Students aren’t the only ones learning these days in Colorado’s Poudre School District (PSD). The school buildings are also benefitting from lessons learned during the construction and operation of seven high performing buildings in the district since 2000.

Bethke Elementary School in Timnath, Colo., represents the district’s latest evolution of its green school prototype.

Located where the high plains meet the Rocky Mountain foothills about 60 miles north of Denver, Bethke’s design has earned accolades. It is the first school in the nation to achieve LEED for Schools Gold certification and is the first to receive three out of four Green Globes from the Green Buildings Initiative.

In its first 12 months of operation, utility data prove that Bethke lives up to expectations, consuming 42 kBtu/ft² at a cost of $0.58/ft². Its ENERGY STAR rating is 99.

PSD started its sustainability initiative in 2000 with the development of Sustainable Design Guidelines. Updated in 2005, the Sustainable Design Guidelines outline the philosophy; strategies for procurement, operation and management; key design features; and lessons learned.

The district’s design approach relies on building long-term relationships with the design team, developing working solutions, and trying new ideas to meet sustainability goals.

District Energy Manager Stu Reeve credits partners like Xcel Energy, the Colorado Governor’s Energy Office, and the Environmental Protection Agency’s ENERGY STAR program for these achievements. “We know people who know what they’re doing,” Reeve said.

PSD’s main facilities include three early learning, 32 elementary, 10 middle, five high schools, and two administrative buildings. Based on performance tracked during the 2008–2009 fiscal year, 34 of the 52 buildings will qualify to receive an ENERGY STAR label for 2009. The seven newest PSD buildings have ratings ranging from 94 to 99 (Table 1).

Sustainable Design Features
The design and construction of Bethke was guided by PSD’s sustainability principles for reducing waste, specifying low-impact materials and creating healthy environments. PSD reduced construction waste by 75%, used recycled materials throughout the school, incorporated daylighting into 90% of occupied spaces and supported high indoor air quality by including CO₂ sensors with demand control ventilation.

PSD applied energy-efficient technologies to improve performance including direct/indirect evaporative cooling, high-efficiency boilers, energy recovery, thermal displacement ventilation, variable frequency drives, energy-efficient lighting, daylighting, ENERGY STAR equipment and an energy-efficient envelope. The solutions applied to daylighting and mechanical systems benefited from the experience gained during several cycles of prototype design, which directed the design’s refinement. The evolved design for Bethke is well suited to the local climate and also works well for the District’s maintenance staff.

This article was published in High Performing Buildings, Winter 2010. Copyright 2010 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Posted at www.hpbmagazine.org. This article may not be copied and/or distributed electronically or in paper form without permission of ASHRAE. For more information about High Performing Buildings, visit www.hpbmagazine.org.
We found that some of our best successes came from dropping our fences and listening to others’ ideas,” Reeve said.

Architectural Energy Corporation has provided energy analysis, daylighting design, and commissioning services on a repeated basis to PSD. This gave the commissioning authority an opportunity to learn the client’s needs and the maintenance staff’s preferences.”

As a result, the authority can better represent PSD’s interests in design team meetings. Daylighting, energy analysis and design advances from one iteration to the next (Table 2). New ideas can readily be incorporated into existing models and calculations.

While a typical project budget allows for 5% to 6% of spending for design, PSD may spend closer to 8%. PSD would rather take longer on the front side of a project to be sure it’s built correctly.

“If you give people the latitude to be innovative, it’s amazing what can be done within tough parameters,” Reeve said.

PSD’s approach has resulted in tightly managed project design and construction costs. Savings reaped from the construction of six buildings between 2002 and 2007 were significant enough to cover the costs to construct Bethke, which was not planned as part of the 2000 school bond that included the other buildings.

Prototype Approach
PSD takes a prototype design approach to reduce the costs and time associated with building new schools. RB+B Architects developed PSD prototypes for a high school, middle school and elementary school.

Four schools have been built from the elementary prototype design. Each of the elementary schools have the same orientation and floor plan, but improvements have been made to the envelope, glazing, solar control, daylighting controls and mechanical systems over time.

The prototype elementary was designed for high performance from the beginning. Set on an east-west orientation, classrooms face true north or true south and are housed.

Collaboration is Key
Over the last decade, PSD has built long-lasting relationships with members of the design team, including not only the architecture and engineering firms but also a commissioning authority, daylighting designer, energy analyst, facility managers, students, staff, administrators, maintenance, operations, designers and their utility companies.

### TABLE 1 METRICS FOR NEW PSD BUILDINGS

The Poudre School District’s seven newest buildings, constructed according to the district’s sustainability design guidelines, all achieve high efficiency and high ENERGY STAR ratings.

