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GUIDELINES FOR USE OF CARBON DIOXIDE FOR DEMAND CONTROLLED VENTILATION

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ABSTRACT

Carbon dioxide (CO_2) sensors can provide a very useful tool in assessing and controlling ventilation in occupied spaces. Numerous standards and regulations throughout the world now make specific reference to the use of carbon dioxide as a ventilation assessment and compliance tool. Unfortunately the utility of CO_2 as a indoor air quality tool is often misinterpreted. This paper is intended to provide guidance for policy makers, building designers, building owners and employers on the appropriate applications of CO_2 based demand controlled ventilation (DCV). When properly applied as part of a comprehensive building ventilation control strategy, CO_2 control can optimize ventilation for air quality control while reducing costly over-ventilation of spaces subject to intermittent or partial occupancy.

KEYWORDS

Carbon Dioxide; Demand Controlled Ventilation

INTRODUCTION

Carbon dioxide is a naturally occurring gas that is produced by combustion processes, or is a byproduct of the natural metabolism of living organisms. Outside concentrations of CO_2 tend to be fairly constant at 350-450 parts per million (ppm).

The concentration of CO_2 in exhaled human breath is typically around 3.8% (38,000 ppm). Once this CO_2 leaves the mouth or nose, the concentrations dissipate and mix in the surrounding air very quickly. Indoor concentrations of CO_2 in occupied spaces typically range from 500 ppm to 2,000 ppm. The difference between inside and outside concentrations in most non-industrial workplaces is primarily due to the CO_2 produced by building occupants.

CO_2 AND OUTSIDE AIR VENTILATION RATES

Carbon dioxide is an excellent indicator of building occupancy because all people exhale CO_2 in similar concentrations based on their level of activity. Table 1 shows this relationship.

An indoor CO_2 measurement can provide a dynamic measure of the combined effect of lower concentrations of CO_2 representing outside ventilation and the constant generation of CO_2 by building occupants. Assuming good air mixing within the space, the concentration of CO_2 can provide an indication of the actual per person ventilation rate occurring within the space. In essence, a CO_2 measurement in a space is a simple tracer gas measurement of ventilation rate. The equation below defines the relationship between CO_2 concentrations an per person ventilation rates within an occupied space assuming equilibrium or steady state conditions have been met (ASHRAE).

Table 1
CO_2 Production & Human Activity (1)

Occupant Activity Level		CO2 Generation Rate L/s	cfm
Very Light Work	Sleeping	0.0040	0.00848
	Seated Quite	0.0045	0.00954
	Office Work*	***0.0050***	***0.01060***
Light Work	Fast Walking	0.0083	0.01767
	Light Machine Work	0.0105	0.02226

* Most Often Used Value For Non Industrial Workplaces

$$Cs = Co + N / Vo \quad (1)$$

Where: Cs = CO_2 concentration in space
Vo = Outdoor air flow rate per person
N = Occupant CO_2 generation rate
Co = Outside CO_2 concentration

The steady state relationship between CO_2 and ventilation rate is not affected by occupant density or the size of the occupied space being measured. For practical application in building ventilation assessment and control, the CO_2 generation rate (N) is the design occupancy of the space times the per person CO_2 generation rate derived base on activity level.

Until recently the only reliable way to measure CO_2 was with high end scientific instrumentation. The high cost and long term drift characteristics of this equipment made it unsuitable for CO_2 DCV. A new generation of simple to operate, microprocessor based, non-dispersive infrared, CO_2 sensors are now available that can provide continuous measurements with much greater longer term stability than provided by traditional scientific devices.

DEMAND CONTROLLED VENTILATION USING CO_2

Active control of ventilation based on the differential in indoor/outdoor CO_2 concentrations is called demand controlled ventilation. A CO_2 sensor is placed in an occupied space or in the return air from the occupied space. The amount of outside air introduced to the space is then regulated based on maintaining CO_2 concentrations near the target equilibrium level considered equivalent to the design per person ventilation rate intended for the space (based on equation 1).

