FOURTH 4 EDITION

SUSTAINABLE CONSTRUCTION

GREEN BUILDING DESIGN AND DELIVERY

CHARLES J. KIBERT

WILEY

Sustainable Construction

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Green Building Design and Delivery

Fourth Edition

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For Charles, Nicole, and Alina,
and in memory of two friends and sustainability stalwarts,
Ray Anderson and Gisela Bosch

Contents

Chapter 11

Chapter 12

Chapter 13

Part IV

Green Building Implementation 465

Chapter 14

Construction Operations and Commissioning 467

Chapter 15

Green Building Economics 491

Chapter 16

The Cutting Edge of Sustainable Construction 513

Preface

The significant additions and changes for this fourth edition of *Sustainable Construction: Green Building Design and Delivery* include revisions to the chapters on LEED and Green Globes, both of which have changed significantly over the past few years. LEED version 4 is now the main building assessment product being offered by the US Green Building Council for projects, and this recent addition is covered in detail. Because the US Green Building Council also allows projects to opt for LEED version 3 and familiarity with both systems is needed to allow flexibility for owners and project teams, LEED v3 is also addressed in an appendix. Green Globes has also changed; version 2 of this important rating system is covered in detail. Information about the other major assessment systems, such as Green Star, Comprehensive Assessment System for Building Environmental Efficiency, Building Research Establishment Environmental Assessment Method, and Deutsche Gesellschaft für Nachhaltiges Bauen, has been updated.

In addition to the changes to bring the information about the major building assessment systems up to date, a new chapter on carbon accounting addresses the increasing interest in reducing the carbon footprint of the built environment, from a green building perspective and also to provide clarity about the contribution of buildings to climate change.

A major emerging issue is transparency, and demands for transparency are appearing regarding several performance issues. These include the provision of information about building product ingredients and the risks of these ingredients to human health and ecosystems. Risk-based assessment, Health Product Declarations, and other approaches are emerging to address this demand, and manufacturers are buying into the concept of being more open about the content of their products. In addition, many major cities are requiring transparency regarding the energy performance of buildings. In New York City, for example, building owners are required to provide information about the performance of their buildings on an annual basis. This requirement dovetails with the shift in building assessment system strategies that explicitly provide credit for reporting of both energy and water data. Transparency is described and discussed in several locations in this fourth edition.

One of the new additions is coverage of the rapid growth in the numbers and quality of green skyscrapers around the world. Ken Yeang, the renowned Malaysian architect, first elaborated this concept in his 1996 book, *The Green Skyscraper: The Basis for Designing Sustainable Intensive Buildings*, and in his two other volumes on the subject, *Eco-Skyscrapers* (2007), and *Eco-Skyscrapers, Volume 2* (2011). In this volume, we address skyscrapers two chapters. In Chapter 1, one of the world's premier green skyscrapers, the Pertamina Energy Tower, located in Jakarta, Indonesia, is described in great detail because it represents perhaps the cutting edge of very large building design. This project is especially noteworthy because it is the first net-zero-energy skyscraper and represents the cutting edge of skyscraper performance. Later in the volume, in Chapter 16, two sets of skyscrapers—one group in New York City and the other group selected from green skyscraper projects around the world—are described and compared. I would like to express my gratitude to the group of architects and engineers at Skidmore, Owings & Merrill (SOM), who designed the Pertamina Energy Tower. These include the Gabriele Pascolini, Sergio Sabada, Luke Leung, Scott Duncan, David Kosterno, Stephen Ray, Elyssa Cohen,

and Jonathan Stein. Although extremely busy with their day jobs designing significant skyscraper projects around the world, they gave generously of their time and resources to assist me. I would also like thank the team at HOK that designed the Lake Nona Research Building for the University of Florida, specifically Van Phrasavath and Mandy Weitknecht. Frank Javaheri, project manager for the University of Florida, was also very helpful in assisting in gaining access to information and documentation.

