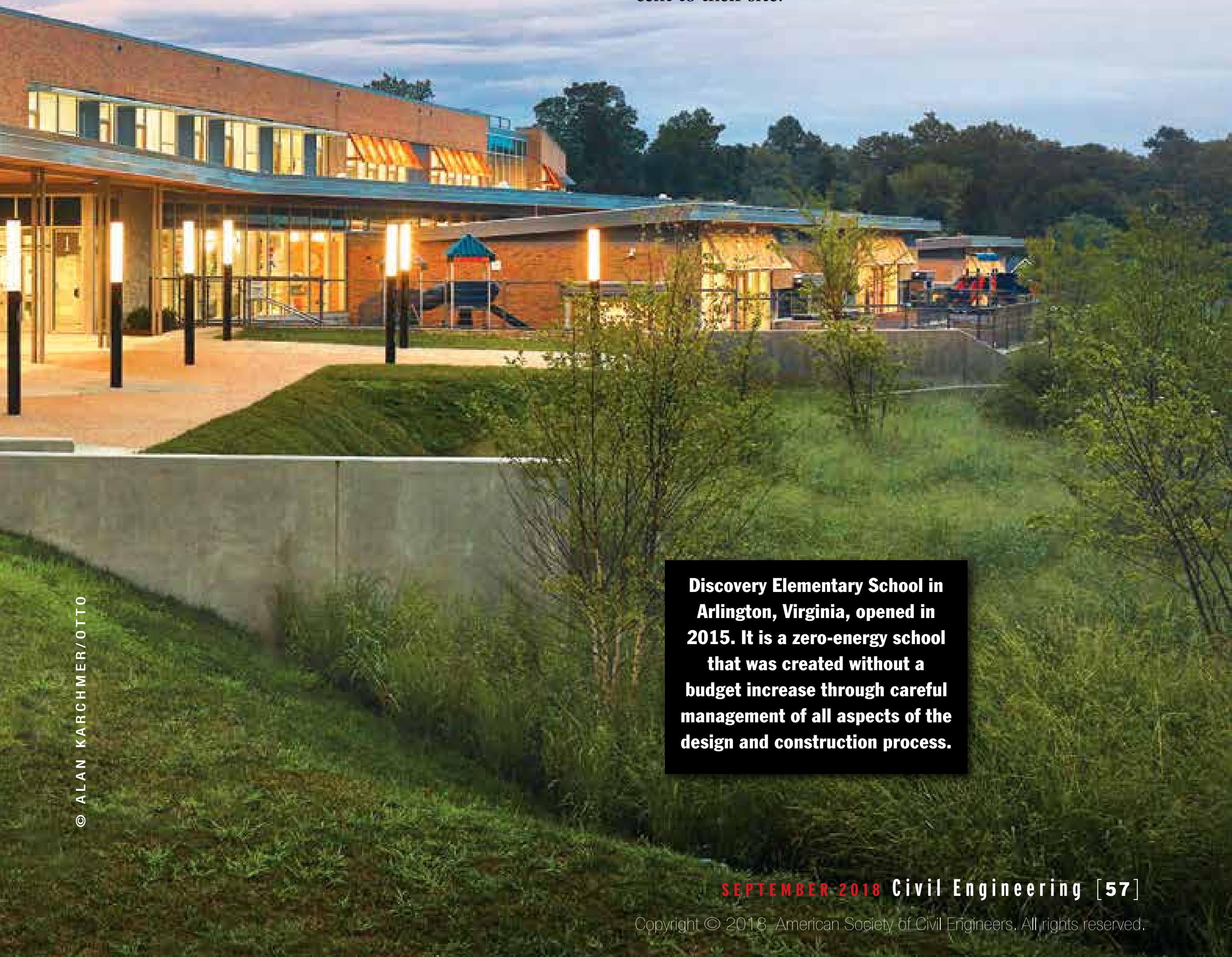
Zeroing In

Across the United States, primary and secondary school buildings are leading the way in the so-called zero-energy movement, in which structures are designed to generate at least as much energy as they use. They tend to be owner-occupied, are located on roomy sites with plenty of roof space for solar panels, and have predictable energy usage patterns, making them the perfect candidates. ••••• **By Catherine A. Cardno, Ph.D.**

