Moving K–12 Zero Energy Schools to the Mainstream: Establishing Design Guidelines and Energy Targets

Preprint

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Presented at the 2018 ACEEE Summer Study on Energy Efficiency in Buildings
Pacific Grove, California
August 12–17, 2018

Suggested Citation
Pless, Shanti D., Paul A. Torcellini, David Goldwasser, and Sarah B. Zaleski. 2018. "Moving K–12 Zero Energy Schools to the Mainstream: Establishing Design Guidelines and Energy Targets: Preprint." Golden, CO: National Renewable Energy Laboratory. NREL/CP-7A40-71700. https://www.nrel.gov/docs/fy18osti/71700.pdf.

Conference Paper
NREL/CP-7A40-71700
September 2018

Contract No. DE-AC36-08GO28308

NOTICE

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Federal Energy Management Program.

Cover Photos by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.

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ABSTRACT

K–12 schools are ideal candidates to lead the market shift from buildings that consume energy to buildings that produce as much renewable energy as they use. There are now resources to guide owners and project teams as they make the shift to these "zero energy" buildings, notably the *Advanced Energy Design Guide for K–12 School Buildings: Achieving Zero Energy* (K–12 ZE AEDG). Starting with a feasibility study to prove that zero energy schools were possible in all climate zones, a committee of industry experts used extensive energy modeling to create a set of energy use intensity targets for school buildings such that on-site renewable energy could meet the buildings' energy loads. Approaching the process from the perspective of the building owner and project team, committee members compared these energy targets with energy use in existing high performance schools. From these targets, they created and developed guidance for achieving a zero energy school and assembled that guidance into the K–12 ZE AEDG. The committee, which included design professionals and building owners responsible for delivering zero energy K–12 schools, stressed the importance of setting absolute energy targets before design begins. The targets represent a "zero energy ready" school, because installing on-site renewables can be limited by utilities, policies, or economics. Integrating energy efficiency into all design decisions before considering renewables results in a school that is cost-effective to build and operate, so owners see immediate benefits even if the renewable energy equipment is not installed until later.

Background

Today's buildings are much more energy-efficient than those of 40 years ago, thanks to improvements in high performance heating, ventilating, and air-conditioning (HVAC) systems; lighting systems; and electrical equipment combined with tighter, better-insulated thermal envelopes with advanced glazing. Over those four decades, much of the work in minimizing building energy impacts has focused on reducing energy use in buildings, typically measured as an energy use intensity (EUI). Considering energy efficiency in every design decision from the beginning of the process is a critical strategy in any building. A substantial change was needed, however, to take the next step in reducing building energy impacts.

The thought experiment of imagining a building with no or minimal energy impact yielded the concept of a balance—extremely energy-efficient buildings could produce as much energy as they consume by adding on-site renewable energy sources, usually solar photovoltaics. To validate this zero energy (ZE) concept at scale, 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 educational buildings.

A framework emerged around the effort to define these ZE buildings, and included the development of calculation methods and a national definition (Pless and Torcellini 2010; Torcellini et al. 2016; Peterson et al. 2016). To clarify what a ZE building is, 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 is not limited to buildings; it can also apply to 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 ASHRAE Advanced Energy Design Guides (AEDGs). This popular series of books—more than 632,000 are in circulation as of June 2018—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 the 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% and 50% guides were developed for K–12 schools (Pless, Torcellini, and Long 2007; ASHRAE 2008; ASHRAE 2012).

The AEDGs’ focus was always on providing design guidance grounded in simulation and goals that are achievable using widely available technologies. The long-range vision was to create a 100% guide or ZE set of guides as soon as energy efficiency and renewable energy technologies advanced to the point that widespread market adoption was possible.

That time has come. 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). The largest category of ZE buildings is primary and secondary schools, which accounts for the interest in this market segment. ZE schools also provide a good collection of case studies with actual measured energy performance.

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.

