

NET ZERO ON THE FARM



BY KEVIN D. MUSSLER, P.E.; STEPHANIE GERAKOS, P.E., MEMBER ASHRAE; AND SUSAN STOKES HILL, AIA

WMB Photography

Amidst 82 acres of rolling Kentucky countryside, high school students gain first-hand experience in managing animals and the land at a working farm. Learning at this agricultural-based vocational school takes place in a variety of settings—from pastures and the barn to the operating on-site veterinary clinic. Students also see sustainability in action, learning in daylit classrooms, raising organically-fed chickens and creating a solar-powered livestock watering system. Rooftop solar panels and an energy-efficient design have resulted in the academic building operating on a net zero energy basis.

In addition to the net zero energy academic building, the project reduces site impact by minimizing municipal water use and includes measures that preclude the need for a storm water sewer or sanitary sewer connection. An integrated design featuring an airtight envelope, expanded indoor temperature setpoints in specified areas, a solar thermal system and a geothermal heat pump greatly reduces energy demand, an approach that serves as a model for communities and school systems seeking to reduce their energy use and environmental impact of new developments.

Campus Components

The Locust Trace AgriScience Center is on the outskirts of the metro area of Lexington, Ky., serving

Fayette County Public Schools and surrounding districts. The project began as a small building with a single classroom and two livestock stalls. Collaboration between the design team and the school district led the project's evolution into an 82 acre campus including an academic building, an automated greenhouse, a livestock barn, and an arena.

The academic building houses five major curriculum labs with associated classrooms, an administration area, veterinary clinic, a media center, assortment of core curriculum classrooms, office spaces, and a 250 student assembly area. This is a traditional academic building in mechanical and electrical systems; however the temperature range is expanded in some of the lab spaces to help in the reduction of energy.

The five major curriculum labs include Plant and Land Science, Environmental and AgScience, AgMechanics, Large and Small Animal Science and Equine Science. The assembly area has a large overhead garage door to accommodate livestock, horses, trailers, tractors and other farm equipment.

The veterinary clinic is a fully functional not-for-profit animal clinic

that includes an operating room with network access for all of the classrooms. This connection allows the students and veterinarians to interact via Web interface rather than requiring the students to be in the operating area during a procedure.

The greenhouse includes a programmable controls system that manages the plant watering, fertilizer content, zone temperature, ventilation and sunshade position. All of these features are programmed separately for each of the three bays and can be adjusted for the type of vegetation the school wants to grow and maintain.

The livestock barn stores the hay, feed and farm equipment required to maintain the pastured animals. This livestock barn only has lighting and power, no HVAC (Table 1). The arena building houses 11 barn stalls, a show arena, office space and an off-hours farm manager apartment.

The show arena allows students to practice different forms of competitions such as dressage, livestock handling and showmanship. The arena also has data ports installed in the stalls so that a foaling or procedure could be recorded to expand the educational opportunities of the building.

Net Zero Goals

The collaborative design process was critical to the success of this project. The design consultants (including the architects, civil engineer, structural engineer, mechanical engineer and electrical engineer) were brought in at the beginning and placed on a team that included future faculty, current faculty, existing students and maintenance personnel.

The site is located on undeveloped farmland near Lexington with



WMB Photography

Above Students work with cattle as well as horses, pigs, goats, fish and chickens as they learn about the many facets of animal science.

Opposite Locust Trace AgriScience Center is an agricultural-based vocational school on the outskirts of the urban/metro area of Lexington, Ky. The academic building (pictured) operates on a net zero energy basis.

BUILDING AT A GLANCE

Name Locust Trace AgriScience Center

Location 6 miles northwest of Lexington, Ky.

