ASHRAE GreenGuide

Design, Construction, and Operation of Sustainable Buildings

Fifth Edition

- Comprehensive guidance on sustainable buildings
- Major revisions to all chapters
- GreenTips with detailed insights for design and operation

ASHRAE®

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This publication was developed under the auspices of ASHRAE Technical Committee (TC) 2.8, Building Environmental Impacts and Sustainability. TC 2.8 is concerned with the impacts of buildings on the local, regional, and global environment; means for identifying and reducing these impacts; and enhancing ASHRAE member awareness of the impacts.

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ASHRAE GreenGuide

Design, Construction, and Operation of Sustainable Buildings

Fifth Edition

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Tomorrow's Child

Without a name, an unseen face,
And knowing not the time or place,
Tomorrow's Child, though yet unborn,
I saw you first last Tuesday morn.
A wise friend introduced us two,
And through his shining point of view
I saw a day, which you would see,
A day for you, and not for me.
Knowing you has changed my thinking,
Never having had an inkling
That perhaps the things I do
Might someday threaten you.
Tomorrow's Child, my daughter-son,
I'm afraid I've just begun
To think of you and of your good,
Though always having known I should.
Begin I will to weigh the cost
Of what I squander, what is lost,
If ever I forget that you
Will someday come to live here too.

by Glenn Thomas, ©1996

Reprinted from
*Mid-Course Correction:
Toward a
Sustainable Enterprise:
The Interface Model*
by Ray Anderson.
Chelsea Green
Publishing Company, 1999

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GREENTIPS

DIGGING DEEPER SIDEBARS

FOREWORD

originally written by the late William Coad
edited by Tom Lawrence for the fifth edition

ASHRAE is the preeminent technical society representing engineers practicing in the fields of heating, refrigeration, and air conditioning—the technology that uses approximately one-third of the global nonrenewable energy consumed annually.

ASHRAE membership has actively pursued more effective means of utilizing precious nonrenewable energy resources for many decades, from the standpoints of source availability, efficiency of utilization, and technology of substituting with renewable sources. One significant publication in *ASHRAE Transactions* is a paper authored in 1951 by G.W. Gleason, Dean of Engineering at Oregon State University, titled "Energy—Choose it Wisely Today for Safety Tomorrow" (Gleason 1951). The flip side of the energy coin is the environment and, again, ASHRAE has historically dealt with the impact that the practice of the HVAC&R sciences have had upon both the indoor and the global environment.

However, the engineering community, to a great extent, serves the needs and desires of accepted economic norms and the consuming public, a large majority of whom have not embraced an energy/environmental ethic. As a result, much of the technology in energy effectiveness and environmental sensitivity that ASHRAE members have developed over this past century has had limited impact on society.

In 1975, when ASHRAE published ASHRAE Standard 90-75, *Energy Conservation in New Building Design* (ASHRAE 1975), that standard served as our initial outreach effort to develop an awareness of the energy ethic and to extend our capabilities throughout society as a whole. Since that time, updated revisions of Standard 90 have moved the science ahead. In 1993, the chapter on energy resources was added to the 1993 *ASHRAE Handbook—Fundamentals*. In 2002, ASHRAE entered into a partnering agreement with U.S. Green Building Council (USGBC), and it is intended that this and future editions of this design guide will continue to assist ASHRAE in its efforts at promoting sustainable design, as well as the many other organizations that have advocated for high-performance building design.

The consuming public and other representative groups of building professionals continue to become more and more aware of the societal need to provide buildings that are more energy resource effective and environmentally compatible. The topics involved with “green building” or “high-performance green buildings” are much more than just energy as well. These include water efficiency, indoor environmental quality, and the materials used in building construction, for example. ASHRAE has been working toward being recognized as one of the preeminent authorities on green buildings in the industry, for example by taking the lead in the creation of ANSI/ASHRAE/USGBC/IES Standard 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. In addition, newer emerging technologies, such as the smart grid or smart buildings, are coming forth. This publication, authored and edited by ASHRAE volunteers, is intended to complement the efforts in all these topical areas and to help the membership keep up to date.

Preface to the Fifth Edition

by Tom Lawrence

This new edition of *ASHRAE GreenGuide* represents another significant update and revision to what has become one of ASHRAE's primary contributions toward sustainable design of the built environment.

The new fifth edition is being released as we close in on the fifteenth anniversary of the release of the first edition in January 2004. A lot has changed in the industry in general, and in green design practices in particular, during those years. Many of the concepts that seemed "out there" in the time period that the first edition was published are now considered mainstream and, in some cases, are now actually required by code. We have tried to incorporate these trends in making revisions to this fifth edition as well as take a look into the crystal ball and anticipate future trends. It has been ASHRAE's plan to update and maintain this book on a regular basis because of this rapidly evolving field and to support ASHRAE's committed goal of global leadership in sustainability and technical education. This also follows the example set by ASHRAE's rebranding in 2012.

Since the release of the fourth edition of the *GreenGuide*, a number of developments have occurred in the green building arena. ASHRAE has continued to refine and modify ANSI/ASHRAE/USGBC/IES Standard 189.1, with a new release of that standard published in late 2014 and another in process for late 2017. A recent agreement between ASHRAE and the International Code Council (ICC) will result in the merging of Standard 189.1 and the *International Green Construction Code* (IgCC) beginning with the 2018 code cycle. ASHRAE is responsible for the technical content and ICC is responsible for the administrative provisions. This will hopefully result in further adoption and use of this code, and other organizations and jurisdictions are using these as the basis for their own codes and design standards. Thus, the industry is witnessing the continued evolution of green building programs from strictly voluntary to being both more mainstream within the industry as well as mandatory in jurisdictions that have adopted these standards for their building codes.

This fifth edition features four entirely new chapters, as well as updated information and GreenTips. The specific Building-Type GreenTips have been located in a new standalone Chapter 18. The new Chapter 19 covers green building design as it relates to existing buildings, and the new Chapter 17 discusses differing aspects of green design for residential structures. Finally, Chapter 20, Emerging Trends and Epilogue, briefly covers new topics that are becoming key to the industry. Chapter 13, Smart Building Systems, including information on building automation systems, has also been extensively revised and expanded in scope.

No one person, or even a small committee of people, can be expected to have the breadth and depth of expertise to create a book that covers the wide range of issues governing the design, construction, and operation of green buildings. Thus, many people with various backgrounds were recruited to help review and edit the existing chapters and to write the new chapters. One of the goals for the editorial committee for this revision was to bring in a large number of additional outside reviewers. We truly appreciate those that contributed their time and talents in reviewing, editing, and writing. Finally, the current edition could not have been possible without all the hard work and dedication put into it by others who created the previous editions. This book truly represents the collaborative nature of the work done by dedicated volunteers within ASHRAE. All work performed—by the authors, editors, developing subcommittees, other reviewers, and technical committee participants—was strictly voluntary.

WHO SHOULD USE *ASHRAE GREENGUIDE*

The original stated purpose for the *ASHRAE GreenGuide* was created primarily for HVAC&R designers, but time has shown that it is also a useful reference for architects, owners, building managers, operators, contractors, students, and others in the building industry who want to understand the technical issues regarding high-performance design from an integrated building systems perspective. Considerable emphasis is placed on teamwork and close coordination between parties.

The *GreenGuide* was originally intended for use by younger engineers or architects, or more experienced professionals about to enter into their first green design projects. However, a survey of those who purchased one of the earlier editions of this publication revealed that it was primarily being used by more experienced individuals. The survey also indicted a higher percentage of the readership from countries outside of North America, perhaps reflecting the growing internationalization of ASHRAE. These trends have been taken into account with the revision process for later editions.

HOW TO USE *ASHRAE GREENGUIDE*

This book is intended to be used more as a reference than as something one would read in sequence from beginning to end. The table of contents is the best place for any reader to get an overall view of what is covered in this publication. Throughout the *GreenGuide*, numerous techniques, processes, measures, or special systems are described succinctly in a modified outline or bullet form. These are called

ASHRAE GreenTips. Each GreenTip concludes with a listing of other sources that may be referenced for greater detail. (Lists of GreenTips and Digging Deeper sidebars can be found in the table of contents.)

All readers should take the time to review Chapter 1, Introduction and Background, which provides some essential definitions and meanings of key terms. Chapter 2 describes green rating systems and the relevant standards and paths to compliance as they relate to the work of the mechanical engineers. The project initial phases are covered, with Chapter 3 providing an overview of project strategies and the early stages of the design process and Chapter 4 covering the commissioning process.

The bulk of this book covers the design process, starting with the architectural design and planning impacts in Chapter 5. These chapters are essential reading for all who are interested in how the green design process works. Other topics in this section include conceptual engineering design, sustainable sites, indoor environmental quality, energy conversion systems, energy and water resources, lighting, water efficiency, smart building systems, and the process for completing design and documentation.

The final chapters finish the book with discussions on construction and operations and maintenance. This final section also includes the chapters on residential buildings, GreenTips for specific building types and existing buildings, and ends with the emerging trends chapter. In prior editions of this book, these tips were contained at the end of the chapter on the architectural design process; however, it is felt that these are important enough to justify as a separate chapter and not get lost in the back pages of one particular chapter.

