Baltic Journal of CLINICAL MEDICINE and RESEARCH • 2024/01 • 001-008
https://doi.org/10.25143/rsu-bjcmr.2024.01.001-008

BJCMR

Changes in Concentration of Carbon Dioxide and Temperature in University Classrooms

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Summary

This study aims to observe variations in temperature, relative humidity, and carbon dioxide concentrations in university classrooms without mechanical ventilation throughout the day. Over three days, two classrooms in Riga Stradiņš University, equipped solely with natural ventilation, were evaluated for variations in indoor air quality. Observations were recorded using the Aranet4 sensor during actual study sessions with varying numbers of occupants, and ventilation periods marked by window operations. The recorded parameters were compared with established indoor air quality guidelines. The results showed that the relative humidity remained within the ideal range (40%–60%) throughout the observation period. Indoor temperature varied between 18 °C to 26 °C, with noticeable increases during practical study sessions and decreases during ventilation periods. The carbon dioxide levels consistently exceeded the safe limit of 1000 ppm during all study sessions, with the time taken to exceed this threshold being directly proportional to the number of occupants. The findings underline the need for strategic ventilation interventions and classroom arrangements, considering occupancy and room size to promote healthier learning environments. Further research incorporating occupant surveys and including diverse educational settings is recommended.

Keywords: indoor air quality, natural ventilation, classroom environment, carbon dioxide, relative humidity, temperature.

Introduction

The significance of healthy indoor air quality to human health and overall wellbeing cannot be overstated. Autrup et al. noted that poor air quality affects individuals primarily indoors, contributing to more than 90% of such cases (Autrup et al., 2007). Enhancing indoor air quality aids in preventing the transmission of infectious diseases, such as Covid-19, while promoting the general wellness and cognitive performance of individuals, as highlighted by Agarwal et al. and Elsaid and Ahmed (Agarwal et al., 2021; Elsaid and Ahmed 2021).

Elaborating on the subject, Marques et al. identified carbon dioxide (CO_2) as a potential indicator of indoor pollutants, thus helping assess the overall quality of indoor air. CO_2, characterized as a colourless, odourless anthropogenic air pollutant by bodies such as the United States Environmental Protection Agency (EPA) and the Intergovernmental Panel on Climate Change (IPCC), is predominantly released indoors through human respiration (Erdmann et al., 2002; Marques et al., 2019). Research has linked moderate to high concentrations of indoor CO_2

to various health and cognitive problems, such as fatigue, headaches, nausea, vomiting, dizziness, reduced decision-making capabilities, impaired learning outcomes, and decreased work performance (Bakó-Biró et al., 2012; Satish et al., 2012; Toftum et al., 2015; Yu et al., 2009). A strong correlation also exists between high indoor CO_2 levels and increased concentrations of other indoor pollutants, necessitating monitoring CO_2 levels to ensure a healthy indoor environment (Marques et al., 2019; Satish et al., 2012).

In their study, Heracleous & Michael discovered that CO_2 peaks reached approximately 3000 ppm, indicating that individuals might not always recognize poor air quality. They noted that thermal comfort, characterized by indoor air temperature and relative humidity, is perhaps the most crucial aspect when assessing indoor environmental quality (Heracleous & Michael, 2019). Thermal comfort, an individual's perception of satisfaction with the indoor thermal environment, varies from person to person and is influenced by factors, such as age, gender, activity level, clothing, among others. It has a direct bearing on respiratory health, overall wellbeing, and productivity (Kim et al., 2022; Lin et al., 2016). A number of studies have documented that high indoor temperatures increase fatigue, dissatisfaction due to thermal discomfort, and reduce concentration and academic performance. Conversely, extremely low temperatures can induce symptoms similar to asthma or flu (De Giuli et al., 2012; Haverinen-Shaughnessy et al., 2012; Kim et al., 2022; Shaughnessy et al., 2012; Melikov et al., 2013).