Owner Fayette County Public Schools

Principal Use Agricultural vocational/technical school

Includes Academic building, greenhouse, animal surgical area, riding arena, stalls, barn, farm equipment

Expected (Design) Occupancy 20 teachers and staff with 150 students
Actual Occupancy 18 teachers and staff, 270 students

Gross Square Footage of Academic Building and Greenhouse 47,994
Academic Building 44,248
Greenhouse Building 3,746

Distinctions/Awards 2014 ASHRAE Technology Awards, Public Assembly, First Place; National Green Ribbon School, 2013

Total Cost \$15.8 million
Cost per Square Foot \$230/ft²

Substantial Completion/Occupancy August 2011

Defining Net Zero Energy for Locust Trace AgriScience Academic Building

The Locust Trace AgriScience Center academic building is considered to operate on a net zero energy basis. Solar photovoltaic arrays, located on the academic building and the arena building, produce more electricity (15 kBtu/ft²) than the academic building uses on an annual basis (13.4 kBtu/ft²). See *Energy at a Glance* for more details.

TABLE 1
CAMPUS BUILDING SERVICES

	Heating	A/C	Lighting	Power
Academic Building	●	●	●	●
Greenhouse	●	●	●	●
Arena			●	●
Livestock Barn			●	●



WMB Photography



WMB Photography

Top The greenhouse at Locust Trace AgriScience Center provides students hands-on experience with plant science.

Above The greenhouse at Locust Trace includes a programmable controls system that manages the plant watering, fertilizer content, zone temperature, ventilation and sunshade position. These features can be adjusted for the types of vegetation the school wants to grow and maintain.

utilities not readily available on the site. The collaborative team decided that the 82 acre site presented several opportunities to create a sustainable beacon for the community.

The concept of net zero was not foreign to the Kentucky Department of Education, as it already had two net zero energy school projects

in design or under construction. Locust Trace was the third net zero school for the state, and the design collaboration team began to shape the idea of a net zero campus as it applied to all of the five major utilities: sanitary waste, domestic water, storm sewer, site irrigation and energy. The team set and achieved campus goals of net zero sanitary waste, storm water and site irrigation; the goal of net zero energy specifically for the academic building was also achieved.

The challenge on the project was how to approach these within the constraints of the budget while providing the best educational opportunities for the students. Due to cost constraints, the energy goal was limited to generate the required renewable energy on-site to support the larger academic building by providing solar photovoltaic arrays on the academic building and the arena building.

Net Zero Sanitary Sewer Waste

The academic and arena buildings address sanitary sewer waste by using a dual system including a standard leach field system and a constructed wetlands system. The project team wanted to implement only the constructed wetlands system; however, the local authorities were not completely comfortable with this system and required a leach field for redundancy.

This requirement allowed the team to design a system large enough to handle the planned Phase 2 addition in the initial design. (Phase 2 will add support spaces and other buildings such as a cafeteria and

additional classrooms to turn the site into a fully functioning high school for 500 students.) The leachfield/wetlands system eliminated the need for a connection to a municipal sanitary sewer system. Analyzing the cost of bringing sewer utilities to the site made the decision to achieve a net zero sanitary sewer system an easy decision for the project.

ENERGY AT A GLANCE

Academic Building/Greenhouse Annual Energy Use Intensity (EUI) (Site)	21.8 kBtu/ft ²
Electricity (From Grid)	16.5 kBtu/ft ²
Electricity (From PV)	5.3 kBtu/ft ²
Annual Source Energy	57 kBtu/ft ²
Carbon Footprint	76.5 lbs CO ₂ e/ft ² · yr
Net Zero Energy Calculation for Academic Building*	
Estimated Annual EUI Academic building	13.4 kBtu/ft ²
On-Site PV-Generated Electricity (From PV Arrays on Academic Building and Arena Building)	15 kBtu/ft ²
Annual On-Site Renewable Additional Energy Used on Campus	1.6 kBtu/ft ²
Academic Building Annual Energy Cost Index (ECI)	\$0.35/ft ²
Academic Building Savings vs. Standard 90.1-2004 Design Building	53%
Heating Degree Days (Base 65°F)	4,865 (June 2012–May 2013)
Cooling Degree Days (Base 65°F)	1,382 (for June 2012–May 2013)
Academic Building Annual Hours Occupied	1,890 (7 a.m.–4 p.m. 42 weeks/yr)

*The energy use for the academic building and the greenhouse is recorded on a single meter. The estimated EUI for the academic building was calculated using the utility metered data for the two buildings, the solar PV meter on the academic building and the estimated annual energy use of the greenhouse (8.4 kBtu/ft²) using the USDA Energy Self Assessment Greenhouse Form.

