AIVC 2017 Workshop: Is Ventilation The Answer To Indoor Air Quality Control In Buildings? Do We Need Performance-Based Approaches?

INDOOR CARBON DIOXIDE AS METRIC OF VENTILATION AND IAQ: YES OR NO OR MAYBE?

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ABSTRACT

Indoor carbon dioxide (CO_2) concentrations have been proposed and employed as metrics for building ventilation and indoor air quality (IAQ) for many decades. In too many cases, such applications have been employed without an adequate understanding of the impacts of CO_2 on building occupants, the relationship between ventilation rates and indoor CO_2 concentrations, and the requirements in ventilation and IAQ standards. While indoor CO_2 concentrations may be a useful metric for ventilation and IAQ, these issues need to be understood and considered in such applications.

KEYWORDS

Carbon dioxide; indoor air quality; metrics; standards; ventilation

1 INTRODUCTION

Indoor CO_2 concentrations have been prominent in discussions of building ventilation and indoor air quality (IAQ) since the 18th century when Lavoisier suggested that CO_2 build-up rather than oxygen depletion was responsible for "bad air" indoors. About one hundred years later, von Pettenkofer suggested that bioeffluents from occupants were causing indoor air problems, not CO_2. Discussions of CO_2 in relation to IAQ and ventilation have continued to evolve, focusing on the impacts of CO_2 on building occupants, how CO_2 concentrations relate to occupant perception of bioeffluents, the use of CO_2 to control outdoor air ventilation rates, and the use of CO_2 as a tracer gas for estimating ventilation rates (Persily, 2015). This paper summarizes these uses, and in some cases misuses, of indoor CO_2 as a ventilation and IAQ metric. The potential uses include the following: comparison to values in IAQ standards; a health-based IAQ metric; and, a surrogate for outdoor air ventilation. Common misuses include using indoor concentrations of 1800 mg/m^3 (1000 ppm$_v$) as an indoor air standard and the improper use of peak concentrations to estimate outdoor air ventilation rates per person

2 CO_2 LIMITS IN STANDARDS

Indoor CO_2 limits exist, but typically only apply to industrial work spaces. For example, in the United States, the health-based ACGIH TLV (Threshold Limit Value) is 9000 mg/m^3 over a 40-h work week and 54 000 mg/m^3 for a 15 min exposure (ACGIH, 2014). Similar levels exist in workplace standards in other countries, but such levels are not observed in non-industrial environments, e.g. homes, schools and office buildings. However, despite many statements to the contrary, IAQ standards do not contain CO_2 limits. ASHRAE Standard 62-1981 contained an indoor CO_2 limit of 4500 mg/m^3 for use when applying the standard's performance approach, i.e., the IAQ Procedure, but that limit was later removed. The current version of that standard (62.1-2016) does not contain any indoor contaminant limits, including for CO_2. It does contain an informative appendix that describes limits for various contaminants issued by other organizations, but those are not requirements of the standard itself. CEN standards 13779 and 15521 do not contain indoor CO_2 limits either, but rather informative annexes that provide default CO_2 concentrations for four classes of IAQ (CEN, 2007a; CEN, 2007b). The highest IAQ class is associated with concentrations about 700 mg/m^3 or less above outdoors, and the lowest class 1800 mg/m^3 or less above outdoors.

Indoor CO_2 concentrations are relevant to ventilation and IAQ standards based on their relation to indoor levels of bioeffluents and associated odors, and their relation to ventilation rates per person. To the first point, several studies of bioeffluent odor perception in chambers showed correlations of dissatisfaction with these odors and both ventilation rate per person and CO_2 level (Persily, 2006). This research resulted in a recommended ventilation rate of 7.5 L/s to 9 L/s per person to achieve a roughly 80 % level of odor acceptability as judged by individuals entering the room from relatively clean air. These ventilation rates can be related to indoor CO_2 levels using a steady-state mass balance of occupant-generated CO_2. For a ventilation rate of 7.5 L/s per person and a CO_2 generation rate of 0.3 L/min per person, such a mass balance yields an indoor CO_2 concentration about 1300 mg/m^3 above outdoors. Using slightly different values of the generation rate and outdoor concentration, one arrives at the familiar CO_2 concentration value of 1800 mg/m^3. This CO_2 concentration (equal to about 1000 ppm$_v$) has become a de facto CO_2 concentration guideline value based on its relationship to recommended ventilation rates, but not based on health effects associated with CO_2.

3 HEALTH IMPACTS OF CO_2

Indoor CO_2 concentrations in non-industrial environments are typically well below values of interest based on health concerns. While several studies have shown associations of elevated CO_2 levels (still below these industrial limits) with symptoms, absenteeism and other effects (Apte et al., 2000; Shendell et al., 2004; Gaihre et al., 2014), these associations are likely due to lower ventilation rates elevating the concentrations of other contaminants with health and comfort impacts at the same time they are elevating CO_2. There have been some studies of individuals completing computer-based tests showing decreases in decision-making performance at CO_2 concentrations as low as 1800 mg/m^3 (Maddalena et al., 2015; Satish et al., 2012; Allen et al., 2016). However, other recent studies did not observe an impact of similar CO_2 levels on occupant performance (Zhang et al., 2016b; Zhang et al., 2016a).

4 PEAK CO_2 CONCENTRTIONS AS AN INDICATOR OF VENTILATION

It is quite common to use indoor CO_2 concentrations to estimate ventilation rates per person based on a single-zone mass balance of CO_2, though in many cases without acknowledgement of the assumptions on which it is based (ASTM, 2012; Persily, 1997). In a ventilated space with a uniform CO_2 concentration, the ventilation rate and CO_2 concentration are related under steady-state conditions assuming the generation rate, ventilation rate and outdoor CO_2 concentration are all constant over the analysis period. This relationship has been discussed in ASHRAE Standard 62 since 1981, in which the steady-state equation is presented as:

$$Q_o = \frac{G}{C_{in,ss} - C_{out}} \quad (1)$$

where Q_o is the outdoor air ventilation rate per person, G is the CO_2 generation rate per person, $C_{in,ss}$ is the steady-state indoor concentration and C_{out} is the outdoor concentration. This steady-state relationship, sometimes referred as the peak CO_2 approach, is an application of the constant injection tracer gas method described in ASTM E741 (2011). It must therefore abide by the following assumptions to yield a valid air change rate: the CO_2 generation rate is known, constant, and uniform throughout the building being tested; the CO_2 concentration is uniform throughout the building and has achieved steady state; the outdoor CO_2 concentration is known and constant; and, the outdoor air ventilation rate is constant. Violation of any of these assumptions will lead to erroneous estimates of ventilation rates. In particular, if Equation 1 is applied before reaching steady state, the ventilation rate will be overestimated.

5 CONCLUSIONS

While reliable information on the proper interpretation of indoor CO_2 concentrations has been available for many years (Persily, 1997), confusion still exists about the relationship of CO_2 to ventilation and IAQ. The only indoor CO_2 limits in standards or guidance documents are either high values applicable in industrial workplaces or lower values that are derived from ventilation requirements combined with a steady-state mass balance of occupant-generated CO_2. Given that this confusion exists, the IAQ and ventilation community needs to educate researchers, practitioners and others through training, presentations and publications for non-academic audiences as well as careful review of technical papers that use indoor CO_2 for estimating ventilation rates or as an indicator of IAQ.

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