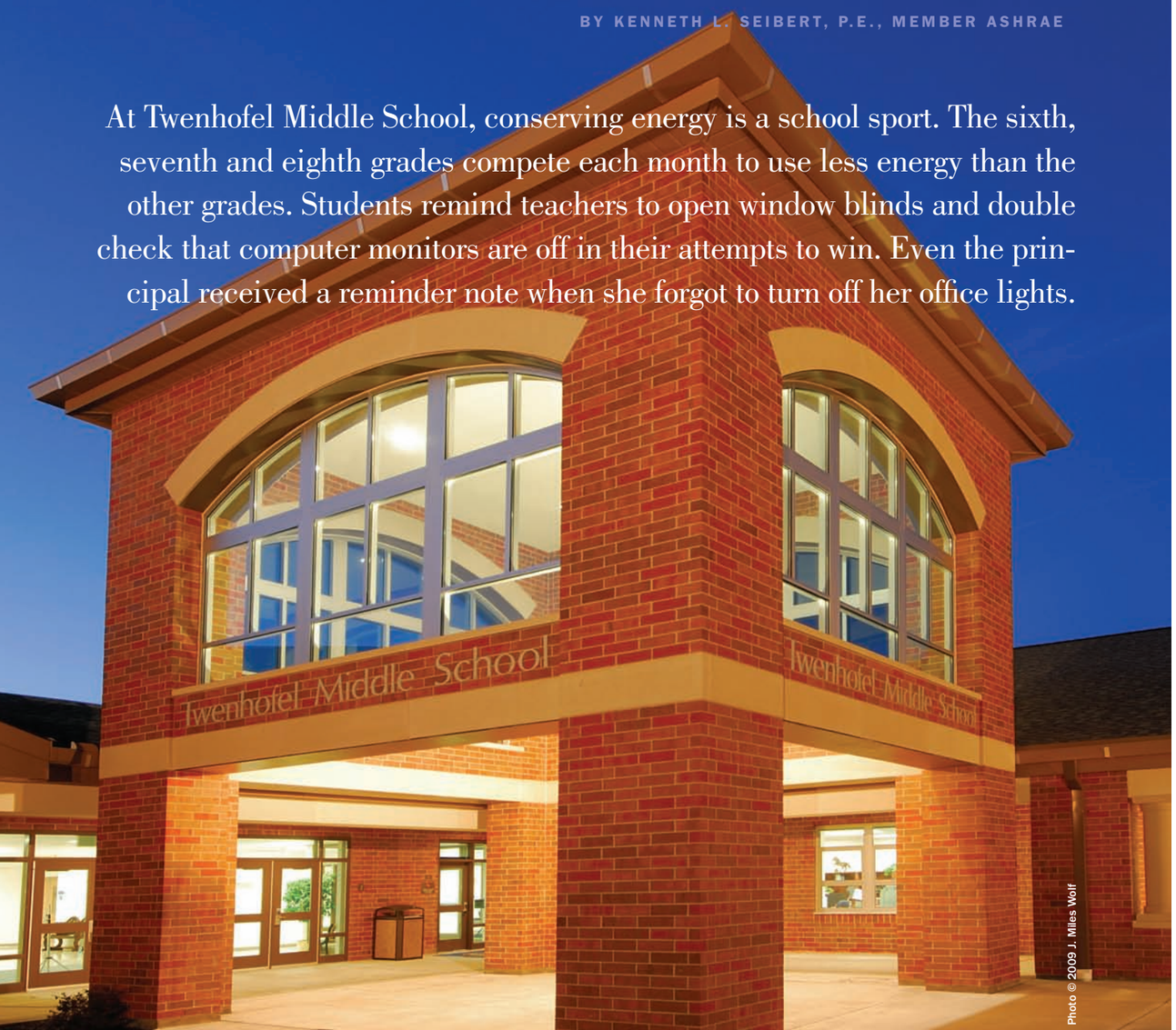
AN ENERGY EDUCATION

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

At Twenhofel Middle School, conserving energy is a school sport. The sixth, seventh and eighth grades compete each month to use less energy than the other grades. Students remind teachers to open window blinds and double check that computer monitors are off in their attempts to win. Even the principal received a reminder note when she forgot to turn off her office lights.