At the end of the guide is a comprehensive References and Resources section, which compiles all the sources mentioned throughout the guide, and an index for rapid location of a particular subject of interest.

HISTORICAL BACKGROUND ON *ASHRAE GREENGUIDE*

The idea for the publication of this guide was initiated by 1999–2000 ASHRAE President Jim Wolf and carried forward by then President-Elect (and subsequently President) William J. Coad. Members of that first subcommittee were David L. Grumman, Fellow ASHRAE, chair and editor; Jordan L. Heiman, Fellow ASHRAE; and Sheila Hayter, chair of TC 1.10 (a precursor to the TC 2.8 of today).

The *GreenGuide* subcommittee responsible for the second and third editions consisted of John Swift and Tom Lawrence, along with the people noted in the Acknowledgments section. Work on the fourth and fifth editions was overseen by a subcommittee of TC 2.8 led by Tom Lawrence.

ACKNOWLEDGMENTS

The following individuals served as coeditors on this edition of *ASHRAE GreenGuide,* provided written materials and editorial content, and formed the Senior Editorial Group of the ASHRAE TC 2.8 *GreenGuide* subcommittee for the fifth edition:

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In addition, the following individuals contributed new written materials on various topics for the fifth edition of *ASHRAE GreenGuide*. All or portions of these contributions were incorporated, with minor editing.

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The committee is deeply thankful for all the individuals who helped with or contributed to the first four editions of the *GreenGuide*. The fifth edition would not be where it is without their help. However, because of space constraints, their names cannot be listed in the fifth edition.

Section 1: Basics

CHAPTER ONE

Introduction and Background

INTRODUCTION

There continues to be a growing awareness about the impact of the built environment on the natural environment. The use of sustainable engineering concepts has evolved quite rapidly in recent years and is now well recognized in HVAC&R and related engineering professions. This in turn is being encouraged by increased client demand for more sustainable buildings, commonly called *green buildings*.

Interest in sustainable or green buildings (the distinction between the two is discussed below) has been particularly evident in the concern about energy and water resource consumption, but also includes broader concerns such as indoor environmental air quality, material use, and "smart" development and planning. Many countries in the world now have green-building rating systems (voluntary) and/or codes (mandatory) in some form or other. Organizations devoted to green buildings now exist in most countries. Even as the concept of green design is reaching mainstream acceptance, these organizations continue to promote these concepts, exhort the industry and society to action, strive to motivate industry practitioners and building owners, warn of consequences from ignoring these concepts, and instruct how to achieve green design.

ASHRAE identified a need for guidance on green building concepts specifically directed toward practicing professionals involved on a day-to-day basis in the mechanical/electrical/plumbing (MEP) building system design process. However, readers may find that this guide may also serve other needs—for example, as the basis for a university course in sustainable building design. From a survey conducted in 2011, a wider range of people now use the *ASHRAE GreenGuide*, including students and other professionals in related disciplines. The topics covered in this guide are global and thus there has been an effort to keep this guide applicable internationally.

Green is one of those words that can have many meanings, depending on the circumstances. One of these is the greenery of nature in the flora around us. This symbolic reference to nature is the meaning this term relates to in this publication. The difference between a green and sustainable design is the degree to which the design helps to minimize the building impact on the environment while simultaneously providing a healthy, comfortable indoor environment. When the term *green* is used, is commonly is thought of as focusing on the energy and resources involved, while *sustainable* is broader in scope and considers the three Ps: people, profit and planet. However, some may not recognize a difference between the two terms and use them interchangeably; this is also the general approach taken in this book. This guide is not intended to cover the full breadth of sustainability, as this would require and extensive series of volumes, but it is a good overview of the main topics and issues involved. For additional key characteristics and detailed discussion of sustainability in buildings and the built environment, refer to the "Sustainability" chapter in the *ASHRAE Handbook—Fundamentals* (ASHRAE 2017a).

It is important to note that the definition of *green buildings* places an emphasis on integrated design of mechanical, electrical, architectural, and other systems. Specifically, a green/sustainable building design is one that achieves high performance, over the full life cycle, in the following areas:

- Minimizing natural resource consumption through more efficient utilization of nonrenewable energy and other natural resources, land, water, and construction materials, including utilization of renewable energy resources to strive to achieve net zero energy consumption.
- Minimizing emissions that negatively impact our global atmosphere and ultimately the indoor environment, especially those related to indoor air quality (IAQ), greenhouse gases, global warming, particulates, or acid rain.
- Minimizing discharge of solid waste and liquid effluents, including demolition and occupant waste, sewer, and stormwater, and the associated infrastructure required to accommodate removal.
- Minimizing negative impacts on the building site.
- Optimizing the quality of the indoor environment, including air quality, thermal regime, illumination, acoustics/noise, and visual aspects to provide comfortable human physiological and psychological perceptions.
- Optimizing the integration of the new building project within the overall built and urban environment. A truly green/sustainable building should not be thought of or considered in a vacuum, but rather in how it integrates within the overall societal context.

Ultimately, even if a project does not have overtly stated green/sustainable goals, the overall approaches, processes, and concepts presented in this guide provide a design philosophy useful for any project. Using the principles of this guide, an owner or a team member can document the objectives and criteria to include in a project, forming the foundation for a collaborative integrated project delivery approach. This can lower design, construction, and operation costs, resulting in a lower total cost for the life of the project.

RELATIONSHIP TO SUSTAINABILITY

The related term *sustainable design* is very commonly used, almost to the point of losing any consistent meaning. While there have been some rather varied and complex definitions put forth (see the Digging Deeper sidebar titled "Some Definitions and Views of Sustainability from Other Sources"), a simple one is adapted in this guide: sustainability is providing for the needs of the present without detracting from the ability to fulfill the needs of the future.

The preceding discussion suggests that the concepts of green design and sustainable design have no absolutes—that is, they cannot be defined in black-and-white terms. These terms are more useful when thought of as a mindset: a goal to be sought and a process to follow. This guide is a means of (1) encouraging designers of the built environment to employ strategies for developing a green/sustainable design, and (2) setting forth some practical techniques to help practitioners achieve the goal of green design, thus making a significant contribution to sustainability.

Another method for assessing sustainability is through the concept of the triple bottom line (Savitz and Weber 2006). This concept advances the idea that monetary cost is not the only way to value project design options. The triple bottom line concept advocates for the criteria to include economic, social, and environmental impacts of building design and operations decisions.

COMMITMENT TO GREEN/SUSTAINABLE HIGH-PERFORMANCE PROJECTS

Green projects require more than a project team with good intentions; they require commitment from the owner and the rest of the project team, early documentation of sustainable/green goals recorded by the Owner's Project Requirement (OPR), and the designer's documented basis of design. The most successful projects incorporating green design are ones with dedicated, proactive owners who are willing to examine (or give the design team the freedom to examine) the entire spectrum of ownership—from design to construction to long-term operation of their facilities. These owners understand that green buildings require more planning, better execution, and better operational procedures, requiring a firm commitment to changing how building projects are designed, constructed, operated, and maintained to achieve a lower total cost of ownership and lower long-term environmental impacts.

Implementing green/sustainable practices could indeed raise the initial design soft costs associated with a project, particularly compared to a code minimum building design. First cost is an important issue and often is a stumbling block in moving building design from the code minimum ("good or adequate design") to one that is more truly sustainable. Implementing the commissioning process early in the predesign phase of a project adds an initial budget line item but can often actually reduce overall total design/construction costs and the ultimate cost of ownership.

In addition, significant savings and improved productivity of the building occupants can be realized for the life of the building, lowering the total cost of ownership and/or providing better value for tenants. To achieve lifelong benefits also requires operating procedures for monitoring performance, making adjustments (continuing commissioning) when needed, and appropriate maintenance.

WHAT DRIVES GREEN PROJECTS

Green-building advocates can cite plenty of reasons why buildings should be designed utilizing integrated green concepts. The fact that these reasons exist does not make it happen in routine building projects, nor does the existence of designers—or design firms—with green design experience. The main driver of green-building design is the motivation of the owner—the one who initiates the creation of a project, the one who pays for it (or who carries the burden of its financing), and the one who has (or has identified) the need to be met by the project in question. If the owner does not believe that green design is needed, thinks it is unimportant, or thinks it is of secondary importance to other needs, then it will not happen. In addition, recent trends in the industry are moving toward green-building practices being made mandatory, either through local adoption of new codes and standards or through an organizational policy. These trends are discussed in more detail in Chapter 2.