WATER AT A GLANCE

Annual Water Use	331,200 gallons
------------------	-----------------

Net Zero Domestic Water

Obtaining the goal of net zero domestic water proved to be too challenging and expensive to be practical for the public school system. Regulations required that the district provide a large storage tank for the fire protection system as well as drill a domestic water well. The school would then have to become a treatment plant frequently testing and treating the well water.

Operating its own treatment plant would have required several expensive forms of permitting and dedicated maintenance personnel on staff. The district decided that this did not make economic sense at the time of the project. Low flow plumbing fixtures help reduce the water consumption of the facility.

Net Zero Site Irrigation and Storm Sewer Collection

Using pervious surfaces to facilitate water runoff was another goal of this project. The driveway and parking areas use a permeable paver system

that allows for the collection and natural drainage of rainwater and keeps the school district from having to maintain any type of storm sewer system on the site. All of the gravel drives are engineered permeable surfaces.

Rainwater at Locust Trace is collected from the academic building and the greenhouse roofs into a 20,000 gallon underground storage tank. The rainwater from the arena roof is collected into a 10,000 gallon underground storage tank.

A large portion of the site is native vegetation and does not require site irrigation, but the animals and crops require watering. The rainwater collected from the academic, arena, and greenhouse buildings is pumped to the pastures, crops, and animal watering stations. Since this water is used only for irrigation and livestock feeding, additional water treatment is not required.

To reduce the amount of domestic water needed, a 140 ft water well was drilled and tested on the site for



WMB Photography

Above High volume fans are used in the media center, allowing for a higher temperature set point while still keeping occupants cool. The fan speed is set so that papers are not rustled.

Below Locust Trace AgriScience Center is located on 82 acres and includes a livestock barn. Because the goal is to expose students to real-world conditions, the barn and many of the buildings are not conditioned.



WMB Photography



WMB Photography

Above An aerial view of Locust Trace AgriScience Center shows (from bottom) the greenhouse, academic building, outdoor teaching space and arena. The building orientations allows for maximum solar exposure for the solar photovoltaic and solar thermal arrays.

Below The arena has space for competition practice, 11 barn stalls (with data ports for recording of animal procedures), office space, and a farm manager apartment.

animal hydration and crop irrigation when the storage tanks run low. Well water is stored in a 20,000 gallon tank backing up the rainwater collection system in the event that the collection tanks are emptied.

Backflow prevention was provided in this system to protect the municipal water system. While the building

was not able to achieve net zero water from a cost perspective, significant municipal water use reduction was achieved through the use of the well and the storm water collection.

Net Zero Energy (Academic Building)

Fayette County Public Schools instituted a district-wide energy reduction focus in 2011. Energy reduction and efficiency is an important goal for the district's new schools.

Expanding on this initiative, the owner and design team wanted to push even further with a practical and responsible approach towards energy reduction for this

opportunity. This campus consists of two main buildings (academic and arena buildings), each with their own utility meter.

During the collaborative design process, the most cost effective approach to provide renewable energy was to use the two main structures of the academic building and arena building as locations for the installation of photovoltaic panels. The combined power production of both arrays achieves net zero energy for the academic building.

A greenhouse was included in conjunction with the academic building late in the design process of the building and was decided by all parties not to be included in the net zero energy parameters due to its high energy use. The greenhouse uses the shared geothermal and solar thermal systems for heating, so separately metered data is not available on its energy use.

