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HVAC – Guide to Demand Control Ventilation

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HVAC – Guide to Demand Control Ventilation

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Introduction

A popular dictionary defines "ventilation" as the admission of "fresh air ... to replace stale or noxious air." In the context of a building, this means introducing outdoor air and circulating it throughout the building to dilute contaminants and odors. Not surprisingly, proper ventilation (in conjunction with proper exhaust) is critical to creating a comfortable indoor environment and dilute gases such as carbon dioxide (CO_2) and human odors.

The amount of air needed for "proper" ventilation largely depends on the population of the building. In most commercial applications, the number of people in the building seldom equals the design occupancy. As a result, at least some spaces in the building are over ventilated ... and that means higher-than-necessary energy costs.

The demand control ventilation (DCV) is a concept where the fresh air intake is actively controlled for the number of people present in a room. There are various strategies such as CO_2 sensors, occupancy sensors or real time measurement techniques that can be incorporated in DCV system; all attempt to reduce operating costs by optimizing the rate of outdoor air intake to something less than maximum capacity.

This course discusses the design criteria for CO_2 based demand-controlled ventilation, with particular attention to ASHRAE Standard 62 as the definitive U.S. reference for ventilation-system design.

What is the required ventilation rate?

The ventilation rate is the quantity of outdoor air intake into the building and is measured in cubic feet per minute (CFM).

In 1895, the American Society of Heating and Ventilating Engineers (ASHVE) adopted a minimum recommendation of 30 CFM. The first American Society of Heating, Ventilation and Air-conditioning Engineers (ASHRAE) Standard 62 appeared in 1973, which provided minimum and recommended outdoor airflow rates "for the preservation of the occupants' health, safety and well-being" in a variety of different spaces. Standard 62-1973 defined a prescriptive approach, meaning that the airflow rates were prescribed (as rules), and became the basis for most state codes. In 1981 the standard was updated and re-titled as ASHRAE Standard 62-1981, *Ventilation for Acceptable Indoor Air Quality*. The net effect was a general reduction in outdoor air usage to 5 CFM.

In the 1989 through 2001 versions of ASHRAE Standard 62, the required ventilation rates were further updated to an average value of 15 -20 CFM, which has since been widely accepted. These ventilation rates are based primarily on the number of occupants in the zone (CFM/person). Table below lists the ventilation air required for various spaces in terms of CFM/person:

ASHRAE 62-89 Recommended Ventilation Rates

Application	Ventilation Rate/Person	Application	Ventilation Rate/Person
Office Space	20 cfm	Smoking Lounge	60 cfm
Restaurants	20 cfm	Beauty Salon	25 cfm
Bars/Cocktail	30 cfm	Supermarkets	15 cfm
Hotel Rooms	30 cfm/room	Auditorium	15 cfm
Conference Rooms	20 cfm	Classrooms	15 cfm
Hospital Rooms	25 cfm	Laboratory	20 cfm
Operating Rooms	30 cfm	General Retail	15 cfm

The latest ASHRAE 62-2004 standard incorporates both occupancy and an area based component to estimate ventilation rate. This standard explicitly allows varying the amount of outside air both in proportion to occupancy and the area. The area based component of the ventilation air requirement is mandatory added in this standard to ensure the minimum outside air for positive pressurization of the building. We will discuss this further later in this course.

*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 air-conditioning and ventilation equipment.

Note that ASHRAE Standard 62 is not used directly in codes because it is not written in the language necessary for code enforcement.

What is a demand-controlled ventilation (DCV) system?

Demand-controlled ventilation (DCV) describes a control philosophy that responds to the actual "demand" (need) for ventilation by regulating the rate at which the HVAC system brings outdoor air into the building. DCV adjusts the amount of outside air based on the number of occupants. This provides an economical means of providing outdoor air to occupied spaces at the rates required by local building codes and ASHRAE Standard 62, *"Ventilation for Acceptable Indoor Air Quality."*

Why Demand Control Ventilation?

Engineers and building owners both lament the high cost of conditioning outdoor air due to high over-ventilation during lean occupancy periods. DCV offers designers the ability to monitor both occupancy and ventilation rates and ensures there is adequate ventilation at all times. Typically, most fixed ventilation systems are set up and adjusted only when they are installed. DCV offers a higher level of control in that it monitors conditions in the space and constantly adjusts the system to respond to real time occupancy variations. Costly over-ventilation that typically results from a fixed ventilation strategy (design occupancy x CFM/person) is avoided and energy usage can be reduced.

What is a difference between DCV and Fixed ventilation?

1. Demand-controlled ventilation (DCV) system controls the amount of outside air brought into the building and maintains a target CFM-per-person fresh air rate based on actual occupancy. It provides the amount of outside air the human occupants need, and no more.

2. Fixed ventilation systems provide constant fresh air on an assumed maximum occupancy, but do so at the cost of heating or cooling excess air.

With the fixed ventilation approach the design airflows will continue to be delivered at for the life of the building. In reality, occupancy patterns and densities may change over time and render the originally established fixed rate inappropriate. With DCV, the system will adjust automatically to the appropriate levels for the space based on actual occupancy. The need for operator adjustments of the ventilation system thus becomes redundant.

How does DCV benefit in comparison to fixed ventilation approach?

Compared to a fixed ventilation approach, DCV offers considerable advantages. Few benefits are listed below:

1. Excessive over-ventilation is avoided while still maintaining IAQ and providing the required air flow (CFM) per- person outside air requirement specified by codes and standards.

2. DCV offer considerable energy saving opportunities. System paybacks can range from a few months to two years and are often substantial enough to help pay for other system or building upgrades.

3. A control strategy can be used to maintain zone-by-zone ventilation rate. This allows for the use of transfer air from under-occupied zones to be redistributed to areas where more ventilation is required.

4. A control strategy can be used to maintain any per-person ventilation rate. As a result this approach is highly adaptable to changing building uses and any changes that may occur in future recommended ventilation rates.

5. DCV provides the building owner/manager with valuable information about occupancy trends, which can be useful for business analysis, operational & maintenance planning of equipment and ensuring safety in the premises.

Which spaces would benefit the most from DCV?

Although no hard and fast rules apply, DCV provides a cost effective means for achieving good energy savings for large assembly areas such as gymnasiums, auditoriums, school, retail establishments, lecture halls, meeting areas, conference rooms, churches, and theaters. These spaces are designed for large numbers of people with high outside air requirements. However, the spaces are frequently only partially occupied. The payback from DCV will be greatest in higher density spaces that are subject to variable or intermittent occupancy.

In spaces with more static occupancies (e.g., offices) DCV still can provide control and verification that adequate ventilation is provided to all spaces. For example a building operator may arbitrarily and accidentally establish a fixed air intake damper position that results in over or under ventilation of all or parts of a space. DCV can ensure the position of the intake air dampers is appropriate for the ventilation needs and occupancy of the space at all times.

How much money will a DCV system save me?

