PROVEN ENERGY SAVINGS with DCV retrofits

Using CO_2 levels to vary fresh air rate saves energy and assures good IAQ

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Every once in a while, a new technology innovation hits a sweet spot where both its benefits and its economic advantages result in widespread adoption and retrofit. This process has been especially noticeable in the field of computer technology over the last decade.

While things move a bit slower in the HVAC and buildings industries, there still are plenty of examples of this kind of innovation in recent years, including variable-speed drives, screw compressors, lighting retrofits, high-efficiency furnaces, and seven-day programmable thermostats.

One such innovation that may be at the threshold of widespread adoption is carbon-dioxide-based demand-controlled ventilation (CO_2 DCV).

TECHNOLOGY COMES OF AGE

A critical criterion for the success of any new technology is how easily it can be integrated into existing systems. For CO_2 DCV, success is dependent on the amount and types of HVAC equipment available that can accept a CO_2-sensor signal.

Today, virtually all major building-control and HVAC equipment manufactures offer CO_2 sensors to complement their product offerings. Plug-and-play simplicity is offered for CO_2 control for all types of equipment, including economizers, rooftop systems, and direct-digital-control (DDC) systems. Even combined-zone-level temperature and CO_2 control are being offered for variable-air-volume systems (VAV).

CODES AND STANDARDS

As the technology has developed, so have codes and standards. For the last four years, the International Mechanical Code (IMC), the mechanical code of reference for most local building code bodies, has included provisions for CO_2-based demand-controlled ventilation.[1]

In the past three years, ASHRAE Standard 62-1999, *Ventilation for Acceptable Indoor Air Quality*, has clarified the use of CO_2 as a parameter that can be used to control ventilation based on actual real-time occupancy while still maintaining target cfm-per-person ventilation rates.[2,3,4]

In California, the energy-conscious Title 24 building code has had specific provisions for CO_2-based demand-controlled ventilation for the past six years.[5]

In the Canadian province of British Columbia, a unique partnership between government and commercial-building owners has established not-to-exceed levels of CO_2 as part of a comprehensive health and safety standard for office workers.[6]

Energy savings is the principal driver for installing CO_2-based ventilation systems.

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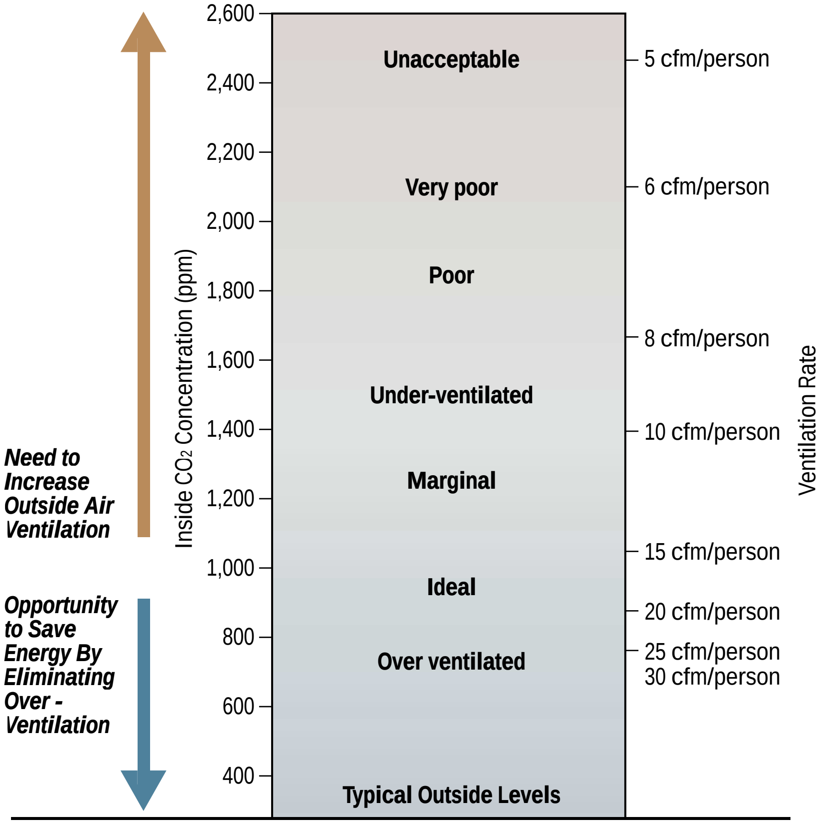

FIGURE 1. The relationship between CO_2 and ventilation rates, assuming adult occupants sitting or involved in office-type activity.

