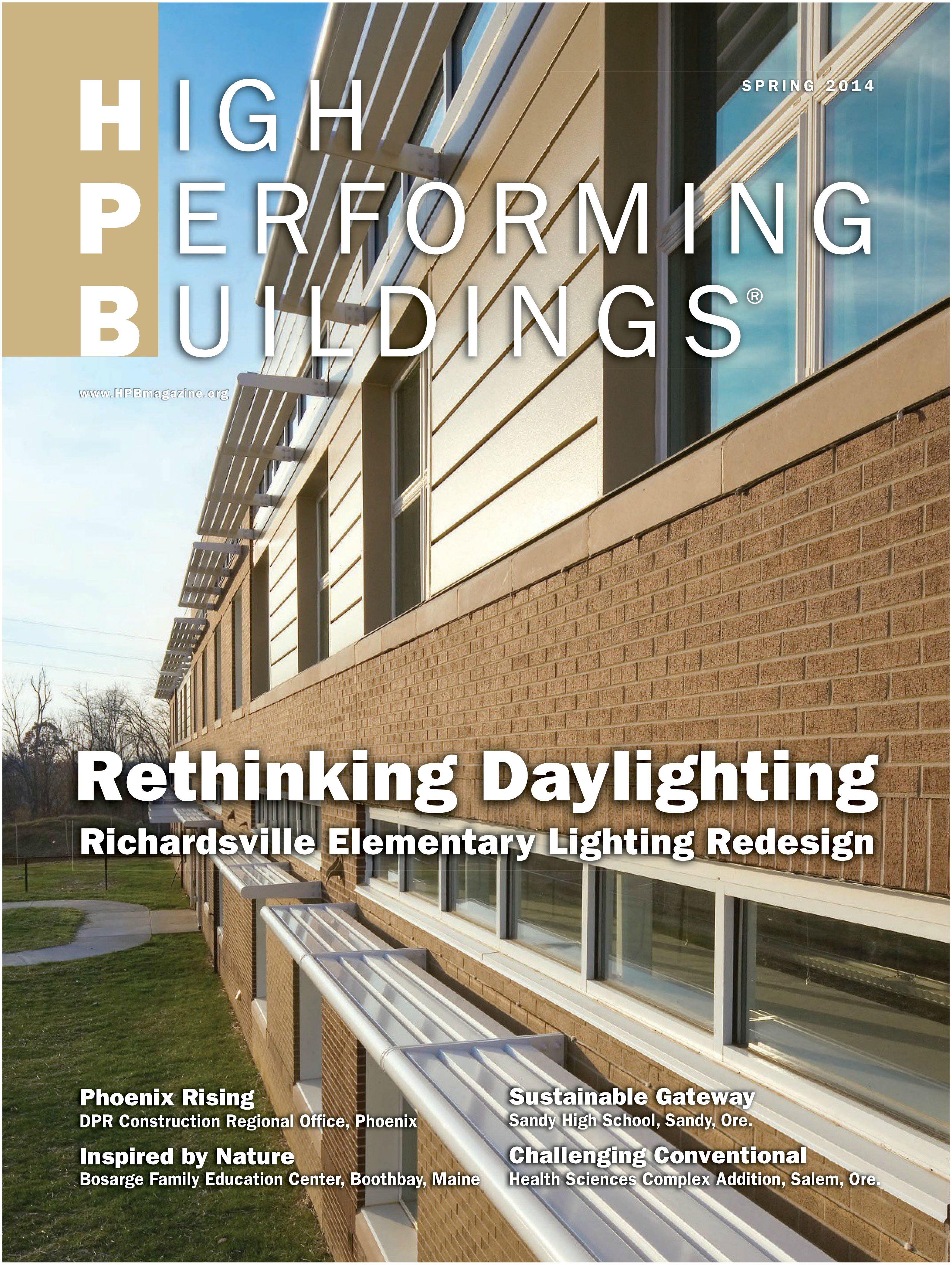

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Rethinking Daylighting

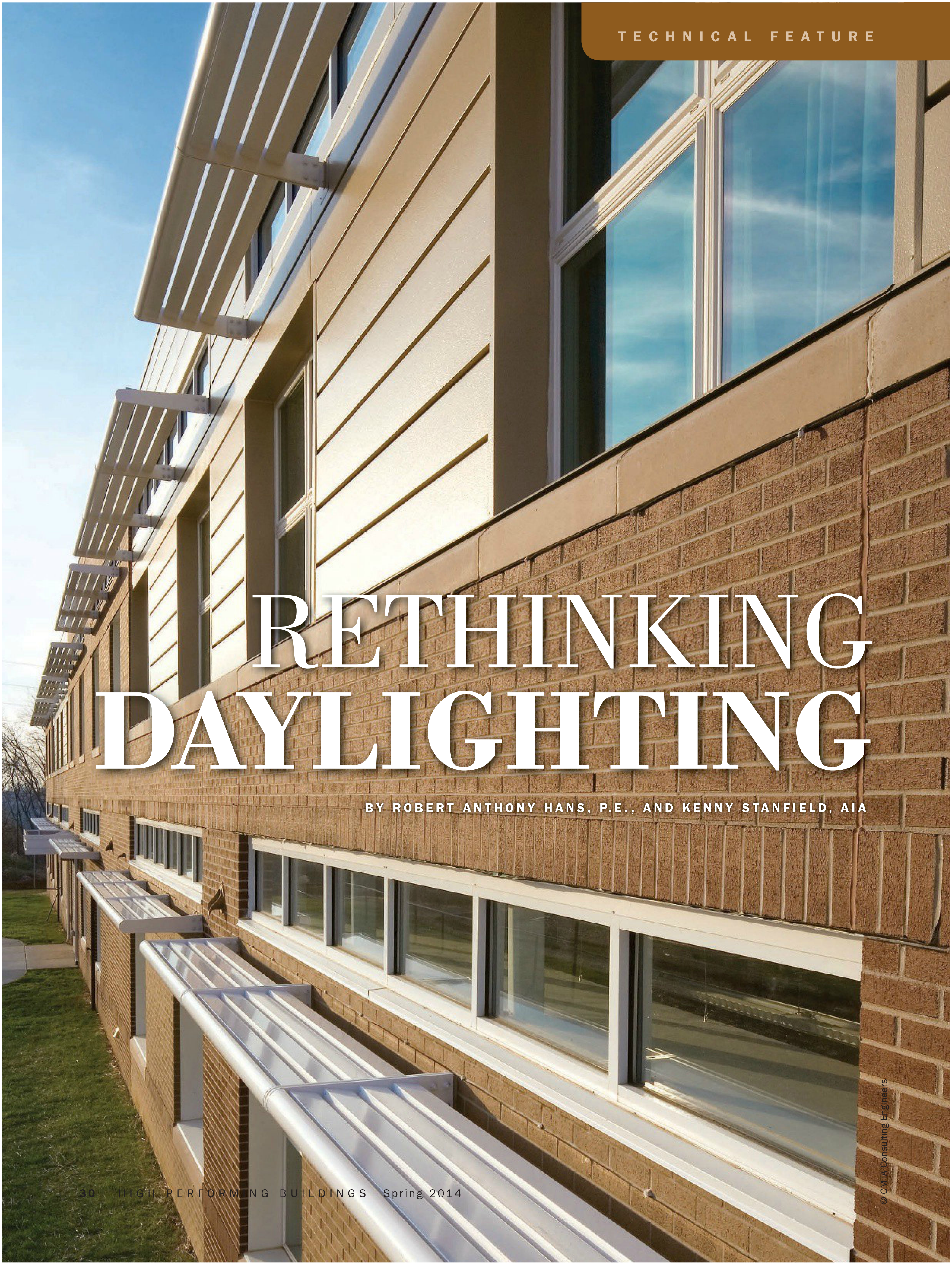
Richardsville Elementary Lighting Redesign

Phoenix Rising
DPR Construction Regional Office, Phoenix

Inspired by Nature
Bosarge Family Education Center, Boothbay, Maine

Sustainable Gateway
Sandy High School, Sandy, Ore.

Challenging Conventional
Health Sciences Complex Addition, Salem, Ore.



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RETHINKING DAYLIGHTING

BY ROBERT ANTHONY HANS, P.E., AND KENNY STANFIELD, AIA

When designers of the first net zero energy school in the U.S. considered how they would approach the lighting design differently using today's LED technology, the results extended far beyond just switching out the lightbulbs. The hypothetical redesign of Richardsville (Ky.) Elementary classrooms involves rethinking the daylighting design based on the evolution of LED lighting and the cheaper cost of photovoltaics (PV).