Broadly, the money can be saved on two accounts. First, it saves energy by not heating or cooling unnecessary quantities of outside air. Second, operating the ventilation system itself at lesser demand will reduce the fan motor energy.

1. Thermal energy – When the ventilation is reduced, there is proportionate reduction in the cooling and heating requirements. Refer to the equations below:

   The air-conditioning load required cooling or heating the outside air may be calculated from the following equation:

   $Q = m * Cp * (T_E - T_L)$

   Where

   - Q = Heating or cooling load in Btu/hr
   - m = mass flow rate of outside air in lbs/hr
   - Cp = specific heat of air at standard conditions – 0.24 Btu/lb-°F
   - TE = Temperature of air entering the air-conditioning equipment in °F
   - TL = Temperature of air leaving the air-conditioning equipment in °F

   In volumetric terms air flow rate in cubic feet per minute (CFM) is estimated below:

   $Q = V * \rho * Cp * (T_E - T_L)$

   Where

   - V = Volume flow rate in cubic feet per minute (CFM)
   - ρ = density of standard air -0.075 lbs/ft^3

   Therefore

   $Q = CFM * 0.075\ (lbs/ft^3) * 60\ (min/hr) * 0.24\ (Btu/lb\text{-}°F) * (T_E - T_L)$

   $Q = (CFM) * (1.08) * (T_E - T_L)$

Clearly the heating or cooling load is dependent on the airflow rate and the entering (T_E) and leaving temperature (T_L) differential from the air-conditioning equipment. Keeping a constant temperature differential, the lower airflow rate shall result in lower air-conditioning requirements.

Consider an office space has a requirement of 1000 CFM of outside air which is to be heated from 40°F to 70°F. The heating requirements can be estimated as 32400 Btu/hr [1000 x 1.08 x (40 – 70)]. This is equivalent to ~ 9.5 kW. Now say with DCV, the outdoor air is reduced by 40% to 400 CFM, the new heating requirements shall be 12960 Btu/hr [400 x 1.08 x (40 – 70)]. This is equivalent to ~ 3.8 kW.

For 2 hours per day lean operation, this will amount to the energy savings of 3420 kWh per annum [(9.5 – 3.8) * 2 hrs * 300 working days].

The energy budget for heating can typically be reduced significantly by careful design. This dollar savings can be significant in large air-conditioned spaces.

2. Mechanical energy - In any given ventilation system, the air velocity varies with air demand - double the supply of air requires doubling the velocity -, in which case the energy requirement of the ventilation fans would increase by a factor of eight: $(2)^3 = 8$. Conversely, if the demand of air is halved, the required mechanical energy delivered by the fans would be *reduced* by a corresponding factor of 8. For example, 30 % reduction of ventilated air would lower the mechanical energy demand to $(0.7)^3 = 0.34$ or 34 % of the original, thus saving 66 % of the fan energy. The fan energy varies directly to the cube of air flow rate or on air velocity inside the ventilation ducts.

Each potential application for DCV must be considered individually, so that the many variables which might affect energy savings in a specific application are weighed appropriately. The real energy savings will vary considerably, obviously affected by many factors such as:

- Building Type - occupancy schedule
- Building Location – heating or cold region
- Space heating and cooling loads
- Ambient temperatures and humidity

- HVAC system type
- Amount of time the system economizes

In general ---

The greatest savings and shortest payback periods occur for buildings with high occupant densities and that have variable and unpredictable occupancy levels.

A study carried out at Berkeley indicates, the largest savings occurred in inland buildings with low occupancy rates and high ventilation loads. 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). No substantial savings were found in buildings with high occupancy rates that varied only a little, such as modular school rooms. Also the potential savings from DCV are greatest in cold climates, where heating dominates such as the Pacific Northwest areas.

What are the different kinds of DCV sensors that can be integrated with HVAC system?

Many of the Heating, ventilation, and air conditioning (HVAC) hardware that is used in controlling outside air may already be in place. The DCV system is typically a modification incorporating electronic sensors into the existing or base system design, 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. There are three common approaches to do this; 1) CO_2-based sensors, which measure the buildup of CO_2 from the occupants present and 2) Occupancy sensors, which use infrared light and sound to detect occupants and 3) Real time demand-controlled ventilation uses characteristics of the building's use to help control ventilation.

CO_2-based sensors - CO_2 sensors are best suited for highly variable occupancy in larger assembly spaces. The larger space (and volume) will allow the concentration of contaminants to grow more gradually and as the occupancy changes, the CO_2 concentration will also vary in proportion. 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 take a little time to respond to changes in the environment. These may or may not represent the entire space needs particularly when the space is divided into multiple zones. 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 - Occupancy sensors detect the presence or number of people in each monitored space. Occupancy sensors typically 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 control system, which will then adjust the outside air dampers accordingly.

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 Counters - Real-time data such as turnstiles counters, ticket sales, registrations, scheduled events, to count occupants is a simple administrative measure. 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. 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. If real-time demand-controlled ventilation control is used, scheduled ventilation can provide fresh air at the correct rates at the right time. If schedule changes are not made at the appropriate times, it also runs the risk of under or over-ventilation.

Regardless of which method is used, DCV strategies vary the outdoor air intake in response to the current population. It is important that building designers and operators understand the application and use the most appropriate ventilation strategy.

What is CO_2 based DCV?

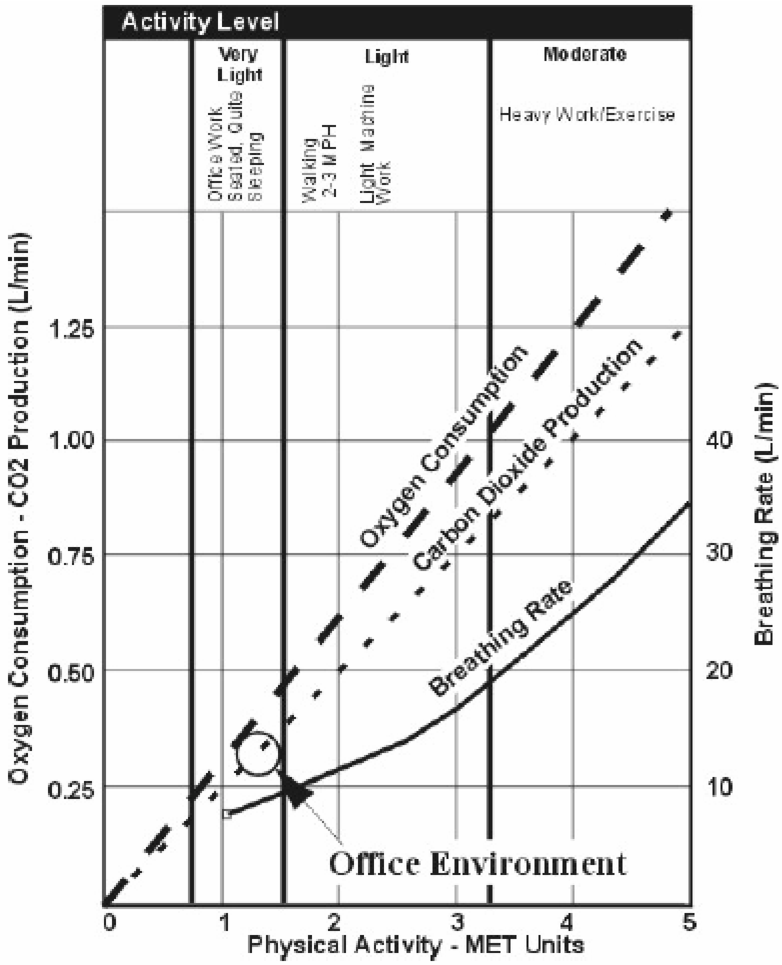
The practice of using carbon dioxide concentrations as an indicator of population or ventilation rate is often called CO_2-based, demand-controlled ventilation.

