Moving Zero Energy Office Buildings to the Mainstream: Establishing Design Guidelines and Energy Targets

Preprint

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Moving Zero Energy Office Buildings to the Mainstream: Establishing Design Guidelines and Energy Targets

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ABSTRACT

Office buildings represent a significant portion of the commercial sector and are ideal candidates to lead the market towards achieving zero energy and zero energy ready buildings. The variety of sizes and uses for office buildings make them challenging to determine set design guidance that can be deployed across the market. The project committee for the ASHRAE/AIA/USGBC/IES Zero Energy - Advanced Energy Design Guide (ZE-AEDG) for small and medium office buildings, comprised of members from four major professional societies with market-pull in commercial buildings, created design guidance for achieving zero energy office buildings for new construction and major retrofit. This design guidance focuses on the process, providing a pathway for both office owners and design teams to achieve zero energy status. Climate specific energy use intensity targets ranging from 16 $kBtu/ft^2 \cdot yr$ to 36 $kBtu/ft^2 \cdot yr$ were established such that office buildings can be "zero-ready," that is, having low energy consumption that can easily be offset with renewables, preferably on-site. The design guidance was rooted in extensive energy modeling, as well as case studies of actual office buildings that have achieved high levels of energy performance and met zero energy or zero energy ready status. A unique aspect of the zero-energy guide is that it is not compared against a baseline but focuses on achieving an absolute target. The paper presents process of creating the targets, the selection of strategies to achieve the targets, and sample case studies that show how the cost-sensitive solutions are achievable for the design community. It also presents outreach strategies to deploy market achievable zero energy measures.

Background

Commercial buildings have become increasingly efficient through continuous improvements in performance of heating, ventilating, and air-conditioning (HVAC) systems; lighting systems; and electrical equipment combined with tighter, better-insulated thermal envelopes with advanced glazing system. These improvements are also in part due to more stringent performance requirements from regulatory bodies that have adopted energy standards, such as those developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Over the past few decades, most of the work related to minimizing building energy impacts have been focused on reducing energy use intensity (EUI). Considering energy efficiency in every design decision and evaluating its impact on overall EUI reduction are critical strategies in any building and particularly important for zero energy buildings.

As commercial buildings become more and more efficient, zero energy (ZE) buildings were envisioned: buildings that can offset their energy requirement by adding on-site renewable energy resources. In line with this, Griffith et al. (2006, 2007, 2008) examined the entire commercial sector with a comprehensive energy model to determine which building types could achieve ZE and what levels of energy efficiency were needed to achieve that goal. The study found that the concept was technically feasible for significant portions of the commercial sector, including office buildings.

DOE published a common definition in 2015 (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 applies to individual buildings, campuses, communities, portfolios, or any other specified boundary. In locations where on-site renewables installations are limited by utilities, policies, or economics, the building can be designed to be ZE ready—that is, it is extremely energy-efficient and ready to accept a solar system when circumstances allow.

As thinking about ZE evolved, so did the Advanced Energy Design Guides (AEDGs). Published by ASHRAE, this popular series of books—more than 680,000 are in circulation as of June 2020—offers recommendations for achieving energy savings beyond current norms in new construction and major retrofits. The AEDGs were based on extensive energy simulation to develop energy efficiency solutions that result in energy savings compared with a current ASHRAE energy standard. From 2004 to 2009, AEDGs that provide guidance for achieving a 30% energy savings compared with ASHRAE Standard 90.1-1999 were produced for six building types. From 2011 to 2015, five guides were produced that demonstrated how to achieve a 50% savings from ASHRAE Standard 90.1-2004. The eleven guides covered a number of building types; most relevant to this discussion, 30% guide for small office buildings and 50% guides for small to medium office buildings were developed ((ASHRAE 2008); (ASHRAE 2011)).

The AEDGs are focused on providing simulation-based energy solutions that are achievable using widely available technologies. Advances in technology and integrated design together with sharp reductions in the cost of renewable energy now make ZE possible and affordable. These trends are corroborated by a dramatic increase in the number of documented ZE buildings (NBI 2018). Office buildings are the second largest category of ZE buildings next to primary and secondary schools.

