TECHNICAL FEATURE

Zero energy schools engage students to meet educational as well as energy goals, exemplified by this rooftop solar laboratory at Discovery Elementary School in Arlington, Va. VMDO Architects/©Lincoln Barbour.

Advanced Energy Design Guide K–12

Next Generation of School Design & Operation

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Driven by energy-efficiency advances and renewable energy cost reductions, zero energy buildings are popping up all around the country. Although zero energy represents a bold paradigm shift—from buildings that consume energy to buildings that produce enough energy to meet their energy needs on an annual basis—it isn't a sudden shift. Zero energy buildings are the result of steady, incremental progress by researchers and building professionals working together to improve building energy performance.

ASHRAE is taking the lead by publishing—in partnership with the American Institute of Architects (AIA), the Illuminating Engineering Society (IES), and the U.S. Green Building Council (USGBC) and with financial and technical support from the U.S. Department of Energy (DOE)—a new series of advanced energy design guides (AEDGs) focused on zero energy buildings. The forthcoming *Advanced Energy Design Guide for K–12 School Buildings: Achieving Zero Energy* (K–12 ZE AEDG) is the first in this series. All the AEDGs are free downloads from ASHRAE (www.ashrae.org/freeaedg).

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A Little History

When the AEDGs debuted in 2004, the idea was to show the market how easy it was to achieve a 30% savings over ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Energy modeling was used to pre-compute a series of solutions, and the AEDGs provided practical guidance on how to hit the 30% energy reduction goal.[1] In 2004, only a few zero energy buildings existed,

School Case Studies

For more details on these schools, see the *Advanced Energy Design Guide for K-12 School Buildings: Achieving Zero Energy*.

Discovery Elementary School

A zero energy school can create a culture in which students, teachers, and parents understand how their actions contribute to maintaining zero energy each year. Discovery Elementary in Arlington, Va., is an impressive example of such a school that has also exceeded its energy target expectations.

Energy Data

Predicted EUI: 21.1 kBtu/ft^2·yr (239.6 MJ/m^2·yr)
Predicted RE: 21.5 kBtu/ft^2·yr (244.2 MJ/m^2·yr)
Predicted Net EUI: –0.4 kBtu/ft^2·yr (–45.4 MJ/m^2·yr)

Actual EUI: 15.8 kBtu/ft^2·yr (179.4 MJ/m^2·yr)
Actual RE: 19.0 kBtu/ft^2·yr (215.8 MJ/m^2·yr)
Actual Net EUI: –3.1 kBtu/ft^2·yr (–35.2 MJ/m^2·yr)

Richard J. Lee Elementary School

The Coppell Independent School District set out to construct a 21st century school that is sustainable while providing the best educational environment for the students. The Richard J. Lee Elementary School in Dallas fits the bill, coming close to zero energy with a low energy use intensity and a 358 kW solar photovoltaic system.

Energy Data

Predicted EUI: 18.5 kBtu/ft^2·yr (210.1 MJ/m^2·yr)
Predicted RE: 18.3 kBtu/ft^2·yr (207.8 MJ/m^2·yr)
Predicted Net EUI: 0.2 kBtu/ft^2·yr (2.3 MJ/m^2·yr)

Actual EUI: 18.9 kBtu/ft^2·yr (214.6 MJ/m^2·yr)
Actual RE: 16.9 kBtu/ft^2·yr (191.9 MJ/m^2·yr)
Actual Net EUI: 2.0 kBtu/ft^2·yr (22.7 MJ/m^2·yr)

Dearing Elementary School

Dearing Elementary School in Pflugerville, Texas, is one of the first zero energy ready schools built in Central Texas. Its innovative design incorporates opportunities for teaching and learning into every aspect of the school. A sophisticated energy management system helps staff make informed decisions about future energy activities.

Energy Data

Predicted EUI: 19 kBtu/ft^2·yr (215.8 MJ/m^2·yr)

Actual EUI: 23.58 kBtu/ft^2·yr (267.79 MJ/m^2·yr)

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Discovery Elementary School students enjoy interacting with the real-time data displayed on the energy dashboard and learning about their school's photovoltaic system.

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The Richard J. Lee Elementary School near Dallas is the first zero energy elementary school in Texas, and it integrates its sustainability features with an innovative educational approach to engage and motivate students.

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The zero energy ready Dearing Elementary School in Pflugerville, Texas, combines an innovative design that includes multiple opportunities for teaching and learning with digital displays that show the building's energy use.

largely because energy-efficiency technologies were expensive; the cost of renewables was very high; and the details of zero energy design, construction, and operation weren't well understood.[2]

Fast Forward 13 Years.

