CHAPTER 10 Principles of Sustainable Construction

CHAPTER OUTLINE

Before the beginning of the twentieth century, buildings contributed little to environmental degradation. Building construction was largely craft based, and most buildings were built by human labor or low-tech tools, occasionally using simple machines. The use of locally produced materials was the norm, and the amount of energy used in mining raw materials and converting them into finished products (referred to as *embodied energy*) was low.

In addition to low embodied energy, the energy used in a building's operation and maintenance (lighting, heating, cooling, water supply, and waste disposal) was low. Air conditioning had not yet been invented. The dominant source of interior illumination was daylight, and the levels of artificial lighting in buildings were modest.

To ensure that buildings were comfortable and healthy, architects spent a great deal of design effort in creating climate-responsive buildings through appropriate site planning, building orientation, fenestration design, and the use of appropriate landscape materials (see the introduction to Chapter 5).

Discovery of Mechanical Air Conditioning

Around the beginning of the twentieth century, several technical discoveries changed the way buildings were constructed and used. The most significant change was the invention of air conditioning (by Willis Carrier in 1902). This produced a ducted system of comfort conditioning using warm or chilled air. By the middle of the twentieth century, most new buildings in North America were fully air conditioned—a technology that spread not only to buildings throughout the world, but also to forms of transportation that carried people and perishable goods (trains, buses, automobiles, etc.). The result was a hefty increase in the world's energy use.

Passenger Elevators and Skyscrapers

Another major development was the elevator developed by Elisha Graves Otis, who publicly demonstrated its safety in 1854 in New York City. The elevator's safety and the subsequent improvements in its efficiency and speed provided the necessary stimuli for the construction of tall buildings. Initially, Chicago and New York City—and later other urban centers throughout the world—began constructing tall buildings, giving birth to an entirely new building form, the skyscraper.

The amount of energy required for the construction of a square foot of a skyscraper is far greater than that required for the construction of a low-rise building. This is due not only to the use of heavy construction equipment (excavators, bulldozers, graders, loaders, cranes, etc.) required for the construction of a skyscraper, but also to the disproportionately large amount of materials needed in its structural frame.

In addition to a large amount of embodied energy, tall buildings consume large amounts of energy for operation and maintenance. On the other hand, because tall buildings yield denser urban habitations, they can reduce the amount of energy required for urban infrastructure—roads, water supply, sewage, and waste-disposal facilities.

The twentieth century also witnessed several major sociopolitical changes that led to further escalation in the world's energy use. The independence of several Asian and African countries and their industrialization led to the expansion of international trade and travel and increased building and infrastructural construction. The population explosion resulting from medical breakthroughs that drastically reduced infant mortality and increased adult life spans was another major reason for the increased use of energy.

Use of Earth's Resources by Buildings

The escalation of energy use continued unabated until the oil embargo of 1973. This event made the world suddenly realize its excessive dependence on energy and the pace at which the earth's finite energy resources were being depleted. An even more significant realization was how the world's excessive use of energy was irreparably damaging the environment and endangering people's health.

For example, the thinning of the ozone layer in the earth's atmosphere due to the use of ozone-depleting chemicals was well established during the latter part of the twentieth century. Global warming, caused by the emission of carbon dioxide and other gases, was no longer a theoretical prediction but a reality that could be proved by irrefutable measurements.

By this time (around the 1970s), the world was beginning to be aware that we were abusing the planet's resources and that unless something was done soon, the damage to our ecosystem could be irreversible. We also realized that energy is only one of the several resources needed for our survival, and, for humankind to have a reasonable future, all resources, such as land (including landfills), water, air, and other materials, must be conserved and protected against depletion, pollution, and degradation.

This realization led to the concept of pursuing an *ecologically benign,* or e*nvironmentally friendly,* existence. The term *sustainable development* eventually stuck because it included the dimension of time. Another commonly used term is *green development,* which emphasizes its association with the environment.

NOTE

Embodied Energy

Embodied Energy in a Building

The embodied energy in a building is the amount of energy consumed by all the processes involved in the production of a building—from the acquisition of raw materials to the delivery and placement of the final product in the building. It includes the energy used in mining, manufacturing, transportation, construction, and administrative functions.

Embodied Energy in a Product

The embodied energy in a material or product is the amount of energy used in its production, including the administrative functions related to its production. It does not include the energy used in the product's transportation to the construction site and its installation in the building.

EXPAND YOUR KNOWLEDGE

Ozone Depletion

The ozone layer lies in the earth's atmosphere—between 10 and 20 mi (18 and 35 km) from the earth's surface. It is in this atmospheric region that the ultraviolet (UV) component of solar radiation converts atmospheric oxygen to ozone. (An oxygen molecule consists of two atoms of oxygen, i.e., O_2, and an ozone molecule consists of three atoms of oxygen, i.e., O_3.)

The other components of solar radiation convert the ozone molecule back to an oxygen molecule, so there is a perpetual cycle of conversion from oxygen to ozone and back to oxygen. If the cycle is not disrupted, a constant thickness of the ozone layer is maintained in the atmosphere at all times. The ozone layer prevents the harmful UV-B rays from reaching the earth by absorbing them. In humans, UV-B rays cause skin cancer and eye cataracts and weaken the immune system.

Substances such as chlorine react aggressively with ozone and disrupt the ozone-oxygen cycle, decreasing the thickness of the ozone layer. Several modern-day chemicals contain chlorine, such as methyl chloroform (used in cleaning solvents, adhesives, and aerosols), carbon tetrachloride (used in dry cleaning), and chlorofluorocarbons (CFCs), used as freon in refrigeration equipment.

Since the 1970s, scientists had warned that the ozone layer was being depleted, but it was not until 1987 that measurements revealed an unexpectedly large ozone-depleted hole over the Antarctic. In response to the revelation, new production of ozone-depleting substances was banned under the 1987 international agreement referred to as the *Montreal Protocol*. Despite this agreement (and provided that all countries seriously adhere to it), the chemicals that are already in use will eventually find their way into the atmosphere, causing further damage.

The first serious worldwide discourse on sustainable development is generally traced to the (1987) United Nations publication entitled the *Brundtland Report* [10.1], named after Gro Brundtland, prime minister of Norway, who chaired the UN World Commission on Environment and Development. The gist of the report is best described by the following excerpt:

> *. . . the challenge faced by all is to achieve sustainable world economy where the needs of all the world's people are met without compromising the ability of the future generations to meet their needs.*

Since the publication of the Brundtland Report, sustainability has become an all-encompassing discipline because truly sustainable development must include all facets of human activity—agriculture, manufacturing, transportation, buildings, and infrastructure.

This chapter begins with a discussion of the fundamentals of sustainability as applied to building design and construction. Subsequently, it deals with the issues of sustainability as applied to materials and construction.

It must be noted that although sustainable materials and construction practices have been growing, they are still in the early stages and are likely to go through extensive evolution as we learn from experience. It is expected that sustainability issues will become mainstream and will be given the same importance in buildings as structural safety, fire protection, and energy conservation. A step in this direction has already been taken in the United States through the draft formulation of the first sustainable building design code by the International Code Council in November 2010, known as the *International Green Construction Code* (IGCC).

NOTE

Resource Consumption by Buildings

Among the five major sectors of the U.S. economy (agriculture, transportation, manufacturing, infrastructure, and buildings), the building sector consumes a large share of the earth's resources,* as buildings:

- Use 36% of total energy
- Use 30% of raw materials
- Use 12% of potable water
- Produce 30% of total waste
- Emit 30% of greenhouse gases

See also the box entitled "Some Interesting Energy Use Data" in Section 5.11.

**Source:* Gregory Kats, et al. "The Costs and Benefits of Green Buildings," A Report to California's Sustainable Building Task Force, October 2003.

10.1 FUNDAMENTALS OF SUSTAINABLE BUILDINGS

As noted earlier, sustainable building design and construction is not a new concept. It is an idea that reemerged in the 1970s and gathered momentum after the 1973 oil embargo. At that time, the focus was limited to energy conservation and the use of alternative energy sources in buildings. As awareness grew that the problem was larger than one of just energy use, a wide range of related environmental issues were also incorporated in the thinking. The work of the architects and designers who propagated this thought came to be known by the more inclusive term *sustainable design*.

More specifically, sustainable design recognizes that buildings are major consumers of resources and continually generate waste and pollution. The processes used for manufacturing materials and the construction of buildings also use resources and produce waste and pollution.

The land used under the buildings and related infrastructure (roads, bridges, water supply, sewage-treatment plants, etc.) disrupts the ecosystems. Several interior materials,

EXPAND YOUR KNOWLEDGE

Greenhouse Gases (GHG) and Global Warming

The earth's atmosphere contains a number of gases—nitrogen (approximately 79%), oxygen (approximately 20%), carbon dioxide (approximately 0.04%), and several others in small amounts. Some of the atmospheric gases, particularly carbon dioxide, are responsible for producing the greenhouse effect on the earth. This allows the sun's radiation to pass through the atmosphere but traps the earth's long-wave radiation. The effect is similar to that produced by glass in a greenhouse (see the box entitled "Some Important Facts About Radiation" in Chapter 30).

