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ACHIEVING NET ZERO

BY KENNETH L. SEIBERT, P.E., MEMBER ASHRAE

"How would one design a net zero energy school and how much would it cost?" Mark Ryles, AIA, then facilities director for the Kentucky Department of Education, asked this question in fall 2007, right after Plano Elementary became the state's most energy efficient school. This question launched a collaboration involving MEP engineers, architects, state regulators, utility companies, school board members, school facility managers and school staff to design the first full-scale net zero energy school in the United States.

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The south side of the building has exterior lightshelves to direct sunlight further into the classroom.

Richardsville Elementary, originally built in 1946, is located in the Warren County Public School District (WCPS) in south central Kentucky. The district has a long history of energy management, being one of the first school districts in the state to hire a full-time energy manager. WCPS had five ENERGY STAR schools when Plano Elementary opened in 2007. Plano was rated at 99 and had an annual energy use intensity (EUI) of 26.8 $kBtu/ft^2$.

After such an achievement, investigating net zero seemed the next logical step. During preparations to replace Richardsville's aging building, designers researched current technologies, performed energy modeling and discussed building envelope and site orientation. They decided photovoltaics were the best way to make Plano's exemplary design work as net zero.

However, a PV system with enough capacity to produce Plano's 26.8 $kBtu/ft^2 \cdot yr$ was too expensive for Warren County's construction budget. Therefore, the team designated a new EUI target of 17 $kBtu/ft^2 \cdot yr$ as the basis for a financial model that indicated a 15-year simple return on investment (ROI) (See 2009 Financial Model sidebar, Page 43).

Setting the EUI and ROI goals were a critical first step in the collaboration process. The collaborating partners realized that they had to change their design paradigms and usual building construction techniques to reach the goal, as well as ask for waivers of agency regulations.

This project demanded innovative energy reduction strategies such as dedicated outdoor air systems (DOAS) with dynamic reset, new IT systems, and even alternative methods to prepare lunches.

The architect supported the project with a building massing model

Opposite Visitors coming into the main entrance of Richardsville Elementary look down the central hallway toward a large window overlooking the gymnasium/cafeteria. This forms the central spine of the building and has clerestory windows to admit natural light. The floors are made of concrete that does not require waxing.

BUILDING AT A GLANCE

Name Richardsville Elementary School

Location Richardsville, Ky. (9.3 miles north of Bowling Green, Ky.)

Owner Warren County Public Schools

Principal Use Elementary school
Includes Gymnasium and cafeteria

Employees/Occupants 460 students, 35 staff

Occupancy 84%

Gross Square Footage 72,285
Conditioned Space 72,285

Distinctions/Awards
First Net Zero Energy School in the United States;

American School and University Magazine, Special Citation, 2008 and 2011; and Andromeda Award, Alliance to Save Energy (Warren County Public Schools), 2009

Total Cost $14,927,000
Cost Per Square Foot $206.50

Substantial Completion/Occupancy
September 2010

For more details on Plano Elementary, see the Fall 2009 issue of *High Performing Buildings* magazine or go to http://tinyurl.com/boapl2c.

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

Above right **The roof is covered with a thin-film solar array. This 208 kW array has been operational since February 2011.**

aimed to reduce heat transfer from the outdoors. The engineer developed energy reduction strategies and energy modeled the project, beginning at the schematic phase to ensure the targeted energy performance would be achieved.

Renewable Energy

Solar photovoltaics were selected as the renewable energy source to offset the energy used by the school. The solar PV system did not bid until later stages of construction to obtain the lowest cost.

A 208 kW thin-film PV system was located on the roof, and a shade structure built in the parking area accommodates 140 kW of crystalline panels. The full PV system became operational in January 2012.

Figure 1 shows that the building has been operating at net zero energy since January 2012. From September to December 2011, only 60% of the solar PV system was operational, resulting in a net EUI of 0.39 $kBtu/ft^2$ for the last 12 months. However, since the PV system became fully operational, power generation has exceeded consumption by 26.5%.