The original design team's goal was to maximize energy-efficiency strategies so the cost of the solar PV system could be minimized. Since the design was completed in 2009, innovations in product technology offer increased energy-efficiency potential and/or lowered costs.

When the Richardsville Elementary case study was published in *High Performing Buildings* in Fall 2012, eight months of energy consumption and power generation were available for the school. *Table 1* shows a full 12 months of data.

The net zero energy (NZE) operational goal was achieved with generation exceeding consumption by 12%. The energy consumption for 2012 was 18.6 kBtu/ft^2 · yr.

Original Daylighting Strategy

Figure 1 shows the original classroom daylighting strategy for Richardsville. Two 6 ft × 6 ft view windows provide students a connection to the outdoors and one 20 ft × 16 in. daylighting window allows natural light into the classroom.

An external sunshade prevents glare from entering the classroom through the view windows, and an interior lightshelf controls glare from the daylighting glass while bouncing light deeper into the classroom. The second-story design also uses two tubular daylighting devices in the rear of the classroom to balance the daylight across the educational area. The classroom floor-to-floor height is 14 ft to allow volume for the daylighting glass and a sloped ceiling for good light reflectance.

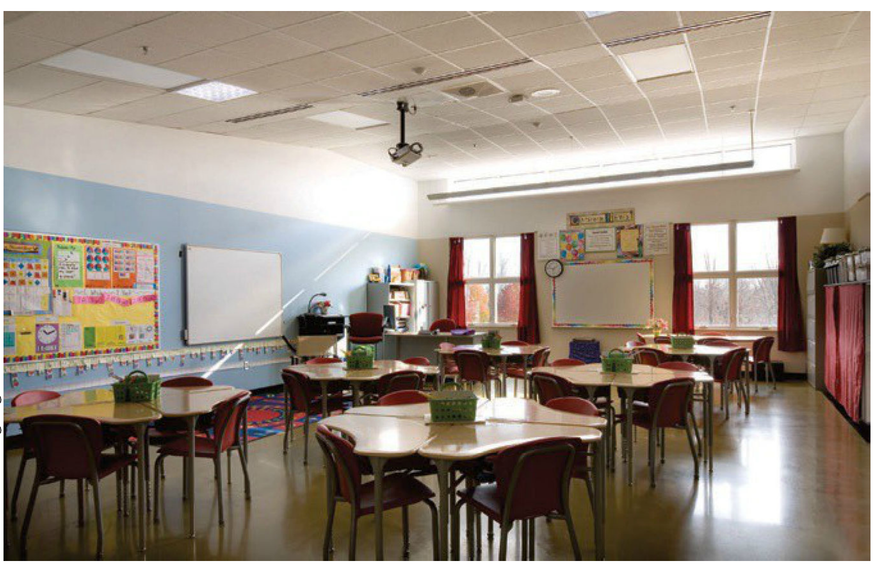
The lighting goal for each classroom was to achieve 40 footcandles at the desktop. A suspended 80%/20%

TABLE 1
NET ZERO ENERGY MWH SUMMARY, 2012

Read Date	MWh Consumed	MWh Generated	MWh Difference
12/16/12	30.2	20.1	10.10
11/16/12	37.1	29.7	7.40
10/16/12	33.2	34.6	(1.40)
9/15/12	45.6	45.1	0.50
8/16/12	36.9	54.2	(17.30)
7/16/12	26.6	56	(29.40)
6/15/12	28	57.5	(29.50)
5/16/12	38.2	45	(6.80)
4/16/12	29.8	35.3	(5.50)
3/15/12	30.6	31.9	(1.30)
2/14/12	33.8	19.5	14.30
1/16/12	26	14.9	11.10
Total	**396**	**443.8**	**(47.80)**

Opposite Richardsville Elementary School, the first net zero energy school in the U.S., was designed in 2009 with extensive daylighting, including the clerestory windows and lightshelves shown here on the south side of the building.

Below The south-facing classroom has an interior lightshelf and sloping ceiling designed to bounce daylight farther into the room and prevent glare from the clerestory windows.



For more details on Richardsville Elementary, see the Fall 2012 issue of High Performing Buildings magazine, or go to https://tinyurl.com/kjt3tfp.

