Strawbridge Elementary School completed an energy retrofit project, featuring a new ground-source heat pump system. The project has resulted in a 44% reduction in energy use intensity (EUI) and a significant improvement of the school's ENERGY STAR score from 23 to 75.

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Lessons *From the Ground Up*

BY ERIC (MIAO) YANG, P.E. BEAP, CPMP, HBDP, MEMBER ASHRAE

Virginia Beach City Public Schools is a national leader for integrating sustainability into buildings and extending it into classroom teaching. An energy retrofit project centered on a new ground-source heat pump (GSHP) system at Strawbridge Elementary School demonstrates how institutions can improve buildings, save energy, and create a culture of sustainability, financial stewardship, and classroom excellence.

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Building Description

Strawbridge Elementary, an 84,948 ft^2 (7892 m^2) one-story facility constructed in 1991, accommodates approximately 750 students and 100 staff members. The project team, engaged through an energy savings performance contract as the financing vehicle, made three significant changes to the existing building: (1) replaced the heating and cooling systems at the school with a substantially more energy-efficient GSHP system; (2) installed more efficient lighting; and (3) upgraded the energy management control system (EMCS).

In the months since commissioning, it has become clear that this project not only achieves substantial energy savings but also provides an innovative new learning platform for students in a more comfortable learning environment.

Prior Heating and Cooling Systems

Until 1996, the school's heating and cooling systems used a two-pipe water-source heat pump system for heating and cooling and several unitary direct-expansion (DX) rooftop units (RTUs) with electric heating for the gymnasium, library, cafeteria, and administrative areas.

As part of a renovation project in 1996–1997, the school closed outdoors air to all water-source heat pumps (WSHPs) in the classrooms. It also installed five outdoor air units (OAUs) with DX coils and heat-pipe energy recovery technology. Closing the outdoor air sections caused the existing WSHPs, each rated at 3.5 to 4 tons (12 to 14 kW), to become oversized for cooling.

Additional summer inefficiencies came from two aging closed-circuit fluid coolers that rejected heat from the condenser loop, using two 25 hp (19 kW) pumps (*Figure 1a*). During winter, two hot water boilers rated at 1,440,000 Btu/h (422 kW) output provided hot water to the WSHP system.

Heating and Cooling Retrofits

The heating and cooling retrofits, shown in *Figure 1b,* were installed in two phases to accommodate the school schedule. Between January and March 2013, the GSHP well-field was drilled (274 bore holes, 300 ft [91 m] deep) and a high-density polyethylene (HDPE) vault was buried in the large sports field behind the school (*Photo 1*). Between June and August 2013, the remaining GSHP components were installed, including two new 40 hp (30 kW) well pumps (lead-lag configuration) with variable frequency drives (VFDs). This new system was properly sized for the heating and cooling load of the entire school.

BUILDING AT A GLANCE

Strawbridge Elementary School

Location: Virginia Beach, Va.

Owner: Virginia Beach City Public School

Principal Use: K–12 education

Includes: Classrooms, library, gymnasium, cafeteria, offices

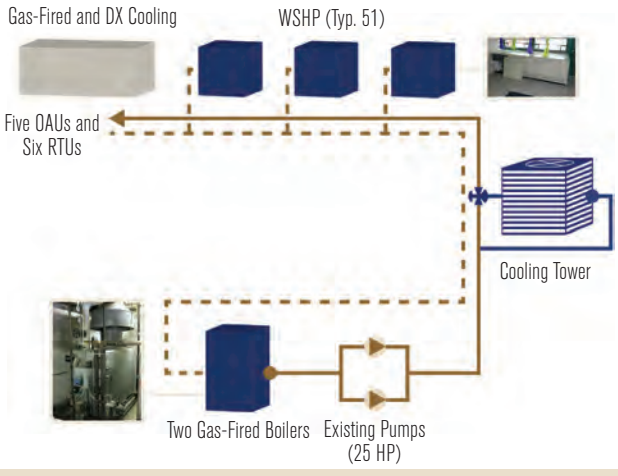
Employees/Occupants: 750 students, 100 staff members

Gross Square Footage: 84,948

Conditioned Space Square Footage: 84,948

Substantial Completion/Occupancy: August 2013

Occupancy: 100%



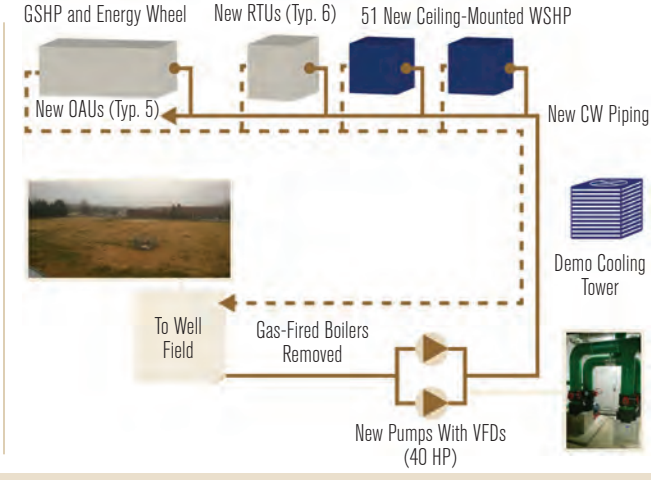


FIGURE 1A (LEFT) Existing oversized WSHPs, aged OAUs, and RTUs consumed more energy and generated maintenance challenges. FIGURE 1B (RIGHT) The upgraded HVAC system features higher efficiency GSHPs and OAUs, which eliminated the need for existing cooling towers and gas-fired boilers.

