**Chapter Twelve**

# Sustainable Architecture Concepts and Principles

The last three decades of the $20^{th}$ Century have seen the emergence of a relatively new set of building design criteria that are based on ecological concerns. These are driven by a genuine fear that mankind has been recklessly ignoring repeated signs that the delicate balance in nature among plants, animals, and the physical environment is in danger of disruption with serious consequences. Contributing factors that are rapidly gaining widespread recognition include: an increasing world population (approaching seven billion in 2009); a fairly sudden change from inexpensive to much more expensive energy; an increasing realization that environmental pollution and lifestyle will have an impact on health and longevity; the detection of a gradual but steady global warming trend; and, the marked transition to an Information Age in which the interests and capabilities of the individual are greatly enabled.

The confluence of these powerful environmental and societal forces is having a profound impact. With the increase in population, agriculture is gradually losing in its competition with residential development. As the cost of land increases, the need for denser habitation also increases the negative human impact on nature. An increasing demand for water, energy and materials is eroding the availability of natural resources on planet Earth. Moreover, the extraction and processing of the large amounts of raw materials to fulfill these needs not only damages the ecostructure, but also increases the pollution of the atmosphere to a level that has in some localized instances threatened the very existence of animal and human life. In particularly, water has emerged as the most precious resource for habitation, agriculture, and the continuation of life itself.

From a more general point of view the impact of these forces can be recognized as trends to which we adapt in both conscious and subconscious ways. For example, as the economy has shifted from an industrial to a service base, women have entered the workforce in much greater numbers. The smaller two-income family has different household and child raising needs with direct architectural implications. If we add to this the enablement of the individual through the availability of computers and global connectivity, then it becomes readily apparent that the architectural criteria for the design of buildings and, in particular, homes have already changed and will continue to change as a means of adapting to these trends.

## 12.1 Human Resistance to Change

The recognition that we need to consider the impact that our actions have on the natural environment has come only gradually over the past several decades, mostly due to painful experience. Human beings have an aversion to change that is rooted in our biological evolution and deeply embedded in our cognitive facilities. To explore the source of the resistance to change and attendant tensions that inevitably accompany a paradigm shift it is necessary to understand that we human beings are very much influenced by our surroundings.

As shown in Figure 12.1, we are *situated* in our environment not only in terms of our physical existence but also in terms of our psychological needs and understanding of ourselves (Brooks 1990). We depend on our surroundings for both our mental and physical wellbeing and stability.

Consequently, we view with a great deal of anxiety and discomfort anything that threatens to separate us from our environment, or comes between us and our familiar surroundings.

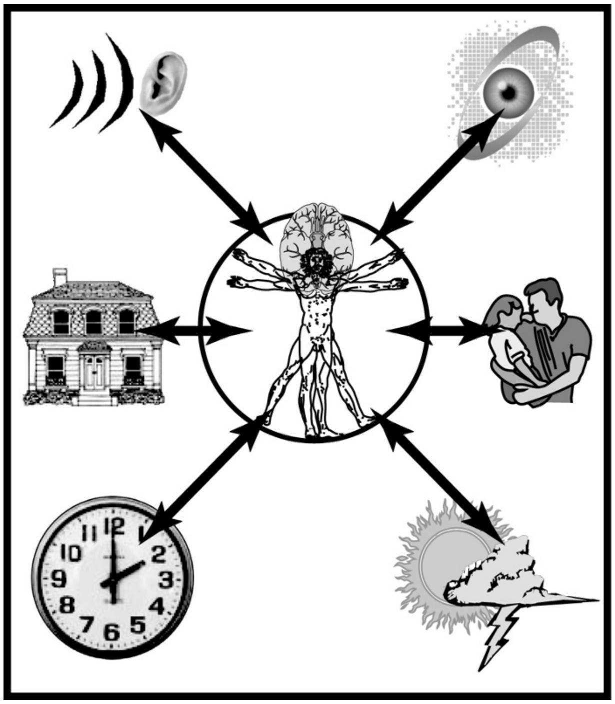

Figure 12.1: Situated in our environment

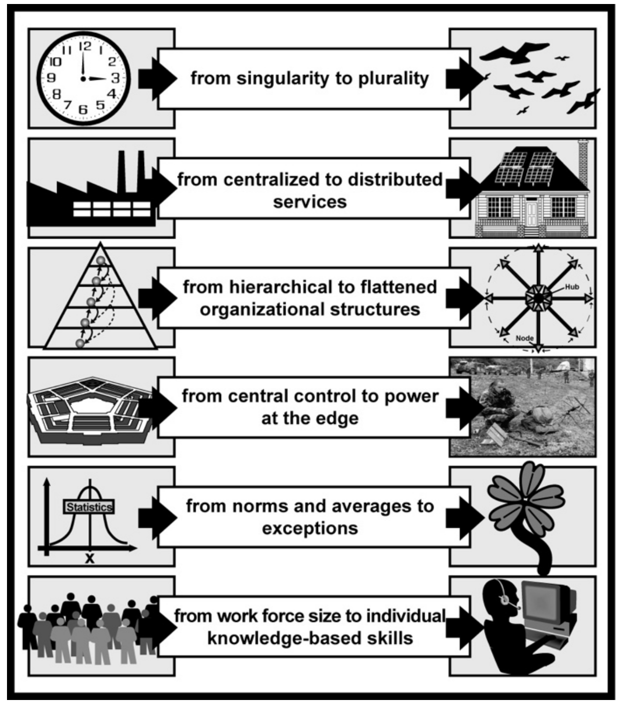


Figure 12.2: Many fundamental changes

This extreme form of *situatedness* is a direct outcome of the evolutionary core of our existence. The notion of evolution presupposes an incremental development process within an environment that represents both the stimulation for evolution and the context within which that evolution takes place. It follows, first, that the stimulation must always precede the incremental evolution that invariably follows. In this respect we human beings are naturally reactive, rather than proactive. Second, while we voluntarily and involuntarily continuously adapt to our environment, through this evolutionary adaptation process we also influence and therefore change our environment. Third, our evolution is a rather slow process. We would certainly expect this to be the case in a biological sense. The agents of evolution such as mutation, imitation, exploration, and credit assignment, must work through countless steps of trial and error and depend on a multitude of events to achieve even the smallest biological change (Waldrop 1992, Kauffman 1992, Holland 1995, Pohl 1999).

In comparison to biological evolution our brain and cognitive system appears to be capable of adapting to change at a somewhat faster rate. Whereas biological evolution proceeds over time periods measured in millenniums, the evolution of our perception and understanding of the environment in which we exist tends to extend over generational time periods. However, while our cognitive evolution is of orders faster than our biological evolution it is still quite slow in comparison with the actual rate of change that can occur in our environment.

Over the past hundred years there have been many fundamental changes in our human values and the way we perceive our environment (Figure 12.2). The Industrial Age placed great value on physical products and devised ingenious ways to maximize the manual contributions of the human work force in a subservient role to a highly automated mass production process. In the

Information Age the focus has moved from the physical capabilities of the human work force to the intellectual capabilities and potential of its individual members. The attendant symptoms of this profound shift are the replacement of mass production with computer-controlled mass customization, virtual products as opposed to physical products, and the creation and exploitation of knowledge.

In respect to the forces that are driving our increased concern for maintaining a sustainable natural environment, the rate of change has not been constant. For example, while there had been earlier warnings about the need to conserve energy from forward thinking individuals, it was not until the energy crisis of the 1970s due to an Arab-Israeli conflict that a larger cross-section of the US population was persuaded to adopt energy conservation measures. Even then it was the pain of increased fuel costs rather than an appreciation of environmental concerns that prompted action. As soon as the fuel prices fell the consumers again purchased large sports utility vehicles[1] with low fuel efficiency ratings.

It is therefore very much due to the foresight and persistence with which the advocates of sustainable development have pursued this important subject that has resulted in public awareness and a general sense of necessary action. However, as discussed at the beginning of this chapter, the availability and cost of energy is only one of the factors that are driving the need to consider sustainability in the design of the built environment. And, even beyond sustainability, there are other equally compelling forces that are changing our lifestyles and thereby the functional requirements of the buildings in which we perform our activities. Foremost among these are the readily affordable information accessibility and exploitation capabilities that advances in computer technology have made available to the individual person, as well as the economic factors that have brought major changes to both the make-up of the workforce and the increasing opportunities for self-employment and entrepreneurship within the workforce. The convergence of these forces produces trends that will continue to dictate the criteria that should be considered in the design of buildings during this Century. The most noticeable of these trends and their likely influence on architectural design will be briefly discussed in the next section.

## 12.2 Discernable Trends

The overarching impact of the trends described in this section is that the design of buildings will become an increasingly more complex undertaking. Whereas architects practicing in the 20th Century already had to deal with a host of often conflicting design issues ranging from space planning and three-dimensional modeling to structural and environmental system selection, 21st Century architects will have many more considerations added to their plate. For example, they will need to justify the use of every material, not only in respect to cost and serviceability but also based on embodied energy and potential toxicity parameters, as well as the ability to recycle the material. The need to minimize water usage will require the use of graywater with the necessary capture and recycling facilities. Most, if not all, of the energy used in a new residential building will most likely have to be captured on-site. Under these circumstances, the

[1] A sports utility vehicle (SUV) is an automobile, similar toa station wagon, mostly equipped with four-wheel drive for occasional off-road driving. SUVs are considered light trucks and have in the past been regulated less stringently than passenger cars under the US Energy Policy and Conservation Act for fuel economy standards, and the US Clean Air Act for emissions standards.

achievement of a building design that would have been acclaimed in the 1990s as an award-winning energy conscious scheme might become a barely baseline solution in the not-too-distant future.

### 12.2.1 The Home as a Workplace

One of the most noticeable and exciting aspect of the Information Age is the enablement of the individual. The combination of inexpensive computer hardware, powerful software tools, and freely available global communication via the Internet, allows a single person to achieve tasks that required a significant team effort in the not-too-distant past. Of course, to exploit this opportunity the individual person must possess the skills that are necessary to fully utilize the capabilities provided by software tools.

As a result, a growing number of young professionally trained persons are seeking self-employment in preference to employment in a larger commercial or government organization. In addition, an increasing percentage of persons who are employed by commercial companies are able to perform at least some of their work external to the organization's facilities. In either case the home becomes the preferred primary or alternative workplace. The impact of the accompanying lifestyle changes is gradually becoming evident in several ways. First, multiple demands are being made on the functional design of the home. Space planning must take into account the multiple purposes that the home may be required to serve, such as an office where business tasks are performed, a place where children are being educated as an alternative to attendance at a public school, as well as all of the traditional functions of a family home. All of these functional requirements must be served in a manner that allows each function to be performed within its own necessary and desirable environment and yet contribute to the operation of the home as an integrated functional unit.

Second, whereas the land-line telephone previously served as the principal facility for immediate communication over any appreciable distance, most business activities performed in the home require greater communication reach, flexibility, redundancy, and convenience. Not only are these requirements being satisfied by technological advances, but those advances in the form of microcomputers, e-mail, Web services, and cell phones, are themselves the main drivers that made the lifestyle changes possible. The home as a workplace is posing new challenges to the building designer in several ways. How should the need for one or more private workplaces be shielded from other family activities, in terms of space planning and noise control? The parent working in the home requires a productive work environment, but at the same time does not wish to be totally disconnected from the household, particularly if there are children in the family.

Third, building designers need to find effective ways of integrating the new Information Age technology into the building, so that it is readily accessible when needed and yet unobtrusive at other times. This requires not only a deeper understanding of the technology itself but also a working knowledge of how it could be employed to best advantage by the occupants of the building. For example, this includes the dual local and centralized control of lighting fixtures. The occupants should have the option of automatically switching off all internal lights, radios and television sets on closing the front door when leaving the house. Relatively inexpensive electronic devices now allow the automated monitoring of almost every activity, the rate of consumption of any resource (e.g., water, electricity, and natural gas), the measurement of most aspects of the physical environment (e.g., temperature, humidity, light levels, noise levels, and pollution), and the ability to alert the occupants to events that may require immediate attention. The question then arises: What should be monitored, how should it be monitored and most importantly, how should these electronic devices be effectively deployed to be readily accessible but not disruptive?

### 12.2.2 Recycling and Waste Management

Based on current and historical building construction and occupancy experience it is quite difficult to imagine the design and operation of a building that is not in some measure destructive to the natural environment. Typically: the site is graded to provide convenient vehicular access and suit the layout of the building and its immediate surroundings; the construction materials and components are produced from raw materials that are extracted from nature and consume a great deal of energy during their production; the materials and components are transported to the site consuming more energy in transit; on-site construction generates waste in terms of packaging material and the fabrication of footings, walls, floors, and roof; during the life span of the building, energy is continuously consumed to maintain the internal spaces at a comfortable level and power the multiple appliances (e.g., lights, communication and entertainment devices, food preservation and preparation facilities, and security systems); despite some concerted recycling efforts, much of the liquid and solid waste that is produced during the occupancy of the building is normally collected and either treated before discharge into nature or directly buried in landfills; and finally, at the end of the life span when the building is demolished most, if not all, of the construction materials and finishes are again buried in landfill sites.

