Energy and Atmosphere

Creating a low energy profile is a major challenge for designers of high-performance green buildings. The environmental impacts of extracting and consuming nonrenewable energy resources such as fossil fuels and nuclear energy are profound. Pronounced land impacts from coal and uranium mining, acid rain, nitrous oxides, particulates, radiation, ash disposal problems, and long-term storage of nuclear waste are just some of the consequences of energy consumption by the built environment. Building energy consumption in the United States is at about the same scale as energy consumption by automobiles, with about 40 percent of primary energy being consumed by buildings and about the same quantity by transportation.[1] In fact, much automotive energy consumption is caused by where buildings are placed on the landscape in the planning process.

Toward the end of the current decade, humankind will face the aforementioned rollover point in petroleum production,[2] the point at which the extraction rate is predicted to peak, and considerable additional energy and financial resources will be needed to extract remaining oil resources. At the same time, economies around the world continue to grow, all of them dependent on abundant, cheap energy, none of them more so than the United States. H. T. Odum, the late, eminent ecologist who founded the branch of ecology known as *systems ecology*, forecasted that, at the rollover point, the energy required to extract the oil would be greater than its energy value.[3] Sounding another warning note, Odum and his colleagues calculated that some key technologies suggested as substitutes for a predominantly fossil-fuel-powered energy system, among them photovoltaics and fuel cells, require more energy to produce than they themselves will ever generate. The point is, the technological optimists who believe a technical solution will always be found to solve our energy, water, or materials problems have no truly viable substitute for fossil-fuel-derived energy. For the built environment, truly dramatic reductions in building energy consumption, accompanied by tremendous progress in passive design, will be needed to meet a potentially costly energy future.

As we approach this day of reckoning, when energy costs are likely to rise dramatically as a result of fierce international demand and competition, we still have time to make some very important decisions with respect to how we live and the types of buildings we create. The green building movement and allied efforts to improve building energy performance are attempting to influence a major shift in how buildings are designed. It is a fundamental transformation that must take place, one that does not just reduce energy consumption by a few percent, but that involves a total rethinking of building design. Advocates of just such a radical change believe that buildings should be *energy-neutral* or even net *exporters* of energy. Advancing the use of solar energy, ground-coupling, radiant cooling, and other radical approaches may indeed enable buildings to generate at least as much energy as they consume. In the interim, however, we must learn how to cut building energy use by a marked quantity, perhaps as by much as 90 percent—a daunting challenge, to be sure.

FIGURE 7.1 *Rinker Hall is a high-performance LEED-certified Gold building at the University of Florida that incorporates advanced energy strategies. (Photograph: Michele R. Moretti.)*

Building Energy Issues

Energy consumption remains the single most important green building issue, not only because of its environmental impacts, but also because of the probability of significantly higher future energy costs. In 2002, 80 million buildings in the United States consumed 33 quads (1 quad equals 1 quadrillion BTUs, or 1,000 billion BTUs), about 36 percent of the country's primary energy. Lighting consumed 31 percent of commercial building energy, heating accounted for 22 percent, and space cooling for 18 percent. Impacts from electrical power generation include global climate change, acid rain, ground-level ozone creation, and a wide range of health effects caused by the emission of particulates. Energy consumption by buildings in 2002 contributed to:[4]

- 47 percent of U.S. sulfur dioxide emissions
- 22 percent of nitrogen oxide emissions
- 35 percent of carbon dioxide emissions

In the future, this situation will only worsen, as 18.4 million new homes and 21.5 billion square feet of new commercial buildings are forecasted to be built between 2002 and 2010. An ambitious federal government program, Buildings for the 21st Century, proposes to reduce energy consumption by 50 percent in new homes and commercial buildings and by 20 percent in existing homes and buildings by 2010. It calls for further reductions of another 50 percent and 20 percent for new and existing homes and buildings by 2020.[5] To accomplish this feat will require technology breakthroughs, better building design tools and simulations, improved construction techniques, and a wholesale shift in the attitude of building owners with respect to investing in high-performance green buildings at the front end to produce greatly reduced operating costs over the life of a building.

One general school of thought with respect to sustainability is that energy consumption worldwide should be reduced by a factor of 10, a concept that has taken root in the development of energy policy in the European Community. (See Chapter 2 for a discussion of Factor 4 and Factor 10.) A nominal U.S. commercial building consumes on the order of 100,000 BTUs per square foot per year (292 Kwhr/square meter/year). Today's green buildings typically reduce this energy requirement to less than 50,000 BTUs per square foot each year (146 Kwhr/square meter/year). But a Factor 10 building would use just 10,000 BTUs per square foot annually (29 Kwhr/square meter/year). Based on today's assumptions about comfort and aesthetics, it is indeed a challenging prospect to create a truly energy responsible building in the spirit of Factor 10.[6]

A green building would ideally use very little energy, and renewable energy would be the source of most of the energy needed to heat, cool, and ventilate the structure. Today's green buildings include a wide range of innovations that are starting to change the energy profile of typical buildings. Many organizations are committed to investing in innovative strategies to help create buildings with Factor 10 performance, notably the U.S. federal government, which has been the leader in requiring life-cycle cost (LCC) analysis as the basis for decision making with respect to building procurement. Some state governments have followed suit, notably Pennsylvania, New York, and California; in contrast, others, such as Florida, have passed legislation requiring decisions based solely on the capital or first cost of a particular strategy. This latter, shortsighted approach will result in enormous expenditures of energy as we approach the point in time at which the energy required to extract fossil-fuel resources exceeds the energy value of the extracted fuel.

