Plowing through the Cost Barrier: Zero Energy K-12 Schools for Less

Preprint

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Plowing through the Cost Barrier: Zero Energy K–12 Schools for Less

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ABSTRACT

There is a perception that zero energy K–12 schools cost more than conventional schools. Zero energy schools provide a number of unique benefits to school districts, students and staff, and communities. Among other things, a zero energy school requires far less energy to operate than a conventional school and uses on-site renewable energy systems to offset that reduced energy load. The money saved on energy can often be used to enhance educational programs.

But does the extra value come at a premium? Research findings indicate that not only can zero energy schools be designed and built on conventional school budgets, they can cost less. In an integrated design and construction process, the cost of zero energy measures can be offset by, for example, downsizing heating, ventilating, and air-conditioning systems, reducing both life cycle and first costs.

These findings are based on an examination of 88 zero energy or zero energy ready schools across the United States built during the last 15 years. The data collected on these schools include capital costs and the experiences of owners and design teams. The goal was to understand the perceived cost barrier, given that each building was built with a predetermined budget.

The results will help future school stakeholders, program administrators, and design teams counter the perceived cost barriers. Successful strategies for achieving zero energy at no initial cost are presented. The lessons learned from existing zero energy schools can help transform the market such that all new schools can be zero energy.

Background

K–12 schools are leading the market shift from buildings that consume energy to buildings that produce as much renewable energy as they use (NBI 2019a). Advances in technology and integrated design together with sharp reductions in the cost of renewable energy make zero energy (ZE) feasible (Bonnema et al. 2016) and affordable now. As the number of ZE schools grows and the benefits become better understood, pressure from local communities can become a factor. ZE schools provide beautiful, well-lit, healthy indoor environments for building occupants as well as many unique learning opportunities for students (DOE 2017). ZE schools are often built for reasons beyond a pure "business case," although there's a strong business case for choosing a ZE school.

A ZE building produces as much energy as it consumes on an annual basis. In some cases, however, owners postpone installing renewable energy resources. These buildings—

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referred to as zero energy ready (ZER)—are so energy-efficient that future on-site renewable resources can offset annual energy use. ASHRAE (2018) provides target energy use intensities (EUIs) for K–12 buildings; buildings that meet these targets can be considered ZER (Pless et al. 2018, DOE 2015).

The dramatic increase in the number of documented ZE buildings confirms the growing interest in ZE. The largest category of ZE buildings is primary and secondary schools, and ZE schools also provide a collection of compelling case studies with measured energy performance data (NBI 2019b).

Still, the widespread perception among building professionals and school officials is that ZE projects cost more than conventional schools. It is important to counter that narrative because the perception of risk alone can drive costs up.

There are now enough U.S. ZE schools operating that the perceived risk associated with tackling a ZE project is diminishing. Firms that commit to ZE can, however, expect to invest in educating staff and clients, improving modeling capabilities, and identifying and adopting cost control strategies. Most companies invest in business development to stay current in their fields, and ZE buildings are early indicators of an increased and accelerating focus on sustainability in general and reduced energy use in particular during building design and construction.

The process is analogous to the switch to computer-aided design (CAD). As that transition demonstrated, once a technological advance gains traction in the market, transformation can happen quickly. Architectural drawing software was released in 1982 for use on small computers; by 1986, it was the most ubiquitous CAD program in the world (Wikipedia 2020). Companies invested in the technology in order to stay relevant.

Making ZE standard practice is a paradigm shift for most school districts and design teams, but the foundation is in place—there are now multiple examples of affordable ZE K–12 schools around the country. Owners and project teams can use the lessons learned from these projects as guides to develop their own cost-effective ZE schools.

Information Collection

To determine whether ZE schools are more expensive than conventional schools, researchers collected project cost, energy performance, and other data on approximately 150 schools. Many of these schools consider themselves ZE or ZER and often these schools publish information about their energy performance. They are self-selecting and schools that report EUIs may be better performers than the overall sector. The purpose of this effort was to examine this collection of schools and evaluate their costs compared with each other as well some industry averages. The information came from websites, public data sources, and nongovernmental organizations (ZESA 2020) as well as discussions with architects, engineers, school district officials, and others familiar with ZE schools. For this study, the sample set will be referred to as ZE or ZER schools, remembering that they are self-selected and have not been "certified" or verified as such. (Note that this sample is not exhaustive; there are likely other ZE schools operating around the country.)

The final data set consisted of 88 new ZE school construction projects for which there were data on costs, EUIs (either projected or measured, expressed as $kBtu/ft^2 \cdot yr$), and location. The information for some schools also included the cost control approaches design teams used to get to ZE or ZER.

Data Analysis

The cost data has limitations in that different schools can have different boundary conditions. For most schools, land acquisition is not included in project costs. Other items such as site infrastructure, school district administrative costs, and furniture, however, may or may not be included in the reported project costs.