THE IDEA OF DESIGNING buildings that generate as much energy as they use goes by many names. "Whether people are talking about net zero, zero net, or zero energy, it's basically all the same thing," says Paul Torcellini, Ph.D., P.E., a principal engineer for the Commercial Buildings Research Group at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, Colorado. The different terminology is largely regional, he says. Those on the West Coast tend to refer to zero-net energy, while those on the East Coast prefer net-zero energy, but policy makers and federal groups have opted for the more streamlined zero energy. Regardless of what it is called, however, "the nice thing about the whole zero-energy discussion is that it is a goal that can be measured operationally about a building," Torcellini says. "At the end of the day, you want to look at the meter and say, 'Have I bought as much energy as I have sold?' And it's kind of as simple as that—conceptually."

It may sound simple, but the end result remains challenging. To attain zero-energy status, a building or site must, over the course of a year, generate as much energy on-site as it consumes, or export as much energy from its own on-site generation as it purchases from the grid. Typically, most zero-energy buildings generate that energy from renewable sources.

In the United States, primary and secondary schools—those serving students in kindergarten through 12th grade, commonly referred to as K–12 schools—tend to be extremely well placed to generate their own energy and sell the excess to their local utility companies. For this reason, they are market leaders in the zero-energy movement. "They generally have more land and they are big landholders in a city {or} outside of a city, and most importantly they are owner-occupied," says Reilly Loveland, the project analyst in charge of zero-energy schools at the New Buildings Institute (NBI) in Portland, Oregon, a nonprofit organization dedicated to improving the energy performance of commercial buildings. In addition to these benefits, Loveland explains, "the building form itself is also generally opportunistic. They sometimes have adequate roof area or layout for passive design, and if they don't have adequate roof area, a lot of the schools that we see do have adequate land so that they can put solar {arrays} on the site or adjacent to their site."



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Discovery Elementary School in Arlington, Virginia, opened in 2015. It is a zero-energy school that was created without a budget increase through careful management of all aspects of the design and construction process.

Additionally, K–12 schools typically have relatively low energy loads compared with office buildings as well as easy-to-predict occupancy patterns—typically eight to nine hours a day, five days a week, for nine or ten months of the year. This makes it easy for building managers to predict energy usage and balance that usage with energy generation.

The NBI sees the zero-energy schools trend as a natural progression. "Zero-energy schools are the next evolution in sustainable, high-performance buildings," Loveland says. "Leadership in Energy and Environmental Design [LEED] or other standards have traditionally been the trajectory for the last few years, so zero energy is the next iteration." Not only does this type of design allow a substantial amount of money to be redirected from the buildings' monthly utility bills for use elsewhere in the school or school district, but with their focus on daylighting and fresh air as energy-saving measures, zero-energy schools can also create healthier and more comfortable environments for students, teachers, and staff.

Roof-mounted solar panels atop Discovery Elementary School generate energy that the school uses, *above*, while sun shades help block the building's interiors from thermal gain, *below*.

Many within the field believe the trend will influence how all buildings are designed in the future. Toward that end, a new series of advanced energy design guides focused on achieving zero energy was launched at the beginning of this year, beginning with *Advanced Energy Design Guide for K–12 School Buildings—Achieving Zero Energy* (Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE], 2018). The series is being developed through a partnership between ASHRAE, the American Institute of Architects (AIA), the Illuminating Engineering Society, and the U.S. Green Building Council, with additional collaboration and support from the Energy Department through its national laboratories. (Torcellini chaired the project committee that developed the K–12 design guide.)

The steering committee for the partnership decided to start with K–12 schools because "school districts are interested in reducing the operating costs of their facilities [and] so are considering zero-energy schools," says Sheila Hayter, P.E., the 2018–19 president of ASHRAE and a group manager with the NREL. "Having a really low-energy or zero-energy building makes it so that in the long run, school districts can spend less on operating costs and instead use their money for other purposes." In addition, because schools typically contain similar types of educational, staff, and special event spaces, the design advice provided in the guide is widely applicable among all types of school buildings, according to Hayter.

And once a district has spent the time to develop one zero-energy building, it becomes even easier to replicate that process in future projects, according to Loveland.