This fourth edition has significantly more graphics than the third edition of *Sustainable Construction*, and a large number of organizations and companies were kind enough to permit the publication of their content in this edition. Thanks to all the contributors of these invaluable materials.

Thanks to Paul Drougas and Margaret Cummings at John Wiley & Sons for once again guiding me through the initial stages of the publication process and to Mike New at John Wiley & Sons for keeping me on track. This edition would not have been possible without the enormous contributions of Tori Reszetar and Alina Kibert, who were extremely dedicated to helping produce a comprehensive, quality outcome. I owe an enormous debt to both of them for their very hard work and dedication.

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Chapter 1

Introduction and Overview

In the short quarter century after the first significant efforts to apply the *sustainability* paradigm to the built environment in the early 1990s, the resulting *sustainable construction* movement has gained significant strength and momentum. In some countries—for example, the United States—there is growing evidence that this responsible and ethical approach is dominating the market for commercial and institutional buildings, including major renovations. Over 69,000 commercial building projects have been registered for third-party green building certification with the US Green Building Council (USGBC), the major American proponent of built environment sustainability, in effect declaring the project team's intention to achieve the status of an officially recognized or certified green building. The tool the USGBC uses for this process is commonly referred to by its acronym, LEED (Leadership in Energy and Environmental Design). Thus far, 27,000 commercial projects have navigated the LEED certification process successfully. Nowhere has the remarkable shift toward sustainable buildings been more evident than in American higher education. Harvard University boasts 93 buildings certified in accordance with the requirements of the USGBC, including several projects with the highest, or platinum, rating and including more than 1.9 million square feet (198,000 square meters [m^2]) of labs, dormitories, libraries, classrooms, and offices. An additional 27 projects are registered and pursuing official recognition as green building projects. The sustainable construction movement is now international in scope, with almost 70 national green building councils establishing ambitious performance goals for the built environment in their countries. In addition to promoting green building, these councils develop and supervise building assessment systems that provide ratings for buildings based on a holistic evaluation of their performance against a wide array of environmental, economic, and social requirements. The outcome of applying sustainable construction approaches to creating a responsible built environment is most commonly referred to as *high-performance green buildings*, or simply, *green buildings.*

The Shifting Landscape for Green Buildings

There are many signs that the green building movement is permanently embedded as standard practice for owners, designers, and other stakeholders. Among these are four key indicators that illustrate this shift into the mainstream. First, a survey of design and construction activity by McGraw-Hill Construction (2013) found that, for the first time, the majority of firms engaged in design and construction expected that over 60 percent of their work would be in green building by 2015. South Africa, Singapore, Brazil, European countries, and the United States all report this same result: that green building not only dominates the construction marketplace but also continues to increase in market share. This same report suggests that around the world, the pace of green building is accelerating and becoming a long-term business opportunity for both designers and builders. The green building market is growing worldwide and is not isolated to one region or culture. According to McGraw-Hill Construction, architects and engineers around the world are bullish on green building. Between 2012 and 2015, the number of designers and building consultants expecting more than 60 percent of their business to be green more than tripled in South Africa; more than doubled in Germany, Norway, and Brazil; and increased between 33 percent and 68 percent in the United States, Singapore, the United Kingdom, and Australia. The reasons for the rapid growth in high-performance green building activity has changed dramatically over time. In 2008, when a similar survey was conducted, most of the respondents felt that the main reason for their involvement was that they were doing the right thing, that they were simply trying to have a positive impact. Fast-forward just six years to 2014, and the reasons had changed significantly. The most cited triggers for green building around the world are client demand, market demand, lower operating costs, and branding/public relations. Green building has become simply a matter of doing good business, and has entered the mainstream in both the public and the private sectors. Although those interviewed indicated that they were still interested in doing the right thing, this reason moved from the top of the list in 2008 to number five in the six-year period between the two surveys.

