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 has always reflected the culture, climate, and resources of the time and place. Eventually, as new forces emerged, architecture moved to its next stage. During the Renaissance, for example, the main influence was the rediscovery of the classical world. What is the predominant influence on architecture 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 us to a sustainable future.

Sustainable architecture can be achieved by using "the best of the old and the best of the new." By using modern science, technology, and ideas of aesthetics combined with traditional ideas that responded to human needs, regionalism, and climate, a new architecture is being created. Such architecture will be richer 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.

Sustainability covers many issues, but none is as important as energy. 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 per cent for the operation of buildings and 8 percent for the construction of buildings (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, or we must do both. 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 unimaginative 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 build buildings that use 80 percent less energy than the standard new building. Presently, there are architects around the world designing "zero-energy buildings." Such buildings are designed to use as little energy as possible, with the small remaining load being met by renewable energy such as photovoltaics (Fig. 1.1b). We have the *know-how* (see Sidebox 1.1); all we need is the *will*.

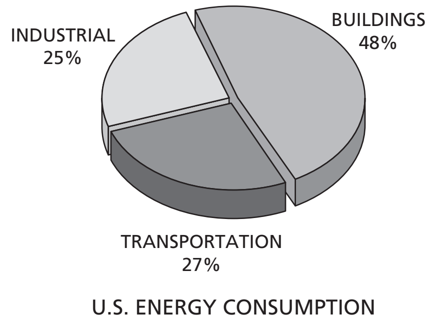

Figure 1.1a Buildings are the main cause of global warming because they use about 48 percent of all energy. Of that 48 percent, about 40 percent is for operating the buildings (heating, cooling, lighting, computers, etc.) and about 8 percent is for their construction (creating materials transportation,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

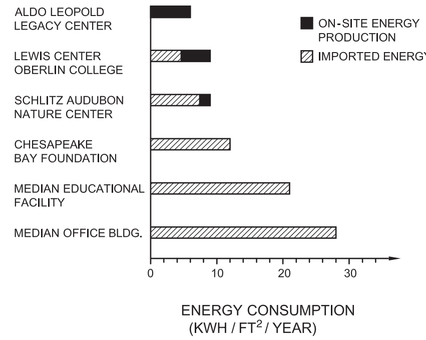

Figure 1.1b The good news is that buildings do not have to use climate-changing fossil fuels. Over the years, we have learned how to design buildings so energy efficient that we can now build zero-energy buildings. The small amount of energy that they still need can be supplied by renewable sources such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

SIDEBOX 1.1

Characteristics of a Zero-Energy House

- 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 heating
- Active solar domestic hot water
- High-efficiency appliances
- High-efficiency electric lighting
- High-efficiency heating and cooling system (e.g., earth-coupled heat pump)
- Photovoltaics on roof that produce the small amount of electricity still needed

This book was written to help the architect 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. Traditional architecture, which used little if any energy, is presented for ideas and inspiration. Folk or indigenous buildings usually responded to their climate, their locality, and their culture, as the next section shows.

1.2 VERNACULAR AND REGIONAL ARCHITECTURE

One of the main reasons for regional differences in architecture is the response to climate. If we look at buildings in hot and humid climates, in hot and dry climates, and in cold climates, we find that they are quite different from one another.

In hot and dry climates, one usually finds massive walls 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, consequently, are available 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. Although temperatures are lower, the high humidity creates great discomfort. The main relief comes from moving air across the skin to increase the rate of evaporative cooling. Although the water vapor in the air weakens the sun, direct solar radiation is still very undesirable. 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 not an advantage. Buildings are, therefore, usually made of lightweight wood construction. High ceilings permit larger windows and allow the air to stratify. As a result, people inhabit the lower and cooler air 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 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).

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).

And finally, in a predominantly cold climate, we 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 feet). 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.

