Monitoring Indoor Environmental Quality in a University Classroom

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Abstract

Indoor environmental quality in educational facilities is a critical factor influencing student well-being and learning efficiency. This study aimed to assess classroom environmental quality by measuring key parameters, including temperature, relative humidity, and carbon dioxide (CO_2) concentration, at two different heights (1.2 m and 2.65 m). The results demonstrated that air quality is significantly affected by the number of students, insufficient air circulation, and inadequate ventilation. CO_2 measurements showed that the recommended threshold of 1000 ppm was often exceeded at the beginning of lessons, with a maximum recorded concentration of 3540 ppm. No statistically significant differences were observed between the two measurement heights. Relative humidity ranged from 34 to 51%, in line with recommended classroom values, whereas temperature occasionally exceeded recommended limits. Based on these findings, measures to improve indoor environmental quality are proposed, with the implementation of efficient ventilation systems identified as a key intervention.

Keywords: Indoor Environmental Quality, Carbon Dioxide, Well-being

1 Introduction

The design of buildings involves a wide range of requirements and factors that must be considered to ensure that the structure is efficient, safe, and functional, also in accordance

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with EU directives (Directive 2002/91/EC, Directive 2010/31/EU, Directive 2012/27/EU). This applies equally to school interiors (De Giuli, 2012). It is of great importance that schools provide an adequate level of indoor comfort that does not negatively affect students' health or intellectual performance (Mendell & Heath, 2005). In school buildings, it is essential to achieve an appropriate balance between energy costs and comfort levels in order to positively influence student outcomes through effective systems for air temperature control, humidity regulation, air velocity management, and air purification (Katić et al., 2021).

Indoor air quality (IAQ) is a key factor influencing health, comfort, and learning performance in educational environments. Among the most common indicators of IAQ, carbon dioxide (CO_2) concentration is widely used as a proxy for ventilation adequacy and occupant density (Daisey, Angell & Apte, 2003; WHO, 2011, Bluyssen, 2013; Zhang et al 2022). Elevated CO_2 levels are mainly the result of insufficient ventilation relative to the number of occupants, which can lead to drowsiness, headaches, reduced attention span, and lower cognitive performance among students (Satish et al., 2012; Bakó-Biró et al., 2012, Tureková et al., 2022a).

Many schools around the world (Piera, 2014; Issa et al., 2011; Schibuola & Tambani, 2020; Ferreira & Cardoso, 2014), as well as in Slovakia, use natural ventilation. The absence of mechanical ventilation systems results in unsatisfactory microclimatic conditions in classrooms. Measurements taken at 28 Slovak schools showed that students and teachers spend hours in classrooms with volatile chemical compounds, dust, and record-high levels of carbon dioxide. This is also associated with high noise levels and overheating of classrooms during the summer period (Vilčeková et al., 2017, Hašková at al., 2019, Tureková et al., 2022b, Tureková et al., 2021).

Carbon dioxide (CO_2) is a colorless and odorless gas naturally present in the atmosphere at about 400 ppm. It is a normal by-product of cellular respiration, the process by which the human body converts oxygen and nutrients into energy (Coley & Beisteiner, 2002). In enclosed environments such as school classrooms, CO_2 levels can rise quickly due to the exhalation of many students. When concentrations exceed approximately 1000 ppm, it can negatively affect children's comfort and performance – causing fatigue, drowsiness, headaches, and reduced concentration during lessons. (Bogdanovica et al, 2020, Küçükhüseyin 2021). Table 1 shows the effect of CO_2 concentration in ppm on the human body.

Concentration	**Effect**
350 to 450 ppm	Typical atmospheric concentration
600 to 800 ppm	Reliable indoor air quality
1 000 ppm	Upper range of reliable indoor air quality
5 000 ppm	Maximum workplace concentration over 8 hours
6 000 to 30 000 ppm	Critical, only short-term exposure
3 to 8%	Increased breathing frequency, headaches
> 10%	Nausea, vomiting, loss of consciousness
> 20%	Rapid loss of consciousness, death

Table 1: Effects of Carbon Dioxide Concentration on Human Health and Perform. (Satish et al., 2012)

In Europe, there are no comprehensive legally binding regulations for quality requirements regarding indoor air. Instead, several evaluation values exist, which are called guide values, orientation values or target values, for example. In Germany, a CO_2 value of 0.15 vol% (= 1 500 ppm) applies as a hygienic guide value according to DIN 1946 - 2.