A second illustration of the green building movement's staying power occurred at the Arab world's first Forum for Sustainable Communities and Green Building held in late 2014. Mustafa Madbouly, Egypt's minister of housing and urban development, told the audience: "Climate change forces upon us all a serious discussion about green building and the promotion of sustainability" (Zayed 2014). According to the United Nations Human Settlement Program (UNHSP), cities in the Arab world need to introduce stronger standards for green building and promote sustainable communities if they are to have this chance of tackling climate change. The UNHSP estimates that 56 percent of the Arab world's population already lives in cities and urban centers. This number quadrupled between 1990 and 2010 and is expected to increase another 75 percent by 2050. In short, applying sustainability principles to the built environment is essential not only for the well-being of the region's population but also for their very survival. According to the World Bank, the unprecedented heat extremes caused by climate change could affect 70 percent to 80 percent of the land area in the Middle East and North Africa.[1] Green building and climate change are now inextricably linked, and the main strategy for addressing climate change must be to change the design and operation of the built environment and infrastructure to reduce carbon emissions dramatically.

Third, in the United States, activity in sustainable construction continues to increase, some of it marking the continued evolution of thinking about how best to achieve high standards of efficiency in the built environment while at the same time promoting human health and protecting ecological systems. The state of Maryland and its largest city, Baltimore, provide a contemporary example of how strategies are being fine-tuned to embed sustainability in the built environment for the long term. In 2007, both Maryland and Baltimore, the 26th most populous city in the United States, adopted the USGBC's LEED rating system, requiring that most new construction be LEED certified. At the time, this move was considered groundbreaking, and it paralleled efforts by many states and municipalities around the country to foster the creation of a much-improved building stock. Baltimore, along with 176 other American jurisdictions, mandated green buildings and supported their implementation with a variety of incentives, including more rapid approval times, decreased permitting fees, and, in some cases, grants and lower taxes. In 2014, in a move that is likely to become more common, both Maryland and Baltimore repealed the laws and ordinances requiring LEED rating certification and instead adopted the International Green Construction Code (IgCC) as a template for their building codes. A construction or building code such as IgCC, in contrast to a voluntary rating system such as LEED, *mandates* green strategies for buildings. This turn of events marks a significant change in both strategy and philosophy because it indicates a shift from third-party certification systems to mainstreaming green building through the use of standards and building codes enforced by local authorities.

The fourth sign of the shifting landscape for high-performance green building is the fact the major tech giants Apple and Google and a range of other tech companies have announced major projects that indicate their industry is embracing high-performance green building. Apple Campus 2 (see Figure 1.1), scheduled for a late 2016 completion, will house 14,200 employees. In first announcing the new project in 2006, the late Steve Jobs referred to it as "the best office building in the world." The architects for this cutting-edge facility are Foster + Partners, the renowned British architecture firm whose founder and chairman, Sir Norman Foster, was inspired by a London square surrounded by houses to guide the design concept. As the building evolved, it morphed into a circle surrounded by green space, the inverse of the London square. Located on about 100 acres (40.5 hectares) in Cupertino, California, the 2.8 million–square–foot (260,000 square meters) building is sited in the midst of 7,000 plum, apple, cherry, and apricot trees, a signature feature of the area's commercial orchards. Only 20 percent of the site was disturbed by construction, resulting in

Figure 1.1 Apple Campus 2 is an NZE building designed to generate all the energy it requires from photovoltaic (PV) panels located on its circular roof. Its many passive design features allow it to take advantage of the favorable local climate such that cooling will be required just 25 percent of the year. (*Source:* City of Cupertino, September 2013)

abundant green space. Apple's Transportation Demand Management program emphasizes the use of bicycles, shuttles, and buses to move its employees to and from two San Francisco Bay regional public transit networks. The transportation program alternatives for Apple Campus 2 include buffered bike lanes and streets near the campus that are segregated from automobile traffic and also wide enough to permit bicycles to pass each other. Hybrid and electric automobile charging stations serve 300 electric vehicles, and the system can be expanded as needed. The energy strategy for Apple's new office building was shaped around the *net zero energy* (NZE) concept, with extensive focus on passive design to maximize daylighting and natural cooling and ventilation. The result is a building that generates more energy from renewable sources than it consumes. Energy efficiency is important for the net zero strategy, and the lighting and all other energy-consuming systems were selected for minimal energy consumption. The central plant contains fuel cells, chillers, generators, and hot and condenser water storage. A low carbon solar central plant with 8 megawatts (MW) of solar panels is installed on the roof, ensuring the campus runs entirely on renewable energy.

