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# Indoor air quality parameters in a didactic room in central Poland

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## ABSTRACT

Indoor air quality has a crucial influence on the well-being of people present in a given room. It is mostly determined by temperature and humidity, which govern the thermal comfort and microclimate of the room, as well as the sensations of people in the room. Another important parameter of indoor air quality is the concentration of carbon dioxide. High carbon dioxide concentration is common in teaching rooms and can lead to decreased cognitive performance especially reasoning, short-term memory, concentration and verbal ability of a person present in such room. The aim of this research was to analyze the concentration of carbon dioxide in a teaching room with the same physical activity of people in it, depending on temperature and relative humidity of the indoor air. A teaching room in a higher education institution located in central Poland, in a temperate climate, was selected for the analysis. The concentration of carbon dioxide, relative humidity and temperature were measured in the room. The assessed indoor air quality parameters, i.e. temperature and humidity, varied depending on date and duration of the measurements, while still meeting the standards for teaching rooms. The greatest changes were observed in the values of carbon dioxide concentration – it exceeded the values recommended in the standards increasing during the measurements and undoubtedly affecting the ability to conduct classes. Furthermore, a high positive correlation was found between the carbon dioxide concentration and temperature in the analyzed teaching room.

**Keywords:** air pollution, carbon dioxide, indoor environment, education building, university buildings.

## INTRODUCTION

Indoor air quality has a crucial influence on the well-being of people present in a given room. The most important parameters determining indoor air quality are temperature and humidity (Voznyak et al., 2024; Ratajczak et al., 2020). They govern the thermal comfort (Ratajczak et al., 2023; Siedlecki et al., 2024) and the microclimate of the room (Tureková et al., 2022; Dumała et al., 2024), as well as the sensations of the people present in the room (Szczepanik-Ścisło et al., 2024; Vidal et al., 2020, Kapalo et al., 2021). An important parameter of indoor air quality is the concentration of carbon dioxide (Nandan et al., 2021). Many studies have been conducted on the assessment of carbon dioxide concentration in various rooms, as well as cars (Dutta and Roy, 2021). Zhang et al. (2021) reviewed the current research on the indoor environment in nurseries. The level of air pollution as well as related environmental and behavioral factors in nurseries in London were presented and linked to the potential results on health in children. This review found that indoor air pollution in nurseries often exceeds current guidelines. Basińska et al. (2021) dealt with a similar topic examining indoor air quality in four nurseries in Poznań. The concentration of carbon dioxide, PM2.5, and PM10 was analyzed inside and outside the buildings. The authors pointed to the possibility of reducing carbon dioxide by supplying outside air to the rooms through mechanical ventilation or natural ventilation, but such actions introduce solid particles in the form of dust from the outside air.

Concentration of carbon dioxide is primarily important in teaching rooms, because it affects the learning ability and focus of the people in them (Asere and Blumberga, 2020; Guo et al., 2023). Lee and Kim (2022) analyzed the frequency of using mechanical ventilation systems in elementary schools, which are spaces where children require higher indoor air quality than adults due to the rapid increase in carbon dioxide concentration during classes. The results showed that at a height of 1.2 m, the carbon dioxide concentration was as high as 3183 ppm. Cognitive performance is essential to support learning (Guo et al., 2023). High carbon dioxide concentration is common in teaching rooms and can lead to reduced cognitive performance. The authors examined the cognitive performance and health of the college students exposed to an environment with high carbon dioxide concentration. The cognitive performance of the participants, including: reasoning, short-term memory, concentration, and verbal ability; was assessed in each case using the Cambridge Brain Sciences tool. Health symptoms were examined using a subjective questionnaire, and the participants' blood pressure, heart rate, as well as lung function were also tested. The results showed that different levels of carbon dioxide had a significant impact on cognitive performance after one hour of exposure and no significant impact after three hours of exposure.

The aim of this research was to analyze the concentration of carbon dioxide in a teaching room with the same physical activity of people in it, depending on temperature and relative humidity of the indoor air.

## MATERIALS AND METHODS

A teaching room in a higher education institution located in central Poland, in a temperate climate, was selected for the research. The room has no mechanical or natural ventilation. The only method of air exchange is opening windows. The concentration of carbon dioxide in the outside air was measured and ranged from 340–440 ppm. This value is within the range reported by Teleszewski and Gładyszewska-Fiedoruk (2018) and Zhou et al., 2021. The facility is located approximately 300 m away from transport routes and is surrounded by plants, which contributes to good outdoor air quality.

