Investigating the indoor air quality of common library study spaces in an Australian university

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SUMMARY
Indoor air quality (IAQ) is a key factor that affects the environmental quality of educational facilities and influence educational outcomes. Yet, the indoor environments of educational institutions in Australia have been much less studied compared to other building types and occupancies. Information on indoor environmental conditions in educational facilities is limited and few studies on measurements of educational environments, particularly on thermal conditions and IAQ, are available. This paper reports on the key findings of the pilot study on the measurement of IAQ of two library spaces in an Australian university. The indoor environmental conditions and daily occupancy of the study spaces in these libraries were monitored across six days in winter and early summer. Results suggest a correlation between CO\textsubscript{2} concentration levels (426-904ppm) and occupancy rates in the spaces (up to 93% occupied). Setting effective ventilation and optimal CO\textsubscript{2} concentration levels based on performance would objectively meet the appropriate requirements of educational facilities.

KEYWORDS
Indoor environments; Indoor air quality; CO\textsubscript{2} concentration levels; Educational facilities

1 INTRODUCTION
The indoor environmental quality (IEQ) plays a significant role in our daily living and wellbeing. Australians spend 90% or more of their time indoors (Department of the Environment 2016). Poor indoor air quality and thermal conditions in buildings have been shown to decrease productivity and cause dissatisfaction for building occupants (Wyon 2004; Zhang, Arens & Pasut 2011). However, much of the research on indoor environments has focused on the performance of adults in offices (Mahbob et al. 2011; Wyon & Wargocki 2006) and little or limited information is available on whether indoor environments, particularly indoor air quality, in educational institutions also have similar effects on the performance of university students and learners (Mendell et al. 2013). IAQ is one of the factors which affects learning performance in schools, besides having health effects on students. Studies show that compromised IAQ is often the cause of absenteeism and poor performance, in both office and school environment (Daisey, Angell & Apte 2003).
2 REQUIREMENT FOR INDOOR AIR QUALITY (IAQ) AND VENTILATION

Acceptable IAQ is generally defined as air with no known contaminants at harmful concentration levels, and in which more than 80% of the occupants do not express dissatisfaction (ASHRAE 2010). The quality of indoor air is attributed to the amount of pollutants present in the indoor environment, and the concentration of these pollutants is dependent on (Bluyssen 2009): (a) The emission rate of pollutants in the space; (b) The ventilation rates of the space; and (c) The concentration of the pollutants in the ventilation air.

Sources of indoor air pollutants are varied, such as human bio-effluents and activities, poor quality of outdoor air taken into the building via mechanical means, emissions from construction materials etc. Among these indoor air pollutants, carbon dioxide (CO\(_2\)) concentration level is most commonly used as a surrogate and indicator for IAQ in many air quality related research and studies. Typical indoor carbon dioxide (CO\(_2\)) concentration levels ranges between 500 to 1,500ppm (parts per million) with normal outdoor level ranges between 350 to 450ppm (Seppänen 2006). High indoor CO\(_2\) concentration levels can have adverse health impacts on individuals (Olesen & Seelen 1993), such as increased headaches, undesired work performance and difficulties in concentration (Seppänen, Fisk & Mendell 1999). Studies also suggest that indoor CO\(_2\) concentration levels beyond 1,000ppm affect decision-making performance (Satish et al. 2012) and increased absenteeism (Shendell et al. 2004). ASHRAE standards recommend the target value of 1,000ppm and indicates the maximum indoor CO\(_2\) concentration level of 2,500ppm (ASHRAE 2010).

IAQ in a building is not constant and it is influenced by changes in building operation, occupant activity and outdoor climate. Indoor quality may be managed by a combination of source control and ventilation. The standards for indoor air quality pertain to reducing the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of occupants by providing the recommended ventilation rates. Seppänen, Fisk and Mendell (1999) suggest that the control of the ventilation is equivalent to control of CO\(_2\) in the same indoor space. There is much reliance on the efficiency of HVAC systems for effective ventilation within the buildings and ventilation rates to achieve the optimum indoor environment and air quality. Although extensive studies on IAQ have been conducted in educational facilities, many of these studies suggest that IAQ conditions do not generally meet the recommended ventilation standards (Daisey, Angell & Apte 2003; Mendell et al. 2013).

