10. Facility Type: K–12 Schools

Revised November 2006

10.1 Challenges and Opportunities

America's schools spend more than $7.5 billion annually on energy—more than they spend on textbooks and computers combined. Energy costs are the largest operating expense for school districts after salaries and benefits, and in recent years those costs have increasingly strained their budgets. The good news is that energy is one of the few expenses that can be decreased without negatively affecting classroom instruction.

As energy has become a larger and less predictable expense, it is imperative that school districts invest in retrofits and ongoing maintenance to assert control over their utility costs. Yet school districts perpetually struggle to budget appropriately for operations, maintenance, and capital projects. High-dollar capital projects are the first to go when budgets are cut, and trimming maintenance expenditures is more palatable to school boards than cutting instructional staff. It's also not unusual for school districts to build new schools or additions without making corresponding increases to maintenance spending and staff.

The result is an accumulation of deferred maintenance, which leads to higher energy costs and more equipment malfunctions. Lack of preventive maintenance reduces the operational life of building equipment, hastening the need to invest in costly capital retrofits.

Increasingly, facility condition is being recognized as an important factor for student learning. Lawsuits regarding inadequate funding for education in dozens of states have shifted the focus from spending per school or per student to the condition of school buildings. This trend is pushing school districts to better manage their facility assets.

Several aspects of building performance are fundamental in providing an environment that is conducive to learning. Research has shown a relationship between facility conditions and absenteeism, teacher turnover rates, and occupant health. The following factors should be considered integral to your energy-saving retrofit choices. Fortunately, many upgrade choices can improve these factors while cutting energy consumption.

- *Security and safety* can be enhanced with proper exterior lighting as well as adequate lighting in hallways and stairwells. Security of operable windows is another consideration.
- *Indoor air quality* can be improved with ventilation as well as by removing the source of pollutants. Indoor pollutants may include gases (such as radon), chemicals (for example, cleaning agents), mold, and particulates. Because children have higher breathing and metabolic rates than adults, they are more vulnerable to many environmental threats. High concentrations of carbon dioxide (CO2) have been correlated with sickness as well as poor academic test performance. Ventilation may be particularly important in factory-built relocatable classrooms that incorporate pressed-wood materials containing formaldehyde.
- *Thermal comfort* also has an impact on student performance. Warm temperatures reduce alertness, whereas cold temperatures reduce dexterity. Frequently and widely fluctuating temperatures can hinder children's ability to focus, although broader fluctuations tend to be more acceptable with natural ventilation.
- *Visual comfort* depends on having an adequate amount of evenly distributed illumination. "Daylighting in Schools: Reanalysis Report" (www.newbuildings.org/downloads/FinalAttachments/A-3_Dayltg_Schools_2.2.5.pdf), a major study conducted in 2003 by the Heschong Mahone Group, found that on average daylighting improves learning by 21 percent.

- *Acoustic comfort* is vital because up to 60 percent of classroom activities involve spoken communication. Noise from outside the building, interior hallways, and building systems (such as fans, boilers, and compressors) can be a significant distraction. Even the way sound reverberates within a classroom can cause levels of discomfort and stress that interfere with learning.

10.2 Energy-Use Profile

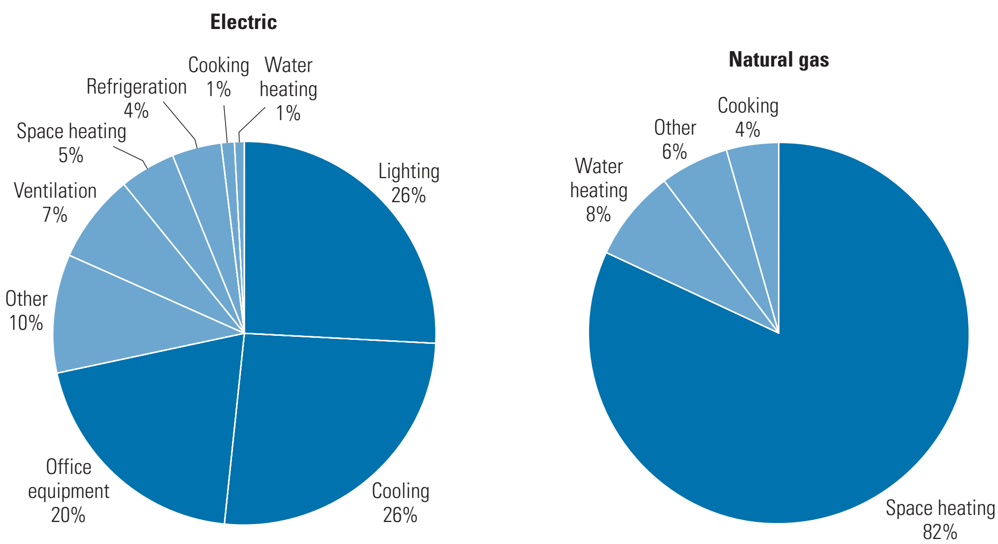
When planning your retrofit strategy, consider a school's largest energy loads. Typically, space heating, cooling, and lighting together account for nearly 70 percent of school energy use (see **Figure 10.1**). Plug loads—such as computers and copiers—constitute one of the top three electricity end uses, after lighting and cooling.

