HEATING, COOLING, LIGHTING

SUSTAINABLE METHODS FOR ARCHITECTS

NORBERT LECHNER

FOURTH 4 EDITION

WILEY

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FOREWORD TO THE FOURTH EDITION

The compelling words written by James Marston Fitch in 1991 in the Foreword to the first edition (which follows) are still valid, but the stakes are now much higher. Because the fate of the planet is at stake, it is no longer just a question of following a particular architectural or design philosophy. Buildings consume about half the energy produced in the United States and around the world. Today, more than 50 percent of the world's population lives in cities, a figure that is likely to rise to 60 percent over the next two decades. It is clear that timing is critical: with 900 billion ft^2 (80 billion m^2) of urban environment projected to be built and rebuilt in the next twenty years (an area equal to three times the total building stock of the United States), we are presented with an extraordinary window of opportunity to meet present and looming threats. Our best chance of doing so is to ensure that the architecture, planning, and development community, the primary agents shaping the built environment through design and construction, have access to the knowledge and tools necessary for the transition to a decarbonized, sustainable, and adaptive world.

Professor Lechner's book describes how to achieve this transition in the built environment. The book illustrates the many sustainable strategies available to designers and provides the information needed during the early phases of the design process, when a building's energy consumption patterns are defined. By using the strategies presented in this book, much of the energy consumed to heat, light, and cool buildings can be dramatically reduced.

Professor Lechner's book is also an important resource for those architects who are concerned about the aesthetic aspects of sustainability. He convincingly explains and demonstrates how lessons learned from vernacular architecture can be combined with the best of modern ideas to create low-impact yet beautifully designed humane architecture. Since carbon neutral buildings can be fully powered by renewable resources, a future of low-impact buildings is not only necessary but also elegantly achievable.

EDWARD MAZRIA, AIA

FOREWORD TO THE FIRST EDITION

Professor Lechner's book differs from most of its predecessors in several important respects: (1) he deals with the heating, cooling, and lighting of buildings, not as discrete and isolated problems, but in the holistic sense of being integral parts of the larger task of environmental manipulation; (2) he deals with the subjects not merely from the engineer's limited commitment to mechanical and economic efficiency but from the much broader viewpoint of human comfort and physical and psychic well being; (3) he deals with these problems in relation to the central paradox of architecture—how to provide a stable, predetermined internal environment in an external environment that is in constant flux across time and space; and finally, (4) he approaches all aspects of this complex subject from a truly cultural—as opposed to a narrowly technological—perspective.

This attitude toward contemporary technology is by no means hostile. On the contrary, Professor Lechner handles it competently and comprehensively. But he never loses sight of the fact that the task of providing a truly satisfactory enclosure for human activity is that one must view the building as a whole. He points out, quite correctly, that until the last century or so, the manipulation of environmental factors was, of necessity, an architectural problem. It was the building itself—and only incidentally any meager mechanical equipment that the period happened to afford—that provided habitable space. To illustrate this point, he makes continuous and illuminating analysis to both high-style and vernacular traditions, to show how sagaciously the problems of climate control were tackled by earlier, prescientific, premechanized societies.

This is no easy-to-read copybook for those designers seeking shortcuts to glitzy postmodern architecture. On the contrary, it is a closely reasoned, carefully constructed guide for architects (young and old) who are seeking an escape route from the energy-wasteful, socially destructive cul-de-sac into which the practices of the past several decades have led us. Nor is it a Luddite critique of modern technology; to the contrary, it is a wise and civilized explication of how we must employ technical and scientific knowledge if we in the architectural field are to do our bit toward avoiding environmental disaster.

JAMES MARSTON FITCH
Hon. AIA, Hon. FRIBA
In memory of James Marston Fitch, architect,
historian, professor, preservationist, and
architectural theorist, 1909–2000.

PREFACE

In this new edition the goal of previous editions remains: to provide the appropriate knowledge at the level of complexity needed at the schematic design stage. In the years since the first edition was published, we have moved from a shortage of information to a flood because of the Internet. This book will aid the designer because it presents the information in a concise, logical, and accessible arrangement and at a useful level.

Since heating, cooling, and lighting are accomplished by adding energy to or removing it from a building, and since the consumption of energy is causing global warming, it is vital for architects to design low energy, sustainable buildings. Although sustainability deals with many issues, the energy issues are the most critical. Thus, an additional goal of this book is to provide architects with the skills and knowledge needed to create low energy and low carbon-emission buildings.