In Finland, the maximum permitted CO_2 concentration in indoor air under usual weather conditions and when the room is in use is 1 200 ppm. The Norwegian and Swedish guidelines fix a maximum CO_2 concentration of 1 000 ppm for living rooms, schools and offices. In Denmark the carbon dioxide concentration in children's day care centres, schools and offices should not exceed 1 000 ppm. The air exchange is described as insufficient when the CO_2 concentration exceeds the value of 2 000 ppm several times a day for a short time (Health and Environment Alliance, 2019; Küçükhüseyin, 2021).

At workplaces which are subject to the stipulations of the Dangerous Substance Directive a workplace limit value of 5 000 ppm CO_2 applies (Government Regulation No 355/2006).
Pettenkofer's criterion (1858) defines the maximum comfortable indoor carbon dioxide (CO_2) concentration at 1000 ppm (0.1% vol.). This value represents the upper limit of good indoor air quality, ensuring suitable conditions for human comfort and concentration. Elevated concentrations indicate insufficient ventilation and may lead to reduced performance or fatigue. This criterion will serve as the reference value against which the measured CO_2 concentrations in classrooms will be compared.

Although numerous studies have focused on primary and secondary schools, similar issues are increasingly recognized in university classrooms, where occupancy patterns and ventilation systems differ significantly (Madureira et al., 2012; Plowman & Smith, 2013). University lecture rooms often rely on natural or manually controlled ventilation, which may not adequately respond to changing occupancy levels and can result in CO_2 concentrations exceeding the recommended limit of 1000 ppm (ASTM D6245, 2002; WHO, 2011).

Continuous monitoring of CO_2 concentrations in university classrooms provides valuable insights into ventilation efficiency, indoor environment dynamics, and the need for implementing automated demand-controlled ventilation systems (Laverge et al., 2011; Luther & Horan, 2014). The aim of this paper is to determine:

- how the concentration of CO_2, air temperature, and humidity change over time and depending on the classroom occupancy by students,
- the difference between the measured values of CO_2 concentration, humidity, and temperature in the classroom at heights of 1.2 m and 2.65 m above the floor,
- to propose measures for maintaining optimal conditions while ensuring energy-efficient ventilation control.

2 Materials and Methods

2.1 Classroom and its Characteristics

Indoor environmental measurements were conducted at the Faculty of Education, Constantine the Philosopher University in Nitra, at the Department of Technology and

Information Technology. The two-floor building is oriented north-south and not insulated. The classroom under study is in a section constructed in 1936 and subsequently renovated in 2004 for educational use. (Figure 1).

Figure 1: Classroom for indoor environmental parameter measurements (Kravčenko, 2025).

The classroom has a rectangular floor plan measuring 6.4 × 5.2 m, a ceiling height of 3.15 m, and a total volume of approximately 104.7 m³. The room is equipped with six ceiling lights (1 × 0.5 m), two large windows (1.75 × 2 m) on one wall, 12 student desks, a teacher's desk, and conventional radiators under the windows. Doors measure 1.95 × 2 m. The windows provide natural lighting and ventilation; no mechanical ventilation systems were used.

2.2 Measured Parameters

The study focused on three indoor environmental parameters:

- Relative humidity (%),
- Temperature (°C),
- CO_2 concentration (ppm).

Measurements were conducted using a Testo 315-3 device (Testo SE & Co. KGaA, Germany) (Figure 2), positioned at the centre of the room. Key specifications of the device are listed in Table 2.

Parameter	Measuring Range	Accuracy	Resolution
Carbon dioxide (CO_2)	0 to 10 000 ppm	±300 ppm (0 to 4,000 ppm); 8% of measured value (4,000 to 6,000 ppm)	10 ppm
Temperature t_0(°C)	-10 to +60 °C	±0,5 °C (±1 Digit)	0,1 °C
Relative humidity φ (%)	+5 do +95%	±2,5% (5 do +95%)	0,1%

Table 2: Key technical specifications of the Testo 315-3 device (https://www.testo.com/sk-SK/testo-315-3/p/0632-3153).

Figure 2: Testo 315-3 used for measurements.

2.3 Measurement Procedure

Measurements were conducted in real time during teaching sessions between November and December 2024, on five selected Wednesdays (6, 13, 27 November, and 4 and 11 December 2024). Each session lasted 90 minutes, with five measurements taken at 20-minute intervals (7:40, 8:00, 8:20, 8:40, and 9:00 h).
During practical exercises, the number of students varied depending on their participation in activities outside the classroom. Prior to the first measurement, the room was ventilated for 10 minutes.

