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Effect of window openings on indoor air quality and CO_2 concentration in classrooms: A Case Study of Primary School, Dhaka

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Abstract

Abstract. This study investigates the impact of window openings on indoor air quality (IAQ) and CO_2 levels in school classrooms in Dhaka, focusing on natural ventilation strategies to improve the learning environment. The importance of effective window design in controlling CO_2 concentrations and enhancing ventilation is critical, particularly in tropical climates like Dhaka's, where indoor air quality is often compromised due to inadequate ventilation. The study aims to explore the effect of window size and ventilation on CO_2 levels, comparing classrooms with different window configurations to identify the best strategies for improving IAQ. Over a period of two measurement campaigns, the study monitored CO_2 levels, indoor temperature, and relative humidity in two elementary schools, revealing that limited window openings, particularly when windows were 75% closed, resulted in significantly higher CO_2 concentrations. The analysis showed a direct correlation between reduced ventilation and increased CO_2 levels, with concentrations peaking at 2560 ppm, well above the recommended threshold of 1000 ppm. Factors like room design, occupancy density, and window placement contributed to variations in CO_2 levels across classrooms. The study emphasizes the need for optimized window openings to promote natural ventilation and reduce CO_2 concentrations, suggesting that opening windows beyond 50% can significantly improve IAQ. Regular monitoring, maintenance, and the implementation of effective ventilation strategies are essential to maintaining healthy indoor air quality in schools, ensuring a conducive learning environment for students. This research highlights the critical role of building design and ventilation systems in enhancing IAQ in educational settings.

Keywords: Window Opening; Indoor Air Quality; Carbon Dioxide Concentration; Classroom; School

1. Introduction

Effective window design plays a crucial role in enhancing natural ventilation and improving indoor air quality (IAQ) in classrooms. By optimizing window openings, it is possible to reduce CO_2 concentrations and prevent the accumulation of indoor pollutants. Studies have shown that poorly ventilated classrooms, particularly those with inadequate window design, tend to have elevated CO_2 levels, leading to health issues like cognitive impairment and respiratory problems [Heal et al., 2012; Dherani et al., 2008; Kurmi et al., 2022]. Proper window placement and size are essential in promoting airflow and ensuring healthy IAQ, which can directly improve students' learning environments.

The importance of maintaining adequate ventilation in indoor spaces has been acknowledged for many years, with carbon dioxide (CO_2) levels serving as a key indicator of ventilation rates. Since CO_2 is produced by human metabolism, its concentration reflects the amount of indoor air already exhaled by occupants, offering insights into ventilation quality (Olesen, 2004; Fan et al., 2021; Kabirikopaei and Lau, 2020). However, ASHRAE (2022) cautions that using CO_2

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as an indicator of outdoor air ventilation must account for factors like space type, occupancy, and occupant characteristics.

While indoor air quality depends on multiple factors beyond ventilation, guidelines such as those by the European Committee for Standardization (2006) and Gobierno de España (2007) use CO_2 measurements to estimate ventilation quality levels. These guidelines recommend that classroom CO_2 levels remain below 500 ppm above outdoor levels, corresponding to the IDA 2 category, although infection risk thresholds cannot be universally fixed due to varying circumstances (Peng and Jimenez, 2021). Recent studies, such as those by Peng and Jimenez (2021) and Bazant et al. (2021), have modeled the correlation between infection risk and CO_2 levels.For example, Harvard T.H. Chan School of Public Health suggests maintaining 5 air changes per hour (ACH) to reduce COVID-19 infection risks, leading to approximately 700 ppm CO_2 in typical classrooms (Joseph Allen et al., 2021).

