Demand-Controlled Ventilation: A Design Guide

June 2003

This guide is intended to assist those implementing demand-controlled ventilation (DCV) systems. It was written by Marty Stipe, P.E. with the Oregon Office of Energy. Funding for the guide was provided by the Northwest Energy Efficiency Alliance.

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Introduction

Ventilation is required so that the human occupants in buildings are provided with fresh air. The purpose is to provide oxygen and dilute other gases such as CO_2 and human odors.

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) is a technical organization in the United States that recommends the systems and procedures for ventilation equipment. It has focused on two basic methods. The "dilution method" is used most frequently where pollutants are diluted by fresh air. Demand-controlled ventilation (DCV) is considered a dilution method. The second method, called the "Indoor Air Quality (IAQ) Procedure," is used to identify and remove specific contaminants. The IAQ method is not addressed in this guide.

The concept of automatic ventilation control based on occupant demand has been known for over 20 years. The barrier to widespread implementation was not having a cost-effective, simple, and reliable sensor. Early sensors did not provide the reliability that was needed in many applications.

In addition, the cost for the sensors was high. They were used in specialized applications primarily for indoor air quality purposes. Other methods were also explored. For example, as computers became used more in theater operations, the operators began to use the computers to track ticket sales to control ventilation rates.

In recent years, advances in sensor technology have shown that demand-controlled ventilation is now both feasible and cost-effective. Interpretations of the ASHRAE guidelines indicate that demand-controlled ventilation is acceptable when properly designed and installed.

What is a demand-controlled ventilation (DCV) system?
Demand-controlled ventilation adjusts outside ventilation air based on the number of occupants and the ventilation demands that those occupants create. DCV is part of a building's ventilation system control strategy. It may include hardware, software, and control strategy and is an integral part of a building's ventilation design.

Which spaces would benefit from DCV?
Large assembly spaces such as gymnasiums, auditoriums, lecture halls, conference rooms, churches, and theaters are good candidates for DCV. These spaces are designed for large numbers of people with high outside air requirements. However, the spaces are frequently only partially occupied. It is expected that, in the future, most spaces with ventilation air capacities of at least 1,500 cubic feet per minute (CFM) and serving areas having an average occupant load factor of 20 or less will be designed with DCV features.

How will the space benefit?
DCV is a ventilation control strategy that provides just the right amount of outside air that is needed by the occupants. Active control of the ventilation system can provide the opportunity to control indoor air quality. It can save energy.

Figure 1 shows the ventilation savings potential (area in gold) for a typical application where DCV replaces fixed scheduled ventilation.