3 INDOOR AIR QUALITY (IAQ) IN EDUCATIONAL FACILITIES

In a study of 30 empirical studies on the relationship between aspects of indoor environments and the academic performance of students, Mendell and Heath (2005) concluded that students’ attention and performance is associated with ventilation rates. A study of UK classrooms show that occupants were exposed to unacceptable air conditions of CO\(_2\) concentrations of up to 5,000 ppm, and indicated that low ventilation rates have negative effect on students’ memory and concentration, and lowers attention and vigilance (Bakó-Biró et al. 2012). Classrooms in the US, Canada and Sweden were reported to have CO\(_2\) concentration levels exceeding 1,000ppm.

There are limited studies done in tertiary educational spaces. A study on CO\(_2\) concentration analysis of lecture rooms at a Malaysian university show an average value of beyond 1,000 ppm (Dadan et al. 2006). Cheong and Lau (2003) also identified high pollutants concerns in a lecture theatre and staff offices at a Singaporean university, and recognized that ventilation could be the solution to improve IAQ. Luther and Horan (2014) carried out indoor CO\(_2\)
concentrations measurements during winter season in Australia, and findings show that requirements of standards have been compromised, arising from inadequate ventilation. It was also concluded that negotiated IAQ is consistent in school classrooms world-wide.

4 STUDY SPACES IN UNIVERSITY LIBRARIES
The primary objective of this pilot study, using university library spaces as case study, is to investigate the indoor air conditions and examine the values of indoor air quality conditions recommended by IAQ standards. Central to the study is the field investigation, which involved both the monitoring of the indoor conditions of two (2) common study spaces using laboratory-grade instrumentation and the observation of the occupancy levels of the spaces. These library study spaces are often seen crowded and densely occupied by students, who typically spend long hours in these spaces.

The indoor environment monitoring instrumentation used for this study is the Testo 480 which consisted of temperature, humidity, CO$_2$, globe thermometer, and omni-directional anemometer sensors and probes. This instrumentation measured the physical quantities of air temperature, relative humidity, globe temperature, air velocity and CO$_2$ concentration levels which described the conditions of the study spaces within the two libraries. The indoor air conditions in each of library spaces were monitored over six (6) days, three (3) in early winter (June 2016) and three (3) days in early summer (October/November 2016), between time periods of 8:00am to 11:00am; 11:00am to 2:00pm and 2:00pm to 5:00pm. The sensors and probes were placed at 900mm above finish floor level. The occupant observations during the field measurements include the headcount of occupants in the space; gender of the occupants and the activities the occupants were engaged in. In the summer period, the flow rates at the supply air diffusers were also measured at the end of each time period.

![A]

Figure 1: Library study spaces, SS1 (A) and SS2 (B).

The two common study spaces, each located in two campus libraries, are similar in spatial characteristics (Figure 1). Both spaces are carpeted and furnished with amenities conducive for learning environments. Study Space 1 (SS1) is located in the campus main library and is a partially enclosed space, with seating capacity of 78, closely arranged across approximately 158m$^2$ of floor area. Study Space 2 (SS2) is located in the auxiliary library of the university and is open plan measuring approximately 72m$^2$, with seating capacity for 52 occupants, and the seats were randomly arranged close to the perimeter walls. Both library spaces are air-conditioned and within the measured spaces, SS1 and SS2 have five (5) and four (4) supply air diffusers, respectively.
5 RESULTS
The physical measurements of air temperature, relative humidity, mean radiant temperature and air speed of the two library spaces were consistent and showed little variations in both winter and summer periods, potentially due to the controlled indoor conditions. The average indoor air temperature for both seasons was 22.8°C and ranged from a minimum of 17.6°C to a maximum of 25.1°C. Some variance in the average air speed was observed; 0.15 m/s⁻¹ in winter compared to 0.23 m/s⁻¹ in summer. However, it was considered that the measured air speed near and around the instrumentation during the time of field measurement may have been affected by the flow and movement of people. The average relative humidity shows some marked difference, with 41.7%RH in winter and a lower 35.9%RH in summer. The mean radiant temperature (MRT) at each study space was calculated from the measured globe temperature and air speed. The average MRT at SS1 in both seasons had little variation, at 22.7°C and 25.8°C in winter and summer respectively. However, the MRT at SS2 was markedly higher in winter at 32.4°C and 23.3°C in summer. This was the result of sunny afternoons during the field measurements. Overall, the measured indoor conditions met the requirements of comfort in accordance with ASHRAE Standard 55 (2013). Across the three days for each measurement period, the average indoor CO₂ concentration levels in SS1 was higher in winter at 758ppm (range of 531-904ppm) compared to the measurements in summer at 556ppm (range of 388-641ppm). For SS2, the CO₂ concentration levels in winter ranged from 426ppm to 542ppm with an average of 459ppm. A slight increase of an average of 494ppm was measured in summer (range of 412-517ppm).

