BUILDING SYSTEMS FOR INTERIOR DESIGNERS

Corky Binggeli a.s.i.d.
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JOHN WILEY & SONS, INC.
To my mother,
who taught me to love learning,
and
to my father,
who showed me how buildings are made.
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The inspiration for Building Systems for Interior Designers came when I tried to teach interior design students about all the ways buildings support our activities and physical needs—without an adequate textbook. I needed an approach that supported the special concerns of the interior designer, while connecting those issues to the work of the rest of the building design team. I had researched building systems in a number of excellent texts intended for architecture, engineering, and even hospitality management students, but I had found that none of those texts taught the necessary combination of related subjects in adequate depth without an emphasis on calculations and formulas.

Interior design has a relatively short history as a profession requiring special training and demanding technical expertise. Over the past half-century, design professionals have evolved from decorators working primarily in private residences to critical contributors in the design of commercial and residential buildings. We are expected to apply building codes and to work closely with engineers and architects. To do this, we must understand what the other members of the design team have to say, how they approach the design process, and how they document their work.

The more we know about the process of designing and constructing a building, the more effective impact we can have on the results. To cite one example from my own largely commercial interior design practice, my discussion with the mechanical engineer on a spa project of alternate methods of supplying extra heat to a treatment room resulted in a design that improved both our client’s heating bills and his customers’ experience.

The approach of architects and engineers to building design has changed from one of imposing the building on its site to one of limiting the adverse impact of the building on the environment by using resources available on site. Sustainable design requires that we select materials wisely to create healthy, safe buildings that conserve energy. Sustainable design solutions cut across disciplines, and successful solutions arise only when all the members of the design team work together. As interior designers, we can support or sabotage this effort. We must be involved in the project from the beginning to coordinate with the rest of the design team. That means we must understand and respect the concerns of the architects and engineers, while earning their respect and understanding in return.

Building Systems for Interior Designers is intended primarily as a textbook for interior design students. The style strives for clarity, with concepts explained simply and delivered in everyday language. Enough technical information is offered to support a thorough understanding of how a building works. The illustrations are plentiful and designed to convey information clearly and visually. I have kept in mind the many students for whom English is a second language—as well as the common technophobes among us—as I wrote and illustrated this text. Featured throughout the book are special "Designer’s Tips.” Look for this icon to find helpful professional advice on a wide range of topics.

Building Systems for Interior Designers covers some subjects, such as heating and air-conditioning systems, that are rarely included in other parts of an interior designer’s education. Other areas, such as lighting, typically have entire courses devoted to them, and are given a less thorough treatment here. While some topics, such as acoustics or fire safety, are intimately tied to the work of the interior designer, others, such as transportation systems, involve the interior designer less directly, or may be absent from some projects altogether. This text assumes that the reader has a basic knowledge of building design and construction, but no special training in physics or mathematics. I have sought to cover all the related systems in a building in sufficient depth to provide the reader with a good general understanding, while avoiding repetition of material most likely covered in other courses and texts.

As the book has evolved, it has become obvious that this material is also valuable for people involved in making decisions about the systems in their own buildings,
whether they are homeowners or facilities managers. Practicing interior designers and architects will also find *Building Systems for Interior Designers* a useful reference when checking facts and researching options. Interior designers preparing for the National Council for Interior Design Qualification (NCIDQ) professional certification exam will also benefit from this text.

*Building Systems for Interior Designers* has evolved from an initial set of lecture notes, through an illustrated outline, to classroom handouts of text and illustrations, and finally into a carefully researched and written illustrated text. In the process, I have enriched my own understanding of how buildings support our needs and activities, and this understanding has in turn benefited both my professional work as an interior designer and my continuing role as a teacher. It is my hope that, through this text, I will pass these benefits along to you, my readers.

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  Arlington, Massachusetts  
  2002
This book owes its existence to the support and talents of many people. In targeting the needs of interior designers, I began by researching the materials already available for students of architecture and engineering. I am especially indebted to the Ninth Edition of *Mechanical and Electrical Equipment for Buildings* by Benjamin Stein and John S. Reynolds (John Wiley & Sons, Inc., NY, 2000), whose comprehensive and clear coverage of building systems was both a standard for excellence and a source for accurate information.

I would never have started on the road to writing this text without the encouragement of Professor Rose-Mary Botti-Salitsky IDEC, IIDA of Mount Ida College, and of Thomas R. Consi Ph.D. at the Massachusetts Institute of Technology, a dear friend whose faith in my ability far exceeds my own. Professor Allan Kirkpatrick of Colorado State University shared his contacts and experience as a textbook author, providing the critical link to making this book a reality.

A number of friends and professional colleagues reviewed the manuscript before submission and offered extremely helpful comments on content and clarity. These include Felice Silverman IIDA of Silverman Trykowski Associates, Josh Feinstein L.C. of Sladen Feinstein Integrated Lighting, Associate Professor Herb Fremin of Wentworth Institute of Technology, and Edward T. Kirkpatrick Ph.D., P.E. Additional technical review was provided by Professor Arlena Hines ASIS, IDEC of Lansing Community College, Professor Novem Mason of the University of North Carolina at Greensboro, Professor Joyce Rasdall of Southeast Missouri State University, Jeff Barber AIA of Gensler Architecture, and Professor Janine King of the University of Florida. Their professional perspectives and teaching experience helped keep the text accurate and focused on the prospective reader, and their enthusiasm and encouragement were wonderfully motivating.

I would also like to thank the staff at John Wiley & Sons, Inc., whose professionalism, support, and good advice guided my efforts. Executive Editor Amanda Miller and Developmental Editor Jennifer Ackerman worked closely with me to see that the text and illustrations reflected the intended content and spirit that I envisioned.

Finally, I am deeply indebted to my husband, Keith Kirkpatrick, who read and commented on every word of the text and who reviewed all of the illustrations as well. This book is a testament to his patience, insight, diligence, and steadfast support in a thousand small ways.
Part

THE BIG PICTURE
Like our skins, a building is a layer of protection between our bodies and our environment. The building envelope is the point at which the inside comes into contact with the outside, the place where energy, materials, and living things pass in and out. The building’s interior design, along with the mechanical, electrical, plumbing, and other building systems, creates an interior environment that supports our needs and activities and responds to the weather and site conditions outdoors. In turn, the environment at the building site is part of the earth’s larger natural patterns.

THE OUTDOOR ENVIRONMENT

The sun acting on the earth’s atmosphere creates our climate and weather conditions. 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 to give us seasonal and daily weather patterns.

Solar energy is the source of almost all of our energy resources. Ultraviolet (UV) radiation from the sun triggers photosynthesis in green plants, which produces the oxygen we breathe, the plants we eat, and the fuels we use for heat and power. Ultraviolet wavelengths make up only about 1 percent of the sun’s rays that reach sea level, and are too short to be visible. About half of the energy in sunlight that reaches the earth arrives as visible wavelengths. The remainder is infrared (IR) wavelengths, which are longer than visible light, and which carry the sun’s heat.

Plants combine the sun’s energy with water and turn it into sugars, starches, and proteins through photosynthesis, giving us food to eat, which in turn builds and fuels our bodies. Humans and other animals breathe in oxygen and exhale carbon dioxide. Plants supply us with this oxygen by taking carbon dioxide from the air and giving back oxygen. Besides its roles in food supply and oxygen production, photosynthesis also produces wood for construction, fibers for fabrics and paper, and landscape plantings for shade and beauty.

Plants transfer the sun’s energy to us when we eat them, or when we eat plant-eating animals. That energy goes back to plants when animal waste decomposes and releases nitrogen, phosphorus, potassium, carbon, and other elements into the 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.
The heat of the sun evaporates water into the air, purifying it by distillation. The water vapor condenses as it rises and then precipitates as rain and snow, which clean the air as they fall to earth. Heavier particles fall out of the air by gravity, and the wind dilutes and distributes any remaining contaminants when it stirs up the air.

The sun warms our bodies and our buildings both directly and by warming the air around us. We depend on the sun's heat for comfort, and design our buildings to admit sun for warmth. Passive and active solar design techniques protect us from too much heat and cool our buildings in hot weather.

During the day, the sun illuminates both the outdoors and, through windows and skylights, the indoors. Direct sunlight, however, is often too bright for comfortable vision. When visible light is scattered by the atmosphere, the resulting diffuse light offers an even, restful illumination. Under heavy clouds and at night, we use artificial light for adequate illumination.

Sunlight disinfects surfaces that it touches, which is one reason the old-fashioned clothesline may be superior to the clothes dryer. Ultraviolet radiation kills many harmful microorganisms, purifying the atmosphere, and eliminating disease-causing bacteria from sunlit surfaces. It also creates vitamin D in our skin, which we need to utilize calcium.

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

All energy sources are derived from the sun, with the exception of geothermal, nuclear, and tidal power. When the sun heats the air and the ground, it creates currents that can be harnessed as wind power. The cycle of evaporation and precipitation uses solar energy to supply water for hydroelectric power. Photosynthesis in trees creates wood for fuel. About 14 percent of the world's energy comes from biomass, including firewood, crop waste, and even animal dung. These are all considered to be renewable resources because they can be constantly replenished, but our demand for energy may exceed the rate of replenishment.

Our most commonly used fuels—coal, oil, and gas—are fossil fuels. As of 1999, oil provided 32 percent of the world's energy, followed by natural gas at 22 percent, and coal at 21 percent. Huge quantities of de-caying vegetation were compressed and subjected to the earth's heat over hundreds of millions of years to create the fossilized solar energy we use today. These resources are clearly not renewable in the short term.

LIMITED ENERGY RESOURCES

In the year 2000, the earth's population reached 6 billion people, with an additional billion anticipated by 2010. With only 7 percent of the world's population, North America consumes 30 percent of the world's energy, and building systems use 35 percent of that to operate. Off-site sewage treatment, water supply, and solid waste management account for an additional 6 percent. The processing, production, and transportation of materials for building construction take up another 7 percent of the energy budget. This adds up to 48 percent of total energy use appropriated for building construction and operation.

The sun's energy arrives at the earth at a fixed rate, and the supply of solar energy stored over millions of years in fossil fuels is limited. The population keeps growing, however, and each person is using more energy. We don't know exactly when we will run out of fossil fuels, but we do know that wasting the limited resources we have is a dangerous way to go. Through careful design, architects, interior designers, and building engineers can help make these finite resources last longer.

For thousands of years in the past, we relied primarily upon the sun's energy for heat and light. Prior to the nineteenth century, wood was the most common fuel. As technology developed, we used wind for transportation and processing of grain, and early industries were located along rivers and streams in order to utilize waterpower. Mineral discoveries around 1800 introduced portable, convenient, and reliable fossil fuels—coal, petroleum, and natural gas—to power the industrial revolution.

In 1830, the earth's population of about 1 billion people depended upon 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. By 1950, petroleum and natural gas split the energy market about evenly. The United States was completely energy self-sufficient, thanks to relatively cheap and abundant domestic coal, oil, and natural gas.

Nuclear power, introduced in the 1950s, has an uncertain future. Although technically exhaustible, nuclear
resources are used very slowly. Nuclear plants contain high pressures, temperatures, and radioactivity levels during operation, however, and have long and expensive construction periods. The public has serious concerns over the release of low-level radiation over long periods of time, and over the risks of high-level releases. Civilian use of nuclear power has been limited to research and generation of electricity by utilities.

Growing demand since the 1950s has promoted steadily rising imports of crude oil and petroleum products. By the late 1970s, the United States imported over 40 percent of its oil. 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. By 1982, the United States imported only 28 percent of its oil. Building designers and owners now strive for energy efficiency to minimize costs. Almost all U.S. building codes now include energy conservation standards. Even so, imported oil was back up to over 40 percent by 1989, and over 50 percent in 1990.

Coal use in buildings has declined since the 1990s, with many large cities limiting its application. Currently, most coal is used for electric generation and heavy industry, where fuel storage and air pollution problems can be treated centrally. Modern techniques scrub and filter out sulfur ash from coal combustion emissions, although some older coal-burning plants still contribute significant amounts of pollution.

Our current energy resources include direct solar and renewable solar-derived sources, such as wind, wood, and hydropower; nuclear and geothermal power, which are exhaustible but are used up very slowly; tidal power; and fossil fuels, which are not renewable in the short term. Electricity can be generated from any of these. In the United States, it is usually produced from fossil fuels, with minor amounts contributed by hydropower and nuclear energy. Tidal power stations exist in Canada, France, Russia, and China, but they are expensive and don’t always produce energy at the times it is needed. There are few solar thermal, solar photovoltaic, wind power or geothermal power plants in operation, and solar power currently supplies only about 1 percent of U.S. energy use.

Today’s buildings are heavily reliant upon electricity because of its convenience of use and versatility, and consumption of electricity is expected to rise about twice as fast as overall energy demand. Electricity and daylight provide virtually all illumination. Electric lighting produces heat, which in turn increases air-conditioning energy use in warm weather, using even more electricity.

Only one-third of the energy used to produce electricity for space heating actually becomes heat, with most of the rest wasted at the production source.

Estimates of U.S. onshore and offshore fossil fuel reserves in 1993 indicated a supply adequate for about 50 years, with much of it expensive and environmentally objectionable to remove. A building with a 50-year functional life and 100-year structural life could easily outlast fossil fuel supplies. As the world’s supply of fossil fuels diminishes, buildings must use nonrenewable fuels conservatively if at all, and look to on-site resources, such as daylighting, passive solar heating, passive cooling, solar water heating, and photovoltaic electricity.

Traditional off-site networks for natural gas and oil and the electric grid will continue to serve many buildings, often in combination with on-site sources. On-site resources take up space locally, can be labor intensive, and sometimes have higher first costs that take years to recover. Owners and designers must look beyond these immediate building conditions, and consider the building’s impact on its larger environment throughout its life.

THE GREENHOUSE EFFECT

Human activities are adding greenhouse gases—pollutants that trap the earth’s heat—to the atmosphere at a faster rate than at any time over the past several thousand years. A warming trend has been recorded since the late nineteenth century, with the most rapid warming occurring since 1980. If emissions of greenhouse gases continue unabated, scientists say we may change global temperature and our planet’s climate at an unprecedented rate.

The greenhouse effect (Fig. 1-1) is a natural phenomenon that helps regulate the temperature of our planet. The sun heats the earth and some of this heat, rather than escaping back to space, is trapped in the atmosphere by clouds and greenhouse gases such as water vapor and carbon dioxide. Greenhouse gases serve a useful role in protecting the earth’s surface from extreme differences in day and night temperatures. If all of these greenhouse gases were to suddenly disappear, our planet would be 15.5°C (60°F) colder than it is, and uninhabitable.

However, significant increases in the amount of these gases in the atmosphere cause global temperatures to rise. As greenhouse gases accumulate in the atmosphere, they absorb sunlight and IR radiation and prevent some of the heat from radiating back out into space, trapping the sun’s heat around the earth. A global rise
in temperatures of even a few degrees could result in the melting of polar ice and the ensuing rise of ocean levels, and would affect all living organisms.

Human activities contribute substantially to the production of greenhouse gases. As the population grows and as we continue to use more energy per person, we create conditions that warm our atmosphere. Energy production and use employing fossil fuels add greenhouse gases. A study commissioned by the White House and prepared by the National Academy of Sciences in 2001 found that global warming had been particularly strong in the previous 20 years, with greenhouse gases accumulating in the earth’s atmosphere as a result of human activities, much of it due to emissions of carbon dioxide from burning fossil fuels.

Since preindustrial times, atmospheric concentrations of carbon dioxide have risen over 30 percent and are now increasing about one-half percent annually. Worldwide, we generate about 20 billion tons of carbon dioxide each year, an average of four tons per person. One-quarter of that comes from the United States, when the rate is 18 tons per person annually. Carbon dioxide concentrations, which averaged 280 parts per million (ppm) by volume for most of the past 10,000 years, are currently around 370 ppm.

Burning fossil fuels for transportation, electrical generation, heating, and industrial purposes contributes most of this increase. Clearing land adds to the problem by eliminating plants that would otherwise help change carbon dioxide to oxygen and filter the air. Plants can now absorb only about 40 percent of the 5 billion tons of carbon dioxide released into the air each year. Making cement from limestone also contributes significant amounts of carbon dioxide.

Methane, an even more potent greenhouse gas than carbon dioxide, has increased almost one and a half times, and is increasing by about 1 percent per year. Landfills, rice farming, and cattle raising all produce methane.

Carbon monoxide, ozone, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), chlorofluorocarbons (CFCs), and sulfur hexafluoride are other greenhouse gases. Nitrous oxide is up 15 percent over the past 20 years. Industrial smokestacks and coal-fired electric utilities produce both sulfur dioxide and carbon monoxide.

The Intergovernmental Panel on Climate Change (IPCC), which was formed in 1988 by the United Nations Environment Program and the World Meteorological Organization, projected in its Third Assessment Report (2001) (Cambridge University Press, 2001) an average global temperature increase of 1.4°C to 5.8°C (2.5°F–10.4°F) by 2100, and greater warming thereafter. The IPCC concluded that climate change will have mostly adverse affects, including loss of life as a result of heat waves, worsened air pollution, damaged crops, spreading tropical diseases, and depleted water resources. Extreme events like floods and droughts are likely to become more frequent, and melting glaciers will expand oceans and raise sea level 0.09 to 0.88 meters (4 inches to 35 inches) over the next century.

OZONE DEPLETION

The human health and environmental concerns about ozone layer depletion are different from the risks we face from global warming, but the two phenomena are related in certain ways. Some pollutants contribute to both problems and both alter the global atmosphere. Ozone layer depletion allows more harmful UV radiation to reach our planet’s surface. Increased UV radiation can lead to skin cancers, cataracts, and a suppressed immune system in humans, as well as reduced yields for crops.

Ozone is an oxygen molecule that occurs in very small amounts in nature. In the lower atmosphere, ozone occurs as a gas that, in high enough concentrations, can cause irritations to the eyes and mucous membranes. In the upper atmosphere (the stratosphere), ozone absorbs solar UV radiation that otherwise would cause severe damage to all living organisms on the earth’s surface. Prior to the industrial revolution, ozone
in the lower and upper atmospheres was in equilibrium. Today, excessive ozone in the lower atmosphere contributes to the greenhouse effect and pollutes the air.

Ozone is being destroyed in the upper atmosphere, however, where it has a beneficial effect. This destruction is caused primarily by CFCs. Chlorofluorocarbons don’t occur naturally. They are very stable chemicals developed in the 1960s, and they can last up to 50 years. Used primarily for refrigeration and air-conditioning, CFCs have also been used as blowing agents to produce foamed plastics for insulation, upholstery padding, and packaging, and as propellants for fire extinguishers and aerosols. In their gaseous form, they drift into the upper atmosphere and destroy ozone molecules. This allows more UV radiation to reach the surface of the earth, killing or altering complex molecules of living organisms, including DNA. This damage has resulted in an increase in skin cancers, especially in southern latitudes. The Montreal Protocol on Substances that Deplete the Ozone Layer, signed in 1987 by 25 nations (168 nations are now party to the accord), decreed an international stop to the production of CFCs by 2000, but the effects of chemicals already produced will last for many years.

**Sustainable Design Strategies**

Sustainable architecture looks at human civilization as an integral part of the natural world, and seeks to preserve nature through encouraging conservation in daily life. Energy conservation in buildings is a complex issue involving sensitivity to the building site, choice of appropriate construction methods, use and control of daylight, selection of finishes and colors, and the design of artificial lighting. The selection of heating, ventilating, and air-conditioning (HVAC) and other equipment can have a major effect on energy use. The use of alternative energy sources, waste control, water recycling, and control of building operations and maintenance all contribute to sustainable design.

The materials and methods used for building construction and finishing have an impact on the larger world. The design of a building determines how much energy it will use throughout its life. The materials used in the building’s interior are tied to the waste and pollution generated by their manufacture and eventual disposal. Increasing energy efficiency and using clean energy sources can limit greenhouse gases.

According to Design Ecology, a project sponsored by Chicago’s International Interior Design Association (IIDA) and Collins & Aikman Floorcoverings, “Sustainability is a state or process that can be maintained indefinitely. The principles of sustainability integrate three closely intertwined elements—the environment, the economy, and the social system—into a system that can be maintained in a healthy state indefinitely.”

Environmentally conscious interior design is a practice that attempts to create indoor spaces that are environmentally sustainable and healthy for their occupants. Sustainable interiors address their impact on the global environment. To achieve sustainable design, interior designers must collaborate with architects, developers, engineers, environmental consultants, facilities and building managers, and contractors. The professional ethics and responsibilities of the interior designer include the creation of healthy and safe indoor environments. The interior designer’s choices can provide comfort for the building’s occupants while still benefiting the environment, an effort that often requires initial conceptual creativity rather than additional expense.

Energy-efficient techniques sometimes necessitate special equipment or construction, and may consequently have a higher initial cost than conventional designs. However, it is often possible to use techniques that have multiple benefits, spreading the cost over several applications to achieve a better balance between initial costs and benefits. For example, a building designed for daylighting and natural ventilation also offers benefits for solar heating, indoor air quality (IAQ), and lighting costs. This approach cuts across the usual building system categories and ties the building closely to its site. We discuss many of these techniques in this book, crossing conventional barriers between building systems in the process.

As an interior designer, you can help limit greenhouse gas production by specifying energy-efficient lighting and appliances. Each kilowatt-hour (kWh) of electricity produced by burning coal releases almost 1 kg (more than 2 lb) of carbon dioxide into the atmosphere. By using natural light, natural ventilation, and adequate insulation in your designs, you reduce energy use.

Specify materials that require less energy to manufacture and transport. Use products made of recycled materials that can in turn be recycled when they are replaced. It is possible to use materials and methods that are good for the global environment and for healthy interior spaces, that decrease the consumption of energy and the strain on the environment, without sacrificing the comfort, security, or aesthetics of homes, offices, or public spaces.
One way to reduce energy use while improving conditions for the building’s occupants is to introduce user-operated controls. These may be as low-tech as shutters and shades that allow the control of sunlight entering a room and operable windows that offer fresh air and variable temperatures. Users who understand how a building gets and keeps heat are more likely to conserve energy. Occupants who have personal control are comfortable over a wider range of temperatures than those with centralized controls.

Using natural on-site energy sources can reduce a building’s fossil fuel needs. A carefully sited building can enhance daylighting as well as passive cooling by night ventilation. Good siting also supports opportunities for solar heating, improved indoor air quality, less use of electric lights, and added acoustic absorption.

Rainwater retention employs local water for irrigation and flushing toilets. On-site wastewater recycling circulates the water and waste from kitchens and baths through treatment ponds, where microorganisms and aquatic plants digest waste matter. The resulting water is suitable for irrigation of crops and for fish food. The aquatic plants from the treatment ponds can be harvested for processing as biogas, which can then be used for cooking and for feeding farm animals. The manure from these animals in turn provides fertilizer for crops.

Look at the building envelope, HVAC system, lighting, equipment and appliances, and renewable energy systems as a whole. Energy loads—the amount of energy the building uses to operate—are reduced by integration with the building site, use of renewable resources, the design of the building envelope, and the selection of efficient lighting and appliances. Energy load reductions lead to smaller, less expensive, and more efficient HVAC systems, which in turn use less energy.

Buildings, as well as products, can be designed for recycling. A building designed for sustainability adapts easily to changed uses, thereby reducing the amount of demolition and new construction and prolonging the building’s life. With careful planning, this strategy can avoid added expense or undifferentiated, generic design. The use of removable and reusable demountable building parts adds to adaptability, but may require a heavier structural system, as the floors are not integral with the beams, and mechanical and electrical systems must be well integrated to avoid leaks or cracks. Products that don’t combine different materials allow easier separation and reuse or recycling of metals, plastics, and other constituents than products where diverse materials are bonded together.

