Chapter 10

Sustainable Construction: The Cutting Edge and Emerging Challenges

Charles J. Kibert & Ravi Srinivasan

M.E. Rinker, Sr. School of Construction Management, University of Florida, Gainesville, Florida, USA

10.1 INTRODUCTION

The sustainable construction concept emerged in the early 1990s as the built environment sector’s response to the then newly emerging paradigm of sustainable development. The physical manifestation of sustainable construction is green buildings and their proliferation around the world is evidence that the sustainable construction paradigm is being widely accepted as the right solution at the right time. The strategy that was most instrumental in the rapid expansion in the number of green buildings worldwide was the emergence of building assessment systems such as BREEAM, LEED, Green Star, and DGNB, to name but a few. Beginning in 1990 with BREEAM, these assessment systems provided both definitions for green building as well as measuring tapes for determining how well the project conformed to the definition. Over 20 years later, the sustainable construction movement is emerging from its infancy and a variety of new directions are being explored. Most prominently among these is the net zero strategy or concept, which is finally providing sorely needed rational targets for building performance. This chapter will focus primarily on net zero as the cutting edge of sustainable construction. Additionally it will cover the emergence of carbon accounting and environmental product declarations (EPDs) as significant and important shifts in the direction of the evolution of sustainable construction.

10.2 NET ZERO CONCEPT

Setting performance targets for green buildings that are in keeping with the sustainability paradigm has been a continuing challenge for both designers and owners. Sustainability suggests that society should live within the limits of nature and within the resources that are locally available. However, the ecological footprint of most societies has been enormous, often necessitating the import of enormous quantities of energy, materials, and water, and the export and disposal of equally enormous quantities of waste. A relatively new concept known as net zero proposes that the built environment and, by extension, building users and owners, be powered and resourced from the local environment, and preferably from the building site. The most advanced of these concepts, net zero energy
buildings, has resulted in actual building projects where on-site renewable energy systems generate as much energy as needed to meet the facility’s energy needs. To achieve a net zero energy target, the building energy consumption must be exceptionally low. Similarly a net zero water building must be designed to match building water consumption with local rainfall, wastewater recycling, and water storage strategies. In the same spirit as the net zero energy and water approaches, the net zero strategy is being extended to materials, carbon, waste, and other building environmental and resource issues. This chapter will address how this new strategy is affecting the design and construction of high-performance buildings in the United States and how national and local governments have begun to incorporate net zero into building regulations.

One of the fastest growing applications is in utility-scale solar power generation systems. Under increasing pressure to reduce domestic dependence on foreign sources of energy, it has been recognized [1] that solar energy represents a huge domestic energy resource for the United States, particularly in the Southwest where the deserts have some of the best solar resource levels in the world. For example, an area approximately 12% the size of Nevada (15% of land in Nevada is federal government property) has the potential to supply all of the electricity needs of the United States. In addition, solar power often complements other renewable power sources such as hydroelectric and wind power. Solar resources are typically higher during poor hydroelectric periods, and solar output peaks during the summer, whereas wind power typically peaks in the winter. Solar can complement fossil power sources as well. Eskom, a coal-dominated power utility in South Africa with one of the lowest power costs in the world, has identified large-scale solar power technologies as a good intermediate load power source for its grid. Although some renewable power technologies provide an intermittent energy supply, large-scale thermal electric solar technologies can provide dispatchable power through the integration of thermal energy storage. Thermal energy storage allows solar thermal energy collected during the day to be used to generate solar electricity to meet the utility’s peak loads, whether during summer afternoons or the winter evenings. Although solar energy is abundant and free, it is a diffuse energy source, so the cost to harness (or harvest) it with solar collectors can be significant. As a result, electricity generated from solar energy is currently more expensive than power from conventional fossil power plants. However, the Western Governors’ Association has determined that even at moderate levels of deployment, large-scale solar power can potentially compete directly with conventional fossil generation [1].

There are two major types of utility-scale solar electric systems. One is solar thermal power generation systems, which can be further categorized by solar collector geometric characteristics as trough and tower systems. The other type is large-scale photovoltaic systems (LSPVs). In this section, we first describe the main technical features of the systems, followed by discussion to compare those two systems in terms of their performance, cost structure, and barriers to wide applications.

10.2.1 Net Zero Energy (nZE)

Owing to the energy crisis, increased emissions and the depletion of fossil fuels, research and development in nZE technologies and integrated processes have attained greater and
renewed interests among stakeholders, especially governments worldwide. nZE buildings achieve net annual operating energy balance. nZE is the culmination of several decades of research, development, and practice in building design, construction, and materials technology. nZE development goes beyond the boundaries of building design and construction, and utilizes scientific knowledge from other sciences such as physics for building-related thermodynamic processes (e.g., conduction, convection, and radiation in the building envelope, airflow prediction using computational fluid dynamics, etc.), chemistry for building material compositions (e.g., polymer technologies used for roof coatings that turn black during winter months and white in summer months, etc.), biology through bio-organism-based technologies (e.g., living machines for on-site wastewater recovery, etc.). In general, it is assumed that the nZE building is connected to the grid and that energy flows to and from the grid over the course of a typical day. Rather than have an on-site energy storage system, the grid is used for storage.

Currently, nZE buildings can be identified based on boundaries determined by energy flow and renewable supply options. While energy-flow-based nZE buildings definitions are determined by means of segregating the boundaries of energy consumption and generation (site or source levels), and their quantification (energy quantity measured or energy costs), the renewable-supply-options-based nZE buildings definitions are established by way of demand-side location of site renewables. The following are several variants of the definition of nZE buildings by the U.S. National Renewable Energy Laboratory [1, 7]:

- **Zero Net Annual Site Energy:** This is probably the most commonly understood definition for nZE buildings and the concept is that on an annual basis, an equal amount of energy is exported from the building footprint as is imported in the form of electricity and/or natural gas. The site generated energy is normally electricity and the accounting is done at the site boundary. Energy derived from wood on site or methane generated on site are not included in the accounting, only energy generated within the building footprint.

