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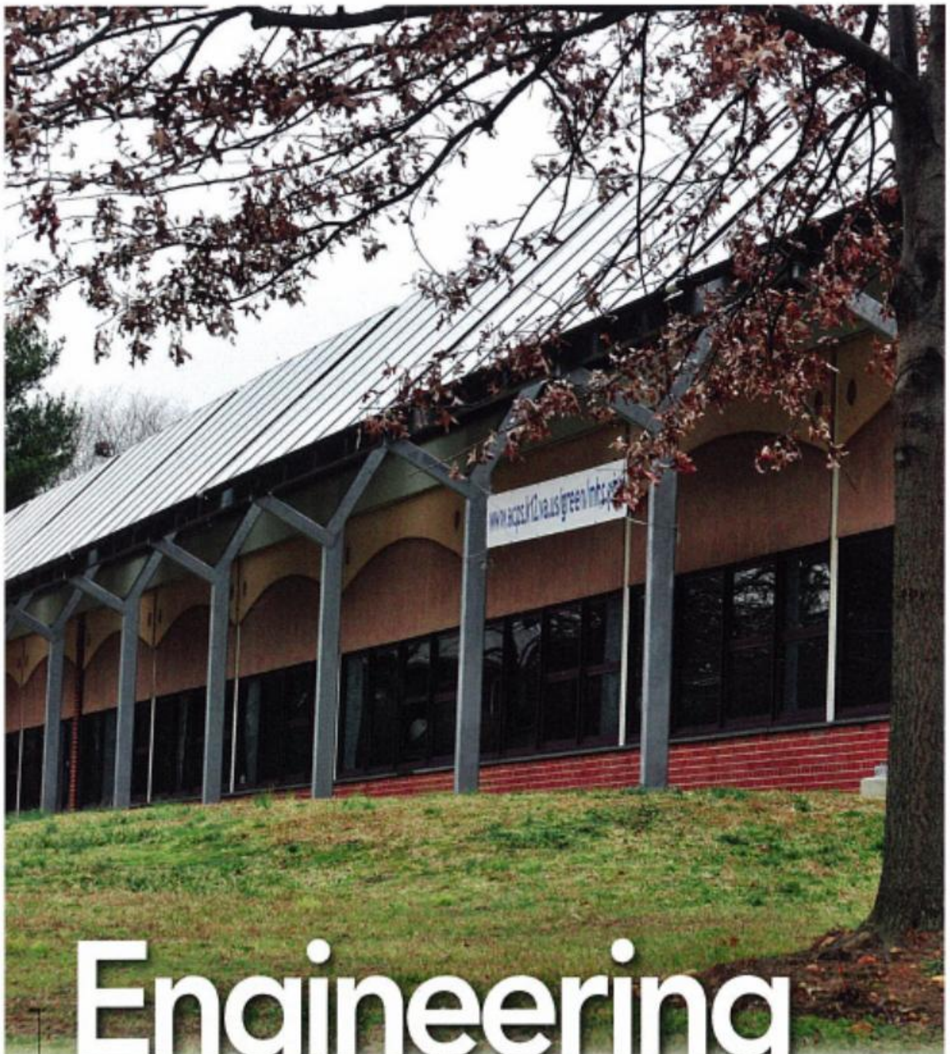

An exterior view of the solar panels at the T.C. Williams High School Minnie Howard Campus is shown from the front lawn. Courtesy: Mattox Photography

Engineering a sustainable school

A Virginia school includes a geo-solar system in its HVAC upgrade. Engineers designed a system that was architecturally integrated, offering students a unique learning tool.

BY BRUCE BEDDOW, PE, *b2E Consulting Engineers P.C., Leesburg, Va.*

Alexandria City Public Schools (ACPS) engaged b2E Consulting Engineers P.C., Leesburg, Va., to design an energy-efficient HVAC replacement for its 134,000-sq-ft T.C. Williams High School Minnie Howard Campus, which serves ninth graders. When completed in 2009, the school's existing building was 43 years old. The existing system consisted of a two-pipe through-wall unit ventilator system with a constant flow air-cooled chiller and two water tube boilers serving the two-story 32-classroom wing, gymnasiums, and locker room areas (about 66,000 sq ft). The remainder of the building (about 68,000 sq ft) was packaged rooftop HVAC units with direct expansion (DX) cooling and natural gas fired heating.

