Designing and Testing Demand Controlled Ventilation Strategies

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Synopsis

Carbon Dioxide (CO_2) based Demand Controlled Ventilation (DCV) is a control strategy to vary the amount of ventilation outside air delivered to a space based on input from a carbon dioxide sensor, which is representative of the quantity of occupants within the space. This provides a precise and appropriate amount of outside air to the space based on actual occupant density, as opposed to a constant outside air amount based on the design occupancy of the space. DCV is being more widely utilized for outside air ventilation control, but many project teams that are implementing this control strategy are not fully aware of how to properly execute DCV. With an ever increasing quantity of projects following the Leadership in Energy and Environmental Design (LEED®) rating system, which awards a credit for implementation of a system capable of monitoring and alarming based on CO_2 levels, and rising energy costs, DCV is getting applied in many projects while the real details of how to execute it properly are being overlooked. DCV offers great potential for retrofit projects to reduce outside air ventilation and therefore reduce heating, cooling and dehumidification energy consumption, but if improperly applied, it can create a negative building pressure environment and lead to undesirable infiltration, building envelope degradation, and indoor air quality problems. This paper provides background on the ASHRAE ventilation standards, as well as California's Title 24 energy code, and will take the reader through the design process and calculations needed to understand how to properly implement DCV. In addition, information on how many carbon dioxide sensors are appropriate, where they should be located, and what type of sensor specifications are appropriate for the HVAC industry is presented. The paper will conclude with information for the commissioning provider, controls contractor and air balance contractor so that they are aware of how to properly setup, program and test a DCV system.

About the Authors

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Defining Demand Controlled Ventilation

Demand controlled ventilation is a control strategy that varies the minimum ventilation outdoor air based on occupancy. Currently, the most economical way we have to measure occupancy in a building is through the use of carbon dioxide (CO_2) sensors. If we had the ability to economically count each person as they entered and exited from a space, then we could provide exactly enough ventilation air to meet the needs of the quantity of people in the space. But in most buildings occupancy is not tracked in real-time, and therefore we have sought out another indicator of quantity of people within a space – carbon dioxide.

Until about 15 years ago, the design engineering community was required to design HVAC systems that always provided enough ventilation air to satisfy maximum occupancy in a space (with some component of diversity allowed in their calculations). But now the HVAC design industry is realizing that there is a high percentage of time that our buildings are not fully occupied, and therefore during these times of partial occupancy, it is acceptable to reduce the ventilation air provided to the space by implementing DCV.

Important Carbon Dioxide Information

- Carbon dioxide is measured in parts per million (ppm).
- Outdoor air CO_2 concentrations range between 300 ppm and 500 ppm, and indoor CO_2 levels are rarely lower than the outdoor levels.
- Indoor CO_2 levels in a typical office building range between 400 ppm and 900 ppm, and generally only rise above 1000 ppm during a high occupancy event, or when the ventilation system is not performing properly.
- CO_2 may rise very high (~1,600 ppm) in one space due to a high occupancy event, but adjacent spaces are only affected by this through re-circulated air that occurs at an air handler.
- CO_2 does not travel through walls, floors or ceilings in noticeable concentrations.

Designing Systems that Utilize DCV

Ventilation Codes and DCV

ASHRAE 62-2004

The discussion of ASHARE standard 62 will be kept to the 2004 version of this standard. ASHRAE 62 is a ventilation standard that explains how to design and construct a space that has an acceptable quantity of ventilation air. This document is a standard, and is only used as a code when the local codes adopt this standard as part of the local mechanical code.

The 2004 standard explains how to calculate the minimum amount of fresh air that is needed to maintain a space at acceptable air quality conditions. The calculation has two main components: a quantity of outside air based on the area of the space in question, and a maximum occupancy loading component. The equation is as follows (tables referenced below are found in ASHRAE 62-2004):

Equation 1

$$\text{Total Min OA} = Air_p * P + Air_a * A$$

Where:

Total Min OA = The total upper limit of outside air required (cfm)
Air_p = Outdoor air flow rate required per person per table 6-1 (cfm)
P = Zone population. Typically the largest quantity of people expected to occupy the space, or an average based on section 6.2.6.2
Air_a = Outdoor air flow rate required per unit area (cfm; see Table 6-1)
A = Zone floor area (ft^2)

As an example, a typical office space has the following numbers: Air_p = 5 cfm/person, Air_a = 0.06 cfm / ft^2. Based on a typical occupant density of 5 people per 1,000 ft^2, this results in 17 cfm / person.

