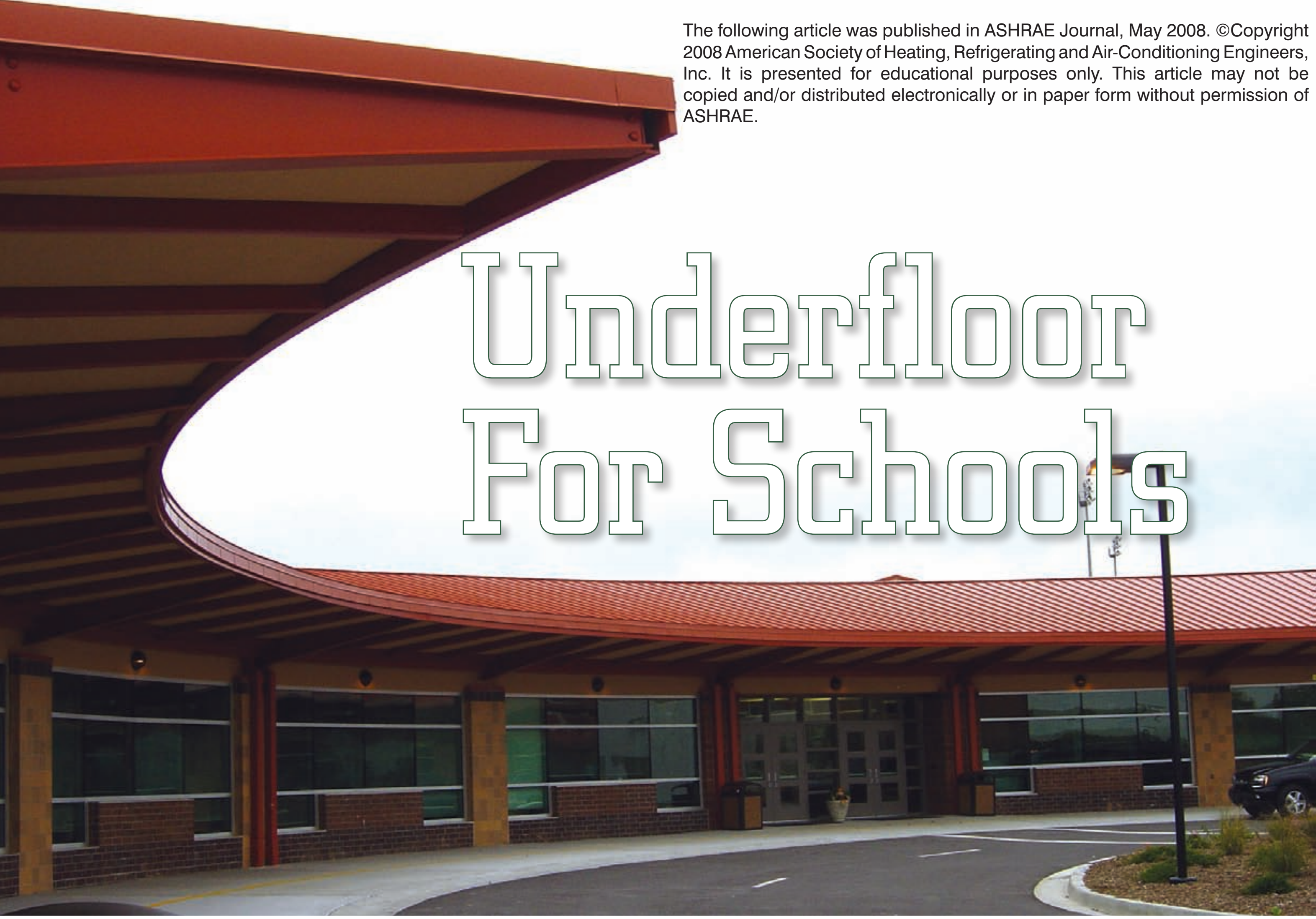

Underfloor For Schools

By **James E. Megerson, P.E.,** Member ASHRAE, and **Christopher R. Larson, P.E.,** Member ASHRAE

When our design team first approached Blue Valley School District of Johnson County, Kansas (a suburb of Kansas City, Mo., that has an ASHRAE 0.4% cooling 96°F/75°F db/wb (36°C/24°C db/wb) and 99.6% heating of –1.0°F [–18°C]) with the idea of using raised access floors in their schools, the district seemed uncertain. However, after they realized that we were serious and had given it a great deal of thought, they decided to consider our recommendation. After more than a year of addressing concerns, visiting operating buildings with underfloor air distribution (UFAD), and countless meetings, the district decided enough substantial benefits existed to give it a try.

