Advanced Ventilation Design

for Commercial, Industrial, and Institutional Facilities

Displacement and demand-controlled ventilation can be applied in combination with enthalpy recovery

By **WILLIAM A. TURNER, PE, MS,**
The H.L. Turner Group Inc.,
Concord, N.H.

The engineering design industry continues to see a growing interest in creating designs that consider the priorities of indoor air quality (IAQ) and energy conservation. Standard designs that provide too much "general dilution ventilation" with outdoor air, in response to IAQ concerns, can result in excessive energy costs and will likely result in undesirable moisture problems for the processes, occupants, the building shell, and the mechanical systems (see accompanying sidebar). Simply using the traditional design approach of minimum code required makeup for exhaust and minimum general ventilation for "dilution" of indoor-generated contaminants, as the primary method of providing good IAQ in a building, often results in unacceptable indoor environments. This is because the use of conventional dilution design approaches often results in occupant exposures to a variety of irritants prior to being sufficiently diluted to acceptable levels and eventually removed from the building. Alternately, excessive general dilution to lower airborne material concentrations to acceptable levels, where irritation is unlikely to occur, will be energy intensive. Based on our forensic work in a variety of buildings, other common issues that accompany poor IAQ typically include:

- inadequate lighting
- poor acoustics
- lack of preventive maintenance
- minimal moisture control
- uncontrolled thermal comfort

Thus to be successful, "healthy" high-performance building design must address indoor environmental quality (IEQ) in its entirety. This article focuses on the indoor air quality components of IEQ; however, it touches on IEQ and "sustainability" concerns along the way. Brief case studies from office, educational, and industrial buildings are presented to support the design concept discussions.

HVAC DESIGN FOR INDOOR AIR QUALITY

Achieving a design that will deliver both superior air quality and occupant thermal comfort as well as minimize energy consumption requires the design team to take an "integrated building systems approach." When using this approach, the designer needs to evaluate carefully where and when the undesirable air contaminant "sources" may exist (either within the facility itself, on the rooftop, or immediately adjacent to the site) as well as use *displacement ventilation air flow* to minimize the occupant exposures to emissions generated inside the building (Figure 1). Additionally, appropriate quantities of general ventilation air need to be provided. Ventilation delivered to buildings based on their occupant loading is known as *demand-controlled ventilation*. Displacement ventilation and demand-controlled ventilation can be applied together in office buildings, industrial settings, and institutional buildings—leading to quality indoor air in an energy-efficient manner.

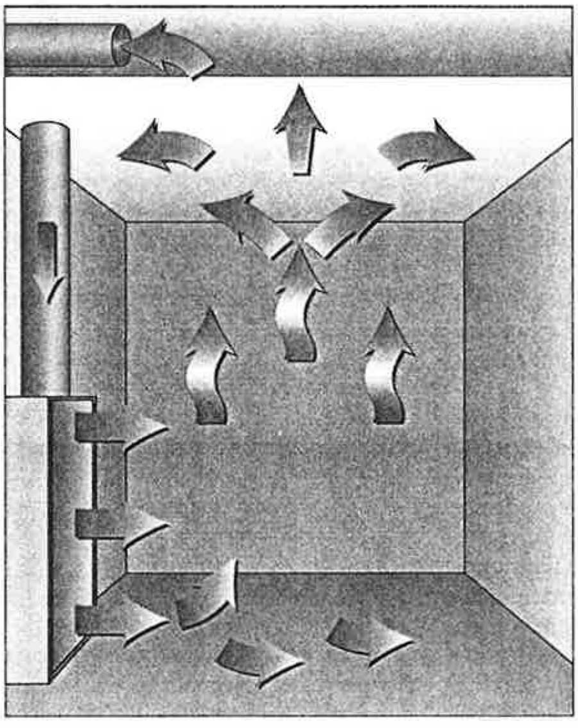
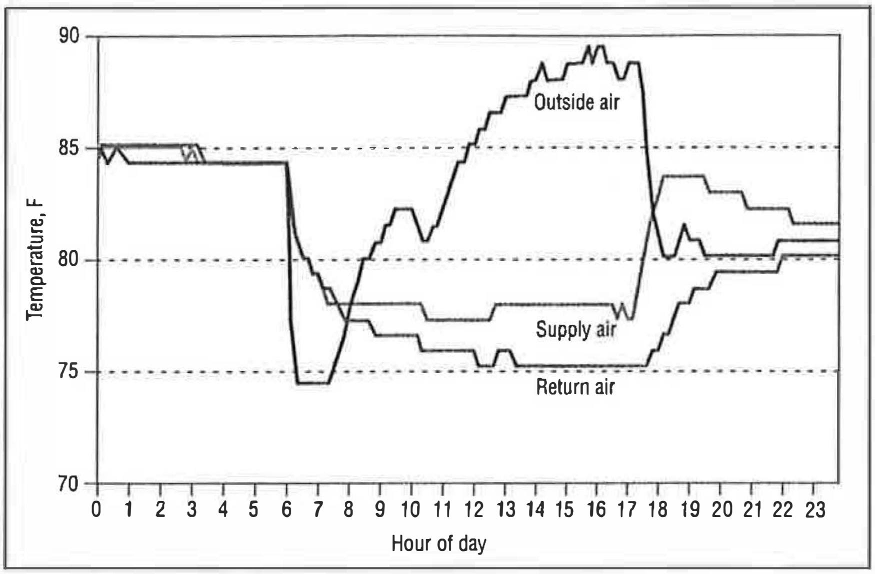