There are additional factors that can increase or decrease the minimum outside air amount as well. One of these factors involves the zone air distribution effectiveness. The air distribution configuration will affect this distribution effectiveness, and needs to be accounted for in the minimum outside air calculation. Table 6-2 in the standard lists the zone air distribution effectiveness values that need to be applied based on configuration type, and can increase the minimum outside air amount by up to 50%, or decrease by as much as 20%.

For multizone systems, the system ventilation efficiency must also be accounted for in the minimum outdoor air calculation. Depending on the ratio of outside air calculated in Equation 1 to the total airflow, the amount of outside air may need to be increased, if this ratio is greater than 15%. Table 6-3 in the standard lists the fractions used to calculate this increase in the minimum outdoor air amount, which can be as great as 40% or more.

VAV systems also warrant special consideration according to this standard. For a VAV system, the design must be capable of delivering the required ventilation rate under all part-load conditions. This means that if the system is not capable of modulating the minimum outdoor air fraction as the total airflow amount changes, the minimum outdoor air fraction must be calculated such that the minimum outdoor air amount during the period of lowest airflow is still provided.

For example, say a VAV system with a static minimum outdoor air fraction provides 10,000 cfm total, and needs to provide 1,000 cfm of outside air. This would suggest that the minimum outdoor air fraction should be 10%. However, since this fraction is not being adjusted based on total airflow, the minimum outdoor air fraction needs to be adjusted, so that the minimum outdoor air amount is still maintained at any supply airflow. Thus, if the system is expected to modulate the airflow as low as 40%, or 4,000 cfm, the actual minimum outdoor air fraction that needs to be used is 1,000 cfm / 4,000 cfm, or 25% outside air.

Along with ventilation rate calculations, this standard also discusses the idea that because occupancy can vary within a space, we are able to adjust the minimum outside air lower than the calculated minimum based on input from either an occupant counter, schedule, or CO_2 sensor. Further, in Appendix C, it is explained that if we maintain the indoor space at a CO_2 level no greater than 700 ppm above outdoor ambient, then "a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents."

Therefore, when we apply both concepts presented, we can deduce that it will be acceptable to vary the outdoor air quantity between the amount calculated based on zero occupants, and the amount required with full occupancy. In the typical office building, this results in a range of 60 cfm of outside air per 1000 ft^2 when minimally occupied, and 85 cfm of outside air per 1000 ft^2 when fully occupied. In a system that has an average airflow of 1 cfm / ft^2, and serves 100,000 ft^2, the range of required outside air is between 6,000 cfm and 8,500 cfm, depending on occupancy (see Table 1). When applied to other occupancy categories, this approach results in a reduction of 20% to 30% of the ventilation air during low occupancy conditions.

California Title 24 Energy Code

Title 24 2005 version has many similarities to ASHARE 62-2004 with respect to the application of DCV strategies. Section 121 in this energy code explains the requirements of minimum ventilation air and the application of DCV. Some important differences are:

- DCV is required in single zone HVAC spaces that have an economizer and serve a space with a design occupant density, or a maximum occupant load factor for egress purposes in the CBC, of 25 people per 1,000 ft^2 or greater (with a few exceptions)
- The indoor CO_2 setpoint is 600 ppm above outdoor ambient
- If outdoor CO_2 is not measured, then the outdoor CO_2 level is assumed to be equal to 400 ppm

An important requirement to be aware of in Title 24 is that when the HVAC system is operating during normal occupied hours, the ventilation rate while DCV is active is not allowed to drop below the values listed in table 121-A, multiplied by the floor area of the conditioned space. The ventilation rate found in this table for a typical office building is 0.15 cfm / ft^2, which results in 15,000 cfm of minimum outside air for the typical 100,000 ft^2 office building presented in the AHSRAE 62 discussion.

