is clearly wrong today since energy consumption is the number-one issue facing the earth.

Like Frank Lloyd Wright, Le Corbusier also felt strongly that the building itself should be effective in heating, cooling, and lighting. He included thermal comfort and energy as functions in his interpretation of "form follows function." His development of the brise-soleil (sunshades) will be discussed in some detail later. A feature found in a number of his buildings is the parasol roof, an umbrella-like structure covering the whole building. A good example of this concept is the Maison de l'Homme, which Le Corbusier designed in glass and painted steel (Fig. 1.3g).

Today, with no predominant style guiding architects, they occasionally use a mild form of revivalism. The buildings in Figure 1.3h use the classical portico for shading. Such historical adaptations can be more climate responsive than the "international style," which typically ignores the local climate. Buildings in cold climates can continue to benefit from

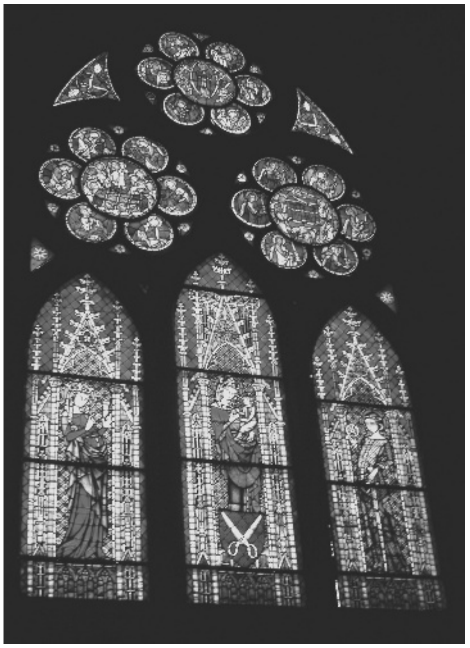


Figure 1.3d Daylight gained a mystical quality as it passed through the large stained glass windows of the Gothic cathedral made possible by groin vaulting. (Photograph by Clark Lundell.)

Figure 1.3e In the linear central atrium of the Marin County Civic Center, Frank Lloyd Wright used white surfaces to reflect light down to the lower levels. The offices facing the atrium have all-glass walls.

Figure 1.3f The exterior windows of the Marin County Civic Center are protected from direct sun by an arcade-like exterior corridor.

Figure 1.3g The Maison de l'Homme in Zurich, Switzerland, demonstrates the concept of the parasol roof. The building is now called Centre Le Corbusier. (Photograph by William Gwin.)

Figure 1.3h These postmodern buildings promote the concept of regionalism in that they reflect a previous and appropriate style of the hot and humid Southeast.

compactness, and buildings in hot and dry climates still benefit from massive walls and light exterior surfaces. Looking to the past in one's locality helps lead to the development of new and sustainable regional styles.

1.4 THE ARCHITECTURAL APPROACH TO SUSTAINABLE DESIGN

The sustainable design of heating, cooling, and lighting buildings can be more easily accomplished by understanding the logic of the three-tier approach to sustainable design (Fig. 1.4a). The first tier consists of all of the decisions that are made in designing any building. When the designer consistently thinks of minimizing energy consumption as these decisions are made, the building itself can accomplish about 60 percent of the heating, cooling, and lighting.

The second tier involves the use of natural energies through such methods as passive heating, passive cooling, and daylighting systems. The proper decisions at this point can reduce the energy consumption another 20 percent or so. Thus, the strategies in tiers one and two, both purely architectural, can reduce the energy consumption of buildings up to 80 percent. Tier three consists of designing the mechanical and electrical equipment to be as efficient as possible. That effort can reduce energy consumption another 5 percent or so. Thus, only 15 percent as much energy is needed as in a conventional building. That small amount of energy can be derived from renewable sources both on- and off-site. Table 1.4A shows some of the design topics that are typical at each of the three tiers.