Relative humidity (RH), which measures the concentration of water vapor in the air, significantly influences body's thermoregulation at high and low temperatures (Aulika et al., 2008). High RH levels can promote the survival and transmission of viruses, mould, bacteria, and dust mites, potentially leading to asthma, allergies, and other respiratory symptoms (Angelon-Gaetz et al., 2016; Derby et al., 2016; Quinn, 2011). On the other hand, low RH can cause stuffy or dry air, increased respiratory symptoms, irritation, asthma, and other sick-building syndrome-type symptoms (Angelon-Gaetz et al., 2016; Bakke et al., 2008; Lukcso et al., 2016; Quinn, 2011).

Therefore, monitoring indoor temperature, relative humidity, and carbon dioxide levels is crucial for promoting health, comfort, and overall satisfaction among occupants.

Aim of the study

The purpose of this study was to observe variations in temperature, relative humidity, and carbon dioxide concentrations in university classrooms without mechanical ventilation throughout the day.

Material and methods

The study was carried out over three days in Riga, Latvia, within a building of Riga Stradiņš University, specifically focusing on two classrooms equipped solely with natural ventilation. The initial day of the study focused on a smaller classroom of 72.3 cubic meters, while the subsequent two days targeted a larger room of 119.7 cubic meters. Throughout the duration of the study, we consistently tracked relative humidity (RH), indoor temperature, and carbon dioxide (CO_2) levels. This was accomplished using the Aranet4 sensor (SAF Tehnika JSC Ltd, Latvia), strategically placed in the centre of the classroom and surrounded by students.

Measurements were collected between the hours of 8:00 and 15:00 on the first two days and were extended until 17:00 on the final day. These measurements were recorded during actual study sessions at Riga Stradiņš University, with three sessions held on the first two days and an additional fourth session on the last day. Noteworthy details such as the number of students present in the classroom and the timing of window operations (opening and closing) were logged. The opening of windows signalled the initiation of ventilation, while their closing marked the end of ventilation, synchronizing with the commencement of each study session.

Upon collecting the data, a detailed analysis was performed comparing the results with established indoor air quality guidelines and regulations. This analytical process considered the optimum relative humidity level between 40 and 60% (Dietz et al., 2020; Noti et al., 2013) and a safe CO_2 level of 1000 ppm, as per the findings of numerous studies concerning occupants' health and wellbeing (Azuma et al., 2018; Satish et al., 2012). In line with Latvia's legislative requirements for the winter season, the indoor temperature range was set between 19 °C and 25 °C (Likumi.lv, 2009), given that the measurements were recorded in November. Lastly, the outdoor weather conditions were verified using the timeanddate.com website (Timeanddate, 2022).

Results

Classroom ventilation schedules varied daily, as shown in Table 1. Across all three days, the classrooms were mostly filled with 8 to 11 occupants (students and a lecturer), barring the morning study session on day two with 4 occupants and the final session on day three with 6 individuals.

The weather during the three-day period was consistently overcast, with light rain or drizzle reported on days two and three. Outdoor temperatures remained within the range of 7.5 °C to 11 °C, and humidity varied between 92% and 96% (Timeanddate, 2022).

Relative humidity

Throughout the three-day period, the relative humidity was within the ideal range of 40% to 60%. The minimum RH recorded was 42% at 10:48 on the first day, while the maximum RH of 55% was recorded on the second day between 08:00 and 08:38, and on the third day between 14:13 and 14:48.

Table 1. The daily schedule for ventilation activities.

Day	Ventilation	The start of the ventilation	The end of the ventilation
Day 1	1	08:00	09:03
	2	10:40	11:23
	3	13:03	13:23
	4	14:38	-
Day 2	1	08:00	09:00
	2	10:00	10:10
	3	11:28	11:34
	4	12:52	13:15
	5	14:33	-
Day 3	1	08:34	09:42
	2	11:07	11:42
	3	13:07	13:32
	4	14:53	15:06
	5	17:10	-

Temperature

Throughout the three-day period, the indoor temperature oscillated between 18 °C and 26 °C (refer to Figure 1). The peak temperature, 25.9 °C, was observed on the first day at 10:18. On this day, measurements were taken in a smaller classroom where the temperature surpassed the permissible maximum of 25 °C three times: at 09:58, at 12:18, and at 14:08. The room temperature exceeded this limit after 55 minutes for the first two instances, while on the third occasion, it was 45 minutes into the session and post-ventilation. Occupancy during these times was 9, 11, and 8 individuals, respectively.