Therefore, as a side by side comparison, the following minimum ventilation rates apply:

Table 1 Comparison of Ventilation Requirements

Code/ Standard	DCV Applicable Building Area	Building Type	Lower Min OA Airflow	Upper Min OA Airflow	Percent OA Reduction
ASHARE 62-2004	100,000 ft^2	Office	6,000 cfm	8,500 cfm	29%
Title 24-2005	100,000 ft^2	Office	15,000 cfm	15,000 cfm[1]	0%
ASHARE 62-2004	100,000 ft^2	K-12 School	12,000 cfm	47,000 cfm	74%
Title 24-2005	100,000 ft^2	K-12 School	15,000 cfm	67,500 cfm	78%

An important concept to note from looking at Table 1 is that when DCV is applied to a typical office building it does not offer a large reduction in outside air during times of low occupancy. However, DCV can offer a large reduction in minimum ventilation air to spaces that are designed to be more densely populated such as schools and auditoriums. In fact, the ASHRAE 90.1 -2004 Energy Standard (section 6.4.3.8) requires that spaces with a design occupancy density greater than 100 people per 1000 ft^2 (i.e.: lecture halls, auditoriums, lobbies) incorporate DCV in the HVAC design.

LEED 2.2 Requirements

The United States Green Building Council (USGBC) created the Leadership in Energy and Environmental Design (LEED®) program to create a consistent way of allowing owners and designers to design and build an environmentally responsive facility. Within this program are credits that directly discuss CO_2 sensor use and designing an HVAC system that is responsive to indoor carbon dioxide concentrations. LEED 2.2 Indoor Environmental Air Quality (IEQ) credit 1 states that when the indoor CO_2 levels rise 10% above the ASHRAE 62-2004 requirements, then the mechanical control system shall be able to send an alarm to the occupants so that they will be informed and can take corrective action. The spaces that should be included in the application of this credit are all densely populated areas such as those with a design occupant density greater than or equal to 25 people per 1,000 ft^2. This would typically include all K-12 and higher education classrooms, restaurants, conference rooms, auditorium, courtrooms, gymnasiums, etc (refer to table 6-1 in ASHRAE 62-2004 for a complete list).

Design Concepts to Consider

Heating, cooling and dehumidification coils are typically sized to meet their heat transfer load during design conditions (winter, summer, wet-bulb, etc) assuming the maximum amount of outdoor air that is entering the air handler is the required minimum ventilation based on full occupancy (potentially with some diversity component). Therefore, the coils that we put into our air handlers are not capable of meeting the temperature or humidity load when the outdoor air entering an air handler is greater than the quantity that was incorporated into the coil sizing load calculations. What this also means is that when DCV is being actively used in a project, during a

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[1] In an office environment with low occupant density, the area based minimum outdoor airflow is often equal to the maximum required ventilation rate. Therefore, Title 24 only shows energy savings due to DCV in spaces that have considerably higher occupancy densities than office buildings.

high CO_2 event, we are unable to open the outdoor air damper beyond the minimum fresh air setting because our coils are not sized to handle more outdoor air than was figured into the original calculations.

Lower and Upper Limits of Minimum Outside

Because ASHRAE 62-2004 has introduced an area based component to the required minimum fresh air calculation, as well as additional ventilation air requirements based on occupancy, it is becoming understood that we can reduce our outside air ventilation quantity if the space is not at full occupancy. Therefore, the authors suggest that we use the area based component of the ventilation air requirement as a lower minimum fresh air quantity, and the area plus full occupancy component as the upper limit of the minimum fresh air quantity required. If we then apply this concept to DCV, the outdoor air damper would be allowed to be at its lower minimum setting while occupancy is low, and then open to the upper limit setting when the occupancy is high or near design. A very important caveat to this concept is that the lower minimum outdoor air flowrate specified must account for building exhaust air flow rates, such that the minimum amount of fresh air that is required to maintain correct building pressure is always maintained. This means that the design engineer must specify in the mechanical schedule an upper and lower minimum ventilation rate requirements, and the test, adjust and balance contractor must coordinate with the controls contractor to program a sequence that properly modulates the damper between these values based on CO_2 readings. This approach will be valid for spaces that do not have stored chemicals or other items that would create poor indoor air quality undetectable by a CO_2 sensor.

A few reasons why it is important to always have at least a small component of outdoor air entering the building through the air handler systems are:

- Outdoor air entering through an air handler is filtered, and conditioned
- Maintain positive building pressure to prevent uncontrolled infiltration
- Keeps moisture from entering through walls

An important note is that removing CO_2 from the air with filters or scrubbers does not allow the air handling system to operate with a DCV strategy.