CO_2 AND VENTILATION

For the purpose of ventilation control, CO_2 is utilized as an indicator for the amount of outdoor air provided to a space for dilution of odors and contaminants.

At the levels normally found in commercial buildings, CO_2 is not considered a health issue itself. An indoor CO_2 concentration is a dynamic measure of the number of people in the space exhaling CO_2 and the amount of low-concentration outside air being introduced for dilution. It can provide an indication of the amount of fresh air introduced into the space on a per-person basis.

In commercial buildings, observations of stuffiness and lethargy often associated with elevated CO_2 levels (e.g., more than 1,000 ppm) are indicative of the lack of ventilation in the space, not the physiological effects of CO_2.

Figure 1 shows the relationship between CO_2 and ventilation rates, assuming adult occupants sitting or involved in office-type activity. Outside levels provide the baseline for a CO_2-control strategy. In the case shown in Figure 1, outside levels are assumed to be 400 ppm.

As a rule of thumb, a difference between inside and outside CO_2 levels of 700 ppm is indicative of ventilation rates of 15 cfm per person. A differential of 500 ppm would be indicative of 20-cfm-per-person ventilation rates.

It is important to note that these values are based on steady-state conditions under which CO_2 levels in a space have had a chance to reach an equilibrium with the fresh-air ventilation rate in the space. Measurements to determine ventilation levels should be made two to three hours after occupancy has stabilized and CO_2 levels have appeared to have peaked.

WHY USE CO_2 DCV?

Energy savings is the principal driver for installing CO_2-based ventilation systems.

Most codes and standards have established ventilation-rate requirements based on providing a minimum cfm-per-person ventilation rate.

Traditionally, ventilation has been provided based on a fixed ventilation rate consisting of the target cfm per person times the design occupancy of the space.

With DCV, target cfm-per-person ventilation rates can be provided based on real-time occupancy. This approach has been recognized by ASHRAE Standard 62-1999 and the International Mechanical Code.

Figure 2 provides a graphical representation of energy-savings potential. The area in brown on the graph represents the typical occupancy of an office building. The dashed line shows a scheduled ventilation strategy that is designed to provide ventilation for maximum occupancy throughout the day. The area shaded in light green shows the potential for energy savings. The figure also shows the importance of providing a base ventilation rate for non-occupant-related contaminants.

ASSESSING RETROFIT POTENTIAL

Much like for a lighting retrofit, it is possible to pre-quantify the potential for energy savings for a CO_2-DCV strategy by looking at how the building is being ventilated, including current CO_2 levels.

A hand-held CO_2 monitor can be used to determine if a building is under- or overventilated.

Figure 1 provides some guidance as to when a building could be considered under- or overventilated. For example, a mid-afternoon CO_2 measurement of a

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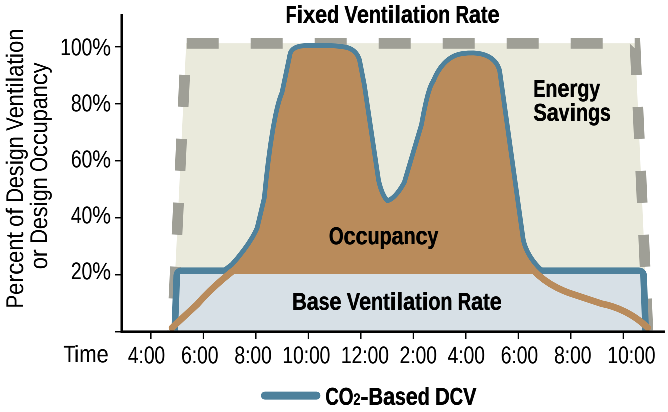

FIGURE 2. A graphic representation of potential energy savings. The dashed line shows a scheduled ventilation strategy for maximum occupancy.

fully occupied office space revealed a CO_2 concentration peak of 630 ppm.