People exhale predictable quantities of CO_2 in proportion to their degree of physical activity. Because CO_2 production is so consistent and predictable, it can be used as a good indicator of general occupancy trends. For example, if the number of people in the space is doubled, the amount of CO_2 produced will double. If one or two people leave a space the CO_2 production will decrease correspondingly. It is important to note that an indoor CO_2 measurement does not provide enough information to actually count people but it can be used in combination with outside air concentrations to calculate measure and control ventilation rates.

This logic was used in the development of ASHRAE Standard 62–1989, Section 6.1.3 of which states *that comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that 1,000 ppm of CO_2 is not exceeded*. The absolute 1,000 ppm value was often interpreted as the *ceiling* CO_2 concentration for acceptable indoor air quality.

But since, an indoor CO_2 measurement is a dynamic measure of the number of people in a space, it is not appropriate to go for absolute value of 1000 ppm. Rather it is much more logical to determine the CFM/person ventilation rates by measuring the indoor-outdoor CO_2 difference. The 1999 edition of ASHRAE revised wording of Section 6.1.3 specifically to include 700 ppm difference between indoor and outdoor CO_2 concentrations as an acceptable level of human bio-effluents. This value is based on a specific ventilation rate (15 CFM/person), activity level (1.2 MET), and outdoor CO_2 concentration (300 ppm). The MET stands for metabolic equivalent task, which indicates the activity level (exertion). Higher the duration and intensity of physical activity, larger will be the oxygen consumption and large will be the exhaled quantity of CO_2. It also varies with the diet and health.

The CO_2 generation rates of individuals can vary widely as illustrated in figure below, based on their activity level.



Building Occupant Activity Level and CO_2 Production

Important Carbon Dioxide Information

1. Carbon dioxide is measured in parts per million (ppm).
2. Outdoor air CO_2 concentrations range between 300 ppm and 500 ppm, and indoor CO_2 levels are rarely lower than the outdoor levels.
3. 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.

4. 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.

5. CO_2 does not travel through walls, floors or ceilings in noticeable concentrations.

6. Is carbon dioxide a contaminant?
   The Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) each established the following concentrations as acceptable limits for carbon dioxide:

- Threshold Limit Value (TLV) – 5000 ppm [Time weighted average over fire 8-hour work days per week]

- Short Term Exposure Limit – 30000 ppm [Fifteen minutes]

Because typical CO_2 concentrations in commercial and institutional buildings range from 400 ppm to 2,000 ppm, experts do not consider it as a harmful indoor contaminant. To avoid confusion, Table 3 in ASHRAE Standard 62–2001 omits carbon dioxide from the list of indoor contaminants.

Measurement of CO_2 concentrations is an accepted scientific methodology to determine the *actual ventilation rate* in a building. Note, that CO_2 concentration is NOT a direct measure of number of people in the space. It is only an indicator of poor indoor air quality.

What is the relationship between CO_2 and the outside airflow rate into a space?

In order to answer that question, one must first understand the mathematical model that describes CO_2 and the assumptions required for its validity. Appendix C of Standard 62 provides a steady-state mass balance equation to predict the difference between indoor and outdoor concentrations of carbon dioxide, given constant rates of ventilation and CO_2 generation (occupant activity). The steady-state mass balance equation is as follows:

$C_S – C_O = N / V_O$

Where,

- C_s = CO_2 concentration in the space, ppm

- C_o = CO_2 concentration in the outdoor air, ppm
- N = CO_2 generation rate, CFM/person
- V_o = outdoor airflow rate, CFM/person

Note: Unless combustion fumes are present, the outdoor CO_2 concentration in most locations seldom varies more than 100 ppm from the nominal value. For most practical purposes it may be assumed 300 ppm.

Assuming steady-state indoor CO_2 generation rate of 0.0105 CFM (0.3 L/min) per person [corresponding to 1.2 MET] and a ventilation rate of 15 CFM/person, it will result in an indoor CO_2 level approximately 700 ppm greater than the level of CO_2 in the outside air.

$C_S – C_O = N / V_O$

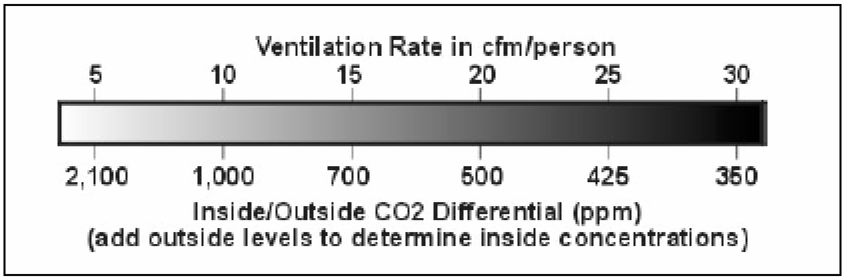
$C_S – C_O = 0.0105 /15 = 0.0007$ [or 700 ppm]

Studies have indicated that 15 CFM is the optimum ventilation rate required to dilute offensive body odor and to limit the CO_2 rise for very light activity level applications. Therefore, the resulting statements appear in the standard:

"Comfort criteria, with respect to human bio-effluents (odor) are likely to be satisfied if the ventilation results in indoor CO_2 concentrations less than 700 ppm above the outdoor air concentration." [6.1.3 ASHRAE 62-2001]

"Using CO_2 as an indicator of bio-effluents does not eliminate the need for consideration of other contaminants." [6.2 ASHRAE 62-2001]

Activity levels of occupants in some spaces are higher than 1.2 MET, just as certain types of spaces require more ventilation airflow than 15 CFM/person to maintain acceptable indoor air quality. For example, Standard 62-2001 currently requires a ventilation rate of 20 CFM/person for an office space. Using the mass balance equation and assuming an activity level of 1.2 MET at steady-state conditions, we can anticipate that the level of CO_2 indoors will exceed the level outdoors by only 525 ppm (0.0105 / 20 = 0.000525). However, if the *actual* indoor CO_2 concentration is 700 ppm higher, the space will be under-ventilated.



