ZERO ENERGY

ACHIEVING
ZERO ENERGY

Advanced Energy Design Guide for Small to Medium Office Buildings

Developed by:
ASHRAE
The American Institute of Architects
Illuminating Engineering Society
U.S. Green Building Council
U.S. Department of Energy



Advanced Energy Design Guide for Small to Medium Office Buildings

Achieving Zero Energy

This is an ASHRAE Design Guide. Design Guides are developed under ASHRAE's Special Publication procedures and are not consensus documents. This document is an application manual that provides voluntary recommendations for consideration in achieving greater levels of energy savings relative to minimum standards.

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Acknowledgments

Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving Zero Energy is the second Advanced Energy Design Guide (AEDG) to provide strategies and recommendations for achieving a zero energy building; that is, a building that can produce as much on-site renewable energy as it consumes. Like the zero energy AEDG for K-12 school buildings that preceded it, this Guide continues shifting buildings from energy consumers to energy producers, with their owners reaping the benefits.

The Guide was primarily written by the 12 committee members of ASHRAE Special Project 140 (SP-140) representing ASHRAE, The American Institute of Architects (AIA), Illuminating Energy Society (IES), U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE).

The chair would like to thank the members of the committee for the countless hours spent, especially the time outside their normal jobs, to make this Guide possible. The creativity and persistence in creating a guide that moves well beyond today's norms will help lead the building industry into the future. This Guide represents the current thinking about next-generation building design and operations, including guidance on plug loads, envelope, lighting, HVAC, and renewable energy systems. The committee brought hundreds of years of experience in low-energy design to this Guide.

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Finally, this Guide would not have been possible without the dedication of Lilas Pratt, ASHRAE staff. Her organizational skills and dedication to taking ideas, thoughts, and draft text from the committee and bringing it all together are what really make this Guide a single document. Her coordination abilities and guidance created this first-rate publication. It is safe to say that this Guide would not exist without her contributions.

The chair hopes that this Guide provides inspiration to build zero energy office buildings and shifts buildings from consumers to producers of energy. It should provide confidence that achieving zero energy is possible today and is not a dream. Together we can change the way buildings use energy.

Paul Torcellini
Chair, ASHRAE Special Project 140
May 2019

Abbreviations and Acronyms

A/E		architectural/engineering
AEDG		Advanced Energy Design Guide
AFF		above finished floor
AFUE	=	annual fuel utilization efficiency
AHRI		Air-Conditioning, Heating, and Refrigeration Institute
AHU		air-handling unit
AIA		The American Institute of Architects
ANSI		American National Standards Institute
ASTM		ASTM International
BAS		building automation system
BOD		Basis of Design
BP		Advanced Energy Design Guide code for “building and site planning”
Btu		British thermal unit
cfm		cubic feet per minute
c.i.		continuous insulation
CO_2		carbon dioxide
COP		coefficient of performance, dimensionless
CRI		Color Rendering Index
Cx		commissioning
CxP		commissioning provider
CZ		climate zone
DCV		demand-controlled ventilation
DL		Advanced Energy Design Guide code for “daylighting”
DOAS		dedicated outdoor air system
DOE		U.S. Department of Energy
DX		direct expansion
ECM		electronically commutated motor
EER		energy efficiency ratio, Btu/W·h
EF		energy factor
EL		Advanced Energy Design Guide code for “electric lighting”
EN		Advanced Energy Design Guide code for “envelope”
E_t		thermal efficiency, dimensionless
EUI		energy use intensity
F		slab edge heat loss coefficient per foot of perimeter, Btu/h·ft·°F
fc		footcandle

