Richardsville Elementary School in Warren County, Kentucky, is the nation's first zero-energy school.

Photo courtesy of CMTA Inc.

Zero-Energy Schools: How Innovative Concrete Systems Are Making It Possible

Advanced energy-efficiency strategies, affordable solar power, and insulated concrete forms make zero-energy schools viable

Sponsored by Build with Strength, a coalition of the National Ready Mixed Concrete Association

Richardsville Elementary School, completed in 2010, is the nation's first zero-energy school. The 77,000-square-foot building combines drastic reduction in energy consumption with on-site photovoltaic panels that produce more energy than required to run the building. The building is so energy efficient that it returns energy back to the grid.

"We are tremendously proud that since its opening in 2010, we have not paid a single utility bill on Richardsville Elementary School. The reason for this cost avoidance is that the building actually generates more electricity than it consumes. At the end of the school year, we usually get a check back from the utility company in excess of $30,000," says Jay Wilson, the director of safety and energy management for Warren County, Kentucky, Public Schools.

"The easiest way to increase a school district's budget is to reduce its energy consumption," explains Kenny Stanfield, a principal at Sherman Carter Barnhart Architects and an architect for Richardsville Elementary School, as well as dozens of other net-zero or near-net-zero schools located in Kentucky. "And the most cost-effective way to save energy is not to need it."

Stanfield, along with CMTA Inc. engineers, lowered the energy use intensity (EUI) for Richardsville Elementary School to 18.2 kBtu/ft^2 compared to 73 kBtu/ft^2 required by the energy code, a 75 percent reduction. Because the energy use was so low and the building construction cost was below budget, the school district absorbed the cost of adding a 349 kW photovoltaic array to provide enough energy to power the school and sell a small amount back to the electric utility.

According to Stanfield, the trend toward zero-energy schools, or net-zero energy or zero-net energy, comes down to three factors:

1. State-of-the-art design strategies and technologies to reduce energy consumption.
2. An innovative building system such as insulated concrete forms (ICFs) that can provide high R-value and low air infiltration at a low cost.
3. Affordable on-site solar energy.

There are several reasons why schools are ideal zero-energy candidates:

1. Schools typically have low energy demand. They operate only nine months out of the year with well-defined and limited operating hours.

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Learning Objectives

After reading this article, you should be able to:

1. Identify the principles and strategies behind zero-energy school design and construction.
2. Discuss how innovative concrete systems such as insulated concrete forms (ICFs) contribute to energy-efficient and resilient buildings that protect the health, safety, and welfare of students.
3. Assess how a combination of energy-efficiency strategies, high-performance building envelopes, and solar power is used to meet zero-energy criteria.
4. Describe the contribution that concrete makes to safe and productive schools by providing energy-efficient, quiet, and resilient structures.

To receive AIA credit, you are required to read the entire article and pass the quiz. Visit **ce.architecturalrecord.com** for the complete text and to take the quiz for free.

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Photos courtesy of CMTA Inc.

Richardsville Elementary School is so energy efficient that it generates enough energy to sell back to the electric utility.

2. Occupancy levels are predictable and controlled, and after-hour occupancy is limited.
3. Plug loads are low compared to other building types that might run a lot of appliances and computer equipment.
4. Schools are ideally suited for renewable energy, especially in the form of solar panels, since they are often limited to two stories and have a relatively large roof-area-to-volume ratio. This means that there is plenty of room to install solar panels. Most of the demand for energy comes during the day when the sun is available to generate electricity.
5. Schools are owner occupied, which means that there is an interest in minimizing operating costs, including the cost of utilities. School boards have bonding authority to fund long-term projects.
6. Schools can meet sustainability goals since zero-energy buildings reduce annual carbon emissions both through energy efficiency and the use of renewable energy.
7. A healthier, more comfortable indoor environment can help stimulate learning, reduce student absences, and lead to increased teacher retention, according to the Center for Green Schools.
8. Since many zero-energy schools are built using concrete construction with safe rooms and can generate their own power, zero-energy schools are disaster resilient; they can serve as a community shelter during and after a disaster.

ZERO-ENERGY STRATEGIES

"The key to achieving zero energy is drastic energy reduction and cost shifting to areas that pay dividends. It starts with efficient floor plans that are fully optimized (high net-to-gross ratio) and less expensive to construct," explains Ben Robertson, an engineer with CMTA Inc. "Sure, any building can be zero energy—but doing it without spending more money is where true success is achieved."