So far two ZE AEDGs are published: *Advanced Energy Design Guide for K–12 Schools: Achieving Zero Energy* (K–12 ZE AEDG) (ASHRAE 2018) and Advan*ced Energy Design Guide for Small to Medium Office Buildings* (ASHRAE, 2019). These AEDGs lay out a pathway to achieving ZE buildings and are based on work done during a feasibility study that showed it was possible to get to ZE using the U.S. Department of Energy’s (DOE’s) ZE definition (Pless et. al. 2016; DOE 2015). The AEDGs use prescriptive and performance-based recommendations for envelope, fenestration, lighting, HVAC, renewable integration, outside air treatment, and service water heating, along with practical how-to tips and climate-specific strategies.

The interest in very low energy buildings and ZE buildings is growing. For example, California adopted ZE targets for 50% of the floor area of existing state-owned buildings by 2025 and for all new or renovated state buildings beginning design after 2025 (SAM 2017). California has also set a target of making all new commercial buildings ZE by 2030 (CPUC 2011). Several other states are thinking along the same lines and have established task forces that are working on the issue.

The Process of Creating Design Guidance

Much has been written about what ZE buildings are, and the idea of a measurable, achievable ZE goal is taking hold in the marketplace (Liu et al. 2017; Torcellini et al. 2016). ZE buildings use an EUI target rather than comparing energy savings with a predetermined base case such as a code-compliant building. The small to medium office buildings ZE AEDG, therefore, unlike the office guides in the 30% and 50% AEDG series, provides no reference building or comparison. Rather, it includes clear guidance on how to achieve an absolute EUI target. Another key difference relative to previous AEDGs is that ZE is an operational goal; success is measured after a minimum of one year of energy performance.

Like the other AEDGs, a steering committee made up of members of five organizations (ASHRAE, IES, USGBC, AIA, and DOE) created a scope for the new ZE AEDG to focus on small to medium office buildings. The steering committee formed a special project committee that consisted of technical experts in HVAC, envelope, architecture, and lighting, with a strong emphasis on experience delivering or operating ZE small to medium office buildings. The project committee helped establish relevant model inputs based on their professional practices and experiences. In addition, project committee members collected case studies with measured energy data and examined those projects' energy efficiency strategies and operational EUIs. They also conducted a demand-side analysis that looked at energy efficiency strategies used in ZE office case studies and evaluated energy simulation results to develop consumption EUIs such that on-site renewable resources could balance the consumption. These results were determined for each climate zone. This approach kept the emphasis on energy efficiency as the prime design driver.

This information formed the inputs for running hourly simulation of energy consumptions for representative small to medium office buildings using OpenStudio® energy modeling platform OpenStudio 2020). OpenStudio uses EnergyPlus as the simulation engine (EnergyPlus 2020). Multiple variants of the building energy models can be run in parallel using cloud computing. Using these models, it is possible to evaluate many different scenarios and identify optimal combinations of design strategies and technologies to achieve ZE. These parametric studies offered insights that the project committee used to identify the solutions included in the small to medium office buildings ZE AEDG. Using the industry-based committee review process grounded the theoretical nature of a simulation-based analysis in the reality of industry practices and norms.

Energy Modeling Summary

The extensive energy modeling helped determine the impact of the strategies considered in this design guide. A "typical" prototype building is an energy model that is a representative example of a small to medium office building. The modelers developed a prototype model based on the DOE Commercial Prototype Buildings Models (Deru et al. 2011; DOE 2014) as well as models from previous AEDG work (ASHRAE 2011). 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 building's sensitivity to the ratio of interior to exterior office spaces and, as a result, limited energy performance differences are seen between the two prototype models. Therefore, one prototype building was assembled to represent office building construction, with information drawn from the sources above.

The project committee then provided changes to the space layouts based on current industry perspectives and practices. The major changes were to:

- Increase the window-to-wall ratio
- Expand the number of HVAC system types
- Update climate zones to ASHRAE Standard 169-2013, with new representative cities and climate zone 0
- Make minor changes to internal loads
- Make minor changes to envelope to comply with ASHRAE Standard 90.1-2016.