On the second and third days, observations were made in a larger classroom, where the temperature remained within the minimum and maximum permitted limits for most of the day, except for a brief period on the third day from 10:43 to 11:13 (as shown in Figure 1). On the second day, classroom occupancy varied between 4 and 9 individuals. When 9 individuals were present, the indoor temperature reached close to but did not surpass 25 °C after approximately an hour and 20 minutes. Conversely, on the third day, the indoor temperature crossed 25 °C an hour into the first study session with 11 occupants. The rest of the day saw an average occupancy of 6 to 9 individuals for roughly an hour and 20 minutes per session, during which the temperature rose but remained below 25 °C.

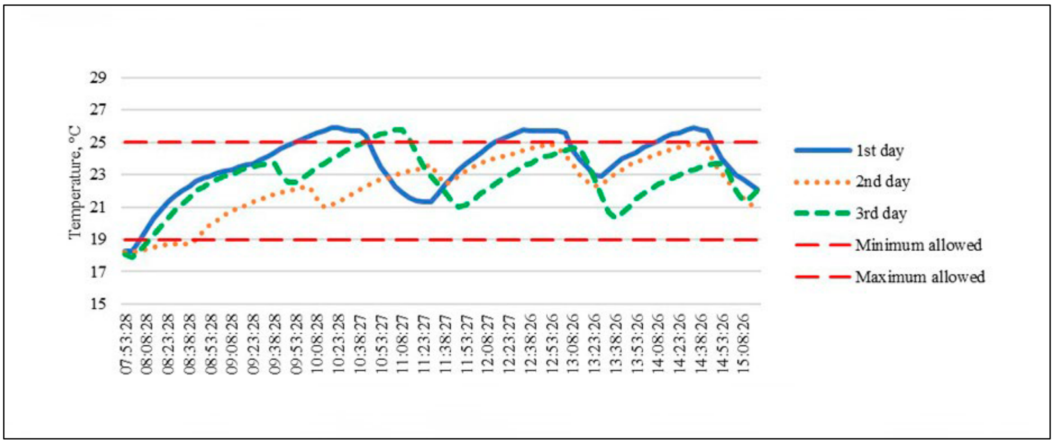

Figure 1. The range of indoor temperature in university classrooms during all three days (°C)

Carbon dioxide

The carbon dioxide levels consistently surpassed the health threshold of 1000 parts per million (ppm) during all study sessions. On the initial day (as illustrated in Figure 2), the CO_2 concentration went beyond 1000 ppm within 30 minutes of the study session commencing with 9 individuals present, and within 20 minutes when 8 individuals were in the room. Interestingly, the CO_2 health level was exceeded in just 15 minutes when the room hosted 11 individuals. At 12:33 on the same day, the CO_2 concentration peaked at 2689 ppm, marking the highest recorded value across the three-day observation period.