Ventilation Rate for Adults involved in Office Work

This example illustrates what can happen if you fail to account for the assumptions underlying the 700 ppm value in your ventilation-system designs. By estimating the correct CO_2 generation rate of the occupants *N,* we can establish the indoor–outdoor difference in CO_2 concentrations for a given ventilation rate, V_O. Thus with this information, we can bring less outdoor air into the building during periods of reduced occupancy and still provide the ventilation rate (CFM/person) required by ASHRAE standard.

A clarification of purpose

"The CO_2 level of 700 ppm above outdoors is a guideline based on the perception of human bio-effluents, not a ceiling value for air quality."

The reference to 700 ppm CO_2 in Section 6.1.3 is only a point of information. This is neither requirement of ASHRAE 62 nor it is a ceiling value and a time-weighted average value. Rather, it can be considered an indicator that the outdoor air ventilation may not meet the minimum requirements of the standard. The CO_2 measurement only indicates the correct ratio of human-generated contaminants in the space versus the quantity of ventilation air delivered per person. It certainly varies with the activity levels of people, which affects the CO_2 generation rate. Refer a typical example below –

Calculation of V_O at various CO_2 Production Levels, C = Δ700ppm

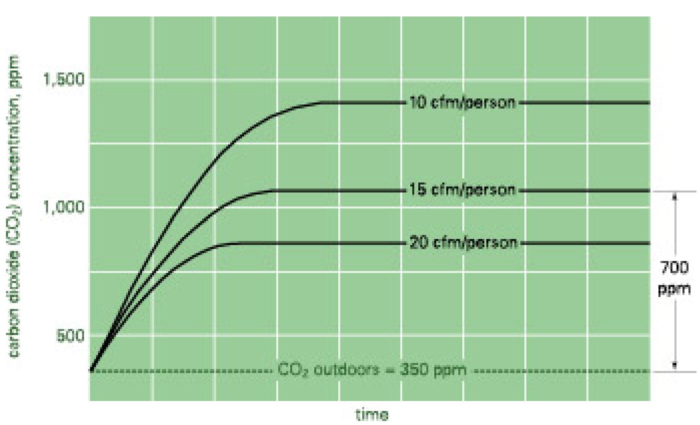
Activity	N (L/min)	Vo (CFM)
Sleeping	0.20	10
Office Work	0.30	15
Walking	0.55	28

Activity	N (L/min)	Vo (CFM)
Light Machine Work	0.60	30
Heavy Work	1.05	53

What is Steady-State Condition?

The mass-balance equation assumes steady-state conditions within the space— that is, a constant rate of CO_2 generation in the space and the delivery of a constant rate of ventilation airflow to the space. During the non-steady-state conditions that are typical of real buildings, the concentration of CO_2 within the space lags behind the actual number of occupants. At the beginning of occupancy, the steady-state condition does not yet exist in the space, so the *measured* difference between indoor and outdoor CO_2 concentrations would result in an under-ventilated space. Considerable time can elapse before the space reaches its steady-state condition — if it ever does. (Most spaces never reach equilibrium because of changing occupancy and operation of the HVAC system.)

Figure below represents the buildup of carbon dioxide, over time and at different ventilation rates, within an office space. Where each curve levels off, the rate of CO_2 generation (occupant activity) in the space balances the rate of CO_2 removal from the space. The amount of time required to reach the steady-state condition depends on the *population density, the volume of the space, and the air circulation rate*. *It can be as short as a few minutes for a densely occupied space with a low ceiling height, or as long as several hours for a space with a high ceiling and few occupants*.



Indoor CO_2 concentrations at various ventilation rates

What are the primary design steps to evaluate applicability of DCV systems?

There are five simple steps to designing DCV applications:

1. Verify that the application is appropriate for DCV.

2. Estimate the building occupancy and calculate the required outdoor airflow for each space based on ASHRAE Standard 62 or other appropriate (local) code requirement.

3. Determine the appropriate base ventilation rate for non-occupant related sources. This will be the minimum ventilation rate provided during all occupied hours.

4. Determine the appropriate control strategy to use for the application and equipment used.

5. Select type of sensor and determine sensor location.

Is Space Appropriate for DCV

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.

The building needs often dictate which system is most cost-effective. Key information to collect includes:

1. What is the design occupancy?

2. What is the expected actual occupancy?

3. Is the occupancy predictable on an hour-to-hour or day-to-day basis?

4. How rapidly do the spaces fill and empty?

5. What activities are conducted in the space?

6. Are there other non-occupant contaminants present?

7. Are the quantities of non-occupant contaminants constant or variable?

8. Are the occupants sensitive to contaminants?

9. Can the occupant maintain the system?

10. What does the system need so it will be properly maintained (access to sensors, etc.)?

11. How will the occupant behavior affect the system (operable windows)?

12. Is it possible that the building use will change in the long-term?

Below are some guidelines on what type of spaces are most suitable for a DCV control strategy.

Recommended	Possible	Not Recommended
Auditoriums, Theaters Music rooms, Ball rooms Shopping malls, Supermarkets Lobbies and waiting areas Conference rooms Casino & Bowling alleys Churches School classrooms Platforms Commercial Laundries	Dining halls, cocktail lounges & cafeteria Laboratories Training shops Smoking lounges Specialty shops (barber, florists, furniture, hardware etc) Patient rooms, recovery rooms	Locker rooms Repair and service stations Pet shops Manufacturing areas Warehouses Operation rooms and ICU Swimming pools

The key parameter for specifying DCV is that the occupants should perceive little or no difference in their environment. When people enter a room, the system will increase ventilation and reduce when people leave the room. This should happen without any noticeable change or buildup of contaminants.

Most applications indicated as “possible” may be suitable applications, but should be evaluated by the HVAC system designer. Separate factors may govern system selection, such as, mandatory ventilation requirements other than ASHRAE Standard 62, pressurization between spaces (e.g., between kitchens and dining rooms), regular periodic release of building-related contaminants that are a health hazard to occupants, and extensive requirements for local exhaust. In addition factors such as building size & arrangement, type of HVAC system used, and separate requirements for control of contaminants not related to human occupancy must be evaluated. Ventilation system design must consider requirements for odor and vapor control.

Ventilation Rate Procedure

The amount of air needed for "proper" ventilation largely depends on the population of the building. The Ventilation Rate Procedure per ASHRAE 62- 2001 was relatively straightforward in comparison with the procedure contained in the ASHRAE 62- 2004 standard. The 2004 Standard requires that the outdoor air required be calculated for each zone. Depending upon whether there is one air handler per zone or one air handler for multiple zones, different correction factors are then applied to produce the total outdoor air required.