- **Zero Net Annual Source Energy:** The total energy used off site to generate the energy imported to the building must be matched by on-site generated energy. In the United States, for electrical energy, each unit of energy generated requires a factor of three units of fuel energy. For natural gas, 1.1 units of fuel energy are required to deliver each unit of natural gas energy to the building. This definition tends to favor the use of fossil fuels over electricity as an energy source.

- **Zero Net Annual Energy Cost:** For a zero net annual energy cost building, the amount of money collected by the building owner from the utility for exporting on-site generated electricity is equal to the electric and natural gas utility bills. Because natural gas is cheaper, less site-generated electricity can be used to offset the same amount of natural gas energy.

- **Zero Net Annual Emissions:** This definition is based on offsetting the emissions of the energy source used to power the building and generally refers to greenhouse
gas emissions. As a result, another name for a zero net annual emissions building is a climate neutral building. Offsets can be created by on-site generated photovoltaic (PV) electricity, or through the purchase of, for example, Renewable Energy Certificates (RECs) or Green Tags that support the generation of off-site renewable energy.

Patxi Hernandez and Paul Kenny [8] added yet one more, but very important, nZE definition, the life cycle zero energy building (LC-ZEB). In addition to the operational primary energy, this definition includes the embodied energy of the building’s materials. In their proposed methodology for annualizing the embodied energy, the total embodied energy is divided by the expected building lifetime to produce the building’s annualized embodied energy (AEE). The term annual energy use (AEU) is their term for the building’s total energy consumption. The result of summing AEE and AEU is the building’s annualized life cycle energy and it is this quantity that would be used as the basis for sizing the renewable energy systems to make the building net zero on an annual basis.

Although nZE generally applies to individual buildings, it can also be applied to groups of buildings. For example, a recently completed research report into the feasibility of using PV energy at large scale by the Florida Department of Transportation concluded that it was possible to make large turnpike plazas self-sufficient for meeting their energy needs [9].

10.2.2 Budgeting for nZE

Achieving nZE is a challenging process because it is heavily dependent on several factors, all of which must be favorably addressed for a building to achieve this level of performance: The building must be designed to consume the minimum energy possible, including the following:

- The occupants must be willing to conserve energy in the operation of the building (system scheduling, set points, maintenance, recommissioning).
- A feedback and control system designed to inform occupants and assist in reducing energy consumption must be provided.
- Adequate site and building roof area must be available for installation of a renewable energy system, most often PV system. These factors point to some significant constraints on PV powered nZE buildings. An average PV panel may generate about 110 kWh/m² annually, which represents the energy consumption of a highly efficient commercial office building. A NREL study that monitored six relatively efficient office or academic buildings across the United States concluded that a single-story office building could achieve nZE building performance but that a two-story building could not [1]. If additional area is available over parking areas or other on-site locations, then there is potential for multistory nZE buildings. If collecting wind energy is feasible, then much larger nZE buildings, even high-rise buildings, may have potential.
Solar insolation worldwide varies from about 1000 kWh/m²/year to a maximum of about 2500 kWh/m²/year. Figure 10.1 indicates the annual solar insolation for the United States, Spain, and Germany. For an nZE building based on PV technology, the location, energy footprint of the building, and efficiency of the PV technology limit the number of floors in the building, assuming it were to be completely solar powered (Fig. 10.2).

The United States has enormous potential for renewable energy for both solar and wind applications. Solar insolation ranges from about 8 kWh/m²/day in some areas of the southwest to 6 in Hawaii to about 5.5 in Florida, 4 in the northeast, 3.5 kWh/m²/day in portions of the Pacific northwest, and to 3 kWh/m²/day or less in Alaska. On average, it is in the 4–6 kWh/m²/day range over most of the United States. By some estimates, virtually all of the energy needs of the United States could be met by solar thermal or solar electric energy systems. At present, the total grid connected solar PV is about 800 MW out of a total 1000 GW of generating capacity in the United States, about 0.1% of generating capacity. This compares to wind energy, which now comprises 35,000 MW of generating capacity, a factor of more than 40 greater than solar PV.

![Annual solar insolation in the United States far exceeds that of Germany and is comparable to the solar energy experienced in Spain and North Africa. This map was created by the National Renewable Energy Laboratory for the U.S. Department of Energy.](image-url)
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ANALYTICS FOR BUILDING-SCALE SUSTAINABLE ECOSYSTEMS

FIG. 10.2: The number of building stories feasible for an nZE building will be a function of its energy footprint, its location, and the type of technology being employed.

10.2.3 Regulations in the U.S. National and Local Governments and Other Programs

Research and development of nZE commercial buildings became national policy in the United States by virtue of the Energy Security and Independence Act of 2007 [10], which established the Net-Zero Energy Commercial Buildings Initiative. The stated goal of this initiative is: To develop and disseminate technologies, practices, and policies for the development and establishment of nZE commercial buildings for: (1) Any commercial building newly constructed in the United States by 2030; (2) 50% of the commercial building stock of the United States by 2040; and (3) all commercial buildings in the United States by 2050 [11,12]. In addition to national and state policy drivers behind the move to produce nZE commercial buildings, the launch of the Building Energy Quotient (Building EQ) program by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) in December 2009 poses nZE buildings as the highest achievement level for commercial buildings (ASHRAE 2009). In fact, at present, there are just eight nonresidential buildings in the U.S. Zero Energy Buildings Database and most of these are relatively small buildings (Table 10.1).