Another tech giant with ambitious high-performance green building plans is Google. Early in 2015, as part of a planned massive expansion, Google announced a radical plan for expansion of its Mountain View, California, headquarters into the so-called Googleplex. The radical design included large tentlike structures with canopies of translucent glass floating above modular buildings that would be reconfigured as the company's projects and priorities change. The area beneath the glass canopy included walking and bicycle paths along meadows and streams that connect to nearby San Francisco Bay. The emerging direction of design by the superstar collaboration between the Danish architect Bjarke Ingels and the London design firm, Heatherwick Studio was an eco-friendly project that would feature radical passive design and integration with nature and local transportation networks. However, in mid-2015, the Mountain View City Council voted to allow Google just one-fourth of its planned expansion, with the remaining site being made available to another tech firm, LinkedIn. In spite of this setback, Google, like many other technology-oriented companies, is committed to greening its buildings and infrastructure. One of its commitments is to investing in renewable energy, and the firm committed $145 million to finance a SunEdison plant north of Los Angeles. This was one of many renewable projects in which Google has invested a total of over $1.5 billion as of 2015.

Other tech firms are also leading the way with investments in architecturally significant, high-performance green buildings. Hewlett-Packard hired the renowned architect Frank Gehry to design an expansion of its Menlo Park, California, campus. It is clear that the behavior of these tech firms is part of an emerging pattern among start-up firms, which often begin their lives in college dorm rooms, storage units, garages, and living rooms. They move out of such locations as they mature, renting offices in industrial parks. Then, when they have become supersuccessful and flush with cash, they tend to build iconic monuments. However, in spite of the desire to make a splash by investing in signature headquarters buildings designed by well-known architects, the tech industries have managed to remain eco-conscious and serve as change agents by pushing society toward more sustainable behavior, particularly with respect to the built environment.

These trends, which mark the current state of high-performance green building around the world, indicate a maturing of the movement. The first of these buildings emerged around 1990, and the movement is now being mainstreamed, as evidenced by the incorporation of high performance building rating systems, such as LEED, into standards and codes. Since the inception of its pilot version in 1998, LEED has dealt with building energy performance by specifying improvements beyond the requirements of these standards to earn points toward certification. The main energy standard in the United States is the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, *Energy Standard for*

Buildings Except Low-Rise Residential Buildings. In the years since 1998, the energy consumption standards for new U.S. buildings has been sliced by more than 50 percent, and each issue of ASHRAE 90.1 makes additional cuts. The outcome is that it is becoming more difficult to use green building rating systems to influence additional energy reductions because following ASHRAE 90.1 already results in highly efficient building. Nevertheless, many issues still need attention, such as the restoration of natural systems, urban planning, infrastructure, renewable energy systems, comprehensive indoor environmental quality, and stormwater management. To its credit, the green building movement has succeeded in creating a dramatic shift in thinking in a short time. Its continued presence is now needed to both push the cutting edge of building performance and to ensure that the success of its efforts are maintained for the long term.