FIGURE 1. Displacement ventilation features fan-powered horizontal supply air flow at floor level and buoyancy-driven vertical air flow pushing air upwards to fan-powered exhaust systems.

Humidity Control

With traditional mixed air systems, the supply air may be cooled to 55 F (over 95 percent saturated) or below to provide enough dehumidification to keep space conditions between 50 to 60 percent RH and 72 to -76 F. The use of 550 F supply air is acceptable in a mixed air system.

With a displacement ventilation system, air is delivered close to the occupants' breathing zone, so the supply air temperatures should be made closer to the room



Supply, ambient room, and exhaust air temperatures measured in the new H.L. Turner Group headquarters building, which features an enthalpy recovery unit.

set point temperature. If warmer, saturated air is supplied to a room with high-occupant loading such as a classroom or a restaurant. The result could be room air at 74 F and RH levels above 70 percent. This is outside the ASHRAE Standard 55 comfort zone and may result in conditions favorable to fungi growth in the indoor environment.

To deliver air that is dry enough to maintain the room air at 50 to 60 percent RH and 74 F, some or all of the supply air stream must be cooled below the dew point temperature. The desired RH levels for the room will be achieved when the supply air is warmed by the loads in the room. For all applications using outside air, the use of enthalpy recovery devices greatly reduces the dehumidification load of the cooling equipment.

When using enthalpy recovery (total energy recovery) devices with 70 percent efficiency or better, the enthalpy of outside air conditioned by the energy recovery device is very close to the exhaust air enthalpy from displacement ventilation.

The results of enthalpy recovery on the performance of the system are dramatic. The exhaust air stream passing through the enthalpy recovery device acts to pre-cool and dehumidify the supply air before the air reaches the cooling coil. In the heat of the day, this can amount to a 10 F or greater differential in supply air temperature, which reduces cooling capacity requirements for the mechanical cooling system substantially.

DISPLACEMENT VENTILATION DESIGN CONCEPT

The vertical displacement ventilation concept is different from conventional-ventilation, mixing-ventilation systems in several important ways. These differences, which are described below, offer many potential benefits over conventional ventilation systems that utilize mixing.

Benefits of Displacement Ventilation

- *No drafts*—In a displacement ventilation system, air is typically supplied to the space near the floor at extremely low velocity (less than 100 fpm), which results in no "throw" of air and subsequently little risk of "drafts."
- *Stratified room air*—Supply air is purposely not mixed uniformly throughout the space. It is intentionally stratified vertically to provide a better quality of air in the breathing zone of the building's occupied sections. Supply air is delivered during occupancy at temperatures slightly lower than desired area temperatures. The supply air moves horizontally across the floor until it naturally rises—driven by convective currents as it warms, due to internal heat from the process, people, lights, computers, etc.

The stratification effect can be observed in data obtained by monitoring carbon dioxide levels where data were gathered from a school classroom that is described later in this article (Figure 2). The carbon dioxide levels were measured at the supply level (floor level), breathing-zone level (5 ft from the floor), and at the exhaust-intake level (ceiling height).

In addition to the stratification of carbon dioxide, it can be seen from the concentration decay rate that there is rapid flushing of the room as the students leave, confirming the achievement of displacement air movement. This room achieved superior flushing of room-generated contaminants with an overall room ventilation rate of only 1.5 air changes per hr. This is less than half the ventilation rate that would be needed with a conventional mixing design, based on ASHRAE 62-1989, drastically lowering electrical energy use through reduced fan-power requirements.