CO_2 Sensor Location and Quantity

Sensor location and quantity is a difficult topic, and does not result in very definitive answers that are easily applied throughout.

Single Zone

What can be said with clarity is that a space that is served by a single-zone air handler can often have one sensor located within the space between 3’ and 6’ above the finished floor. This is most applicable to auditoriums, gymnasiums, conference rooms, and other large single-zone, single air handling unit applications. The argument can also be made that measuring the CO_2 in the return air duct of these types of spaces is acceptable, and sometimes even more representative of the space conditions if the space is large, as one room mounted sensor may not properly sense CO_2 produced by occupants in the space.

Multiple Spaces

Because ASHRAE does not explicitly state where to locate CO_2 sensors, Title 24 may be the best reference to tell us where and how many sensors to use with air handlers serving more than one zone. Therefore, according to Title 24, if in a given zone the design occupancy density is greater than 25 people per 1,000 ft^2, the space would be considered a likely candidate for DCV, and should receive its own sensor. If Title 24 is not applicable to the project, then we may consider using less sensors, and lowering the threshold setpoint to account for less CO_2 sampling, and increased dilution of air within the space. An example application of this concept would involve placing a sensor in the return air duct of an air handler that serves multiple classrooms, and use an upper limit setpoint of 500 or 600 ppm above ambient (instead of 700 ppm). This approach will still create a system that reacts to an increase in occupancy, and accounts for the dilution that occurs in systems with larger supply airflow. The caveat to this approach is that the AHU system needs to be serving spaces that are generally occupied with very similar occupancy patterns and rates.

Zones that are served by one air handler that are not loaded to the same level or frequency should have their own sensors, provided DCV shows opportunity for worthwhile ventilation airflow reduction.

DCV Control Sequences

The following are some sample sequences of operation for a single zone system that incorporates the DCV strategies explained in this paper.

> Economizer Control:
> When the outdoor air conditions allow for economizer operation to occur, the mixed air damper shall modulate as needed to maintain the supply air temperature setpoint, and shall be subject to maintaining at least the minimum outside air setting. When the outdoor air conditions do not meet the economizer mode criteria, then the outside air damper shall be at its minimum setting (see above for a definition of "minimum setting").
>
> 1) Minimum Outside Air Setting (Simplified):
> If the CO_2 sensor input is less than the setpoint, then the OA damper shall be at the lower minimum setting. If the CO_2 reading rises above the setpoint, then the OA damper shall modulate open as needed to bring the CO_2 back down below the setpoint. The CO_2 control routine shall not be allowed to open the OA damper beyond the upper minimum ventilation rate as specified in the mechanical schedule.
>
> 2) Minimum Outside Air Setting (with direct measurement of OA):
> The outside air damper shall modulate to maintain the minimum outdoor airflow setpoint, which is a value between the lower minimum and upper minimum quantities, based on the following linear reset schedule:

Table 2: Outside Air Ventilation Reset Schedule

Space CO_2	Outdoor Airflow Setpoint
100 ppm above ambient	Lower minimum OA cfm
700 ppm above ambient	Upper minimum OA cfm

Both concepts presented above are acceptable, but the differences are worth understanding. Concept #1 presented above has an inherent time lag of response due to the fact that the outside air damper does not rise beyond its minimum setting until the space has crossed over its indoor CO_2 setpoint. The drawback to this approach is that the space will have brief times when the CO_2 in the space is above the setpoint until the newly introduced fresh air mixes in the space. Concept #2 is preferred because it does not wait for the space to rise beyond setpoint before reacting, rather it tracks continuously to self–adjust and provide the minimum outdoor air that is needed at any given time to meet the ventilation demand. Additionally, direct measurement of the outdoor air is always preferred because it ensures that the correct amount of outdoor air is entering the air handling unit at all times. As a final note, with multiple zone systems, the zone CO_2 controls should first increase the airflow rate at the space by increasing air terminal unit airflow (and subsequently reheat if applicable) and then increase the outdoor air rate at the air handler.