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The excitement over energy conservation doesn't end with the competition. Students lead tours of their school, explaining to visitors how daylight harvesting illuminates their classrooms, how the geothermal HVAC system draws energy from the earth, how solar panels impact the electric grid and how much rainwater is collected from the roof to flush toilets and water the school's athletic fields.

Twenhofel is one of the first results from the Kenton County (Ky.) School District's decision in 2004 to incorporate sustainable principles and energy conservation measures into its buildings, and integrate lessons based on the building systems into the curriculum. This approach not only led to a new method of designing and constructing school facilities, it prompted a district-wide focus on reducing energy use involving the students, teachers and staff.

Twenhofel Middle School in Independence, Ky., uses daylighting, a geothermal heat pump system, photovoltaics and rainwater harvesting, which provides water for the school's toilets. The school incorporates real-time data from its sustainable systems into its curriculums.

Cheryl Jones, principal of Twenhofel, said, "From my perspective as principal, I've seen a renewed interest in environmental issues. Students are learning a lot of real-life science."

The Kenton County School District sits on the edge of the Cincinnati metropolitan area, and Twenhofel's sustainable systems and its curriculum integration are unique among the area's schools. Since Twenhofel opened in 2006, more than 40 groups have toured the school, including representatives from other school districts, state and local officials, architects and engineers.

Daylighting

Daylighting the classrooms and other education areas was the priority for the architect, engineer and school officials. At the time of Twenhofel's construction, daylighting was not a priority for Kentucky schools. As commonplace as it is in 2009 to orient the building's glazing exposures north/south, it was a significant paradigm shift in 2004 for Kentucky; schools were usually aligned with the street.

BUILDING AT A GLANCE

Name Twenhofel Middle School

Location Independence, Ky. (Kenton County)

Owner The Kenton County School District

Principal Use
Middle School (Grades 6, 7, 8)
Includes 39 classrooms, media center, gymnasium, cafeteria, multipurpose room, band/choral spaces, offices/support areas

Employees/Occupants
900 students plus teachers and staff

Gross Square Footage 112,000 ft^2

Total Cost $19 million

Cost Per Square Foot $170

Substantial Completion/Occupancy
January 2006

Occupancy 80%

Distinctions/Awards LEED Silver; ENERGY STAR label 2007, 2008; National District of the Year Award, National Education Energy Development (NEED) Project

Photo © 2009 J. Miles Wolf

Twenhofel is the first school in Kentucky oriented to take maximum advantage of daylighting. Windows supplement artificial lighting in the media center and throughout the school. Before Twenhofel's construction, most Kentucky schools were oriented with the street.

Photos © 2009 J. Miles Wolf

Roof dormer windows provide daylighting in Twenhofel Middle School classrooms. This design provides natural light deeper into the classrooms than some other configurations. Fluorescent lighting systems automatically dim as daylight increases.

For this project, orienting the building to take advantage of daylight was complicated by a site with significant grade variations. To accommodate the site constraints, the team developed a design approach using daylight from the ceiling with roof dormers to supplement the artificial lighting. This approach also provides natural light deeper into the classrooms than some configurations. In the morning as the light increases, the fluorescent lights automatically dim. The natural light maintains the state's required lighting levels at the students' desks.

Mark Ryles, the Kentucky Department of Education's director of facilities, said, "Kenton County's success with their daylit classrooms has encouraged other districts to follow."

Ryles was so impressed with the schools that the Kentucky Department of Education reduced the artificial lighting requirement from 50 footcandles to 40 footcandles for daylit classrooms. This change acknowledges the abundance of natural lighting during 95% of the school's occupied hours. This allows the design team to shift construction dollars from the artificial lighting systems to daylighting components.

The north-facing classrooms and the south-facing classrooms have the same surface area of glazing. (For subsequent projects, the south glazing surface is being reduced.) Ceiling baffles restrict glare in the south facing classrooms. As the natural light increases, fluorescent lighting dims in response to a single ceiling-mounted photosensor. The artificial lights turn off when they dim to 10% capacity. Teachers have override capability of the dimming system and can reduce the artificial lighting in an A/V mode.

