International Journal of Engineering Research And Management (IJERM)
ISSN : 2349- 2058, Volume-1, Issue-4, July 2014

DEMAND CONTROLLED VENTILATION USING CO_2 SENSORS FOR HVAC SYSTEM

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Abstract— **In this paper the demand controlled ventilation for systems serving multiple zones has been analyzed and the result for the effective DCV is discussed. The study is undertaken on HVAC systems for the construction of Eco House, Higher college of Technology, Sultanate of Oman. The main theme of this paper is to identify the problems with CO2 sensors for systems serving multiple zones having variable occupancies. In conventional systems the CO2 sensors will be used to find the CO2 concentrations, and depending upon the concentrations the OA will be varied. This system may not meet the actual demand at each zone. This paper summarizes the analysis of demand controlled ventilation for HVAC systems serving schools and the results are discussed. Carbon Dioxide (CO2) based demand controlled ventilation (DCV) is 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." CO2 -based DCV offers designers and building owners an ability to monitor both occupancy and ventilation rates in a space to ensure there is adequate ventilation at all times.**

INTRODUCTION

With a conventional DCV system, discrete CO2 sensors are installed in the spaces to be controlled. These sensors generally report to a building-management system (BMS) or, in the absence of a BMS, directly control outside-air dampers or variable-air-volume boxes. The conventional system may not satisfy the variable occupancy conditions in the multiple zones which is served by a single system. Spaces with high design occupant densities offer an excellent opportunity for demand controlled ventilation (DCV) systems since these spaces are seldom occupied at their design occupancy. DCV systems modulate the amount of outdoor air supplied to a space as a function of the number of people present, providing significant energy savings when spaces are only partially occupied. The Standard requires DCV for all ventilation systems with design outside air capacities greater than 3000 CFM serving areas having an average design occupancy density exceeding 100 people per 1000 ft². DCV systems must maintain ventilation rates in accordance with ANSI/ASHRAE Standard 62.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.

Demand-controlled ventilation (DCV) using carbon dioxide (CO_2) sensing is a combination of two technologies: CO_2 sensors that monitor the levels of CO_2 in the air inside a building, and an air-handling system that uses data from the sensors to regulate the amount of outside air admitted for ventilation. DCV operates on the premise that basing the amount of ventilation air on the fluctuating needs of building occupants, rather than on a pre-set, fixed formula, will save energy and at the same time help maintain indoor air quality (IAQ) at healthy levels. CO_2 sensors continually monitor the air in a conditioned space. Because people constantly exhale CO_2, the difference between the indoor CO_2 concentration and the level outside the building indicates the occupancy and or activity level in a space and thus its ventilation requirements.

CO_2 LEVELS IN INDOOR

Indoors in commercial buildings people are the principal source of CO_2 Plants, due to their low level of metabolic activity contribute an insignificant amount of CO_2 to indoor spaces. Unvented combustion sources can also contribute to indoor CO_2 concentrations but are generally not present in commercial buildings. 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 byproducts of combustion and can account for 8% to 15% by volume of the content of a combustion exhaust. For ventilation control, it is people as a source of CO_2 that we are interested in. People exhale predictable

Manuscript received July 07, 2014

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quantities of CO_2 in proportion to their degree of physical activity.

DEMAND CONTROLLED VENTILATION (DCV)

DCV as a ventilation control strategy was clarified in 1997 in interpretation IC 62-1999-33 (formerly IC 62-1989-27). The use of CO_2 is applied using the Ventilation Rate Procedure of Standard 62, which establishes specific CFM/person ventilation rates for most applications. By definition, ASHRAE Standard 62 says that acceptable indoor air quality is achieved by providing ventilation air of the specified quality and quantity (Table 1 in the Standard) to the space. The standard states. CO_2 is applied using the provisions of section ASHRAE 6.1.3.4 of the standard that address variable and intermittent occupancy. The CO_2 control strategy can be used to modulate ventilation below the design ventilation rate while still maintaining Table 1 ventilation rates (e.g., 15 CFM per person). Sensor location and selection of the control algorithm should be based on achieving the rates.