Green building advocates often note that there are some cases of high-performance buildings where the strategies used to heat, cool, ventilate, and light these superior buildings allow a significant downsizing of the mechanical plant and a parallel reduction in the overall capital costs of the building. This is clearly the ideal outcome, wherein both capital and operating costs are lower than a comparable base-case building. However, there are very few of these cases in typical U.S. climactic zones, for a variety of reasons, including building code constraints. LCC analysis of a building's performance is key for giving designers the creative freedom to optimize a given building's energy consumption.

High-Performance Building Energy Design Strategy

The basic steps in designing an energy-efficient building are as follows:

1. Use building simulation tools to assist designers in minimizing energy consumption.
2. Optimize the passive solar design of the building.
3. Maximize the thermal performance of the building envelope.
4. Minimize internal building loads.
5. Design an efficient HVAC system that minimizes energy use.
6. Incorporate renewable energy use to the maximum extent possible.
7. Incorporate innovative, emerging strategies where appropriate, for example ground-coupling and radiant cooling.

For the purposes of the USGBC LEED-NC 2.1 building assessment standard and many building codes, the building must of course meet and prefer-

Greening Federal Facilities, 2nd ed. 2001. Washington, DC: Department of Energy, DOE/GO-102001-1165. Downloadable from www.eere.energy.gov/femp/technologies/sustainable_greening.cfm.

"Radiant Cooling," Energy Design Brief. 2000. Energy Design Resources. Downloadable from www.energydesignresources.com/publication/db/.

Reference Package for New Construction & Major Renovations (LEED-NC), Version 2.1, 2nd ed. May 2003. U.S. Green Building Council, Washington, DC.

"Tips for Daylighting with Windows: The Integrated Approach." 1997. Lawrence Berkeley National Laboratory, Berkeley, California, LBNL-39945.

CHAPTER EIGHT

The Building Hydrologic System

Of the various resources needed for the built environment, water is arguably the most critical. In his book *The Bioneers*, Kenny Ausubel notes that biologists occasionally refer to this resource as "Cleopatra's Water" because, like all other materials on the planet, water stays in a closed loop. The water you sip from a drinking fountain may have once been used by the Egyptian queen in her bath. The human body is 97 percent water, and water is more crucial to survival than food. It serves as a buffer in human metabolism for the transfer of oxygen at small scale, as a damper on rapid changes in the planet's environment at large scale, and as a shock absorber in cellular function at microscopic scale. Water plays a role in most of the world's spiritual traditions and religions, from baptism in the Christian faiths to sweat lodges in Native American rituals to the cleanliness traditions of the Baha'i faith. Water is the source of life for both humans and other species, yet it also has the power to destroy. It is used as a metaphor for truth and as a symbol for redemption and the washing away of sin. Water serves as habitat for a substantial fraction of the Earth's living organisms, and the remainder are totally dependent on it for their survival.

In spite of its symbolic and practical values, water resources around the planet are badly stressed. During World Environment Day in 2003, Kofi Annan, the secretary general of the United Nations, noted that on Earth, one person in six is without safe drinking water, and double that number, about 2.4 billion, lack adequate sanitation. Several problems are contributing to these shortages. Of all the Earth's water, only 2.5 percent is freshwater, and of that, three-quarters is sequestered or "locked up" in glaciers and permanent snow cover. Only 0.3 percent of water is surface water found in rivers and lakes, and thus readily accessible. The remainder is buried deep in the ground, and in some cases, once removed, it cannot be replenished except over hundreds of years. In much of the world, freshwater removed from both ground and surface sources is being used up far faster than it is being replenished. West Asia has the most severe water supply problem in the world, with over 90 percent of the regional population experiencing severe water stress. In Spain, over half of the country's approximately 100 aquifers are overexploited. In the United States, the situation is better but not significantly, and perhaps not for long. In Arizona alone, more than 400 million cubic meters (520 million cubic yards) of water are removed from aquifers each year, double the replenishment rate from rainwater (see Figure 8.1).

Perhaps the best-known case of water supply depletion is the Aral Sea, which in the 1960s began supplying water to Soviet collective farms for the production of cotton. Formerly a source of large fish, by the early 1980s, they had been virtually eliminated. By the 1990s, the Aral Sea was half its original area, and it had shrunk in volume by 75 percent. A once beautiful, large, rich, and deep lake with complex ecosystems had been largely destroyed in about 40 years due to human activities.