The design team and school officials extensively discussed the pros and cons of blinds for the daylight glass and the necessity to completely shut out the natural lighting. Three years later, their experience has led to blinds on the south

KEY SUSTAINABLE FEATURES

- Daylighting
- Geothermal HVAC
- Solar PV
- Rainwater Harvesting
- Occupancy Controls
- District Energy Management Program
- Building as a Teaching Tool

Photo © 2009 J. Miles Wolf

Ceiling baffles (top right) restrict the sunlight in the cafeteria and other south-facing rooms.

glazing at Twenhofel because projections were too hard to see. The amount of glazing per classroom was modified in subsequent projects.

HVAC

Until 2004, the district's older schools used two-pipe unit ventilators with boilers and air-cooled chillers. The later schools were designed using variable air volume (VAV) systems with central boilers and air-cooled chillers. One school was constructed using a water source heat pump system with fluid coolers and boilers. District officials selected a geothermal heat pump system for Twenhofel. While the energy-efficient geothermal system supports the district's sustainable vision, ease of maintenance and occupant comfort also impacted the decision.

The heat pump units are located on a mechanical platform constructed over most corridors. This location allows for easy maintenance access during school hours and places a potential noise source farther from the classrooms. One heat pump unit provides air conditioning to two classrooms where zoning is similar.

All heat pump units are connected to a common loop with a variable speed pumping system using 190 vertical wells as a heat sink/source. The heat pump units have a direct return duct connection with an independent filter frame adjacent to the unit. Frames are sized to accommodate a single 24 in. by 24 in. filter or multiples of that size. Having a consistent filter size throughout the school makes filter stocking much easier.

Outdoor air ventilation is independent of the geothermal HVAC system. Three dedicated constant-volume air-handling units with heat recovery wheels circulate outdoor air. Downstream of the heat recovery wheel, a two-pipe coil is placed in the unit. The air is dehumidified further or heat is added as dictated by the season. The coil is piped to a geothermal heat pump chiller that can provide chilled or hot water as necessary.

"We really like geothermal systems, and all of our new schools are being constructed with this system. We avoid the annual boiler inspections and tear-downs.

"Our experience has been that it is easier to find qualified technicians to service this system compared to VAV. Failure of any one component does not take down the entire system. Finally, with the winter temperature swings we can have in Kentucky, it is great to be able to heat or cool at any time," said Chris Baker, Kenton County's energy systems coordinator.

Solar PV

To enhance the district's vision and commitment to sustainability, a solar photovoltaic (PV) system was incorporated as a key component of the project. The initial goal of the system was merely to support the power requirements of one science classroom for teaching purposes.

The final installed system was the largest for an educational building in Kentucky at that time. The 22 kW system consists of 206 crystalline silicon PV panels, each rated for 110 watts, configured in four arrays that are each connected to a 6,000 watt dc/ac power inverter. The PV system can export power to the utility grid if not needed for the building.

This larger system would not have been possible without a partnership

BUILDING TEAM

Owner
The Kenton County School District: Tim Hanner, Superintendent; Rob Haney, Director of Support Operations

Architect
Robert Ehmet Hayes and Associates: Ehmet Hayes, Principal Architect

General Contractor
Messer Construction;
Mechanical: Hudson Piping;
Electrical: ESI Electrical Contractors

MEP Engineer
CMTA: Ken Seibert, P.E., LEED AP, Principal in Charge; Tony Hans, P.E., LEED AP, Project Manager; Jess Farber, P.E., LEEP AP, Mechanical Engineer

Structural Engineer
Graham, Obermeyer and Partners: Michael Frank, P.E.

Civil Engineer
James W. Berling Engineers and Land Surveyors: Jim Berling, P.E.

Other Consultants
Innovative Design: Mike Nicklas, Principal in Charge; Padia Consulting: Harshad Padia, Principal in Charge

Photo © 2009 J. Miles Wolf

The roof dormer glazing provides natural light to classrooms. After daylighting was successfully implemented at Twenhofel, the Kentucky Department of Education reduced the artificial lighting requirements for daylit classrooms to 40 footcandles.