Table 1 highlights high-level parameters of office buildings. Table 2 provides detailed information about the space types considered. All the ASHRAE climate zones were considered as part of the modeling, because different climate zones yield different solutions and energy targets. Table 3 provides the representative cities for each climate zone (ASHRAE 2013).

Table 1. Office characteristics used in modeling

Characteristic	Values
Size	20,000 ft^2
Number of floors	2
Window-to-wall ratio	40%
Wall construction	Metal-framed
Roof construction	Insulation entirely above deck

Table 2. Space type breakdown in design guide simulations

Space Type	Area (ft^2)	Percentage of Total
Open Office	8,000	40%
Private Office	2,400	12%
Conference	2,400	12%
Corridor	2,000	10%
Active Storage	1,000	5%
Restrooms	800	4%
Lounge	800	4%
Electrical/Mechanical	400	2%
Stairway	600	3%
Lobby	1,200	6%
Data	400	2%
Total	20,000	100%

Table 3. Climate zones represented in the design guide

Climate Zone	Location	Energy Plus Weather (EPW) Filenames
0A	Hanoi	VNM_Hanoi.488200_IWEC.epw
0B	Abu Dhabi	ARE_Abu.Dhabi.412170_IWEC.epw
1A	Honolulu	USA_HI_Honolulu.Intl.AP.911820_TMY3.epw
1B	New Delhi	IND_New.Delhi.421820_ISHRAE.epw
2A	Tampa	USA_FL_MacDill.AFB.747880_TMY3.epw
2B	Tucson	USA_AZ_Davis-Monthan.AFB.722745_TMY3.epw
3A	Atlanta	USA_GA_Atlanta-Hartsfield-Jackson.Intl.AP.722190_TMY3.epw
3B	El Paso	USA_TX_El.Paso.Intl.AP.722700_TMY3.epw
3C	San Diego	USA_CA_Chula.Vista-Brown.Field.Muni.AP.722904_TMY3.epw
4A	New York	USA_NY_New.York-J.F.Kennedy.Intl.AP.744860_TMY3.epw
4B	Albuquerque	USA_NM_Albuquerque.Intl.AP.723650_TMY3.epw
4C	Seattle	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMY3.epw
5A	Buffalo	USA_NY_Buffalo-Greater.Buffalo.Intl.AP.725280_TMY3.epw
5B	Aurora	USA_CO_Aurora-Buckley.Field.ANGB.724695_TMY3.epw
5C	Port Angeles	USA_WA_Port.Angeles-William.R.Fairchild.Intl.AP.727885_TMY3.epw
6A	Rochester	USA_MN_Rochester.Intl.AP.726440_TMY3.epw
6B	Great Falls	USA_MT_Great.Falls.Intl.AP.727750_TMY3.epw
7	International Falls	USA_MN_International.Falls.Intl.AP.727470_TMY3.epw
8	Fairbanks	USA_AK_Fairbanks Intl.AP.702610_TMY3.epw

Getting to Zero Energy

To develop the small to medium office buildings ZE AEDG, project committee members built on the technologies and strategies used to achieve a 50% energy reduction in small to medium offices (ASHRAE 2011), recommendations from Main Street Net-Zero Energy buildings (Torcellini et al. 2010) and successful design and construction approaches from existing high performance and ZE offices (NBI 2018). The new guide contains additional efficiency technologies, equipment parameter improvements, design refinements, and other guidance to help project teams get to zero. Here are a few examples.

Plug Loads

As building energy efficiency increases, plug loads account for a larger percentage of building loads. Plug loads include anything that is not HVAC or lighting, including computers, coffee makers, elevators, security systems, audio/visual equipment. Considerable plug loads reduction can be achieved through use of ENERGY STAR equipment where possible and implementation of control strategies such as occupancy sensors at workstations, on vending machines, and on break room equipment. The objective is to have the building "turn off" when the building is not occupied, which is 50% to 70% of the year.