Let us consider the other extreme, a building that has been designed on ecological principles and is operated as a largely self-sufficient micro-environment. Ecological design has been defined in broad terms as being in symbiotic harmony with nature (Van Der Ryn and Cowan 1996, Kibert 2005). This means that the building should integrate with nature in a manner that is compatible with the characteristics of natural ecosystems. In particular, it should be harmless to nature in its construction, utilization, and eventual demolition. The closest we come to being forced to comply with such stringent design and occupancy requirements is in the realm of extraterrestrial habitats, such as an outpost on the Moon or Mars. The constraints imposed by the severe transportation limitations and the hostility of the environment to human, animal, and plant life, require careful consideration of even the smallest component or quantity of material and the most minute energy requirement and need for non-recyclable material. The designers of such extraterrestrial buildings will be faced with design criteria that are only slightly more stringent than those called for by a truly ecological design on Earth. For example:

- In the absence of any excavation equipment the footings of the building will need to adjust to the site topography, rather than the converse. Under these circumstances careful site selection will be a necessary prerequisite to any successful construction project. Also, to accommodate changes in topography that could occur due to environmental influences, the footings will need to be adjustable at least in height. While ecological design on Earth may tolerate a slightly larger building footprint, any significant reshaping of the site topography and certainly larger areas covered by building footings or paving should be avoided.

- The building will need to be designed as a minimum weight structure, since every pound of material would need to be transported from Earth with an enormous consumption of energy. While the use of on-site materials would circumvent the transportation problem, this alternative is unlikely to be a feasible option at least during the early stages of extraterrestrial settlement due to the absence of the necessary extraction and manufacturing facilities. The adoption of minimum weight structural principles on Earth could also be a desirable ecological design criterion. It would serve to minimize the size of footings, reduce the consumption of energy required for transporting materials and components to the site, and require fewer raw materials to be mined from the Earth's surface.

- The building will need to be largely self-sufficient in terms of the energy required to sustain its occupants. This includes environmental control (i.e., temperature, humidity, air quality, and air composition), food preservation and preparation equipment, water and other waste recycling systems, communication and computer hardware devices, and any other electronic monitoring and control facilities. With the exception of the need to maintain an artificial atmosphere (i.e., air composition) within the building, these requirements are essentially the same as those prescribed by ecological design principles on Earth.
- The occupants of the extraterrestrial building will depend on the treatment and reuse of graywater and the recycling of solid waste to virtually the same extent as a building on Earth that adheres strictly to ecological design principles. In both cases water emerges as one of the most precious and essential resources for the sustainment of human life.
- Apart from the treatment and reuse of graywater, the building will need to incorporate a waste management system that is capable of sorting dry waste as a precursor to recycling and processing wet waste in an anaerobic or similar treatment facility for composting purposes.
- Regardless of whether the building is intended for an extraterrestrial or terrestrial location, it should be designed for a fixed life span. The building materials and component products will need to be reusable in some form at the end of that life span. To satisfy this ecological design requirement the building must be deconstructable, the materials must be recyclable, the products must be disassemblable, and the materials dissipated from recycling must be harmless (Kibert 2005, 279). The concept of a *closed-loop* building material strategy is central to ecological design and *green building* principles.

A major advantage of a building based on ecological design principles on Earth over an extraterrestrial structure is that the site environment is not hostile and can be used to facilitate the recycling and waste management processes. For example, the reuse of composted materials in an extraterrestrial building would likely be confined to a small greenhouse facility, while on Earth the opportunities for the effective use of compost extend beyond the confines of a greenhouse structure to the entire site.

### 12.2.3 Water as a Precious Commodity

Water is such a precious commodity that even though buildings account for only about 12% of the total use of water there is increasing pressure to reduce this amount through recycling. In fact, it is generally suggested that it should be possible to reduce the freshwater draw of buildings by as much as 90% in *high-performance* buildings (Kibert 2005, 408). There is a need for much education in this area as a precursor to making appreciable progress. Currently, with a few exceptions neither building designers nor building owners draw a distinction between freshwater and graywater by simply referring to water. Increasingly building designers will be required to include water treatment and recycling facilities in their designs.

However, water conservation in buildings is as much a human behavioral problem as it is a mechanical solution. For example, whether or not the building occupants abide by guidelines that suggest soaping of hands before turning on the water during hand-washing, is a behavioral issue. However, how the waste water from the hand-washing operation is captured, treated, and reused as graywater, is a mechanical issue. These issues require different solution approaches.

The solution of the behavioral problem relies mostly on education and motivation. Much can be achieved in this regard by making the building occupants aware of the amount of freshwater that they are using, at the time of usage. The near real-time measurement of the amount of water that has just been used by a building occupant and the concurrent display of this measurement as immediate feedback to the occupant is likely to be more effective in the longer term than automatically stopping the water flow as soon as the recommended freshwater draw has been exceeded. At the same time, communication on a continuous basis of the cumulative water usage to each individual building occupant, in comparison to all other occupants, can motivate occupants to use less water on a competitive basis. Again, inexpensive electronic measurement and alerting devices are already available to meet these objectives.

The capture, treatment and reuse of graywater are amenable to a range of mechanical solutions that are largely independent of user control. However, all of the solutions that are currently available and even those that may become available in the foreseeable future will result in an increase in capital costs. They all require the addition of plumbing equipment and devices as part of a somewhat more complex water reticulation system. Nevertheless, within the context of the overall cost of the building this increase will be a relatively small percentage[2]. On the other hand, faced with dwindling freshwater resources building codes will increasingly mandate water conservation measures that will force building designers to give the plumbing design of a building a great deal more attention than has typically been the case to date.

### 12.2.4 Energy Self-Sufficiency

Prior to the energy crisis precipitated by an Arab-Israeli conflict in the early 1970s, energy was so inexpensive in the US that its conservation was rarely considered as a design criterion. Buildings were commonly designed with little regard to the climatic determinants of orientation and the performance of the building envelope in respect to heat flow and daylighting was often at best a secondary consideration. This situation changed drastically in the succeeding 30 years with the adoption of new building energy codes that mandated building designs based progressively on more and more stringent energy conservation standards.

[2] If the plumbing costs (including fixtures) of a typical home are currently about 5% of the total cost of the building then even a 40% increase in plumbing costs is only a 2% increase in the capital cost of the building.

During the 21st Century there will be increasing pressure on architects to devise building designs that aim at energy self-sufficiency. While this goal may not be reachable in less favorable climates, the expectation will be that the requirements for active heating, cooling and ventilation are minimized. Foremost, this will require a very thorough evaluation of the regional or macro climatic conditions, as well as the micro climatic factors such as the local topography that may apply to a particular site. The specific characteristics of the site's climatic profile will determine the extent to which passive thermal design concepts and principles can be applied in the design solution. The decisions that are made during this detailed climatic analysis will largely determine the overall shape and orientation of the building, the degree to which the building can become energy self-sufficient, and the potential need for additional thermal provisions.

Consideration of passive design approaches and strategies will require not only an in-depth knowledge of the different passive building types and their implementation principles, but also detailed analysis and design tools to simulate different design scenarios for comparative purposes. One focus of this analysis will be to determine how renewable energy sources such as solar radiation and natural air movement can facilitate each alternative passive design solution. The outcome of the simulation results will also determine to what extent the building envelope will need to resist the flow of heat by conduction, convection and radiation. Most of these determinations will require access to software design tools that not only consider each factor in isolation, but are also capable of considering the impact of each factor on all other factors as an integrated building system. This is a complex undertaking requiring the designer to have both breadth and depth of knowledge, and is unlikely to be achievable without access to subject matter experts and/or a set of sophisticated design tools.

### 12.2.5 A Healthy Building Environment

The transition from the Industrial Age to the Information Age is continuing to enable the individual. Increasingly, the assets of an organization are being measured in terms of the ability of the organization to manage the knowledge contributed by its members (Pohl 2003). Under these circumstances it is not surprising that there should be a parallel concern for health maintenance. Examples include the concerted government campaigns aimed at curtailing and eventually eradicating the smoking and chewing of tobacco, the government mandated descriptions of the ingredients on the packaging of food products, and the emphasis on diet and exercise by an increasing proportion of the public.

This concern for good health and longevity also extends to the built environment. In a 1983 report the World Health Organization projected that up to 30% of buildings world-wide were subject to excessive complaints about indoor air quality (WHO 1984). A 2002 article by a toxicologist of the US Environmental Protection Agency (USEPA) estimated a productivity loss of over (US) $150 billion per year due to building-related illnesses, taking into account direct and indirect costs (Smuts 2003). However, it is only in recent years that a spate of lawsuits have brought terms such as Sick Building Syndrome (SBS), Building-Related Illness (BRI), and Multiple Chemical Sensitivity (MCS) into prominence.

There are several potential causes of an unhealthy internal building environment, including: toxic chemical *off-gassing* of materials that might continue for several years after the construction of a building; the growth of allergy producing molds in moist areas such as those caused by condensation; ductwork that has been contaminated during construction; and, glare due to excessive daylight at external windows or inadequately shielded artificial light fixtures. In each case there are readily available remedies that can be applied at the design stage. For example, dehumidification and ultraviolet radiation will reduce the growth of molds and can effectively kill molds and bacteria that have invaded a ventilation system, respectively.

Nevertheless, the selection of construction and finish materials will become a much more demanding and complex design task in future years. Not only synthetic materials may have potentially toxic ingredients, such as volatile organic components. Natural materials may also contain pollutants that are harmful. The material selection process is further complicated by the fact that ecological design principles will require the building designer to not only avoid materials that may be toxic in use, but also consider toxicity during extraction, manufacturing, and deconstruction. This also includes intermediate materials that are used in the production, application, joining, and finishing of other construction materials, such as: paints; solvents; lubricants; adhesives; mastics; detergents; bleaches; and, acids.

### 12.2.6 Quality of Life Expectations

In addition to the increasing concern for the impact of buildings on the environment, the health of the occupants, the recycling of materials and waste, the minimal use of freshwater, and the avoidance of fossil fuels, the building designer will need to deal with another overarching trend. The enablement of the individual in a world in which entrepreneurship and self-employment will increasingly replace traditional long-term employment opportunities, is likely to be accompanied by a marked consumer insistence on efficiency and convenience. The quality-of-life expectations of the individual person are likely to increase as an indirect consequence of the greater value that an Information Age society is placing on the knowledge-based capabilities of each person.

This trend has already started to manifest itself in several ways. For example, the increasing use of the Internet as a convenient shopping mall with the expectation that the purchased goods will be shipped within 24 hours and packaged in a way that will facilitate their almost immediate use on receipt by the customer. Even relatively major purchases that would have in the past involved a lengthy period of careful deliberations are today often concluded in an e-business environment in a matter of hours rather than days. Buildings, particularly the home, will be expected to function with the same level of efficiency, speed and convenience.

Only electronic devices will be able to deliver the level of monitoring, control, and customization that is required to realize such expectations. This suggests that the building will need to be *electronically enabled* from a functional point of view. Full use of available electronic capabilities will include the monitoring of energy and water consumption, both at the point of utilization and cumulatively over a daily, weekly, monthly, and annual period. In other words, not only will the building occupants wish to know exactly how much water they have just used for washing their hands or for taking a shower, but they will also wish to compare this water usage with their average usage and the usage levels mandated or recommended by the authoritative government agency. It will take some ingenuity by building designers to devise ways for communicating this kind of information to building occupants so that it is readily available when desired and yet unobtrusive at other times.

Similar monitoring and control requirements will apply to environmental systems and devices such as electricity and gas consumption, the movement of blinds and sunshading devices, the dimming of artificial lights, the enabling and disabling of active noise control systems, and the operation of integrated entertainment suites. In all cases the expectation of the building occupants will be the convenient availability of high-quality monitoring and control facilities for the full range of building services. Particularly the continuous monitoring of energy and water usage will contribute indirectly to the heightened awareness of the ability of each individual person to contribute to the conservation of these resources.

## 12.3 Fundamental Concepts and Definition of Terms

As discussed previously in this chapter, the *sustainable development* movement is far more encompassing than the design of buildings that are accountable for the natural resources that they consume, the amount of pollution that they produce, and the impact that they have on the health of their occupants. Rather, the increased sensitivity to the natural environment, the concern about global warming trends, and the increasing awareness of the benefits of proactive health maintenance, are a direct outgrowth of the enablement of the individual in a knowledge-based Information Age. It makes a great deal of sense that as the individual members of society gain access to powerful tools and inexpensive global communication facilities, they will also come to value their capabilities and increasingly have higher quality of life expectations.