THE IMPACT OF CARBON CONSIDERATIONS

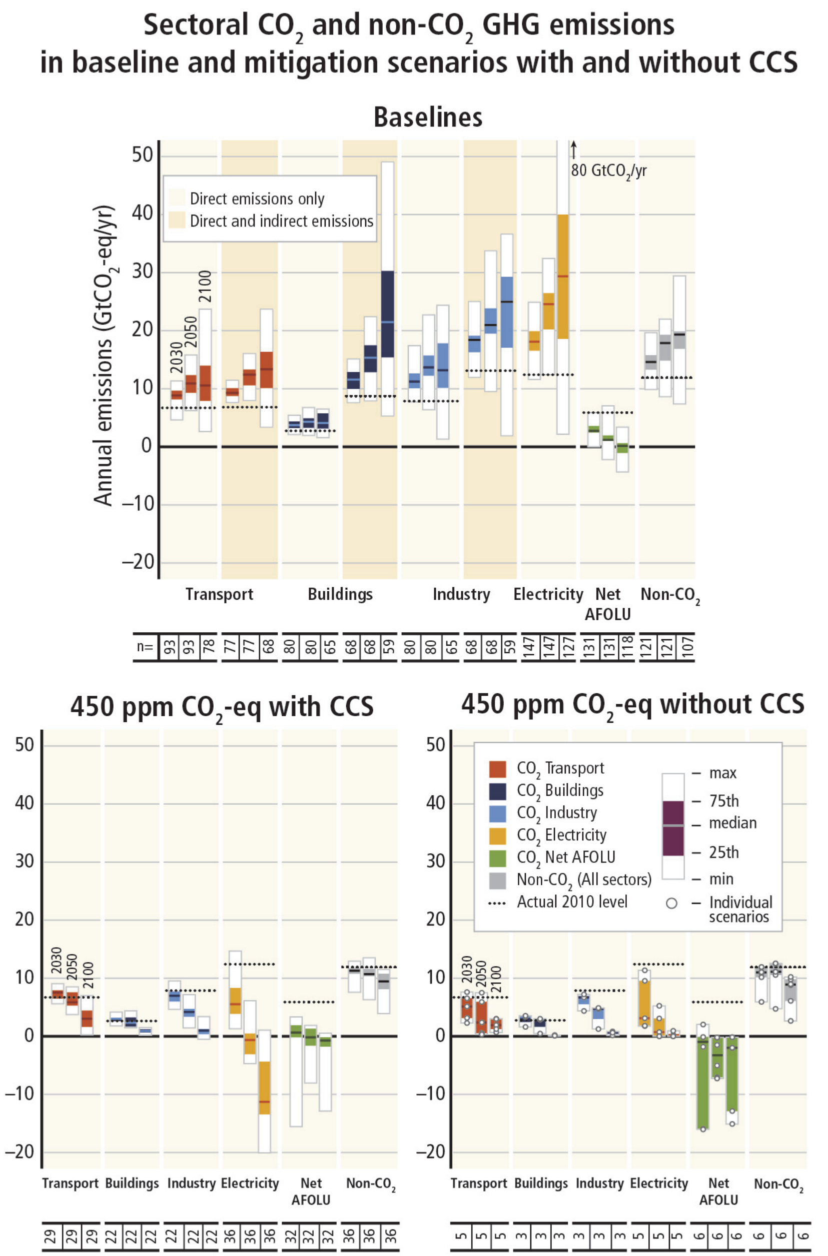
The attention paid to concerns about greenhouse gas emissions has certainly increased in much of the world. During the first decade of the twenty-first century, two organizations issued challenges to the industry to design and implement buildings that had a significantly lower energy consumption compared to current typical designs. The Architecture 2030 Challenge (see the "References and Resources" section at the end of the chapter for more information) is one of these. Architecture 2030 was initiated by Edward Mazria in 2002, setting a goal of net zero energy and net zero carbon buildings by the year 2030. This goal is to be realized by achieving substantially better building energy performance on a sliding scale from 2010 through 2030. The near-term focus of the challenge was adopted by the American Institute of Architects (AIA). The Architecture 2010 Imperative achieved a goal of constructing new buildings that show a 50% improvement in energy efficiency compared to those built using the 1999 version of ANSI/ASHRAE/IES Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*

(ASHRAE 1999). In Europe, there is an ongoing parallel effort to meet an ambitious goal of nearly zero energy buildings after 2020, according to the Energy Performance of Buildings Directive (EPBD) (European Commission 2010).

There is bad news and good news when we look at how buildings are involved with greenhouse gas (GHG) emissions. First, the bad news: buildings (commercial and residential) are responsible for approximately 30% of the GHG emissions in the United States and most developed countries, and the trend is also holding up in key developing nations. The good news is that buildings have also been identified as the economic sector with the best potential for cost-effective mitigation of GHG emissions, as highlighted in Figure 1-1. In this figure, the carbon dioxide (CO_2) emissions by sector and total non-CO_2 GHG emissions across sectors are shown in the baseline scenario at top while the bottom portion of Figure 1-1 shows the net result from mitigation scenarios that reach an average of about 450 ppm (in a range of 430 to 480 ppm) CO_2 equivalent (CO_2-eq) emissions (likely to limit warming to 3.6°F [2°C] above preindustrial levels) with CO_2 capture and storage (CCS, left) and without CCS (right). The difference between the baseline and mitigation scenarios in this figure represent the net emissions decrease possible for each sector, and the buildings sector represents one of the highest potential options. Therefore, the buildings industry can and should take responsibility for reducing GHG emissions, primarily through a reduction in energy consumption for new construction, in refurbishing existing buildings, and planning for the operation and maintenance to maintain the high level of efficiency.

The Conference of the Parties meeting in Paris in late 2015 (COP21) was recognized as a breakthrough event where the first significant changes to a global approach to address climate concerns were made in nearly 25 years. More importantly for the buildings industry, the important role of buildings in addressing this problem was recognized at this conference and a new organization, the Global Alliance for Buildings and Construction, was created. This alliance has a four-step strategic approach to: (1) reduce the energy demand of buildings (in particular, existing buildings), (2) decarbonize the energy and power supply for buildings, and (3) reduce the embodied greenhouse gases in materials and equipment through life cycle analysis, and increase resiliency by adaptations against climate change and associated other risks.

ASHRAE took the lead in meeting these challenges in several ways. To address the Architecture 2010 Imperative, significant effort was put into modifying Standard 90.1 (ASHRAE 1999) to drastically improve energy efficiency. The 2010 version of Standard 90.1, in essence, met the AIA challenge for 2010 by introducing requirement changes that were developed and introduced during that decade. Subsequent versions of Standard 90.1 continue to increase the minimum energy efficiency requirements. Although the specific requirements may differ in some cases, ANSI/ASHRAE/USGBC/IES Standard 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings* (ASHRAE



Source: IPCC (2014)

Figure 1-1 Cross-sectoral mitigation strategies.

2017b) and the *International Green Construction Code* (IgCC) have energy efficiency levels that exceed the minimum code values in Standard 90.1.

Another way this is being accomplished is through the production of the ASHRAE Advanced Energy Design Guide (AEDG) series. The series covers prescriptive measures that result in significant energy efficiency improvements, with the first series dealing with measures that should achieve 30% and 50% savings over Standard 90.1 (ASHRAE 1999) with even more strenuous improvements in the planning process. Additional details on these guides can be found in Chapter 2.

The HVAC&R engineer can provide a significant benefit to society (as well as to the building project's owners) via CO_2 emissions reduction associated with lower energy consumption. All new building projects that wish to comply with green principles should at least estimate the CO_2 equivalent emissions footprint of the building (of which a large part is produced through energy consumption). Using publicized emissions factors, these calculations are not complicated and can provide insight. For existing buildings, the goal is to compute the reduction in emissions associated with proposed energy conservation measures. In both cases, the GHG emissions factor used should be based on source energy and not on energy consumed on site alone. A good initial reference source for emissions factors is a 2007 National Renewable Energy Laboratory (NREL) report (Deru and Torcellini 2007). The emissions factors for site electricity consumption in the United States have been updated by the U.S. Environmental Protection Agency (EPA) to reflect recent trends away from coal-based electricity production to more natural gas and other renewable energy systems such as solar and wind. Along the same lines, the European Commission is reviewing the methodology for the calculation of a primary energy factor in the context of revising the Energy Efficiency Directive (EED) and preparing the upcoming legislative proposals on the 2030 Climate and Energy Framework. Currently, a default coefficient of 2.5 may be used for converting kilowatt-hour electricity (EED 2006/32/EC), although EU Member States may apply a different coefficient provided they can justify it. The ongoing efforts underline the need to regularly revise the conversion factor for electricity and that the methodology adequately reflects the strong efforts of the European power sector to decrease the carbon footprint and increase the share of renewables in the power generation mix. European informative default values for various energy carriers are available in ISO 52000-1, *Energy Performance of Buildings—Overarching EPB Assessment*

SUSTAINABILITY IN ARCHITECTURE

The emergence of green-building engineering is best understood in the context of the movement in architecture toward sustainable buildings and communities. Detailed reviews of this movement appear elsewhere and fall outside the scope of this document. A brief review of the history and background of the green design movement is provided, followed by a discussion of its applicability. Several leading

Digging Deeper

INTERNATIONAL PERSPECTIVE: REGULATIONS AND COMMENTARY

Society has recognized that previous industrial and developmental actions caused long-term damage to our environment, resulting in loss of food sources and plant and animal species, and changes to the Earth's climate. As a result of learning from past mistakes and studying the environment, the international community identified certain actions that threaten the ecosystem's biodiversity, and, consequently, it developed several governmental regulations designed to protect our environment. Thus, in this sense, the green design initiative began with the implementation of building regulations. An example is the regulated phaseout of fully halogenated chlorofluorocarbons (CFCs) and partially halogenated refrigerant hydrochlorofluorocarbons (HCFCs).

