

ASHRAE GreenGuide

Design, Construction, and Operation of Sustainable Buildings

Sixth Edition

- Completely revised by experienced industry professionals
- Updated information on building decarbonization and zero energy emissions
- Focused and in-depth GreenTips and Digging Deeper sidebars

ASHRAE®

ASHRAE GreenGuide

Design, Construction, and Operation of Sustainable Buildings

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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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Design, Construction, and Operation of Sustainable Buildings

Sixth Edition



Peachtree Corners

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PREFACE TO THE SIXTH EDITION

by Tom Lawrence

ASHRAE GreenGuide has become one of ASHRAE's primary contributions toward the sustainable design of the built environment. The industry and the people in it have evolved significantly since the original edition was released in January 2004. By the time this new edition of *ASHRAE GreenGuide* is released, it will be roughly 20 years since work began on the very first edition of the book. When the planning for the first *GreenGuide* was being done, the intent was to provide guidance for the young professional or for a person who was about to begin their first green project. Back then, awareness and knowledge of sustainable design practices were not commonplace nor mainstream. That has changed, which is a good thing. There is still a need for a resource that helps inform the young professional or student about the concepts of green design (more on the terminology of what to call this practice later). ASHRAE addressed this with the publication in late 2019 of *High-Performance Buildings Simplified* (I was the primary author of that book along with Dr. Julia Keen). ASHRAE and the team writing this book agreed that the *GreenGuide* would be evolved to include material and concepts focused more toward the level of understanding of a practicing professional. This helps avoid overlap and serves two distinct needs for the industry and the ASHRAE membership.

A lot has changed in the industry in general, and in green design practices in particular, since the first edition's release. Many of the concepts that seemed "out there" in the period that the first edition was published are now considered mainstream and, in some cases, are now actually required by code. That is the main reason why ASHRAE has adopted an unofficial "continuous maintenance" process for this book, with the goal of having a new edition every three to four years that incorporates new concepts and improves upon the treatment of technologies from prior editions. ASHRAE has a committed goal of global leadership in sustainability and technical education, and continuously updating this book follows the example set by ASHRAE's rebranding for a focus on sustainability in 2012.

Since the fifth edition of *GreenGuide*, several key developments have occurred in the industry related to green building practices. Perhaps the biggest of which has

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been the merging of ANSI/ASHRAE/USGBC/IES Standard 189.1 with the *International Green Construction Code* (IgCC). In this arrangement with the International Code Council (ICC), 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 sixth edition was edited to remove material that felt too basic for the practicing professional while including other material that will help guide them in their design and operation of better-performing buildings. One change is that the chapters on Construction and Construction Documents were eliminated. These chapters never were a key part of the *GreenGuide*, and the committee working on this new edition concluded that space would be better allocated to the design features and technologies. Material from the Operations and Maintenance chapter was incorporated into the chapter on Existing Buildings. While no new chapters were added, we decided to focus on the impacts of buildings on the climate in the Emerging Trends and Epilogue chapter. As buildings impact the climate, climate change also impacts the design and operation of buildings. Therefore, new material is included on the topics of designing and operating buildings and their systems in response to current and expected climate change and accompanying extreme weather events; the need to increase resilience in the built environment; and identifying the interrelationship of sustainability, efficiency, and smart technologies with building resilience. Significant edits were performed on a number of the chapters, and we have reached out to others beyond the traditional group that has worked on this chapter to provide updates and modernization of chapters (for example, to the Illuminating Engineering Society [IES] and members of that community with the chapter on Lighting).

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 provide edit suggestions for the prior edition's existing chapters. One of the goals of the editorial committee for this revision was to bring in a large number of additional outside reviewers. We truly appreciate those who contributed their time and talents to review, edit, and write this guide. 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.

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WHO SHOULD USE *ASHRAE GREENGUIDE*

The original stated purpose for the *ASHRAE GreenGuide* was to primarily guide HVAC&R designers and operators in creating and operating green buildings, 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 and architects or more experienced professionals about to enter their first green design projects. However, a survey conducted several years ago of those who purchased one of the earlier editions of this publication revealed that more experienced individuals were primarily using it. The survey also indicated a higher percentage of the readership from countries outside North America, perhaps reflecting the growing internationalization of ASHRAE. *High-Performance Building Design Simplified* acts as the reference material for the original target audience of *ASHRAE GreenGuide*, which allowed this edition to evolve its target audience toward more experienced professionals.

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 overview of what this publication covers. Throughout *GreenGuide*, numerous techniques, processes, measures, or special systems are described succinctly in a modified outline or bullet form. These are termed *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.)

Readers are encouraged to review Chapter 1, Introduction and Background, which provides essential definitions and meanings of key terms (for example, is the correct term a *green building* or maybe a more recently preferred term a *high-performance building*?). Chapter 2 describes green rating systems and the relevant standards and paths to compliance. The project's initial phases are covered, with Chapter 3 providing an overview of project strategies and the early stages of the design process. Chapter 4 addresses this subject from the architectural design and planning perspective, emphasizing how the changing climate informs how building design needs to change. Chapter 5 discusses how commissioning fits into the delivery of a green building.