<table>
<thead>
<tr>
<th>Building</th>
<th>Year Constructed</th>
<th>Floor Area (ft²)</th>
<th>Max Peak Demand (W/ft²)</th>
<th>Energy Cost ($/ft²·yr)</th>
<th>Energy Use (kBtu/ft²·yr)</th>
<th>ENERGY STAR Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operations Office</td>
<td>2002</td>
<td>8,753</td>
<td>3.4</td>
<td>0.44</td>
<td>19.0</td>
<td>99</td>
</tr>
<tr>
<td>Zach Elementary*</td>
<td>2002</td>
<td>67,412</td>
<td>1.7</td>
<td>0.54</td>
<td>42.6</td>
<td>96</td>
</tr>
<tr>
<td>Bacon Elementary</td>
<td>2003</td>
<td>65,299</td>
<td>1.6</td>
<td>0.54</td>
<td>45.7</td>
<td>97</td>
</tr>
<tr>
<td>Fossil Ridge High School</td>
<td>2004</td>
<td>296,375</td>
<td>2.3</td>
<td>0.56</td>
<td>40.9</td>
<td>94</td>
</tr>
<tr>
<td>Kinard Middle</td>
<td>2006</td>
<td>112,735</td>
<td>2.6</td>
<td>0.39</td>
<td>21.6</td>
<td>98</td>
</tr>
<tr>
<td>Rice Elementary</td>
<td>2007</td>
<td>62,691</td>
<td>1.4</td>
<td>0.75</td>
<td>41.5</td>
<td>99</td>
</tr>
<tr>
<td>Bethke Elementary</td>
<td>2008</td>
<td>62,691</td>
<td>1.5</td>
<td>0.58</td>
<td>41.7</td>
<td>99</td>
</tr>
</tbody>
</table>

*Includes 7,200 ft² of modular classrooms

Ninety percent of occupied spaces use natural light and more than 80% of the windows are operable. Classrooms are housed in a two-story portion of the building, which reduces the building envelope size and roof area.

Advanced technology, design flexibility, world-class efficiency... Multi-V Mini sets a new standard in innovative comfort solutions.

Benefits Include:
- One of the industry’s highest EER ratings – Multi-V Mini uses state-of-the-art inverter technology for enhanced energy efficiency.
- Design flexibility – Whether for new construction or a retrofit, a broad range of condenser and evaporator capacities are available to suit any application.
- Simplified Installation – Industry-leading pipe lengths connect up to 8 indoor systems to a single outdoor unit.
- Total comfort – Room-by-room temperature control plus some of the industry’s lowest noise levels.

To see LG’s complete line of AC products, visit www.LGHVAC.com
PSD has applied lessons learned from past building designs to increase efficiency, comfort, and maintainability.

The design team sought to create an engaging facility that helps further education both inside and outside the classroom. The exposed red fire sprinkler pipes and HVAC ducts allow students to view the school’s mechanical components.

The coffered ceiling, designed to disperse daylight from top lighting via solar tubes, was simplified at Bethke to improve constructability.

**Evolving Design**

For Rice Elementary and Bethke Elementary, the already efficient envelope design was improved by using a spray-applied polyurethane/soy-based insulation on the exterior of the insulated stud wall. This modification was incorporated after infrared camera images showed heat loss through the metal stud wall. The spray foam insulation has a high R-value per inch and forms a seamless monolithic barrier that prevents air and water infiltration.

The daylighting design in the schools has evolved to address solar control issues. Materials used for exterior overhangs were refined to eliminate gaps or perforations. Vision glazing has gotten lighter (more clear) with each school.

In the previous schools, interior shades or a system designed to redirect daylight and control solar glare were used to improve glare control for daylight glass around the winter solstice. The Bethke design has less south glazing in the classrooms. The south glazing in the gym has been replaced with a translucent insulating panel daylighting system.

Toplighting from skylights has increased throughout the school. Bethke incorporates 140 solar tubes, which explains the high percentage of daylit space.

The four elementary schools have overhead variable air volume air distribution systems. For large spaces, such as the gym and cafeteria, a thermal displacement ventilation system design introduces conditioned air close to the floor at a low velocity.

The system provides fresh air at the occupant level and encourages zone stratification, which results in greater distribution system efficiency. The schools also use demand control ventilation to minimize the outdoor air introduced into the larger building spaces during low occupancy periods.