The Leadership in Energy and Environmental Design System

The U.S. Green Building Council, a nonprofit coalition representing the building industry, has created a comprehensive system for building green called LEED™, short for Leadership in Energy and Environmental Design. The LEED program provides investors, architects and designers, construction personnel, and building managers with information on green building techniques and strategies. At the same time, LEED certifies buildings that meet the highest standards of economic and environmental performance, and offers professional education, training, and accreditation. Another aspect of the LEED system is its Professional Accreditation, which recognizes an individual’s qualifications in sustainable building. In 1999, the LEED Commercial Interior Committee was formed to develop definitive standards for what constitutes a green interior space, and guidelines for sustainable maintenance. The LEED program is currently developing materials for commercial interiors, residential work, and operations and maintenance.

Interior designers are among those becoming LEED-accredited professionals by passing the LEED Profes-
More and more architects, engineers, and interior designers are realizing the business advantages of marketing green design strategies. This is a very positive step toward a more sustainable world, yet it is important to verify the credentials of those touting green design. The LEED Professional Accreditation Examination establishes minimum competency in much the same way as the NCIDQ exam seeks to set a universal standard by which to measure the competency of interior designers to practice as professionals. Training workshops are available to prepare for the exam.

Receiving LEED accreditation offers a way for designers to differentiate themselves in the marketplace. As green buildings go mainstream, both government and private sector projects will begin to require a LEED-accredited designer on the design teams they hire.

The LEED process for designing a green building starts with setting goals. Next, alternative strategies are evaluated. Finally, the design of the whole building is approached in a spirit of integration and inspiration. It is imperative to talk with all the people involved in the building’s design about goals; sometimes the best ideas come from the most unlikely places. Ask how each team member can serve the goals of this project. Include the facilities maintenance people in the design process, to give feedback to designers about what actually happens in the building, and to cultivate their support for new systems. Goals can be sabotaged when an architect, engineer, or contractor gives lip service to green design, but reacts to specifics with “We’ve never done it that way before,” or its evil twin “We’ve always done it this way.” Question whether time is spent on why team members can’t do something, or on finding a solution—and whether higher fees are requested just to overcome opposition to a new way of doing things. Finally, be sure to include the building’s users in the planning process; this sounds obvious, but it is not always done.

In 1999, the U.S. government’s General Services Administration (GSA) Public Building Service (PBS) made a commitment to use the LEED rating system for all future design, construction, and repair and alterations of federal construction projects and is working on revising its leases to include requirements that spaces leased for customers be green. The Building Green Program includes increased use of recycled materials, waste management, and sustainable design. The PBS chooses products with recycled content, optimizes natural daylight, installs energy-efficient equipment and lighting, and installs water-saving devices. The Denver Courthouse serves as a model for these goals. It uses photovoltaic cells and daylighting shelves, along with over 100 other sustainable building features, enabling it to apply for a LEED Gold Rating.

The Energy Star® Label

The Energy Star® label (Fig. 1-2) was created in conjunction with the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) to help consumers quickly and easily identify energy efficient products such as homes, appliances, and lighting. Energy Star products are also available in Canada. In the United States alone in the year 2000, Energy Star resulted in greenhouse gas reductions equivalent to taking 10 million cars off the road. Eight hundred and sixty four billion pounds of carbon dioxide emissions have been prevented due to Energy Star commitments to date.

The Energy Star Homes program reviews the plans for new homes and provides design support to help the home achieve the five-star Energy Star Homes rating, by setting the standard for greater value and energy savings. Energy Star–certified homes are also eligible for rebates on major appliances.

The program also supplies EnergySmart computer software that walks you through a computerized energy audit of a home and provides detailed information on energy efficiency. The PowerSmart computer program assesses electric usage for residential customers who use more than 12,000 kW per year, and can offer discounts on insulation, refrigerators, thermostats, and heat pump repairs. Energy Star Lighting includes rebates on energy-efficient light bulbs and fixtures. The program offers rebates on Energy Star–labeled clothes washers, which save an average of 60 percent on energy costs and reduce laundry water consumption by 35 percent.

Beyond Sustainable Design

Conservation of limited resources is good, but it is possible to create beautiful buildings that generate more energy than they use and actually improve the health of...
their environments. Rather than simply cutting down on the damage buildings do to the environment, which results in designs that do less—but still some—damage, some designs have a net positive effect. Instead of suffering with a showerhead that limits the flow to an unsatisfactory minimum stream, for example, you can take a guilt-free long, hot shower, as long as the water is solar heated and returns to the system cleaner than it started. Buildings can model the abundance of nature, creating more and more riches safely, and generating delight in the process.

Such work is already being done, thanks to pioneers like William McDonough of William McDonough + Partners and McDonough Braungart Design Chemistry, LLC, and Dr. David Orr, Chairman of the Oberlin Environmental Studies Program. Their designs employ a myriad of techniques for efficient design. A photovoltaic array on the roof that turns sunlight into electric energy uses net metering to connect to the local utility’s power grid, and sells excess energy back to the utility. Photovoltaic cells are connected to fuel cells that use hydrogen and oxygen to make more energy. Buildings process their own waste by passing wastewater through a man-made marsh within the building. The landscaping for the site selects plants native to the area before European settlement, bringing back habitats for birds and animals. Daylighting adds beauty and saves energy, as in a Michigan building where worker productivity increased, and workers who had left for higher wages returned because, as they said, they couldn’t work in the dark. Contractors welcome low-toxicity building materials that don’t have odors from volatile organic compounds (VOCs), and that avoid the need to wear respirators or masks while working.

William McDonough has been working on the Ford River Rouge automobile plant in Oregon to restore the local river as a healthy, safe biological resource. This 20-year project includes a new 55,740 square meter (600,000 square ft) automobile assembly plant featuring the largest planted living roof, with one-half million square feet of soil and plants that provide storm water management. The site supports habitat restoration and is mostly unpaved and replanted with native species. The interiors are open and airy, with skylights providing daylighting and safe walkways allowing circulation away from machinery. Ford has made a commitment to share what they learn from this building for free, and is working with McDonough on changes to products that may lead to cars that actually help clean the air.

The Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio, represents a collaboration between William McDonough and David Orr. Completed in January 2000, the Lewis Center consists of a main building with classrooms, faculty offices, and a two-story atrium, and a connected structure with a 100-seat auditorium and a solarium. Interior walls stop short of the exposed curved ceiling, creating open space above for daylight.

One of the project’s primary goals was to produce more energy than it needs to operate while maintaining acceptable comfort levels and a healthy interior environment. The building is oriented on an east-west axis to take advantage of daylight and solar heat gain, with the major classrooms situated along the southern exposure to maximize daylight, so that the lighting is often unnecessary. The roof is covered with 344 square meters (3700 square ft) of photovoltaic panels, which are expected to generate more than 75,000 kilowatt-hours (kW-h) of energy annually. Advanced design features include geothermal wells for heating and cooling, passive solar design, daylighting and fresh air delivery throughout. The thermal mass of the building’s concrete floors and exposed masonry walls helps to retain and reradiate heat. Overhanging eaves and a vine-covered trellis on the south elevation shade the building, and an earth berm along the north wall further insulates the wall. The atrium’s glass curtain wall uses low-emissivity (low-e) glass.

Operable windows supplement conditioned air supplied through the HVAC system. A natural wastewater treatment facility on site includes a created wetland for natural storm water management and a landscape that provides social spaces, instructional cultivation, and habitat restoration.

Interior materials support the building’s goals, including sustainably harvested wood; paints, adhesives, and carpets with low VOC emissions; and materials with recycled contents such as structural steel, brick, aluminum curtain-wall framing, ceramic tile, and toilet partitions. Materials were selected for durability, low maintenance, and ecological sensitivity.

The Herman Miller SQA building in Holland, Michigan, which remanufactures Herman Miller office furniture, enhances human psychological and behavioral experience by increasing contact with natural processes, incorporating nature into the building, and reducing the use of hazardous materials and chemicals, as reported in the July/August 2000 issue of Environmental Design & Construction by Judith Heerwagen, Ph.D. Drawing on research from a variety of studies in the United States and Europe, Dr. Heerwagen identifies links between physical, psychosocial, and neurological-cognitive well-being and green building design features.
Designed by William McDonough + Partners, the 26,941 square meter (290,000 square ft) building houses a manufacturing plant and office/showroom. About 700 people work in the manufacturing plant and offices, which contain a fitness center with basketball court and exercise machines overlooking a country landscape, and convenient break areas. Key green building features include good energy efficiency, indoor air quality, and daylighting. The site features a restored wetlands and prairie landscape.

Although most organizations take weeks to months to regain lost efficiency after a move, lowering productivity by around 30 percent, Herman Miller’s performance evaluation showed a slight overall increase in productivity in the nine-month period after their move. On-time delivery and product quality also increased. This occurred even though performance bonuses to employees decreased, with the money going instead to help pay for the new building. This initial study of the effects of green design on worker satisfaction and productivity will be augmented by the “human factors commissioning” of all of the City of Seattle’s new and renovated municipal buildings, which will be designed to meet or exceed the LEED Silver level.
The way sunlight moves around a building site influences the way the building is positioned, the size and location of windows and skylights, the amount of daylighting, and the design of mechanical and natural heating and cooling systems. The distance above or below the equator determines how sunlight moves across the site (Figs. 2-1, 2-2). The amount of sunlight that reaches the site depends on its altitude above sea level, how close it is to bodies of water, and the presence of shading plants and trees.

Fountains, waterfalls, and trees tend to raise the humidity of the site and lower the temperature. Large bodies of water, which are generally cooler than the land during the day and warmer at night, act as heat reservoirs that moderate variations in local temperatures and generate offshore breezes. Large water bodies are usually warmer than the land in the winter and cooler in the summer.

Forests, trees, other buildings, and hills shape local wind patterns. The absorbency of the ground surface determines how much heat will be retained to be released at night, and how much will be reflected onto the building surface. Light-colored surfaces reflect solar radiation, while dark ones absorb and retain radiation. Plowed ground or dark pavement will be warmer than surrounding areas, radiating heat to nearby surfaces and creating small updrafts of air. Grass and other ground covers lower ground temperatures by absorbing solar radiation, and aid cooling by evaporation.

LOCAL CLIMATES

Local temperatures vary with the time of day and the season of the year. Because the earth stores heat and releases it at a later time, a phenomenon known as thermal lag, afternoon temperatures are generally warmer than mornings. The lowest daily temperature is usually just before sunrise, when most of the previous day’s heat has dissipated. Although June experiences the most solar radiation in the northern hemisphere, summer temperatures peak in July or August due to the long-term effects of thermal storage. Because of this residual stored heat, January and February—about one month past the winter solstice—are the coldest months. It is usually colder at higher latitudes, both north and south, as a result of shorter days and less solar radiation. Sites may have microclimates, different from surrounding areas, which result from their elevation, closeness to large bodies of water, shading, and wind patterns.

Cities sometimes create their own microclimates with relatively warm year-round temperatures produced
by heat sources such as air conditioners, furnaces, electric lights, car engines, and building machinery. Energy released by vehicles and buildings to the outdoors warms the air $3^\circ C$ to $6^\circ C$ ($5^\circ F$–$11^\circ F$) above the surrounding countryside. The rain that runs off hard paved surfaces and buildings into storm sewers isn’t available for evaporative cooling. Wind is channeled between closely set buildings, which also block the sun’s warmth in winter. The convective updrafts created by the large cities can affect the regional climate. Sunlight is absorbed and reradiated off massive surfaces, and less is given back to the obscured night sky.

**CLIMATE TYPES**

Environmentally sensitive buildings are designed in response to the climate type of the site. Indigenous architecture, which has evolved over centuries of trial and error, provides models for building in the four basic climate types.

**Cold Climates**

Cold climates feature long cold winters with short, very hot periods occurring occasionally during the summer. Cold climates generally occur around 45 degrees latitude north or south, for example, in North Dakota. Buildings designed for cold climates emphasize heat retention, protection from rain and snow, and winter wind protection. They often include passive solar heating, with the building encouraging heat retention without mechanical assistance.

In cool regions, minimizing the surface area of the building reduces exposure to low temperatures. The building is oriented to absorb heat from the winter sun. Cold air collects in valley bottoms. North slopes get less winter sun and more winter wind, and hilltops lose heat to winter winds. Setting a building into a protective south-facing hillside reduces the amount of heat loss and provides wind protection, as does burying a building in earth. In cold climates, dark colors on the south-facing surfaces increase the absorption of solar heat. A dark roof with a steep slope will collect heat, but this is negated when the roof is covered with snow.

**Temperate Climates**

Temperate climates have cold winters and hot summers. Buildings generally require winter heating and summer cooling, especially if the climate is humid. Temperate climates are found between 35 degrees and 45 degrees latitude, in Washington, DC, for example. South-facing walls are maximized in a building designed for a temperate region. Summer shade is provided for exposures on the east and west and over the roof. Deciduous shade trees that lose their leaves in the winter help to protect the building from sun in hot weather and allow the winter sun through. The building’s design encourages air movement in hot weather while protecting against cold winter winds (Fig. 2-3).

**Hot Arid Climates**

Hot arid climates have long, hot summers and short, sunny winters, and the daily temperatures range widely between dawn and the warmest part of the afternoon.
Arizona is an example of a hot arid climate. Buildings designed for hot arid climates feature heat and sun control, and often try to increase humidity. They take advantage of wind and rain for cooling and humidity, and make the most of the cooler winter sun.

Windows and outdoor spaces are shaded from the sun, and summer shade is provided to the east and west and over the roof. Enclosed courtyards offer shade and encourage air movement, and the presence of a fountain or pool and plants increases humidity. Even small bodies of water produce a psychological and physical evaporative cooling effect. Sites in valleys near a watercourse keep cooler than poorly ventilated locations. In warm climates, sunlit surfaces should be a light color, to reflect as much sun as possible.

**Hot Humid Climates**

Hot humid climates have very long summers with slight seasonal variations and relatively constant temperatures. The weather is consistently hot and humid, as in New Orleans. Buildings designed for hot, humid climates take advantage of shading from the sun to reduce heat gain and cooling breezes. East and west exposures are minimized to reduce solar heat gain, although some sun in winter may be desirable. Wall openings are directed away from major noise sources so that they can remain open to take advantage of natural ventilation. If possible, the floor is raised above the ground, with a crawl space under the building for good air circulation.

**THE SITE**

The climate of a particular building site is determined by the sun’s angle and path, the air temperature, humidity, precipitation, air motion, and air quality. Building designers describe sites by the type of soil, the characteristics of the ground surface, and the topography of the site.

Subsoil and topsoil conditions, subsurface water levels, and rocks affect excavations, foundations, and landscaping of the site. Hills, valleys, and slopes determine how water drains during storms and whether soil erosion occurs. Site contours shape paths and roadway routes, may provide shelter from the wind, and influences plant locations. Elevating a structure on poles or piers minimizes disturbance of the natural terrain and existing vegetation.

The construction of the building may alter the site by using earth and stone or other local materials. Construction of the building may bring utilities to the site, including water, electricity, and natural gas. Alterations can make a positive impact by establishing habitats for native plants and animals.

The presence of people creates a major environmental impact. Buildings contribute to air pollution directly through fuel combustion, and indirectly through the electric power plants that supply energy and the incinerators and landfills that receive waste. Power plants are primary causes of acid rain (containing sulfur oxides) and smog (nitrogen oxides). Smoke, gases, dust, and chemical particles pollute the air. Idling motors at drive-up windows and loading docks may introduce gases into building air intakes. Sewage and chemical pollutants damage surface or groundwater.

Other nearby buildings can shade areas of the site and may divert wind. Built-up areas upset natural drainage patterns. Close neighbors may limit visual or acoustic privacy. Previous land use may have left weeds or soil erosion. The interior of the building responds to these surrounding conditions by opening up to or turning away from views, noises, smells, and other disturbances. Interior spaces connect to existing on-site walks, driveways, parking areas, and gardens. The presence of wells, septic systems, and underground utilities influences the design of residential bathrooms, kitchens, and laundry areas as well as commercial buildings.

Traffic, industry, commerce, recreation, and residential uses all create noise. The hard surfaces and parallel walls in cities intensify noise. Mechanical systems of neighboring buildings may be very noisy, and are hard to mask without reducing air intake, although
newer equipment is usually quieter. Plants only slightly reduce the sound level, but the visually softer appearance gives a perception of acoustic softness, and the sound of wind through the leaves helps to mask noise. Fountains also provide helpful masking sounds.

As you move up and down a site or within a multistory building, each level lends itself to certain types of uses. The sky layer is usually the hardest to get to and offers the most exposure to wind, sun, daylight, and rain. The near-surface layer is more accessible to people and activities. The surface layer encourages the most frequent public contact and the easiest access. The subsurface layer confers isolation by enclosure and provides privacy and thermal stability, but may have groundwater problems.

**Wind and Building Openings**

Winds are usually weakest in the early morning and strongest in the afternoon, and can change their effects and sometimes their directions with the seasons. Evergreen shrubs, trees, and fences can slow and diffuse winds near low-rise buildings. The more open a windbreak, the farther away its influence will be felt. Although dense windbreaks block wind in their immediate vicinity, the wind whips around them to ultimately cover an even greater area. Wind speed may increase through gaps in a windbreak. Blocking winter winds may sometimes also block desirable summer breezes. The wind patterns around buildings are complex, and localized wind turbulence between buildings often increases wind speed and turbulence just outside building entryways.

Openings in the building are the source of light, sun, and fresh air. Building openings provide opportunities for wider personal choices of temperature and access to outdoor air. On the other hand, they limit control of humidity, and permit the entry of dust and pollen. Window openings allow interior spaces to have natural light, ventilation, and views. Expansive, restricted, or filtered window openings reveal or frame views, and highlight distant vistas or closer vignettes.

**Water**

Rainwater falling on steeply pitched roofs with overhangs is collected by gutters and downspouts and is carried away as surface runoff, or underground through a storm sewer. Even flat roofs have a slight pitch, and the water collects into roof drains that pass through the interior of the building. Drain leaders are pipes that run vertically within partitions to carry the water down through the structure to the storm drains. Interior drains are usually more expensive than exterior gutters and leaders.

Rainwater can be retained for use on site. Roof ponds hold water while it slowly flows off the roof, giving the ground below more time to absorb runoff. The evaporation from a roof pond also helps cool the building. Water can be collected in a cistern on the roof for later use, but the added weight increases structural requirements.

Porous pavement allows water to sink into the earth rather than run off. One type of asphalt is porous, and is used for parking lots and roadways. Low-strength porous concrete is found in Florida, but wouldn’t withstand a northern freeze-thaw cycle. Incremental paving consists of small concrete or plastic paving units alternating with plants, so that rainwater can drain into the ground. Parking lots can also be made of open-celled pavers that allow grass or groundcover plants to grow in their cavities.

Sites and buildings should be designed for maximum rainfall retention. In some parts of North America, half of residential water is consumed outdoors, much of it for lawn sprinklers that lose water to evaporation and runoff. Sprinkler timing devices control the length of the watering cycle and the time when it begins, so that watering can be done at night when less water evaporates. Rain sensors shut off the system, and monitors check soil moisture content. Bubblers with very low flow rates lose less water to evaporation. With drip irrigation, which works well for individual shrubs and small trees, a plastic tube network slowly and steadily drips water onto the ground surface near a plant, soaking the plants at a rate they prefer. Recycled or reclaimed water, including graywater (wastewater that is not from toilets or urinals) and stored rain, are gradually being allowed by building codes in North America.

**Animal and Plant Life**

Building sites provide environments for a variety of plant and animal life. Bacteria, mold, and fungi break down dead animal and vegetable matter into soil nutrients. Insects pollinate useful plants, but most insects must be kept out of the building. Termites may attack the building’s structure. Building occupants may welcome cats, dogs, and other pets into a building, but want
to exclude nuisance animals such as mice, raccoons, squirrels, lizards, and stray dogs. You may want to hear the birds’ songs and watch them at the feeder while keeping the cardinals out of the kitchen.

Grasses, weeds, flowers, shrubs, and trees trap precipitation, prevent soil erosion, provide shade, and deflect wind. They play a major role in food and water cycles, and their growth and change through the seasons help us mark time. Plants near buildings foster privacy, provide wind protection, and reduce sun glare and heat. They frame or screen views, moderate noise, and visually connect the building to the site. Plants improve air quality by trapping particles on their leaves, to be washed to the ground by rain. Photosynthesis assimilates gases, fumes, and other pollutants.

Deciduous plants grow and drop their leaves on a schedule that responds more to the cycles of outdoor temperature than to the position of the sun (Figs. 2-4, 2-5). The sun reaches its maximum strength from March 21 through September 21, while plants provide the most shade from June to October, when the days are warmest. A deciduous vine on a trellis over a south-facing window grows during the cooler spring, shades the interior during the hottest weather, and loses its leaves in time to welcome the winter sun. The vine also cools its immediate area by evaporation. Evergreens provide shade all year and help reduce snow glare in winter.

The selection of trees for use in the landscape should consider their structure and shape, their mature height and the spread of their foliage, and the speed with which they grow. The density, texture, and color of foliage may change with the seasons. For all types of plants, requirements for soil, water, sunlight, and temperature range, and the depth and extent of root structures are evaluated. Low-maintenance native or naturalized species have the best chances of success. To support plant life, soil must be able to absorb moisture, supply appropriate nutrients, be able to be aerated, and be free of concentrated salts.

Trees’ ability to provide shade depends upon their orientation to the sun, their proximity to the building or outdoor space, their shape, height, and spread, and the density of their foliage and branch structure. The most effective shade is on the southeast in the morning and the southwest during late afternoon, when the sun has a low angle and casts long shadows.

Air temperatures in the shade of a tree are about 3°C to 6°C (5°F–11°F) cooler than in the sun. A wall shaded by a large tree in direct sun may be 11°C to 14°C (20°F–25°F) cooler than it would be with no shade. This temperature drop is due to the shade plus the cooling evaporation from the enormous surface area of the leaves. Shrubs right next to a wall produce similar results, trapping cooled air and preventing drafts from infiltrating the building. Neighborhoods with large trees have maximum air temperatures up to 6°C (10°F) lower than those without. Remarkably, a moist lawn will be 6°C to 8°C (10°F–14°F) cooler than bare soil, and 17°C (31°F) cooler than unshaded asphalt. Low growing, low-maintenance ground covers or paving blocks with holes are also cooler than asphalt.
The earliest shelters probably provided only a bit of shade or protection from rain, and were warmed by a fire and enclosed by one or more walls. Today we expect a lot from our buildings, beginning with the necessities for supporting human life. We must have clean air to breathe and clean water to drink, prepare food, clean our bodies and our belongings, and flush away wastes. We need facilities for food preparation and places to eat. Human body wastes, wash water, food wastes, and rubbish have to be removed or recycled.

As buildings become more complex, we expect less protection from our clothing and more from our shelters. We expect to control air temperatures and the temperatures of the surfaces and objects around us for thermal comfort. We control the humidity of the air and the flow of water vapor. We exclude rain, snow, and groundwater from the building, and circulate the air within it.

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 for visual privacy. We seek spaces where we can hear clearly, yet which have acoustic privacy.

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

The building’s structure gives stable support for all the people, objects, and architectural features of the building. The structure resists the forces of snow, wind, and earthquake. Buildings protect their own structure, surfaces, internal mechanical and electrical systems, and other architectural features from water and precipitation. They adjust to their own normal movements without damage to their structure or contents. They protect occupants, contents, and the building itself from fire. Buildings support our comfort, safety, and productive activity with floors, walls, stairs, shelves, countertops, and other built-in elements.

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 ENVELOPE**

The building envelope is the transition between the outdoors and the inside, consisting of the windows, doors,
floors, walls, and roofs of the building. The envelope encloses and shelters space. It furnishes a barrier to rain and protects from sun, wind, and harsh temperatures. Entries are the transition zone between the building's interior and the outside world.

 Traditionally, the building envelope was regarded as a barrier separating the interior from the outdoor environment. Architects created an isolated environment, and engineers equipped it with energy-using devices to control conditions. Because of the need to conserve energy, we now see the building envelope as a dynamic boundary, which interacts with the external natural energy forces and the internal building environment. The envelope is sensitively attuned to the resources of the site: sun, wind, and water. The boundary is manipulated to balance the energy flows between inside and outside.