In this section we will define some of the fundamental concepts and new terms that have been coined over the past half-century in the field of sustainable development, as it applies to the built environment.

### 12.3.1 Sustainability

In the context of the built environment *sustainability* is the overarching concept that acknowledges the need to protect the natural environment for future generations[3]. It proposes that anything that we build today should be sustainable throughout its life span. Furthermore, at the end of its life span it should be amenable to deconstruction and the reuse of all of its materials in some form. This is indeed a paradigm shift when we consider that most recycling efforts are still in the earliest and most primitive stages. While the sorting of household, business and public waste into categories such as paper products, bottles and cans, landscaping material, and all other waste, is now reasonably well established in many parts of the world, comparable large scale recycling programs have yet to be initiated in the construction industry.

Since the 1970s the emphasis has been placed on energy conservation during the life span of a structure. Only a very small number of buildings have been certified to date (2009) to comply at least partially with the concept of *sustainability*, and in each case the certification process has been undertaken on a voluntary basis by the building owner. These are very small, first steps in the quest for a sustainable built environment when we consider what needs to be achieved. For a building to meet the full intentions of *sustainability* it would need to:

- be constructed only of materials and products that are reusable in some form or another at the time of deconstruction of the building and, by implication, most of these materials would already contain recycled ingredients;

[3] The Bruntland Report (1987) defined *sustainable development* as "… meeting the needs of the present without compromising the ability of future generations to meet their needs" (UN (1987); 'Our Common Future'; United Nations, World Commission on Environment and Development, A/42/427 Supplement 25, 4 August, New York, New York).

- be constructed of materials and products that used as little energy (i.e., embodied energy) as possible during their manufacture;
- be constructed of materials that are not subject to toxic off-gassing;
- be as close to energy self-sufficiency as possible subject to climatic and technology limitations;
- employ water harvesting, treatment and reuse strategies to reduce its freshwater draw to the smallest possible amount (i.e., about 10% of existing usage based on current predictions); and,
- incorporate a waste management system that is capable of recycling most, if not all, of the dry and wet waste produced in the building.

Clearly, it will take some time before the construction industry and its professions will be able to meet these stringent requirements. Supportive industries, such as an economically viable recycling industry, will need to be established. Governments will need to incrementally increase building code requirements, despite industry and potentially even public objections. Due to the intrinsic human aversion to change it is unlikely that building owners will be willing to voluntarily meet requirements that do not serve their needs during the ownership period of the building. These are just some of the reasons why full acceptance of the concept of *sustainability* will witness a change in lifestyle that will evolve during the 21$^{st}$ Century. While this change is inevitable, it is difficult to predict how long it will actually take.

### 12.3.2 Ecological Design

Van Der Ryn and Cowan defined *design* as "… the intentional shaping of matter, energy, and process to meet a perceived end or desire" and *ecological design* as the effective utilization of resources in synchrony with natural processes in the ecosystem (Van Der Ryn and Cowan 1996). These two definitions distinguish between a design process that is intent on meeting the objectives of the designer regardless of what those might be and one that demands synergy with the natural environment. Based on this definition *ecological design* is much more complex than what has been practiced by designers in the past. It adds a whole new dimension to design that on the one hand constitutes a new set of design constraints and on the other hand requires a deep understanding of the nature of natural systems that does not necessarily exist. According to Kibert (2005, 110) the "… key problem facing ecological design is a lack of knowledge, experience, and understanding of how to apply ecology to design".

Adherence to ecological design concepts does not mean that we should attempt to slow down technological progress and down-grade our lifestyle. Instead, we should build on natural systems in a complimentary manner. What Kibert and others have pointed out is that this is a difficult undertaking when most of our existing knowledge is based on the machine as the model for design (Kibert 2005, McHarg 1999, Odum 1983, Holling 1978, Mumford 1967). Nevertheless, the objectives of ecological design are sufficiently clear for the formulation of at least some broad guidelines.

- The built environment should not unduly disturb the natural environment by disrupting ecosystem processes. Any disruption that cannot be avoided should be temporary and reparable by natural processes.

- Materials that are used for the construction of the built environment should not be toxic to the natural environment (including the human occupants of buildings) and should be to a large degree recyclable at the conclusion of the life span of the structure that they were part of.
- Freshwater should be drawn from the natural environment sparingly and recycled as its quality progressively downgrades through multiple uses. Certainly, technology will play a major role in maximizing the reuse of water.
- The selection of energy sources and the efficient use of energy should be a major design criterion. The use of fossil fuels should be minimized and avoided wherever possible, because the processes used to harvest, manufacture, and utilize these fuels are typically disruptive to the natural environment. Again, this is an area where technology will be helpful.

The ecological design objectives related to the efficient use of water and energy will be much easier to achieve than those related to materials of construction and site planning. In the first case, designers will be able to build directly on the existing body of scientific and technical knowledge that was developed during the Industrial Age. For example, the efficient use of natural sources of energy (e.g., sun and wind) and the treatment of water for recycling purposes depend largely on the exploitation of man-made technology. However, in respect to materials, urban planning and even site planning the available body of knowledge is much more limited. Little is known about the processes and time-scales involved in ecological systems that can be readily applied to the design of the built environment. For example, while we do have some understanding of the relationship between pollution of the atmosphere and global warming, we know very little about the extent to which nature is able to utilize its own processes to counteract atmospheric pollution. Once we have gained an understanding of those natural processes, it will be necessary to translate that knowledge into methodologies and strategies that will allow designers to create the appropriate solutions for the built environment.

### 12.3.3 Eco-Efficiency

The term *eco-efficiency* was coined by the World Business Council on Sustainable Development in the early 1990s to describe competitive goods and services that reduce ecological impacts throughout their life-cycle in accordance with the ability of nature to support these impacts (WBCSD 1996). More specifically, WBCSD established the following eco-efficiency objectives: reduction of both the material and energy requirements of goods and services; maximization of the recyclability of materials and the sustainability of renewable resources; containment of toxic dispersions from materials and processes; and, the achievement of improvements in product durability and service intensity of goods and services.

WBCSD believes that these objectives can be achieved through the judicious application of five strategies:

1. *Improved Processes:* The adoption of well-designed manufacturing processes and service deliveries that avoid the generation of pollution in preference to the employment of end-of-process pollution clean-up procedures.
2. *Product Innovation:* The design of new products and re-design of existing products based on resource-efficiency principles.

3. *Virtual Organizations:* The exploitation of information technology to share resources in a networked environment and thereby increase the effective use of physical facilities.
4. *Business Strategies:* The exploration of alternative marketing models, such as the leasing of products as services rather than goods for sale and thereby refocusing the design emphasis on durability and serviceability.
5. *Waste Recycling:* The utilization of the by-products of one process as the ingredients of another process, with the objective of minimizing resource waste.

It is readily apparent that the concepts and principles of eco-efficiency are well aligned with the objectives of *sustainable development* and *sustainability* discussed earlier in this chapter.

### 12.3.4 Ecological Footprint and Rucksack

The concept of *ecological footprint* was proposed by Rees and Wackernagel in 1996 as an appropriate measure of the land area required in support of a particular human activity requiring resources (Rees and Wackernagel 1996). It represents the area of productive land and shallow sea required to support a single person in terms of food, water, housing, energy, transportation, commerce, and waste disposal. As such, it provides a convenient index for comparing the resource consumptions associated with the different lifestyles of nations. For example, Wilson (2002) has estimated the average ecological footprints for the US and for the world population as a whole to be approximately 24 acres and 5 acres, respectively. If the more than five billion people in developing countries were to achieve even half of the US levels of resource consumption then based on current technological capabilities, we would require at least two Earth planets to support the world population.

The term *ecological rucksack* has been proposed to quantify the mass of material required to be moved to extract a particular resource. It is defined by the European Environmental Agency as the material input required by a product or service minus the weight of the product (EEA 2009). Material input includes the total quantity of natural material that will be displaced during the entire life-cycle of the product from raw material extraction, through manufacture, recycling, to final disposal. Variations of the ecological rucksack among different materials are quite large. For example, the ecological rucksack for new aluminum (85) is more than 20 times greater than for recycled aluminum (4) and more than four times greater than for new steel (21) (Weiszäcker et al. 1997).

### 12.3.5 Life-Cycle Assessment and Costing

While *life-cycle assessment (LCA)* methods determine the environmental and resource impacts of a building or one of its components (e.g., material or product), *life-cycle costing (LCC)* determines the financial performance of a building. In each case the analysis is performed over a time period that typically encompasses the entire life span of the building or component and is quite complex. The LCA analysis of a product such as a television set must consider all energy and material resources that have been used in the extraction of the raw materials and manufacture of the product, as well as the energy used during its operation, recycling and the disposal of those components that cannot be recycled. Finally, the impact of all of those material extraction, manufacturing, recycling, and disposal operations on the natural environment must be measured. This is a complex undertaking that not only requires a great deal of knowledge, reliable data, and access to evaluation tools, but also depends on reasonable assumptions in respect to useful life span and utilization.

The objective of LCC is to determine the economics of a product in present value terms. For example, the financial return of a solar hot water system requires the amortization of the initial cost of the system and its installation over the probable years of operation, taking into consideration projected energy savings and maintenance costs. An appropriate discount rate is selected and the net benefits for each year are tabulated to determine the payback period of the system. Clearly a LCC evaluation is a much simpler undertaking than a LCA analysis, because there are fewer factors involved and these are considered only from the financial point of view. However, sometimes the LCC evaluation is combined with a LCA analysis to determine the combined environmental and financial impact of a particular material, product, component or entire building.

### 12.3.6 Embodied Energy

The *embodied energy* of a component or product refers to the entire energy that is expended during the extraction of the raw materials, transportation, and manufacture. About 50% of the *embodied energy* of a material is used in the production process and approximately 40% of the energy is used in the extraction of the material. The *embodied energy* of a material is an important consideration in the selection of materials and products in respect to sustainability criteria. For example, the *embodied energy* of an aluminum window frames is seven times greater than a steel window frame and the *embodied energy* of polystyrene insulation is almost nine times greater than fiberglass insulation and about 35 times greater than cellulose insulation. Yet the thermal insulation performance ratio of these materials is quite similar (Table 12.1). In other words, from an ecological design point of view cellulose thermal insulation in the form of milled paper or wood pulp is a far superior choice than polystyrene.

Table 12.1: Comparison of embodied energy and thermal insulation effectiveness

| | cellulose | fiberglass | polystyrene |
|---|---|---|---|
| ratio of *embodied energy* consumption | 1 | 4 | 35 |
| ratio of thermal insulation effectiveness | 1.00 | 1.08 | 1.35 |

The values of *embodied energy* for specific materials are likely to vary for different countries and different years (Baird et al. 1984). This is due to variations in production sites, climate, raw material quality, extraction and processing methods, distances between extraction and production sites, and transportation methods. According to Adalberth (1997) the transportation energy component can be as much as 10% of the manufacturing energy for a construction material. The difficulties encountered in determining the *embodied energy* value for any particular material are discussed in detail by Heidrich (1999). For example, values for thermal insulation materials may be quoted per volume or weight. Such data are not comparable because they involve assumptions about the density of the material, which varies widely for such materials. Methods for estimating the energy cost of materials are discussed by Chapman

(1974).

### 12.3.7 Factors 4 and 10

The concepts of *Factor 4* and *Factor 10* are similar in principle although suggested by different persons. They both propose in very general terms a course of action for maintaining a balance between human habitation and the natural environment on planet Earth. *Factor 4*, proposed by Weiszäcker and the Lovins, requires resource consumption to be reduced to one quarter for humanity to reach sustainability based on 1997 conditions (Weiszäcker et al. 1997). Their proposal, published in the form of a book, was in fact a report to the Club of Rome. It was intended as a follow-up to a 1972 report to the Club of Rome, which was published under the well-known title *Limits of Growth* (Meadows et al. 1972). The latter projected that as a result of resource consumption and environmental impact, growth on Earth would be halted within a century.

Schmidt-Bleek of the Wuppertal Institute in Germany suggested that long term sustainability will require humanity to reduce its resource consumption to one tenth[4]. While the *Factor 4* proponents believed that the technology required for reducing resource consumption to 25% of current levels was already available in the 1990s, it is generally agreed that the *Factor 10* goals are much more difficult to achieve. Even though it can be shown that by abandoning the common practice of oversizing mechanical equipment (e.g., chillers, pumps, fans) up to 90% reductions in energy consumption are possible, this strategy represents only a relatively small part of the measures necessary for achieving *Factor 10* goals (Kibert 2005, 47).