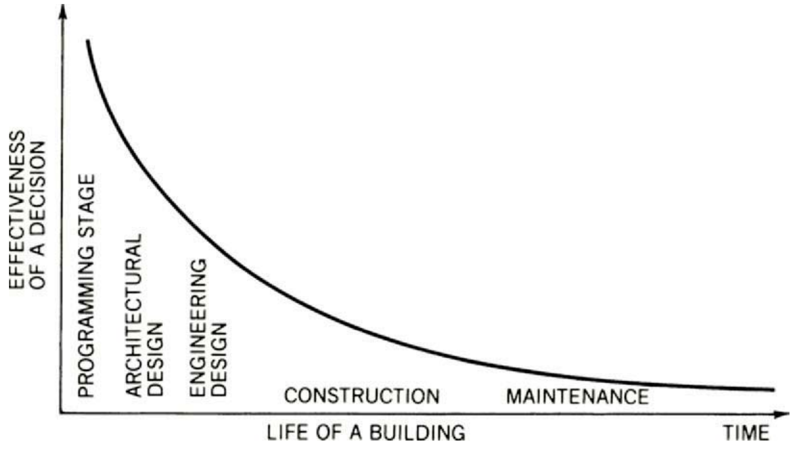
In addition to improving and updating every chapter, three new chapters have been added. Chapter 17 on tropical architecture was added because a large portion of the world's population lives in the tropical zone and because many architects trained in designing buildings in temperate climates end up designing buildings in the tropics. Case studies, formerly in Chapter 17, are now in Chapter 18. Because of the extensive information available on the Web, only a brief description is given of a personal selection of buildings.

Chapter 19, the third new chapter, presents a checklist to help in the design of low energy, sustainable buildings. The checklist guides the designer through the decision-making process so that important options are considered at the appropriate time.

This book focuses on the schematic design stage, where the key decisions are made. The graph below points out how the earliest decisions have the greatest impact on a project. A building's cost and environmental impact are established mainly at the schematic design stage. The most basic decisions of size, orientation, and form often have the greatest impact on the resources required during both construction and operation. Thus, designs for sustainable buildings are achieved primarily by the earliest decisions in the design process rather than by add-ons and engineering decisions made after the architectural design of the building has been essentially completed.

The information in this book is presented to support the three-tier approach to sustainable design of the heating, cooling, and lighting of buildings. The first tier is load avoidance. Here the need for heating, cooling, and lighting is minimized by the design of the building itself. The second tier consists of using natural energies through methods such as passive solar, passive cooling, natural ventilation, and daylighting. This tier is also accomplished mainly by the design of the building itself. The third and last tier uses mechanical and electrical equipment to satisfy the needs not provided for by the first two tiers.

With the knowledge and information presented in this book, the first two tiers can provide most of the thermal and lighting requirements of a building. As a consequence, the mechanical and electrical equipment of the third tier will be substantially smaller and will use much less energy than is typical now, thereby resulting in more sustainable buildings. Since tiers one and two are the domain of the architect, the role of the engineer at the third tier is to provide only the heating, cooling, and lighting that the architect could not.



ACKNOWLEDGMENTS

For the fourth edition, I would like to thank especially John Marusich for his excellent work on the new and revised drawings. Since this book is built on the previous three editions, I also want to thank again all of the people who helped me write those earlier editions. The typing and proofreading for the fourth edition were done by my son, Walden Lechner. And again, I want to thank my wife, Prof. Judith Lechner, whose help, support, and love are invaluable to me.

NORBERT LECHNER
Prof. Emeritus and Architect
Auburn University

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.

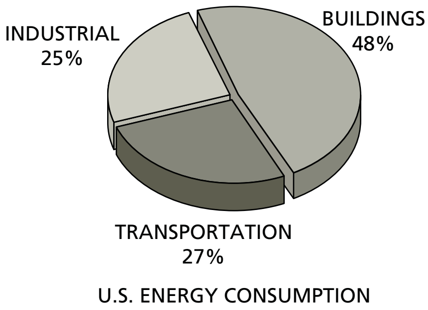


Figure 1.1a Buildings are the main cause of global warming because they use about 48 percent of all energy. Of that 48 percent, about 40 percent is for operating the buildings (heating, cooling, lighting, computers, etc.) and about 8 percent is for their construction (creating materials, transportation,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

