Faced with a declining student population and an aging high school with mechanical problems, Minnesota’s Lake Superior School District decided to replace Two Harbors High School and an elementary school with a larger facility that would include sixth through 12th grades. LHB, a Duluth, Minn., design firm, created an integrated design to complete a project that cost less than similar schools constructed in Minnesota at that time. While limited energy modeling was performed during design, performance monitoring of the facility after construction validated its energy-efficient performance.
intake louvers and low fan speeds (where the fan was run at all). Overall ventilation within the building was below acceptable levels. A number of the educational programs were housed in inadequate spaces, and life safety concerns could be only partially addressed due to the existing physical plant. Building a larger facility would remedy these conditions and further lower operating costs by eliminating one of the district’s elementary facilities and creating a sixth to 12th-grade high school.

The selected 70-acre site sits on the slopes of Lake Superior above the town about 0.5 miles from the original high school. The formerly farmed site, which slopes toward Lake Superior, was partially covered with mixed forest and wetlands. The region’s impermeable layers of clay and rock have led to the formation of many wetlands in the area. Natural gas, three-phase power and city water and sewers were extended from the nearby utilities to the site.

High on the school district’s list of priorities for the new school were low operating costs and an improved indoor environment. The design of the 900-student, sixth to 12th-grade school met the district’s goals for a durable, low-maintenance facility with multi-use spaces that also serves the community’s residents. This high performance project was delivered at $127 per square foot, lower than the $161 per square foot average for school projects bid in the state of Minnesota in 2005. The design team’s sustainable design practices provided benefits beyond the initial vision.

**Site Management**

A number of high performance design features were included in the site design. The use of native plantings and limited grass areas resulted in no fixed irrigation, with only the main competition field being irrigated. Ninety-five percent of the storm water that hits the site is retained.

A system of paved walking and bicycle paths was created to link the new site with the town and other nearby recreational areas. The parking lots were created without curb and gutter to enhance the performance of the storm water management system.

**Architectural Integration**

The building sections allow enhanced performance of the daylighting controls and ventilation systems. The mechanical systems selected reduce the amount of ductwork, which enhances the building section design. Long-lasting exterior materials, such as brick and zinc cladding contribute to the long service life expected for this project.

In 2006, Two Harbors High School ranked in the 85th percentile of school projects for its energy use intensity of 56 kBtu/ft²·year. The school’s energy-saving features include a thermal displacement ventilation diffuser, a low temperature high delta T hydronic heating system that distributes hot water out to a radiant floor system, demand controlled ventilation and automated lighting systems.
Energy Efficiency

This project performed in the 85th percentile of school projects with a site Energy Use Intensity (EUI) of 56 kBtu/ft²·year during the 2006 calendar year. Limited cooling capacity was provided due to the few days per year that cooling is needed.

Early on, the design team focused on dedicated outdoor air systems (DOAS) delivering air through thermal displacement ventilation (TDV) diffusers and high delta T low temperature hot water distribution as techniques to reduce energy consumption. By moving air only for ducted ventilation and using high delta T hot water distribution, energy transport loads were reduced.

Additional reductions in transport and heating energy were achieved by instituting demand controlled ventilation in the classrooms, providing an average of only 30% maximum airflow for room ventilation during school hours, or the equivalent of 15 cfm per person for normal classroom occupancy, and using a 150% CO₂ override set point for high occupancy conditions.

Preconditioning of the outside air relies on energy recovery ventilators using membrane type fixed cores and conventional central station air-handling units equipped with MERV 13 filters and heating coils. A smaller, distributed mechanical room allowed the DOAS air handlers and ductwork to be limited in size and length by being close to the areas served (another transport energy reduction technique).
Conventional return air type central station units serve the media center and administrative suites, while ceiling cassette minisplit units serve the computer instruction areas. A thermal displacement ventilation (TDV) diffuser from the air-handling units serves the small amount of air-conditioning load. The air-conditioning AHU uses chilled water coils fed by small, air-cooled water chiller units with integral pumps and chilled water buffer tanks. The chilled water allows the discharge air temperature to be controlled to a closer tolerance.

Something the design team thought was necessary to successfully apply TDV cooling. The hydronic heating system distributes hot water out to the building at 140°F and returns it to the boilers at 100°F. This water temperature was a good match to the design radiant floor temperature of 80°F and allowed the German-made stainless steel condensing boilers (natural gas or propane/air mix) to achieve high combustion efficiencies. Air-handling coils and the limited amount of perimeter radiation and unit heaters did require larger coil sizes to compensate for the low water temperatures. A combustion air control system increases the boiler plant efficiency further by pre-heating the combustion air.

The school is equipped with a championship swimming pool. An engineered pool energy recovery unit processes pool area ventilation air. The design team considered a refrigerant dehumidification unit, but the simpler unit was selected as a

Photo © John Gregor, Coldsnap Photography
Minimal duct was required due to the system design. This complemented the visual appeal of assembly spaces.
But high performance wall insulation and windows, along with coordination with the classroom layout, allowed the use of a single diffuser at the front wall of the classroom to provide proper performance at a lower cost. The MERV 13 filters located in the air-handling unit prevent respirable particles from being distributed by the HVAC system. The TDV system integrates well with the natural ventilation strategies that are designed into the architecture due to the low supply/high exhaust arrangement.

The TDV cooling system in the media lab allowed the lab to be open to a two-story commons while remaining conditioned space. Cool air remains in a cost-savings measure. This appears to have been a good choice as no humidity-related concerns have ever been expressed by staff or users.