Carbon Dioxide Sensors

Many different manufacturers presently manufacture CO_2 sensors, and there are many different specifications that need to be considered when selecting a sensor. Generally speaking, the manufacturers' suggested retail prices for HVAC grade sensors range between $350 and $450, and it can be assumed that the installed cost of a CO_2 sensor is between $1,500 and $2,500. There are also other types of CO_2 sensors that are used more in the gas and chemical industry and these sensors are three to five times the cost of the sensors we traditionally use in the HVAC industry. Because the indoor CO_2 concentration should never be above 1,500 ppm, an upper limit range of 2,000 ppm is appropriate for the HVAC industry.

Below is a list of CO_2 sensor specifications that are appropriate for the HVAC industry:

- Range: 0-2,000 ppm
- Accuracy: +/- 50 ppm
- Stability: <5% Full Scale for 5 years
- Linearity: +/- 2% Full Scale
- Manufacturer recommended minimum calibration frequency: 5 years

Other considerations when specifying a sensor include whether or not it should be duct mounted or wall mounted, if it needs be outdoor rated, and if an alarm dry contact relay is needed. Additionally, the ease of calibration should be investigated and an LED display should be considered to provide real-time displayed readings on the front of the sensor. Generally speaking, the CO_2 sensor should be located between 3' and 6' above the floor when mounted indoors.

Energy Impacts of DCV

Energy Model Predictions

The energy savings associated with this concept are the direct result of having less outside air to condition at the air handing unit, thereby reducing the cooling, heating, or dehumidification energy associated with conditioning the ventilation air. Thus, when the occupancy of the space served by the air handler is less than maximum, the application of DCV reduces the energy associated with conditioning the outside air.

The authors of this paper have estimated energy and cost savings associated with the application of the DCV control strategy on some existing buildings. The Department of Energy's DOE-2 building energy simulation tool was used to estimate these energy savings, and illustrate some examples of the range of savings that can be achieved with this control strategy (see Table 3).

Obviously, many factors can affect the energy savings associated with this control strategy. Some examples include:

- Occupancy schedule
- Space heating and cooling loads
- Ambient temperatures and humidity
- HVAC system type
- Amount of time the system economizes

Thus, the savings presented in the following table are presented simply to illustrate some of the savings ranges that have been previously achieved, and may not necessarily be indicative of the savings for these types of buildings in all applications. Savings from a few other case studies obtained from the Oregon Department of Energy are also presented for additional comparison.

Table 3 DCV Annual Energy Savings Estimates

Building Type	**Spaces DCV Applied**	**Location**	**Cost Savings per ft^2 / Year**
Elementary Schools (8 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.09 - \$0.33
Middle Schools (6 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.05 - \$0.20
High Schools (4 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.05 - \$0.14
University Building	Large classrooms, offices	Boulder, CO	\$0.31
University Building	Large classrooms, offices	Boulder, CO	\$0.34
University Building	Large classrooms, offices, lobby, conference room	Denver, CO	\$0.23
Ice Rink	Ice rink	Edmonton, Canada	\$0.04
University[2]	Lecture halls	Indiana	\$0.14 - \$0.23
High-rise Office[2]	Open office	Oregon	\$0.11
Convention Center[2]	Convention halls	Oregon	\$0.10

The savings calculations presented here illustrate a significant range of potential savings, and are meant to illustrate that it is difficult to apply a “rule of thumb” as to when it is best to apply DCV. Although no hard and fast rules apply, it is usually stated that DCV provides a cost-effective means for achieving good energy savings for larger spaces with large variations in occupancy (such as cafeterias, gyms, lecture halls, meeting rooms, etc.). That said, the authors suggest that each potential application for DCV be considered individually, so that the many variables which might affect energy savings in a specific application are weighed appropriately.

Commissioning Requirements of DCV

Commissioning the DCV components and strategies is an ongoing process that has activities throughout the project delivery process. California’s Title 24 now has acceptance testing requirements for energy conservation concepts which include DCV. In the 2005 non-residential Title 24 manual there are acceptance tests written to test DCV equipment and operation which are very useful for all members of the HVAC industry when needing to test DCV strategies. The following is a list of activities that the commissioning authority should undertake on projects that incorporate DCV.