In addition to carbon dioxide, there are several other gases, such as methane, nitrous oxide, and water vapor, that are responsible for the greenhouse effect. They are collectively referred to as the *greenhouse gases* (GHG). The greenhouse effect is useful because, in its absence, the earth would have been much colder, making life more difficult in several regions.

However, due to the rapidly increasing use of fossil fuels, the amount of carbon dioxide released in the atmosphere has increased substantially. Additionally, the use of nitrogen-based fertilizers for farming has increased the release of nitrous oxide. Consequently, the greenhouse effect has become more pronounced in the past century and has raised the average temperature of the earth.

Scientists believe that if the present trend continues, the earth's temperature could rise further, melting most of the polar ice and causing sea levels to rise so that low-lying countries, such as the Netherlands and Bangladesh, could be submerged. Cities such as New York, London, and Bangkok may also be at risk. Perhaps the most frightening part of global warming is the chain reaction that could ensue, upsetting ecosystems and causing increased flooding, severe droughts, heat waves, and so on.

However, despite two major United Nations Framework Conventions (the 1997 Kyoto Convention and the 2009 Copenhagen Convention), there is little agreement among major industrialized nations on curbing GHG emissions because of serious disagreement between the developing and developed worlds. While the developed world believes that emission curbs must be shared by all countries, the developing world believes that, being the major emitters and the original creators of the problem, the developed world must currently carry most of the burden.

finishes, and furnishings emit unhealthy gaseous products, causing harm to humans. The goals of sustainable architecture, therefore, are as follows:

Integrated Site Design: Promote development of the built environment that minimizes its impact on the natural systems and processes of the site or restores and improves sites that have been poisoned or altered greatly over time. Strategies include minimizing site disruption, increasing development density, minimizing the buildings' footprints, using pedestrian-friendly neighborhoods, developing links to public transportation, using landscaping that conserves water and reduces the heat island effect; and so on.

Water Conservation: Use water-conservation strategies that reduce storm water runoff and introduce water-harvesting techniques to increase local aquifer recharge; reduce or limit the use of potable water for landscaping; use low-flow plumbing fixtures, water-efficient appliances and heating, ventilation, and air-conditioning (HVAC) equipment; and so on.

Energy Conservation and Atmosphere Protection: Minimize energy use through energy-efficient HVAC, lighting, and other equipment; increase the use of renewable energy sources; reduce atmospheric ozone depletion, and so on.

Resource Efficiency: Reuse existing buildings; design long-lasting buildings that can be adapted for changing uses over time; reduce construction waste and implement construction waste management; increase the use of durable and reusable materials; use materials with greater recycled content; use locally or regionally produced products; and so on.

Indoor Environment: Maintain good indoor air quality; increase ventilation effectiveness; reduce the emissions of volatile organic compounds (VOCs) and other contaminants by interior materials; increase the use of daylighting of interiors; and so on.

Experts [10.2] claim that although a sustainable building generally has a higher initial cost, the financial payback through energy savings and lower waste-disposal and water-consumption costs is rapid. Additionally, there are several financial payback features that cannot be easily quantified: lower employee health costs and greater productivity due to the building's healthier indoor environment (cleaner air, increased amount of daylight, and greater tenant control of temperature and lighting).

10.2 ASSESSING THE SUSTAINABILITY OF BUILDINGS

Without standards to guide the design and construction for sustainability, it is difficult for a designer to make decisions that successfully address the numerous diverse and interrelated sustainability issues encountered in a project. For that reason, several organizations have worked for years to develop objective, practical, and fair systems to evaluate the sustainability of buildings of various types.

One organization that has become a key player in the United States is the U.S. Green Building Council (USGBC). It was formed in 1993 by a diverse group of individuals representing various interest groups, such as building owners, architects, engineers, constructors, environmentalists, building material manufacturers, utility companies, financial and insurance experts, and local, state, and federal governments.

The USGBC has devised a system to rate the sustainability of a building's design and construction. The rating system is voluntary, is based on consensus, and provides a third-party, independent measure of a building's sustainability. It is called the *Leadership in Energy and Environmental Design* (*LEED*®) *Green Building* rating system. Starting in 1998 as a pilot version (LEED 1.0), the rating system has gone through a number of updates and refinements (LEED 2.0, LEED 2.1, and LEED 2.2). The current version, introduced in 2009, is LEED 3.0, also called LEED v3.

NOTE

Major Differences Between the LEED v3 Rating System and Its Prior Version

- The total number of points has been raised to 100 in LEED v3 from 69 in the previous version (64 in five topical categories and 5 for innovation and design). The topical categories, across which 100 points are distributed, remain unchanged at five.
- According to the USGBC, the point redistribution across categories in LEED v3 is based on a more rigorous scientific foundation than in its previous version.
- The relative weights of three categories have been increased: Energy and Atmosphere—from 27% to 35%; Sustainable Sites—from 22% to 26%; and Water Efficiency—from 8% to 10%. The relative weights of Indoor Environmental Quality and of Materials and Resources have been reduced.
- A new nontopical Bonus Points category has been introduced in LEED v3 with a total of 10 points. The Innovation and Design category that existed as a separate category in the previous version has been moved to the Bonus Points category, which also includes Regionalization—a new concept that did not exist in the previous version.
- Although the green building certification levels—Certified, Silver, Gold, and Platinum—remain the same, the minimum number of points required to achieve these levels has been rationalized to 40%, 50%, 60%, and 80%, respectively. The larger point gap between the Gold and Platinum levels emphasizes the higher bar set for Platinum-rated buildings.
- A more predictable development cycle is proposed to be introduced by USGBC for future changes in the LEED rating system.

Because different building types pose different challenges, there are several variations in the rating system, which include

- LEED for new construction and major renovations (LEED-NC)—a comprehensive rating for the entire building, most commonly sought.
- LEED for existing buildings: operations and maintenance (LEED-EB)—applies to existing buildings to improve their impact on the environment by selecting sustainable equipment.
- LEED for commercial interiors (LEED-CI)—applies to tenant improvement of facilities.
- LEED for core and shell (LEED-CS)—applies to new buildings in which none or little interior work is done by the owner.
- LEED for schools (LEED-S)—a comprehensive rating system like LEED (NC) but recognizes the special sustainability requirements of schools (kindergarten to 12th grade).
- LEED for healthcare (LEED-HC)—a comprehensive rating system that recognizes the special sustainability requirements for health-care facilities.
- LEED for homes (LLED-H)—a comprehensive rating system for homes.
- LEED for neighborhood development (LEED-ND)—sustainable urban and city planning.

The LEED rating systems are based on the performance of a building (or a neighborhood) under the following five topical categories, as shown here and in Figure 10.1. The maximum possible point score in each category is

- Sustainable Sites (SS)—26 points
- Water Efficiency (WE)—10 points
- Energy and Atmosphere (EA)—35 points
- Materials and Resources (MR)—14 points
- Indoor Environmental Quality (EQ)—15 points

A building can score points in all five categories, with the total number of points in all categories adding up to a maximum of 100. The measure of a building's sustainability is determined by the sum of all points it scores, and the total score determines the *LEED certification level*, as shown in Figure 10.1. A building with a total score of 39 points or less is not considered a *green* building per the LEED rating system.

