

THIRD EDITION

# BUILDING SYSTEMS FOR INTERIOR DESIGNERS



CORKY BINGGELI, ASID

WILEY



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# **Building Systems for Interior Designers**

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**Corky Binggeli, ASID**

**WILEY**

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# Preface

The first edition of *Building Systems for Interior Environments* arose from my need for a textbook to use in teaching interior design students that gave them the understanding and skills to work with architects and engineers. This third edition of *Building Systems for Interior Environments* updates the role of interior designers as part of the building design team, and addresses their special needs for information on today's building system design and equipment.

Interior designers today work closely with other design and construction professions to provide functional, sustainable, and healthy buildings. Sophisticated digital control systems permit design that supports varied occupancy and work styles and schedules. This results in more individualized control of the interior environment, which is conducive to worker satisfaction and productivity.

Sustainable design supports a holistic approach to building systems, where the older territorial distinctions between the various building system and architectural/engineering disciplines are opening up. Existing buildings are being adapted and reused for new purposes. The impact of energy efficiency and water conservation in buildings is widely recognized. This third edition of *Building Systems for Interior Environments* reflects these changes.

In addition, the third edition benefits from the comments of experienced educators as to the best ways to organize and focus the information. The updated contents are arranged to flow smoothly in an order that facilitates the teaching process.

Part I looks at environmental conditions and the site, the building envelope and the building design process, sustainable design, the interaction of the human body with the built environment, and how building codes protect us. Part II addresses building forms, structures, and elements including floor/ceiling assemblies, walls, stairs, windows, and doors. Part III introduces acoustic design principles and architectural acoustics. Part IV addresses water supply, waste, and reuse systems, as well

as plumbing fixtures and appliances. Part V covers principles of thermal control, indoor air quality, ventilation, and moisture control, and heating and cooling. Part VI explains electrical system basics and electrical distribution, as well as lighting systems. Part VII concludes the book with coverage of fire safety design, conveyance systems, and communications, security, and control equipment.

More than 40 percent of the third edition's text is new. This edition contains over 485 illustrations, approximately 260 of which are new and 160 redrawn or revised. There are also over 175 tables, 125 of which are new or significantly revised. References to related materials in other chapters are included. Tips indicating material of assistance and interest to interior designers are also included. Key terms are defined in the text and indicated in **bold**. Quotations from architectural and engineering sources aid in understanding the perspective of other design professionals.

Interior designers need to understand the viewpoints and respect the expertise of other design professionals. *Building Systems for Interior Designers* provides the information they need to do this, without delving into engineering calculations. It focuses on the parts of the building design process that most affect the occupants' functional needs, and provides a technical but readily understandable foundation for the design of interior spaces. Residential as well as commercial and institutional spaces are included.

*Building Systems for Interior Designers* is listed by the National Council for Interior Design Qualification (NCIDQ) as a reference for preparation for the NCIDQ exam. The third edition is supplemented by online materials including an Instructors Manual with knowledge areas, topics for discussion, and definitions of key terms, PowerPoint presentations for each chapter, and a Test Bank with sample questions. Supplemental material is available at [www.wiley.com/go/bsid3e](http://www.wiley.com/go/bsid3e).

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The authorship of a book involves a great amount of solitary work and persistence. Turning the manuscript and illustrations into a published book involves the efforts of many others. I have now published seven books—plus second and third editions of some of them—with the team at John Wiley & Sons, and I want to thank them once again for their professionalism, support, and good advice.

I especially want to thank my editors, Paul Drougas, Lauren Poplowski, and Seth Schwartz, their able assistants Michael New and Melinda Noack, and production editor Amy Odum.

The feedback of my colleagues and students is invaluable in assuring that this edition meets their needs. I especially

benefitted from the review team of Dr. Jane L. Nichols, IDEC, NCIDQ, High Point University; Ji Young Cho, LEED AP, Kent State University; and Brian Sweny, AIA, IIDA, LEED AP, IDEC, SEED, Savannah College of Art and Design.

As is the case with all my books, I am indebted to my husband, Keith Kirkpatrick, for his support and assistance. He puts up with my obsessive focus, makes sure I am properly fed, and gives solid advice when I'm struggling with a decision. Keith also reviewed and commented on all of the illustrations. Thank you, Keith!

# PART

# I

---

## **THE BUILDING, THE ENVIRONMENT, AND HEALTH AND SAFETY**

Interior designers today work closely with other design and construction professionals to provide functional, sustainable, and healthy buildings. Sustainable design is supporting a holistic approach to building systems, and older territorial distinctions between various architectural and engineering disciplines are opening up. Existing buildings are valued for the materials and energy they embody, and many projects involve the renovation of building interiors.