FC	filled cavity
GSHP	ground-source heat pump
Guide	*Advanced Energy Design Guide for Small to Medium Office Buildings—Achieving Zero Energy*
HSPF	heating seasonal performance factor, Btu/W·h
HV	Advanced Energy Design Guide code for "HVAC systems and equipment"
HVAC	heating, ventilating, and air-conditioning
IEER	integrated energy efficiency ratio, Btu/W·h
IES	Illuminating Engineering Society
in.	inch
in. w.c.	inches of water column
IPLV	integrated part-load value, dimensionless
ISCOP	integrated seasonal coefficient of performance
ISMRE	integrated seasonal moisture removal efficiency
kW	kilowatt
kWh	kilowatt-hour
LC	Advanced Energy Design Guide code for "lighting controls"
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LLLC	luminaire-level lighting control
LPD	lighting power density, W/ft^2
LPW	lumens per watt
Ls	liner system
M&V	measurement and verification
MERV	Minimum Efficiency Reporting Value
N/A	not applicable
NEMA	National Electrical Manufacturers Association
NPLV	nonstandard part load value
NREL	National Renewable Energy Laboratory
OPR	Owner's Project Requirements
OSHA	Occupational Safety and Health Administration
PL	Advanced Energy Design Guide code for "plug loads and power distribution systems"
PPL	plug and process load
ppm	parts per million
PV	photovoltaic
QA	quality assurance
R	thermal resistance, $h \cdot ft^2 \cdot °F/Btu$
RE	Advanced Energy Design Guide code for "renewable energy"
REC	renewable energy certificate
RFP	request for proposals
rh	relative humidity
SAT	supply air temperature
SEER	seasonal energy efficiency ratio, Btu/W·h
SHGC	solar heat gain coefficient, dimensionless
SWH	service water heating
U	thermal transmittance, $Btu/h \cdot ft^2 \cdot °F$
UEF	uniform energy factor
USGBC	U.S. Green Building Council
VAV	variable air volume
VRF	variable refrigerant flow
VSD	variable-speed drive
VT	visible transmittance, dimensionless
W	watt
WH	Advanced Energy Design Guide code for "service water heating"
WWR	window-to-wall ratio
ZE	zero energy

Foreword: A Message to Building Owners and Managers

The first time I heard someone talk about zero energy buildings was in 2003. A group of us were working on a residential green demonstration home in western Washington, one of the team had heard the term, and it was thrown out as a goal. Frankly, we weren't even completely sure what it meant. While that project ended up a long way from being zero energy, I was immediately captivated, sank my teeth in, and have yet to let go.

In the following 15 years, the concept of and the know-how, technology, and design integration around zero energy have grown enormously. Rather than head-scratching about how to get there, a number of leading engineering, design, and contractor firms have a firm handle on the approach. Supportive technologies and their relative costs have improved, from envelope to mechanical systems to switching technologies to renewables. I view this Guide as a coming of age of sorts for zero energy—a transition from awkward teenage years to early adulthood.

Even though the overall maturity of the zero energy building ecosystem has grown quickly, buildings actually performing at zero energy number in the low hundreds. I believe a major factor in this is the 2008 economic downturn—in many ways, the market has only recently fully recovered, in that developers' and companies' financial footing has been solidly restored. Reflecting this is the significant spike in interest and focus on zero energy buildings in the last couple of years, and I anticipate a rapid market shift.

A good example of this is the Catalyst Building, the brainchild of McKinstry's CEO, Dean Allen. Currently under construction, Catalyst, located in Spokane, Washington, will be one of the world's largest zero energy office/education buildings. Catalyst includes an array of next-generation zero energy elements, including a brand new all-electric district energy system; cross-laminated timber construction; utility-controlled, grid-integrated thermal storage; and an advanced plug-load management system. But what is most remarkable about Catalyst is that it is a market-rate project, being developed with normal returns and no subsidy. Catalyst is proof that zero energy is scalable today.

And it is that scaling to which we must pivot. Given that 40% of all energy used in the United States today is used by buildings, zero energy buildings must quickly become the norm and not the exception.