The benefits of a zero-energy school project expand beyond specific school districts as well. Successful zero-energy projects will make it possible for more of these buildings to be built elsewhere because designers will have larger portfolios of projects to present to their clients to demonstrate that capability, says Hayter. Torcellini adds, "If you've got groups of design teams that have done it…they now have marketing tools to go out to other folks and say, 'We can provide value added to your school project if you hire us because not only are we going to meet your educational and programmatic needs, but we can also help you control your energy costs long term.'"

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Because balancing energy used with energy collected is at the foundation of creating a zero-energy building, a measurement called energy use intensity (EUI) must be carefully determined. "EUI is the metric by which we decide how efficiently a building performs," says Mark Madorsky, P.E., CxA, LEED AP BD+C, the president of Houston-based LEAF Engineers, a PBK company, which is dedicated to designing energy-efficient and automated buildings. "It starts by trying to create a building that has the lowest possible initial EUI. Then getting to net zero becomes a lower hurdle to clear."

Discovery Elementary School uses a variety of windows and shades, *above*, and clerestories, *below*, to enable daylighting in its classes, offices, and gym, minimizing the need for artificial lighting within the school and the heat gain that it introduces into buildings.

There are a number of ways to increase a building's energy efficiency, including passive approaches like orientation on the site, improved building envelope performance,

self-shading elements, and the optimization of daylight and natural ventilation within the building. The selection of energy-saving equipment and systems to operate within the buildings are also important variables. (The ASHRAE design guide provides a number of strategies and EUI targets to meet to reach zero energy.)

Using geothermal systems can also lower a building's initial EUI, although the ability to use these systems depends on a site's underground characteristics. "You're basically either taking heat from the ground or rejecting heat to the ground, and it affords you the ability to offset some of your mechanical equipment load because you're using the ground as a heat sink," Madorsky explains. "So that would mean a building that used geothermal might consume twenty percent less energy, so when you look at getting to net zero, your hill is twenty percent smaller to climb."

Once a building's EUI has been lowered as much as possible, it is time to look for ways to generate renewable energy on-site. The most common way to do this on K–12 school sites is through the use of photovoltaic solar systems, though in rare instances it is possible to use other types of renewable energy. "There is a school in Kansas [part of Kiowa County Schools, in Greensburg] that has a wind turbine, [but] that's Kansas—it works pretty well there," Torcellini explains. "But in general, if you have to make a blanket statement [covering] the United States, photovoltaics is really what's going to be meeting that load."

Earlier this year the NBI released its annual report tracking the developing market for zero-energy buildings, *2018 Getting to Zero Status Update and Zero Energy Buildings List*. While zero-energy buildings represent a small fraction of new buildings under construction in the United States, their market share is growing quickly, the report reveals. Of that percentage, K–12 schools are the leaders, representing 18 percent of the current zero-energy projects. Education facilities as a broader category encompass 37 percent of all zero-energy projects, according to the report.

Currently the West Coast—specifically California and Oregon—is leading the move toward zero-energy construction, and those two states account for half the buildings of every type on the NBI's 2018 project list. "California's leading energy policies, ambitious energy reduction goals, and effective utility programs, as well as Oregon's early [zero-energy] pilot programs and incentives are clearly driving their rapid uptake in zero energy buildings," the report states. The East Coast has 123 current projects compared with 214 in California alone. (Oregon has 24 and Washington State has 10.)

Loveland says one factor influencing the slower pace of zero-energy school construction on the East Coast is simply that there are fewer new schools of any type being built there; many communities are fully developed. And two factors affect the slower growth of zero-energy buildings there in general. One is that natural gas is abundantly available and inexpensive on the East Coast, so it is harder to persuade planners to go all-electric so that renewable on-site resources can be utilized. The other is that it is harder to achieve zero-energy status with the climate characteristics and variability of the East Coast. As a general rule, it is hotter in summer, colder in winter, and far more humid on the East Coast than is typically the case on the West Coast. These characteristics are challenges, but they can be addressed, Loveland says.

However, "both in the Northeast and the Southwest, there has been a ninety percent uptick in zero-energy buildings since 2014, so it's not like the East Coast is lagging behind too much, but the West Coast is definitely moving forward," Loveland says.

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So while zero energy is a noticeable trend with significant benefits, it certainly isn't universal just yet. This is, in part, because there are challenges to creating zero-energy buildings, not the least of which is cost. Estimates vary according to a site's location within the United States, but in general, a zero-energy school could potentially cost 5 to 8 percent more than a traditional one. But careful planning can result in a zero-energy design that costs exactly the same, some experts say. "The problem is the perception that you have to spend more in order to get to zero," Hayter says. "The reality is that you don't."