In addition to problems of water supply, public health and hygiene are important issues. Waterborne diseases, including diarrhea, typhoid, and cholera, are responsible for 80 percent of illnesses and death in developing

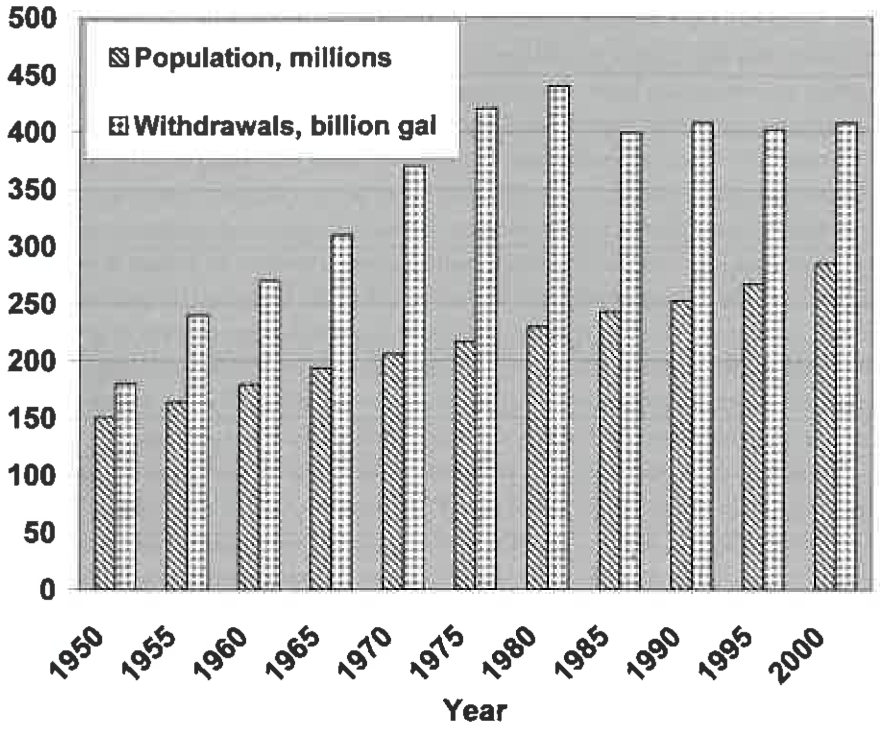

FIGURE 8.1 *Water consumption in the United States has leveled off in the past few decades, with potable water withdrawals presently at around 400 billion gallons per year. However, shortages of potable water around the country indicate that, in spite of the flattening out of consumption, the current level of withdrawals is not sustainable.*

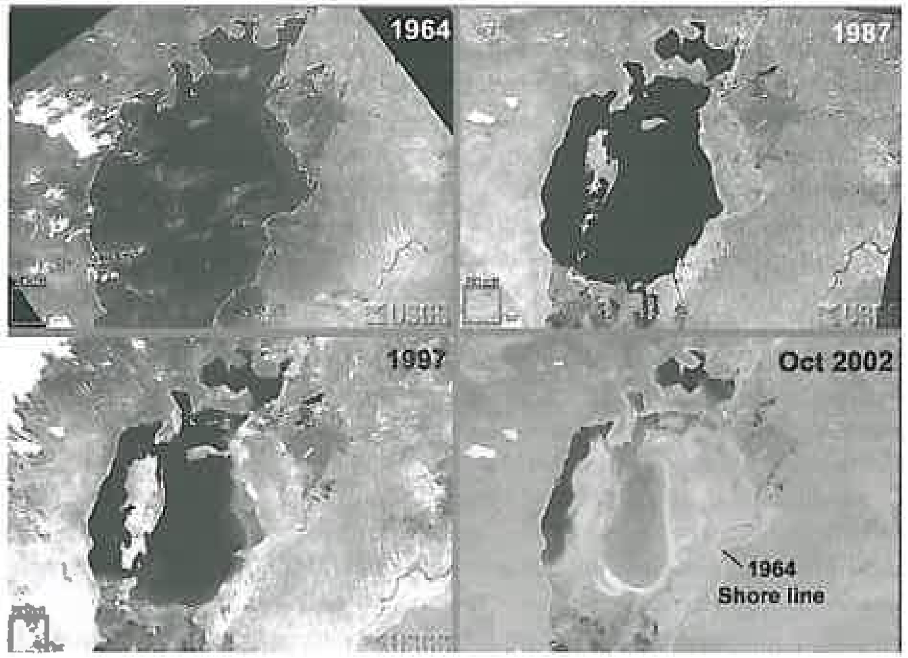

FIGURE 8.2 *In 1964, the Aral Sea in central Asia was a very large and deep saltwater lake with diverse ecosystems (upper left). Heavy withdrawals for agriculture resulted in dramatic shrinkage of its area and volume as shown in pictures from 1987 (upper right), 1997 (lower left), and 2002 (lower right). (Photographs: U.S. Geological Survey.)*

countries. Some 15 million children per year die from these waterborne diseases. Raw sewage and toxic materials, including industrial and chemical waste, human waste, and agricultural waste, are dumped into water systems at the rate of 2 million tons per day. About 300,000 gallons (1.1 million liters) per minute of raw sewage are dumped into the Ganges River in India, which also happens to be a primary source of water for many Indians. Wastewater treatment lags in most of the world: only 35 percent is treated in Asia and approximately 14 percent in Latin America.