The good news for designers, developers, and owners alike is that, done right, zero energy buildings have the potential to be much better buildings than the norm—*zero energy* is a concept with bundled benefits. Often, total cost of ownership is less. Properly designed and constructed, better insulated and tighter envelopes mean a quieter, more thermally comfortable workspace and a more durable building. Well-daylighted buildings connect workers to nature.

Thoughtful design which is ethically responsive to today's environmental realities is inspiring and comforting. The reality is also that zero energy buildings call on not just muscle power but also brain power—the kind of high-value-added construction that results in well-paying jobs and a strengthening of the domestic economy. A more efficient economy makes the country more competitive and resilient to fuel-price shocks. Another unsung benefit to zero energy buildings is that team members bring their A game. I have yet to meet someone working on a zero energy building who was not profoundly excited to be contributing. Every time, the result is a better building overall. And each of these elements results in a more valuable asset, a future-proofed, forward-looking building for the twenty-first century.

Another exciting element of zero energy as a concept and practice is that it continues to grow and evolve, each time making greater impacts and better results. Emerging topics include the following:

- Full integration of nature into design, not just taking advantage of nature-provided services. At our core as humans, we are animals, and animals thrive in nature—why do we spend so much time when indoors pining to be outside?
- Recognition that zero energy buildings rely on and have a relationship with the electrical grid. Grid-aligned zero energy buildings will grow to respond to the grid energy curve, reducing their own footprints while using and providing electricity at optimal times for maximum grid efficiency.
- Embodied energy and environmental footprint of construction—as buildings become more efficient, the embodied carbon of the construction of the building comes to the fore. The global warming potential of refrigerants is a particularly critical element of this growth edge, for which the HVAC world must take leadership.

A final benefit and reality of zero energy buildings is their interdisciplinary, integrated nature. The best zero energy buildings are a seamless blend of shelter, design, and systems, blending to provide an ideal environment for peak human happiness and performance. I am very impressed that ASHRAE has created a testimony to this reality in this Guide, reflecting a highly integrated design approach.

The engineering profession has been called on in many crises of the past, and it is being called upon once again. But at the end of the day, all decisions are personal decisions. Make zero energy personal. Make it your personal mandate to be part of and drive one of the first thousand modern zero energy buildings ever built (recognizing that many buildings were zero energy prior to electricity!). Leave your mark on history. Use this Guide to be part of the zero energy revolution, a revolution which will play a key role in transitioning humanity to a sustainable, renewably powered future.

Brad Liljequist
McKinstry

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Introduction

1

Buildings consume 40% of the energy consumption in the United States and a similar percentage globally (EIA 2018). To make significant improvements to building energy use, ambitious and measurable goals need to be set. Zero energy buildings are designed first to significantly reduce energy consumption and then to meet remaining loads with renewable resources, ideally located on site. These buildings are usually connected to the utility grid to receive energy whenever renewable energy production is insufficient to meet required loads and to return energy to the grid when renewable energy production exceeds the loads. This Guide provides insight on how to achieve a zero energy office building at a cost that is comparable to office buildings built to typical energy codes in use today.

A zero energy office building can lead to healthy, high-performance work environments and allow occupants to be more productive while saving operational expenses. For an organization, zero energy buildings can demonstrate a corporate commitment to excellence. This leadership can in turn help retain employees, gain customers, and increase client satisfaction. All these benefits contribute to minimizing the impact of the built environment as well as making good business sense.

GOALS OF THIS GUIDE

The goals of this Guide are to demonstrate that zero energy office buildings are attainable and to provide direction through recommendations, strategies, and solution packages for designing and constructing zero energy office buildings in all climate zones. Like the zero energy Advanced Energy Design Guide (AEDG) for K-12 school buildings that preceded this Guide, absolute energy targets are provided rather than showing a percentage of energy reduction from a designated baseline.

This Guide provides design teams with strategies for achieving energy savings goals that are financially feasible, operationally workable, and readily achievable. Energy efficiency and renewable energy technology are rapidly improving, and technologies that did not make sense financially or technically a few years ago are feasible today. As a result of this progress, zero energy office buildings can be achieved today within the budget of conventional buildings. This Guide provides a pathway to zero energy that will help lead to a fundamental shift from buildings as consumers of energy to buildings as producers of energy.