In Europe, the main regulatory instrument for tackling the energy consumption of buildings is the Energy Performance of Buildings Directive (EPBD) recast (European Commission 2010), which took effect in 2012 and replaced the original EPBD Directive (European Commission 2002). All EU member states introduced national laws, regulations, and administrative provisions for setting minimum requirements on the energy performance of new and existing buildings that are subject to major renovations and for energy performance certification of buildings. Additional requirements include regular inspection of boilers and air conditioning systems in buildings, an assessment of the existing facilities, and provision of advice on possible improvements and alternative solutions. Moreover, the EPBD recast strengthens the energy performance requirements and clarifies and streamlines some of the original EPBD provisions to reduce the large differences between EU member states' practices. In particular, it requires that EU member states lay down the requirements so that new buildings are nearly zero energy by 2020 (2018 for public buildings) and the application of cost-optimal levels for setting minimum energy performance requirements for both the building's thermal envelope and technical systems.

Energy performance certificates (EPC) are issued when buildings are constructed, sold, or rented out. The EPC documents the energy performance of the building and is expressed as a numeric indicator or a letter grade that allows benchmarking of primary energy consumption. The certificate also includes recommendations for cost-effective improvement of the energy performance, and is valid for up to ten years. National efforts and examples of EPCs are detailed in the works by Arcipowska et al. (2014) and Maldonado (2016).

The Concerted Action EPBD launched by the European Commission provides updated information on the implementation status in the various European countries (www.epbd-ca.org).

Buildings are at center stage of the ambitious European efforts and energy strategies for secure, competitive, and sustainable energy toward 2020, 2030, and 2050 (https://ec.europa.eu/energy/en/topics/energy-strategy).

It is not just in developed countries that green-building design and energy efficiency concerns are taking hold. The later part of the past decade has seen an explosion of adopting building energy efficiency standards and green-building design programs. For example, India was the first expansion of the Leadership in Energy and Environmental Design® (LEED®) Green Building Rating System programs outside of the United States, with the establishment of the India Green Building Council in 2003. India also created a nationwide energy efficiency standard, the Energy Conservation Building Code, in 2008. This code was based on ANSI/ASHRAE/IES Standard 90.1 but modified for the local climates and situations. Similarly, ASHRAE's Standard 90.2 was used as the basis for energy efficiency in residential construction in Kuwait (knowns as Kuwait 90.2), as modified for Kuwait's local climate and construction practices.

Energy efficiency standards throughout the world generally adopt two approaches. One is to have a set of mandatory requirements and then offer a prescriptive or a performance-based path for compliance (examples include the approaches taken for energy codes in the U.S., Canada, India, and Australia). Another approach is to have a set of mandatory items, then build on this with a point system for other features, with a minimum number of points required. This approach is the one taken by Japan and South Korea, for example.

As documented by the existing and emerging, green-building programs around the world (Mills et al. 2012), it is evident that the green-building movement is not just a fad, but truly is transforming the marketplace worldwide.

Digging Deeper

methodologies for performing and evaluating green-building design efforts are reviewed.

Prior to the industrial revolution, building efforts were often directed throughout design and construction by a single architect—the so-called *master builder model*. The master builder alone bore full responsibility for the design and construction of the building, including any engineering required. This model lent itself to a building designed as one system, with the means of providing heat, light, water, and other building services often closely integrated into the architectural elements. Sustainability, semantically if not conceptually, predates these eras, and some modern unsustainable practices had yet to arise. Sustainability in itself was not the goal of yesteryear's master builders. Yet some of the resulting structures appear to have achieved an admirable combination of great longevity and sustainability in construction, operation, and maintenance. It is interesting to compare the ecological

Digging Deeper

SOME DEFINITIONS AND VIEWS OF SUSTAINABILITY FROM OTHER SOURCES

- "The best chance we have of addressing the combined challenges of energy supply and demand, climate change and energy security is to accelerate the introduction of new technologies for energy supply and use and deploy them on a very large scale." —Thomas Friedman*, Hot, Flat and Crowded* (Friedman 2008)
- "Humanity must rediscover its ancient ability to recognize and live within the cycles of the natural world." *—The Natural Step for Business* (Nattrass and Altomare 1999)
- Development is sustainable "if it meets the needs of the present without compromising the ability of future generations to meet their own needs." *—Our Common Future* (Brundtland Report) (WCED 1987)
- To be sustainable, "a society needs to meet three conditions: Its rates of use of renewable resources should not exceed their rates of regeneration; its rates of use of nonrenewable resources should not exceed the rate at which sustainable renewable substitutes are developed; and its rates of pollution emissions should not exceed the assimilative capacity of the environment." —Herman Daly (Nattrass and Altomare 1999)
- "Sustainability is a state or process that can be maintained indefinitely. The principles of sustainability integrate three closely intertwined elements—the environment, the economy, and the social system – into a system that can be maintained in a healthy state indefinitely." *—Energy Management Handbook,* eighth edition (Doty and Turner 2012)
- "In this disorganized, fast-paced world, we have reached a critical point. Now is the time to rethink the way we work, to balance our most important assets." —Paola Antonelli, Curator, Department of Architecture and Design, New York City Museum of Modern Art (Antonelli 2008)

footprint (a concept discussed later in this book) of Roman structures from two millennia ago heated by radiant floors to a twentieth century structure of comparable size, site, and use.

In the nineteenth century, as ever more complicated technologies and the scientific method developed, the discipline of engineering building systems and design emerged separate from architecture. This change was not arbitrary or willful, but rather was due to the increasing complexity of design tools and construction technologies and a burgeoning range of available materials and techniques. This complexity continued to grow throughout the twentieth century and continues today. With the architect transformed from master builder to lead design consultant, most HVAC&R engineering practices performed work predominantly as a subcontract to the architect, whose firm, in turn, was retained by the client. Hand-in-hand with these trends emerged the twentieth century doctrine of *buildings over nature*, an approach still widely demanded by clients and supplied by architectural and engineering firms.

Under this approach (buildings are designed under the architect, who is prime consultant, following the buildings over nature paradigm) the architect conceives the shell and interior design concepts first. Only then does the architect turn to structural engineers, then HVAC&R engineers, then electrical engineers, etc. (Not coincidentally, this hierarchy and sequence of engineering involvement mirrors the relative expense of the subsystems being designed.)

With notable exceptions, this sequence has reinforced the trend toward buildings over nature: relying on the brute force of sizable HVAC systems that are resource-intensive—and energy-intensive to operate—to build and maintain conditions acceptable for human occupancy. In this approach to the design process, many opportunities to integrate architectural elements with engineered systems are missed—often because it's too late. Even with an integrated design team to bridge back over the gaps in the traditional design process, a sustainable building with optimally engineered subsystems will not result if not done by professionals with appropriate knowledge and insight.

When Green Design is Applicable

Perhaps the obvious answer is "When is green design *not* applicable?" However, practicalities do exist in the design process, funding, and expectations of stakeholders in the process that may, in some people's opinion, preclude consideration of green design. This book is intended to help overcome these impediments.

One leading trend in architecture, especially in the design of smaller buildings, is to invite nature in as an alternative to walling it off with a shell and then providing sufficiently powerful mechanical/electrical systems to perpetuate this isolation. This situation presents a significant opportunity for engineers today. Architects and clients who take this approach require fresh and complementary engineering approaches, not tradition-bound engineering that incorporates extra capacity to overcome the natural forces a design team may have invited into a building. Natural ventilation and hybrid mechanical/natural ventilation, radiant heating, radiant cooling, and solar-assisted air conditioning are just a few examples of the tools with which today's engineers are increasingly required to acquire fluency. Some of these "new" techniques have been well known for centuries and used around the world. In the green-building era, they can be enhanced with new capabilities allowed by technology advancements, better understanding of the physical processes involved, and for modern buildings.

Fortunately, there is a great deal of information available about green-building design, including this *GreenGuide*. Further, tools for understanding and defending engineering decisions in such projects are available, for example, ANSI/ASHRAE Standard

55, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2017a), includes an adaptive design method that is more applicable to buildings that interact more freely with the outdoor environment. ASHRAE Standard 55 also accommodates an increasing variety of design solutions intended both to provide comfort and to respect the imperative for sustainable buildings.

Another more widely demanded approach to green HVAC engineering presents a significant opportunity for engineers. This approach applies to projects ranging from flagship green-building projects to more conventional ones where the client has only a limited appetite for green design. The demand for environmentally conscious engineering is evidenced by the expansion of engineering groups, either within or outside architectural practices, that have built a reputation for a green approach to building design. In addition, many younger engineers and architects just entering the profession are more committed to the concept of sustainable design than their more established predecessors.

Green HVAC engineering can be provided, for its own sake, independent of any client or architect demand. Ideally, the end result is an energy-efficient system that is more robust and provides for better thermal control and indoor environment than the cookie-cutter conventional design. The appetite for environmentally conscious engineering must be carefully gaged, and opportunities to educate the design team carefully seized. In this way, engineers can bring greater value to their projects and distinguish themselves from competing individuals and firms.