Energy intensity in schools varies widely and is influenced by both weather conditions and specific operating characteristics such as building size, classroom seating capacity, and the presence of an on-site cafeteria. On-site energy intensity in schools can range from under 10,000 Btu per square foot (ft^2) to over 500,000 Btu/ft^2 (**Figure 10.2**). Given this large variation and skewed distribution, it can be misleading to assess a school building's performance by comparing its average energy intensity.

The EPA's national energy-performance rating system is designed to provide a meaningful benchmark for a school building. The rating system is accessible online as part of the EPA's free Portfolio Manager tool (www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager). It evaluates a school's energy intensity, normalizing for weather and operating characteristics. The rating is expressed as a score on a scale of 1 to 100, signifying the percentile of performance.

Figure 10.1: Electric and natural gas end-use profiles for educational facilities

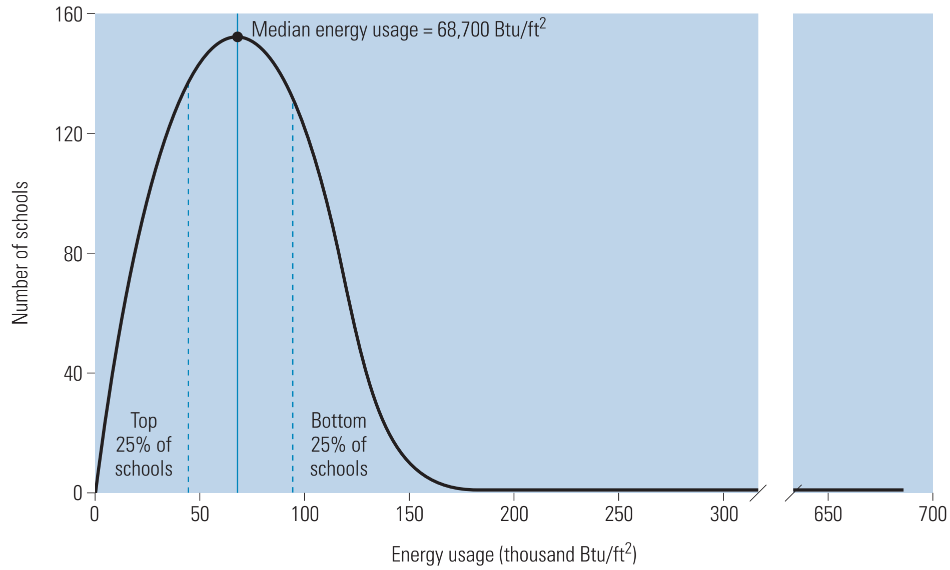
Most of the electricity consumed by educational facilities is used to for lighting, cooling, and plug loads such as computers and copiers; most of the natural gas is used for space heating. Each school's energy profile is different, so these charts are not representative of all schools. For example, school buildings in warmer climates will tend to show a larger share of electricity used for space cooling than those in cooler climates.



Courtesy: E SOURCE; from Commercial Building Energy Consumption Survey, 1999 data

Figure 10.2: Distribution of energy intensity in school buildings

This curve shows the overall distribution of energy use intensity among a national sample of K–12 school buildings. By fitting a curve to the survey data, we can see that most schools tend to cluster around the median energy use intensity of approximately 68,700 Btu per square foot (ft^2) from all energy sources. Many school buildings are significantly more energy-intensive than the median.



Courtesy: E SOURCE; from Commercial Building Energy Consumption Survey, 2003 data

Schools that earn a score of 75 or higher are performing in the top quartile and may be eligible to earn the ENERGY STAR label. The score serves as a standard of comparison against other schools and a way to evaluate performance after upgrades are implemented.

All upgrade projects should begin by establishing a benchmark. Use the ENERGY STAR rating system to identify your best- and worst-performing facilities. Although any school may benefit from retrocommissioning, operational improvements, and retrofits, you may choose to begin with low-scoring facilities.

10.3 Technical Recommendations

Considering that schools spent nearly $75 per student on gas bills and $130 per student for electricity in 2005—up 20 percent overall from 2003—it makes sense to invest some effort and capital to contain these mounting costs. Because maintenance resources are in short supply for school districts, it's also important to consider the maintenance implications of any systems a district plans to retrofit or replace.

Although school designs and systems vary, some common reasons for initiating energy-related school upgrades are:

- Frequent equipment malfunctions and shortened equipment lifetime due to years of deferred maintenance;
- Piecemeal additions to buildings and internal changes to existing spaces that haven't been accompanied by corresponding changes to heating and cooling systems;

- Previous attempts to reduce energy use by inappropriate measures, such as blacking out windows or covering vents;
- Portable classrooms with inadequate ventilation systems, high levels of indoor air pollutants, and poor acoustics;
- Multiple rooftop air-conditioning units that are hard to control and maintain properly as compared with a central cooling system; and
- Major capital equipment, such as a boiler or a roof, that is nearing the end of its useful life.

