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Indoor Carbon Dioxide Air Quality and Thermal Comfort in Primary School Classrooms of Maisan Province, Iraq

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Abstract

The comfort and health of students may be affected by contaminated interior environments. One of the key elements for improving academic performance is ensuring proper ventilation and indoor thermal comfort. This study aimed to assess the effectiveness of ventilation and measure temperature and humidity levels in several primary school classrooms in southern Iraq's Maisan Province. Utilizing a high-precision sensor, the study was conducted in 26 schools (22 public and 4 private) dispersed throughout the province, where thermal conditions and carbon dioxide (CO_2) concentrations were tracked for seven months as an alternative to evaluate ventilation efficiency by Smart air monitoring device. According to the results of CO_2 concentration were around 516 - 3,477 ppm, most classrooms had high CO_2 levels owing to poor ventilation, exceeding the ASHRAE standard of 62.1. During several monthly readings, the temperature was around 15 - 32.3 ^{0}C and relative humidity levels were 18.9 - 79.4%, exceeding the ASHRAE standard 55%. This can be ascribed to the considerable number of pupils occupying the space in the room and the effect of classroom and school building characteristics on indoor air quality. As a result, practical, straightforward steps are required to improve ventilation efficiency.

Keywords: Carbon dioxide; Children; Classrooms; Iraq; Schools; Ventilation

1. Introduction

Schools are considered one of the most important types of internal environment because of the impact of their internal conditions on the health and comfort of their occupants (Haddad *et al.,* 2021). Children spend more time at school than in any other place but their home (Bluyssen *et al.,* 2018) in crowded indoor environments such as classrooms, healthy ventilation is an essential strategy for improving indoor air quality (Vassella *et al.,* 2021). Globally, studies have shown that the quality of ventilation in buildings can be assessed by measuring indoor carbon dioxide levels. Indoor CO_2 levels that exceed international standards indicate inefficient ventilation and the possible accumulation of other pollutants that may have significant health impacts on building occupants (Lazovic *et al.,* 2016; Vilcekova *et al.,* 2017; Deng & Lau, 2019; Alshrefy *et al.,*2020). High carbon dioxide concentrations can lead to headaches, drowsiness, and the possibility of asthma, dry cough, and wheezing in children. Inadequate school ventilation is associated with higher rates of student absenteeism and lower educational performance (Cai *et al.,* 2021; Choe *et al.,* 2022).

Thermal comfort improves the indoor air quality (Kumar *et al.,* 2016). Inappropriate classroom temperatures are common in many countries (Wargocki *et al.,* 2007). The degree of thermal comfort varies from person to person and is related to metabolic rate, clothing insulation, indoor air velocity, and relative humidity (Majewski *et al.,* 2020). Maintaining indoor humidity at appropriate levels is critical for ensuring satisfactory indoor environments (Liu *et al.,* 2023). It has been shown that heat discomfort caused by high temperatures in the classroom has negative consequences for effective learning. This reduces pupils' ability to perform typical school tasks, impairs their concentration or distraction, and reduces their results on learning tests (Wargocki *et al.,* 2019). Therefore, monitoring indoor temperature, relative humidity, and CO_2 concentrations has become a guideline to ensure a safe indoor environment for pupils (Bain-Reguis *et al.,* 2022).

Most studies conducted in Iraq concentrated on outdoor air pollution (Shehabalden and Azeez,2017; Taher *et al.,* 2023; Alsabbagh *et al.,* 2023). This study was carried out to assess the thermal environment and ventilation in Iraqi primary schools. This study deals with the long-term monitoring of temperature, relative humidity, and indoor carbon dioxide levels in 26 classrooms in Maisan Province. This study on the indoor air quality in primary school classrooms highlights the specific challenges and urgent need for targeted interventions to protect the health and wellbeing of students in similar settings.

2. Materials and methods

2.1 Area of Study

The study area is in Maisan Province, located in the southeastern part of Iraq, with an area of 16,072 km^2, and is characterized by a hot and dry summer climate (NCCI, 2015). Twenty-six primary schools were selected, and three classrooms from each school were selected as samples for the study and indoor air monitoring. The coordinates of the school locations were determined using a Global Positioning System (GPS). Figure 1 shows the locations of the selected schools in this study.