Although data were collected on school renovations that resulted in a substantial reduction in energy use, this analysis focused on new construction. The many differences between renovations and renovations plus additions make comparisons difficult.

The data were normalized to average 2019 costs (last available) and to a fictitious location that represents the "average" construction cost location. When they were available, cost data were as of the bid date. If the bid date was not known, the occupancy date minus 2 years was used to establish the cost basis.

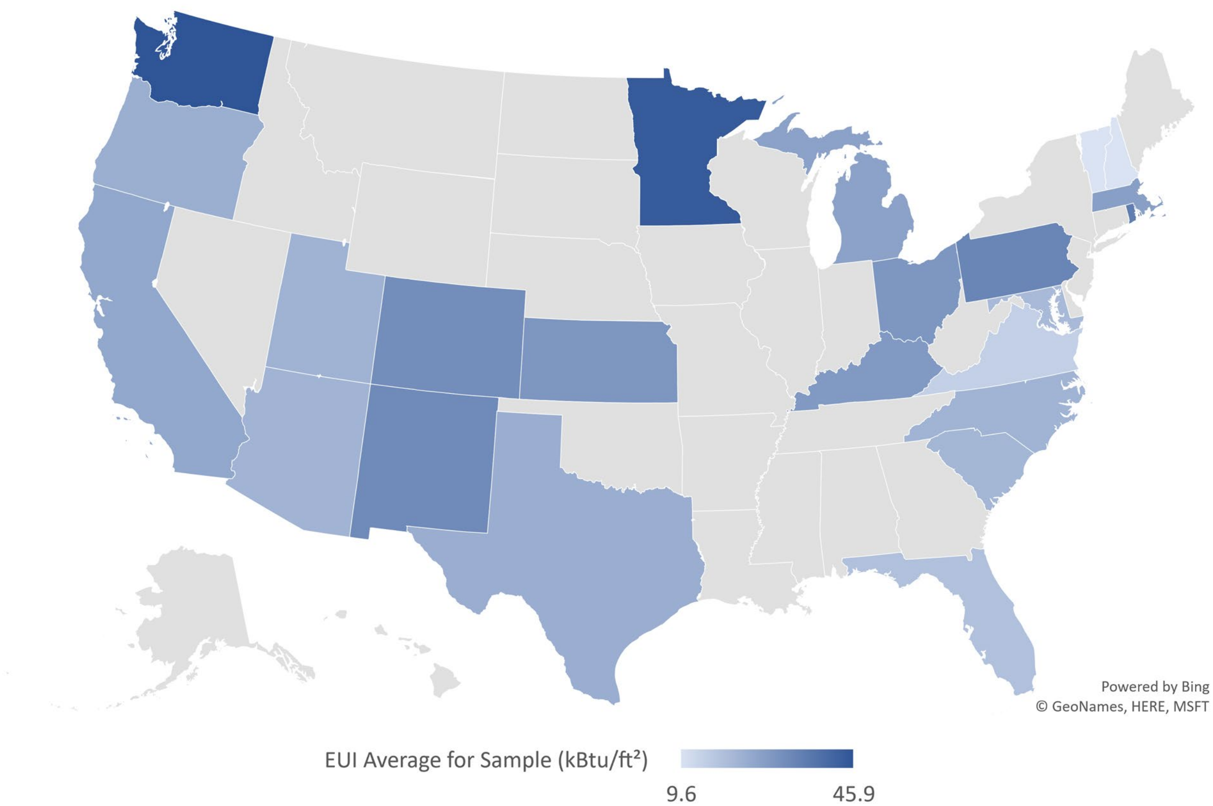

Figure 1. Eighty-eight zero energy or zero energy ready schools around the United States including average energy use intensities for each state.

The schools in Figure 1 are very energy-efficient buildings gleaned from several sources. They were selected based on the availability of information, so they represent a range of energy efficiency values. In addition, some of the EUIs are higher than the target EUI values established for ZER schools in the *Advanced Energy Design Guide for K−12 School Buildings: Achieving Zero Energy* (ASHRAE 2018) because the sample includes older, more energy-intensive schools. Newer schools tend to have lower EUIs, and many of them are operating at better than ZER.