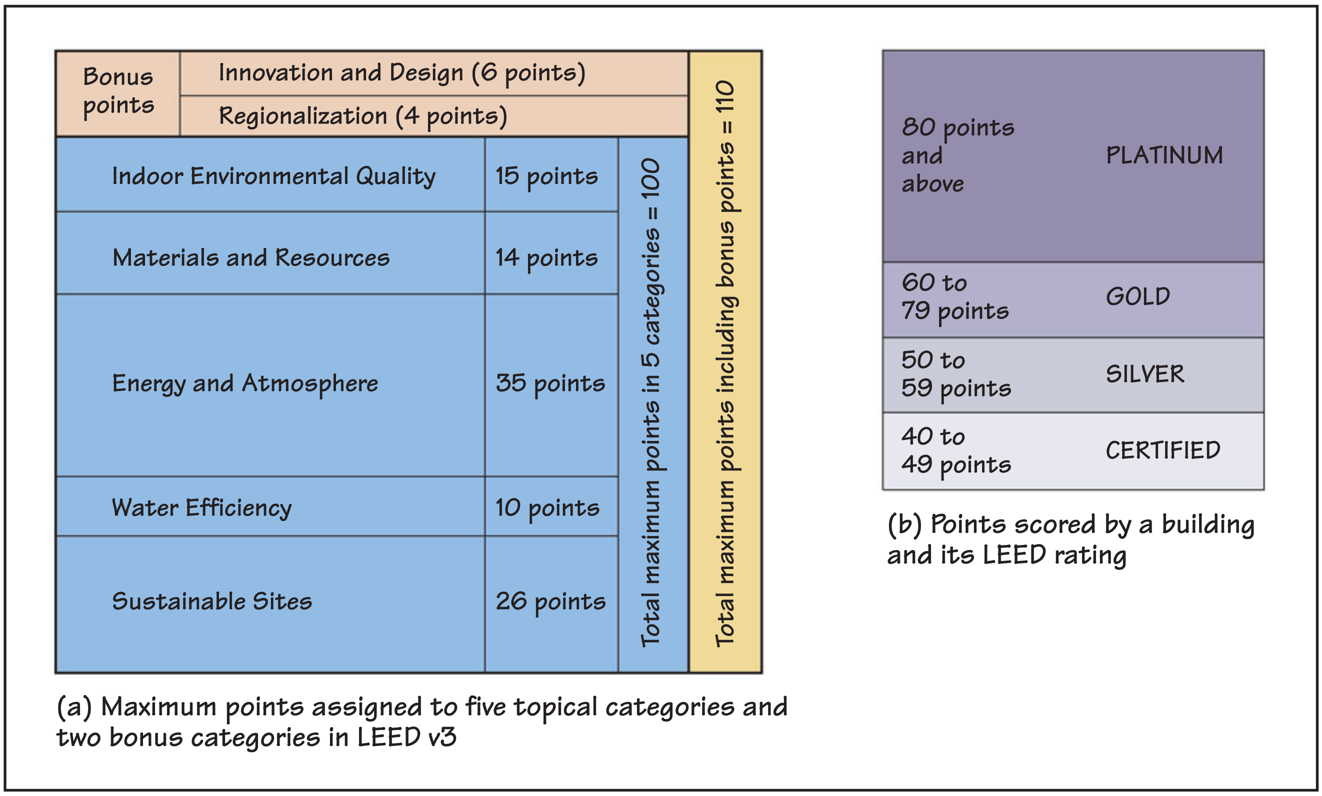


FIGURE 10.1 **(a)** Relative importance of five topical and two bonus categories in the LEED v3 rating system. **(b)** Point scores required by a building for four LEED ratings: Certified, Silver, Gold, and Platinum.

In addition to the 100 points distributed across five topical categories, the LEED v3 rating system provides the opportunity to earn 10 bonus points (6 points for innovation and design and 4 points for regionalization—consideration of the special environmental requirements of a region). The 10 points are over and above the regular 100 points to help a project achieve certification through design innovation and consideration of the specific regional environment. Thus, the maximum possible number of points a project may score is 110. For example, a building that scores 54 points (out of 100) from the five topical categories and 6 bonus points (out of 10) will earn a total score of 60 points, changing its LEED rating from Silver to Gold.

Each topical category is further subdivided into several subcategories, which delineate the requirements of that subcategory and the number of points that can be earned by meeting the stated requirements. Additionally, each category has a few prerequisites that must be met before any points can be assigned in that category.

For example, a prerequisite in the Sustainable Sites (SS) category is that the construction of the building must include measures for *construction activity pollution prevention*. This requires controlling soil erosion, waterway sedimentation, and airborne dust generation during construction. Similarly, in the Energy and Atmosphere (EA) category, one of the prerequisites is the *commissioning of the building energy systems* by an independent commissioning authority. The commissioning authority appointed to satisfy the prerequisite in the EA category may also be used as the overall commissioning authority for the project.

Overall Commissioning Authority

To ensure that the building's performance after completion is as intended and designed (with respect to energy use, envelope design, water use, waste management, indoor air quality, etc.), the LEED rating system recommends that the building be commissioned. *Commissioning* is a systematic evaluation to verify that the basic building components and systems have been installed and calibrated to function as intended.

Engaging an independent *commissioning authority* (also called a *commissioning agent*) helps the owner obtain an objective evaluation of the design and construction team's work. Engaging a commissioning authority early in the project-delivery process (preferably during the design phase) ensures that the postcompletion verification strategies used by the authority are clear to the design and construction teams.

PRACTICE QUIZ

Each question has only one correct answer. Select the choice that best answers the question.

1. The embodied energy in a building is a measure of the energy consumed
   - **a.** to extract raw materials from the earth and manufacture a finished building product.
   - **b.** in the administrative functions related to raw material extraction and product manufacturing.
   - **c.** to transport the finished product to the building site and install it in the building.
   - **d.** all of the above.
   - **e.** (a) and (b).
2. The increased use of a few modern-day chemicals has increased the thickness of the ozone layer.
   - **a.** True
   - **b.** False
3. Global warming has been caused mainly by the
   - **a.** thickening of the ozone layer in the atmosphere.
   - **b.** increase in the emission of greenhouse gases.
   - **c.** decrease in the cloud cover over the earth.
   - **d.** deforestation of the earth's surface.
   - **e.** all of the above.
4. One of the major U.S. organizations that deals with sustainable architectural design is the
   - **a.** USEBC.
   - **b.** USFBC.
   - **c.** USGBC.
   - **d.** USHBC.
   - **e.** none of the above.
5. The total number of topical categories in the LEED-NC rating system is
   - **a.** 10.
   - **b.** 8.
   - **c.** 5.
   - **d.** 4.
   - **e.** 2.
6. Per the LEED-NC rating system, a building may receive recognition as a green building at the following levels:
   - **a.** Platinum, Gold, Silver, and Bronze
   - **b.** Gold, Silver, Bronze, and Certified
   - **c.** Gold, Silver, and Bronze
   - **d.** Gold, Silver, and Merit
   - **e.** Platinum, Gold, Silver, and Certified
7. A building that receives a total score of 55 points in the LEED–NC rating system will be recognized at the
   - **a.** Sustainable level.
   - **b.** Certified level.
   - **c.** Silver level.
   - **d.** Gold level.
   - **e.** Green level.

10.3 CHARACTERISTICS OF SUSTAINABLE BUILDING PRODUCTS

Because building materials constitute a large part of the environmental burden created by a building, the use of green building materials and products is one of several constituents that make a building sustainable. Extracting materials from the earth and processing them into a finished product require energy and water resources and produce waste, some of which may be hazardous.

Some products give off toxic gases after installation. Others require cleaning with chemicals that may do likewise. Postconsumer disposal of products consumes landfills, some of which may pollute groundwater.

Materials whose overall environmental burden is low are referred to as *green materials*. The relative greenness of a material is based on the same basic determinants as for the building as a whole. More specifically, the greenness of a product is a function of the following factors:

- Renewability
- Recovery and reusability
- Recyclability and recycled content
- Biodegradability
- Resource (energy and water) consumption
- Impact on occupants' health
- Durability and life-cycle assessment of product

NOTE

Current Laws on Emissions and Manufacturing

Several federal and state laws currently control toxic emissions from products during and after manufacturing. Laws also exist to control, regulate, and monitor the entire raw-material use, manufacturing, and use cycle of products. The goals of sustainability, however, aim for even higher standards.

RENEWABILITY

The *law of conservation of matter* states that all matter on the earth and within its atmosphere can neither be destroyed nor created. In other words, whatever existed on the earth at the dawn of time will always exist. Its physical or biological state may, however, change, either through natural or human-made processes. The basic elements of which a material is composed continue to exist forever on the earth or in its atmosphere. For example, when iron corrodes, it becomes iron oxide. The amounts of iron and oxygen on the earth remain unchanged in this transformation.

The transformation of matter (contained within both physical and biological realms) from one state to the other and in various combinations is cyclical. In other words, matter cycles back and forth within physical realms and also from the physical to biological realms.

For example, there is a constant amount of water on the earth, held within the oceans, in the atmosphere, and in other terrestrial entities—both living and nonliving. The processes of evaporation, condensation, consumption, and disposal of water simply move it from one state to another and from one realm to another. There may be drought in one region and excessive rainfall in another region, but the total quantity of water on the earth and in its atmosphere remains constant.

Thus, all materials are theoretically renewable. However, some materials renew over a short-duration cycle, whereas the cycles of others are long, and for some materials the cycle may extend over millions of years. Materials that have a short renewal cycle and require limited processing input to convert them to a usable form are referred to as *renewable materials*. Conversely, materials that have long renewal cycles and require large processing input are called *nonrenewable materials*. A renewable material is greener than a nonrenewable material.

The renewal cycle of forests is brief—usually 25 to 50 years. To transform trees into wood products requires a small amount of additional resources. Wood is, therefore, a renewable material. Perhaps one of the most renewable building materials is adobe. We can dig earth from the ground, shape it into adobe bricks, and construct buildings with them with a negligible amount of processing. When an adobe building is no longer needed, it can be demolished, and its material can be reprocessed for use in a different building with zero renewability duration. Alternatively, the material may be returned to the earth in almost the same state in which it was first obtained.

Metals, stone, glass, and plastics are examples of nonrenewable materials because they take much longer to renew and require excessive processing resources to convert them into usable states. Take the example of steel again. If left unprotected, it rusts. Rust is essentially

FOCUS ON SUSTAINABILITY

Reduce, Reuse, and Recycle—Three Tenets of Sustainability

Reduce, reuse, and recycle are considered to be the three most important tenets of sustainable construction. These tenets are listed in order of their importance. The first tenet (reduce), in fact, far outweighs the other two in importance.