Lighting

The ZE small to medium office buildings AEDG recommends an average LPD of 0.4 W/ft^2. This can be achieved through the use of 100% LEDs with an efficacy of 125 LPW or more. Daylighting is an important component of a ZE small to medium office buildings lighting strategy, and is typically employed in the perimeter zones near view windows, while the rest of the zones are electrically lit. As lower lighting power densities become achievable, the need for aggressive daylighting design strategies with light shelves, clerestories, or skylights can be reduced.

LEDs also provide exterior lighting in ZE office buildings. Controls turn the lights on based on sunrise and sunset. Another energy-saving feature is to reduce lighting to 25% of typical output from midnight to 6 a.m. LEDs turn on quickly, so motion sensors can be used to increase and decrease lighting levels with minimal occupant disruption.

Envelope

A tight, well-insulated envelope is a critical element in any energy-efficient building. Setting an absolute energy goal (Leach et al. 2012) before design begins shifts the burden of responsibility for meeting that goal from the owner to the project team. The ZE small to medium office buildings AEDG contains detailed information on designing a building envelope for a ZE offices, including recommendations for envelope infiltration rates. All envelope penetrations used for ingress and egress or lighting such as windows, doors, and skylights must also be carefully designed and selected.

Heating, Ventilating, and Air Conditioning

Several different types of HVAC systems are used in office buildings. Various factors affect system selection including building configuration, owner preference, zone configuration, and the magnitude of the loads to be served. While many innovative systems can be considered, the systems recommended in the ZE AEDG are common and readily available in order to encourage zero energy adoption for a larger audience of building owners.

Four HVAC system are discussed in the guide as a candidate for office buildings: Multizone Variable Air Volume (VAV) with Hydronic Heating/ Cooling, Air-Source Variable Refrigerant Flow (VRF) Heat Pump with Dedicated Outdoor Air System (DOAS), Ground-Source Heat Pump (GSHP) with DOAS, and Sensible Cooling Chilled-Water Fan-Coils with DOAS.

Building Shape

Building planning, including massing and site layout were also examined. Long east-west axis which increases the amount of glazing on the north and south facades can help with daylighting (coupled with lighting controls) and solar heat gain (coupled with appropriate awnings). East and west glazing can be minimized as it is difficult to control glare which hurts daylighting and solar heat gains increasing air conditioning loads. Note that in northern climates there is a slight benefit from passive solar gains; however, the south overhang is critical to minimize the solar gains in the summer. This is also balanced with the solar heat gain coefficient on the glazing. Building shape has less of an impact with the zero energy guide in part because of highly efficient glazing systems and highly efficient lighting systems; however, it will provide a positive impact to the energy consumption without much, if any, additional cost.

Analysis Methodology

The objective of the analysis was to create a set of climate specific EUI targets for ZE ready office buildings with a focus on energy efficiency. Once the building is as energy-efficient as it can be cost-effectively, project teams must determine how much solar is required to get to ZE. To provide guidance for this process, project committee members examined solar radiation levels in each climate zone. Assuming 50% roof coverage by solar panels (to allow for roof access, HVAC equipment, daylighting penetrations, and plumbing vents), an initial EUI was established for each climate zone.

Some energy efficiency solutions are independent of climate, such as plug load management and electric lighting design. Daylighting solutions are climate dependent, but to a lesser degree. These solutions were fixed across the other climate zones while project committee members examined further possible improvements in envelope and HVAC design. The result was that less than 50% of the roof area was required to achieve ZE in many climate zones. In the extreme north zones (climate zone 8), the solar resource is greatly diminished, making it difficult to achieve ZE, but these climates show the largest energy savings of any of the climate zones when compared to ASHRAE 90.1-2016 (ASHRAE 2016). In contrast, in the extreme hot and humid climate (climate zone 0A), it is difficult to achieve ZE due to very high cooling demand. Source EUI target, site EUI target, and percentage of roof area required for PV for each climate zone is given in Table 4. Both site EUI and source EUI are given in the table because the site-source conversion is an important part of achieving ZE using DOE's ZE definition (DOE 2015). Note that the target EUI values are based on the office building models utilizing variable air volume (VAV) systems with hydronic heating and cooling.