**TABLE 2**

<table>
<thead>
<tr>
<th>Building</th>
<th>Envelope</th>
<th>Daylighting</th>
<th>Air Distribution System</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operations Office</td>
<td>Insulated stud wall plus rigid board</td>
<td>Daylight/vision glazing Dimming daylighting control No solar tubes</td>
<td>Ground source heat pump</td>
<td></td>
</tr>
<tr>
<td>Zach Elementary</td>
<td>Insulated stud wall plus rigid board</td>
<td>Daylight/vision glazing Dimming daylighting control Some solar tubes</td>
<td>Variable air volume Air-cooled chiller Ice thermal storage Energy efficient boilers</td>
<td></td>
</tr>
<tr>
<td>Bacon Elementary</td>
<td>Insulated stud wall plus rigid board</td>
<td>Daylight/vision glazing Dimming daylighting control Some solar tubes</td>
<td>Variable air volume Air-cooled chiller Ice thermal storage Energy efficient boilers</td>
<td></td>
</tr>
<tr>
<td>Fossil Ridge High School</td>
<td>Insulated stud wall plus rigid board</td>
<td>Daylight/vision glazing Dimming daylighting control Some solar tubes</td>
<td>Variable air volume Indirect/direct Four pipe fan coils</td>
<td>Air-cooled chiller Ice thermal storage Energy efficient boilers</td>
</tr>
<tr>
<td>Kinard Middle</td>
<td>Insulated stud wall plus 3 in. spray foam</td>
<td>Daylight/vision glazing On/off daylighting control More solar tubes</td>
<td>Variable air volume Energy recovery</td>
<td>Ground source heat pump</td>
</tr>
<tr>
<td>Rice Elementary</td>
<td>Insulated stud wall plus 2 in. spray foam</td>
<td>Daylight/vision glazing On/off daylighting control More solar tubes</td>
<td>Variable air volume Cooling tower Energy efficient boilers</td>
<td></td>
</tr>
<tr>
<td>Bethke Elementary</td>
<td>Insulated stud wall plus 2 in. spray foam</td>
<td>Daylight/vision glazing On/off daylighting control Even more solar tubes</td>
<td>Variable air volume Indirect/direct Energy recovery</td>
<td>Cooling tower Energy efficient boilers</td>
</tr>
</tbody>
</table>

**BUILDING ENVELOPE**

- **Roof**
  - Type: Built-up roof with continuous insulation
  - Overall R-value: R.30
  - Reflectivity: 0.3
- **Walls**
  - Type: Insulated steel stud with 2 in. spray foam, brick face
  - Overall R-value: R.19
  - Glazing percentage: 26%
- **Basement/Foundation**
  - Slab edge insulation R-value: R.15
- **Windows**
  - U-value: 0.42 (overall)
  - Solar Heat Gain Coefficient (SHGC): 0.28 vision, 0.38 daylight
  - Visible Transmittance: 0.36 vision, 0.47 daylight
- **Location**
  - Latitude: 40.5° N
  - Orientation: long east-west axis

The four elementary schools all use high-efficiency builders for heating and domestic hot water. The cooling systems, however, differ between Zach/Bacon and Rice/Bethke because they are served by...
The Media Center’s floor-to-ceiling height permits daylight from clerestories to enter deep into the core.

Design Impact on Performance

Four elementary schools based on the same prototype design and operating schedule provide the opportunity to see actual performance benefits from design modifications. (See Table 1 and Figure 1 for normalized building energy use data.)

While differences exist between the rate schedules and cooling plant designs of the elementary schools, they have surprisingly similar energy use intensity. Rice’s energy use is similar to the other schools, but its energy costs are higher due to its gas contract.

Bethke has energy recovery, while Rice does not. However, the utility data do not show lower gas use for Bethke. This raises questions about the effectiveness of Bethke’s energy recovery system.

Rice and Bethke have similar energy costs even though the latter school’s electric rate schedule differs. This demonstrates PSD’s active management of ice storage charging/discharging for load control at Zach and Bacon.

Zach and Bacon have similar energy costs even though the latter school’s electric rate schedule differs. This demonstrates PSD’s active management of ice storage charging/discharging for load control at Zach and Bacon.

For example, the target consumption for Bethke was 40 kBtu/ft² yr. Actual consumption in its first year of operation was 42 kBtu/ft² yr.

In the two buildings with ground source heat pumps, the operations office and Kinard Middle School, energy use and costs are noticeably lower. Normalized energy use is about half that of the other buildings, and normalized energy costs are lower by about 20%.

For the GSHP buildings, normalized peak demand is about double that of the other buildings and occurs in winter. It decreases by about 30% in summer, but is still noticeably higher than the other schools.

Rice and Bethke, with their indirect/direct evaporative cooling systems, have the most consistent peak demand over the year, which varies by only about 10 kW. Again, the data show that PSD has matched its system design well to the rate structure of its buildings.

Considering Carbon

Carbon emissions for the seven PSD buildings were determined using factors published in the EPA eGRID database for Colorado electricity generation and those published by EIA for piped natural gas (Figure 2). PSD’s actual emissions are lower because it subscribes to wind energy programs that offset 100% of the district’s energy use. PSD pays its utilities an additional $0.01/kW h to have its electricity generated by wind power sources. The programs are Green-e certified, which protects customers from paying for renewable energy that is double sold to other customers or used simultaneously to meet regulatory mandates.