Agriculture is the cause of serious water supply problems because it is responsible for over 80 percent of water consumption; and 60 percent of irrigation water is wasted due to leaky canals, evaporation, and mismanagement. A similar phenomenon occurs in the cities of many developing countries, with about 40 percent of the water in large cities being lost to leaky systems.

It is important to note the actual amount of water needed by a population because it defines the limits of supply and consumption for a region. For bare survival, the World Health Organization (WHO) suggests that 0.5 to 1 gallon (2 to 4.5 liters) of water is needed per person for drinking, and another 1 gallon (4 liters) for cooking and food preparation. The U.S. Agency for International Development (USAID) uses a figure of 26.4 gallons (100 liters) a day per person as being required to maintain a reasonably good quality of life. In the United States, direct per capita daily water use is approximately four times higher, about 100 gallons (400 liters) per capita daily; and if agricultural and industrial water use is included, the amount per person per day is approximately 1,800 gallons (7,000 liters)—an enormous quantity of a limited and precious resource.

Although direct consumption by people in buildings is not a large fraction of total water use in the United States, water shortages in many areas of the country are having an impact on development and construction. Buildings account for about 12 percent of freshwater withdrawals. The building hydrologic cycle, characterized by the input of high-quality potable water and the release of used, contaminated water, is inefficient, wasteful, and illogical. In its more extended context, the building hydrologic cycle also includes the irrigation of landscaping and the handling of stormwater (see Chapter 6, "Sustainable Sites and Landscaping," relative to stormwater, which is generally included with the general theme of the building site). As pointed out in *Natural Capitalism* (1999), the invention of the water closet by Thomas Crapper was perhaps the start of an unfortunate trend in decision making with respect to building water use.[1] In order to dispense with the human waste generated in buildings, water closets mix high-quality potable water with disease-ridden feces and relatively clean urine for the purpose of diluting this mix. Consequently, enormous quantities of water are wasted and a potentially useful source of fertilizer is released into sanitary sewer systems to combine with industrial waste. The end result is a complex, chemically intense, energy-consuming, pollution-producing system of wastewater treatment plants. Major rethinking of the building hydrologic system is clearly needed to make better use of increasingly scarce and expensive potable water and to reduce the impact and cost of treating effluent from buildings.

Within the United States, water crises are occurring almost in every corner of the country, apparent in the moratoriums imposed on development and growth because of either a shortage in water supplies or insufficient wastewater treatment capacity. At present, there is active discussion of a growth moratorium in Las Vegas, currently the fastest-growing municipality in the United States. In the Diamond Valley, near Las Vegas, water levels dropped over 100 feet during the 1970s and 1980s and have never recovered.[2] In January 2004, in Emmitsburg, Maryland, the town commissioners passed an ordinance that invokes a growth moratorium for lots not already approved for development until the 800,000 gallons per day maximum design capacity of the city's wastewater treatment plant is not exceeded for 180 days.[3]

Current Building Fixtures and the Energy Policy Act of 1992

One of the landmark pieces of legislation concerning potable water consumption is the Energy Policy Act of 1992 (EPAct). EPAct requires all plumb-

12. An excellent source of information about natural landscaping is the nonprofit organization called Wild Ones: Native Plants, Natural Landscapes. Information and free downloads are available at its website, www.for-wild.org/.

REFERENCES

Ausubel, Kenny. 1997. *The Bioneers: A Declaration of Interdependence.* White River Junction, VT: Chelsea Green Publishing Company.

Campbell, Craig S., and Michael H. Ogden. 1999. *Constructed Wetlands in the Sustainable Landscape.* New York: John Wiley & Sons, Inc.

"Graywater Guide." 1995. Sacramento, CA: California Department of Water Resources, Publications Office; www.dwr.water.ca.gov.

Greening Federal Facilities: An Energy, Environmental and Economic Resource Guide for Federal Facility Managers and Designers, 2nd ed. May 2001. Washington, DC: Federal Energy Management Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, DOE/GO-102001-1165. Available at www.eere.energy.gov/femp/techassist/green_fed_facilities.html.

Hawken, Paul, Amory Lovins, and L. Hunter Lovins. 1999. *Natural Capitalism: Creating the Next Industrial Revolution.* Boston: Little, Brown and Company.

Kibert, Charles J., ed. 1999. *Reshaping the Built Environment: Ecology, Ethics, and Economics.* Washington, DC: Island Press.

Lorion, Renee. August 2001. "Constructed Wetlands: Passive Systems for Wastewater Treatment," a Technology Status Report for the U.S. Environmental Protection Agency's Technology Innovation Office. Available at www.epa.gov/swertio1/download/remed/constructed_wetlands.pdf.

Ludwig, Art. 1999. *Builder's Greywater Guide.* Santa Barbara, CA: Oasis Design; www.oasisdesign.net/.