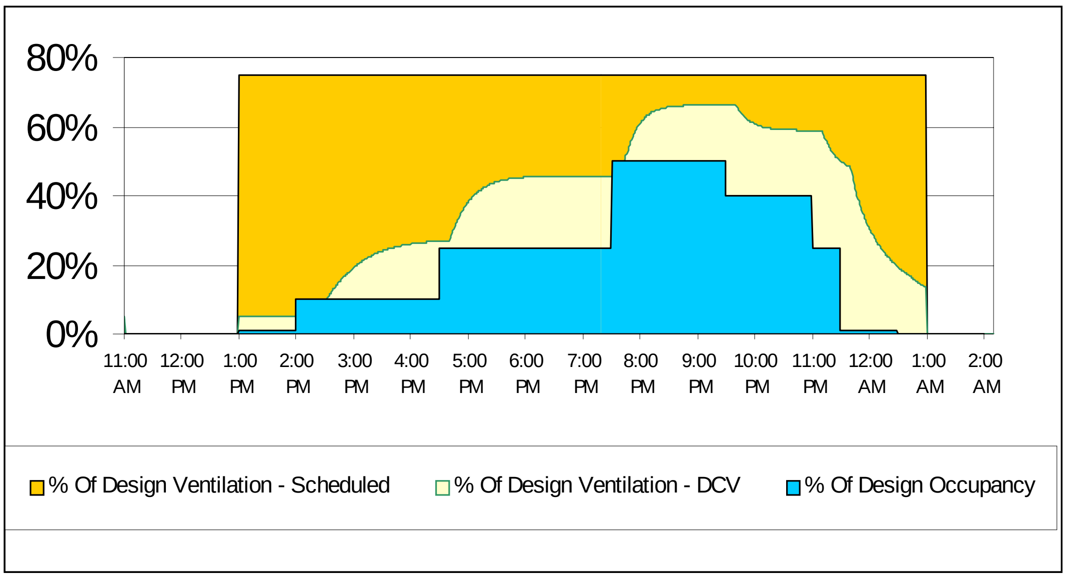

Figure 1 - Comparison of ventilation rates for different system designs

What are the typical components for each type of system?
Many of the components that are used in controlling outside air may already be in place. These existing components could include an economizer or air makeup unit with modulating dampers. The additional components would be control sensors to communicate either directly with the economizer or with a central computer. The extra components might include carbon dioxide (CO_2) sensors, occupancy sensors, or turnstile counters. Programming, while not a physical component, is a critical element of system operation.

What is the Design Guide?
Good communication among those implementing DCV systems is critical to a successful project. The building owner, architect and engineer, installer, commissioning agent and

building inspector have different perspectives, but should work together to produce a good ventilation system.

This guide is organized into multiple sections that focus on the needs of a particular group. The sections are:

· Building Owners
· Architects and Engineers
· Installers
· Building Inspectors and Commissioning Agents
· Case Studies

For Business Owners

What is a demand-controlled ventilation system?
A demand-controlled ventilation (DCV) system controls the amount of outside air brought into the building. It should provide the amount of outside air the human occupants need, and no more. This accomplishes two things. First, it saves energy by not heating or cooling unnecessary quantities of outside air. Second, it can provide assurance that sufficient outside air is being supplied to the occupants. Fixed ventilation systems provide constant, sufficient fresh air, but do so at the cost of heating or cooling excess air. Scheduled ventilation can provide fresh air at the correct rates at the right time, but run the risk of under or over-ventilation if schedule changes are not made at the appropriate times.

How much money will a DCV system save me?
The savings will vary greatly depending upon the building. However, energy savings are calculated to be as high as 60 percent for spaces that are lightly used but designed for large numbers of people (for example, gymnasiums). Also, buildings in predominantly heating climates such as the Pacific Northwest will get most of their savings during the heating season.

How does a DCV system work?
The system will use one or more sensors or systems to determine how many people are in a space. The ventilation system, typically part of the heating and cooling system, will adjust a damper to let more or less outside air into the building depending on what the sensor detects. For theaters, ticket sales or turnstile counters will provide the occupancy number. For gymnasiums, CO_2 sensors will detect the presence of people.

What do I have to do?
First, it is important to work with the architect and designer to make sure they know how you will use the building. This will help them design appropriate systems. Future use of the building should also be considered. Some larger systems will contain most of the ventilation equipment due to building code requirements. There would be some

additional sensors and controls to provide the demand-control features. It is important to commission the system to assure that the sensors are properly integrated.

Once installed, the system will run automatically. Annual building maintenance should include a check of system performance. The designer or builder should provide a procedure for the building owner on proper maintenance procedures.

What will the tenants think of the DCV system?
The tenants should not notice anything unusual. Proper ventilation should prevent the spaces from becoming stuffy, which should reduce complaints. It has been reported that the presence of a monitor actually improves tenant confidence in the quality of the air. Respond to serious tenant concerns by consulting with an air quality specialist and mechanical systems engineer.

How does the DCV system manage new building odors?
In new construction, there may be additional sources of odors. New furniture, carpeting, paint, office equipment, or other commercial processes may add contaminants that overwhelm the designed ventilation or occupants' perceptions. Sensors will not likely detect these unusual odors unless they are specifically designed to do so.

In these cases, the ventilation should be increased until the situation is resolved. Discuss with the designer and builder the options for modifying initial ventilation requirements.