The calculation for the amount of outdoor air required per zone is based upon a formula and variables whose values are obtained from Table 6.1 in the ASHRAE 2004 Standard. Table 6.1 replaces Table 2 of the previous standard. Table 2 from the previous standard had outdoor air requirements based on the number of occupants in a space, the square footage of the space, or the type of space. For example the outdoor air requirement for an office was 20 cubic feet per minute (cfm) per person, for a corridor in a public space it was 0.05 cfm per square foot (ft^2), and for a hotel bedroom it was 30 cfm regardless of the square footage or occupancy. The new ASHRAE 62-2004 standard bases the outdoor air requirements on both the occupancy and the square footage of the space for most spaces, but retains just a square footage component for spaces such as corridors.

Now, the outdoor air requirement for an office is 5 cfm per person plus 0.06 cfm/ft^2, for a corridor is 0.06 cfm/ft^2, and for a hotel bedroom is 5 cfm/ft^2 plus 0.06 cfm/ft^2. It would appear that the requirements for the office and the hotel bedroom are now the same. This is true except in cases where the occupant density (occupants per 1000 ft^2) varies, or is unknown at the time of the ventilation system design. In the case of unknown occupancy, the new Table 6.1 has default values to be used for occupant density and provides a calculated combined outdoor air rate for each type of space. The table below compares the outdoor rates from the previous standard with the new standard based upon the default values in Table 6.1:

Space Type	2001 Outdoor Air Requirement	2004 Occupant Density #/1000 ft^2	2004 Outdoor Air Requirement
Office	20 cfm/person	5	17 cfm/person
Corridor	0.05 cfm/ft^2	-	0.06 cfm/ft^2
Hotel Bedroom	30 cfm/room	10	11 cfm/person

The reason for using both occupancy and square footage to determine the outside air requirement is that the occupancy contribution is intended to dilute human bio-effluents and the square footage portion is intended to dilute contaminants off-gassing from building materials. Another reason for using for the change to using both occupancy and square footage to calculate the total outdoor airflow is that designs based on the previous standard, when based solely on occupancy, would overestimate the required outdoor airflow when occupant densities were high. It should also be noted that the values contained in Table 6-1 are all for non-smoking areas; smoking areas are no longer addressed by the standard.

How to Determining Minimum Design Ventilation Rate?

In most commercial applications, the number of people in the building seldom equals the design occupancy. Thus during lean occupancy, at least some spaces in the building will always be ventilated ... and that means higher-than-necessary energy costs. The ASHRAE interpretation IC-62-1999-33 clarified the use of CO_2 DCV to allow for reducing the ventilation air whenever space is sparsely occupied.

Does this mean that ventilation air can be dropped to zero in even of zero occupancy?
The answer is NO.

In ASHRAE Standard 62 - 2004, a comment is provided that the designer should ensure that in cases of low occupancy "a non-zero base ventilation rate" is provided to handle non-occupant related sources whenever the space is occupied. So, a DCV system must be designed to maintain a minimum ventilation airflow rate to control non-occupant related contaminants that may be given off by furnishings, equipment or other materials within the space. This is termed as "Base Ventilation Rate" that should not be confused with the minimum outdoor air rate required by ASHRAE Standard 62.

Minimum ventilation airflow 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.

Base ventilation airflow is required to achieve two primary goals: 1) Balance supply, exhaust and building pressurization requirements and 2) Establish the lowest outdoor air rate permissible during times when the building is sparsely occupied (i.e., immediately prior to or after business hours, weekends, and holidays). The base ventilation rate is the lowest point to which CO_2 controls may modulate outdoor air intake dampers. Note that it is the ventilation rate for non-occupant related sources.

The ASHARE standard 62, version 2004 explains how to calculate the minimum amount of fresh. 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".

$V_D = (V_P \times P) + (V_A \times A)$

Where,

V_D = *Minimum design ventilation quantity (CFM)*

V_P = required outdoor airflow rate per person, CFM/person

P = zone population, number of people

V_A = required outdoor airflow rate per unit area, CFM/ft²

A = zone floor area, ft²

$(V_A \times A)$ is the base ventilation rate.

As an example, a typical office space has the following numbers: V_P = 5 CFM/person, V_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.

Let's take another example to compare the ventilation rates based on ASHRAE 62 (1989 thru 2001 version) with new ASHRAE 62 (2004 version) applicable to new installations.

ASHRAE 62 (1989 thru 2001)

In the 1989 through 2001 versions of ASHRAE Standard 62, the required ventilation rates were based on either the number of occupants in the zone (CFM/person) or the floor area of the zone (CFM/ft²).

As an example, let's consider the ventilation rate for a lecture classroom with a design population of 70. ASHRAE 62-1989 through -2001 required 15 CFM of outdoor air per person in this space type. Therefore, classroom must receive 1050 CFM of outdoor air (15 CFM/person × 70 people). If the population drops to 20, the required quantity of outdoor air drops, too, to 300 CFM (15 CFM/person × 20 people).

In both the cases i.e. fully occupied (70 people) and sparsely occupied (20 people), the classroom receives the same rate of outdoor airflow per person—15 CFM/person. Therefore, the desired differential between indoor and outdoor CO_2 concentrations remained constant too, regardless of how many people actually occupied the zone. By controlling to this constant differential, *Cs – Co,* CO_2-based demand-controlled ventilation can maintain the same per-person ventilation rate (*Vo*) to the space during periods of reduced occupancy.

Note that the CO_2 *generation rate* (N) *varies with occupant activity level, diet, and health; the required ventilation rate* (Vo) *differs by space type under ASHRAE 62-1989 through -2001; and the outdoor* CO_2 *concentration* (Co) *can vary from location to location.*

ASHRAE 62-2004

The 2004 standard changes the method for determining the base ventilation rate (V_B). Now the required rate is based on the number of occupants in the zone (CFM/person) *and* the zone's floor area (CFM/ft²).

Let's revisit the classroom example. ASHRAE 62.1-2004 requires 7.5 CFM of outdoor air per person *plus* 0.06 CFM of outdoor air per square foot of floor area.

With a design population of 70 and a floor area of 1000 ft², the 2004 standard requires delivery of 550 CFM of outdoor air

$V_B = (V_P \times P) + (V_A \times A)$

$V_B = 7.5\ \text{CFM/person} \times 70\ \text{people} + 0.06\ \text{CFM/ft}^2 \times 1000\ \text{ft}^2 = 585\ \text{CFM}$

And with only 20 people in the classroom, the required quantity of outdoor air drops to 210 CFM

V_B = 7.5 CFM/person × 20 people + 0.06 CFM/ft² × 1000 ft² = 210 CFM

Here, the classroom receives 8.35 CFM/person [585/70 = 8.35] at design rate and 10.5 CFM/person [210/20 = 10.5] at reduced occupancy.

Assuming the CO_2 generation rate of 0.0105 CFM (0.3 L/min) per person and the design ventilation rate of 8.35 CFM per person, the resulting indoor-to-outdoor CO_2 concentrations differential will be 1240 ppm.

$C_S - C_O = N / V_O$

$C_S - C_O = 0.0105 / 8.35 = 0.00126$ [or 1260 ppm]

Similarly, at 10.5 CFM/person, the desired difference in indoor-to outdoor CO_2 concentrations drops to 1000 ppm.