Although a great deal of stress is currently being placed on reusability and recyclability, the same level of concern is lacking for appropriate sizing of buildings, automobiles, and other items of human consumption. Regardless of how successful we are with reusability and recyclability, sustainability will not be achieved without seriously addressing the *reduction* tenet.

A worrying statistic about buildings is the gradual increase in the average size of new homes built in the United States during the past three decades. In 1970, a typical new house was 1,500 ft^2. In 2005, the corresponding size was 2,300 ft^2—an increase of approximately 50% [10.3]. At the same time, the average family size has become smaller.

NOTE

Difference Between Renewal and Recycling

The difference between the renewal and recycling of a material is subtle. *Renewal* refers to the process of recycling that occurs in nature. *Recycling* is a deliberate process.

the same as iron ore but in a highly diluted form. To obtain iron from the rust—which, by mingling with the other constituents of the earth's surface, becomes further diluted in iron concentration (i.e., becomes a low-grade iron ore)—requires enormous processing energy and produces enormous waste and pollution. Natural geological processes can provide iron ore with a high iron concentration, but these processes would take millions of years.

RECOVERY AND REUSABILITY

An effective way of greening a building is by using materials that have been recovered from the demolition of existing buildings. This reduces raw-material extraction and also reduces the burden on landfills. Obviously, salvaged materials must be obtained from nearby sources (to reduce transportation) and must be of usable quality, and their remaining life spans must meet the requirements of their reuse. The economics of recovery and reuse are more favorable with durable materials, such as bricks, natural stone, steel, and aluminum, than with materials with short life spans.

It is expected that as the use of salvaged materials becomes an accepted part of architectural practice, demolition recovery will become a more important commercial enterprise. The role of manufacturers in this area cannot be overemphasized. As the manufacturing industry moves further toward sustainability and assumes responsibility for the entire life cycle of the materials it produces, salvage and reuse could become part of the manufacturers' responsibilities.

In this scenario, the manufacturer retains ownership of the product, which is transferred to the consumer for only a certain period. At the end of that period, the buyback of the product by its manufacturer is mandated, and it is to be refurbished, remanufactured, or recycled as needed. The ultimate disposal of the product in a landfill also remains the manufacturer's responsibility. This should make product manufacturing and its use in buildings approach a closed-loop system, Figure 10.2.

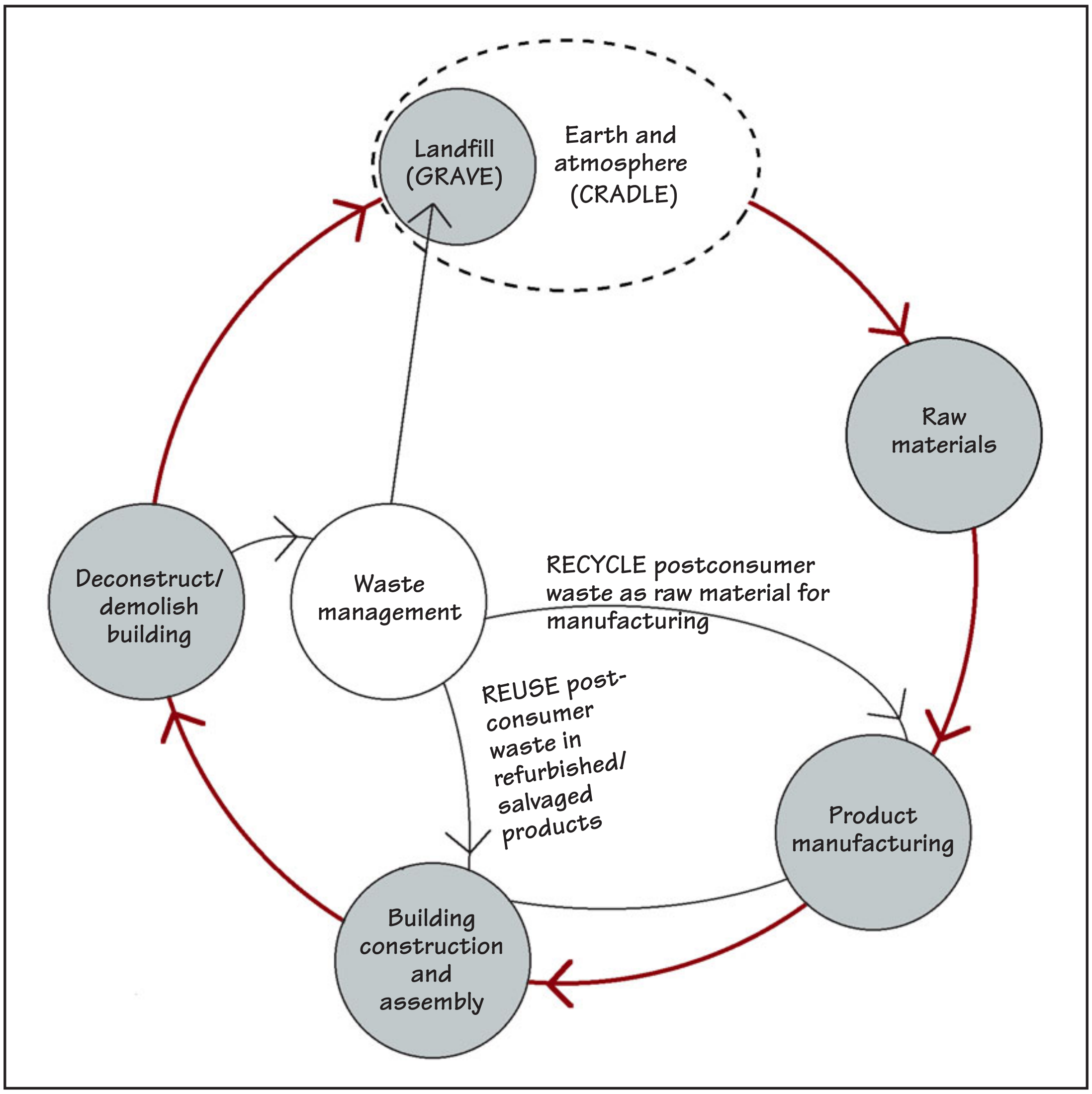


FIGURE 10.2 A closed-loop (cradle-to-cradle) building product life cycle. Note that in an ideal closed-loop life cycle, any waste sent to a landfill should be biodegradable so that it becomes food for living creatures, and all emissions into the atmosphere should be benign.

As environmental legislation makes waste management and disposal more costly, manufacturers will be increasingly forced to make their products greener. Removing hazardous contents, if any, before disposal and ensuring rapid degradability of materials (e.g., computers, furniture, or carpets) in landfills will be the manufacturers' responsibility.

An obvious extension of demolition recovery is the concept of *building deconstruction*, which implies that when a building has served its useful life, it is not demolished but deconstructed into its components. The deconstructed components can be refurbished if necessary and sold for use in another building.

Conceptually, deconstruction is the reverse of construction. Only those components of a deconstructed building that cannot be reused are disposed of as waste.

Recyclability and Recycled Content

The greater the amount of recycled content in a material, the greener it is. Recycling is generally classified into two types: *internal recycling* and *external recycling*.

Internal recycling is the reuse of materials that are by-products or waste products from manufacturing. The brick- and glass-manufacturing industries and several others have used internal recycling for a long time. Broken or defective bricks or glass are reused as raw materials in the manufacturing process. Ready-mix concrete manufacturing plants recycle wastewater reclaimed from washing concrete mixers after they return for recharge and delivery.

External recycling, on the other hand, is reclaiming a material for use in the manufacturing process of the same or a different product after it has become obsolete or unnecessary in its present application. This is referred to as *postconsumer waste recycling*.

For example, concrete obtained from a demolished building can be crushed and used as a drainage layer under a new concrete slab-on-grade in place of crushed stone. In some cases, crushed old concrete may be used as coarse aggregate in new concrete. Similarly, reinforcing or structural steel recovered from a demolished building can be melted and processed as new steel.

The amount of recycled content in a material depends on the economics of procuring post consumer waste. Recycling of aluminum (beverage) cans became successful early in recycling history because of the large amount of resource input (particularly energy) required to manufacture new aluminum from its ore, as compared with procuring recycled cans and converting them into a new or identical product.

Other products with significant recycled content are steel, carpets, gypsum board, rubber, plastics, and fiberglass insulation. Increasingly larger number of products are being manufactured with recycled materials, and their recycled content is also increasing. Consequently, recycling has become a major and diverse industry that employs a large number of skilled and unskilled workers.

The number of highly skilled scientists and engineers in the recycling industry is quite large because manufacturing with recycled materials is technically as complex as (if not more complex than) manufacturing from virgin materials. For example, one of the major recycling problems in the glass industry has been to remove color from used glass—a problem that has engaged the brains of several top glass scientists.