The PV system was designed for a 20-year life-cycle, and it was expected that surplus power would be generated in the initial years.

FIGURE 1 NET ZERO ENERGY MWH SUMMARY

Read Date	MWh Consumed	MWh Generated	MWh Difference
8/16/2012	36.4	54.8	(18.4)
7/11/2012	26.6	56.0	(30)
6/11/2012	28.0	57.5	(29.5)
5/16/2012	38.2	45.0	(6.8)
4/16/2012	29.8	35.3	(5.5)
3/15/2012	30.6	31.9	(1.3)
2/14/2012	33.8	19.5	14.3
1/16/2012	26.0	14.9	11.1
Subtotal (100%PV)	248.8	314.9	(66.1)
12/14/2011	29.2	7.5	21.7
11/17/2011	31.8	12.2	19.6
10/17/2011	34.6	19.3	15.3
9/15/2011	41.2	23.5	17.7
Subtotal (60%PV)	136.8	62.5	74.3
Total	**385.6**	**377.4**	**8.2**

MWh summary documenting eight months of operation with the power generation system at 100% and four months at 60% operation.

AUTHOR'S NOTE ON NZEB

Due to of the groundbreaking nature of this project, this article has been published prior to having one year of full data on the power generation system. Because the school opened in September 2010, more than 12 months of energy consumption data is available; however, the full renewable energy system did not become operational until January 2012.

Figure 1 shows the MWh summary documenting eight months of operation with the power generation system at 100% and four months at 60% operation. Since the power generation system began full output, generation has exceeded consumption by 26.5%.

Looking at the previous 12 months, consumption exceeded generation by only 2.2%, which included the four months with only 60% capacity. Using this data, even without the full 12 months of 100% solar PV output, it is clearly evident this building is operating as a net zero energy building.

ENERGY AT A GLANCE

Annual Energy Use Intensity (EUI) (Site) 18.2 $kBtu/ft^2$
Electricity (From Grid) 18.2 $kBtu/ft^2$

Annual Source Energy 60.5 $kBtu/ft^2$

Annual Energy Cost Index (ECI) $0.30/$ft^2$ credit

Annual On-Site Renewable Energy Exported (From PV) 17.8 $kBtu/ft^2$

Annual Net Energy Use Intensity 0.39 $kBtu/ft^2$

Savings vs. Standard 90.1-2004 Design Building 52.8%

ENERGY STAR Rating 100

Heating Degree Days (base 65°F) 2,710

Cooling Degree Days (base 65°F) 2,650

Average Operating Hours per Week 45

WATER AT A GLANCE

Annual Water Use 421,000 gallons

The gymnasium serves as gym and cafeteria. The cafeteria setup is pictured here. The clerestory windows that form the spine of the building and admit daylight into the main hall and gymnasium/cafeteria can be seen at the top of the photo. None of the overhead lights were on when this picture was taken.

Because the output of the panels deteriorates over time, the system was designed so at year 10, generation would match consumption. *Figure 2* graphs the production of each PV system over the last 12 months.

Energy Consumption

The net zero operation has grabbed public attention, but the low energy consumption is a source of pride for the design team. During the past 12 months, actual building energy consumption has been 18.2 kBtu/ft^2, while the design energy goal was 17 kBtu/ft^2.

The school is equipped with a power monitoring system that can measure and trend HVAC, lighting, kitchen, plug load, and IT power consumption individually (*Figure 3*). *Figure 4* compares Richardsville's energy consumption to baseline energy use according to ASHRAE/IESNA Standard 90.1-2004 and data from ASHRAE's *Advanced Energy Design Guide (AEDG) for K–12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building.*

Energy Reduction Strategies

Envelope. Energy benchmarking data from past projects provided clear evidence that an efficient thermal envelope can have a substantial impact on energy performance.

Richardsville Elementary was constructed with insulated concrete form (ICF) walls. The district had first used ICF walls in the construction of Alvaton Elementary, and the thermal performance, along with the thermal mass it provided, is a proven strategy to reduce HVAC energy.