Embodied Energy and Life-Cycle Assessment

Building materials used in the construction and operation of buildings have energy embodied in them due to the manufacturing, transportation, and installation processes of converting raw materials to final products. The material selection process should consider the environmental impact of demolition and disposal after the service life of the products. Another new type of building life-cycle assessment (beyond life cycle costing) focuses on the environmental impact of products and processes. This is termed *life-cycle environmental assessment* or simply *life-cycle assessment* (LCA). This is a cradle-to-grave approach that evaluates all stages of a product's life to determine its cumulative environmental impact. In the case of a building, the structure is a product itself, but it also is comprised of a large number of other individual products (e.g., materials, equipment). Thus, the combined impact of the entire building as a system should be quantified. Different issues and priorities should be considered. For example, the selection of building materials with a lower embodied energy may be desirable for the construction phase, but it may be more environmentally conscious to consider a more energy-intensive one if it results in higher operational energy savings during the building's life cycle or the product's lifetime, whichever comes first. Similarly, during building refurbishment and the evaluation of different energy conservation measures, one should also consider the embodied energy in the new building materials (e.g., adding thermal insulation) or the replacement of building elements or systems (e.g., replacing windows or boilers), by comparing them against the resulting operational energy savings.

Several international efforts are underway to develop a standard approach, along with professional and easy-to-use tools to overcome cumbersome calculations and facilitate performing an LCA in routine, day-to-day projects. This is critical to ensure that these issues are addressed during the early stages of the decision-making process, when most critical decisions are made, for new building design or refurbishment. For large projects, use of building information modeling (BIM) can support LCA by reducing the time to reenter data (e.g. material quantities) and facilitate calculations, once ontology and semantic issues for the exchange of data and relevant information are properly handled.

A detailed description of the LCA approach has been developed by the EPA, and more detail can be found on their website on LCA, included in the Online Resources section at the end of this chapter. LCA databases and tools are used to calculate and compare the embodied energy of common building materials and products. Designers should give preference to resource-efficient materials and reduce waste by recycling and reusing whenever possible.

The building design team has a variety of options to consider in conducting an LCA analysis. The International Organization for Standardization (ISO) 14000 series of standards on environmental management serves as a method to govern the development of these tools. LCA tools are available from private commercial as well as governmental or public domain sources. The Building for Environmental and Economic Sustainability (BEES) tool was developed by the National Institute for Standards and Technology in the United States, with support from the U.S. Environmental Protection Agency. The Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) from the EPA focuses on chemical releases and raw materials usage in products. In Canada, the Athena life-cycle inventory database contains detailed, high-quality and regional construction data and complies with ISO 14040/14044 standards (Athena 2014). Some commercial firms also offer LCA tools.

The European Commission has long recognized that LCA provides the best framework for assessing the potential environmental impacts of products and underlined the need for more consistent data and consensus LCA methodologies. A European platform from the European Commission Joint Research Centre is available to facilitate the availability of quality-assured life-cycle data. The European reference Life Cycle Database (ELCD) is composed of life-cycle inventory data from front-running European business associations and other sources for key materials, energy carriers, transport, and waste management. Data sets can be used free of charge and also distributed to third parties.

In summary, tremendous growth has occurred in the development of green building programs and practices over the past couple of decades. This *GreenGuide* provides insight into the making the design and operation of buildings more sustainable.

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GreenSpec® Product Guide
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www.iisbe.org/.

International Living Building Institute, The Living Building Challenge
https://living-future.org/lbc/.

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The Natural Step
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New Buildings Institute
www.newbuildings.org/.

Rocky Mountain Institute
www.rmi.org.

Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)
https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci.

U.S. Green Building Council, Leadership in Energy and Environmental Design, Green Building Certification System
www.usgbc.org/leed.

The Whole Building Design Guide
www.wbdg.org.

CHAPTER TWO

Green Rating Systems, Standards, and Other Guidance

Rapid growth in interest in green buildings over the past two decades has occurred with corresponding growth in the number, depth, and breadth of green-building resources available.

There are three general types of programs or resources that exist to encourage green-building design. The first type is composed of green-building rating systems (sometimes referred to as *green building label* programs), such as the LEED program. Second are general guidelines or resources, such as this guide, that have been created and published to encourage and assist designers in achieving green-building design. Third is the more recent trend of green-building practices incorporated as part of design standards and the code enforcement process. This chapter provides a brief summary of each type and cites several specific examples.

GREEN-BUILDING RATING SYSTEMS—INTRODUCTION

Various rating systems, developed by organizations around the world, strive to indicate how well a building meets prescribed requirements and to determine whether a building design is green and to what level. They all provide useful tools to identify and prioritize key environmental issues. These tools incorporate a coordinated method for accomplishing, validating, and benchmarking sustainably designed projects. As with any generalized method, each has its own limitations and may not apply directly to every project's regional, political, and owner design-intent-specific requirements.

There are a wide variety of labeling and certification programs available to measure the environmental impact and performance of existing buildings. These programs can be divided into two general categories: those narrowly focused on energy (and in some cases, water) use, and those more broadly focused on those and other sustainability categories, such as indoor environmental quality (IEQ). Key programs in the first category include the U.S. Environmental Protection Agency's (EPA) ENERGY STAR® Portfolio Manager, ASHRAE's Building EQ, and country-specific energy performance certification established in Europe. Key programs in the second category include U.S.

Green Building Council's Leadership in Energy and Environmental Design® (LEED®) rating system and the Building Research Establishment (BRE) Global Environmental Assessment Method (BREEAM®).

While this guide does not endorse or recommend use of any one particular green-building rating system or program, it does encourage their use when the application will produce an exceptional green design and encourages the building operators to maintain and operate the building in a manner that provides its occupants a continuing healthy and energy-efficient living/work space.

It could easily be said that the green-building movement really started in earnest with the initial establishment of the BREEAM rating system in 1990. BREEAM is a creation of the Building Research Establishment (BRE) in the UK. This is a voluntary, consensus-based, market-oriented assessment program. With one mandatory and two optional assessment areas, BREEAM encourages and benchmarks sustainably designed office buildings. The mandatory assessment area is the potential environmental impact of the building; the two optional areas are design process and operation/maintenance. Several other countries and regions have developed or are developing related spinoffs inspired by BREEAM, and BREEAM has been adopted in other countries. Although initially focused on specific building types, it is been adapted to include a wider range of different types of buildings. Similar to what has happened with other green rating systems, BREEAM has been adapted to various type of programs (called *schemes*), such as BREEAM for new construction, domestic refurbishment, communities, in-use (existing buildings), and for homes (EcoHomes).

The rating method primarily used in the United States is the LEED program, created by U.S. Green Building Council (USGBC). USGBC started offering this system in the 1990s and it is intended to be a voluntary, consensus-based, market-driven green-building certification system. It evaluates environmental performance from a "whole-building" perspective over a building's life cycle, providing a numerical standard for what constitutes a green building. USGBC's goal has been to raise awareness of the benefits of building green, and it has transformed the marketplace. Additional discussion on LEED can be found in the following section.

Another rating method that was originally developed in Canada and is being used in the United States is the Green Globes program. Green Globes is an online auditing tool that includes many of the same concepts as LEED. While both aim to help a building owner or designer develop a sustainable design, Green Globes is primarily a self-assessment tool (although third-party assessment is an option) and also provides recommendations for the project team to follow for improving the sustainability of the design. In the United Kingdom, Green Globes is known as the Global Environmental Method program.

Other green-building rating programs exist in countries throughout the world, for example, Australia's Green Star and National Australian Built Environment Rating System (NABERS), Japan's Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Hong Kong's Building Environmental Assessment Method (BEAM), and the Estidama program in the United Arab Emirates.

The procedures used by those organizations and governments providing building rating systems vary. Many building rating programs use static building labels—that is, the building's energy (or other green attributes) is evaluated once, the label is applied, and the providing organization does no reassessment to determine if the building continues to actually meet the original specifications. The application of dynamic labeling is preferred. A few of the building rating programs actually do include a reassessment (e.g., every two years), and buildings not continuing to perform lose their building label (Means and Walters 2010).

THE LEED RATING SYSTEM

Since its development and introduction in the late 1990s, the LEED program has become a major factor in the advancement of green buildings in the United States and elsewhere, as well as an influence on how all buildings are thought of in the design and construction process. LEED has been applied to numerous projects over a range of project certification levels, and its use has grown rapidly over the past several years. The LEED rating system started out with a basic program for new construction, but because a large majority of buildings already exist, a LEED for existing buildings was released in 2004 and has been revised several times since. LEED rating systems have also been developed for a variety of specific building types. These include building core and shell and commercial interiors for project developers and tenants (respectively), as well as schools, retail, hospitality, data centers, warehouses and health care, and homes. Growing in importance is the role of LEED for Existing Buildings Operations and Maintenance (EBOM). The LEED program and registered building projects have already been, or are being, established in other countries including India, Australia, Canada, and China, and new project registrations in countries outside the United States make up about 40% of the total, according to recent trends. Many other countries have developed their own green building rating systems following the basic criteria in LEED or other rating systems.

LEED is a voluntary program that uses a point-based rating system for a given building project. USGBC has been continuously working to update and modify the LEED program since its initial release. Over the years the revisions have, among other things, reworked the point ratings to provide a more effective focus to drive positive environmental and health benefits. Part of the revisions were based on using the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) developed by the U.S. Environmental Protection Agency (EPA).