Texas Guide to Rainwater Harvesting, 2nd ed. 1999. Austin: TX: Texas Water Development Board, in collaboration with the Center for Maximum Potential Building Systems. Available at www.twdb.state.tx.us/publications/reports/RainHarv.pdf or from the Texas Water Development Board.

Vickers, Amy. 2001. *Handbook of Water Use and Conservation.* Amherst, MA: WaterPlow Press. Book details available at www.waterplowpress.com.

CHAPTER NINE

Closing Materials Loops

The selection of building materials and products for a high-performance green building project is by far the most difficult and challenging task facing the project team. In *Green Building Materials: A Guide to Product Selection and Specification* (1999), one of the first books about the subject of green building materials, the authors, Ross Spiegel and Dru Meadows, defined green building materials as "those that use the Earth's resources in an environmentally responsible way."[1] At present, however, there is no clear consensus about the criteria for materials and products that would characterize them as *environmentally preferable, environmentally responsible,* or *green.* As a matter of fact, alternative terminologies are rapidly infiltrating the language of high-performance building green materials and products. For example, *environmentally preferable products* (EPP) is a commonly used label that can be found in U.S. government specifications for building materials and products. As a result, the question of what is or is not environmentally preferable has not been settled and is open to much controversy. For example, some organizations promote green products based on a narrow range of attributes they specify as being important for this purpose. The Forestry Stewardship Council, represented in the United States by the SmartWood Program and Scientific Certification Systems, Inc., defines green products as wood products derived from a sustainably managed forest. The Greenguard Environmental Institute relies on levels of chemical emissions that affect indoor environmental quality (IEQ) to describe what constitutes a green product.[2]

Clearly, it would be advantageous for green products to carry a certification, or ecolabel, to designate them as being preferable on the basis of consensus standards that address each type of building product. In Europe, several ecolabels cover at least some building materials. The Blue Angel ecolabel in Germany, the Nordic Swan ecolabel of the Nordic countries, and the European Union ecolabel all have programs for labeling some types of building products. For example, the Blue Angel Standard, RAL-UZ-38, addresses the requirements for certification of wood panels.[3] Unfortunately, the range of products covered by these labeling programs is very limited and consequently they provide only minimal assistance in identifying those that might be considered green. Thus, the project team must rely on their own best judgment as to which materials fit the criteria for environmental "friendliness."

On the positive side, there are several tools available to assist in this process, with the most familiar being life-cycle assessment (LCA). LCA provides information about the resources, emissions, and other impacts resulting from the life cycle of materials use, from extraction through disposal, and incorporates a high degree of rigor and science into the evaluation process. Two readily available LCA programs, ATHENA[4] and Building for Environment and Economic Sustainability (BEES),[5] apply to North American projects and can provide the project team with a decision system for materials selection that is based on science.

This chapter addresses the issues of green building materials and products, the criteria for defining environmentally friendly products, and the application of the LCA as a tool in decision making for materials selection. It also offers information about specific materials and product groups where new technologies and approaches are beginning to take hold in support of the green building movement.

Issues in Selecting Green Building Materials and Products

Determining the merits of building materials and products in terms of how they will affect the environment is the central unresolved problem of the green building movement. Even evaluating the relative worth of using recycled versus virgin materials—which should be a relatively simple matter—can result in controversy. One school of thought, here referred to as the *ecological school,* maintains that keeping materials in productive use, as in an ecological system, is of primary importance, and that the energy and other resources needed to feed the recycling system are a secondary matter. Nature, after all, does not use energy *efficiently,* but it does employ it *effectively;* that is, it matches the energy needed to the available energy sources. Another school of thought, here referred to as the *LCA school,* suggests that if the energy and the emissions due to energy production are higher for recycling than for the use of virgin materials, then virgin materials should be used. The LCA school also generally

FIGURE 9.1 *Partial demolition of the University of Florida Law School Library for a building expansion project. Truly green buildings of the future should be designed for deconstruction to maximize the reuse and recovery of building components and materials. (Photograph: Michele R. Moretti.)*

contends that too much attention is given to solid waste and that greater emphasis should be put on global warming as an issue.[6]

Nothing, in fact, is obvious when it comes to using renewable resources in construction. Consider wood from old-growth forests: although certainly a renewable resource, using it is generally frowned upon by environmental groups and the green building movement is in favor of protecting the biodiversity of these beautiful and increasingly rare natural assets. Rather, it is generally agreed, these resources should come from plantation forests and, even better, from rapidly renewable species. Even the USGC's LEED standard, which defines rapidly renewable resources as species with a growth and harvest cycle of 10 years or faster, must be called into question, because plantation forestry can require large quantities of water, fertilizer, pesticides, and herbicides to support the rapid growth cycle and protect the company's financial investment, not to mention that monoculture forestry runs counter to the notion of biodiversity. The definition of rapidly renewable as 10 years or faster is itself arbitrary, and any number of other definitions are equally applicable.