 This dynamic approach leads the architect to support proper thermal and lighting conditions through the design of the building's form and structure, supported by the mechanical and electrical systems. Engineers design these support systems with passive control mechanisms that minimize energy consumption.

 A building envelope can be an open frame or a closed shell. It can be dynamic and sensitive to changing conditions and needs, letting in or closing out the sun's warmth and light, breezes and sounds. Openings and barriers may be static, like a wall; allow on-off operation, like a door; or offer adjustable control, like venetian blinds. The appropriate architectural solution depends upon the range of options you desire, the local materials available, and local style preferences. A dynamic envelope demands that the user understand how, why, and when to make adjustments. The designer must make sure the people using the building have this information.

 BUILDING FORM

 Energy conservation has major implications for the building's form. The orientation of the building and its width and height determine how the building will be shielded from excess heat or cold or open to ventilation or light. For example, the desire to provide daylight and natural ventilation to each room limits the width of multistory hotels.

 At the initial conceptual design stage, the architect and interior designer group similar functions and spaces with similar needs close to the resources they require, consolidating and minimizing distribution networks. The activities that attract the most frequent public participation belong at or near ground level. Closed offices and industrial activities with infrequent public contact can be located at higher levels and in remote locations. Spaces with isolated and closely controlled environments, like lecture halls, auditoriums, and operating rooms, are placed at interior or underground locations. Mechanical spaces that need acoustic isolation and restricted public access, or that require access to outside air, should be close to related outdoor equipment, like condensers and cooling towers, and must be accessible for repair and replacement of machinery.

 Large buildings are broken into zones. Perimeter zones are immediately adjacent to the building envelope, usually extending 4.6 to 6 meters (15–20 ft) inside. Perimeter zones are affected by changes in outside weather and sun. In small buildings, the perimeter zone conditions continue throughout the building. Interior zones are protected from the extremes of weather, and generally require less heating, as they retain a stable temperature. Generally, interior zones require cooling and ventilation.

 BETWEEN FLOORS AND CEILINGS

 A plenum is an enclosed portion of the building structure that is designed to allow the movement of air, forming part of an air distribution system. The term plenum is specifically used for the chamber at the top of a furnace, also called a bonnet, from which ducts emerge to conduct heated or conditioned air to the inhabited spaces of the building. It is also commonly used to refer to the open area between the bottom of a floor structure and the top of the ceiling assembly below. In some cases, air is carried through this space without ducting, a design called an open plenum.

 Building codes limit where open plenum systems can run in a building, prohibit combustible materials in plenum spaces, and allow only certain types of wiring. Equipment in the plenum sometimes continues vertically down a structurally created shaft. The open plenum must be isolated from other spaces so that debris in the plenum and vertical shaft is not drawn into a return air intake.

 The area between the floor above and ceiling below is usually full of electrical, plumbing, heating and cooling, lighting, fire suppression, and other equipment (Fig. 3-1). As an interior designer, you will often be concerned with how you can locate lighting or other design elements in relation to all the equipment in the plenum.
SERVICE CORES

In most multistory buildings, the stairs, elevators, toilet rooms, and supply closets are grouped together in service cores. The mechanical, plumbing, and electrical chases, which carry wires and pipes vertically from one floor to the next, also use the service cores, along with the electrical and telephone closets, service closets, and fire protection equipment. Often, the plan of these areas varies little, if at all, from one floor to the next.

Service cores may have different ceiling heights and layouts than the rest of the floor. Mechanical equipment rooms may need higher ceilings for big pipes and ducts. Some functions, such as toilets, stairs, and elevator waiting areas, benefit from daylight, fresh air, and views, so access to the building perimeter can be a priority.

Service cores can take up a considerable amount of space. Along with the entry lobby and loading docks, service areas may nearly fill the ground floor as well as the roof and basement. Their locations must be coordinated with the structural layout of the building. In addition, they must coordinate with patterns of space use and activity. The clarity and distance of the circulation path from the farthest rentable area to the service core have a direct impact on the building’s safety in a fire.

There are several common service core layouts (Fig. 3-2). Central cores are the most frequent type. In high-rise office buildings, a single service core provides the maximum amount of unobstructed rentable area. This allows for shorter electrical, mechanical, and plumbing runs and more efficient distribution paths. Some buildings locate the service core along one edge of the building, leaving more unobstructed floor space but occupying part of the perimeter and blocking daylight and views. Detached cores are located outside the body of the building to save usable floor space, but require long service runs. Using two symmetrically placed cores reduces service runs, but the remaining floor space loses some flexibility in layout and use.

Multiple cores are sometimes found in broad, low-rise buildings. Long horizontal runs are thus avoided, and mechanical equipment can serve zones with different requirements for heating and cooling. Multiple cores are used in apartment buildings and structures made of repetitive units, with the cores located between units along interior corridors.

BUILDING MATERIALS

The selection of building materials affects both the quality of the building itself and the environment beyond the building. When we look at the energy efficiency of a building, we should also consider the embodied energy used to manufacture and transport the materials from which the building is made.
Power plants that supply electricity for buildings use very large quantities of water, which is returned at a warmer temperature, or as vapor. Mechanical and electrical systems use metals and plastics, along with some clay. These materials are selected for their strength, durability, and fire resistance, as well as their electrical resistance or conductivity. Their environmental impact involves the energy cost to mine, fabricate, and transport them.

THE DESIGN TEAM

In the past, architects were directly responsible for the design of the entire building. Heating and ventilating consisted primarily of steam radiators and operable windows. Lighting and power systems were also relatively uncomplicated. Some parts of buildings, such as sinks, bathtubs, cooking ranges, and dishwashers, were considered separate items in the past, but are now less portable and more commonly viewed as fixed parts of the building. Portable oil lamps have been replaced by lighting fixtures that are an integral part of the building, tied into the electrical system.

Today, the architect typically serves as the leader and coordinator of a team of specialist consultants, including structural, mechanical, and electrical engineers, along with fire protection, acoustic, lighting, and elevator specialists. Interior designers work either directly for the architect as part of the architectural team, or serve as consultants to the architect. Energy-conscious design requires close coordination of the entire design team from the earliest design stages.
Buildings provide environments where people can feel comfortable and safe. To understand the ways building systems are designed to meet these needs, we must first look at how the human body perceives and reacts to interior environments.

MAINTAINING THERMAL EQUILIBRIUM

Our perception that our surroundings are too cold or too hot is based on many factors beyond the temperature of the air. The season, the clothes we are wearing, the amount of humidity and air movement, and the presence of heat given off by objects in the space all influence our comfort. Contact with surfaces or moving air, or with heat radiating from an object, produces the sensation of heat or cold. There is a wide range of temperatures that will be perceived as comfortable for one individual over time and in varying situations. We can regulate the body’s heat loss with three layers of protection: the skin, clothing, and buildings.

The human body operates as an engine that produces heat. The fuel is the food we eat, in the form of proteins, carbohydrates, and fats. The digestive process uses chemicals, bacteria, and enzymes to break down food. Useful substances are pumped into the bloodstream and carried throughout the body. Waste products are filtered out during digestion and stored for elimination.

The normal internal body temperature is around 37°C (98.6°F). The internal temperature of the human body can’t vary by more than a few degrees without causing physical distress. Our bodies turn only about one-fifth of the food energy we consume into mechanical work. The other four-fifths of this energy is given off as heat or stored as fat. The body requires continuous cooling to give off all this excess heat.

An individual’s metabolism sets the rate at which energy is used. This metabolic rate changes with body weight, activity level, body surface area, health, sex, and age. The amount of clothing a person is wearing and the surrounding thermal and atmospheric conditions also influence the metabolic rate. It increases when we have a fever, during continuous activity, and in cold conditions if we are not wearing warm clothes. Our metabolic rates are highest at age 10, and lowest in old age. The weight of heavy winter clothing may add 10 to 15 percent to the metabolic rate. Pregnancy and lactation increase the rate by about 10 percent.

The amount of heat our bodies produce depends on what we are doing. An average-sized person who...
is resting gives off about the same amount of heat as a 70-watt (70-W) incandescent lightbulb (Fig. 4-1). When that person is sitting at a desk, the heat generated rises to about that of a 100-W lightbulb (Fig. 4-2). The same person walking down the street at two miles per hour generates around the amount of heat given off by a 200-W lightbulb (Fig. 4-3). During vigorous exercise, the amount rises to between 300 and 870 W (Fig. 4-4). This is why a room full of people doing aerobic exercise heats up fairly quickly.

The set of conditions that allows our bodies to stay at the normal body temperature with the minimal amount of bodily regulation is called thermal equilibrium. We feel uncomfortable when the body works too hard to maintain its thermal equilibrium. We experience thermal comfort when heat production equals heat loss. Our mind feels alert, our body operates at maximum efficiency, and we are at our most productive. As designers of interior spaces, our goal is to create environ-
ments where people are neither too hot nor too cold to function comfortably and efficiently.

Studies have shown that industrial accidents increase at higher and at lower than normal temperatures, when our bodies struggle to run properly. When we are cold, we lose too much heat too quickly, especially from the back of the neck, the head, the back, and the arms and legs. When the body loses too much heat, we become lethargic and mentally dull. The heart pumps an increased amount of the blood directly to the skin and back to the heart, bypassing the brain and other organs. This puts an increased strain on the heart. Because we transfer heat from one part of the body to another through the bloodstream, it is sometimes difficult to figure out where the heat loss is actually occurring. We may need to wear a hat to keep our feet warm!

Our skin surface provides a layer of insulation between the body's interior and the environment, about equal in effect to putting on a light sweater. When the body loses more heat to a cold environment than it produces, it attempts to decrease the heat loss by constricting the outer blood vessels, reducing the blood flow to the outer surface of the skin. Goose bumps result when our skin tries to fluff up our meager body hairs to provide more insulation. If there continues to be too much heat loss, involuntary muscle action causes us to shiver, which increases heat production. We fold our arms and close our legs to reduce exposed area. When the level of heat loss is too great, muscle tension makes us hunch up, a strained posture that produces physical exhaustion. Ultimately, when deep body temperatures fall, we experience hypothermia, which can result in a coma or death. The slide toward hypothermia can be reversed by exercise to raise heat production, or by hot food and drink and a hot bath or sauna.

When we get too hot, the blood flow to the skin's surface increases, sweat glands secrete salt and water, and we lose body heat through evaporation of water from our skin. Water constantly evaporates from our respiratory passages and lungs; the air we exhale is usually saturated with water. In high humidity, evaporation is slow and the rate of perspiration increases as the body tries to compensate. When the surrounding air approaches body temperature, only evaporation by dry, moving air will lower our body temperature.

Overheating, like being too cold, increases fatigue and decreases our resistance to disease. If the body is not cooled, deep-body temperature rises and impairs metabolic functions, which can result in heat stroke and death. We will be looking at strategies for designing spaces that allow occupants to keep warm or cool enough to function in comfort.

EARS AND EYES

The buildings we design should help us use our senses comfortably and efficiently. We can easily block out unwanted sights by closing our eyes or turning away, but we can’t stop our ears from hearing, and we receive unwanted sounds with little regard for the direction we face. Loud sounds can damage our hearing, especially over time. We have trouble hearing sounds that are much less intense than the background noise. The art and science of acoustics addresses how these issues affect the built environment.

Our eyes can be damaged if we look even quickly at the sun, or for too long at a bright snow landscape or light-colored sand. Direct glare from lighting fixtures can blind us momentarily. Interior designers should avoid strong contrasts that can make vision difficult or painful, for example, a very bright object against a very dark background or a dark object against light. Low illumination levels reduce our ability to see well. The adjustment to moderately low light levels can take several minutes, an important consideration when designing entryways between the outdoors (which may be very bright or very dark) and the building’s interior. Lighting levels and daylighting are important parts of interior design.

OTHER HUMAN ENVIRONMENTAL REQUIREMENTS

We need a regular supply of water to move the products of food processing around the body. Water also helps cool the body. We need food and drinking water that is free from harmful microorganisms. Contaminated food and water spread hepatitis and typhoid. Building systems are designed to remove body and food wastes promptly for safe processing. We look at these issues in Part II of this book, on Water and Wastes.

We must have air to breathe for the oxygen it contains, which is the key to the chemical reactions that combust (burn) the food-derived fuels that keep our body operating. When we breathe air into our lungs, some oxygen dissolves into the bloodstream. We exhale air mixed with carbon dioxide and water, which are produced as wastes of combustion. Less than one-fifth of the air’s oxygen is replaced by carbon dioxide with each lungful, but a constant supply of fresh air is required to avoid unconsciousness from oxygen deple-
tion and carbon dioxide accumulation. Building ventilation systems assure that the air we breathe indoors is fresh and clean.

The human body is attacked by a very large assortment of bacteria, viruses, and fungi. Our skin, respiratory system, and digestive tract offer a supportive environment for microorganisms. Some of these are helpful, or at least benign, but some cause disease and discomfort. Our buildings provide facilities for washing food, dishes, skin, hair, and clothes to keep these other life forms under control. Poorly designed or maintained buildings can be breeding grounds for microorganisms. These are issues for both the design of building sanitary waste systems and indoor air quality (IAQ).

Our buildings exclude disease-carrying rodents and insects. Pests spread typhus, yellow fever, malaria, sleeping sickness, encephalitis, plague, and various parasites. Inadequate ventilation encourages tuberculosis and other respiratory diseases. Adequate ventilation carries away airborne bacteria and excess moisture. Sunlight entering the building dries and sterilizes our environment.

Our soft tissues, organs, and bones need protection from hard and sharp objects. Smooth floor surfaces prevent trips and ankle damage. Our buildings help us move up and down from different levels without danger of falling, and keep fire and hot objects away from our skin. The interior designer must always be on the alert for aspects of a design that could cause harm from falling objects, explosions, poisons, corrosive chemicals, harmful radiation, or electric shocks. By designing spaces with safe surfaces, even and obvious level changes, and appropriately specified materials, we protect the people who use our buildings. Our designs help prevent and suppress fires, as well as facilitating escape from a burning building.

**SOCIAL REQUIREMENTS**

Buildings give us space to move, to work, and to play. Our residential designs support family life with a place for the reproduction and rearing of children, preparing and sharing food with family and friends, studying, and communicating verbally, manually, and electronically. We provide spaces and facilities to pursue hobbies and to clean and repair the home. Our designs create opportunities to display and store belongings, and many of us now work at home, adding another level of complexity to these spaces. The spaces we design may be closed and private at times, and open to the rest of the world at others. We design buildings that are secure from intrusion, and provide ways to communicate both within and beyond the building’s interior. We provide stairways and mechanical means of conveyance from one level to another for people with varied levels of mobility.

Our designs also support all the social activities that occur outside of the home. We provide power to buildings so that workshops, warehouses, markets, offices, studios, barns, and laboratories can design, produce, and distribute goods. These workplaces require the same basic supports for life activities as our homes, plus accommodations for the tasks they house. Humans also gather in groups to worship, exercise, play, entertain, govern, educate, and to study or observe objects of interest. These communal spaces are even more complex, as they must satisfy the needs of many people at once.
When people gather together for activities, building functions become more complex, and there is a greater chance that someone will be injured. Governments respond to concerns for safety by developing building codes. These codes dictate both the work of the interior designer and architect, and the way in which the building's mechanical, electrical, plumbing, and other systems are designed and installed.

Around 1800, many of the larger U.S. cities developed their own municipal building codes in response to a large number of building fires. In the middle of the nineteenth century, the National Board of Fire Underwriters provided insurance companies with information for fire damage claims, resulting in the National Building Code in 1905. This became the basis for the three model codes we use today.

The Building Officials Code Administrators International (BOCA) publishes the BOCA National Building Code (NBC). The Southern Building Code Congress International (SBCCI) publishes the Standard Building Code (SBC), and the International Conference of Building Officials (ICBO) publishes the Uniform Building Code (UBC). Each state or community either adopts one of these three model codes or bases its own code on one of them. Because different parts of the United States have their own environmental and climatic issues that affect building construction, each model code is somewhat different from the others.

For interior design use, the three model building codes are very similar. Each includes chapters relating to the design of the building's interiors, including Use or Occupancy Classifications, the Special Use or Occupancy Requirements, and the Types of Construction sections. You will find yourself referring often to the sections covering Fire-Resistant Materials and Construction, Interior Finishes, Fire Protection Systems, Means of Egress, and Accessibility when laying out spaces and selecting materials.

The ICC International Performance Code (IPC) is a fourth model building code that attempts to unify code requirements across geographic barriers. Introduced by the International Codes Council (ICC) in 2002, the IPC is in the process of being adopted by states and other jurisdictions.

The model building codes frequently refer to other codes and standards. Each model code organization also publishes other codes, including a plumbing code, a mechanical code, a fire prevention code, and an existing structures code.

The jurisdiction of a project is determined by the location of the building. A jurisdiction is a geographical area that uses the same codes, standards, and regu-
lations. A jurisdiction may be as small as a township or as large as an entire state.

Most jurisdictions have strict requirements as to who can design a project and what types of drawings are required for an interior project. Often, drawings must be stamped by a licensed architect or licensed engineer registered within the state. In some cases, interior designers are not permitted to be in charge of a project, and may have to work as part of an architect’s team. Some states may allow registered interior designers to stamp drawings for projects in buildings with three or fewer stories and below a certain number of square feet. Working out the proper relationships with the architects and engineers on your team is critical to meeting the code requirements.

Another important task is keeping current on code requirements. Some states have statewide codes based on a model code, while others have local codes, and sometimes both state and local codes cover an area. Not every jurisdiction updates its codes on a regular basis, which means that in a particular jurisdiction, the code cited may not be the most current edition of that code. The designer must check with the local jurisdiction for which codes to follow. When codes are changed, one or more yearly addenda are published with the changes, and incorporated in the body of the code when the next full edition of the code is published. Designers must make provisions for acquiring these addenda, through a code update subscription service or other notification process.

**CODE OFFICIALS**

The codes department is the local government agency that enforces the codes within a jurisdiction. The size of the codes department varies with the size of the jurisdiction it serves. A code official is an employee of the codes department with authority to interpret and enforce codes, standards, and regulations within that jurisdiction. The plans examiner (Fig. 5-1) is a code official who checks plans and construction drawings at both the preliminary and final permit review stages of the project. The plans examiner checks for code and standards compliance, and works most closely with the designer.

The fire marshal usually represents the local fire department. The fire marshal checks drawings with the plans examiner during preliminary and final reviews, looking for fire code compliance.

The building inspector visits the project job site after the building permit is issued, and makes sure all construction complies with the codes as specified in the construction drawings and in code publications.

**SPECIAL CODES AND THE INTERIOR DESIGNER**

In addition to the basic building code, jurisdictions issue plumbing, mechanical, and electrical codes. Interior designers are not generally required to know or to research most plumbing or mechanical code issues. On projects with a major amount of plumbing or mechanical work, registered engineers will take responsibility for design and code issues. On smaller projects, a licensed plumber or mechanical contractor will know the codes. However, the interior designer needs to be aware of some plumbing and mechanical requirements, such as how to determine the number of required plumbing fixtures.

The interior designer often meets with the architect and engineers in the preliminary stages of the design process to coordinate the interior design with new and existing plumbing, mechanical, and electrical system components. The location of plumbing fixtures, sprinklers, fire extinguishers, air diffusers and returns, and other items covered by plumbing and mechanical codes must be coordinated with interior elements. The plumbing, mechanical, and electrical systems are often planned simultaneously, especially in large buildings. Vertical and horizontal chases are integrated into building cores and stairwells. Suspended ceiling and floor sys-
tems house mechanical, electrical, and plumbing components. The locations of these components affect the selection and placement of finished ceiling, walls, and floor systems. We look at the details of this coordination in other parts of this book.

STANDARDS AND ORGANIZATIONS

Codes cite standards developed by government agencies, trade associations, and standard-writing organizations as references. A standard may consist of a definition, recommended practice, test method, classification, or required specification.

The National Fire Protection Association (NFPA) was formed in 1896 to develop standards for the early use of sprinklers to put out fires. The NFPA develops and publishes about 250 standards in booklet form. The Life Safety Code and the National Electric Code (NEC) are both NFPA publications that provide guidelines for fire safety. The NFPA establishes testing requirements covering everything from textiles to fire fighting equipment to the design of means of egress.

The American National Standards Institute (ANSI) originated in 1918 to coordinate the development of voluntary standards and approve standards developed by other organizations, with an eye to avoiding duplications and establishing priorities. The standards developed by ANSI were the first to focus on achieving independence for people with disabilities by focusing on accessible features in building design, and provided a basis for the Americans with Disabilities Act (ADA).

The American Society for Testing and Materials (ASTM) dates to 1898, and its standards are used to specify materials and assure quality. The ASTM methods integrate production processes, promote trade, and enhance safety. While ASTM’s 69 volumes of standards include all types of products, a separate two-volume set of about 600 standards covers the building construction industry.

In 1959, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) was formed to sponsor research projects and to develop performance level standards for heating, ventilating, and air-conditioning (HVAC) and refrigeration systems. Mechanical engineers and refrigeration specialists and installers use ASHRAE standards. As an interior designer, you will typically not need to refer to ASHRAE standards. However, Provision 90A: Energy Conservation in New Building Design, is the basis of most building code energy provisions in the United States, and will affect the total amount of energy use permitted for lighting, heating, and cooling, and other functions in the projects you design.

Underwriters Laboratories (UL) is a testing agency that tests products, systems, and materials, and determines their relationship to life, fire, casualty hazards, and crime prevention. Underwriters Laboratories, Inc. lists all the products it tests and approves in product directories. You will find UL tags on many household appliances, as well as on lighting and other electrical fixtures. Interior designers will find the Building Materials, Fire Protection Equipment, and Fire Resistance directories the most useful. Codes will require UL testing and approval for certain products, and you should specify tested products when they are required.

FEDERAL REGULATIONS

The federal government regulates the building of federal facilities, including federal buildings, Veterans Administration hospitals, and military establishments. The construction of federal buildings is typically not subject to state or local building codes and regulations. The federal government issues regulations for government built and owned buildings, similar to the model codes. On a particular project, the authorities involved may opt to comply with stricter local requirements, so the designer must verify what codes apply.

There are over 1000 separate codes and a wide variety of federal regulations. In an effort to limit federal regulation, the Consumer Product Safety Commission encourages industry self-regulation and standardization, and industry groups have formed hundreds of standards-writing organizations and trade associations representing almost every industry.

Congress can pass laws that supersede all other state and local codes and standards. The Federal Register publishes federal regulations daily. They are collected in the Code of Federal Regulations, which is revised annually. The Occupational Safety and Health Act (OSHA), Federal Housing Act (FHA), and Americans with Disabilities Act (ADA) are examples of congressionally passed laws with wide implications for interior designers and architects.

Occupational Safety and Health Administration

In 1970, the Occupational Safety and Health Act established the Occupational Safety and Health Administra-
tion (OSHA) as a branch of the Department of Labor responsible for protecting employees in the workplace. This administration adds to code requirements by regulating the design of buildings and interior projects where people are employed, in order to ensure the safety of employees in the workplace. Contractors and subcontractors on construction projects must strictly adhere to OSHA requirements. The regulations put forth by OSHA stress safe installation of materials and equipment in order to create a safe work environment for construction workers and for future building occupants. Interior designers should be aware that these regulations exist and that they affect the process of building construction and installation of equipment and furnishings.

**Americans with Disabilities Act**

The term “accessible” in building codes refers to handicapped accessibility as required by codes, the Americans with Disabilities Act (ADA), and other accessibility standards. The Departments of Justice and Transportation developed the provisions of the ADA, which was passed by Congress in 1990 and became enforceable in 1992 and 1993. In addition, some states also have their own accessibility standards.