Since 2004, ASHRAE, AIA, IES, USGBC, and DOE completed a set of 30% guides and later produced a series of 50% guides that further pushed commercial building energy-efficiency limits, the number of energy simulation tools has multiplied, and the ability to execute thousands of simulations in the cloud is a reality (who'd even heard of the cloud in 2004?). The cost of solar photovoltaic (PV) systems—the renewable energy technology considered in the K–12 ZE AEDG—has also dropped 70% and the cost of many energy-efficiency technologies has also dropped.[3,4]

In 2007, a National Renewable Energy Laboratory assessment[5] showed that zero energy was technically feasible with the use of on-site renewables. More recently, California adopted zero energy 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.[6] California has also set a target of making all new commercial buildings zero energy by 2030.[7] Several other states are thinking along the same lines and have established task forces that are working on the issue. Although still a very small portion of the market, approximately 400 potential zero energy buildings have been identified in the United States and the number is growing rapidly.[8]

Much has been written about what zero energy buildings are, and the idea of a measurable, achievable zero energy goal is taking hold in the marketplace.[9,10] The discussion has now shifted from "what" to "how." As they did when they developed other AEDGs, a steering committee made up of each participating organization (ASHRAE, USGBC, AIA, and IES) created a scope for the new AEDG series that focused on primary and secondary schools. DOE serves an ex-officio member because it provides much of the funding to develop the AEDGs as well as directing the national labs to assist with analysis.

The steering committee then formed a special project committee (ASHRAE SP-139) made up of technical experts representing the school sector, HVAC, envelope, architecture, and lighting, with a strong emphasis on choosing members who had experience delivering and operating a zero energy school. The project committee was tasked with creating comprehensive design guidance to achieve zero energy in school buildings by looking at aggressive market-ready energy-efficiency strategies that reduce energy use to the point that a PV system can meet the remaining energy loads.

Why Schools?

The decision to focus on K–12 schools for ASHRAE's first zero energy AEDG was based on several factors. First, a number of schools have been built over the last few years that either are zero energy or could be if a PV system was added to their rooftops.

In addition, schools are generally high profile buildings with considerable educational impact and influence on students, teachers, parents, and the community at large. Schools tend to be one to three stories, which helps make zero energy an achievable goal with on-site renewables. (As the number of stories increases, the energy intensity relative to the area of the roof increases, making it harder to meet the on-site renewable energy requirement with a PV system on the building.)

As a submarket, the 232,000 U.S. K–12 schools account for 7.7% of commercial building energy consumption.[11] This is substantial, given that most school buildings have very similar activities and functions. In contrast, the total office building energy use is approximately three times that of schools in the United States, but office building sizes and shapes vary widely and the range of their uses is broader.

Zero energy buildings are still relatively rare, but—given that K–12 schools touch the lives of many more people than most buildings—successful zero energy schools can help familiarize the general public with the concept and benefits of zero energy. Zero energy is also easy to explain and understand, making it attractive as a portal to teaching schoolchildren and community members about the broader consequences of energy use.

