Using Demand-Controlled Ventilation to Reduce HVAC Costs

Across the United States, Wal-Mart stores are open for long hours every day, and although they may be full of browsing customers some hours of the week, at other times relatively few customers are milling about the huge floor space. Occupancy fluctuations like these offer retail stores and other commercial facilities an opportunity for annual energy savings that can amount to as much as $1 per square foot. Instead of continuously ventilating the space at a constant rate designed to accommodate the maximum number of customers, building operators can implement demand-controlled ventilation (DCV), in which the amount of outside air drawn in for ventilation depends on the actual occupancy of the building at any given time. This strategy results in energy savings because it reduces the amount of air that needs to be heated or cooled.

DCV is old hat to some companies—Wal-Mart specifies DCV for all new facilities and uses it in more than 1,000 stores—but many energy managers, HVAC contractors, and building designers are still unfamiliar with it. That is changing, however, with improvements in DCV technology. Historically, DCV has been applied primarily in office buildings, but the consistently high rate of its growth—between 20 and 30 percent annually over the past decade—has reduced equipment costs, improved performance, and led to the development of "DCV-ready" HVAC equipment. These changes have vastly expanded the range of new and existing facilities to which DCV can be applied.

What Is DCV?

Many ventilation approaches could be called "demand-controlled," including the use of operable windows or simple scheduling of air handlers to shut down the outside air damper when the building is unoccupied. This pamphlet describes systems that control a building's ventilation based on carbon dioxide (CO_2) concentration. This is what is most commonly referred to as DCV.

Many building codes in the United States base their ventilation requirements on a standard written by ASHRAE (the American Society of Heating, Refrigeration, and Air-Conditioning Engineers), which requires that a commercial building bring in a specified minimum amount of fresh air to ensure adequate indoor air quality (IAQ). To adhere to this standard, the choice made in most buildings is to ventilate at the fixed minimum rate per person based on the building type and the assumed occupancy—usually the building's design occupancy. But because the number of people actually occupying the space at any given time can vary widely, the ASHRAE standard offers another way to ventilate based on actual occupancy numbers.

Because the average amount of CO_2 a person at a given activity level will exhale in a fixed time period is well known, the concentration of CO_2 in the air inside a building is a good indicator of the number of people in a space and the rate at which the air in the space is being diluted with outdoor air. For a constant volume of fresh ventilation air, the more occupants a building has at any given time, the higher the level of CO_2 in the air. The AHSRAE standard allows building operators to use DCV to bring in only the air necessary for the actual occupancy. In this system, sensors monitor the CO_2 levels inside and send a signal to the HVAC controls, which regulate the amount of outside ventilation air that is drawn into the building. Though ASHRAE doesn't set a maximum allowable CO_2 concentration, the most recent version of the standard recommends that the indoor CO_2 level be no more than 700 parts per million above the outdoor level.

Benefits of DCV

DCV provides multiple benefits to building operators and occupants. It can:

- *Reduce energy consumption.* DCV systems save energy by reducing the need to heat or cool outside air. The only system change is the ratio of recirculated air to outside air—fan power is usually unaffected. DCV systems can save from US$0.05 to $1.00 per square foot, depending on the occupancy schedule and climate. This can make a big difference for retailers in the U.S., for example, which incur average HVAC operating costs of $1.11 per square foot per year.
- *Provide proper ventilation.* If a building is not drawing in enough outside air, a DCV system may actually increase energy use, but it will also bring the building into compliance with ventilation codes and do so more efficiently than a simple increase in the constant ventilation rate. Because DCV provides the proper amount of ventilation for building occupants, it prevents underventilation, which can make buildings seem stuffy and increase the chances that occupants will get sick.
- *Show that buildings are in compliance with building codes.* It is relatively easy to prove that buildings are properly ventilated when you can simply check to see that CO_2 sensors read at or below the maximum allowable CO_2 concentration. If the DCV system is working properly, this will always be the case.