Of particular importance in reducing U.S. energy consumption are residential buildings, especially single-family homes. Table 10.2 indicates the characteristics of housing in the United States from the latest version of “American Housing Survey for the United States” for the year 2007. Although most housing is comprised of the existing housing stock, an enormous number of new homes, estimated at 34 million, were forecast to be
TABLE 10.1: List of nonresidential nZE buildings in the United States (adapted from [15])

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Building type</th>
<th>Floor area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldo Leopold Center</td>
<td>Wisconsin</td>
<td>Commercial office</td>
<td>1190</td>
</tr>
<tr>
<td>Audubon Center at Debs Park</td>
<td>California</td>
<td>Recreation center</td>
<td>502</td>
</tr>
<tr>
<td>Challengers Tennis Club</td>
<td>California</td>
<td>Recreation building</td>
<td>350</td>
</tr>
<tr>
<td>Environmental Technology Center</td>
<td>California</td>
<td>Higher education/laboratory</td>
<td>220</td>
</tr>
<tr>
<td>Hawaii Gateway Energy Center</td>
<td>Hawaii</td>
<td>Commercial office</td>
<td>360</td>
</tr>
<tr>
<td>IDeAs Z2 Design Facility</td>
<td>California</td>
<td>Commercial office</td>
<td>656</td>
</tr>
<tr>
<td>Oberlin College Lewis Center</td>
<td>Ohio</td>
<td>Higher education/library</td>
<td>1360</td>
</tr>
<tr>
<td>Science House</td>
<td>Minnesota</td>
<td>Museum/interpretive center</td>
<td>153</td>
</tr>
<tr>
<td>NREL Research Support Facility</td>
<td>Colorado</td>
<td>Commercial / laboratory</td>
<td>20,446</td>
</tr>
</tbody>
</table>

TABLE 10.2: Characteristics of residential buildings in the United States (adapted from [16])

<table>
<thead>
<tr>
<th>Total housing units (millions)</th>
<th>Single-family houses (millions)</th>
<th>Multifamily housing (millions)</th>
<th>Manufactured housing (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.2</td>
<td>87.5</td>
<td>31.9</td>
<td>8.7</td>
</tr>
</tbody>
</table>

constructed between 2005 and 2030 [13]. Consequently, rapidly raising the bar for new residential construction is crucial to reducing U.S. energy consumption and shifting to renewable energy resources.

Some jurisdictions are already making policy changes that would require nZEH and other buildings in the not too distant future. Every two years, the California Energy Commission (CEC) releases an Integrated Energy Policy Report in which it makes recommendations for energy policy in the state, including changes to Title 24, the energy efficiency portion of the building codes [14]. In its 2007 report, CEC recommended adjusting Title 24 to require net zero energy performance in residential buildings by 2020 and in commercial buildings by 2030. The CEC believes that new legislation to incorporate these goals is not needed and is already moving to put them in place. The goals set in California were inspired by the 2030 Challenge goals, in which the nonprofit organization, Architecture 2030, called for no fossil fuel use by buildings by 2030. California’s goals are focused on net zero energy performance instead of fossil fuel use. CEC based its definition of net zero energy performance, and many of its recommendations, on a report by the California Public Utility Commission (CPUC), which states that a goal of “no net purchases from the electricity or gas grid” may be met with energy-efficient design and “onsite clean distributed generation.”

On September 5, 2007, the City Council of Austin, Texas, passed a resolution to establish the Zero Energy Capable Homes (ZECH) program, which requires new single-family homes to be nZEH capable by 2015. These homes will be 65% more efficient than homes built to the Austin Energy Code in 2006, and it will be cost effective to install renewable
on-site generation and develop zero energy homes. The program will be implemented in phases. The first of four planned local amendments to the International Energy Conservation Code (IECC) was approved by the city council in October, 2007. Austin’s program demonstrates that increasing energy efficiency and decreasing greenhouse gas emissions can both be cost effective. When the increased cost of building the home is rolled into a 30-year mortgage, reduced energy costs are greater than increased mortgage payments. Historically, the main obstacle to adopting effective energy codes has been resistance from the home building industry and affordable housing advocates, due to cost concerns. Austin overcame this resistance by forming a task force that included representatives from these groups as well as industry trade associations, energy efficiency advocates, the Electric Utility Commission, Texas Gas Service, and city staff. A positive and productive task force addressed the needs of stakeholder groups, increased buy-in from the community, enhanced participation in the program, and will help insure the long-term success of the project. These programs’ initial amendments increased the overall efficiency of homes by 11% and electric energy efficiency by 19%. For 2008, based on average annual construction of 6400 new homes, this translates into an annual reduction of 9367 metric tons of CO$_2$. The first amendments also reduced annual household energy consumption by 2515 kWh and 4 therms of gas. This decreases household energy costs by $227.68 per year, with an estimated payback of 5.2 years. And finally, the changes will reduce SO$_2$ emissions by 3.9 tons and NO$_x$ by 19.8 tons.

On July 14, 2009, General Electric (GE) unveiled plans for a “Net Zero Energy Home” (nZEH) project that combines GE’s most efficient appliances and lighting, the company’s new energy management systems, and GE power generating and storing technologies in new home construction [17]. When applied together, the system would enable a homeowner to achieve net zero energy costs by 2015. The Net Zero Energy Home project—and new smart grid consumer poll data from the United States and the U.K.—were introduced at GE’s smart grid symposium at its Global Research Center in upstate New York. As part of the company’s Ecomagination strategy, the GE Net Zero Energy Home offerings will be comprised of three major groups within the product portfolio: energy-efficient products including appliance and lighting products that will reduce energy consumption in the home; energy management products that will enable consumers to manage their costs and energy consumption; and energy generation/storage products such as solar PV, advanced energy storage, and next-generation thin-film solar that will play an integral part in the net zero energy home. In 2010, GE will introduce the Home Energy Manager, their version of a central nervous system for the nZEH that will work in conjunction with all the other enabling technologies in the home to help homeowners optimize how they consume energy. GE will also introduce a line of smart thermostats in 2010 that, together with the Home Energy Manager, will inform consumers on their energy use and empower them to make smarter decisions on their energy.