FIGURE 1 **ORIGINAL CLASSROOM DAYLIGHTING STRATEGY**

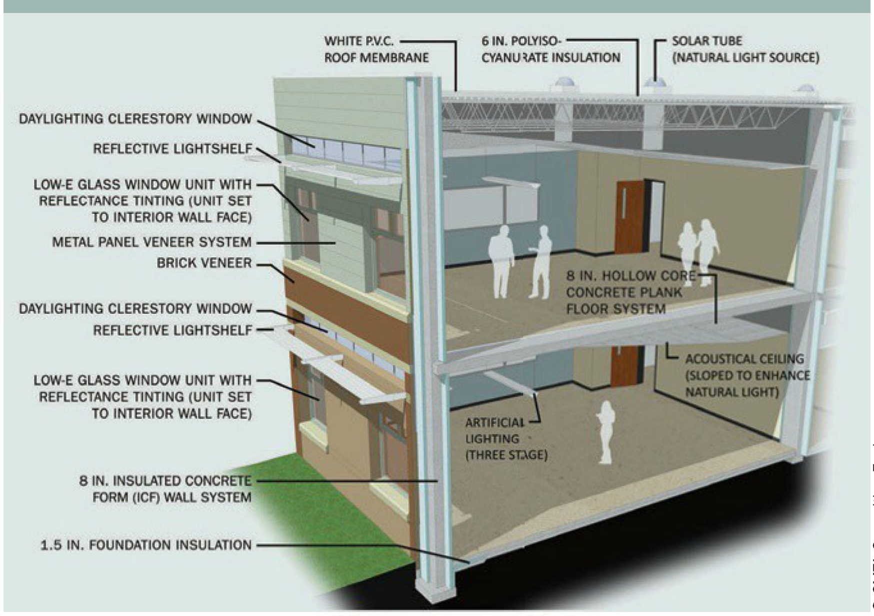


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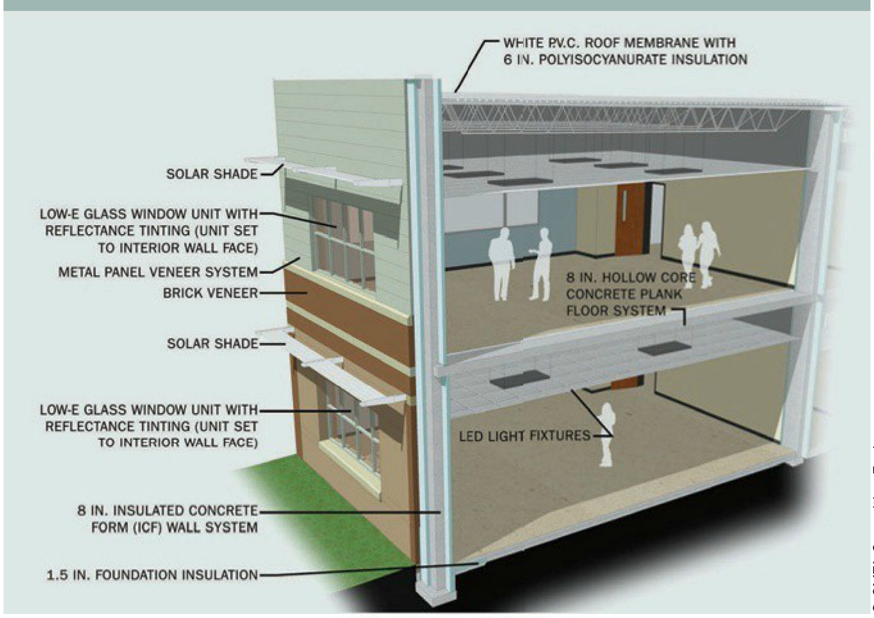
FIGURE 2 **REVISED CLASSROOM DAYLIGHTING STRATEGY**



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DAYLIGHTING GOALS FOR THE EXISTING RICHARDSVILLE ELEMENTARY

Educational benefits of naturally daylighting the classroom are well documented, and daylit classrooms were a goal for the original Richardsville project. The critical goals of a successful daylighting strategy include:

- Reducing artificial light energy with supplemental natural daylight;
- Controlling glare at the desktop;
- Orienting all classrooms with north-south exposure;
- Maintaining the building envelope's performance; and
- Creating an aesthetically pleasing façade.