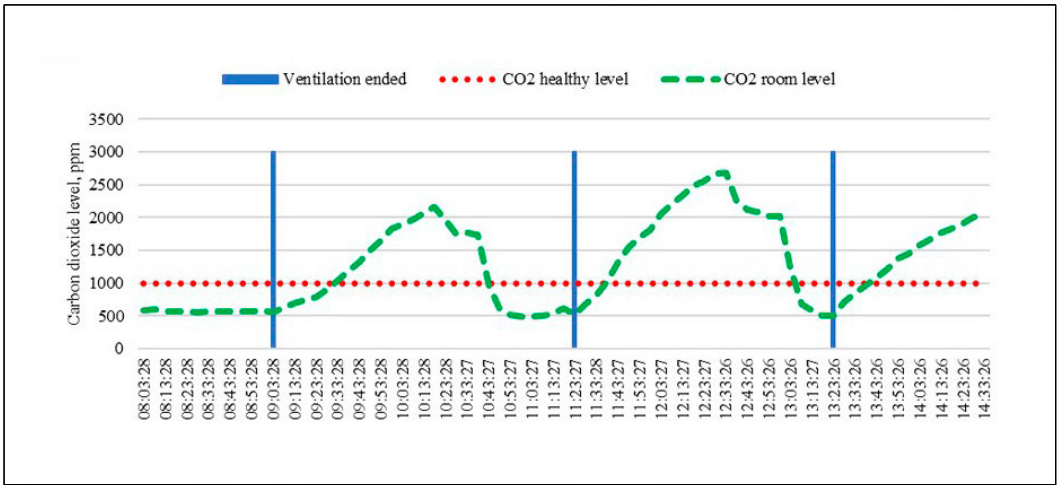

Figure 2. The concentration of CO2 in the smaller classroom during the first day (ppm)

In the more spacious classroom, where data was collected on the second and third days, CO2 levels crossed the 1000 ppm threshold when the room was occupied by 4 people for 53 minutes, 6 people for 36 minutes, and 8 people for 30 minutes (refer to Figure 3). During three distinct study sessions where the classroom housed 9 individuals, the CO2 levels went beyond the 1000 ppm mark between 18 to 27 minutes. Notably, on the third day (refer to Figure 3), in a single session when 11 occupants were present, the CO2 concentration passed the 1000 ppm level merely 20 minutes after the initiation of the study session. In this particular session, approximately an hour and 20 minutes post the closure of the windows, the CO2 levels peaked at 2131 ppm, which represented the highest CO2 concentration recorded in this room.

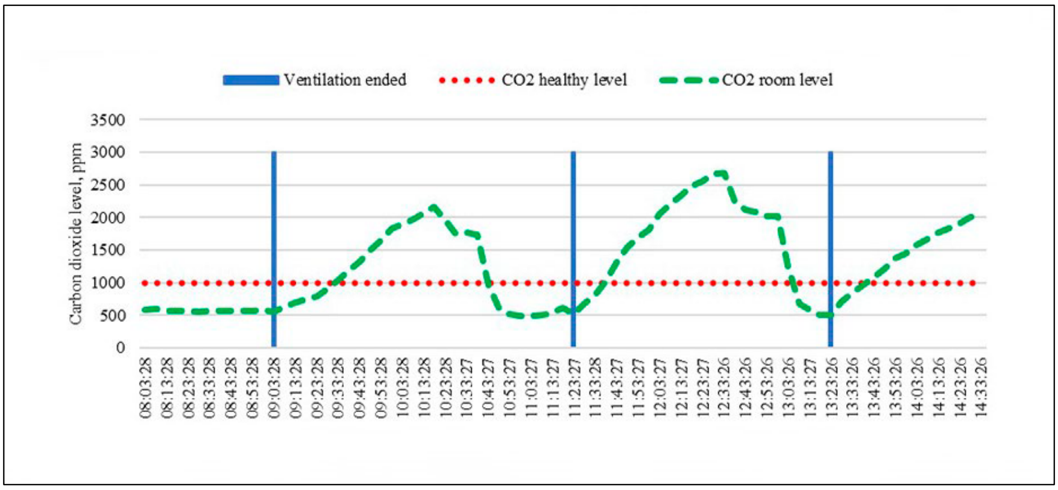

Figure 3. The concentration of CO2 in the larger classroom during the third day (ppm)