Most engineers recognize schools have unique needs that influence the selection of an HVAC system. ANSI/ASHRAE/IESNA Standard 90.1's goals to reduce energy use and ANSI/ASHRAE Standard 62.1's goals to maintain acceptable indoor air quality sometimes diametrically oppose one another (more outdoor air equals more energy to heat and cool). However, both are important and have substantial impact on system design. Creating a learning environment that is healthy and conscious of energy use can be a difficult problem to solve. We have found that UFAD is a system that when designed and constructed properly can solve these challenges effectively.

The Blue Valley School District developed and used prototypes for their elementary schools since the late 1980s. Once it developed a prototype design, it then site adapted it multiple times. This reduced design duration and enabled the district to somewhat fine-tune the school's design over time. When Liberty View Elementary in Overland Park, Kan., was designed it was the fourth site adaptation of a prototype, with the exception that its HVAC systems had been changed from an overhead mixing system to a combination of UFAD and displacement ventilation (DV).

About the Authors

James E. Megerson, P.E., is vice president and **Christopher R. Larson, P.E.,** is CEO, president and founder at Larson Binkley, Inc. in Overland Park, Kan.

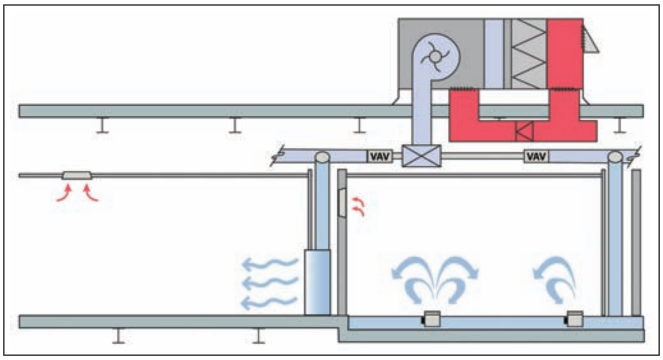

Figure 1: UFAD/DV schematic.

Displacement Ventilation (DV)

- Air is delivered between 60°F and 65°F (18°C and 16°C);
- Air is delivered low in the occupied zone, usually ducted to vertical diffusers;
- Promotes stratification;
- May need heating at perimeter depending on climate;
- Higher ventilation effectiveness (1.2);
- Lower velocity discharge air (approximately 50 fpm [0.25 m/s]);
- Uses thermal plumes to promote air movement; and
- Not a mixing system.

Underfloor Air Distribution (UFAD)

- Air is delivered between 60°F and 65°F (18°C and 16°C);
- Air is delivered low in the occupied zone through a raised access floor;
- Promotes stratification;
- May need heating at perimeter depending on climate;
- Ventilation effectiveness is believed to be between 1.1 and 1.2;
- Higher velocity discharge air (usually greater than 250 fpm [1.27 m/s]);
- Partially mixed system that provides increased mixing (compared to DV) in the occupied zone (up to 6 ft. [1.83 m] in height); and
- Fan energy savings are expected due to lower plenum pressures (approximately 0.05 in. w.g. [12.45 Pa]).

UFAD works well in offices and classrooms because accessing a building infrastructure through raised access flooring (RAF) offers attractive benefits. Specific to the Blue Valley School District, we found that it regularly updates its information technology infrastructure, moving data and power outlets around to accommodate different teaching curriculums. This can be costly, as is providing multiple outlets to accommodate change in the first cost of construction. When it is time to rearrange an area for a different teaching curriculum, RAF makes this a simpler and less costly task. However, RAF doesn't make as much sense in corridors, kitchens, cafeterias, restrooms, and gymnasiums. The challenge is to use the right system for these spaces that can take advantage of the similar performance characteristic for consistency of maintenance and air delivery philosophy. We have found that displacement ventilation is a good complement to UFAD. *Figures 1* and *2* show that it uses similar discharge air temperatures and the same methods for dehumidification. It also promotes better IAQ as compared to a mixing system.

Displacement ventilation is usually a ducted system that requires slightly higher duct static pressures to operate properly. UFAD requires low static pressure and can provide the opportunity for smaller air-handling unit motor horsepower. When we converted the overhead VAV mixing system of the prototype to the new UFAD/DV design, we saw a decrease in installed fan horsepower of 30% to 50% for the UFAD systems. This was due in part to the lower static pressures expected in the system. It is probable that this lower horsepower results in less overall power consumption.

Public school construction often has a strict budget. Some methods of designing UFAD have the opportunity to reduce, or at least maintain the status quo, when comparing first cost to other HVAC systems. As most engineers recognize, cost comparison outcomes depend on what systems the comparison is referencing, and every building is different and must be analyzed independently. In the case of Liberty View, we found that the amount of overhead VAV ductwork, VAV boxes, and associated electrical power, equals or exceeds the cost of the raised access flooring. Using the construction cost data of the previous site adaptations of this prototype, and the bids from the schools with the UFAD systems, Liberty View realized a savings of approximately $7/ft^2 ($75/m^2) in reduced ductwork cost.