Although installing on-site renewable energy infrastructure such as solar arrays is coming down in price, it still requires an up-front investment. Making the building as energy efficient as possible helps to reduce the size of the renewable power infrastructure needed, thus keeping initial costs down. In addition, using cost-effective construction methods and materials allows room in the budget for the initial investment in power-generating equipment. The following are the key strategies to achieving these goals.

PASSIVE SOLAR STRATEGIES

Building orientation, daylighting, building volume, and thermal mass are all building properties that can be optimized by designers to help reduce energy consumption without increasing cost or compromising function and aesthetics. Passive solar strategies include:

- **East/west building orientation:** If possible, line up the building's main circulation axis in an east/west orientation with academic spaces along the north and south walls of the building to control natural light.
- **Daylighting:** Use daylighting for classrooms with a combination of exterior solar shades to block sun during high sun orientation or light shelves to reflect light deep into interior spaces during low-sunlight conditions. Use clerestories or windows mounted at higher elevations with ceilings sloped to the interior to allow light to penetrate further. Use aerogel insulated glazing or low-e coatings to reduce solar heat gain.
- **Compact building volume:** Use rectangular, multistory designs (at least two stories) to reduce the exterior wall-to-floor area, window-to-floor area, and roof-to-floor area ratios.
- **Thermal mass:** Use building systems that have high thermal mass, such as concrete, for the walls and floors of the structure.

High-Performance Envelope and Structure

Sherman Carter Barnhart, along with other architects highlighted in the case studies below, have come to the realization that ICFs incorporate all of the properties needed for zero-energy school construction. ICFs are used for the following reasons:

- They act as load-bearing walls with super insulation, thermal mass, and air barrier all in one. ICFs create one of the tightest envelopes available. Low air-infiltration rates can be achieved with other systems, but it is significantly more complex.
- They reduce sound transmission from outside and between classrooms, as well as for gymnasiums, music rooms, and theaters.
- They keep students and teachers safe from Mother Nature's wrath. Concrete systems are resistant to fire, tornados, hurricanes, floods, and earthquakes.

Image courtesy of Sherman Carter Barnhart Architects and CMTA Inc.

East/west orientations, daylighting, and compact volume all helped to reduce the energy consumption of Richardsville Elementary School.

Energy-Efficient HVAC Systems and Technology

The use of energy-efficient mechanical systems and active-control technology is critical to keeping EUI as low as possible. Strategies include:

- Use efficient geothermal HVAC systems with variable-speed heat pumps. Use one heat pump for two classrooms.
- Use occupancy sensors for lighting and other occupancy dependent systems.
- Control outside air ventilation with dedicated outside air systems, heat-recovery wheels, and demand-control ventilation based on occupancy.
- Use automated dimming to reduce artificial lighting requirements. Although if using LED lighting, automated dimming can be eliminated since LED lighting is extremely energy efficient.
- Use ENERGY STAR convection ovens as a healthier option to traditional fryers and skillets, which eliminate the need for energy-intensive Type I ventilation hoods.
- Use ENERGY STAR laptops on carts that permit computers to be transported to classrooms instead of having dedicated computer labs with energy-intensive desktops.
- Use dark-sky approach to exterior lighting. Use security lighting with motion sensors to alert local police if there is activity on school property after dark.

On-site Power Generation

Most schools, including Richardsville Elementary, use photovoltaic panels as the main source of on-site power generation. Solar panels are becoming more common at schools across the United States. According to the Solar Energy Industries Association report titled "Brighter Future: A Study on Solar in U.S. Schools," there are approximately 5,500 K–12 schools with solar photovoltaic installations in the country. A precipitous decline in the cost of solar panels has made installations financially viable. According to National Renewable Energy Laboratory, the cost of commercial solar installations has fallen to $2.80 per watt in 2017 compared to $7.24 per watt in 2010, a 60 percent decline in just seven years. This explains why 61 percent of the solar capacity in K–12 schools has been installed in the past five years.

With that said, there is still a capital cost of solar-panel installation that must be accounted for to meet the strict budget limitations of most school boards. The following are key strategies:

- Minimize the EUI of the building using all of the strategies previously mentioned. According to the New Building Institute, the target EUI for zero-energy schools is 20–24 kBtu/ft^2 or lower if possible.
- During construction, utilize design strategies and building systems that are efficient and cost-effective to help offset the initial cost of solar panel installation.