Interior designers are increasingly working as part of environmentally aware design teams. Sustainable design involves interior designers observing the impact of a building's site, climate, and geography on its interior spaces. Building interiors are increasingly open to natural settings and views, and the interior designer's work may bridge interior and exterior spaces. Wise energy use dictates awareness of how sun, wind, and heat or cold affect the building's interior.

While focusing on building elements that affect interior designers, *Building Systems for Interior Designers, Third Edition* addresses this multidisciplinary approach to building design. We begin our study of building systems in Part I by looking at the relationships among the environment, the building, and human health and safety.

Chapter 1, "Environmental Conditions and the Site," looks at climate change, energy sources and consumption, and how site conditions affect building design.

Chapter 2, "Designing for the Environment," investigates the building envelope and the role of insulation in heat flow. Energy efficient design, the building design process, and sustainable design are introduced.

Chapter 3, "Designing for Human Health and Safety," addresses the interaction of the human body with the built environment and how building codes protect us.

A common thread ... is the attitude that buildings and sites should be planned and developed in an environmentally sensitive manner, responding to context and climate to reduce their reliance on active environmental control systems and the energy they consume. (Francis D.K. Ching, *Building Construction Illustrated* (5th ed.), Wiley, 2014, Preface)





# Environmental Conditions and the Site

Buildings evolved from our need for shelter. In addition to shelter, we depend on buildings for sanitation, visual and acoustic environments, space and means to move, and protection from injury.

A building's form, scale, and spatial organization are the designer's response to a number of conditions—functional planning requirements, technical aspects of structure and construction, economic realities, and expressive qualities of image and style. In addition, the architecture of a building should address the physical context of its site and the exterior space. (Francis D. K. Ching and Corky Binggeli, *Interior Design Illustrated* [3rd ed.], Wiley 2012, page 4)

We depend on the building's site to provide clean air and to help control thermal radiation, air temperature, humidity, and airflow. Building structures rely on site conditions for support and to help keep out water and control fire. The site can also play a role in providing clean water, removing and recycling wastes, and providing concentrated energy.

Once these basic physical needs are met, we turn to creating conditions for sensory comfort, efficiency, and privacy. We need illumination to see, and barriers that create visual privacy. We seek spaces where we can hear others speak clearly, but which offer acoustic privacy. The building's structure gives stable support for all the people, objects, and architectural features of the building.

The next group of functions supports social needs. We try to control the entry or exit of other people and of animals. Buildings facilitate communication and connection with the world

outside through windows, telephones, mailboxes, and computer and video networks. Our buildings support our activities by distributing concentrated energy to convenient locations, primarily through electrical systems.

Finally, a building capable of accomplishing all of these complex functions must be built without excessive expense or difficulty. Once built, it must be able to be operated, maintained and changed in a useful and economical manner. The building should be flexible enough to adapt to changing uses and priorities. Eventually, the building's components may be disassembled and returned to use in other construction.

The design of a building that incorporates all these functions requires coordination between building systems' designers, builders, and users. The building's environmental conditions and its site generate complex factors for architects, engineers, and other design professionals. They, along with landscape architects, examine the site's subsoil, surface water levels, topsoil, and rocks with regard to excavations, foundations, and landscaping. Hills, valleys, and slopes affect stormwater drainage and soil erosion, and the location of roads and paths. Shelter from the wind or exposure to sunlight help determine where the building can be built and the type of landscaping. Nearby buildings create shade, divert wind, and change the natural drainage patterns; they can also result in a lack of acoustic and/or visual privacy.

## INTRODUCTION

In Chapter 1, we begin to examine the design of the building and its site. Interior designers benefit from a general understanding of both passive systems and mechanical systems that meet the

environmental requirements of buildings. Awareness of building systems provides interior designers with the terminology and basic requirements to ask intelligent questions of architects, engineers, and contractors.

This awareness starts with a basic understanding of environmental and site conditions. Climate affects how buildings are designed in different places and how they relate to their sites. An understanding of energy sources and their history helps put their use in buildings in perspective. As interior designers seek to open building interiors to their surroundings, it is important that they understand what opportunities and challenges are involved.

Throughout history, buildings have looked both out towards the surrounding site and environment, and in towards the people, activities, and objects they contain. (See Figure 1.1) Although interior designers are primarily concerned with the building's interior, their work is often influenced by the building's exterior construction and site.

