REAL-TIME VENTILATION Control

Operational control of ventilation systems using sensors that measure CO_2 concentrations

Editors Note: A longer version of this article is available at no cost on HPAC Engineering's *Website at* www.hpac.com, *in the April 2002 Interactive Feature. In addition to this article being available, three additional sidebars, which contain guidance for optionally monitoring outdoor CO_2 levels, considerations for low-occupancy spaces or conditions, and a case study for a retrofit application that includes a control sequence, are included with the online version of this article.*

By **MIKE SCHELL**
AirTest Technologies
Santa Barbara, Calif.

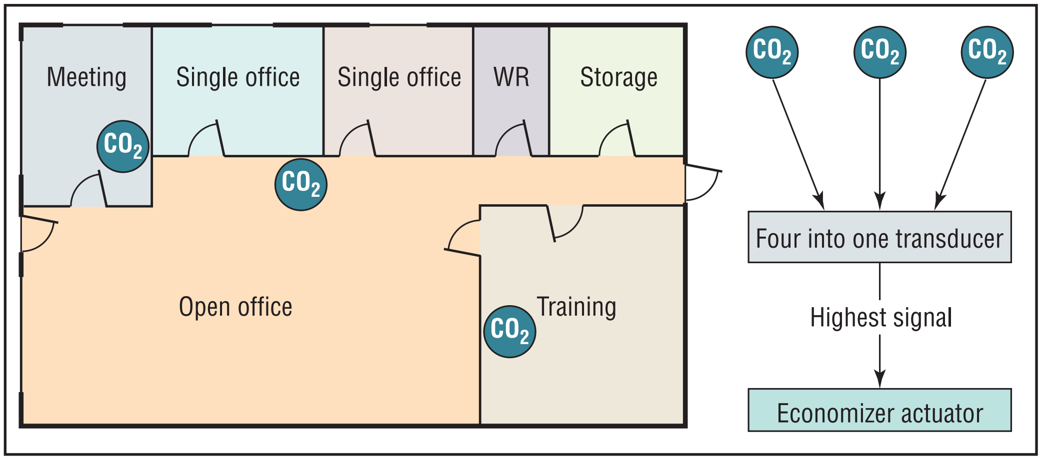
Ventilation control using carbon dioxide (CO_2) has achieved widespread application in spaces with high densities or high variable occupancy, such as theaters, conference areas, and meeting rooms. At the same time, equipment and control manufacturers have been lowering costs and adapting their equipment to easily take CO_2 sensor inputs and integrate this type of ventilation control into all their equipment. The result is that even for spaces with low density or minor changes in occupancy, the cost to integrate CO_2 sensing and ventilation control at the zone level is becoming more affordable. While energy savings has always been a driver for ventilation control, many building operators also recognize the value in being able to measure and control fresh-air ventilation in each zone rather than just measuring the volume of air at the fresh-air intake.

This article provides guidelines on the application of zone-control ventilation using CO_2 for both new construction and retrofit applications.

DEMAND-CONTROLLED VENTILATION

In most buildings today, we design ventilation systems and provide temperature control. There is an important distinction between the two. Design is the first critical step in establishing capacities based on a set of well-founded assumptions. Once the design is established, control is an operational parameter based on real-time measurements within the building that optimizes comfort and energy usage. There is little operational control of ventilation in most buildings today. Even the air-flow measurement stations often used in large buildings are in-

FIGURE 1. Office space that is served by one central air handler with several different occupancy zones can still benefit from CO_2 sensors.



Mike Schell is director of marketing and sales for AirTest Technologies (604 517-3888), a provider of CO_2 sensors. Shell has been involved in the HVAC industry for more than 15 years and has published more than 70 articles and technical papers on building science, IAQ, and energy efficiency for building control. He can be reached at mschell@airtesttechnologies.com.

tended to maintain fixed design rates of ventilation. They are not intended to provide control-based on operational variables.

