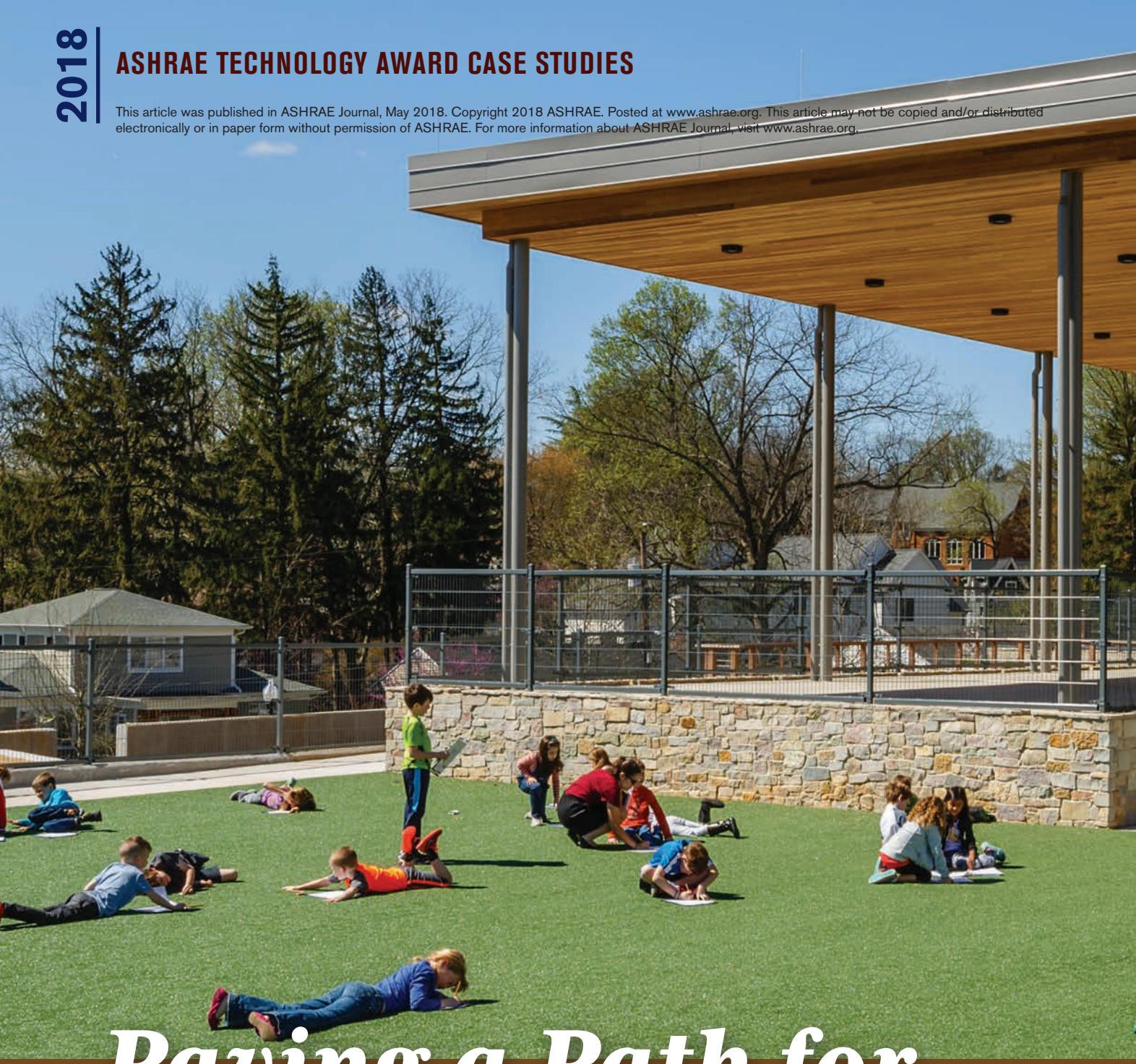

Paving a Path for Zero Energy Schools

Building massing, optimized mechanical systems and rooftop PV contribute to zero energy performance.