When taking measurements, it is important to understand the building's operational mode to ensure that, for example, it is not operating in economizer mode, which would cause CO_2 levels to be unusually low.

As shown in Figure 1, a concentration of 630 ppm on the left side of the chart would translate into a ventilation rate of approximately 30 cfm per person on the right side. According to ASHRAE Standard 62-1999, office spaces require 20 cfm per person. This means that the space is overventilated by 10 cfm per person for its current occupancy and that there may be opportunities to reduce ventilation and associated energy costs. Further investigation would be warranted to verify that this indeed is the case.

Readers interested in more technical details on using CO_2 to measure ventilation rates can consult ASTM Standard D62-45-98, *Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation*.[7]

DOCUMENTING ENERGY SAVINGS

The energy savings possible with CO_2 DCV have been well-established. A recent literature review revealed numerous studies in which energy savings from various DCV control approaches ranged from 5 to 80 percent versus a fixed-ventilation strategy.[8]

Verification of energy savings is one of the most important parts of an energy-efficiency upgrade.

An example of well-documented energy savings from a DCV project is LaSalle Plaza in downtown Minneapolis.

La Salle Plaza is a 25-story commercial office building designed to provide 6,000 cfm per floor off a central, fresh-air plenum. Large fans located in the penthouse and sub basement supplied the fresh-air plenum through a set of steam-heated coils intended to maintain a 55-F air-delivery temperature. Steam and chilled water is purchased from the Minneapolis Energy Center. One air-handling unit is located on each floor.

The owners of the building realized that occupancy density and patterns varied significantly from floor to floor and hoped to reduce electrical and chilled-water use with the installation of CO_2 sensors.

The building's state-of-the-art DDC system allowed for a simple and low-cost installation of the CO_2 DCV system. One sensor was installed in the return-air duct of each floor. The CO_2-control signal was used to modulate the newly installed variable-speed-drive fans at each air-handling unit.

In the control strategy, a base ventilation rate of 30 percent of design was maintained at all times to control non-occupant-related sources during scheduled periods of occupancy. Air delivery to the floor was proportionately modulated from the 30-percent position to the design-ventilation rate (6,000 cfm) as CO_2 levels increased from 500 to 900 ppm.

A computer-based comparison of the cost of ventilation for a fixed-ventilation approach versus demand-controlled ventilation showed that annual savings of $87,500 were possible with the installation of the CO_2-sensing system.

LaSalle management keeps extensive records of energy usage. Energy use for the initial eight months the CO_2 DCV system was in operation was compared to the energy use for the same eight months the previous year. Heating-degree days for the two time periods were very similar. They were 6-percent higher for the non-DCV case. Cooling-degree days were 3-percent higher for the DCV case.

Aside from the CO_2-DCV installation, there were no other major building changes in equipment or occupancy dur-

Extended Monitoring Can Pin-point Building Problems

Once a building has been characterized using a hand-held CO_2 monitor, further investigation often is warranted, according to Doug Smith, a principal with Energy Savers Inc., a Satellite Beach, Fla.-based energy consulting and building commissioning firm.

To help building owners assess the savings potential for DCV, Energy Savers will trend-log seven days of CO_2 measurements in various parts of a building. The company uses a software analysis program that uses local climatic conditions and energy costs to compare the annual cost of ventilation at a fixed design ventilation rate to a strategy of ventilating based on CO_2 measurements and actual occupancy patterns.

"In many cases, CO_2 monitoring has helped quickly identify problems with mechanical systems that would have been difficult to identify with physical inspection," Smith said. He cited the example of work performed for an owner of a number of conference/hotel complexes where CO_2 monitoring helped identify two malfunctioning air handlers, one blocked air intake, and one case in which short-circuited kitchen exhaust was being reintroduced into a rooftop air handler.

The results of the energy analysis are presented to the building owner to assess the potential payback from CO_2 DCV. In the case of a convention area in a hotel in Florida, actual monitored results were within 20 percent of Energy Saver's estimate of $32,000 in annual energy savings. This resulted in a two-month return on investment on the CO_2-DCV-system installation.

A CO_2 DCV Case Study

David Bearg of Life Energy Assoc., an air-quality consultant based in Massachusetts, often uses CO_2 monitoring to characterize a space as part of an indoor-air-quality investigation.