ENERGY AT A GLANCE

Annual Energy Use Intensity (Site)
46 kBtu/ft^2

Annual Source Energy 141 kBtu/ft^2

Annual Energy Cost Index (ECI)
\$1.11/ft^2·yr

ENERGY STAR Rating 89

BUILDING ENVELOPE

Roof
Type Shingles, 3 in. rigid insulation on metal deck
Overall R-value R-22

Walls
Type Brick, 1.5 in. insulation with 8 in. concrete masonry units (CMU)
Overall R-value R-15
Glazing Percentage 24%
Foundation 1.5 in. rigid slab edge insulation

Windows
U-value 0.5
Solar Heat Gain Coefficient (SHGC) 0.4
Visual Transmittance 60%

Location
Latitude 38° 54.9' N
Orientation North/South

Photo © 2009 J. Miles Wolf

A geothermal heat pump system serves the music room and the rest of Twenhofel Middle School.

TWENHOFEL ENERGY USE 2008

	Gas (kBtu)	Electric (kWh)
Jan	165,200	158,850
Feb	92,726	163,330
Mar	51,092	144,034
Apr	27,036	106,849
May	21,485	87,879
Jun	12,130	76,668
Jul	17,065	55,611
Aug	6,476	74,638
Sep	28,270	132,316
Oct	24,878	108,643
Nov	27,550	105,203
Dec	80,801	137,705

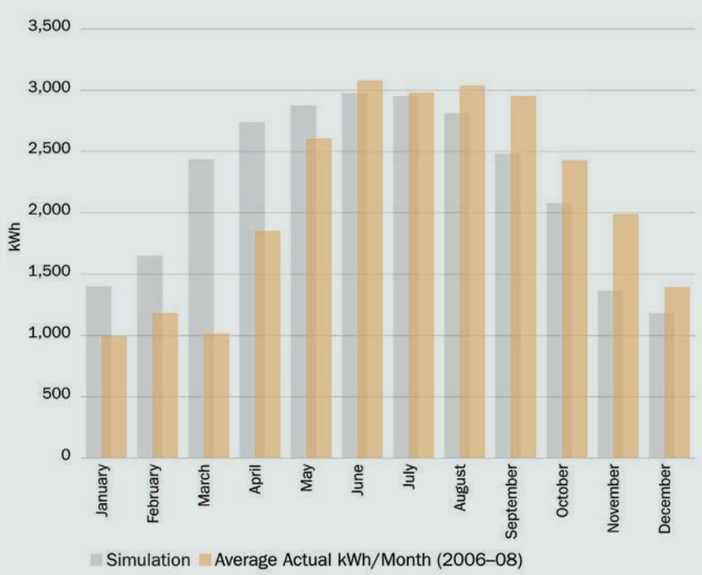
with the local electrical utility provider, Cinergy Inc. (now Duke Energy). The utility company felt that the district's sustainability vision aligned with their priorities of renewable energy. Cinergy donated the PV equipment valued at $100,000. The costs for installation and wiring were absorbed into the construction cost for the school.

The design team has been tracking the actual electrical generation of the solar PV system for three years. Prior to this, little data was available regarding the effectiveness of solar PV systems in Kentucky where cloudy, rainy and even snowy days are common. The design team wanted to collect data comparing actual electrical production versus computer simulations (*Figure 1*).

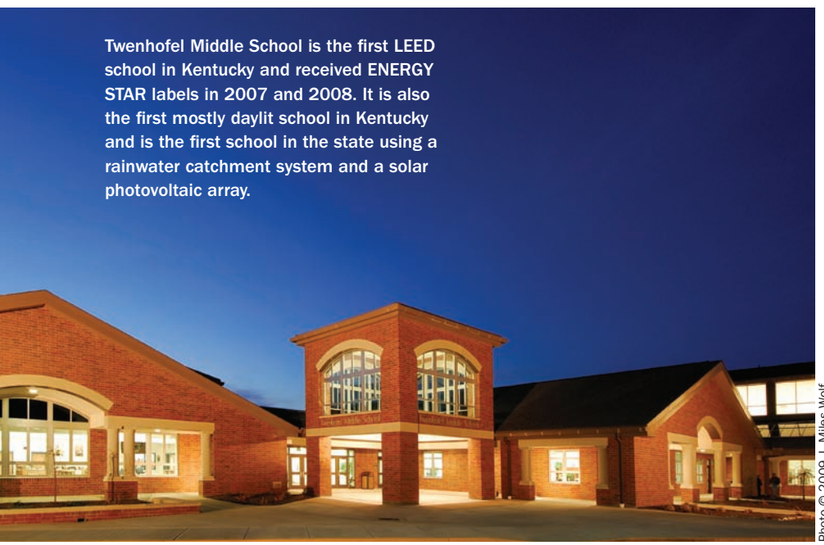
The data indicates that the PV system has generated 94% of the predicted power output.