Key to the nZEH strategy are radical improvements in the energy performance of homes, with reductions in typical home energy consumption on the order of 60–70% needed to bring nZEH to reality. This improvement in performance, coupled with advanced control technology and an optimized feedback system, and on-site generation of
electricity from solar photovoltaic systems, provides a realistic and achievable pathway to nZEHs. Although nZEHs are rapidly becoming a reality, there are several gaps in technology that make the transition difficult. The advent of the smart grid will help close some of the key gaps needed to make the overall building stock shift to nZE status. A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources [18]. The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are now being integrated and rebundled as society addresses traditional problems in new ways, adapts the system to tackle new challenges, and discovers new benefits that have transformational potential.

Although the smart grid provides some level of data that a homeowner can access to understand and respond to reduce their energy consumption, it does not provide adequate feedback for an nZEH owner to be immediately aware of the home’s energy consumption profile and patterns. Additionally, the owner must log into a utility Website to view data that is not real time and not adequately fine-grained for response. Ultimately, the control of an nZEH and the integration of feedback loops will be key to the successful implementation of this concept. An advanced controls system for net zero energy homes (AFCS-nZEH) will have two major components: (i) an automatic control system that minimizes energy consumption based on inputs by the owner to the controller, and (ii) a real-time feedback system that provides the homeowner with information on energy generation, consumption, and costs, and allows the nZEH owner to change strategies based on their response to the feedback.

The automatic control system will be connected, either via hard wiring or wireless connection, to the major energy consuming devices in the home: air-conditioning, hot water heater, refrigerator, range, clothes dryer, lighting system, and plug loads. It will also be connected to the renewable energy system powering the home to optimize its performance based on conditions. For example, it could be used to help a photovoltaic system track the sun to maximize electricity production and could provide information about the performance of the system to indicate any unexpected degradation of performance. The control system would similarly monitor all major appliances to assess their performance and indicate when performance is degraded. For an air-conditioning system, this could occur due to dirty filters, leaking coolant, corroded condenser or evaporator coils. The control system could, for example, close windows or indicate windows are open when the air-conditioning system is operating. It could also indicate when outside conditions are such that leaving the windows open during cooler periods would minimize energy consumption. Indoor air quality (IAQ) will be also be monitored with ventilation air controlled via the automatic control system.

The feedback component of the AFCS-nZEH will provide the owner with real-time information about the energy performance of the home including instantaneous power consumption, daily energy consumption and costs, monthly and billing period energy
consumption and costs, renewable energy generation and energy value, and net energy for the month and billing period. It could also provide other information such as trends in consumption, energy generation, net energy, and performance of major systems. As important, the feedback system would allow the owner to alter the current strategy of the home by changing set points and schedules and providing them the opportunity to change their behavior. For example, if energy consumption was trending to exceed energy production, the owner could raise the set point of the air-conditioning system from 24°C to 26°C. The owner could opt to hang clothes out to dry instead of using electrical energy for this purpose, or they could opt to purchase a clothes dryer that relies on much higher spin rates to remove moisture from clothes. They would be informed that perhaps plug loads are trending high and also be informed of the levels of so-called vampire loads.

Vampire loads are energy consumption caused by computers, printers, chargers for cell phones, iPods, home video games, microwaves, laptops, and high definition televisions, the sum of which can add 10–20% to the energy consumption of an average home. By using smart switches connected to the feedback component that turns off devices that cause vampire loads, significant reductions in energy consumption can be experienced.

The Living Building Challenge, perhaps the leading-edge building assessment system in the world, aggressive approach to building energy forces the building to rely only on current solar income. The entire energy needs of the project must be supplied by on-site renewable energy systems on a net annual basis, i.e., nZE, at a minimum.

10.3 NET ZERO WATER (nZW)

Building occupants account for about 12% of freshwater withdrawals. Among others, one of the critical components of a building is its hydrologic cycle, which is the flow and storage of all types of water on sites altered from their natural state for the purposes of building and infrastructure. They include potable water, rain water, storm water, gray water, black water, and reclaimed water that are used, processed, stored, and moved by employing a variety of technologies that may be coupled with natural systems [19]. It is also extended to the water used for irrigation.

The built environment hydrologic cycle involves the handling and use of water both internal and external to buildings. nZW building balances its hydrologic cycle through optimal design of water, wastewater, and storm water systems. In other words, an nZW strategy is based on one of the core ideas of sustainability, i.e., resource use should be constrained to what nature provides. nZW follows a three-fold approach, as follows:

- Minimize the consumption of potable or drinking quality water from wells or the municipal wastewater system.
- Minimize wastewater generation.
- Maximize rain water infiltration into the ground.
10.3.1 Budgeting for nZW

nZW strategy for high-performance built environment hydrologic cycle comprises a series of logical steps [19]. These steps are targeted to minimize consumption of potable water and wastewater generation (steps 1–6), and maximize rainwater infiltration into the ground (steps 7 and 8):

1. Select the appropriate water sources for each consumption purpose.
2. For each purpose, employ the technologies that minimize water consumption.
3. Evaluate the potential for a dual wastewater system.
4. Analyze the potential for innovative wastewater treatment strategies.
5. Apply life cycle costing.
6. Design landscaping to use minimal water for its maintenance and upkeep.
7. Design parking, paving, roads, and landscaping to maximize the infiltration of stormwater.
8. Incorporate green roofs.

To best evaluate water use, water use calculators may be used. These calculators compare projected water use with baseline models that incorporate EPAct 1992 data. These calculators use a three-step process to determine water savings potential: (i) estimation of daily potable water—this involves occupant type (full-time equivalent, visitor, male/female), fixture type, and water use data; (ii) number of workdays; and (iii) EPAct 1992 data. An estimated water quantity for a conventional water system can then be used to estimate the quantity of wastewater quantity for the building.