Low-Impact Development Strategies

Conserving water is another way to reduce environmental impact and construction cost. The following low-impact development strategies help meet zero-energy goals:

- Utilizing native plantings and rain gardens helps reduce irrigation demands.
- Using permeable pavements reduces stormwater runoff, filters stormwater, and reduces the need for expensive stormwater infrastructure.
- Permeable pavements and rain gardens can eliminate the need for detention basins, leaving more space for athletic fields and outdoor education opportunities for students.

Energize the Curriculum

Finally, make sure you engage the students and teachers by providing learning opportunities about energy efficiency and how the zero-energy building is helping reduce environmental impacts. Richardsville Elementary School used the following displays and interactive stations to help students visualize their contributions to reducing environmental impacts:

- **Geothermal energy:** Provide detail on how geothermal energy works, and expose piping with a temperature gauge so that students can monitor the system's performance.
- **Solar energy:** Provide detail on how solar energy is captured and converted to

INSULATED CONCRETE FORMS

Insulated concrete forms (ICFs) combine two well-established building products: reinforced concrete for strength and durability, and expanded polystyrene (EPS) insulation for energy efficiency. ICF walls are made up of two layers of rigid insulation held together with plastic ties to form ICF units with a cavity in the center. The ICF units are stacked in the shape of the wall, reinforcing steel is added into the cavity, and then concrete is placed into the form. The result is a reinforced concrete wall with a layer of insulation on each side. What makes ICFs different than traditional concrete construction is that the forms remain in place after the concrete is cured to provide thermal insulation. The combination of reinforced concrete and insulation provides an ideal load-bearing wall, thermal envelope, air barrier, fire barrier, and sound barrier.

Ease of Construction

The efficient construction process is what sets ICF building systems apart from other building systems, such as wood-frame, steel-frame, and masonry construction. ICF construction can help contain construction costs and reduce construction time because of the inherent efficiencies of the installed assembly that serves nine functions:

1. Concrete form (that stays in place)
2. Thermal barrier
3. Air barrier
4. Moisture barrier
5. Fire barrier
6. Sound barrier
7. Substrate for running utilities
8. Substrate for attaching finish materials
9. Reinforced-concrete structure

In other forms of construction, these functions are installed by several different trades, usually at significantly added cost. General contractors can realize a number of on-site efficiencies, including fewer trades, reduced crew size, and accelerated construction schedules. Because construction schedules are usually much shorter with ICF construction, the general contractor is able to finish on time and within budget. The building owner can then put the building into service sooner, cutting short financing costs.

There are many different ICF manufacturers with similar ICF systems. The blocks range in size from 48 to 96 inches long and 12 to 24 inches high depending on the manufacturer. The most common configuration of an ICF unit is made up of two layers of 2³/₈-inch to 2¾-inch-thick EPS insulation spaced 4, 6, 8, 10, or 12 inches apart depending on design requirements. The most common spacing is 6 inches or 8 inches for most low- to mid-rise buildings. But for taller buildings, taller walls, or exceptionally large loadings, thicker walls are necessary. For simplicity, ICFs are generally called out by the width of their cavity. Hence, an ICF with a 6-inch cavity is called a 6-inch ICF and so forth.

ICF manufacturers have a variety of ICF blocks to accommodate any design condition and offer outstanding technical support, including design manuals, design details, engineering support, and all of the test reports needed for school construction, including fire, energy, and noise. They also have special components, including straight blocks, corner blocks, brick ledges, angled blocks, curved blocks, and half-height units, minimizing the need for field modifications, which further reduces construction time.

Photo courtesy of Sheman Carter Barnhart Architects

Richardsville Elementary School used an ICF system.

Image courtesy of BuildBlock

Shown are ICF wall and floor components.

Another benefit of ICFs is that construction projects can continue through the coldest and hottest weather because of the insulating quality of the ICF forms. This means that concrete will continue to gain strength within the protective formwork despite freezing conditions and not overheat during extreme summer conditions. In addition, all ICF systems have furring strips integrated into the plastic ties that permit easy attachment of any interior or exterior finish.