At Discovery Elementary School in Arlington, Virginia, which opened in 2015, the design team was able to create a zero-energy school without a budget increase through careful management of all aspects of the design and construction process, according to Robert W. Moje, FAIA, LEED AP, a founding partner of Charlottesville, Virginia-based VMDO, the architect for the project.

"You really need to have a design team working together—the architects that are designing the building, the energy consultants, and the engineers that are figuring out how to make that a zero-energy building from an engineering perspective," Hayter says. "And then it is iterations back and forth saying, for example, 'Okay, if we rotated the building ninety degrees, it would help us more easily achieve zero energy,' or, 'All you have to do is make that overhang six inches longer, and it's going to significantly reduce our cooling loads,'" she says. Making sure that every member of the design and construction team has the zero-energy goal in mind and communicates clearly with one another is also crucial so on-site construction decisions seamlessly support the zero-energy goals rather than working against them, she says.

Charles Y. Kaneshiro, AIA, LEED AP, the president and chief operating officer of Honolulu-based G70, the architect of Hawaii's first zero-energy school, expects no net cost increase for that school either. According to Kaneshiro, who wrote in response to questions posed by *Civil Engineering*, work has begun at the Maui County site, and the school, called the New High School, should open by 2021. "The only downside to a net-zero school is they require the proper time to plan and design," Kaneshiro noted. "Fast-track school development is not an ideal approach if your goal is net zero."

This was one of the key reasons behind the *Advanced Energy Design Guide for K–12 School Buildings*, according to Hayter. The project committee wanted "to help those who are trying to work within the fast-track timeline to be able to make design decisions that result in a zero-energy school building," she says.

Working within a set budget should be considered just another constraint on a project that allows creativity to thrive, according to Torcellini. "Engineers and architects actually work well with constraints. They do it every day; it's what we're trained to do," Torcellini says. "At the end of the day, it just becomes, 'How are we going to solve the puzzle?' Maybe it's a little bit harder, or maybe we need to think a little bit differently about it, but that's okay."

Taking time to adequately plan a zero-energy building also includes the need to consider all the ways in which energy generated and energy used might not balance perfectly. "From an engineering point of view, it's not enough to just get there," Torcellini says. If, for example, the school is relying on solar energy, engineers must account for cloudy, misty, rainy, or snowy days. "I actually often use an example about building bridges, and if you say, 'Well, I'm going to design the bridge just to barely meet the load limits of the vehicles running over the bridge,' no engineer would say, 'Oh that's a good idea,'" Torcellini says. While a building won't fall down if the energy calculations are incorrect, it is just as important to calculate safety margins in energy loading scenarios, he explains. "If you really are committed to making a zero-energy building, you also have to account for what things might happen that [might prevent you from getting] there," he says. "The building might use a little more energy than you thought; the photovoltaics might put out a little less energy than you thought."

A good starting point, Torcellini says, would be to build in a 20 percent margin for energy generation, although with design experience that margin could possibly be narrowed, he notes.

Another challenge relates to how local energy utilities operate, Torcellini says. Some are not currently allowed by law to accept distributed renewable energy into their grids. "The historical way of thinking about electrical production and consumption is that everything has to flow downhill," Torcellini explains. "And so the electrons start, basically, at the power plant, and they work their way down through the distribution system to the buildings. Our entire grid infrastructure has been set up around that [concept]." With the establishment of zero-energy buildings that generate energy on-site, utilities must determine how to make their systems work backward. "From a safety point of view, some systems can accept that, [but] some have been engineered to not accept that," Torcellini says. "It depends where you are [and] what