2.2 Monitoring

The thermal environment of school buildings was monitored monthly. Monitoring was conducted in the morning throughout the study period from 9:00 am to 11:30 am. A Smart Air Monitor sensor was used for this purpose (Figure 2). It is a device of Taiwanese origin calibrated by the manufacturer.

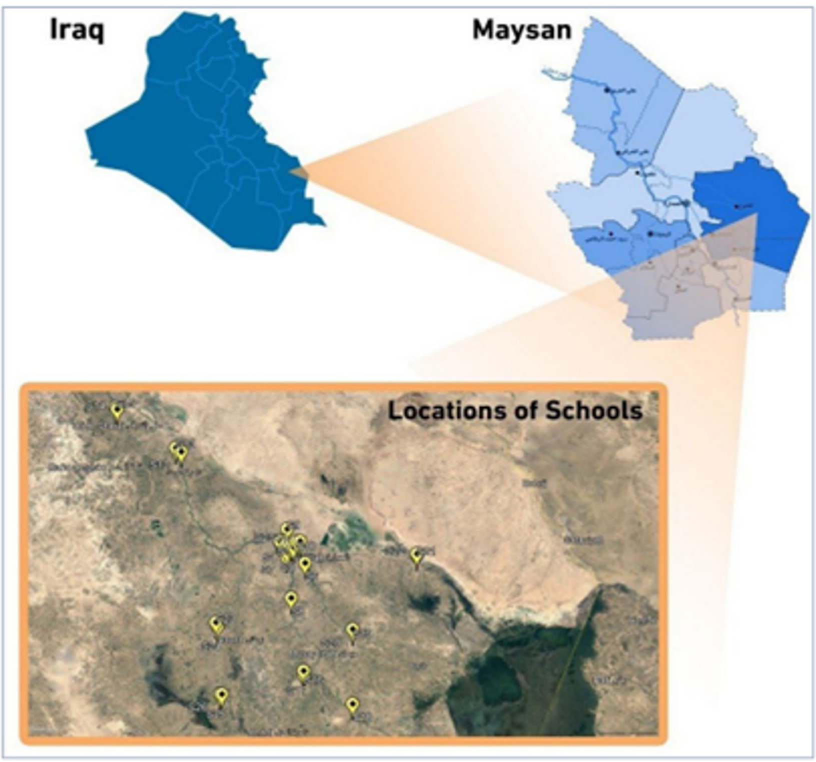

Figure 1. Distribution of primary schools in the Maisan Province, Iraq

The sensor was positioned inside the classroom at a height of one meter, which is ideal for children's exposure when seated on benches. The sensor recorded six readings, separated into 7 or 8-minute intervals, for not less than 45 min, which is the standard duration of one lesson. The study included monitoring and evaluating indoor air in classrooms, with a total of 182 samples.

The classrooms were natural ventilated, and the assessment was by monitoring and measuring indoor CO_2 levels throughout the study period from October 2022 to the end of April 2023.

2.3 Statistical analysis

Pearson's correlations were used to investigate the impact of the characteristics of classroom occupancy on ventilation and the thermal environment, and generalized linear models were fitted. In addition, the lowest, maximum, mean, and standard deviation of the descriptive statistics were calculated. Normality of the distribution was evaluated using a histogram. A statistical analysis program was used to compare the concentrations of CO_2 and to ensure the significance of the results. Probability value tests (P-values) were carried out by applying one-way ANOVA to examine whether there were statistically significant differences in the values of the quantitative variables at a significance level of 0.05. The statistical package IBM SPSS Statistics 22 was used for correlation analysis, and Microsoft Excel 2016 was used for data analysis.

3. Results and discussion

3.1 School infrastructure

School buildings differ in location; therefore, the indoor air quality is expected to provide different temperatures and humidity. Seventy-three percent of the schools were built more than 30 years ago. Figure 3 shows the ages of the school buildings that participated in the study. Classrooms varied in space and number of windows (77% of schools had two windows, and the rest had three windows). Regarding the presence of curtains, 38% of the targeted classrooms did not have curtains in their windows. Only five schools had air conditioning and the approach to ventilation in all classrooms was natural ventilation.