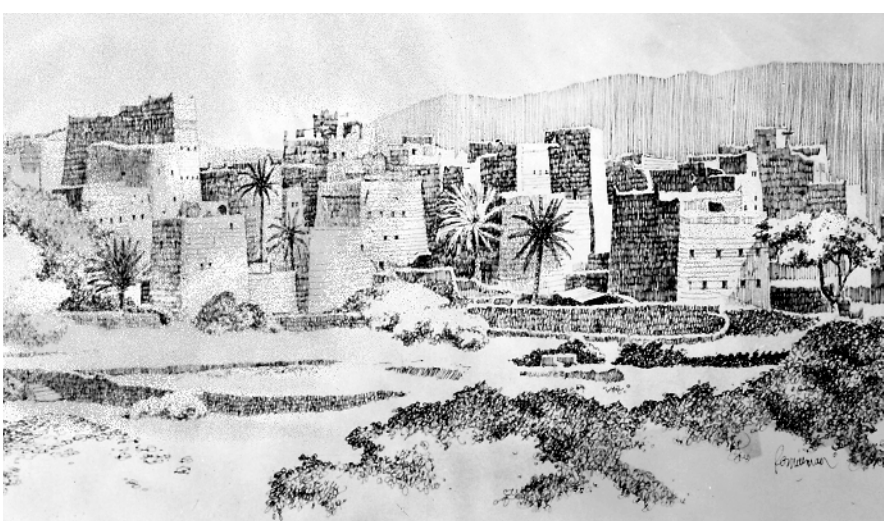

Figure 1.2a Massive construction, small windows, and light colors are typical in hot and dry climates, as in this Yemeni village. It is also common, in such climates, to find flat roofs and buildings huddled together for mutual shading. (Drawing by Richard Millman.)

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 the windows, as well as to create cool outdoor living spaces. The white color and roof monitor are also important in minimizing summer overheating.

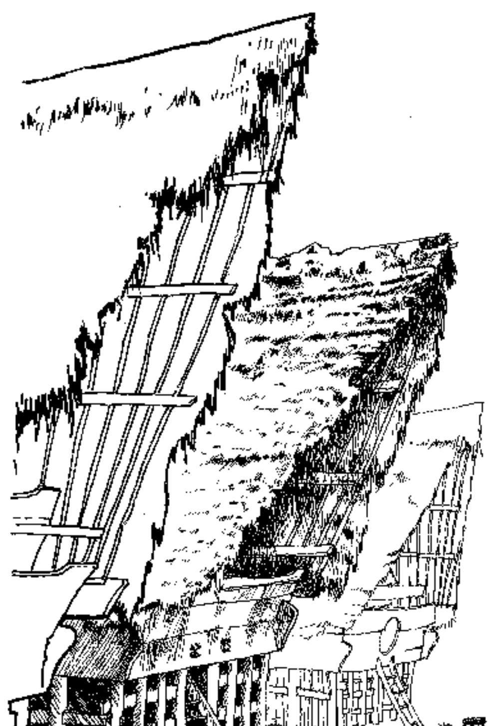

Figure 1.2c In hot and humid climates, such as Sumatra, Indonesia, native buildings are often raised on stilts and have high roofs with open gables to maximize natural ventilation.

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. (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.

1.3 FORMAL ARCHITECTURE

Not only vernacular structures but also buildings designed by the most sophisticated architects have responded to the need for environmental control. 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 not only on aesthetic but also on practical grounds. There is hardly a better way to shade windows, walls, and porches than with large overhangs supported by colonnades or arcades (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 an inspired structural system, they sent an abundance of daylight through stained glass (Fig. 1.3d).

The need for heating, cooling, and lighting has also affected the work of the twentieth-century masters, such as Frank Lloyd Wright. The Marin County Court House 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, Frank Lloyd Wright shows them hanging from the building.