TABLE 10.1 EMBODIED ENERGY IN SELECTED MATERIALS

Material	Embodied energy MJ/kg	Embodied energy MJ/m^3
Adobe	0.42	819
Bricks	2.5	5,170
Concrete block	0.94	2,350
Concrete (4,000 psi)	1.3	3,180
Stone	0.79	2,030
Lumber	2.5	1,380
Plywood	10.4	5,720
Particle board	8.0	4,400
Aluminum (virgin)	227	515,700
Aluminum (recycled)	8.1	21,870
Steel (virgin)	32.0	251,200
Steel (recycled)	8.9	37,200
Copper (virgin)	70.6	631,164
Glass (float)	15.9	37,550
Gypsum board	6.1	5,890
Fiberglass insulation	30.3	970
Extruded polystyrene	117	3,770
Cellulose insulation	3.3	112

Biodegradability

Everything else being identical, biodegradable materials, such as adobe, wood, and paper, are greener than nonbiodegradable materials such as metals and plastics. Thus, building product packaging, if required, consisting of paper-based products should, therefore, be preferred.

Ideally, all waste sent to landfills should be biodegradable and nontoxic so that it becomes food for plants and other living creatures. Some ecologists have coined the axiom *waste must equal food*. Waste that cannot be converted to a biodegradable material should be recycled over and over again.

Resource Consumption

Two resources that are critical in product manufacturing are energy and water. Both are, therefore, determinants of a material's greenness. As stated previously, the amount of energy used in manufacturing a material is called its *embodied energy*. Embodied energy is generally measured in megajoules per kilogram (MJ/kg) or MJ/m^3.

Table 10.1 gives approximate values of the embodied energy in selected building materials [10.4]. Because all materials are not equal in terms of their use and properties, embodied energy cannot be used directly in comparing the energy efficiency of one material with that of another. However, it is a good measure for comparing the energy efficiency of similar products—those that belong to the same application group. For example, embodied energy may be used in comparing plywood with oriented strandboard, one carpet with another carpet, or one type of gypsum board with another.

Regardless of the materials' embodied energy, the use of locally produced materials reduces the building's embodied energy by reducing transportation energy use. It also improves the local economy.

Data for total water used in manufacturing a product, similar to embodied energy data, are not generally available.

Impact on Occupants' Health

The relative greenness of a material is also a function of its impact on human health. A number of modern building materials, particularly adhesives used in wood products and floor finishes (carpets, linoleum, and vinyl and rubber floorings), paints, sealers, and sealants, emit volatile organic compounds, which are harmful to humans beyond a certain level of concentration. These emissions adversely impact indoor air quality (IAQ) and, hence, the health of building occupants and are regulated by the U.S. Environmental Protection Agency (EPA).

Poorly ventilated spaces with high moisture contents and the use of fibrous materials may support the growth of mold when the materials become wet. Mold has been known to cause human health problems.

In addition to the impact of materials on building occupants, their impact on the earth and its biosphere must be accounted for, because some materials will either leach toxic materials during their use or degrade into hazardous substances in landfills.

Durability and Life-Cycle Assessment (LCA) of a Product

A product's durability is closely related to its sustainability. A material with high embodied energy but a long service life may be more sustainable than one with low embodied energy but a short service life. Additionally, a material may not emit hazardous compounds when installed in the building, but the chemicals required for its manufacture or periodic maintenance may do so. Therefore, the overall ecoburden of a product should be determined based on its expected service life. In other words, a life-cycle assessment (LCA) of a product's greenness is more important than its initial greenness.

The LCA of a product evaluates the environmental impact of the product over its entire life cycle, including the product's production, transportation, use, reuse, and its final disposal. Environmental impact measures include global warming, ozone depletion, production of pollutants and toxic waste, resource consumption, land use, and so on.

10.4 ASSESSING THE SUSTAINABILITY OF BUILDING PRODUCTS AND ASSEMBLIES

The growing public acceptance of and demand for sustainable building design and construction has brought building material and product manufacturers under increasing pressure to develop green products. Manufacturers that do not respond to this demand know that they are at risk of marginalization.

The public demand for green products has been accompanied by two important developments: (a) the issuance by the FTC of the "Guides for the Use of Environmental Claims" (16 CFR Part) and (b) the development of metrics to assess the sustainability (greenness) of products. The objective of the FTC's guidelines is only to ensure that the green claims made by manufacturers avoid consumer deception by refraining from overstatement and the use of language that may lead to unintended implications.

There are two types of metrics (objective methods of measuring performance) to assess the greenness of building products and assemblies:

1. Metrics based on a single attribute or a few selected environmental attributes
2. Metrics based on a comprehensive, life-cycle assessment (LCA) of all important environmental attributes

It is important to note that the use of green products (and sustainable construction in general) is largely voluntary at the present time. The situation is rapidly evolving, however, as more and more U.S. states and cities introduce sustainability requirements for new

NOTE

Environmental Marketing Claim Guides for Products

As the green building movement became popular with owners, designers, and constructors, almost every product manufacturer began to claim its product as green (greenwashing). In an attempt to protect consumers against deceptive marketing practices, the U.S. Federal Trade Commission (FTC) issued "Guides for the Use of Environmental Marketing Claims" in 1992, popularly known as the "Green Guides." It was revised in 1998. Another major revision has been completed, is out for public comment (as of early 2011), and is expected to be finalized for conformance by the industry.

The "Green Guides" provides comprehensive guidance to manufacturers on how to formulate their green marketing claims, including labels, logos, emblems, and promotional materials in graphical, text, digital, and electronic formats, and so on, in a manner that has an acceptable, unambiguous, transparent and independent, third-party substantiation. It does not deal with or establish any specifications or measurement standards for the greenness of products. The "Guides" applies to the product, its components, and its packaging.

construction. It is also important to note that any acceptable sustainability metric must be transparent, independent, and substantiated by third-party evaluation that is based on a recognized evaluation standard. (Even a third-party evaluation must be transparent, resulting from the use of a recognized standard.)

Subjective claims of greenness are unacceptable because almost every product has some green virtues. For example, manufacturers of products made from metals (steel, aluminum, copper, etc.) claim that their products are green because metals can be fully recycled. Manufacturers of wood-based products claim greenness because wood is rapidly renewable and is a biodegradable material. Masonry product manufacturers promote their products for reasons of reuse, recyclability and zero VOC emissions, and so on.

10.5 ASSESSING PRODUCT SUSTAINABILITY BASED ON A SINGLE ATTRIBUTE OR A LIMITED SET OF ATTRIBUTES

It may appear at first that sustainability metrics based on a single attribute or a limited number of environmental attributes have little use because they are not comprehensive. This is not true provided that the metric is significantly relevant to the product's performance. For example, the most important environmental attribute of paints and adhesives is VOC emissions. Emission ratings of these products, therefore, provide valuable information for facility executives, who may use these ratings along with several other factors (such as color, cost, etc.) in making their selection. Similarly, ratings of windows and glass curtain walls based on thermal performance (i.e., their impact on energy consumption) are useful metrics because energy conservation is arguably the single most important sustainability attribute.

An additional advantage of single- or limited-attribute metrics is that they can be provided in the form of labels or marks (the Energy Star label, the Green Seal label, etc.), which are easy to comprehend and, therefore, better disposed to adoption. Table 10.2 provides an overview of some of the commonly used metrics for assessing the greenness of building products based on single or limited environmental attributes.

Energy Star Label

The Energy Star label was introduced by the U.S. Environmental Protection Agency (EPA) in 1992 to recognize energy-efficient computers. The program's success led to its extension to other product areas and its acceptance by several other countries. Thus, Energy Star is now an international energy-labeling system that rates and labels

- appliances (refrigerators, air conditioners, washing machines, and so on)
- products (light bulbs and fixtures, office products, building products, and so on)
- homes
- commercial and industrial buildings

TABLE 10.2 COMMONLY USED METRICS FOR ASSESSMENT OF SUSTAINABILITY OF BUILDING PRODUCTS BASED ON A SINGLE ATTRIBUTE OR A LIMITED SET OF ENVIRONMENTAL ATTRIBUTES

Rating label or certificate	Rating organization and its headquarters	Attributes considered in rating	Building products rated
Energy Star label	U.S. Environmental Protection Agency (EPA) Washington, D.C.	Energy efficiency	Doors, windows, and skylights; appliances, HVAC equipment, lighting, exit signs, etc.
Green Seal certification mark	Green Seal Washington, D.C.	Several product-specific attributes	Paints, coatings, adhesives, windows, and doors
Greenguard certificate	Greenguard Environmental Institute (GEI) Marietta, Georgia	Indoor air quality	Adhesives, paints, and wallpapers
Green Label and Green Label Plus	Carpet and Rug Institute (CRI) Dalton, Georgia	Indoor air quality	Carpets, rugs, and cushions
Certified Wood under Forest Stewardship Council (FSC) rules	SmartWood Richmond, Vermont Scientific Certification Systems (SCS) Emeryville, California	(a) Sustainability of forests from which wood is derived (b) Chain-of-custody certification of wood-based products	Wood used in any product

Among the building products, only those used in the building envelope are Energy Star rated, such as windows, skylights, and exterior doors; insulation, radiant barriers, and air sealing products; and roofing products. Because different climate zones in the country have different energy efficiency requirements, the Energy Star label on a door, window, or skylight shows the climate zone(s) for which the label is appropriate. An Energy Star–labeled door, window, or skylight certifies that its performance either equals or exceeds the requirements of the International Energy Conservation Code (see Chapter 5).