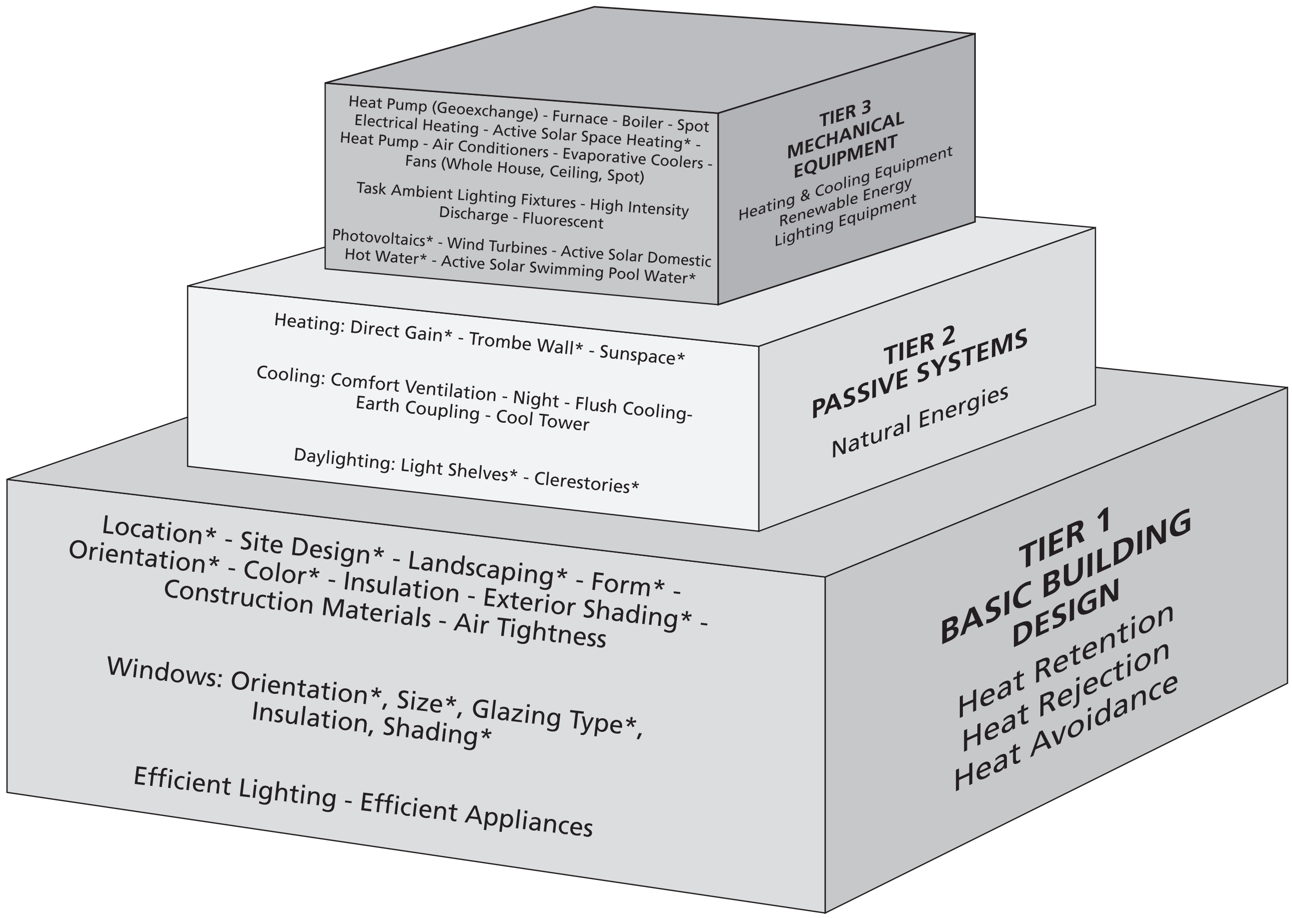


Figure 1.4a The three-tier approach to the sustainability design of heating, cooling, and lighting is shown. Tiers one and two are the domain of the architect, and proper design decisions at these two levels can reduce the energy consumption of buildings as much as 80 percent. All items with an asterisk are part of solar-responsive design. This image can be downloaded in color for free and used as a poster. It is available at www.heliodons.org.

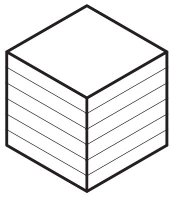
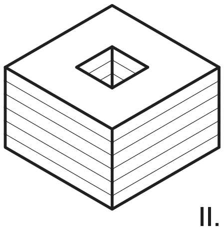
Table 1.4A The Three-Tier Design Approach

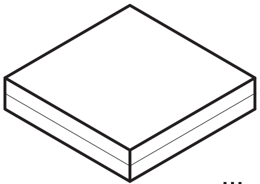
	Heating	Cooling	Lighting
Tier 1	*Conservation*	*Heat avoidance*	*Daylight*
Basic Building Design	1. Surface-to-volume ratio 2. Insulation 3. Infiltration	1. Shading 2. Exterior colors 3. Insulation 4. Mass	1. Windows 2. Glazing type 3. Interior finishes
Tier 2	*Passive solar*	*Passive cooling*	*Daylighting*
Natural Energies and Passive Techniques	1. Direct gain 2. Trombe wall 3. Sunspace	1. Evaporative cooling 2. Night-flush cooling 3. Comfort ventilation 4. Cool towers	1. Skylights 2. Clerestories 3. Light shelves
Tier 3	*Heating equipment*	*Cooling equipment*	*Electric light*
Mechanical and Electrical Equipment	1. Furnace 2. Boiler 3. Ducts/Pipes 4. Fuels	1. Refrigeration machine 2. Ducts 3. Geo-exchange	1. Lamps 2. Fixtures 3. Location of fixtures

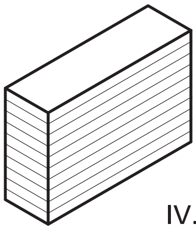
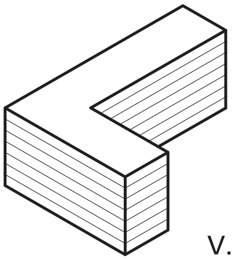
The heating, cooling, and lighting design of buildings always involves all three tiers, whether consciously considered or not. Unfortunately, in the recent past minimal demands were placed on the building itself to affect the indoor environment. It was assumed that it was primarily the engineers at the third tier who were responsible for the environmental control of the building. Thus, architects sometimes designed buildings that were at odds with their environment. For example, buildings with large glazed areas were designed for very hot or very cold climates. The engineers were then forced to design giant, energy-guzzling heating and cooling plants to maintain thermal comfort. Ironically, these mostly glass buildings had their electric lights on during the day, when daylight was abundant, because they were not designed to gather quality daylighting. As this shows, a building's energy consumption for heating, cooling, and lighting is mainly determined by the architect at the conceptual design stage.

In some climates, it is possible to reduce the mechanical equipment to zero. For example, Amory Lovins designed his home/office for the Rocky Mountain Institute in Snowmass, Colorado, where it is very cold in the winter and quite hot in the summer, to have no heating or cooling system at all. He used the strategies of tiers one and two to accomplish most of the heating and cooling, and he used photovoltaics, active solar, and very occasionally a wood-burning stove for any energy still needed.

Table 1.4B Building Form Implications

	Advantages	Disadvantages
 I.	• compactness to minimize surface area, thereby reducing heat gain/loss • minimum footprint on land • good for cold climates	• cannot be oriented to give most windows the ideal orientation of north and south • minimum potential for daylighting, passive solar, and passive cooling
 II.	• better for daylighting and natural ventilation than form I • more people have access to views, although some only to the atrium	• cannot be oriented to give most windows the ideal orientation of north and south • less compact than form I unless atrium is covered • larger footprint on land than form I

 III.	• daylighting for whole space if one story and daylighting for most if two stories
	• very high quality daylighting since it is mostly top lighting
	• very high potential for passive solar heating through south-facing clerestories
	• high potential for passive cooling through:
	  • roof vents for natural and forced ventilation
	  • solar chimneys
	  • direct evaporative cooling from roof
	• no vertical circulation needed if one story and little vertical circulation if two stories
		• very large footprint on land
		• very large surface-area-to-volume ratio
		• all windows cannot face the ideal orientation of north and south, but clerestories can

 IV.	• if site permits, all or most windows can face the ideal orientation of north and south • very high potential for daylighting • high potential for cross ventilation • very high potential for passive solar heating	• larger surface to volume ratio than either form I or II • if the site requires the long facades to face east and west, the building will perform poorly; cooling loads will be very high due to all or most windows facing east or west; quality daylighting will also be poor
 V.	• can fit on sites that may not work for form IV • good potential for daylighting especially for the windows facing north and south • very good potential for cross ventilation	• only some windows can face the ideal orientation of north and south • many windows will be facing the problematic orientations of east and west