Has anyone used a DCV system before?
Yes. Adoption of this technology was promoted as early as the 1970s. However, sensor technology made significant improvements in the 1990s. Infrared and CO_2 sensors are now being used in creative, successful applications (see Case Studies). Schools are using CO_2 sensors to monitor classroom air quality conditions, large department stores are using CO_2 sensors to save energy, and large office buildings are retrofitting their ventilation systems to take advantage of both energy conservation and fresh air benefits.

For Architects and Engineers

What is a demand-controlled ventilation system?
Demand-controlled ventilation is a control strategy that adjusts the amount of outside air based on the number of occupants and the ventilation demands that those occupants create. This strategy is used to both control energy costs as well as assure sufficient ventilation.

How will a demand-controlled ventilation system impact the occupants' living/working environment?
The occupants should perceive little or no difference in their environment. A properly designed, installed, and maintained HVAC system will have appropriate fresh air and temperature control. The demand-controlled ventilation (DCV) system will reduce outside air intake at times when it is not needed. When people enter a room, the system

will increase ventilation. This should happen without any noticeable change or buildup of contaminants.

Actions needed:

1. Obtain a summary of the particular technology proposed by the mechanical system designer.
2. Share information with the building owner.

The building occupants may be aware of the presence of this system. Often, the system provides a sense of security for occupants that some issue is being resolved. If the system also serves the purpose of monitoring indoor air quality, a display can be provided for the customer to view. This might consist of a CO_2 monitor in a common area, or a damper position feedback to the HVAC control system.

Actions needed:

1. Review the customer's need to monitor system status.
2. Share the customer's needs with the design group.

How might the DCV system interact with architectural design?

The design of any ventilation system should be integrated with the architectural and customer needs. It is important to be aware of conditions that may disrupt proper sensor operation. For example, flooring that is commonly buffed with propane-powered floor buffers can create temporarily high levels of CO_2.

Actions needed:

1. Establish a list of the different operating conditions (seasonal business cycles, occupancy cycles, and transition periods).
2. Obtain from the customer the business-related ventilation needs (non-people-based pollutants: raw material odors, fugitive process gases, water vapor, or particulate).
3. Meet with the customer and HVAC designer to compare ventilation design to expected operating conditions.
4. Identify the responsible party for each of the system's implementation and maintenance phases.

How will the customers have to interact with the DCV system?

The customer should not have to interact with the system unless they are the owner/operator. The maintenance requirements of the HVAC system will need to cover the routine calibration checks. Technicians should be called in to make the adjustments if there are perceived problems. Larger facilities may have in-house staff that can be trained to do the routine maintenance.

Action needed:

1. Ensure customer is provided with a maintenance plan.

What are likely questions the customers will ask about the DCV system?

What is demand-controlled ventilation? It is fresh air ventilation that is actively controlled for the number of people present in a room.

How much does the extra equipment cost? It ranges from $300 - $1000 per zone. This covers the sensors and their integration.

What do I get out of it? It saves energy and energy costs. Paybacks are often as short as two years. It also assures fresh air needs are met.

What if it malfunctions? The failure mode of the system is based on the design. It can be set to go full open, to minimum, or some other preset value that allows proper ventilation to occur. The system should also notify the user or maintenance organization that a failure has occurred.

System Design Issues
It has been said that demand-controlled ventilation is more of a system control effort as opposed to a new technology development. This is primarily because ventilation needs are known and ventilation hardware is available. With the maturity of the CO_2 sensor, there are now enough systems to provide an array of options from which the designer can choose.

What information do I need to collect to select a DCV system?
The building needs often dictate which system is most cost-effective. Key information to collect includes:

- What is the design occupancy?
- What is the expected actual occupancy?
- Is the occupancy predictable on an hour-to-hour or day-to-day basis?
- How rapidly do the spaces fill and empty?
- What activities are conducted in the space?
- Are there other non-occupant contaminants present?
- Are the quantities of non-occupant contaminants constant or variable?
- Are the occupants sensitive to contaminants?
- Can the occupant maintain the system?
- What does the system need so it will be properly maintained (access to sensors, etc.)?
- How will the occupant behavior affect the system (operable windows)?
- Is it possible that the building use will change in the long-term?

