Using CO_2 as a Ventilation Clue in Classrooms

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SUMMARY

In the era of COVID19, we need to quickly find and fix classrooms that have inadequate ventilation to reduce long-range airborne transmission of diseases. Historically, the limited available data has shown classrooms in the United States to be under ventilated in relation to consensus standard ventilation values that do not consider airborne infectious disease risk. Carbon dioxide (CO_2) is a reasonable proxy of emissions from humans. This presentation will discuss the assumptions and uncertainties in using carbon dioxide concentrations as a proxy for ventilation in classrooms. Specifically, the influence of student density and activity level on carbon dioxide concentration will be modeled for a range of student ages and activities. This analysis shows classrooms with high carbon dioxide concentrations (above 2,000 ppm_v) are unlikely to be meeting United States ventilation standards. However, uncertainties mean conclusions cannot be easily made about ventilation rates in classrooms with lower carbon dioxide concentrations.

KEYWORDS

ventilation, consumer grade monitors, public understanding

1 INTRODUCTION

The concentration of COVID-19 laden particles can build up in spaces with poor ventilation, with the potential to lead to infection. Adequate ventilation is one way to reduce long-range airborne disease transmission risk in classrooms. ASHRAE is an organization that writes consensus standards for design of buildings including ventilation rates in classrooms. However, these values do not consider airborne infectious disease risk. For typical classrooms, the ASHRAE required ventilation rate of outdoor air is around 7 L s^{-1} $person^{-1}$. However, in surveys a majority of classrooms fall below that value.

Given its relatively high concentration and ease of measurement compared to other chemicals and emissions from people, carbon dioxide is a good proxy of emissions from humans. It is important to note the CO_2 is only a proxy for human emissions and many other things impact indoor air quality. Building materials, furniture, cleaning supplies, indoor chemical reactions and outdoor contaminants all impact indoor air quality. Hence, low indoor CO_2 concentrations do not necessarily indicate good indoor air quality.

When we use CO_2 as a ventilation clue, we need to make sure non-human sources of CO_2 are not present, such as indoor combustion or vehicles idling outside air intakes.

Widespread use of consumer grade indoor air quality monitors can be used to monitor CO_2 concentrations in classrooms, as has been demonstrated by the over 4,000 that were deployed by the Boston Public School System (https://www.bostonpublicschools.org/Page/8810) in 2021. One goal of using CO_2 meters in classrooms is to find poorly ventilated rooms where long-range airborne transmission of disease is more likely to occur.

There are three potential approaches to using CO_2 data collected in classrooms to evaluate ventilation:

1. Evaluate relative risk by determining how much air we rebreathe that has previously been in other people's lungs (rebreathed fraction).
2. Examine the maximum daily CO_2 concentration in a classroom.
3. Determine the outdoor air change rate from CO_2 concentration decay.

2 MATERIALS/METHODS

This talk will examine the second case by comparing the maximum CO_2 concentration in a classroom to model concentrations. NIST has a web-based single zone, mass balance tool (**https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/**) that allows the user to determine what the CO_2 concentration would be in a range of school density and activity scenarios IF the room ventilation system was operating as designed. The tool assumes the assumes the entire building has a uniform CO_2 concentration and all air entering the space comes from outside

3 RESULTS

For a given scenario, the NIST tool can be used to determine a relationship between ventilation rates and the maximum steady state CO_2 concentration in a classroom (Figure 1). The purple line shows potential maximum CO_2 concentrations when the students and teacher have minimal activity (low met values). The green line shows the same potential maximum CO_2 concentrations when the students and teacher have a higher activity level. If the room was operating at the ASHRAE requirement of 6.7 L/s/p the maximum CO_2 concentration could be anywhere from 800 ppm_v to 1250 ppm_v depending only on the activity levels of the occupants.

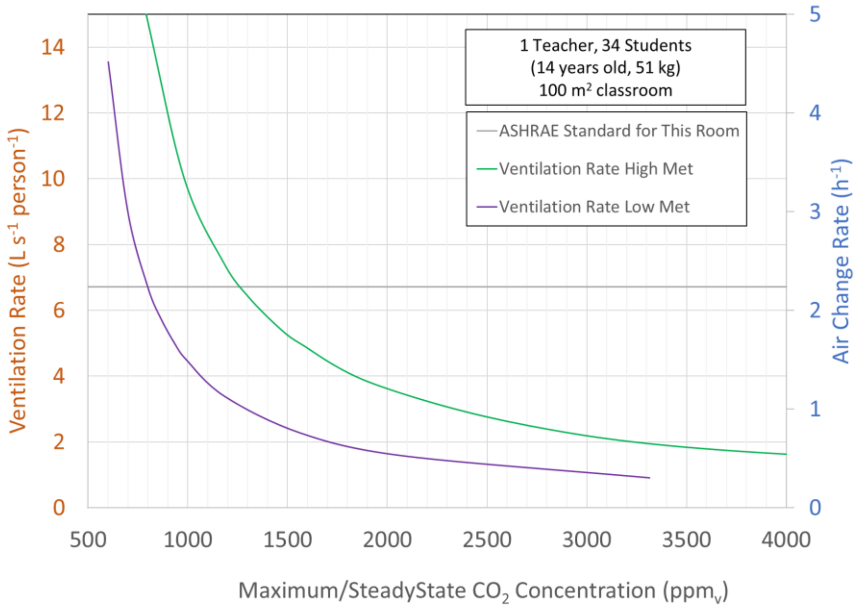

Figure 1. Example relationship between maximum CO_2 concentration in classroom with ventilation rate

4 DISCUSSION

Modeled rooms give a sense of the uncertainty in the model due to activity level, age and number of students. Despite this uncertainty, high maximum daily CO_2 readings are indicative of low outdoor ventilation rates. If the maximum daily CO_2 readings are below 700 ppm_v we can be fairly confident the ventilation rates are high, especially if reading are repeated over multiple days, HVAC operating modes and weather conditions. If the maximum daily CO_2 readings are consistently above 2000 ppm_v we can be fairly confident the ventilation rates are low and the rooms ventilation system should be inspected and/or addressed, and the room usage (student density) should be checked.