Measurements of the carbon dioxide concentration in the teaching room were taken on rainless days from March 28$^{th}$ to May 24$^{th}$, 2024. The days with rainfall were excluded due to the increase in humidity in the outside and inside air. During the measurements, the windows were closed, creating stable conditions. The carbon dioxide measurements lasted 90 minutes without interruption. The teaching room has a volume of 127 $m^3$ (Figure 1) and was occupied by 30 people +/- 2. The room's windows are located along the long wall of the room and face northeast. During the measurements, the windows were half-covered to eliminate the effect of sunlight on the internal conditions in the room. The people in the room showed moderate activity, performing mental work in a sitting position.

**Figure 1.** The teaching room where measurements were carried out

The parameters of the internal and external environment were measured in accordance with the recommendations given in the literature (ASHRAE). The gauges in the room were placed at a height of approximately 1.05 m from the floor. It was assumed that this is the height at which a student's head is located. In addition to the concentration of carbon dioxide, relative humidity and temperature were measured in the room.

These air parameters were measured with a Testo 435 meter with an IAQ probe, the parameters of which are given in Table 1. The frequency of recording measurements made with the Testo 435 meter was 5 minutes, average of 30 measurements. The recorded result is the average of 150 measurements (Gajewski and Teleszewski, 2023). Before the start of the experiment, the device was calibrated by an external calibration laboratory. The analysis was performed using an Excel spreadsheet based on the obtained measurement results. The results are given as averages of 150 measurements of temperature, humidity, carbon dioxide concentration inside the room, and the same measurements outside, at the beginning of each series of tests and at the end in each month analyzed. Then, the correlation for carbon dioxide concentration was calculated as a function of temperature and indoor air humidity.

The error account of the measured values was carried out in accordance with the recommendations contained in publication (Moffat, 1988).

## RESULTS AND DISCUSSION

The measurement results are presented in Table 2. It contains the averages of 150 measurements of temperature, humidity, carbon dioxide concentration inside the room, and the same measurements outside. The results are given at the beginning of each series of tests and at the end in each month analyzed. The parameters of the outside air differed between the measurements periods. The lower outside air temperature was recorded in March, and similar temperatures were recorded in April and May. The humidity of the outside air was similar during the measurements and ranged from 41.29 to 50.88%. The concentration of carbon dioxide in the outside air did not differ significantly, depending on the date of the measurements.

The parameters of the indoor air varied during the measurement periods. The lowest indoor

**Table 1.** Description of measuring equipment

| Measuring items | Measuring range | Resolution | Accuracy |
|---|---|---|---|
| Temperature [°C] | –20°C to +50°C | 0.1°C | ±0.3°C |
| Humidity [%] | +2 to +98% RH | 0.1% RH | ±2 % RH |
| Carbon dioxide concentration [ppm] | + 0 and + 5000 ppm | 50 ppm | ± 3% CO2 |

**Table 2.** Indoor and outdoor air parameters at the beginning and end of the experiments

| Parameter | | | Temperature | Humidity | Carbon dioxide concentration |
|---|---|---|---|---|---|
| Place and data | | | [°C] | [%] | [ppm] |
| March | Indoor | Start | 17.7 | 45.8 | 664 |
| | | End | 18.6 | 44.2 | 1701 |
| | Outdoor | Start | 10.63 | 50.88 | 340.13 |
| | | End | 13.7 | 43.6 | 388.9 |
| April | Indoor | Start | 22.2 | 46.1 | 634 |
| | | End | 23.1 | 46.9 | 1320 |
| | Outdoor | Start | 21.3 | 47.37 | 440.42 |
| | | End | 22.12 | 42.84 | 358.88 |
| May | Indoor | Start | 22.6 | 57.7 | 589 |
| | | End | 23.5 | 54.1 | 1983 |
| | Outdoor | Start | 23.88 | 41.29 | 404.72 |
| | | End | 24.94 | 42.15 | 406.85 |

air temperature was recorded in March and was too low for the thermal comfort of the listeners in the room (Figure 2). The measurement point is time-related because recording took place every 4 minutes. In April and May, the temperature was similar and around 22 °C. In the case of temperature measurements, there was a certain regularity of a slight increase towards the end of the measurements in each month. The humidity in the room in March and April was similar and decreased towards the end of the measurements (Figure 3). This regularity was not observed in the case of humidity in the tested air in May (Table 2). Both parameters met the requirements of the standards for teaching rooms (ASHEARE, PN-EN 16798-1:2017-06).