There are also ICF concrete floor and roof systems. The concept is similar in that the ICF floor or roof is made with rigid insulation to function as a one-sided form at the bottom surface. The forms are installed to span between concrete walls, reinforcing steel is installed, and then concrete is placed onto the forms. The result is a reinforced-concrete floor or roof with rigid insulation on the bottom. Other types of floor systems often used in combination with ICF walls include precast hollow-core plank and composite concrete floors over steel joists.

electricity for use in the building. Provide a gauge to show how much energy is being produced. Provide a laptop computer battery-charging station where students can see the energy being received from the solar panels.

- **Water conservation:** Provide a station on water conservation that enables students to monitor the amount of rainwater collected and used in the rain garden.

BEYOND ZERO-ENERGY SCHOOLS

Schools are not the only building type going zero energy, nor are they the only building type using ICF construction. There are examples of high-performance ICF buildings all over the United States and Canada, including single-family residential, multifamily residential, hotels, dormitories, assisted living facilities, offices, health-care facilities, and manufacturing and warehouse buildings. Theaters are also trending toward ICF construction for superior sound attenuation.

CONCLUSION

Zero-energy schools are becoming more popular. High-performance envelopes using ICFs along with lower cost of renewable energy is making it possible. ICF systems result in construction that is faster, easier, and less labor intensive than other construction methods, making it possible to offset the cost of solar panels. ICF systems combine reinforced concrete with fire, sound, thermal, air, and moisture barriers in one step, which reduces the number of trades required on-site. Construction can continue all year long since the forms provide an ideal curing condition for concrete during the hottest and coldest weather.

All this leads to a construction system that is ideal to meet the demands of zero-energy buildings. ICFs create a modern building system that is easy to use and cost competitive. To find out more about ICF construction and concrete construction in general, visit www. buildwithstrength.com and www.icf-ma.org.

Photo courtesy of Neenan Archistruction

CASE STUDY

Alamosa Elementary School, Alamosa, Colorado

Completed in 2010, Alamosa Elementary School is a design-build project located in one of the most economically challenged areas of southern Colorado. Two connected school buildings (grades K–2 and 3–5) with a combined area of 145,000 square feet had the shells of both buildings constructed with 51,400 square feet of insulated concrete forms (ICFs), including 75 percent of the exterior walls, in just 90 days. A LEED Gold certification was awarded for integrating various sustainable design aspects, including under-slab hydronic heating and ICFs. Combined, these systems reduce energy loads by 72 percent when compared to metal framing, thereby allocating money to classroom needs instead of utility bills. Also, energy modeling found that the building could be designed without air-conditioning and still be comfortable. Solar thermal and solar panels provide hot water and heat when needed. Just as important, nearly every space in the building has daylight and views to the outdoors.

Photo: Luis Ayala

CASE STUDY

Dearing Elementary School, Round Rock, Texas

Dearing Elementary School was one of the first zero-energy schools built in Central Texas. The 2-story, 93,376-square-foot school is a compact design that fits on a 7-acre site to save on energy costs. The planning process redefined the district's vision on energy efficiency and led to a transformational facility design where this school acted as a catalyst for future zero-energy strategies for the school district. Design features included geothermal for electricity and heating, a sophisticated building energy management system, 100 percent LED lighting, advanced HVAC systems, and 100 percent daylight in each room. The design also incorporated insulated concrete forms (ICFs) for exterior walls. These combined strategies resulted in a EUI of 17 kBtu/ft^2, which is 76 percent lower than the average school in its climate zone. Polished concrete floors were used to reduce maintenance costs and increase the floor's life cycle. Additionally, since the school is located in "Tornado Alley," it was important for it to withstand extreme weather events, including 200 mile per hour winds and debris traveling at more than 100 mph. *Engineering News-Record Texas & Louisiana* gave this project a Best Green Project Award for 2015.

Photo courtesy of Bowie Gridley

CASE STUDY

St. Anne's Belfield School, Charlottesville, Virginia

St. Anne's Belfield is a 4-story, 105,000-square-foot school. Educating students in pre-school through 8th grade, it is also known as the Learning Village. This was a multi-building project with significant attention given to the use of sustainable technologies. The facility integrated several green elements, including a geothermal HVAC system, which has more than 100 wells that efficiently heat and cool the building. Large, energy-efficient windows bring natural light into the building to reduce its dependence on artificial lighting. The school also has an underground cistern with the capacity to store 75,000 gallons of rainwater and runoff for irrigation. Construction on the new school began in 2009 and was completed in mid-2010. The school features insulated concrete form (ICF) walls that make the building very energy efficient. ICF installation took only seven months of the entire construction schedule. When constructed, it was the first school in Virginia to be built with ICFs. The school secured LEED Gold certification, and due to the ICFs and other technologies, earned every available point in the Optimizing Energy Performance credit.