Water (and wastewater) budget rules of thumb [19] include: for the low-flow fixture strategy, high-efficiency fixtures are aggressively used, and the result is about a 50%, or Factor 2, reduction in potable water consumption compared to code requirements. For a combination of low-flow fixtures and alternative water strategies, an 80% reduction in potable water consumption was achieved. Consequently, it is possible to develop water reduction strategies that are in excess of Factor 4 for an aggressive strategy that includes alternative water sources and low-flow fixtures and at least Factor 2 for a less aggressive strategy that uses a simple low-flow fixture strategy.

Similarly, constructed wetlands may be used to treat wastewater on site. A well-known, proprietary approach is the Living Machine. These natural ecosystem setups can generate fuel, grow food, restore degraded environments, and even heat and cool buildings. For landscaping, the best known strategy is xeriscaping, or the use of drought-tolerant native and adapted species of plants and turfgrass.
10.3.2 Regulations in the U.S. National and Local Government and Other Programs

As discussed in Sustainable Construction: Green Building Design and Delivery (Kibert, 2012), the U.S. Energy Policy Act of 1992 [20] is a landmark piece of legislation concerning potable water consumption. EPAct 1992 requires all plumbing fixtures used in the United States to meet ambitious targets for reducing water consumption; as a result, building codes now mandate these dramatically lower levels of water consumption. Additional requirements for water efficiency for prerinse spray valves in commercial kitchens were set by the Energy Policy Act of 2005 [21].

Other regulations and programs include the following:

- **WaterSense:** In 2006, a voluntary labeling program emerged that certified fixtures that utilize 20% less water that requirement of EPAct 1992. The label is awarded based on third-party certification that the fixture meets EPA requirements.

- **California:** In 2007, California passed stringent requirements for toilets and urinals; from 1.6 gpf (gallons per flush) to 1.28 gpf for toilets; 1.0 gpf to 0.5 gpf.

- **New York:** In New York City, a widespread toilet replacement program for apartment buildings resulted in an average 29% reduction in total water use for the buildings. In all, over 1.3 million toilets were replaced saving over 60–80 million gallons a day of water.

- **California, Florida, Arizona, Nevada, and Texas:** In states that have chronic water problems such as these, there are programs to provide reclaimed water to the building’s location. The water has been treated for non-potable purposes such as landscaping, golf course maintenance or agricultural irrigation, decorative features such as fountains, cooling tower makeup, boiler feed, once-through cooling, concreted mixing, snowmaking, and fire main water.

The Living Building Challenge calls for nZW that has to be met in order to gain the certification. If not all, some of the imperatives of this certification program are very demanding. The Water Petal comprises two imperatives, namely, 05-Net Zero Water and 06-Ecological Water Flow. The nZW mandates for 100% of the project’s water needs that must be supplied by captured precipitation or other natural closed loop water systems that account for downstream ecosystem impacts, or by recycling used project water. Additionally, water use be appropriately purified without the use of chemicals. For the imperative 6 -Ecological Water Flow, that requires that 100% of storm water and building water discharge be managed on site to meet the project’s internal water demands or released onto adjacent sites for management through acceptable time scale surface flow, groundwater recharge, agricultural use, or adjacent building reuse.

10.4 NET ZERO MATERIALS (nZM)

The nZM should close material loops using the following five cardinal rules [19]:

1. Buildings must be deconstructable.

2. Products must be disassemblable.

3. Materials must be recyclable.

4. Products/materials must be harmless in production and in use.

5. Materials dissipated from recycling must be harmless.

The cardinal rules state that the complete dismantling of the building and all of its components is required so that materials input at the time of the building’s construction can be recovered and returned to productive use at the end of the building’s useful life. These rules also establish the ideal conditions for materials and products used in buildings. While rules 1 and 2 focus on whole-building and systems integration (for instance, the design of structural system for disassembly), rule 3 focuses on the recyclability of the product or materials used in the building. Rules 4 and 5 are significant owing to materials’ impact on the environment.

Assessing the environmental impacts and material resource consumption associated with various approaches to the built environment is currently achieved using life cycle assessments (LCAs). LCA emerged as a defining concept during the last two decades, largely due to the increasing awareness of environmental issues associated with the manufacturing sector, along with the waste generated by manufacturing processes. LCA was formalized by the International Standards Organization (ISO) to examine industrial systems’ performance, from the point of extraction of raw materials, through the manufacturing process, and finally to the product disposal. According to ISO14040, which refers to principals and framework for environmental management, LCA considers the entire life cycle of a product, in terms of energy and materials used in order to manufacture such product, as well as the end of life of that given product [22]. LCA consists of four major sections: goal and scope definition, life cycle inventory (LCI), impact assessment, and interpretation of results. The goal and scope definition defines the purpose as well as the boundaries of the LCA. The LCI is where data is collected and analyzed in order to determine the energy input and outputs of the LCA analysis. The impact assessment determines potential environmental damage created by the manufacturing of such product (from extraction of raw material to disposal), and, finally, the interpretation is where conclusions are reached in order to make recommendations about the manufacturing and life of the product (ISO 1998).

Many studies have demonstrated the usefulness of LCA in improving the manufacturing process, or in the assessment of environmental impacts for manufacturing processes [23–25]. The boundaries associated with the traditional LCA start from energy associated with the extraction of raw material, expand to the manufacturing end point of a product, and continue up until the end of life of the product [26]. Other researchers have taken a more holistic approach by going beyond initial embodied energy of building materials, and including a more detailed accounting of energy expenditure and environmental...
impacts throughout the life cycle of the building. Such inclusions are energy used in construction of the building, as well as energy used in the operation of the building [27, 28].

Although great efforts have been made to quantify energy expenditures as well as environmental impacts within the built environment, few studies show the complete holistic LCA approach (manufacturing of building material through demolition of building) that quantifies energy use throughout the life of the building, along with the building’s associated environmental impacts. One such study was conducted by Scheuer et al. [29], where the authors determined the energy and mass needed for a 7300 m$^2$ six-story building with a life span of 75 years. The study also measured environmental impacts caused by the production of primary energy used through the life cycle of the building (petroleum, coal, natural gas, and nuclear energy), and their contribution to global warming, ozone depletion, acidification and nitrification of soils and water, and solid waste generation. Ramesh et al. [30] demonstrated, through a compilation of studies, that the most energy used throughout the life cycle of a typical building is through its operation.

