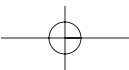
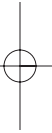
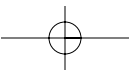
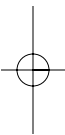
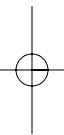
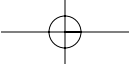


P a r t

THE BIG PICTURE





Chapter

Natural Resources

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.

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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

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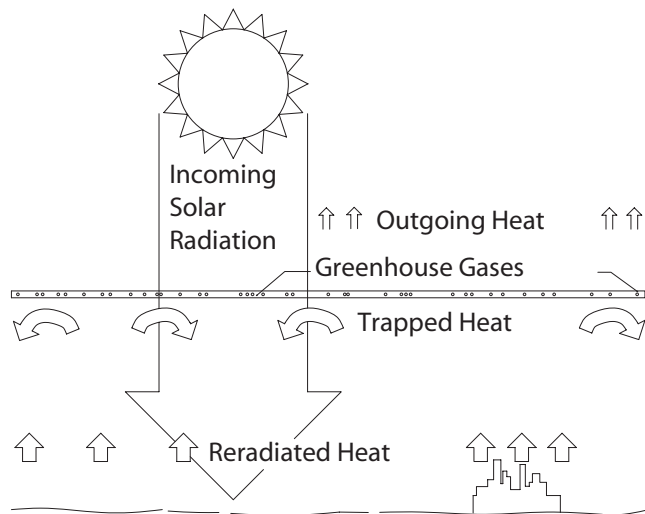


Figure I-1 The greenhouse effect.

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 effects, 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.



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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-



When a New York City social services agency prepared to renovate a former industrial building into a children's services center, they sought a designer with the ability to create a healthy, safe environment for families in need. Karen's awareness of the ability of an interior to foster a nurturing environment and her strong interest in sustainable design caught their attention. Her LEED certification added to her credentials, and Karen was selected as interior designer for the project.

The building took up a full city block from sidewalk to sidewalk, so an interior courtyard was turned

into a playground for the children. The final design incorporated energy-efficient windows that brought in light without wasting heated or conditioned air. Recycled and nonpolluting construction materials were selected for their low impact on the environment, including cellulose wall insulation and natural linoleum and tile flooring materials. Karen's familiarity with sustainable design issues not only led to a building renovation that used energy wisely and avoided damage to the environment, but also created an interior where children and their families could feel cared for and safe.

sional Accreditation Examination. 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



Figure 1-2 ENERGY STAR label.

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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 collab-

oration 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 vinecovered 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 produc-

tivity 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.