Besides determining which materials are environmentally preferable or green, the question must be raised about which products or materials will have low environmental impact. Many building products are selected to help reduce the overall environmental impact of the building, not for their low environmental impacts. Using an energy recovery ventilator (ERV), for example, a relatively complex device containing desiccants, insulation, wiring, an electric motor, controls, and other materials, contributes to an exceptionally low energy profile for the building, but cannot considered to be inherently green because its constituent materials cannot be readily recycled. In the present era, the challenge in designing a high-performance green building is how to select materials and products that lower the overall impact of the building, including its site. As time progresses, a hoped-for outcome is the development of more products that both contribute to low environmental impact and are inherently green—that is, can be disassembled into recyclable constituent materials.

Distinguishing Between Green Building Products and Green Building Materials

The terms used to refer to the materials and products used in high-performance building can be contradictory and confusing. *Green building products* generally refer to building components that have any of a wide range of attributes that make them preferable to the alternatives. For example, low-emissivity, or low-e, glass is a spectrally selective type of glass that allows visible light to pass through but rejects a substantial part of the heat-producing, infrared portion of the light spectrum. As a product, it is preferable to ordinary float glass in windows because of its energy performance. *Green building materials* refer to basic materials that may be the components of products or used in a stand-alone manner in a building. Green building materials would have low environmental impacts compared to the alternatives. As noted earlier, an example of a classic green building material is wood products certified by the Forestry Stewardship Council (FSC) as having been grown using sustainable forestry practices. Wood is a renewable resource, the forest is managed to produce wood at a replenishable rate, and the biodiversity of the local ecosystems is protected. In short, it meets all the criteria for a green building material as a raw input to the production process. However, the processing of the sustainably harvested wood may produce significant waste, require large quantities of energy and water, and may contribute to the degradation of the environment. Consequently, although the raw material may be ideal from an environmental point of view, the entire life cycle must be considered to fully assess the environmental performance of a product.

The point is, depending on how they are defined, green building products may not even be made of green building materials. For example, the glass in the low-e window may be difficult or impossible to recycle because of the films utilized to provide the spectral selectivity, which are glued to the glass. In contrast, ordinary float glass can be readily recycled; therefore, with respect to materials, it may be considered "greener" than the low-e product. This example is illustrative of the complexity of the product and materials selection process for high-performance buildings.

➤GREEN BUILDING MATERIALS

The basic materials of construction and construction products have changed over time from relatively simple, locally available, natural, minimally processed resources to a combination of synthetic and largely engineered products, especially for commercial and institutional buildings. Vernacular architecture—that is, design rooted in the building's location—evolved to take advantage of local resources such as wood, rock, and a few low-technology products made of metals and glass. Today's buildings are made of a far wider variety of materials, including polymers, composite materials, and metal alloys. A side effect of these evolving building practices and materials technology is that neither buildings nor the products that comprise them can be readily disassembled and recycled. There is some controversy over the relative merits of materials from natural resources versus those of synthetic materials made from a wide variety of materials, some which do not even exist in nature. Most ecologists would in fact agree that there is nothing fundamentally wrong with synthetic materials. For example, it could be argued that recyclable plastics can be more environmentally friendly than cotton, whose cultivation requires large quantities of energy, water, pesticides, herbicides, and fertilizer. Nonetheless, debate continues in the contemporary green building movement about the efficacy of synthetic materials versus materials derived from nature.

➤GREEN BUILDING PRODUCTS

A basic philosophical approach to selecting materials for building design is sorely lacking in today's green building movement. Consequently, there are many different schools of thought, many varied approaches, and abundant controversy. It is not obvious, for example, that building products made from postcommercial, postindustrial, or postagricultural waste are in fact "green." Many of the current green building products contain recycled content from these various sources.

To shed light on this topic, this section describes three philosophies or points of view about what constitutes a green building product: the Natural Step, the Cardinal Rules for a Closed-Loop Building Materials Strategy, and a pragmatic approach suggested by *Environmental Building News*.

✔*The Natural Step and Construction Materials*

One philosophical approach to designing the built environment is to use the well-known Natural Step, a tool developed to assess sustainability, as guidance for materials, product, and building design. The Natural Step, which is based on four scientifically based "System Conditions," was developed in the 1980s by Dr. Karl Henrik Robèrt, a Swedish oncologist. These conditions are as follows:[7]