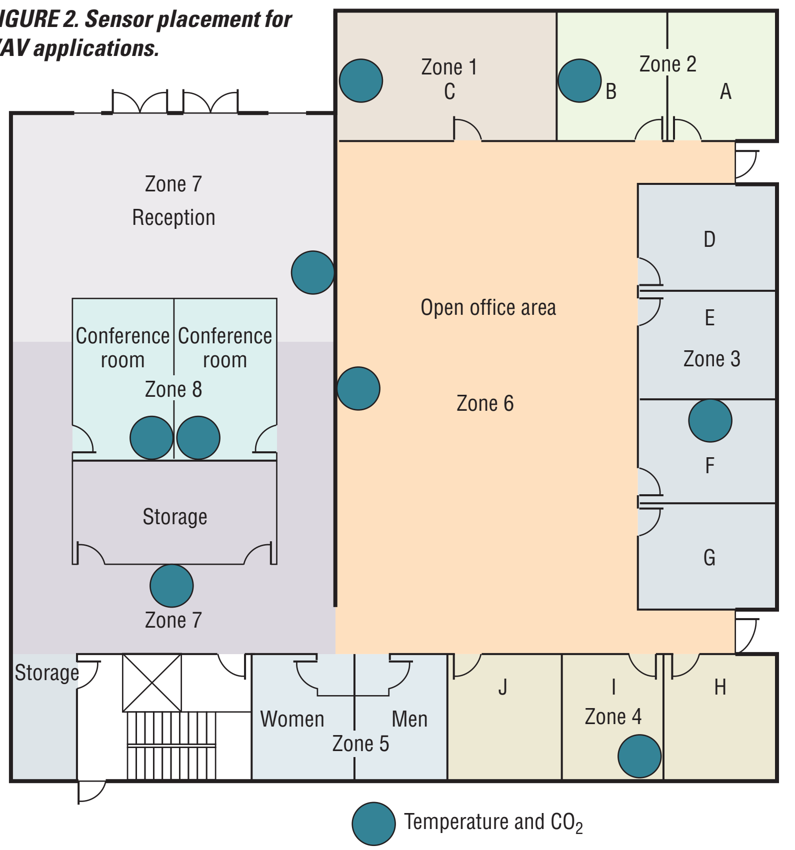
Ventilation control using CO_2 can become the operational strategy that complements and ensures that the design intent of a ventilation system is achieved after initial installation and commissioning. In fact, by collecting trends of CO_2 concentrations over time, the ventilation system's performance can be documented. Trend data can be used to indicate over- or underventilation. If concentrations significantly change from what is typical, a building owner can further investigate the cause (e.g., change in occupancy or malfunctioning equipment). This is much like how we control temperature in a building. The design determines the capacity of heating and cooling required, and in-space temperature measurements modulate the system to maintain target comfort conditions. Adding an operational strategy for ventilation control means that:

• Ventilation is regulated based on actual demand and use of the space, rather just on design assumptions made at the beginning of the engineering process.

• The system can automatically react when changes in initial occupancy design assumptions occur, and if the changes exceed the design, the building control system can alert the building operator.

• Building owners and code officials actually have a parameter they can use to verify that the ventilation system is operating to design requirements at the zone level. Previously, a building owner could measure airflow at the air intake but have no indication if outside air is properly delivered to all zones.

FIGURE 2. Sensor placement for VAV applications.



BEST PRACTICES FOR VENTILATION CONTROL USING CO_2

Zone ventilation control using CO_2 builds upon what already has been established as best practice for ventilation design and CO_2 control. This includes:

• Ventilation control using CO_2 is an operational strategy and does not affect the design capacity of the system. A properly designed control strategy will not allow the design ventilation rate for the entire system to be exceeded.

• A base ventilation rate should be provided during all occupied periods to control potential contaminants not directly related to occupancy. As a rule of thumb, this base ventilation rate should be 20 to 30 percent of design, but can easily be adjusted by the building operator if more or less base ventilation is required. The ventilation control strategy then modulates the delivery of ventilation air between the base ventilation rate and the design ventilation rate for the space with the objective of maintaining the target cfm-per-person ventilation rate in the space.

• The ventilation control algorithm is developed based on inside/outside differential of CO_2 concentrations and the target ventilation rates required in the space. For most urban areas, an outside concentration of 400 ppm can be assumed. However, if outside-air levels have been found to vary more than 100 ppm over the course of a day, outside-air sensing of CO_2 may be necessary. The target ventilation rate dictates the modulation band of the control strategy. For example, a ventilation rate of 20 cfm per person typically would result in a modulation band of 500 to 900 ppm. A target rate of 15 cfm per person would result in a modulation band of 500 to 1,100 ppm.

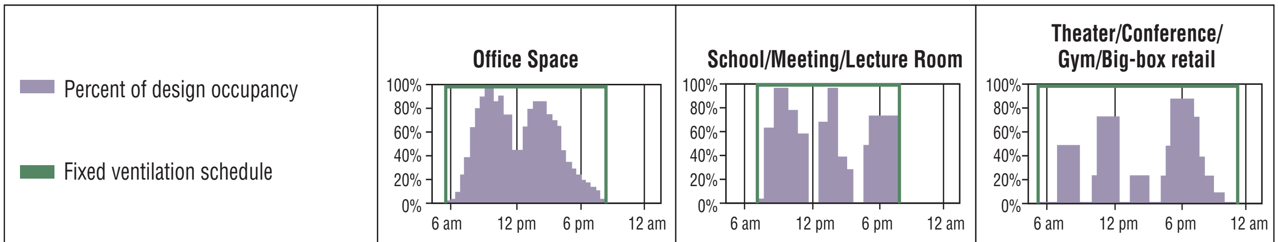
• Other operational strategies, such as economizer control and providing a pre-occupancy purge, are highly complementary to CO_2 control. Economizer operation should in all cases override CO_2 control. The pre-occupancy purge ensures a reservoir of new air is available for building occupants when they enter the building.