### 10.4.1 Budgeting for nZM

Process-based and economy input-output are two major approaches to LCA. Detailed tracking of each of the diverse materials used in the manufacturing process is essential for the process-based LCA approach. This is a cumbersome process that may lead to high cost, time, and issues related to data confidentiality and verifiability.

Three readily available LCA tools are (i) Athena EcoCalculator, (ii) Athena Impact Estimator, and (iii) Building Industry Reporting and Design for Sustainability (BIRDS), all of which can be applied to North American projects as follows:

- Athena EcoCalculator uses defined building assemblies (structural systems such as columns, beams, floors, etc.) to estimate embodied fossil energy use and impacts.
- Athena Impact Estimator provides a cradle-to-grave life cycle inventory profile for a whole building.
- BIRDS is an extension to the Building for Environmental and Economic Sustainability (BEES). Both BIRDS and BEES calculate life cycle costs and TRACI 2.0 impact categories. BIRDS, in addition to all the capabilities of BEES, emphasizes on building energy use based on building energy standards and codes.

All of the three LCA tools are process-based LCA tools. Other process-based LCA tools include SimaPro, which utilizes the EcoInvent database. On the other hand, a top-down approach such as EIO-LCA uses the whole economy as the boundary of analysis [31]. Although robust and easy to use, the EIO-LCA approach uses aggregate data and may not be subjective to a particular process in the manufacturing of the product under investigation. Hendrickson et al. [32] provides a detailed comparison of EIO-LCA with process-based models. It is to be noted that LCA has limitations in that it does not adequately address the closed-loop materials cycle.
Another approach to maximize material reuse crucial for replacement of virgin building materials is discussed in Srinivasan et al. [33]. In this approach, emergy (spelled with an “m”) calculation is conducted to balance reuse materials to attain the maximum renewable emergy potential. Using this approach, there are two scenarios related to reuse of building materials at the end of building life-time: (i) If material reuse is pursued at the end of the building lifetime, the emergy content of reuse material must be subtracted from the total emergy content of building materials during “formation-extraction-manufacturing.” Essentially, reuse of building materials at the end of the building lifetime is a strong incentive toward energy balance backed by energy systems theory. (ii) If material reuse is not pursued at the end of the building lifetime, it is a disadvantage to the building, and is not recommended. In this scenario, energy use in material reuse and waste at the end of the building lifetime is not included. Similarly, the replacement of emergy content of reuse materials is also not included. If this approach was adopted to guide building construction, it would expand conscious decision making to make buildings more sustainable and, possibly, lead to a paradigm shift in the way non-renewable resources are used in the manufacturing of building materials, which is currently of interest, but remains unchecked.

10.4.2 Regulations in the U.S. National and Local Governments and Other Programs

The emergence of environmental product declarations (EPDs) and environmental building declarations (EBDs) to determine the environmental efficacy of materials and products used in construction is the first step toward nZM. While EPDs can be used to compare products used for the same purpose (e.g., steel versus concrete structural systems), EBDs can be used for whole-building declarations to allow trade-offs between systems with an end goal of minimizing total impact (e.g., impacts of triple glazing to the effects of reducing system sizing). The EPD presents quantified environmental data for products and systems based on information from an LCA that was conducted using a standard approach as defined by ISO. An EPD based on the output of an LCA, and its format is governed by ISO 14025, Environmental Labels and Declarations—Type III Environmental Declarations—Principles and Procedures. Basically, an EPD is a statement of product ingredients and environmental impacts that occur during the life cycle of a product (similar to a nutrition label of a food product). Two other applicable standards in relation to EPD in the United States include the ASTM WK23356—New Specification for Product Category Rules for Building Products and Systems, and US Part 260 Guidelines for Use of Environmental Market Claims.

Managed by the U.S. Environmental Protection Agency and the U.S. Department of Energy, EnergyStar is a popular program that labels products based on their manufacture and operative energy data. The Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is a German certification program that requires whole-building impact assessment as part of the scoring system for the certification.

The Living Building Challenge has stringent measures for materials, particularly with the “red list” (a list of chemicals that should stay from building materials) and embodied
carbon footprint. Primarily, the project should account for all the construction-related embodied carbon. Currently, simple LCA tools are used for this calculation and offset, potentially using RECs.

10.5 NET ZERO EMISSIONS (nZEm)

Among others, one of the critical issues is the environmental emissions such as carbon dioxide (CO₂), sulfur dioxide (SO₂), volatile organic compounds (VOCs), particulate matter (PM10), carbon monoxide (CO), and nitrous oxides (NOₓ) emitted to the atmosphere. These are harmful to human health and biodiversity. nZEm is not the same as zero net annual emissions, where the later refers to the offsetting the emissions (carbon dioxide equivalent, or CO₂E) of the energy source used to power the building. A building’s entire life cycle includes four phases, and it is imperative that all environmental emissions related to all these four phases are taken into consideration as follows:

- Material resource: This phase denotes all the energy used in the extraction, manufacture, and transportation of the material. Additionally, all the energy used up to produce the mineral ore can be estimated using emergy concepts.

- Material placement: This includes the energy used to construct the building.

- Operations and maintenance: Energy used in the operation of the building including its maintenance. Energy used in the replacement of building components are also included in this phase.

- Decommissioning: This phase comprises recycling/reuse, deconstruction, demolition, and landfill, and includes all energy used in transportation, etc.

The nZEm strategy calls for significant reduction in environmental emissions through conscious decision making during the entire life cycle of a building.

EIO-LCA models and Athena tools may be used to determine these emissions. For instance, the human toxicity resulting from the emissions of the manufacturing of structural steel, cement, gypsum boards, and aluminum storefront frames was calculated based on the disability adjusted life years and illustrated using a Florida state map (Fig. 10.3).