A rectangular shape was chosen early to minimize heat transfer surface areas. The ratio of exterior wall-to-floor area is 38.9%, window-to-floor area is 26.9% and roof-to-floor area is 62.7%. The same ratios for the prototypical school modeled in ASHRAE's 50% school buildings AEDG, by comparison, are 49%, 34% and 100%, respectively. The architects' building design minimized the exterior heat transfer surfaces, which helped achieve the energy performance goals.

Lighting Strategies. The lighting energy consumption is 3.8 kBtu/ft^2 · yr. The primary strategies to reduce this energy use were minimizing the lighting energy intensity and naturally daylighting the classrooms. The average lighting energy intensity of the school is 0.68 W/ft^2, 43% lower than the code maximum 1.2 W/ft^2.

The rectangular shape did not compromise the daylighting design. The building floor plan is aligned on an east/west spine. All classrooms are located on the south and north exposures to capture the best daylight. The gymnasium and cafeteria are located in the center of the school, and the central spine has a raised clerestory to allow them to also be naturally lit.

Each upper-level, south-facing classroom is lit with four 2 ft by 4 ft light fixtures with three 32 watt, super T8 lamps and one 16 ft linear direct/indirect fixture with eight 32 watt, super T8 lamps.

The south-facing classroom daylighting design includes interior and exterior lightshelves to allow natural light into the classroom while minimizing direct glare at student desks, and tubular daylighting devices in the back of the room to supplement the daylight.

The upper-level, north-facing classrooms have six 2 ft by 4 ft light fixtures with three 32 watt, super T8 lamps.

In addition to the view glass, four supplemental tubular daylighting devices provide a source of natural light. A digital addressable control system modulates the artificial lighting output to supplement natural light as needed.

The lower-level classrooms have the same lighting layout with the exception of the tubular daylighting devices.

HVAC. The HVAC system consists of geothermal water source heat pumps with a dedicated outdoor air system (DOAS), which consumes 7.8 kBtu/ft^2 · yr. The installed cooling capacity is 120 tons, which equates to 1 ton per every 602 square feet. The goal was to right-size the HVAC equipment and cost shift the savings to support energy-conservation technologies.

NEW VS. OLD VIDEO

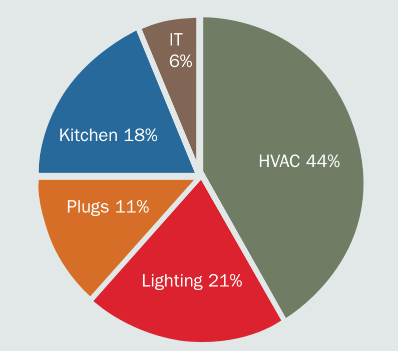
New vs. Old Richardsville Elementary Schools battle in a five-minute video that stars two Richardsville students. The video is a parody of the "Get a Mac" PC vs. Mac ad campaign that ran from 2006 to 2009 (http://tinyurl.com/5t2tzvo).

The New Richardsville Elementary School constantly foils Old Richardsville Elementary School by touting all of the sustainable features of the new school, including its being built to be net zero energy.

In the end, Old Richardsville School decides he wants to attend the new school, too.

View the New vs. Old Richardsville Elementary School video at http://tinyurl.com/cw5par2.

FIGURE 3 ENERGY USE BREAKDOWN



KEY SUSTAINABLE FEATURES

Water Conservation The school is exceeding its design water use goal of 600,000 per year (40% savings per LEED 2.0). Actual use is 421,000 gallons per year.

Recycled Materials Recycled a portion of the old school's gym floor.

Daylighting South facing classrooms have interior and exterior lightshelves. North facing classrooms have tubular daylighting devices.

Individual Controls HVAC and lighting.