We hired Hayes Large Architects (HLA) from Leesburg, Va., to assist in developing a master plan of sustainable design initiatives for the facility. In the process of meeting with ACPS, we determined that the client wanted an HVAC system concept that could be incorporated throughout the school district. ACPS wanted to use the energy-saving features of the building as an educational showcase with a "Greenovation Lab" to teach students the fundamentals of energy savings. In addition, ACPS wanted the energy-saving features of the building to be visible to the general public.

A ductless variable refrigerant multiple zone (VRMZ) heat pump system was appropriate for this building because it has a low slab-to-slab height. Ductwork had to be greatly reduced. The VRMZ system delivers heating and cooling through refrigerant piping using ductless ceiling-mounted terminal units in lieu of hot water (HW) and chilled water (CHW) piping and ducted ceiling-mounted fan coil units. The engineers used the Mitsubishi City-Multi System as the basis of design.

We decided that double-plate heat exchanger energy recovery ventilation units would be used to deliver 14,000 cfm 100% outside air to meet IBC-2006 code required ventilation. These units could not be supported on the existing pre-stressed concrete plank roof structure, so they had to be fit into the basement.

The existing **building HVAC system energy consumption** was determined using the existing utility bills.

b2E Consulting Engineers decided that the VRMZ system should be connected to a ground loop heat exchanger in lieu of an air-cooled or typical hydronic (boiler and cooling tower) solution. The bus loop was the only location available for the ground exchanger. The available space was so limited that a creative solution was necessary.

Local zoning required that if more than 2,500 sq ft of land is disturbed, a site grading plan would be required. The estimated time (12 months) to complete the civil plans was unacceptable to ACPS because the existing system was failing. We met with the local zoning board and worked out a plan whereby work on the well field under the existing bus loop would not be considered in the disturbed area because the final product would be the same as before the construction. Zoning asked ACPS to add some Filteras (planters that collect stormwater runoff from the pavement to improve surface runoff water quality), and ACPS agreed.

We helped ACPS procure a conductivity test of the site. The test results indicated that the borings could be 310 ft deep with a conductivity of 0.9 kBTU/ft F hr. The available area could only support 65 wells at 300 ft deep. However, this fell short of the 80 tons of cooling needed for the two-story classroom wing and locker room area renovation.

The well field was calculated using a double loop high-density polyethylene (HDPE) PEXa piping system. Capacity of the 65-well field increased from 68 to 80 tons. This system delivers approximately 15% more capacity using the same number of borings.

The engineers wanted to eliminate redundant systems and decided a separate hot water heating boiler was not necessary. Domestic hot water boilers were already required. The domestic hot water heating system would be used to heat the energy recovery unit (ERU) ventilation air from plate heat exchanger-2 leaving air temperature (PHX-2 LAT) to neutral 72 F supply air temperature to the classrooms.

The locker room—which also needed to be renovated—had too many showers and no office or conference areas. HLA developed a new concept to reconfigure the space. A ground-source heat pump (GSHP) unit was designed to deliver 100% ventilation air to the space.

Because the school's students do not use the showers often, the heat stored in the domestic hot water (DHW) storage tank is primarily used for the kitchen, building service closet mop sinks, hand sinks, and lavatories. Knowing this, the engineers designed the hot water storage tanks to accommodate auxiliary double-wall tube bundles for heating non-potable water.

The DHW heating system was designed using condensing boilers with thermal stratification DHW tanks in lieu of mixing-type tanks. This reduces the boiler entering water temperature, which increases DHW boiler efficiency. Two tanks were used and piped in series: Domestic hot water storage tank-1 (DHWST-1) is a preheat tank and DHWST-2 is a final DHW tank.

Solar hot water

To reduce natural gas consumption, a solar hot water array was used to generate solar-heated hot water year-round. The solar panel angle was set at 45 deg. to maximize hot water generation in winter.