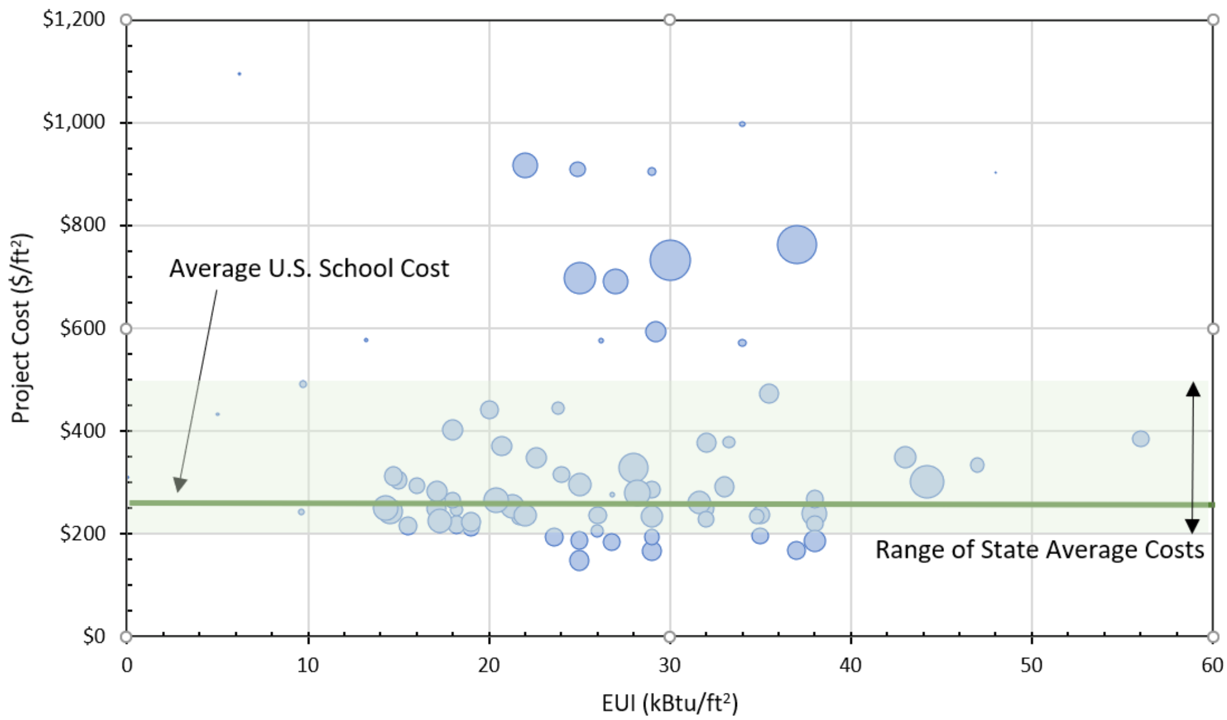

Figure 2. Graph of project cost and energy use intensity for the 88 K–12 schools studied

In Figure 2, bubble sizes represent school floor area, with larger bubbles representing larger schools. The green line is the U.S. average cost of schools as reported in the *State of Our Schools* report (Filardo 2016). Average school cost by state ranges from \$205 to \$495 per ft^2 depending on location, and most ZE schools studied are within this range. There is a set of higher-priced outlier schools with EUIs in the 20 to 30 range. Some other high-cost outliers are very small projects, often one or two classroom buildings on a campus.

Many of the ZE schools are less expensive than an average school and fall within a tight cost range. For most of the schools in this analysis, project costs are essentially independent of EUI; most school districts are under considerable pressure to keep costs for schools under control and the process is public and transparent. School districts respond to public pressure and are sometimes subject to state requirements that mandate school costs. Like all schools, ZE schools must be responsive to these cost pressures.

During the past 15 years, design strategies and building technologies have been refined to the point that school buildings can generate as much energy as they use with on-site renewable energy at costs comparable to and often less than conventional schools. The progression of energy efficiency improvements over the years is summarized in Figure 3.