The building's form and orientation on the site are major concerns of the building's architect. A building's climate and surrounding natural and built features are priorities for the architect, landscape architect, and engineers. During the last decades of the twentieth century, architects began to expand their view of architecture to include areas of social concern, including accessibility and sustainable design, both of which are important to interior designers.

The design of the building, including its massing, configuration, and orientation, generate the relationship between the interior space and the exterior environment. In order to be active and responsible members of the building design team, interior designers must understand the roles and concerns of the architects, engineers, and other consultants who make up the design team. In turn, the rest of the design team will benefit from an awareness of the concerns they share with interior designers.

The interior designer's concern about climate change and renewable energy sources leads to caring about how a building responds to its site and climate and how it fuels its operation. Although they are not directly responsible for deciding on the site and building energy sources, interior designers can play a major

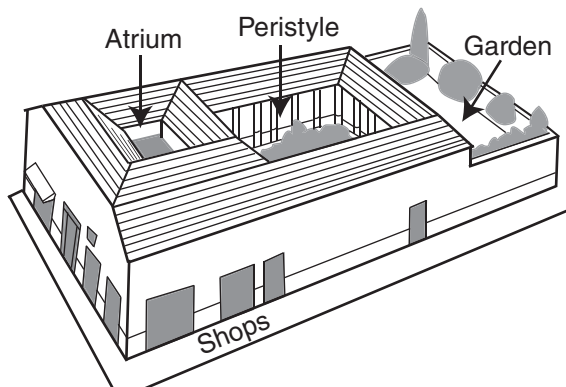


Figure 1.1 Roman residence

role in selecting interior materials that support the conservation of energy and the use of energy sources available on-site.

The interior layout can support or block solar radiation to help keep the interior warm or cool. Selecting thermally massive interior materials can aid passive solar design. In many instances, the project is in an existing building, and most of the work is interior design. In addition, interior designers may be involved in the design of outdoor spaces such as patios adjacent to the building.

## CLIMATE CHANGE

Interior designers' concern for how a building responds to its site and climate, and how it fuels its operation are involved in their selection of interior materials that do not contribute to greenhouse gases and that support the conservation of energy and the use of sustainable energy sources.

According to the 2014 report of the Intergovernmental Panel on Climate Change (IPCC), the warming of the climate is unequivocal, and mostly caused by human-created greenhouse gases. (See Figure 1.2) The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. (IPCC Fifth Assessment Synthesis Report, Climate Change 2014 Synthesis Report Summary for Policymakers, [www.ipcc.ch/](http://www.ipcc.ch/))

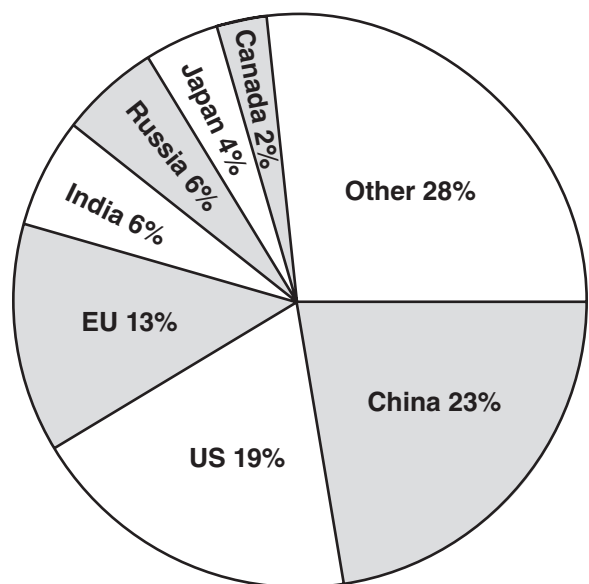


Figure 1.2 Global greenhouse gas emissions, 2008

Small increases in global temperatures are already resulting in hotter summers, changes in precipitation patterns, and rising sea levels. More droughts are occurring in some areas, with floods in others. Warm climate diseases such as malaria are likely to spread. Species extinction is anticipated.

Damaging results include the melting of permafrost in northern Canada, Alaska, and Russia, which can cause huge amounts of organic material to decompose, giving off **carbon dioxide (CO<sub>2</sub>)** and methane. According to the US **Environmental Protection Agency (EPA)**, permafrost melting is already causing sinking land that can damage buildings and infrastructure.