A further indication of the growing acceptance of ZE is ASHRAE’s publication of the first ZE AEDG, *Advanced Energy Design Guide for K–12 Schools: Achieving Zero Energy* (K–12 ZE AEDG) (ASHRAE 2018), which lays out a pathway to achieving ZE in K–12 schools. The K–12 ZE AEDG is 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). It divides schools broadly into primary and secondary schools, consistent with the previous 50% guide. Middle schools are discussed as a combination of primary and secondary schools, but were not explicitly modeled. The K–12 ZE AEDG uses 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 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 K–12 ZE AEDG, therefore, unlike 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.

The discussion has now shifted from “what” to “how.” Like the other AEDGs, a steering committee made up of members of five organization (ASHRAE, IES, USGBC, AIA, and DOE) created a scope for the new ZE AEDG, which focused on primary and secondary schools.

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 a ZE school. The project committee started with the results of the feasibility study (Pless et. al. 2016) and acted as a peer review council, modifying the school model to make it relevant to what was being built in 2017 based on their professional practices and experiences. In addition, project committee members collected case studies with measured and verified 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 the case study schools, and developed consumption EUIs that could be met with on-site renewable resources in various climate zones. This approach kept the emphasis on energy efficiency as the prime design driver.

This information formed the inputs for hourly energy computer simulation models of the primary and secondary schools. Multiple variants of these models can be run in parallel using cloud computing. Using these simulation 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 K–12 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

This extensive energy modeling helped determine the impact of the strategies considered in this design guide. A “typical” prototype model is an energy model that is a representative example of a school facility. The modelers developed two prototypes—a primary and a secondary school—based on the DOE Commercial Prototype Buildings Models (Deru et al. 2011; DOE 2014) as well as models from previous AEDG work (Bonnema et al. 2013). Middle schools are usually a mix of space types found in elementary and secondary schools, so they were not modeled separately. The range between elementary and high school energy use isn't that large, so it's relatively easy to, for example, take the average of elementary and high schools to represent a middle school if the need arises. ASHRAE Standards 90.1-2016, 62-2016, and 55-2017 provided input parameters as a starting point—in other words, the modeled buildings had to meet or exceed current standards.

Table 1. School characteristics used in modeling

Characteristic	Primary School	Secondary School
Size (ft²)	82,500	227,700
Number of floors	2	3
Number of students	650	1,200
Window-to-wall ratio	30%	30%
Wall construction	Steel-framed	Steel-framed
Roof construction	Insulation entirely above deck	Insulation entirely above deck

Table 2. Space type breakdown in design guide simulations

Space Type	Primary School		Secondary School	
	Area (ft²)	Percentage of Total	Area (ft²)	Percentage of Total
Auditorium	0	0%	10,634	5%
Art classroom	1,744	2%	1,744	1%
Cafeteria	3,391	4%	6,717	3%
Classroom	35,464	43%	72,668	32%
Corridor	17,954	22%	57,474	25%
Gym/multipurpose room	3,843	5%	34,702	15%
Kitchen	1,808	2%	2,325	1%
Library/media center	4,295	5%	9,042	4%
Lobby	3,100	4%	6,780	3%
Mechanical room	2,713	3%	7,364	3%
Office	4,747	6%	11,452	5%
Restroom	3,444	4%	6,780	3%
Total	82,503	100%	227,682	100%

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

- Increase the number of stories such that the primary school was two stories and the secondary school was three stories
- Increase the window-to-wall ratio

- Expand the number of HVAC system types (rather than only including ground source heat pumps [GSHPs])
- Electrify kitchen loads and art kilns
- Update climate zones to ASHRAE Standard 169-2013, with new representative cities
- Add climate zones 0, 1B, and 5C (not used in the feasibility study)
- 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 the primary and secondary schools. Table 2 provides detailed information about the space types considered in primary and secondary schools. 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. Note that these climate locations are different from previous guides due to the ASHRAE Standard 169-2013 update (ASHRAE 2013).