A comprehensive Energy Star label is available for homes and commercial/industrial buildings. The label for new homes requires the energy analysis of the proposed home through the Home Energy Rating System (HERS)—a software package developed by the Residential Energy Services Network (RESNET). The analysis is performed by RESNET-approved raters based on the proposed home's construction drawings. The analysis yields a HERS index that determines if the proposed home meets the requirements of the Energy Star label and, if not, what improvements are needed.

The analysis is followed by inspections during construction and tests of air leakage after completion, called *blower tests*. Two blower tests are performed; one test determines the air leakage in the building envelope, and the other test determines the leakage in the HVAC duct system.

Homes built to the minimum requirements of the International Energy Conservation Code (IECC) receive a HERS rating of 100. A HERS index greater than 100 indicates that the home does not meet the code requirements. Many older homes built prior to IECC's adoption belong in this category. A HERS index of less than 100 indicates that the proposed home is more energy efficient than the minimum code requirements. Each 1-point decrease in the HERS index implies 1% greater energy efficiency. Thus, a HERS index of 90 means that the proposed home is 10% more efficient than the minimum code-required home. To receive an Energy Star label, a proposed home must have a HERS index of at least 85 in climate zones 1 to 5 and an index of 80 in climate zones 6 to 8, Figure 10.3.

Green Seal Label

The Green Seal organization has developed fairly stringent standards for measuring the greenness of several building products (such as paints, coatings, doors, and windows) based on a number of environmental attributes that are particularly relevant to the products. However, it is best known for its seals on residential and commercial cleaning products (hand cleaners, carpet cleaners, floor cleaners, and so on).

Greenguard Certificate

Greenguard certification focuses primarily on indoor air quality to certify products such as paints, adhesives, sealants, and interior furnishings and is provided by the Greenguard Environmental Institute (GEI), which is particularly well known for certifying building construction that meets standards for mold prevention.

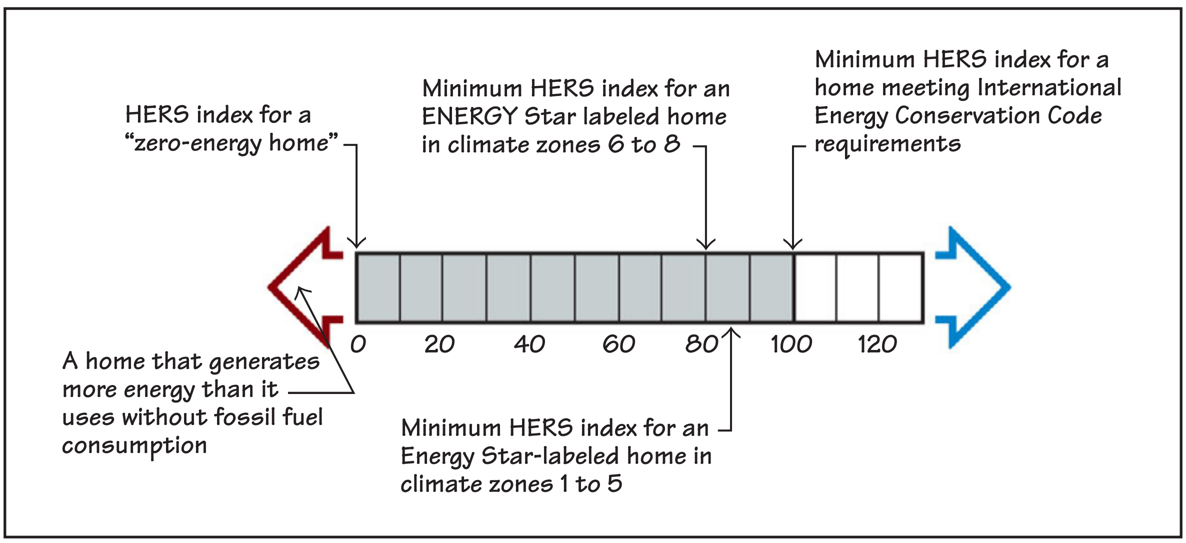


FIGURE 10.3 HERS index and Energy Star label requirements for homes.

Green Label and Green Label Plus

Green Label is the mark assigned by the Carpet and Rug Institute (CRI) to carpets, rugs, and cushion materials that have low VOC emissions. Green Label Plus is a more stringent mark than Green Label.

Certified Wood Label

The Certified Wood label is carried by wood products that have been produced by manufacturers according to the guidelines promulgated by the Forest Stewardship Council (FSC). The FSC guidelines prescribe responsible management practices for forest growth and harvesting that meet the social, economic, and environmental needs of the present and future generations. The FSC maintains a number of independent certifiers around the world.

The two major FSC-accredited certifiers in the United States are SmartWood and Scientific Certification Systems. (See Chapters 13 and 14 for additional details.) Note that FSC's Certified Wood label refers only to the environmental management aspects of forests. It does not include other sustainability concerns, such as embodied energy or emissions of VOCs by engineered wood products.

An additional certificate for wood or products that have some wood content is the chain-of-custody certificate. It is an inventory-control system that traces a wood product from its origin to the consumer to provide quality assurance.* *Chain of custody*, a term borrowed from criminology, refers to the entire chain of processes through which wood originating from a certified forest is transformed through various processes into a finished product, including its distribution and sale. The product may be an all-wood or a composite wood product.

Sustainability Verification of Products by the International Code Council

The sustainability evaluation of building products by the International Code Council, called the Sustainable Attributes Verification and Evaluation (SAVE) program, is limited to evaluating a product for the following attributes: recycled content, bio-based content, regional manufacturing, certified wood content, solar reflectance and emissivity of roofing products, and VOC emissions from paints and adhesives.

PRACTICE QUIZ

Each question has only one correct answer. Select the choice that best answers the question.

8. Which of the following building materials is most renewable?
a. Steel **b.** Aluminum
c. Natural stone **d.** Wood

9. The embodied energy of a product is a good index for comparing the energy efficiency of
a. one material with another material regardless of the type of material.
b. similar materials—materials that belong to the same group.

10. Weight for weight, which of the following materials has the highest embodied energy when made from virgin raw materials?
a. Steel **b.** Aluminum
c. Natural stone **d.** Lumber

11. The durability and sustainability of a material are related to each other.
a. True **b.** False

12. The Certified Wood label considers all aspects of sustainability of wood.
a. True **b.** False

13. The life-cycle assessment (LCA) of a product refers to its cost over its entire service life.
a. True **b.** False

14. The Energy Star labeling program applies to
a. appliances.
b. products, such as windows and doors.
c. buildings.
d. all of the above.
e. only (a) and (b).

15. Green Label and Green Label Plus programs apply to
a. appliances.
b. products, such as windows and doors.
c. homes.
d. all of the above.
e. none of the above.

16. The HERS index is used in rating for the
a. Green Seal label. **b.** Certified Wood label.
c. Green Seal Plus label. **d.** Energy Star label.
e. none of the above.

*Chain-of-custody certification: A wood product manufacturer generally manufactures certified as well as regular (noncertified) products. The same applies to a distributor, who may store certified as well as noncertified wood products. Therefore, a chain-of-custody certificate implies that a Certified Wood product is what it has been certified for and that it has not been mixed with noncertified products during manufacturing distribution, or sales.

10.6 ASSESSING THE SUSTAINABILITY OF BUILDING PRODUCTS AND ASSEMBLIES BASED ON A COMPREHENSIVE SET OF ATTRIBUTES

Unlike labels or certificates based on single- or limited-attribute metrics, a comprehensive assessment of sustainability is obtained only by evaluating the greenness of a product over its entire life—life-cycle assessment (LCA). This complex assessment is feasible only through computer-based analysis. The two more commonly used software programs for this purpose are

- Building for Environmental and Economic Sustainability (BEES) software—developed by the U.S. National Institute of Standards and Technology (NIST) to determine the greenness of building products
- EcoCalculator for Assemblies—developed by the Athena Institute (Ontario, Canada) to determine the greenness of building assemblies

BUILDING FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY (BEES) SOFTWARE FOR BUILDING PRODUCTS

BEES is a Windows-based program that determines the LCA of building products along with their life-cycle cost (LCC). The two features, environmental performance (through LCA) and economic performance (through LCC), have been combined because while LCA should be an important consideration in product selection, it is generally not the sole criterion in practice and has to be balanced with the cost of the product.

The software is, however, flexible and allows the determination of LCA and LCC independent of each other or in any user-defined combination by assigning different weights to LCA and LCC. For example, LCA and LCC can be given equal weights (i.e., 50% each), or 60% LCA and 40% LCC, and so on. The weights can also be set at 100% for LCA and 0% for LCC, or vice versa, to obtain individual values of LCA and LCC. Thus, the software generates an LCA score, an LCC score, and an overall score of the product, Figure 10.4.