The control strategy should also be developed considering inside/outside CO_2 levels. The control strategy must provide adequate lag time response as required in the Standard. If CO2 control is used, the design ventilation rate may not be reduced to consider peak occupancies of less than 3 hours (often called diversity). In other words, the variable provision of 6.1.3.4 cannot be applied to lower the estimated maximum occupancy for the purpose of reducing the design ventilation rate while using DCV. CO_2 filtration or bio effluents removal methods other than dilution should not be implemented in the space. A base ventilation rate should be provided during occupied periods to control for non-occupant related sources. Implementing CO2-based DCV is a matter of estimating the CO2 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 CO2 sensor, most designers use either a one-time reading of the outdoor CO2 concentration at the building site or a conservative value from historical readings.

SYSTEMS SERVING MULTIPLE ZONES WITH VARIABLE OCCUPANCY

In this school also a single system is serving more than 30 rooms with variable occupancy. In these applications, if a duct-mounted sensor is used, it will sample the average of all the spaces and may not control levels based on the actual conditions in the space. By considering an average of all spaces, this approach cannot ensure that target per person rates established by local codes or Standard 62-1999 would be met in all spaces (often termed .critical. spaces). As a result, the use of duct sensors in this application would likely not meet the requirements of local codes and Standard 62-1999. An effective, but slightly more costly approach is to install a wall-mount sensor in each of the occupied spaces. Each sensor output is then sent to a signal transducer that will read all the sensors and pass through one signal that represents the sensor with the highest reading to the air handler. As a result, ventilation rates will be controlled to ensure the most critical space is always adequately ventilated. This approach also can be used with large spaces such a retail establishments or large floor plates on multiple story buildings.

STANDARS FOR VENTILLATION

Ventilation rates for schools and office spaces are defined by various codes and standards. The most widely accepted standard is the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62. Some state and local codes have adopted the ASHRAE Standard 62 ventilation requirements. According to ASHRAE Standard 62, classrooms should be provided with 15 cubic feet per minute (CFM) outside air per person, and offices with 20 CFM outside air per person. Ventilation rates for other indoor spaces are also specified. Standard 62 is currently being revised, so these rates may change. Using CO_2 as an indicator of ventilation, ASHRAE has recommended indoor CO_2 concentrations be maintained at or below 1,000 ppm in schools and 800 ppm in offices (see chart below). Clearly the outdoor CO_2 concentration directly impacts the indoor concentration. Therefore, it is critical to measure outdoor CO_2 levels when assessing indoor concentrations. ASHRAE recommends indoor CO_2 levels not exceed the outdoor concentration by more than about 600 ppm.

To properly use CO2 for DCV, the system should be designed as follows

1. Determine the design outdoor air rate based on the maximum (design) number of people expected to occupy the space. No diversity is allowed in the design population assumption. Some standards, such as Standard 62 (6.1.3.4), allow a designer to reduce the

design occupant count by some percentage because people are not expected to be present for a period long enough to reach steady state. A good example is a perfection area of an assembly space; it can have a very high peak occupancy, such as during the intermission of a performance, but the peak seldom lasts more than a half hour or so. Credit for such occupant diversity cannot be taken when DCV systems are used because the outdoor air rate tracks the occupant load; the space is not over ventilated before and after the occupant peak the way it would be if no outdoor air controls were specified.

2. CO_2 sensors must be located within the occupied zone of the space served.

Alternatively, the sensor may be located in the space return air grille provided the set point or sensor reading is adjusted to reflect any short circuiting that may occur in the air distribution system. Fortunately, most densely occupied spaces are always in a cooling mode (the temperature of the air being supplied to die space is less than the space temperature), which results in nearly perfect mixing even with less than ideal ceiling supply and return systems. In this case, die CO_2 sensor may be located almost anywhere in the room or in the return air duct from the room. If located in the return air duct, the sensor should be located as close to the room as possible so that return air duct leakage does not distort the concentration reading.

For systems serving more than one room, locating the sensor in the common return from all zones is not acceptable since it would indicate only average CO_2 concentration, possibly allowing some spaces to be under ventilated while others were over ventilated. Doing so is analogous to controlling room temperature, in multiple rooms with a return air temperature sensor. For systems serving multiple rooms, CO_2 sensors must be installed either in all rooms, or possibly only in those rooms that are judged to be "critical." Critical rooms are those requiring the highest percentage of outdoor air. If CO_2 is not measured for all rooms, spaces for which CO_2 concentration is not measured should be assumed to be occupied at peak occupancy conditions at all times the system is operating.