## ENERGY SOURCES

According to the EPA, US buildings account for 41 percent of total energy use and 65 percent of all electricity consumption. The sources of the energy that is used to construct and operate buildings are important to interior designers concerned about global climate change and energy conservation. As part of the building design team, interior designers can support the use of sustainable energy sources as well as efforts toward passive design. Conserving energy and using clean and renewable energy sources in buildings reduces the amount of air pollution produced by electric power plants and by burning fuels in buildings.

Energy sources are often categorized as renewable or non-renewable. **Renewable energy** is energy that comes from naturally occurring resources such as sunlight, wind, or geothermal heat that are naturally replenished on a human timescale.

All of our energy sources are derived from the sun, with the exception of geothermal, nuclear, and tidal power. Before 1800, solar energy was the dominant source for heat and light, with wood used for fuel. Wind was used for transportation and processing of grain. Early industries located along rivers and streams utilized waterpower. In the 1830s, the earth's population of about one billion people depended on wood for heat and animals for transportation and work. Oil or gas were burned to light interiors. By the 1900s, coal was the dominant fuel, along with hydropower and natural gas. Around the beginning of the nineteenth century, mineral discoveries led to the introduction of portable, convenient, and reliable coal, petroleum, and natural gas fuels to power the industrial revolution.

Fossil fuels such as coal, petroleum, and natural gas were formed from decaying plant and animal matter over vast periods of time beneath the earth's surface. Although fossil fuels continue to be formed, their timeframes are such that they are not replaceable at anything like the rates that they are being used, and they are not considered to be sustainable materials. Remaining world fossil fuel reserves are limited, with much of it expensive and environmentally objectionable to remove. Buildings being built today could outlive fossil fuel supplies used at current rates.

As the world's supply of fossil fuels diminishes, buildings must use non-renewable fuels conservatively if at all, and look to on-site resources such as daylighting, passive solar heating,

passive cooling, solar water heating, and **photovoltaic (PV)** electricity.

Some types of energy, such as solar energy, can be used directly by a building for heating and cooling. Others, such as electricity, are produced from another fuel source.

## Electricity

Today's buildings are heavily reliant on electricity because of its convenience of use and versatility. Electricity is considered a high-quality energy source; however, only one third of the source energy (often coal) used to produce electricity actually reaches its end use, with most of the rest wasted during production and transmission. As of 2009, consumption of electricity has begun to decline for the first time since World War II, with reductions in all world regions except Asia and the Middle East.

Electric lighting produces heat, which in turn increases air conditioning electrical energy use in warm weather. The use of daylighting is an important sustainable design technique. However, daylight is dependent on weather and time of day, so electric lighting continues to have an important role.

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*For more information on daylighting and electric lighting, see Chapter 17, "Lighting Systems."*

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The use of electricity for space heating employs a high-quality source for a low-quality task. Passive or active solar heating design uses this unlimited, free source of energy to heat building interiors.

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*See Chapter 14, "Heating and Cooling," for more information on solar heating design.*

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## Renewable Energy Sources

Renewable sources include solar (heat, light, and electricity), wind, hydroelectric, geothermal, and biomass. Electricity produced by solar or wind energy can in turn be used to generate hydrogen, a high-grade fuel, from water. The above are all considered to be renewable resources because they can be constantly replenished, but our demand for energy may exceed the rate of replenishment. Some, such as hydroelectric power, can have negative impacts on the environment.

### SOLAR ENERGY

The sun acts on the earth's atmosphere to create climate and weather conditions. The earth's rotation determines which part of the earth faces the sun, controlling day and night. Plant life depends on the sun's energy for growth, and humans and other animals depend on plants for food and shelter. Solar energy is the source of almost all of our energy resources. It does not produce air, water, land, or thermal pollution, and is decentralized

and very safe to use. It is used for space heating, hot water heating, and photovoltaic electrical energy.

During the day, the sun's energy heats the atmosphere, the land, and the sea. At night, much of this heat is released back into space. The warmth of the sun moves air and moisture across the earth's surface and generates seasonal and daily weather patterns.

### SOLAR ENERGY HISTORY

The sun has long been used to heat and illuminate buildings. The Romans incorporated glass windows into their buildings around 50 BCE to bring in daylight and solar heat, and wealthier Romans often added sunrooms to their villas.

In *The Ten Books on Architecture*, Roman architect and engineer Marcus Vitruvius Pollio wrote:

If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built. . . . This is because one part of the earth is directly under the sun's course, another is far away from it, while another lies midway between these two. (Translated by Morris Hickey Morgan, Harvard University Press 1914, republished by Dover Publications, Inc., 1960, page 170)

Italian Renaissance architect Andrea Palladio (1508–1580), author of *The Four Books of Architecture*, was influenced by Vitruvius. Palladio placed summer rooms on the north side and winter rooms on the south side of his buildings to take advantage of the sun.