The overall environmental burden of a product over its entire life cycle (cradle-to-gate, that is, beginning with raw materials to processing to the finished product as delivered at the gate of the manufacturing facility) is accounted for by considering 12 parameters, referred to as *environmental impact categories* in the LCA part of BEES. These categories are shown in Figure 10.5, along with the relative weights of each category considered in BEES. For example, global warming has a weighting of 29%, human health, 13%, and so on.

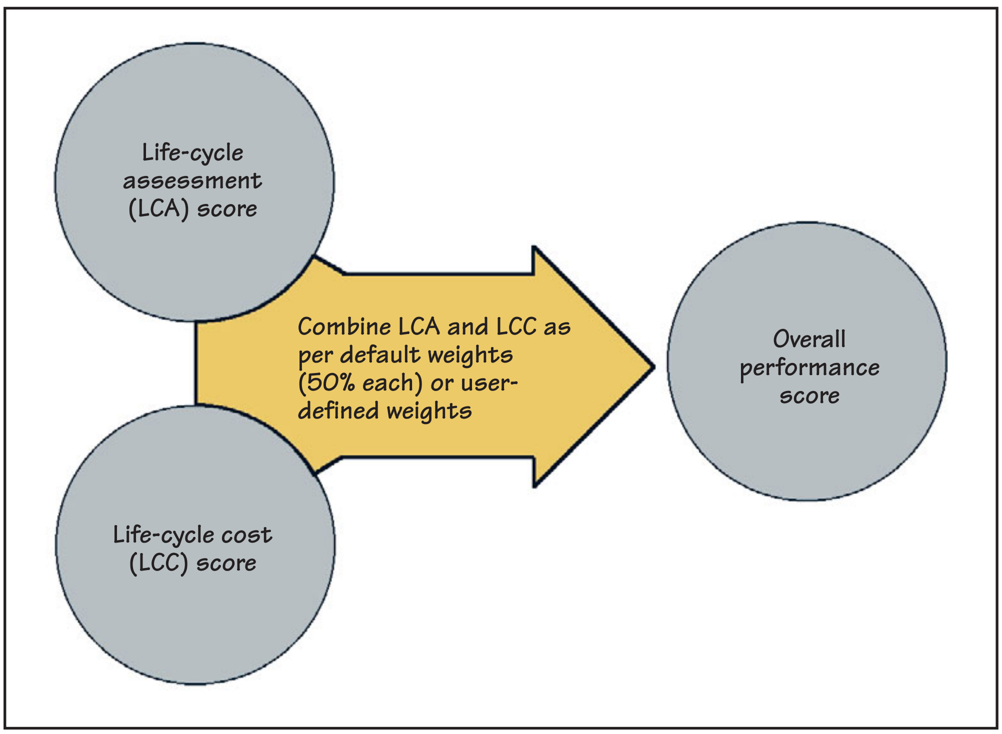


FIGURE 10.4 The output from BEES software for a product consists of an LCA value and an LCC value, and a combination of the two values provides the overall performance of the product.

NOTE

More About BEES

BEES 4.0, the current BEES software, is a fourth-generation product that includes environmental and economic performance data on 230 building materials and products. The software is downloadable free from the Web, including the accompanying manual. The LCA part of BEES is based on the International Standards Organization (ISO) Standard 14040-06, "Environmental Management—Life Cycle Assessment—Principles and Framework," and the LCC is based on ASTM Standard E917-05, "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems."

The LCC provided by BEES includes the initial cost of the product plus any future costs needed for its maintenance and replacement. The future costs are converted to the present value so that the total LCC of the product is given in present-value terms. Because the future costs are generally higher than the present cost due to inflation, they must be discounted to obtain their present value. The discount rate, which is related to the inflation rate, is set at 3% in BEES, but it can be changed to any desired value by the user to reflect an estimate of the future inflation rate.

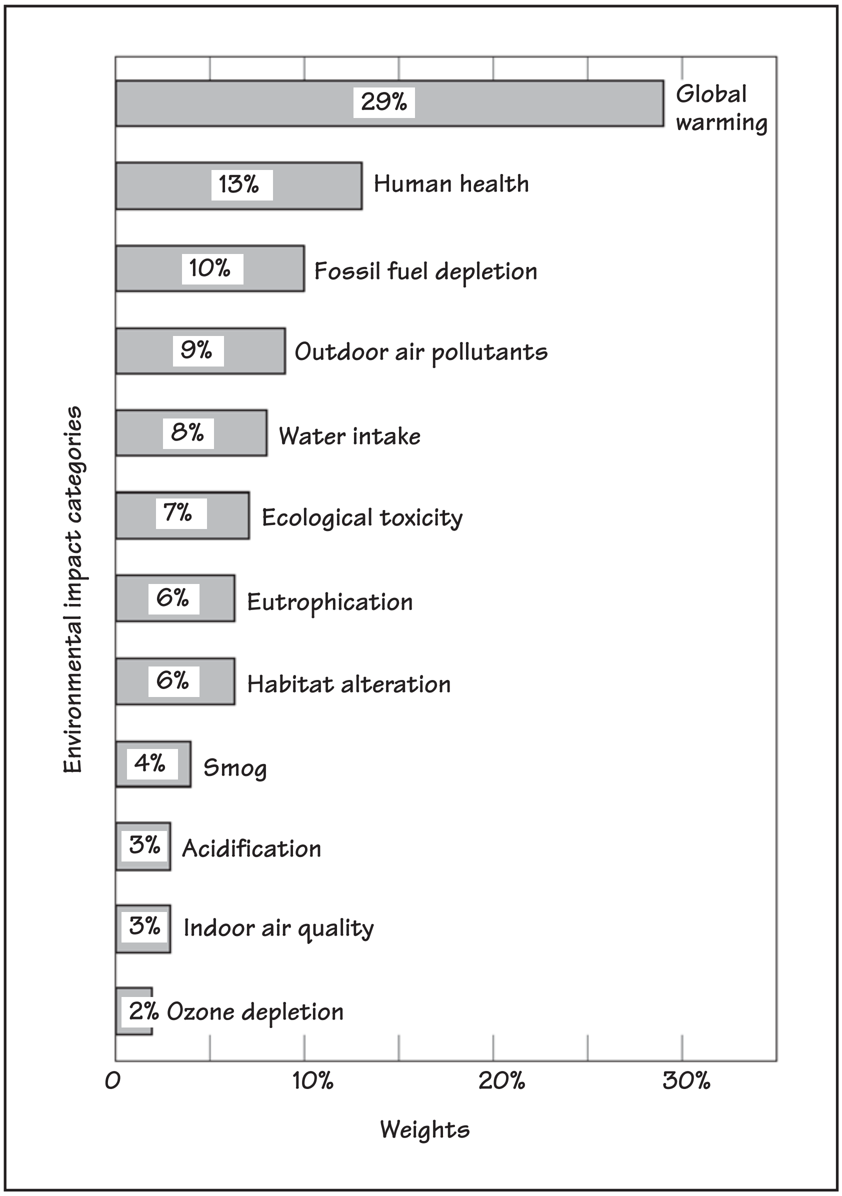


FIGURE 10.5 Environmental impact categories with their relative (default) weights used in BEES. The software allows the user to redistribute weights across categories so long as the aggregate weight equals 100.

These weights, based on both science and value judgments, are default weights used in BEES, developed by a panel of experts assembled by U.S. National Institute of Standards and Technology (NIST), called the BEES Stakeholder Panel. However, the software user can customize the relative weights. This flexibility allows the program to accommodate new environmental knowledge as it becomes available and to account for regionalization. For instance, for a water-logged region, the software user may delete the water intake category and distribute its weight (8%) over other categories.

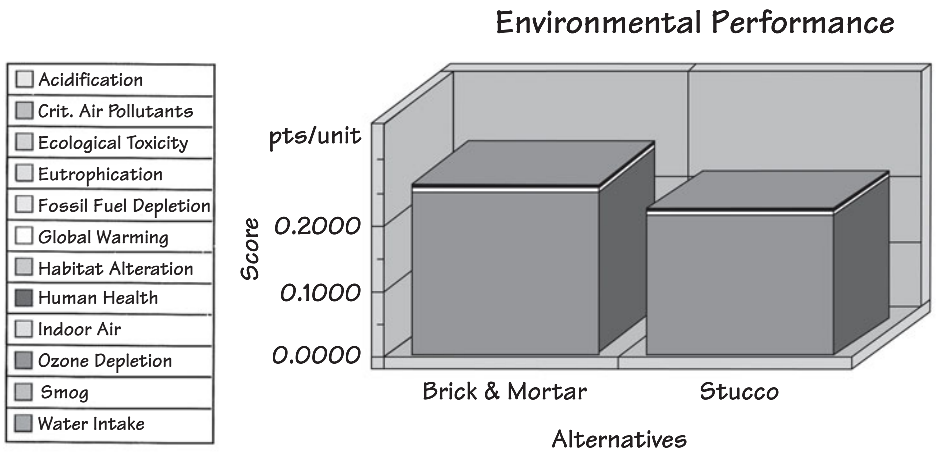
To compare the performance of one product with that of another, two factors have been standardized in BEES across products. One is the time period over which LCA and LCC are computed. In BEES, this is a constant of 50 years for all products. The other factor is the "functional unit" for measuring the amount of product. The functional units have been standardized for each product category. For floor finishes, the functional unit is 1 ft^2 of floor surface; for concrete beams, columns, and slabs, the unit is 1 yd^3; for roof coverings, exterior coatings, and sealers, the unit is 100 ft^2; and so on.