ACPS wanted to showcase renewable energy systems, but the ground loop heat exchanger piping would be hidden under the bus loop. However, the solar array could be visible—the front of the building faces due south. HLA performed a study to set the panels in front of the single-story classroom wing

The T.C. Williams High School Minnie Howard Campus includes solar-powered water heaters in the mechanical room. Courtesy: Mattox Photography

Proposed geo-solar energy consumption breakdown

Energy user	Electricity cost ($)	Natural gas cost ($)	Energy (MBtu)	Total utility ($)
Heating energy (RTU)	---	$15,521	1,149.7	---
Heating energy (boilers)	---	$0	---	---
Heating energy (DHW)	---	$4,266	316.0	---
Subtotal HW heating	$19,787	1,465.7	$19,787	---
Cooling energy (RTU DX)	$10,286	---	425.4	---
Cooling energy (HP AHU, ERU)	$5,254	---	217.3	---
Subtotal cooling	$15,540	---	642.7	$15,540
Fan energy (RTU)	$4,812	---	199.0	---
Fan energy (AHU, ERU)	$3,269	---	135.2	---
Subtotal fans	$8,081	---	334.2	$8,081
Subtotal pumps	$2,667	---	110.3	$2,667
Subtotal lighting (T-5)	$25,929	---	882.4	$25,929
Computers and plug loads	$33,089	---	1,372.6	$33,089
House systems	$21,335	---	882.4	$21,335
Total annual energy cost	$106,741	$19,787	5,914.3	$126,528

Note: Actual metered annual energy savings are ~$35,000 per year (~7% better than expected). This is due to the fact that the HW boilers seldom operate. The solar HW collector contribution was underestimated, and the installed system is providing more renewable heating energy than originally calculated.

Table 1: The proposed geo-solar energy consumption breakdown is shown. The design energy budget (DEB) for this system is 44.42 KBtu/sq ft year over the 134,000-sq-ft building area. Courtesy: b2E Consulting Engineers P.C.

The energy cost savings for the actual geo-solar system as compared to pre-renovation energy cost is about $640,000.

to shade the fenestration in summer and allow daylight UV radiation to enter the classroom in winter. A self-supporting steel structure was designed to hold 42 38-sq-ft panels in a linear array in public view.

The concept of the geo-solar system is to have one or two DHW storage tanks designed to store the solar hot water continuously generated by the array. This array is designed to generate 500,000 Btuh. The heat is stored in the tanks using a solar double-wall tube bundle in the bottom half of each tank. The solar panels can make up to 180 F water in full sun and no cooler than 85 F water on cloudy days.

The system uses two 500,000 Btuh DHW condensing boilers connected in a stratifying piping arrangement to charge the tanks from top to bottom when there is inadequate solar contribution. The dispersion tube in the top of the tank must be designed carefully not to break the stratification layer during charging.

The mechanical room at the T.C. Williams High School Minnie Howard Campus includes six Mitsubishi Electric W Series (water source) heat pumps. Courtesy: Mattox Photography

Lifecycle analysis

The existing building HVAC system energy consumption was determined using the existing utility bills. A base case new four-pipe CHW and HW system was evaluated using fan coil units in classrooms with energy recovery units in the basement, an air-cooled chiller on the roof (due to the noise ordinance), and condensing hot water boilers with a primary piping arrangement for both CHW and HW plants. The HW plant has a variable speed pumping system.

The proposed new Geo-Solar HVAC System for the two-story classroom wing, including areas of the building renovated using rooftop DX cooling and natural gas fired heating units, was included in the calculations. This was done because the new HVAC system is not submetered. The renovated building was calculated to save approximately $32,500 per year over the base case CHW/HW system.

The National Institute of Standards and Technology (NIST) Building Life-Cycle Cost (BLCC) Program calculation procedures were used to evaluate the energy consumption measures in this analysis. A real discount rate of 3% was used excluding general inflation.

The initial capital investment cost to install the geo-solar system over the four-pipe CHW/HW system was $675,000. The energy cost savings for the actual geo-solar system as compared to pre-renovation energy cost is about $640,000 in present-value dollars over the 20-year study period. The base case air conditioning chiller and HW boiler systems were assigned $10,000 higher annual maintenance cost due to the required service contract for the systems. The non-annual repair and replacement costs were estimated to be the same for both systems; the chiller was given a $10,000 rebuild overhaul in year 10.