Another change to the LEED program since its initial release was the inclusion of regional priority credits. These are used to put additional emphasis on design

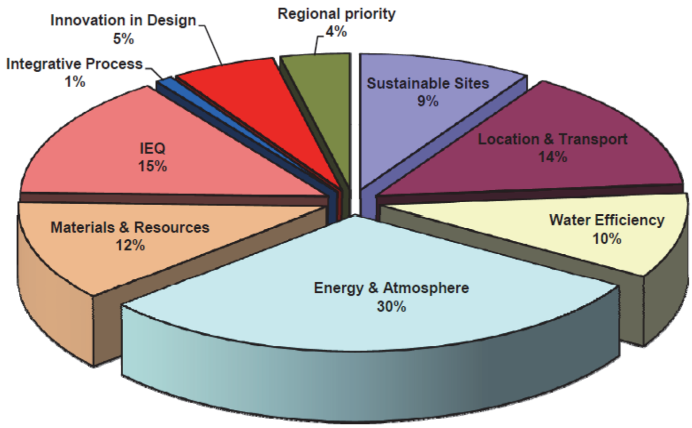

Image courtesy of Brendan Owens, U.S. Green Building Council.

Figure 2-1 Credit point distribution for LEED for new construction, v4.

features that are particularly important in relation to the local climate and region where the project is to be located. For example, in areas with known stormwater problems, the Sustainable Sites Credit 6.1 for Stormwater Design—Quantity Control may be included in this priority list. A full list of the Regional Priority credits can be found on the USGBC website (see the References and Resources section at the end of the chapter).

The fourth version of the LEED program is now known as LEED v4, and was finalized in 2013. Achieving 40 points will earn LEED Certified status, and the higher levels of silver, gold, and platinum can be achieved with 50, 60, and 80 points, respectively. The percentage distribution of these credits is illustrated in Figure 2-1. "Energy and Atmosphere" is the category with the highest number of points available, and this is in the direct purview of the HVAC&R engineer.

Further discussion on how LEED may evolve to more closely align with other green-building codes is given in the section on ANSI/ASHRAE/USGBC/IES Standard 189.1 and the *International Green Construction Code*.

OTHER GUIDELINES, RESOURCES, AND CERTIFICATION PROGRAMS

Beside the rating systems discussed above, there are other types of programs that are available to measure the environmental impact and performance of buildings (existing or new construction). Some of these are more broadly focused on the broad range of sustainability categories and IEQ. Other key programs that narrowly focus on energy (and in some cases, water) use include the EPA Portfolio Manager, ASHRAE's Building EQ, and mandatory country-specific energy performance certification in the European Union. Key programs that are more broadly focused on energy and water use, along with other sustainability categories and IEQ, include the LEED and the BREEAM rating systems, discussed earlier in this chapter.

This section outlines just some of those additional resources that the green building designer can access. ASHRAE has publications that can help the inexperienced and experienced industry professional alike. These include the following:

- ANSI/ASHRAE/IES Standard 202, *Commissioning Process for Buildings and Systems* (ASHRAE 2013).
- Advanced Energy Design Guide series. (The 30% Guides were developed initially and were intended to offer a 30% savings compared to ANSI/ASHRAE/IES Standard 90.1-1999, while the more recent guides are designed for 50% and more savings compared to the 2004 version of Standard 90.1. These design guides are available for free download courtesy of a collaboration between ASHRAE and the U.S. EPA.
- *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning* (ASHRAE 2009a).
- *The ASHRAE Guide for Buildings in Hot and Humid Climates*, 2nd edition (ASHRAE 2009b).
- *Cold-Climate Buildings Design Guide* (ASHRAE 2015).
- ASHRAE also developed user's manuals for many of its most widely used standards, such as Standards 62.1, 62.2, 90.1 and 189.1.
- *High Performing Buildings* magazine. This publication was created by ASHRAE to provide real-world, case study examples for reference.

Many of these are also discussed elsewhere in this guide but are mentioned here as a reminder.

The Advanced Energy Design Guide series is a series of books that provide a set of prescriptive technical approaches to achieve significant energy savings. The documents are focused on specific building types, typically smaller building projects that may not have resources available for much engineering study and analysis of energy saving technologies (e.g., small retail stores). Recommendations are provided based on the climate zone the project is located in. The initial series of guides was targeted toward achieving 30% energy savings compared to Standard 90.1-1999, and the intent is to repeat the series with increasing efficiency levels leading to net zero designs. The more recent 50% Guides are designed for 50% savings compared to the 2004 version of Standard 90.1. Additional guides with a higher efficiency target are in the planning process, and funding considerations will determine how far they go (e.g., a net zero target by 2020 for the AEDG series is one consideration).

These energy guides were produced in collaboration with the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), and USGBC, with assistance provided by the U.S. Department of Energy (DOE). These guides are available for free from the ASHRAE website and have been widely distributed since their release.

The *Indoor Air Quality Guide* was released in January of 2010 and was developed in conjunction with AIA, the Building Owners and Managers Association (BOMA), the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), the U.S. EPA and USGBC. A summary of the guidance offered is available for free download from the ASHRAE website, while the detailed document is available for purchase.

BUILDING ENERGY QUOTIENT (Building EQ)

ASHRAE unveiled a building energy labeling program known as the Building Energy Quotient (Building EQ) program in 2009. The program provides a method to rate a building's energy performance both "As Designed" (Asset Rating) and "As Operated" (Operational Rating).

ASHRAE's Building EQ assessment is designed to be performed by either an ASHRAE-certified Building Energy Assessment Professional (BEAP) or by a licensed Professional Engineer. This assessment includes both utility bill analysis and an ASHRAE Level 1 Energy Audit, which is described in the next section of this chapter. ASHRAE produces an energy rating ranging from "A+" to "F", with a "C" representing median energy performance in comparison to the building's peers (Figure 2-2). The building owner also receives a report with recommendations for how to reduce energy and water use while maintaining acceptable IEQ. Note that ASHRAE offers a related "as designed" Building EQ rating, so that owners can compare the actual performance of their building to its potential performance (Figure 2-3).

ASHRAE's Building EQ program provides the general public, building owners and tenants, potential owners and tenants, and building operations and maintenance staff with information on the potential and actual energy use of buildings. This information is useful for the following reasons:

- Building owners and operators can see how their building compares to peer buildings to establish a measure of their potential for energy performance improvement.
- Building owners can use the information provided to differentiate their building from others to secure potential buyers or tenants.
- Potential buyers or tenants can gain insight into the value and potential long-term cost of a building.
- Operation and maintenance staff can use the results to inform their decisions regarding maintenance activities, influence building owners and managers to

Figure 2-2 Sample Building EQ plaque.

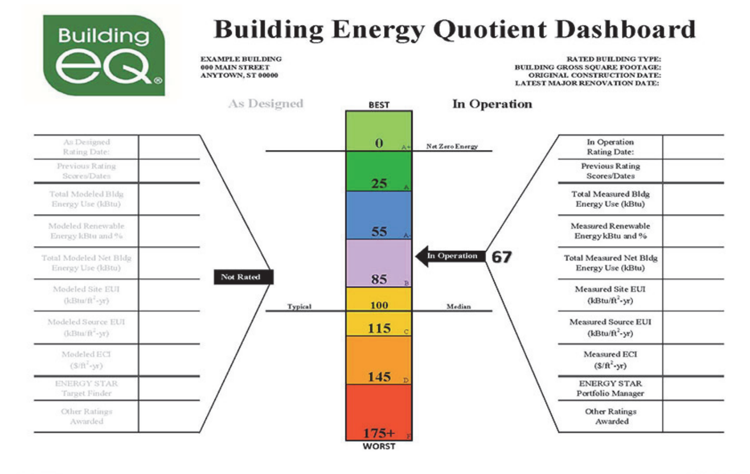

Figure 2-3 Sample Building EQ dashboard.

pursue equipment upgrades, and demonstrate the return on investment for energy efficiency projects.

Beyond the benefit received by individual building owners and managers, the increased availability of building data (specifically the relationship between the design and operation of buildings) will be a valuable research tool for the building community.

The EPA Portfolio Manager is an online tool that uses utility bills and basic building information to develop building energy performance reports, water performance reports, and greenhouse gas emissions reports. It is intended for use by building owners and managers. The tool assigns a normalized ENERGY STAR score of 1 to 100 to each building, with a score of 50 indicating median energy performance compared to its peers. Buildings receiving a score of 75 or above are eligible for ENERGY STAR certification, which must be obtained by a Professional Engineer or a Registered Architect. This tool also makes high-level recommendations on how to reduce water and energy use.

EUROPEAN PROGRAMS

In 2002, the European Parliament approved the Energy Performance of Buildings Directive (EPBD), which required member nations to develop methodologies for the calculation of the energy performance of buildings, to establish minimum energy performance requirements for both new buildings and existing "large" buildings subject to "major" renovation, and to develop energy performance certification programs. An energy performance certificate (EPC) must be issued when any building (commercial or residential) is constructed, sold, or rented to a new tenant. The EPC documents the building's energy performance, expressed as letter score from A to G, based on primary energy consumption, carbon dioxide emissions, or energy cost per unit floor area to facilitate comparisons between similar buildings. The EPC also includes cost-effective recommendations for improving the building's energy performance, which specify the initial cost, estimated annual energy and carbon dioxide emissions savings, and the simple payback period.

