SMALL STEPS, BIG SAVINGS

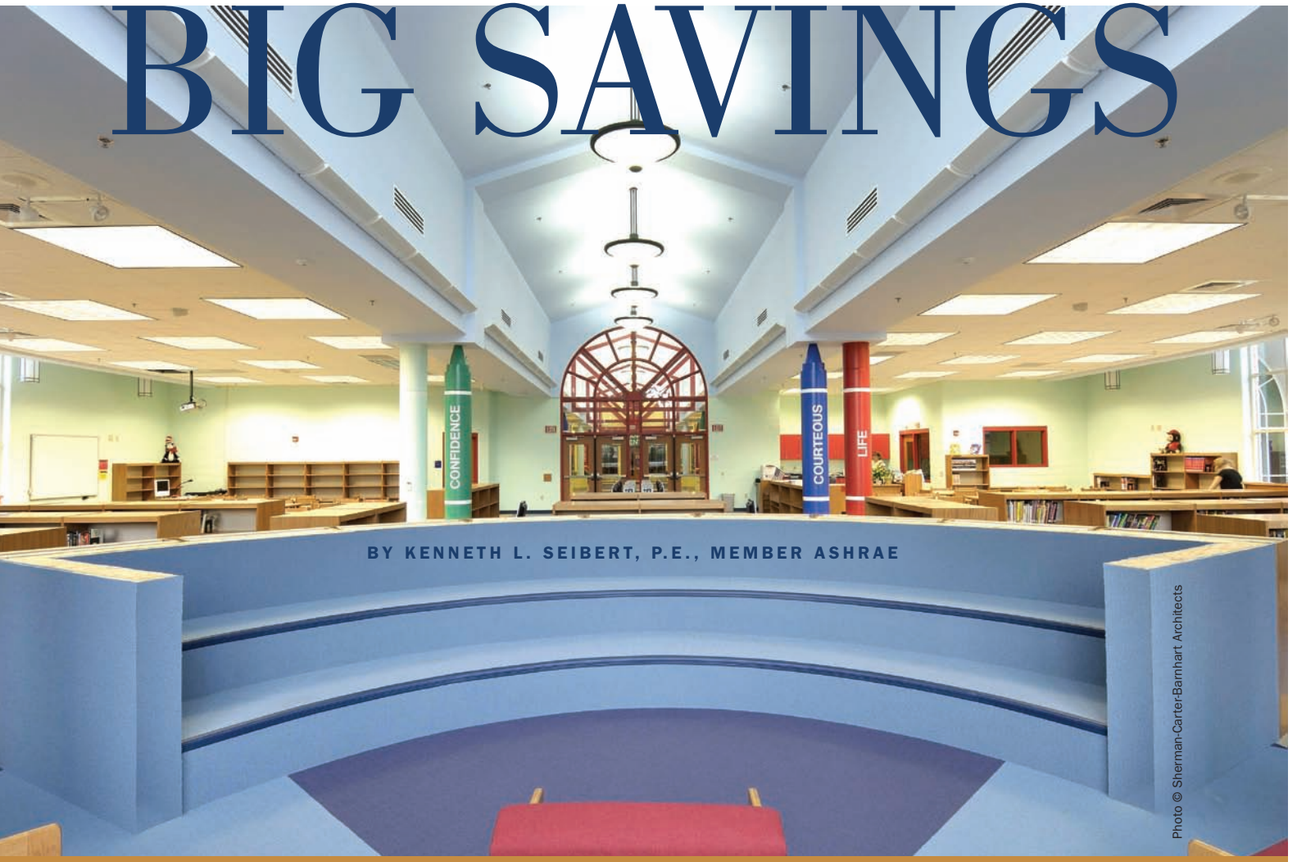


Photo © Sherman-Carter-Barnhart Architects

Dual compressor heat pumps serve the media center and the rest of Plano Elementary. The enhanced geothermal heat pump system had the most impact on the increased energy efficiency of the school.

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

Warren County Public Schools set a goal in 2003 of saving $3 million in energy costs over eight years. The district surpassed its goal in less than six years, saving more than $4 million in energy costs.

Plano Elementary is one of five schools in the Warren County Public Schools District that has received an ENERGY STAR label. It is the most efficient, using 26.8 kBtu/ft^2·yr.