BUILDING ENVELOPE	
Roof	
Type	Standing seam metal on 2:12 and 3:12 roof slopes (2-ply modified bitumen on "flat" roof areas)
Overall R-value	R-26 continuous insulation
Solar Reflectivity Index	68
Walls	
Type	Insulated concrete forms (ICF) exterior walls
Overall R-value	R-23.6 continuous insulation
Glazing Percentage	20.4%
Basement/Foundation	
Slab Edge Insulation R-value	1 in., extruded polystyrene (taped)
Windows	
Effective U-factor for Assembly	0.46
Solar Heat Gain Coefficient (SHGC)	0.36
Visual Transmittance	65
Location	
Location	38.106° N, 84.57° W
Orientation	East/west



WMB Photography

KEY SUSTAINABLE FEATURES

Water Conservation Rainwater catchment, well water, rain gardens, constructed wetlands for sanitary sewer waste (which eliminates the need for a connection to a municipal sanitary sewer system).

Recycling Site composting and muck bins (used to collect livestock sewage, which is used as fertilizer for the site).

Daylighting Passive and solar by windows, clerestories, and transoms between inside and outdoor spaces.

Geothermal Water Source Heat Pumps

Demand Control Ventilation

Solar Thermal Radiant Heating

Individual Controls HVAC and lighting.

Photovoltaics 175 kW crystalline panels.

Carbon Reduction Strategies Solar PV, geothermal HVAC, solar thermal radiant heating, demand control ventilation, daylighting, LED lighting, occupancy sensors connected to lighting and HVAC, insulated concrete form walls, aggressive indoor temperature setpoints.

The energy use of the greenhouse is estimated to be 111,600 kWh annually based upon the USDA Energy Self Assessment Greenhouse Form. Energy modeling was used throughout the



WMB Photography

The media center features daylighting and expansive views to the outdoors.

design process to assist in achieving the net zero energy goal of the academic building.

The result was an integrated approach that impacted the building design, systems and operation. The academic building was initially modeled with an energy use intensity (EUI) of 18. The academic building has significantly exceeded the model, performing at an estimated 13.4 kBtu/ft².

It should be noted that a portion of the solar PV tripped in July 2012 for 27 days during this evaluation period, resulting in limited production during that month.



WMB Photography

The main entry hall, looking toward the assembly space, is filled with daylight from storefront glass and from the overhead clerestory. The mariner's compass cut into the polished concrete floor occurs at the intersection of the north-south entry hall and the east-west academic hallway.

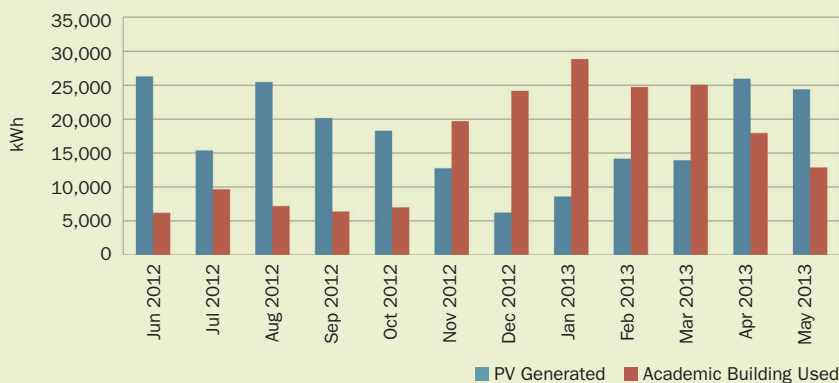
Figure 1 indicates the solar PV generated in comparison with the kWh consumed.

Energy Reduction Strategies

Envelope. The academic building is constructed of insulated concrete forms (ICF) walls with steel structure and an insulated standing seam metal roof. The walls have an R-value of 24 versus code minimum of R-19; however, they perform much better than this based upon their thermal massing and airtight construction.

The standing seam metal roof assembly has an R-value of 26, which is above the code required R-20. The glazing has an overall value of R-3.8 compared to the code required R-2.5. The building was oriented so that the majority of the roof surfaces are angled due south, taking advantage of the large solar initiative on this building.

