CO_2 Based Demand Controlled Ventilation

Do the Risks Outweigh the Rewards?

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INTRODUCTION

Today's HVAC designs emphasize energy conservation. Unfortunately, design strategies often loose focus on other core objectives which include occupant health, productivity and the long term integrity of the building structure. The widespread use of CO_2 demand controlled ventilation is a widely used strategy that has sacrificed many of our core objectives in the name of "conservation".

DEMAND CONTROLLED VENTILATION

A typical building has two significant components that lead to unsatisfactory indoor air quality. One source is the building itself, which in many cases can result in greater than 50% of the pollutants that require removal or dilution[4,5]. The second source is body odor produced by the occupants as a result of their activities. This latter source has driven many designers to reset outside airflow rates in facilities with variable occupancy.

The concept of DCV makes complete sense. Building managers can clearly see an energy benefit from reductions of outside air intake flow rates as the occupant density decreases. However, systems are rarely implemented that account for the actual number of people in a particular ventilation zone.

Since people produce carbon dioxide (CO_2) as a direct result of respiration, the use of CO_2 has been a "logical" choice for many of today's designers and owners. Unfortunately, many have not fully understood the relationship between CO_2 levels and ventilation. CO_2 is neither a pollutant nor a direct measure of occupancy.

CO_2 LEVELS AND VENTILATION

CO_2 based demand controlled ventilation (CO_2DCV) is often implemented with little regard to the actual relationship between ventilation rates and CO_2 levels.

The Ventilation Rate Procedure in ASHRAE Standard 62 specifies ventilation rates, not CO_2 levels for acceptable indoor air quality.

> *"Indoor air quality shall be considered acceptable if the required rates of acceptable outdoor air in Table 2 are provided for the occupied space."* [6.1.3 ASHRAE 62-2001]

Systems must provide adequate dilution airflow rates for compliance. However, even though the standard clearly does not specify acceptable CO_2 levels for compliance, many believe that maintenance of space CO_2 levels will result in acceptable 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.

The relationship between CO_2 levels and outside air ventilation rates can be described using a simple, two chamber mode (Appendix C, ASHRAE Standard 62-2001 parent document).

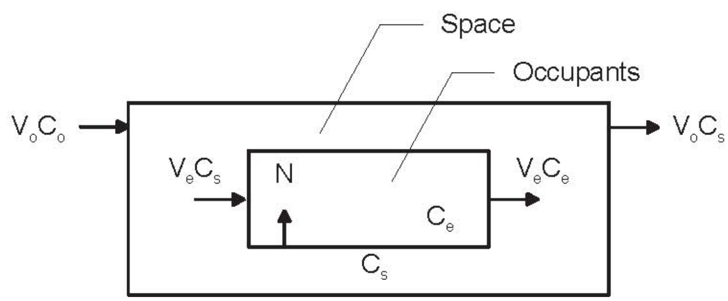

Figure 1 – 2 Chamber Model

Equation 1 - Outside Airflow Calculation

$$V_o = N/(C_s - C_o)$$

where
V_o = outdoor airflow rate per person
V_e = breathing rate N = CO_2 generation rate per person
C_e = CO_2 concentration in exhaled breath
C_s = CO_2 concentration in the space
C_o = CO_2 concentration in outdoor air

This model relates the CO_2 level of the space to the airflow rate **per person** when the following **steady-state** conditions are true:

1. The occupants are generating CO_2 at an assumed constant rate: N (i.e. their metabolic rate, diet, and level of activity are identical).
2. Outside air, of known CO_2 concentration: C_o, is introduced into the space at a constant rate: V_o.
3. The indoor CO_2 level: C_i, represents the population within the ventilation zone and is accurately measured.

Calculating V_o = 7.5 L/sec (≈15 CFM) with an assumed CO_2 generation rate of 0.31 L/min will result in an indoor CO_2 level approximately 700 ppm greater than the level of CO_2 in the outside air. Studies have indicated that 15 CFM is the rate of outside air required to dilute offensive body odor and is the CO_2 rise referenced in Standard 62. Therefore, the resulting statements appear in the standard:

> *"Comfort criteria, with respect to human bioeffluents (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 bioeffluents does not eliminate the need for consideration of other contaminants."* [6.2 ASHRAE 62-2001]

As an indicator of adequate ventilation for the dilution of body odor, the 700 ppm rise criteria may represent a valid indicator for the space being evaluated. The CO_2 generation rate assumed is based on a low activity level and as a result would tend to indicate a lower outside airflow rate than actual for the space. Confidence can be raised if the ventilation rate into the building and space are held constant during the evaluation and the population density is maintained. The technique is best suited for handheld, frequently calibrated, devices in the hands of trained professionals for use in localized areas. Unfortunately, there is a significant difference between monitoring for evaluation and monitoring for control. The CO_2 generation rates of individuals can vary widely as indicated in Figure 2 based on their activity level. As a result, there will be a significant error in the CFM per person calculation (Table 1).