Design guides are also available from HVAC manufacturers that provide step-by-step instructions.

What DCV systems are available?
Some of the options include:
· CO_2-based sensors, which measure the buildup of CO_2 from the occupants present
· Occupancy sensors, which use infrared light and sound to detect occupants
· Real-time data such as turnstiles, ticket sales, registrations, scheduled events, to count occupants and or know with high reliability when they are occupying a space

CO_2 sensors are best suited for highly variable occupancy in larger assembly spaces. They are an accepted method of determining occupancy for the purpose of controlling ventilation. The larger space (and volume) will allow the concentration of contaminants to grow more gradually. CO_2 sensors take a little time to respond to changes in the environment. As the occupancy changes, the ventilation can easily keep up.

The largest benefit of CO_2-based DCV is that the ventilation system can manage a wide range of occupancy and respond accordingly. This saves energy as well as providing good ventilation during peak periods. Single rooms, with single or multiple air handling systems are the most easily controlled.

The drawback to CO_2 is that the sensors are subject to local concentrations of CO_2 and they may or may not represent the entire space needs. A sensor placed near an entryway or in a dead-air corner may provide false high or low readings. A single CO_2 sensor placed in a return duct senses an average CO_2 concentration of the air returning through that duct. It does not take into account actual room conditions, short circuit airflow, and the concentrations that are leaving the room through doors and windows. In variable-air-volume (VAV) and constant-air-volume (CAV) multi-room systems, there may be the cost of additional room sensors and related maintenance.

Occupancy sensors are commonly used to control lighting. These sensors are also available with an extra set of electrical contacts. This extra set of contacts can be used to reduce ventilation when the room is not occupied. This is a low-cost option if the design already has occupancy sensors to control the lighting and computer controls to control the HVAC system. The additional costs will be for a different model occupancy sensor and to pull an extra set of control wiring. Consideration needs to be given to the occupancy patterns in the area. If occupants leave the rooms that contain the sensors yet still remain in the zone (hallways, commons area) ventilation must be maintained. This can be accommodated with additional occupancy sensors or a CO_2 sensor in the return duct.

"Real time" demand-controlled ventilation uses characteristics of the building's use to help control ventilation. Examples include theater ticket sales that track occupants, or turnstiles that count occupants entering a space, initiating ventilation when a preset number of people enter the space. In using this method there may be assumptions (e.g. a ticket holder will actually go to the showing for which they hold a ticket.) The benefit to these systems is that there is little lag in ventilation. When occupancy changes rapidly, there is a rapid buildup of contaminants. With a real-time actual count of occupants, ventilation rates can be increased before contaminants build up to threshold limits. The drawback is that some energy savings may be forfeited. The ASHRAE standards allow lag time in ventilation for some cases. For short duration events, the contaminants may be allowed to build up. The minimum ventilation following the event will gradually dissipate those contaminants. If real-time demand-controlled ventilation control is used, the minimum ventilation can be adjusted accordingly less, given that the occupant-based ventilation occurred during the actual occupancy.

What systems are impacted?
HVAC systems are impacted. There are additional sensors, design calculations, programming needs, and maintenance requirements. In addition, there may be additional damper controls required. The ventilation system design must be designed for the maximum occupancy. This could increase the size of the outside air mechanical equipment.

Economizers are frequently installed to use the free cooling effects from outside air when temperatures permit. They will normally be programmed to override the ventilation requirements and provide additional outside air for cooling. In this situation, it is frequently a small additional cost to add the sensors to upgrade the system to demand-controlled ventilation.

Other equipment that affects the sensitivity or calibration of the demand sensors must also be considered. This includes CO_2 scrubbers or stray infrared sources that will cause the sensors to provide incorrect signals from which to control ventilation.