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[2] Courtesy of Oregon Department of Energy

Design Phase Issues

- Verify that the commissioning specification is present and appropriate for the scope
- Verify that the upper and lower min OA values are specified on the mechanical schedule
- Verify that the sequences are properly written
- Verify that the CO_2 sensor requirements are clearly and properly specified
- Verify that the CO_2 sensors are located on plans, and the mounting height is clearly marked

Submittal Phase Issues

- Verify that the submitted CO_2 sensor meets the specification requirements
- Verify that the appropriate sensors have been selected for outdoor use, duct mount or space mount
- Verify that the control submittal reflects design requirements and all sensors have been incorporated into the engineered control submittal drawings
- Verify that the “packaged” mechanical equipment factory wiring is compatible with submitted sensor

Construction Phase

- Verify that the submitted (and approved) sensors have been installed in the correct locations, and have proper covers or guards as needed

Acceptance Phase

- Perform a documented relative calibration check by recording the readings on all sensors early in the morning when there have been no occupants in the building for 8 hours and the air handlers have been on for an our or more. All sensors should read within 50-70ppm or should be calibrated.
- Functionally test all DCV related sequences, including the worst case scenario of minimum flow, and then verify proper building pressurization is still maintained.
- Ensure that the owner’s maintenance staff is aware of how to calibrate the sensors (calibration generally is not necessary on new sensors)

Seasonal Testing/ Short-Term Monitoring

- Take trend data (1-2 weeks) on the CO_2 sensor signal, the damper operation of air handler and terminal units, exhaust fans status and building pressure to validate proper operation under normal occupied operating conditions
- Generate a report or memo with plots indicating proper operation of the DCV strategy

Conclusion

Concerns about rising energy costs, as well as growing interest in the LEED rating system, are two reasons for the increased attention paid to space CO_2 monitoring, and in particular DCV. CO_2 levels are typically indicative of space occupancy, and can subsequently be used to determine the amount of ventilation air required for a given space at any given time. DCV controls vary the ventilation rate to limit CO_2 levels and subsequent levels of airborne contaminants. By reducing the ventilation rate during less occupied periods, energy is saved (in many cases significant amounts of energy) because the amount of outside air that must be heated, cooled or dehumidified is reduced.

The ASHRAE 62-2004 standard, which is adopted by many local codes, explains how to calculate minimum outside air quantities using an equation that incorporates both an occupancy and an area based component. The authors suggest that the area based component of the ventilation air requirement be used as a lower minimum fresh air quantity when applying DCV, subject to the minimum outside air needed to makeup for any exhaust, to ensure a positively pressurized building. The area based component plus full occupancy component should be used as the upper limit of the minimum fresh air quantity required. The DCV strategy then modulates the minimum fresh air amount between these two values, when not in economizing mode, based on suggested CO_2 levels of 100 ppm to 700 ppm above ambient respectively. The lower minimum fresh air quantity based on area is important, because it ensures a positive pressure in the building to prevent uncontrolled infiltration.

CO_2 sensors with a range of 0 to 2,000 ppm, and an accuracy of +/- 50 ppm are adequate for DCV applications. Sensor location and quantity is a difficult topic, and definitive answers that are easily applied throughout do not generally exist. However, Title 24 suggests that spaces with occupant densities greater than 25 people per 1,000 ft^2 should have individual sensors dedicated to the space. The sensors should typically be placed between 3’ and 6’ above the floor. Sensors in return ducts are discouraged, unless they serve a single zone. In some cases however, sensors can be considered for placement in return ducts that serve multiple zones, if the zones are the same space type and have similar schedules (all classrooms for example). In these cases, a more conservative upper CO_2 threshold of 500 to 600 ppm is recommended, to ensure adequate ventilation air to these spaces.

Energy studies performed by the authors using DOE-2 energy models on existing buildings suggest that energy savings can vary widely, from \$0.04 / ft^2 to as high as \$0.34 / ft^2. This is due to a number of variables, including occupancy schedule, heating and cooling loads, ambient conditions, HVAC system type, and the amount of time the system economizes. Thus, the authors recommend that although typically DCV should provide a cost-effective means for generating energy savings in areas with large variation in occupancy, each application should be considered individually, so that all of these variables can be appropriately weighed.

Finally, the commissioning process involves activities that are performed throughout the project delivery process, from the design phase through the acceptance phase. These commissioning activities represent an important and integral part of the implementation process, and help to ensure the ultimate success of this control strategy.

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