### 12.3.8 Green High-Performance Buildings

The term *green building* has been accepted internationally as describing buildings that are designed and constructed based on the principles of sustainability. It is not possible to define in absolute terms what exactly constitutes a *green building* because the definition is based on what is acceptable and reasonably achievable at any particular point in time. Arguably, the term *green building* represents a goal based on parameters that are measured by what are considered to be attainable resource and energy conservation levels at any particular time. Both the target areas of the concept of sustainability and the desired level to be aspired to in each target area depend on prevailing societal pressures (i.e., economic and political) and government mandates (i.e., codes and regulations).

Since the 1970s the focus has been on post-construction energy conservation, suggesting that we are still very much in the initial stages of the quest for a sustainable planet. While there is some concern for the conservation of freshwater, marked by the more prevalent appearance of low flow shower heads and dual flush toilets, water treatment and recycling systems are still rare in buildings. The selection of construction materials based on recyclability, non-toxicity, and minimum embodied energy criteria remains a distant goal outside the realm of normal consideration. Nevertheless, the *green building* movement is gaining strength. Significant strides have been made in several parts of the world, including the US, since the 1980s.

---

[4] The *Factor 10* concept continues to be promoted by the Factor 10 Club and the Factor 10 Institute whose publications are available at: www.factor10-institute.org.

In Europe, the Conseil International du Batiment (CIB), a well-established international construction research association located in Rotterdam (The Netherlands), and the International Union for Experts in Construction Materials, Systems, and Structures (RILEM) based in Bagneux (France) advocated the need for building assessment tools and standards. In 1992, CIB formed Task Group 8 for this purpose. This was followed by the formation of CIB Task Group 16 to promote the application of sustainability concepts and principles to construction. Since 1998 the International Institute for a Sustainable Built Environment (iisBE) has held biannual Green Building Challenge and Sustainable Building Conferences at which international green building entries are rated using iisBE's Green Building Tool (GBT) assessment method[5].

Although the beginnings of the green building movement in the US may be traced back to the 1970s[6] it was really a succession of events that has focused US attention on the environment in more recent times (BDC 2003). These included the publication of the Bruntland Report (UN 1987) in 1987, the formation of the Committee on the Environment (COTE) by the American Institute of Architects in 1989, the United Nations Conference on Environment and Development in Rio de Janeiro (Brazil) in 1992, and the World Congress of Architects sponsored jointly by the International Union of Architects and the American Institute of Architects held in Chicago in 1993. The manifesto issued at the conclusion of the Chicago World Congress of Architects represents perhaps the most important milestone in the evolution of the *green building* movement in the US. Under the title of "Declaration of Interdependence for a Sustainable Future" it boldly pronounced the following five commitments (UIA-AIA 1993).

> "We commit ourselves as members of the world's architectural and building-design professionals, individually and through our professional organizations, to:
>
> - place environmental and social sustainability at the core of our practices and professional responsibilities;
> - develop and continually improve practices, procedures, products, curricula, services, and standards that will enable the implementation of sustainable design;
> - educate our fellow professionals, the building industry, clients, students, and the general public about the critical importance and substantial opportunities of sustainable design;
> - establish policies, regulations, and practices in government and business that ensure sustainable design becomes normal practice; and
> - bring all the existing and future elements of the built environment - in their design, production, use, and eventual reuse – up to sustainable design standards."

The first prominent US examples of green buildings appeared from the mid 1980s onward with the design of the New York offices of the Environmental Defense Fund organization in 1985 and the Natural Resources Defense Council in 1989. However, it was the renovation of Audubon House in New York City in 1992 by the Croxton Collaborative firm that drew attention to the necessary involvement of a much broader group of stakeholders in the design of a green

[5] The iisBE Web site address is: www.iisbe.org. The next Green Building Challenge Conference is scheduled for London, UK in 2011.

[6] In 1970 Earth Day was founded in the US by Senator Gaylord Nelson (D-Wisconsin) as an environmental teach-in. Since then Earth Day has been celebrated in the US on April 22 each year. In other countries Earth Day is celebrated in Spring in the Northern Hemisphere and in Autumn in the Southern Hemisphere.

building. The process employed by the Croxton Collaborative for the Audubon project was documented and became a template model for achieving the extensive cooperation and collaboration that is required in the design of green buildings (Audubon 1992).

The US Green Building Council (USGBC) was formed in 1993 and according to available records started certifying green buildings in 2000. With its Leadership in Energy and Environmental Design (LEED) certification standard USGBC has become the preeminent green building organization in the US. The strength of LEED lies in the fact that it is controlled by a non-government organization. It was produced collaboratively by representatives of the USGBC's membership, which presumably includes the principal stakeholders. In this respect the LEED standard is market-driven and is therefore likely to continue to reflect at any particular point in time what building owners would like to achieve and what the design professions and construction industry is able to deliver.

The first LEED v1.0 test version was released in 1998. It led to a pilot evaluation project under the auspices of the Federal Energy Management Program. The purpose of the pilot effort was to test the assumptions and assessment framework employed by LEED on 18 building projects representing over 1 million square feet of floor area. As a result of this evaluation and the support of its increasing membership (i.e., over 300 by 2000) USGBC released a greatly improved LEED v2.0 in 2000. This version provided for a maximum of 69 possible credits and four levels of certification, namely: Platinum; Gold; Silver; and, Bronze.

From 2002 onward separate LEED certification standards have been released for different construction types and occupancies, such as new construction (LEED-NC), existing buildings (LEED-EB), commercial interiors (LEED-CI), homes (LEED-H), and core and shell (LEED-CS). For new construction, only slightly modified LEED-NC v2.1 and LEED-NC v2.2 were released in 2002 and 2005, respectively. The roll-out of a more user-friendly LEED v3.0 with Minimum Program Requirements (MPR) and higher standards commenced in April 2009 (LEED 2009).

## 12.4 Assessment of High-Performance Buildings

As can be seen from the definition of terms in the previous section the design of a *green* or *high-performance* building is a much more complex undertaking than the design of a building that does not have to consider sustainability criteria. What makes this undertaking particularly difficult is not just the need to consider more issues such as the carbon content and embodied energy of the construction materials, the treatment and recycling of water and all forms of waste, and the potential impact of the finishes on the health of the occupants, but the relationships among all of the design issues.

The complexity of a building design problem is seldom due to the difficulties encountered in coming to terms with any one design issue in isolation, such as the avoidance of glare in the maximization of daylight or the provision of sound insulation when a building is located in a noisy environment. Difficulties arise when these solutions have to be combined into an acceptable holistic design solution. For example, the conflict that arises when the maximization of daylight requires large windows but the existence of an external noise source, such as a major freeway adjacent to the building site, calls for a high degree of noise insulation.

The notion of assessing the design and performance of a building is relatively new to the design and construction professions. Apart from design competitions and post-occupancy performance evaluations, typically contracts provide for a defects liability period during which the contractor is obligated to correct construction faults such as cracks in walls, poorly fitting doors and windows, leaking pipes, and non-operational equipment. Even in the case of design competitions there are no commonly accepted evaluation frameworks and individual review committee members are normally left to their own devices on how they will compare the merits of the submissions. The approach has been more formal in respect to assessing the performance of a building during its occupancy with the proposal of several methodologies (Daish 1985, Pena et al. 1987, Preiser et al. 1988, Preiser 1989, AIA 2007).

Therefore, the assessment of buildings prior to occupancy for the purpose of gaining a *green building* certification adds a whole new dimension to the building design process. Currently, such certifications are conducted entirely on a voluntary basis, with the incentive that a building that achieves a high *green building* ranking will have greater economic value. Eventually, however, it is likely that many of the sustainability criteria that have been defined by organizations such as USGBC will find their way into national building codes as mandatory requirements.

### 12.4.1 Assessment Framework Concepts and Principles

Even though the design of a building and even more so in the case of a *green building* must take into account a host of factors and their interrelationships, it is convenient to be able to express the final result of the assessment as a single score. This is the method adopted by USGBC and the basis of the LEED Certified, Silver, Gold, and Platinum ratings. However, the single score is an amalgamation of a point system that allocates individual scores to different categories and subcategories of desirable higher performance features.

The disadvantage of such an assessment system is that the manner in which a building achieved its final rating is not represented in the rating. It might therefore seem appropriate to include in the certification documentation a graph that shows how the building scored in each category of the assessment framework. This would also allow the setting of minimum standards that must be reached in each category for the building to qualify for a particular overall rating. However, there is an opposing argument to this concept that also has merit. It may be a desirable incentive for design innovation if a building is able to obtain a certain ranking by scoring very high in some categories and much lower in other categories.

In any case, there does not appear to be an alternative to the kind of assessment approach adopted by USGBC to form the basis of the LEED certification process. The different features that must be considered in the design of a *green building* such as site planning, water efficiency, energy, materials, and so on, are too diverse in nature to be able to be combined into a single index. Each feature has different units of measurement and applies at a physical scale that is directly tied to its unique context (Kibert 2005, 70). For example, it does not appear to make any sense to attempt to combine the building health aspects of a material with its embodied energy and carbon content characteristics. If this is not possible when dealing with the same type of component (i.e., a particular construction material) then it is even less likely that different types of components will be able to be combined into a single index.

### 12.4.2 The LEED Assessment Framework

The LEED v3.0 certification process was launched in April 2009, together with a new *Green Building Design and Construction Reference Guide* (LEED 2009) that now serves as a single guide for LEED-Schools, LEED-NC (i.e., New Construction), and LEED-CS (i.e., Core & Shell). While the feature categories of LEED v2.2 have remained the same in LEED v3.0, their relative weightings and the total number of points allocated increased from 69 to 110.

The structure of the LEED standard includes a set of minimum requirements that must be met for a particular project to be eligible for LEED certification. These requirements are quite general in nature and appear to be intended to ensure that a submitted project does in fact comply with applicable laws and is definable as a component of the built environment. For example, the project must comply with existing environmental laws, minimum building to site area ratios, minimum floor area and occupancy rates, include at least one building, and provide USGBC access to the water and energy consumption data. All except two of the seven feature categories include one or more prerequisites, followed by a list of desirable attributes with assigned credit points. In the case of LEED-NC v3.0 the seven feature categories cover the principal *sustainable development* considerations discussed in Section 12.3, as follows:

***Sustainable Sites [26 possible points]:*** As a prerequisite to certification some pollution prevention measures are required to be implemented during construction. Multiple credit points are allocated to: development density and proximity to existing community services (5 points); public transportation access (6 points); fuel efficient and low emittance vehicles (3 points); and, parking provisions (2 points). The remaining 10 attributes deal with various aspects of site selection and development and carry one point each.

***Water Efficiency [10 possible points]:*** As a prerequisite to certification a 20% reduction in freshwater usage is required. The five desirable features are weighted equally with two points each and are concerned with water usage for landscaping, wastewater treatment, and additional freshwater usage reductions by 30% and 40%.

***Energy and Atmosphere [35 possible points]:*** As a prerequisite to certification the submission must provide evidence that specified requirements will be met during the commissioning process and that certain minimum standards will be adhered to in both energy performance and refrigerant management. Multiple credit points are allocated to the enhancement and optimization of energy performance (up to 19 points) and on-site renewable energy (3 to 7 points). The measurement and verification of energy performance is allocated three points and the remaining three desirable features relating to further enhancements in commissioning, refrigerant management, and the generation of at least 35% of the electricity requirement from renewable sources, are allocated 2 points each.

***Materials and Resources [14 possible points]:*** As a prerequisite to certification provision must be made for the on-site or off-site collection and storage of recyclable materials and products. Two credit points are allocated to the building reuse of 75% of existing walls, floors and roof. The remaining desirable features ranging from additional reuse of external and internal building materials, the diversion of construction waste from disposal to recycling, the use of regional materials, to the use of rapidly renewable materials and at least 50% of wood-based material and products that are certified by the Forrest Stewardship Council (FSC), are allocated one point each.

***Indoor Environmental Quality [15 possible points]:*** As a prerequisite to certification the submission must meet specified indoor air quality requirements[7] and prevent the building occupants from being exposed to tobacco smoke. The 15 desirable features under this category are all rated equally with one credit point each. They include: monitoring of the inlet air flow rates and carbon dioxide content with the ability to generate an alarm whenever the conditions vary by 10% or more from the set-point; increased ventilation rates; protection of the HVAC system during construction and testing of the air contamination level prior to occupancy; selection of low-emitting (VOC[8]) materials for wall, floor, and ceiling finishes; control of the entry of pollutants from the outside, as well as containment and air exhaust facilities for pollutants originating from sources inside the building (e.g., cleaning substances); a high degree of individual lighting and thermal control; a comfortable thermal environment[9]; a monitoring system of thermal comfort conditions; and, daylight and external views for 75% and 90% of the internal spaces, respectively.