In the seventeenth century, solar heating was revived in Northern Europe for growing exotic plants in greenhouses. Improved glassmaking techniques led to the popularity of greenhouses (conservatories) attached to upper-class residences.

American modernist architect George Frederick Keck (1895–1980) designed the “House of Tomorrow” for the Century of Progress exhibition in Chicago in 1933. His realization that the all-glass house was warm on sunny winter days, even without a furnace led to his designing solar houses in the 1930s and 1940s. (See Figure 1.3)

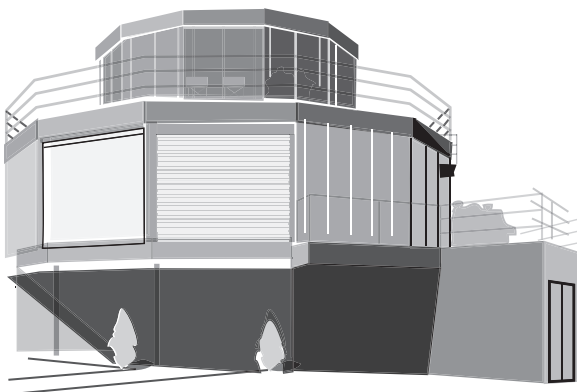


Figure 1.3 George Frederick Keck “House of Tomorrow,” 1933

### SOLAR RADIATION

Solar radiation drops with the distance from the sun, as solar rays spread out. The path of solar rays through the atmosphere is longer in the morning and evening than at noon, and longer at noon at the poles than at noon at the equator. (See Figure 1.4)

The **electromagnetic spectrum** of radiation emitted by the sun includes wavelengths ranging from extremely short x-rays to very long radio waves. (See Figure 1.5) Radiation is reflected, scattered, and absorbed by dust, smoke, gas molecules, ozone, carbon dioxide, and water vapor in the earth's atmosphere. Radiation that has been scattered or re-emitted is called diffuse radiation. The portion of the radiation that reaches the earth's surface without being scattered or absorbed is referred to as direct radiation.

**Ultraviolet (UV)** wavelengths make up only a small percentage of the sun's rays that reach sea level, and are too short to be visible by the human eye. UV radiation triggers **photosynthesis** in green plants, producing the oxygen we breathe, the plants we eat, and the fuels we use for heat and power. During photosynthesis, plants take carbon dioxide from the air and give back oxygen. Humans and other animals breathe in oxygen and exhale carbon dioxide. Plants transfer the sun's energy to us when we eat them, or when we eat plant-eating animals. That energy goes back into the environment when animal waste decomposes and releases nitrogen, phosphorus, potassium, carbon and other elements into the air, soil, and water. Animals or microorganisms break down dead animals and plants into basic chemical compounds, which then reenter the cycle to nourish plant life.

UV radiation kills many harmful microorganisms, purifying the atmosphere and eliminating disease-causing bacteria from

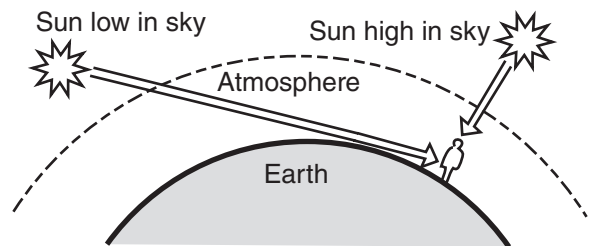


Figure 1.4 Sun's path through the atmosphere

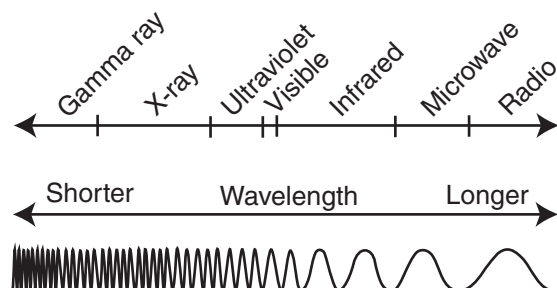


Figure 1.5 Electromagnetic spectrum



sunlit surfaces. It also creates vitamin D in our skin, which we need to utilize calcium. Photosynthesis also produces wood for construction, fibers for fabrics and paper, and landscape plantings for shade and beauty.

**Infrared (IR)** radiation, with wavelengths longer than visible light, carries the sun's heat. The sun warms our bodies and our buildings both directly and by warming the air around us.