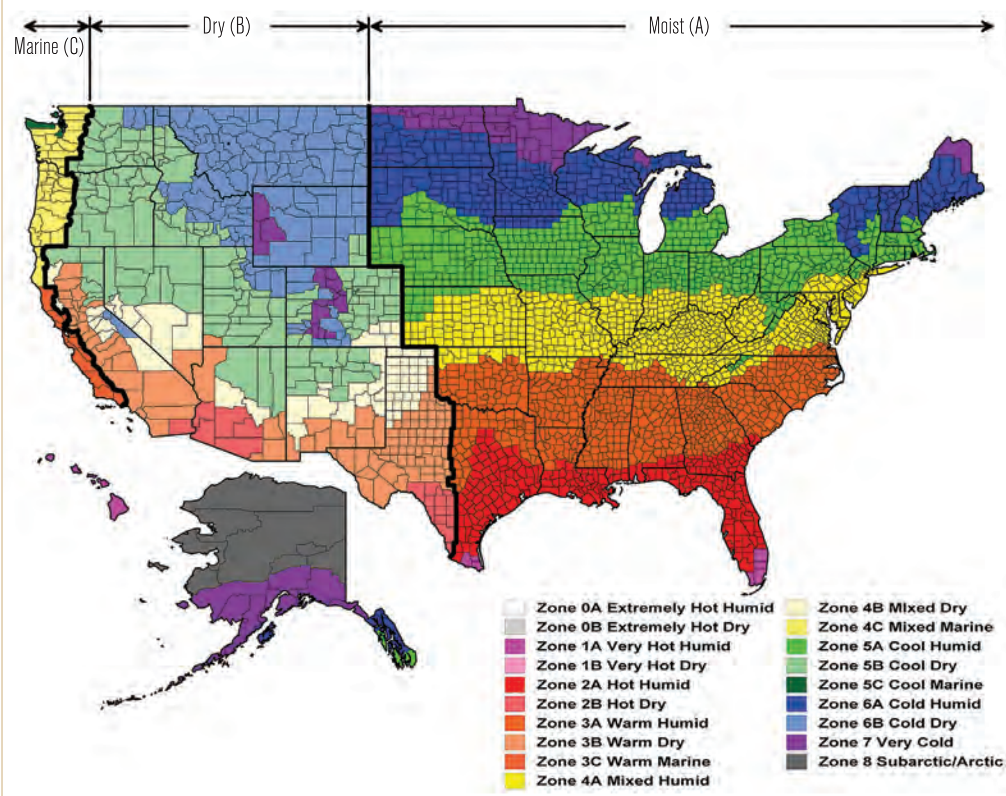
A Unique Approach

Zero energy buildings use an absolute energy use intensity (EUI) target rather than comparing energy savings with a predetermined base case such as a code-compliant building. Unlike the 30% and 50% AEDG series, the K–12 ZE AEDG provides no reference building or comparison. It does, however, provide clear guidance on how to achieve an absolute energy consumption target.

To clarify what a zero energy building is, DOE published a common definition in 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."[12] Note that this definition is not limited to buildings; it can also apply to campuses, communities, portfolios, etc.

The DOE definition uses source energy as the metric measured at the site. The K–12 ZE AEDG provides targets to meet that definition.

FIGURE 1 Climate zone map for U.S. states and counties. Source: ASHRAE Standard 169, Normative Appendix B.



A few characteristics of zero energy building design include:

- Increased emphasis on early stage energy modeling (predictive modeling);
- Prioritization on reducing the energy consumption of the building;
- Integration of renewables at a scale appropriate to the building's energy consumption;
- Innovative procurement processes and owner engagement; and
- Verification that the goal is met based on actual operations.

The last characteristic shifts the discussion from savings compared with a baseline as a design exercise to actual measured data that can prove the energy target has been met. This is the real objective—show that zero energy buildings perform according to their design intent and that the intent is to reduce the energy and environmental impact of the building.

One of the major barriers to the widespread acceptance of zero energy buildings is that design teams and contractors are not confident that zero energy can be achieved at a reasonable cost using today's technologies and strategies. Maintaining the theme of using energy modeling to help drive decisions, NREL completed a feasibility study in 2016 showing that zero energy K–12 schools could be designed and built successfully in different climate zones.[13]

The recommendations in the K–12 ZE AEDG meet the zero energy requirements in the eight U.S. ASHRAE climate zones (1–8) and the three corresponding subzones. This has changed slightly from the 50% design guides in that Standard 169-2013[14] was used with updated climatic data. In addition, Climate Zone 0 was added. In total, 19 climate zones were analyzed with the U.S. zones shown in *Figure 1*. Note that Standard 169 has world-wide information including maps and city tables.

The audience for this K–12 ZE AEDG is primarily design teams looking for guidance on processes and strategies to achieve a zero energy school design. In addition, there is useful information for school administrators, school boards, facility managers, and anyone who procures school buildings. It is also anticipated that the K–12 ZE AEDG will provide inspiration to students and those looking to push the limits of school energy performance.

Establishing Energy Targets

To establish reasonable energy targets for achieving ZE performance in all U.S. climate zones, two prototypical school models based on DOE prototypical models (which were also used for the 50% design guide for K-12 schools)—an 82,500 ft^2 (7665 m^2) elementary school (two stories) and a 227,700 ft^2 (21 154 m^2) secondary school (three stories)—were developed and analyzed using hourly building simulations. A typical elementary school layout is shown in *Figure 2*.

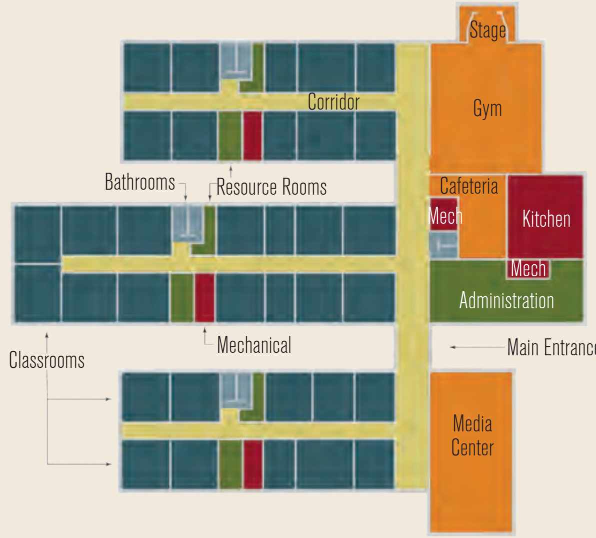


FIGURE 2 Example baseline building for an elementary school.