10.6 NET ZERO CARBON (nZC)

Net zero carbon is the rebalance of carbon emissions into the atmosphere by greatly reducing the carbon associated with building construction and operation, and with the distribution of buildings in communities. The latter point addresses the problem of how buildings and their location drive energy consumption and carbon emissions and transportation systems. The carbon emissions related to built environment has the following four major components:

- The output of carbon due to building operation (operation energy).
FIG. 10.3: Location-based disability assisted life in years (DALY) values for materials used in Rinker Hall, University of Florida. Manufacturing locations were obtained from LEED v2.0 submittals for the building. DALY values/Kg of emission values were adapted from Eco-Indicator 99, and Ref. [33].

- The carbon invested in the materials and products of construction (embodied energy).
- The carbon emissions from transportation energy.
- The output of carbon associated with processing and moving water, wastewater, and storm water.

Reducing atmospheric carbon will require a concerted effort on the part of all stakeholders to the built environment to shift building design onto a course that focuses on long-term strategies to rebalance carbon. Doubling the lifetime of a building from 50 to 100 years in effect cuts the embodied carbon emissions into half. Good planning with a long time horizon will ensure that frequent redesign of urban areas that requires removal of large numbers of buildings is unnecessary. Although many technical fixes have been proposed
to reduce and absorb carbon in the atmosphere, thus far, no technical fix has been proven to work at large scale to remove the enormous quantities of carbon that would be required to stabilize the atmosphere [19].

Several strategies may be employed to reduce the built environmental carbon emissions [19], as follows:

- Dramatically reducing energy consumption.
- Shifting to renewable energy sources.
- Emphasizing compact forms of development.
- Shifting to mass transportation.
- Designing buildings for durability and adaptability.
- Restoring natural systems.
- Designing low-energy building environment hydrologic systems.
- Designing buildings for deconstruction and material reuse.
- Selecting materials for their recycling properties.

Additionally, tools and strategies discussed for any of the above net zero techniques would be effective in reducing carbon emissions in order to rebalance.

10.7 ENVIRONMENTAL PRODUCT DECLARATIONS (EPDs)

Life cycle assessment (LCA) for products and materials and the use of the resulting data in selecting building systems is well accepted and slowly being embedded into green building assessment systems such as LEED, Green Globes, BREEAM, and others. An EPD presents quantified environmental data for products or systems based on information from an LCA that was conducted using a standard approach defined by the International Organization for Standardization (ISO). Specifically, the LCA approach is defined by ISO 14040, Environmental Management—Life Cycle Assessment—Principles and Framework. An EPD is based on the output of an LCA, and its format is governed by ISO 14025, Environmental Labels and Declarations—Type III Environmental Declarations—Principles and Procedures. The LCA includes information about the environmental impacts associated with a product or service, such as raw material acquisition; energy use and efficiency; content of materials and chemical substances; emissions to air, soil, and water; and waste generation. It also includes product and company information. An EPD is a voluntarily developed set of data that provides third-party, quality-assured, and comparable information regarding the environmental performance of products based on an LCA. It is a statement of product ingredients and environmental impacts that occur during the life cycle of a product, from resource extraction to disposal. An EPD is
similar to a nutrition label on a box of cereal, but instead of nutrients and calories, it indicates raw material consumption; energy use; air, soil, and water emissions; water use and waste generation; and other impacts. An EPD is not a certification, a green claim, or a promise; it simply shows product information in a consistent way, certified to a public standard, and verified by a credible third party. Although a potential breakthrough in the arena of selecting high-performance building materials and products, EPDs are not especially helpful in isolation. A significant number of EPDs must be available in each product class (e.g., ceiling tiles) to allow comparison among like products. And, as noted earlier, the ultimate goal is whole-building comparisons that combine EPDs into an EBD to allow trade-offs between systems. InterfaceFLOR is now the North American leader in issuing EPDs and, as noted earlier, has made a commitment to issuing EPDs for all of its products by the end of 2012. Extracts from its EPD for GlasBac nylon carpet tiles are shown in Figs. 10.4–10.6.

10.8 CARBON ACCOUNTING

Significantly reducing built environment energy consumption is a very important goal of sustainable construction. More recently, the issue of how to reduce the climate change impacts of the built environment has become equally important. Climate change is being caused by human activities that are increasing the concentrations of heat-trapping, carbon-containing gases, particularly CO$_2$, in the atmosphere. The quantity of these gases being released is a function of both the quantity of energy being consumed and the source of the energy. The term carbon footprint is commonly used to describe the quantity of CO$_2$

<table>
<thead>
<tr>
<th>Layer</th>
<th>Component</th>
<th>Material</th>
<th>Availability</th>
<th>Mass %</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear Layer</td>
<td>Face</td>
<td>Nylon 6 Post Industrial &amp; Post Consumer Recycled</td>
<td>Recycled material, abundant</td>
<td>17%</td>
<td>IT</td>
</tr>
<tr>
<td></td>
<td>Cloth/Yarn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier</td>
<td>Tufting Primary</td>
<td>Polyester</td>
<td>Fossil resource, limited</td>
<td>3%</td>
<td>US</td>
</tr>
<tr>
<td>Backing</td>
<td>Latex</td>
<td>Ethylene vinyl acetate</td>
<td>Fossil resource, limited</td>
<td>5%</td>
<td>US</td>
</tr>
<tr>
<td></td>
<td>Filler</td>
<td>CaCO3</td>
<td>Mineral resource, non-renewable, abundant</td>
<td>15%</td>
<td>US</td>
</tr>
<tr>
<td>Stabilization</td>
<td>Fiberglass</td>
<td>Silica</td>
<td>Mineral resource, non-renewable, abundant</td>
<td>1%</td>
<td>US</td>
</tr>
<tr>
<td>Structural Backing</td>
<td>GlasBac Backing</td>
<td>Polyvinyl chloride copolymer</td>
<td>Ethylene – Fossil resource, limited and Salt – Mineral resource, non-renewable, abundant</td>
<td>10%</td>
<td>US</td>
</tr>
<tr>
<td></td>
<td></td>
<td>di-isononyl phthalate</td>
<td>Fossil resource, limited</td>
<td>10%</td>
<td>US</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calcium alumina glass spheres, post industrial</td>
<td>Recycled material, abundant</td>
<td>39%</td>
<td>US</td>
</tr>
</tbody>
</table>