When we were analyzing UFAD/DV for the client to determine its potential for the schools, we estimated several opportunities for savings. It was determined we could reduce the height of the prototype building by as much as 2 ft. (0.61 m) It was estimated that every foot of building height reduction would result in a savings of approximately $50 per linear foot ($164 per linear meter) of exterior wall. Savings were also realized in reduced ductwork. The owner elected to allocate the savings towards upgrading from direct expansion rooftop units to chilled water air-handling units with hot water perimeter heating.

Each classroom wing, the media center, and administrative area of the school incorporates RAF and UFAD. The RAF plenums are constructed as a concrete bathtub, eliminating the majority of opportunities for air leakage. However, we did experience some air leakage to the return plenum at each duct entrance to the RAF plenum. This was addressed and corrected so that adequate pressures could be obtained. On subsequent school designs, we became increasingly better at identifying potential areas for leakage before the RAF was installed, now there are relatively no detectable amounts of leakage.

Each plenum is pressurized with supply ducts for each 4,000 ft^2 (372 m) with a maximum distance of 30 ft. (9 m) from the perimeter where the plenums are pressurized. Each supply duct contains a discharge air control damper that modulates to maintain plenum pressure of 0.05 in. w.c. (12.45 Pa) static pressure with respect to the space. On subsequent projects a pressure and temperature reset control has been used to further optimize the system and compensate for any leakage into the space. As the return air temperature increases, the plenum pressure is reset up from 0.035 to 0.05 in. w.c. (8.7 to 12.45 Pa) static pressure. The variable frequency drives modulate supply fans to maintain approximately 0.35 to 0.75 in. w.c. (85 to 185 Pa) static pressure in the supply duct. As the space is satisfied, the duct dampers modulate in response to VAV UFAD diffusers, modulation also occurs with the air-handling VFDs.

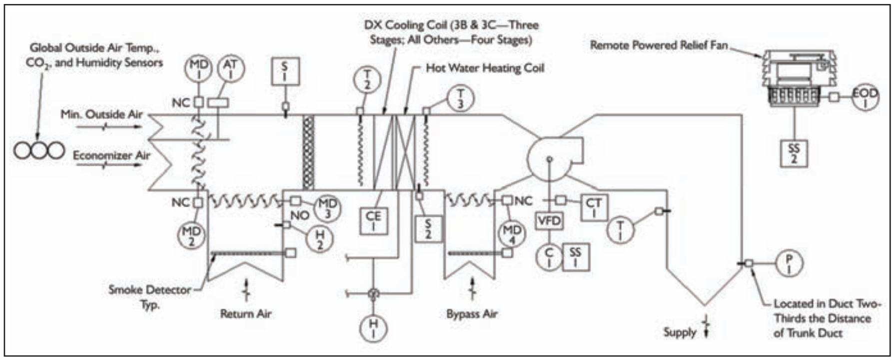

Figure 2: Recommended LBI schematic AHU arrangement for UFAD/DV.

A return air temperature sensor per supply air plenum is used to employ a supply air temperature reset schedule. The supply air is maintained at 62°F (17°C) when the return air temperature is 78°F (26°C), and 68°F (20°C) when the return air is 74°F (23°C). This allows the system to be optimized based on the load in the space per classroom wing, as well as compensate for any leakage to the space through diffusers, electrical boxes, or the raised access floor. All UFAD diffusers are thermostatically controlled by zone (typically one zone per classroom).

Humidity control is a concern that must be addressed in warmer, more humid climates such as Kansas City. We have found that the psychrometrics work out well when the supply air temperature is brought down to less than 55°F (13°C) leaving the coil and then reheated to the desired supply air temperature. One of the most cost-effective means of accomplishing this is using draw-through air-handling units with integral return air bypass to maintain supply air temperature (*Figure 2*). The return

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air bypass and chilled water coil or DX cooling are modulated to maintain supply air temperature based on the reset schedule and the return air humidity sensor. When the humidity in the space exceeds 55%, the coil leaving air temperature is dropped and the bypass damper is modulated as necessary to maintain the supply air temperature according to the reset schedule.

In the winter season, the air handlers use a hot water coil that heats mixed air according to the supply air reset schedule if there isn't high enough return air temperature to obtain the desired supply air temperature. Each exterior space uses hot water decorative radiators or finned tubes to overcome the exterior wall heat loss. The perimeter heat is controlled by a perimeter zone thermostat. All spaces have a CO_2 sensor to control outdoor air. The worst case CO_2 level is used to set the outdoor air setting for each classroom wing. The system is set up to maintain CO_2 levels in spaces no higher than 700 ppm above ambient CO_2 levels. The typical ambient level of CO_2 in the region is between 350 ppm and 450 ppm. Historical trend data on the schools have shown that the CO_2 levels in the spaces rarely exceed 650 ppm.