As demonstrated throughout this Guide, setting measurable goals is the key to success. Setting measurable goals is the first commitment toward completing a successful zero energy project while maintaining a reasonable budget. The Guide is written with two key concepts in mind:

- Achieving very low energy use intensity (EUI) is the primary goal, whether or not on-site renewable energy is a feasible goal in the near or long-term future of the facility.
- Maintaining this level of performance requires a continuing commitment to skillful, adaptive operation; responsible maintenance; and monitoring of building performance.

The intended audience of this Guide includes building owners, developers, architects, design engineers, energy modelers, contractors, commissioning providers, facility managers, and building operations staff. Much of the information provided in this Guide may be applicable to those seeking to achieve zero energy on other building types as well as on both new and retrofit projects.

ZERO ENERGY DEFINITION

There are a number of different terms commonly used to describe buildings that achieve a balance between energy consumption and energy production: *zero energy*, *zero net energy*, *net zero energy*. The term used throughout this Guide is *zero energy* (ZE) for consistency with the U.S. Department of Energy (DOE) definition of zero energy. The specific definition of a zero energy building used in this Guide is based on source energy, as defined by DOE (2015):

> An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

This definition provides a standard accounting method for zero energy using nationwide average source energy conversion factors, facilitating a straightforward assessment of zero energy performance of buildings. Although the DOE national averages do not take into account regional differences in energy generation and production, nor precise differences in transmission losses due to a project's location, they do provide an equitable and manageable formula intended to facilitate scaling-up of zero energy buildings across the country and beyond. Because of its wide adoption across the country, this definition also facilitates alignment with federal policy and incentives as well as with many state and municipal initiatives.

This Guide provides target EUI information in both site energy and source energy. Either can be used to calculate the energy balance of a project.

- *Site energy* refers to the number of units of energy consumed on the site and typically metered at the property line or the utility meter.
- *Source energy* refers to the total amount of energy required to produce and transmit a given amount of energy of each fuel type to the site. Each step from energy extraction to actual consumption has energy losses. Source energy takes into account the efficiency of the production and transport process. It is calculated by multiplying the site energy of each fuel source by a factor specific to that fuel. For example, for electrical energy it takes approximately 3 kWh of total energy to produce and deliver 1 kWh to the customer because the production and distribution of electrical energy is roughly 33% efficient.

On the energy generation side of the equation, the on-site renewable energy generation is then also multiplied by these same factors, to give credit for the total avoided source energy consumption.

This Guide focuses on the design decisions needed to achieve energy goals and accommodate renewable energy on site, which is the last step needed to achieve a zero energy building. In many situations, renewable energy is limited by site constraints, local regulations, and utility restrictions. Regardless of the limitations, the energy efficiency of a building has a large impact

because it reduces the renewable energy needed, whether that energy is produced on site or somewhere else. This Guide focuses on achieving energy use targets to achieve a zero energy ready building. Renewable energy may then be added on site, if available, or procured off site, if desired. Chapter 3 provides details on setting goals, setting energy boundaries, and using the definition of a zero energy building to achieve success.

BENEFITS OF A ZERO ENERGY OFFICE BUILDING

ENVIRONMENTAL STEWARDSHIP AND CORPORATE IMAGE

Completing a zero energy office building, or an office building with the low EUI required to be ready for zero energy when renewable energy sources are added, demonstrates leadership and a clear commitment to sustainability and environmental stewardship. A zero energy office building signals a shift toward excellence in expectations that can also impact other areas of how an organization operates and delivers for its employees, customers, and other stakeholders. Investing in a zero energy building is one of the most impactful things an organization can do to protect natural resources and mitigate climate change.