$C_S - C_O = N / V_O$

$C_S - C_O = 0.0105 / 10.5 = 0.001$ [or 1000 ppm]

This shows that with ASHRAE 62-2004 standard, not only the effective CFM/person ventilation rate (V_O) varies with population but also the desired indoor-to-outdoor CO_2 concentrations differential, *Cs – Co,* varies [1260 ppm at peak occupancy of 70 and 1000 ppm at reduced occupancy of 20]. Controlling to a constant differential that's based on design occupancy will under-ventilate the zone at partial occupancy.

Comparison of ASHRAE 62 standards (1989 thru 2001) with 2004

Comparison of ASHRAE standards (1989 thru 2001) with 2004 reveals two important aspects -

First, the ASHRAE 62.1-2004 results in lower design ventilation rates (585 CFM versus 1050 CFM). [Note that, if this comparison is made on densely occupied spaces—such as auditoriums, gyms, conference rooms, and cafeterias — the rates will drop dramatically.]

Second, as the zone population decreases, the required ventilation rate drops less rapidly … in this case, by 7.5 CFM for every person who leaves the zone under the 2004 standard versus 15 CFM/person under ASHRAE 62-1989 through -2001.

For these two reasons, *CO_2-based DCV under ASHRAE 62.1-2004 provides less potential energy savings for most space types*.

Bottom line, although ASHRAE 62.1-2004 explicitly allows the use of demand-controlled ventilation, it also reduces the value of implementing CO_2-based DCV in most space types by reducing the required design ventilation rates. The 2004 standard also complicates implementation of CO_2-based DCV because of the effective CFM / person, and (therefore) the desired indoor-to-outdoor difference in CO_2 concentrations, variations as the zone population changes.

DCV Settings - Lower and Upper Limits of Minimum Outside

Since ASHRAE 62-2004 has introduced mandatory 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, it is prudent to 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 flow rate 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.

Additional factors to note:

The designer should consider the age, condition, and contents of a building when establishing the minimum ventilation airflow rate. A new or remodeled building with newly installed furnishings and finishes will experience higher concentrations of building-related contaminants than will an older building and may initially require a higher base ventilation rate over the first few months of operation.

Retail sales areas, such as furniture and carpet stores, may experience relatively high concentrations of building-related contaminants regardless of the building age. Experience with DCV systems to date suggests that the minimum ventilation flow for older (well aged) buildings should not be less than 20 to 30% of the design ventilation rate. For new buildings this rule of thumb may be higher at about 40 to 50% of the design ventilation rate.

Affect of Air Distribution Configuration on Ventilation Air

Two basic HVAC air distribution configurations are the Constant Air Volume (CAV) system and the Variable Air Volume (VAV) system.

Base ventilation setting for CAV systems

Setting the base ventilation rate in a constant volume system can be done by calculating the base ventilation rate as a percentage of the total supply airflow and setting the outside air damper to this percentage. For a more accurate value, the outside air duct can be traversed for the base ventilation airflow, and then the outside air damper can be set to match this reading.

Base ventilation setting for VAV systems

VAV systems warrant special consideration. 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.

The following process will take care of setting the base ventilation rate for a VAV system:

1. Set all zone dampers to their design ventilation rate.

2. Ensure the VFD or inlet guide vanes have modulated to maintain the design static pressure set point.

3. Traverse the Outside Air Duct and set the AHU controller's Outside Air damper actuator to maintain the system design base ventilation. This will typically be set as a percentage of damper position. Since the lowest volume of air the VAV system can produce at any given time equates to the base ventilation rate, the above setup will ensure that the outside air damper will always deliver the base ventilation rate, even at very light loads.

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 based DCV is not applicable to the air handler units equipped with chemical or charcoal filter units.

What are the appropriate CO_2 Sensors Specifications?

The CO_2 sensors are the most important components in a DCV system and need to be reliable and accurate: Too low readings might reduce the indoor air quality, while too high readings would lead to systematic excess ventilation and waste of energy. In both cases, serious consequences would result for the operation of DCV in relation to given technical, economical and IAQ standards.

Many different manufacturers presently manufacture variety of CO_2 sensors each with different specifications. There are sensors that are used more in the gas and chemical industry and these sensors are three to five times the cost of conventional 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.

So-called "self calibrating" CO_2 need a minimum of 4 hours of excess ventilation every day to "self calibrate" to an assumed outdoor air quality - at the expense of increased operational cost and reduced energy savings in the DCV system. CO_2 sensors are now being made that essentially maintain their calibration indefinitely. With superior stability, sensitivity, programmability and user economy in addition, such sensors satisfy all technical and economical requirements that allow DCV to be implemented on a broad scale. The sensors are based on advanced IR technology processed by digital electronics, with output signals communicated on digital serial bus formats (e.g., BACNet) or else converted to standard analog formats such as 4 - 20 mA or 0 - 4 (10) V are widely considered along Building Management Systems.

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

1. Range: 0-2,000 ppm
2. Accuracy: +/- 50 ppm
3. Stability: <5% Full Scale for 5 years
4. Linearity: +/- 2% Full Scale
5. 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 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.

How to evaluate CO_2 Sensor Location & Quantity?

Sensor location and quantity is not explicitly defined in ASHRAE or any other code. The exact criteria will vary between different buildings and system types. The key is to select a location where the sensor can accurately measure the CO_2 concentration and is representative of the area or zone served. A special consideration for CO_2 sensor placement is to ensure it is not located in an area where people might be directly breathing on the sensor (e.g., near water cooler/coffee service areas).

Sensor Location - In-space or Duct Mounted

Measurement of CO_2 in the space using wall mounted sensors is preferred for the same reason as offered by thermostats. In multiple space applications, duct-mounted sensors may reflect an average of all spaces and will not provide indication of ventilation requirements in individual zones. The result is that ventilation to the individual spaces (i.e., the "critical" space) may not be maintained in compliance to ASHRAE 62 requirements and will be a compromise.

Space-mounted sensors provide a good indication of the ventilation effectiveness in the space and will operate the system based on the characteristics of the space. Duct-mounted sensors cannot ensure ventilation effectiveness. The principal driver for use of duct-mounted sensors is to reduce costs by reducing the number of sensors required for a job. In the past few years, CO_2 sensor pricing has dropped dramatically meaning that the cost difference between using duct-mounted and multiple space-mounted sensors is a minimal portion of job cost. Hence individual zone wise wall mounted CO_2 is a better choice.

Guidelines for Placement of Wall Mounted Sensors

1. Select a location that is reasonably centered in the zone and is 3' to 6" above the finished floor level.

2. When a single sensor serves multiple spaces, the space most sensitive to the ventilation rate should be selected.

3. A sensor should be installed in each zone that is separately controllable (e.g., multi-zone systems or variable-air-volume systems with multiple zones).

4. Avoid locations near doorways, operable windows or air vents. Duct-mounted CO_2 sensors are best suited to single zone systems that run continuously.