The Roots of Sustainable Construction

The contemporary high-performance green building movement was sparked by finding answers to two important questions: What is a high-performance green building? How do we determine if a building meets the requirements of this definition? The first question is clearly important—having a common understanding of what comprises a green building is essential for coalescing effort around this idea. The answer to the second question is to implement a *building assessment* or *building rating* system that provides detailed criteria and a grading system for these advanced buildings. The breakthrough in thinking and approach first occurred in 1989 in the United Kingdom with the advent of a building assessment system known as *BREEAM* (Building Research Establishment Environmental Assessment Method). BREEAM was an immediate success because it proposed both a standard definition for green building and a means of evaluating its performance against the requirements of the building assessment system. BREEAM represented the first successful effort at evaluating buildings on a wide range of factors that included not only energy performance but also water consumption, indoor environmental quality, location, materials use, environmental impacts, and contribution to ecological system health, to name but a few of the general categories that can be included in an assessment. To say that BREEAM is a success is a huge understatement because over 1 million buildings have been registered for certification and about 200,000 have successfully navigated the certification process. Canada and Hong Kong subsequently adopted BREEAM as the platform for their national building assessment systems, thus providing their building industries with an accepted approach to green construction. In the United States, the USGBC developed an American building rating system with the acronym LEED. When launched as a fully tested rating system in 2000, LEED rapidly dominated the market for third-party green building certification. Similar systems were developed in other major countries: for example, *CASBEE* (Comprehensive Assessment System for Building Environmental Efficiency) in Japan (2004) and *Green Star* in Australia (2006). In Germany, which has always had a strong tradition of high-performance buildings, the German Green Building Council and the German government collaborated in 2009 to develop a building assessment system known as *DGNB* (Deutsche Gesellschaft für Nachhaltiges Bauen), which is perhaps the most advanced evolution of building assessment systems. BREEAM, LEED, CASBEE, Green Star, and DGNB represent the cutting edge of today's high-performance green building assessment systems, both defining the concept of high performance and providing a scoring system to indicate the success of the project in meeting its sustainability objectives.

In the United States, the green building movement is often considered to be the most successful of all the American environmental movements. It serves as a template for engaging and mobilizing a wide variety of stakeholders to accomplish an important sustainability goal, in this case dramatically improving the efficiency, health, and performance of the built environment. The green building movement provides a model for other sectors of economic endeavor about how to create a consensus-based, market-driven approach that has rapid uptake, not to mention broad impact. This movement has become a force of its own and, as a result, is compelling professionals engaged in all phases of building design, construction, operation, financing, insurance, and public policy to fundamentally rethink the nature of the built environment.

In the second decade of the twenty-first century, circumstances have changed significantly since the onset of the sustainable construction movement. In 1990, the global population was 5.2 billion, climate change was just entering the public consciousness, the United States had just become the world's sole superpower, and Americans were paying just $1.12 for a gallon of gasoline. Fast-forwarding almost a quarter century, the world's population is approaching 7.4 billion, the effects of climate change are becoming evident at a pace far more rapid than predicted, the global economic system is still floundering from debt crises in Europe, and Japan is still recovering from the impacts of a tsunami and nuclear disaster. Prices for gasoline have fluctuated widely due to a recent abundance of oil produced by fracking but are about two times higher than in 1990. The convergence of financial crises, climate change, and increasing numbers of conflicts has produced an air of uncertainty that grips governments and institutions around the world. What is still not commonly recognized is that all of these problems are linked and that population and consumption remain the twin horns of the dilemma that confronts humanity. Population pressures, increased consumption by wealthier countries, the understandable desire for a good quality of life among the 5 billion impoverished people on the planet, and the depletion of finite, nonrenewable resources are all factors creating the wide range of environmental, social, and financial crises that are characteristic of contemporary life in the early twenty-first century (see Figure 1.2).