The final output from the software is graphic as well as tabular. Figures 10.6 to 10.8 show examples of typical outputs generated by BEES. Note that because BEES computes the impact on various environmental parameters, the lower the LCA score, the better it is. The same applies to LCC, that is, a lower LCC score is a better score. This similarity between LCA and LCC provides an easy way of combining the scores.

NOTE

Eutrophication, Acidification, and Habitat Alteration

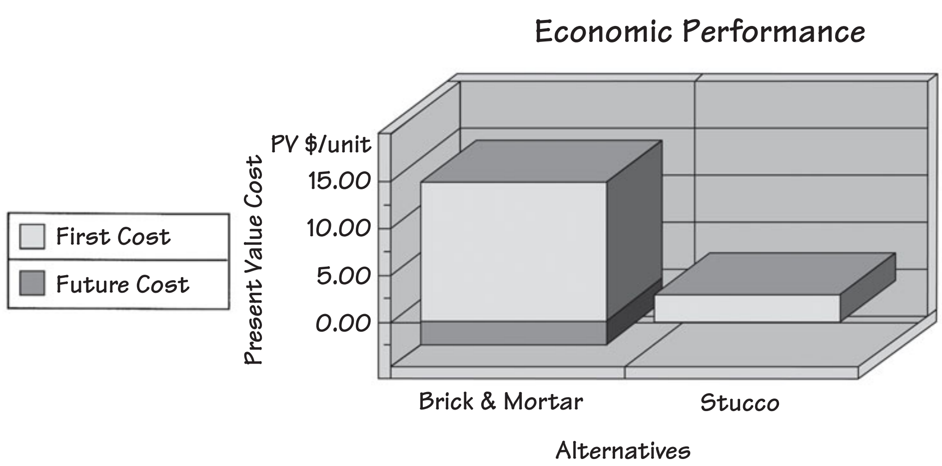
Eutrophication refers to the addition of mineral nutrients to the soil or water, such as nitrogen and phosphorus, which, in large quantities, reduce ecological diversity by increasing algae growth that leads to the lack of oxygen, killing species such as fish. *Acidification* refers to compounds released in air in a gaseous state or as solid particles, which, when dissolved in water, produce acids (referred to as *acid rain*) that adversely affect soil, buildings, trees, and other living creatures. *Habitat alteration* refers to the use of land by humans that may adversely impact threatened and endangered species.



Note: Lower values are better

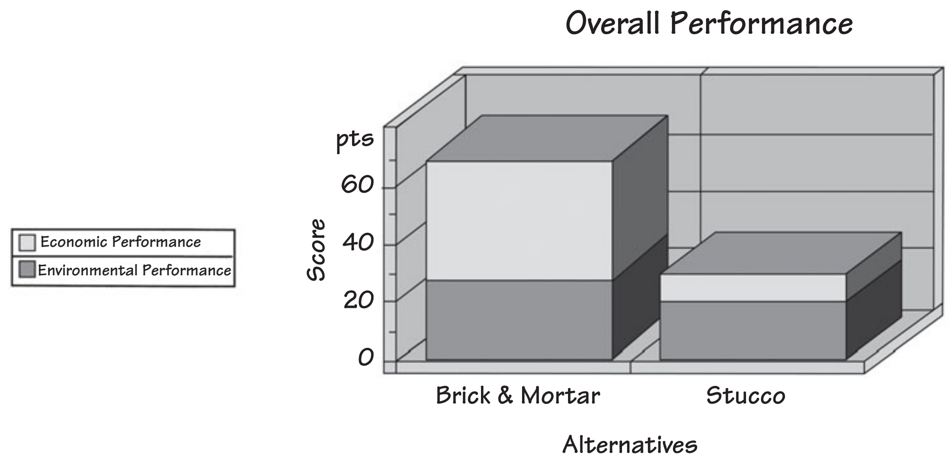
Human Health—13%	0.2479	0.2036
Indoor Air—3%	0.0000	0.0000
Ozone Depletion—2%	0.0000	0.0000
Smog—4%	0.0007	0.0008
Water Intake—8%	0.0001	0.0000
Sum	0.2603	0.2175

FIGURE 10.6 Typical output from BEES software that compares the environmental performance in terms of the LCA of two materials (in this case, two commonly used exterior wall finishes—brick veneer and stucco).



Category	Brick	Stucco
First Cost	13.30	2.56
Future Cost—3.0%	-2.28	0.03
Sum	11.02	2.59

FIGURE 10.7 Typical output from BEES software that compares the economic performance in terms of the LCC of two materials (in this case, two commonly used exterior wall finishes—brick veneer and stucco).



Category	Brick	Stucco
Economic Perform.—50%	40.5	9.5
Environ. Perform.—50%	27.2	22.8
Sum	67.7	32.3

FIGURE 10.8 Typical output from BEES software that compares the overall performance as a combination of the LCA and LCC of two materials (in this case, two commonly used exterior wall finishes—brick veneer and stucco). In this output, LCA and LCC have equal weights (50% each).

NOTE

Limitations of BEES

The versatility of BEES is dependent on the size of its database. At the present time, the database includes mostly generic products. The environmental impact data of these products are based on the average of similar products manufactured by various manufacturers. Thus, the software does not provide the performance differences between products from competing manufacturers. However, the database is being constantly expanded, and data on proprietary products are being added. As the software gains greater acceptance from design and construction professionals, its database is expected to grow.

Athena EcoCalculator for Assemblies

EcoCalculator is Mac- and Windows-compatible software (developed on the Microsoft Excel platform) that is downloadable free of charge from the Web site of the Athena Institute. It determines the LCA of building assemblies, which are classified in the following six categories:

1. Exterior walls
2. Interior walls
3. Roofs
4. Windows
5. Intermediate floors
6. Columns and beams

The LCA of assemblies is based on a number of environmental impact categories similar to those used in BEES but using a different database. The software has been customized for several different U.S. and Canadian cities (e.g., Atlanta and Pittsburgh in the United States and Toronto and Calgary in Canada). It has also been customized for building height—low-rise (up to four stories) and high-rise (five or more stories). Therefore, a software version that is specific to the city and building height is available. Because EcoCalculator has not yet been customized for all major U.S. cities, two regional versions of the software, representing average conditions (one for the southern United States and the other for the northern United States) are also available.

Unlike BEES, which computes the LCA of building products (such as floor coverings), EcoCalculator computes the LCA of building assemblies (e.g., concrete masonry backup wall with brick veneer cladding). Another difference between BEES and EcoCalculator is that the latter does not compute the product's economic performance.

To arrive at the LCA value, EcoCalculator contains a number of assumptions (glazing-to-opaque-wall ratio of 40%, floor-to-floor height of 10 ft, and so on), which allows the software to standardize assemblies for comparison and assessment purposes. EcoCalculator is related to the parent software from the Athena Institute, called the Impact Estimator, which computes the LCA of (entire) buildings.

Each question has only one correct answer. Select the choice that best answers the question.

17. Which of the following environmental impact categories has the highest weight in the default weights set in BEES software?
a. Human health **b.** Fossil fuel depletion
c. Outdoor pollutants **d.** Global warming
e. Ozone depletion

18. Which of the following environmental impact categories has the lowest weight in the default weights set in BEES software?
a. Human health **b.** Fossil fuel depletion
c. Outdoor pollutants **d.** Global warming
e. Ozone depletion

19. In comparing various products based on their LCA scores, the product with the lowest score is the worst.
a. True **b.** False

20. The time period used in BEES for determining the LCC of a product is
a. 25 years. **b.** 50 years.
c. 75 years. **d.** 100 years.
e. none of the above.

21. The life-cycle cost (LCC) of a product obtained from BEES is its
a. equivalent future cost. **b.** equivalent present cost.

22. EcoCalculator for assemblies has been developed by the
a. National Institute of Standards and Technology (NIST).
b. American Society of Testing and Materials (ASTM).
c. International Code Council (ICC).
d. International Standards Organization.
e. none of the above.

23. EcoCalculator for assemblies uses the same database as BEES.
a. True **b.** False

REVIEW QUESTIONS

1. In the LEED v3 rating system, list the categories that are used to measure the sustainability of buildings.
2. Explain the role of commissioning in the LEED rating system for new construction.
3. List various factors that determine the sustainability of a building product.
4. Using a sketch and notes, explain an ideal closed-loop product life cycle.
5. Explain which materials are considered renewable and which are considered nonrenewable and why.
6. Using a sketch and notes, explain the HERS index and Energy Star label requirements for homes.
7. Describe the important features of BEES and its current limitations.