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BY RAY BEAUFAIT, P.E., MEMBER ASHRAE

Discovery Elementary School in Arlington, Va., is the nation's largest zero energy elementary school and has become a model for other local school districts seeking to reduce their energy consumption. The two-story, 97,600 ft^2 (9067 m^2) school was built in 2016 for a total occupancy of 715 teachers and students. Its name honors astronaut John Glenn who traveled in the Discovery space shuttle 36 years after his historic Mercury flight.

Arlington Public Schools did not start with aspirations to reach zero energy. The Request for A/E Services Proposal was similar to the district's previous requests. The budget matched the last school constructed, and the project had a sustainability goal of LEED Silver.

The evolution of Discovery into the largest zero energy school in the U.S. demonstrates that exceptional outcomes can occur when the design team and owner share a common vision to design a school that provides a better environment for student education and a building that can be a part of the education process.

Energy Efficiency

This project was designed with the goal of having the lowest energy consumption (energy use index [EUI]), integrating zero energy within the budgetary cost constraints, positively impacting the region's watershed and creating an immersive energy dashboard linking the building and education curriculum.

The design started with energy modeling to identify building massing. The architect provided the engineer with multiple schematic sketches to determine a massing model that best met the energy goal, site constraints and desired student learning experience. This early collaboration set expectations for the entire design process.

The energy model indicated a school EUI of 21.2 kBtu/ft^2·yr (240.8 MJ/m^2·yr) based on a building envelope cooling load of less than 50 tons (176 kW). The ventilation load was calculated at another 32 tons (113 kW), resulting in a building block load and final geothermal ground heat exchanger designed for 133 tons (468 kW) or 731 ft^2/ton (19.3 m^2/kW).

The five major systems that consume energy in a school are HVAC, lighting, kitchen, IT, and plug loads,

Ray Beaufait, P.E., is a principal and mechanical engineer with CMTA Inc., in Louisville, Ky.

Building at a Glance

Discovery Elementary School

Location: Arlington, Va.

Owner: Arlington Public Schools

Principal Use: K – 5 Elementary

Includes: Classrooms, kitchen, multipurpose gym, media center, teacher breakout spaces and administration space

Employees/Occupants: 715

Gross Square Footage: 97,600

Conditioned Space Square Footage: 97,600

Substantial Completion/Occupancy: June 2016

Occupancy: 100%

so strategies were developed to reduce energy consumption of each.

HVAC

A ground source heat pump system (GSHP) was provided with variable speed heat pump units and a single dedicated outdoor air system (DOAS). 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 maintenance and construction cost. The water pumping system was also distributed with an individual water pump at each heat pump. All heat pump units were installed in mechanical rooms or closets to allow easier maintenance access and proper sound attenuation. A single DOAS unit was installed to serve the entire school, taking full advantage of building occupant diversity. This resulted in reduced first cost (by providing smaller equipment and system tonnage). The DOAS unit airflow is varied based individual room CO_2 measurements.

The building has 38% glazing, but the solar heat gain was controlled through building orientation, large canopies and external solar shading devices. The exterior wall system is insulated concrete forms (ICF), and Discovery is the first school in the district to use an ICF system. The building was air pressure tested to avoid undesired air infiltration.

The designers worked together with the school district to eliminate the central pumps and associated variable-frequency drive units, using a distributive 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.

The closed loop piping system was designed to minimize the water pressure drop in the geothermal piping system. Typical design using fundamental velocities results in a typical loop pressure drop of 75 ft (23 m) total developed head (TDH), while Discovery's loop pressure drop was 35 ft (11 m) TDH. To accomplish this reduced pressure drop requires the mains in the building to be increased one pipe size. The geothermal piping distribution uses high density polyethylene (HDPE) piping (interior and exterior) in the building instead of traditional steel piping, reducing the first cost of the piping system (even with one size larger piping).

TABLE 1 Electrical use and generation, and net energy use for 2016 – 2017.