For the GSHP buildings, is worse than using electricity generated from coal.

For many owners, the increased capital and maintenance costs associated with GSHPs often build a case against them. And a cursory consideration of carbon might make one think that with GSHPs often build a case against them.

Figure 2 shows that Rice and Bethke have lower emissions than the elementary schools with chillers and ice thermal storage. But how do they compare to the buildings with GSHPs? Even with coal comprising 75% of Colorado electricity generation, the emissions level for the GSHP middle school (Kinard) is lower than the indirect/direct elementary schools’ (Rice and Bethke) emission levels.

For many owners, the increased capital and maintenance costs associated with GSHPs often build a case against them. And a cursory consideration of carbon might make one think that using electricity generated from coal for heating, as is the case with these GSHP systems, is worse than using a free-cooling economizer mode. An indirect/direct system makes the most of free cooling. But higher supply air temperatures tend to increase fan energy use.

For many owners, the increased capital and maintenance costs associated with GSHPs often build a case against them. And a cursory consideration of carbon might make one think that using electricity generated from coal for heating, as is the case with these GSHP systems, is worse than using a free-cooling economizer mode. An indirect/direct system makes the most of free cooling. But higher supply air temperatures tend to increase fan energy use.
While Reeve has seen school GSHP systems with high installation costs and maintenance issues, PSD did not encounter those issues with its two GSHP projects. Reeve believes a critical component was the collaboration between the mechanical engineer and the geo-exchange consultant. Also, heat pump components should come from a reputable manufacturer.

The mechanical system costs for Kinard fell under $15/SF, the benchmark for PSD’s standard mechanical system cost. Reeve would like to have more GSHP systems in the district. But modifying a prototype with a major system change takes extra time and money, so Bethke was constructed with the elementary prototype plant design.

For this case, the benefit of having a coefficient of performance (COP) greater than one for heat generation appears to outweigh the carbon penalty associated with relatively low electric utility plant conversion efficiency.

Figure 2 presents the annual carbon emissions for the seven PSD buildings. Surprisingly, even with coal comprising 75% of Colorado electricity generation, the emissions from on-site natural gas for heating. Yet data from PSD tell a different story. While Reeve has seen school GSHP systems with high installation costs and maintenance issues, PSD did not encounter those issues with its two GSHP projects. Reeve believes a critical component was the collaboration between the mechanical engineer and the geo-exchange consultant. Also, heat pump components should come from a reputable manufacturer. The mechanical system costs for Kinard fell under $15/SF, the benchmark for PSD’s standard mechanical system cost. Reeve would like to have more GSHP systems in the district. But modifying a prototype with a major system change takes extra time and money, so Bethke was constructed with the elementary prototype plant design.

Energy Analysis
The Bethke project participated in an Xcel Energy demand-side management program that provides design assistance for new construction to commercial and industrial customers in Colorado and Minnesota. The utility’s program supports an integrated design approach and provides modeling and financial incentives for achieving increased energy efficiency in new construction design. Through the support of the utility, Architectural Energy Corporation developed a computer simulation model to evaluate the proposed design and to design alternates for Bethke. A model was previously developed for Rice, but the financial support from the utility’s program enabled the firm to develop a more detailed simulation model and evaluate additional energy conservation strategies for Bethke.

Some strategies that were analyzed include indirect cooling with heat exchange from a lake, tower free cooling, thermal displacement ventilation, demand-control ventilation, daylighting controls, black-out emergency lighting, overhangs and high-efficiency transformers. The model also checked whether the proposed design maintained classroom comfort conditions.

Large spaces such as the gymnasium and cafeterias use thermal displacement ventilation to deliver low velocity conditioned air into the occupied zone. This results in less mixing and more effective ventilation.
The energy use for Bethke is close to what was anticipated relative to the historical performance data collected for other elementary schools. The M&V plan prepared for the project includes points to track to identify control and operational issues as well as the Option D International Performance Monitoring and Verification Protocol (IPMVP) approach for reconciling predicted and actual performance and calculating energy savings. The energy modeler aims to give PSD a value proposition in implementing the M&V plan. As part of the M&V, the firm will look into the performance data deep enough to explain the difference between predicted and actual energy consumption. Once the difference is understood and reconciled, the baseline model will be updated and savings will be recalculated.

Future Path

Two terms define PSD’s future energy path—net zero energy and flex energy. PSD hopes to achieve net zero energy by establishing tougher performance goals and incorporating renewable energy sources like solar and biomass into projects. The district is aiming for 60% lower energy costs than a minimally compliant Standard 90.1-2004 building and 35 kBtu/ft²-yr or better in energy consumption. Like Bethke, PSD buildings will be built using low-carbon technologies today, flex energy, and more affordable. While it might not make sense to invest in new low-carbon technologies today, flex energy buildings are designed to accommodate them in the future.