When the goal is energy savings, it may be tempting to focus on the lowest-cost retrofits with the quickest return on investment, such as lighting. But combining a mix of lower- and higher-cost measures will produce better results in the end. This approach allows you to use savings from the lower-cost fixes to help purchase big-ticket items—and get a bigger and longer-term return overall. For example, a boiler replacement can have a payback of less than 6 years when combined with other energy-saving retrofits; otherwise, a school district may not reach payback for that new boiler for as long as 60 years. And using the staged approach that is advocated throughout this manual can reveal opportunities for saving on capital costs by "right-sizing" major equipment. After lighting and load reduction measures have been implemented, it may be possible to specify smaller heating and cooling equipment.

Many of the following recommendations provide not only energy savings but also maintenance savings. Please note that this should not be considered an exhaustive list of measures appropriate for schools. School facility directors are encouraged to refer to the full guidelines presented throughout this manual when planning and managing a retrofit program.

Retrocommissioning

Energy savings and other benefits. Problems uncovered during commissioning tend to have energy implications. Most concern HVAC systems—in particular, air distribution systems. At a typical 100,000-ft^2 school, retrocommissioning can uncover about $10,000 to $16,000 in annual energy savings, on average. The amount of savings will depend on the types of problems that are identified and the remedies that are implemented.

In addition to saving energy, retrocommissioning can reduce equipment downtime and keep maintenance expenditures in check. Because poorly performing ventilation systems can be a culprit in student sickness rates, retrocommissioning may also reduce absenteeism and improve learning.

Another reason to regularly perform retrocommissioning on schools is to create a body of documentation demonstrating that building systems are operating properly. Such information can be invaluable in the event that a related lawsuit is filed. Retrocommissioning is an important tool for ensuring that a school district's indoor air quality standards are met. Safety is another consideration if the fire alarm and smoke-detection systems are integrated with other building systems. Problems with low-voltage electrical systems such as lighting, alarm, and building management systems are frequently identified during retrocommissioning.

Best practices. Some school districts are implementing guidelines and establishing standard contractual requirements to ensure that retrocommissioning is done properly and in a timely fashion. If district staff have sufficient expertise and familiarity with a building's systems, they may carry out commissioning, but otherwise, it's advisable to outsource the work.

The Collaborative for High Performance Schools (www.chps.net) recommends that selected building systems undergo retrocommissioning every two to three years. Retrocommissioning should also be performed after major remodels or additions.

Even if a school was commissioned when it was first built, the building's use patterns may have changed over time, settings may have been altered, and equipment may no longer be functioning the way it should. If a school appears to be using more energy than expected when compared with past performance or with other schools, retrocommissioning is a great place to start looking for energy-savings opportunities. A simple, accurate way to benchmark energy performance is to enter energy consumption and building data for all schools in a district into the ENERGY STAR rating system and then compare scores. Other signs that it's time for retrocommissioning include inadequate ventilation (see sidebar) or a high volume of comfort-related calls from occupants.

Training and documentation. The benefits of retrocommissioning can be sustained through proper training of maintenance staff. A retrocommissioning contract should always specify that maintenance staff will receive initial training and manuals. Multiple copies of manuals that document system warranties, instructions for operations, and maintenance requirements should be kept on-site and by the district manager of facilities.

Training can cover topics such as equipment warranties and maintenance, operational schedules and setpoints, start-up and shutdown, emergency procedures, and an overview of air quality and comfort issues. Other staff—including regular and substitute teachers as well as office staff—should receive training and reminders on how to operate controls, window coverings, and computers properly. Such training could be repeated during the school year if there were significant staff turnover. Instruction can be provided at meetings, in special training sessions, or in printed manuals and videos of training sessions.

Integration with facility planning. School districts that establish multiyear maintenance plans that are approved at the board level are more likely to fund maintenance needs continuously. A multiyear plan can be used for prioritizing projects (depending on the funding available) while keeping the longer-term impact of those decisions in perspective. This type of plan can

CASE STUDY: Retrocommissioning in Minnesota

A facility manager at Farmington Middle School West in Minnesota noticed some telltale signs that the building was not operating efficiently: Positive building pressure sometimes prevented the exterior doors from closing, and variable-frequency drives for air handlers were running at top speed almost continuously. A retrocommissioning study partially subsidized by the school's energy provider uncovered $12,000 in possible annual electricity savings. The energy conservation measures implemented at the school yielded a payback period of just 2.4 years after additional utility rebates. (Payback would have taken 3.5 years without the rebate.)

At another school in Minnesota, outside air ventilation rates were insufficient and test-and-balance contractors had been unable to solve the problem. That was the primary reason retrocommissioning contractors were called in, but the school turned out to be an ideal candidate for retrocommissioning because it had been through several rounds of remodeling and additions. The result was a hodgepodge of HVAC systems, including 48 air handlers for a single-story, 220,000-ft^2 building. The retrocommissioning was implemented with other retrofits under a performance contract, and the resulting energy savings substantially exceeded the contractor's forecasts. The unexpected additional energy savings, which were attributed to the retrocommissioning work, were retained by the school district.

be structured around the results of a complete retrocommissioning of select facilities as well as an assessment of the condition of all buildings in the district. A typical facility condition assessment includes reviewing the age and condition of building components and then estimating their remaining expected lifetime and replacement costs. The "Guide for School Facility Appraisal," one model for condition assessment, is available from the Council of Educational Facility Planners International (www.cefpi.org/pubs.html).