The first quarter of each year shows the largest deviation, which can be attributed to extended power outages in the rural area where

FIGURE 1 SOLAR PV ELECTRICAL GENERATION



The Twenhofel design team compared predicted solar PV electrical generation with actual electrical generation from 2006–08. Actual generation reached 94% of the predicted output level. Before this project, little data was available on the effectiveness of solar PV systems in Kentucky where cloudy, rainy and snowy weather is common.



Twenhofel Middle School is the first LEED school in Kentucky and received ENERGY STAR labels in 2007 and 2008. It is also the first mostly daylit school in Kentucky and is the first school in the state using a rainwater catchment system and a solar photovoltaic array.

Photo © 2009 J. Miles Wolf

Photo courtesy of Kenton County School District

The 22 kW solar photovoltaic array, seen from the front entrance of the school, consists of 26 crystalline silicon PV panels, each rated for 110 watts and configured in four arrays that are each connected to a 6,000 watt dc/ac power inverter.

GLAZING LESSONS FROM CAYWOOD

The Kenton County School District simultaneously designed and constructed Twenhofel and another new facility, Caywood Elementary School. LEED was not a goal of this project, but daylighting and a geothermal system to reduce annual energy consumption were incorporated. The daylighting designed for this elementary school differed considerably from Twenhofel. All daylight glazing was integrated in the exterior wall and was oriented to the south.

The school district built its first two daylit facilities concurrently, attempting two different designs. In its first year of operation, Caywood Elementary School was the most efficient in the Commonwealth, using 35 kBtu/ft^2·yr.

While satisfied with Caywood's performance, field experiments were conducted to determine if the daylight glazing area could be reduced in future projects. CMTA designed an experiment that involved the students taking daily lighting measurements. The results of this experiment indicated that daylight glazing can be reduced. These results were incorporated into the next school's design, Turkey Foot Middle School, where the glazing is reduced by 50%.

Photo courtesy of Kenton County School District

The Kenton County School District constructed Caywood Elementary at the same time that it built Twenhofel. Caywood was designed differently, with all daylighting glazing integrated in the exterior wall and oriented to the south.

Twenhofel is located and snow covering the panels. This trending provides valuable data.

Reducing Water Use

The next step in realizing the district's sustainable vision for Twenhofel was reducing water use. This action was not because of a lack of water; water is abundant in this region. However, Twenhofel is in the rural southern area of Kenton County where the utility infrastructure is inconsistent and impact fees are charged for utility extensions.

The desire to minimize domestic water use and storm water runoff led to the design of a rainwater harvesting system. This system consists of a 100,000 gallon underground tank, a separate pump house and a grey water piping system within the school to serve the toilets and urinals. The system also provides water for the athletic field irrigation system. The 120,000 ft^2 roof area is the water collection source for the harvesting system. The pump house includes a surge tank, water particulate filters, a chemical feed system for algae control and independent water pumps for the grey water system and ball field irrigation.

Curriculum Integration

Integrating the high performance building features into the curriculum was primarily accomplished through the Twenhofel Vital Signs System. This real-time interactive building information interface integrates Twenhofel's high performance building features into the Kenton County curriculum. The graphics and building data are displayed on a 42 in. touch screen in the school lobby and to teachers, students and the world at www.twhvac.kenton.kyschools.us.

The interface provides custom animated graphics targeted toward middle school students. Real-time data from the building's solar PV, geothermal HVAC, rainwater catchment, daylighting and energy management systems are shown on the screens.