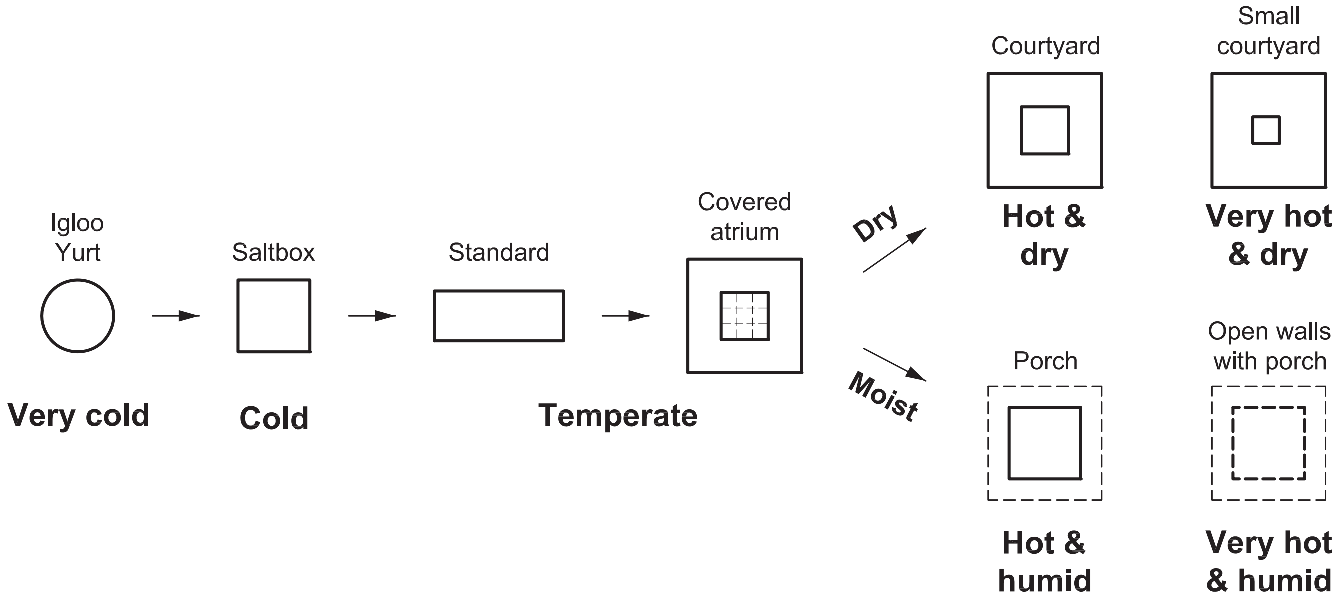


Figure 1.4b The ideal building form is greatly influenced by the local climate. The building form can minimize heat loss or gain, affect maximum daylighting, and maximize natural ventilation.

When it is consciously recognized that each of these tiers is an integral part of the heating, cooling, and lighting design process, buildings are improved in several ways: they can be less expensive because of reduced mechanical equipment and energy needs; they are usually also more comfortable because the mechanical equipment does not have to fight such giant thermal loads; and they are often more interesting because some of the money that is normally spent on the mechanical equipment is spent instead on the architectural elements. Unlike hidden mechanical equipment, features such as shading devices are a very visible part of the exterior aesthetic—thus, the name of this chapter is "Heating, Cooling, and Lighting as Form-Givers in Architecture."

Table 1.4B outlines the advantages and disadvantages of the main massing schemes. Figure 1.4b illustrates how massing relates to climate in traditional building. The appearance of a building is also impacted by surface treatments such as shading devices, balconies, and green walls, which further impact the heating, cooling, and lighting of a building.

1.5 DYNAMIC VERSUS STATIC BUILDINGS

Is it logical that a static system can respond to a dynamic problem? A building experiences a very dynamic environment: cold in the winter, hot in the summer, sunny one day, cloudy the next, sunshine from the east in the morning and west in the afternoon, and the angle of sunrays changing minute by minute and day by day. Nevertheless, most buildings are static except for the mechanical and electrical equipment. Would it not make more sense for the building itself to change in response to the environment? The change can occur continuously over a day as, for example, a movable shading device that extends when it is sunny and retracts when it is cloudy. Alternatively, the change could be on an annual basis, whereby a shading device is extended for the summer and retracted for the winter, much like a deciduous tree. The dynamic aspect can be modest, as in movable shading devices, or it can be dramatic, as when the whole building rotates to track the sun (Figs. 9.15b to 9.15d). Since dynamic buildings are more energy efficient than static ones, it is likely that all future buildings will have dynamic facades. A major objection has been the difficulty of maintaining movable systems exposed to the weather. However, the present reliability of cars shows that movable systems can be made that need few if any repairs over long periods of time. With good design and materials, exposed building systems have become extremely reliable even with exposure to salt water and ice in the winter. Perhaps the modern airplane is an even better example of a reliable movable system than the automobile. Since no one shape of wing is ideal for all stages of flight, modern passenger jets change the shape of their wings as conditions change (Fig. 1.5). If planes can do this flying at hundreds of miles per hour in all weather conditions, certainly a building on the ground moving zero miles per hour can also have extremely reliable dynamic facades.

Not only will dynamic buildings perform much better than static buildings, but they will also provide an exciting aesthetic, the aesthetic of change. Numerous examples of dynamic buildings are included throughout the book, but most will be found in the chapters on shading, passive cooling, and daylighting.

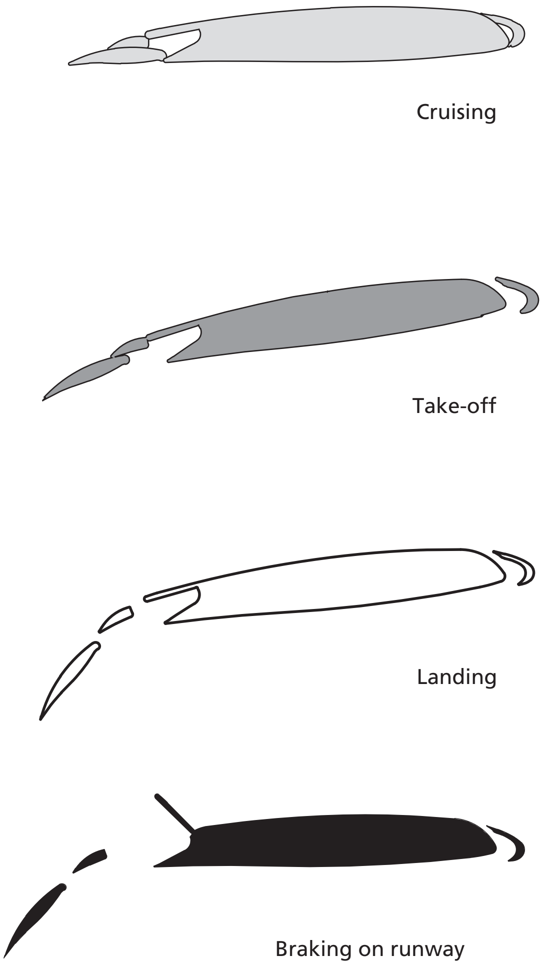


Figure 1.5 Dynamic building facades are often rejected in the belief that exposed movable systems are doomed to fail. The changing shape of the wings on a jet airliner indicates that movable exterior systems can be completely reliable even with snow, ice, rain, and winds of several hundred miles per hour.

1.6 RESILIENT DESIGN

We should design buildings not only to sustain the planet but also to sustain its occupants during an emergency. For example, houses on stilts had a better chance to survive the storm surges of Hurricanes Katrina and Sandy than the typical houses built close to the ground.