According to Berg, "CO_2 monitoring is a very valuable tool for measuring the ventilation performance within a space."

Berg's company recently evaluated a space occupied by directory-assistance telephone operators. The space featured a number of cubicles at a relatively high density of 60 people. The center was staffed to correspond to peak demand periods during the course of the day. Therefore, it had highly variable occupancy.

Initial CO_2 measurements in the space (Figure 3) showed concentrations well above 900 ppm, the level corresponding to a ventilation rate of 20 cfm per person. In this case, the issue was not saving energy, but providing adequate ventilation at all times.

This space of about 5,600 sq ft was served by a single air-handling unit (AHU). Outside air was ducted to the centrally located unit. To provide adequate ventilation during peak occupancy without a wholesale increase in the amount of ventilation provided or a significant redesign of the system, a booster fan was installed in the outdoor-air ductwork. Its operation was tied to CO_2 levels in the space.

In addition, the AHU had electric heat; so there was no worry about freezing coils if the increased outside air was necessary during cold weather.

Figure 4 shows CO_2 trends logged after the CO_2-control system was installed and how the system was able to maintain CO_2 levels under the 900-ppm target.

For this application, the prime motivation was to ensure adequate ventilation rates while avoiding a costly upgrade of the ventilation equipment.

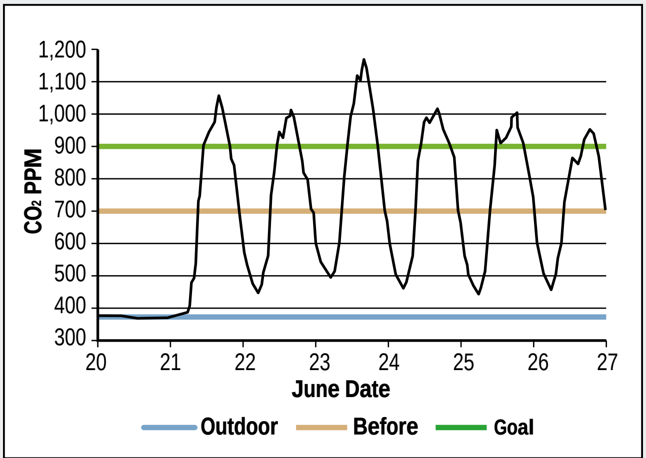

FIGURE 3. Initial CO_2 measurements.

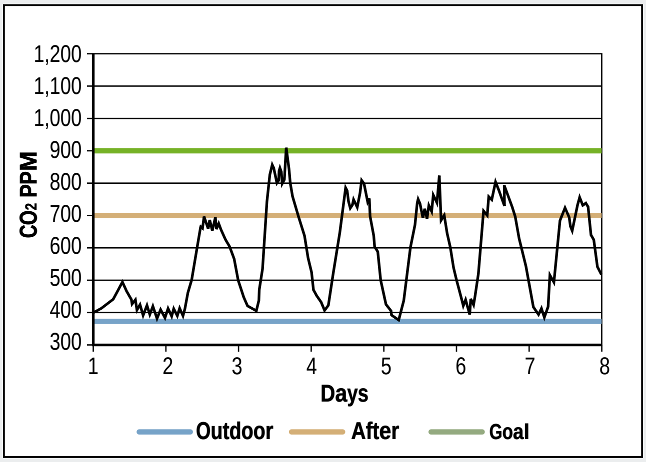

FIGURE 4. CO_2 trends logged after a CO_2-control system was installed.

ing the comparison period.

Results of the comparison of the eight-month operating periods showed actual savings of $150,503 broken down as follows:

- Chilled water reduced by 181,900 ton-hrs (14-percent reduction) = $51,136.
- Mechanical-system electrical usage reduced by 549,200 KWH (6-percent reduction) = $29,657.
- Steam usage reduced by 5.8 million lb (32-percent reduction) = $69,710.

The combined installation of CO_2 control and VFD-controlled fans on every floor paid for itself in energy savings in less than two years.

The great disparity between the simulated results and the actual results are attributed to two principal factors:

- Although the actual air volumes delivered for fresh air were not measured prior to the CO_2 DCV-installation, it is suspected that the original ventilation rates in the building were actually significantly greater than that assumed in the energy analysis.
- Occupancy levels estimated in the energy analysis may have been greater than those that actually occurred in the building, resulting in an underestimation of energy savings.