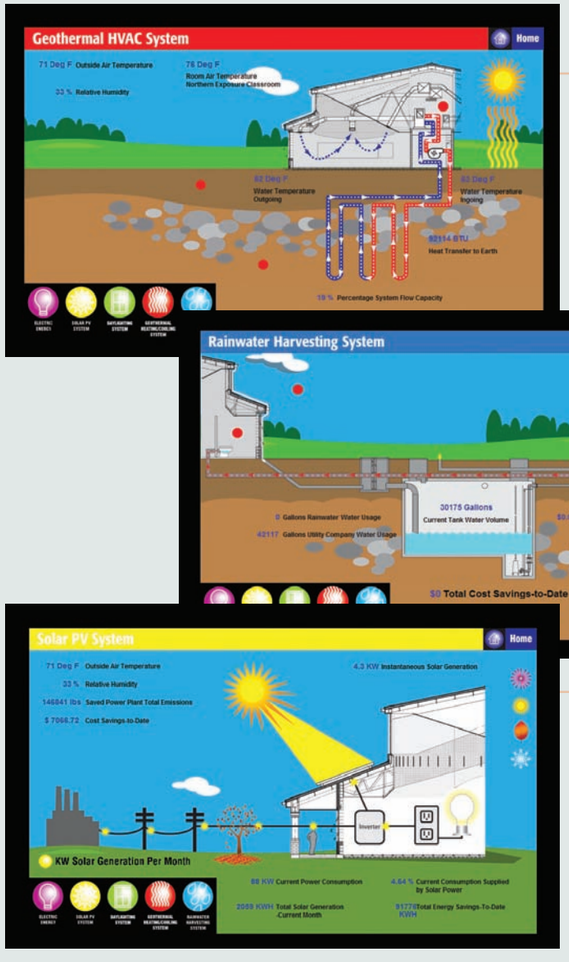
Teachers use this information for real-world problems tied to the science and math curriculums. The building serves as a teaching tool, allowing students to see how a building functions and the enormous effect the occupants (students, teachers and staff) have on its performance.

The design team met with the school staff to determine what

VITAL SIGNS SYSTEM

A student demonstrates the Vital Signs system using the touchscreen located in Twenhofel's lobby. The system provides real-time data from the building's solar PV, geothermal HVAC, rainwater catchment and daylighting systems. Teachers incorporate the information into science and math curriculums.

Photo courtesy of Kenton County School District



◀ The Vital Signs Geothermal HVAC screen shows the how a geothermal heat pump system uses the constant temperature of the earth to heat and cool the school.

◀ Twenhofel Middle School uses rainwater to flush toilets and irrigate the athletic field. A 100,000 gallon underground storage tank collects water from the roof. Students can visit the pump house to see the water levels. Public water supplements the rainwater system.

◀ When students view the Vital Signs Solar PV System screen, they see how many kilowatts the solar array is generating. The screen also compares the percent generated by the solar array to the total electricity used by the school. Several pop-ups provide additional information about the school's system and how it interacts with the power grid.

LESSONS LEARNED

Twenhofel's energy performance earned an 89 ENERGY STAR rating, but district officials and the design team realized the building could be more efficient. During the first winter of operation, the ceiling space near the classroom exterior wall was cold and a sprinkler pipe froze, revealing that the building was allowing too much outdoor air infiltration. Trending of the HVAC units indicated significant runtime during unoccupied periods even though setpoint temperatures were reduced and the outdoor air ventilation systems were deactivated.

The building has brick exterior walls with a ventilated brick cavity and a tall sloping asphalt shingle roof with a ventilated air space. Isolating the wall and roof ventilated air space from the actual thermal envelope proved difficult. The daylighting design used roof dormers; however, this concept creates multiple penetrations of the roof's thermal envelope. The eave on a shingle pitched roof building creates difficulties in maintaining a continuous thermal envelope between the exterior wall and roof. In addition, the roof dormer daylighting system provides many opportunities for infiltration.

Twenhofel's daylighting system was an innovative design for the region. In addition to the construction challenge, the initial roofing contractor went bankrupt during the project. A lack of continuity between contractors increased the opportunity for errors, contributing to the outdoor air infiltration.