Figure 2. Smart Air Monitor sensor used in this study

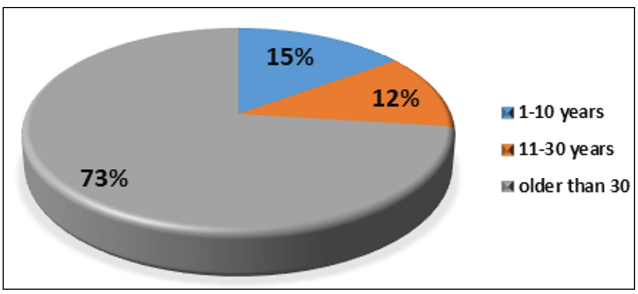

Figure 3. Age of school buildings participating in the study.

3.2 Classroom occupancy rate

Detection of the degree of occupancy of buildings and interior spaces is necessary to maintain appropriate indoor air quality standards regarding temperature, humidity, and carbon dioxide concentrations (Franco & Schito, 2020). Compared to the educational standards for primary schools recommended by the Iraqi Ministry of Education, the area given to each pupil in classroom is 1.6 square meters, indicated by Kazem & Al-Kazzaz (2022). The results showed a large variation in the number of students with an extremely high degree of occupancy compared to the educational standard above, in most of the schools participating in the study. Table 1 shows the occupancy rates of the students in the classrooms. The Pearson correlation coefficient for the given data is 0.637, indicating a positive correlation between the actual number of pupils in the classroom and the occupancy rate.

3.3 Indoor temperature

There was a significant effect of weather on the internal environments of the school buildings during the study period, as the results showed an increase in indoor air temperatures during the warm months and a decrease in the cold months, which ranged between 15.5 - 32.3 ^{0}C, while the standard were 20 to 28 ^{0}C. The feeling of heat in people is related to their level of activity, age, and natural body temperature, which varies from person to person, as well as their clothing (Saif, 2020). Children are usually more sensitive than adults and prefer cooler temperature conditions in classrooms because of the high rates of their metabolism and their level of physical activity throughout the school day. This causes an increase in their body heat and the air they breathe, as this heat can be transferred to the classroom air (Whitlock *et al.,* 2020). It has been proven that heat discomfort caused by high temperatures in the classroom reduces

Table 1. Standard and actual numbers of students with occupancy density in the target classroom area.

Schools	Classroom area (m^2)	No. of pupils according to the standard (Pupils/1.6 m^2)	The actual number of pupils in the classroom	Occupancy rate (%)
S1	32	20	18	90
S2	35	22	40	182
S3	22	14	22	157
S4	48	30	17	57
S5	24	15	19	127
S6	44	28	21	75
S7	24	15	34	227
S8	32	20	45	225
S9	35	22	46	209
S10	35	22	28	127
S11	48	30	27	90
S12	30	19	26	137
S13	24	15	40	267
S14	24	15	50	333
S15	54	34	22	65
S16	24	15	47	313
S17	20	13	14	108
S18	28	18	44	244
S19	40	25	22	88
S20	32	20	47	235
S21	48	30	42	140
S22	35	22	36	164
S23	28	18	24	133
S24	35	22	33	150
S25	24	15	19	127
S26	32	20	35	175

students' ability to perform school tasks and the results of learning tests (Wargocki *et al.,* 2019). By contrast, supplying a comfortable thermal environment can enhance academic learning and health (Shrestha & Rijal, 2023).

The characteristics and conditions of the classrooms in the current study contributed to an increase and decrease in indoor air temperatures, as the student occupancy rate reached 313% in the classroom, which recorded the highest temperature value, in addition to the lack of air conditioning equipment in the school. The record of the lowest indoor air temperature in S7 school can be attributed to the presence of an opening in the classroom wall dedicated to placing an air conditioner that was not tightly isolated from the outside environment, with some damage to the windows, which allowed cold air to enter during the winter months, as well as the absence of curtains and heaters inside the classroom. In the current study, the average indoor temperatures did not exceed all school ASHRAE standard limits of 55 ºC (20 - 28 ºC) (Afroz *et al.,* 2022). The minimum and maximum indoor temperature readings exceeded the above standards in some schools, as shown in Table 2.