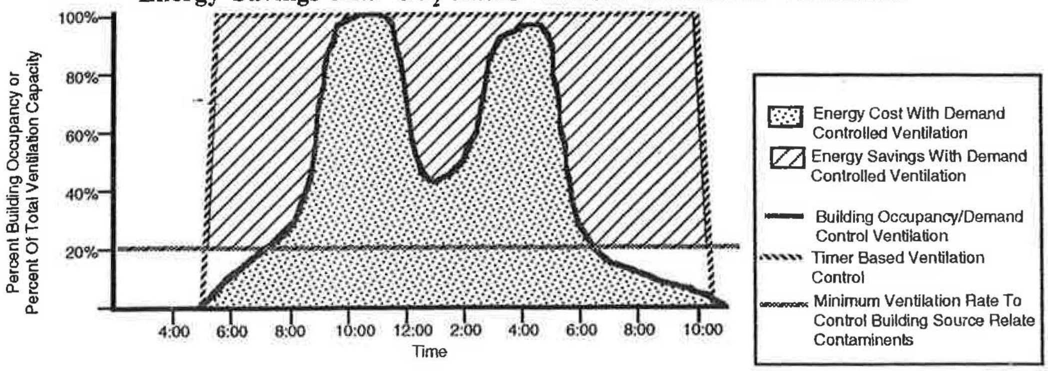
Traditional approaches to building mechanical system design and operation involve continuous ventilation of occupied spaces based on the design ventilation rate of a space (design occupancy X per person ventilation rate target). This can result in potentially significant over-ventilation of a space if it is partially occupied or only occupied on an intermittent basis. In contrast, a CO_2 based DCV strategy can ensure that design per person ventilation rates are maintained at all times. If a space is occupied at half the design occupancy then CO_2 based ventilation control will ensure that adequate ventilation is provided even though the actual ventilation rate will be at half of the system's actual ventilation design capacity. There are two principal advantages that can result from a CO_2 DCV strategy.

First, if a space is partially or intermittently occupied, CO_2 based ventilation control can provide significant energy savings. The degree of savings that can be achieved will be dependent on how significantly actual occupancy in the space deviates from the design occupancy. Figure 1 shows a occupancy profile for a typical office space and provides a graphical indication of potential savings. Numerous studies have examined the impact of CO_2 based demand control ventilation on various applications (Meckler) (International Energy Commission) (Janssen). In general the studies show that energy consumption related to fresh air ventilation can be reduce by 5% to 50% while providing simple paybacks ranging from a few months to three years.

Second, continuous monitoring of CO_2 concentrations by HVAC zone as part of a control strategy can indicate if all areas within a building are being provided with adequate ventilation based on their occupancy. Balancing and distribution problems can be quickly identified. If the ventilation control

Figure 1

Energy Savings And CO_2 Based Demand Controlled Ventilation



system is integrated into a computerized building management system, excessively high, low or erratic CO_2 concentrations can provide an indication of HVAC system problems. Automatic data logging features in many building management systems can also help document compliance with ASHRAE 62-1989 recommended ventilation rates. Other possible applications or spin-offs of CO_2 control in buildings include the ability to estimate the percent outside air introduced by an air handler and the ability to diagnose if supply air is short circuiting into a ceiling return plenum (Telaire).

APPLICATION OF CO_2 BASED DEMAND CONTROLLED VENTILATION

Demand control ventilation can be applied in retrofit and new building design. Some important design considerations based on four years of in the installation and operation of CO_2 demand control ventilation systems are outlined below.