- *Improved effective ventilation*—Because of convective currents originating from people and processes in high density or industrial applications, there is a general upward flow of effluents above the occupied zone as long as they are not disturbed significantly by fan-forced air streams (as happens in conventional, mixing-based distribution systems). Air rises from the lower level of the room around stationary processes and people due to the development of convective currents over heat-emitting machinery and people. This means that occupants located in the lower levels of a room will

continued on page 64

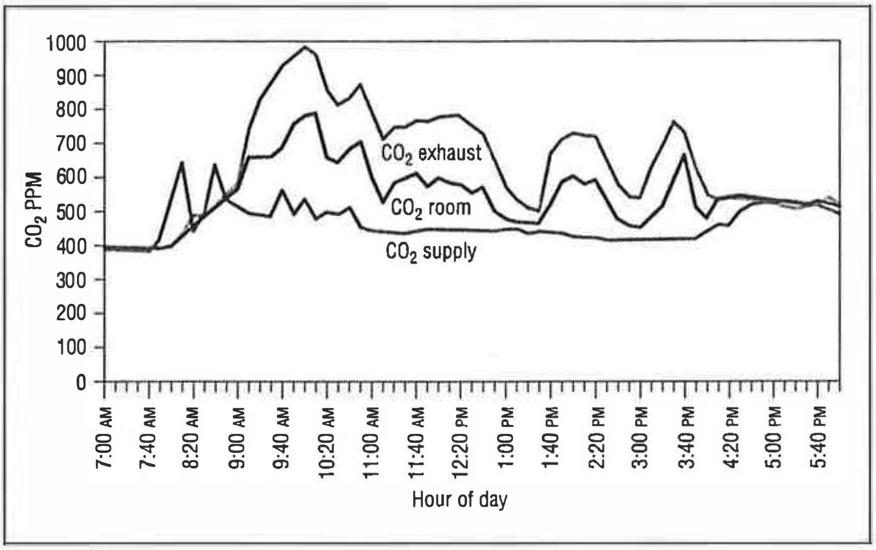


FIGURE 2. Carbon dioxide levels in an occupied classroom having a displacement ventilation system.

continued from page 62

breathe air closer to supply air conditions, rather than the air being exhausted from the space at the ceiling level.

- *No recirculated stale air*—In our designs for school classrooms and industrial applications, all supplied air is "preconditioned" 100 percent outdoor air. All air removed from the facility is exhausted outdoors—none is recirculated. Both the sensible and latent energy are captured from the exhaust air stream using an enthalpy heat recovery unit and recycled when needed.
- *Individual room VAV*—When there are few or no internal loads, such as an unoccupied area with the lights off and little solar gain, the upper-room air will be slowly displaced upward by the air beneath it. In this case, the area will eventually be approximately the same temperature as the supplied air, which is only slightly cooler than the desired temperature. This often eliminates the need and expense for individual area VAV to prevent over-cooling, depending on the specific conditions. Additionally, using demand-controlled ventilation methods for the total air supply in a specific building will minimize energy use during periods of cold weather or low-occupant density by reducing or increasing ventilation rates as needed. Design engineers consider the varying rates of occupancy when deciding which "specific" areas need demand-controlled ventilation.
- *Reduced cooling capacity needed*—Thermal stratification also allows for some reduction of internal cooling requirements. Approximately 50 percent or more of the heat from the lights and other sources located above the occupants will not reach the occupied zone. Using displacement ventilation techniques, this heat is exhausted when not needed, thus reducing the cooling load.
- *Less fan horsepower needed*—In this design approach, supply air flows needed to achieve adequate temperature control and provide adequate ventilation are often lower than conventional systems. This reduces the fan horsepower requirement considerably compared to mixing-based systems. For example, many of our school classrooms work well at less than 1 cfm per sq ft.
- *Less room noise*—Low velocity supply of air cannot be accomplished using conventional ceiling-mounted, mixing-type diffusers; conventional heating ventilators (air makeup units); or non-ducted fan-coils. Reducing the total air flow quantities and supply air exit velocities leads to an appreciable reduction in noise levels, compared to mixing-based systems that forcefully mix air in the room with high total air flows.
- *Less inter-zone pollutant transport*—The supply air "quality" to individual areas is also improved because, with 100 percent outdoor air, the supply air is not already premixed with contaminated air thar has been transported from other areas or zones in the building.