Photo © Sherman-Carter-Barnhart Architects

The Kentucky school district started with small steps, such as encouraging schools to turn off lights in unoccupied gymnasiums and classrooms. Soon, the district began looking for more opportunities to improve efficiency and committed to designing energy-efficient buildings when new construction or renovations were needed. The school board hired an energy manager to ensure that energy was used wisely and comfort levels in the schools were maintained. Architects and engineers have built upon lessons learned from each previous project to improve energy efficiency.

Plano Elementary School is the district's latest success in the design and operation of energy-efficient buildings. Plano received its first EPA ENERGY STAR label in April. The building's energy consumption was determined to be 26.8 kBtu/ft^2·yr, which ranked it in the 99th percentile in ENERGY STAR program. This achievement is even more significant because Plano is an all electric building.

Warren County Public Schools has 20 schools in the district, and five of those schools have received ENERGY STAR labels. The district leads Kentucky with the most ENERGY STAR schools.

The WCPS board has supported efforts to continually improve the energy performance of its schools. The district's use of geothermal heat pump systems, improved thermal envelopes and an established energy policy have led to their success and $4 million in energy savings.

Plano Elementary School uses 16.2% less energy than the next most efficient new ENERGY STAR school in Kentucky. Its operation has attracted much attention, including the notice of John Davies, deputy commissioner of the Kentucky Department for Energy Development and Independence.

"Going forward, if we build our new schools to these standards, we will save tens of millions of dollars, dollars that can be used to help our students achieve their fullest potential," Davies said.

HVAC System

Plano's new, enhanced geothermal HVAC system consists of dual compressor heat pump units and decentralized pumping. Emphasis was placed on "right sizing" the heat pump units during the design phase. One heat pump unit serves two classrooms to maximize efficiency and reduce construction cost and maintenance *(Figure 1)*. A typical unit serving two classrooms has 4 tons of cooling capacity.

BUILDING AT A GLANCE

Name Plano Elementary School

Location Bowling Green, Ky.

Owner Warren County Public Schools

Principal Use Elementary School

Includes 32 classrooms, 14 offices/administrative support areas, six resource centers, media center, gym, server room, cafeteria with kitchen

Employees/Occupants 435 students plus teachers and staff

Gross Square Footage 81,147 ft^2

Total Cost $11.4 million

Cost Per Square Foot $140

Substantial Completion/Occupancy August 2007

Occupancy 80%

Distinctions/Awards ENERGY STAR label; Andromeda Star of Energy Efficiency, Alliance to Save Energy

BUILDING TEAM

Owner Warren County (Ky.) Public Schools: Dale Brown, Superintendent; Charles Rector, Director of Facilities

Architect Sherman-Carter-Barnhart: Kenny Stanfield, Principal Architect

General Contractor Alliance Corporation; Mechanical: Ernie Davis and Sons Mechanical; Electrical: Division 16

MEP Engineer CMTA: Mark Seibert, P.E., LEED AP; Project Manager: Ken Seibert, P.E., LEED AP, Principal in Charge

Energy Modeler CMTA: Mark Seibert, P.E., LEED AP

Structural Engineer Structural Design Group

Civil Engineer Sherman-Carter-Barnhart

Landscape Architect Sherman-Carter-Barnhart

KEY SUSTAINABLE FEATURES

- Geothermal HVAC: dual compressor units with distributive water pumping
- Geothermal domestic water heating
- Occupancy controls
- District energy management program

Photo courtesy of Warren County Public Schools

Approximately 435 students attend Plano Elementary School. Warren County is one of Kentucky's fastest growing counties.

WCPS and CMTA Consulting Engineers chose dual compressor heat pump units to increase system efficiency. During part-load operating conditions, a dual-compressor unit will operate more efficiently than a single-compressor unit. Full load operating efficiencies occur infrequently.

CMTA trended the first and second stage operating hours for one year after the building was occupied using Plano's direct digital controls system. CMTA determined that 87% of all operating hours were in the first stage.

A 3.5 ton unit was field tested to determine the efficiency improvements. The heat pump unit consisted of a 1.5 ton and 2.0 ton compressor connected to a single 3.5 ton refrigerant circuit. Stage one efficiency is significantly higher than full load condition because the 1.5 ton compressor has 3.5 tons of evaporator and condenser coil surface area for heat exchange.