FIGURE 1 TOTAL SITE PV ELECTRICITY GENERATION VS. ACADEMIC BUILDING ENERGY USE



Note: PV generation data reflects a 27-day period in July when the PV system was not fully operational.



Courtesy of Fayette County Public Schools

Top The not-for-profit veterinary clinic includes an operating room. Students can view medical procedures in real time via a network that connects classrooms to the operating room.

Above The veterinarians at Locust Trace Veterinary Clinic provide care for large and small animals while teaching the next generation. The clinic is open to the public.

HVAC. The design team went through multiple design charrettes to determine the optimum HVAC system for this building due to its location, educational responsibility, and its goal to be a net zero building. The staff at Locust Trace believes that the

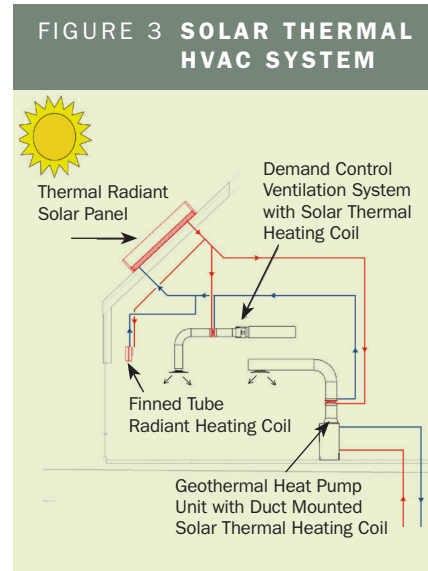
students need to experience a real-world working agricultural environment, which doesn't usually occur in an air-conditioned building. This focus resulted in expanded temperature ranges in the building.

The building includes several heating-only zones, wide range cooling/heating zones and typical heating/cooling thermostatic zones. The design team included thermal breaks in the building to account for these different types of thermal environments.

Figure 2 represents the different areas and their corresponding acceptable temperature ranges. This strategy greatly reduced the energy consumption of the building and the required solar power generation.

Traditionally the school district has used variable refrigerant flow systems; however, everyone agreed to look at alternative strategies for this building. Because the building was designed to be a net zero building, a geothermal HVAC system was selected as the base system.

This consists of high efficiency, dual stage water source heat pumps using an energy recovery dedicated outside air unit to provide code required ventilation air. A



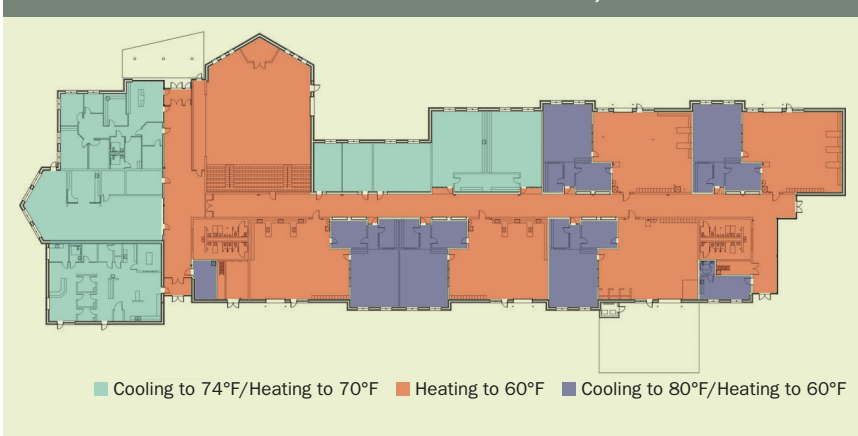
demand-control ventilation system was used in the building to measure the carbon dioxide in the spaces and adjust the outside air to each space based upon its CO₂ load.