1. *In order for a society to be sustainable, nature's functions and diversity are not systematically subjected to increasing concentrations of substances extracted from the Earth's crust.* In a sustainable society, human activities such as the burning of fossil fuels and the mining of metals and minerals will not occur at a rate that causes them to systematically increase in the ecosphere. There are thresholds beyond which living organisms and ecosystems are adversely affected by increases in substances from the Earth's crust. Problems may include an increase in greenhouse gases leading to global climate change, contamination of surface and groundwater, and metal toxicity, which can cause functional disturbances in animals. In practical terms, the first condition requires society to implement comprehensive metal and mineral recycling programs and decrease economic dependence on fossil fuels.
2. *In order for a society to be sustainable, nature's functions and diversity are not systematically subjected to increasing concentrations of substances produced by society.* In a sustainable society, humans will avoid generating systematic increases in persistent substances such as DDT, PCBs, and freon. Synthetic organic compounds such as DDT and PCBs can remain in the environment for many years, bioaccumulating in the tissue of organisms, causing profound deleterious effects on predators in the upper levels of the food chain. Freon, and other ozone-depleting compounds, may increase the risk of cancer due to added ultraviolet radiation in the troposphere. Society needs to find ways to reduce economic dependence on persistent human-made substances.
3. *In order for a society to be sustainable, nature's functions and diversity are not systematically impoverished by overharvesting or other forms of ecosystem manipulation.* In a sustainable society, humans will avoid taking more from the biosphere than can be replenished by natural systems. In addition, people will avoid systematically encroaching upon nature by destroying the habitat of other species. Biodiversity, which includes the great variety of animals and plants found in nature, provides the foundation for ecosystem services that are necessary to sustain life on this planet. Society's health and prosperity depend on the enduring capacity of nature to renew itself and rebuild waste into resources.
4. *In a sustainable society resources are used fairly and efficiently in order to meet basic human needs globally.* Meeting the fourth system condition is a way to avoid violating the first three system conditions for sustainability. Considering the human enterprise as a whole, we need to be efficient with regard to resource use and waste generation in order to

TABLE 9.1 Violation of Natural Step System Conditions in the Application of Construction Materials[8]

		System Condition			
Item	*Violation Examples*	*1*	*2*	*3*	*4*
Durables	Use of less abundant mined metals and minerals (copper, chromium, titanium)	X		X	
	Use of heavy metals (mercury, lead, cadmium)	X			
	Use of persistent, synthetic materials (PVC, HCFC, formaldehyde)		X		
	Wood from rainforests and old-growth timber that is harvested unsustainably			X	
Consumables	Use of petroleum-based products (solvents, oils, plastic film)	X	X	X	X
	Excessive packaging and other disposables		X	X	X
Solid Waste	Landfill disposal of construction and demolition waste, including toxic components such as lead and asbestos	X	X	X	X

be sustainable. If 1 billion people lack adequate nutrition while another billion have more than they need, there is a lack of fairness with regard to meeting basic human needs. Achieving greater fairness is essential for social stability and the cooperation needed for making large-scale changes within the framework laid out by the first three conditions. To achieve this fourth condition, humanity must strive to improve technical and organizational efficiency around the world, and to live using fewer resources, especially in affluent areas. System condition number four implies an improved means of addressing human population growth. If the total resource throughput of the global human population continues to increase, it will be increasingly difficult to meet basic human needs, as human-driven processes intended to fulfill human needs and wants are systematically degrading the collective capacity of the Earth's ecosystems to meet these demands.

Applying the System Conditions to new building construction, with a particular focus on building materials, produces a matrix as shown in Table 9.1. The matrix indicates the relationship between the System Conditions and the various major types of materials used or generated in construction: durables, consumables, and solid waste. It also shows which System Conditions are violated when contemporary practices are used.

In practical terms, applying the Natural Step to the employment of building materials would result in the following materials practices:[9]

1. All materials are nonpersistent and nontoxic and procured either from reused, recycled, renewable, or abundant (in nature) sources.
   a. Reused means reused or remanufactured in the same form, such as remilled lumber, in a sustainable way.
   b. Recycled means the product is 100 percent recycled and can be recycled again in a closed loop in a sustainable way.
   c. Renewable means able to regenerate in the same form at a rate greater than the rate of consumption.
   d. Abundant means human flows are small compared to natural flows, for example, aluminum, silica, iron, and so on.
   e. In addition, the extraction of renewable or abundant materials has been accomplished in a sustainable way, efficiently using renewable energy and protecting the productivity of nature and the diversity of species.
2. Design and use of materials in the building will meet the following in order of priority:
   a. Material selection and design favor deconstruction, reuse, and durability appropriate to the service life of the structure.
   b. Solid waste is eliminated by being as efficient as possible; or,
   c. Where waste does occur, reuses are found for it on-site; or,
   d. For what is left, reuses are found off-site.
   e. Any solid waste that can not be reused is recycled or composted.

On a systemwide—in this case planetary—scale, the Natural Step contends that, unless we are willing to severely compromise human health, we need to ultimately eliminate the extraction of ores and fossil fuels mined and extracted to produce energy and materials. Additionally it calls for the ultimate elimination of synthetic materials whose concentration in the biosphere is compromising not only human health, but the very health of the biosphere in which we reside. The Natural Step also cautions against the degradation of the biosphere by human activities because it is the very source of the resources needed to sustain life. And, finally, it addresses the social aspects of sustainability by noting that human needs in all parts of the world must be met. In sum, the message of the Natural Step is to reduce resource extraction, increase reuse and recycling, and minimize emissions that affect both ecosystems and human systems.