A field test measured the condenser and evaporator pressures/temperatures and found that when both compressors operate, the 1.5 ton compressor has an energy efficiency ratio rating of 11. The compressor efficiency increases to 18 when running solely in the first stage *(Figure 2)*. This results in a 64% efficiency boost when the dual compressor heat pump unit operates in stage one.

The mezzanine location of the heat pumps allows the units to be serviced without disrupting classes.

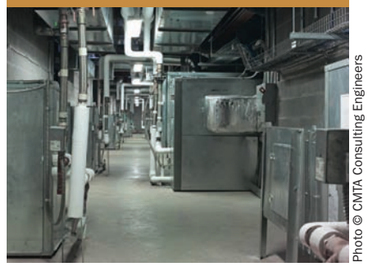


Photo © CMTA Consulting Engineers

Distributed Water Pumping

The next significant system change in the Plano design was distributed water pumping. One of the significant benefits of geothermal HVAC for a school district is the

FIGURE 1 **TYPICAL CLASSROOM SECTION**

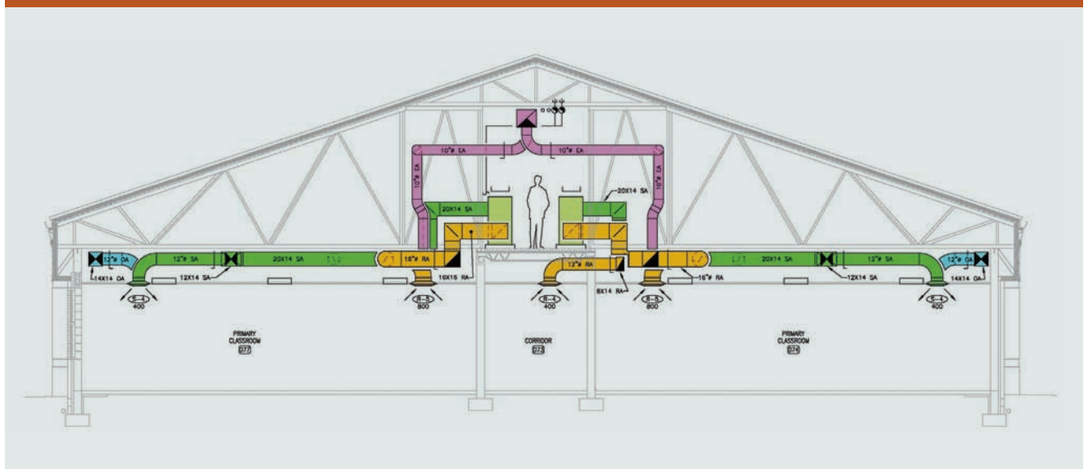


FIGURE 2 **1.5 TON PARTIAL COMPRESSOR TEMPERATURE**

	Both Stages	Stage 1 Only
360 psi/110°F Condenser	142 psi/50°F Evaporator	157 psi/55°F Evaporator
Capacity (Btu/h)		29,488
Power (W)		1,608
Current (Amps)		7.1
Mass Flow (lb/h)		378.9
Energy Efficiency Ratio (Btu/W·h)		18.34
Efficiency (%)		67.7
475 psi/130°F Condenser		
Capacity (Btu/h)	20,330	
Power (W)	1,868	
Current (Amps)	8.2	
Mass Flow (lb/h)	296.1	
Energy Efficiency Ratio (Btu/W·h)	10.88	
Efficiency (%)	66.4	

Note: These are reciprocating compressors that use R-410A.

elimination of large central equipment such as boilers, chillers and cooling towers. This reduces maintenance costs in addition to improving efficiency. Distributed pumping eliminated the last remnants of central plant equipment—the main recirculating water pumps and the associated speed control system.

WCPS previously tried various geothermal pumping systems. These included constant flow/single pump, variable flow/single pump and primary/secondary pumping with variable flow. The performance of the variable flow system was not successful in reducing the water flow of the central recirculating pumps to match loads.

CMTA and WCPS worked together on Plano Elementary to eliminate the central pumps and associated variable-frequency drive units, attempting a new pumping concept. Each heat pump unit has an individual water pump to recirculate the water through the entire geothermal water loop, including the well field. The water pump will not operate unless its respective heat pump unit is in operation. This ensures variable water flow, which only responds to demand.