***Innovation and Design Process [6 possible points]:*** No prerequisites to certification are stipulated in this category. Up to 5 credit points may be obtained by a submission that substantially exceeds LEED-NC v3.0 requirements in one or more feature categories. An additional point may be earned if a LEED Accredited Professional (AP) is a principal member of the design team.

***Regional Bonus Credits [4 possible points]:*** This category takes into account that ecological conditions and priorities may vary from region to region. The USGBC Website (2009) provides six features for each US state (by zip code) that have been determined by the regional authority to be of benefit above the point value set by the LEED Green Building Rating System. Compliance with up to four of the applicable priorities adds one point for each claimed agreement, up to a maximum of four credit points.

The maximum number of points that can be earned in LEED-NC v3.0 is 110. The importance assigned to each category in terms of the number of points allocated and the selection of the desirable features stipulated is based on the judgment of the LEED-NC committee members who participated in the preparation of the standard. This is both the weakness and the strength of the LEED rating system. Not all of the stakeholders may be represented on the USGBC working groups. In particular, the views of the Government may not be adequately represented. Furthermore, the deliberations, recommendations and/or decisions made by any of the working groups may be unduly influenced by special interests.

---

[7] For LEED-NC v3.0 the minimum requirement for mechanically ventilated buildings is ASHRAE Sections 4-7 (62.1-2007) and ASHRAE Section 5 Paragraph 5.1 (62.1-2007) for naturally ventilated buildings.

[8] Volatile Organic Compounds (VOC) are gases or vapors emitted by various solids or liquids, which may have a deleterious health impact. Typical building materials that emit VOC include paint, paint strippers, glues and adhesives, floor coverings, building materials, and furnishings.

[9] To obtain the allocated single credit point the HVAC system must be designed to meet the requirements of ASHRAE Standard 55-2004.

However, on the other hand, the market driven non-governmental structure of USGBC is also a significant strength. It will tend to ensure that the direction of the evolving LEED standard over the foreseeable future will remain closely aligned with what the AEC industry and the associated architecture and engineering professions are capable of delivering. Based on market-driven incentives and voluntary participation, USGBC and its LEED standard have made quite remarkable progress over the past decade. However, at some point in the future voluntary compliance with sustainability standards may no longer be acceptable and the Government may have to step in and require mandatory compliance with part or all of the standards. Hopefully, this will be accomplished by the gradual absorption of LEED standards into building codes, without negatively impacting the excellent proactive work being performed by USGBC and similar organizations outside the US.

## 12.5 Energy Design Strategies

Reduction of energy consumption is currently and will remain for the foreseeable future one of the principal goals of *green high-performance* buildings. In the US the energy consumed by buildings and transportation is approximately equal and accounts for 80% of the total national energy consumption. A typical legacy US commercial building consumes about 100,000 BTU per square foot of building area per year (Kibert 2005, 181). A *green* building based on LEED standards will reduce this annual energy requirement by at least 50% to less than 50,000 BTU per square foot, whereas buildings based on Factor 4 and Factor 10 criteria would reduce this energy requirement to 25,000 and 10,000 BTU per square foot, respectively.

Beyond these current energy saving goals, some advocates of ecological design principles are suggesting that in the future the majority of buildings should be at least energy-neutral (i.e., they should not consume more energy than they generate) and where feasible should become net energy producers (i.e., they should generate more energy than they consume). This is indeed a tall order that will require not just a reduction of energy consumption, but a paradigm shift in how architects will need to approach the design of buildings.

In this section, we will briefly explore energy conservation measures that are either already available today or are being actively pursued for near term application, in four areas, namely: passive building design strategies; building envelope performance; hot water systems; and, lighting design. It will become quite clear to the reader that in virtually all cases the design strategies that are employed will require a much deeper analysis of the technical issues involved. Designers will not be able to achieve this based on intuition, experience, or manual methods alone. Instead, they will require sophisticated simulation tools that are user-transparent and seamlessly integrated as semi-automated services within the kind of intelligent computer-aided design environment that has been made possible by a distributed Web-enabled environment based on service-oriented architecture principles (Pohl 1994, Pohl et al. 2000).

### 12.5.1 Passive Building Design Strategies

Well known passive solar building types and design strategies have been discussed previously in Chapter 5 (see Sections 5.9 and 5.10). The underlying concept of a passive solar solution is to design the building so that it can function intrinsically as a collector, distributor, and store for solar energy. This requires an intricate balance of design parameters related to the shape of the building and internal layout of spaces, the location and size of windows, sun path angles and shading devices, and the selection of building materials with the appropriate thermal properties.

For this reason, in current tertiary-level architecture degree programs students are taught to undertake an extensive climate analysis study prior to the commencement of the preliminary design phase. The establishment of the regional (i.e., macro) climate profile and the identification of the local site-specific (i.e., micro) factors that may significantly modify the regional climate profile are considered essential prerequisites for the development of a building design solution. The results of such investigations typically include an assessment of the regional vernacular[10], a summary narrative description of regional climatic conditions and the incidence of special events such as storms and tornadoes, charts of the principal climatic parameters on a monthly scale (i.e., average minimum and maximum dry-bulb temperatures, relative humidity, heating and cooling degree-days, average wind speeds and directions, solar radiation intensities, cloud cover, precipitation (i.e., rain and snow), and, daylight levels), and a topographical analysis of the site.

This climate profile information is then used by the students to categorize the type of climate that they are dealing with and select at least in general terms the appropriate thermal design strategy. Of course, in many cases the climatic profile is seasonal, requiring a hybrid solution of the potentially conflicting strategies applicable to different climate types. For example, hot-humid summer conditions may call for natural cooling through cross-ventilation (i.e., a building envelope with large openings) and cold winter conditions may require a sealed envelope with maximum thermal insulation.

To translate this information into accurate passive building design decisions is a very difficult undertaking. Apart from the level of complexity there are a number of obstacles. First, without simulation tools that are capable of taking into account both thermal parameters such as temperature, humidity, and air movement (i.e., wind), and topographical site conditions such as contours, vegetation, and surrounding structures, only general (i.e., rule of thumb) design decisions can be made. Second, tools that are able to perform the required thermal analysis and capable of producing accurate results, will require more detailed data such as hourly temperature variations. Third, there is currently still insufficient knowledge for the design of simulation tools that are capable of accurately modeling the influence of micro-climatic factors and topographical site features to accurately assess their impact on the projected thermal conditions. Without the ability to accurately model these parameters the most accurate thermal analysis based on hourly temperatures can be quite misleading.

The tools that are available today will allow a designer, with the assistance of an expert consultant, to make sound design decisions in respect to the shape, orientation, space layout, window placement and sizing, massing, and solar control of a building. However, the ability to fine tune these decisions for achieving a *Factor 10* or energy-neutral design solution will in most cases require a much more granular design analysis and access to more sophisticated design and simulation tools than are currently available.

---

[10] The regional vernacular-built environment is often an indicator of indigenous architectural prototypes that reflect historical solutions to ambient climatic conditions, such as adobe construction in desert regions (see Chapter 3, Section 3.2 and Chapter 4, Section 4.9).

### 12.5.2 The Building Envelope

The building envelope serves as the interface between the uncontrollable natural environment and the internal building environment, which is desired to be maintained within quite narrow boundaries. While the external environment can be characterized based on statistical data that have been collected over a considerable number of years, the resulting profile does not tell us much about the local micro-climate and the sudden short-term weather changes that can radically deviate from the average regional conditions.

The traditional approach to the design of the building envelope has been to reduce the flow of heat out of the building by embedding thermal insulation in the envelope and to control the heat flow into the building by means of sunshading devices or by treating the building envelope as a heat sink that will shield the desirable constant comfort conditions of the interior building spaces from the diurnal temperature swings of an external arid climate. In the US, since the oil embargo of the 1970s, government building codes have placed the emphasis on thermal insulation and the prevention of air infiltration and heat leakage through the envelope.

Roof overhangs and other sunshading devices are used to shield the envelope and the building interior from direct solar radiation or in colder climates to control the amount of solar radiation that is permitted to penetrate into the building interior as a natural source of heat. While manually movable and automatically controlled sunshading devices have been commercially available for many years, their use in buildings is only gradually becoming prevalent. For various reasons, including cost and maintainability, fixed sunshading devices are still prevalent. Manually openable windows and internal blinds are still by far the most common and preferred form of natural thermal and daylighting control in low to mid-rise buildings.

Fortunately, this leaves considerable scope for the implementation of the far superior thermal control strategies that will be required to meet the future objectives of sustainable architecture in terms of energy-neutral and net energy export buildings. First, thermal insulation will need to be considered as a dynamic rather than static approach for achieving energy efficiency. It should be possible to automatically generate thermal insulation on a near real-time basis as external climatic conditions change[11]. This will require the development of new *thermal insulation on demand* technologies that are tightly coupled with external electronic monitoring devices. Second, the level of fine tuning required to achieve very high degrees of energy efficiency mandates the continuous monitoring of internal and external environmental conditions. The necessary technology to support the precise monitoring of temperature, humidity, air movement, radiation, precipitation, and air quality, has been commercially available at relatively low cost for more than a decade. Third, the same level of monitoring and precision will need to be applied to the control of sunshading devices. Much headway can be made in this area by simply taking advantage of existing electronically controlled devices before considering more elaborate technologies, such as the ability of a building or portion of a building to change its configuration in unison with the movement of the sun. This can be achieved by rotational movement or by components of the building receding or protruding in response to changes in external and internal thermal conditions (Fisher 2009).

[11] In 1967 Laing proposed an approach for generating *thermal insulation on demand* through multi-layered membranes in which the width of interstitial air cavities is controlled by either electrostatic or pneumatic forces (Feder D. (ed.) (1967), Proceedings of the 1st International Colloquium on Pneumatic Structures, IASS, University of Stuttgart, Stuttgart, Germany, (pp. 163-179)).

The ability of a building to change its configuration in direct response to environmental changes or occupant desires is a more complex issue than would appear at face value. It is certainly not just dependent on innovation and design ingenuity. What will be required is a paradigm shift in attitude of both the building designer and the building owner or occupant. In addition, the construction industry will be required to respond with new manufacturing methods and processes. As buildings become more dynamically responsive to short-term changes in conditions, they will necessarily also become more dependent on mechanical and electronic capabilities. This will require a shift from on-site construction to factory production of integrated prefabricated modules and entire buildings. The building owner will need to be prepared to accept a building on terms similar to a manufactured car. Such a paradigm shift will occur only if driven by the strongest forces (e.g., potential economic loss or threat to human life) to overcome the natural human aversion to change. Finally, the designer will need to be able to cope with the increasing complexity of the resultant design solution. This is not just a matter of academic preparation and experience, but more importantly the ability of the designer to apply sufficient technical depth and breadth to the development of the design solution. Such an ability will increasingly depend on the availability of an arsenal of readily accessible and seamlessly integrated design tools.

### 12.5.3 Hot Water Systems

In building types where bathing and showering, washing clothes, or cooking are principal activities there is a relatively heavy demand for hot water. This includes health club facilities, drycleaners and laundromats, restaurants, and also residences. The two methods that have become quite prevalent in recent years for providing hot water under energy conservation constraints are solar and tankless hot water services.

The concept and implementation principles of a *solar hot water service* are quite straightforward and have been described in more detail in Chapter 5. The heat collector typically consists of a flat metal plate with a matt black finish that sits on top of a set of closely spaced pipes through which water is circulated. By inclining the flat plate at a fixed slope that is as close as possible to maintaining a 90° angle to the rays of the sun during the major part of the day, the plate transfers much of the collected heat to the water circulating on its underside. Assuming a high degree of thermal insulation, applied to the sides and bottom of the collector, the efficiency of such an active solar collector varies from approximately 20% to 70% depending on the number of glazings (i.e., none, single, double, and triple) and the temperature differential between the incoming water and the collector plate. The greater the temperature differential the more efficient the heat transfer between the plate and the circulating water.

In most cases a solar hot water service will require a storage facility and since water has very limited thermal stratification properties the storage facility will often consist of two tanks, a large tank and a small tank. The larger tank will at most times be at a temperature that is not sufficiently high for direct usage, while the smaller tank will be at a higher temperature. This requirement would not exist in the case of a solar collector system in which the heat transfer medium is air instead of water, because the associated rock storage facility has excellent heat stratification properties. However, the additional requirement of transferring the heat from the air medium to the water that will be used will normally favor a water-based solar collector solution.

The *tankless hot water service*, as implied by its name, does not require a heat storage facility. It is based on the concept that water can be rapidly heated at the time that it is required. The heating facility is activated by the flow of water that occurs as soon as the hot water faucet or valve is opened. If the heating facility has been sized correctly, based on the volume of hot water required at the time that it is activated, then the tankless system will deliver a constant and endless amount of hot water at the desired temperature and flow rate. The two alternative heat sources that are readily available to deliver the fairly intense amount of heat that is required to raise the temperature of the water on such an instantaneous basis are electricity and gas. While gas would appear to be the more energy conservative heat source, its efficiency is significantly lowered unless the need for a pilot light can be avoided through alternative technology.