✔*Cardinal Rules for a Closed-Loop Building Materials Strategy*

A truly green building product should ideally be composed of several different materials that are also green. As pointed out earlier in this chapter, currently there are many green building products that are not themselves inherently green: for example, low-e windows, T-8 lighting fixtures, and energy recovery

ventilators, to name but a few. Although there are many arguments about what constitutes a green building product, perhaps the primary question relates to the ultimate fate of the product and its constituent materials. Presuming that ecology is the ideal model for human systems, and that in nature there is said to be no waste, it follows that the building materials cycle be closed and as waste-free as the laws of thermodynamics permit. A *closed-loop* building product and materials strategy must address several levels of materials use in its implementation: the building, the building products, and the materials used in building products and in construction. Ideally, the building materials system should follow the Cardinal Rules for an Ideal Closed-Loop Building Materials Strategy listed in Table 9.2.

The Cardinal Rules provide for the complete dismantling of the building and all of its components so that materials input at the front end of the building's construction can be recovered and returned to productive use at the end of the building's useful life. These rules also establish the ideal conditions for materials and products used in building. It is, however, important to point out that very few materials and products today can adhere to these five rules, meaning that the behavior of materials is far from its ideal state. As it stands, devising a system of materials, products, and buildings to support closed-loop behavior is in the distant future. Nonetheless, this thought process can be used as a touchstone for making decisions about the development of new products, materials, and technologies that support the high-performance green building movement.

➤PRAGMATIC VIEW OF GREEN BUILDING MATERIALS

In order to take a pragmatic view of green building materials, it is useful to examine contemporary efforts to wrestle more directly with these issues based on our current understanding, capabilities, and technologies. As noted several times in previous chapters, *Environmental Building News* is an excellent source

TABLE 9.2 Cardinal Rules for a Closed-Loop Building Materials Strategy

1. Buildings must be deconstructable.
2. Products must be disassemblable.
3. Materials must be recyclable.
4. Products/materials must be harmless in production and in use.
5. Materials dissipated from recycling must be harmless.

of well-reasoned approaches to most matters connected to high-performance buildings, and the subject of building materials and products is no exception. According to EBN, green building products can be broken down into five major categories:[10]

1. Products made from environmentally attractive materials:
   a. Salvaged products
   b. Products with postconsumer recycled content
   c. Products with postindustrial recycled content
   d. Certified wood products
   e. Rapidly renewable products
   f. Products made from agricultural waste material
   g. Minimally processed products
2. Products that are green because of what is not there:
   a. Products that reduce material use
   b. Alternatives to ozone-depleting substances
   c. Alternatives to products made from PVC and polycarbonate
   d. Alternatives to conventional preservative-treated wood
   e. Alternatives to other components considered hazardous
3. Products that reduce environmental impacts during construction, renovation, or demolition
   a. Products that reduce the impacts of new construction
   b. Products that reduce the impacts of renovation
   c. Products that reduce the impacts of demolition
4. Products that reduce the environmental impacts of building operation:
   a. Building products that reduce hearing and cooling loads
   b. Equipment that conserves energy
   c. Renewable energy and fuel cell equipment
   d. Fixtures and equipment that conserve water
   e. Products with exceptional durability or low maintenance requirements
   f. Products that prevent pollution or reduce waste
   g. Products that reduce or eliminate pesticide treatments
5. Products that contribute to a safe, healthy indoor environment:
   a. Products that do not release significant pollutants into the building
   b. Products that block the introduction, development, or spread of indoor contaminants
   c. Products that remove indoor pollutants
   d. Products that warn occupants of health hazards in the building
   e. Products that improve light quality

This pragmatic view of building materials and products is a useful starting point because it deals with the contemporary supply chain and with today's technologies and practices. The question then is: how do we evolve closer to the ideal of green building materials and products espoused by the Natural Step and the Cardinal Rules for a Closed-Loop Building Materials Strategy?

Priorities for Selecting Building Materials and Products

There are three priorities when it comes to selecting building materials for a project.

1. As with energy and water resources, the primary emphasis should be on reducing the quantity of materials needed for construction.
2. The second priority is to reuse materials and products from existing buildings; this is a relatively new strategy called *deconstruction*. Deconstruction is the whole or partial dismantling of existing buildings for the purpose or recovering components for reuse.
3. The third priority is to use products and materials with recycled content and that are themselves recyclable, or to use products and materials made from renewable resources.

➤TECHNICAL AND ORGANIC RECYCLING ROUTES

There are two general routes for recycling: technical and organic. The *technical recycling route* is associated with synthetic materials, that is, materials that do not exist in pure form in nature or are invented by humans. These include metals, plastics, concrete, and nonwood composites, to name a few. As noted earlier, only metals and plastics are fully recyclable, hence can potentially retain their engineering properties through numerous cycles of reprocessing. Materials in the technical or synthetic category require major investments of energy, materials, and chemicals for their recycling. Materials recyclable through the *organic recycling route* are described in the previous section under renewable resources. Composting is the best known organic recycling route. This route is designed to allow nature to recycle building materials and turn them back into nutrients for ecosystems. Although feasible in theory, it has not actually been attempted at large scale in the United States. For the organic route to work, it would have to incorporate products from a wide range of applications, to include agricultural waste, landscape clearing debris, as well as organic waste from construction.