These changing conditions are affecting the built environment in significant ways. First, there is an increased demand for buildings that are resource-efficient, that use minimal energy and water, and whose material content will have value for future populations. In 2000, the typical office building in the United States consumed over 300 kilowatt-hours per square meter per year ($kWh/m^2/yr$) or 100,000 BTU/square foot/year ($BTU/ft^2/yr$). Today's high-performance buildings are approaching 100 $kWh/m^2/yr$ (33,000 $BTU/ft^2/yr$).[2] In Germany, the energy profiles of high-performance buildings are even more remarkable, in the range of 50 $kWh/m^2/yr$

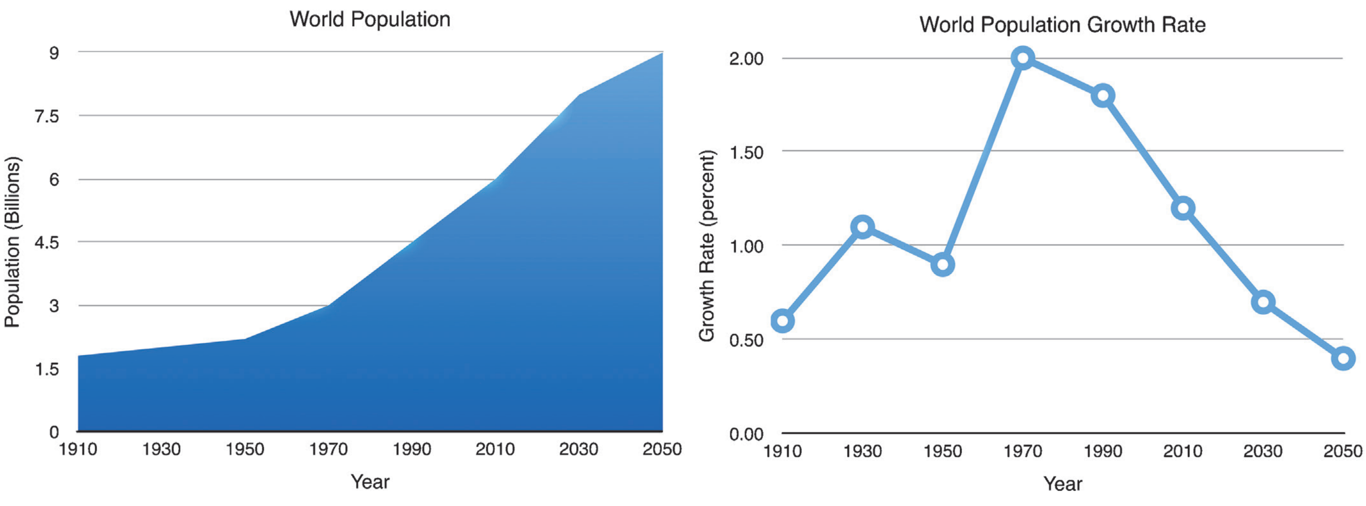

Figure 1.2 World population continues to increase, but the growth rate is declining, from about 1.2 percent in 2012 to a forecasted 0.5 percent in 2050. (*Source:* US Census Bureau, International Database, June 2011)

(17,000 BTU/ft^2/yr). It is important to recognize that reduced energy consumption generally causes a proportional reduction in climate change impacts. Reductions in water consumption in high-performance buildings are also noteworthy. A high-performance building in the United States can reduce potable water consumption by 50 percent simply by opting for the most water-efficient fixtures available, including high-efficiency toilets and high-efficiency urinals. By using alternative sources of water, such as rainwater and graywater, potable water consumption can be reduced by another 50 percent, to one-fourth that of a conventionally designed building water system. This is also referred to as a Factor 4 reduction in potable water use. Similarly impressive impact reductions are emerging in materials consumption and waste generation.

Second, it has become clear over time that building location is a key factor in reducing energy consumption because transportation energy can amount to two times the operational energy of the building (Wilson and Navaro 2007). Not only does this significant level of energy for commuting have environmental impacts, but it also represents a significant cost for the employees who make the daily commute. It is clear that the lower the building's energy consumption, the greater is the proportion of energy used in commuting. For example, a building that consumes 300 kWh/m^2/yr of operational energy and 200 kWh/m^2/yr of commuting energy by its occupants has 40 percent of its total energy devoted to transportation. A high-performance building in the same location with an energy profile of 100 kWh/m^2/yr and the same commuting energy of 200 kWh/m^2/yr would have 67 percent of its total energy consumed by transportation. Clearly, it makes sense to reduce transportation energy along with building energy consumption to have a significant impact on total energy consumption (see Figure 1.3).