Virtually all hot water services, including solar and tankless hot water services, suffer from a potential heat and water wastage problem. The location of the hot water tank or heat source in the case of a tankless facility is typically at some distance from the point of delivery (e.g., faucet or valve). This means that for the hot water to reach the point of delivery it has to fill the entire length of the pipe from the source to the delivery point. After the faucet or valve has been closed the hot water remains in that section of the pipe and gradually cools down, even though the pipe may be well insulated. Later, after an appreciable time interval, when the faucet or valve is opened again the standing volume of water between the heat source and the delivery point is wasted unless special provisions are made for its collection and recycling. In a tankless system this problem can be avoided only if the heat source is placed in very close proximity of the outlet. This tends to be expensive if there are multiple outlets at some distance from each other, requiring several tankless hot water installations.

### 12.5.4 Daylight and Artificial Lighting

Daylight is an abundantly available resource on most building sites. However, its effective utilization for the lighting of interior spaces is not without challenges. First, the actual amount of daylight available varies from hour to hour during the day as the sun appears to move across the sky from east to west[12]. Second, the variations in daylight can be even more radically and suddenly influenced by cloud conditions. Third, although we consider the sky to be the source of daylight, it is the sun that lights up the sky. Therefore, particularly under clear sky conditions the sun will greatly influence the brightness of the sky in its vicinity. Accordingly, the brightness of the portion of the sky seen through a window could vary greatly with the time of day. Fourth, because the sky is likely to be much brighter than the interior building spaces, side windows acting as an interface between external and internal daylighting conditions can easily become a source of glare. Finally, to optimize energy consumption we need to control the transmission of light and heat separately. Fortunately, in recent years much headway has been made in the manufacture of window glass with low-emissivity (Low-E) coatings[13]. Low-E glass can reduce heat transfer by more than 50%, while reducing the visible transmittance by less than 25%.

The balancing of these somewhat conflicting considerations can be a complex undertaking. This is particularly true in cases where there is a desire to maximize the amount of daylight in deep

---

12 This is of course an illusion. The sun appears to move across the sky when viewed from Earth. In fact, planet Earth rotates around the sun.

13 See Chapter 3, Section 3.3 for a more detailed explanation of Low-E glass.

rooms with minimum ceiling heights. In such rooms there will be a considerable difference between the light levels at the window and in the rear of the space, giving rise to glare conditions. While light shelves can mitigate this condition by reflecting some of the superfluous light at the window into the rear of the room, they typically provide only a partial solution. An alternative and complementary approach is to utilize artificial lighting to reduce the brightness differences in the room by gradually increasing the artificial light level from a minimum required illumination level in the rear sections to whatever level is required to eliminate glare conditions at the window. This approach, referred to as Permanent Supplementary Artificial Lighting of Interiors (PSALI)[14], provides visual comfort at the expense of increased energy consumption and is particularly wasteful of energy in regions where clear skies predominate.

While every effort would be made by the designer to maximize the availability of daylight in a *green high-performance* building, some degree of artificial lighting is likely to be necessary even during daylight hours. Therefore, after ensuring that all daylighting opportunities have been fully exploited, any additional efforts to reduce the energy consumed by lighting will rely largely on advances in artificial light source technology. As discussed previously in Chapter 8 (particularly Section 8.2), most existing artificial light sources are quite inefficient. For example, the light production efficiency of a fluorescent lamp is only about 20%. Although this is three times the efficiency of an incandescent lamp, in the context of *sustainability* it must still be considered as being unacceptably low. Considerably more efficient artificial light sources will be required to achieve the order of reduction in building post-occupancy energy consumption that is postulated by *Factor 10*, or even *Factor 4*.

Perhaps the most promising candidate for increasing the efficacy[15] of artificially produced light is the Light Emitting Diode (LED) that is based on electroluminescence principles. The ability of a semiconductor diode to emit light when it is subjected to an electric current was first observed by the Russian engineer Oleg Losev (1903-1942) in the mid-1920s (Zheludev 2007). However, it was not until the early 1990s that the Japanese firm Nichia Corporation invented the first high brightness indium gallium chip that was able to produce white light through the wave shift provided by a phosphor coating. Although the efficacy of current commercially available LED light sources is only in the 20 to 30 lumen/watt (lm/w) range, which is barely comparable with fluorescent lamps, much higher efficiencies are likely to become available in the near future[16]. In 2006, the US firm Cree Inc. (Durham, North Carolina) demonstrated a white LED with an efficacy of 131 lm/w. At the writing of this book (2009) Cree is marketing the XLamp (XR-E R2) white LED with a tested efficacy of 100 lm/w[17].

---

[14] See Chapter 8, Section 8.7 for a more detailed explanation of the PSALI concept.

[15] Efficacy defines energy efficiency in terms of the light flux (lumen) produced per electric power (watt) consumed (i.e., lumens/watt).

[16] However, there are some technical barriers that have to be overcome before the full potential of LED lighting can be realized. For almost a decade researchers have been trying to understand why the efficiency of blue light-emitting diodes drops off sharply with increasing current (Stevenson 2009). This phenomenon, referred to as *droop*, currently defies explanation with several competing theories under discussion. It is one reason why LED technology has been used most effectively in low power applications such as the backlit screens of mobile telephones and indicator panels.

[17] Based on 20,000 hours of continuous testing, Cree Inc. estimates that the brightness deterioration of the XR-E series of LED lamps is about 30% over a life span of 50,000 hours.

While the application of LEDs was initially limited to indicators and signs (e.g., digital equipment displays, traffic lights, signs, and vehicle brake lights) they are now increasingly incorporated in the lighting schemes of building interiors. Particularly attractive from a *sustainability* point of view are the 50,000-hour life of LEDs, their relatively high efficacy, their lower carbon dioxide emission[18], and their non-toxicity. However, LEDs also have some disadvantages. Primary among these are their high initial purchase price, their sensitivity to higher ambient temperatures in the operating environment, and potential health risks. There is some concern that with increasing efficacy blue and cool-white LEDs will exceed eye safety limits in respect to the blue-light hazard.

### 12.5.5 Active Heating, Cooling, and Ventilation

After exploiting every opportunity for the application of passive building design principles the need for active heating, cooling and ventilation requirements will be at least minimized. However, even in the mildest climatic regions the need for HVAC systems will persist in most commercial buildings and many mid to high-rise apartment complexes. The question then arises: What strategies can be applied to reduce the energy consumption of HVAC systems?

***Electric Motors:*** The answer begins with consideration of the power unit that normally drives the distribution of air in buildings that utilize either a partial or full HVAC system. The electric motor typically consumes energy each year at a cost that is many times over its initial purchase price. For example, an electric motor driving a fan fairly continuously for one year is likely to cost more than eight times its purchase price in the consumption of electricity.

Both improvements in the efficiency of the motor and the equipment that it drives can save energy. For example: large-diameter copper wire in the stator can reduce resistance losses; thinner steel laminations in the rotor will reduce magnetization losses; and, high quality bearings will reduce friction losses. While the increase in overall efficiency of a high-efficiency electric motor may not exceed a standard model by more than 5%, even this apparently small increase in efficiency can lead to an appreciable energy saving over time if the motor is in continuous operation.

It is important to note that electric motors perform most efficiently at or near full load. Therefore, the size of the motor should be determined on the basis of the expected load without making allowance for possible future increases in load. This is in conflict with noise control strategies discussed in Chapter 11 (Section 11.6.1) that call for the operation of air distribution fans at less than full capacity. We must expect such conflicts between different design objectives to arise quite frequently over the next several decades as *sustainability* considerations increase in priority. The resolution of these conflicts, apart from further increasing the complexity of the design process, will depend largely on technical innovation and design ingenuity.

***Chiller Plants:*** The chiller component of air-cooling systems is the largest energy user in commercial buildings, accounting for more than 20% of the total building energy consumption. The impact of the chiller is exacerbated because its greatest energy

---

[18] While a 40-watt incandescent lamp will generate about 196 pounds of carbon dioxide per year, a 13 watt LED with comparable light output will produce only about 63 pounds of carbon dioxide per year.

consumption normally occurs during the day and therefore coincides with peak electric power demand. In addition, there are two design considerations that mitigate against achieving an energy efficient chiller plant solution. First, it is a well-established engineering design practice to oversize cooling systems for fear that assumed loads may be exceeded during the life span of the HVAC installation. Second, while chillers have to be designed for peak loads, they operate most of the time under part-load conditions. To compound matters, just as in the case of electric motors, chillers also operate at their greatest efficiency when they are operating at maximum capacity.

Driven partly by building codes and market forces manufacturers have been addressing the energy efficiency of chillers through the incorporation of new technologies such as direct digital control and variable frequency drives. However, the selection of the most energy efficient chiller plant for a given set of building design conditions can be a complicated undertaking requiring a great deal of engineering expertise. Based on the ratio of cooling power to input power, water-cooled rotary screw or scroll type chillers are more than twice as efficient as electrically operated air-cooled chillers. However, a water-cooled chiller requires a cooling tower to dissipate the heat absorbed from the building interior. While absorption chillers have a much lower cooling power to input power ratio, they could utilize the heat recovered from other plant components (e.g., solar energy) to significantly increase their overall energy efficiency.

***Air Distribution:*** The energy efficiency of an air distribution system depends largely on the ability to deliver no more than the required quantity and quality of air to all parts of the given building domain, under often greatly varying operating conditions. US government guidelines for federal buildings suggest the following design approach for energy efficient air distribution systems (DoE 2006):

1. Use variable-air-volume systems in preference to constant volume systems to deliver the precise volume of air, based on actual loads, to each building space.
2. Use local variable-air-volume diffusers with individual temperature control to allow for temperature variations within multi-room zones.
3. Size fans based on actual loads and use electronic controls to match fan speed and torque with variable load conditions.
4. Use a displacement ventilation system to reduce or eliminate the need for ducting by feeding the conditioned air through a floor-plenum and returning the used air through a ceiling plenum.
5. Use low-face velocity air handlers to take advantage of the ability to reduce the air velocity, due to increased coil size. Since the pressure drop across the coils decreases with the square of the air velocity, smaller fans and variable frequency drives as well as slightly higher chilled water temperatures will be acceptable. The savings in capital costs together with the downsizing of the chilled water plant can be significant.
6. Increase the duct size and avoid sharp turns to reduce duct pressure drop and fan size. Since the pressure drop in ducts is inversely proportional to the fifth power of the duct diameter, the savings in energy that can accrue from relatively small increases in duct size are appreciable.

***Energy Recovery:*** Air conditioning systems have a mandated requirement for fresh air, which means that as much as 50% of the conditioned internal air is replaced by unconditioned external air. This can be a considerable energy cost, particularly in hot or cold climates. For example, on a hot-humid summer day external air may be at a temperature of 90°F with a relative humidity of more than 90%. At the same time the conditioned internal air that is being exhausted from a building may be at a temperature of 78°F with a relative humidity of less than 60%. Under these conditions the preconditioning of the incoming external air with the outgoing internal air should result in considerable energy savings. The same applies in the case of a cold winter day, where the cold external incoming air can be preheated by the conditioned outgoing air. Also, it should be possible to use external air directly for conditioning the building whenever the external climatic conditions are close to the thermal comfort zone.

Technologies that are available to take advantage of these energy saving opportunities include economizers and energy recovery ventilators. Economizers are designed to monitor external conditions and shut down those components of the HVAC plant that are not required to operate at any particular time and then reactivate these components as external conditions become less favorable. The difficulties encountered with this concept are virtually all related to operational failures that can lead to significant energy wastage. Common failures include corroded dampers that stick in place, failure of temperature sensors, and failure of actuators. Past surveys have indicated that less than 50% of economizer-based systems may be operating correctly after several years of use.

Energy recovery ventilators are essentially heat and humidity exchangers that are placed between the conditioned outgoing air and the unconditioned incoming air. They are usually in the form of a fairly large diameter rotating wheel made of a thermally highly conductive material, such as metal. The wheel is actually a disk with a desiccant material inside it. The desiccant bed is responsible for drying the air and the metal enclosure is responsible for the heat transfer during the air exchange. The technology is mature and not subject to the kind of operational failures that have plagued economizers.

***Radiant Cooling:*** The concept of cooling a building space with air incorporates some intrinsic inefficiencies. Since air has a very low heat capacity and is highly compressible relatively large volumes of air are required to cool a space and a considerable amount of energy is required to move the air to the space. Water, on the other hand, has a high heat capacity and is incompressible. It can be moved (i.e., pumped) with the expenditure of relatively little energy. Therefore, radiant cooling systems that circulate water through tubes that are embedded in floor, wall and/or ceiling elements, have started to be viewed as a more energy efficient alternative to forced-air cooling systems.