2.4 Measurement Heights

Measurements were performed at two heights:

- 1.5 m above the floor, representing the students' breathing zone,
- 2.65 m above the floor (0.5 m below the ceiling), chosen to test the hypothesis of lower CO_2 concentration near the ceiling due to its higher density relative to air.

3 Results and Discussion

Measurements were conducted on five selected days (6 November 2024, 13 November 2024, 27 November 2024, 4 December 2024, and 11 December 2024) at the same times and are labelled as follows: Measurement 1 at 7:40, Measurement 2 at 8:00, Measurement 3 at 8:20, Measurement 4 at 8:40, and Measurement 5 at 9:00. Measurements were performed at two heights above the floor: 1.5 m and 2.65 m.

Measurement date	Measurement no.	CO_2 (ppm)		Temperature t_0 (°C)		Relative humidity φ (%)		No. of students in the classroom
		Height 1.2 m	Height 2.65 m	Height 1.2 m	Height 2.65 m	Height 1.2 m	Height 2.65 m	
06/11/2024	1	1210	1200	20.4	21.1	40.0	43.0	15
	2	2160	2170	22.6	22.9	42.0	44.0	13
	3	3000	2860	23.0	23.1	44.5	50.6	10
	4	3020	3040	23.4	23.5	52.8	56.3	14
	5	3540	3540	23.6	23.6	54.4	61.2	14
13/11/2024	1	1640	1430	23.1	23.1	40.5	40.5	12
	2	2130	2070	23.4	23.4	43.2	43.2	13
	3	2320	2270	23.5	23.5	44.5	44.5	7
	4	2840	2320	23.6	23.6	44.8	44.8	10
	5	2910	2890	23.8	23.8	45.0	45.0	11
27/11/2024	1	1150	1100	23.1	23.5	35.4	35.5	15
	2	1710	1730	23.7	24.1	38.6	38.0	9
	3	2400	2360	24.4	24.6	39.3	40.1	7
	4	2420	2390	24.8	25.0	40.3	40.3	7
	5	2450	2440	25.1	25.3	41.5	41.1	15
04/12/2024	1	1400	1290	22.7	22.9	39.5	38.0	14
	2	1620	1640	23.9	24.4	42.0	39.6	9
	3	2180	2180	24.7	25.0	45.5	45.9	10
	4	2410	2430	25.2	25.4	45.0	48.5	11
	5	2690	2690	25.5	25.8	46.7	50.8	15
11/12/2024	1	640	640	18.8	19.2	32.5	30.9	10
	2	800	810	19.6	21.0	32.5	32.4	13
	3	1350	1370	22.1	22.5	32.6	32.3	8
	4	1660	1670	23.2	23.8	35.5	35.4	15
	5	2270	2270	23.8	24.1	40.0	39.5	15

Table 3: Results of CO_2 concentration, temperature, and relative humidity measurements at different heights, including classroom occupancy.

3.1 Evaluation of CO_2 Concentration Results in the Classroom

Based on the obtained results, it can be stated that during all measurements—except for the last one, which was preceded by a 10-minute ventilation period—the classroom was not sufficiently ventilated. The concentration of carbon dioxide exceeded the reference limit of 1000 ppm in all such cases. Figures 3–7 illustrate the progression of CO_2 concentration over time during the individual measurements.

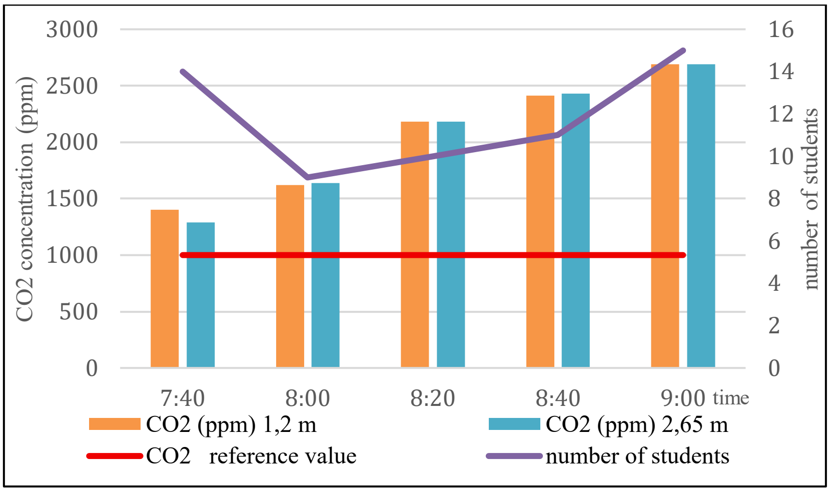

Figure 3: Increase in carbon dioxide concentration on 6 Nov 2024 at heights of 1.5 m and 2.65 m.