The ADA is a comprehensive civil rights law with four sections. Title I protects individuals with disabilities in employment. Title II covers state and local government services and public transportation. Title III covers all public accommodations, defined as any facility that offers food or services to the public. It also applies to commercial facilities, which are nonresidential buildings that do business but are not open to the general public. Title IV deals with telecommunications services, and requires telephone companies to provide telecommunications relay services for individuals with hearing and speech impairments. Titles III and IV affect the work of interior designers most directly, and we refer to ADA provisions throughout this book.

The regulations included in Title III have been incorporated into the Americans with Disabilities Act Accessibility Guidelines (ADAAG). The text of the ADAAG is law, but its appendix, which offers helpful information on interpretation and compliance, is not binding. The ADAAG deals with architectural concerns such as accessible routes and the design of restrooms for wheelchair access. Communication issues covered include alarms systems and signage for people with vision and hearing impairments.

All new buildings with public accommodations and/or commercial facilities must conform to specific ADAAG requirements. This includes a wide range of project types, including lodging, restaurants, hotels, and theaters. Shopping centers and malls, retail stores, banks, places of public assembly, museums, and galleries are also covered. Libraries, private schools, day care centers, and professional offices are all included. State and local government buildings and one- and two-family dwellings are not required to conform.

The requirements of the ADA are most stringent for new buildings or additions to existing buildings. The laws are not as clear concerning renovation of existing buildings and interiors. When an existing building is renovated, specific areas of the building must be altered to conform to ADA requirements. These alterations are limited to those deemed readily achievable in terms of structure and cost. Exemptions may be made for undue burden as a result of the difficulty or expense of an alteration. These situations are determined on a case-by-case basis by regulatory authorities or the courts, and often involve difficult judgment calls. For example, if a restaurant must add an elevator in order to expand into a second floor space, will the added seating create enough income to offset the cost of the alterations? If the business expands but doesn’t provide access for people who aren’t able to use stairs, they risk the bad publicity and embarrassment of a lawsuit and perhaps a public protest, and the even greater cost of retrofitting the space after the initial renovation. Sometimes there is no fair and easy answer.

**Federal Housing Act**

The U.S. Department of Housing and Urban Development (HUD) enforces the Federal Housing Act, which prohibits discrimination and provides protection for people with disabilities and for families with children. It applies to housing with four or more units. Such buildings must have public and common areas accessible to people with disabilities. At least the ground floor units must be accessible and must meet specific construction requirements. The FHA is essentially a residential version of the ADA.

The three model code organizations recognize the One and Two Family Dwelling Code (OTFDC). This is not a federal regulation, but has been adopted by many jurisdictions in the United States. The OTFDC is the main code used for construction of single and duplex family residences.
Part

WATER AND WASTES
Water makes up most of our bodies and also most of what we eat. In addition to the water we drink, the average home in the United States uses 53 liters (14 gallons) per person each day for washing clothes and dishes, and 79 liters (21 gallons) a day for bathing and personal hygiene. The typical home flushes 121 liters (32 gallons) per day down the toilet. That adds up to 958 liters (253 gallons) of water each day (Figs. 6-1, 6-2, 6-3). As interior designers, we want to help our clients conserve water while maintaining a good quality interior environment. In order to understand the role of water in the design of our buildings, let's start by looking at how we use it and where it comes from.

Water holds heat well and removes large quantities of heat when it evaporates. Because water will vaporize at skin temperatures, our bodies use evaporation to give off excess heat.

We associate water psychologically with cooling, and find water and splashing brooks or fountains refreshing. We employ sprays of water, evaporative coolers, and cooling towers to cool our buildings. We protect our buildings from fire with a system of very large pipes and valves that deliver water quickly to sprinkler systems.

In the past, communities used a municipal fountain or well as a water supply, and its sculptural form and central location made it the community's social hub. Today, a fountain or pool in the town center or in a shopping mall becomes a meeting place.

We celebrate the importance of water in our lives with ceremonial uses, which influence our feelings about the presence of water in our buildings. Christian churches practice baptism with water, sometimes including complete immersion of the person being baptized. The Jewish tradition includes ritual purification baths. Catholic churches have containers for holy water at their entrances, and pools are found in the forecourts of Islamic mosques.

Rivers and seas have historically connected countries. With the advent of the industrial revolution, factories were located along rivers to take advantage of water for power and for transportation. We use water to generate electricity at hydroelectric plants.

Water is often the focus of landscaping, inside or outside of the building. Reflections in water contrast with plantings and ground covers, and the sparkle, sound, and motion of water attract our attention. Water in a garden supports the growth of desirable plants and animals. Traditional Islamic architectural gardens in arid regions take advantage of small, tightly controlled channels to bring water into the center of buildings.
The total amount of water on the earth and in the atmosphere is finite, unless little icy comets melt in our atmosphere and contribute a small additional amount. The water we use today is the same water that was in Noah's proverbial flood. Ninety-nine percent of the earth's water is either saltwater or glacial ice. A quarter of the solar energy reaching the earth is employed in constantly circulating water through evaporation and precipitation, in a process known as the hydrologic cycle (Fig. 6-4).

The most accessible sources of water for our use are precipitation and runoff. Rain, snow, and other precipitation provide a very large but thinly spread supply of relatively pure water. Precipitation can be captured on a local basis in cisterns (containers for rainwater), a strategy that is rarely used in the United States but widely found in other parts of the world where rains are rare and water is precious. Water that runs off the earth's surface results in a more concentrated flow that is more easily captured in cisterns or ponds. Any daily precipitation that doesn't evaporate or run off is retained as soil moisture. After plants use it to grow, it evaporates back into the atmosphere.

Groundwater sinks into the soil and fills the open spaces with water. The upper surface of the groundwater is called the water table. Groundwater makes up the majority of our water supply. It can also be used to store excess building heat in the summer for use in the building in winter. Groundwater can harm building foundations when it leaks into spaces below ground.
RAINWATER

The earliest agrarian societies depended upon rain for agriculture. Historically, rain falling in the countryside ran into creeks, streams, and rivers, and rivers rarely ran dry. Rainfall was absorbed into the ground, which served as a huge reservoir. The water that accumulated underground emerged as springs and artesian wells, or in lakes, swamps, and marshes. Most of the water that leaked into the ground cleansed itself in the weeks, months, or years it took to get back to an aquifer, which is a water-bearing rock formation.

Early towns developed near rivers for access to transportation and wells. Streets sloped to drain in the river, which ran to river basins and the sea. Later on, marshy areas were filled in and buildings were built, along with paved streets and sidewalks. Storm sewers and pumping stations were constructed to carry away the water. The rapid runoff increased the danger of flooding, and concentrated pollutants in waterways. Water ran out of the ground into overflowing storm sewers, without recharging groundwater levels.

Today, subdivisions slope from lawns at the top to street storm drains at the bottom. Once water enters a storm drain, it dumps out in rivers far away from where it started. Huge amounts of storm water also leak into sewer pipes that mix it with sewage and take it even farther away to be processed at treatment plants. The result is a suburban desert, with lawns that need watering and restricted local water supplies.

In most of the United States, the rainwater that falls on the roof of a home is of adequate quality and quantity to provide about 95 percent of indoor residential water requirements. However, a typical U.S. suburban household could not meet all its water needs with rain off the roof without modifying the members’ water use habits. Rainwater can make a major contribution to the irrigation of small lawns and gardens when a rain barrel below a downspout or cisterns located above the level of the garden collect and store water for later release.

For centuries, traditional builders have incorporated rainwater into their designs. In the world’s drier regions, small cisterns within the home collect rainwater to supplement unreliable public supplies. With the advent of central water and energy supplies in industrial societies, rainwater collection and use became less common. It has become easier to raise the funds (with costs spread to consumers in monthly bills) to build a water treat-
ment plant with the related network of pipes than to convince individuals to collect, store, and recycle their own water. An individual who chooses to use rainwater to flush toilets must pay for this private system up front, and continue to pay through taxes for municipal water treatment, so conservation can add expense.

Designing buildings to hold onto even a part of the 50 to 80 percent of rainwater that drains from many communities requires a radical rethinking of how neighborhoods are built. Recently, progress has been made in designing building sites to improve surface and groundwater qualities. The community master plan for the Coffee Creek Center, a new residential development located 50 miles southeast of Chicago, was completed in 1998 by William McDonough + Partners. Coffee Creek itself is being revived with deep-rooted native plants that build healthy and productive soil and assure biological resiliency and variety. A storm water system makes use of the native ecosystem to absorb and retain rainwater, while wastewater will be treated on site, using natural biological processes in a system of constructed wetlands.

In Bellingham, Massachusetts, workers are ripping up unnecessary asphalt to let rainwater into the ground. Concrete culverts are being replaced with tall grasses to slow runoff from parking lots. Cisterns under school roofs will catch rainwater for watering lawns. Tiny berms around a model home’s lawn are designed to hold water until it is absorbed into the ground, and a basin under the driveway will catch water, filter out any motor oil, and inject the water back into the lawn.

In Foxborough, Massachusetts, the Neponset River is being liberated from under the grounds of Foxborough Stadium. The Neponset was partially buried in culverts in the late 1940s, and weeds and debris choked the remaining exposed portion. Plastic fencing and hay bales appeared to imprison the stream in an attempt to halt erosion. The river is now being freed into a 20-meter (65-ft) wide channel and wetlands corridor on the edge of the new stadium complex, creating a 915-meter (3000-ft) riverfront consisting of an acre of open water, four acres of vegetated wetland, and three acres of vegetated upland. The new 68,000-seat Gillette Stadium will use graywater to flush the toilets that football fans use on game days. Storm basins that drain into retention ponds filter out the oil, salt, and antifreeze that collect in parking areas. The project also includes a 946,000-liter (250,000-gallon) per day wastewater treatment facility and extensive use of recycled construction materials.

Acid rain, a result of air pollution in the northeastern United States, Canada, and some other parts of the world, makes some rainwater undesirable. Dust and bird droppings on collection surfaces and fungicides used for moss control can pollute the supply. Steep roofs tend to stay cleaner and collect less dirt in the rainwater.

### PROTECTING THE WATER SUPPLY

Individual water use has increased dramatically in the recent past. People in Imperial Rome used about 144 liters (38 gallons) a day, and the use in London in 1912 was only 151 liters (40 gallons) per person. Just before World War II, typical daily use in American cities was up to about 435 liters (115 gallons). By the mid-1970s, Los Angeles inhabitants were using 689 liters (182 gallons) per person each day.

Our current practices use large amounts of high-quality water for low-grade tasks like flushing toilets. Better conservation practices reserve high-quality water for high-quality tasks like drinking and preparing food, reduce overall use, and recycle water for lower quality uses.

The increasing population and consumption per person puts pressures on the limited supply of clean water, threatening world health and political stability. When people upstream use more than their share of water, people downstream suffer. Agriculture and industry use very large quantities of water. Building and landscape designs often disregard water conservation to make an impression through water use. Extravagant watering of golf courses and swimming pools in desert areas flaunt an affluent lifestyle at the expense of other priorities. Water pumped out of coastal areas pulls saltwater into freshwater aquifers.

As the world’s water use rose from about 10 to 50 percent of the available annual water supply between 1950 and 1980, available potable water declined rapidly. Potable water is water that is free of harmful bacteria and safe to drink or use for food preparation. The water carried from the public water supply to individual buildings in water mains—large underground pipes—must be potable.

Protecting and conserving our clean water supplies is critical to our health. Until recently, a reliable supply of clean water was not always available, and epidemic diseases continue to be spread through unsanitary water supplies. Water from ponds or streams in built-up areas is unsafe to drink, as it may contain biological or chemical pollution.

Bacteria were unknown to science until discovered in Germany in 1892. In 1817, thousands of people in India died from cholera. The epidemic spread to New
York City by 1832, causing panic. A breakthrough came in 1854, when a London physician showed that local cases could be traced to one water pump that had been contaminated by sewage from a nearby house. Cholera remains a great danger today, with an epidemic originating in Indonesia in 1961 traveling slowly around the world to reach Latin America in 1991.

In 1939, typhoid carried through the water supply killed 30 people at an Illinois mental hospital. Typhus and enteritis sickened people in Rochester, New York, when polluted river water was accidentally pumped into supply mains in 1940. As recently as 1993, cryptosporidiosis microorganisms in a poorly maintained public water supply in Milwaukee, Wisconsin, killed 104 people and made 400,000 people ill.

Proper collection, treatment, and distribution of water protect our supplies. Rainwater has almost no bacteria, and only small amounts of minerals and gases. Many communities collect clean water from rain running down mountainsides into valleys in reservoirs. They limit human access to these areas to avoid contamination. Large aqueduct pipes carry the water from the reservoir to communities, usually by gravity flow. Communities without access to relatively uninhabited mountain areas make do with water of less purity from rivers, or tap underground water flows with wells.

The availability of clean water determines where homes and businesses are located, and how many people can live in or visit an area. Water from wells and mountain reservoirs needs relatively little treatment. River water is sent through sand filters and settling basins, where particles are removed. Additional chemical treatment precipitates iron and lead compounds. Special filters are used for hydrogen sulfide, radon, and other dissolved gases. Finally, chlorine dissolved in water kills harmful microorganisms. The result is an increased supply of clean water to support the development of residential and commercial construction.

WATER SUPPLY SYSTEMS

Water mains (Fig. 6-5) are large pipes that transport water for a public water system from its source to service connections at buildings. A service pipe installed by the public water utility runs from the water main to the building, far enough underground so that it doesn't freeze in winter. Within the building or in a curb box, a water meter measures and records the quantity of water passing through the service pipe and usually also monitors sewage disposal services. A control valve is located in the curb box to shut off the water supply to the building in an emergency or if the building owner fails to pay the water bill. A shutoff valve within the building also controls the water supply.

In rural areas and in many small communities, each building must develop its own water supply. Most rely on wells, supplemented by rainwater and by reliable springs where available.

Wells

Wells supply water of more reliable quantity and quality than a rainwater system. Water near the surface may have seeped into the ground from the immediate area, and may be contaminated by sewage, barnyards, outhouses, or garbage dumps nearby. Deep wells are expensive to drill, but the water deep underground comes from hundreds of miles away, and the long trip filters out most bacteria. Well water sometimes contains dissolved minerals, most of which are harmless. Hard water results from calcium salts in the water, which can build up inside hot water pipes and cause scaling. Hard water can also turn soap into scum. A water softener installed on the pipe leading to the hot water heater will help control it.

Well water is usually potable, if the source is deep enough. It should be pure, cool, and free of discoloration and odor problems. The local health department will check samples for bacterial and chemical content before use. Wells are sunk below the water table so that they are not affected by seasonal fluctuations in the water level. Pumps bring the water from the well to the surface, where it is stored in tanks under constant pres-
sure to compensate for variations in the flow from the well. The water can be filtered and chlorinated at this point. Pumps and pressure tanks are usually housed in outbuildings kept above freezing temperatures.

The use of water should be related to its quality. Almost every North American building has potable water. In most buildings, the majority of this clean water is used to carry away organic wastes.

When water is used efficiently and supplied locally, less water is removed from rivers, lakes, and underground aquifers. Less energy and chemicals are required for treatment and delivery, and less storm water is wasted and discharged to pollute rivers, eliminating the need for additional expensive water treatment plants. Interior designers can help to conserve clean water by specifying efficient fixtures and considering the use of recycled water where appropriate.

**Municipal Water Supply Systems**

The water in a community’s water mains is under pressure to offset friction and gravity as it flows through the pipes. The water pressure in public water supplies is usually at or above 345 kilopascals (kPa), which is equal to 50 lb per square in. (psi). This is also about the maximum achieved by private well systems, and is adequate pressure for buildings up to six stories high. For taller buildings, or where the water pressure is lower, water is pumped to a rooftop storage tank and distributed by gravity, a system called gravity downfeed. The water storage tank can also double as a reserve for a fire protection system.

Once the water is inside the building, its pressure is changed by the size of the pipes it travels through. Bigger pipes put less pressure on the water flow, while small pipes increase the pressure. If the water rises up high in the building, gravity and friction combine to decrease the pressure. The water pressure at individual fixtures within the building may vary between 35 and 204 kPa (5–30 psi). Too much pressure causes splashing; too little produces a slow dribble. Water supply pipes are sized to use up the difference between the service pressure and the pressure required for each fixture. If the pressure is still too high, pressure reducers or regulators are installed on fixtures.
Whether you are working on a new building or a renovation, problems may arise with the quality of the water. Pesticides, cleaning solvents, and seepage from landfills pollute groundwater in some rural areas of the United States (Fig. 7-1). In urban areas, the level of chlorine added to prevent bacterial contamination sometimes results in bad tasting water and deterioration of pipes and plumbing fixtures.

Electric power plants discharge great amounts of waste heat into water, which can change biological and chemical conditions and threaten fish. Steel, paper, and textiles are the most polluting industries. The textile industry employs large quantities of water in fiber production and processing and in fabric finishing, especially dyeing. As a designer, you have the power to avoid products whose manufacturing includes highly toxic technologies, and to seek out ones with low environmental impact.

### Physical Characteristics

Even though cloudy or odd-smelling water may not actually be harmful to drink, we generally object to these physical characteristics. Turbidity—a muddy or cloudy appearance—is caused by suspended clay, silt, or other particles, or by plankton or other small organic material. Color changes can be due to dissolved organic matter, such as decaying vegetation, or other materials like rust. Like turbidity, color changes don’t usually threaten health. Unpleasant taste and odor can be caused by organic materials, salts, or dissolved gases, and can often be treated after being diagnosed. Foaming is not necessarily a health threat, but may indicate concentrations of detergents present in water contaminated by domestic wastes.

Most people prefer water at a temperature of 10°C
to 16°C (50°F–60°F) for drinking. When water standing in pipes becomes warmer, people often run it down the drain until it cools.

When water is piped under pressure throughout the plumbing system, air can become trapped in the water and cause cloudiness. This is only temporary and the water clears up in a short time. You can safely drink, cook with, or bathe in this water.

**Chemical Characteristics**

Groundwater dissolves minerals as it moves slowly down through the soil and rocks. Testing individual water supplies will detect harmful substances, corrosive chemicals, or chemicals that may stain fixtures and clothing. Corrosion produces scale that lines pipes and clogs openings. It is affected by water acidity, electrical conductivity, oxygen content, and carbon dioxide content. Acid neutralizers and corrosion inhibitors help, along with various preventive coatings and linings for pipes.

Tests for water pH determine relative alkalinity or acidity. A pH of 7 is neutral, with numbers as low as 5.5 indicating acid, corrosive conditions and as high as 9 representing alkaline conditions. If tap water stains tubs and sinks a bluish-green, it is overly acidic, and a neutralizing filter should be installed.

High alkaline or base levels entail bitter, slippery, and caustic qualities and are due to the presence of bicarbonate, carbonate, or hydroxide components. Bases have the ability to combine with acids to make salts. Hard water, caused by calcium and magnesium salts, inhibits the cleaning action of soaps and detergents and deposits scale inside hot water pipes and cooking utensils. The simplest way to acquire a supply of soft water for washing clothes is to collect rainwater in a cistern.

Toxic substances, including arsenic, barium, cadmium, chromium, cyanides, fluoride, lead, selenium, and silver, sometimes contaminate water. Lead poses the greatest threat to infants and young children with developing nervous systems. It is possible that lead levels in one home may be higher than levels at other homes in the same community as a result of lead solder or pipes used in the plumbing. Infants and children who drink water with high levels of lead may experience delays in their physical or mental development, showing slight deficits in attention span and learning abilities. Adults who drink this water over many years may develop kidney problems or high blood pressure. If you are concerned about a possibility of elevated lead levels in a water supply, you should have the water tested (municipal water utilities will usually do this for you). Flushing the tap for 30 seconds to two minutes before using the water will help the water supply stay fresh, but wastes a lot of water. Don’t use hot water from the faucet for drinking or cooking, especially when making baby formula or other food for infants.

Arsenic occurs naturally in some water supplies. Arsenic in water can cause symptoms such as dry, hacking coughs and burning hands and feet, and increases the risk of lung, skin, or bladder cancer. A federal study in 2000 of the water supply in Fallon, Nevada, showed that customers were exposed to 90 parts per billion (ppb) of arsenic, more than any other large system. This is almost
twice the standard set in 1975, and nine times the amount currently recommended by scientists and public health doctors. Even if the community supply is cleaned up, residents outside city limits rely on private wells where the arsenic frequently reaches 700 ppb and up to 2000 ppb.

Seepage of drainage from livestock manure can contaminate shallow wells with nitrates, which in high concentrations cause a condition commonly known as “blue baby” disease in infants. Wells near homes treated for termites may contain pesticides.

Chlorides from marine sediments, brine, seawater, or industrial or domestic wastes can affect the taste of groundwater. When copper enters the water supply from natural deposits or from corrosion of copper piping, it gives the water an undesirable taste.

Iron is frequently present in groundwater, or from corroded iron pipes. Changes in water speed or direction in local pipes can carry rust along. This can happen when the valves are being repaired, the system is being flushed or tested, or fire hydrants are in use. Iron produces a red, brown, or yellow color in water, and can cause brownish stains on washed clothes. Iron affects the water’s taste, but it is not harmful to health.

Iron manganese is similar in color and taste to iron and acts as a natural laxative. Sulfates from natural deposits of Epsom salts or Glauber’s salts are also natural laxatives. Zinc is derived from natural deposits. Zinc does not pose a health threat but leaves an undesirable taste.

Too much sodium in water may be dangerous for people with heart, kidney, or circulatory problems who need to observe low-sodium diets. Sodium can enter water through salts used for ice on roads. Some water softeners also increase sodium levels.

**Biological Contaminants**

Disease-producing organisms, such as bacteria, protozoa, and viruses, are sometimes found in water. A positive test for one particular kind of bacteria that is present in the fecal wastes of humans and many animals and birds—*E. coli*—indicates possible problems with others. Coliform bacteria, including *E. coli*, outnumber all other disease-producing organisms in water.

To avoid the growth of coliform bacteria, communities choose water sources without much plant or animal life, such as groundwater rather than surface water, and try to keep human activity away from watersheds (the areas that drain into the water supply) to protect against contamination. Fertilizers and nutrient minerals from farms and lawns can encourage bacterial growth. Water stored in the dark and at low temperatures is less likely to promote bacteria. When microorganisms do get into the water supply, they are destroyed at water treatment facilities.

Sometimes microorganisms do not pose a health danger, but multiply and clog pipes and filters. They can affect the water’s appearance, odor, and taste. Surface water reservoirs may contain algae. Cooling towers can also have high bacterial counts.

**Radiological Characteristics**

Radioactivity from mining and radioactive material used in industry, power plants, and military installations can contaminate water. Even low concentrations pose a danger because radioactive contamination accumulates in the body over time.

**WATER TREATMENTS**

It is best to prevent contamination of safe water supplies, and conserve them for high-quality uses. When all else fails, water is treated. Distillation, the process of heating water to produce water vapor, is a simple, low-tech way to eliminate pollution and purify water for drinking, cooking, and laboratory use. Distilled water is pure but has a flat taste.

The most important health-related water treatment is disinfection to destroy microorganisms. It is required for surface water, or for groundwater in contact with surface water. Primary water treatment begins with filtration, followed by disinfection to kill microorganisms in the water. Secondary treatment keeps the level of disinfectant high enough to prevent microorganism regrowth. Disinfection is accomplished by a variety of means, including chlorination, nanofiltration (filtration for extremely small organisms), ultraviolet (UV) light, bromine, iodine, ozone, and heat treatment.

Suspended particles and some materials affecting color or taste can be removed by filtration. Filters can also remove some bacteria, including *Giardia* cysts. The water is passed through permeable fabric or porous beds of filtering material.

Aeration, also called oxidation, improves taste and color and helps to remove iron and manganese. Water is sprayed or run down turbulent waterfalls to expose
as much of its surface to air as possible. Sculptural waterfalls called flowforms, which have rhythmical, pulsating, or figure-8 patterns, are both efficient and beautiful. The retailer Real Goods in Hopland, California, uses flowforms as part of a recycled water irrigation system. Aeration improves the flat taste of distilled and cistern water, and removes odors from hydrogen sulfide and algae. Aeration may make the water more corrosive.