Photo courtesy of Sherman Carter Barnhart Architects

CASE STUDY

South Warren Middle and High School, Bowling Green, Kentucky

At the time of construction, South Warren was the largest K–12 school building in the state of Kentucky. Comprising 332,000 square feet, the building sits on an 85-acre site. Goals of the project included energy efficiency, speed of construction, student safety, and green design principles. The design team identified targets for potential energy reduction, such as a super-insulated roof system, an optimized geothermal HVAC system, and daylight harvesting. But in terms of a critical path for these decisions, which also included safety, the building envelope was determined to be most important.

Subsequently, this was the first educational project anywhere to utilize insulated concrete form (ICF) construction for the entire structural wall system of the building, including both exterior and interior bearing walls. Construction spanned the winter without delay. ICFs allowed the concrete to be protected and insulated when placed, permitting continuity of the construction schedule. Even with a gymnasium with 40-foot-tall ICF walls, two "cafetoriums" with 35-foot-tall walls, and a performing arts center with a compound curve, the 8-inch and 12-inch ICF wall system provides students a safer building even during severe tornadic activity, which is common during Kentucky's spring and summer seasons. The inherent core strength of the concrete in the ICF wall system, coupled with the hollow core concrete plank floor system, created a building structure capable of resisting 250 mile per hour winds. By combining all sustainable elements, South Warren is zero-energy ready operating at only 24.3 kBtu/ft^2 EUI, which equates to a 70 percent reduction in energy use compared to the average school in Climate Zone 4. Additionally, it was calculated that the ICF construction costs less per square foot than traditional masonry and steel framing.

Photo courtesy of Sherman Carter Barnhart

CASE STUDY

Glasgow High School, Glasgow, Kentucky

Glasgow High School is a 180,000-square-foot building with many sustainable elements. When the footers were poured in April 2011 until the school opened in August 2012, the project was constructed on schedule despite the seemingly constant rain. The project team met the challenge to achieve a timeless aesthetic with balancing modern energy efficiency. Technologies such as rigid roof insulation, a white TPO single-ply roof system to reduce solar heat gain, and solar tubes were installed in corridors and interior classrooms. Bringing daylighting into these spaces was a major design consideration and was balanced with sensors that adjust the artificial lighting based on both the amount of natural daylight and occupancy needs. Building with 31,000 square feet of of 8-inch and 12-inch insulated concrete forms (ICFs) was also a key factor to meet energy and design goals, especially since windows were large and plentiful including a 52-foot radius wall having numerous arched openings and windows 30 feet high. All combined, the building earned LEED certification, with a level of craftsmanship that pleased the owner. Total construction was 420 days, with 70 days devoted to ICF installation and concrete placing. Installation was shared between two different installers due to the project schedule, indicating the ease of installation and workflow of ICF systems.

Photo: Alan Karchmer

CASE STUDY

Discovery Elementary School, Arlington, Virginia

Discovery Elementary School opened in 2015 and was the first elementary school building to be built in the local public school system in more than a decade. The design utilized every nook and cranny of the school to integrate design, sustainability, and learning, and served as a catalyst for future zero-energy design requirements in the district. It promotes student engagement and environmental stewardship, while advancing the municipality's carbon and energy goals. Upon opening, the school was the first zero-energy school in the mid-Atlantic. With a floor plan of 97,588 square feet, the 2-story school was built using 3,000 linear feet of insulated concrete form (ICF) bearing wall. To meet energy goals, sustainable building elements comprised of 1,706 roof-mounted solar panels, a geothermal well field, solar preheat of domestic water, 100 percent LED lighting, and ICF exterior walls. Actual EUI is approximately 16 kBtu/ft^2, which is 76 percent lower than the national school average for Climate Zone 4. With the photovoltaic array, the school is net-positive energy—producing more power than it uses. An energy dashboard is on display for teacher curriculum and student projects. The school was named a U.S. Department of Education Green Ribbon School and is a recipient of various design accolades, including the AIA COTE Award and A4LE National Award. The project was completed under budget, returning millions of dollars to the district to fund other projects, and it annually saves more than $100,000 per year in utility costs—therefore directing funds to academic needs.

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