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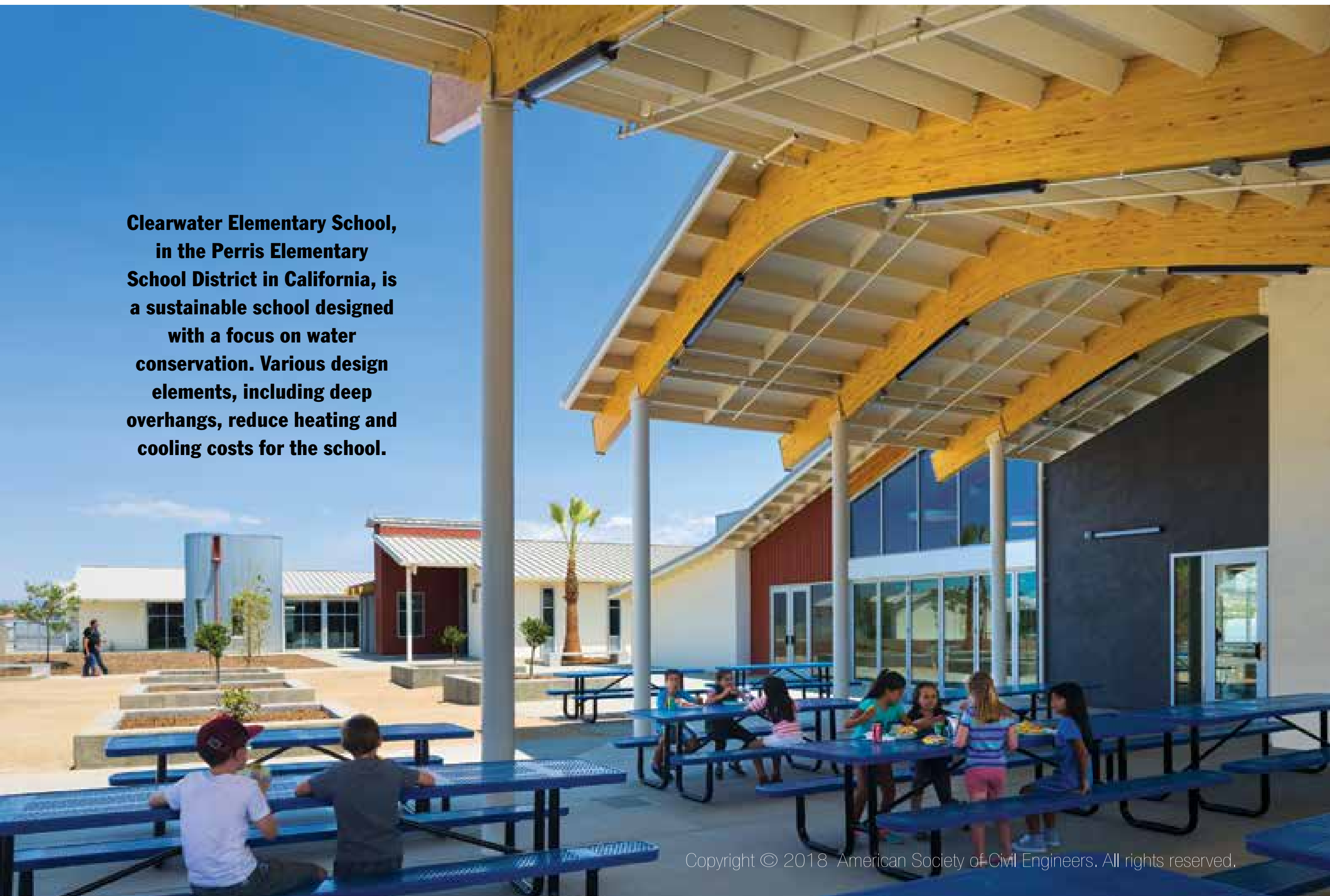


Clearwater Elementary School, in the Perris Elementary School District in California, is a sustainable school designed with a focus on water conservation. Various design elements, including deep overhangs, reduce heating and cooling costs for the school.

Once daylighting has been maximized, the use of electric lighting systems can be minimized.

the utility is comfortable with. They are primarily concerned with safety {and reliability} on their grid." Developing utility systems that can safely accept renewable energy generated on individual sites is a crucial step.

When it comes to school buildings, there are certain questions that need to be answered, according to Hayter. For example, how will the space be lit in order to enhance the learning environment while decreasing the amount of energy needed? If windows are used for that purpose, how will the buildings be oriented so that they do not overheat due to solar gain? What can be done with self-shading?