• The foundation for zone ventilation control is to measure CO_2 concentrations in each major occupancy zone. Placement criteria is identical to that of a thermostat, with the added provision that the CO_2 sensor should not be positioned in a location where people will regularly breath on the sensor (e.g., at standing level near the coffee machine). In large open areas (e.g., up to 5,000 sq ft), one sensor can be used to control a number of ventilation delivery devices (e.g., VAV boxes). This is due to the fact that CO_2 as a gas will readily diffuse and equalize in a large open area.

• The control strategy should be designed to modulate ventilation as CO_2 levels increase, rather than waiting for a specific CO_2 setpoint to be achieved. This is especially important in low-density spaces to ensure that adequate ventilation is provided as CO_2 levels rise, not just when they reach a specific level. Standard proportional or proportional integral control algorithms available with most HVAC controls can be applied to this type of ventilation control. Software programs are also available from some manufacturers that allow modeling of the control strategy to make sure actual target cfm-per-person ventilation rates are provided within a reasonable lag time of initial occupancy or changes in occupancy.

ZONE VENTILATION CONTROL

The application and, in some cases, the costs of zone ventilation control will vary depending if a system is constant volume or variable air volume. There will also be differences depending if the sys-



	Office Space		School/Meeting/Lecture Room		Theater/Conference/Gym/Big-box retail	
Floor area	10,000 sq ft		800 sq ft		10,000 sq ft	
Ceiling height	10 ft		10 ft		30 ft	
Design occupancy	100 people		30 people		1,000 people	
Ventilation rate (cfm per person)	20 cfm per person		15 cfm per person		15 cfm per person	
Base ventilation rate for DCV	30 percent of design		30 percent of design		30 percent of design	
Heating/Cooling	Natural gas/electric		Natural gas/electric		Natural gas/electric	
Ventilation schedule	Weekdays 5:30 a.m. to 10 p.m. Low Saturday occupancy		Weekdays 7:30 a.m. to 9 p.m. Unoccupied weekends		7 days per week	

Location	Fuel	Cost in dollars	Office Space Annual savings Total dollars	Office Space Annual savings Dollars/sq ft	School Annual savings Total dollars	School Annual savings Dollars/sq ft	Theater Annual savings Total dollars	Theater Annual savings Dollars/sq ft
Miami	Gas/therm Electricity/KWH	0.804 0.074	1,608.10	0.20	169.00	0.39	12,664.00	1.27
Baltimore	Gas/therm Electricity/KWH	0.798 0.079	2,593.50	0.29	271.00	0.58	17,603.00	1.76
Boston	Gas/therm Electricity/KWH	0.104 0.798	2,714.40	0.30	283.00	0.62	18,729.00	1.87
Chicago	Gas/therm Electricity/KWH	0.622 0.088	2,282.80	0.25	235.00	0.52	18,001.00	1.80
St. Louis	Gas/therm Electricity/KWH	0.681 0.070	2,213.90	0.25	234.00	0.52	17,243.00	1.72
Houston	Gas/therm Electricity/KWH	0.554 0.076	1,576.90	0.18	162.00	0.38	12,549.00	1.25
Los Angeles	Gas/therm Electricity/KWH	0.762 0.167	755.30	0.08	76.00	0.17	5,998.00	0.60
Portland	Gas/therm Electricity/KWH	0.705 0.065	1,740.70	0.18	178.00	0.27	11,530.00	1.15
Toronto	Gas/therm Electricity/KWH	0.722 0.088	2,876.90	0.31	294.00	0.64	22,527.00	2.25

FIGURE 3. Estimated energy savings for three building types in different U.S. climate zones represented by selected cities. Occupancy densities are different for each building type.

tem is purely a retrofit to existing equipment for CO_2 control or if CO_2 is installed as part of an equipment upgrade. The balance of this article will consider three different application examples, the issues involved in installation and estimated energy savings, and return on investment. The three examples include:

- An air-handling system where modulation of outside air can only occur at a central point that serves a number of zones, such as a rooftop air handler or a floor-level fresh-air intake for a multistory building.
- A new VAV installation where the CO_2-ventilation-control capability has been designed into the overall VAV control system by the manufacturer.
- A retrofit of an existing VAV system that did not have built-in logic for ventilation control using CO_2.