The difference between CO_2 concentrations measured at the two heights was not significant, and all deviations were within the margin of measurement tolerance. At the end of the lesson, the concentration reached 3540 ppm, representing a critical level that can substantially affect students' cognitive performance and health. This value was the highest among all measurements.

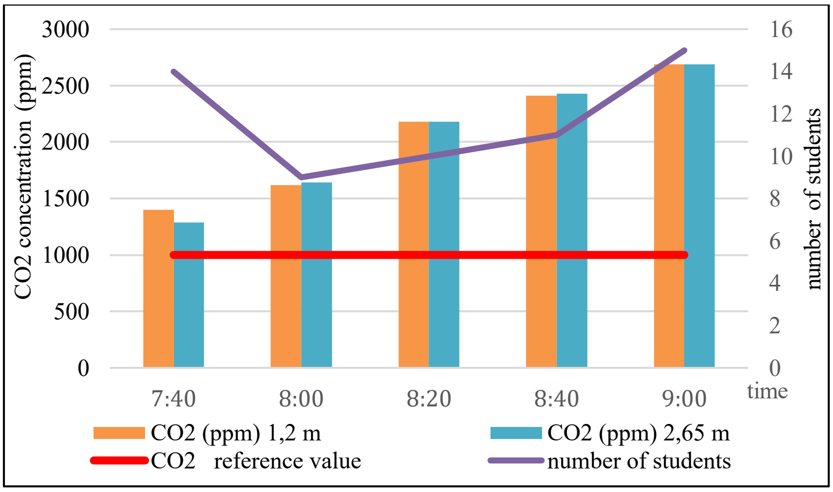

Figure 4: Increase in carbon dioxide concentration on 13 Nov 2024 at heights of 1.5 m and 2.65 m.

Similarly, during the second series of measurements, no significant difference in CO_2 concentration was observed between the two measurement heights. The concentration at the beginning of the lesson was 1640 ppm (1430 ppm) and did not exceed 3000 ppm at the end. However, even this level is associated with reduced concentration ability, increased fatigue, drowsiness, and lower productivity. The results are consistent with findings from other studies (e.g., Satish et al., 2012), which report that at 1000 ppm, performance may decrease by approximately 10%, and at 2500–3000 ppm, by 20–50%.

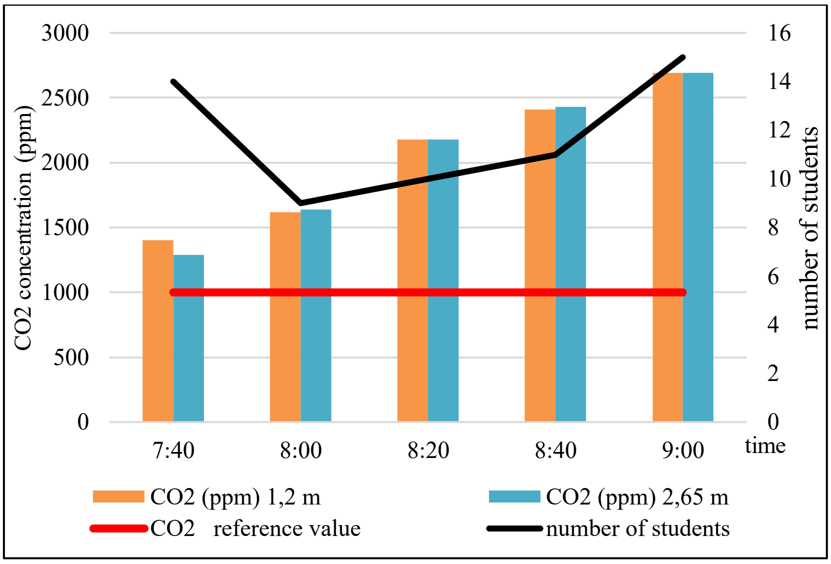

Figure 5: Increase in carbon dioxide concentration on 27 Nov 2024 at heights of 1.5 m and 2.65 m.

The third measurement series began with a concentration slightly above the reference limit (1150 ppm) and ended at 2450 ppm. Compared with the first measurement, this lower final concentration may have been influenced by a smaller number of students present in the classroom. Nevertheless, the measured value again exceeded the recommended limit. The concentrations recorded at both heights were almost identical.