***Ground-Coupling:*** At even fairly shallow depths in any but the coldest climates the temperature of the earth and groundwater below the surface of the building site remains relatively stable. This provides an opportunity for using the ground as a heat sink for cooling and as a heat source for heating a building. Both horizontal and vertical ground-coupling systems are possible. In horizontal implementations pipes are placed in trenches in a single or multiple pipe arrangement. More effective are vertical systems in which pipes are placed in bore holes that reach down to the groundwater table. Alternatively, it is possible to bring external air into a building through relatively large-diameter (3 to 6 feet) underground pipes. In addition, hybrid systems that combine the direct ground-coupling approach with the indirect vertical or horizontal strategy are possible. All of these are variations of the same concept, namely to use the natural thermal inertia of the ground to maintain constant thermal conditions inside a building with the objective of minimizing the energy required for air conditioning.

## 12.6 Water Conservation Strategies

While much of the early interest in *green high-performance* buildings has focused on energy conservation, within the next two decades and perhaps sooner the attention may shift to freshwater as an even more important resource. Water is critical for human survival and although four fifth of the Earth's surface is covered by water less than 3% of that enormous amount of water is freshwater. Almost 90% of freshwater is essentially unavailable in the form of ice and snow, as glaciers. In most parts of the world freshwater is being withdrawn at a much faster rate than it can be replenished. There are many examples of serious freshwater depletion, such as: reduction of the size of the Aral Sea in Russia by 75% in the 20-year period between 1960 and 1980, due to the Soviet collective farms program for the production of cotton; the annual withdrawal in some regions of the US (e.g., Arizona) of twice as much water as is being replaced by rainwater; and, the severe water shortage being experienced by 90% of the population in West Asia. In the US, even though the population is continuing to grow at a steady rate, the water consumption has leveled off since the mid-1980s. However, despite this per capita reduction there are clear signs that the annual withdrawal of around 400 billion gallons of water is not sustainable.

More than 80% of the water consumption is for agricultural purposes. Therefore, the leveling off of the water consumption in the US is more than likely due to slight improvements in irrigation systems. However, it is estimated that more than 50% of irrigation water is still wasted due to evaporation, leaking canals, and mismanagement.

Water is also a major factor in respect to public health and hygiene. Waterborne diseases such as typhoid, cholera, and dysentery are responsible for the deaths of over 2 million persons each year (Gleick 2002, Hunter et al. 2000, Hunter et al. 1997). Much of this is due to a lack of water treatment plants in developing countries. Consequently, raw sewage is dumped into rivers at an alarming rate, For example, 300,000 gallons are dumped into the Ganges River in India every minute (Kibert 2005, 245). It is estimated that only 35% of wastewater is treated in Asia and less than 15% in Latin America. According to a 2000 survey by the World Health Organization more than 1.1 billion people around the world lack access to safe freshwater and more than 2.4 billion lack access to satisfactory sanitation (WHO 2000).

### 12.6.1 Water Consumption Goals

The World Health Organization has defined the daily water requirements for bare survival to be 0.5 to 1 gallon per person for drinking and another 1 gallon per person for food preparation. However, for maintaining a reasonable quality of life the US Agency for International Development (USAID) suggests a much higher requirement of 26.4 gallons per person per day. The current daily consumption of water in the US is estimated to be in the vicinity of 100 gallons per person. If we add the use of water for agricultural and industrial purposes then that estimate increases the US per capita figure to around 1,800 gallons per day.

Buildings account for approximately 12% of the total freshwater withdrawal. Although this is a relatively small fraction of water usage when compared with the 80% consumed by agriculture, it still represents a meaningful target for water conservation measures. The building hydrologic cycle, which includes the irrigation of landscaping and the management of stormwater, is currently very wasteful. For example, the irrigation of landscaping is typically accomplished with potable water from sprinklers or handheld hoses, toilets are flushed almost exclusively with potable water, and the majority of residential buildings have one or more dripping faucets.

Clearly, the prospects for reducing the use of potable water in buildings and introducing water treatment facilities are quite favorable. As a starting point this will require architects to become familiar with the differentiation of the common term *water* into its multiple forms within the building hydrologic cycle (TGF 2009).

***Potable Water:*** Water of a quality suitable for drinking. It is either untreated (e.g., from a water well) or has been filtered, tested and possibly mixed with certain chemicals (e.g., fluoride) prior to release into a municipal water system.

***Freshwater:*** Naturally occurring water that contains by definition less than 500 parts per million of dissolved salt. While freshwater is found in naturally occurring lakes, rivers, and underground aquifers, the source of almost all freshwater is precipitation from the atmosphere in the form of mist, rain, and snow.

***Rainwater:*** Water that is collected during rainfall. Rainwater is typically collected on the roof and used directly for landscape irrigation or subjected to purification treatment prior to use as potable water.

***Groundwater:*** Water found below the surface of the ground in aquifers, underground rivers, and between soil particles.

***Graywater:*** Water from showers, bathtubs, kitchen and bathroom sinks, hot tub and drinking fountain drains, and washing machines.

***Blackwater:*** Water containing human excreta, such as wastewater from toilets.

In the US the Energy Policy Act of 1992 (EPAct) requires all plumbing fixtures to meet specific water consumption standards, as follows:

Table 12.2: EPAct water usage standards for plumbing fixtures

| Plumbing Fixture | Maximum Flush and Flow Requirements |
|---|---|
| water closets (toilets) | 1.6 gallons per flush |
| urinals | 1.0 gallon per flush |
| showerheads | 2.5 gallons per minute at 80 psi water pressure<br>2.2 gallons per minute at 60 psi water pressure |
| faucets | 2.5 gallons per minute at 80 psi water pressure<br>2.0 gallons per minute at 60 psi water pressure |
| replacement aerators | 2.5 gallons per minute |
| metering faucets | 0.25 gallons per cycle |

While these standards (Table 12.2) constitute a welcome increase in code requirements, *green high-performance buildings* will generally improve on them by employing strategies such as specifying ultra-low-flow fixtures and drought-tolerant landscaping plants that require minimal or no water[19]. The cost benefits of these strategies can be determined on the basis of a fairly simple life-cycle cost (LCC) analysis that may consider only the cost of potable water. A more detailed and complex LCC would also take into account reductions in the energy required to move and treat both wastewater and potable water.

Based on Kibert (2005, 250-251), the following additional steps for developing a building hydrologic design strategy are suggested:

Step 1: Selection of the appropriate water source (i.e., type) for each purpose. Potable water should be used only for human consumption such as drinking, cooking, washing, and cleaning.

Step 2: For each water usage the technology that ensures minimum water consumption should be employed. For example, the specification of low-flow and no-flow fixtures, as well as sensors for control purposes.

Step 3: Consideration of the implementation of a dual wastewater system that will automatically separate graywater from blackwater as a prerequisite for water treatment and recycling.

Step 4: Consideration of the implementation of a wastewater treatment facility. For example, at the very least consideration should be given to the provision of a constructed wetland[20] to process effluent.

The primary objective of the hydrologic design strategy is to minimize the consumption of potable water by reducing the flow rate of plumbing fixtures and finding ways of recycling wastewater for all uses that do not require potable water.

### 12.6.2 Lower Flow Rate Fixtures

If we consider plumbing fixtures that comply with the EPAct of 1992 to be low-flow fixtures then plumbing fixtures that exceed these standards can be referred to as ultra-low-flow fixtures. The kinds of plumbing fixtures that are becoming increasingly available as commercial products in the ultra-low-flow category are dual-flush toilets and electromechanical flush toilets. The dual-flush concept is based on the recognition that the most frequent use of toilets is for urinating, which requires a much smaller volume of water for flushing. Electromechanical flushing systems incorporate electrically powered pumps and compressors that require less than 1 gallon of water to remove blackwater under increased pressure.

Relatively new technologies, such as chemical toilets that use no water at all and composting toilets are still relatively rare and generally not yet considered suitable for normal building

[19] Also referred to as *xeriscaping* or *xerogardening*, which is an environmentally friendly form of landscaping that relies on the use of indigenous and drought-tolerant plants, shrubs, and ground cover.

[20] An artificially constructed wetland is a landscaping area that is saturated by wastewater and takes advantage of natural processes involving soil development and plant growth.

application. However, the technology for waterless urinals has matured to the point where office, school, and recreational facility applications are not only feasible but economically attractive. A waterless urinal utilizes an odor trap with a biodegradable oil that allows urine to pass through, but prevents odors from escaping into the restroom.

Showerheads that reduce the flow rate to between 1.0 and 2.5 gallons per minute and provide adjustable spray patterns have been commercially available for some time. What is required in addition are technologies that will eliminate the wastage of water that occurs during soaping and while waiting for hot water to reach the showerhead or faucet from the hot water source. Manual and electronic controls could eventually solve part of this problem, but are unlikely to overcome the hot water delay issue. It appears that the latter will require a different solution approach.

### 12.6.3 Graywater Systems

The key requirement for graywater management is the separation of graywater from blackwater at the origin, before the two are mixed. This requires a dual waste-pipe system that collects the graywater and carries it to a holding tank in a central location. Once that first step has been taken several additional second step options are available. The graywater can be pumped directly to an irrigation system for landscape maintenance purposes, or it can be treated and then recycled within the building.

Some municipalities already provide reclaimed water to buildings. In these cases, consideration should be given to the converse possibility of sending all or a portion of the graywater produced in the building to the municipal wastewater treatment plant. If piping already exists for the delivery of reclaimed water from the municipal plant to the building, then the provision of piping for the transmission of graywater from the building to the plant is worthy of consideration. Certainly, in the future such two-way piping connections, at least between larger buildings and municipal wastewater treatment plants, are likely to become available. To achieve *Factor 10* water and energy conservation goals the greater efficiency that should be able to be realized in larger scale water treatment plants is likely to be necessary.

### 12.6.4 Rainwater Capture

Rainwater harvesting systems have been used in rural communities when a municipal water system is not available and well-water is fragile or scarce. Such systems have been used extensively in Australia for many years and in the more arid states of the US such as Texas, but are mostly confined to single-story buildings (Texas-WDB 1999). The principal components of a rainwater harvesting system include:

- A large *catchment area* such as the roof of a building. Since the roof area has to be quite large rainwater systems are typically limited to low-rise buildings. Metal roof surfaces are most suitable because they are smooth and provide less opportunity for the growth of algae, mold, and moss.
- A *roof-wash system* that prevents the initial run-off during rain from being collected. In other words, the initial run-off is sacrificed for purposes of cleaning the surface of the roof.
- Protection of open inlets with *pre-storage filtration devices* such as stainless steal

screens, to prevent leaves and other debris from entering the storage tank. Depending on site conditions this may have to include leaf guards over gutters.

- A *storage tank* that is large enough to supply sufficient water in between rainfalls. The tank may be located inside the building or external to the building and normally constitutes the most expensive component of the system.
- A *booster pump* to deliver the water under pressure (ideally at least 60 psi) from the tank to the point of use. Seldom is a gravity feed arrangement possible, because the tank would need to be at least 60 feet above the point of use[21].
- A *water treatment facility* to protect plumbing and irrigation lines. Such a facility typically consists of a filtration unit to remove particulates in the case of graywater uses and a considerably more sophisticated treatment unit in the case of potable water uses (e.g., microfiltration, reverse osmosis, ozonation, ultra-violet sterilization, chemical treatment, or any combination of these).

Since rainwater, like solar energy, is readily available in virtually all regions it presents an opportunity for taking advantage of a natural source of water. Therefore, it is likely that *green high-performance buildings* will in coming years increasingly incorporate rainwater harvesting systems.

## 12.7 Closed-Loop Building Materials

While the concept of closed-loop building materials is sound and highly laudable, a comprehensive implementation of this concept based on the current body of knowledge does not appear to be feasible. As mentioned previously in Section 12.3.6, the definition of embodied energy is very broad and includes not only the energy consumed during the extraction of the raw materials. It also includes the energy used during the transportation and initial processing of the raw material, the preparation of the final construction material or product, the marketing and distribution of the material or product, and the transportation to the building site. The current barriers are numerous.

***General Variations:*** The embodied energy of a material or product varies from country to country and with time. Factors that influence this variation include the quality of the raw material, the climate, processing methods, age and type of plant, distances between extraction, production and construction sites, and transportation modes.

***Transportation Modes:*** The proportion of energy consumed by transportation depends not only on the transportation mode but also on the weight (i.e., density) of the raw material. For example, according to Adalberth (1997) the transportation component of embodied energy accounts for 5% to 10% of the manufacturing energy. To arrive at this estimate he assumed 2.7 MJ/km[22] for distances less than 50 km and 1.0 MJ/km for distances greater than 50 km, 0.5 MJ/km for coastal vessels, and 0.2 MJ/km for ocean vessels.