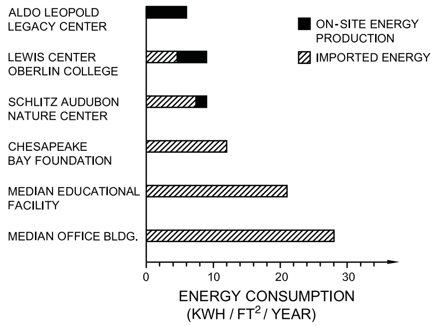


Figure 1.1b The good news is that buildings do not have to use climate-changing fossil fuels. Over the years, we have learned how to design buildings so energy efficient that we can now build zero-energy buildings. The small amount of energy that they still need can be supplied by renewable sources such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

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.

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).

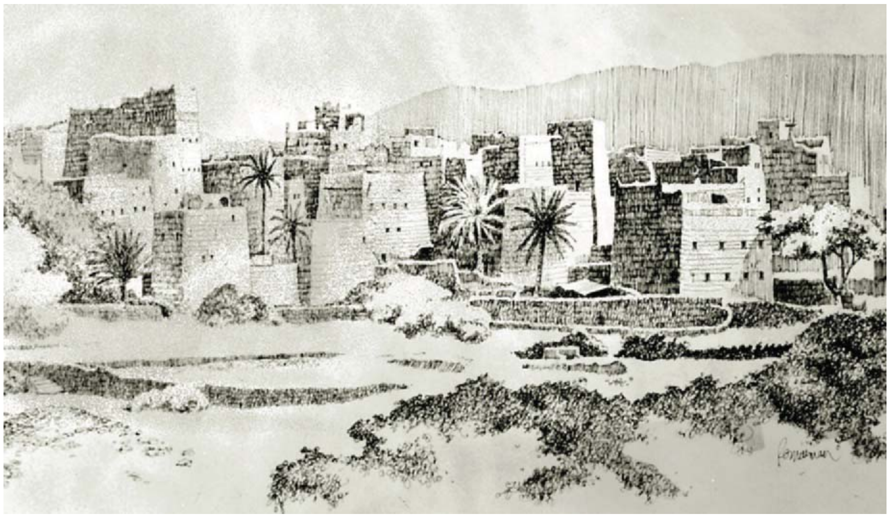


Figure 1.2a Massive construction, small windows, and light colors are typical in hot and dry climates, as in this Yemeni village. It is also common, in such climates, to find flat roofs and buildings huddled together for mutual shading. (Drawing by Richard Millman.)

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.

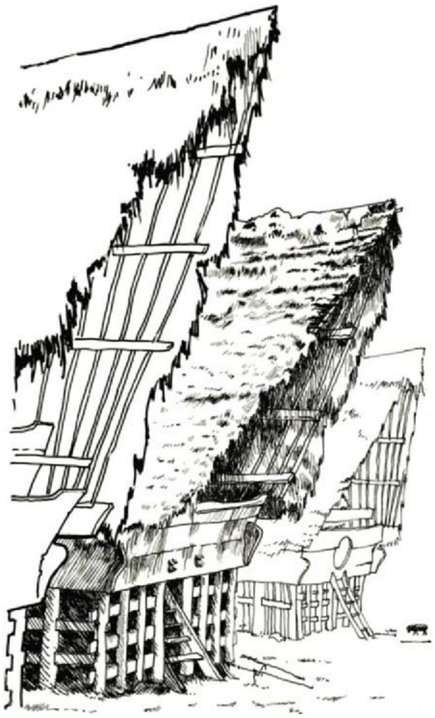


Figure 1.2c In hot and humid climates such as in Sumatra, Indonesia, native buildings are often raised on stilts and have high roofs with open gables to maximize natural ventilation.