Discussion

Throughout the three-day observation period, the relative humidity consistently stayed within the optimal range of 40% to 60%, mirroring the findings of Sarbu & Pacurar's research in university classrooms (Sarbu & Pacurar, 2015). The temperature in the classroom fluctuated between 18 °C in the early mornings to near 26 °C at different times throughout the days. Notably, a drop in temperature was observed during ventilation periods, while increases were linked to practical study sessions. The outside temperature, averaging 9 °C during the day, positively influenced natural ventilation. On the first day, the classroom temperature surpassed Latvia's legally permissible indoor maximum of 25 °C more frequently than on the other days. The time taken for the room temperature to hit 25 °C was found to be consistent, whether occupied by 9 or 11 individuals. Surprisingly, with just 8 occupants, the temperature crossed this threshold quicker, within 45 minutes. This prompted an adjustment on the third day's third study session, where ventilation was conducted in a shorter duration (20 minutes) than earlier in the day. Consequently, the starting classroom temperature was already 22.8 °C, leading to a faster warming of the room.

In the larger classroom (119.7 m^3), the indoor temperature surpassed 25 °C only after an hour with 11 occupants. However, the temperature reached but did not exceed 25 °C when the classroom was filled with 9 occupants for one hour and 20 minutes. Hence, it was concluded that this room could comfortably accommodate 9 individuals (8 students and a lecturer) for up to one hour and 20 minutes. Comparable observations were noted in studies using solely natural ventilation (25.4 °C) or those facing HVAC system issues (25.8 °C), remedied by keeping windows or fire doors ajar, although this resulted in energy loss and an increased demand for space heating (Bakó-Biró et al., 2012; Gao et al., 2014).

Other studies have reported indoor temperatures during academic sessions ranging from 19.5 – 24.6 °C (Heracleous & Michael, 2019; Kim et al., 2022; Sarbu & Pacurar, 2015; Stabile et al., 2017), with 55% of study participants finding 21.5 °C "too cold" (Kim et al., 2022) and 44% perceiving 19.5 °C as "slightly cool" (Sarbu & Pacurar, 2015). This underlines the subjectivity of thermal comfort.

Regarding CO_2, the rapidity with which the 1000 ppm level was attained was directly proportional to the number of classroom occupants. In the smaller classroom (72.3 m^3), this threshold was surpassed within 15 to 30 minutes. The larger classroom (119.7 m^3) displayed a similar trend, but due to its greater size, more time was required to exceed 1000 ppm. These findings align with other studies that were performed in different educational buildings where the maximum indoor CO_2 concentration had exceeded 1000 ppm, reaching 1450 ppm (Sarbu & Pacurar, 2015), 1500 ppm (Bakó-Biró et al., 2012; Cornaro et al., 2013; Stabile et al., 2017; Turanjanin et al., 2014), or 3000 ppm (Bakó-Biró et al., 2012; Heracleous & Michael, 2019). High CO_2 concentrations were attributed to reluctance to open windows in colder weather and insufficient break durations for adequate CO_2 reduction, leading to compromised indoor air quality (Bakó-Biró et al., 2012; Cornaro et al., 2013; Gao et al., 2014; Heracleous & Michael, 2019; Turanjanin et al., 2014).

According to these researchers, CO_2 concentration is influenced by factors such as classroom size, number of occupants, their activity levels, ventilation rate, and time spent in the room (Heracleous & Michael, 2019; Turanjanin et al., 2014). Hence, there is a pressing need for more comprehensive discussions among educational institution staff regarding classroom arrangements for specific student groups, considering the potential maximum attendance, classroom size, and ventilation conditions. Furthermore, educators should be informed of the ventilation status and be encouraged to ventilate the room during breaks and consider adding more ventilation intervals during study periods. This would promote a healthier learning environment with ample oxygen for better concentration, memory, and overall well-being.

Conclusions

Our results indicate that natural ventilation was not sufficient during university study sessions within two selected classrooms. The findings underline the necessity for strategic ventilation interventions and classroom arrangements, considering occupancy and the size of the classroom to promote healthier learning environments. Future research could incorporate surveys of occupants' subjective experiences and well-being during class sessions. Expanding the study to other educational buildings, such as primary or secondary schools, could provide a broader perspective.

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