This building also has a much larger heating load than cooling load since portions of the building are not air conditioned. To take advantage of this, a large solar thermal radiant heating system was installed in the building consisting of 168 evacuated tube panels that produce an average of 40,000 Btu per day (Figure 3).

This array acts as the first stage of building heat, and then the highly efficient geothermal water-to-water heat pumps are used when the solar exposure is insufficient. Because this building has an unbalanced heating versus cooling load, provisions were made to allow the solar thermal system to regenerate the well field in the summer if the ground temperature begins to lose much heat capacity over time.

Domestic Water. The domestic water heating system includes flat plate solar thermal panels as well

FIGURE 2 ACADEMIC BUILDING HEATING/COOLING ZONES



as an electric heating element for backup. The facility uses some low flow plumbing fixtures such as 0.5 gpm lavatory aerators.

Plug Loads. A plug load control system, which turns off all nonessential outlets in the building at a set schedule, is implemented throughout the academic building; however, dedicated circuits are provided for equipment that has to remain on, such as terrariums, aquariums and refrigerators.

BUILDING TEAM

Building Owner/Representative
Fayette County Public Schools

Architect Susan Hill, Tate Hill Jacobs

General Contractor
Messer Construction Company

Mechanical Engineer, Energy Modeler
Stephanie Gerakos

Electrical Engineer David Higgins

Structural Engineer
Poage Engineers & Associates

Civil Engineer, Landscape Architect
Carman

Lighting Design CMTA, Inc.

Interior hallways serve as a learning tool for students, showcasing piping for outdoor air, nonpotable water, and hydronic solar and geothermal water.



The solar thermal panels heating the domestic water have an electric heating element for backup.

Lighting. The academic building is designed for 0.5 W/ft² compared to a lighting system capable of the code compliant 1.3 W/ft². The lighting system includes a mixture of T5 compact fluorescent, T5 high bay compact fluorescent, LED fixtures and tubular daylighting devices.

The lighting controls system is equipped with occupancy sensors, an occupied/unoccupied schedule for the building, and a dimming system for most of the labs. The large windows and high north facing clerestory windows allow for maximum daylighting in the spaces; however, there is no active daylight harvesting that automatically dims lights on and off based upon natural light in the building.

The design team shifted the costs from this system towards the solar renewable energy based upon the life-cycle cost analysis. Site lighting is comprised of LED fixtures with occupancy sensors on the pole-mounted fixtures.

Renewable Energy. To meet the net zero goals of the project, the site includes a 91 kW solar photovoltaic system on the roof of the arena building and an 81 kW solar photovoltaic system on the roof of the academic building. *Figure 4*

LESSONS LEARNED

Electrical Anomalies Impact PV Production. The building is located in a remote part of the city and can be susceptible to electrical anomalies. This has resulted in some gaps in power production from a large scale PV system. While the systems are being monitored via the direct digital controls (DDC) system, this type of system should also require additional notification to a predetermined person who can act quickly upon a loss of power production.

Importance of Commissioning. When pursuing a net zero building, commissioning of the structure is very important to achieve these lofty goals. Commissioning, however, was not included in the contract requested by the owner due to budget concerns. The design team took it upon themselves to provide this commissioning to make sure that the building was operating properly. By including the commissioning at the beginning of the project and incorporating it into the construction project, these issues could have been found and corrected much easier with the contractors still on site rather than after the building was occupied.

Select Submeters from a Single Vendor. The electrical use of several systems is submetered. Different types of meters from different manufacturers are used due to the main electrical gear integrated meters, lighting control meters, and current transformer meters placed on subcircuits. The process of integrating these meters into the BACnet DDC system could have been expedited if all of the submeters had been provided by one vendor.

Account for Thermal Expansion and Contraction of a Metal Roof. The architect designed an angled standing seam metal roof to house the solar photovoltaics and the evacuated tube solar thermal panels. The panels were fastened directly to the metal roof, but designers did not take into account that the metal roof thermally expands and contracts throughout the day. The team discovered that several copper piping connections at the evacuated tube panels were disconnected due to the movement of the roof structure. The team retrofitted flexible connections at the panels to handle the expansion and contraction.