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

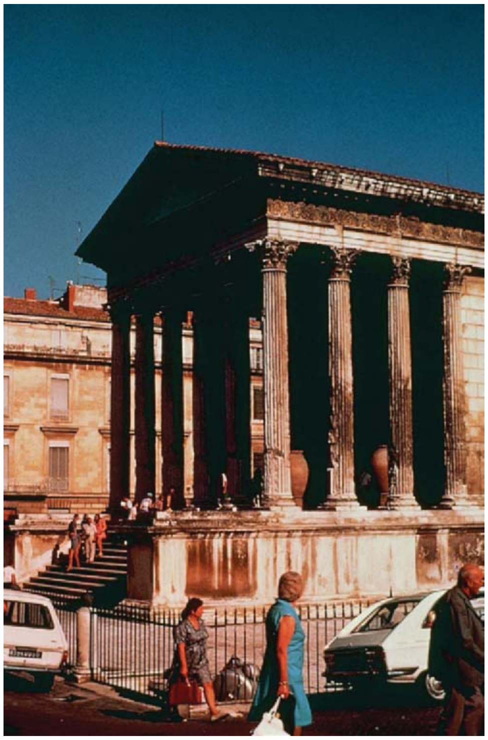


Figure 1.3a The classical portico has its functional roots in the sun- and rain-protected entrance of the early Greek megaron. Maison Carrée, Nîmes, France.

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

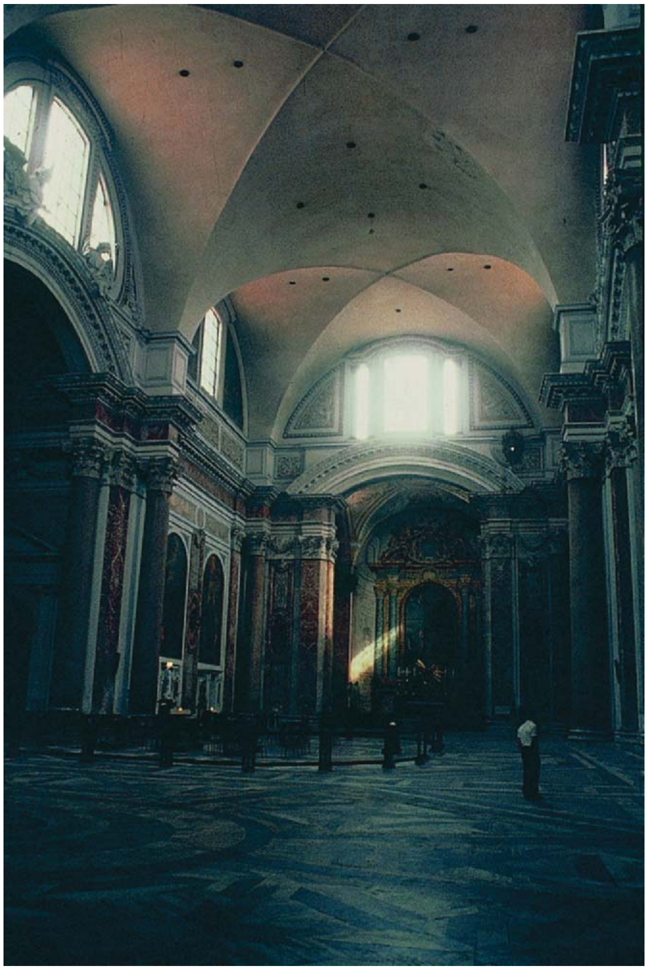


Figure 1.3c Roman basilicas and the Christian churches based on them used clerestory windows to light the large interior spaces. The Thermae of Diocletian, Rome (A.D. 302), was converted by Michelangelo into the church of Santa Maria degli Angeli. (Photograph by Clark Lundell.)

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.)

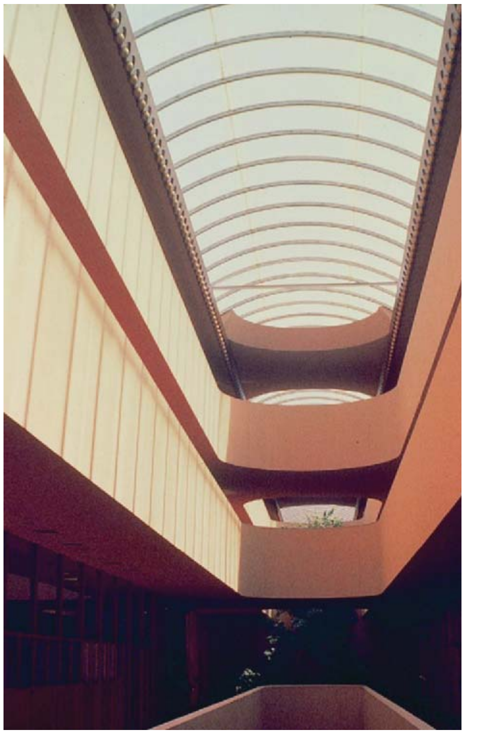


Figure 1.3e In the linear central atrium of the Marin County Civic Center, Frank Lloyd Wright used white surfaces to reflect light down to the lower levels. The offices facing the atrium have all-glass walls.