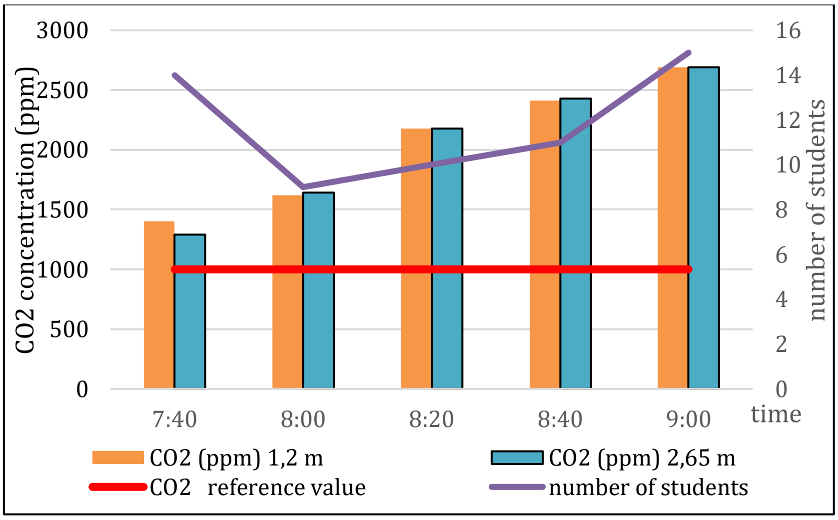

Figure 6: Increase in carbon dioxide concentration on 4 Dec 2024 at heights of 1.5 m and 2.65 m.

In this case as well, the classroom was not sufficiently ventilated, as the CO_2 concentration exceeded the reference limit at the start of the measurement. The concentration increased gradually with time and the number of students, reaching 2690 ppm at the end of the lesson. The difference between the two measured heights was not statistically significant.

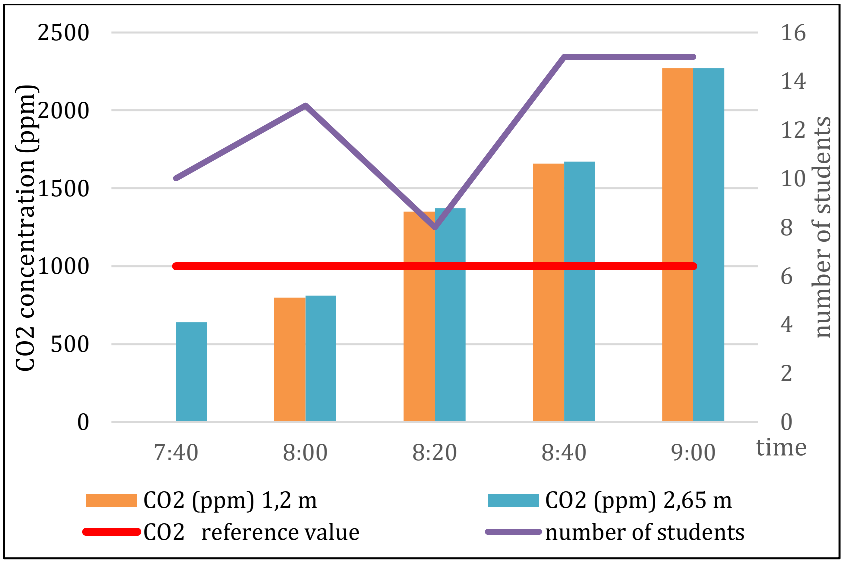

Figure 7: Increase in carbon dioxide concentration on 11 Dec 2024 at heights of 1.5 m and 2.65 m.

Unlike the previous cases, the classroom was sufficiently ventilated during this measurement. The initial CO_2 concentration was 640 ppm at both heights. After 20 minutes, it rose to 800–810 ppm, and after another 20 minutes, it exceeded the reference limit of 1000 ppm. The maximum recorded value during this measurement was 2270 ppm—the lowest among all sessions—yet, still considerably above the recommended level, indicating unsuitable indoor air.

Overall, all measurements confirmed an increase in CO_2 concentration above the recommended threshold of 1000 ppm during lessons. The recorded maximum values (3540 ppm, 2910 ppm, 2450 ppm, 2690 ppm, and 2270 ppm) substantially exceeded this limit. Comparing the measurements at two different heights (1.5 m and 2.65 m above the floor) revealed that the height of the measuring point had no significant influence on the CO_2 concentration, as the observed differences were within the allowable measurement error range.