3.4 Indoor relative humidity

Indoor humidity is one of the factors that affects indoor air quality. High humidity may cause mold growth and spread of odors, which affects the health of the respiratory system of building occupants (Sada & Salih, 2017). In contrast, studies have indicated that a dry indoor environment can lead to dry eyes, skin, and sinus congestion (Jones *et al.,* 2022). The results of relative humidity ranged from 18.9 to 79.4% and showed a significant increase in humidity levels during January and February 2023. This is because classroom air is affected by the external climate, which is characterized by increased precipitation and fog at most school sites. It can add floor-cleansing activities, children's sweating after playtime, and more moisture in the indoor air for the classroom. In the current study, the high occupancy density of classrooms contributed to an increase in humidity rates, and the results showed a significant positive relationship between the number of students and indoor air humidity, with a correlation coefficient of 0.65, as shown in Figure 4.

In a study by Szunerits *et al.* (2023), the water content of human respiration, which is equivalent to 100 parts of water spray with a diameter of 1 μm per liter of exhaled air, was suspended in the air and can lead to an increase in internal humidity with poor ventilation and high occupancy density. In the current study, the mean indoor relative humidity did not exceed the ASHRAE standard 55 limits (30 – 65%) in all schools (Afroz *et al.,* 2022). The minimum and maximum indoor relative humidity readings exceeded the above standards in some schools, as shown in Table 2.

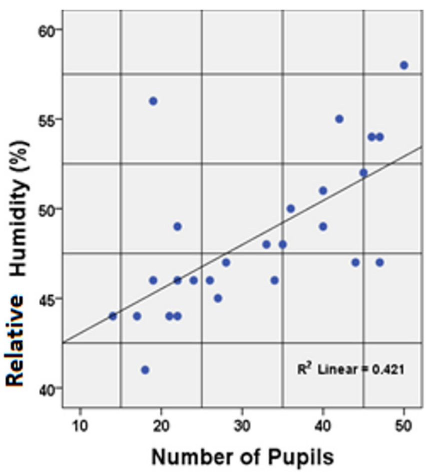

Figure 4. Correlation between the number of pupils and indoor relative humidity.

3.5 Carbon dioxide concentration

Most classrooms were crowded with pupils, and a significant increase in carbon dioxide concentrations was recorded. The monthly values for this gas in the targeted schools ranged between 516 and 3,477 ppm. Studies indicate that reducing carbon dioxide concentrations in indoor school environments leads to enhanced comfort and reduces feelings of fatigue, which increases productivity and improves the performance of students and educational staff (Haddad *et al.,* 2021; Zapata *et al.,* 2023). ASHRAE standard 62.1(2019) specifies the recommended concentration of carbon dioxide in classrooms to be 1,100 ppm (Meiss *et al.,* 2021). In contrast, the World Health Organization (WHO) recommends maintaining a CO_2 concentration of less than 1000 ppm in indoor spaces (WHO, 2010). Compared to the above two standards, the CO_2 means shown in Table 2 exceeded the ASHRAE standard by 65% and the WHO standard by 77% for the targeted schools.

CO_2 levels inside classrooms that exceed the approved standards indicate inefficient ventilation, with the possibility of accumulating other pollutants that harm student health (Asif *et al.,* 2018). The results showed a significant direct relationship between the number of classroom pupils and the mean indoor CO_2 concentration during the study period, with a correlation coefficient of 0.4, as shown in Figure 5.