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.

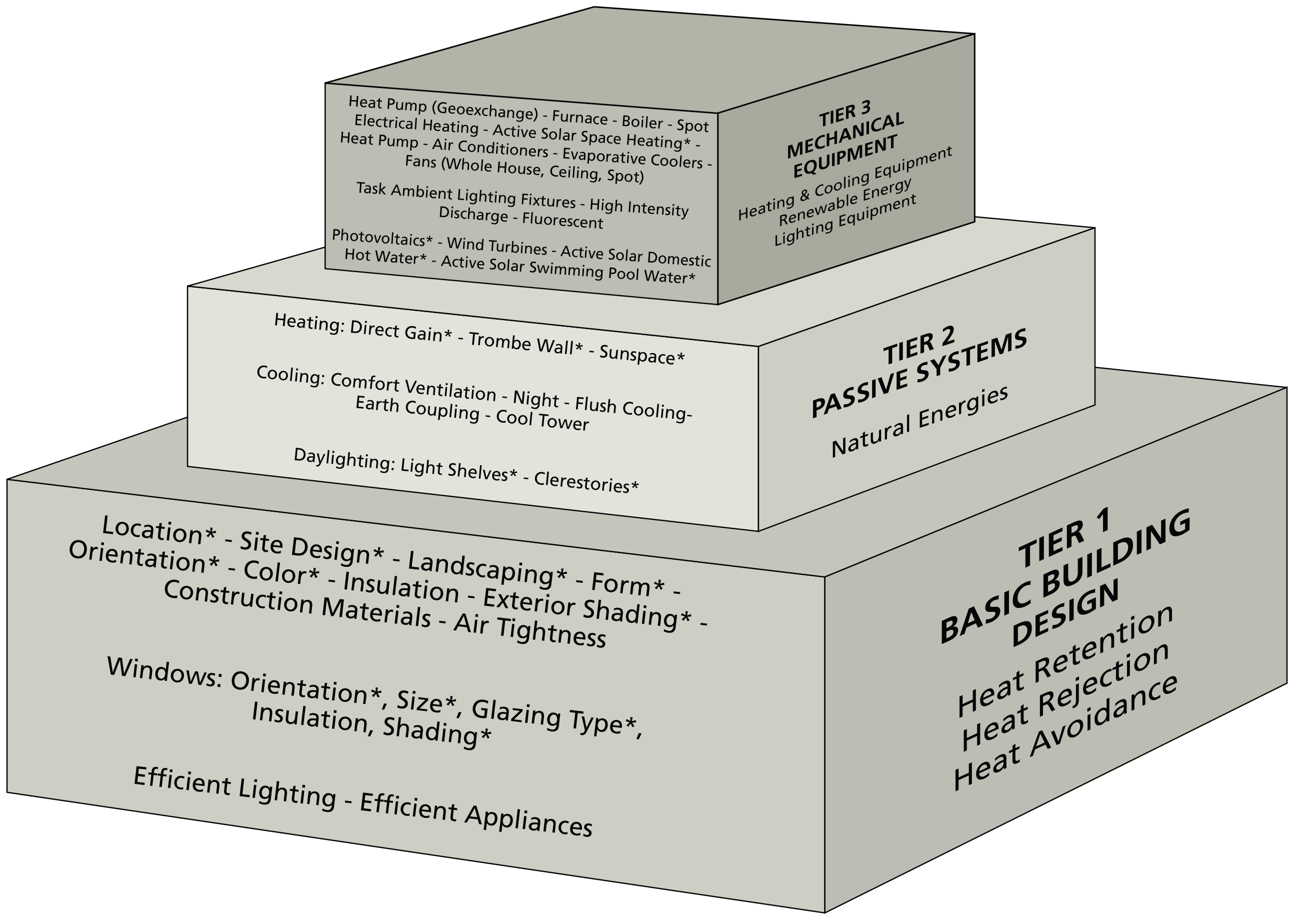


Figure 1.4a The three-tier approach to the sustainability design of heating, cooling, and lighting is shown. Tiers one and two are the domain of the architect, and proper design decisions at these two levels can reduce the energy consumption of buildings as much as 80 percent. All items with an asterisk 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