Modern architecture prided itself on its foundation of logic. "Form follows function" was seen as much

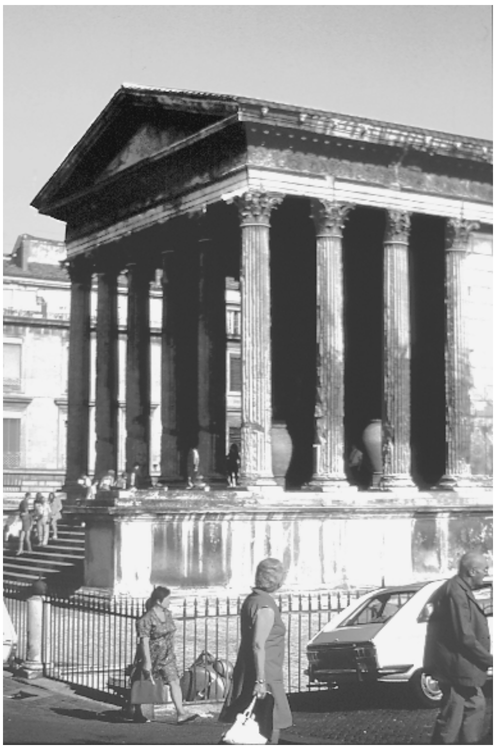

Figure 1.3a The classical portico has its functional roots in the sun- and rain-protected entrance of the early Greek megaron. (Maison Carée, Nimes, France.)

Figure 1.3b The classical revival style was especially popular in the South because it was very 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 (302 A.D.), was converted by Michelangelo into the church of Saint Maria Degli Angeli. (Photograph by Clark Lundell.)

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 but usually was not considered at all. Although that belief was never logical, it is clearly wrong today since energy is the number one issue facing the earth.

One exception was Le Corbusier, who also felt strongly that the building should be effective in heating, cooling, and lighting itself. His development of the "brise soleil" 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 d'Homme," which Le Corbusier designed in glass and painted steel (Fig. 1.3g).

Today, with no predominant style guiding architects, revivalism is common. The buildings in Fig. 1.3h use the classical portico for shading. Such historical adaptations can be more climate responsive than the "international style," which often ignores the local climate. Buildings in cold climates can continue to benefit from 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 will lead to the development of a new and sustainable regional style.

1.4 THE ARCHITECTURAL APPROACH

The sustainable design of heating, cooling, and lighting buildings can be accomplished in three tiers (Fig. 1.4). The first tier is the architectural design of the building itself to minimize heat loss in the winter, to minimize heat gain in the summer, and to use light efficiently. Poor decisions at this point can easily double or triple the size of the mechanical equipment and energy eventually needed. On the other hand, making

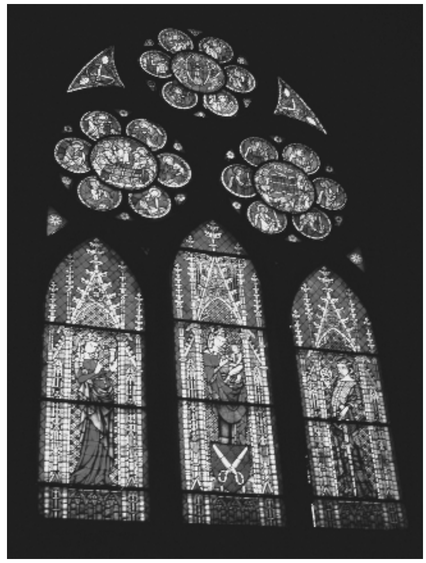

Figure 1.3d Daylight was given a mystical quality as it passed through the large stained-glass windows of the Gothic cathedral. (Photograph by Clark Lundell.)