This is consistent with the findings of Vilcekova *et al.* (2017) that indoor CO_2 levels are directly proportional to the number of students and time spent inside the classroom. Additionally, Meiss *et al.* (2021) indicated that students and teachers are primary sources of indoor carbon dioxide. This explains the relationship between CO_2 levels inside classrooms and the degree of their occupancy. Luther *et al.* (2018) found the three most important criteria for the concentration of CO_2 gas inside a classroom during its occupancy period: the rate of air exchange with the outside environment, the number of students

Table 2. Lower, upper, and mean values with standard deviations for temperature and relative humidity during the study period 2022/2023

Schools	Temperature (°C)				Relative humidity (%)			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
S1	20.4	26.7	23.5	2.37	25.5	61.5	41	11
S2	18.2	29.6	23.9	3.6	37.3	63.2	49	10
S3	19.7	30.2	24.0	3.3	29.3	70.3	49	13
S4	17.9	26.3	22.1	2.6	35.1	64.9	44	10
S5	20.1	29.1	23.0	2.97	38.3	75.7	56	13
S6	16.9	26.3	22.6	3.56	24.5	59.7	44	13
S7	15.5	29.7	22.4	4.97	35.2	65.5	46	11
S8	18.7	30.5	23.9	4.18	41.5	67.7	52	10
S9	20.0	29.5	23.0	3.0	31.9	72.6	54	14
S10	21.2	26.7	23.0	1.8	27.3	67.5	47	14
S11	18.5	31.1	23.0	4.1	21.6	68.1	45	15
S12	15.7	25.5	21.1	3.4	25.3	72.7	46	17
S13	16.6	27.9	22.5	4.3	33.8	75.9	51	14
S14	18.6	29.2	22.9	3.7	44.7	79.4	58	12
S15	19.1	24.4	22.4	2.1	29.4	61.7	46	14
S16	21.2	32.3	25.7	3.8	35.6	69.8	47	12
S17	19.7	29.7	23.6	3.0	26.5	72.2	44	15
S18	18.4	30.0	24.0	3.9	34.6	73.6	47	14
S19	16.9	26.9	23.0	3.4	18.9	69.9	44	16
S20	18.2	29.8	24	3.8	37.7	73.4	54	13
S21	19.2	28	23.6	3.2	38.3	72.2	55	12
S22	16.9	26.1	22	3.1	32.2	68.2	50	12
S23	20.7	27.5	24	2.5	26.3	66.1	46	15
S24	19.1	28.4	23.9	3	30.6	68.2	48	13
S25	18.7	26.3	21.9	2.6	27.6	71.3	46	15
S26	19.4	29.2	23.6	3.2	37.6	73.7	48	13

in the classroom, and the exhalation rate of CO_2. Franco and Schito (2020) showed that the amount of carbon dioxide exhaled by humans is related to an individual's age, metabolic rate, and activity.

According to the results in Table 1 and Figures 4 and 5, there is a relationship between the number of pupils and the occupancy rate of classrooms. The study found a significant variation in the number of students with a high degree of occupancy compared to the educational standard above in most participating schools. Moreover, the high occupancy density of classrooms contributed to an increase in humidity rates, and there was a significant positive relationship between the number of students and indoor air humidity, with a correlation coefficient of 0.65, as shown in Figure 4. This suggests that classroom overcrowding can lead to poor indoor air quality due to increased occupancy rates and inadequate ventilation.

The current study revealed that there are exceptions to the above correlation, where private schools with rented buildings showed completely different results, despite the low degree of student occupancy relative to the classroom space. However, the highest CO_2 gas means were recorded during the study period, such as schools S3, S5, and S17, as shown in Figure 6, which can be attributed to the low ventilation efficiency, small space of the school, and lack of a courtyard inside the building that allows air exchange with the outside environment, where the custom design of the building differs from current use. The doors and windows are often closed during the lesson throughout the school day, and the students' continuous excretion of CO_2 gas leads to its accumulation inside the classrooms at extremely high levels.

The results of this study are compatible with the findings of Alsubaie (2014), as carbon dioxide levels in government school buildings were better than those in private schools because of large classrooms and wider ventilation windows. At the same time, it did not agree with the findings of El-Sharkawy *et al.* (2014), where the results showed higher levels of CO_2 in public schools than in private schools due to insufficient ventilation with a high degree of student occupancy.

There was a significant direct correlation between the means of carbon dioxide concentrations and indoor relative humidity during the study period, with a correlation coefficient of 0.71, as shown in Figure 7.

The results of the current study showed that the maximum monthly values of indoor CO_2 gas occurred in the cold months, specifically January and February 2023, and a variation in the other months of the study period, which can be attributed to the closing of windows and doors to keep the classrooms warm and avoid the transmission of sounds from neighboring classes. In addition, students still inside the classroom during break times can contribute to the insufficient supply of fresh air and the short duration of this period, which is limited to only five minutes.