The distance that radiation must travel through the earth's atmosphere, as well as atmospheric conditions, largely determine the amount of solar radiation that reaches the earth's surface. The distance varies with the angle of the earth's tilt toward or away from the sun. The angle is highest in the summer, when direct solar radiation strikes perpendicular to the earth's surface. The angle is lowest in the winter, when solar radiation travels a longer path through the atmosphere. Consequently, the greatest potential solar gain (in the Northern Hemisphere) for a south-facing interior space occurs during the winter. (See Figure 1.6) Nearer to the equator, the sun remains more directly overhead throughout the year. (See Figure 1.7)

The sun illuminates the indoors through windows and skylights during the day. Direct sunlight is often too bright for comfortable vision. When daylight is scattered by the atmosphere or blocked by trees or buildings, it offers an even, restful illumination. Under heavy clouds and at night, artificial light provides adequate illumination.

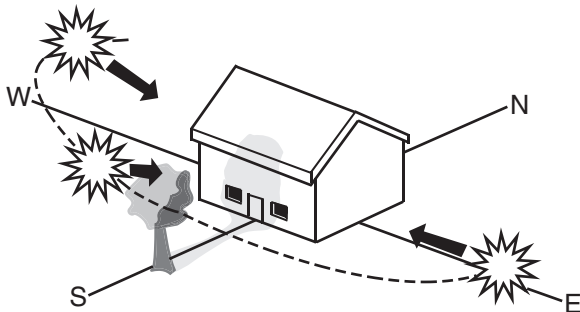


Figure 1.6 Sun angles in northern latitudes

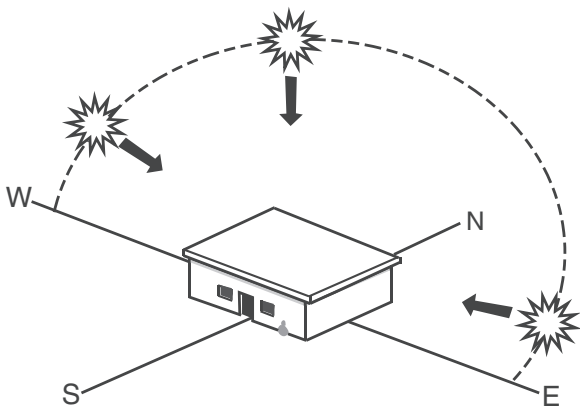


Figure 1.7 Sun angles in tropical latitudes

Sunlight can also be destructive. Most UV radiation is intercepted by the high-altitude ozone layer, but enough gets through to burn our skin painfully. Over the long term, exposure to UV radiation may result in skin cancer. Sunlight contributes to the deterioration of paints, roofing, wood, and other building materials.

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Fabric dyes may fade, and many plastics decompose when exposed to direct sun. This is an issue for interior designers when specifying materials.

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Photovoltaic (PV) technology converts solar energy directly into electricity at a building's site. PV collectors provide energy for heating water or for electrical power. PV cells are often made of silicon, the most common material in the earth's crust after oxygen. PV cells are very reliable and have no moving parts. They produce no noise, smoke, or radiation.

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*See Chapter 15 Electrical System Basics for more information on photovoltaic (PV) technology.*

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The use of solar energy for heating requires consideration of shading to avoid overheating. Greek and Roman buildings used porticoes and colonnades for both shade and protection from rain. Following their example, Greek Revival architecture in the southern United States adopted large overhangs supported by columns, as well as large windows for increased ventilation and white exterior colors for maximum solar reflectance.

## WIND POWER

Wind power derives from currents created when the sun heats the air and the ground. Wind power uses a turbine to convert the energy of wind flow into mechanical power that a generator can turn into electrical energy.

By 200 BCE, windmills were used in China to pump water. By the eleventh century CE, windmills were used in the Middle East to grind grain. Their use declined as steam engines dominated during the Industrial Revolution. Larger **wind turbines** were developed in Denmark by 1890 to generate electricity. In the 1930s, wind turbines brought low-cost electrical power to rural areas of the United States. (See Figure 1.8)

Wind energy is plentiful in most of the United States. Wind turbines require a windy site, and raising the turbine as high as possible accesses higher wind speeds. (See Figure 1.9) Although wind is an intermittent source, turbines can be connected to the electrical grid for steady power. Stand-alone systems require battery storage. Hybrid systems combine wind with photovoltaics, with wind power dominating in less sunny, windier winters and solar power providing electricity in summers. The noise produced by small wind turbines is generally not objectionable to most people, and larger turbines are being engineered to reduce noise levels.