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

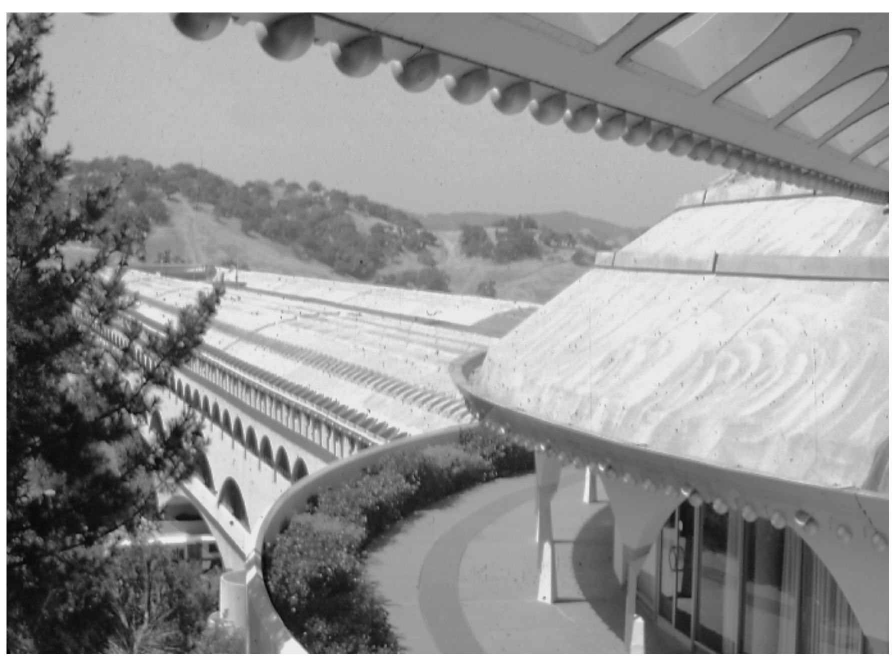

Figure 1.3f The exterior windows of the Marin County Court House are protected from direct sun by an arcade-like exterior corridor.

Figure 1.3g The "Maison d'Homme" in Zurich, Switzerland, demonstrates well the concept of the parasol roof. The building is now called "Centre le Corbusier." (Photograph by William Gwinn.)

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.

the right design choices in tier one can reduce the energy consumption of buildings as much as 60 percent.

The second tier involves the use of natural energies through such methods as passive heating, cooling, and daylighting systems. The proper decisions at this point can reduce the energy consumption another 20 percent. Thus, the strategies in tiers one and two, which are both purely architectural, can reduce the energy consumption of buildings up to 80 percent. Tier 3 consists of designing the mechanical equipment to be as efficient as possible. That effort could reduce energy consumption another 8 percent. Thus, only 12 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 1.4 shows some of the design topics that are typical at each of the three tiers.