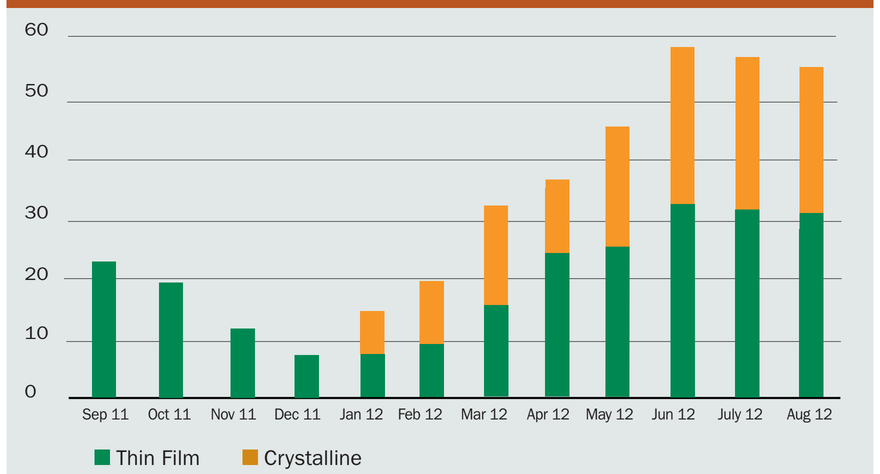
Photovoltaics 208 kW thin-film rooftop system, 140 kW crystalline panels parking lot array

Carbon Reduction Strategies Solar PV, geothermal HVAC, daylighting, demand control ventilation, ICF walls, energy efficient kitchen.

Other Major Sustainable Features Interactive "green screen" allows students to monitor the building's performance and allows teachers to integrate building into the curriculum; energy efficient kitchen; outdoor classroom with weather station; green interior finishes.

Richardsville was constructed using insulated concrete form (ICF) walls that enhance the building's thermal envelope.

FIGURE 2 SOLAR PHOTOVOLTAIC GENERATION (MWH)



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The north-facing classrooms don't have lightshelves. In addition to the view glass, four supplemental tubular daylighting devices provide a source of natural light.

The heat pumps have dual compressors on a single refrigerant circuit, which maximizes energy efficiency when the equipment is operating at part-load capacity. (Variable speed compressors provide better efficiency but were not available in 2009.)

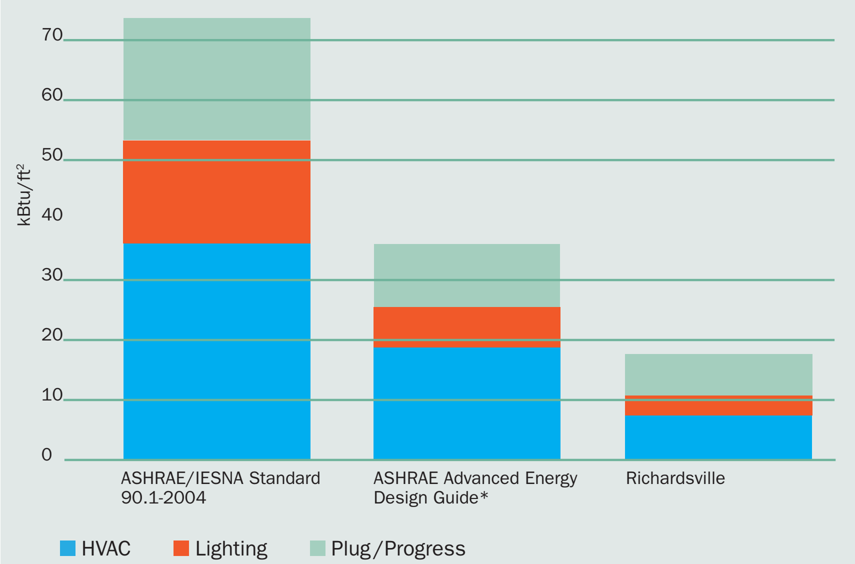
A distributed water pumping system was used in lieu of central pumps with variable frequency drives. A small water pump installed adjacent to each heat pump recirculates water through a low pressure drop building loop to the geothermal borefield. This approach ensures variable water flow operation is obtained and reduces installed pump horsepower to 0.12 W/ft².