SCHOOL CLASSROOM APPLICATIONS

In 1996, a new 48,000 sq ft elementary school was occupied with 400 students and staff located in Boscawen, N. H. (Figure 3). Designed by our firm, this school is the first in the U.S. to utilize the concept of displacement ventilation and demand-controlled ventilation as the primary means for achieving good IAQ and thermal comfort with reduced energy costs. Our integrated "sustainable" design concepts for the facility address other important factors including:

- siting
- programming (specific design elements that consider the educational plan)
- social dynamics
- lighting
- acoustics
- energy efficiency
- classroom computer usage
- ample access to HVAC equipment for preventive maintenance

Ventilation and thermal comfort objectives are achieved through 100 percent outdoor air in a displacement

FIGURE 3. A typical classroom at Boscawen Elementary School showing a vaulted ceiling that facilitates displacement air flow.

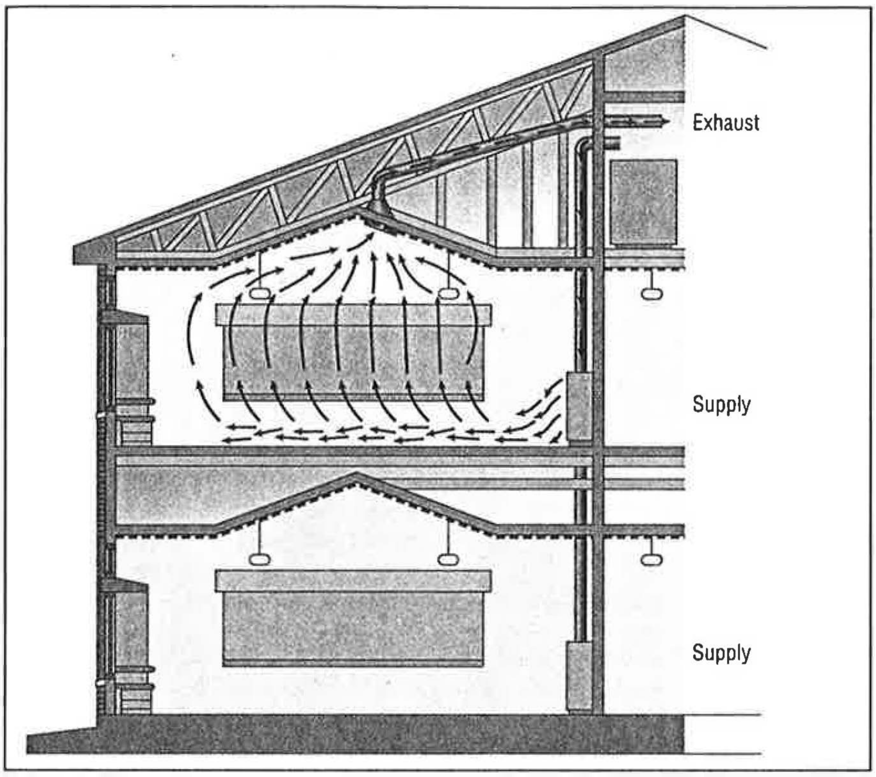


FIGURE 4. Air flow patterns (design) of Boscawen Elementary Schools displacement ventilation system.

ventilation scheme in tandem with demand-controlled ventilation.

An innovative ceiling/roof structure that provides a vaulted ceiling was incorporated into the classroom design to enhance both the classroom space use and to provide room volume to enhance the performance of the displacement distribution system (Figure 4). This approach also facilitates appropriate lighting and acoustical design.

COMMERCIAL OFFICE SPACE APPLICATION

In July 1998, we occupied our new corporate headquarters in Concord, N. H. (Figure 5). Designed and constructed by our firm, this 14,000 sq ft office building is one of the first in the U.S. to utilize exclusively the concept of displacement ventilation and demand-controlled ventilation as the primary means of providing high-performance design aimed at good IAQ, improved thermal comfort, and reduced energy costs. As with our school designs, the integrated "sustainable" design concepts of the facility address other important factors including:

- siting
- programming
- social dynamics
- lighting
- acoustics
- energy efficiency
- access for preventive HVAC maintenance

Unlike our design used for Boscawen Elementary School, which is dominated by high-density classroom occupancy, only a large conference room training area utilizes demand-controlled ventilation with 100 percent outdoor air. The remainder of the facility is served by a displacement ventilation system, which provides a minimum of 25 percent outdoor air during design heating and cooling conditions and up to a maximum of 100 percent outdoor air during most daytime operations. However, unlike conventional office design, all of the air that leaves spaces with known irritants, such as emissions from reprographics, cooking, and major printing operations, is captured at the source and exhausted out of the facility after passing through an enthalpy recovery unit. These point-of-use exhaust systems operate only when the facility is occupied.