It is known that the quality of air, both external and internal, has a significant impact on human health. Achieving adequate air quality in rooms, including teaching rooms, should comply with the guidelines of the European Union and WHO 2000. The WHO 2000 standards state that the maximum concentration of carbon dioxide in teaching rooms should not exceed 1000 ppm.

Adequate air quality reduces the occurrence of many diseases as well as contributes to better work and learning. This is particularly important during the adolescence of young people, because during this period the body is most susceptible to pollutants, including high concentrations of carbon dioxide. The concentration of carbon dioxide underwent the greatest changes in the indoor air. At the beginning of the measurements, it was 590 ppm, and at the end, it was several times higher – 1983 ppm (Figure 4).

It turns out that other researchers obtained higher concentrations of carbon dioxide in their studies (Lee and Kim, 2022; Guo et al., 2023). Natural ventilation is the cheapest and easiest way to effectively remove pollutants from the room and maintain fresh air, as emphasized by Antczak-Jarząbska and Niedostatkiewicz (2020).

During the measurements, the concentration of this parameter increased, and a clear direct proportional relationship was observed with respect to the time the listeners spent in the teaching room. It also varied during the research period. In May, the carbon dioxide concentration was the highest

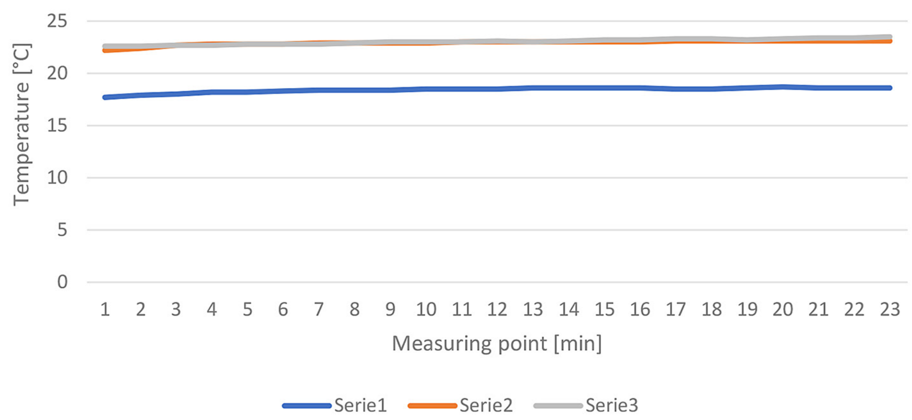


**Figure 2.** The course of changes in indoor temperature during the test period [°C]

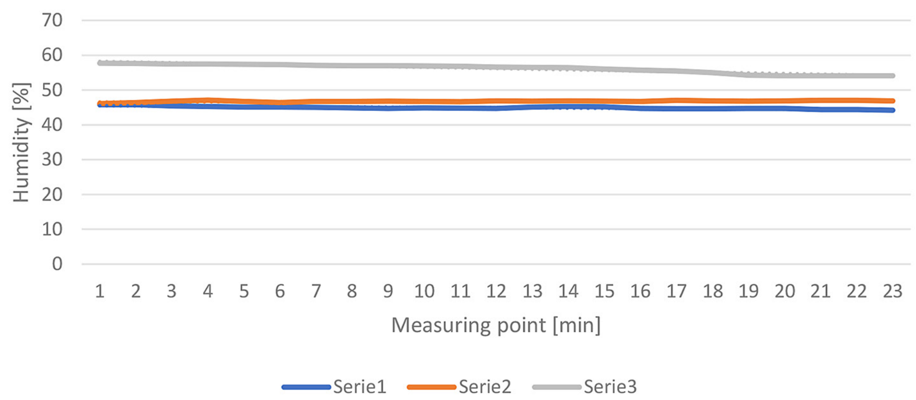


**Figure 3.** The course of changes in indoor relative humidity during the study period [%]

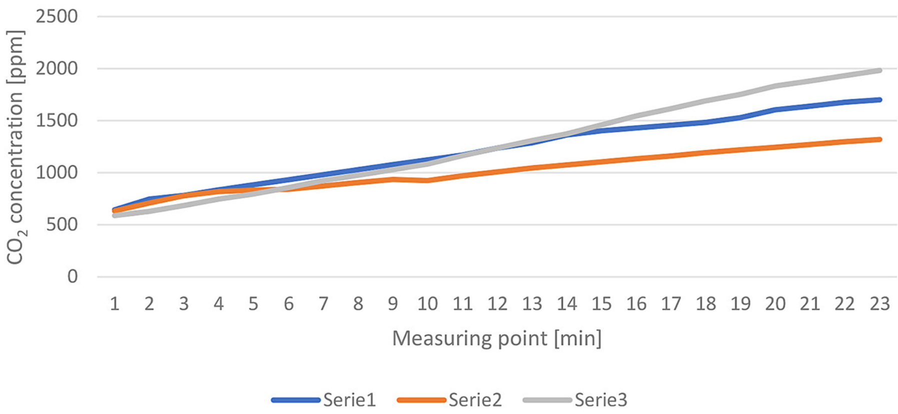


