“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
Please note that figure numbers are keyed to sections. Gaps in figure numbering result from sections without figures.

1.1 INTRODUCTION

Until about 100 years ago, the heating, cooling, and lighting of buildings was the domain of architects. Thermal comfort and lighting were achieved with the design of the building and a few appliances. Heating was achieved by a compact design and a fireplace or stove, cooling by opening windows to the wind and shading them from the sun, and lighting by windows, oil lamps, and candles.

By the 1960s, the situation had changed dramatically. It had become widely accepted that the heating, cooling, and lighting of buildings were accomplished mainly by mechanical equipment as designed by engineers. Our consciousness has been raised as a result of the energy crisis of 1973. It is now recognized that the heating, cooling, and lighting of buildings are best accomplished by both the mechanical equipment and the design of the building itself. Some examples of vernacular and regional architecture will show how architectural design can contribute to the heating, cooling, and lighting of buildings.

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 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 permit 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 very humid climates (Fig. 1.2c).

Buildings are sited as far apart as possible for maximum access to the cooling breezes. In some of the 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).
FIGURE 1.2b In hot and humid climates, natural ventilation from shaded windows is the key to thermal comfort. This Charleston, SC, 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.)
And finally, in a predominantly cold climate we see a very different kind of architecture again. 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.

1.3 FORMAL ARCHITECTURE

Not only vernacular structures but also buildings designed by the most sophisticated architects have responded to the needs for environmental control. After all, the Greek portico is simply a feature to protect against the rain and sun (Fig. 1.3a). The repeating 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 in 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 (Figs. 1.3e and 1.3f). The outside windows are shaded from the direct sun by an arcade-like overhang (Fig. 1.3g). Since the arches are not structural, Frank Lloyd Wright shows them hanging from the building.

**FIGURE 1.3a** The classical portico has its functional roots in the sun- and rain-protected entrance of the early Greek megaron. (Maison Carée, Nîmes, 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.)
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 The Marin County Court House, California, designed by Frank Lloyd Wright, has a central gallery to bring daylight to interior offices.

FIGURE 1.3f White surfaces reflect light down to the lower levels. The offices facing the atrium have all-glass walls.

FIGURE 1.3g The exterior windows of the Marin County Court House are protected from the direct sun by an arcade-like exterior corridor.
Le Corbusier 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. 1.3h).

Today, with no predominant style guiding architects, revivalism is common. The buildings in Fig. 1.3i 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 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 suitable regional style.

1.4 THE ARCHITECTURAL APPROACH

The design of the heating, cooling, and lighting of buildings is 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...
Figure 1.4 The three-tier approach to the design of heating, cooling, and lighting systems produces comfortable, energy-efficient, economical, and sustainable buildings.

Table 1.4 The Three-Tier Design Approach

<table>
<thead>
<tr>
<th>Tier 1</th>
<th>Heating</th>
<th>Cooling</th>
<th>Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Building Design</td>
<td>Conservation</td>
<td>Heat avoidance</td>
<td>Daylight</td>
</tr>
<tr>
<td></td>
<td>2. Insulation</td>
<td>2. Exterior colors</td>
<td>2. Glazing type</td>
</tr>
<tr>
<td></td>
<td>3. Infiltration</td>
<td>3. Insulation</td>
<td>3. Interior finishes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tier 2</th>
<th>Heating</th>
<th>Cooling</th>
<th>Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Energies and Passive Techniques</td>
<td>Passive solar</td>
<td>Passive cooling</td>
<td>Daylighting</td>
</tr>
<tr>
<td></td>
<td>1. Direct gain</td>
<td>1. Evaporative cooling</td>
<td>1. Skylights</td>
</tr>
<tr>
<td></td>
<td>2. Trombe wall</td>
<td>2. Convective cooling</td>
<td>2. Clerestories</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tier 3</th>
<th>Heating equipment</th>
<th>Cooling equipment</th>
<th>Electric light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical and Electrical Equipment</td>
<td>1. Furnace</td>
<td>1. Refrigeration machine</td>
<td>1. Lamps</td>
</tr>
<tr>
<td></td>
<td>2. Ducts</td>
<td>2. Ducts</td>
<td>2. Fixtures</td>
</tr>
<tr>
<td></td>
<td>3. Fuels</td>
<td>3. Diffusers</td>
<td>3. Location</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>of fixtures</td>
</tr>
</tbody>
</table>

Reduced the loads as much as possible. Table 1.4 shows the design considerations that are typical at each of these 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 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 for 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.

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 better in several ways. The buildings are often less expensive because of reduced mechanical-equipment and energy needs. Frequently, the buildings are 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.

Proper attention to tiers one and two can easily cut the size of the mechanical equipment by 50 percent, and with extra attention as much as 90 percent. In certain climates, some buildings can even be designed to use no mechanical equipment at all. The Lovins’ home/office, which maintains full comfort high in the Rocky Mountains, has no mechanical equipment at all.

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, intelligent 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. Alternately, the change could be on an annual basis where a shading device is extended during the summer and retracted in the winter, much like a deciduous
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. 9.15c to 9.15e). 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 ENERGY AND ARCHITECTURE

The heating, cooling, and lighting of buildings is 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 35 percent of all the energy consumed in the United States (Fig. 1.6). Clearly then, the building industry has a major responsibility in the energy picture of this nation. 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 heating and cooling equipment that is required. To avoid the negative connotations, the more positive and flexible phrases of 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 needs for expensive, polluting, and nonrenewable energy. Because of the benefit to planet Earth, such design is now frequently called sustainable or green. The importance of energy consciousness is discussed in more detail in the next chapter.

1.7 ARCHITECTURE AND MECHANICAL EQUIPMENT

The following design considerations have impact on both the appearance and the heating, cooling, and lighting of a building: 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 architecture, and, as such, must be considered at the earliest stages of the design process.

(The plumbing and electrical wiring systems do not have this same form-giving and integral relationship with architecture. Since these systems are fairly small, compact, and flexible, they are easily buried in the walls and ceilings. Thus, they require little or no attention at the schematic design stage and are not discussed in this book.)

1.8 CONCLUSION

The heating, cooling, and lighting of buildings is 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 an environmentally responsible way. The importance of that is explained in the next chapter on sustainability.
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 yield environmentally responsive buildings.

3. It is a twentieth-century development that only the engineers with their mechanical and electrical equipment respond to the environmental needs of buildings. Architects resolved these needs in the past, and they can again be important players in the future.

4. The heating, cooling and lighting needs of buildings should 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 35 percent of all the energy consumed in the United States.

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. There is great aesthetic potential in energy-conscious architecture.

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**Resources**

**FURTHER READING**

(See Bibliography in back of book for full citations. The list includes valuable out-of-print books.)

- Duly, C. *The Houses of Mankind.*
- Fathy, H. *Natural Energy and Vernacular Architecture.*
- Fitch, J. M. *The Architecture of the American People.*
- Fitch, J. M. *Shelter: Models of Native Ingenuity.*
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- Konya, A. *Design Primer for Hot Climates.*
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- Rudofsky, B. *Architecture Without Architects: A Short Introduction to Non-Pedigreed Architecture.*
- Rudofsky, B. *The Prodigious Builders.*
- Stein, R. G. *Architecture and Energy.*

**PAPERS**

- Knowles, R. “Rhythm and Ritual,” http://www.rcf.usc.edu/~rknowles
- Knowles, R. “The Rituals of Place,” http://www.rcf.usc.edu/~rknowles