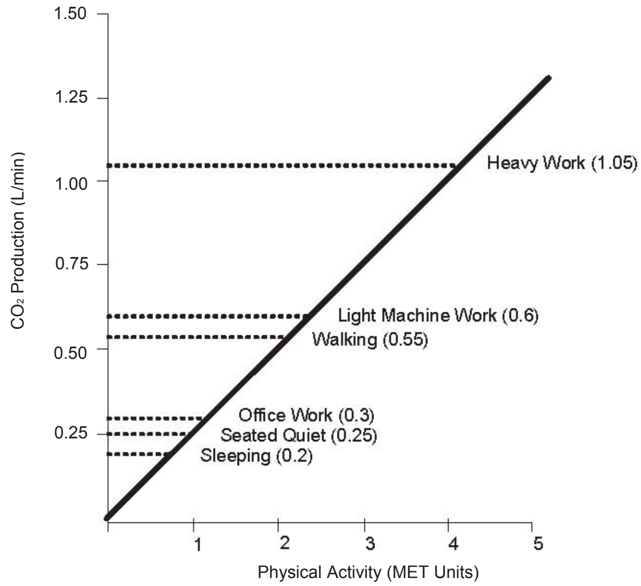

Figure 2 - CO_2 Production vs. Metabolic Activity

Table 1 - Calculation of V_o at Various CO_2 Production Levels, ΔC=700ppm

Activity	N (L/min)	Vo (CFM)
Sleeping	0.20	10
Office Work	0.30	15
Walking	0.55	28
Light Machine Work	0.60	30
Heavy Work	1.05	53

The model is also only valid under steady-state conditions. CO_2DCV, by design, is dynamic and implementation often negates the validity of the model. In addition, the placement and reliability of the CO_2 sensor is critical and the performance of today's sensors is questionable (Figure 3). Additionally, outside CO_2 levels vary widely. Outdoor levels are generally not measured, as a result of the sensors inability to measure accurately at low ambient air temperatures. These uncertainties can result in significant risk for both the designer and building owner implementing a CO_2DCV strategy (Figure 4). Mounting airflow measurement devices in the outside air intake to limit turndown of outside air intake flow rates during periods of low occupancy can reduce IAQ risk.

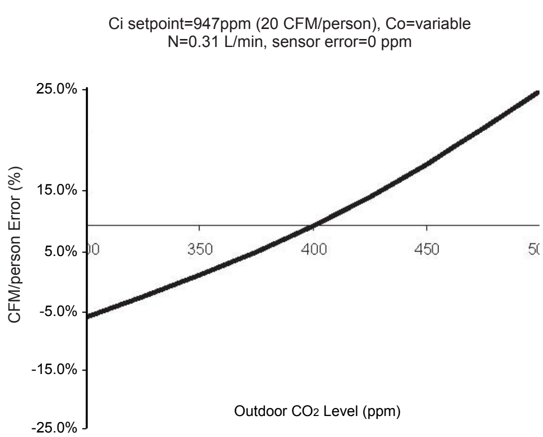

Figure 3 - Sensor Error

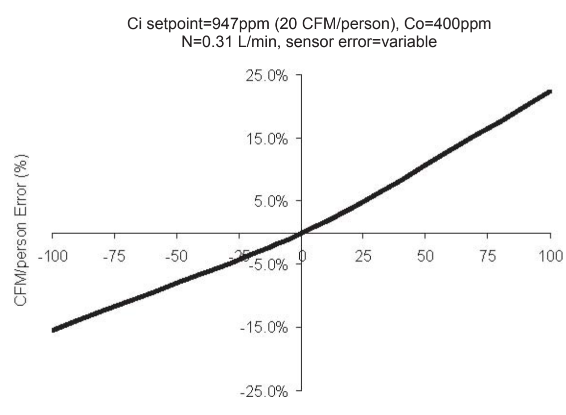

Figure 4 -Assumed Outdoor C_o Error

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. Recent publications have recognized the relationship between building pressure and mold growth[1,2,7,9,10,11,15]. 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.

CO_2DCV AND ASHRAE 62: Complications from *Addendum n* changes

Changes to the Ventilation Rate Procedure of ASHRAE Standard 62 result in outside airflow rates that significantly vary on a "per person" basis (Table 2). *Addendum n* recognizes the magnitude of building generated pollutants. Under ideal conditions, CO_2 levels can only relate the rate that outside air enters the building on a per person basis (i.e. CFM/person). Therefore it is difficult to envision how CO_2DCV can be implemented under the new requirements of Standard 62.

Table 2 - Required CO_2 Level at Various Population Densities in an Office Space (Area = 1,000 sq.ft.)

Total OA CFM Required = 0.06 CFM/sq.ft. + 5 CFM/person (ASHRAE 62, Addendum *n*, offices)

# People	Total OA CFMRequired	CFM/Person	Required C_i-C_o	Comments
7	95	13.5	807 ppm	} Overventilated at 700 ppm
6	**90**	**15**	**700 ppm**	
5	85	17	644 ppm	} Underventilated at 700 ppm
3	75	26	438 ppm	

ENERGY VS. OCCUPANT BENEFIT

As stated from the onset, today's designs emphasize energy efficiency. In part, the strategy is promoted by the requirements of ASHRAE Standard 90.1. However, owners can clearly relate to an energy savings benefit and energy conscious designs are the civil responsibility of all good engineers. However, the human benefit should not be ignored. Table 3 illustrates the potential benefit of a 5% productivity gain. Literature suggests that such a gain could be realized if outdoor airflow rates were maintained at acceptable levels[3,6,8,12,13,14]. When compared to potential energy savings, improved ventilation significantly outweighs its counterpart.