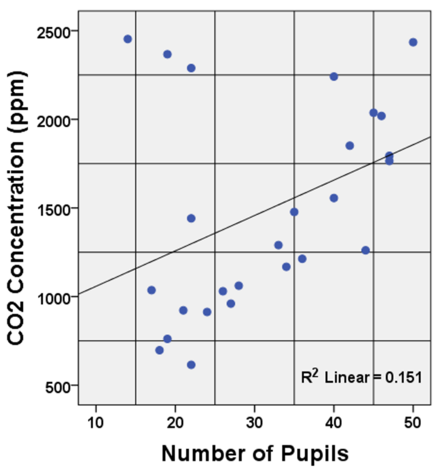

Figure 5. Correlation between the number of pupils and indoor CO_2 concentrations.

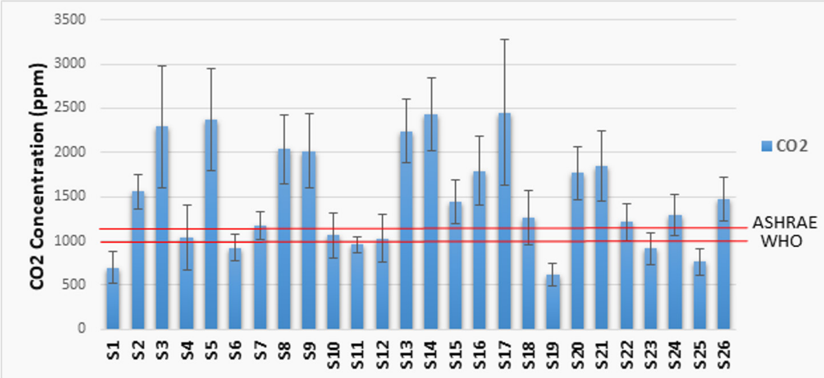

Figure 6. Comparison of mean carbon dioxide concentrations during the study period with international standards.

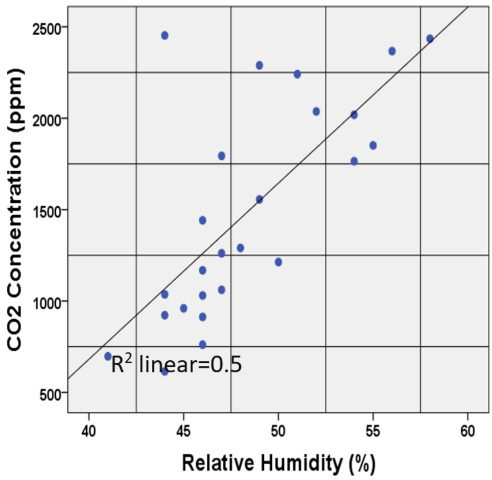

Figure 7. Correlation between the mean CO_2 concentration and indoor relative humidity

In addition, there was a rapid increase in the concentration of CO_2 gas at the start of the lesson because of the high physical activity of the children during breaks, which caused an increase in the breathing rate and excretion of CO_2 at higher levels. The problem of carbon dioxide accumulation inside classrooms worsens in school buildings that operate on a two-meal system, as the second school hours usually start immediately after the end of the first school, and it is not allowed to take enough time to exchange air with the outside environment.

4. Conclusion

It can be concluded that some classroom temperature and relative humidity values exceeded the ASHRAE standard 55 recommendations for thermal comfort and humidity. In addition, some classrooms had high carbon dioxide concentrations that exceeded the 1,100 ppm limit advised by ASHRAE Standard 62.1 (2019). These high concentrations were attributed to several variables, including classroom crowding, building design features, behavioral trends, and operational schedules. Additionally, it was shown that the effectiveness of ventilation, rather than just student preparation in the classroom, affected indoor CO_2 levels. To address these problems, it is recommended that the natural ventilation used in most classrooms be improved by placing air evacuators in windows, distributing students equally in packed classrooms, and increasing the number of plants inside schools to supply fresh air.

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Conflict of interest

The authors declare no conflicts of interest.

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