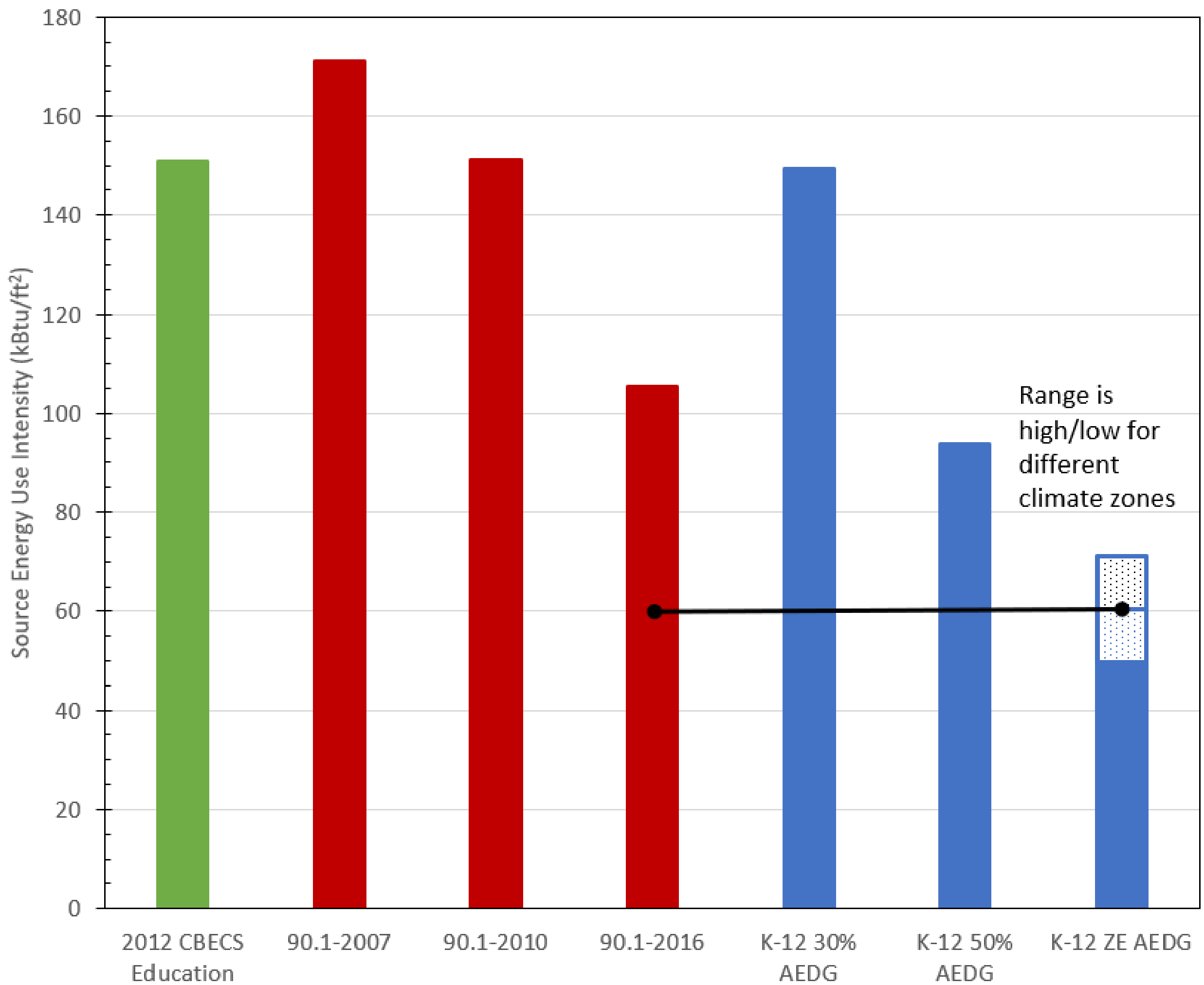

Figure 3. Comparison of U.S. average energy use intensity data for K–12 schools compared to ASHRAE Standards and *Advanced Energy Design Guides*

The first *Advanced Energy Design Guide* (AEDG) for K–12 schools demonstrated ways to achieve a 30% energy savings compared with ASHRAE Standard 90.1-1999. When the guide was updated to a 50% energy reduction, the basis was ASHRAE 90.1-2004. The K–12 ZE AEDG is different from the 30% and 50% guides in that it does not reference a baseline. Rather, in the ZE guide ZE is an absolute goal.

The ZE guide establishes EUI targets, however, and these targets are 42% better than ASHRAE 90.1-2016, which is a substantial improvement over ASHRAE 90.1-2010 as shown with the black line in Figure 3. This shows that the EUIs are not only decreasing for the standards, but the EUIs are also decreasing almost as fast for advanced design guidance. This level of high performance is maintaining a pace at least 40% better than the standards.