We rely on our buildings' mechanical systems and imported energy supplies to keep us warm in the winter, cool in the summer, and out of the dark all year. Yet, in January 1998, an ice storm in eastern Canada left four million people without power for weeks during the height of the winter. Heat waves in the United States and Europe are becoming more severe and frequent. Is it wise to rely on mechanical equipment and uninterrupted energy supplies? There is a growing conviction that buildings should be designed for passive survivability, today more commonly called **resilience**. Others prefer the word "adaptive" because we must now design buildings that can adapt to a changing climate.

For a building to be resilient it must be able to operate at least for a while without energy or water inputs from the outside, and it must be able to survive storms and floods. Because we heat, cool, and light buildings with energy, this book focuses only on resilience related to energy. Fortunately, sustainable buildings are more resilient because they require much less energy to operate through efficiency, passive design, and possibly on-site energy production. When power or other energy supplies are not available, resilient (i.e., sustainable) buildings will get only moderately cold in the winter and moderately hot in the summer, and they will be illuminated with daylight most of the day. Thus, from an energy standpoint resilience is just another argument for sustainable design.

1.7 BIOPHILIC DESIGN

The biophilia hypothesis states that human beings have a need for connection with living things such as pets, wild animals, plants, and views of nature. Recent research in neuroscience and endocrinology support what social research and traditional knowledge have long indicated: experiencing nature has significant benefits. Consequently, bringing nature into, onto, and around buildings is not a luxury but is instead important for health, productivity, energy conservation, and, crucially, as this book will show, aesthetics (Colorplates 27, 30, and 34).

1.8 COLOR AND ORNAMENTATION

White is the greenest color outdoors as well as indoors. White roofs have half the heat gain of black roofs. White walls also reduce heat gain, and in urban canyons they deliver more daylight to lower floors and the streets. White cities will experience cooler heat islands than typical cities. Indoors, white ceilings and walls reflect precious daylight and electric lighting. White is unquestionably the most sustainable color.

Polished metal and glass are also used as exterior wall finishes, but both materials perform more poorly than flat white. All-glass facades are popular, but without shading devices or light shelves they have disadvantages besides the most serious of poor energy performance. Whatever sunlight is not transmitted indoors or absorbed by the glass is reflected like a mirror to adjacent buildings and the ground below. This reflected sunlight causes serious glare and overheating where it was not expected, such as on the north facade of neighboring buildings. Flat white walls, on the other hand, reflect some solar radiation back into space and the rest becomes a source of quality daylight for other buildings and the ground, which is especially important in urban areas. Glass buildings are also responsible for killing millions of birds each year. Because all-glass building facades are not energy efficient, they are not sustainable. The aesthetic of a facade should come from limited glazing, shading devices, light shelves, and ornamentation.

At its peak influence, modern architecture had no tolerance for ornamentation. Instead the emphasis was on form. Basing the aesthetic only on complex forms has strong energy implications, since more compact buildings are generally more sustainable. They require less material to build and less energy to operate for their lives. Thus, compact designs with ornamentation, small patches of color, or murals usually produce the most sustainable design (Fig. 1.8 and Colorplate 25). Fortunately, some types of ornamentation are again acceptable. The role of ornamentation in architecture is discussed by Brent C. Brolin in his book *Architectural Ornament: Banishment & Return*.

Figure 1.8 Exterior murals have become quite popular, especially in cities where the demolition of some buildings expose property line walls that were never meant to be seen. A type of mural called trompe l'oeil creates architectural illusions, as in this Chicago building. Such murals create "architecture" with a minimum of materials and energy.

1.9 ENERGY AND ARCHITECTURE

The heating, cooling, and lighting of buildings are accomplished by either adding or removing energy. Consequently, this book is about the manipulation and use of energy. In the 1960s, the consumption of energy was considered a trivial concern. For example, buildings were sometimes designed without light switches because it was believed that it was more economical to leave the lights on continuously. Additionally, the most popular air-conditioning equipment for larger buildings was the terminal reheat system, in which the air was first cooled to the lowest level needed by any space and then reheated as necessary to satisfy the other spaces. The double use of energy was not considered an important issue.

The building in which the author taught architecture for thirty years was built in 1974. At that time, the "rational economic decision" was to put no insulation in the walls since it would not pay for itself quickly enough. Today we think that decision was idiotic. Will our "rational economic decisions" today seem just as shortsighted thirty years from now?

Buildings now use about 40 percent of all the energy consumed in the United States for their operation. To construct them takes another 8 percent of all the energy. Clearly, then, the building industry has a major responsibility in the energy picture of this planet. Architects have both the responsibility and the opportunity to design in an energy-conserving manner.

The responsibility is all the greater because of the effective life of the product. Automobiles last only about ten years, and so any mistakes will not burden society too long. Most buildings, however, should have a

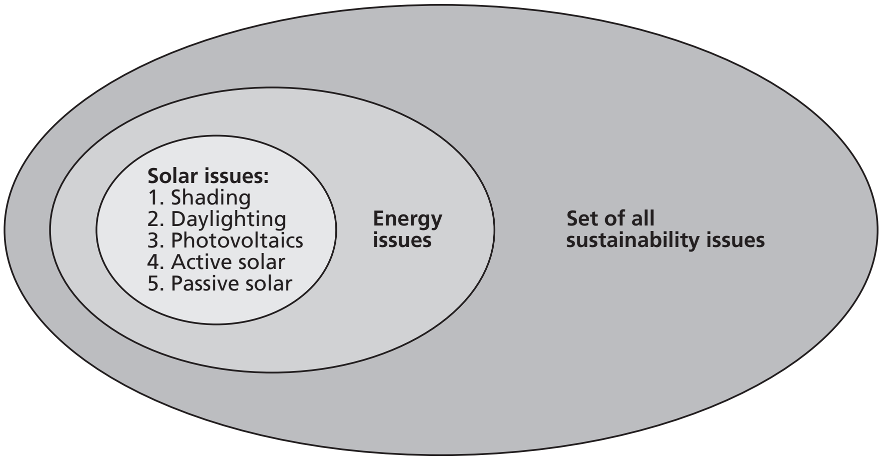


Figure 1.9 Sustainable design includes a large set of issues, and the energy issues are a large subset thereof. The solar issues are a much larger subset of the energy issues than most people realize. This image can be downloaded for free and used as a poster. It is available at www.heliodons.org.

useful life of at least fifty years. The consequences of design decisions now will be with us for a long time.

When people realize that the fossil energy that buildings consume causes global warming, the immediate reaction is to support the production of renewable energy that causes no pollution and no global warming. The quickest, most effective, and least expensive ways to fight global warming, however, come from using less energy.

Unfortunately, the phrase "energy conservation" has negative connotations. It makes one think of shortages and discomfort. Yet architecture that conserves energy can be comfortable, sustainable, humane, and aesthetically pleasing. It can also be less expensive than conventional architecture. Operating costs are reduced because of lower energy bills, and first costs are often reduced because of the smaller amount of heating and cooling equipment that is required. To avoid negative connotations, the more positive and flexible phrases "energy-efficient design" or "energy-conscious design" have been adopted to describe a concern for energy conservation in architecture. Energy-conscious design yields buildings that minimize the need for expensive, polluting, and nonrenewable energy. Because of the benefit to planet Earth, such design is now called sustainable, green, or low carbon.