Additionally, a separate re-roofing project at the school replaced all existing RTUs and OAUs with new GSHP rooftop units. The five OAUs were replaced with five new units featuring high efficiency energy recovery wheels with VFDs. The unit serving the administrative areas was replaced with a variable refrigerant flow system, also with a dedicated outdoor air system coupled with an energy recovery wheel.

The design relies on a weather-based bin-model developed through extensive engineering analyses. By trending the supply water temperature of the existing GSHP systems with various outdoor temperatures and trending the supply water temperature of an existing, nearby GSHP installation, engineers were able to estimate the supply water temperature of the new well-field. They then incorporated the equipment efficiency data to calculate the existing and proposed cooling and heating energy. With these calculations in hand, they optimized zone schedules and temperature setpoints to maximize the energy savings.

Gains in energy efficiency performance were truly groundbreaking, resulting in a 44% reduction to the energy use intensity. Similarly, the resulting ENERGY STAR score improved significantly from 23 to 75.

The majority of this energy reduction resulted from the more efficient lighting, the GSHP system, and the elimination of two gas–fired boilers.

Improvements to Indoor Air Quality and Thermal Comfort

Upon project completion, the setpoints for space occupied air temperatures were 70°F (21°C) for heating and 75°F (24°C) for cooling. Night setback and unit scheduling were defined in the EMCS based on the school's occupancy schedule. A demand control ventilation strategy was also implemented, with new carbon dioxide sensors at the space level of selected areas: four sensors in the gymnasium, two sensors in the cafeteria, and one sensor at the library.

Several old OAUs were inoperable with mechanical issues and were replaced with new OAUs which, of course, greatly improve the indoor air quality in the classrooms.

Similarly, the old classroom WSHP consoles were ineffective—circulating air only near the windows—and noisy, due to the age and oversizing of the compressors. Replacing these with new ceiling-mounted supply/return systems greatly improved air distribution and delivered better acoustical performance.

PHOTO 1 Horizontal HDPE piping, trenched at minimum 4 ft (1.2 m) below the grade level, connects the supply and return piping from each bore hole to the HDPE vault in a reverse-return arrangement, which minimizes system pressure drop and the corresponding pumping energy.

As evidenced by a 74% reduction in complaints, the new system significantly improved thermal comfort. Jim Morris, assistant director of energy/environment, Virginia Beach City Public Schools, stated, "Before the work was started, there were 101 work orders with temperature, humidity, and other comfort complaints. Last year [2014], the number was 26."

Fewer Operation and Maintenance Demands

This project eliminated the need to maintain the aging cooling towers, the leaking condensing piping, and the oversized WSHP systems. As another example of sustainable leadership, managers facilitated reuse of two existing boilers for other schools. Maintenance staff participated in four training sessions about EMCS, provided in conjunction with the project. The project team implemented extensive commissioning for GSHP systems, new EMCS, and the new well-field before delivery to Virginia Beach City Public Schools, the project owner. Additionally, the project team helps the district with its annual ENERGY STAR survey.

Phased Construction and Implementation

Maintaining a safe, secure, and healthy environment for students and teachers while replacing all HVAC equipment during the existing school's schedule was a key planning concern. One solution was to phase the project installation. The well-field was installed first, followed by the rest of the replacement during the school's summer break. Although the replacement of outdoors air units and rooftop units was contracted separately, the team responsible for the performance contract also collaborated on that design/construction

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TABLE 1 Annual baseline energy use summary.

Utility Cost	Electrical Demand	Electrical Consumption	Natural Gas Consumption
$171,007	7,061 kW	1,827,456 kWh	17,661 therms

effort because each affected the same campus community.

Financial Stewardship and Cost Effectiveness

Utility data provided by the school district enabled the project team to establish the project baseline for Strawbridge Elementary, against which improvements are measured (*Table 1*).

The school's blended electricity rate of $0.085/kWh and average natural gas rate of $0.872/therm ($8.27/GJ) are the baseline for project savings calculations.

Figures 2 and *3* compare the electricity and natural gas consumption before and after the project. Electricity consumption dropped by at least 32% for the years measured so far, and natural gas consumption dropped by at least 84%.