Third, the threat of climate change is enormous and must be addressed across the entire life cycle of a building, including the energy invested in producing its materials and products and in constructing the building, commonly referred to as

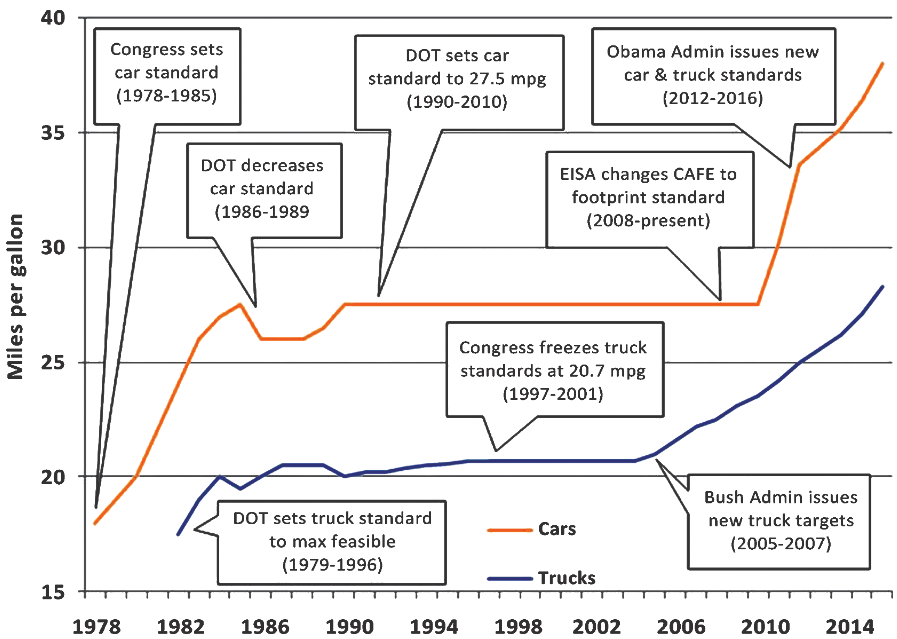

Figure 1.3 The fuel efficiency of US vehicles languished for decades before federal standards, due to the energy crises of the 1970s, demanded significant improvements in fuel performance. More recent requirements have increased dramatically the miles per gallon performance of both automobiles and trucks. (*Source:* Center for Climate and Energy Solutions)

embodied energy. The energy invested in building materials and construction is significant, amounting to as much as 20 percent of the total life cycle energy of the facility. Furthermore, significant additional energy is invested by maintenance and renovation activities during the building's life cycle, sometimes exceeding the embodied energy of the construction materials. Perhaps the most noteworthy effort to address the built environment contribution to climate change is the *Architecture 2030 Challenge* whose goal is to achieve a dramatic reduction in the greenhouse gas (GHG) emissions of the built environment by changing the way buildings and developments are planned, designed, and constructed.[3] The 2030 Challenge asks the global architecture and building community to adopt the following targets:

- All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70 percent below the regional (or country) average/median for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70 percent of the regional (or country) average/median for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to 80 percent in 2020, 90 percent in 2025, and be carbon-neutral in 2030 (using no fossil fuel energy to operate).[4]

The *2030 Challenge for Product* addresses the GHG emissions of building materials and products and sets a goal of reducing the maximum carbon-equivalent footprint to 35 percent below the product category average by 2015 and eventually to 50 percent below the product category average by 2030.

The emerging concept of NZE, which, in its simplest form, suggests that buildings generate as much energy from renewables as they consume on an annual basis, also supports the goals of the 2030 Challenge. Every unit of energy generated by renewables that displaces energy generated from fossil fuels results in less climate change impact. An NZE building would, in effect, have no climate change impacts due to its operational energy. It is clear that influencing energy consumption and climate change requires a comprehensive approach that addresses all forms of energy consumption, including operational energy, embodied energy, and commuting energy.