![Image of CO₂ concentration levels during winter (A) and summer (B)](image)

The observed occupancy level was visibly higher at SS1 in both seasons, with maximum 73 occupants in winter and 53 in summer. SS1 is the main library of the university and as it was pre-examination week when the field measurement was carried out in winter, the levels of occupancy was expected. The maximum occupancy at SS2 ranged from 16 in winter to 22 in the summer, due as well to vocational education pre-examination week. The slight rise however did not seem to impact the CO₂ concentration levels.

6 DISCUSSION
The consistent air temperature and RH measurements in the study spaces is due to the controlled air-conditioned environments. The direct effects of the outdoor conditions were negligible. However, as expected, there is a strong correlation between occupancy and CO₂ concentration levels.
The effects of the occupancy rate on the CO\textsubscript{2} concentration levels in SS1 library space is noticeable in the morning for both seasons, due to the consistent flow of students entering and using the space. However, this correlation between the occupancy and CO\textsubscript{2} levels decreased as the day progressed seemingly suggesting that a peak CO\textsubscript{2} levels was reached (904ppm in winter; 641ppm in summer) (Figure 2) and appears to be maintained by the HVAC systems. In contrast, observations at SS2 library space show that CO\textsubscript{2} concentration levels increased as the day progressed regardless of occupancy levels. As occupancy levels in the morning was negligible due to small number, this was insufficient to draw conclusions as to the effect on the indoor CO\textsubscript{2} concentration levels. However, the observed increase in CO\textsubscript{2} levels in the afternoon seem to point to the accumulation of CO\textsubscript{2} in the observed space from the start of day (Figure 2). While both library spaces, SS1 and SS2, achieved acceptable IAQ, below 1,000ppm indoor CO\textsubscript{2} concentration levels, the spaces have fallen short of the required minimum floor area requirement. SS1 is approximately 2.0m\textsuperscript{2} per occupant and 1.4m\textsuperscript{2} per occupant for SS2. At its occupancy peak of 93% with 73 occupants, SS1 CO\textsubscript{2} concentration levels remained below 1,000ppm (904ppm). However, with its highest occupancy of 30% at SS2, the CO\textsubscript{2} concentration levels was 542ppm. Hence, it is assumed that CO\textsubscript{2} concentration levels will continue to rise should the space were to be fully occupied.

The ventilation rates in this case study are assumed to comply with the requirements of Standards Australia (1991): with outdoor air flow rate of 10 ls\textsuperscript{-1} per occupant, and a minimum of 5m\textsuperscript{2} per occupant. To compare the measured ventilation rates with the 1991 ventilation requirements, a simple online calculator was used to convert air speed in the duct measured at the end of each time-period to air flow rates, using supply air diffuser (ceiling) of 450/600 neck/face size (observed). Based on the existing seating capacity for both study spaces, the average ventilation rates at SS1 and SS2 were 7.72 ls\textsuperscript{-1} and 15.65 ls\textsuperscript{-1}, respectively. It was also observed that certain areas within SS2 experienced air draft, and two (2) of the four (4) supply air diffusers have much higher air speeds.

7 SUMMARY
Using the findings of this pilot study, the indoor occupancy level and occupant activities were found to contribute to increased indoor CO\textsubscript{2} concentration levels. Simply prescribing ventilation rates, specifying occupancy levels and minimum floor area per occupant do not equate to good indoor air. The prescribed indoor air conditions and limits recommended by the standards for educational facilities were based on studies which often do not take student performance into account. This pilot study on university library spaces establishes the need for a further study grounded on addressing the absence of clear documentation on the state of indoor air quality in educational facilities in Australia, backed by measurements and surveys of indoor quality and the relationship between these aspects of indoor environments and student performance.

8 REFERENCES
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