There is also one limitation of DCV that end users need to be aware of: Ventilation control based on CO_2 levels is an important tool that can help control occupant-related pollutants and satisfy occupant-based ventilation standards, but relying on CO_2 sensors alone to indicate or control the ventilation rate will not always guarantee good IAQ, particularly in buildings that have significant nonhuman sources of air pollutants. A thorough IAQ strategy should also include a complete audit of potential pollutant sources in the building, such as vapors from copiers, building materials, furniture, cleaning solutions, or, in a retail or warehouse setting, the products on the shelves.

DCV's Cost-Effectiveness

The overall cost for implementing DCV has dropped substantially in recent years, opening up new opportunities for savings and spurring changes in some building codes. The main improvement has come from CO_2 sensors, some of which are now priced below US$200 (compared to over $500 a decade ago). Today's sensors can self-calibrate, so they need far less maintenance than their predecessors. Also, several HVAC equipment manufacturers now offer DCV-ready rooftop units and variable air volume (VAV) boxes. This equipment is shipped with terminals for the CO_2 sensor wires and controls that are preprogrammed to implement a DCV strategy. By limiting installation costs to the cost of mounting the sensor and running wires to the rooftop unit or VAV box (wireless models are available), DCV-ready HVAC equipment substantially reduces the cost of implementing DCV.

This reduction in cost is spurring code-setting agencies to take another look at the types of buildings for which this technology is required. ASHRAE is currently contemplating changing its standard governing the energy efficiency of nonresidential buildings (which forms the basis of building codes across the U.S.) to require DCV in buildings that have design occupancies equal to or greater than 100 people per 1,000 square feet (about 1 person per square meter). And in California, the state's building code, known as Title 24, was revised in 2005 to require DCV in any building with a design occupancy of 25 people per 1,000 square feet (or about 1 person every 4 square meters)—down from the previous level of 100 people per 1,000 square feet.

But the opportunities for DCV extend well beyond the applications that are currently or even soon to be required by building codes. For example, a study conducted in 2003 at Purdue University shows favorable paybacks for DCV in a variety of buildings. The study investigated four types of buildings—a restaurant, a retail store, a school, and an office—in each of two cities in California and three cities outside the state. The restaurants and retail stores showed the most opportunity for DCV, with savings estimated at around 50 percent of the total energy operating cost in some cities (**Table 1**). Paybacks across all the cities and buildings ranged from 0.2 to 6.8 years, although 16 of the 20 modeled scenarios had a payback of less than two years and 12 had a payback of one year or less (**Table 2**). And the modeling used more-conservative numbers for design occupancy than those in the relevant ASHRAE standard for all but the office buildings, so it's likely that actual payback periods would be even shorter.

DCV Simulation Tools

Several free computer simulation tools are now available. They allow you to evaluate the cost-effectiveness of DCV for a particular application, helping to reduce the risk and uncertainty of choosing appropriate DCV applications. Some of the simulation tools can be found online at no charge, including the following:

- Hourly Analysis Program from Carrier Corp.; go to www.commercial.carrier.com/commercial/hvac/general/1,,CLI1_DIV12_ETI496,00.html
- Savings Estimator from Honeywell; go to http://content.honeywell.com/building/components/economizerpromo.asp
- CO_2 Ventilation Control & Energy Analysis from AirTest; go to www.airtesttechnologies.com/support/energy-analysis/

Table 1: Percentage of annual energy cost savings from DCV

Although savings will depend heavily on actual occupancy patterns, the relatively larger percentage of savings in restaurants and retail stores highlights these types of facilities as particularly good candidates for demand-controlled ventilation (DCV).