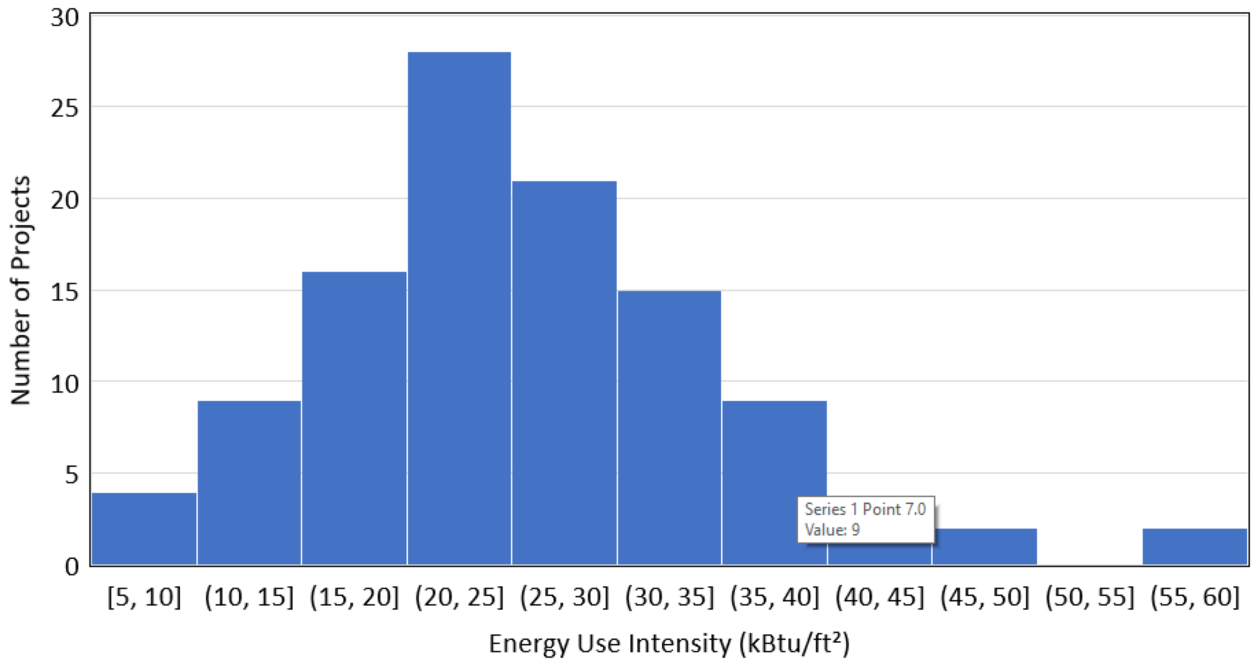

Figure 4. Histogram of the frequency of energy use intensities for sample set of K-12 schools

Figure 4 shows the frequency of the sample set binned by EUIs. Fifty-seven of the schools or 65% of the sample set have a reported EUI of less than 25 kBtu/ft^2·yr. Many schools can achieve an EUI of less than 25 and a significant percentage are at less than 20 kBtu/ft^2·yr.

For a select number of projects (see Figure 5), the incremental PV cost as a percentage of project cost was available. Before 2011, the incremental cost of providing enough PV to offset building energy consumption was more than 7% of total project costs. As project EUIs drop, less PV is required to meet the reduced loads.

In addition, the cost of PV has been dropping rapidly. Actual costs of PV in schools exceeded the NREL reported national average before 2016 and has dropped below the national average more recently. This could be due to experienced designers and contractors implementing the technology more cost-effectively as they gain experience and technologies mature (Fu, Feldman, and Margolis 2018).

The incremental cost of adding PV is less than 3% for this collection of commercial buildings. Some of this increment can be attributed to design teams specifying PV at the outset of the project and including infrastructure to easily incorporate PV. Some of the cost decrease is also a result of lower building EUIs, which in turn reduce the amount of PV required to achieve ZE.

The percent PV increases a budget today is smaller than a typical 5% cost estimating error (Tony Hans, National Director of Sustainable Products, CMTA, Inc., pers. comm.). As a result, PV can be added to school projects as an add-alternate in the bid package. An add-alternate list includes amenities or features offered to owners and the prices of those extras. Owners can then accept the features they prefer and can afford. If the bid comes in within the total ceiling, PV can easily be incorporated into the project.