Because of global warming, it is now widely recognized that reducing the energy appetite of buildings is the number one green issue. As Figure 1.9 illustrates, the energy issues are a very large subset of all of the sustainability issues. Figure 1.9 also demonstrates that the solar issues are a surprisingly large subset of the energy issues. One reason for this is that "solar" refers to many strategies: photovoltaics (solar cells), active solar (hot water), passive solar (space heating), daylighting, and shading. Although shading is the reverse of collecting solar energy, it is one of the most important solar design strategies, because it can save large amounts of air-conditioning energy at low cost.

1.10 CLIMATE AND ARCHITECTURE

In extreme climates, as are found in Russia and Indonesia, it is clear whether heating or cooling are the architect's main concern, but in temperate climates, buildings must be designed for both heating and cooling (Fig. 1.10a). However, the energy used and the money spent on heating or cooling are rarely equal in temperate climates. Figure 1.10b shows the heating and cooling degree-days, which predict the energy required for heating and cooling, for four

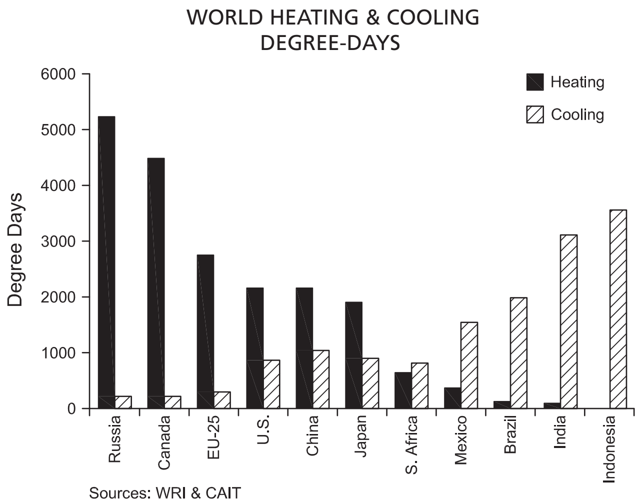


Figure 1.10a Heating and cooling degree-days predict how much energy (money) is required during the heating and cooling seasons. They can also be used to help set design priorities to achieve low energy climate responsive buildings.

American cities. For an explanation of degree-days, see Section 5.6(k).

Some aspects of building design are equally valid for both the heating and cooling loads. Insulation levels and an east-west building orientation reduce energy requirements in both summer and winter. However, other aspects of building design favor one season over another. For example, high ceilings are appropriate for a cooling-dominated climate while low ceilings are better for a heating-dominated climate. Because a building designed for its climate will be more energy efficient, it is important for the architect to know if heating or cooling loads dominate. For this reason, Chapter 5 gives detailed climate information for seventeen climate regions in the United States and Canada.

The problem of designing for a climate is further complicated because the heating and cooling loads vary with building type in the same climate. For example, an office building will have smaller heating and larger cooling loads than a house in the same climate. For simplicity, this book places building types into one of two categories: "internally dominated" buildings such as large office buildings and "envelope-dominated" buildings such as houses.

Because most people in the world live in hot climates, and because they are becoming wealthier, the use of air-conditioning is growing exponentially (Fig. 1.10c). Even in the United States,

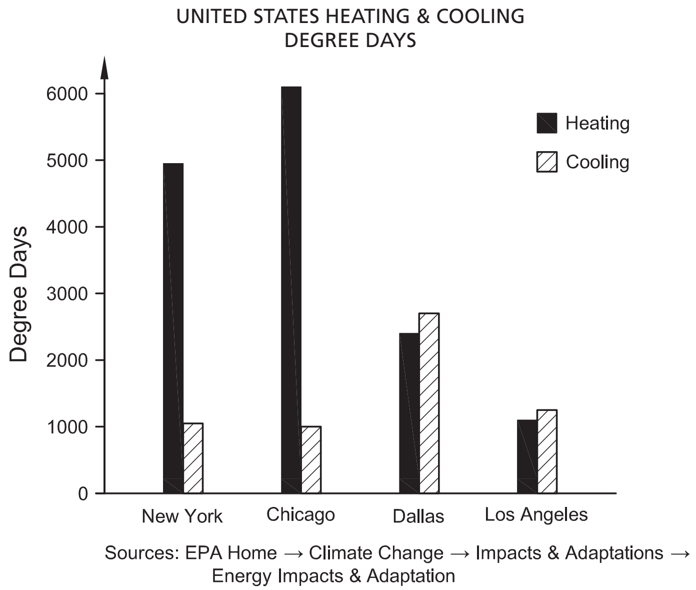


Figure 1.10b It may not be surprising that buildings in New York and Chicago need to emphasize the heating season, but it may be surprising that heating is also important in Dallas and Los Angeles. Note that the heating and cooling degree-days in those cities are almost equal.

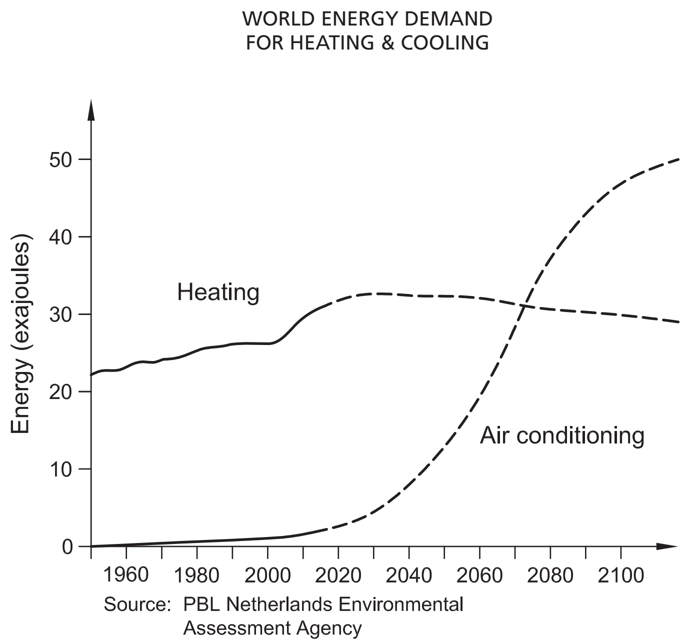


Figure 1.10c Because most people live in hot climates and because the number of people who can afford air conditioners is increasing rapidly, the energy needed for cooling is increasing exponentially. Thus, heat avoidance strategies such as shading will dominate future world architecture.

the energy for cooling is increasing as more people can afford it and as more people move to the South. To reduce the growth of energy consumption for air-conditioning, architects must focus on heat avoidance strategies such as shading and light colors.