Improving the energy efficiency of the DOAS was mandatory to achieving the goal. Power monitoring data from Plano Elementary, also a geothermal project, indicated that 40% of HVAC energy was consumed by the DOAS. A variable flow, outdoor air system with dynamic reset was selected for Richardsville.

A constant volume system can significantly over-ventilate the school because of the many "swing" spaces such as the library, art, music, science, gym, cafeteria, etc., with the requirement that each space must be designed for full capacity when dynamic reset is not used. If all spaces at Richardsville were designed to ASHRAE Standard 62.1-2004, the occupancy would total 1,340, when the known maximum occupancy, including staff and visitors is 625.

ASHRAE Standard 62.1-2004 includes the dynamic reset provision to allow ventilation rates to modulate as room occupancy or building population changes. Measuring CO_2 indoor and outdoor levels can be used as a

FIGURE 4 **BASELINE ENERGY USE COMPARISON**



*50% AEDG for K-12 school buildings

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BUILDING ENVELOPE

Roof
Type Metal roofing with two, 3 in. layers of R-17 polyisocyanurate insulation
Overall R-value 34.9
Reflectivity/Emittance 69%/87%

Walls
Type 6 in. and 8 in. thick insulated concrete form walls
Overall R-value 28
Glazing percentage 26.8%

Basement/Foundation
Slab Edge Insulation R-value 24
Basement Wall Insulation R-value 24
Basement Floor R-value 0

Windows

	View Window	Daylighting Window
Effective U-factor for Assembly	0.29	0.47
Solar Heat Gain Coefficient (SHGC)	0.38	0.78
Visual Transmittance	0.7	0.81

Location
Latitude 36.8°N
Orientation East/West

BUILDING TEAM

Building Owner/Representative
Tim Murley, Superintendent

Architect Kenny Stanfield, AIA, Sherman-Carter-Barnhart

General Contractor
RG Anderson Company, Inc.

Mechanical Engineer
Mark Seibert, PE, LEED AP, CMTA, Inc.

Electrical Engineer, Lighting Design
Brian Baumgartle, PE, LC, LEED AP, CMTA, Inc.

Energy Modeler Kosuke Kato, PE, LEED AP, CMTA, Inc.

Structural, Civil Engineer and Landscape Architect Sherman-Carter-Barnhart

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Above The gymnasium floor is made from sustainable bamboo. The parquet floor from the old gymnasium was recycled for the free-throw areas. Clerestory windows distribute enough daylight into the gymnasium for the overhead lights to remain off.

Above left Truly a "teaching tool," Richardsville Elementary's themed hallways—Geothermal, Solar, Water Conservation, and Recycling—integrate the school's energy-saving features into the curriculum as students learn conservation principles from the building itself.

basis for estimating occupancy, in addition to using occupancy sensors.

This project uses a system that centrally tests the air quality in each space. A pneumatic air system returns air from each occupied space to have it "tested" at a common location. This air quality testing system communicates with the BAS. As CO_2 levels increase, the VAV box increases airflow to the space and reduces airflow as the CO_2 levels decrease. When no occupancy is sensed, the classroom is placed in the unoccupied mode.

Other Green Strategies

Designing a net zero energy building aligns with other sustainable goals such as daylighting, reducing energy consumption and green power production. Other strategies included water conservation, green finishes and using the building as a teaching tool.

Water. WCPS focuses on water conservation. This project was designed for 40% water use reduction primarily by using low-flow fixtures. Actual water use was 421,000 gallons per year, substantially lower than the modeled use.

The design included permeable pavers and bioswales to reduce and filter storm water runoff. Native, drought-resistant landscaping was also used.

Finishes. Finishes were another priority. Stained concrete floors, which reduce maintenance costs, are used throughout the school. Richardsville was the first school in the district to try this. The gym floor is bamboo with the free-throw lanes made from the parquet flooring from the original school's gym.