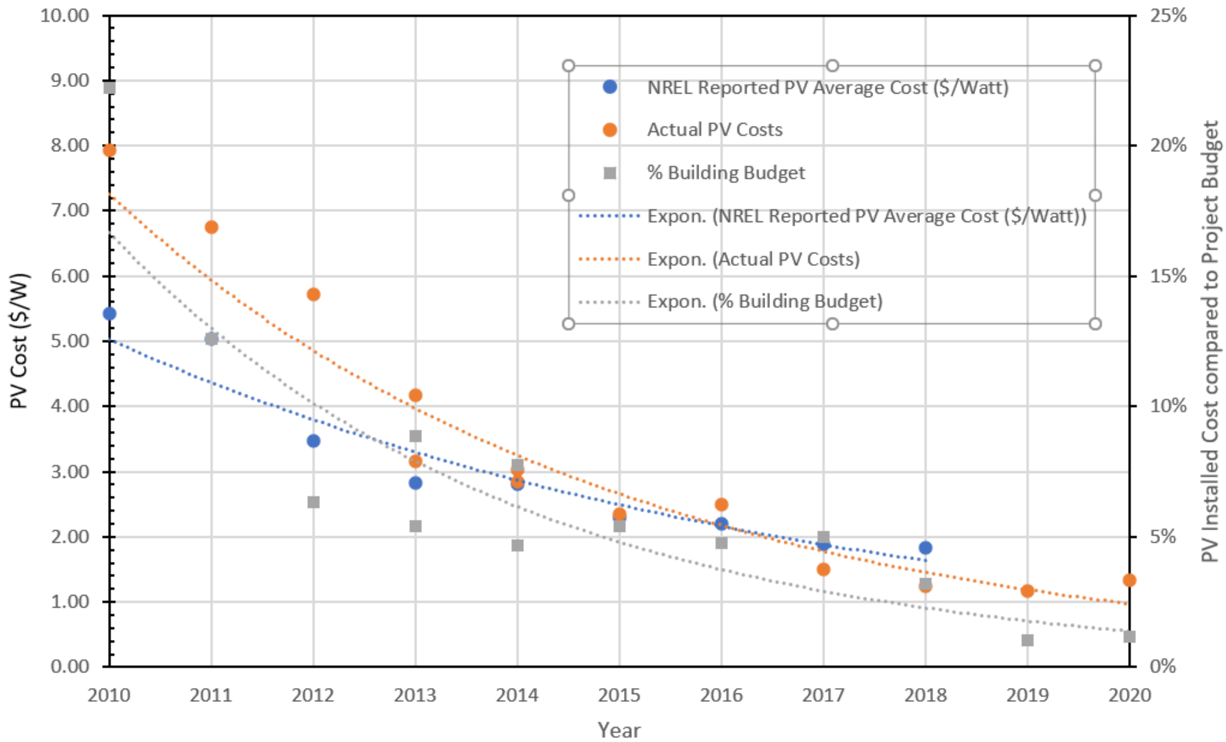

Figure 5. Cost of photovoltaics for actual projects compared with average photovoltaic costs for U.S. commercial buildings (200 kW average size) and the percentage of building budgets required for photovoltaics sufficient to achieve zero energy

Cost Control Strategies

In conversations with architects, engineers, and school district officials working on ZE or ZER schools, innovations emerged that help contain costs. ZE can dramatically reduce energy and operating costs over a building's lifetime, which is a key benefit for a school district (Torcellini et al. 2019). Architects and engineers, however, report that most clients are more interested in first costs.

That can make redirecting owners' attention to life cycle or operating costs a hard sell, which puts pressure on project teams to reduce first costs as well as energy costs. Fortunately, dramatic energy efficiency improvements such as those in ZE schools not only save energy and money but also unlock synergies that can reduce first costs. Changing the conversation from "how much more will ZE cost" to "how can we achieve ZE within our budget" can reveal opportunities for energy and dollar savings that a more conventional approach would miss. Incorporating the energy goal early will contain the costs. Schools that can achieve ZE without additional cost need not perform life cycle cost analyses. If such an analysis can add capital funds to a project and those funds are used to further enhance energy efficiency, however, additional savings are possible because energy efficiency strategies can provide attractive returns on investment.

Project teams have developed and refined the strategies discussed here during the process of designing and building existing ZE schools. Adopting these approaches can keep costs in line with conventional schools and counter the perception that ZE schools are untested and therefore risky to the design team, contractor, and school district. As noted earlier, the perception of risk alone can drive costs up as project team members increase bids to limit exposure.

Establishing a Budget and Energy Goal

Establishing a fixed budget and setting an absolute EUI target at the outset of the project can take some of the uncertainty and attendant risk out of a ZE school project, especially for districts and project teams new to ZE and ZER buildings. Establishing an EUI goal is not standard practice for most building projects, even those characterized as “green” or “energy-efficient.” Typically, an energy use projection is calculated after the design is substantially complete, and energy performance is determined during the design process. In a ZE school project, however, energy performance is a driver of the design process (Torcellini et al. 2019).

Energy goals can be established and validated several ways. A starting point is the *Advanced Energy Design Guide for K–12 School Buildings: Achieving Zero Energy* (ASHRAE 2018). In this publication, computer models combined with actual building case studies were used to create energy goals for a ZER school. To establish the target EUI:

- Use the recommended values from ASHRAE (2018) and demonstrate to stakeholders that the EUI targets are attainable by providing case studies of similar schools that achieved low EUIs (Torcellini et al. 2019).
- Determine whether the school will have specialty functions and add these uses to the energy total; examples include swimming pools, ice rinks, television-quality lighting for sports fields, laboratories, technical education centers, and spaces with higher energy and ventilation requirements.
- Adjust the EUI goal down whenever possible to achieve higher efficiencies, further reducing the size and cost of the on-site renewable generation required to meet the building’s energy loads.
- Always include PV in the project design, even if the actual panels are an add-alternate to the project.

Shifting Costs

Rather than trying to sell clients on life cycle costs, seasoned ZE project teams break down costs to help owners understand how affordable a carefully designed ZE school can be. Here are few examples:

- As Warren County [Kentucky] Public Schools learned, geothermal heating and cooling systems can be more expensive initially but are much cheaper over the long term.
- Improving the building envelope can reduce the size and cost of the geothermal or other HVAC system.
- Rather than spend $119,000 to upgrade Arlington [Virginia] Public Schools’ Discovery Elementary School’s windows from double- to triple-panes, engineers calculated that it would cost $9,000 to keep the double-pane windows and slightly increase the size of the solar system to achieve ZE status (Wyck Knox, Principal, VMDO architects, pers. comm.). Note that the final EUI was 20% less than the recommendation from the *Advanced Energy Design Guide* (ASHRAE 2018).
- An investment of $200,000 in Discovery Elementary School’s envelope first costs allowed a savings of about $500,000 in HVAC first costs (Wyck Knox, Principal, VMDO architects, pers. comm.)