---

[21] A 60 feet height difference would result in a water-head due to gravity of a little under 30 psi.

[22] Mega joules per kilometer (MJ/km). For conversion to American units of measurement 1 MJ/km is approximately equivalent to 592.4 BTU/mile or 0.174 kWh/mile or 149.3 Cal/mile.

***Units of Measurement:*** The units of measurement for embodied energy have not been internationally standardized to date (2009). Some sources provide their data per material volume ($MJ/m^3$) and others per material mass (MJ/kg). For example, the embodied energy for bricks is given in volumetric terms ($MJ/m^3$) in Australia and in weight terms (MJ/kg) in Germany, while the US first published brick data per volume in 1967 and then changed to per mass in 1996. Although the US has not generally changed to the metric system of units, it has adopted metric units for embodied energy values[23]. A comparison of embodied energy by volume and mass is shown in Figure 12.3 and Table 12.3 (Heidrich 1999). The data based on volume provide a clearer impression of the amount of energy that would be embodied in a building constructed of these materials.

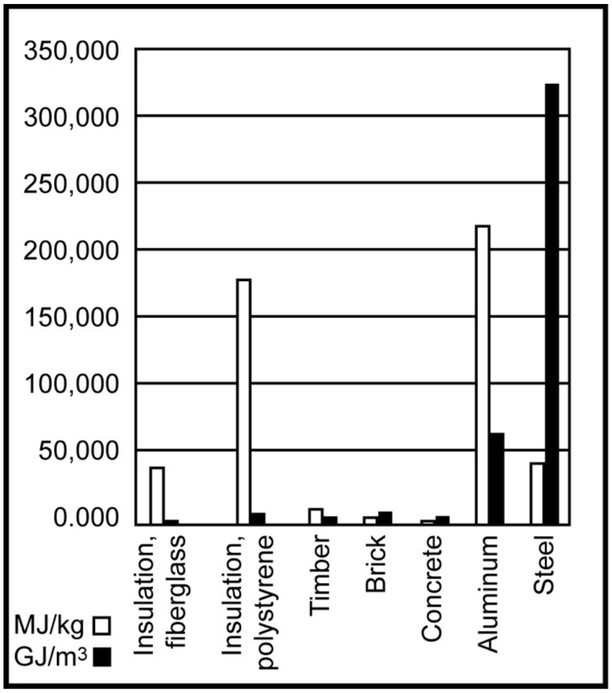


Table 12.3 Embodied energy in volume and mass

| Material | MJ/kg | $GJ/m^3$ |
|---|---|---|
| Insulation, fiberglass | 35.360 | 0.460 |
| Insulation, polystyrene | 177.240 | 4.254 |
| Timber | 6.230 | 3.425 |
| Brick | 3.480 | 5.918 |
| Concrete | 1.020 | 2.346 |
| Aluminum | 214.270 | 58.067 |
| Steel | 39.040 | 305.800 |

Figure 12.3: Volume versus mass (Source of Figure 12.3 and Table 12.3 is: Heidrich 1999)

***Continuous Change:*** Industry is continuously striving for greater energy efficiency and has achieved significant reductions over the past several decades. In 1993 Cole reported the following substantial improvements: chemical industry (40%); iron and steel (8%); cement (27%); glass (33%); petrochemicals (39%); textiles (26%); and, wood products (39%). Therefore, to maintain at least a reasonable level of accuracy embodied energy values for materials and products need to be updated on a regular basis.

***Assessment Complexity:*** Virtually all of the individual components that make up the total embodied energy of a material or product, from extraction through production to on-site delivery, are difficult to assess because of the number of variables involved and the indefinite nature of most of those variables. For example, the methods used in the

[23] The prevalent units of measurement for energy in the American system are British Thermal Unit (BTU), Kilowatt Hour (kWh), and Calorie (Cal). In respect to embodied energy the conversion factors from metric to American units are as follows: 1 $MJ/m^3$ = 26.84 BTU/$FT^3$ = 0.0079 kWh/ $FT^3$ = 6.762 Cal/ $FT^3$; and, 1 MJ/kg = 429.9 BTU/LB = 0.126 kWh/LB = 108.5 Cal/LB.

growth, extraction and preparation of structural timber can vary widely not just from country to country but even within the same country. If the source of the timber is a plantation forest, then large quantities of fertilizers, herbicides and water may have been used to accelerate the growth cycle. The accessibility of the timber source will be a major factor in determining the type of equipment used and the energy cost incurred in hauling the rough timber logs to the sawmill for initial preparation.

The first step in determining the embodied energy of a material or product is to establish the boundaries for each component stage in the path from extraction to delivery to the construction site, including the boundaries of the overall end-to-end process. The wider the overall boundaries are drawn, the more complex the process and the less definite the outcome.

### 12.7.1 Methods for Determining Embodied Energy

Several methods have been used to determine the embodied energy of materials and products. Due to the factors discussed in the previous section, the results obtained by the application of two or more different assessment methods to the same material can vary widely (Chapman 1974). If the energy measurements are in terms of primary sources such as coal or crude oil, then the loss of energy during conversion to electricity should be considered. Therefore, in countries using mostly hydroelectric power the embodied energy will be lower than in countries that depend mostly on fossil fuel as the primary source of energy. In the case of nuclear power, the boundaries drawn for assessment in respect to the period of maintenance of the power plant and the management of the nuclear waste material can have an appreciable impact on the end result. The following four assessment approaches are described in the literature.

***Process Analysis:*** This approach considers both direct and indirect energy consumptions. Direct energy refers to the energy that is directly related to a particular process. For example, the energy used in a smelter during the manufacture of steel is considered to be direct energy. The direct energy component can normally be determined with a fairly high degree of accuracy. However, the indirect energy consumed during the extraction of the iron ore, transportation, and the manufacture of the equipment and facilities used during the production of steel, requires many assumptions to be made. As a very general rule of thumb Baird et al. (1984) have suggested that approximately 40% of the embodied energy is consumed during extraction, 50% during manufacture, and 10% for the equipment employed. This method is time consuming because of the level of detail required for a complete analysis. It can be argued that the effort involved is not justifiable due to the potential vagueness of the assumptions that have to be made in the analysis of the indirect energy component.

***Input-Output Analysis:*** This method is based on examination of national financial data that track the flow of money in and out of the energy consuming and producing sectors. In this way the monetary output value of each sector can be equated with the energy consumed by that sector. The results tend to be superficial, because they are based on industry groups rather than individual material types or products.

***Hybrid Analysis:*** This method attempts to combine the process analysis method with the input-output method. Starting with the data that are readily available, such as the information relating to material preparation or product manufacturing processes, the method proceeds with process analysis. When the readily available data have been exhausted the hybrid approach switches over to the input-output method. The quality of the results depend on how much of the less granular input-output data had to be used.

***Statistical Analysis:*** This approach relies on published statistical data relating to the energy profile of a particular industry (i.e., energy consumption and industrial output). Similar to the input-output method, the analysis is based on industry groups rather than a particular material or product. It therefore lacks detail. However, order of magnitude estimates can be rapidly generated.

Clearly, these methods are only approximate. While the process analysis method has the potential of providing fairly accurate results for the direct energy component, it suffers from the same problem as the other three methods in respect to the indirect energy component. From this point of view all four of the methods are useful for indicating trends and identifying materials that should be avoided because of their relatively high embodied energy, rather than determining precise embodied energy values.

### 12.7.2 Deconstruction and Disassembly

The need to consider the recycling of all of the materials that have been used in the construction of a building at the end of the life span of that building is an onerous requirement. Historically, building components such as the structural frame, external and internal walls, floors, and ceilings, have not been designed for disassembly. Buildings are typically custom designed and the manufacturing industry has found ways to adapt to an increased desire for customization without any appreciable cost increase. This has been made possible by computer-controlled manufacturing that allows for customization during a mass production process. While this serves the interests of the customer it complicates the reuse of building components. For example, the customization of window sizes makes it very difficult to recycle complete window units. The availability of the required number of reusable window units would need to be known at the design stage of a new building. With the very large variation in window sizes and configurations such a dependency between new construction and the deconstruction of existing buildings is not commercially viable.

The life span of a building is normally not predictable and can often exceed 50 years. In fact, one of the criteria of the *green* building movement is to consider the renovation or remodeling of an existing building in preference to the construction of a completely new building. For example, LEED New Construction 2009 allocates 4 points to building reuse under the Materials & Resources category (LEED 2009). Over such a relatively long-life span deconstruction and recycling assumptions that were made at the design stage may no longer be applicable at the final deconstruction stage. Few would argue with the notion that profound technologic, economic, and societal changes are occurring at an increasing rate.

Given the indefinite nature of some of the issues involved the concept of deconstruction and disassembly requires careful consideration at the building design stage. In his doctoral thesis Crowther (2002) suggests a framework of 27 principles for considering deconstruction at the building design stage. The proposed framework can be divided into several categories of considerations:

***Overall Design:*** Adopt a modular design approach that includes prefabricated subassemblies within a clearly defined grid layout. The design emphasis should be on an open building system that provides flexibility through interchangeable components.

***Material Selection:*** Reduce the number of different types of materials and place the emphasis on existing materials that have been recycled and can be again reused after deconstruction. In addition, criteria for material selection should include the avoidance of toxic and hazardous materials, as well as composite materials that cannot be easily separated into their component parts after deconstruction. This includes avoidance of secondary material finishes.

***Structural Layout:*** Use a standard structural grid and separate the structure from the building envelope.

***Structural Frame:*** Use mechanical (e.g., bolted, nailed, screwed) in preference to chemical (e.g., welded, glued) connections. Design components to facilitate assembly and disassembly, with particular regard to component size (for ease of handling), number of connectors and types (limit the number of different connector types), and joint tolerances.

***Deconstruction Provisions:*** Design joints and connectors to facilitate disassembly and allow for parallel deconstruction sequences. Use assembly technologies that are compatible with standard building practices and capabilities (by default this will equally apply to deconstruction).

***Documentation:*** Provide standard and permanent identification of each material type and each component. Record and retain comprehensive descriptions of the building and its components, the assembly and disassembly sequences, and component handling procedures.

***Maintenance:*** Apart from drawings and descriptions of the principal building components, allocate storage space for maintaining at least a minimum inventory of critical spare parts.

Crowther's framework treats a building as a set of components that can be as easily disassembled as they can be assembled during the initial construction of the building. In the past such design criteria have been applied by architects only in very special cases such as temporary and mobile structures. Typically, still today by far the majority of buildings are designed and constructed with little thought (if any) to how they might be deconstructed let alone how their materials and principal components such as the structural frame and envelope might be salvaged for recycling.

### 12.7.3 Selecting Green Building Materials

Conceptually a *closed-loop* building material or product should consist of materials that are non-persistent, non-toxic, and originate from reused, recycled, renewable, or abundantly available sources (ORTNS 2004, Kibert 2005, 277-8). The material or product should not be new but a remanufactured or refurbished version of a previous use. The emphasis is on recycling, not only in terms of past use but also in respect to future use. In other words, the material should also be able to be recycled at the end of the life span of the building. The notion of renewable requires the material to come from a source that will be regenerated in nature at a rate that is greater or at least equal to the rate of consumption. Finally, the material should be abundantly available in nature so that the human use of the material is small in comparison with its availability.

How will the architect be able to consider all of these additional construction material selection criteria that are a prerequisite for meeting *sustainability* objectives? Certainly, the architect will have neither the time nor expertise to calculate embodied energy values for materials and products from first principles. Instead, the building designer will have to rely on material vendors and product manufacturers to take responsibility for researching and certifying their offerings. It could be quite misleading for the building designer to assume this responsibility. For example, when conducting a comparative analysis of the embodied energy of different materials it would appear that there are specific materials that should be avoided. Regardless of the variations among different data sources (see the discussion at the beginning of Section 12.7.1) certain materials such as aluminum, polystyrene and fiberglass insulation, paper, and steel, almost always appear among the top 10 most energy intensive materials. However, this does not mean that these materials should be necessarily avoided in new building construction. There are several other factors that could reverse such an a priori decision. First, the energy intensive material may be the best choice for the function to be performed and the amount of the material required to perform this function may be relatively small. Second, the material may lend itself to recycling and may in its present form already be a product of recycling. If it is already a product of recycling then its embodied energy is likely to be much reduced. For example, the embodied energy of recycled aluminum is only 5% of the energy consumed when aluminum is produced from bauxite ore. Third, there may be additional factors such as maintenance, commercial availability, cost, and energy savings related to other components that are indirectly influenced by the selection of the energy intensive material, which should be considered in the final design decision.