A residual value of 50% ($102,500 in present-value dollars) was given to the ground-loop heat exchanger because it should last 60 years or three system lifetimes. However, we only assigned two system lifetimes in the analysis.

A year's worth of actual utility bills was

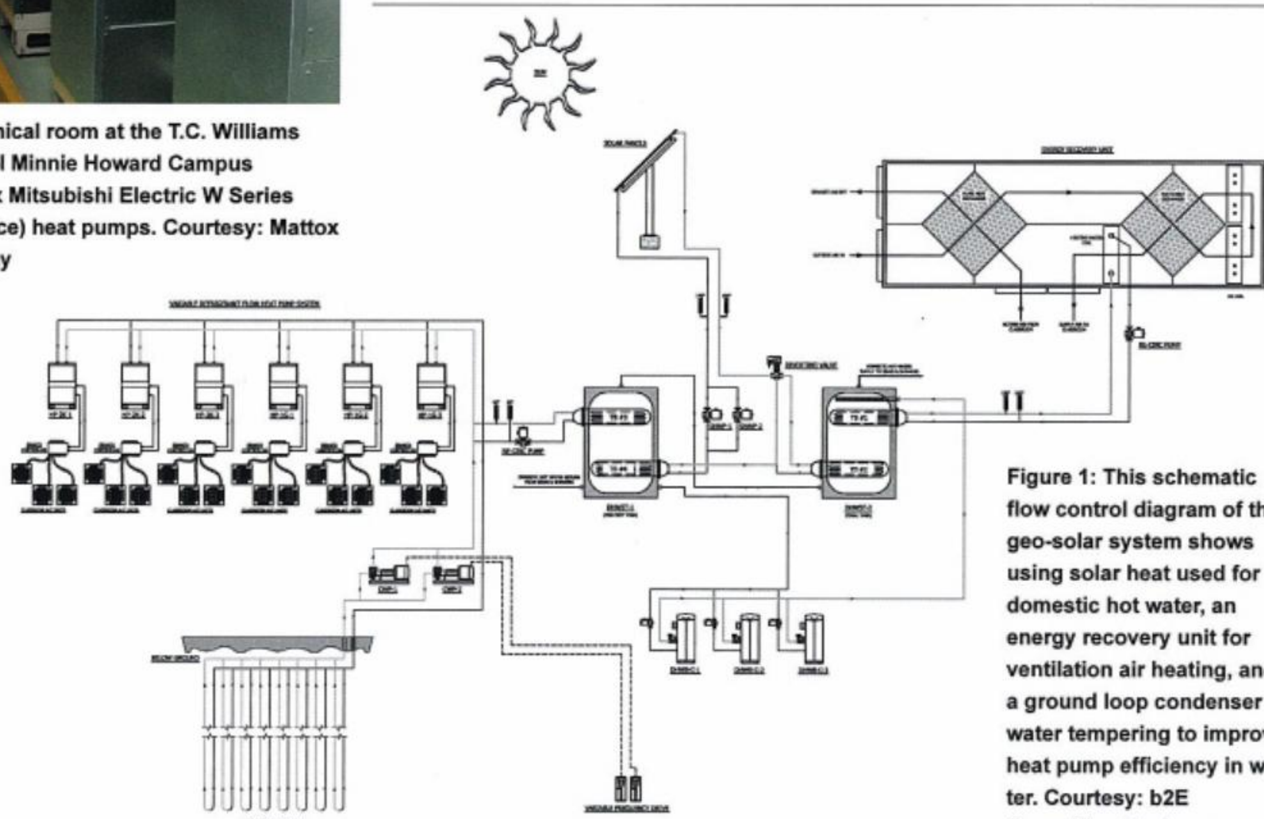

Figure 1: This schematic flow control diagram of the geo-solar system shows using solar heat used for domestic hot water, an energy recovery unit for ventilation air heating, and a ground loop condenser water tempering to improve heat pump efficiency in winter. Courtesy: b2E Consulting Engineers

Complete commissioning was included in the construction documents.

used for comparing the renovation of the existing building to the installed geo-solar system. The results are economically, ecologically, and politically positive. The school system will pay off the initial incremental investment cost and provide a calculated net savings of about $406,500 over the 20-year system lifecycle. The simple payback period is only five years and the discounted payback is 12 years, which is less than the system lifetime (20 years). The system will save approximately 54,630 MBtu, 6,426 metric tons CO_2, 27.1 metric tons SO_2, and 11.7 metric tons NO_x over its lifetime (see Table 2).