3. Determine the CO_2 concentration set point using the following equation:

$$C_R = C_{OA} + \frac{8400\, m}{R_P}$$

Where C_R is the room CO2 concentration, C_{OA} is the outdoor air CO_2 concentration, m is the metabolic rate (1 met = 58.2 W/m², see Table 1for typical values), and R_P is the rate of outdoor air per person. This equation assumes that the air change effectiveness of the air distribution system is near unity (a good assumption for systems in the cooling mode). An outdoor air CO2 sensor is not required if the outdoor air CO_2 concentration in the equation is set to a conservatively low value (e.g., 350 ppm). As an example, a movie theater CO2 concentration at 15 CFM/p, 350 ppm outdoor air CO_2 concentration, and a metabolic rate of 1.0 would be 910 ppm.

4. If separate CO_2 sensors are used for room and outdoor air concentration measurement, they each should have an accuracy of ±50 ppm in the range 300 ppm to 2000 ppm. If a single sensor is used to measure both points, or only an indoor sensor is used, the sensor should have an accuracy of ±100 ppm in the range 300 ppm to 2000 ppm.

5. The system must be designed to ensure that a minimum outdoor air intake is maintained regardless Of CO_2 concentrate. Ton to account for contaminant sources from building materials, furnishings, etc. Unfortunately, Standard 62-1989 and most building codes do not provide any data on what this minimum rate should be. An addendum to Standard 62 to provide building related air flow requirements is being developed. Contact ASHRAE for current information on the status of this addendum.

6. Outdoor air rates must be controlled to maintain the measured space CO_2 concentration at or below the set point determined above. Any type of control logic is acceptable that meets this criterion, including on/off and modulating control. The latter is preferred for system stability and to avoid rapidly changing space temperatures when outdoor air conditions are extreme.

ANALYSIS OF DCV IN SCHOOLS

For analysis of the Demand controlled ventilation (DCV), the HVAC systems for the schools constructed by Ministry of manpower and The research council is utilized. The single floor building has 30 class rooms with 25 students each. It also has labs, multipurpose hall, and etc. The total built area of the eco house is about 743 m^2.The HVAC system of the school consist of 7 AHUs, served by a chiller plant. The AHUs are serving near about 131 rooms and most of the rooms are class rooms and office rooms. The requirements of outdoor for the systems are summarized below. In this case one AHU is serving the following multiple zones, and most of the zones are having variable occupancy. For the breathing zone the ventilation should be provided based on ventilation rate procedure by ASHRAE 62.1-2007.Based on that the zones ventilation requirement is summarized below for a single AHU.

No of people	As per ASHRAE 62.1-2007 lps/person	Area (m^2)	As per ASHRAE 62.1-2007 lps / m^2	Total OA as per ASHRAE	From heat load calculation cooling lps (V_{dz})	No. of stalls toilet	Exhaust lps/m^2 or lps/unit	Exhaust lps	Final OA lps V_{oz}	Discharge outdoor air fraction(as per ASHRAE) $Z_d = V_{oz}/V_{dz}$	Zone ventilation efficiency(as per ASHRAE) $E_{vz} = 1+X_s-Z_d$
26	5	88	0.6	182.8	409.0				182.8	0.45	0.88
		10	0.3	3.0	180				3.0	0.02	1.31
		38		0.0	61	8	25	200	0.0	0.00	1.32
8	2.5	38	0.3	31.4	185				31.4	0.17	1.16
26	5	74	0.6	174.4	386				174.4	0.45	0.87
26	5	74	0.6	174.4	386				174.4	0.45	0.87
26	5	74	0.6	174.4	358				174.4	0.49	0.84
26	5	74	0.6	174.4	358				174.4	0.49	0.84
26	5	74	0.6	174.4	346				174.4	0.50	0.82
		10	0.3	3.0	200				3.0	0.02	1.31
		32		0.0	36			26.4	0.0	0.00	1.32
		27	0.3	8.1	98				8.1	0.08	1.24
		112	0.3	33.6	296				33.6	0.11	1.21
		38		0.0	48	8	25	200	0.0	0.00	1.32
		10	0.3	3.0	153				3.0	0.02	1.31
164		773		0.0	3500.0			426	1137		