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

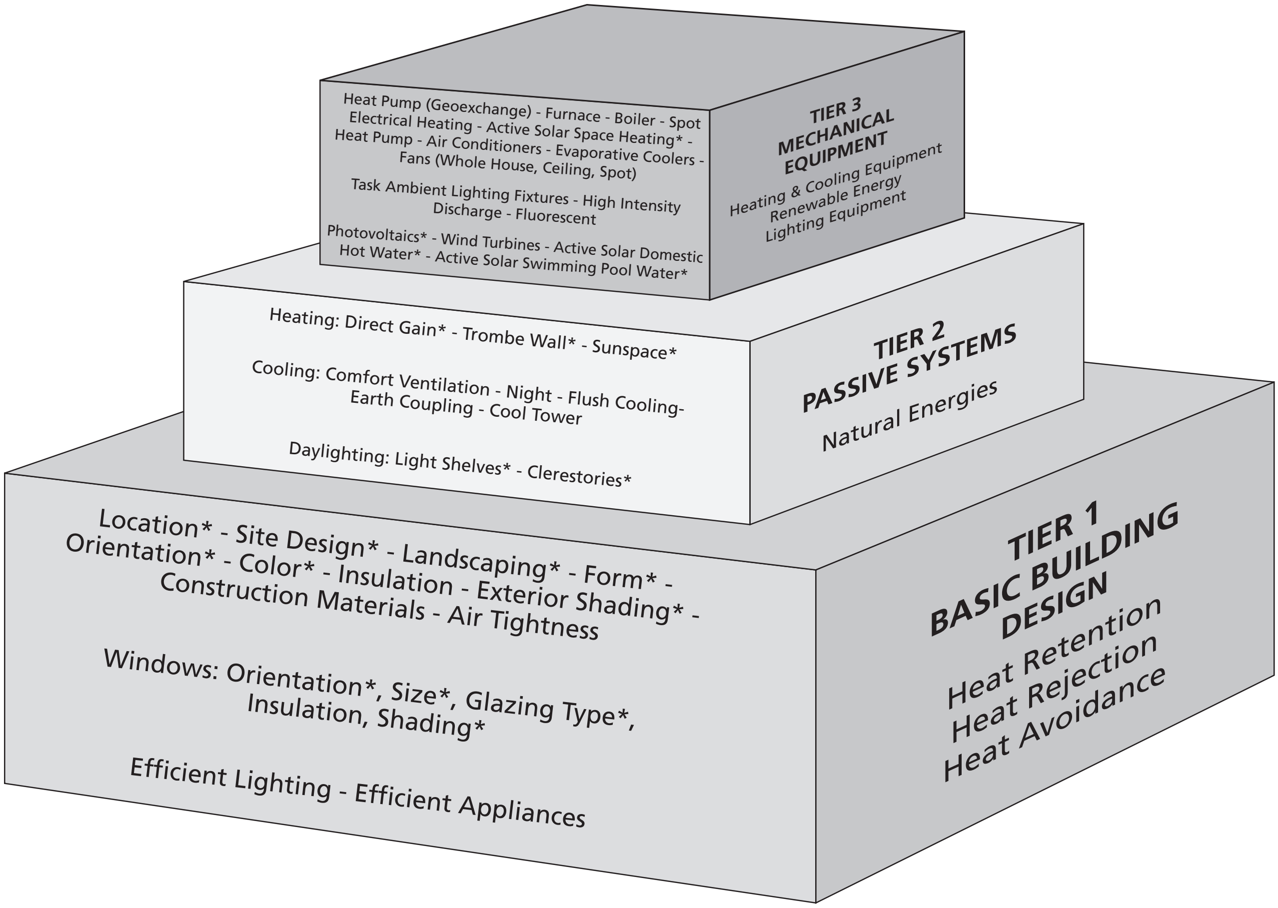

Figure 1.4 The three-tier approach to the sustainability design of heating, cooling, and lighting is shown. Tiers one and two are the domain of the architect, and proper design decisions at these two levels can reduce the energy consumption of buildings as much as 80 percent. All items with an asterisk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

Table 1.4 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	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

were responsible for the environmental control of the building. Thus, architects, who were often indifferent to the heating, cooling, and lighting needs of buildings, 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. The size of the mechanical equipment can be seen as an indicator of the architect's success, or lack thereof, in using the building itself to control the indoor environment.

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 and active solar for any energy still needed.

When it is consciously recognized that each of these tiers is an integral part of the heating, cooling, and lighting design process, the buildings are improved in several ways. The buildings are often 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. Furthermore, the buildings 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."

1.5 DYNAMIC VERSUS STATIC BUILDINGS

Contemporary buildings are essentially static with a few dynamic parts, such as the mechanical equipment, doors, and sometimes operable windows. On the other hand, smart, sustainable buildings adapt to their changing environments. This 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 during the summer and retracted in 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. 9.16b to 9.16d). Not only will dynamic buildings perform much better than static buildings, but they also will 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.

1.6 PASSIVE SURVIVABILITY

We should design buildings not only to sustain the planet but also to sustain us during an emergency. For example, houses on stilts had a better chance to survive the storm-surge of Hurricane Katrina 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 4 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? Alex Wilson of the *Environmental Building News* suggests that building design should include a new mandate: **passive survivability**.

Fortunately, a sustainable building will also have more passive survivability than a conventional building. The strategies mentioned in this book, such as higher levels of insulation, passive solar, passive cooling, and daylighting, all increase the passive survivability of a building.

1.7 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. Also, 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, then reheated as necessary to satisfy the other spaces. The double use of energy was not considered an important issue.

Buildings now use about 40 percent of all the energy consumed in the United States (Fig. 1.1a). 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, have a useful life of at least fifty years. The consequences of design decisions now will be with us for a long time.

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 the 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. For example, in 2007 the U.S. Green Building Council (USGBC) increased the energy requirements for LEED (Leadership in Energy and Environmental Design) certification. As Fig. 1.7 illustrates, the energy issues are a very large subset of all of the sustainability issues. Figure 1.7 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.

In describing "The Next Industrial Revolution," William McDonough and Michael Braungart say that it is based on three basic principles:

1. *Waste equals food*—Everything must be produced in such a manner that, when its useful life is over, it becomes a healthy source of raw materials to produce new things.
2. *Respect diversity*—Designs for everything will respect the regional, cultural, and materials of a place.
3. *Use solar energy*—All energy sources must be nonpolluting and renewable, and buildings must be solar responsive.