	Office				Restaurant				Retail store				School			
Location	Energy	Demand	Gas	**Total**	Energy	Demand	Gas	**Total**	Energy	Demand	Gas	**Total**	Energy	Demand	Gas	**Total**
Oakland, California[a]	2.3	8.4	56.8	**7.5**	–5.3	9.2	100.0	**17.9**	–2.2	19.0	100.0	**16.6**	–0.3	8.2	99.0	**6.5**
El Centro, California[a]	8.4	11.8	54.5	**9.0**	18.4	25.4	100.0	**20.2**	22.6	35.7	100.0	**24.3**	13.1	17.4	100.0	**13.7**
Phoenix, Arizona	7.4	5.0	53.7	**6.4**	16.4	12.5	99.7	**17.3**	20.1	19.5	100.0	**20.9**	11.8	9.5	95.5	**11.0**
Charleston, South Carolina	12.3	10.5	46.5	**12.3**	16.6	23.4	98.1	**27.0**	21.9	35.7	99.5	**32.6**	13.8	13.5	91.4	**15.5**
Fargo, North Dakota	6.2	11.0	37.3	**19.0**	7.2	20.8	82.3	**49.8**	10.5	31.8	90.7	**53.4**	6.8	12.2	61.4	**28.2**

Note: a. Oakland is the representative city in California Climate Zone 03 and El Centro is the representative city in California Climate Zone 15. For more information on California Climate Zones, visit the California Energy Commission's Climate Zone Map at www.energy.ca.gov/maps/climate_zone_map.html.

Source: E SOURCE; adapted from Jim Braun et al., "Evaluation of Demand-Controlled Ventilation, Heat Pump Heat Recovery, and Enthalpy Exchangers," report prepared for the California Energy Commission (August 2003).

Table 2: Payback periods for DCV, in years

Based on simulations of building energy use, restaurants and retail stores should see the quickest paybacks for demand-controlled ventilation (DCV).

Location	Office	Restaurant	Retail store	School
Oakland, California[a]	6.8	2.1	1.0	4.0
El Centro, California[a]	1.9	0.6	0.3	0.9
Phoenix, Arizona	3.4	0.9	0.6	1.5
Charleston, South Carolina	1.1	0.7	0.4	0.9
Fargo, North Dakota	1.5	0.3	0.2	0.5

Note: a. Oakland is the representative city in California Climate Zone 03 and El Centro is the representative city in California Climate Zone 15.

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Buildings That Are Good Candidates for DCV

In general, buildings that make the best candidates for DCV are distinguished by:

- *Highly variable occupancy.* DCV offers the greatest potential for energy savings in buildings with wide or unpredictable swings in occupancy, such as auditoriums, restaurants, bars, cafeterias, theaters, retail stores, classrooms, and conference rooms. Buildings with highly variable occupancy and buildings that rarely or never reach design occupancy will likely save more energy than facilities with predictable near-design occupancy, such as office buildings or schools.
- *Moderate to extreme heating or cooling climates.* Given that DCV can reduce the amount of outdoor air brought in, buildings in climates where a lot of energy is required to heat or cool the outdoor air stand to gain the most, while those in climates where little conditioning is required and where economizer operation is common will save less. Facilities with large refrigeration loads, such as supermarkets, will also benefit from the reduced humidity load that the display cases would otherwise have to remove.
- *Conventional HVAC systems.* Buildings that have packaged air-conditioning systems offer opportunities for greater energy savings than do facilities using certain other cooling systems, such as evaporative cooling. These other systems use 100 percent outside air during normal operation, which means that ventilation performance cannot be improved. However, these buildings may benefit from the use of DCV in winter, because it will reduce the amount of outside air that must be heated.
- *Long operating hours.* Buildings that are only open for a few hours per day are unlikely to be good candidates for DCV. Those facilities might be better off using timers to shut off ventilation fans during unoccupied hours.

A lot of facilities meet these descriptions, including grocery stores, supermarkets, big-box stores, theaters, lecture halls and other performance spaces, places of worship, sports arenas, restaurants and bars of all types, and department stores. In fact, the majority of commercial facilities that are not now using DCV are at least potential targets for the technology.