In summary, high-performance building projects are now addressing three emerging challenges: (1) the demand for high-efficiency or *hyperefficient* buildings, (2) consideration of building location to minimize transportation energy, and (3) the challenges of climate change. These challenges are in addition to issues such as indoor environmental quality, protection of ecosystems and biodiversity, and risks associated with building materials. Building assessment systems such as LEED are being affected by these changes as is the very definition of green buildings. As time advances and more is learned about the future and its challenges, the design, construction, and operation of the built environment will adapt to meet this changing future landscape.

Sustainable Development and Sustainable Construction

The main impetus behind the high-performance green building movement is the sustainable development paradigm, which is changing not only physical structures but also the workings of the companies and organizations that populate the built environment, as well as the hearts and minds of the individuals who inhabit it.[5] Fueled by examples of personal and corporate irresponsibility and negative publicity resulting from events such as the collapse of the international finance system that triggered the Great Recession of 2008–2010, increased public concern about the behavior of private and public institutions has developed. As a result, accountability and transparency are becoming the watchwords of today's corporate world. Heightened corporate consciousness has embraced comprehensive sustainability reporting as the new standard for corporate transparency. The term *corporate transparency* refers to complete openness of companies about all financial transactions and all decisions that affect their employees and the communities in which they operate. Major companies, such as DuPont, the Ford Motor Company, and Hewlett-Packard, now employ triple bottom line reporting,[6] which involves a corporate refocus from mere financial results to a more comprehensive standard that includes environmental and social impacts. By adopting the cornerstone principles of sustainability in their annual reporting, corporations acknowledge their environmental and social impacts and ensure improvement in all arenas.

Still, other major forces, such as climate change and the rapid depletion of the world's oil reserves, threaten national economies and the quality of life in developed countries. Both are connected to our dependence on fossil fuels, especially oil. Climate change, caused at least in part by increasing concentrations of human-generated carbon dioxide (CO_2), methane, and other gases in Earth's atmosphere, is believed by many authoritative scientific institutions and Nobel laureates to profoundly affect our future temperature regimes and weather patterns.[7] Much of today's built environment will still exist during the coming era of rising temperatures and sea levels; however, little consideration has been given to how human activity and building construction should adapt to potentially significant climate alterations. Global temperature increases now must be considered when forming assumptions about passive design, the building envelope, materials selection, and the types of equipment required to cope with higher atmospheric energy levels.

The state of the global economy and consumption continue to significantly affect the state of Earth's environment. The Chinese economy grew at an official rate of 7 percent in 2015 with some estimates that it will continue to grow at or above this pace over the next few years. China produced about 2 million automobiles in 2000, about 6 million in 2005, and 14 million in 2015. China's burgeoning industries are in heavy competition with the United States and other major economies for oil and other key resources, such as steel and cement. The rapid economic growth in China and India and concerns over the contribution of fossil fuel consumption to climate change will inevitably force the price of gasoline and other fossil fuel–derived energy sources to increase rapidly in the coming decades. At present, there are no foreseeable technological substitutes for large-scale replacement of fossil fuels. Alternatives such as hydrogen or fuels derived from coal and tar sands threaten to be prohibitively expensive. The expense of operating buildings that are heated and cooled using fuel oil and natural gas will likely increase, as will industrial, commercial, and personal transportation that is fossil fuel dependent. A shift toward hyperefficient buildings and transportation cannot begin soon enough.

The Vocabulary of Sustainable Development and Sustainable Construction

A unique vocabulary is emerging to describe concepts related to sustainability and global environmental changes. Terms such as *Factor 4* and *Factor 10*, *ecological footprint*, *ecological rucksack*, *biomimicry*, the *Natural Step*, *eco-efficiency*, *ecological economics*, *biophilia*, and the *precautionary principle* describe the overarching