New buildings should meet minimum energy performance requirements (i.e., energy class B), as should existing buildings or building units that undergo major renovation where technically and economically feasible. Most national schemes have implemented an asset rating system based on calculated energy use for new and small existing nonpublic buildings; some have chosen an operational rating system based on billed energy for large and complex nonresidential buildings. The majority of the national schemes require a certified energy inspector to perform a building energy audit to collect all relevant data, which are then used to perform the calculations for issuing a certificate. Implementation and oversight of the certification process is typically the responsibility of the national government. Additional information concerning European EPCs is provided in Arcipowska et al. (2014).

Finally, BRE Global developed and maintains the BREEAM "in-use" standard. This program encompasses nine sustainability and IEQ categories: energy, water, materials, pollution, land use and ecology, health and well-being, waste, transport, and management. Points may be obtained in each category and are then converted to a weighted score ranging between 0% and 100%. Assessments range upward from "Acceptable" (one star) to "Outstanding" (six stars). Organizations either self-assess or obtain formal certification. Obtaining formal certification requires engaging the services of an assessor licensed by BRE Global.

IMPLEMENTATION THROUGH GREEN BUILDING STANDARDS AND CODES

Since the middle part of the past decade, there has been a movement to make green-building practices a more mandatory part of the normal building code process. Several cities in the United States now require LEED certification for building projects above a certain size or classification (such as a government building). In addition, ASHRAE has initiated a process to create a series of new standards for high-performance green buildings, releasing in early 2010 the initial version of Standard 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings*. This Standard is under continuous maintenance and has had several subsequent new releases, most recently (as of this writing) in 2017 (ASHRAE 2017).

ANSI/ASHRAE/USGBC/IES STANDARD 189.1 AND THE *INTERNATIONAL GREEN CONSTRUCTION CODE* (IgCC)

In 2006, ASHRAE (in conjunction with USGBC and IES) began a process to create a standard that would address a growing need within the industry for a code-language document for green buildings suitable for adoption as part of building codes. ANSI/ASHRAE/USGBC/IES Standard 189.1-2009, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings* (ASHRAE 2009) was developed during a more than three-year process with extensive public review and was initially published in early 2010. This standard is in a continuous maintenance process, and an updated version was released in 2017.

The standard differs from LEED or other products in that it is not a rating system, nor is it a design guideline per se. The purpose of Standard 189.1 is to provide minimum requirements for the siting, design, construction, and plans for operation of high-performance green buildings, while attempting to balance environmental responsibility, resource efficiency, occupant comfort and well-being, and community sensitivity. One key point of this is that Standard 189.1 is not targeted for any building project, but rather specifically for high-performance building projects. This document is intended to help fill a perceived gap in the evolving building codes in this area, as localities begin to adopt green-building designs as a requirement.

Image courtesy of Tom Lawrence and ASHRAE

Figure 2-4 Relation of Standard 189.1 to other ASHRAE Standards.

While many of the topics and criteria may overlap or seem similar to LEED for new construction, Standard 189.1 differs in that it establishes mandatory, minimal requirements across all topical areas. Besides the obvious intent of providing a vehicle for adoption into building codes, this standard may also be used by developers, corporations, universities, or governmental agencies to set requirements for their own building projects.

Standard 189.1 is not intended to do away with other ASHRAE standards. Rather, it builds upon key ASHRAE standards and adopts these with modifications when considered necessary to develop a document that deals with high-performance green buildings, as illustrated in Figure 2-4.

This standard includes mandatory criteria in all topical areas (for example, water or energy) and provides for two compliance paths. The prescriptive path includes simple compliance criteria; simple in the sense that they are more like a checklist of technologies or system requirements. The performance path is more complicated in that it requires more analysis to verify that compliance is indeed achieved.

A brief overview of some key criteria in Standard 189.1 that the typical ASHRAE member or design professional should be aware of is given below. This is just a brief overview and is not intended to be an all-inclusive summary.

Sustainable Sites

In addition to a cool-roof requirement for cooling-dominated climates (Climate Zones 0–3), the standard also has provisions for building walls to be shaded or to have a minimum solar reflective index value for opaque wall materials in all but the coldest climate zones.

Water Use Efficiency

Standard 189.1 puts limits on the number of cycles of water through a cooling tower. It also requires condensate collection on air-handling units above 5.5 tons (19 kW) of cooling capacity in more humid regions (areas with a design wet-bulb temperature greater than 72°F [22°C]).

Standard 189.1 is also unique in that it requires the installation of meters with data storage and retrieval capability on systems and areas above a given threshold in water usage. Similar provisions are included in the energy section for energy use and IEQ section for monitoring of outdoor airflow.

Energy Efficiency

While the LEED program, through Energy and Atmosphere Credit 1, provides for a sliding scale of points awarded for energy efficiency improvements above Standard 90.1, Standard 189.1 began with the intended goal of providing mandatory measures that would result in buildings using 30% less energy than what is designed according to the existing Standard 90.1 at that time, including process loads.

During the development of Standard 189.1, many concepts and requirements were considered for improvements. At the same time, addenda to Standard 90.1 were developed that increased the overall efficiency levels of Standard 90.1. The net result is that the difference in overall average energy utilization index (EUI) for buildings designed according to Standard 189.1 and Standard 90.1-2016 is not that great. It has been ASHRAE's intent to have the energy efficiency levels for Standard 189.1 improve at a faster rate than those for Standard 90.1, with an ultimate goal of having Standard 189.1 reach nearly net zero or cost-effective net zero status by the year 2020 (although the definition of an optimum nearly net zero value has yet to be established).

One of the key considerations when developing the energy requirements for Standard 189.1 was whether to include on-site renewable energy and, if so, to what extent. Many renewable energy systems are not yet fully cost competitive with conventional energy sources, depending on the local energy costs and particularly when excluding incentive programs that may go away at any time. Therefore, the standard only includes the provisions for being "renewable ready" with provisions for allowing ease of future installation of renewable energy systems as a mandatory requirement. Exceptions are included for areas with low solar incidence or local shading. In the prescriptive path, on-site renewable energy is included, but a project can still comply with this standard using other methods that would have equivalent benefits or the engineers and designers may elect to go with the performance compliance path.

Energy metering is required for key systems (e.g., HVAC) above certain thresholds, because even when a building is initially designed to be energy efficient, it can quickly slip into having less than stellar energy efficiency if not continuously monitored and well maintained.

Standard 189.1 makes numerous modifications to the requirements in Standard 90.1 regarding HVAC systems. The following is a summary of key points:

- The threshold for occupancy levels requiring demand-controlled ventilation is lowered.
- The minimum size requirement for economizers is reduced. Other specific exception and requirement changes are included, but a description is beyond the scope of this guide.
- Fan power limits (per volume of air moved) are lowered.
- The requirements for energy recovery from exhaust air are expanded and the minimum effectiveness of the energy recovery device is set at 60%.
- Levels of duct insulation are increased.
- Unoccupied hotel/motel guest room controls are included.

Depending on the project approach, additional requirements for equipment efficiency beyond Standard 90.1 may also be incorporated. In addition, requirements are set for automated peak demand reduction of the building.

The performance path for showing compliance with the energy section of ANSI/ASHRAE/USGBC/IES Standard 189.1 includes demonstrating equivalent performance in terms of both energy cost and CO_2 equivalent emissions, compared to if the building project had been designed strictly to the criteria in the prescriptive path.

IEQ

Several aspects of indoor environmental quality are relevant to HVAC design: tobacco smoke control, outdoor air monitoring, filtration /air cleaning, and determination of outdoor airflow rate.

The minimum ventilation design for outdoor airflow is to be according to ANSI/ASHRAE Standard 62.1 (ASHRAE 2016b) using the Ventilation Rate Procedure. Outdoor air monitoring is to be done using permanently mounted, direct outdoor airflow measurement devices. In contrast to LEED, CO_2 monitoring in densely occupied zones is not included as part of Standard 189.1.

Tobacco smoke control is achieved by simply banning smoking within the building and near entrances, outdoor air intakes, or operable windows.

Materials and Resources

A number of requirements included in this section parallel those included with the LEED program for new construction. Items of particular note include a construction waste management provision to divert a minimum of 50% of nonhazardous waste and demolition debris from being sent to a landfill, a ban on CFC-containing equipment, and for fire suppression systems to contain no ozone-depleting substances.

Construction and Plans for Operation

Standard 189.1 includes provisions for not only how a building should be constructed, but also for planning for how it should be operated once occupied. Since the standard is written and intended for adoption into building codes, only items that would be expected to be developed and in place at the time a certificate of occupancy is issued could reasonably be considered for inclusion in this standard. The approach taken within Standard 189.1 is to set requirements for the development of plans for operation in critical areas.

This standard includes requirements for building acceptance testing and/or commissioning, erosion control, IAQ, moisture control, and idling of construction vehicles to be implemented during construction. Commissioning is to be done according to requirements that in essence parallel those in ASHRAE guidelines. IAQ requirements during construction and before occupancy are similar to those in the LEED program but not identical and when different are generally more stringent.

Plans for operation are required in key areas that would be needed to help ensure the building performs as would be expected for a high-performance green building. These include criteria in setting up long-term monitoring and verification of water and energy use, as well as IAQ through provisions such as outdoor air monitoring.

Maintenance and service life plans are required as well, and these involve equipment and systems relevant to the HVAC&R or MEP engineer.