The buildings were modified by the project committee to reflect current design trends. For example, increasing the number of stories makes the model more relevant to urban and suburban in-fill buildings and replacement schools. However, this created a challenge of having enough roof area to accommodate the PV system to balance the energy needs of the building.

One set of hourly simulations was run for each prototype in each climate zone using the recommendations in the K–12 ZE AEDG. All materials and equipment used in the simulations are commercially available from two or more manufacturers. The simulation results led to target EUIs for each climate zone, and each was verified not to exceed the amount of renewable solar energy that could be generated by a PV system on the building's roof. These EUIs are intended not as a prescriptive requirement, but as a starting point of minimum performance that could be cost-effectively attained. Further optimization through building simulation and integrated design is recommended to reach the lowest possible EUI for the specific conditions of a particular project.

The previous 30% and 50% design guides documented a prescriptive path to achieving the energy goal;[15] that is, if you followed the list of recommendations, you would achieve the goal. The solutions were pre-computed and recommendations were put into tables.

The K–12 ZE AEDG takes an energy-performance-based approach that considers whole-building energy use. Energy targets are presented and a series of how-to tips outline methods and techniques to achieve these energy targets. These strategies are based on modeling as well as expert opinions from project committee members. In addition, case studies provide examples of completed school buildings operating near the target EUIs and detail the strategies used to achieve the targets.

Most of the guidance is practical and can be readily applied to school designs. The project committee focused on providing simple, easy-to-follow guidance that would result in a large number of zero energy schools. The recommendations and strategies all meet or exceed ASHRAE/IES Standard 90.1-2016 and ASHRAE/IES/USGBC Standard 189.1-2014, which are the current standards for energy efficiency in commercial buildings.

The steering committee provided specific scope to the project committee concerning space types. The K–12 ZE AEDG includes administrative and office areas, classrooms, hallways, restrooms, gymnasia, locker rooms with showers, assembly spaces, libraries, and dining and food preparation areas. The K–12 ZE AEDG does not cover atypical spaces, such as indoor swimming pools, laboratories, career and technical education, and other spaces with higher energy loads and ventilation requirements. The K–12 ZE AEDG also does not cover modular classrooms, specialty laboratories, maintenance areas, domestic water well pumping, or sewage disposal. Although only elementary and high schools were modeled, middle schools are typically a combination of the two.

For Owners, It Starts With Measurable Goals

The first part of the K–12 ZE AEDG targets school administrators, school boards, and other district staff and discusses how high performance learning environments can use a zero energy school building as a catalyst. Chapter 1 covers the fiscal aspects of building a school and the environmental aspects of zero energy. It makes it clear that zero energy schools are attainable within a standard school budget and discusses the advantages of setting an energy goal as an absolute number rather than comparing performance against a code or standard.

Measurable goals are key to the success of any zero energy building, particularly setting an energy use goal. Setting and achieving an energy use goal means the building is ready for a renewable energy future—whether the renewable energy is included during construction or not. Such a building is "zero energy ready."

The chapter points out that zero energy is an operational as well as a design goal, and looks at actual measured data after the building has operated for at least 12 months. Meeting a measurable energy goal demonstrates success, and that success can be shared with the design team, school administration, teachers, and students. A major advantage of building a zero energy school—as opposed to a less public zero energy building—is that the community shares in the success of the energy achievement.

Chapter 1 also discusses that the goal must be persistent—the first year of performance is good, but the real proof is year-over-year performance. For that reason, the owner needs to select a design team that represents its interests. Often, this team comprises administrators, teachers, security personnel, operations and maintenance staff and capital construction professionals. Team members must be consulted and included and must agree on the goals from the beginning of the process.

Zero Energy Schools Are Exemplary Schools

Chapter 2 of the K–12 ZE AEDG identifies the principles fundamental to creating a zero energy school. For example, it is important to ensure good indoor environmental quality in any building, and a zero energy school is no exception.

The functionality of the school as a learning environment is critical, so this chapter discusses the integration of the curriculum with building elements. For example, engaging students in data collection through energy dashboards can be educational, but can also be structured such that it supports the energy performance of the building.