3.2 Evaluation of Temperature and Relative Humidity Results in the Classroom

The Decree of the Ministry of Health of the Slovak Republic No. 259/2008 Coll. on detailed requirements for the indoor environment of buildings and on minimum requirements for low-standard apartments and accommodation facilities specifies the parameters of the thermal-humidity microclimate. These include the operative temperature t_o, relative humidity of air φ, and air exchange rate n.

For premises with special requirements, such as school and preschool facilities, the values of these parameters are presented in Table 4.

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Space	Temperature t_0 (°C)	Relative humidity φ (%)	Air exchange rate n (h^{-1})
Gymnasiums	15 – 17	30 – 70	5
Dormitories (DJ, kindergarten)	18 – 20	30 – 70	5
Classrooms, playrooms, day rooms	20 – 24	30 – 70	3 – 8
Isolation rooms	22 – 24	30 – 70	5
Gyms	15 – 17	30 – 70	5

Table 4: Parameters of thermal-humidity microclimate for spaces with special requirements (schools and pre-school facilities).

Another legal regulation (Decree of the Ministry of Health of the Slovak Republic No. 75/2023 Coll. on detailed requirements for facilities for children and youth) stipulates that in classrooms and other spaces where students perform activities for more than four hours a day, the temperature must be at least 20 °C. Although no specific limit value is defined for university classrooms, as continuous four-hour occupancy may not be typical, the reference parameters presented above can be used for comparison with the measured results.

The comparison of operative temperatures was carried out at a height of 1.5 m above the floor, as defined in the applicable regulation. The results show that the temperature increased progressively during all measurement sessions, depending on the duration of occupancy. The upper limit of 24 °C was exceeded during the third, fourth, and fifth measurements on 27 November 2024 (24.4–25.1 °C), and a similar trend was observed on 4 December 2024 (24.7–25.5 °C). In these cases, the temperature in the classroom did not meet the recommended microclimatic parameters.

When comparing temperatures measured at a height of 2.65 m, no statistically significant differences were detected. Minor deviations, when present, were likely due to measurement errors or local air movement.

Regarding the relative humidity of the indoor air, none of the measurements exceeded the recommended interval of 30–70%. The measurement height also did not have a significant influence on the recorded humidity values, indicating a relatively homogeneous humidity distribution within the classroom environment.

4 Conclusion

Buildings, particularly educational facilities, must be designed to fulfil their intended function — to provide a safe, functional, and healthy environment for their users. This includes not only spatial and technical design but also the assurance of adequate indoor environmental quality. Modern approaches to school building design increasingly emphasize minimizing environmental impact using sustainable materials, improved energy efficiency, and optimization of indoor microclimatic conditions (SIEA, 2023). The indoor environment —

especially air temperature, humidity, and air quality — has a demonstrable effect on the health, concentration, and performance of students (Bettinger, 2005).

The results of the measurements conducted in the university classroom showed a significant increase in CO_2 concentration during teaching hours, reaching values above 3000 ppm, i.e., more than three times the recommended limit of 1000 ppm. Such concentrations negatively affect students' alertness, comfort, and cognitive performance. The temperature in the classroom ranged between 20.4 °C and 25.5 °C, occasionally exceeding the recommended upper limit of 24 °C, which can cause thermal discomfort and decreased focus. The relative humidity was within the recommended range of 32.–52.8%.

Based on these findings, the main issue identified in the observed classroom is insufficient air exchange, related to both the number of students and the duration of teaching sessions. To optimize the indoor microclimate, it is recommended to implement regular ventilation before and during lessons, ideally every 30 minutes, or by using cross-ventilation to ensure rapid air exchange. Continuous air quality monitoring through CO_2, temperature, and humidity sensors is also advised to enable timely response to suboptimal conditions. Classroom design should consider the optimal number of students and ensure a minimum fresh air supply of 5 L/s per person.

Where natural ventilation is insufficient, automatic ventilation or heat recovery systems should be implemented to maintain adequate air exchange without excessive energy loss. Additionally, the placement of indoor plants can effectively improve air quality by reducing airborne pollutants and maintaining humidity balance.

Improving indoor environmental quality in classrooms can directly enhance students' health, concentration, and academic performance. As noted by Liptajová (2021), optimizing indoor air quality may improve student performance by up to 15%, with positive effects on attention, working speed, and task efficiency. Properly designed, well-ventilated, and environmentally sustainable classrooms therefore represent a key prerequisite for an effective and healthy educational process.

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