The closed loop piping system was designed to minimize the water pressure drop in the geothermal piping system. Previous projects had a typical loop pressure drop of 75 ft total developed head (TDH), while Plano's loop pressure drop was 35 ft TDH. The "installed" total horsepower of pumping capacity was reduced by half compared to the district's previous school.

Most pipe mains in the building were increased one pipe size to

ENERGY AT A GLANCE

Energy Use Intensity (Site) 26.8 kBtu/ft^2

Electricity 26.8 kBtu/ft^2

Annual Source Energy 89.51 kBtu/ft^2

Annual Energy Cost Index (ECI) $0.87/ft^2·yr

ENERGY STAR Rating 99

BUILDING ENVELOPE

Roof 1

Type Standing seam metal with 3 in. rigid insulation on metal decking

Overall R-value R-22

Reflectivity 30.3, SRI 31

Roof 2

Type Single-ply membrane, 3 in. rigid insulation, metal decking

Overall R-value R-24.85

Reflectivity 85, SRI 108

Walls

Type Brick, 1.5 in. insulation, 8 or 12 in. concrete masonry unit (CMU)

Overall R-value 11.6 (average between 8 and 12 in. CMU assembly)

Glazing percentage 8% (43,327 ft^2 of wall, 3,841 ft^2 of glazing/storefront)

Basement/Foundation

Slab edge insulation R-value: R-6 (horizontal and vertical insulation)

Windows

U-value 0.41

Solar Heat Gain Coefficient (SHGC) 0.66

Visual Transmittance 49%

Location

Latitude 36° 53' 13.34" N

Orientation East/West

Photo © CMTA Consulting Engineers

Warren County Public Schools' energy savings total more than $4 million since 2003. The savings started with changes in existing schools, such as turning out lights in unoccupied rooms. The district identified more opportunities to improve school energy efficiency during renovation and construction projects.

reduce the system pressure drop. CMTA generally specified schedule 40 black steel with mechanical joints for loop piping materials in the past. Plano used uninsulated schedule 80 PVC piping for all interior piping to keep construction costs from rising. Warren County Public Schools has used schedule 80 PVC for many years and has had no problems with leaks.

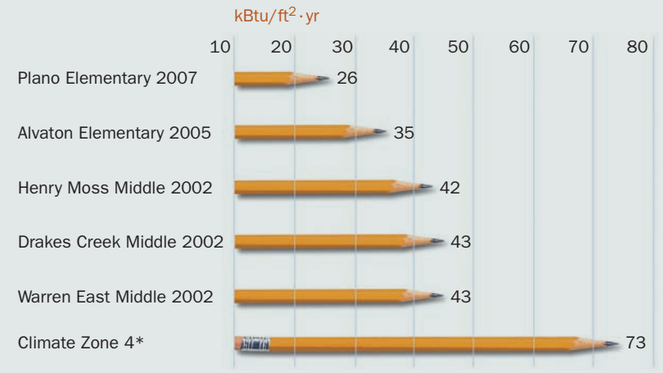
Outdoor air is introduced to the school through the use of central equipment. Three dedicated outdoor air-handling units provide fresh air to the building and provide an exhaust air path for building pressurization control. This allows the use of a desiccant heat recovery wheel in each outdoor air unit.

A supplemental two-pipe coil is located in the outdoor air path downstream of the heat recovery wheel. The original purpose of this coil was to provide additional heat to the airstream in the winter months and supplemental dehumidification during the summer months.

Centrally located geothermal heat pump chillers provide a source of heating hot water in the winter and chilled water in the summer. The geothermal heat pump chillers now operate in the winter months only.

WCPS tested operation of the system during the hot and humid summer months and found that building humidity is controlled without supplemental cooling of the outdoor air. This is attributed to the classroom heat pump's excellent dehumidification capabilities in the first stage cooling, the desiccant heat recovery wheel in the outdoor air unit and a tight building thermal envelope.

WARREN COUNTY ENERGY STAR SCHOOLS EUI



Advanced Energy Design Guide for K–12 Schools

Note: Years denote new construction or renovation. Energy use intensity was measured in the year that each school received the ENERGY STAR label.

Domestic Water Heating

The building's domestic water heating system is unusual. The entire building's 110°F domestic water is heated by one geothermal unit serving the gym. The gym's air-conditioning system consists of two 15 ton heat pump units.