What does ASHRAE say about demand-controlled ventilation?
ASHRAE standard 62-2001, Ventilation for Acceptable Indoor Air Quality, addresses the issue of intermittent or variable occupancy (section 6.1.3.4). This section allows the adjustment of ventilation for variable occupancy provided ventilation needs are met. When contaminants do not present short-term health hazards, and are dissipated during subsequent unoccupied periods, the outside air may lag occupancy. A committee of design professionals has provided interpretations to the ASHRAE standard to clarify how the standards may be used. The interpretations include many examples of how demand-controlled ventilation can be acceptably implemented and what conditions apply.

It is not appropriate to reduce the size (capacity) of the ventilation system when demand-controlled ventilation is being used. There is a common practice to size ventilation systems when the diversity of the space usage will allow the size to be reduced. ASHRAE standard advises that the reduction be no more than one-half. This concept depends on the purging effects of a system that is not demand-controlled. However, demand-controlled systems may reduce ventilation after the occupants leave the space, eliminating this purge period. Demand-controlled ventilation should be sized based on the peak occupancy. Systems with economizers may already have sufficient capacity to meet this need.

What building codes apply?
The State of Oregon building codes allow demand-controlled ventilation. A recent code change will require demand-controlled ventilation for larger spaces with high occupant densities.

The State of Washington building codes allow demand-controlled ventilation via the use of "alternate methods" utilizing ASHRAE 62.

The State of Idaho adopted the International Building Code (IBC) effective January 1, 2003. There is a clause in the IBC that permits reduced ventilation during reduced occupancy.

The State of Montana has adopted the Model Energy Code for residences and ASHRAE 90.1 for commercial spaces. These ASHRAE standards allow for ventilation to be adjusted for variable occupancy.

Plan on commissioning
Systems must be designed, installed, and operated properly to provide the intended results. Proper use of a commissioning agent to review the design and performance of the DCV system, along with the HVAC system, can help assure good performance. If a commissioning agent is used in a project, involve the agent in the design development stage of the project. This will help the agent understand the decisions on system design and integration, and reduce review delays during startup. Guidelines for commissioning and indoor air quality are addressed by the LEED Green Building Rating system sponsored by the U.S. Green Building Council.

Construction material off gas
Ventilation is intended to displace contaminants in the air. The predominant source of contaminants is normally from human occupants. There are also contaminants from the paints, solvents, glues, cleaners, and materials used in construction and retrofit. The ventilation required following construction might be high for a period of time. The ventilation rates should be set to provide higher dilution following construction, and then periodically reviewed and reprogrammed as off gas rates diminish. This review should be included in the maintenance plan for the new space.

Large Buildings
Ventilation for assembly spaces in large buildings may be integrated with demand-controlled ventilation for the entire facility. Design considerations can be found at by clicking here.

For Installers

Basically, what is demand-controlled ventilation system designed to do?
Demand-controlled ventilation (DCV) system is designed to provide the amount of outside air the human occupants need, and no more. This accomplishes two things. First it saves energy by not heating or cooling unnecessary quantities of outside air. Secondly, it can provide assurance that sufficient outside air is being supplied for the number of occupants present.

How are DCV systems hooked up?
The heating, ventilation, and air conditioning (HVAC) system already contains ventilation hardware. The DCV system is typically a modification incorporating CO_2 sensors into the existing or base system design. CO_2 sensors commonly use 4-20 mA

calibrated signals that are sent back to the HVAC computer or economizer. The computer or economizer must be able to accept these signals.

Occupancy sensors used for lighting control can be purchased with auxiliary contacts that will close when the space is occupied. Signals from the occupancy sensors will be sent to the HVAC computer for analysis. The computer will then adjust the outside air dampers accordingly. Turnstiles or ticket sale systems likewise will communicate with the HVAC computer to indicate the needed outside air.