At Richardsville Elementary the classroom daylighting strategy not only had to optimize the classroom learning environment, it had to effectively reduce energy consumption to help achieve the net zero energy goal. Balancing these goals proved to be more challenging than initially assumed. Each design strategy explored was found to have a direct or indirect impact on energy consumption.

For example, there comes a point where a "vista wall" of daylighting glass will compromise the building envelope enough to cause an HVAC energy increase greater than the planned artificial light energy savings. A thorough cost-benefit analysis is necessary when considering strategies for NZE operation.

direct/indirect fluorescent fixture is used closest to the exterior wall where the ceiling height is greatest. This design lowers the lighting source closer to the desktop while providing some uplight in the high ceiling area.

Four three-lamp troffers are spaced evenly across the middle and rear of the classroom. Fixtures use dimmable National Electrical Manufacturers Association (NEMA) premium ballasts and high lumen per watt "super" T8 lamps. Lighting power density for the classrooms using this technique is 0.8 W/ft^2.

Each classroom is provided with two light sensors to control dimming of the artificial lighting. These sensors provide year-round control by assessing daylighting values across the majority of the classroom. A corner-mounted, dual-technology occupancy sensor enables lighting when occupied and uses the daylight dimming system to appropriately add only the artificial light needed.

Solar PV Market Changes

The solar PV system at Richardsville is comprised of 208 kW of roof-mounted thin film panels and 140 kW of canopy-mounted crystalline panels. The PV system

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Above A 140 kW crystalline array mounted on a parking shade structure and a 208 kW thin-film rooftop array provide the school's renewable energy.

Above right At the time Richardsville's 208 kW thin-film array was installed, thin film generated more kWh annually at a lower first cost than crystalline panels.

was bid in January 2010 at a cost of $2,766,000 or $7.95/W. The design maximized the installation of thin film panels because at that time thin film generated more kWh annually at a lower first cost.

Since 2010, the cost of a crystalline panel PV system has dropped drastically. Recent project bids now average about $3/W installed for a similarly sized project, compared to $7.95/W in 2010. This represents a cost decrease of 62% over the last four years.

New Daylighting Strategy

Taking into account the changes in LED lighting and PV costs (see *LED Technology Changes* sidebar on this page), several changes to the 2009 Richardsville classroom design could be made to the architectural, lighting and PV systems to create a project that remains NZE, but at a cheaper project cost. The new classroom design focuses on:

- Improving the student outdoor view connection;
- Eliminating daylighting glass and reducing building height;
- Adding LED light fixtures;
- Simplifying the lighting control system; and
- The lower costs of PV systems.

Figure 2 illustrates the architectural changes that would be made if the school were designed today. The clerestory daylighting windows and interior lightshelves are eliminated. A single 12 ft×6 ft window with an exterior sunshade is used in lieu of two 6 ft×6 ft view windows. The sloped ceilings are eliminated, and the overall height of the building is reduced by 8 in. on each floor or 1 ft, 4 in. total.

Even though the clerestory window is eliminated, natural daylighting is still a critical component of creating an optimal learning environment. The daylight is provided by the 12 ft×6 ft picture window. Combined with the exterior sunshade, the window provides a good source of controlled daylight with a strong view connection to the outdoors.

The next change involves incorporating LED lighting to decrease the lighting power density. Reducing the building height and eliminating the sloped ceiling allows the elimination of the suspended light fixture in the original design.

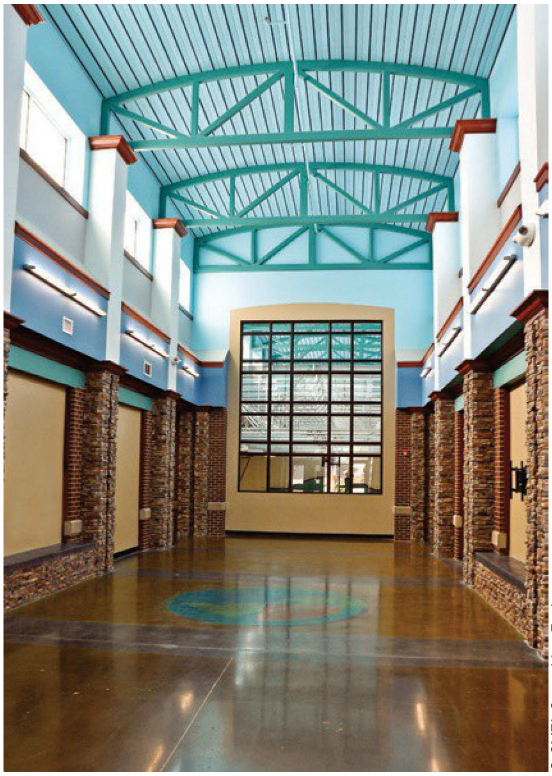
The LED light fixtures should be located close to the desktop, but comfortable to the occupant. Less