Commissioning process

The consulting engineers included a complete commissioning specification in the construction documents including the commissioning process, the functional checklists, and the performance verification checklists.

- Commissioning process: The commissioning specification required that the contractor self-commission system operation first then demonstrate system operation to the owner/engineer.
- Functional checklists: These lists, one for each specification section, are provided to verify that the physical installation complies with the construction documents' details and the manufacturer's installation manuals, and to confirm that the system start-ups are complete. The lists also require that final documentation such as balancing reports, operational and maintenance manuals, and as-built drawings are submitted for final review.
- Performance verification: This is a point-by-point checkout procedure written by the engineer of record for the contractor's benefit. The energy management control system contractor ensures the system functions in accordance with the sequence of operation, then demonstrates the operation to the engineer of record. This process worked very well on this project because it is a rather new system application. However, we do it on all of our projects when authorized by the client. We find it is quicker and less costly to the owner than the traditional commissioning process. cse

Bruce Beddow, PE is principal of b2E Consulting Engineers P.C. He has worked in Switzerland, Germany, and the United States as a consulting engineer. His expertise is the application of energy-efficient technologies in innovative ways to maximize energy and cost savings for clients.

Lifecycle cost analysis

Economics measures	Existing system replacement (two-pipe system)	Base case model (four-pipe system)	Geo-solar model (GSHP/HW solar)	Actual geo-solar (GSHP/HW solar)
Initial cost	$0	$5,700,000	$6,190,000	$6,155,000
Investment cost	(Note 1)	$200,000	$690,000	$655,000
Energy costs	$2,246,282	$2,042,112	$1,628,267	$1,606,951
Annual operations, maintenance, and repair costs	$221,690	$221,690	$59,517	$59,517
Nonannual operations, maintenance, and repair costs	$5,661,651	$11,014	$3,721	$3,721
Residual value (ground-loop heat exchanger)	$0	$0	($102,826)	($102,245)
BLCC (20 years)	$8,129,623	$7,974,816	$7,778,678	$7,722,943
Net savings (20 years)	---	$154,807	$350.944	$406,680
Savings to investment ratio	---	1.03	1.06	1.07
AIRR Annual internal rate of return	---	3.14%	3.29%	3.34%
Simple payback	---	5 years	5 years	5 years
Discounted payback	---	6 years	13 years	12 years
Energy savings (20 years)	---	15,184 MBtu	52,337 MBtu	54,633 MBtu
Emissions savings (20 years)	---	2,496 metric ton CO_2	6,306 metric ton CO_2	6,426 metric ton CO_2
		8.3 metric ton SO_2	26.1 metric ton SO_2	27.1 metric ton SO_2
		4.9 metric ton NO_x	11.5 metric ton NO_x	11.7 metric ton NO_x

Note 1: The initial investment cost was 0 in year 1, but the system replacements were made to achieve the base case system over a longer period of time. The nonannual operations, maintenance, and repair costs are broken down as follows:
Year 1: AC chiller: $350,000
Year 2: UVs in classrooms: $650,000; boilers: $425,000; piping: $820,000
Year 3: Electric service: $425,000; lighting systems: $350,000
Year 4: Packaged rooftop units: $2,400,000
Year 5: DHW heating: $30,000
Total cost by postponing projects in parts: $5,500,000 over 5 years. These costs are indicated in present value dollars under "Nonannual Operations, Maintenance and Repair Costs."

Table 2: Building lifecycle cost analysis in present-value dollars over the 20-year study period. Courtesy: b2E Consulting Engineers P.C.

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