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Ventilation for Energy Efficiency and Improved Indoor Air Quality in University Classrooms

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ABSTRACT

This paper reports preliminary analysis from a large field study of 100 university classrooms in Central Texas. Lecture classrooms and auditoriums were sampled for three consecutive weekdays in the 2019 – 2020 academic year. Carbon dioxide (CO_2) concentrations, used as a marker for both ventilation and exposure, and temperature were measured in the general room area and when able, the supply airstream. HVAC control data that relates to ventilation was also saved for comparison. Preliminary results of typical CO_2 concentrations during occupied hours suggest that university classrooms rarely exceed ASHRAE 62.1 recommendations for classrooms. Contrastingly to K-12 classrooms that are often under-ventilated, our data shows that university classrooms are well-ventilated if not over-ventilated. The reason for this over-ventilation is due to non-uniform classroom temporal usage in university buildings resulting in empty classrooms and therefore the variable air volume (VAV) systems, typically found in university buildings, cannot properly adjust ventilation rates.

INTRODUCTION

A school's indoor environmental quality is known to have an effect on student performance, productivity, and health (Shendell et al. 2004; Mendell et al. 2013; Brink et al. 2021). Engineering approaches, including ventilation control, can be employed to optimize indoor air quality and subsequently better conditions for students and staff. Yet, a two-part problem arises: many classroom studies have found inadequate ventilation rates as per ASHRAE 62.1 standards on ventilation for acceptable IAQ, and proper ventilation often imposes additional energy and/or ventilation retrofit-related cost on schools (Fisk 2017). Most often CO_2 concentrations, released by occupants, are used as a proxy for ventilation rates; the CO_2 level can indicate if a classroom is under-ventilated or over-ventilated. While overventilation leads to energy losses, under-ventilation can lead to accumulation of pollutants associated with occupants such as: odors, personal care products, or viruses that may lead to adverse health effects for building occupants. Two comprehensive review articles of epidemiology and ventilation/HVAC building parameters found sufficient and strong evidence to demonstrate a relationship between ventilation rates, movement of air, and airborne infectious disease (e.g., influenza, SARS, measles, tuberculosis) transmission (Li et al. 2007; Luongo et al. 2016). Given the growing body of evidence of the airborne route of influenza transmission and other respiratory illnesses, ventilation controls need to be evaluated for their effectiveness.

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Although many existing studies have characterized ventilation problems in primary and secondary schools, few comprehensively address ventilation and building systems in university classrooms. In the United States, university campuses are heavily occupied indoor spaces that account for approximately 20 million students as well as staff and professors (National Center for Education Statistics 2020). The complexity of campus building ventilation systems is driven by diversity in classroom type, air handling unit (AHU) configuration, and dynamic occupancy patterns across classrooms. This study aims to a) characterize building ventilation control systems and air handling unit configurations (single zone vs. multizone) across a university campus; b) estimate ventilation and recirculation rates in highly occupied classrooms; and c) investigate the potential for human health exposure as well as typical energy costs associated with ventilation.

METHODS

To achieve the research objectives, data was collected as part of a multi-year field mapping ventilation across a university's campus. Measurements were taken in highly occupied classrooms across The University of Texas at Austin's campus, representative of a hot and humid climate, to monitor temporal variation in CO_2, temperature, and relative humidity. CO_2 sensors (Telaire 7001, Onset Corporation, Bourne, MA) and a temperature/relative humidity sensors (HOBO U12, Onset Corporation, Bourne, MA) were placed in classrooms across the campus during the 2019-2020 academic year for three to four-day periods to capture repetition and variability in classroom schedules. Measurements were sampled at a one-minute frequency with a precision of ± 50 ppm (or 5%), ± 0.3 ^{o}F, and ± 2.5% RH respectively. Measured buildings are 11 – 91 years in age and classrooms range in size, type, (e.g., classrooms, lecture halls, and auditoriums), and AHU configurations (single zone vs. multi-zone). Sensors were placed typically on chalk boards away from human interruption. When applicable, CO_2 sensors were placed in the exhaust and supply vents in rooms and the mechanical systems to characterize total fraction of outdoor air for multi-zone systems. Control data on the classrooms and AHUs (e.g., air flow rates, recirculation rates, and when available space and return CO_2 levels) were recorded and applied in analyses to understand existing ventilation controls. The start of the COVID-19 pandemic abruptly stopped data collection; further sampling will occur in the Spring 2022 academic semester to ensure a analysis is representative of typical classrooms and buildings systems.