**Figure 4.** The course of changes in carbon dioxide ($CO_2$) concentration in indoor air during the study period

after the measurements, and in April, the lowest. The concentration of carbon dioxide in the outdoor air did not deviate from the standards (ASHEARE, WHO), while in the room, the standards were exceeded by 98%. Particularly high results were recorded at the end of the series of measurements. The transitional spring-autumn period is the most effective for natural ventilation, as indicated by the timing of the measurements in March with low external and internal temperatures. Other authors report that high concentrations of carbon dioxide occur in the teaching rooms without mechanical ventilation (Rajšić et al., 2004, Pajek et al., 2017, Basińska et al., 2021). Studies conducted in Latvia showed that 75% of educational institutions exceeded the carbon dioxide concentration of 1000 ppm (Stankevica and Lesinskis, 2012). These were rooms ventilated naturally.

**Table 3.** Correlation strength between air humidity [%], temperature [°C] and carbon dioxide concentration (y) [ppm]

| Series | Equation | $R^2$ |
|---|---|---|
| Temperature [°C] | | |
| 1 | $y = 0.0007x + 17.57$ | $R^2 = 0.7633$ |
| 2 | $y = 0.001x + 21.886$ | $R^2 = 0.7665$ |
| 3 | $y = 0.0006x + 22.305$ | $R^2 = 0.9587$ |
| Humidity [%] | | |
| 1 | $y = -0.001x + 46.207$ | $R^2 = 0.6709$ |
| 2 | $y = 0.0008x + 45.983$ | $R^2 = 0.4507$ |
| 3 | $y = -0.0028x + 59.707$ | $R^2 = 0.9419$ |

A high positive correlation was found between carbon dioxide concentration and temperature in the teaching room (Figure 5). In the first and second series (March and April) of studies, the coefficient of determination was similar and amounted to 0.7633 and 0.7665, and in May it was the highest and amounted to 0.9587 (Table 3). These differences undoubtedly result from the influence of higher external and internal temperatures. Yuliang et al., (2017) in their research emphasize the high dependence of carbon dioxide