The DOE ZE definition allows for a tradeoff with different on-site fuel sources including natural gas, propane, and fuel oil as an offset in those fuels being used for power generation. Most ZE buildings tend towards all-electric to comply with utility requirements on the amount of exported electricity compared to purchased electricity. In this case, using a site energy and the corresponding source energy target will yield the same result. The modeling examined both gas-fired heating and heat pump technologies to determine the energy targets. In general, the heat pumps have larger EUIs for the very cold climates compared to gas-fired equipment and therefore it is harder to achieve ZE in the cold climates for all-electric especially when combined with less solar availability.

Derivative Works

Because the measures used in the small to medium office building ZE AEDG were modeled with standard code elements, the design community can use the same basis for further simulations and introduce improvements by investigating alternative strategies while continuing to achieve the design EUI goal. This allows the design community to apply the prescriptive recommendations to their own building layouts and operational schedules. For example, this was useful during a DOE-sponsored university Solar Decathlon Build Challenge. In this effort students designed a ZE ready office building and the teams had to demonstrate an ability to perform analysis (DOE 2019). In addition, online learning modules for continuing education credits are being developed for architects and engineers, expected to be available during the fall of 2020.

Table 4. Small to medium office buildings energy use intensities: zero energy ready targets

Climate Zone	Site Energy ($kBtu/ft^2 \cdot yr$)	Source Energy ($kBtu/ft^2 \cdot yr$)	% of Roof Area for PV
0A	23.2	73.1	63
0B	27.6	86.9	50
1A	23.4	73.9	45
1B	25.7	81.1	56
2A	22.2	69.9	44
2B	22.8	71.8	40
3A	21.4	67.3	42
3B	21.1	66.6	35
3C	16.0	50.3	31
4A	21.7	68.5	44
4B	20.6	64.9	34
4C	17.3	54.4	43
5A	23.2	73.0	46
5B	22.9	72.0	37
5C	17.5	55.2	40
6A	27.7	87.3	48
6B	24.7	77.8	46
7	30.3	95.5	54
8	36.0	113.5	79

Consistencies with Other Methods of Setting Energy Goals

The project committee identified existing ZE ready office buildings and compared the EUIs and systems deployed with the analysis results. A sampling of these case studies and their climate zones and EUIs are show in Table 5. These offices were designed and built before the small to medium office buildings ZE AEDG was developed but achieved low operational EUIs, so they were good examples of how offices could be operated within the recommended EUIs for a ZE ready small to medium offices.

As another point of reference, the EUIs were compared against different versions of ASHRAE Standard 90.1, CBECS (EIA 2012a; EIA 2012b), and the 30% and 50% series of Advanced Energy Design Guides. The ASHRAE Standard 90.1 values are weighted by climate zone based on the actual number of buildings in each climate zone. These results point to a highly energy-efficient building, so the project committee also performed an analysis comparing CBECS and ASHRAE standards. Results indicate that ZE ready offices perform, on average, 14% better than ASHRAE Standard 90.1-2016 as shown by the black line in Figure 1. Note that climate specific values for the 30% AEDGs are not available by climate zone based on the analysis performed.

Table 5. Energy use intensity recommendations and achieved values for office buildings

Offices	Site EUI (kBtu/ft²·yr)	ZE Small to Medium office AEDG Recommended Site EUI (kBtu/ft²·yr)	Climate Zone
DPR Construction Regional Office (Phoenix, AZ)	26	22.8	2B
DPR Construction Regional Office (San Diego, CA)	14	21.1	3B
CMTA INC (Lexington, Kentucky)	15.5	21.7	4A
NREL Research Support Facility (RSF) (Golden, CO)	20.9 (without data center)	22.9	5B

Results from the ENERGY STAR® Target Finder were also compared with the EUI targets. Meeting EUI targets in the small to medium office buildings ZE AEDG required an ENERGY STAR score ranging from 85 to 100, depending on the climate zone.