RESULTS AND DISCUSSION

Over the course of the 2019 - 2020 academic year, CO_2, temperature, and relative humidity was measured in 100 classrooms (84 lecture, 16 auditoriums) across 21 buildings on campus. Most of the auditoriums on campus have their own air handling unit, and therefore can be considered single-zone, with CO_2 sensors in the return ducts. Of the 21 buildings, only classrooms in two of the buildings were on multi-zone air handling units that served only classrooms. All other lecture classrooms monitored in other buildings are on air handling units that serve conference rooms, office spaces, and even laboratories. Most of the CO_2 based demand control ventilation in university classrooms is based on return air concentrations except for newer buildings that have space-level CO_2 sensors. Figure 1 below presents preliminary results on several typical classroom; it shows the CO_2 concentrations during occupied hours, 8am - 6pm. CO_2 concentrations for each classroom were averaged on a five-min time interval and then binned into five different concentration bins. The 1000 - 1200 ppm bin, as per ASHRAE Standard 62.1, was representative of being 'well-ventilated' and anything below and above that threshold was consider over-ventilated and under-ventilated respectively (ASHRAE 2019). Of the classrooms that were monitored with, typically CO_2 concentrations rarely, <20% of occupied time, exceed 1200 ppm. This indicates that most university classrooms are over-ventilated, and this is due to the varying occupancy patterns across classrooms. As more than half of university buildings don't have occupancy sensors the ventilation rate in these buildings is constant and assumes for the full occupancy. We detected significant overventilation even in the classrooms that have CO_2 sensors installed in the return air ducts of the air handling units that serve these classrooms. However, the number of classrooms per air handling unit is large, and the non-uniform occupancy patterns across these classrooms connected to the air handling unit diminishes benefits of ventilation adjustment based on CO_2

sensors in the return air.

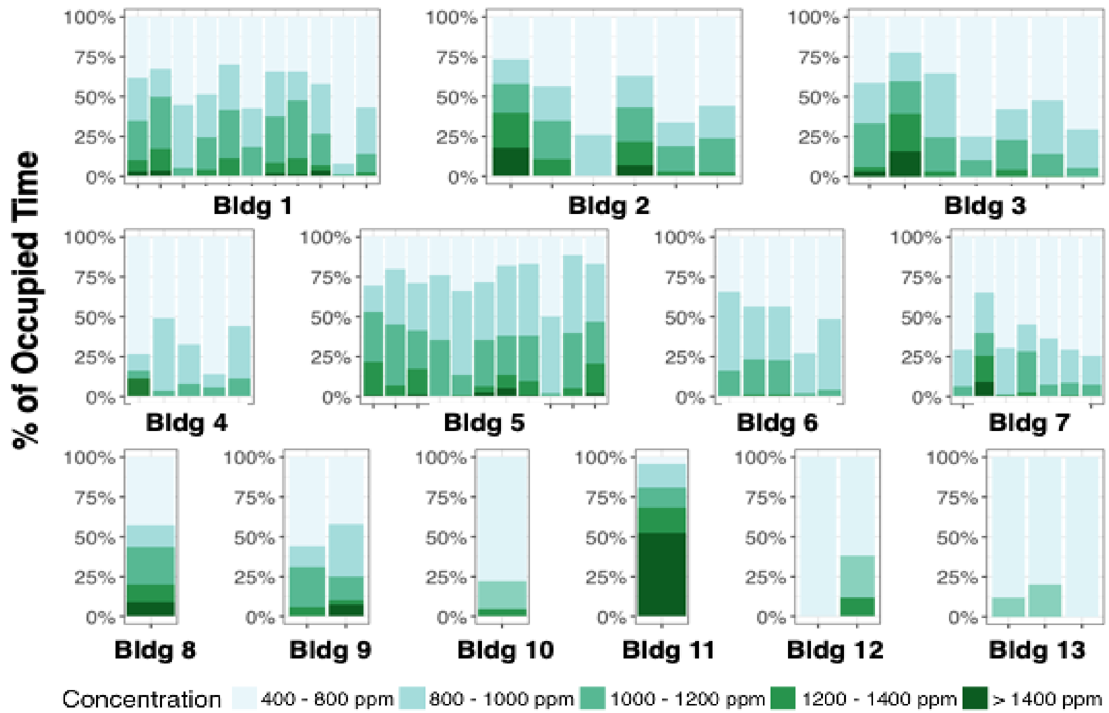

Figure 1 Typical CO2 concentrations in university classrooms during occupied hours.

In the future work: the following metrics will be compared across building system configuration, classroom type, control type, and time of data. Ventilation rates will be computed using steady-state and pseudo steady-state periods of indoor CO_2 concentrations, occupant CO_2 emission rates, and attendance data. Ventilation rates will also be quantified for unoccupied periods in indoor spaces by CO_2 decay analysis to compare rates during periods of occupancy and no occupancy. As able, recirculation rates will be approximated using measurements in AHU exhaust ducts and saved control data. Initial analysis suggests that given typical condition loads, approximately 70% of supplied air to classrooms is recirculated. Rebreathed fractions of air, that fraction of indoor air that is exhaled breath, will also be calculated for each classroom and class period as a proxy for airborne exposure (Rudnick and Milton 2003).

CONCLUSION

This study characterizes typical ventilation rates and building systems as well as potential for exposure to human generated contaminants across university campus buildings. The results from this study compliment and extend existing literature on ventilation in classrooms. Further analysis and data collection will robustly improve statistical significance of results. Results from this study will inform which building systems and control mechanisms lead to specific ventilation conditions as well as which type of classrooms have the strongest potential for benefiting from advanced ventilation systems.

ACKNOWLEDGEMENTS

The research presented in this paper is funded by The University of Texas at Austin's Office of Sustainability Green Fund grant program.

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