WMB Photography

A 40,000 Btu/day solar thermal radiant heating system was installed in the building consisting of 168 evacuated tube panels. This array acts as the first stage of building heat and then uses the highly efficient geothermal water-to-water heat pumps when the solar exposure is insufficient.

shows the relationship between the modeled generation of the solar PV and the actual production of the solar PV system.

The modeled production capacity was 198,640 kWh annually; however, the arrays produced 211,630 kWh from June 2012 to May 2013. This includes a partial 27-day down time in July. This power generation coupled with the efficient operation of the building means that the entire campus (excluding the greenhouse) is now approaching full net zero energy. The design team is working with the school district to reduce energy use further in hopes of achieving a full net zero energy campus.

The academic building was built for approximately \$230/ft², which includes the purchase of the solar panels. The school district

negotiated a rebate from the local utility for the energy generated on site at the AgriScience Center. The utility reimburses the district at approximately half the rate the district pays for the energy it consumes.

Life-Cycle Cost Analysis

All of the sustainable design team decisions were made based on a life-cycle cost analysis. The school district used these numbers to make informed decisions about which sustainable features were a proper fit for its building.

For instance, in a simple payback model the demand control ventilation system pays back in just over one year, and the permeable pavers pay back immediately due to the storm water tax in Fayette County. Items that were included in the project even though they did not have reasonable paybacks, but helped achieve overall energy and sustainability goals were solar

OCCUPANT SURVEY

Findings from a post-occupancy survey include:

High volume ventilation fans were not being controlled, causing disturbances with papers in the classrooms. Additional overrides were also needed on these fans in the expanded conditioning zones.

Additional training was needed on lighting control and plug load control.

Additional lighting was requested in the north-south corridors.

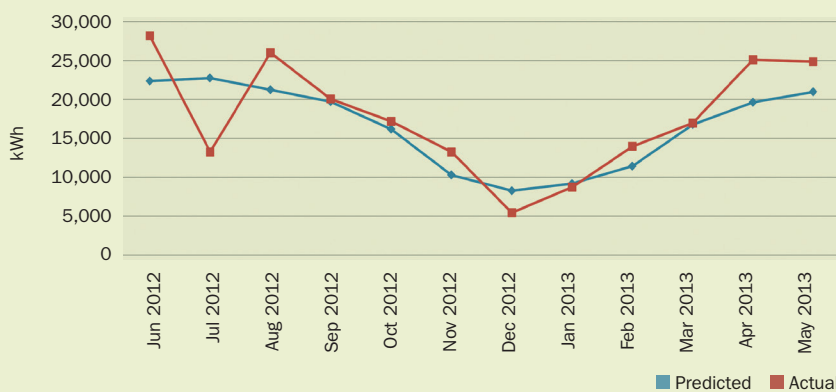
Some occupants reported elevated temperatures in a few offices and requested that the temperatures be lowered slightly.

photovoltaics, fixed exterior louvers over south windows and the solar hot water coil in the outside air unit.

Conclusion

An integrated design team approach allowed for the net zero conceptual goals (net zero sanitary waste, storm water and site irrigation plus net zero energy for the academic building) of this project to become a reality for the Locust Trace AgriScience Center. The owner's dedication to sustainability coupled with the collaborative design team process created this agricultural facility that teaches environmental stewardship by example. ●

FIGURE 4 TOTAL PV GENERATION



Note: Actual PV generation data reflects a 27-day period in July when the PV system was not fully operational.

ABOUT THE AUTHORS

Kevin D. Mussler, PE., LEED AP is the managing partner of CMTA's Lexington, Ky., office.

Stephanie Gerakos, PE., Member ASHRAE, LEED AP was the mechanical engineer on the project.

Susan Stokes Hill, AIA, LEED AP BD+C, is a principal with Tate Hill Jacobs Architects in Lexington, Ky.