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 K–12 ZE AEDG, project committee members built on the technologies and strategies used to achieve a 50% energy reduction in schools (ASHRAE 2012; Bonnema et al. 2012; Bonnema et al. 2013), results from the ZE K–12 schools feasibility study (Pless et al. 2016), and successful design and construction approaches from existing high performance and ZE schools (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 and visual equipment, etc. (Fisher et al. 2006). The ZE K–12 feasibility study found that careful plug load management can yield an overall 40% reduction in plug loads (Pless et al. 2016).

Lighting

Achieving a 0.5 W/ft^2 whole-building lighting power density typically requires 100% LEDs and careful control design, a goal that has been met in existing ZE K–12 schools. Daylighting is an important component of a ZE K–12 lighting strategy, and is typically employed in the half of each classroom near view windows, while the other half of the classroom is 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 K–12 schools. 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.

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 feasibility study determined it is possible to cut total infiltration by half during occupied hours (Pless et al. 2016). The ZE K–12 AEDG contains detailed information on designing a building envelope for a ZE school, 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

Although many types of HVAC systems can be used in K–12 schools, GSHPs with dedicated outside air systems for ventilation are common choices, mainly because they are simple to maintain and operate. In climates where building heating and cooling loads are severely imbalanced, the bore field ground temperature can drift from its equilibrium point over a period of many years, affecting the system's ability to operate at its designed efficiency. Many steps can be taken during system design to mitigate long-term temperature drift and/or its impact on the operation of the GSHP system, including upsizing the bore field or coupling a heating or cooling source to the GSHP loop. Given the large number of practical design solutions available and the successful deployment of GSHP systems in extremely cold climates (Meyer et al. 2011), GSHPs are often used in ZE schools.

Analysis Methodology

The objective of the analysis was to create a set of climate-specific EUI targets for ZE ready schools 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.

In milder climates, the large amount of solar gain coupled with relatively small HVAC loads yielded high EUI allowances, in contrast with zones 5 and 6, where the heating dominance mixed with some cooling loads made meeting the on-site renewable expectations harder. Thus the parametric analysis started with climates 5 and 6 and determined a ZE ready pathway that matched available solar resources. Note that the emphasis was on optimizing energy efficiency in every climate zone so that projects could achieve ZE with the smallest (and least expensive) solar system possible.

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 (8 and to some extent 7), 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). Note that the source EUI target is listed along with the site EUI target in Table 4, because the site-source conversion is an important part of achieving ZE using DOE's ZE definition (DOE 2015).

Derivative Works

Because the measures used in the K–12 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 competition called Race to Zero in which students designed a ZE ready elementary school and the teams had to demonstrate an ability to perform analysis (DOE 2018). In addition, training modules are being developed for architects and engineers.

Consistencies with Other Methods of Setting Energy Goals

The project committee looked at case studies of existing ZE ready schools 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 schools were designed and built before the K–12 ZE AEDG was developed but achieved low operational EUIs, so they were good examples of how schools can be operated within the recommended EUIs for a ZE ready school.

Table 4. K–12 school energy use intensities: Zero energy ready targets

Climate Zone	Primary School Site Energy (kBtu/ft²·yr)	Secondary School Site Energy (kBtu/ft²·yr)	Primary School Source Energy (kBtu/ft²·yr)	Secondary School Source Energy (kBtu/ft²·yr)
0A	22.5	22.9	69.1	70.5
0B	23.1	23.2	71.4	71.6
1A	21.3	21.1	65.5	65.0
1B	21.7	21.6	66.6	66.6
2A	20.9	21.3	63.8	65.1
2B	19.6	19.9	59.7	60.8
3A	18.8	19.1	56.7	60.8
3B	19.0	19.4	57.3	58.8
3C	17.5	17.6	52.6	52.8
4A	18.8	18.9	56.3	56.7
4B	18.4	18.5	55.1	55.5
4C	17.5	17.6	51.9	52.3
5A	19.2	19.1	57.1	56.9
5B	18.7	19.0	55.6	56.6
5C	17.4	17.6	49.7	52.3
6A	21.1	20.6	62.8	61.2
6B	19.5	19.5	57.9	57.9
7	22.3	21.5	66.2	63.7
8	25.2	23.8	71.1	70.7

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 a ZE ready school performs, on average, 43% better than ASHRAE Standard 90.1-2016 as shown by the black line in Figure 1.