Choosing a Procurement Process

Procuring a ZE school on a conventional school budget requires an integrative design approach (Torcellini et al. 2019). This process considers each strategy, system, and component from the perspective of an overall ZE goal, namely achieving an EUI low enough that the building's energy needs can be met with an on-site renewable energy system.

There is no "perfect" procurement process, but the delivery method for a ZE school can be key to the success of a project. Design-bid-build, construction manager at risk, and design-build are three project delivery methods used to design and build schools.

Energy-related goals can be inserted into all three but incorporating energy goals is easier in some procurement processes than in others. For example, a performance-based design-build procurement process (DBIA 2009; Idaho 2014; Pless et al. 2012) requires that the project team deliver a building that meets the energy and other performance-based goals for a firm fixed price.

Regardless of the procurement process, contracts for designers and contractors should clearly describe energy and other performance criteria. The owner should then allow the design team the freedom to use its problem-solving skills to develop creative solutions. The request for proposal should not prescribe solutions to avoid placing unnecessary constraints on the designers and contractors. A better strategy is to let the professionals develop innovative solutions within the constraints of the budget.

When ZE is a school goal, selection of the design and construction team should be based on qualifications and best value. Selecting the lowest bid is less likely to result in a design and construction team that can deliver a ZE operational performance goal. It's more important to hire designers and contractors that understand and are committed to achieving the ZE goal.

In design-bid-build projects, for example, architects and engineers estimate construction costs during the design process. If the construction contractor's estimate is higher than that estimate, the design may be modified to meet the budget.

Equipment included in the design expressly to meet energy goals may have higher up-front costs than less energy-efficient choices. Switching the energy-efficient options for the less energy-efficient options to meet the budget, however, can ruin a building's chances of meeting EUI targets, and, in turn, achieving ZE. School owners should be aware of these trade-offs and put processes in place that prevent energy efficiency compromises.

A good design-build process defines all the rules in advance and determines the best value for the owner through a competitive process. This process can produce an environment that encourages open discussions about how to achieve the ZE goal and identify the design team best qualified to successfully complete the project.

Measuring and Verifying Performance

To ensure that the projected savings materialize, every ZE school should undergo a rigorous measurement and verification process (Torcellini et al. 2019). Some engineering firms pressure test every building. The envelope is critical to the sizing of the HVAC system, and a trend in ZE building cost control is to pay for additional envelope pressure testing, with the procedure outlined in the specification documents. By assuring envelope performance, the engineering team can downsize the HVAC to reflect the performance of the envelope that will actually be built.

Acquiring a Solar Photovoltaic System

The cost of PV has come way down, but some ZE schools are opting to enter into a power purchase agreement with a solar developer rather than purchasing the system outright. This arrangement has the advantage of not requiring additional capital for the PV system, and the district buys power from the solar developer at a lower price than the local utility rate. An additional advantage to the power purchase agreement model is that a private company can pass some of the tax benefit to the school, although that benefit will be decreasing in coming years.

In some places, incentives are available for purchasing PV (see the Database of State Incentives for Renewables & Efficiency® [DSIRE 2020] for local incentives). For example, in Connecticut, it makes more sense to buy the PV system because the state will reimburse 60% of the capital costs. School districts need to be cautious and educate themselves about PV pricing models, however, because utility demand charges or connection fees vary widely and can impact the cost analysis. (Note that DSIRE [2020] is also an excellent source for local energy efficiency incentive programs. For more information on PV for ZE schools, see ASHRAE [2018, 191-01])

Case Study: Warren County [Kentucky] Public Schools

Warren County is Kentucky's fastest-growing county, and, in 2003, as part of an effort to serve its growing K–12 student population, Warren County Public Schools (WCPS) set a goal of saving $3 million in energy costs in 8 years. The effort began with simple, no-cost energy efficiency strategies like turning lights off in unoccupied spaces. As existing schools were renovated and new schools were planned and built, the district adopted other cost-effective energy efficiency measures and soon exceeded its goal, saving more than $4 million in less than 6 years (Siebert 2009).

As energy efficiency lessons learned were applied to new and renovated schools, the process was steadily refined. When Plano Elementary School opened in 2007, it was Kentucky's most energy-efficient school and it still operates at an EUI of 26.8 $kBtu/ft^2 \cdot yr$. For context, new schools in Kentucky typically consume 65 $kBtu/ft^2 \cdot yr$ (Siebert 2012).