(a) OA calculation for multiple zone as per ASHRAE 62.1		
1)	Total supply V_{ps} =	**3500.0**
2)	OA as per calculation $V_{OU=}$	**1137**
3)	Average outdoor air fraction $X_s = V_{OU}/V_{PS}$	**0.32**
4)	Outdoor air intake $V_{ot}=V_{ou}/\min E_{vz}$	**1385**

Table 1: calculation of total air volume

(b) OA by considering exhaust & pressurization		
5)	5% of SA + Exhaust	**601**
	Use the governing of the above value	**1385L/S**

The total OA requirement is 1385 L/s, if we supply all the 1385 L/s at all conditions, then the energy requirement will be high and the running cost also will be very high. The zones will not be occupied by the student at all time, depending upon the schedule the requirement will change. At that time for the particular zone we can supply reduced OA. The presence of occupancy will be sensed by CO2 sensors.CO2 based ventilation control is very good at modulating ventilation based on actual occupancy. In some cases, the thought is there may not be a great opportunity to save energy because classrooms at a particular school are always full. However in many cases classrooms may be subject to variable occupancy for the following reasons:

1. Lunch hours, recesses and staggered classroom hours may cause unoccupied periods.

2. Night school or other after hour activities may not result in the same densities that occur through the day in all classrooms.

3. Field trips, assemblies, teacher days and other events may cause a classroom to be unoccupied for one to three days per month that may not be accounted for in automated operational schedules.

4. Classrooms may be near full but even a classroom that is 80% full can reduce ventilation costs with CO2 controlled ventilation.

All of these conditions can lead to enough variability where the use of CO_2 sensors makes sense both by reducing over-ventilation and by modulating ventilation based on occupancy. Energy analysis programs are available that can estimate the impact of even minor variation in occupancy on energy savings.

The outdoor air requirement for the various zones is calculated based on the ASHRAE 62.1-2007, ventilation procedure. Because depending upon the class schedules the occupancy in the class rooms may change. If the system is serving the same outdoor air at all conditions, then some areas may under ventilated or over ventilated. In order to avoid this problem the CO2 sensors are used to vary the OA rate. The usage of CO_2 sensors will be very effective in systems serving single zones, and depending upon the CO_2 concentration the unit will supply the outdoor. In our case the systems are serving the class rooms along with variation in occupancy. If we use the CO_2 sensors to identify occupancy, it may not give the actual occupancy, but it can be possible by using individual sensors in each zones. The individual sensor usage will make the total control system as a complicated one. If we follow the first one, that is using common CO_2 sensor to find the occupancy then also we cannot able to identify the actual occupancy. Because when we place the CO_2 sensor in the common return duct it will read the average concentrations, and again the proper ventilation will not be obtained.

LOCATING CO_2 SENSORS FOR DCV

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. The exact criteria will vary between different buildings and system types. In each case, the designer must apply good engineering judgment to assure that both the sensors and the complete ventilation system performs effectively. In general, a CO_2 sensor will be less susceptible to stratification issues than temperature sensors due to the tendency of gases to quickly equalize within a space. 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. In two methods we can locate the sensors, 1. Wall mounted type, 2. Duct mounted type.

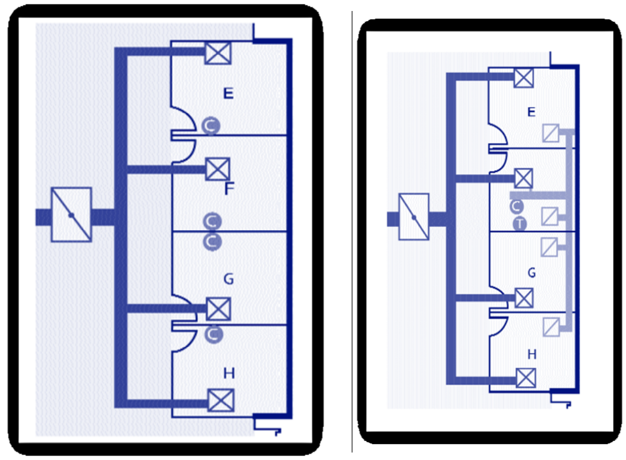

Fig1: Locating CO_2 sensor for DCV

Measurement of CO_2 in the space using wall mounted sensors is preferred for the same reason that temperature sensors are mounted within the space. 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 and compliance to ASHRAE 62 requirement will be compromised. Space-mounted sensors can also give 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 indicate ventilation effectiveness. The principal driver for use of duct-mounted sensors has been 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. Some sensors now even combine temperature and CO_2 measurement functionality to further reduce purchased and installed cost.