Teaching Tool. A "geothermal hallway" exposes the piping manifolds and equips the pipes coming to and from the wellfield with a temperature gage so students can monitor the performance of the system. The "solar hallway" has a battery charging station where students can see the energy transferred from the solar panels to the laptop computer batteries.

The "water conservation hallway" allows student to monitor the amount of rainwater collected and filtered through the site's bioswales. The "recycling hallway" contains bins for all recyclable materials collected. An outdoor weather classroom allows students to monitor year-round the impact the weather has on the building's performance.

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Light-duty cooking appliances make it possible to use Type II range hoods in the kitchen, which significantly reduce kitchen energy use.

Behavior Changes

The kitchen and IT systems consume significant energy, but have been off limits to energy reduction strategies on past projects. When Richardsville's owner was shown energy data indicating these systems are consuming 32% of the building energy in the district's most efficient school, he was supportive of kitchen and IT changes to reach the energy goal.

'ENERGY FREE' LUNCHES

The school has adopted the saying, "A healthy kitchen is a green kitchen." Accordingly, it sometimes serves a brown bag lunch. In addition to brown bag staples such as sandwiches, fresh fruit, and crackers, the school offers a popular "salad in a bag." Students pour in salad dressing and eat the salad out of the bag.

Source: http://tinyurl.com/cbkncap

2009 FINANCIAL MODEL

A financial model showing the ROI for an NZE school as compared to the "typical" school was necessary to obtain buy-in from the school district, state agencies and legislators. The building, less the PV system, would have to be constructed within the typical budget assigned by the State Department of Education for a new 550-student elementary school. The cost to construct the solar PV power generation system was budgeted at $2.8 million and would require a 15-year simple payback. That would not be possible if the construction cost of the solar PV system were offset only by the revenue from the power it produced.

The financial model would be based on the total energy cost of Richardsville Elementary compared to the total energy cost of a new school built to the latest energy code. This financial model integrates the energy reduction strategies and generated renewable energy into the ROI. ASHRAE's 50% AEDG for K–12 school buildings suggests the average annual energy use is 73 kBtu/ft^2, but the Kentucky Department of Energy advised that new schools in Kentucky were typically consuming 65 kBtu/ft^2·yr, so the latter EUI was used as the basis for comparison (*See below*).

When Richardsville Elementary was being designed, the Tennessee Valley Authority was setting up a program to encourage renewable energy generation on site. The final program pays $0.12/kWh more than the selling price for each kWh of renewable energy generated. The $0.12/kWh applies only to the actual energy usage cost and excludes the demand charge. In return for the higher usage price paid by TVA, Warren County Public Schools relinquished the solar renewable energy credits (SRECs) to TVA.

The school is operating net zero with respect to cost and has accumulated a credit of $21,663 over the past 12 months. The credit will be returned to the school district on an annual basis. In 2009, when this model was generated, the solar cost was budgeted at $8/kW. Because solar PV costs have fallen significantly, a similar 2012 financial model would indicate an ROI closer to 10 years.

Year	Typical School 65 kBtu Energy Cost	Richardsville 17 kBtu Energy Cost	Richardsville PV Revenue	Annual Savings (Savings Plus Revenue)
1	$109,039	$46,080	$84,183	$147,142
2	$112,310	$47,462	$86,708	$151,556
3	$115,679	$48,886	$89,310	$156,103
4	$119,150	$50,353	$91,989	$160,786
5	$122,724	$51,863	$94,749	$165,610
6	$126,406	$53,419	$97,591	$170,578
7	$130,198	$55,022	$100,519	$175,695
8	$134,104	$56,673	$103,534	$180,965
9	$137,127	$58,373	$106,641	$185,395
10	$142,271	$60,124	$109,840	$191,987
11	$146,539	$61,928	$113,135	$197,746
12	$150,935	$63,785	$116,529	$203,679
13	$155,464	$65,699	$120,025	$209,790
14	$160,127	$67,670	$123,626	$216,083
15	$164,931	$69,700	$127,334	$222,565
	$2,027,004	**$857,037**	**$1,565,713**	**$2,735,680**

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Students show University of Kentucky President Dr. Eli Capilouto the school's "green screens," which exhibit the school's real-time energy performance.