The chapter builds confidence that zero energy is achievable today in any climate zone within a conventional school budget. It also discusses the importance of communicating that clearly to multiple stakeholder groups in terms they can understand. The architects and other team members can use their expertise and experience to engage the community and assure them that the pathway to zero is attainable. Because the design team is pivotal in achieving project goals, the chapter also describes the characteristics of a successful design team to help owners choose wisely.

People, Process, Procurement

With the foundation of zero energy set, Chapter 3 presents the keys to success. When owners, design/construction team members, teachers, school administrators, operations and maintenance staff, and other stakeholders embrace the zero energy concept and—especially—a measurable energy consumption goal, the chances of success increase dramatically.

Zero energy "champions" may or may not be the same people during different stages of a project. For that reason, a broad range of stakeholders should be included in the process from the outset. For example, including operations and maintenance staff or kitchen and food service personnel during planning and design can ensure that the building operates as it's designed.

Chapter 3 provides high-level strategies as a "loading order" or pathway to achieving zero in a logical design progression. The chapter also offers examples of ways to calculate whether a building is zero energy and discusses how to verify the end result. In addition, it covers commissioning as a process that begins in design and continues through occupancy.

The focus for the owner is to hire a design team committed to the goal and willing to work creatively and collaboratively throughout the process to find the best solutions for meeting the energy target and optimizing the learning environment. Toward that end, this chapter discusses procurement strategies and provides guidance so that the design team can respond effectively to the owner's needs.

Procurement strategies are important to achieving a zero energy goal.[16] They provide a framework for decision making as well as clear direction and motivation to guide design teams and construction contractors. Many school districts have established procurement policies, and this chapter can help them incorporate energy goals into those policies or may even prompt them to adapt existing policies so that they support the routine delivery of zero energy schools.

Some owners know from the outset that they want a zero energy building and create procurement methods geared to selecting an appropriate design team. In other projects, it's the design team that champions zero energy by promising to deliver a zero energy building without increasing the budget, giving that team a significant competitive advantage.

Even when they're committed to the zero energy concept, many owners and design teams need guidance setting energy targets. To develop that guidance, NREL researchers started with baseline buildings and applied a number of strategies to a computer model. The researchers also established the on-site solar allowance or the expected amount of sun for each climate zone. They then compared models across climate zones for consistency, and established maximum EUI targets for a school to be zero energy ready. Those targets are shown in *Table 1*. As a tangible outcome of this work, energy models will be available in Spring 2018 at www.ashrae.org/freeaedg for design teams to use as a starting point for their own analyses.

TABLE 1 Target energy use intensity.

CLIMATE ZONE	SITE ENERGY		SOURCE ENERGY	
	PRIMARY SCHOOL EUI ($KBTU/FT^2 \cdot YR$)	SECONDARY SCHOOL EUI ($KBTU/FT^2 \cdot YR$)	PRIMARY SCHOOL EUI ($KBTU/FT^2 \cdot YR$)	SECONDARY SCHOOL EUI ($KBTU/FT^2 \cdot YR$)
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	57.7
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

Model Early and Often

Chapter 4 discusses energy simulation methods and how building simulation can be a valuable decision-making tool as the design team frames and refines the design. Energy models are often used only for code compliance or to provide an energy rating for a certification program.

In fact, they are not only effective design tools, but can also help ensure that the building operates at zero energy from year to year. Therefore, the building should be modeled throughout design, construction, commissioning, and operations to evaluate decisions and measure progress. The key is keeping the building model up-to-date with the as-built design (and condition) of the school.

Modeling first considers climate, building massing, energy, daylighting, and lighting. It should then be used to help select and size mechanical systems. Models can also help evaluate acoustics, air movement, heat and moisture migration, and thermal comfort. The investment in modeling can effectively make design decisions, creating a better school environment that hits its energy targets as well as helping to keep the school operating at zero energy throughout its lifetime.

Getting the Details Right

Chapter 5 contains the bulk of the how-to guidance, broken into specialty areas—building and site planning, envelope, daylighting, electric lighting, plug loads, kitchens and food service, water heating, HVAC, and renewable generation. Each section contains multiple tips that move the design incrementally toward the zero energy goal.

Cross references are provided where strategies overlap and rely on another strategy. The cautions and best practices provided throughout the chapter are based on the practical experiences of project committee members.

As the many educational, fiscal, and environmental benefits of zero energy schools become better understood, these innovative buildings will become more common. The purpose of the K–12 ZE AEDG—the most comprehensive source of practical wisdom for designing, building, and operating a zero energy school currently available—is to speed that shift.

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