How is the DCV system initially adjusted?
The CO_2 sensor is normally factory calibrated. However, to assure proper performance, the sensor should be flooded with a reference test gas to check for accuracy. Another method is to use a second, hand-held unit as a reference. The sensor data should be reflected on the HVAC computer. At the same time, the HVAC system should be monitored to assure that the outside air dampers open to the expected position. Additional sensors are sometimes needed for critical spaces. If there are multiple CO_2 sensors, they should all be tested. Current models of CO_2 have built-in capability to do in-place calibration if needed by using a reference gas from a small cylinder.

Occupancy sensor sensitivity is normally adjusted at the sensor per manufacturer's instructions. It should sense occupants in the room, not those in adjacent spaces. The sensor may directly control the lights or HVAC in the room. In this case, an additional wire will be required to run to the HVAC system computer or ventilation controls.

If using occupancy sensors, a trip through each room of a particular HVAC system or zone will create an increase in the fresh air demand. Once all rooms have been sensed as "occupied," the outside air damper should be in its maximum position. The outside air damper will then close a pre-set amount as each lighting circuit timer turns to "unoccupied."

In both cases, the flow rate of outside air should be measured at maximum conditions and compared to designed values. These measurements should be made during balancing and commissioning. The designed value of outside air should not be reduced for "diversity" due to the fact that the dampers are closing when the rooms are unoccupied. This does not allow time to purge out stale air.

For Inspectors and Commissioning Agents

What is a demand-controlled ventilation system?
A demand-controlled ventilation system is an integral part of a building's ventilation design. It adjusts outside ventilation air based on the number of occupants and the ventilation demands that those occupants create. What systems typically qualify? Systems could include those based on CO_2, occupancy sensing, turnstile counting, or methods where the building system tracks occupancy (through occupant activity) or ventilation demand.

What are the typical components for each type of system?
Many of the components that are used in controlling outside air may already be in place. These existing components could include an economizer or air makeup unit with modulating dampers. The additional components would be control sensors to communicate either directly with the economizer or with a central computer. Programming, while not a physical component, is a critical element of system operation.

What systems would have DCV?
Large assembly spaces such as gymnasiums, auditoriums, lecture halls, conference rooms, churches, and theaters are good candidates for DCV. These spaces are designed for large numbers of people with high outside air requirements. However, the spaces are frequently only partially occupied. It is expected that, in the future, most spaces with ventilation air capacities of at least 1,500 CFM and serving areas having an average occupant load factor of 20 or less will be designed with DCV features.

What critical components would be expected?
Each space being controlled should have some form of occupant sensing. One CO_2 sensor can serve a single conference room. In some cases, multiple sensors would be needed. It would normally take multiple sensors for a large Variable Air Volume (VAV) system serving multiple spaces.

How are the sensors attached?
The sensors could be connected directly to the economizer or to the Direct Digital Control (DDC) system. Equally as important, the economizer or DDC system should be properly programmed to accept the sensor's input. Improper programming can negate any potential benefits. For example, if the system is set up to open up the outside air full-open at the first sign of people, it will over-ventilate unless the group of people is normally a very large group.

What drawings show the sensors?
The sensors should be indicated on the HVAC drawings. Notations should include sensor ID number and to which control device the sensor is attached. This will permit the drawing inspector to know which control sequence to review, as well as the installer to know where to run the signal wire.

What building codes apply?
The State of Oregon building codes allow demand-controlled ventilation. A proposed code change would require demand-controlled ventilation for larger spaces with high occupant densities.

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ASHRAE standard 90.1 allow for ventilation to be adjusted for variable occupancy.

How should the system be properly installed and tested?
There are different methods for confirming that the system is functioning properly. The sensor type, control hardware, damper hardware, and programming affect how the system should be checked. For example, a CO_2-based system would require a known purge gas to be applied to the sensor. The system should detect the change and the dampers respond accordingly. The response to a change in occupancy sensing would depend upon the system design. An occupancy-based system that reported to an HVAC computer may modulate the outside air differently than a system where only the VAV terminal boxes were affected. The designers should provide a test plan to facilitate this inspection.

The programmed interaction between the economizer and DCV system should be checked carefully. When the system is in free cooling mode, it should override the DCV system. If indoor air quality becomes a problem, additional fresh air will be required.