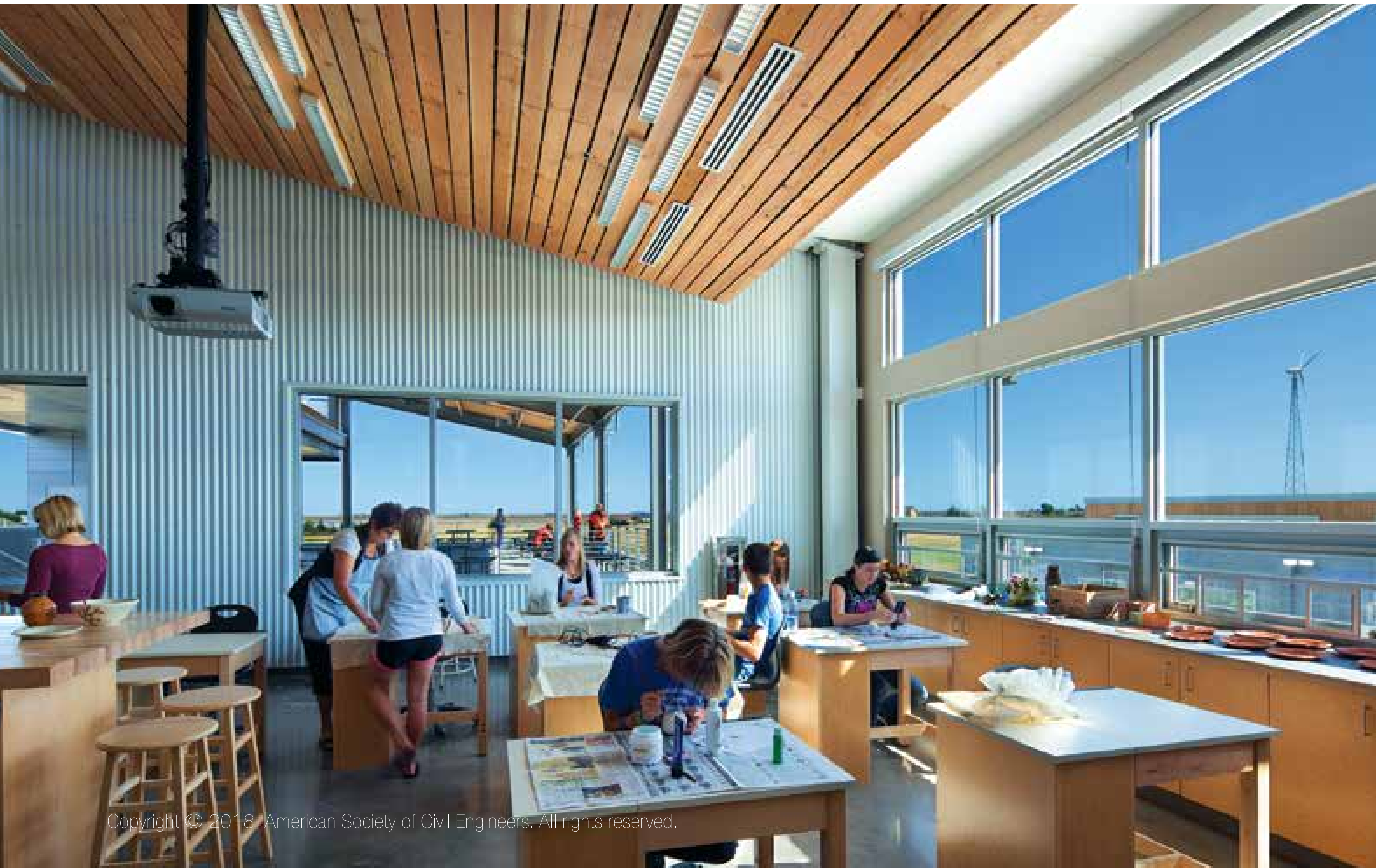
As with other areas of design, building information modeling (BIM) is innovating how zero-energy designs are accomplished. By creating a digital model of the planned structure and orienting it in various ways on a site, the design team can determine what effect the sun will have so that daylight can be maximized and glare reduced, according to Madorsky. The team can also determine if a large, flat, square or a tall, slender, stack will work better as a building form for a particular project, depending on how much energy the photovoltaics are predicted to collect and the amount of excess energy a utility is capable of accepting into the grid.

Once daylighting has been maximized, the use of electric lighting systems can be minimized. This serves a dual purpose: not only does it save on energy usage for the lights themselves, but electric lighting and heating costs can go hand in hand, depending on an area's climate. "The reason that a lot of our buildings in this country have air-conditioning is because we put lots of lights in them, and the lights are literally adding heat to the building," Torcellini says. Combining daylighting with light-emitting diode (LED) lighting technology, for example, means less heat given off in a building.