Thus, we see again how solar energy and solar responsive design will play a critical role in any thoughtful plan for a sustainable future.

Besides the sustainability rating system mentioned above (i.e., LEED), in the United States and Canada there is also Green Globes,™ which was developed by the Green Building Initiative (GBI). Other systems are used in other parts of the world, and two important components of all of these rating systems are energy efficiency and the use of solar energy.

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. Energy responsiveness is an important criterion.

Since global warming is by far the most critical issue of sustainability, the organization **Architecture 2030** was formed to reduce the greenhouse gas emissions of buildings to zero by the year 2030. The organization asks architects and building groups to implement the 2030 Challenge, which requires that buildings reduce their greenhouse gas emissions by 50 percent by the year 2010 and then incrementally reduce it further until the emissions are zero in 2030. Among the numerous groups that have signed on are the American Institute of Architects (AIA), the U.S. Green Building Council (USGBC) which operates Leadership in Energy and Environmental Design (LEED), the U.S. Conference of Mayors, the U.S. government for its own buildings, and numerous foreign groups.

The target dates of the **2030 Challenge** are based on the scientific evidence for how much time we have before humans lose control of climate change brought about by our greenhouse gas emissions. To accomplish these real and necessary targets, building design must incorporate as many energy-saving strategies as possible. Most of the required architectural strategies are covered in this book.

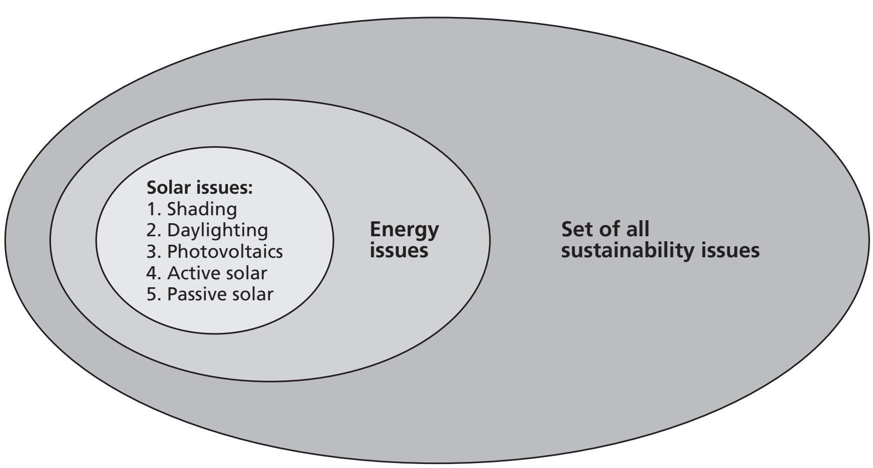

Figure 1.7 Sustainable design includes a very large set of issues, and the energy issues are a large subset thereof. The solar issues are a much larger subset of the energy issues than most people realize. This image can be downloaded for free and used as a poster. It is available at www.cadc.auburn.edu/sun-emulator.

1.8 ARCHITECTURE AND HEATING, COOLING, AND LIGHTING

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 start to design the appearance of 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.

1.9 CONCLUSION

The heating, cooling, and lighting of buildings are accomplished not just by mechanical equipment, but mostly by the design of the building itself. The design decisions that affect these environmental controls have, for the most part, a strong effect on the form and aesthetics of buildings. Thus, through design, architects have the opportunity to simultaneously satisfy their need for aesthetic expression and to efficiently heat, cool, and light buildings. Only through architectural design can buildings be heated, cooled, and lit in a sustainable way. The next chapter explains the nature of sustainability in more detail.

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, only the engineers, with their mechanical and electrical equipment, responded to the environmental needs of buildings. Architects provided 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 the continually 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 "passive survivability" in case of power outages or high fuel costs.
8. Because of global warming, it is imperative that buildings use less energy and achieve zero greenhouse gas emissions by 2030.
9. 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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ORGANIZATIONS

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