OCCUPANT SATISFACTION

Occupant satisfaction should be a key consideration for all building owners and employers. Focusing on the occupant benefits of a zero energy office can be an excellent business strategy, because staff salaries represent over 90% of the total operating costs in commercial office buildings (CBE 2007). Just 10% of costs come from energy, maintenance, and mortgage/rent (Terrapin 2012). This makes staff retention a high priority, and satisfied occupants are less likely to seek other job opportunities. Carnegie Mellon University's Center for Building Performance and Diagnostics has summarized recent findings for productivity gains and health gains related to views, natural ventilation and daylighting (B&D 2018).

Occupant satisfaction is complex, but some aspects of satisfaction, such as physical and visual comfort, access to daylighted spaces, views to the outdoors, and natural ventilation, are achieved through effective building design and operation as discussed throughout this Guide. One useful resource when exploring design for improved occupant performance and well-being in offices is World Green Building Council's *Health, Wellbeing and Productivity in Offices: The Next Chapter for Green Building* (WGBC 2014).

Occupants have a large influence over the performance of a building, governing operations, and many of the energy loads. They are the champions for energy efficiency and can help achieve organizational energy and environmental goals. They are also the organization's most valuable resource. Therefore, the productivity of occupants can be improved with a healthy, comfortable, energy-efficient work environment. Zero energy buildings can be a vehicle for providing workplaces with these characteristics. The Bullitt Center's zero energy office is one example of a building that offers occupants daylight, views, and natural ventilation, as shown in Figure 1-1.

SOUND FISCAL MANAGEMENT

Zero energy buildings often have substantially reduced energy bills compared to traditional buildings. Typically energy is the largest cost for an organization outside of salaries and benefits. This makes it the largest controllable cost. Reducing this cost has a dramatic impact on the bottom line. Zero energy office buildings can both reduce energy consumption dramatically and mitigate the risk of future energy cost volatility. Utilities and utility rate structures will not remain static as the generation mix and distribution system is changing. Investing in energy efficiency and renewable energy minimizes the risk associated with fluctuations in util-



Figure 1-1 Bullitt Center Net Zero Energy Office
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ity prices. One way to think about this is that today's investment "locks in" future energy costs through the savings.

As this Guide shows, zero energy office buildings can also have lower maintenance costs. Many energy-efficiency strategies result in less operational time for mechanical and electrical equipment. Reducing the strain on this equipment yields reduced maintenance costs. The most effective systems are simpler and smarter. Effective design should create less complex buildings where heating, ventilating, air-conditioning, and control systems may be operated and maintained by less highly skilled technicians, who are generally easier to recruit. Wall, window, and roof systems are critical for achieving low EUI goals. These systems are designed for the life of the building; creating them to be durable and long-lasting will help maintain the energy savings for the life of the building. The testing and commissioning recommended by this Guide ensures that zero energy buildings are constructed and will perform as designed. Zero energy office buildings should have lower life-cycle costs than other buildings and continue to conserve resources throughout the lifetime of the building.

SCOPE

This Guide was developed through a collaboration of ASHRAE, The American Institute of Architects (AIA), Illuminating Engineering Society (IES), U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE). A project committee that represents a diverse group of professionals and practitioners in HVAC, lighting, and architectural design as well as building owners drafted the guidance and recommendations presented herein.

The Guide provides user-friendly guidance for the construction of new small to medium office buildings. Much of the guidance also applies to retrofits of existing buildings, depending on the depth and breadth of the retrofits. The guidance addresses processes, polices, strategies, and technologies and includes energy-efficiency targets and how-to strategies. The recommendations in this guide are voluntary and are not designed to be code-enforceable. As a result, they are not intended to replace, supersede, or circumvent any applicable codes in the jurisdiction within which a building is constructed. In addition, there are many pathways to zero energy and, as technologies improve, more pathways will be developed. Therefore, this Guide provides ways, but *not the only ways*, to achieve energy-efficient and zero energy office buildings.