HOW TO WORK WITH CO_2

Conventional wisdom suggests that CO_2 DCV is best applied in spaces with high densities and highly variable occupancy, such as theaters, conference areas, and classrooms.

However, increasingly, CO_2 control is proving to be economically viable in applications such as commercial office buildings, in which occupancies are relatively static, but densities can vary greatly from zone to zone.

Commercial buildings often are well-designed, but may be operated or occupied in a manner that the mechanical system designer never anticipated. In some cases, well-meaning facility managers may set and operate air intakes in an arbitrary manner, according to the "feel" of the building, which results in overventilation. In other cases, air-intake dampers may be set up in a way that makes accurate setting and measurement of actual air-flow delivery difficult.

All of these factors result in buildings that tend to be unnecessarily overventilated, a problem that can be ameliorated with CO_2 DCV.

Designers, owners, and installers of CO_2-DCV systems should be aware of the potential problems that can be created by in-duct sensing, including:

- CO_2 should not be measured in-duct for the same reasons that temperature sensing for spaces is not measured in-duct. Measurements of in-duct concentrations will reflect the average of all locations and may not reflect the conditions in any one space. Some spaces could be overventilated and others underventilated with this approach. Critical spaces may not be properly ventilated, and, therefore the requirements of ASHRAE Standard 62-1999 may not be met.

• The CO_2 concentrations in ceiling return-air plenums can be diluted by leakage from supply-air ducts and by infiltration through outside walls. Building managers can check for this problem by comparing CO_2 concentrations in the plenum versus those in the space.

One approach for avoiding this problem when a single air handler serves multiple occupancy zones is to install space sensors in all major zones. A low-cost transducer can be used to collect the measurements from each zone and control ventilation off the highest concentration measured. In this way, an adequate level of ventilation is provided for all zones at all times.

It is important to note that demand-controlled ventilation does not discriminate where fresh air comes from. If a window or door is open or if outside-air infiltration brings fresh air into a space, the CO_2 sensor will sense that fresh air, reducing demand on the mechanical system. Because a CO_2-DCV system measures the actual dilution rate of fresh air in the space, a CO_2-control strategy can recognize when fresh air is underutilized in some zones because of low occupancy. In these cases, the air-circulation system can redistribute fresh air within the building rather than increase outside-air ventilation.

Since CO_2 is primarily an occupancy parameter, it is important to ensure that ventilation rates are sufficient to control non-occupancy-related sources when occupancy is low. As illustrated in Figure 2, it is highly recommended that a base ventilation rate be provided during all occupied periods to control for these other sources.

As a rule of thumb, the base ventilation rate should be 20 to 30 percent of the design-ventilation rate for the space.

If a space is newly furnished or renovated, the building operator may want to consider a higher base ventilation rate for the first six to 12 months of operation, to deal with the higher levels of outgassing contaminants typical when furnishings are first installed.

MAINTENANCE

A critical criterion affecting the economics of CO_2-based DCV is sensor maintenance.

All CO_2-measurement technologies have an inherent tendency to drift. This can be compensated for by regular, manual calibration. Some manufacturers have developed techniques to automatically compensate for drift.

For example, one manufacturer's sensor is designed to automatically calibrate itself every evening when a space goes unoccupied and concentrations drop to outside background levels.

In selecting a CO_2 sensor, it is important to consider how the sensor deals with calibration. While first cost may in some cases be lower, the maintenance requirements for a poorly performing sensor can far exceed any energy savings generated.

SUMMARY

CO_2 DCV can save energy by reducing unnecessary overventilation, while still ensuring that target cfm-per-person-ventilation rates are met at all times. Such systems benefit both building owners/operators and building occupants.

Even in cases in which a building has been identified as being underventilated, CO_2 control can be used to provide targeted ventilation when it is required, rather than providing a constant, fixed ventilation rate throughout the day.

CO_2 levels also can be used to better understand how a building's mechanical system is operating. Portable instruments can be used to qualify the ventilation characteristics of a space before any work is undertaken. Such measurements provide the foundation for energy usage and savings calculations.

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