The bulk of this book covers the design process, starting with the concept design phase in Chapter 6. These chapters are essential reading for all looking for guidance in specific areas of a building design. Other topics in this section include sustainable

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sites, indoor environmental quality, energy use, conversion and distribution, energy and water resources, lighting, water efficiency, and smart building systems.

The final portion of the book includes a chapter focusing on the sustainable design and operation of residential buildings and another on how these topics can be applied to existing buildings (which make up the bulk of the structures that will be around by 2030). The last chapter of this book includes a discussion on emerging trends in the industry, focusing on the impacts on climate and other key topics such as resilience in the built environment. The Appendix contains a collection of common building type GreenTips followed by 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 Technical Committee (TC) 1.10 (a precursor to today's TC 2.8).

As stated earlier, ASHRAE sees this book as one of their key resources for use by Society members and potentially by society as a whole. Therefore, ASHRAE has published several revisions and updates to the books, with TC 2.8 in charge of the development of each revision. Over the years, many people have contributed to the continued evolution and refinement of this publication, and this book truly represents the team effort of ASHRAE to provide leadership to meet ASHRAE's vision statement of providing "a healthy and sustainable built environment for all." Key people who contributed toward the development of this book are mentioned in the Acknowledgments section, but the large number of contributors, reviewers, and the like who helped with portions of this edition and with prior editions make it impossible to include everyone; but their efforts are well appreciated.

Tom Lawrence
Senior Editor of the fourth, fifth, and sixth editions of *ASHRAE GreenGuide*
Athens, Georgia, May 2021

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

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The committee, and indeed ASHRAE as a Society, are deeply thankful for all the individuals who helped with or contributed to the first five editions of the *GreenGuide*. This new edition would not be where it is without their help. However, because of space constraints, their names cannot be listed here.

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Section 1: Basics

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CHAPTER ONE

INTRODUCTION AND BACKGROUND

INTRODUCTION

There is a growing awareness about the impact of the built environment on the environment around us and on the human occupants of buildings. The use of sustainable engineering concepts has evolved quite rapidly in recent years and is now well recognized as mainstream in the 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 green buildings 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 also 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 be useful for professionals in other disciplines related to the design, construction, and operation of buildings. From a survey conducted in 2011, a wider range of people were using the *ASHRAE GreenGuide* than originally anticipated, 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. As mentioned in the Preface, the focus of this book has evolved to meet the needs of more experienced practicing professionals (of any discipline) rather than those of

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students or people just entering the profession (for whom ASHRAE's parallel publication *High-Performance Buildings Simplified* was developed).

There has even been an evolution in terminology to describe the concepts presented in this book. Originally the term used was *green buildings*, which was the prevailing description when this book and organizations such as the U.S. Green Building Council were first conceived of. Since then, two other terms have come into use: *sustainable design* and *high-performance buildings*. *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. For brand continuity, ASHRAE is continuing to use the term *green* in this book's title. However, some may not recognize the difference the terms green, sustainable, or high-performance 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 an 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 *ASHRAE Handbook—Fundamentals* (ASHRAE 2021).

The remaining portions of this Introduction chapter cover a few topics that do not easily fit in one chapter or another but are more pervasive throughout this Guide. These include a brief discussion of the need to maintain a commitment to green/sustainable/high-performance design throughout the project; a reminder of how important achieving high-performance is to addressing climate change; a comparison of how green design issues are being addressed in various parts of the world; and finally the concept of considering the embodied energy and using life-cycle assessments to evaluate the overall impact of the building.

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.

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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.