Because cooling requirements for the gymnasium are much greater than the heating requirements, one of the units is equipped with a double wall type domestic water/refrigerant heat exchanger as required by code. The building's domestic hot water is stored in two tanks with no back-up heat source.

When the gym heat pump is in the cooling mode, the heat is rejected to the domestic water in lieu of the well field. All domestic water is heated

with virtually no additional energy used. When the domestic water requires heat and gym cooling is not required, the heat pump operates in the heating mode as required to maintain the tank water temperature.

The geothermal system heats water efficiently. During the building's unoccupied mode, the heater and domestic water pump operation are disabled.

Learning From Plano

Everyone associated with the construction and operation of the new Plano Elementary School is proud of its 26.8 kBtu/ft^2·yr energy performance. The school district, architect and engineer all agree that the next project will be even more efficiently designed and operated. The lessons learned from Plano give the design team confidence that even more efficient schools can be designed and operated.

To put this to the test, the next WCPS school, Richardsville Elementary School, is designed to be a net zero energy school. The school is under construction and will open for fall 2010 classes. The energy model predicts Richardsville's energy consumption will be 18 kBtu/ft^2·yr.

The significant changes to the Richardsville design compared to Plano's include: a better thermal envelope with insulated concrete form (ICF) walls; a more efficient footprint, which has less exterior wall surface area per building square foot; daylight harvesting with light dimming controls in all classrooms; a demand-based variable flow outside air system; kitchen redesign with type II commercial cooking hoods; a wireless computer system; and a solar photovoltaic panel array with a capacity of 350 kW.

A net zero energy public school would not be possible without WCPS's commitment to innovation in school design, construction and the energy policy that the district adopted. The policy includes top-down leadership, benchmarking, custodial training and the realization that each person in the school is an energy consumer and energy saver.

It also holds each principal accountable for energy management on his or her campus. Effective energy management of the campus is included in each principal's annual evaluation.

A district-provided energy manager supports the principals. This person provides training to the principals, teachers, custodial staff and students; benchmarks energy use and cost; creates monthly reports for each school; and provides weekly walk-through audits of each school. The audits are unannounced and may occur at any time during occupied or unoccupied hours.

The audit is designed to review HVAC system operation, thermal envelope failures, lighting status, water use and miscellaneous other issues such as computers in operation when the school is unoccupied. The availability of accurate benchmarking data gives the school real-time knowledge of the effectiveness of their programs. These data can highlight conservation success or pinpoint a system operation malfunction before it costs the system thousands of dollars.

PLANO ELEMENTARY ENERGY USE 2008

	Use (kWh)	Cost
January	72,400	$5,674.55
February	65,600	$5,176.41
March	50,800	$5,143.00
April	55,600	$4,949.46
May	44,400	$5,355.05
June	30,400	$4,385.06
July	38,000	$4,075.32
August	64,400	$5,869.47
September	64,000	$6,589.33
October	48,800	$5,434.99
November	54,400	$6,339.65
December	47,600	$5,868.09
2008	636,400	$64,860.38

INSULATED CONCRETE FORM WALLS

Until Plano opened, WCPS's Alvaton Elementary School was the best performing school in Kentucky at 35 kBtu/ft^2·yr. It was built to accommodate 840 occupants and is 79,500 ft^2.

As with Plano, Alvaton uses a geothermal heat pump system. It was the first school in Kentucky to use insulated concrete form (ICF) walls. The success of ICF on this project led to ICF being adopted as a typical construction technique in Kentucky.

ICF walls decrease construction time, are cost competitive and improve energy performance. CMTA trended operation of the heat pump units at Alvaton during unoccupied hours and found minimal operation of the heat pumps because the ICF walls maintain the indoor air temperature.

Kentucky's Department of Education has applauded WCPS's commitment to energy conservation.

"[Warren County] is used as a resource for other districts to improve energy performance of schools throughout the Commonwealth of Kentucky," noted Mark Ryles, director of facilities, Kentucky Department of Education.

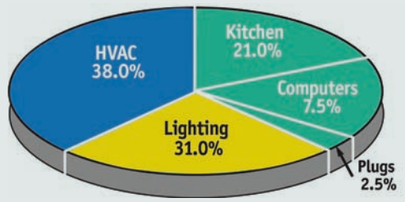
In conclusion, the goal to reduce energy consumption can be accomplished if all parties involved in the facility (A/E team, occupants and owner) work together to achieve that goal. To maximize the impact of the design and operational policies on energy consumption, thorough monitoring and evaluation of actual operation data is imperative.