ENERGY TEAM

Tour groups at Richardsville Elementary School are greeted by the Energy Team, a group of 4th, 5th, and 6th graders. They have led tours for university presidents, legislators, government officials, school facility managers, architects and engineers, and the general public.

One visitor this year was University of Kentucky president Dr. Eli Capilouto, who visited after receiving a letter from a second grader at the school.

The Energy Team also shares information about energy and energy conservation with their classmates, leads the school's recycling efforts, and takes part in community events related to energy conservation.

—Warren County Public Schools website

Kitchen. Food service staff spent time in a test kitchen to learn alternative methods to prepare food that consumed less energy, while maintaining taste and quality. Kitchen staff learned to prepare hot food primarily with combi-ovens (ovens operating by both conventional heating and microwaves) and 40 gallon tilting kettles (a large, relatively shallow, tilting pot used for braising, stewing, and, occasionally, steaming).

This equipment allows the use of Type II range hoods in lieu of Type I. Building codes allow the exhaust and makeup air quantities to be considerably reduced for Type II range hoods. The kitchen has consumed 3.3 kBtu/ft^2 for the last 12 months.

IT. Kentucky's classroom technology standards for an elementary school required one computer classroom and six student workstation computers in each classroom. All technology was hard-wired.

The design team petitioned the state to eliminate the computer classroom and all classroom workstation computers, and allow Richardsville to be the first truly wireless school in Kentucky. Significant first cost savings were realized by removing the 1,000 ft^2 computer classroom and the power/data wiring infrastructure for the classroom computers. These savings were cost shifted into wireless technology and seven laptop carts.

The laptop carts allow teachers more flexibility to work with computers anywhere in the school and not be tethered to a single classroom. Energy savings were another bonus of the wireless school. The server rooms and plug loads consume only 3.1 kBtu/ft^2 · yr.

Conclusion

Richardsville is an example of the success that can be accomplished when a goal is set and all team members are willing and passionate participants. The school's net zero energy status has attracted visitors from around the U.S., and students lead these tours explaining the sustainable features of the school.

While all projects may not be able to fund renewable energy systems and achieve NZE status, Richardsville Elementary School shows that deep energy reduction can be achieved when all team members work together to plan and implement strategies that drastically reduce energy consumption. ●

LESSONS LEARNED

The power monitoring system proved helpful during measurement and verification. It was used to trend power consumption, system by system, during occupied and unoccupied hours. The hourly trend reports made it easy to verify if equipment was shutting off as intended.

The HVAC energy use during unoccupied periods appeared high. After cross-referencing the energy use with the school's BAS system, most equipment appeared to be shutting down at the correct times. Working with the heat pump manufacturer led to the realization that the reciprocating compressors have 40 W crankcase heaters that operate continuously. The heat pump units have dual compressors, so many units actually have two heaters, totaling 80 W. After discussion with the compressor manufacturer, these heaters were disabled.

Fifty watt ultraviolet lights were provided in all heat pump units for improved air filtration and air quality. These were shipped by the manufacturer to operate 24/7. The UV light operation schedule was changed to be operated only when the supply air fan was running.

Energy use during the unoccupied hours in the kitchen was higher than expected. A post-occupancy tour revealed that there was a portable ice cream cooler in the cafeteria not included in the original design, but was vendor-provided and intended to be a source of revenue for the school. However, the thermal envelope of the portable freezer was poor, and the unit's compressor operated at 90% percent runtime. The source of revenue proved a net loss to the district, increasing the cost of the school's energy consumption by $650/yr. The ice cream cooler would have required $43,000 worth of PV panels to maintain net zero operation. To reduce the extra energy needed to operate the ice cream freezer, it is only turned on during the lunch period. The ice cream to stock the portable freezer is stored in the walk-in freezer the rest of the time.

ABOUT THE AUTHOR

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