1.11 SUSTAINABILITY CODES AND VOLUNTARY PROGRAMS

All over the world, codes and programs have been put in place to impel buildings to be low energy and low carbon. In the United States, the main codes are ASHRAE 90.1 and 189.1, the International Energy Conservation Code (IECC), and the International Green Construction Code (IGCC). However, it is mostly up to states and municipalities to pass laws that make codes mandatory.

To supplement the impact of codes, a number of programs have been created to spur the movement to low energy buildings. The most famous by far is Leadership in Environmental and Energy Design (LEED), created and run by the United States Green Building Council (USGBC). With each new version, the LEED program increases its focus on creating low energy buildings. The Green Building Initiative's Green Globes program is an alternative to LEED in the United States. Passive House is a rigorous program most appropriate to cold climates, and maybe the most demanding program of all is the Living Building Challenge.

The Environmental Protection Agency (EPA) of the United States government administers the voluntary **Energy Star** program, which produces ratings for products and appliances. The program also promotes efficient building methods.

Another method for encouraging sustainable design is to give awards. Every year the American Institute of Architecture Committee on the Environment (AIA/COTE) announces the "Top Ten" from all the submissions of sustainable design it receives. Energy responsiveness is an important criterion.

Perhaps the most important organization for making buildings adapt to climate change is Architecture 2030. In 2006 it issued the 2030 Challenge, which would reduce greenhouse gas emissions of buildings to zero by 2030 in steps—70 percent reduction by 2015, 80 percent reduction by 2020, 90 percent reduction by 2025, and 100 percent reduction by 2030. The 2030 Challenge has been adopted by the AIA; the U.S. Council of Mayors; the National Association of Governors; the U.S. Green Building Council; the U.S. government, which requires all new and renovated federal buildings to meet the challenge (2007 Energy Independence and Security Act); and numerous other governmental, for-profit, and nonprofit organizations.

The reader is encouraged to visit Architecture 2030s website: www.architecture2030.org.

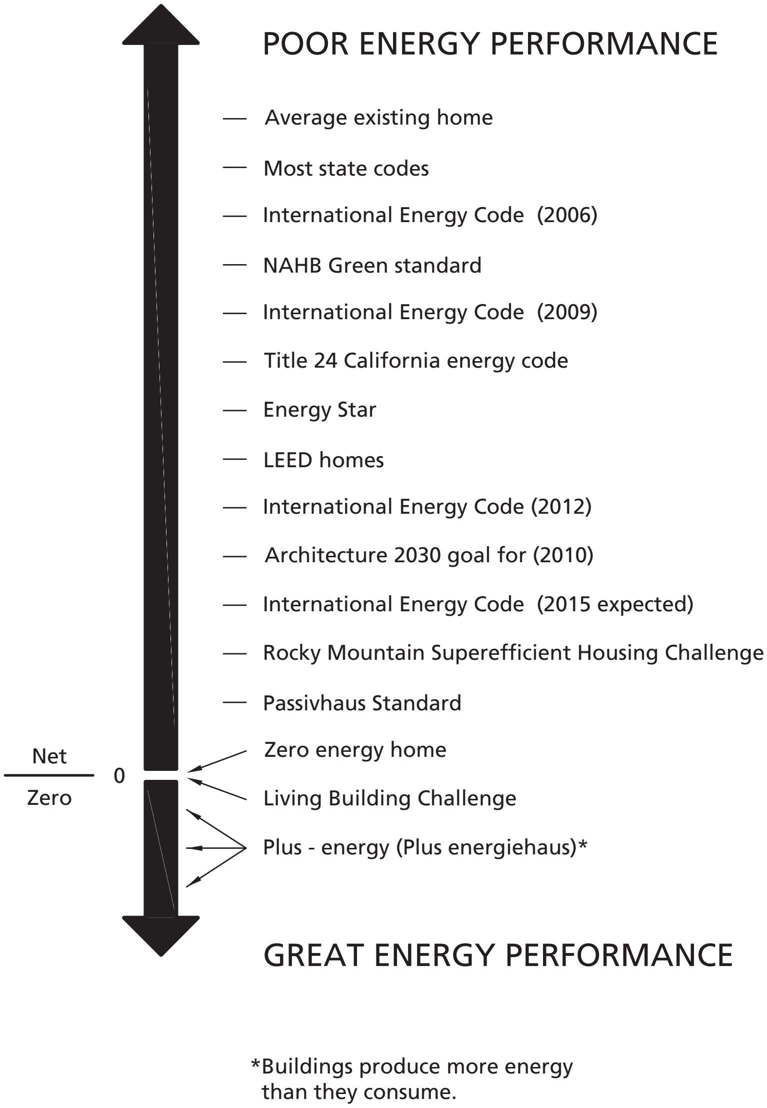


Figure 1.11 The energy performance of buildings constructed under the influence of energy codes and voluntary programs varies greatly, as this diagram indicates. The ranking is based on the Home Energy Rating System (HERS) index. (After the Rocky Mountain Institute.)

The combination of codes and voluntary programs is having a profound effect on how America builds. See Figure 1.11 on how the various codes and programs compare in achieving great energy performance.

1.12 INTEGRATED DESIGN

Buildings have become too complex for any one individual to design, and the need for sustainability has further increased the complexity of buildings. The traditional linear design process, where the various building professions make their contributions sequentially, is not suited to creating high-performing buildings (Fig. 1.12a). In such a design process, the various building systems are not able to work together most efficiently. Instead, they are often competing with one another. For example, an all-glass facade will result in a huge energy guzzling mechanical system. In the sequential design process, it is usually too late to redesign the glass facade when the mechanical equipment is being designed and found to be excessively large. In the integrated whole-building design process, on the other hand, the needs of the various systems are considered at the very beginning of the architectural design so that they can all work

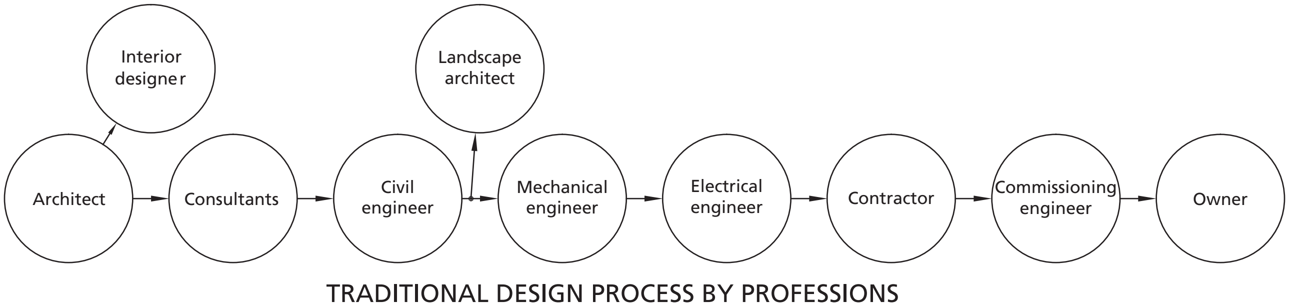


Figure 1.12a In the traditional linear design process, the various building design professionals work on a project sequentially. Unfortunately, this method does not promote the design of high-performing sustainable buildings.