Duct-mounted CO_2 **sensors** are best suited to single zone systems that run continuously. 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. Locate the sensor as near as possible to the space being served. When using duct-mounted sensors for a demand controlled ventilation system, the designer must consider ventilation effectiveness in the occupied space (just the same as is necessary when using the Ventilation Rate Procedure). Locate duct-mounted sensors where they are accessible for inspection and maintenance.

SEQUENCE OF OPERATION

1. The DCV strategy would be timed to operate during all occupied hours. The economizer would be programmed to override DCV control if outside air could be used for free cooling.
2. A morning pre-occupancy purge would be included in the sequence of operation of the air handler.
3. The maximum position of the air handler for delivery of ventilation under the DCV strategy would be would be 3500 L/S.
4. The base ventilation rate would be set to 600 L/S
5. The air handler would be set up to begin modulation of outside air when inside concentrations were 100 ppm over outside concentrations (500 ppm). The damper position on the air handler would be proportionally modulated so that when levels reached the equilibrium anchor point the design ventilation rate of 1385 L/S would be provided.

CONTROL STRATAGY

Set Point control would probably work very well for a single school classroom given the relatively high density of the space and small volume of air. This strategy could become much more complicated when trying to control ventilation for spaces simultaneously and may result in excessive damper movement and wear as the damper continually opens and closes. For this application proportional modulated control was chosen because the rooftop system selected has proportional modulation capability.

The outside air damper will be modulated between the minimum position described above and the maximum position described above necessary to provide the DVR to the space based on CO_2 concentrations. It is highly recommended that a proportional control approach be used to modulate the damper based on CO_2 readings between a lower and upper control limit. This proportional modulation will ensure that 15 CFM per person of outside air is provided at all times based on actual occupancy.

Upper Control Limit: The proportional control strategy should be designed to position the damper to provide the DVR when the CO_2 levels are equivalent to the equilibrium concentration Of CO_2 corresponding to the target CFM per person ventilation rate in the space. For 20 CFM/person the upper set point is 930 ppm, for 15 CFM per person the upper set point is 1100 ppm. (This assumes a typical outside concentration of 400 ppm)

Lower Control Limit: The proportional control strategy would position the damper in the minimum position until indoor levels exceed a certain CO_2 threshold above outside levels. Typically this threshold should be set at 150 to 200 ppm CO_2 above outside levels of at 550 to 600 ppm.

Multiple Sensors Controlling a Single AHU: Control should be based on the highest CO_2 concentration measured in all spaces served by the air handler. This can be accomplished within the programming capabilities of most building control systems. Alternatively, transducers are available that can take in multiple inputs and pass through the highest value.

Benefits:

DCV saves energy by avoiding the heating, cooling, and dehumidification of more ventilation air than is needed. CO_2 sensors are the most widely accepted technology currently available for implementing DCV. Additional benefits of CO_2-based DCV include

- Improved IAQ—By increasing ventilation if CO_2 levels rise to an unacceptable level,
- Improved humidity control—in humid climates, DCV can prevent unnecessary influxes of humid outdoor air that makes occupants uncomfortable and encourages mold and mildew growth.

CONCLUSION

CO_2 demand control ventilation is a real-time, occupancy based ventilation approach that can offer significant energy savings over traditional fixed ventilation approaches, particularly where occupancy is intermittent or variable from design conditions. Properly applied, it allows for the maintenance of target per-person ventilation rates at all times. Even in spaces where occupancy is static, CO_2 DCV can be used to ensure that every zone within a space is adequately ventilated for its actual occupancy. Air intake dampers, often subject to adjustment or arbitrary adjustments over time can be controlled automatically avoiding accidental and costly over or under ventilation. Measurement and control technology using CO_2 sensors is quickly evolving to a stage of maturity where cost and reliability will likely approach that of conventional temperature measurement and control in the near future. As a result, the use of CO_2 as an indoor comfort, ventilation and air quality control parameter has the potential to be as widely used as temperature and humidity measurements are today. There also exists a good opportunity to reduce energy consumption due to reduced.

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