LED TECHNOLOGY CHANGES

The changes in LED technology since Richardsville was designed in 2009 have had a significant impact on the design of NZE buildings. In addition to the advantages in total cost of ownership, reliability, and efficacy, current LED technology can also provide a quality of light that is not achievable with other high-efficiency artificial light sources.

When comparing quality of light from different sources, the typical approach is to compare color rendering index (CRI) values. Cost-effective LED technology is already achieving CRI values greater than 90, an improvement over the CRI of fluorescent sources; however, CRI does not tell the whole story.

Fluorescent lamps typically produce light in some of the most prominent wavelengths in the visual spectrum, "fooling" our eyes into believing they are seeing the whole picture. Current LED technologies using phosphor-coated blue LEDs or red, green and blue (RGB) LEDs produce wavelengths across much of the visual spectrum. This allows the environment to be more accurately perceived by the human eye in any setting and is much closer to natural daylight than typical CRI fluorescent lamps.



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Clerestory windows in the main entrance hall of Richardsville Elementary admit natural daylight. The large window at the corridor's end looks down into the gymnasium/cafeteria and provides additional natural light.

volume translates into a lower lighting power density.

For this comparison, six 2 ft × 4 ft non-planar LED recessed troffers were modeled with a ceiling height of 9 ft above the finished floor. The non-planar LED provides light high on the wall to fill the space full of light, resulting in a better classroom environment. Lighting for classrooms using LED in this model resulted in 0.45 W/ft^2.

Controls are greatly simplified to two manual dimmers with an occupancy sensor. The first dimmer controls the lights adjacent to the teaching wall, and the second controls the remaining classroom lighting. A corner-mounted, dual technology occupancy sensor enables lighting when occupied and is programmed for automatic-on/automatic-off.

This new classroom design adheres to the lighting section of ASHRAE Standard 90.1-2013 for reduced artificial lighting power density requirements and automatic daylighting control. Automatic daylighting controls are not required because the lighting wattage within the primary sidelighted area is below 150 W.

FIGURE 3 ORIGINAL DESIGN ENERGY RESULTS

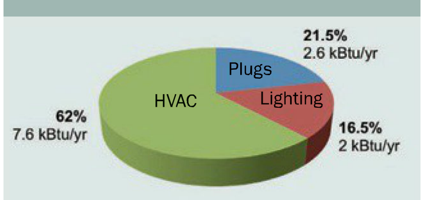
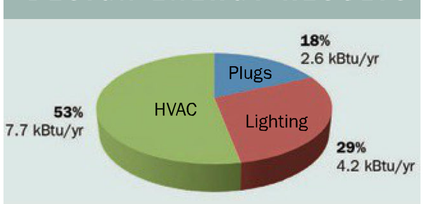


FIGURE 4 PROPOSED DESIGN ENERGY RESULTS



Energy Model Results

An energy model was completed for the original and revised classroom designs. Two south-facing classrooms — one on the first floor and one on the second floor — were modeled together for a total of 1,760 ft^2 as shown in *Figures 1* and *2*. The results indicate that the revised classroom design consumes 14.5 kBtu/yr, while the original classroom design consumes 12.2 kBtu/yr. *Figures 3* and *4* show the energy model results for each design.

Evaluating the energy model results indicates that while the lighting power density is significantly reduced with the revised LED lighting design, the active daylighting system in the original design dims the artificial lights the majority of occupied hours. This reduces the annual lighting and cooling energy consumed. The revised classroom design has a lower peak cooling load of 11,900 Btu/h compared to 12,700 Btu/h for the original design.