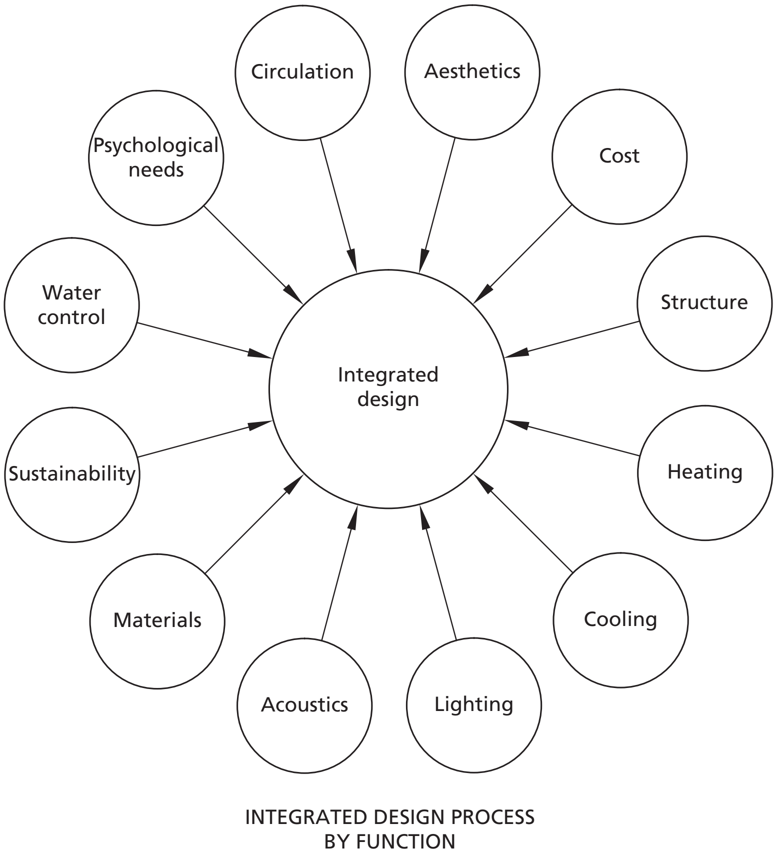


Figure 1.12b In the whole-building integrated design process, the needs of the various building systems are considered from the very beginning of the design process. The resultant designs are then harmonious with the needs of the various systems to create high-performance buildings. It also makes possible synergies that further improve the performance and sustainability of a project.

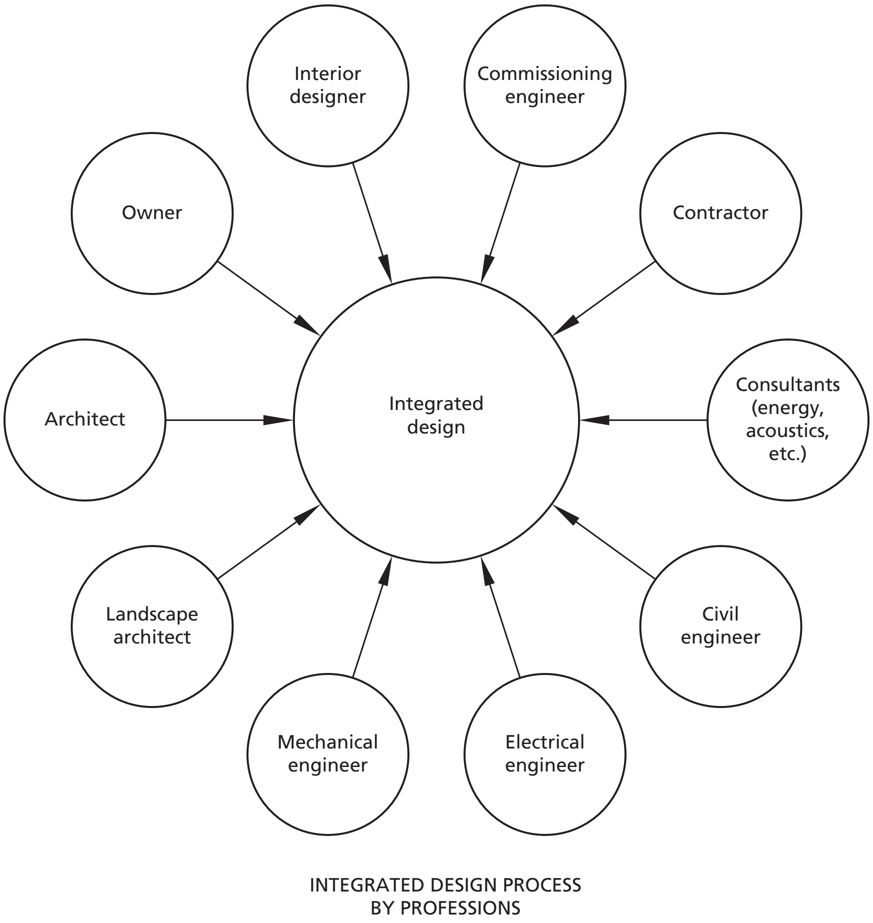


Figure 1.12c The integrated design process requires the key building professionals to work as a team even before the first line on the first drawing is made. The architect is then able to create a whole-building design with high performance.

together to create a high-performance building (Fig. 1.12b). For example, the heating and cooling loads on the mechanical equipment influence not only the facade design but also the orientation and form of the building. For the various building systems to work together, the appropriate professionals must form a team that together creates the design (Fig. 1.12c). The team must start meeting before the first line is drawn because that first line has so many significant consequences.

1.13 DECISION MAKING

The design process is essentially a decision-making process based on asking the right questions in the right order. For example, the first line in the first drawing should be made only after the many consequences of the building's location, orientation, and length have been considered. That first line will have great impact on the heating, cooling, and lighting energy that that building will consume. The wrong orientation of a building, for instance, will have great negative consequences later on when design decisions are made about shading, passive solar, and daylighting.

The set of decisions necessary to create a sustainable building can be divided into three subsets: decisions for which a clear-cut best answer exists; decisions which are not clear-cut but modeling can give the best answer; and decisions which are essentially subjective (Fig. 1.13). The architect and other building professionals should be aware of the issues that are clear-cut, and they should start the design process using these proven ideas. To use an extreme example, in designing a car the decision that the wheels should be round must come at the beginning. It is not necessary to model square wheels to find out if they are the best choice. Indeed, it is not appropriate to use square wheels even if they are visually more consistent with a square body. The shape of the wheels is not open to a subjective decision. Similarly, to create high-performance sustainable buildings most subjective decisions should made only after the important objective decisions have been considered.