- Calculate the equilibrium setpoint for CO_2 control base on the recommended ventilation rate for the intended application and the outside concentrations typical for the area that the building is in. Data logging of outside CO_2 concentrations over a week or more in the vicinity of the building location should provided a good indication of background CO_2 concentrations. Local weather or environmental monitoring offices may also be able to provide local data on average outside CO_2 concentrations. If outside concentrations appear to fluctuate 300 ppm or more over a week, active monitoring of outside concentrations should be part of the control strategy.
- If outside air intake concentrations exceed 700 - 800 ppm, outside combustion sources are likely present in high concentrations. In these situations, some system designers are closing air intake dampers until outside concentrations drop below 600 ppm. Buildings with air intakes close to loading docks and high traffic areas may be subject to elevated concentrations on a regular basis.
- Ventilation based on CO_2 only considers occupant activity within a space. Pollutants from other building relate contaminants can build up regardless of occupancy. Ventilation control strategies such as maintaining a minimum continuous ventilation rate (e.g. 20% of design occupancy or higher for new buildings) or activation of regular building purge cycles should be considered in addition to a demand control ventilation strategy.
- Ideally, there should be one sensor for every major HVAC zone. If areas within the zone are subject to diverse applications or occupancies, a CO_2 sensor should be considered for each area. A number of HVAC manufacturers are now developing zoning systems that can operate on both temperature and CO_2.
- Sensors can be installed in the space much like a thermostat. Alternatively they can be installed in the return air of the air handling system. If a sensor is installed in the return air of a ceiling plenum system where supply ducts are also present, supply leakage may dilute return air concentrations making them unrepresentative of the occupied space.

The most critical aspect of a DCV design is applying the correct control strategy for the intended application. Three common control approaches and guidelines for their use are provided below. All of these approaches are proven and have been used in temperature control of buildings for years.

<u>Set Point Control</u>: Set point control employs a simple on/off or damper open/closed strategy based on the CO_2 concentration in the space. Typically, a damper would be opened at a set point and closed

when levels drop 50 to 100 ppm below the set point. This simple strategy is best applied in applications where occupancy densities are high (20 - 50 people per 1,000 ft^2 or 100 m^2.). Ideally, occupancy patterns range from no occupants to full design occupancy over a very short period of time. Theaters, conference rooms and some school classrooms are good applications for this strategy.

Proportional Control: In proportional control of ventilation systems a CO_2 sensor emits a signal (e.g., 4-20 ma) that is proportional to the CO2 concentrations. Using this signal, damper position or injection fan volume is adjusted in proportion to the CO_2 concentration. Control would typically begin when inside concentrations exceed outside concentrations by 100 ppm. Air delivery to the space would be proportionally increased until 100% of the design ventilation rate would be provided. Compared to set point control, this approach allows for the ventilation system to react to varying occupancy levels much faster than waiting for CO_2 levels to build up to the desired equilibrium level control point. This type of control approach is best applied in applications where occupancy densities range from 7 to 30 people per 1,000 ft^2 or 100 m^2. It is ideal for ventilation control in spaces where occupancies are highly variable and unpredictable such as bars, restaurants, conference rooms, , courtrooms, classrooms or retail spaces.

Proportional - Integral - Derivative Control (Rate Of Rise): In low density applications (below 7-10 people per 1,000 ft^2 or 100 m^2), in large or complex buildings a potential disadvantage of CO_2 control is the time it will take for CO_2 to build up to equilibrium conditions. These problems can be further aggravated if occupancy is staggered or varies over the course of a day as is typical in many high rise office buildings. A solution to this type of complex control problem for CO_2 (and temperature) control is the use of a PID control (Proportional - Integral - Derivative). In CO_2 control, a PID control would look at trends and rate of rise or decrease of CO_2 concentrations. For example, at the start of a business day, a PID control would notice a rapid buildup of CO_2 concentrations as people began entering a building in the morning. Within minutes the HVAC system could begin to react and adjust fresh air delivery based on actual occupancy as predicted by the rate of rise of CO_2 concentrations.. PID control algorithms are built into most modern building control systems. Public Works Canada has utilize this approach in a number of their buildings (Valculik), and recommends it in a recently published ventilation control guide (Plett).

Summary

- The equilibrium concentrations of CO_2 corresponding to target ventilation rates provide the critical set-points for the effective control of ventilation using CO_2 . The time lag associated with the buildup of CO_2 to equilibrium conditions can be overcome using a variety of control strategies often applied in temperature control. Actual outside CO_2 concentrations must be considered when determining CO_2 control setpoints.
- Carbon dioxide DCV offers an unique opportunity for building designers to employ ventilation control strategies that ensures that target per person ventilation rates are always met to provide acceptable air quality. If variable or intermittent occupancies occurs, a CO_2 control strategy will regulate ventilation to avoid costly and unnecessary over-ventilation. Significant energy savings are possible.

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