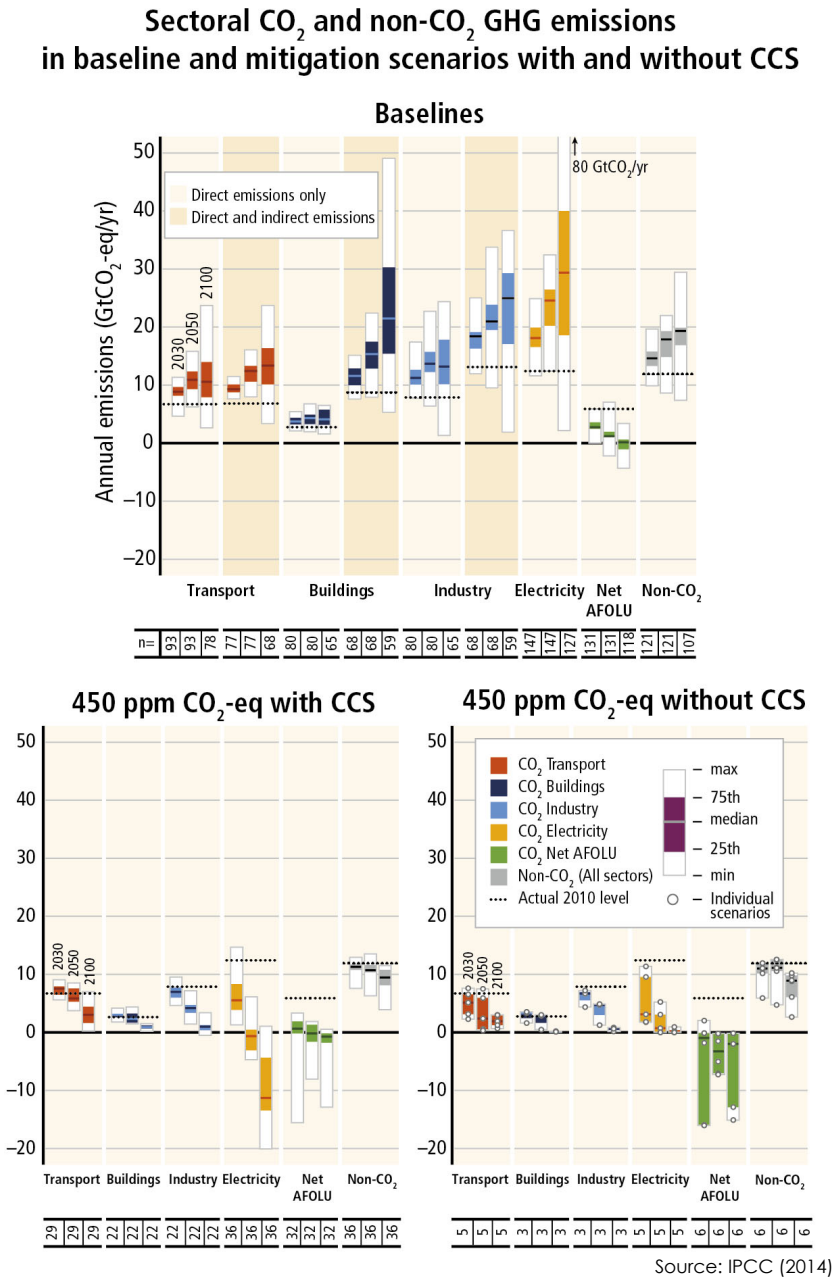
In addition, significant savings and improved productivity of the building occupants can be realized for the life of the building, lowering the total cost of ownership and/or providing better value for tenants. To achieve lifelong benefits also requires operating procedures for monitoring performance,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

THE IMPACT OF CLIMATE CONSIDERATIONS

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 directly or indirectly responsible for nearly 40% 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, at the time, 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,

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Source: IPCC (2014)

Figure 1-1 Cross-sectoral mitigation strategies.

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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 has been a leader in meeting the challenges to reduce GHC emissions associated with building operations in several ways. Significant effort was put into modifying ANSI/ASHRAE/IES Standard 90.1 to drastically improve energy efficiency. The 2010 version of Standard 90.1, in essence, met an AIA challenge 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, and hence their associated GHG emissions. Although the specific requirements may differ in some cases, the *International Green Construction Code* (IgCC), which has its technical basis in the ASNI/ASHRAE/USGBC/IES Standard 189.1, *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings* (ICC 2021), has 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 *Advanced Energy Design Guide* (AEDG) series. The series covers prescriptive measures that result in significant energy efficiency improvements, with the initial series of guides dealing with measures that should achieve 30% savings over the 1999 version of Standard 90.1 (ASHRAE 1999) and the 50% guides working to achieve that level of savings over the 2004 version of that Standard. More recently, ASHRAE has started to produce AEDG publications with a goal of achieving net zero energy (on an annualized basis).

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 recently updated the value of the primary energy factor in the context of revising the Energy Efficiency Directive (EED). This coefficient is used for calculating energy savings in primary energy terms using a bottom-up approach based on final energy consumption. Currently, a default coefficient of 2.1 may be used to convert kilowatt-hour electricity (European Commission 2018) to primary energy units,

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down from the previous value of 2.5 that was used since 2015. EU member states may define a different coefficient based on the energy mix and other justified national circumstances. By the end of 2022 and every four years thereafter, the European Commission shall revise the default primary energy factor on the basis of observed data. 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*.

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 2018), which took effect in 2020 and replaced the original EPBD Directive (European Commission 2002). EPBD is on continuous maintenance along with the Energy Efficiency Directive (EED) and the Renewables Energy Directive (RED), with amended directives of the trilogy in the final stages of being published (Balaras and Dascalaki 2022). 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

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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, ANSI/ASHRAE/IES 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.

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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. Design teams looking to achieve a green building must focus not just on the life-cycle cost of system design and equipment, but also on the environmental impact of products and processes used. 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, which implies the combined impact of its individual parts as well as how they interact together to operate as a system. 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

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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.

Resilience and Other Emerging Trends

This edition of the *GreenGuide* has added more material and emphasis on other emerging trends, including the concept of resilience. Buildings are an integrated part of the overall built environment and society structure, and events (both human-induced, such as the 9/11 terror attacks, and natural, such as strong hurricanes and heavy flooding) over the past couple of decades have underlined the importance of building resilience. More recently, we have seen the important role of building systems' design in helping with medical resilience during the COVID--19 pandemic that started in 2020.

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

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