International Green Construction Code (IgCC)

Soon after the initial release of Standard 189.1, ASHRAE and the International Code Council (ICC) reached an agreement whereby the standard would be included as an appendix to the *International Green Construction Code* (IgCC). The IgCC was first released in March 2012 and initially specified Standard 189.1 as a compliance option. By that it was meant that the project team had a choice for compliance: they can comply with the IgCC or with Standard 189.1.

After several years of a dual set of standards, ASHRAE and ICC agreed that the two standards should be merged. Starting with the 2018 code cycle, ASHRAE will be the subject matter expert for technical content while ICC will ensure that the resulting standard/code will be responsible for the administrative provisions in the 2018 IgCC. The 2018 version of the IgCC will reflect this merger. This “IgCC powered by 189.1” will hopefully lead to more widespread adoption of green building codes.

USGBC is also expected to review the measures in the IgCC in 2018 by comparing these to the LEED requirements, hopefully leading to closer alignment of LEED to the IgCC.

RESIDENTIAL BUILDINGS

The situations surrounding the residential building market vary widely around the world based on local situations. The joint ICC/ASHRAE 700 National Green Building Standard was released in 2015 (ICC 2015), and since then ASHRAE has expanded its emphasis with respect to the residential market. A local jurisdiction may elect to include compliance with ICC 700 as part of their adoption of the IgCC. The 2018 version of the IgCC will be “deemed to comply” for residential construction.

OTHER BUILDING CODES

In 2010, California became the first state in the Untied States to adopt a green building code (known as CALGreen). See the accompanying Digging Deeper sidebar for more information on CALGreen.

A compilation showing where in the United States states and jurisdictions have surpassed minimum energy code requirements and an outline of several green rating systems is available online by the Building Codes Assistance Project (http://bcapcodes.org). Major cities across the Untied States that have taken exceptional steps towards increasing the energy efficiency of their buildings include Chicago, New York, San Francisco, and Washington, DC. An overview of international building energy efficiency policies (e.g., codes, incentives, and labels for all types of buildings including mandatory, model code, and voluntary programs) is maintained by the IEA in a publicly available database (www.iea.org/beep/).

Other Resources

Further information regarding these resources can be found in the References and Resources section at the end of the chapter. Other guides and methods include the following:

CALGREEN CODE: AMERICA'S FIRST STATEWIDE GREEN-BUILDING CODE

In 2010, the California Green Building Standards Code (CALGreen) was developed to promote the design of efficient and environmentally responsible residential and nonresidential buildings in California. The CALGreen code is part of the overall California Building Standards Code and is the first statewide green code established in the United States. It was developed, in part, in an effort to meet the provisions of Assembly Bill (AB) 32, which requires a cap on greenhouse gas emissions by 2020, with mandatory reporting. The 2010 CALGreen Code became effective January 1, 2011 and a modified 2016 version took effect in January 2017.

To reduce the overall environmental impact of new buildings constructed in California, and to meet their maximum environmental efficiency targets, the CALGreen Code adopts many green-building practices as mandatory building code requirements. The CALGreen Code includes requirements (divisions) for planning and design, energy efficiency, water efficiency and conservation, material conservation and resource efficiency, and environmental quality. The code also requires building commissioning to verify and ensure that all building systems operate as designed to meet their maximum energy efficiency targets.

Some similarities to LEED programs include standards for stormwater pollution prevention, light pollution reduction, indoor and site water savings, construction waste management, energy performance, outdoor air delivery, carbon monoxide monitoring, and materials selection. In some cases, CALGreen has stricter targets than LEED, in others, LEED is stricter, and in many others, the requirements are identical. There are several CALGreen requirements not found in LEED, such as installing water meters on buildings with area greater than 50,000 ft^2 (4600 m^2), providing weather-resistant exterior walls and foundation envelopes, defining the type of fireplace that can be installed, and employing acoustical control (interior and exterior).

In addition to the mandatory statewide CALGreen requirements, a city or county may adopt local ordinances to require more restrictive standards that go above and beyond the mandatory measures. These packages of voluntary measures, called Tier 1 and Tier 2, include a set of provisions from each code division. These provisions are additional measures that are stricter than the mandatory codes. For instance, building energy performance must exceed the California Energy Code (Title 24) by 15% and 30% for Tier 1 and Tier 2, respectively. Additionally, Tier 1 includes one additional elective from the water efficiency division, whereas Tier 2 includes 3. Some of the cities that have adopted Tier 1 include Burlingame, Napa, and Santa Rosa. As of the writing of this edition, only Palo Alto has adopted Tier 2.

Digging Deeper

- The Whole Building Design Guide
- *The Living Building Challenge* V2.0 (An updated version 2.1 of this program was released in May 2012)
- Green Building Advisor
- California Collaborative for High Performance Schools
- Minnesota Sustainable Design Guide
- New York High Performance Building Guidelines (Released in 1999 by the nonprofit Design Trust for Public Space, but still has relevant information for today)

Work referred to by architects includes:

- *The Hannover Principles* (William McDonough Architects 1992)
- GreenSpec® Product Guide
- Information from The Natural Step (a nonprofit organization)
- International Organization for Standardization (ISO 14000 family of standards)
- Building for Environmental and Economic Sustainability (BEES). (This software tool to analyze the impact of a building uses a life-cycle assessment approach as specified in ISO 14040. An online version was released in 2010.)
- Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)

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Online

The American Institute of Architects
www.aia.org.

ASHRAE Building Energy Quotient
www.buildingenergyquotient.org/.

ASHRAE Advanced Energy Design Guides
www.ashrae.org/standards-research--technology/advanced-energy-design-guides.

BuildingGreen
www.greenbuildingadvisor.com.

Building Codes Assistance Project
http://bcapcodes.org

Building Research Establishment Environmental Assessment Method (BREEAM®) rating program
www.breeam.org.

Center of Excellence for Sustainable Development, Smart Communities Network
www.smartcommunities.ncat.org.
Collaborative for High Performance Schools
www.chps.net.
European Commission—Nearly Zero Energy Buildings
https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings.
Estidama (United Arab Emirates)
https://www.upc.gov.ae/en/estidama/estidama-program.
Green Building Advisor
www.greenbuildingadvisor.com.
Green Globes
www.greenglobes.com.
GreenSpec® Product Guide
https://www.buildinggreen.com/product-guidance.
Green Star (Australia)
www.gbca.org.au/green-star/.
International Code Council (ICC).
https://www.iccsafe.org/
International Energy Agency, Building Energy Efficiency Policies Database
http://www.iea.org/beep/.
International Initiative for a Sustainable Built Environment.
www.iisbe.org/.
International Living Building Institute, The Living Building Challenge
http://living-future.org/lbc.
International Organization for Standardization family of 14000 standards,
https://www.iso.org/iso-14001-environmental-management.html.
Intergovernmental Panel on Climate Change
www.ipcc.ch.
International Performance Measurement and Verification Protocol
www.evo-world.org.
Lawrence Berkeley National Laboratories, Environmental Energy Technologies Division
http://eetd.lbl.gov.
Minnesota Sustainable Design Guide
www.sustainabledesignguide.umn.edu.
National Australian Built Environment Rating System (NABERS)
https://nabers.gov.au/public/webpages/home.aspx.
National Institute for Standard and Technology, Building for Environmental and Economic Sustainability (BEES)
www.nist.gov/el/economics/BEESSoftware.cfm.

National Renewable Energy Laboratory, Buildings Research
www.nrel.gov/buildings.

Natural Resources Canada, Evaluation of the Built Environment Portfolio.
/www.nrcan.gc.ca/evaluation/reports/2014/16317

The Natural Step
www.naturalstep.org.

New Buildings Institute
www.newbuildings.org.

Rocky Mountain Institute
www.rmi.org.

Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)
https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci.

U.S. Green Building Council, Leadership in Energy and Environmental Design, Green Building Certification System
www.usgbc.org/leed.

U.S. Green Building Council, Regional Priority Credit Listing
www.usgbc.org/rpc.

The Whole Building Design Guide
www.wbdg.org.

Section 2:
The Design Process

CHAPTER THREE

PROJECT STRATEGIES AND EARLY DESIGN

INGREDIENTS OF A SUCCESSFUL GREEN PROJECT ENDEAVOR

The following ingredients are essential in delivering a successful green design:

- Commitment from the entire project team, starting with the owner.
- Establishing Owner's Project Requirements (OPR), including green design goals, early in the design process.
- Integration of team ideas.
- Effective execution throughout the project's phases—from predesign through the end of its useful service life.

Establishing Green Design Goals Early

Establishing goals early in the project planning stages is a key to developing a successful green design and minimizing costs. It is easy to say that goals need to be established, but many designers and owners struggle with what green design is and what green/sustainable goals should be established. The following are typical questions to ask:

- What does it cost to design and construct a green project?
- Where do you get the best return for the investment?
- How far should the team go to accomplish a green design?

Today there are many guides a team can use with ideas on which green/sustainable principles should be considered. Chapter 2 of this guide presents several rating systems and references on environmental performance improvement. The essence of these documents is to provide guidance on how to reduce the impact the building will have on the environment. While the approaches and goals contained in each differ, all suggest common principles that designers may find helpful to apply to their projects.