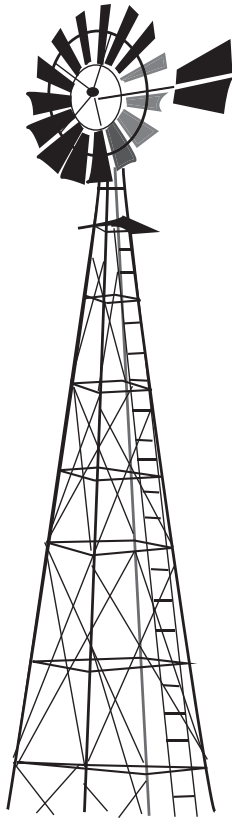


Figure 1.8 Wind turbine, 1930s

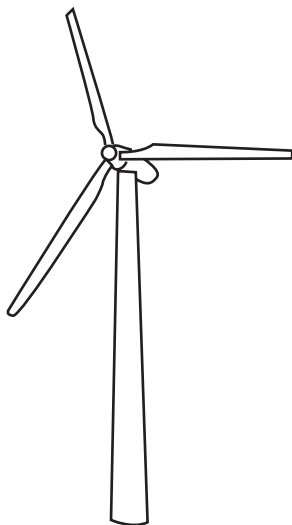


Figure 1.9 Wind turbine today

## HYDROELECTRIC POWER

Hydroelectric power (hydropower) is energy that is produced when water stored behind a dam is released at high pressure. This energy is transformed into mechanical energy, which is used by a turbine to generate electricity. In the United States, about 5 percent of energy is produced by falling water.

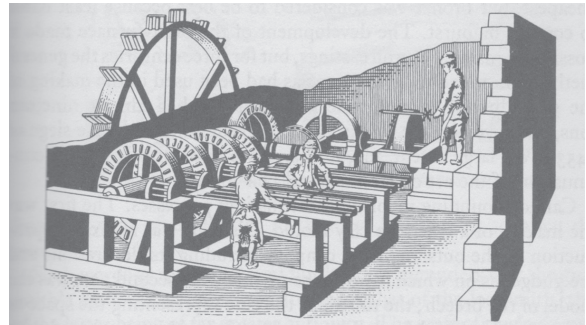


Figure 1.10 Water-powered machinery for boring gun barrels

Source: Reproduced from Diderot's Encyclopedia (1777), in T.K. Derry and Trevor I. Williams, *A Short History of Technology*, Oxford University Press 1960, republished by Dover 1993, page 149

Hydroelectric power has a long history. (See Figure 1.10) The world's first hydroelectric power plant began operation on the Fox River in Appleton, Wisconsin, in 1882. By 1907, hydropower was providing 15 percent of US electrical generation.

Today hydroelectric power is almost exclusively used to generate electricity. The dams needed typically require flooding large areas of land to produce storage lakes. This disturbs the local ecology and can prevent fish from reaching their spawning grounds. Some outdated, dangerous, or ecologically damaging dams in the United States are being demolished.

Micropower systems are very small hydroelectric systems that rely on running river water without a dam. They require at least 3 feet (1 m) of elevation change, but work better with more.

## GEOTHERMAL ENERGY

Geothermal energy consists of the earth's internal heat. About ten feet below the surface, the earth maintains a fairly constant temperature. A geothermal system collects, concentrates, and distributes this energy. There are two common applications of geothermal energy: extraction of heat originating deep within the earth, and geo-exchange of heat near the surface using a heat pump.

Geothermal energy can be extracted where sufficient heat is brought near the surface by conduction, bulging magma, or ground water that has circulated to great depths. Geothermal energy is used to heat buildings in Iceland and Japan. In Boise, Idaho, direct geothermal energy heats over 65 downtown businesses.

The second process, geo-exchange, uses a **heat pump** to extract heat from the ground just below the surface in the winter, and uses the ground as a heat sink for summer cooling, so the same heat pump can be used for both heating and cooling. Geo-exchange heat pumps can significantly reduce energy consumption and emission of pollution and greenhouse gases. A ground-source heat pump offers much greater efficiency than an air-source heat pump, is between three and four times as efficient as electric resistance heating, and uses 70 percent less energy than standard air conditioning equipment.

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For more information on heat pumps, see Chapter 14, “Heating and Cooling.”

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## BIOMASS ENERGY

**Biomass** is the organic matter of plants. Photosynthesis provides the materials for biomass conversion, which includes the combustion of firewood, crop waste, and animal wastes. Biomass can replace chemicals made from fossil fuels to generate electricity and as fuel for transportation vehicles.