School districts can use the EPA's Healthy School Environments Assessment Tool (HealthySEAT, http://epa.gov/schools/healthyseat/index.html) to store and track data on facility conditions. The program is customizable for managing a variety of facility conditions, including nonenvironmental issues. The EPA recommends that an assessment be conducted at each school at least once a year.

Lighting

Energy savings. Lighting represents about 26 percent of electricity consumption in a typical school, not including its impact on cooling loads. Lighting retrofits can save as much as 30 to 50 percent of lighting energy, plus 10 to 20 percent of cooling energy.

Best practices. Having enough light—but not too much—is the most important lighting criterion for classrooms (see **Table 10.1**). Students must be able to view the teacher and the work on their desktops comfortably, while quickly and frequently alternating between these positions. They should not have to strain their eyes to adjust to different types of tasks, as is the case with inadequate or high-contrast lighting.

The Illuminating Engineering Society of North America (IESNA) sets illumination standards by task. Keep in mind that the IESNA guidelines do not heavily emphasize energy savings or daylighting. When daylighting is incorporated into a classroom lighting strategy, the range of illumination levels can vary much more widely than with electric lighting alone.

Outdoor nighttime light levels may depend on local ordinances, but can generally be fairly low, depending on the level of activity and the potential hazards.

Daylighting. Natural daylight has been shown to enhance learning and so should be utilized wherever it is possible without negatively affecting other important aspects of lighting design. Energy savings is another major benefit of daylighting, and a significant portion of energy savings

Table 10.1: Illumination recommendations for classrooms with daylighting

The level of illumination in daylit classrooms can vary from 30 to 250 foot-candles and still be acceptable for most tasks. Usually, an average of 40 to 45 foot-candles is acceptable, which means that much of the room would have about 50 foot-candles of illumination.

Activity	Task light level (average at student desks)	Acceptable variation of task light level	Other considerations
Reading, artwork, social time	45 foot-candles (minimum 30)	30 to 250 foot-candles	Daylight glare should be controlled
Lecture with chalkboard or whiteboard	45 foot-candles (minimum 30)	30 to 250 foot-candles; may benefit from dimming to lower levels	May require additional vertical surface lighting for chalkboard or whiteboard
Multimedia lecture with screen projection (film, slides, or television)	15 foot-candles	Dimming to lower levels is acceptable; higher levels should be avoided	Maximum lighting on screen is 5 vertical foot-candles; use shades as required

Courtesy: Collaborative for High-Performance Schools from a lighting retrofit can come from better utilizing natural light. In Johnston County, North Carolina, two daylit middle schools averaged energy bills that were more than 30 percent less than at similar schools, which school officials attribute to the schools' daylighting approach.

Daylighting is an excellent strategy not only for classrooms, but also for administrative offices, gymnasiums, and meeting rooms. Whenever possible, any lighting renovation should start by using daylighting as much as possible and reducing electric lighting accordingly. Good daylighting design will not introduce excessive heat gain, heat loss, glare, or uneven illumination. These problems can arise in cases where bright daylight streams through a bank of windows on one wall in a classroom. In its daylighting implementation, Bacon Elementary in the Poudre School District in Colorado alleviates these problems by using highly reflective paint on the ceiling and the upper portion of walls to distribute light more evenly. In addition, a system of dimmers and light sensors that uses photocell technology enables supplemental electric lighting to automatically adjust as needed.

Although a complete redesign of a lighting scheme to incorporate daylighting may be too costly for most renovation projects, some measures can be cost-effective. Light pipes, which deliver daylight from roof or exterior wall-mounted collectors through reflective tubes, can be a fairly low-cost retrofit for schools, particularly for meeting rooms or other staff rooms that lack windows. Newer light-pipe designs that make it possible to adjust the light flow can also be used in media centers.

Proper shading on existing windows can reduce heat gain and glare while still providing enough daylight to eliminate electric light usage for much of the school day. Check that blinds are in good condition. In rooms with high windows or transoms, try separate shades for the main (lower) and upper windows. This way, bright light can flow through the upper windows even when the lower shades are down to keep out glare and heat. This strategy would be particularly effective with dimmable lights and reflective ceilings. Then, when the teacher needs to darken the room for a video presentation, both the upper and lower shades can be closed. Additionally, consider applying window films that block solar heat and installing light shelves and exterior shades or overhangs.

Electric lighting. A mixture of light sources can create a pleasing and comfortable environment that is suitable for a variety of tasks. Electric lighting should be coordinated with a daylighting scheme or adjusted in response to it. A blend of direct and indirect electric lighting can provide soft and uniform illumination.

If a facility uses T12 fluorescent lamps, relamping with modern T8 lamps and electronic ballasts can reduce lighting energy consumption by 35 percent. Adding specular reflectors, new lenses, and occupancy sensors or timers can double the savings. Paybacks of one to three years are common. This retrofit is appropriate for most space types in a school, including classrooms, cafeterias, and offices.

Compact fluorescent lamps (CFLs) can replace incandescent lamps in many applications, reducing energy use by two-thirds and yielding savings of up to $20 per lamp per year. Use CFLs in sconces and downlights in hallways and auditoriums, as well as in task lamps for teachers' desks and in the library. They are also appropriate for task lighting in computer labs and study areas.