When the 50% K-12 AEDG was released in 2011, an aggressive target was a 50% energy savings compared with Standard 90.1-2004. Technology has improved, and design and construction professionals have become more knowledgeable, so the original 50% savings target is only slightly better than Standard 90.1-2016; it is possible to achieve EUIs more than 40% better than Standard 90.1-2016—a level needed to be ZE ready.

Results from the ENERGY STAR® Target Finder were also compared with the EUI targets. Meeting EUI targets in the K–12 ZE AEDG required an ENERGY STAR score ranging from 95 to 100, depending on the climate zone.

Conclusion

As part of the development of the K–12 ZE AEDG, EUI ZE ready targets for 19 climate zones were determined for K–12 schools such that the EUIs can then be balanced with on-site renewable energy resources. The target values were also 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 K–12 ZE schools. Finally, these values were compared with the ENERGY STAR® Target Finder scoring system.

Table 5. Energy use intensity recommendations and achieved values for selected schools

School	Site EUI (kBtu/ft²·yr)	ZE K–12 AEDG Recommended Site EUI (kBtu/ft²·yr)	Climate Zone
Discovery Elementary (Arlington, Virginia)	15.8	18.8	4A
Richard J. Lee Elementary (Dallas, Texas)	18.9	20.9	2A
Dearing Elementary (Pflugerville, Texas)	23.6	20.9	2A
Friends School of Portland (Cumberland, Maine)	11.7	21.1	6A

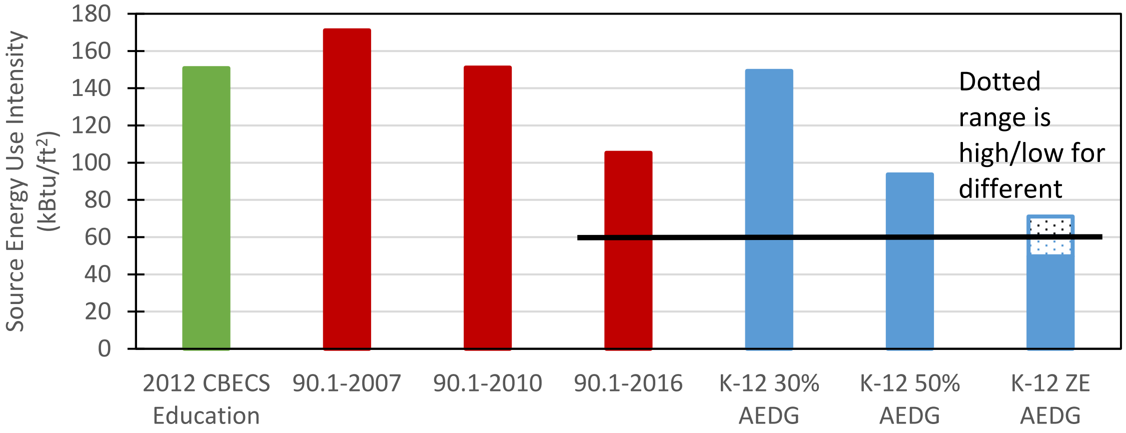

Figure 1. Comparison of energy use intensities for the Commercial Buildings Energy Consumption Survey, ASHRAE Standard 90.1, and the Advanced Energy Design Guides

This analysis established that it is technically possible for new K–12 construction projects to achieve ZE ready status in all climate zones across the continental United States. 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 schools.

The target EUIs developed in this study provide excellent starting points for all K–12 school 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.

Acknowledgment

This work was authored in part by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Building Technology Office. The views expressed in this paper do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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