CENTRAL SYSTEM CONTROL

A simple application of the zone ventilation control concept is when room CO_2 sensors are integrated to control fresh air on a constant volume system serving a number of spaces having different occupancy patterns or densities. A good example of this would be an office served by one central air handler with several different occupancy zones, as depicted in Figure 1.

One CO_2 sensor is placed in each major occupied zone. The output from each of the CO_2 sensors is then fed to a simple transducer available from most control companies. The transducer determines which CO_2 sensor is providing the highest concentration readings and passes this signal on to the outside air damper actuator. The damper is then proportionally modulated based on the CO_2 concentration in the space that requires the most ventilation. This approach requires no special modification of the air handler or its control sequence. The CO_2 input from the transducer can easily be wired into the actuator, which also provides economizer control.

The estimated cost of this installation would be approximately $225 for each sensor (three sensors), $60 for the transducer, and $400 for wiring and installation, resulting in a total cost of just over $1,100. Savings in this hypothetical example would be very dependent on how frequently the meeting and training rooms were used.

ZONED VENTILATION FOR NEW CONSTRUCTION

Many control manufacturers have now integrated CO_2-ventilation-control algorithms directly into VAV control systems. The result is that adding zone-level CO_2 control is no more complex than wiring a thermostat (Figure 2). To reduce system costs, some manufactures have integrated the temperature sensing and CO_2 sensing capabilities into one device.

Continued on Page 81

Continued from Page 61

With these types of systems, the incremental cost of adding zone CO_2 sensors is a few hundred dollars per zone. When integrated into a DDC-controlled system, the only adjustment necessary is to establish a base ventilation rate and the target ventilation rate (in cfm per person), which can be done through the control system's computer interface. For larger open spaces served by a number of VAV boxes, the system can be configured so that one sensor can control the boxes for an entire occupancy zone.

The sequence of operation for the system modulates individual VAV terminals based on both CO_2 and temperature readings in the space. If the demand for additional ventilation causes the space temperature to drop below the temperature control setpoint, reheat is applied at the terminal to ensure the space temperature is maintained. The rationale for using reheat is that it is cheaper to slightly warm up air for a zone that it is to overventilate an entire building to ensure air gets to just one or two zones.

Given the small incremental cost associated with this type of system of a few hundred dollars per zone, the energy savings alone could provide a return on investment in less than two years based on the occupancy patterns (density of people over time) in the space. Figure 3 provides an example of estimated energy savings for three different types of buildings for different U.S. cities based on simulations of a proportional control strategy.

RETROFIT VAV VENTILATION CONTROL

A building owner may wish to upgrade an existing building control system to include CO_2 control, which often is more involved than just adding sensors. Building owners should be aware that extra costs may be incurred, such as:

- Adding additional input points into the building automation system.
- Modifying or creating new BAS programs.
- Replacing equipment to ensure compatibility with the new system.

Prior to embarking upon a project, an engineering services company can install a temporary data logger to measure and store CO_2 concentrations for a minimum time period of one week in various areas of the building. The resulting profile of the existing ventilation rates will help determine if spaces are currently over- or underventilated. This allows for up-front assessment of potential energy savings that can be compared to the proposed project cost, which, in turn, will help the owner decide if the project fits within return-on-investment expectations. After the project is completed, the actual building energy performance can be tracked for the life of the building, resulting in a profile of energy and ventilation system performance. This real life data can then be used to assess whether similar retrofits are worthwhile for other buildings in the portfolio.

The ease of implementation and cost of a CO_2 retrofit is highly dependent on the characteristics and capabilities of the current system in place. This is true of both pneumatic and DDC systems, though energy savings resulting from integrating CO_2 control can be used to help justify an equipment upgrade from pneumatic to DDC.

SUMMARY

The integration of CO_2 ventilation control strategies into mainstream building controls and equipment allows new buildings to control for ventilation on a zone basis with a small incremental cost to the overall system. The use of CO_2 does not impact system design, but does allow for an effective operational strategy that can save energy and ensure adequate ventilation rates throughout the life of a building based on actual usage.

This is the case for low-density static occupancies or highly variable occupancies. Energy savings will increase in proportion to the occupant density and variability. In retrofit applications, it has been shown that a pre-assessment of building ventilation rates allows for realistic assessment of the potential energy savings to be gained, and project feasibility can be weighed against the cost of modifying the existing system to incorporate ventilation control.