Guidelines for Installation of Duct-mounted Sensors

1. Duct-mounted CO_2 sensors should be located to serve a single zone, or multiple spaces within a single zone that have similar activity levels.

2. Locate the sensor as near as possible to the space being served.

3. When using duct-mounted sensors for a demand controlled ventilation system, the designer must consider ventilation effectiveness in the occupied space.

4. Locate duct-mounted sensors where they are accessible for inspection and maintenance.

Sensors for Constant Air Volume (CAV) Systems

In applications of single-zone system, install a CO_2 sensor on the wall (column) or in the return-air duct. For large area single-zone system, it will be costly to install multiple CO_2 sensors and centralized return duct mounted CO_2 sensor will be better representative of the space conditions.

Guidelines for locating sensors for CAV systems

1. A single CO_2 sensor is suitable for open areas up to about 5,000 square feet.

2. If a building is designed with a large open area as a single zone greater than 5,000 square feet, multiple CO_2 sensors should be used.

3. If a large open area is conditioned with multiple units (e.g., multiple rooftop units) each separate unit should be equipped with a CO_2 sensor that is located centrally in the area conditioned by that unit.

4. In systems that have multiple zones, but only one location to control the flow of outdoor air (e.g., constant-volume, single-zone rooftop units), multiple CO_2 sensors may be required. This is especially true if there are different zones in the space with different occupancy patterns. In this situation a CO_2 sensor should be placed in each of the major occupied zones and the outdoor air delivery should be modulated off the sensor with the highest reading. Inexpensive transducers are readily available that are able to take multiple analog signals and pass thorough the signal that is highest to the equipment.

Sensors for Variable Air Volume Systems

For multiple-zone systems served by variable air volume (VAV) system, consider installing CO_2 in each major zone of occupancy or at least in those spaces that experience widely varying patterns of occupancy and are likely to become critically under ventilated. In some cases this may mean that one CO_2 sensor can be used for multiple VAV boxes, if all serve a common area with similar occupancy patterns and densities. Do not however use a single sensor located in a common return to control ventilation rates for multiple spaces with different occupancies.

Quantity of Sensors

According to California Title 24 Energy Code, 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 fewer sensors, and lowering the threshold set point to account for less CO_2 sampling, and increased dilution of air within the space.

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.

Table below provides the summary-

Building Arrangement	**CO_2 Sensors**	
	One HVAC Unit	**2 or More HVAC Units**
Single space, single zone Area < 5000 ft2	One	One sensor per unit
Single space, single zone Area > 5000 ft2	Quantity as required. The area covered by each sensor shall be less than 5000 ft2	One sensor per unit (up to 5000 ft2 each)
Multiple spaces, single zone Area < 5000 ft2	One, Locate sensor in space that is most ventilation sensitive	One sensor per unit
Multiple spaces, single zone Area > 5000 ft2	One sensor per space	One sensor per unit
Multiple spaces, multiple zones	One sensor per zone	One sensor per zone

Do you need an Outdoor Air Sensor?

Not really. Because the outdoor concentration of carbon dioxide seldom varies by more than 100 ppm from the nominal value, designers often use the control system to automatically apply a one-time reading or historical value for the outdoor CO_2 concentration in lieu of an outdoor sensor.

How the DCV system is 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.

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.

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.

DCV Control Sequences

The control strategy and sequences used to modulate ventilation based on CO_2 levels is the most critical step in the DCV design process. The control strategy affects the responsiveness of the ventilation system to control ventilation rates based on actual occupancy and will significantly affect the possible energy savings achievable over a fixed ventilation approach. The following are some sample sequences of operation for a single zone system -

Economizer Control

The economizer determines whether or not free outside air can be used for cooling, rather than running the system compressor. The DCV CO_2 sensor is located in the indoor occupied space. When it detects an increase in space occupancy, it commands the system dampers to increase the amount of ventilation to the space. Some systems also have an air quality sensor located outdoors that is used to determine if the outdoor air is clean enough to bring indoors. Should the indoor and outdoor air quality sensors both sense that the indoor and outdoor air are of poor quality, an alarm signal is generated that is used to alert the building maintenance people and/or to notify an automated building management system..

Minimum outside Air Setting (Simplified)

If the CO_2 sensor input is less than the set point, then the OA damper shall be at the lower minimum setting. If the CO_2 reading rises above the set point, then the OA damper shall modulate open as needed to bring the CO_2 back down below the set point. 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.

Minimum outside Air setting (with direct measurement of OA)

The outside air damper shall modulate to maintain the minimum outdoor airflow set point, which is a value between the lower minimum and upper minimum quantities, based on the following linear reset schedule:

Space CO_2 Outdoor Airflow set point

	Space CO_2	**Outdoor Airflow Set-point**
#1	100 ppm above ambient	Lower minimum OA CFM
#2	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 set point. The drawback to this approach is that the space will have brief times when the CO_2 in the space is above the set point 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 set point 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.

What are the Commissioning Requirements for DCV Systems?

Commissioning the DCV components and strategies is an ongoing process that has activities throughout the project delivery process. California's Title 24 Energy Code has acceptance testing requirements for energy conservation concepts which include DCV. The following is a list of activities that the commissioning authority should undertake on projects that incorporate DCV.

Design Phase Issues

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

Submittal Phase Issues

1. Verify that the submitted CO_2 sensor meets the specification requirements.
2. Verify that the appropriate sensors have been selected for outdoor use, duct mounted or space mounted.

3. Verify that the control submittal reflects design requirements and all sensors have been incorporated into the engineered control submittal drawings.

4. 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

1. 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.

2. Functionally test all DCV related sequences, including the worst case scenario of minimum flow, and then verify proper building pressurization is still maintained.

3. 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

1. 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.

2. Generate a report or memo with plots indicating proper operation of the DCV strategy.

Key Design issues and challenges

Implementing CO_2 based DCV is a matter of estimating the CO_2 generation rate of the occupants (*N*), measuring the concentration difference in the space versus outdoors (*Cs* – *Co*), and then using this difference to determine the rate at which ventilation air (*Vo*), on a per-person basis, is delivered to the space.

In most locations, the outdoor concentration (*Co*) of carbon dioxide seldom varies by more than 100 ppm from the nominal value. Because of this and in lieu of installing an outdoor CO_2 sensor, most designers use either a one-time reading of the outdoor CO_2 concentration at the building site. This simplifies control, lowers the installed cost, and usually increases accuracy because it avoids the potential inaccuracy of an outdoor sensor.

Here are few areas that need attention.

Intermittent Occupancies - For most space types, the design ventilation rate is calculated by multiplying the maximum occupancy of the space by the ventilation requirement (CFM/person). The intermittent occupancy provision of Section 6.1.3.4 permits calculation of the design ventilation rate based on the *average* occupancy of the space, rather than the *maximum* occupancy ... but only if the duration of maximum occupancy in that space does not exceed three hours. Using the intermittent occupancy provision instead of implementing DCV sometimes simplifies system control and permits smaller HVAC equipment without sacrificing operating costs appreciably. When using DCV, however, it is <u>improper</u> to use this provision to lower the maximum occupancy for the sake of reducing the design ventilation rate.