Table 3 - Potential Benefit of 5% Productivity Gain

Annual Income	Benefit/Person/Year	Benefit/sq.ft./Year*
$20,000	$1,000	$6.94
$40,000	$2,000	$13.89
$60,000	$3,000	$20.83
$80,000	$4,000	$27.78
$100,000	$5,000	$34.72

*based on 144 sq.ft./person

ANALYSIS OF RISK

Compared to the benefit, implementing a strategy with significant assumption flaws is extremely risky. Based on *Addendum n* changes, the reduction in outside airflow rates with decreasing occupancy is small. A 57% reduction in the population (7 to 3 people per 1000 sq.ft.) only results in a 21% decrease in the required outside air. Is it really worth the risk?

In addition, recent changes to commercial general liability insurance policies now exclude compensation for mold damage. Lowering outside air ventilation rates decreases the margin of error for proper building pressure control. Effective and stable pressurization strategies, such as those that directly control the pressurization flow (i.e. use airflow measurement), will have to be implemented to minimize designer and owner risk.

CONCLUSIONS

Clearly energy benefits can be realized by implementing a demand controlled ventilation strategy if the number of occupants can be determined with a reasonable degree of accuracy and building pressure can be maintained. Unfortunately, assumptions made using the CO_2DCV approach leave designers and owners vulnerable to unnecessary risk. Changes to the ASHRAE Standard 62 Ventilation rate procedure may result in lesser benefits, hence higher risk. Designers and owners should carefully weigh the risks and benefits prior to implementing the strategy. Consider mounting an airflow measuring station in the outside air intake and maintain design levels of outside air. When a more reliable method to determine occupancy can be implemented, simply adjust the outside air intake flow rates to comply with the standard.

REFERENCES

1. Ask, Andrew C., P.E., 2003, "Building Scientists Meet in New England: Air Barriers are More Important than Ever; Vapor Barriers are Not", Today's A/C & Refrigeration News, September, 2003.
2. Ask, Andrew C., P.E., 2003, "Ventilation and Air Leakage", ASHRAE Journal, November, 2003.
3. Djukanovic, R., P. Wargocki, and P.O. Fanger, 2002, "Cost-benefit analysis of improved air quality in an office building." Proceedings of Indoor Air 2002, The 9th International Conference on Indoor Air Quality and Climate. Monterey, Calif. Vol. 1. Pgs. 808-813.
4. Fanger, P.O., 1988, "Introduction to the olf and decipol Units to Quantify Air Pollution Perceived by Humans Indoors and Outdoors", Energy and Buildings, 12.
5. Fanger, P.O., 1990, "New principles for a future ventilation standard", Fifth International Conference on Indoor Air Quality and Climate", Toronto, Canada, July, pp. 353-363.
6. Fisk, William J., Arthur H. Rosenfeld, 1997, "Estimates of Improved Productivity and Health From Better Indoor Environments", Lawrence Berkley National Lab & U.S. Department of Energy, ISSN 095-6947
7. Harkins, Paul, 2003, "Moisture Control, Remediation are Keys to Mold Control in Buildings", National Underwriter, page 21, Vol. 107, No. 7, February 17, 2003.
8. Kumar, Satish and William J. Fisk, 2002, "IEQ and the Impact on Building Occupants", ASHRAE Journal, April, 2002.
9. MacPhaul, David, P.E., 2003, "The Basics of HVAC Systems in Humid Climates - What Goes Wrong and Why", Energy Engineering, Vol. 100, No. 3.
10. Mold Litigation Task Force of the AGC of America, Inc., Rick Poppe, Chairman, "Managing the Risk of MOLD in the Construction of Buildings", Constructor Magazine, May, 2003.
11. Murray, Steven, P. Eng., 1999(?), "Solving Roof Leaks with Fans", Roof Consultants Institute - 14th International Conference and Trade Show, Canada.
12. Wargocki, Pawel, 2002, "Making the Case For IAQ", ASHRAE IAQ Applications, Fall 2002.
13. Wargocki, Pawel, D.P. Wyon, and P.O. Fange, 2000, "Pollution source control and ventilation improve health, comfort and productivity." Proceedings of Cold Climate HVAC. Sapporo. Pgs. 445 - 450.
14. Wargocki, Pawel, L. Lagercrantz, T. Witterseh, J. Sundell, D.P. Wyon, and P.O. Fanger, 2002, "Subjective perceptions, symptom intensity and performance: a comparison of two independent studies, both changing similarly the pollution load in an office." Indoor Air 12: 74-80.
15. Weber, Blaine J., 2003, "Unwrapping modern building envelopes", A&E Perspectives, www.djc.com/news/ae/11151058.html, November 20, 2003.