The addition of fluoride to public water supplies has greatly reduced the amount of childhood tooth decay. Once we develop our adult teeth, we no longer benefit from the fluoride, and too much fluoride can cause yellow mottling on the teeth.
Throughout history, a primary concern of architects, builders, and homeowners has been how to keep water out of buildings. It wasn’t until the end of the nineteenth century that supplying water inside a building became common in industrial countries. Indoor plumbing is still not available in many parts of the world today. Today, interior designers work with architects, engineers, and contractors to make sure that water is supplied in a way that supports health, safety, comfort, and utility for the client.

For indoor plumbing to work safely without spreading bacteria and polluting the fresh water supply, it’s necessary to construct two completely separate systems. The first, the water supply system (Fig. 8-1), delivers clean water to buildings. The second, a system of drains, called the sanitary or drain, waste, and vent (DWV) system, channels all the waste downward through the building to the sewer below.

In small wood-frame buildings, indoor plumbing is usually hidden in floor joist and wall construction spaces. Masonry buildings require spaces that are built out with wood furring strips or metal channels to hide horizontal and vertical plumbing. In large buildings with many fixtures, piping is located in pipe chases. These are vertical and horizontal open spaces with walls (or ceiling and floor) on either side. They often have access doors so that the pipes can be worked on without disrupting the building’s occupants. The water supply plumbing and the sanitary drainage plumbing must be coordinated with the building’s structure and with other building systems.

The weight of the vertical supply pipes and the water they contain is supported at each story and horizontally every 1.8 to 3 meters (6–10 ft). Adjustable hangers are used to pitch the horizontal waste pipes downward for drainage.

**DISTRIBUTION SYSTEMS**

In small, low buildings with moderate water use, the pressure from water mains or pumped wells is adequate to get the water to its highest point. This is called upfeed distribution. The resulting pressure is usually more than is required at the fixtures. If it causes splashing at a lavatory, a flow restrictor can be used in the faucet outlet. In medium-sized buildings where the pressure from the street main is inadequate, pumps provide extra pressure. This is referred to as pumped upfeed distribution. In hydropneumatic systems, pumps force water into sealed tanks. Compressed air then maintains the water
pressure. Downfeed systems raise water to storage tanks at the top of a building, from which it drops down to plumbing fixtures. The rooftop storage tanks may have to be heated to prevent freezing. The water in a rooftop storage tank is also available for fire hoses. The heavy tank requires extra structural support.

A water storage tank shares the uppermost zone in most high-rise buildings with two-story elevator pent-houses, chimneys, plumbing vents, exhaust blowers, and air-conditioning cooling towers. Solar collectors for hot water heating are sometimes also on the roof. All of this equipment is usually surrounded by a band or screen two or more stories high.

**SUPPLY PIPES**

Lead was used for plumbing pipes by the Romans 2000 years ago, and the word “plumbing” is derived from the Latin word for lead, “plumbum.” Lead pipes were used through the 1950s. As a result, the U.S. Environmental Protection Agency (EPA) is concerned even today that lead may leach out of lead pipes and copper pipes joined with lead solder and enter the water supply. Fortunately, lead on the inside surface of a pipe quickly reacts with sulfates, carbonates, and phosphates in the water to form a coating that keeps it from leaching out of the pipe. Experts believe, however, that the lead content in water is likely to exceed safe guidelines when the water is highly acidic or is allowed to sit in the lead pipes for a long time.

Plumbing supply pipes are made of copper, red brass, galvanized steel, and plastic. Galvanized steel pipe was the standard for water supply until copper took over in the 1960s. Steel pipe is strong and inexpensive, but is subject to corrosion, and eventually rusts and springs leaks. Steel pipes last from about 20 to 50 years. Mineral deposits build up inside, reducing the inside diameter and resulting in reduced water pressure at faucets.

Red brass and copper tubing offer the best corrosion resistance, with copper being less expensive, easier to assemble, more resistant to acids, and lighter weight than brass. Copper pipe lasts about twice as long as galvanized pipe. However, it costs nearly twice as much by length. Both flexible (soft temper) and rigid copper tubing can be soldered, but only the flexible copper tubing will accept compression fittings or flare fittings without soldering.

Iron (ferrous) pipes and large brass pipes use threaded connections. Copper pipes are joined with solder. Solder, which was formerly made of lead, is now a tin and antimony alloy. The molten solder is drawn into the joint. This allows piping to be set up without turning the parts to be connected, greatly facilitating installation. It also permits pipes with thin walls, because no threads have to be cut into their thickness. The smooth interiors contribute less friction to flowing water.

Plastic pipe is lightweight, low-cost, corrosion resistant, and easy to work with. It is available in flexible form for outdoor use, and as rigid pipe. Plastic pipe is made from synthetic resins derived from coal and petroleum. Rigid polyvinyl chloride (PVC, white or gray)
and acrylonitrile-butadiene-styrene (ABS, black) pipes are suitable for various cold-water applications. Both ABS and PVC are thermoplastics, which can be molded under heat. Because of their sensitivity to heat, however, ABS and PVC are not used for hot water lines.

Chlorinated PVC (CPVC) pipe, which is usually cream color, may be used for hot or cold water. It is a thermoplastic and can be solvent welded, but it can be used at higher temperatures than ABS or PVC. Poly-butylene (PB) pipe cannot be welded with solvent, and uses compression fittings. It is flexible, and can be snaked through walls. It is also less susceptible to damage from freezing.

More access to plastic pipes must be supplied in case fittings need to be repaired than where soldered joints are used with metal pipes. Plastic pipe used for potable water is required to have a seal from the National Sanitation Foundation (NSF). Because plastic pipes are shockproof, they are used in mobile homes where vibration would be a problem for other types of plumbing.

Engineers determine pipe sizes by the rate at which the pipes will transport water when there is the most demand. Pipes in the supply network tend to be smaller as they get farther from the water source and closer to the point of use, since not all of the water has to make the whole trip. The sizes depend on the number and types of fixtures to be served and pressure losses due to friction and vertical travel. Water flowing through a smaller pipe is under greater pressure than the same amount of water in a larger pipe. Each type of fixture is assigned a number of fixture units. Based on the total number of fixture units for the building, the number of gallons per minute (gpm) is estimated. The engineer assumes that not all the fixtures are in use at the same time, so the total demand is not directly proportional to the number of fixture units. The interior designer needs to give the engineer specific information about the number of plumbing fixtures and their requirements as early in the process as possible.

Pipes sweat when moisture in the air condenses on the outsides of cold pipes. The condensation drops off the pipes, wetting and damaging finished surfaces. Cold water pipes should be insulated to prevent condensation. Insulation also keeps heat from adjacent warm spaces from warming the water in the pipes. When pipes are wrapped in glass fiber 13 to 25 mm (1/2–1 in.) thick with a tight vapor barrier on the exterior surface, the moisture in the air can’t get to the cold surface. Hot water pipes are insulated to prevent heat loss. When hot and cold water pipes run parallel to each other, they should be a minimum of 15 cm (6 in.) apart, so that they don’t exchange heat.

In very cold climates, water pipes in exterior walls and unheated buildings may freeze and rupture. Avoid locating fixtures along exterior walls for this reason. If water supply pipes must be located in an exterior wall, they should be placed on the warm side (inside, in a cold climate) of the wall insulation. A drainage faucet located at a low point will allow the pipes to be drained before being exposed to freezing weather.

**SUPPLY LINES AND VALVES**

From a branch supply line, a line runs out to each fixture (Fig. 8-2). Roughing-in is the process of getting all the pipes installed, capped, and pressure tested before actual fixtures are installed. The rough-in dimensions for
each plumbing fixture should be verified with the fixture manufacturer so that fixture supports can be built in accurately during the proper phase of construction.

It is a good idea to have a shutoff valve to control the flow of water at each vertical pipe (known as a riser), with branches for kitchens and baths and at the runouts to individual fixtures. Additional valves may be installed to isolate one or more fixtures from the water supply system for repair and maintenance. Compression-type globe valves are used for faucets, drain valves, and hose connections.

A dead-end upright branch of pipe located near a fixture is called an air chamber. When a faucet is shut off quickly, the water’s movement in the supply pipe drops to zero almost instantly. Without the air chamber, the pressure in the pipe momentarily becomes very high, and produces a sound like banging the pipe with a hammer—appropriately called water hammer—that may damage the system. The air chamber absorbs the shock and prevents water hammer.

Vacuum breakers keep dirty water from flowing back into clean supply pipes. They also isolate water from dishwashers, clothes washers, and boilers from the water supply.

**CHILLED WATER**

Most public buildings provide chilled drinking water. Previously, a central chiller with its own piping system was used to distribute the cold water. More recently, water is chilled in smaller water coolers at each point of use, providing better quality at less cost. A pump constantly circulates the chilled water, so you don’t have to wait for the water to get cold. The chilled water piping must be covered with insulation in a vapor-tight wrap to avoid condensation.
Domestic hot water (DHW) is hot water that is used for bathing, clothes washing, washing dishes, and many other things, but not for heating building spaces. Domestic hot water is sometimes called building service hot water in nonresidential uses. Sometimes, when a well-insulated building uses very little water for space heating but uses a lot of hot water for other purposes, a single large hot water heater supplies both.

**HOT WATER TEMPERATURES**

Excessively hot water temperatures can result in scalding. People generally take showers at 41°C to 49°C (105°F–120°F), often by blending hot water at 60°C (140°F) with cold water with a mixing valve in the shower. Most people experience temperatures above 43°C (110°F) as uncomfortably hot.

Some commercial uses require higher temperatures. The minimum for a sanitizing rinse for a commercial dishwasher or laundry is 82°C (180°F). General-purpose cleaning and food preparation requires 60°C (140°F) water. Temperatures above 60°C can cause serious burns, and promote scaling if the water is hard. However, high temperatures limit the growth of the harmful bacterium *Legionella pneumophila*, which causes Legionnaire’s disease. Water heaters for high temperature uses have larger heating units, but the tanks can be smaller because less cold water has to be mixed in. Some appliances, such as dishwashers, heat water at the point of use. Codes may regulate or limit high water temperatures.

Lower temperatures are less likely to cause burns, but may be inadequate for sanitation. Lower temperature water loses less heat in storage and in pipes, saving energy. Smaller heating units are adequate, but larger storage tanks are needed. Solar or waste heat recovery sources work better with lower temperature water heaters. For energy conservation, use the lowest possible temperatures.

**WATER HEATERS**

Water heating accounts for over 20 percent of the average family’s annual heating bill. Hot water is commonly heated using natural gas or electricity. It is also possible to use heat that would be wasted from other systems, or heat from steam, cogeneration, or wood-burning systems.
Solar Water Heaters

Solar energy is often used for the hot water needs of families in sunny climates. In temperate climates with little winter sun, solar water heaters can serve as preheating systems, with backup from a standard system. The solar water heater raises the temperature of the water before it enters the standard water-heating tank, so that the electric element or gas burner consumes less fuel. Solar water heaters can cut the average family’s water-heating bill by 40 to 60 percent annually, even in a cold climate. Heavy water users will benefit the most. Although initial costs of solar water heaters may be higher than for conventional systems, they offer long-term savings. A complete system costing under $3000 can provide two-thirds of a family’s hot water needs even in New England. This is competitive with the still less expensive gas water heater. Some states offer income tax credits, and some electric utilities give rebates for solar water heaters. Solar water heaters are required on new construction in some parts of the United States.

Solar water heating isn’t always the best choice. When considering a decision to go solar, the existing water heater should first be made as efficient as possible. A careful analysis of the building site will determine if there is adequate sun for solar collectors, which will need to face within 40 degrees of true south. Trees, buildings, or other obstructions should not shade the collectors between 9 a.m. and 3 p.m.

Solar water heaters use either direct or indirect systems. In a direct system, the water circulates through a solar collector (Fig. 9-1). Direct systems are simple, efficient, and have no piping or heat exchanger complications. In an indirect system, a fluid circulates in a closed loop through the collector and storage tank. With an indirect system, the fluid is not mixed with the hot water, but heat is passed between fluids by a heat exchanger. This allows for the use of nonfreezing solutions in the collector loop.

Solar water heater systems are categorized as either active or passive. In passive systems, gravity circulates water down from a storage tank above the collector. The heavy tanks may require special structural support. These systems tend to have relatively low initial installation and operating cost and to be very reliable mechanically. Active systems use pumps to force fluid to the collector. This leaves them susceptible to mechanical breakdown and increases maintenance and energy costs. Active systems are more common in the United States.

Solar energy can heat outdoor swimming pools during the months with most sun. Solar pool heating extends the swimming season by several weeks and pays for itself within two years. The pool’s existing filtration system pumps water through solar collectors, where water is heated and pumped back to the pool. More complex systems are available for heating indoor pools, hot tubs, and spas in colder climates.

Heat Pump Water Heaters

A heat pump water heater takes excess heat from the air in a hot place, like a restaurant kitchen or hot outdoor air, and uses it to heat water. In the process, the heat pump cools and dehumidifies the space it serves. Because the heat pump water heater moves the heat from one location to another rather than heating the water directly, it uses only one-half to one-third of the amount of energy a standard water heater needs. Heat pump water heaters can run on the heat given off by refrigeration units such as ice-making machines, grocery refrigeration display units, and walk-in freezers.

Because a heat pump water heater uses refrigerant fluid and a compressor to transfer heat to an insulated
storage tank, they are more expensive than other types of water heaters to purchase and maintain. Some units come with built-in water tanks, while others are added onto existing hot water tanks. The heat pump takes up a small amount of space in addition to the storage tank, and there is some noise from the compressor and fan.

**Storage Tank Water Heaters**

Residential and small commercial buildings usually use centrally located storage tank water heaters. Some buildings combine a central tank with additional tanks near the end use to help reduce heat lost in pipes. Circulating storage water heaters heat the water first by a coil, and then circulate it through the storage tank.

Storage-type water heaters are rated by tank capacity in gallons, and by recovery time, which is the time required for the tank to reach a desired temperature when filled with cold water. This shows up as the time it takes to get a hot shower after someone takes a long shower and empties the tank. Storage water heaters usually have 20- to 80-gallon capacities, and use electricity, natural gas, propane, or oil for fuel. The water enters at the bottom of the tank, where it is heated, and leaves at the top. The heat loss through the sides of the tank continues even when no hot water is being used, so storage water heaters keep using energy to maintain water temperature. The tanks usually are insulated to retain heat, but some older models may need more insulation. Local utilities will sometimes insulate hot water tanks for free. High-efficiency water heaters are better insulated and use less energy.

**Tankless Water Heaters**

Small wall-mounted tankless water heaters (Fig. 9-2) are located next to plumbing fixtures that occasionally need hot water, like isolated bathrooms and laundry rooms. They can be easily installed in cabinets, vanities, or closets near the point of use. Although they use a great amount of heat for a short time to heat a very limited amount of water, these tankless heaters can reduce energy consumption by limiting the heat lost from water storage tanks and long piping runs. Because they may demand a lot of heat at peak times, electric heaters are usually not economical over time where electric utilities charge customers based on demand.

These small tankless water heaters (also called instantaneous or demand heaters) raise the water temperature very quickly within a heating coil, from which it is immediately sent to the point of use. A gas burner or electrical element heats the water as needed. They have no storage tank, and consequently do not lose heat. With modulating temperature controls, demand water heaters will keep water temperatures the same at different rates of flow.

Without a storage tank, the number of gallons of hot water available per minute is limited. The largest gas-fired demand water heaters can heat only 3 gallons of water per minute (gpm), so they are not very useful for commercial applications, but may be acceptable for a residence with a low-flow shower and limited demand. Gas heaters must be vented.

The largest electric models heat only 2 gpm, and are used as supplementary heaters in home additions or remote locations, or as boosters under sinks. Electric heaters require 240V wiring.

Instant hot water taps use electric resistance heaters to supply hot water up to 88°C (190°F) at kitchen and bar sinks. They are expensive and waste energy. Instant hot water dispensers require a 120V fused, grounded outlet within 102 cm (40 in.) from the hot water dispenser tank, plus a water supply.

Some tankless coil water heaters take their heat from an older oil- or gas-fired boiler used for the home heating system. The hot water circulates through a heat exchanger in the boiler. The boiler must be run for hot water even in the summer when space heating isn’t needed, so the boiler cycles on and off frequently just to heat water. These inefficient systems consume 3 Btus of heat energy from fuel for each Btu of hot water they produce.
Indirect Water Heaters

Indirect water heaters also use a boiler or furnace as the heat source, but are designed to be one of the least expensive ways to provide hot water when used with a new high-efficiency boiler. Hot water from the boiler is circulated through a heat exchanger in a separate insulated tank. Less commonly, water in a heat exchanger coil circulates through a furnace, then through a water storage tank. These indirect water heaters are purchased as part of a boiler or furnace system, or as a separate component. They may be operated with gas, oil, or propane.

Integrated Water Heating and Space Heating

Some advanced heating systems combine water heating with warm air space heating in the same appliance. A powerful water heater provides hot water for domestic use and to supplement a fan-coil unit (FCU) that heats air for space heating. The warmed air is then distributed through ducts. Integrated gas heaters are inexpensive to purchase and install. They take up less space and are more efficient at heating water than conventional systems.

Water Heater Safety and Energy Efficiency

Either sealed combustion or a power-vented system will assure safety and energy efficiency in a water heater. In a sealed combustion system, outside air is fed directly to the water heater and the combustion gases are vented directly to the outside. Power-vented equipment can use house air for combustion, with flue gases vented by a fan. This is not a safe solution in a tightly sealed building.

In 1987, the National Appliance Energy Conservation Act set minimum requirements for water heating equipment in the United States. Equipment is labeled with energy conservation information. The U.S. Department of Energy (DOE) developed standardized energy factors (EF) as a measure of annual overall efficiency. Standard gas-fired storage tank water heaters may receive an EF of 0.60 to 0.64. Gas-fired tankless water heaters rate up to 0.69 with continuous pilots, and up to 0.93 with electronic ignition. The 2001 DOE standards for water heaters will increase efficiency criteria, and should result in significant utility savings over the life of gas-fired water heaters and electric water heaters.

Water heaters lose less heat if they are located in a relatively warm area, so avoid putting the water heater in an unheated basement. By locating the water heater centrally, you can cut down on heat lost in long piping runs to kitchens and bathrooms.

Existing water heaters can be upgraded for improved efficiency. By installing heat traps on both hot and cold water lines at a cost of about $30 each, you will save about $15 to $30 per year in lost heat. The cold water pipe should be insulated between the tank and the heat trap. If heat traps are not installed, both hot and cold pipes should be insulated for several feet near the water heater.

Low-flow showerheads and faucet aerators save both heat and water. United States government standards require that showerheads and faucets use less than 2.5 gpm. Low-flow showerheads come in shower massage styles. Faucets with aerators are available that use $\frac{1}{2}$ to 1 gpm. By lowering water temperatures to around 49°C (120°F), you save energy and reduce the risk of burns.

A relatively inexpensive counterflow heat exchanger can save up to 50 percent of the energy a home uses to heat water. It consists of a coil of copper tubing that's tightly wrapped around a 76- to 102-mm (3–4-in.) diameter copper pipe, and installed vertically in the plumbing system. As waste water flows down through the vertical pipe section, more than half the water’s heat energy is transferred through the copper pipe and tubing to the incoming cold water. There is no pump, no storage tank, and no electricity used. The counterflow heat exchanger only works when the drain and supply lines are being used simultaneously, as when someone is taking a shower.

Spas and hot tubs must be kept tightly covered and insulated around the bottom and sides. Waterbeds are found in up to 20 percent of homes in the United States, and are sometimes the largest electrical use in the home. Most waterbeds are heated with electric coils underneath the bed. Your clients can conserve energy by keeping a comforter on top, insulating the sides, and putting the heater on a timer.

HOT WATER DISTRIBUTION

Hot water is carried through the building by pipes arranged in distribution trees. When hot water flows through a single hot water distribution tree, it will cool off as it gets farther from the hot water heater. To get hot water at the end of the run, you have to waste the
cooled-off water already in the pipes. With a looped hot water distribution tree, the water circulates constantly. There is still some heat loss in the pipes, but less water has to be run at the fixture before it gets hot. Hot water is always available at each tap in one to two seconds.

Hot water is circulated by use of the thermosiphon principle. This is the phenomenon where water expands and becomes lighter as it is heated. The warmed water rises to where it is used, then cools and drops back down to the water heater, leaving no cold water standing in pipes. Thermosiphon circulation works better the higher the system goes.

Forced circulation is used in long buildings that are too low for thermosiphon circulation, and where friction from long pipe runs slows down the flow. The water heater and a pump are turned on as needed to keep water at the desired temperature. It takes five to ten seconds for water to reach full temperature at the fixture. Forced circulation is common in large one-story residential, school, and factory buildings.

Computer controls can save energy in hotels, motels, apartment houses, and larger commercial buildings. The computer provides the hottest water temperatures at the busiest hours. When usage is lower, the supply temperature is lowered and more hot water is mixed with less cold water at showers, lavatories, and sinks. Distributing cooler water to the fixture results in less heat lost along the pipes. The computer stores and adjusts a memory of the building’s typical daily use patterns.

Hot water pipes expand. Expansion bends are installed in long piping runs to accommodate the expansion of the pipes due to heat.

Where the pipes branch out to a fixture, capped lengths of vertical pipe about 0.6 meters (2 ft) long provide expansion chambers to dampen the shock of hot water expansion. Rechargeable air chambers on branch lines adjacent to groups of fixtures are designed to deal with the shock of water expansion. They require service access to be refilled with air.
Each building has a sanitary plumbing system that channels all the waste downward through the building to the municipal sewer or a septic tank below. The sanitary system begins at the sink, bathtub, toilet, and shower drains. It carries wastewater downhill, joining pipes from other drains until it connects with the sewer buried beneath the building. The sanitary system has large pipes to avoid clogs. Since the system is drained by gravity, all pipes must run downhill. Underground pipes for sewage disposal are made out of vitrified clay tile, cast iron, copper, concrete pipe, polyvinyl chloride (PVC) or acrylonitrile-butadiene-styrene (ABS) plastic. The large size of waste pipes, their need to run at a downward angle, and the expense and difficulty of tying new plumbing fixtures into existing waste systems means that the interior designer must be careful in locating toilets.

Until the advent of indoor plumbing, wastes were removed from the building daily for recycling or disposal. Historically, table scraps were fed to animals or composted. Human wastes were thrown from windows into the gutters of the street, or deposited in holes below outhouses. Urban inhabitants continued to dump sewage and garbage in gutters until the 1890s. Rural people dumped wastes into lakes, rivers, or manmade holes in the ground called cesspools, which were fed by rainwater or spring water. These cesspools generated foul smells and created a health hazard.

In the 1700s, shallow wells, springs, or streams provided potable water for farms. Widely separated dry-pit privies (outhouses) produced only limited ground pollution. By the nineteenth century, natural streams were enclosed in pipes under paved city streets. Rain ran into storm sewers and then to waterways. When flush toilets were connected to the storm sewers later in the nineteenth century, the combined storm water and sanitary drainage was channeled to fast-flowing rivers, which kept pollution levels down. Some sewers continued to carry storm water only, and separate sanitary sewers were eventually installed that fed into sewage treatment plants. Older cities still may have a combination of storm sewers, sanitary sewers, and combined sewers, in a complex network that would be difficult and expensive to sort out and reroute.

**WASTE PIPING NETWORKS**

With the advent of readily available supplies of water inside the house, water began to be used to flush wastes down the drain. Water pipes from sinks, lavatories, tubs, showers, water closets (toilets), urinals, and floor drains form a network drained by gravity (Fig. 10-1). In order to preserve the gravity flow, large waste pipes must run...
downhill, and normal atmospheric pressure must be maintained throughout the system at all times. Cleanouts are located to facilitate removal of solid wastes from clogged pipes.