The ongoing monitoring and evaluation process provides insight into opportunities to further improve the efficiency of any building. The whole team (architects, engineers, occupants and owners) can learn from the successful strategies implemented in the past and build on those strategies for future success. ●

LESSONS LEARNED

Plano's low energy use and electrical demand attracted the attention of their electrical energy provider, Tennessee Valley Authority (TVA). In an effort to continue WCPS's goal of reducing energy consumption and understand where electrical consumption was actually occurring, TVA volunteered to install electrical meters in representative areas in the building.

Ideally, the meters would have been installed for an entire year, but due to limited funding, the meters were connected during January only. The building's electrical panels segregated the HVAC system, lighting, computers, kitchen and plug loads, which allowed these areas to be directly monitored. The results are illustrated in the pie chart. This data confirmed the performance of the new HVAC system while identifying potential areas to reduce energy consumption in future projects.



The Tennessee Valley Authority metered Plano Elementary during January 2008.

Results of the metering study included:

HVAC—The measured data indicated that 38% of the energy was consumed by the HVAC system, which is lower than the 48% predicted. This consumption drop confirms that the enhanced geothermal system was successful.

When CMTA dissected the data further, it discovered that the outdoor air system was consuming half of the HVAC energy. The data led to changes in the outdoor air system to a variable flow, demand control ventilation system on the next WCPS project.

Additionally, the project was built with a traditional block and mortar system, not ICF walls. The previous school project, Alvaton Elementary, had ICF walls, and data from that building indicate that ICF walls with better thermal properties and mass hold the heat better. Alvaton's heat pump units operate at night less frequently.

Lighting—was reduced below the maximum allowed by code. But the design failed to reduce the percentage of energy consumed by lighting at Plano compared to other recently constructed schools. Lighting efficiency will be more aggressively pursued for WCPS's net zero energy school. Changes from the Plano design will include reducing the installed lighting energy intensity and incorporating daylight harvesting with a dimming control system in each classroom.

Kitchen—The kitchen electrical consumption was unexpected. The kitchen was consuming 21% of the building's power, which included all-electric cooking equipment, range hood exhaust/makeup air system, lighting and HVAC. (The kitchen meters did not include the cafeteria.)

This led to the conclusion that reducing total building energy consumption in future designs would require a reduction in kitchen energy consumption. To assist in designing the net zero energy school, the WCPS dietary staff and A/E design team participated in a three-day workshop to design a kitchen that prepared the same quality of food while reducing energy consumption. Changes for the net zero project include less hood area, changing from type I to type II hoods, and specifying food preparation equipment that is more energy efficient and can operate beneath type II hoods.

Computers—Another surprise was that the school's IT systems were consuming 7.5% of the building's total energy. All Plano classrooms have seven desktop computers and the school has one dedicated computer classroom for a total of 256 computers in addition to two server rooms. The desktop computers individually consume between 150 to 175 W.

The Kentucky Department of Education requires "wired" schools, so all computer stations have both data and power drops; however, for the net zero energy school, the state has allowed a completely wireless design. The computer classroom will be eliminated and six computer carts will be equipped with 30 laptop computers each (180 computers) instead of permanent workstations. The laptop computers consume between 25 to 50 W depending on charging status.

To further reduce demand, TVA asked that laptop charging occur at night during off-peak hours. However, night charging of laptops did not result in financial savings for the school because Kentucky does not have an additional charge for peak hour energy use. The reduction in the number of computers as well as the decreased electrical consumption by each laptop will significantly decrease the energy consumption at Richardsville.

One heat pump serves every two classrooms at Plano Elementary. This design maximizes energy, reduces construction costs and reduces maintenance costs. The dual compressor heat pumps operate more efficiently during part-load operating conditions than a single compressor unit. The compressors operated in the first stage 87% of the time during the school's first year.

Photo © Sherman-Carter-Barnhart Architects

ABOUT THE AUTHOR

Kenneth L. Seibert, P.E., LEED AP, is the president of CMTA, an 80-person MEP consulting engineering firm with offices in Louisville and Lexington, Ky., and Houston.