While this Guide cannot specifically address all possible configurations of buildings, the recommendations apply to office buildings ranging from roughly 10,000 to 100,000 ft^2 with a building height of less than 75 ft. Many larger office buildings are made up of sections in this size range, thus the guidance herein can be extended to larger buildings. The Guide does not cover process loads or atypical spaces such as those for food service or laboratories or other spaces with higher energy loads and ventilation requirements. Space types covered by the Guide include office areas, circulation spaces, storage areas, break rooms (with a refrigerator, ice machine, dishwasher, microwave, sink, small appliances, and vending), small data centers/closets, workout rooms, and conference and meeting spaces. The Guide does not consider specialty spaces with extraordinary heat generation, large ventilation requirements, or pollution generation.

Much of the Guide may also be applicable to buildings undergoing complete or partial renovation, additions, and or changes to one or more building systems; however, upgrading existing exterior building envelopes to achieve the low EUIs needed to reach zero energy is likely to be very challenging. With that in mind, any time changes are made to a building, there is an opportunity to move that building toward zero energy. This may entail replacement of a boiler, changing out light fixtures, or simply painting the space. Design decisions can be made that will reduce the energy impact of the building. The icons next to the how-to strategies in Chapter 5 indicate strategies that are particularly well suited for existing buildings to be renovated or modernized. Any time design decisions are made is an opportunity to save energy.

This Guide focuses on reducing energy consumption in a building. There are also overlaps with other important aspects of sustainability. Acoustics, indoor air quality (IAQ), water efficiency and quality, landscaping, access to views, and effective space planning are just some of the other benefits of an effective design. The objective of creating a zero energy building that is cost-effective is designing with all these parameters in mind at once. All these create buildings for the future.

DEVELOPING THE GUIDE

To establish reasonable energy targets for achieving zero energy performance in all climate zones, a prototypical office building was modeled and analyzed using hourly building simulations. In previous AEDGs for office buildings, two prototypes were used—one to represent smaller buildings and one to represent buildings with deep floor plates. However, advancements in lighting have reduced the sensitivity of the ratio of interior to exterior office spaces and, as a result, limited differences are seen within the size range discussed in this Guide. Therefore, one prototype building was carefully assembled to represent office building construction, with information was drawn from several sources. A typical office building layout is shown in Figure 1-2.

Hourly simulations were run using the recommendations in this Guide. The prototype was simulated in the climate zones adopted by the International Energy Code Council (IECC) and ASHRAE in developing energy codes and standards. These include nine primary climate zones subdivided into moist, dry, and marine regions for a total of 19 climate locations. All materials and equipment used in the simulations are commercially available from two or more manufacturers.

The simulation results led to the determination of a target EUI for each of the 19 climate locations. The target EUIs are shown in Figure 1-3. Figure 1-3a shows the site EUIs by climate zone and Figure 1-3b shows the source EUIs by climate zone. Chapter 3 shows specific EUI target values in Table 3-1 and a map of U.S. climate zones in Figure 3-1.

The EUIs were verified to not exceed the amount of renewable solar energy that could be generated by photovoltaic (PV) panels reasonably accommodated on the roof of the prototype building. These EUIs are intended not as prescriptive requirements but as starting points of minimum performance that can be cost-effectively attained. Further optimization through