Biomass makes use of energy from two types of sources: plants grown for their energy content, and organic waste from agriculture, industry, or garbage. When biomass decomposes, it creates food for new plants; converting it into energy diverts it from this use. Biomass can be considered to be carbon neutral, removing the same amount of carbon dioxide as it grows that is returned to the atmosphere when it is burned.

Biofuels derived from biomass include ethanol alcohol, biodiesel, and methane. Biomass conversion into fuel may require more energy than is obtainable from the product itself, in which case it is not a sustainable process.

## HYDROGEN

The most abundant element on earth, hydrogen is found in many organic compounds as well as water. Although not occurring naturally as a gas, it can be separated from other elements and burned as a fuel. Used in fuel cells, hydrogen combines electrochemically with oxygen to produce electricity and heat, with only water vapor emitted in the process. When used as a fuel, hydrogen is nonpolluting, producing only water when it is burned, and does not contribute to global warming.

Chemical bonds must be broken to free the hydrogen locked within compounds such as water. The most practical method involves production from water by electrolysis, which breaks water into hydrogen and oxygen by passing electrical current through water, using wind or PV-generated electricity.

Hydrogen can be used to generate pollution-free electricity in fuel cells, or to power automobile engines. Hydrogen must be stored in heavy and expensive high-pressure tanks. If stored as a liquid, it must be cooled to  $-423^{\circ}\text{F}$  ( $-253^{\circ}\text{C}$ ).

## STORING RENEWABLE ENERGY

Both wind and solar energy are not easily stored. With any energy storage option, some energy is lost. Batteries lose some of the electrical energy they store as heat, and it takes a large volume of batteries to store a lot of energy.

Wind and hydropower generate electricity by mechanical means, and their energy can be stored before it is converted into electricity. Hydrogen produced by electrolysis can be stored and later recombined with oxygen to recover energy. Hydrogen fuel cells can produce a controlled release of stored energy.

Connecting a photovoltaic system to the existing electrical grid allows the grid to supply electricity when the PV system is inactive at night. Extra PV energy is sent onto the grid. Using

a special PV electrical meter, **net metering** only charges the user for electricity used in excess to what they produce.

## Non-Sustainable Energy Sources

Petroleum and natural gas split the energy market about evenly by 1950. The United States was completely energy self-sufficient, thanks to relatively cheap and abundant domestic coal, oil and natural gas.

Beginning in the 1950s, the United States experienced steadily rising imports of crude oil and petroleum products. In 1973, political conditions in oil-producing countries led to wildly fluctuating oil prices, and high prices encouraged conservation and the development of alternative energy resources. The 1973 oil crisis had a major impact on building construction and operation. Unstable political conditions led to an emphasis on reducing imported oil. Between 2005 and 2011, the amount of oil imported by the United States dropped by 33 percent.

Our most commonly used fuels—oil, gas, and coal—are fossil fuels. We started using fossil fuels around 1850. Although limited supplies still remain, it is becoming continually more difficult to access them without causing environmental damage. Burning fossil fuels produces most of the air pollution and smog we experience, plus acid rain and global climate change. These resources are clearly not renewable in the short term, and are not sustainable resources.

## OIL

Petroleum is a liquid mixture of hydrocarbons that is present in certain rock strata and can be extracted and refined to produce fuels including gasoline, kerosene, and diesel oil. It is often called “oil,” especially when used as a fuel or lubricant. Oil is used to heat buildings and to make lubricants, plastics, and other chemicals, as well as to power vehicles.

The first oil wells were dug in China starting around the fourth century CE. Oil was first distilled into kerosene for lighting in the mid-nineteenth century. In 1859, the first oil well was drilled in Titusville, Pennsylvania. Fuel oil began to replace coal for building heating in the 1920s.

New wells are deeper, underwater, or in almost inaccessible locations. Oil shale is becoming a more common source of oil. It requires huge amounts of energy to extract oil from tar sands, resulting in a high cost to mine and a very high cost to the environment.

## GAS

The first well intentionally drilled to obtain natural gas was drilled in 1821 in Fredonia, New York. It was originally used as a fuel for streetlights. In 1855, Robert Bunsen invented the Bunsen burner so that gas could be used to provide heat for cooking and warming buildings. However, there were very few pipelines for natural gas until the 1940s.

Natural gas is used to generate electricity, and for industrial, residential, and commercial uses. More than half of US commercial establishments and residences are heated using gas.