	Month	Electrical Use (MWh)	Electrical Generation (MWh)	Net Energy Use (MWh)
2016	June	30.1	62.2	(32.1)
	July	32.7	59.4	(26.7)
	August	40.8	58.8	(18.0)
	September	29.6	47.9	(18.3)
	October	39.8	44.6	(4.8)
	November	29.4	30.0	(0.6)
	December	43.6	23.2	20.4
2017	January	43.7	19.7	24.0
	February	41.3	33.5	7.8
	March	42.0	47.5	(5.5)
	April	32.0	58.0	(26.0)
	May	36.8	58.6	(21.8)
	Totals	**441.8**	**543.4**	**(101.6)**

Lighting

The thermal envelope and lighting systems were designed to abundantly light the school with glare-free natural lighting and reduce the need for artificial lighting. Shortly after occupancy, the principal called the architect and informed him the school lost power for several hours, but teachers were able to continue teaching because the natural lighting strategies were so successful. All interior and exterior lighting is LED. The interior lighting has a power density of 0.44 W/ft^2 (4.7 W/m^2). Daylighting control strategies were limited to those required by codes.

Kitchen

Two primary strategies were used to reduce kitchen energy use: reduce the size/type of the kitchen range hood and use equipment that more efficiently cooks food. The kitchen is the district's first to use combi ovens and a tilting skillet to prepare food. As a result, a smaller type two range hood was installed, greatly reducing makeup/exhaust air requirements.

IT and Plug Loads

Discovery is a wireless school using all tablets and laptop computers, which reduces energy use. The server

PHOTO CREDIT: DIGITAL IMAGING & DESIGN, INC. USED BY PERMISSION.

PHOTO 1 Discovery Elementary, which opened in 2016, is the nation's largest zero energy school. The 97,600 ft^2 school is Arlington (Virginia) Public Schools' first zero energy project.

room is designed to allow for night shutdown of the servers. Convenient teacher break rooms are provided so individual classroom refrigerators, coffee makers and microwaves can be eliminated. All domestic hot water generation outside the kitchen is via instantaneous water heater devices. The kitchen water heating uses a central system for 140°F (60°C) water where the first stage of heat is solar thermal.

Power Monitoring

The power monitoring systems measure the energy consumed in each of these five energy consuming systems and creates daily, weekly, monthly or yearly trends for measurement and verification. This information is incorporated into the curriculum integration system for use in teaching and learning. Twelve months of utility invoices and power monitoring data are shown in *Table 1*. The building is consuming 16.4 kBtu/ft^2·yr (186.2 MJ/m^2·yr) of energy and is the best performing school in the district.

Zero Energy

The building is equipped with a 500 kW solar photovoltaic system (*Photo 1*) that is completely roof mounted. The design team's preference was to roof mount all the solar PV panels and avoid costly parking shade structures or ground-mounted systems that would limit student recreation areas. The roof area was oriented to the south, and the building stepped higher to the north to avoid any undesired shading. Metal standing seam roofs were integrated into the low slope roofs to increase panel mounting efficiency. Also, rooftop HVAC equipment was avoided, except for exhaust fans and daylighting devices. The PV system generated 543.4 MWh of electrical energy in the measured year, which is approximately 23% more than the energy consumed, and returned 101.6 MWh of energy to the electrical grid.

Operation and Maintenance

The geothermal HVAC system performs exceptionally well with regard to energy. It also offers operation and maintenance (O&M) advantages since it eliminates central plant chillers, boilers, cooling towers and pumping systems, all of which require external service contracts. In the event of a heat pump unit failure, only a single zone has its environment impacted.

Design strategies to simplify O&M include:

- The DOAS unit was selected with a 2-pipe coil in lieu of internal refrigerant compressors. A single water-to-water heat pump chiller provides the source of chilled or hot water.
- The DOAS unit includes heat recovery and central exhaust to minimize the use of roof-mounted exhaust fans.
- All HVAC equipment is located in mechanical rooms instead of being roof mounted or located above ceilings to ease maintenance and extend equipment life. All heat pump units are on 12 in. (305 mm) stands to make service easier.

- All heat pump units have custom air filter frames that use 24 in. × 24 in. (610 mm × 610 mm) filters only. The number of filters change with cfm.
- All unitary controls were installed on the front of the unit.
- The geothermal piping distribution uses HDPE piping (interior and exterior) in the building instead of traditional steel piping, reducing chemical treatment.

Indoor Air Quality and Thermal Comfort

The variable flow DOAS (*Photo 2*) provides outdoor air to all spaces in compliance with ASHRAE Standard 62.1-2007. Discharge air temperature is maintained at 68°F (20°C), slightly colder than room temperature, and is partially dehumidified through the use of face and bypass dampers on the chilled water coil. The single, variable flow unit tracks student movements through CO_2 sampling and adjusts the outdoor air (OA) flow to each space in response to occupancy via variable air volume boxes in the OA ductwork. All CO_2 sensing results are trended by the direct digital control and creates an alarm for high CO_2 levels. As research continues to evolve on the effect of indoor air quality and student cognition, the setpoints for the system can be changed to accurately reflect best practices.