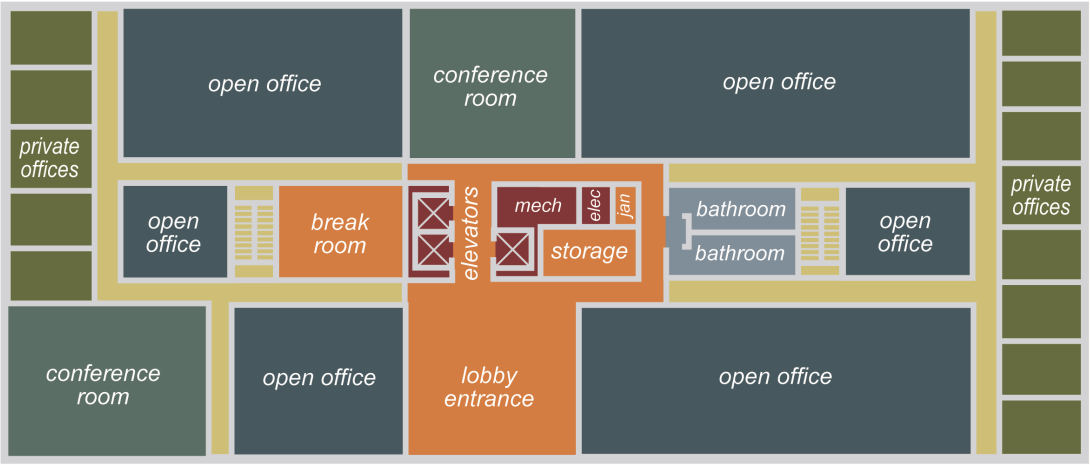


Figure 1-2 Typical Office Plan

building simulation and integrated design is recommended to reach the lowest possible EUI for each project striving for zero energy.

To facilitate reaching these EUI targets, the Guide provides recommendations for the design of the building configuration and of building components, including the building outside envelope, fenestration, lighting systems (including electrical interior and exterior lights and daylighting), HVAC systems, building automation and controls, outdoor air requirements, service water heating, renewable energy generation systems, and plug and process loads. These recommendations are discussed in Chapter 5.

HOW TO USE THIS GUIDE

This chapter outlines the case for zero energy, a general idea of what to expect in the Guide, how the Guide was developed, and how to use it.

Chapter 2, Principles for Success, identifies the main principles fundamental for success in implementing a zero energy building.

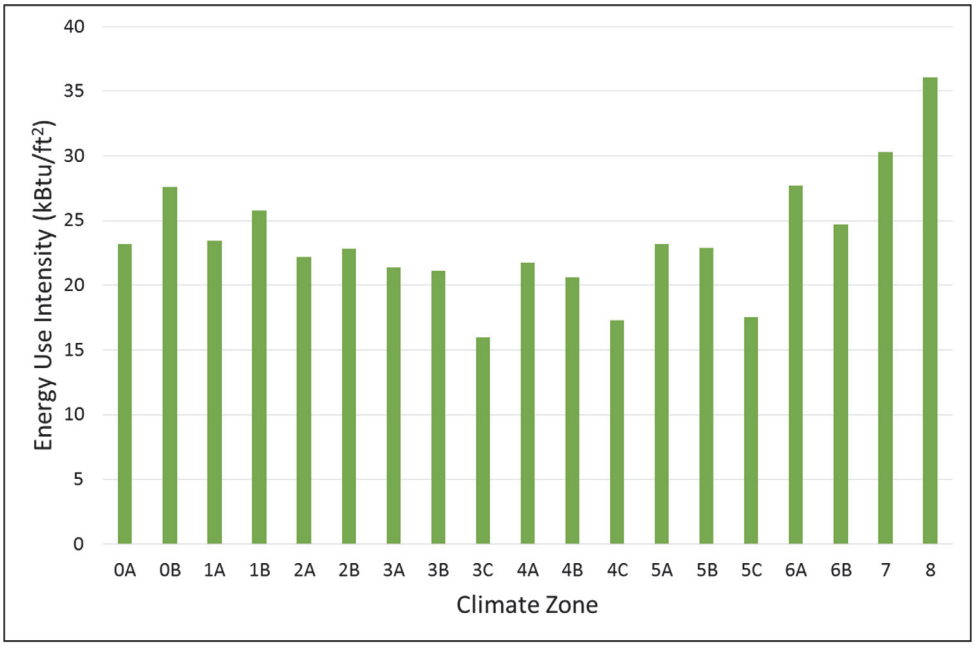
Chapter 3, A Process for Success, outlines how to achieve a zero energy building from a process standpoint. The chapter discusses how to determine a target EUI and provides recommended EUI targets in both site and source energy.