**FIG. 10.4:** Extract from the EPD for InterfaceFLOR’s GlasBac type 6 carpet tiles showing materials selection.
and other carbon gases being released by an activity, e.g., electrical energy generation or the manufacture of drywall. The carbon footprint of the built environment has four major components: (i) the output of carbon gases due to building operation (operational energy); (ii) the carbon invested in the materials and products of construction (embodied energy); (iii) the carbon emissions from transportation energy; and (iv) the output of carbon gases associated with processing and moving water, wastewater, and storm water. As noted earlier in this chapter, the total energy associated with the built environment is probably on the order of 65\% of total U.S. energy consumption, or about 100 quads. Although there are some differences in energy sources for building, transportation, and industry, the carbon footprint of the built environment is likely about this percentage of the total human carbon footprint. Of the 100 quads of energy being consumed annually in the United States, 40 quads are consumed by building operations, and another 25 quads are
consumed by transportation energy, the embodied energy of the materials and products of construction, and water pumping and processing. Consuming 100 quads of energy annually produces 6600 million metric tons of carbon dioxide equivalent (CO₂E), with the built environment contributing about 4300 million metric tons of CO₂E. The equivalent notation is used because each greenhouse gas has different impacts. For example, each mass of methane has 21 times the impact of the same mass of CO₂. Thus, each gram of methane has 21 g CO₂e/kWh of impact (see Table 10.3). This is sometimes referred to as the greenhouse multiplier for a given gas. To reverse course with respect to climate change requires that the built environment be the main focus of activities addressing this, the most serious issue of the twenty-first century.

Note: The multiplier indicates how many grams of CO₂ equivalent impact each gram of gas causes. Although some gases have large multipliers, the vast mass of CO₂ being emitted dwarfs the mass of other gases, causing over 99% of the climate change impact.

There are several strategies that can be used to reduce the built environment carbon footprint, among them are the following:

1. Dramatically reducing energy consumption.
2. Shifting to renewable energy sources.
3. Emphasizing compact forms of development.
4. Shifting to mass transportation.
5. Designing buildings for durability and adaptability.
6. Restoring natural systems.
7. Designing low-energy built environment hydrologic systems.

**TABLE 10.3:** Greenhouse effect multiplier for various atmospheric gasses

<table>
<thead>
<tr>
<th>Atmospheric gas</th>
<th>Greenhouse multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (carbon dioxide)</td>
<td>1</td>
</tr>
<tr>
<td>CH₄ (methane)</td>
<td>21</td>
</tr>
<tr>
<td>NO₂ (nitrous oxide)</td>
<td>310</td>
</tr>
<tr>
<td>CFC-11 (CCl₃F)</td>
<td>1320</td>
</tr>
<tr>
<td>CFC-12 (CF₂Cl₂)</td>
<td>6650</td>
</tr>
<tr>
<td>HCFC-22 (CHClF₂)</td>
<td>1350</td>
</tr>
<tr>
<td>Surface ozone</td>
<td>100</td>
</tr>
</tbody>
</table>

Note: The multiplier indicates how many grams of CO₂ equivalent impact each gram of gas causes. Although some gases have large multipliers, the vast mass of CO₂ being emitted dwarfs the mass of other gases, causing over 99% of the climate change impact.
8. Designing buildings for deconstruction and material reuse.

9. Selecting materials for their recycling properties.

10. Including the carbon footprint of buildings in building assessment systems.

Reducing atmospheric carbon will require a concerted effort on the part of all stakeholders to the built environment to shift building design onto a course that focuses on long-term strategies that rebalance the emissions of carbon into the atmosphere by greatly reducing the carbon associated with building construction and operation and with the distribution of buildings in communities. This latter point addresses the problem of how buildings and their location drive energy consumption and carbon emissions and transportation systems. Additionally, enormous efforts must be made to restore the quantity of biomass on the planet to help in the reabsorption of carbon. Although many technical fixes have been proposed to reduce and absorb carbon in the atmosphere, thus far no technical fix has been proven to work at large scale to remove the enormous quantities of carbon that would be required to stabilize the atmosphere.

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10.9 CONCLUSIONS

This chapter addresses the cutting edge of sustainable construction and articulates the direction in which this approach to the built environment is changing. It covers how net zero strategy is affecting the design and construction of high-performance buildings in the United States and how national and local governments have begun to incorporate net zero into building regulations. The chapter discusses five components of the net zero concept, namely, nZE (energy), nZW (water), nZM (materials), nZEm (emissions), and nZC (carbon). Strategies and technologies to create net zero buildings are a response to rapidly rising energy prices, overdependence on foreign energy sources, and the imperative to take action regarding climate change. In all of these components, one of the major take home messages is that built environment (and the society) should live within the limits of nature and within the resources that are available. This chapter also notes that two other trends are emerging, i.e., environmental product declarations (EPDs) and carbon accounting. EPDs provide standard life cycle assessment information on products and are created based on third-party evaluation of the product using ISO Standard 14025. The result of uniform and universal use of EPDs would be the ability to select products and materials that would produce a high-performing building with the lowest overall impact. Carbon accounting provides an assessment of the contribution of buildings to climate change and is a tool for minimizing the impacts of building construction, operation, maintenance, and demolition, plus location-dependent transportation and travel in the drive to address climate change on a large-scale basis.

REFERENCES