An automated dust collector valve system allowed a smaller dust collector to serve the woodshop by leveraging the available exhaust airstream to serve only running equipment. A semi-instantaneous condensing domestic water heater supplies the group bathrooms, locker rooms, and kitchen, while point-of-use electric water heaters supply classroom sinks. This eliminates standby losses. Self-regulating electric hot water temperature maintenance systems also reduce standby losses on the hot water distribution piping to the locker rooms and pool area.

The rooms’ arrangement allows plenty of natural daylight, and the lighting control systems take advantage of its availability. Lighting systems, integrated with the building management system through lighting control panels, use occupancy schedules, daylighting sensors and occupancy sensors that also function as part of the security system.

In the energy usage chart, note the long thermal lag of the systems due to the uninsulated radiant slab.

Indoor Air Quality
TDV provides ventilation effectiveness at least 20% better than conventional mixing type systems and 40% better than all air overhead heating and ventilation systems within the occupied spaces. Design software provided by a major manufacturer of TDV diffusers recommended the use of two diffusers per room to reduce the affected zone where uncomfortable drafts can occur.

Energy Use Compared to Heating Degree Days

Energy Usage 2006–2008

The site design uses no-mow native plantings and a number of scattered storm water management ponds. This reduces irrigation water use, site maintenance and runoff while providing wildlife habitat.

High clerestory windows allow daylighting and promote natural ventilation.
the enclosed first floor until it warms enough to rise into the commons. ASHRAE Standard 62.1-2001 criteria were used to determine required ventilation rates for each space. The majority of spaces are supplied by 100% air VAV box controllers so most rooms have a traceable method of assuring ventilation rates. Additionally, each AHU system is equipped with airflow measurements for supply and exhaust/return. Touring groups frequently comment that the air inside is as fresh as that found outside.

Thermal Comfort
The radiant floor, efficient glazing systems, and low-velocity air-distribution system result in thermal comfort that exceeds the industry standard of 90% satisfied. Humidity control is not an issue in this climate due to the low dew points during the school year.

Innovations
To improve the available wall space for classroom cabinets it was desired to provide room heating without the use of fin tube radiation. This suggested the use of radiant floor systems to handle sensible loads. Research by the design team did not find U.S. examples of systems combining radiant floor heating with TDV, but engineering analysis suggested that as long as the floor temperature was kept at less than 90°F, a system combining the two technologies would work as intended. TDV diffuser suppliers were asked to supply either CFD modeling or full-scale testing of a sample classroom to confirm the design team’s design theory. Full-scale physical modeling was conducted by the TDV diffuser supplier to confirm proper airflow, especially at the “cold” window wall where downdrafts occur. Custom-made TDV diffusers were designed for the commons area. The diffusers served as a base for tables and allowed integration into the architecture.

The 20 miles of radiant floor tubing was the largest such installation in the area. Additionally, no thermal insulation was provided between the floor slabs and the active radiant slab to control installation costs, again a first for this region. Also, 140°F to 100°F high delta T low temperature heating water distribution and design had not been used in our region. The TDV reduced duct space in the rooms, thus allowing higher ceilings for the given wall height, which allowed higher window head elevations thereby improving daylight penetration and improving the effectiveness of the indirect lighting systems.

Operation & Maintenance
Full BMS systems included off-site monitoring. Smaller distributed air handling equipment allows portions of the building to be shut down if not required for instruction. Stacked air-handling units/exhaust units provide a compact system, increasing usable space. High-quality air filtration keeps coils and ductwork cleaner.

Cost Effectiveness
The project’s mechanical, electrical, and plumbing systems cost less than a conventional AHU-based, VAV system due to less ductwork, smaller ductwork, fewer diffusers and smaller pipes. Although some additional costs were incurred to the owner due to some higher priced equipment and systems, the integration of the architectural, mechanical and electrical systems allowed for what Rocky Mountain Institute calls “tunneling through the cost barriers.” Because of this, the design team believes that approximately $50,000 per year in savings did not cost the school district anything as the project was built to meet the budget and exceed the program requirements with a lower than average cost per square foot.

LESSONS LEARNED

• The combustion air preheater system was not installed with a glycol loop. This maximized efficiency and simplified installation. However, during a pumping system malfunction, the coil froze and allowed the heating loop to lose pressure and circulation.

• The hot water temperature maintenance system was specified as a mechanical item, but was installed by an electrical contractor and had a number of start-up issues that continued for over a year. We will specify factory commissioning and startup until local contractors become more familiar with such systems.

• The remotely operated windows failed early and took some time. Generally, it seems that manufacturers produce these systems to meet residential demands, not commercial standards. This issue has been noted in the active façade research being done by Lawrence Berkeley National Laboratory and requires more robust products, perhaps from Europe.

• The clerestory windows’ southward orientation assists with natural ventilation, but a northerly orientation would have reduced glare. Additional analysis of northerly facing versus southerly facing clerestories should have been performed to understand all aspects of this issue.

• Due to tightening budgets and a failed operating levy, the school has reduced the operation of the pool as a cost-saving measure.

• A closer examination of the hours that various parts of the gymnasium unit would be in use may have allowed the use of a smaller energy recovery unit at the expense of additional controls.

• Energy recovery unit bypass ductwork would have been advantageous for those rooms with significant solar heat gain at the expense of more complicated ductwork and controls. At this time conditions sometimes require manual intervention by operation of the windows, which is not a bad thing with the normal airflow in the rooms and the high exhaust, but is a point of discussion for future projects.

• LHB continues to propose design solutions using thermal displacement ventilation and radiant heating (and cooling) for many of our clients as we believe these technologies can provide a superior interior environment at a lower operating cost and at more than fair installation costs.

ABOUT THE AUTHOR
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