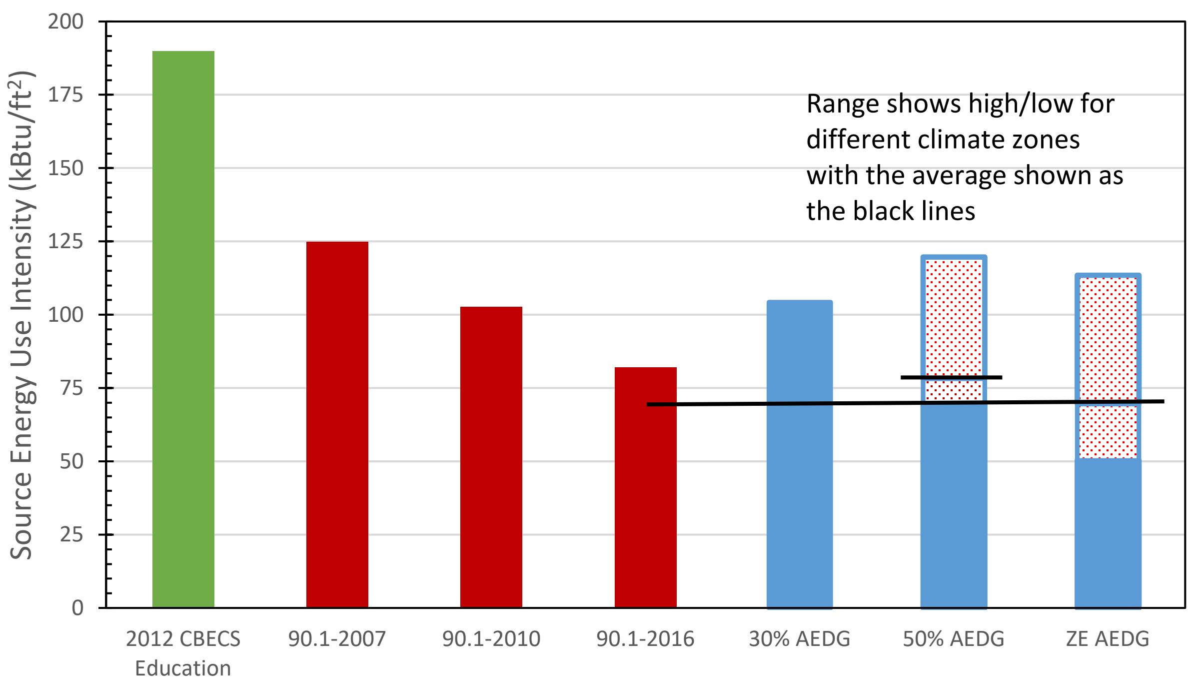

Figure 1. Comparison of energy use intensities for the Commercial Buildings Energy Consumption Survey, ASHRAE Standard 90.1, and the Advanced Energy Design Guides

Conclusion

As part of the development of the small to medium office buildings ZE AEDG, energy use intensity targets for zero energy ready performance were determined for 19 climate zones. Buildings that achieve these EUI's are well positioned to have on-site renewables provide the same amount of energy as consumed by the building. The target values were compared with ASHRAE Standard 90.1-2016 and shown to be substantially lower than the standard. The target values were consistent with case studies of operating ZE offices. Finally, these values were compared with the ENERGY STAR® Target Finder scoring system.

This analysis established that it is technically possible for new office building projects to achieve ZE ready status in all climate zones across the continental United States. Including climate zone 0 and climate zone 8 extends the analysis to most of the developed portion of the world. Temperate climates require a smaller percentage of solar panel coverage than very hot or very cold climates. In extremely cold climates (climate zone 8), roof space alone is not sufficient to get to ZE ready, but it can be achieved with additional solar panels installed outside the building footprint to balance energy demand. It is noteworthy that the largest energy savings can be achieved for these cold climate zones.

The target EUIs developed in this study provide excellent starting points for all office building owners who want their projects to be as energy efficient as possible. These values have been incorporated into energy models for industry use, so that design teams can start with viable pathways to ZE and adjust those pathways based on local market conditions and needs.

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