High-intensity fluorescent lamps are a good alternative for gymnasiums, where high-intensity discharge (HID) lamps, such as metal halide and high-pressure sodium lamps, are often used. High-intensity fluorescents, either high-performance T8 lamps or high-output T5 lamps, feature virtually instant start-up and restrike times (making them candidates for occupancy sensors), better dimming capability than HIDs, and lower heat output, which means reduced air-conditioning loads. At Bryant College in Smithfield, Rhode Island, school officials replaced HID fixtures in the gymnasium with fluorescent fixtures, partly so lights could be dimmed. This retrofit also improved the distribution of illumination throughout the facility and eradicated hot spots that made some areas in the bleachers uncomfortable for spectators. The combination of high-intensity fluorescents with occupancy sensors in gyms reduces both the risk of lights being left on unnecessarily and the inconvenience of waiting for lights to start up. High-intensity fluorescents may also be useful for auditoriums and libraries where ceilings are more than 15 feet high.

If you're not already using light-emitting diodes (LEDs) in exit signs, this is one retrofit that is usually a clear winner, not only for how much energy it can save but also for maintenance savings. An ENERGY STAR–rated LED exit sign can last 25 years without lamp replacement, compared with less than 1 year for an incandescent sign. LEDs are also excellent for gymnasium scoreboards. In this application, LEDs outperform incandescents in many ways: They withstand impacts better, typically feature lower maintenance costs, and their brightness and clarity provide better viewing from a wider range of vantage points and in a variety of ambient light levels. Full-matrix displays are also entirely flexible, so they can support multiple types of sporting events. LED scoreboards still cost more up front, but those costs have dropped significantly and the operational savings are substantial.

Often, school athletic fields are illuminated by incandescent and quartz lighting systems, but these are being replaced. Lighting professionals recommend metal halide lights that use less energy, last three times longer, and reduce glare. In 2003, Hillsborough County in Florida upgraded to metal halide lamps at 130 outdoor fields and courts and estimated savings in the first year of $7.7 million in energy costs, plus maintenance savings.

Controls. Occupancy sensors save energy but also help to reduce maintenance costs by lengthening the relamping interval. Turning fluorescents off for 12 hours each day can extend the expected calendar life to nearly seven years—a 75 percent increase. Controls that provide continuous rather than stepped dimming will be less disruptive in classrooms. Wall switches should be available in classrooms so that teachers can override occupancy sensors if they need to. In large restrooms, ceiling-mounted ultrasonic occupancy sensors detect occupants around partitions and corners. For hallways, a recommended strategy is to use a combination of scheduled lighting and dimming plus occupancy sensor controls after hours. Occupancy sensors are also appropriate for storage and faculty rooms.

Load Reductions

Energy savings. Load reduction measures that reduce the operational time or intensity of HVAC equipment while still maintaining a comfortable work environment can offer substantial savings. Plug loads from equipment such as computers and copiers represent about 20 percent of electricity used in education buildings. Cooking equipment represents a much smaller portion of total energy used by schools, but equipment purchases and operational measures for school kitchens can be very cost-effective. When purchasing these types of items, look for ENERGY STAR–qualified products (www.energystar.gov/index.cfm?c=bulk_purchasing.bus_purchasing), which use 10 to 50 percent less energy than conventional models without compromising quality or performance. Not only do they offer significant return on investment because of these savings, many also feature longer operating lifetimes and lower maintenance requirements.

Best practices. The quickest and easiest way to implement load reductions is to ensure that equipment is turned off when it's not needed. This can be accomplished by recruiting student volunteers or custodial staff as monitors. Students are often eager to participate in initiatives like Michigan's Green School program, which was enacted by the state legislature in 2006. For example, students can form teams to circulate through the school at the end of the day, leaving reminders where they discover lights and computers left on.

Even if computers are shut down at nights and on weekends, at least half the energy consumed by computers may be wasted because they are on continuously through the school day. A computer monitor can use two-thirds of the total energy of a desktop system, so it is important to power down monitors whenever they are not in use. The ENERGY STAR Power Management program provides free software that can automatically place active monitors and computers into a low-power sleep mode through a local area network (www.energystar.gov/index.cfm?c=power_mgt.pr_power_management). Whole-computer power management can save $15 to $45 annually per desktop computer; managing only monitors can save $10 to $30 per monitor annually.

As an example, though the North Thurston Public Schools in Washington State were already using monitor power management, the school district also installed ENERGY STAR's free EZ GPO network software to apply computer power management. North Thurston has more than 4,000 computers and is now saving $45,000 per year.

For schools with pools, simply using a cover on a heated pool can save 50 to 70 percent of the pool's energy use, 30 to 50 percent of its makeup water, and 35 to 60 percent of its chemicals. In the kitchen, food preparation equipment shouldn't be turned on for preheating more than 15 minutes before it is needed—simply reducing the operating time of kitchen appliances can cut cooking-related energy consumption by up to 60 percent. Hot water waste should be reduced in kitchens, bathrooms, and locker rooms; some measures to consider include automatic faucet shutoff, single-temperature fittings, and low-flow showerheads with pause control.