The electric rate charged by the local electrical utility is $0.083/kWh for usage and $9.7/kW for demand. The cost of energy for the two energy modeled classrooms is $660/yr for the original design and $742/yr for the revised design. Extrapolating this for the 24 daylit classrooms in Richardsville yields an annual increase in energy cost of $984/year.

NZE Status

The revised classroom design consumes 2.3 kBtu/yr more than the original classroom design. To maintain NZE status for the revised design, an additional 0.5 kW of solar power would be required to generate the additional 2.3 kBtu/yr annually. To balance the increased energy use of all 24 classrooms, the building's PV array would increase from 348 kW to 354 kW.

First-Cost Analysis

Bidding both designs would be the fair, but not practical, method of evaluating construction costs. The original design is already built, so the construction manager for that project was contacted to provide cost information for the variations in the two designs.

The most significant differences between the designs are architectural. The original design included a 20 ft × 16 in. clerestory daylighting window, an interior lightshelf and 16 in. of additional building height that the revised classroom design does not include.

The revised electrical design changes the fluorescent lighting to LED and omits the daylight dimming control system. The original lighting and dimming controls supplier was contacted to supply cost data for the proposed design. The proposed design also includes 0.5 kW of additional PV.

Table 2 summarizes the cost differences between the two designs. The result is that the revised design is $7,500 less expensive to achieve NZE operation for the two classrooms modeled.

The building has 24 classrooms total, so the approximate savings for a redesigned Richardsville Elementary School would be $90,000. The $90,000 savings then could be "cost shifted" to the building's solar photovoltaic system to reduce its first cost. The revised design requires 354 kW of PV. At the cost of $3/W, the savings will purchase 30 kW of PV or 8.5% of the total PV system cost.

Conclusion

If Richardsville Elementary School was designed today with the revised NZE classroom design modeled in this article, clerestory glass and lightshelves would be eliminated. Natural lighting into the educational space would be preserved while maintaining a view connection to the outdoors with the large 12 ft × 6 ft window. New LED lighting technology would be used to narrow the energy-efficiency gap between a daylit and non-daylit classroom.

Richardsville's original design goal was to maximize energy reduction strategies so the cost of the PV system would be minimized. Since the project's completion, two significant improvements in building sciences — the evolution of LED lighting and the reduction in costs of the PV systems — have changed the NZE cost/benefit equation.

Funding the PV system for NZE projects always proves to be difficult. The revised design saves significant first cost, which can be cost shifted to the PV system to lower its installation cost. For this specific example, an 8.5% PV cost reduction was obtained. ●

TABLE 2 FIRST-COST SAVINGS OF PROPOSED DESIGN FOR TWO CLASSROOMS

Architectural	
Delete two 20 ft × 16 in. daylight windows.	$5,300
Infill above daylight openings with insulated concrete forms (ICF) and brick.	($2,000)
Delete two interior lightshelves.	$2,000
Reduce building height 16 in. (total building savings prorated for two classrooms).	$2,800
Lighting	
Change fluorescent lighting to LED lights.	($1,100)
Simplify lighting control system.	$2,300
Solar PV	
Add 0.5 kW solar PV.	($1,800)
Savings	**$7,500**

MAINTAINING DAYLIGHTING CONTROLS

The energy model for the original building design was simulated with all controls working properly, dimming the artificial lights when natural light can support the classroom requirements. Real-world experience has indicated that maintaining a properly operating daylighting dimming system can be difficult without retrocommissioning every few years or a well-trained maintenance staff. The proposed revised design of the Richardsville classrooms eliminates the daylighting dimming system, opting for manual controls instead.

The HVAC and lighting systems for Richardsville were fully commissioned at the project's completion, and the building has been occupied for three years. Engineers recently visited the school to measure classroom lighting levels and evaluate the operation of the lighting control systems. They found that the majority of classrooms were being over-lit.

The daylighting controls were not sensing natural light accurately and artificial lighting was excessively compensating the natural light. The result was that lighting levels were higher than designed. This results in the school consuming more lighting and cooling energy than predicted by the energy model.

Active daylighting systems are difficult for most owners to maintain, and schools systems are reluctant to purchase service contracts, which can negate the energy savings. On the other hand, manual dimming is a dependable control system and gives teachers control over their environment.

With proper training, manual dimming switches save energy by having the teacher (or students) balance the natural light. Any energy reduction created by manual daylight dimming will only decrease the energy consumed in the revised classroom energy model.

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