As with our other designs, an innovative ceiling/roof structure provides a high-vaulted ceiling in many areas. Additionally, reflected daylighting is delivered to most core areas. With this office building design, we have combined a radiant floor heating system along with the use of the vertical displacement ventilation concept. This approach will also enhance all of the expected benefits of the displacement design such as:

- no drafts
- stratified room air for improved ventilation effectiveness
- enhanced comfort with minimal VAV zones
- reduction of cooling capacity needs by one-third over conventional design
- less fan horsepower requirements during operating conditions

In areas where the office design does not use 100 percent outdoor air, we have incorporated the use of 95 percent (ASHRAE Dust Spot) efficiency multi-pleat particle air filters in the central air handlers. We also chose to incorporate factory-installed and tested direct digital controls on the HVAC units when assembled at the factory. Only the radiant floor controls required major field controls installation at each of the tubing manifolds.

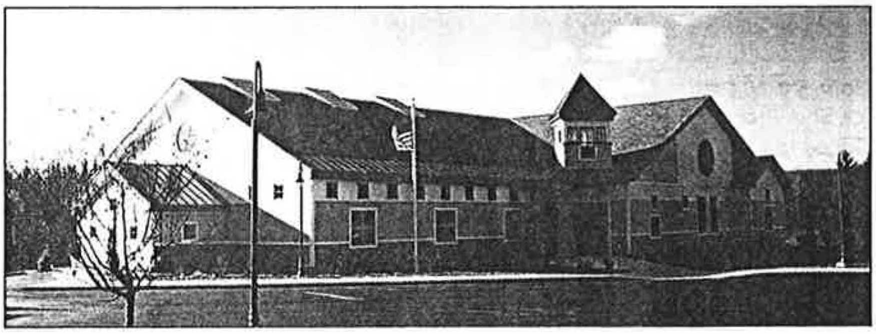


FIGURE 5. The new headquarters building of The H.L Turner Group, Inc.

INDUSTRIAL ASSEMBLY AREA APPLICATION

In January 1997, we were asked to work with a major manufacturer of construction-related products to assist them with improvements in air quality in an assembly area. After careful analysis of the plant conditions, including the temperatures of the materials that were being assembled, the need for full climate control in the assembly area, and the necessary locations of the operators, we chose a modified displacement ventilation design approach (Figure 6). For this situation, we were able to use the same exhaust rates that were currently in place. The major change that we implemented was to use a displacement ventilation flow to move the emissions generated in the assembly process away from the operators and to blanket the assemblers with clean, conditioned, 100 percent outdoor air. This concept performed so well that all major assembly operations in the plant have been changed to this design. This approach reportedly lowered operator exposures to product emissions and is expected to improve product quality. By utilizing a modified displacement ventilation design, we were able to develop a high-performance HVAC system compared to all other conventional approaches that had been attempted by the manufacturer.

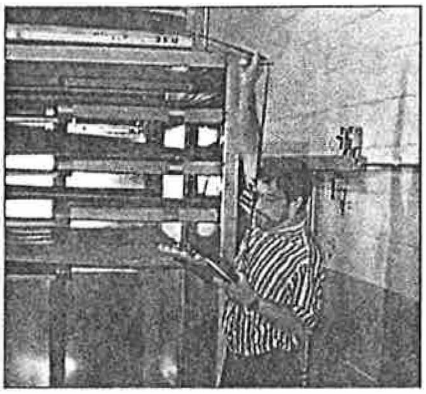


FIGURE 6. Recording air flow measurements at the face is required for proper industrial displacement ventilation system design.

CONCLUSION

We have now completed the application of the advanced ventilation design principles in multiple school projects, two office facilities, and an industrial complex located across the U.S. Northeast in buildings as large as 165,000 sq ft. We have also recently completed the design of a 600-seat performing arts auditorium complex, which will also have a demand-controlled, displacement ventilation system. Based on our experience in designing healthy buildings, we see the application of advanced ventilation technology to be an integral component of enhanced learning and working environments. **HPAC**

Circle 506 on reader service card if this article was useful; circle 507 if it was not.