Cast iron is used for waste plumbing in both small and large buildings. Cast iron was invented in Germany in 1562 and was first used in the United States in 1813. It is durable and corrosion resistant. Cast iron is hard to cut, and was formerly joined at its hub joints using molten lead. Today, cast-iron pipes use hubless or bell-and-spigot joints and fittings or a neoprene (flexible plastic) sleeve.

Plastic pipes made of ABS or PVC plastic are lightweight and can be assembled in advance. Copper pipes have been used since ancient times. Some building codes also allow galvanized wrought iron or steel pipes.

Engineers size waste plumbing lines according to their location in the system and the total number and types of fixtures they serve. Waste piping is laid out as direct and straight as possible to prevent deposit of solids and clogging. Bends are minimized in number and angled gently, without right angles. Horizontal drains should have a 1 : 100 slope (\(\frac{1}{100}\) in. per foot) for pipes up to 76 mm (3 in.) in diameter, and a 1 : 50 slope (\(\frac{1}{50}\) in. per foot) for pipes larger than 76 mm. These large, sloping drainpipes can gradually drop from a floor through the ceiling below and become a problem for the interior designer.

Cleanouts are distributed throughout the sanitary system between fixtures and the outside sewer connection. They are located a maximum of 15 meters (50 ft) apart in branch lines and building drains up to 10 cm (4 in.). On larger lines, they are located a maximum of 30.5 meters (100 ft) apart. Cleanouts are also required at the base of each stack, at every change of direction greater than 45 degrees, and at the point where the building drain leaves the building. Wherever a cleanout is located, there must be access for maintenance and room to work, which may create problems for the unwary interior designer.

Figure 10-1 Waste piping network.

Fixture drains extend from the trap of a plumbing fixture to the junction with the waste or soil stack. Branch drains connect one or more fixtures to soil or waste stacks. A soil stack is the waste pipe that runs from toilets and urinals to the building drain or building sewer. A waste stack is a waste pipe that carries wastes from plumbing fixtures other than toilets and urinals.

It is important to admit fresh air into the waste plumbing system, to keep the atmospheric pressure normal and avoid vacuums that could suck wastes back up into fixtures. A fresh-air inlet connects to the building drain and admits fresh air into the drainage system of the building. The building sewer connects the building drain to the public sewer or to a private treatment facility such as a septic tank.

Floor drains are located in areas where floors need to be washed down after food preparation and cooking. They allow floors to be washed or wiped up easily in shower areas, behind bars, and in other places where water may spill.

Interceptors, also known as traps, are intended to block undesirable materials before they get into the waste plumbing. Among the 25 types of interceptors are ones designed to catch hair, grease, plaster, lubricating oil, glass grindings, and industrial materials. Grease traps are the most common. Grease rises to the top of the trap, where it is caught in baffles, preventing it from congealing in piping and slowing down the digestion of sewage. Grease traps are often required by code in restaurant kitchens and other locations.

Sewage ejector pumps are used where fixtures are below the level of the sewer. Drainage from the below-grade fixture flows by gravity into a sump pit or other receptacle and is lifted up into the sewer by the pump. It is best to avoid locating fixtures below sewer level where possible, because if the power fails, the equipment shuts down and the sanitary drains don’t work. Sewage ejector pumps should be used only as a last resort.
Residential Waste Piping

The waste piping for a residence usually fits into a 15-cm (6-in.) partition. In smaller buildings, 10-cm (4-in.) soil stacks and building drains are common. It is common to arrange bathrooms and kitchens back-to-back. The piping assembly can then pick up the drainage of fixtures on both sides of the wall. Sometimes an extra-wide wall serves as a vertical plumbing chase, which is a place between walls for plumbing pipes. Fitting both the supply and waste plumbing distribution trees into the space below the floor or between walls is difficult, as larger waste pipes must slope continually down from the fixture to the sewer. Some codes require that vertical vents that penetrate the roof must be a minimum of 10 cm (4 in.) in diameter, to prevent blocking by ice in freezing weather; such a requirement, of course, adds another space requirement between walls.

Large Building Waste Piping Systems

In larger buildings, the need for flexibility in space use and the desire to avoid a random partition layout means that plumbing fixtures and pipes must be carefully planned early in the design process. The location of the building core, with its elevators, stairs, and shafts for plumbing, mechanical, and electrical equipment, affects the access of surrounding areas to daylight and views.

When offices need a single lavatory or complete toilet room away from the central core (as for an executive toilet), pipes must be run horizontally from the core. In order to preserve the slope for waste piping, the farther the toilet room is located from the core, the greater amount of vertical space is taken up by the plumbing.

Wet columns group plumbing pipes away from plumbing cores to serve sinks, private toilets, and other fixtures, and provide an alternative to long horizontal waste piping runs. Wet columns are usually located at a structural column, which requires coordination with the structural design early in the design process. Individual tenants can tap into these lines without having to connect to more remote plumbing at the core of the building.

When running pipes vertically, a hole in the floor for each pipe is preferred over a slot or shaft, as it interferes less with the floor construction. Where waste piping drops through the floor and crosses below the floor slab to join the branch soil and waste stack, it can be shielded from view by a hung ceiling. An alternative method involves laying the piping above the structural slab and casting a lightweight concrete fill over it. This raises the floor 127 to 152 mm (5–6 in.). Raising the floor only in the toilet room creates access problems, so the whole floor is usually raised. This creates space for electrical conduit and to serve as an open plenum for heating, ventilating, and air-conditioning (HVAC) equipment as well.

Waste Components of Plumbing Fixtures

Originally, the pipe that carried wastewater from a plumbing fixture ran directly to the sewer. Foul-smelling gases from the anaerobic (without oxygen) digestion in the sewer could travel back up the pipe and create a health threat indoors.

The trap (Fig. 10-2) was invented to block the waste pipe near the fixture so that gas couldn’t pass back up into the building. The trap is a U-shaped or S-shaped section of drainpipe that holds wastewater. The trap forms a seal to prevent the passage of sewer gas while allowing wastewater or sewage to flow through it. Traps are made of steel, cast iron, copper, plastic, or brass. On water closets and urinals, they are an integral part of the vitreous china fixture, with wall outlets for wall-hung units and floor outlets for other types.

Drum traps are sometimes found on bathtubs in older homes. A drum trap is a cylindrical trap made from iron, brass, or lead, with a screw top or bottom. Water from the tub enters near the bottom and exits near the top, so the wastewater fills the trap and creates a water plug before flowing out. Sometimes the screw-off top, called a cleanout, is plated with chrome or brass and left exposed in the floor so it can be opened for cleaning. Drum traps can cause drainage problems because debris settles and collects in the trap. If not cleaned out regularly, these traps eventually get com-
pletely clogged up. Drum traps should be replaced during remodeling.

Every fixture must have a trap, and every trap must have a vent. Each time the filled trap is emptied, the wastewater scour the inside of the trap and washes debris away. Some fixtures have traps as an integral part of their design, including toilets and double kitchen sinks. There are a few exceptions to the rule that each fixture should have its own trap. Two laundry trays and a kitchen sink, or three laundry trays, may share a single trap. Three lavatories are permitted on one trap.

Traps should be within 0.61 meters (2 ft) of a fixture and be accessible for cleaning. If the fixture isn’t used often, the water may evaporate and break the seal of the trap. This sometimes happens in unoccupied buildings and with rarely used floor drains.

VENT PIPING

The invention of the trap helped to keep sewer gases out of buildings. However, traps were not foolproof. When water moving farther downstream in the system pushes along water in front of it at higher pressures, negative pressures are left behind. The higher pressures could force sewer water through the water in some traps, and lower pressures could siphon (suck) water from other traps, allowing sewer gases to get through (Fig. 10-3).

Vent pipes (Fig. 10-4) are added to the waste piping a short distance downstream from each trap to prevent the pressures that would allow dirty water and sewer gases to get through the traps. Vent pipes run upward, join together, and eventually poke through the roof. Because the roof may be several floors up and the pipes may have to pass through other tenants’ spaces, adding vent pipes in new locations can be difficult. The vent pipe allows air to enter the waste pipe and break the siphoning action. Vent pipes also release the gases of decomposition, including methane and hydrogen sulfide, to the atmosphere. By introducing fresh air through the drain and sewer lines, air vents help reduce corrosion and slime growth.

The vent pipes connect an individual plumbing fixture to two treelike configurations of piping. The waste piping collects sewage and leads down to the sewer. The vent piping connects upward with the open air, allowing gases from the waste piping to escape and keeping the air pressure in the system even. This keeps pressure on foul gases so that they can’t bubble through the trap water, and gives them a local means of escape to the outdoors.

The vent must run vertically to a point above the spillover line on a sink before running horizontally so that debris won’t collect in the vent if the drain
clogs. Once the vent rises above the spillover line, it can run horizontally and then join up with other vents to form the vent stack, eventually exiting through the roof.

When all fixtures are on nearly the same level, a separate vertical vent stack standing next to the soil stack is not required. In one-story buildings, the upper extension of the soil stack above the highest horizontal drain connected to the stack becomes a vent called the stack vent. It must extend 31 cm (12 in.) above the roof surface, and should be kept away from vertical surfaces, operable skylights, and roof windows.

When a sink is located in an island, as in some kitchen designs, there is no place for the vent line to go up. Instead, a waste line is run to a sump at another location, which is then provided with a trap and vent. A fresh-air vent, also called a fresh air inlet, is a short air pipe connected to the main building drain just before it leaves the building, with a screen over the outdoor end to keep out debris and critters.
In the United States, each person generates almost 75,700 liters (20,000 gallons) of sewage each year. Fruits, vegetables, grains, milk products, and meats derived from nutrients in the soil are brought into cities, to be later flushed out as sewage. Some communities discharge bacteria-laden sewage into nearby lakes, rivers, or the ocean. Most cities and towns send the sewage to treatment plants, where the solid matter (sludge) settles out. The remaining liquid is chlorinated to kill bacteria and then dumped into a local waterway.

The sludge is pumped into a treatment tank, where it ferments anaerobically (without oxygen) for several weeks. This kills most of the disease-causing bacteria and precipitates out most minerals. The digested sludge is then chlorinated and pumped into the local waterway.

Waterways can’t finish the natural cycle by returning the nutrients back to the soil, and end up with increasing amounts of nutrients. This nutrient-rich water promotes the fast growth of waterweeds and algae. The water becomes choked with plant growth, and the sun is unable to penetrate more than a few inches below the surface. Masses of plants die and decay, consuming much of the oxygen in the water in the process. Without oxygen, fish suffocate and die. The waterway itself begins to die. Over a few decades, it becomes a swamp, then a meadow. Meanwhile, the farmland is gradually drained of nutrients. Farm productivity falls, and produce quality declines. Artificial fertilizers are applied to replace the wasted natural fertilizers.

Designers can step into this process when they make decisions about how wastes will be generated and handled by the buildings they design. Sewage treatment is expensive for the community, and becomes a critical issue for building owners where private or on-site sewage treatment is required. In a geographically isolated community, like Martha’s Vineyard off the Massachusetts coast, restaurants have been forced out of business by the high cost of pumping out their septic tanks. One local businessman calculates that it costs him about one dollar per toilet flush, and if his septic tank fills up, he will have to shut down before it can be pumped. In 1997, Dee’s Harbor Café was closed after its septic system failed, and the owner lost her life savings. Even in less remote locations, dependence on a septic tank often limits the size of a restaurant and prohibits expansion.

Sewage disposal systems are designed by sanitary engineers and must be approved and inspected by the health department before use. The type and size of private sewage treatment systems depend on the number of fixtures served and the permeability of the soil as de-
termined by a percolation test. Rural building sites are often rejected for lack of suitable sewage disposal.

RURAL SEWAGE TREATMENT

In times past, rural wastes ended up in a cesspool, a porous underground container of stone or brick, which allowed sewage to seep into the surrounding soil. Cesspools did not remove disease-causing organisms. Within a short time, the surrounding soil became clogged with solids, and the sewage overflowed onto the surface of the ground and backed up into fixtures inside the building.

Cesspools have mostly been replaced by septic systems (Fig. 11-1). A typical septic system consists of a septic tank, a distribution box, and a leach field of perforated drainpipes buried in shallow, gravel-filled trenches. Septic tanks are nonporous tanks of precast concrete, steel, fiberglass, or polyethylene that hold sewage for a period of days while the sewage decomposes anaerobically. Anaerobic digestion produces methane gas and odor.

During this time, the sewage separates into a clear, relatively harmless effluent and a small amount of mineral matter that settles to the bottom. Soaps and slow-to-degrade fats and oils float to the top of the tank to form a layer of scum. Inlet and outlet baffles in the tank prevent the surface scum from flowing out. The liquid moves through a submerged opening in the middle of the tank to a second chamber. Here finer solids continue to sink, and less scum forms. This part of the process is known as primary treatment.

When the effluent leaves the septic tank, it is about 70 percent purified. The longer sewage stays in the tank, the less polluted is the effluent. If the building and its occupants practice water conservation, less water and wastes flow through the septic tank, the effluent stays in the tank longer before being flushed out, and it emerges cleaner. Every few years, the sludge is pumped out of the septic tank and is hauled away and processed to a harmless state at a remote plant. The methane gas and sewage odor stay in the tank.

Each time sewage flows into the tank, an equal volume of nitrate-rich water flows out and is distributed into the leach field, which provides secondary treatment. There the water is absorbed and evaporates. Nitrate-hungry microbes in the soil consume the potentially poisonous nitrates. In the process, plant food is manufactured in the form of nitrogen.

Nothing that can kill bacteria should ever be flushed down the drain into a septic system. Paints, varnishes, thinners, waste oil, photographic solutions, and pesti-

Figure 11-1 Septic system.
cides can disrupt the anaerobic digestion. Coffee grounds, dental floss, disposable diapers, cat litter, sanitary napkins and tampons, cigarette butts, condoms, gauze bandages, paper towels, and fat and grease add to the sludge layer in the bottom of the tank. Some systems include a grease trap in the line between the house and the septic tank, which should be cleaned out twice a year.

Trained professionals must clean the tank at regular intervals. As the sludge and scum accumulate, there is less room for the bacteria that do their work, and the system becomes less effective. If the scum escapes through the outlet baffle into the leach field, it clogs the earthen walls of the trenches and decreases the necessary absorption. Most tanks are cleaned every two to four years.

Most septic systems eventually fail, usually in the secondary treatment phase. If the septic tank or the soil in the leaching field is not porous enough, or if the system is installed too near a well or body of water, or beside a steep slope, the system can malfunction and contaminate water or soil. Most communities have strict regulations requiring soil testing and construction and design techniques for installing septic tanks. If the site can’t support the septic tank, the building can’t be built.

Aerobic (with oxygen) treatment units (ATUs) can replace septic tanks in troubled systems. By rejuvenating existing drainfields, they can extend the system’s life. Air is bubbled through the sewage or the sewage is stirred, facilitating aerobic digestion. After about one day, the effluent moves to the settling chamber where the remaining solids settle and are filtered out. Because aerobic digestion is faster than anaerobic digestion, the tank can be smaller. However, the process is energy intensive and requires more maintenance. The effluent then moves on to secondary treatment.

Secondary treatment can use a number of different techniques, with varying impact on the building site. Disposal fields are relatively inexpensive, and do not require that the soil be very porous or that the water table be very deep below the surface. Drainlines of perforated pipe or agricultural tile separated by small openings are located in shallow trenches on a bed of gravel and covered with more gravel. The effluent runs out of these lines and through the gravel, until it seeps into the earth. The gravel’s spaces hold the liquid until it is absorbed.

Buried sand filters that use sand, crushed glass, mineral tailings, or bottom ash are also used for secondary treatment. They are applied where the groundwater level is high, or in areas of exposed bedrock or poor soil. A large site area is required, but the ground surface can become a lawn or other nonpaved surface. Buried sand filters can be a remedy for failed disposal fields.

Seepage pits are a form of secondary treatment appropriate for very porous soil and a low water table only. Seepage pits can also be used as dry wells to distribute runoff from pavement gradually.

**MUNICIPAL SEWAGE TREATMENT PLANTS**

Larger scale sewage treatment plants continue to improve the efficiency of their processes, and municipalities are active in reducing the amount of sewage they process. Larger plants use aerobic digestion plus chemical treatment and filtration, and can produce effluent suitable for drinking. Clean effluent is pumped into the ground to replenish depleted groundwater. Digested sludge is dried, bagged, and sold for fertilizer. Some plants spray processed sewage directly on forests or crop-land for irrigation or fertilizer.

**ON-SITE LARGE-SCALE TREATMENT SYSTEMS**

After years of sending sewage to distant treatment plants, it is becoming more common for groups of buildings to treat their wastes on site. The advantages include savings to the community, reusable treated water for landscaping and other purposes, and even pleasant and attractive outdoor or indoor environments. In some campus-type industrial, educational, or military facilities, septic tanks are installed at each building, and the outflow is combined for the secondary treatment process. Use of sand filters for secondary treatment offers simple maintenance, very low energy use, and greater available usable land area.

**Constructed Wetlands**

By constructing an environment that filters and purifies used water and recycles it for additional use, we can reduce municipal sewage treatment costs and support local plant and animal life. Free-surface (open) wetlands use effluents to nourish vegetation growing in soil. Human contact with these secondary treatment areas must be controlled.

The Campus Center for Appropriate Technology at Humboldt State University in Arcata, California, uses a graywater treatment marsh that consists of an open...
channel of water with a gravel-filled channel planted with vegetation. A primary treatment tank filters out large particles such as hair, grease, and food scraps. Water then penetrates down through the gravel in the channel. Once it reaches the end of the channel, the water is removed from the bottom of the marsh by a perforated pipe. This pipe then conveys water to the next gravel marsh box, a process that supplies it with oxygen. After treatment in the graywater marsh, water from the sinks and shower is reused on the lawns and ornamental plants. Except for periodic maintenance, very little energy is used.

Subsurface flow wetlands consist of a basin lined with large gravel or crushed rock, and a layer of soil with plants above. Plants encourage the growth of microorganisms, both anaerobic and aerobic, and bring air underwater through their roots. The effluent is then filtered through sand and disinfected. It is then safe to use for many purposes, including landscape watering. This secondary treatment option is safer for human contact, and also attracts birds. The master plan for the Coffee Creek Center southeast of Chicago features constructed wetlands for on-site treatment of wastewater from homes and businesses.

**Pasveer Oxidation System**

The Pasveer oxidation sewage treatment system was used by the New York Institute of Technology in Old Westbury on Long Island in New York. Purified effluent returns to the ground through 48 leaching wells under the school’s athletic field. The sludge is processed using a mechanical aerator for aerobic digestion. There is no compressor, only the noise of splashing water. The process has a low profile and is screened by trees.

**Greenhouse Ecosystems**

Greenhouse ecosystems (Fig. 11-2) are secondary sewage treatment systems that are constructed wetlands moved indoors. Marine biologist John Todd developed *Living Machines* at Ocean Arks International. They consist of a series of tanks, each with its own particular ecosystem. The first is a stream, and the second is an indoor marsh that provides a high degree of tertiary wastewater treatment. The system costs less to construct and about the same to maintain as a conventional sewage treatment system. It uses less energy, depending upon solar energy for photosynthesis and on gravity flow. There is no need for a final, environmentally harmful chlorine treatment. The system produces one-quarter of the sludge of other systems.

These greenhouse environments are pleasant to look at and smell like commercial greenhouses. They are welcome in the neighborhoods they serve, and can save huge costs in sewer lines that would otherwise run to distant plants. Greenhouse ecosystems offer an opportunity to enrich the experience of an interior environment while solving a serious ecological problem.

Within the greenhouse ecosystems, aerobic bacteria eat suspended organic matter and convert ammonia to nitrates, producing nitrites. Algae and duckweed eat the

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**Figure 11-2** Greenhouse ecosystem.
products of the bacteria. Snails and zooplankton then eat the algae. The floating duckweed creates shade that discourages algae growth in the later stages of production. Finally, fish eat the zooplankton and snails. The systems support water hyacinth and papyrus, canna lilies, bald cypress, willows, and eucalyptus, which remove phosphorus and heavy metals during the lives of the plants, returning them to the earth when the plants die. Small fish (shiners) are sold as bait, and dead plants and fish are composted.

On-site wastewater treatment has a significant impact on the design of the building’s site. Interiors are also affected, as the system may use special types of plumbing fixtures and may include indoor greenhouse filtration systems.

**RECYCLED WATER**

Water is categorized by its purity. Potable water has usually been treated to be safe for drinking. Rainwater offers a sporadic supply of pure water that can be used for bathing, laundry, toilet flushing, irrigation, or evaporative cooling with little or no treatment. Graywater is wastewater that is not from toilets or urinals. It comes from sinks, baths, and showers. Blackwater is water with toilet or urinal waste.

Graywater may contain soap, hair, or human waste from dirty diapers and other laundry. It can be treated and recycled for uses like toilet flushing and filtered drip irrigation. Dark graywater comes from washing machines with dirty diaper loads, kitchen sinks, and dishwashers, and is usually prohibited by codes from being reused. If graywater contains kitchen wastes, grease and food solids are a problem. Currently, few communities allow the reuse of graywater; and those that do tend to restrict its use to underground landscape irrigation for single-family houses. New York-based architect William McDonough has used gray and blackwater in designs for Eurosud-Calvission, a software research and development facility in southern France.

Future water conservation measures may include the use of water from bathing for flushing toilets, which would save 21 gallons per person each day. The 14-gallons per person used daily for laundry can help with irrigation, preferably through underground distribution systems that limit contact with people.

The Aquasaver Company in England has developed a system that diverts and cleans water from lavatories, baths, and showers for flushing toilets, washing clothes, washing cars, and irrigation. A low-pressure system installed behind panels in the bathroom pumps graywater through a series of filters, removing soaps, detergents, and other impurities. The water then goes to a storage tank in the attic or above points of use. The system uses nonhazardous cleaning agents and a network of carbon filters.
As part of the building design team, interior designers are responsible for making sure that the solid wastes generated during construction and building operation are handled, stored, and removed in a safe, efficient, and environmentally sound way. Whether we are designing an office cubicle to include a recycling basket or making sure that an old fireplace mantle is reused rather than discarded, we can have a significant impact on how the building affects the larger environment.

Nature operates in closed cycles. One organism’s waste is another’s food. Nothing is really wasted except a small amount of renewable energy from the sun. Insects and microorganisms feed on the excrement and corpses of higher animals, releasing soil nutrients for plants. Dead vegetable matter is attacked, broken down, and used again.

In agrarian societies, people, along with water, air, earthworms, and bacteria, convert animal and vegetable wastes into rich soil. Sun and rain on the soil encourage plants to grow, feeding families and animals, and providing fuel for heating and cooking. Animals also provide food and clothing for people. Ashes from spent fuel and animal excrement return to replenish the soil’s nutrients.

Today we discard many more materials: paper, plastics, glass, and metals; cinders, dust, dirt, and broken or worn-out machinery; kitchen garbage, and old clothes; and industrial by-products and radioactive and chemical wastes from laboratories and industries. All of this averages out to about 45 kg (100 lb) of waste per person annually in the United States. Some of these materials, such as food scraps and paper, are links in the biological recycling chain. Some, such as metals and plastics, represent nonrenewable resources. Many waste substances contain useful energy, but separation and recycling of the mingled refuse is a Herculean task. Solid waste is the main source of land and soil pollution, next to the agricultural use of pesticides and fertilizers. Most cities burn and bury ashes, or bury the refuse itself in landfills. The organic components decompose, but glass, metals, and plastic remain.

**CONSTRUCTION WASTE**

It is best to reuse, then to use up, and to recycle last of all. This applies to the construction and operation of the building. As interior designers, we can work with contractors to ensure that the materials removed during renovation and the waste generated by construction has a second life, possibly by including recycling requirements in demolition specifications.

Nationwide, demolition debris adds up to 165 mil-
tailing. Despite the need to build recycling markets and recycling programs, including grants to nonprofit re-
california have embarked on state-mandated construction in crowded ur-
project, consider which elements can be reused in your design or salvaged for another project.