Efficient equipment procurement. A simple way to ensure that purchased equipment is energy efficient is to request that school district procurement officials specify ENERGY STAR–qualified products in their contracts or purchase orders. Additionally, the product recommendations for federal government procurement officials from the U.S. Department of Energy's Federal Energy Management Program (www.eere.energy.gov/femp/procurement) may be appropriate for items not covered under the ENERGY STAR program. Some ENERGY STAR–qualified products that are relevant for schools include:

- Commercial refrigerators and freezers
- Commercial fryers
- Commercial steam cookers
- Televisions, DVD players, and audio equipment
- Computers and monitors
- Printers, fax machines, mailing machines, and scanners
- Copiers
- Vending machines
- Roof products

For example, one ENERGY STAR–qualified commercial refrigerator can save a school $160 per year and reach simple payback in just 1.3 years. Replacing three conventional vending machines with ENERGY STAR–approved models would mean annual operational savings of $460 because they are 40 percent more energy efficient. Purchasing 100 15-inch LCD (liquid crystal display) monitors that meet ENERGY STAR specifications could save a school $700 annually compared with conventional models.

Retrofits. Several load-reducing retrofits are applicable to schools. For example, many schools have few floors yet a large footprint, which means they have a high ratio of roof area to total facility square footage. This makes them good candidates for cool-roof solutions. If a school's roof needs recoating or painting, white or some other highly reflective color can minimize the amount of heat that the building absorbs. This change can often reduce peak cooling demand and cooling energy use by 15 to 20 percent, depending on the climate zone in which the school is located. When a roof requires replacement, adding insulation will reduce heat gain and loss.

Proper placement of deciduous trees not only offers energy savings (by providing cooling shade in summer without blocking sunlight in winter), but also enhances the school grounds.

Replacing purchased energy with on-site generation is an effective but capital-intensive load reduction strategy. Although photovoltaic (PV) systems are expensive, schools may be able to find utility or state rebates not available to private companies and may also have access to federal subsidies. The Clark County School District in Nevada received a $250,000 rebate from Nevada Power to help purchase roof-mounted PV panels for four schools. The systems will have a combined generating capacity of 50,000 watts, and they will be connected to the school computer network, enabling students to monitor their operation for hands-on learning about renewable energy.

Air Distribution Systems

Energy savings. On average, ventilation systems consume 7 percent of the electricity used in education buildings. Savings can be found by installing efficient fan motors and sizing the system to match your load (which may now be lower due to other measures you have already adopted). Even more savings are possible by using energy-recovery equipment and variable speed drives.

Best practices. A ventilation system must be designed, operated, and maintained to provide adequate fresh air intake and prevent mold growth from unwanted moisture accumulation. Ventilation rates at most schools are below recommended levels. Some schools have taken inadvisable measures to reduce fresh air intake in an attempt to reduce energy costs: In Brevard County, Florida, the ventilation sources in two junior high schools were covered, with the vents into classrooms sealed off. The result was an outdoor air volume that was substantially below recommended standards. Although the schools' intent was apparently to reduce the need for additional mechanical cooling and combat humidity, the buildings suffered from high humidity and mold. With increased public awareness of the health issues relating to indoor air quality and mold, such careless methods to control costs can no longer stay under the radar.

It is also possible to supply insufficient volumes of fresh air inadvertently. This may occur with scheduled ventilation and variable air volume systems or may be caused by wind, stack effects, or unbalanced supply and return fans. Installing an outdoor air measuring station that modulates the outdoor air damper and return damper is relatively simple and ensures sufficient fresh air supply.

Increasing ventilation to safe and comfortable levels will likely increase energy consumption and so should be combined with other energy-saving measures. A study by Science Applications

International Corp. of four New York schools found that, in combination with energy conservation measures, it was possible to increase outside air ventilation rates to mitigate radon problems and achieve overall energy savings of 7.4 to 14.2 percent.

Often, insufficient ventilation air in classrooms is simply due to clogged intake screens that are difficult to access for inspection and cleaning. To prevent this problem, ensure that all HVAC system air supply diffusers, return registers, and outside air intakes are clean and unobstructed. Replace filters regularly. These measures to improve ventilation rates should not raise energy consumption. Similarly, economizers should be checked regularly to ensure that their dampers are functioning properly—dampers that are stuck open could be letting in too much outside air, and ones that are stuck closed won't provide the benefit of free cooling.

Selecting a ventilation system. Generally speaking, central air handling units that serve several rooms via ductwork tend to be a better choice for schools than unit ventilators that serve a single room. Individual room units have some advantages (such as reduced floorspace requirements), but it is more challenging to maintain multiple units than one central unit. Additionally, unit ventilator systems can create moisture problems. Central air handling units are quieter, less drafty, and less prone to inadvertently reducing fresh air flow; they also control humidity better.

For humid climates and high-occupancy buildings, dedicated outdoor air systems (DOASs) improve humidity control and may offer first-cost as well as operational savings. Preconditioning fresh air with a desiccant dehumidification system eliminates the need to use mechanical air conditioning systems for that purpose. The Willis Forman Elementary School in Augusta, Georgia, took this approach to generate energy savings and improve occupant comfort. Not only can the DOAS approach save energy—perhaps 8 to 20 percent—it also provides assurance, verifiable in a court of law, that a conditioned space is receiving the mandatory minimum ventilation air.