The main corridors, gymnasium, cafeteria and kitchen use constant-volume ducted displacement ventilation diffusers. It was determined that these areas were not conducive to RAF because there was no need to access the infrastructure for future reconfiguration. The same air-handling configuration and controls sequences, less pressure control, are also used for these spaces.

Calculating the sensible load for spaces using UFAD/DV is different than for overhead mixing systems. Conventional wisdom may lead an engineer to think that with a higher supply air temperature, more air volume is needed to maintain setpoint. Typical overhead mixing systems are designed to deliver the air from above at higher velocities to mix the heat in the space with the colder supply air, so that the blend of the two results in maintaining setpoint. Displacement ventilation delivers supply air low in the space at a lower velocity to minimize mixing and allow heat plumes to stratify heat out of the occupied zone. This reduces the needed airflow to the space to maintain setpoint as compared to an overhead mixing system. Most UFAD diffuser designs still promote mixing in the lower portions of the occupied zone, so not as much stratification occurs as compared to a displacement ventilation system. We have found that typical airflow quantities for DV range between 0.7 to 0.9 cfm/ft^2 (3.6 to 4.6 L/s·m^2) and UFAD values between 0.8 to 1.0 cfm/ft^2 (4.1 to 5.1 L/s·m^2), depending on load densities.

The cooling load for UFAD/DV systems is not less than mixing systems. The load is still present. It's the way in which the load is handled that changes and becomes coil load. Much of the space cooling load is moved to the return air and becomes coil load. That is, unless these loads are exhausted from the building entirely.

Conclusion

Liberty View has been operating since 2002. Two other prototype schools similar to it have operated since 2004 and 2006. Utility data has been monitored and analyzed. Two of the elementary schools have been attached to middle schools with combined utilities and shared kitchens. One of the schools was designed with occupancy sensors for lighting and only one of the schools was commissioned by a third party. All schools have different operating schedules due to space rentals, afterschool and weekend activities. The results are difficult to normalize and evaluating the energy efficiency resulting from these systems is inconclusive. The district believes that indoor air quality is better, and that the energy use of the buildings is acceptable.

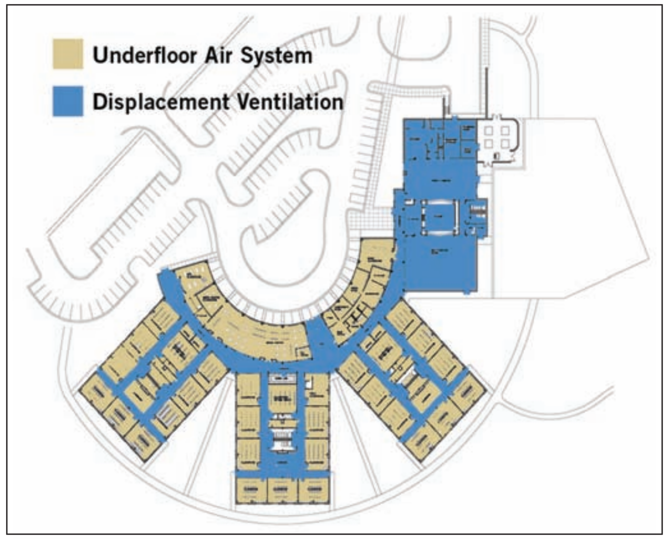

Figure 3: Floor plan of Liberty View Elementary.

The Blue Valley School District has standardized its HVAC systems around underfloor air conditioning and displacement ventilation. RAF is isolated to areas where access to building infrastructure is necessary. Displacement ventilation is used in any space where RAF is not necessary. According to district personnel, IAQ complaints have been reduced significantly on schools using these systems. Occasional independent monitoring of space IAQ by school technicians supports that they are experiencing better IAQ. In fact, the Blue Valley school district has been awarded the EPA's Tools for Schools Indoor Air Quality Excellence award in 2003, and recently received the nation's first Model of Sustained Excellence award.

In summary, energy use when compared to overhead mixing systems in the district is inconclusive, yet the schools still fall within the district's energy budget. It may be difficult, if not impossible, to create a working laboratory of schools or buildings to compare traditional VAV system application with UFAD or DV. Even if the comparative buildings were within the same city, they would need the same orientation, maintenance, equipment, building contractors, population, schedules, events, etc., to make a fair comparison, and that isn't likely to happen. In this district, school designs that use UFAD or DV are being built with the same budgets as their overhead ducted equivalents.

Although we can't prove UFAD and DV systems save energy based on current data, properly designed and bid systems cost about the same to construct as traditional mixing systems, and at minimum, IAQ is improved. Given that perspective, the only downside to UFAD and DV is learning how to properly implement and construct them.