Figure 2 is a typical cross section of the classroom wing. The building is one story, but the typical classroom wing ridge vent height is 28 ft. In the gym, the height of the roof ridge vent is 45 ft. The infiltration is primarily a winter issue because a large indoor/outdoor temperature differential exists, encouraging a chimney effect. Pressurization tests of the building showed a negative pressure at the exterior windows and positive pressure at the roof peak. Warm air could be felt at the ridge vents and other high roof thermal envelope penetrations.

The mechanical outdoor air introduced into the building was 4,000 cfm less than total exhaust when all building exhaust fans were operating, including the range hoods and dust collection system. This equaled 0.035 cfm/ft^2, which added to the infiltration issue. The mechanical system was modified to supply additional outdoor air and corrective action was taken to seal infiltration points; however, it is very difficult to seal a building after occupancy without rebuilding exterior surfaces. Efforts to address the infiltration continue.

This school was the first in Kentucky to be commissioned through both the design and construction phases. Unfortunately, the commissioning scope did not include testing the thermal envelope, which could have identified and avoided the infiltration issues. The commissioning process was successful in minimizing system start-up problems for the systems that were commissioned. All Kenton County projects are fully commissioned now.

Twenhofel fulfilled the vision of the district with daylighting, energy-efficient HVAC systems, solar PV and rainwater catchment. District officials used the data gained through the Twenhofel design and construction experience to improve new facilities. Introducing insulated concrete form walls (ICF), daylight via the south exterior walls, geothermal HVAC and full student involvement in the design and construction process are some of the improvements instituted in district schools since 2004.

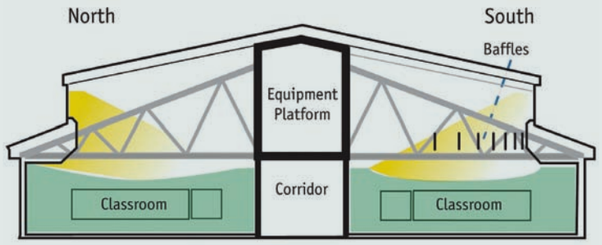


Figure 2 Typical cross section of the classroom wing.

curriculum-based information could be pulled directly from these systems and integrated into the middle school's curriculum. For example, teachers did not want all data readily available to students. Some information was to be recorded and logged but not displayed so students could perform the calculations and compare them to the real world values.

The Vital Signs system provides a direct connection between the sustainable features of Twenhofel and the curriculum used by its teachers. Its goal of using the building as a teaching tool is being achieved on a daily basis.

"Twenhofel's design had a huge impact on students," said Rob Haney, director of support operations for Kenton County Schools. "They have more environmental and energy awareness and understand how the operation of the building affects the environment."

The project's successful integration of sustainable design into the curriculum has prompted the district to create a green campus magnet program. This green campus will consist of a new middle school, elementary school and area technology center.

LEED Silver certification validated the success of Twenhofel's sustainable design. When the project started, Kentucky did not have a LEED K–12 facility. The initial goal was to obtain Certified status, but as the project progressed, enough credits were attained for a Silver certification.

As of late 2009, Twenhofel remained the only LEED certified school in the state. In addition to obtaining LEED Silver, Twenhofel received an ENERGY STAR label in 2007 and a second ENERGY STAR label in 2008.

The school's ENERGY STAR rating was 89. It uses 46 kBtu/ft^2·yr and is consuming 31% less energy than an average Kentucky school.

Kenton County School District also received the National District of the Year Award from the National Education Energy Development Project (NEED).

"Twenhofel Middle School, with all its high performance features, is a perfect match for the NEED student energy teams. From the time construction began, the building has given the students real-world experience by connecting energy management with applied science," said Karen Reagor, southeast regional coordinator of the NEED project.

The systems introduced in Twenhofel Middle School informed subsequent Kenton County construction projects. Now geothermal HVAC, daylit classrooms and using the building as a teaching tool are the norm for Kenton County school construction. The district continues to expand its vision with the construction of the green campus concept. ●

Photo courtesy of Kenton County School District

A rainwater harvesting system stores storm water runoff in a 100,000 gallon underground tank. This water is used to irrigate the athletic field and serves the water requirements of toilets and urinals in the school.

ABOUT THE AUTHOR

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