Some contractors sort excess or used building ma-
to develop strategies for dealing with wood covered with toxic lead paint, asbestos, or other nonrecyclables, con-
struction-recycling programs promise to extend the lives of overcrowded landfills. The donated materials may also provide a tax deduction, and can help build affordable housing.

In some communities, demolition auctioneers arrange for do-it-yourselfers to deconstruct buildings by hand and take away salvageable materials. Deconstruc-
tion specialists say they can take most homes and many other buildings to their foundations, saving 80 percent or more of the material for resale or reprocessing. Some communities train welfare recipients for deconstruction jobs, which can eventually lead to carpentry apprentice programs and careers in construction. Although deconstruc-
tion takes longer than conventional demolition, the salvaged materials can often offset increased labor costs.

According to a 2001 report by the U.S. Department of Housing and Urban Development (HUD) that exam-
ishes deconstruction activities in El Paso, Miami, Mil-
waukee, and Nashville, deconstruction fosters the cre-
tation and expansion of small businesses to handle the salvaged material from deconstruction projects. Reusing building materials can benefit the environment by div-
erting valuable resources from crowded landfills into profitable uses, which in turn would enable decon-
struction to pay for itself by generating revenues and re-
ducing landfill and disposal costs.

PLANNING FOR RECYCLING

The design of a building includes tracking the flow of supplies in and of refuse out. Solid wastes can take up more space than the water-borne waste systems we have discussed. The accumulation of solid wastes in a build-
ing can create fire danger, and their removal may present severe local environmental problems. The separa-
tion of solid waste to permit resource recovery has significant energy and environmental consequences. It is now common to install mechanical equipment for handling solid waste in buildings.

Since the late 1940s, the amount of packaging ma-
teral used for consumer products has greatly increased. We buy food in bags and cans that we then discard. In-
dividual packaging takes up more space in stores than does bulk storage. Wastes are stored in the home until collection day, requiring increased space allocation. It takes energy to make and transport packaging and to collect trash. Trash compactors take up space and use
WATER AND WASTES

electricity. Landfills continue to fill up, releasing methane and leaching out chemicals.

High-grade resources are valuable materials that can be recycled. Paper and some plastics can be collected and stored within the building. Glass bottles can be returned for reuse or recycling. If recyclable materials are kept separate at the site of their use, resource recovery is much easier. Glass bottles should be washed for reuse, not broken and recycled.

Recycled paperboard (cardboard or pasteboard) saves 50 percent of the energy required to process pulp from wood. Recycled aluminum saves an astounding 96 percent of the electrical energy required for its original production. A 52-percent energy savings is achieved by recycling steel.

Wood scrap chopped into wood fiber is worth more than when it is burned as a fuel. Oriented strand board (OSB), made of wood chips and scraps, is used in the manufacture of structural insulated panels (SIPs), window frames, and other building products. Plastics are more difficult to recycle. Due to consumer preferences and regulations, recycled plastic is not often used in food-related items. Recycled plastic pellets are used in toys, building materials, and sports products. Recycled plastic bottles are used in fabrics and some carpets.

It is possible to burn for fuel some materials that are impractical to recycle. These are referred to as low-grade resources, and include gaseous wastes, liquid and semiliquid wastes, and solid wastes. Some industrial wastes give off a lot of heat when you burn them, but some are very toxic. Some cities use the heat generated by burning rubbish to fuel electric power plants or central heating installations. Trash burning is limited by environmental regulations. Burning vinyl wallcoverings poses serious environmental problems.

When composted in landfills, some of these materials produce methane gas, which can be collected for use as a high-grade fuel. Cities extract methane gas from old garbage dumps by drilling wells to tap underground pockets of decomposition gas. The quantities produced by livestock farming or sewage treatment plants are adequate to justify building gas-generating equipment. Many municipal water treatment plants(121,711),(991,997)

Sorting and storing recyclable materials within the building requires more time and effort by the building’s occupants. In an urban apartment, space and odor issues can make recycling difficult. Containers for different recyclables take up floor or cabinet space. A good community recycling program with curbside pickup helps keep accumulation down and provides some organization to the process. Some recycling programs are set up to recycle valuables in the trash automatically by mechanized sorting.

SOLID WASTE COLLECTION
IN SMALL BUILDINGS

Most of the waste in a home comes from the kitchen. Finding recycling space within a pantry, air-lock entry, or cabinet or closet that opens to the outside makes daily contributions easier, facilitates weekly removal, and simplifies cleaning (Fig. 12-1).

Trash compactors take up space in the kitchen, and may have odor and noise problems. Some trash compactors have a forced-air, activated-charcoal filter to help control odors, and sound insulation to control noise. A trash compactor requires a grounded electrical outlet.

Garbage disposals are often installed below the kitchen sink, frequently along with the dishwasher. The garbage disposal grinds organic food scraps, mixes them with water, and flushes them to the sewer. Waste with less moisture goes into the garbage can. The finely chopped organic matter biodegrades better at the sewage treatment plant than it would at a landfill. However, the garbage disposal uses energy and water—2 to 4 gallons for each minute of operation. The water co-

Figure 12-1 Residential recycling.
agulates grease so that it can be chopped, washes the blade, and cools the motor. More energy is used when the waste reaches the sewage treatment plant.

If you specify a garbage disposal, look for one with adequate motor horsepower and grind chamber capacity to grind quickly and efficiently. Deluxe disposal models use stainless steel extensively in the grind system to prevent corrosion. Insulated sound shells shield grind chamber noise, and some models offer a secondary sound baffle. Disposals require an electrical connection, usually a 120V, 60-Hz, AC, 15- or 20-A three-wire grounded circuit.

An alternative to the garbage disposal is the compost bin. Composting is a controlled process of decomposition of organic material. Naturally occurring soil organisms recycle nitrogen, potash, phosphorus, and other plant nutrients as they break down the material into humus. When decomposition is complete, a dark brown, powdery material called humus has been produced. As you can tell by its rich earthy aroma, the finished compost is full of nutrients essential for the healthy growth of plants and crops. Compost happens as long as there is air and water to support it.

Composting is a convenient, beneficial, and inexpensive way to handle organic waste and help the environment. Composting reduces the volume of garbage requiring disposal, saves money in reduced soil purchases and reduced local disposal costs, and enriches the soil. Self-contained units are available, and some community groups sell bins made from recycled plastics for very reasonable prices. Food wastes can be collected in a covered container beside or under the sink. Meats and animal wastes usually are not included, as they attract animals and create odors. Collected food wastes are then carried to the compost pile, where they slowly decompose into clean, rich soil for gardens. Yard wastes (leaves, grass clippings) are also added. The compost pile should have a cover, to keep out unwanted animals. The odor of a well-maintained compost pile is not unpleasant, and the compost itself has a pleasing earthy smell.

Vermiculture is a simple, if somewhat unusual, method of using worms to turn kitchen waste into extremely rich castings for use in the garden. The vermiculture bin is a very effective means of reducing the amount of waste that goes into the landfill while also producing an organic fertilizer to return to the earth. Red wiggler worms are placed in one section of the worm box with wet, shredded newspaper. Food scraps from the kitchen are added to the box as they accumulate. Worms feed on fruit and vegetable peels, tea bags, coffee grounds, and pulverized eggshells, and can consume approximately half of their body weight per day. With one pound of worms, approximately one pound of soil can be removed from the box each month, while the worms stay behind to carry on the process.

Garbage compactors are designed to cut down on storage space for solid wastes. They can be used to compact separated items for recycling, such as aluminum, ferrous metals, and box cardboard. When dissimilar materials are crushed together, recycling becomes difficult. In a single family home, a garbage compactor may not save more space than it takes up, but small stores and businesses may find one beneficial.

**LARGE BUILDING SOLID WASTE COLLECTION**

Large apartment complexes fence in their garbage can areas to keep out dogs and other pests. This area is a good place for bins for recycling, and even a compost pile for landscaping. The solid waste storage area needs garbage truck access and noise control, and should be located with concern for wind direction to control odors.

Both the building’s occupants and the custodial staff must cooperate for successful recycling in a large building. Office building operations generate large quantities of recyclable white paper, newspaper, and box cardboard, along with nonrecyclable but burnable trash, including floor sweepings. Offices also produce food scraps (including coffee grounds) and metals and glass from food containers. Dumping this all into one collection bin saves space, but with high landfill use costs, separation and recycling spaces are becoming more and more common.

The collection process for recycling in larger buildings has three stages (Fig. 12-2). First, white paper, recyclables, compostables, and garbage are deposited in separate compartments near the employees’ desks. In order to make an office building recycling system work, the interior designer must often design a whole series of multiple bins and the trails that connect them. Office systems manufacturers are beginning to address some of these needs. The process often needs to be coordinated with the sources of the materials, such as paper suppliers, and with the recycling contractors who pick them up.

Next, custodians dump the separate bins in a collection cart. There are also bins for white paper in the computer and copy rooms and for compostables and garbage in the employee lunchroom. Floor sweepings
are added to the garbage. The custodians take the full cart to a service closet at the building’s core and deposit each type of separated waste in a larger bin. The storage closet also has a service sink to wash the garbage bins, and may have a paper shredder.

Finally, white paper is shredded and stored for collection by recycling and garbage trucks at the ground floor service entrance, near the freight elevator. Compostables are stored or sent to a roof garden compost pile. Garbage is compacted and bagged. Compactors reduce wastes to as little as a tenth of their original volume. The storage area should be supplied with cool, dry, fresh air. Compactors and shredders are noisy and generate heat, and must be vibration-isolated from the floor. A sprinkler fire protection system may be required, and a disinfecting spray may be necessary. Access to a floor drain and water for washing is a good idea.

In some buildings, wastes are ground and transported by a system of very large vacuum pipes, which suck the wastes to a central location for incineration or compression into bales. Garbage grinders flush scraps into sewers, adding to sewage system loads.

The renovation of a late nineteenth century New York building for the National Audubon Society is an excellent example of making recycling work. Designed by the Croxton Collaborative, the eight-story building was renovated in the 1990s. The collection system uses two desktop paper trays, one for reuse and one for recycling. Central recycling points are located near four vertical chutes that pass through each floor. The chutes carry collected materials to a subbasement resource recovery center for recycling. The one for white paper is near the copier. Food wastes and soft soiled paper, returnable plastic bottles and aluminum cans, and mixed paper (colored paper, file folders, paperboard, and self-stick notes) are all collected in a pantry area near staff kitchens. Shelves in the pantry hold returnable glass bottles, coated papers (from juice and milk cartons), magazines, and newspapers.

Custodians pick up the wastebasket contents from work areas and the materials from the pantries, and take them to the subbasement to sort. In the subbasement, large movable bins collect material dropped down the chutes. Glass bottles, newspapers, and other items are boxed or baled. Recycled materials are taken to the delivery dock for pickup by recycling and garbage collectors. Organic wastes are refrigerated until enough accumulates for screening and adding to a composter. This
composter is closed for odor control, but supplied with air for aerobic digestion. After about three months, the waste turns to humus and is used for a roof garden.

Food and organic waste represents a significant portion of the waste stream, and states and communities are creating opportunities for businesses to begin organic waste diversion programs. In Boston, Slade Gorton fishing company has established an effective source-separation process that captured 15 tons of fish by-products in its first two months. The Massachusetts Institute of Technology implemented a pilot source-separation system in the year 2000 in the primary on-campus dining hall. Food preparation waste from the kitchen is collected daily for composting, helping MIT to achieve its 30 percent recycling goal and reducing the cost of waste disposal. MIT is now developing plans to divert all of the school’s organic waste, including yard waste and food, for composting. This will help to maximize recycling while minimizing costs, odor complaints, and the need for workers to carry all that trash.
Interior designers are often involved in the selection and specification of plumbing fixtures. Let’s start our discussion of this topic with a brief look at the history of plumbing fixtures.

Indoor bathrooms were not common in homes until around 1875, but their history goes back thousands of years. Archeologists in Scotland’s Orkney Islands discovered a latrine-like plumbing system dating to 8000 BC that carried wastes from stone huts to streams in a series of crude drains. Hygiene has been a religious imperative for Hindus since 3000 BC, when many homes in India had private bathroom facilities. In the Indus Valley of Pakistan, archeologists have found ancient private and public baths fitted with terracotta pipes encased in brickwork, with taps controlling the flow of water.

The most sophisticated early baths belonged to Minoan royal families. In their palace at Knossos on Crete, bathtubs were filled and emptied by vertical stone pipes cemented at their joints. These were eventually replaced by pottery pipes slotted together much like modern pipes. They provided both hot and cold water, and removed drainage waste from the royal palace. The Minoans also had the first flush toilet, a latrine with an overhead reservoir fed by trapping rainwater or by filling with buckets from a cistern.

By 1500 BC, aristocratic Egyptian homes used copper pipes for hot and cold water. Whole-body bathing was part of religious ceremonies, and priests were required to immerse themselves in cold water four times a day. The Mosaic Law of the Jews (1000–930 BC) related bodily cleanliness to moral purity, and complex public waterworks were built throughout Palestine under the rule of David and Solomon.

Bathing became a social occasion in the second century BC in Rome, when massive public bath complexes included gardens, shops, libraries, exercise rooms and lounge areas for poetry readings. The Baths of Caracalla offered body oiling and scraping salons; hot, warm, and cold tubs; sweating rooms; hair shampooing, setting, and curling areas; manicure shops; and a gymnasium. Shops sold cosmetics and perfumes. Up to 2500 members at a time visited the spas and the adjacent gallery of Greek and Roman art, library, and lecture hall. In another room, slaves served food and wine to spa visitors. All of this was only for men, but women had their own smaller spa nearby. Eventually, men and women mixed at spas, but apparently without major promiscuous behavior, a practice that lasted well into the Christian era until the Catholic Church began to dictate state policy.

All this luxury ended around 500 AD, when invad-
ing barbarians destroyed most tiled baths and terracotta aqueducts, leading to a decline in bathing and personal cleanliness during the Middle Ages. The Christian view at the time emphasized the mortification of the flesh, and whole-body bathing was linked to temptation and sin. Nobody bathed, but the rich used perfume to cover body odors. Outhouses, outdoor latrines and trenches, and chamber pots replaced indoor toilets. Christian prudery and medical superstitions about the evils of bathing led to an end to sanitation and the rise of disease and epidemics. In the 1500s, the Reformation’s emphasis on avoiding sin and temptation led people to expose as little skin as possible to soap and water. There was almost no bathroom plumbing, even in grand European palaces. A 1589 English royal court public warning posted in the palace, and quoted in Charles Panati’s Extraordinary Origins of Everyday Things (Harper & Row, Publishers, New York, 1987, p. 202), read, “Let no one, whoever, he may be, before, at, or after meals, early or late, foul the staircases, corridors, or closets with urine or other filth.” Apparently this was quite a common problem. Around 1700, a French journal cited by the same source noted, “Paris is dreadful. The streets smell so bad that you cannot go out . . . . The multitude of people in the street produces a stench so detestable that it cannot be endured.”

From medieval times on, wastes from chamber pots were tossed into streets. Legally, wastes were supposed to be collected early in the morning by night soil men, who carted them to large public cesspools, but many people avoided the cost of this service by throwing waste into the streets. Many cartoons of the period show the dangers of walking under second story windows late at night. Ladies kept to the inside of sidewalks to avoid the foul gutters.

By the 1600s, plumbing technology reappeared in parts of Europe, but indoor bathrooms did not. The initial seventeenth century construction of Versailles included a system of cascading and gushing outdoor water fountains, but did not include plumbing for toilets and bathrooms for the French royal family, 1000 nobles, and 4000 attendants who lived there.

Urbanization and industrialization in Britain in the 1700s resulted in overcrowding and squalor in cities. There was no home or public sanitation, and picturesque villages turned into disease-plagued slums. Cholera decimated London in the 1830s, and officials began a campaign for sanitation in homes, workplaces, public streets, and parks. Throughout the rest of the nineteenth century, British engineers led the western world in public and private plumbing innovations.

**PLUMBING FIXTURE SELECTION AND INSTALLATION**

On commercial projects, the architect and mechanical engineer usually select and specify plumbing fixtures. On residential projects, the interior designer or architect helps the client with the selection. The interior designer is often the key contact with the client for the selection of fixtures, representing their preferences and providing specification information to the engineer. Kitchen and bath designers, who usually work for businesses selling fixtures, often help owners select residential fixtures on renovation projects.

Several inspections by the local building inspector are required during the construction process, to assure that the plumbing is properly installed. Roughing-in is the process of getting all the pipes installed, capped, and pressure-tested for leaks before the actual fixtures are installed. The interior designer should check at this point to make sure the plumbing for the fixtures is in the correct location and at the correct height. The first inspection usually takes place after roughing-in the plumbing. The contractor must schedule the inspector for a prompt inspection, as work in this area can’t continue until it passes inspection. The building inspector returns for a final inspection after the pipes are enclosed in the walls and the plumbing fixtures are installed.

The design of the building and the choice of fixtures affect the water and energy consumption over the life of the building. The designer can encourage conservation both by the selection of appropriate fixtures and by increasing the user’s awareness of the amount of water being used.

Visible consumption measures allow the user to see how much water is being used, and to modify use patterns for better conservation. Rainwater storage tanks with visible water level indicators outside the bathroom window show how much water is used in each flush. Slightly undersized pipes allow users to hear the water flowing. This is especially useful for outdoor taps, where water may be left on.

**LAVATORIES AND SINKS**

Despite the hundreds of lavatory designs available in the interior design market, few consider the way our bodies work and the way we wash. Lavatories (bathroom sinks) are designed as collection bowls for water, but we use them for washing our hands, faces, and teeth quickly with running water. Because of the design of the spout,
you usually have to bend at the waist and splash water upwards to wash your face. Most lavatory fittings dump running water directly down the drain. They are hard to drink from and almost impossible to use for hair washing. Most handles are hand-operated, as the name implies, and you have to move your hands out of the water stream to turn them on and off. Foot-operated controls solve this problem. The sink and adjacent counter area are often difficult to keep clean and dry.

For cleanliness and durability, lavatories must be made of hard, smooth, scrubable materials like porcelain, stainless steel, or resin-based solid surfacing materials. Look for faucet designs that are washerless, drip-free, and splash free, and made of noncorrosive materials. Models are available that have permanent lubrication, easy-to-change flow control cartridges, and controlled compression to eliminate overtightening and wear on seals. Check for fixed faucet handle travel and features that make servicing easy.

Faucets that comply with the American with Disabilities Act (ADA) come in a variety of spout heights, and feature single-lever, easy-to-grab models, wing handles, and 4- and 5-in. blade handle designs.

Public restroom lavatories should have self-closing faucets that save water and water-heating energy. Faucet flow should be limited to a maximum of 1.9 liters (0.5 gallons) per minute. Low-flow faucets that use 1.89 to 9.46 liters (0.5–2.5 gallons) per minute employ aerators, flow restrictors, and mixing valves, which control temperatures. They function as well as or better than the 15- to 19-liter (4–5-gallon) per minute standard faucets. Low-flow aerators save up to half the amount of water used.

The term "sink" is reserved for service sinks, utility sinks, kitchen sinks, and laundry basins. Utility sinks are made of vitreous china, enameled cast iron, or enameled steel. Kitchen sinks are made of enameled cast iron, enameled steel, or stainless steel. The building code requires sinks in some locations, and local health departments may set additional requirements. Kitchen or bar sinks in break rooms and utility sinks for building maintenance are often installed even when not required by code. Kitchen sinks are limited to a maximum flow of 11.4 liters (3 gallons) per minute. Foot-operated faucets free the hands, a great convenience and water saver at kitchen sinks. The ADA sets standards for accessible kitchen sinks, including a maximum depth of 15 cm (6 in.). Service sinks, also called slop sinks, are located in janitor's rooms for filling buckets, cleaning mops, and other maintenance tasks. Wash fountains are communal hand-washing facilities sometimes found in industrial facilities.

Lavatories and other plumbing fixtures should have an air gap, a clear vertical distance between the spout of the faucet or other outlet of the supply pipe and the flood level of the receptacle. The flood level is the level at which water would overflow the rim of the plumbing fixture. Bathroom sinks have overflow ports that drain excess water before it can reach the end of the faucet. Air gaps are required to prevent the siphoning of used or contaminated water from the plumbing fixture into a pipe supplying potable water as a result of negative pressure in a pipe. Even if the water pressure fails, there is no chance of contaminated water being drawn into pipes as fresh water is drained back away from the fixture.

**BATHTUBS**

The Saturday night bath was an American institution well into the twentieth century. Bathing vessels were portable and sometimes combined with other furniture. A sofa might sit over a tub, or a metal tub would fold up inside a tall wooden cabinet. Homes had a bath place rather than a bathroom, and the bath and the water closet were not necessarily near each other.

Modern bathing is done on a very personal scale, in private, although tubs for two are currently in style. Social bathing is limited to recreation, not cleansing, in swimming pools, bathhouses, and hot tubs with spouts, jets, and cascades.

Standing water is good for wetting, soaping, and scrubbing, but running water is better for rinsing. We use tubs primarily for whole-body cleansing, and also for relaxing and soaking muscles. We follow a sequence of wetting our bodies, soaping ourselves, and scrubbing—all of which can be done well with standing water. Then we rinse, preferably in running water. Tubs work well in the wetting through scrubbing phase, but leave us trying to rinse soap off while sitting in soapy, dirty water. This is particularly difficult when washing hair.

Moderately priced all-in-one shower/bath enclosures in acrylic or fiberglass are very common. Fiberglass is the most cost effective, but acrylic has more durability and luster. Showers and tubs are often installed as separate entities, sometimes separated by a half wall or a door.

Tubs are often uncomfortable and dangerous for people to get into and out of. The design of the tub should ideally support the back, with a contoured surface and braces for the feet. A seat allows most of the body to be out of the water, and makes it easier to enter and leave the tub safely. A hand-held shower is very
helpful for rinsing body and hair. Bathtubs are made of vitreous china, enameled cast iron, or enameled steel.

Old-fashioned cast-iron claw-foot tubs are still available. Thermformed acrylic tub liners that can be installed over existing fixtures are a fast and economical way to upgrade a bathroom. Tubs are available with integral skirts for easy installation and removable panels for access.

For high-end designs, deeper than normal tubs made of cultured marble, fiberglass, cast iron, or acrylic may include whirlpools. Air tubs have a champagne bubble-type effect, while river jets simulate the undulating motion of white water river flow. Underwater lights, vanity mirrors, and wall-mounted CD/stereo systems with remote control are other luxurious options. Some tubs have built-in handrails and seats, while others have integrated shower or steam towers.

Clients may request big, two-person tubs with whirlpools, but often they don’t use them as much as they think they will. Whirlpool baths are available in a great variety of shapes, including corner tubs 150 by 150 cm (60 by 60 in.) with built-in television monitors. Consider 183 by 107 cm (72 by 42 in.) a maximum practical size. As people become more conscious of water use, they don’t necessarily want to fill up a 1136-liter (300-gallon) tub.

For safety’s sake, all tubs should have integral braced grab bars horizontally and vertically at appropriate heights, and no unsafe towel or soap dishes that look like grab bars. Manufacturers offer very stylish grab bars that avoid an institutional look. Tubs should be well lit, and have easily cleaned but nonslip floors.

A shower pan that converts a standard 152-cm (60-in.) tub to a shower without moving the plumbing can improve safety. In this process, the old tub is removed and replaced with a slip-resistant shower pan. An acrylic wall surround can cover up old tile and unsightly construction work.

A single-lever faucet offers two advantages. First, the lever is easier to manipulate than round handles for those who do not have full use of their hands. Second, both temperature and flow rate can be adjusted with a single motion. To protect children and people with disabilities who have limited skin sensation, scald-proof thermostatically controlled or pressure-balanced valves should be used to control the flow of hot water.

Where a bathtub is required to be accessible, the ADA specifies the clear floor space in front of the tub, a secure seat within the tub, the location of controls and grab bars, the type of tub enclosure, and fixed/hand-held convertible shower sprays. One of the best tub seats extends from outside the tub into the head of the tub, allowing a person to maneuver outside the tub before sliding in.