A better building envelope is also crucial for creating a zero-energy building. "If you get a good enough envelope, then long term, you should need less heating and cooling, which means less heating and cooling equipment," Torcellini says. Recent technological developments also enable a building to be pressurized so that leaks can be found and fixed so that heating and cooling are not lost to the outside. "That then becomes a quality check on how well the contractor does," Torcellini says.

Self-shading can be accomplished by shades, overhangs, or other innovations. Hawaii's 80-acre New High School campus will combat solar gain with a structure that the design team has dubbed a "super trellis." The feature covers a substantial portion of the classroom buildings and outdoor spaces on the school's campus, providing shade for the buildings to lessen the heating and cooling costs while creating appealing outdoor spaces, according to Kaneshiro.

Once all these aspects have been considered in a design—better siting, reduced lighting and energy loads, a good envelope, and self-shading—far



A wind turbine helps generate energy for Kiowa County Schools, in Greensburg, Kansas.

FARSHID ASSASSI/ASSASSI PRODUCTIONS COURTESY OF BNIM

The New High School in Maui County, which will be Hawaii's first zero-energy school, will include a "super trellis" that will shade classroom buildings and outdoor spaces.

less heating and air-conditioning can be used for climate control. And the systems that are used can be further optimized with room-level controls so that every space does not have to be designed to operate at peak capacity at all times, according to Torcellini. "At the end of the day, you end up with buildings that are more comfortable, less drafty, better educational environments—and you're saving money," he says.

Once a zero-energy school has been built and its energy collection and use monitored for a year, it can be certified as a zero-energy building by the International Living Future Institute, the Seattle-based organization that administers the Living Building Challenge. And schools can use their buildings as learning labs for their students. Discovery Elementary School has highlighted its zero-energy status and energy generation and usage through the development of a student learning center and online building energy dashboard (http://158.59.255.83), according to Moje. These enable teachers to use the raw data on energy used in the classrooms and generated at the school in their lessons. Students feel a vested interest in understanding how their day-to-day actions impact the school's energy usage as a whole and learn valuable lessons about energy savings at the same time.

Many school clients tend to be reactionary rather than proactive when it comes to design, according to Eric Carbonnier, Ph.D., LEED AP BD+C, an architect and the vice president of sustainability at the Los Angeles office of HMC Architects. "You have to take into the context who the client is, and the [K–12] industry has very different types of mechanisms that allow them to move forward and innovate," he notes.

Moje argues that educators and school administrators "can and should be leaders for thought and change" in addition to the "design professionals…advocating and promoting progress like net zero and energy, environmental, economic, and educational benefits," he says.

Opportunities to do so arise when the design team can be the leader in finding creativity within the budget to push beyond the compulsory code minimums when it comes to zero-energy design, according to Carbonnier. Indeed, he is an advocate for design professionals looking beyond zero energy and toward what he refers to as "regenerative design." Rather than working to balance the energy generated with the energy used, regenerative design's goal is to collect as much energy as possible so that buildings are actively supporting their communities by returning renewable energy to the grid.

Regardless of whether the ultimate goal is zero-energy design or regenerative design, "sustainable, high-performance schools are better for the environment and healthier places to be—they cultivate learning, [create] environmental leaders, and provide [a] dynamic learning environment," Loveland says. "Across all market sectors, NBI has seen a growth rate of seven hundred percent for zero-energy verified and emerging buildings since 2012. These buildings are nearly doubling every year, so the future is very bright." **CE**

Cardno

Catherine A. Cardno, Ph.D., is the senior editor of Civil Engineering.

ADDITIONAL READING

For more information on net-zero energy buildings, read these articles in ASCE publications:

- "'Net-Zero-Energy' Elementary School Opens in Northern Virginia," by Robert L. Reid. *Civil Engineering*, November 2015, pages 25–26.
- "Seeking Zero Energy," by Roger E. Frechette III, P.E., LEED AP, and Russell Gilchrist. *Civil Engineering*, January 2009, pages 38–47.
- "Toward Grid-Friendly Zero-Energy Buildings," by Philipp Bruggmann, M.Sc., and Gregor P. Henze, Ph.D., P.E. *Journal of Architectural Engineering*, June 2018.