What can CO_2 measurements tell us about ventilation and infection risk in classrooms?

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ABSTRACT

Indoor air quality in schools is of critical importance for the health and well-being of pupils and staff. The COVID-19 pandemic highlighted the essential role that ventilation systems play in limiting the spread of airborne diseases and consumer CO_2 monitors were deployed in UK classrooms as a cost-effective tool to help manage the ventilation supply. In such settings, which are occupied for long periods by the same group of people, CO_2 measurements have also been used to infer the risk of far-field airborne infection. Often, only a single point measurement is available and so it is crucial to understand how exposure might differ depending on the infector location and/or sensor position. This is particularly important in UK classrooms which are typically naturally ventilated, and where spatial variations in the concentration of CO_2 and infected breath can be expected.
CO_2 data gathered across 5 years prior to the pandemic from 45 classrooms in 11 different schools were first analysed and estimates of the likelihood of airborne infection were calculated. Even without accounting for the variation in disease prevalence, the data highlight significant variation in infection risk between the seasons, with January being nearly twice as risky as July. Results also show that the risk can vary widely between classrooms of the same school despite similar ventilation provisions. The second part of this work provides a detailed examination of the validity of using CO_2 as a proxy for far-field exposure. For this, a generic naturally ventilated UK classroom in wintertime was simulated using computational fluid dynamics (CFD). The ratio between actual exposure arising from a single infected individual and proxy exposure calculated from point measurements of CO_2 was also analysed. In doing so, the proxy exposure is found to be within a factor of two of the actual far-field exposure. While this factor of two might appear large, it is small relative to the typical uncertainties associated with airborne disease modelling.

KEYWORDS

CO_2 measurements; classrooms; natural ventilation; CFD;

1 INTRODUCTION

Schools are an important setting for indoor air quality. In the UK alone, 11 million pupils and staff regularly attend schools, with the majority of the time spent in classrooms. This came to the forefront of public attention during the COVID-19 pandemic. During this time, the use of carbon dioxide (CO_2) sensors became widespread in classrooms to help manage ventilation provision. In addition, CO_2 sensors have also been shown to be cheap and effective tools to assess the risk of far-field airborne infection to respiratory diseases such as COVID-19, following for instance the work of Rudnick and Milton (2003). However, in existing studies, only a limited number of measurement locations have been considered (ASHRAE, 2022) and for practical reasons often single-point measurements are available in classrooms. In naturally ventilated spaces (which includes the majority of classrooms in the UK) this can be problematic as the indoor spaces are rarely well-mixed. If CO_2 sensors are to achieve widespread success in managing indoor air quality and limiting the spread of airborne diseases, then these limitations need to be addressed.

2 METHODOLOGY

This work uses both CO_2 measurements in operational classrooms and Computational Fluid Dynamics (CFD) simulations to determine how CO_2 measurements can be used to assess the ventilation provision and airborne infection risk in UK classrooms.

2.1 CO_2 measurements in schools

A dataset of CO_2 concentration in UK schools spanning 5 years before the pandemic (2015-2020) is obtained and analysed. Measurements are made in 45 classrooms from 11 different schools across the UK in both primary and secondary schools. Following the work of Rudnick and Milton (2003), the CO_2 concentration is used to assess the rebreathed fraction and the resulting risk of airborne infection for the 32 occupants if one infector is to attend regularly the classroom for a pre- or asymptomatic period of 5 days.

2.2 CFD simulations

Simulations of a generic naturally ventilated classroom are performed using OpenFOAM. A wintertime scenario is considered where ventilation is solely buoyancy driven. The heat input (both from occupants and the heating provision) is input uniformly across the floor and drives the ventilating flow through high- and low-level vents. The presence of occupants is modelled via the addition of passive scalars at breathing height representing both the overall CO_2 output and tracers representing a potentially infected breath. This allows the comparison of both distributions to determine how exposure estimates are affected by the use of CO_2 as a proxy.

3 CONCLUSIONS

Historical measurements of CO_2 spanning 5 years in UK schools highlight the seasonal variations in ventilation provisions and resulting impact on airborne infection: notably the risk doubles in January when compared to July (the least risky month). Numerical simulations allow the measurement of the uncertainty introduced by the use of a single measurement in a naturally ventilated classroom. Although the CO_2 distribution is shown to vary spatially, point measurements are shown to be good indicators of the ventilation provision, especially when compared to other sources of uncertainties such as knowledge of the number of occupants and their activity levels. When used to assess the risk of airborne infection, using CO_2 as a proxy leads to exposure within a factor of two of exposure to infected breath. This uncertainty is lower in magnitude relative to that from other sources including estimates of the quanta generation rates which can vary by three orders of magnitude.

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5 REFERENCES

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