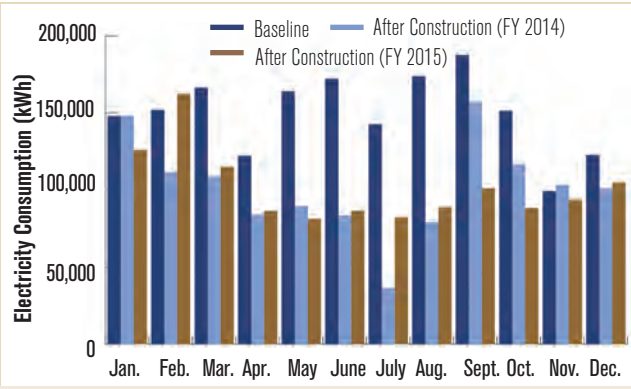

FIGURE 2 Lighting, EMCS, and GSHP result in 32% reduction in electricity consumption in fiscal year 2014 and fiscal year 2015.

Implementation of the GSHP project was bundled with other energy conservation measures for a comprehensive project with payback metrics that met the school district's financial objectives. Total project cost was $3 million including the new GSHP system and lighting improvements, together with capital improvements such as condensing pipe/pump replacement, EMCS replacement, and all WSHP replacement.

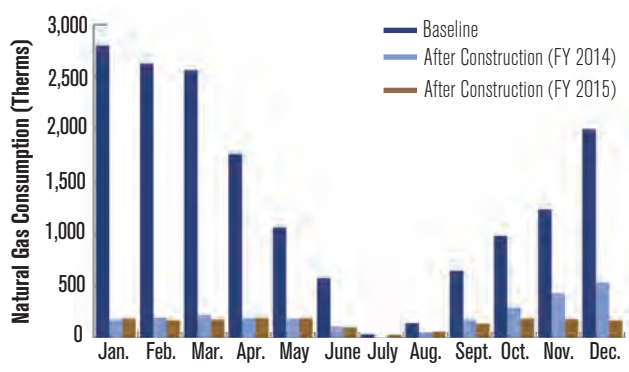

FIGURE 3 GSHP and EMCS contribute the majority of the 84% (fiscal year 2014) and 89% (fiscal year 2015) reduction in natural gas consumption.

Environmental Impact

This project has cumulatively eliminated 1,053 tons (955 metric tons) of equivalent carbon dioxide emissions (FY 2014 and FY 2015) and eliminated harmful chlorofluorocarbons by using a more environmentally balanced refrigerant, R-410A.

Furthermore, the design team adjusted the well-field design to minimize the costs, environmental impact, and safety risks associated with relocating the existing playground area.

Innovative Footprint

Installing ceiling-mounted GSHP units to replace floor-mounted units provides extra floor space in the classroom. The change provides more aesthetic appeal, and the reclaimed square footage is often used as bookshelves or storage to complement the classroom environment.

When replacing equipment in place, it can be difficult to match the original equipment footprint. The ceiling-mounted solution kept the equipment selection open to a broader number of manufacturers, avoiding the risk that longer lead-times for more customized equipment could have delayed implementation.

Innovative Culture

The project at Strawbridge Elementary benefited from more holistic work within the district. A green operations team assessed teachers' and support staff members' attitudes and perceptions about energy conservation

TABLE 2 Cost/savings summary.

System Size	280 tons
Number of Wells and Depth	274 wells, 300 ft deep
Annual Energy Cost Savings	$48,795
Annual Utility Baseline Cost	$171,000
Savings Cost %	29%
Installed Cost*	$3,046,000

* Installed cost did not include the OAU replacement cost, which is not financially part of this project.

district-wide. Based on 666 completed responses from the baseline survey (margin of error 3.7%) results indicate that teachers and staff are personally concerned and willing to engage in energy conservation.

To leverage favorable attitudes toward energy conservation, the green operations team had already collaborated with district science teachers in other VBCPS schools to build interactive, unique learning tools to help students better understand physical science

Teachers used the animation of a district building heated and cooled by a GSHP to educate students about concepts such as heat transfer, laws of thermodynamics, and geo-science. Related homework assignments sent students to their backyards for dirt samples. Thermal properties of the samples were compared and contrasted, allowing students to generate recommendations for a GSHP at their home.

Curriculum development based on geo-science led to ideas for other teaching platforms and grade-level audiences at more schools. The green operations team and the school district later secured grant funding to integrate plans for a future local offshore wind installation with the science curriculum. Lesson plan deployment included a variety of engaging learning tools, including interactive animations, a scaled wind turbine model, and a competition for students to test their newfound knowledge in a fun yet practical manner.

Students applied the concepts learned in class to build wind turbines, which were tested for energy generation and sturdiness in an on-site wind tunnel. Practicing the scientific process, students used feedback from the wind tunnel tests to fine-tune their designs. This activity and other sustainable learning initiatives at the district bolster the district's reputation locally, regionally, and nationally.

Conclusion

Strawbridge Elementary and its stakeholders engaged in this energy retrofit project with multiple objectives, not just to solve a singular problem at hand. The project can be deemed a success for all parties involved not only because of its energy and financial savings, but especially because students and teachers enjoy learning in a more comfortable classroom environment. As the sustainability gurus say, that is a win-win-win.

Acknowledgments

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