Once Plano was operating, Mark Ryles, then facilities director for the Kentucky Department of Education, posed a question: "How would one design a net ZE school and how much would it cost?" (Siebert 2012). That question launched an effort that involved engineers, architects, state regulators, utility companies, school board members, school facility managers, and school staff, and resulted in the design and construction of Richardsville Elementary, the first ZE school in the United States.

Being the first is risky, but the risk was mitigated somewhat by funding from the American Recovery and Reinvestment Act of 2009 (ARRA) that allowed Kentucky school districts to hire energy managers and included a $1.36 million grant to WCPS that paid about half the cost of the PV system (Edelstein 2017). Still, concerns persisted in some quarters.

"When Richardsville was in design, there was chatter about how much it was going to cost," said Kenny Stanfield, the project architect. "Zero energy was all theory at the time, so there was lots of pushback."

In addition, the project team faced a constraint unique to Kentucky—the Kentucky Department of Education mandates the maximum cost of every school in the state. To get to ZE, the school budget would have to include the cost of PV.

Energy modeling showed that a PV system large enough to offset the Plano EUI of 26.8 $kBtu/ft^2 \cdot yr$ would push Richardsville's cost beyond the state-mandated maximum, even with the ARRA monies. Clearly, the project team had to revisit the design, reduce the EUI, and cut costs.

"We had an advantage in that we'd done all the schools for Warren County and we had tracked the lessons learned," explained Stanfield. "On the Plano project—prompted by our facilities folks and engineers—we went with geothermal heating and cooling and improved the building envelope to achieve a low EUI."

Based on that experience, the district again used geothermal heating and cooling for Richardsville but chose integrated concrete forms (ICFs) for the exterior walls. ICF walls are well-insulated, contain thermal mass, reduce construction time, create a very tight building envelope, and resist winds of up to 250 mph. (Kentucky schools must be able to withstand 225 mph winds.)

"Geothermal is more expensive initially, but much cheaper over the long term," said Mike Wilson, WCPS Facilities Director. "Districts have to decide between lowest first cost and the best long-term value for students and the community—for us, the choice was clear."

Once Plano was operating, its low energy use caught the attention of the local utility, the Tennessee Valley Authority (TVA), which installed meters to monitor energy end uses in the building.

"We had never measured anything except total building consumption, but the TVA meters allowed us to look at all the end uses, which was very useful." said Stanfield.

The project team used the metered data to guide decision making. The result was that Richardsville Elementary School opened in 2010, came in on budget—including the PV system—and has operated at an EUI of about 18 $kBtu/ft^2 \cdot yr$ ever since (Siebert 2012).

WCPS' latest ZE school, Jennings Creek Elementary, opened in 2018 and demonstrates what's possible when a district commits to ZE best practices. Jennings Creek cost $1.5 million less to build than the average Kentucky school and had a design EUI of 17.5 $kBtu/ft^2 \cdot yr$. The school is exceeding expectations, operating at 15 $kBtu/ft^2 \cdot yr$ (CMTA 2020) and saving more than $195,000 a year in energy costs (SCB 2020).

According to Stanfield, the bottom line is that "from our little corner of the world, cost isn't a barrier to ZE K–12 schools."

Conclusion

The findings of this research indicate that pursuing ZE in K–12 schools does not have to increase design and construction costs and ZE schools can cost less than conventional schools. The research also demonstrates that low-EUI ZER schools are currently operating around the United States. Successful ZE design teams have identified approaches that help avoid the challenges and optimize the benefits, notably:

- **Establishing a budget and energy goal early in the process** and considering the budget and ZE goal expressed as an EUI in every design decision, contract, and construction document; in short, making energy performance a major driver of the design and construction process
- **Shifting costs** by using integrative design to offset increased costs in one area (the building envelope, for example) with cost savings in others (the HVAC system, for example); the result can be reductions in both life cycle costs *and* first costs, a major focus for most school districts
- **Choosing a procurement process** that can get the project to ZE; although there is no perfect procurement process, a well-executed performance-based design-build process can lock in a ZE goal and a fixed budget early in project development
- **Measuring and verifying performance** to ensure that the building operates at ZE during its lifetime; include input from measurement and verification professionals early in the project and design in approaches to educate students, replacement staff, and new teachers

about how the building operates and how everyone can be involved in maintaining ZE status
- **Acquiring a PV system** to get to ZE can be complicated by utility demand charges, connection fees, and pricing for electricity fed back to the grid; districts can choose between a number of acquisition options, from power purchase agreements to owning the system outright.

Even when there are challenges to acquiring a PV system cost-effectively, making the building ZER by improving energy efficiency is a good investment for schools. Energy efficiency is independent of grid related issues and low energy can be achieved in all school projects.

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