**SHOWERS**

Showers are seen as a quick, no-nonsense way to clean your whole body. They waste lots of fresh running water while we soap and scrub, but do an excellent job rinsing skin and hair. With luck, you get a nice invigorating massage on your back, but a real soak is impossible. If you drop the soap, you may slip and fall retrieving it. It is safer to sit when scrubbing, especially the legs and feet, so an integral seat is a good idea.

Some showerheads encourage water waste. A flow of 23 liters (6 gallons) per minute is typical, and as much as 45 liters (12 gallons) per minute was once common, using 22 liters (60 gallons) for a five-minute shower. Most codes require limited showerhead flow, with 9.5 liters (2.5 gallons) per minute being common. These low-flow showerheads can be designed in new showers or retrofitted, and save up to 70 percent when compared with standard models. Smaller pipes and heads increase the pressure, to give a satisfying shower with less water. The cost of installing low-flow faucets or showerheads results in savings of water, lower water bills, and energy savings for hot water. Domestic hot water accounts for 40 percent of U.S. energy use. An extra minute in the shower puts another 0.23 kg (½ lb) of carbon dioxide in the air.

When helping children bathe, you should be able to reach the controls from the outside without wetting your arm. Even with soap in your eyes, you should be able to manipulate controls from inside without seeing them. Adjustable handheld shower wall bars allow each person to adjust the showerhead to the perfect height. Shower controls and heads are available grouped together into a cleanly designed panel. Some showers feature multiple shower sprays and a steam generator. Systems that allow the sprays to be moved accommodate people of different sizes, and some systems come with programmable showerheads.

Where there is more than one shower in a public facility, the ADA requires that at least one must be accessible. There are two types of accessible showers: transfer showers and roll-in showers. Accessible showers have specified sizes, seats, grab bars, controls, curb heights, shower enclosures, and shower spray units. How the bather with disabilities will enter the shower is an important design issue, particularly if a person is in a wheelchair. For the bather who can physically transfer
from a wheelchair to a shower seat, the seat and grab bars must be positioned to facilitate that entry. For those who must shower in a wheelchair, the threshold cannot be more than 25 mm (1 in.) high to permit roll in, and the shower floor must be sloped to contain the water.

Moderately priced shower stalls are made of fiberglass or acrylic. More upscale options include marble and other stones, larger sized ceramic tile with borders, glass block, and solid surfacing materials. Pre-plumbed, all-in-one shower enclosures that include a steam generator are also available. Shower pans are typically made of terrazzo or enameled steel and are available in solid surfacing materials as well. Barrier-free shower pans are available. Grab bars, seats, anti-scald valves, nonslip bases, and adjustable shower arms all add to safety.

Different kinds of shower seats are available—adjustable, fold-up, and stationary. Regardless of type, the seat must be installed where it will allow a seated bather to reach the showerhead, valves, and soap caddy. An adjustable showerhead can be hand-held by a seated bather or bracket-held by a standing bather.

Grab bars, positioned to help the bather enter and exit the shower, cannot extend more than 38 mm (1.5 in.) from the wall; this is to prevent a hand or arm getting caught between bar and wall. Walls behind the seat and grab bars must be reinforced to support up to 114 kg (250 lb). This is done by installing 2” × 4” or 2” × 8” blocks horizontally between framing joists. Controls should be installed above the grab bar.

Shower enclosures are usually enameled steel, stainless steel, ceramic tile, or fiberglass. Frames for shower doors come in a variety of finishes. The handle that comes with the door can be upgraded to match the bathroom decor. Etched glass doors add a design element to the bathroom. Glass panel anti-derailing mechanisms add to safety. Open, walk-in styles of showers with no doors are also an option.

Heavy glass frameless enclosures that can be joined with clear silicone are available up to 13 mm (½ in.) thick, although the thinner 10 mm (⅜ in.) is usually adequate. Body sprays with lots of jets pounding right at a frameless door will inevitably leak, so pointing them against a solid wall may be a better option. A vinyl gasket can deter leaks, but may defeat the visual effect of the frameless glass, and is unlikely to be effective for very long. Totally frameless enclosures always lose a certain degree of water, and glass doors generally don’t keep steam in and don’t retain the heat as well as framed doors. Complete water tightness may encourage mildew growth, so a vented transom above the door may be necessary.

Prefabricated modular acrylic steam rooms are available in a variety of sizes that can comfortably fit from two to eleven people. They include seating and low-voltage lighting. An average steam bath consumes less than one gallon of water. Steam generators are usually located in a cabinet adjacent to the shower enclosure, but may be located up to 6 meters (20 ft) away. Look for equipment with minimal temperature variations, an even flow of steam, quiet operation, and steam heads that are cool enough to touch. Plumbing and electrical connections are similar to those of a common residential water heater. Controls can be mounted inside or outside the steam room.

Modular saunas combine wood and glass in sizes from 122 × 122 cm (4 × 4 ft) to 366 × 366 cm (12 × 12 ft). There are even portable and personal saunas that can be assembled in minutes. Heating units are made of rust-resistant materials and hold rocks in direct contact with the heating elements. Models are available in cedar, redwood, hemlock, and aspen.

Showers may be required by code in assembly occupancies such as gyms and health clubs, and in manufacturing plants, warehouses, foundries, and other buildings where employees are exposed to excessive heat or skin contamination. The codes specify the type of shower pan and drain required.

There are alternatives to our typical showers and tubs. Traditional Japanese baths (Fig. 13-1) have two phases. You wet, soap, and scrub yourself on a little stool over a drain, rinse with warm water from a small bucket, then (freshly cleansed) you soak in a warm tub. An updated version uses a whirlpool hot tub for the soak. Locate the hot tub in a small bathhouse with a secluded view, and you approach heaven.

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Figure 13-1 Traditional Japanese bath.
TOILETS, URINALS, AND BIDETS

In 1596, Queen Elizabeth had a toilet installed by Sir John Harrington, who came from Bath, giving us two euphemisms still in use today. A high water tower was located on top of the main unit, with a hand-operated tap for water flow to the tank, and a valve that released sewage to a nearby cesspool. Harrington’s toilet was connected directly to the cesspool, with only a loose trap-door in between. The queen complained about cesspool fumes in this toilet without a trap. The new toilet fell into disuse because Sir John wrote an earthy, humorous book about it, which angered the queen.

British watchmaker and mathematician Alexander Cummings put a backwards curve into the soil pipe directly underneath the toilet bowl in 1775, which retained water and cut off the smell from below. Cummings’s patent application for a “stink trap” introduced the trap that has been used on all subsequent designs.

What most of us call a toilet is technically called a water closet. Toilets are not usually designed to facilitate proper washing while eliminating. A toilet seat that provides a cleansing spray is available from several American manufacturers for use on existing toilets. Bidets, which are popular in Europe and less often seen in the United States, are designed for personal cleansing. Toilets are available without a separate toilet seat, with a warmer for the seat, and with warm water within the toilet for washing.

Water closets, urinals, and bidets are made of vitreous china. Toilet bowls could never be leak proof and free of contamination until all the metal and moving parts were eliminated. In 1885, an English potter named Thomas Twyford succeeded in building the first one-piece earthenware toilet that stood on its own pedestal base. Porcelain toilets will not accumulate bacteria-harboring scratches when cleaned. His toilet design is essentially the same as the one used in the modern bathroom.

The height of the conventional toilet seat is a compromise. A lower toilet seat is healthier for the average person, as it approximates a squatting position, but is more difficult for standing male use, and for some elderly people or people with some disabilities. Higher toilets provide more support. Toilets are often used as chairs in the bathroom, and low ones are not at a comfortable chair height. The standard toilet is somewhere in between the lower and higher limits. Toilet manufacturers offer toilets with seats at the same height as a standard chair seat, marketed as comfortable for people of all ages and statures. The recommended height for a toilet that is accessible for people with disabilities is 457 mm (18 in.). Toilets are available at this height, or an existing toilet can be retrofitted with special thick seats or with a spacer ring placed between the toilet rim and a standard seat. In addition, a grab bar next to the toilet will help the user get up and down. Urinals for use by men in wheelchairs are either wall mounted at lower heights, or floor mounted.

Water closets and urinals can’t be designed to have the type of air gaps found in lavatories. For example, water closets and urinals in public buildings have a supply pipe connected directly to the rim. Consequently, it is a legal requirement in most areas that at each fixture where a connection between the supply and waste plumbing is possible, a vacuum breaker must be installed on the supply line. When the pressure fails, air is allowed to enter the line, destroying the siphon action and preventing contaminated water from being sucked into the system. You may have noticed the chrome plated flush valve on every public toilet fixture; this contains the vacuum breaker. Vacuum breakers are also manufactured for outdoor faucets, where the end of a hose may be left in a swimming pool or garbage pail full of water.

Most codes require that all water closets specified for public use have elongated bowls and seats with open fronts. Specific clearances are required on each side and in front of the bowl. Automatic flushing controls add to the toilet’s accessibility and keep toilets clean. They work by radiant heat from body pressure or by reflecting a light off the user and back to the control. Toilets designed for handicapped accessibility are usually wall-hung and have elongated fronts.

The ADA doesn’t apply to private residences, but many designers incorporate the principles of universal design to accommodate present or future needs of their clients. The Federal Housing Act (FHA) applies to multiple unit housing built with government funds, and may require partial or full accessibility or provisions for easy conversion of some units. Structural reinforcement for future grab bars and wall-mounted water closets may be required, and is a good idea anyway.

Toilet Plumbing

Our modern toilet (water closet) emerged in the 1940s with tanks that hold about 19 liters (5 gallons) of water mounted on the backs of the bowls. When you trip the handle on the toilet, a flapper valve opens in the bottom of the tank, releasing the water to flush waste away and rinse the bowl clean. A portion of the water flows
out around the top rim, swirling to wash down the sides of the bowl (Fig. 13-2). Most of the water flows rapidly through a hole near the bowl bottom and propels waste out through the drain trap.

The volume of water needed to do a thorough job determines the size of the tank, so some tanks are bigger than others, depending on the bowl design. Once the tank empties, the flapper valve falls closed, and the tank and bowl refill from the household water supply. Water closets have large traps that are forced to siphon rapidly during the flushing process and are refilled with fresh water to retain the seal. The water closet must be vented nearby to prevent accidental siphoning between flushes. The small supply piping available in houses can't provide the quick, ample rush of water necessary to operate a toilet's siphon trap. Instead, water is slowly collected in a tank at the back of the fixture. In public buildings with frequent flushing of toilets, slow-filling tanks could not keep up with the demand. Consequently, commercial toilet installations use larger supply pipes with special valves to regulate the strength and duration of each flush.

Toilets That Conserve Water

Approximately 70 percent of the water flushed down traditional-sized toilets isn't required for effective sewage transport. If a toilet predates 1985, it probably uses between 19 liters and 28 liters (5–7.5 gallons) per flush. The older the toilet, the more water it probably uses. Studies performed in Massachusetts show that in an average 3.2 person household where each person flushes four times a day, the 27 liters (7 gallons) per flush toilet uses 123,770 liters (32,700 gallons) of water a year. Even a 13-liter (3.5-gallon) toilet reduces water use per household to 62,074 liters (16,400 gallons) per year. Studies done at various places around the country show that toilets account for anywhere from 35 to 42 percent of all indoor household water use.

Low-consumption toilets lower building water use by 30 to 40 percent. This reduces the load on municipal sewer systems and saves fresh water supplies. Beginning in 1994, it became illegal to make or sell in the United States any toilet that uses more than 6 liters (1.6 gallons) per flush. These toilets became the center of controversy when the law got ahead of technology, resulting in steep price increases, problems with performance, and unhappy consumers. Once they decided to take a serious look at water consumption levels and water conservation, fixture manufacturers responded with only slight modifications in the basic product design. The flush valve on existing water closets was shut off prematurely, and less water was used with minimum changes to the china fixture. What resulted has contributed more to the negative impressions about 1.6 gpf (gallons per flush) low-consumption toilets than any other factor. Repeated flushing was often necessary to clean the bowl after use.

Even so, two 6-liter flushes still use less water than the former 13 liters (3.4 gallons) per flush, and most times only one flush is actually needed. Over time, manufacturers found ways to increase the swirling effect of the water and clean the bowl better. To achieve low-consumption gravity performance, the size of the trap and other openings were decreased. This resulted in a stronger siphoning action to withdraw the waste, and much improved performance. Still, there was double flushing going on, and modifications continued to be made to enlarge the trapway and water surface areas.

Although no longer legal for new installations in the United States, many older, higher consumption toilets are still in place in existing buildings. Older styles include two-piece, lower pressure models, shallow trap models, and one-piece styles that eliminate the seams between the tank and the toilet. The mechanical systems range from flush-valve commercial toilets to wash down toilets, siphon jets, siphon vortex toilets, and blowout toilets. These styles range between 9.5 liters (2.5 gallons) and 30 liters (8 gallons) per flush. Toilet dams installed in toilet tanks limit the amount of water used in existing toilets.
Watersaver toilets use 6.4 liters to 13.2 liters (1.7–3.5 gallons) of water per flush, which may not be enough of a water savings to meet strict U.S. requirements. They use a conventional flushing action, but save water by employing higher water pressure and better bowl shapes, better methods of filling and emptying, and improved trap configurations.

Some toilets conserve water by offering variable flushing controls. Dual cycle controls allow you to choose how much water you need, as do vertical flush sleeve valves. Pressure-reducing valves save water coming in on supply lines.

There are two types of ultra-low-flow (ULF) toilets currently available to homeowners that meet the legal requirements: the gravity ULF and pressurized ULF. Gravity ULF toilets have steeper-sided bowls to increase the flushing velocity. The tanks are taller and slimmer than older models, raising the water higher and increasing the flushing power. These taller tanks also hold more than 6 liters (1.6 gallons) of water, but the flush valves don’t release it all, harnessing only the force of the topmost 1.6 gallons. The tank never empties its entire capacity, and it’s a clever way to increase flushing power.

Pressurized ULF toilets look conventional from the outside but use a unique air-assisted flush mechanism inside the tank. The pressure-assist vessel inside the toilet’s tank traps air, and as it fills with water, it uses the water supply line to compress the trapped air inside. The compressed air is what forces the water into the bowl, so instead of the pulling or siphon action of a gravity-fed toilet, the pressure-assist unit pushes waste out. This vigorous but somewhat noisy flushing action cleans the bowl better than gravity units.

Pressure-assist flushing systems (Fig. 13-3) reduce water use by elimination of leakage and double flushing. The U.S. Department of Housing and Urban Development (HUD) has calculated that a fixture can leak up to 95 liters (25 gallons) per day, depending on the age of the parts inside, but the pressure-assist unit holds the water within the tank, eliminating leaks. A larger water surface keeps the bowl cleaner, and a larger trapway and fewer bends eliminate stoppages. Because the water is contained inside the vessel within the tank, condensation doesn’t form on the toilet tank. Fewer moving parts reduce maintenance.

Pressure-assist toilets install in the same space as conventional toilets, and require 138 kPa (20 pounds per square inch, psi) of water pressure, which is typical in residential housing. Pressure-assist toilets are used in homes, hotels, dormitories, and light commercial applications, and are available in handicapped accessible models. More and more states are mandating the use of pressure technology in commercial structures, primarily to prevent blockages.

In 1986, a severe drought brought the water supplies of San Simeon, California, to a severe crisis level at the same time that the wastewater treatment plant demand was reaching full capacity during the peak use season. The choices were rather grim: new, supplemental water sources, additional waste treatment capacity, or more rationing that would close some of the motel rooms that the city depended on for income. The alternative on which the city finally settled was replacing all toilets with low-consumption pressure assisted types, which reduced water consumption in the town by 39 percent compared to the older 3.5-gpf toilets. As a bonus, bowl stoppages were almost completely eliminated.

With a central compressed-air system, very low water consumption can be achieved. The Microphor flush toilet has a design with two chambers for a flush that uses only 1.4 liters (1.5 quarts) per flush. In the Envirovac system, a vacuum is used to provide a 1.4-liter flush. This system can be used in basements, as the sewer line may run horizontally or even vertically.

Some toilets use a mechanical seal rather than a water trap, and use only about 5 percent of the usual amount of water. Chemical toilets use even less.

An alternative type of toilet is made by Incinolet.
Available as a toilet or a urinal, it has no plumbing connections and reduces waste to a small volume of ash. It requires connection to electric power and a 10-cm (4-in.) diameter vent to the outside.

Composting toilets, sometimes called biological toilets, dry toilets, and waterless toilets contain and control the composting of excrement and toilet paper by aerobic bacteria and fungi. Aerobic digestion generally produces much less odor than anaerobic processes. The composting process transforms the nutrients in human excrement into forms that can be used as a soil conditioner. Composting toilets can be installed where a leaching field or septic tank, with their inherent problems and expenses, are undesirable or impractical, including areas that have placed limits on new septic systems, and in parks and nature sanctuaries.

All composting toilets require a continuous supply of room air drawn into the composting chamber and vented out through the roof to provide oxygen for the aerobic microorganisms that digest the wastes. Composting toilets eliminate or greatly reduce water for flushing but increase energy consumption, although the amount needed to run a fan and keep the compost from freezing is small, and is often supplied by a solar panel on the roof. Grates, screens, electric fans, and ventilation chimneys can provide ventilation. Airtight lids on the toilet, screens over vents, proper maintenance, and keeping kitchen scraps from the composting toilet will deter unwanted insects. Some government agencies require a permit before installing a composting toilet.

Waterless urinals use a floating layer of a special biodegradable and long-lasting liquid that serves as a barrier to sewer vapors in the trap while still allowing urine to pass.

**Urinals**

Urinals reduce contamination from water closet seats and require only 46 cm (18 in.) of width along the wall. Urinals are not required by code in every occupancy type. They are usually substituted for one or more of the required water closets. Many bars and restaurants install urinals in addition to the number of required toilets to accommodate large crowds. The wall-hung type (Fig. 13-4) stays cleaner than the stall type, but tends to be too high for young boys and for men in wheelchairs. Where urinals are provided, the ADA Accessibility Guidelines (ADAAG) requires that a minimum of one of them comply with access requirements: a stall-type urinal or a wall-hung fixture with an elongated rim at a specified maximum height above the floor. Clear front space must be allowed for a front approach.

Although uncommon, urinals can be built into residential walls for pullout use, where they might be a solution to the eternal male/female toilet seat dilemma.

**PLUMBING CONSIDERATIONS FOR APPLIANCES**

Although such appliances as dishwashers and clothes washers are not usually considered to be plumbing fixtures, we are including them here as an aid to interior designers, who frequently assist clients in selecting them, and who locate them on their plans. We also discuss appliances under the section on electricity.

A conventional dishwasher uses 45 to 68 liters (12–18 gallons) of water per cycle, much of it heated beyond the 49°C (120°F) household hot water supply. Optional shorter cycles use around 26 liters (7 gallons).

Washing machines use 151 liters to 208 liters (40–55 gallons) per full-size load cycle. Older-style washers with “suds savers” allowed soapy, hot wash water to be reused. Newer models have wider water quantity and temperature selections, saving water and...
energy. Front-loading machines greatly reduce the quantity of hot water used per wash cycle. They also give you cleaner clothes with less detergent and less energy than agitator-type machines, and reduce wear and damage to clothes.

Dishwashers and clothes washers have relatively simple plumbing requirements. Be sure to leave adequate space for access, especially in front of front-loading machines. Both dishwashers and clothes washers use vacuum breakers to prevent clean and dirty water from mixing. Kitchens need regular water supply lines for the sink and dishwasher, and waste lines for the sink, garbage disposal, and dishwasher.

**Fixture Layout and Installation**

As with other plumbing, fixtures should never be installed in exterior walls where there is any chance of below-freezing weather. Small-scale fixture plumbing will fit into a 15-cm (6-in.) interior partition, but wall-hung fixtures require chases 46 to 61 cm (18–24 in.) thick. Plumbing chases are required where there are more than two or three fixtures. Plastic pipes are not allowed in residences in many jurisdictions.

Fixtures should be located back-to-back and one above the other wherever possible for economical installation. This allows piping space to be conserved and permits greater flexibility in the relocation of other partitions during remodeling. Wherever possible, locate all fixtures in a room along the same wall.

Bathroom fixtures should be located with space around the fixture for easy cleaning and for access for repair and part replacement. Faucets and toilet valves are subject to constant repairs, and drains must be kept free of obstructions. Waste piping clogs with hair, paper, cooking fats, and tree roots. When water supply piping fills with mineral scale, it must be replaced, which is something to be checked when the bathroom is undergoing a major renovation. Access panels may be required in the walls of rooms behind tubs, showers, and lavatories. Trenches with access plates may be required for access to pipes in concrete floors. Water heaters are especially prone to scale from mineral-rich water, and their electrical or fuel-burning components need periodic attention.

Prefabricated bathrooms are available, with manufactured assemblies of piping and fixtures. One-piece bathrooms have no seams between the fixtures and the floors. Fixture replacement is difficult and expensive, and access for plumbing repairs must be provided through adjacent rooms.

Some types of occupancies present special plumbing design challenges. Plumbing fixtures for schools should be chosen for durability and ease of maintenance. Resilient materials like stainless steel, chrome-plated cast brass, precast stone or terrazzo, or high-impact fiberglass are appropriate choices. Controls must be designed to withstand abuse, and fixtures must be securely tied into the building’s structure with concealed mounting hardware designed to resist exceptional forces.

Prisons employ extreme measures to prevent plumbing fixtures from becoming weapons. Heavy-gauge stainless steel fixtures with nonremovable fittings are very expensive and require tamper-proof installation.

**Compressed Air and Vacuum Lines**

In some urban locations, vacuum lines, compressed air lines, or high-pressure water mains for driving tools were once run below streets as utility systems. Today, gas, electric, and steam are the only energy utilities in common use.

An electric-powered compressor in some buildings furnishes compressed air, which is supplied through pipelines for use in workshops and factories. Compressed air is used to power portable tools, clamping devices, and paint sprayers. Air-powered tools tend to be cheaper, lighter, and more rugged than electrical tools. Vacuum lines are installed in scientific laboratory buildings.
The design of bathrooms and public restrooms involves not only the plumbing system, but also the mechanical and electrical systems. There are special space planning considerations in bathroom design as well, which have an impact on the plumbing layout.

**DESIGNING PRIVATE BATHROOMS**

The minimum code requirements for a residence include one kitchen sink, one water closet, one lavatory, one bathtub or shower unit, and one washing machine hookup. In a duplex, both units may share a single washing machine hookup. Each water closet and bathtub or shower must be installed in a room offering privacy. Some jurisdictions require additional plumbing fixtures based on the number of bedrooms. Many homes have more than one bathroom. Here are some guides to terminology and to area requirements.

The basic three-fixture bathroom with lavatory, toilet, and combination tub/shower is designed for one user at a time. You should allow a minimum of 3.25 square meters (35 square ft), although elegant master baths may be much larger. A compartmented bathroom has the lavatory in a hallway, bedroom, or small alcove, with the toilet and bath in a separate space close by. The toilet can also be separate, with its own lavatory. Compartmented bathrooms are very convenient for couples or multiple children using the components simultaneously. They are often found in hotels. A guest bath generally includes a lavatory, toilet, and shower stall, rather than a full bathtub. You should allow a minimum of 3 square meters (30 square ft). The term half-bath refers to a lavatory and toilet, and uses about 2.3 square meters (25 square ft). The classic powder room under the stairs is a half-bath. If located near the mudroom entrance, they work very well for kids playing outdoors, allowing a quick visit without tracking dirt through the house.

Bathrooms are often the victims of the one-size-fits-all philosophy. Pullout step stools help children at lavatories. Counters and mirrors at varying heights for seated and shorter people help accommodate everyone.

Within such a usually limited space, storage can become a major problem. Families often buy toilet paper and other supplies in bulk, and need storage for at least some of these supplies within the room and the rest nearby. Towels should be stored within the room. Multiple users can leave a plethora of toiletries and grooming supplies on counters and shelves, and building in