In some regions, natural ventilation through operable windows can provide fresh air and comfortable temperatures without introducing excessive humidity. Teachers generally appreciate the additional control over the classroom environment. Students and teachers in naturally ventilated schools tend to be comfortable in a wider range of thermal conditions than in schools with continuous mechanical cooling. Normally, the optimal temperature range for reading and mathematical tasks is between 68° and 74° Fahrenheit (F). With natural ventilation, the range of comfortable temperatures may extend from 62° to 86°F. Yet whether student performance is better in classrooms with operable windows or those that rely solely on mechanical HVAC has not been determined. Highly variable temperature as well as exposure to outside noise distractions and air pollutants can be negative factors in some areas. Uncontrolled outdoor air ventilation can allow contaminants to bypass filters, affect the balance of mechanical ventilation equipment, and introduce excess humidity.

Add-on monitors and controls. Economizers can be added as a retrofit to many systems. The energy savings will be most pronounced for low-occupancy spaces such as libraries or administration areas, but this retrofit will also be cost-effective in other space types, including classrooms and assembly rooms. Differential enthalpy controllers are appropriate for economizers in humid areas.

Demand-controlled ventilation is best used in spaces with occasionally high occupancy such as auditoriums, gyms, and cafeterias. It will be less cost-effective in classrooms. However, be careful not to reduce outdoor air below the recommended minimum.

Design and program tools. When designing a ventilation system that provides thermal comfort, proper humidity, and overall good indoor air quality without squandering your energy budget, the EPA's School Advanced Ventilation Engineering Software (SAVES, www.epa.gov/iaq/schooldesign/saves.html) can help to assess the payback and air quality benefits of various types of systems.

The Indoor Air Quality Tools for Schools Kit (www.epa.gov/iaq/schools/index.html) provides guidance for establishing and implementing an effective indoor air quality management program. The school district's facility director is a logical choice to lead this type of program. The kit provides a variety of tools, including checklists and instructional videos, to help develop an indoor air quality management plan.

Heating and Cooling Systems

Energy savings. Together, heating and cooling represent well over half of the energy used by schools. In most climates, the boiler is typically the largest single piece of energy-using equipment in a school. ENERGY STAR–qualified boilers use about 10 percent less energy than standard equipment. Alternative heating and cooling technologies offer as much as 50 percent energy savings.

Best practices. When replacing heating or cooling equipment, select a high-efficiency system. As energy prices escalate, payback calculations may adjust enough to enable early replacement. This is also an excellent opportunity to capitalize on the myriad other measures taken to reduce loads and losses throughout the facility. Optimize savings from all building improvements by right-sizing heating and cooling equipment to meet actual needs, rather than relying on rule-of-thumb sizing estimates. Too often this equipment is oversized, which means the systems rarely operate at peak efficiency. Right-sizing offers first-cost savings, as well.

Selecting a heating or cooling system. If a school is planning a comprehensive renovation of its heating and cooling system, then evaporative cooling, geothermal heat pumps, two-pipe systems, and thermal storage can be good options depending on the area's climate and energy rate structures. For example, evaporative cooling is especially effective in warm, dry climates. Thermal storage is appropriate where demand charges are high or time-based rates are used. The Energy Smart Schools program's Energy Design Guidelines for High Performance Schools provide a variety of technology recommendations by climate zone, many of which are applicable for existing buildings (www1.eere.energy.gov/buildings/energysmartschools/).

The latest two-pipe systems are ideal for retrofitting buildings that have never had central heating and cooling systems before or for upgrading existing systems when budgets are constrained. Digital sensors and controls coupled with creative mechanical design make it possible to circulate heated and chilled water to fan-coil units throughout a building using only two pipes, rather than the four pipes typically installed in schools. The new two-pipe design is not only simpler than its four-pipe counterparts, it is also far more energy-efficient, less expensive to install (typically by as much as 30 percent), and easier to maintain. The updated two-pipe design has seen a resurgence of popularity for school facilities (see sidebar).

Geothermal heat pumps, also known as ground-source heating and cooling, can use 25 to 50 percent less energy than traditional systems while also providing flexibility to distribute heating and cooling as needed to the individual zones of a building (see sidebar). Portable classrooms are good candidates for high-efficiency individual heat pumps (with enthalpy recovery ventilation) because they are independent structures that tend to rely on electric heating.

Schools that need to retrofit a chiller system can consider a relatively new compressor innovation that uses magnetic levitation instead of oil-lubricated bearings. Manufactured by Danfoss

CASE STUDY: Evansville-Vanderburgh School District

When the Evansville-Vanderburgh School District in Indiana decided it needed to install air conditioning in its school buildings, an engineer at the architectural and engineering firm Veazey Parrott Durkin & Shoulders proposed a two-pipe HVAC system that came in at a significantly lower installation cost than comparable four-pipe versions. To boost operational savings, the schools' T12 lighting was replaced with T8s. Despite the addition of air conditioning, the schools' annual energy cost per square foot averaged $0.54, compared with $0.66 before the retrofits—a difference of $0.12 per square foot. Districtwide, overall savings came to around 18.2 percent, with the highest savings for one school at $0.28 per square foot per year.