Chemical Filtration - When considering CO_2 based DCV, make sure that, carbon dioxide is <u>NOT</u> removed from the space by methods such as gas-sorption filtration. When CO_2 is used to indicate occupancy, any means of reducing its concentration (other than dilution with outdoor air) will result in an under ventilated space.

System Sizing - Demand-controlled ventilation should be sized based on the peak occupancy. It is <u>NOT</u> appropriate to reduce the size (capacity) of the ventilation system when demand controlled ventilation is being used.

Combustion Sources - Un-vented combustion sources can contribute to high indoor CO_2 concentrations. In fact highly elevated levels of CO_2 (e.g., 3000 to 5000 ppm) can indicate the presence of potentially dangerous combustion fumes. CO_2 is one of the most plentiful by products of combustion and can account for 8% to 15% by volume of the content of a combustion exhaust.

Unoccupied periods - It is important to consider the potential for contaminant buildup during unoccupied periods. Potential sources of contamination may include off-gassing from building materials and furnishings, from areas with microbial contamination, or from activities performed by maintenance staff. To help achieve an acceptable indoor condition before occupancy, the standard defines minimum requirements for ventilation lead-time.

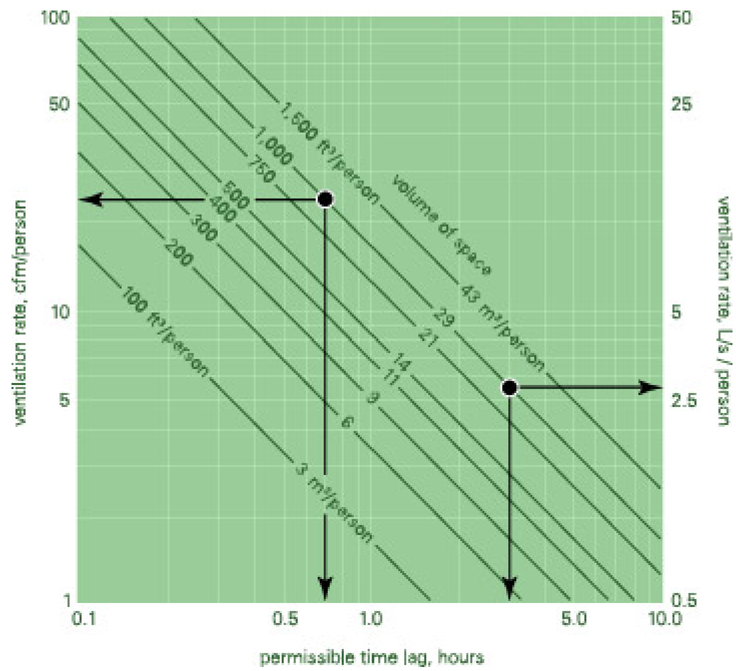
Non-zero base ventilation rate - A nonzero minimum ventilation rate will keep non-occupant sources of indoor contamination at acceptable levels. It helps to establish minimum ventilation rates based on the expected types and strengths of pollutant sources.

Lag time for ventilation - Depending on the application, Standard 62 allows ventilation to lag occupancy, provided that the ventilation system achieves an acceptable indoor condition within the permissible time frame.

"When contaminants are associated only with occupants or their activities, do not present a short-term health hazard, and are dissipated during unoccupied periods to provide air equivalent to acceptable outdoor air, the supply of outdoor air may lag occupancy". [Section 6.1.3.4]

Although the non-zero base ventilation rate can help meet the permissible lag time for ventilation, the sensors and control system also must respond quickly enough to both the CO_2 concentration and its rate of change to take appropriate action within the required lag time.

Maximum lag time permissible for ventilation



DCV and Building Pressure - When the outside dew point exceeds 65°F, humidity levels in negatively pressurized building envelopes can exceed 70% RH. High humidity conditions in and near the building envelope will result in mold growth. Some molds may be toxic to humans while others may damage the building structure. The widespread use of DCV has limited the amount of outside air introduced into a building. Without a positive pressurization flow (the difference between the outside air intake flow rates and the total exhaust flow rates), a building cannot be pressurized. Designers must carefully consider building pressurization when utilizing demand controlled strategies (CO_2 or others). Building pressurization becomes even more critical if energy recovery is used since the differential used to pressurize the building is significantly reduced, even at system design maximums.

Economizer Control - In buildings with an economizer cycle, allow the economizer to override the DCV system at times when the additional ventilation would provide "free" cooling. Select DCV systems that are able to increase outdoor air intake before the building opens in the morning to deal with concentrations of contaminants that may build up overnight.

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 building codes/standards other than ASHRAE apply to DCV?

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.

1. **BOCA, ICBO and SBCCI -** The majority of local and state code making bodies does not usually have the expertise and resources to write their building codes from scratch. As a result, three model codes have been established that develop standardized building code documents that can be adopted in whole or in part by local jurisdictions. These code bodies are known as BOCA (Building Officials and Code Administrators International), ICBO (International Conference of Building Officials) and SBCCI (Southern Building Code Congress International). Recently these three model code bodies have jointly adopted the International Mechanical Code (IMC) which establishes minimum regulations for mechanical systems using prescriptive and performance related provisions. Like the ASHRAE 62 standard, the IMC also provides provisions for modulation of outside air based on occupancy as long at target CFM-per person ventilation rates are maintained. This is addressed in section 403.3.1 of the 2000 International Mechanical Code that states:

"The minimum flow rate of outdoor air that the ventilation system must be capable of supplying during its operation shall be permitted to be based on the rate per person indicated in Table 403.3 and the actual number of occupants present. The IMC has also created a commentary document to provide clarification to the intent of the code. In reference to section 403.3.1, the commentary uses CO_2 control as an example of a ventilation system that can provide a specific "rate per person" based on the "actual number of people present."

An excerpt from the commentary is provided below.

"The intent of this section is to allow the rate of ventilation to modulate in proportion to the number of occupants. This can result in significant energy savings. Current technology can permit the design of ventilation systems that are capable of detecting the occupant load of the space and automatically adjusting the ventilation rate accordingly. For example, carbon dioxide (CO_2) detectors can be used to sense the level of CO_2 concentrations, which are indicative of the number of occupants. People emit predictable quantities of CO_2 for any given activity, and this knowledge can be used to estimate the occupant load in a space."

2. 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 features are:

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. *Another 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 0.15 CFM / ft^2 for a typical office building*.

3. **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).

Summarizing…..

Demand-controlled ventilation can reduce the cost of operating the HVAC system—especially in applications where contaminant levels result primarily from people (or their activities) and where population varies significantly. The most common applications include gymnasiums, meeting rooms, and auditoriums.

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. 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.

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 sensors, there are now enough systems to provide an array of options that a designer can choose.

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