Chapter 4, Building Performance Simulation, provides information on how to incorporate building simulation into the design process. Though it is not a definitive source for how to use simulation tools, the chapter provides an overview on most relevant approaches for analyzing the various components of design covered in the Guide.

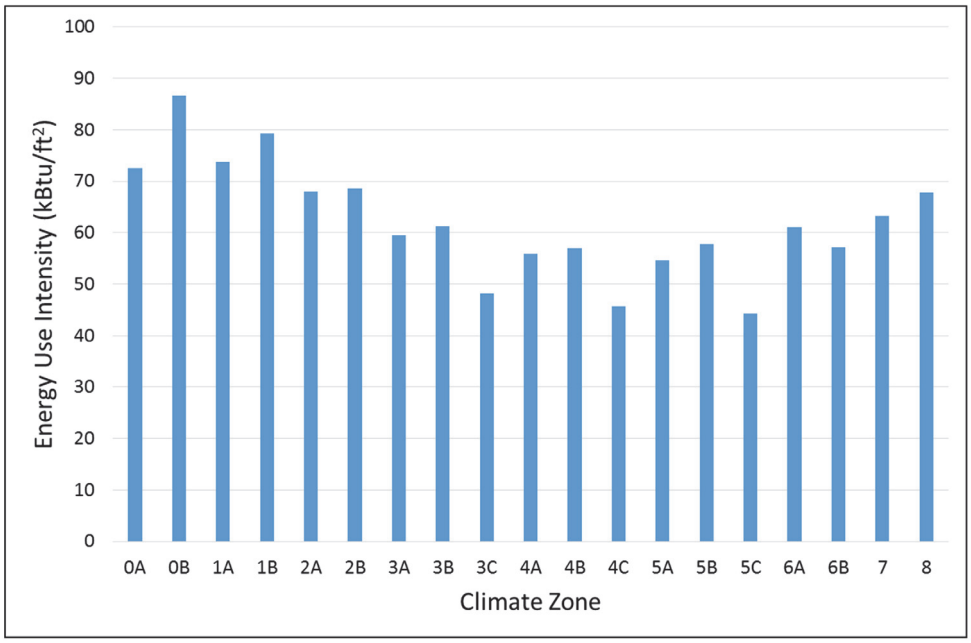
Chapter 5, How-to Strategies, provides specific strategies and recommendations regarding the design, construction, and operation of zero energy office buildings. The chapter has suggestions about best design practices, how to avoid problems, and how to achieve the energy targets advocated in this Guide. The chapter is organized into easy to follow how-to strategies.

Icons next to the how-to strategies in Chapter 5 highlight those strategies that contribute to four different categories of information:

- Reducing peak demand and increasing alignment with the electricity grid
- Energy resilience
- Capital cost savings
- Building retrofit strategies



(a)



(b)

Figure 1-3 (a) Site EUI Comparison by Climate Zone and (b) Source EUI Comparison by Climate Zone

Appendices provide additional information:

- Appendix A—Envelope Thermal Performance Factors
- Appendix B—International Climatic Zone Definitions
- Appendix C—Quantifying Thermal Transmittance Impacts of Thermal Bridges

Case studies and technology example sidebars are interspersed throughout the Guide for examples of how to achieve zero energy and to provide additional information relevant to that goal.

The Zero Energy Buildings Resource Hub (www.zeroenergy.org) provides additional information, resources, and case studies for zero energy buildings.

Note that this Guide is presented in Inch-Pound (I-P) units only; it is up to the individual user to convert values to metric.

The recommendations in this Guide are based on typical prototype operational schedules and industry best practices as well as typical costs and utility rates. The operational schedule, actual costs, and utility rates of any one project may vary, and life-cycle cost analysis (LCCA) is encouraged for key design considerations on each specific project to properly capture the unique project costs and operational considerations.

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