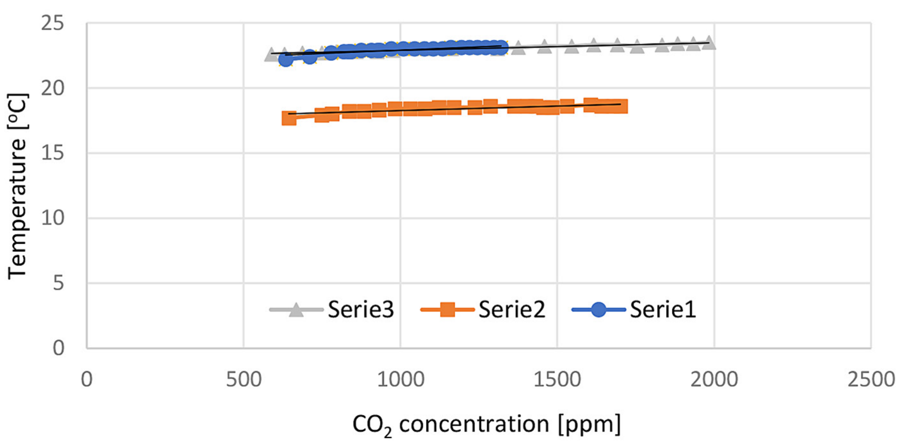


**Figure 5.** Relationship between carbon dioxide ($CO_2$) concentration and temperature

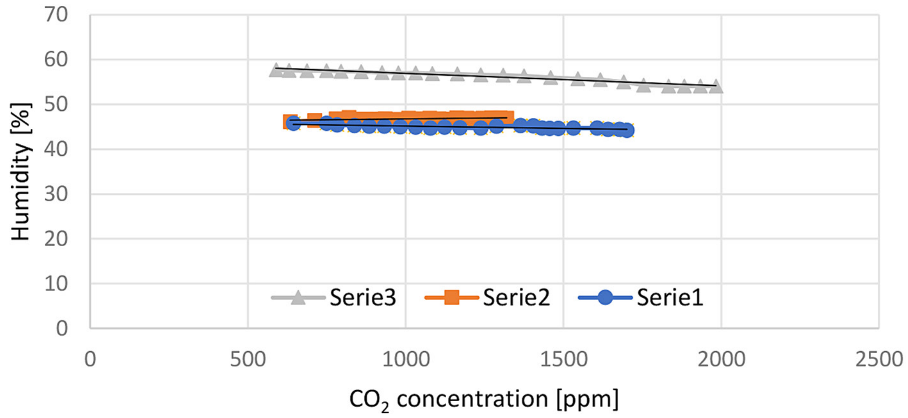


**Figure 6.** Relationship between carbon dioxide ($CO_2$) concentration and relative humidity

concentration on temperature. They argue that the carbon dioxide concentration decreases along with the air temperature. They made similar statements regarding the dependence of carbon dioxide concentration on relative humidity values. In the conducted research, a similar relationship emerged, most visible in the third series of studies (Figure 6). Kapolo et al. found dependencies of carbon dioxide concentration on temperature and relative humidity in enclosed spaces.

It should be emphasized that under the same indoor air conditions Figure 4), with the same physical activity, with similar initial conditions, the nature of changes in carbon dioxide concentration is similar, but the values of exhaled carbon dioxide are completely different. People exhale more carbon dioxide at higher outdoor air temperatures, as if their activity was greater.

The results of the experiment indicate the need for further research in a wider scope of the influence of outdoor air quality parameters on indoor air quality, which may contribute to the construction of better-adapted controllers for the operation of natural ventilation systems (Antczak-Jarząbska and Niedostatkiewicz 2020, Antczak-Jarząbska et al., 2021), as well as mechanical ventilation (Amai and Novoselac 2016, Mikola et al. 2019, Rodrigues et al. 2019).

## CONCLUSIONS

The evaluated parameters of indoor air quality, namely temperature and humidity, varied depending on the timing and duration of the measurements. The air temperature in the room was too low in March, while in April and May it was appropriate for the people staying in the room, who showed moderate mental effort. Nevertheless, these two parameters met the standards for this type of room, such as teaching rooms. The relative humidity of the indoor air varied slightly during the tests and was within the limits of the standards. The concentration of carbon dioxide changed the most, ranging from 589-1983 ppm and exceeding the values recommended in the standards (PN-EN 16798-1:2017-06, ASHRAE 62–2007, WHO 2000). It increased during the measurements and undoubtedly affected the well-being of the students and the ability to perform the classes. The concentration of carbon dioxide varied in the study periods and significantly depended on the temperature as well as relative humidity in the room. A high positive correlation was found between carbon dioxide concentration and temperature in the teaching room. Under the same conditions of indoor air, with the same physical activity, the nature of changes in carbon dioxide concentration is similar, although the values of exhaled carbon dioxide are completely different. People exhale more carbon dioxide at higher outdoor air temperatures, as if their activity was greater. The research on indoor air quality should be continued, also taking into account outdoor air quality factors. The obtained results may be useful for adjusting the operation controllers of natural ventilation systems.

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