This project uses multiple geothermal heat pumps to condition all occupied areas of the building. This decentralized approach allows excellent thermal comfort in each zone. Rooms with similar envelope, people, light and equipment loads have been grouped together in distinct zones so temperature can be controlled effectively. The HVAC is designed to condition the space per ASHRAE Standard 55-2004. Several typical areas of the building were analyzed based on Figure 5.2.1.1 from ASHRAE Standard 55-2010 by demonstrating acceptable indoor comfort conditions throughout the school.

The design team chose variable speed compressor heat pump units to increase system efficiency. During part-load operating conditions, a reduced speed compressor unit will operate more efficiently than a single-stage compressor unit. Full-load operating efficiencies occur infrequently. Trending of the compressor operation for the first year indicated most of the units were operating below 50% for a majority of the hours of operation. The part-load efficiency of the heat pump units is three times more efficient than full-load efficiency. The variable speed heat pump operation also provides the additional benefit of the cooling capacity matching the building and occupant load. The many hours operating at lower speed provides the added benefit of reducing the overall building humidity.

PHOTO CREDIT LINCOLN BARBOUR PHOTO, INC., USED BY PERMISSION.

PHOTO 2 A single DOAS unit was installed to serve the entire school, taking full advantage of building occupant diversity. This resulted in reduced first cost (by providing smaller equipment and system tonnage).

Innovation

While many aspects of this project can be considered innovative, including a solar lab where students experiment with solar PV, the immersive curriculum integration program is the most innovative aspect of this project. After the Discovery Elementary contract was awarded, the owner interviewed several dashboard providers and none could satisfactorily integrate STEM-based learning opportunities into the dashboard, so they turned to the designers for help. The designers developed an engineer's solution to a better building energy dashboard. It is an engaging and interactive virtual reality experience that reinforces core content by linking teachers to live data as well as STEM, energy and sustainability examples throughout the school.

Erin Russo, the principal of Discovery, speaks about its impact, "The dashboard recreates the experience of watching a zero energy school come to life for those new cohorts of students. Teachers use the dashboard to create complex learning opportunities. They ask students to solve, critically think and research aspects of the dashboard. Giving students a portal to the inner workings of their school creates pride and a sense of collective responsibility for their environment."

Cost Effectiveness

The district's budget for this project was $249/ft^2

($2680/m^2) plus a site cost of $295,000/acre ($728 958/ha). The low bid accepted was $32,305,000, including the solar PV system and was significantly under the design budget of $36,257,000. (The budget was based upon the last middle school built and only included a LEED Silver goal.) The design team challenged the sustainability goal and collaborated to design a zero energy school that could be delivered within budget while meeting the energy goals and prioritizing education. A cost-shifting approach was developed that examined all energy performance improvements in terms of the return on investment with respect to the solar PV system.

An example of this cost shifting approach was the large glass wall system in the cafeteria. It provided great views to the outdoors, but would reduce the thermal envelope's effectiveness. Designers investigated the cost of triple pane glass and compared that cost to adding additional PV panels. The results were the triple pane glass would cost $109,000 extra, while the additional solar PV panels just $9,000; therefore, it was more cost-effective to invest in the additional PV.

Environmental Impact

Discovery's PV system positively affects air quality since all energy consumed is produced via renewable energy, with surplus returned to the grid. The environmental impact of this project results in a reduction in greenhouse gas emissions equivalent to 1,021,000 fewer miles driven by a passenger car. CO_2 emissions were reduced by the equivalent of 456,000 lb (206 838 kg) of coal burned or 417 metric tons of CO_2.

Conclusion

Just as John Glenn helped pave the way to space exploration, Discovery Elementary is paving a path for other districts in the region to follow. The energy success story has shown other local school districts they can construct zero energy schools. Several schools in Virginia and Maryland are now attempting zero energy. The Arlington Public School district has been so pleased with Discovery Elementary's zero energy results that new RFPs for A/E services now include zero energy as a prerequisite. ■