CASE STUDY: Daniel Boone High School

Daniel Boone High School in Tennessee opted to install a geothermal heating system even though it cost an additional $197,000 compared with the next best two-pipe system it reviewed. This turned out to be a smart choice—the geothermal system saved $62,000 during its first year of operation. That's a savings of $0.39 per square foot compared with the school's original two-pipe system. Additionally, the new system also has the flexibility to vary temperature setpoints for individual zones using direct digital controls.

Turbocor, these compressors are available through major cooling equipment manufacturers. Although they can prove expensive for new installations, when used in a retrofit, the additional cost can be rapidly returned through energy savings. Other benefits make this chiller technology particularly well-suited to schools and could even outweigh the energy savings: The Turbocor compressor is quieter than conventional chillers; it is simpler to operate, so it requires less attention from maintenance staff; and maintenance costs are about 50 percent less.

10.4 Financial and Implementation Issues

Although capital budgets are tight, schools do have something working for them that can help make major retrofit projects possible: a long-term perspective. Most school districts can expect to be using their facilities for 50 years or more, giving them leeway to take full consideration of life-cycle costs when implementing upgrades. This makes it possible to minimize operating expenses and maximize energy efficiency. It can also open the door to a wider array of retrofit options than other commercial facilities are prepared to undertake because schools may accept payback periods of 5 years, 10 years, or even more.

Yet because capital budgets for school facilities are perpetually lacking, in practice it is a challenge for schools to adopt a long-term perspective. The ENERGY STAR Cash Flow Opportunity Calculator (www.energystar.gov/index.cfm?c=assess_value.bus_financial_value_calculator) can help school districts calculate how much they can afford to invest in retrofits from the anticipated savings and whether it would make sense to borrow funds to finance building upgrades.

Performance or shared-savings contracting provides a mechanism to fund not only energy-saving retrofits but also to cover deferred maintenance and capital renewal projects at the same time—all off-budget for the school district. Additionally, including ongoing maintenance in a performance contract can help to keep operating and maintenance costs under control and predictable (see sidebar). Although school district officials often prefer to keep facility operations in-house to preserve accountability and public approval, reducing the need to hire specialized expertise is one reason that schools privatize some functions. Additionally, having a long-term contract in place should ensure consistent funding for maintenance as well as provide an impetus for long-term strategic planning of equipment upkeep and replacement.

Apart from capital upgrades, many schools find that they can achieve energy savings of up to 25 percent through behavioral and operational measures alone. It is wise to implement these approaches first and track their impact on facility energy performance, particularly if you plan to invest in capital upgrades through a shared-savings contract. This way the school can demonstrate and claim energy savings from behavioral and simple operational changes. Shared-savings performance contracts can then be based on the new lower energy use baseline for the facility.

Another type of shared-savings program rewards schools within a district based on energy savings from behavioral and operational changes (see sidebar). The Alliance to Save Energy's Green Schools Program (www.ase.org/section/program/greenschl) provides guidelines and tools for school districts to create their own shared-savings initiatives.

CASE STUDY: Baltimore City Public School System

The Baltimore City Public School System embarked on a performance contract that is typical in many ways. Its contract with Energy Systems Group includes facility improvements at 32 schools, including digital control system upgrades, energy-efficient lighting, new boilers in six schools, and complete HVAC overhauls in another three. The $20 million contract features financial performance guarantees. An unusual element in the contract is an agreement that the contractor will perform on-site maintenance services at all 32 schools over 15 years.

BEST PRACTICE: Districtwide Shared-Savings Initiatives

Schools in the Gresham-Barlow district in Oregon accumulate financial rewards based on a variety of metrics, including the savings achieved during particular periods of the year and whether the school created a resource committee. In Wake County, North Carolina, schools get to keep 10 percent of the annual savings achieved, which has been a primary factor in rounding up over $600,000 per year in energy savings at the district's 100 campuses. Much of Wake County's savings are due to student and faculty activity as well as training. The school district of Philadelphia, Pennsylvania, discovered that a similar program brought in unexpected savings from demand-charge reductions. Those unanticipated funds were channeled into capital retrofits to capture even more savings.

Other benefits and savings from the types of retrofits recommended here are more difficult to quantify but may help in making a case for funding to a school board or community. The state of Washington determined that evidence of better teacher retention was sufficient to incorporate estimated dollar savings from lower teacher turnover in its cost/benefit analysis of sustainable building design. A case could also be made for the economic value of improved student performance, calculated based on the funds invested per student and a conservative estimate for performance improvement. So a conservative estimate of a 5 percent increase in student performance could translate to $250 per student in additional educational value, based on a per-student cost of $5,000 per year.

No less important is the benefit for students to have the opportunity to learn about energy savings with their own school as a laboratory. One study concluded that students at schools with systemic environmental education programs have higher test scores on state standardized tests over students at other comparable schools. Participating in energy-efficiency programs at their schools and witnessing the results of their efforts helps students to both learn practical skills and become actively engaged in improving their learning environment.

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