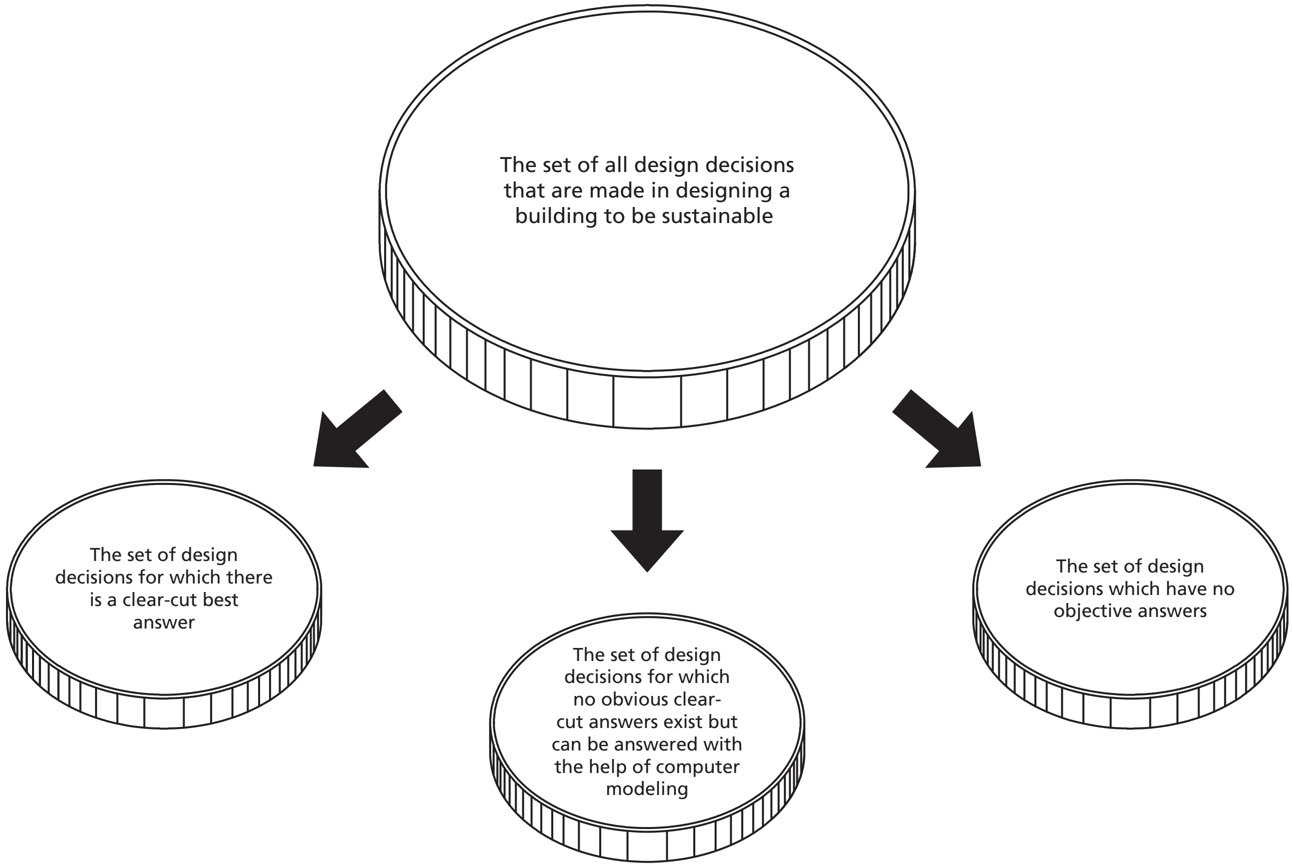


Figure 1.13 To create a high-performing, sustainable building, the decisions made at the beginning of the schematic design stage are critical. The decisions based on hard, well-known principles should be made first, and the decisions based on subjective principles should be made last.

1.14 CONCLUSION

The following design considerations have an impact on both the appearance and the heating, cooling, and lighting of a building: form, orientation, compactness (surface-area-to-volume ratio), size and location of windows, and the nature of the building materials. Thus, when architects draw the first line at the schematic design stage to design a building, they simultaneously start the design of the heating, cooling, and lighting. Because of this inseparable relationship between architectural features and the heating, cooling, and lighting of buildings, we can say that the environmental controls are form-givers in architecture.

It is not just tiers one and two that have aesthetic impact. The mechanical equipment required for heating and cooling is often quite bulky, and because it requires access to outside air, it is frequently visible on the exterior. The lighting equipment, although less bulky, is even more visible. Thus, even tier three is interconnected with the architectural aesthetics, and, as such, must be considered at the earliest stages of the design process.

KEY IDEAS OF CHAPTER 1

1. Both vernacular and formal architecture were traditionally designed to respond to the heating, cooling, and lighting needs of buildings.
2. Borrowing appropriate regional design solutions from the past (e.g., the classical portico for shade) can help in creating sustainable buildings.
3. In the twentieth century, engineers dealing with mechanical and electrical equipment had the primary responsibility for the environmental needs of buildings. Architects had provided for these needs in the past, and they can again be important players in the future.

4. The heating, cooling, and lighting needs of buildings can be designed by the three-tier approach:

    TIER ONE: the basic design of the building form and fabric (by the architect)
    TIER TWO: the design of passive systems (mostly by the architect)
    TIER THREE: the design of the mechanical and electrical equipment (by the engineer).

5. Buildings use about 40 percent of all the energy consumed in the United States. Their construction takes another 8 percent.
6. Currently, the dynamic mechanical equipment responds to thecontinually changing heating, cooling, and lighting needs of a building. There are both functional and aesthetic benefits when the building itself is more responsive to the environment (e.g., movable shading devices). Buildings should be dynamic rather than static.
7. Sustainable buildings also provide resilience ("passive survivability") in case of power outages or high fuel costs.
8. Sustainable buildings should also be adaptive by anticipating a more severe climate due to global warming.
9. Sustainable buildings should consider biophilia for both functional and psychological reasons.
10. White is the greenest color. Roofs and walls should be white in order to create cooler buildings and cooler cities.
11. Because a compact "shoebox" building is often the most sustainable form, color and ornamentation should be used to create interest.
12. Energy codes are necessary to make most buildings more energy efficient. Voluntary programs like LEED are helping to change the worldview of the building industry.
13. The integrated whole-building approach to design creates much higher performing, more sustainable buildings.
14. The design process is a decision-making process. The early decisions in the process are the most important because they affect the available options later on.
15. Because of global warming, it is imperative that buildings use less energy and achieve zero greenhouse gas emissions by 2030.
16. There is great aesthetic potential in energy-conscious architecture.

Resources

Further Reading

See the Bibliography in the back of the book for full citations.

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