Studies on ventilation and CO_2 levels in schools reveal that students frequently spend extended periods in poorly ventilated spaces. Zemitis et al. (2021) observed average CO_2 levels of 2400 ppm, peaking at over 4400 ppm, in a naturally ventilated school in Latvia, signaling inadequate ventilation. Similarly, Toftum et al. (2015) reported that CO_2 levels in 820 Danish classrooms exceeded 1000 ppm most of the time, with naturally ventilated classrooms showing higher concentrations than mechanically ventilated ones. Research from milder climates, such as Portugal (Almeida et al., 2017), and Southern Europe, including Spain (Fernández-Agüera et al., 2019) and Serbia (Turanjanin et al., 2014), also found CO_2 levels frequently surpassing 1000 ppm in classrooms.

The most common method for monitoring CO_2 levels involves using one analyzer per classroom, as noted in studies like Toftum et al. (2015), Alonso et al. (2021), Vouriot et al. (2021), Zemitis et al. (2021), and Turanjanin et al. (2014). Alternatively, some studies, such as Park et al. (2021) and Almeida et al. (2017), average results from multiple sensors. Vouriot et al. (2021) highlighted that placing multiple sensors within a space can reveal variations in CO_2 levels, offering valuable insights into differing risk levels within the room.

However, effective building design plays a crucial role in enhancing the functionality of school buildings. A key aspect of this design is strategically positioning and designing windows, as they significantly influence indoor air quality (IAQ), particularly in classrooms. Factors such as temperature and humidity affect CO_2 levels, which are critical for maintaining a healthy indoor environment. Poor ventilation, coupled with indoor air pollution, as pollutants from activities indoors. High CO_2 levels can lead to various health problems, including respiratory issues, cognitive impairment, sleep disturbances, headaches, dizziness, and coughing [Heal et al., 2012; Dherani et al., 2008; Kurmi et al., 2022; WHO, 2021].

Designing windows for classrooms is complex, as it involves balancing several factors, with natural airflow being a primary consideration. Proper window design promotes natural ventilation, which helps lower CO_2 levels and improves IAQ. This raises important research questions: (a) Are new school buildings designed to meet clients' needs without adequately considering IAQ, resulting in poor indoor air quality? (b) Do classroom designs in schools effectively promote natural ventilation and improve IAQ?

This research underscores the significance of natural ventilation in enhancing indoor air quality, focusing on reducing elevated CO_2 levels and improving the air quality in classrooms. Effective window design is essential to improving natural ventilation in schools, ultimately helping to reduce CO_2 concentrations and enhance overall indoor air quality.

1.1. Aims and Objectives

To investigate the effect of window openings on indoor air quality and carbon dioxide (CO_2) concentration in school classrooms in Dhaka, with the goal of identifying strategies to enhance ventilation and improve the learning environment

- To investigate how variations in window size and ventilation affect indoor air quality (IAQ), with a specific focus on CO_2 levels, in schools in Dhaka City.
- To compare and analyze the results regarding the impact of window opening size on CO_2 concentration levels in indoor air and temperature.
- To explore the potential of natural ventilation strategies in reducing CO_2 levels and enhancing indoor air quality in schools.
- How does the design of window openings affect indoor air quality (IAQ) and CO_2 levels in schools in Dhaka City?

2. Literature review

Table 1 Literature based

Study (Year)	**Source of CO_2**	**Methodology**	**Key Findings**
Kumar et al. (2022)	Human respiration, building occupancy	Field measurements in 12 school buildings	CO2 levels in classrooms exceeded 1000 ppm during peak occupancy, affecting comfort and concentration
Nahar et al. (2016)	Human respiration, poor ventilation	Indoor air quality assessment in schools in Dhaka	CO2 concentrations ≥600 ppm were linked to respiratory issues in 67% of schoolchildren
García et al. (2019)	Human respiration, classroom design	Case study of school classrooms in Bogota	High CO2 concentrations were found in classrooms with insufficient natural ventilation, negatively affecting students' cognitive performance
Willers et al. (2006)	Gas appliances in kitchens (schools with cafeterias)	Controlled experiments and monitoring in school kitchens	High CO2 concentrations were observed in school kitchens with gas appliances, particularly in poorly ventilated cafeterias
Daisey et al. (2003)	Human respiration, building systems	Field measurements in office and school buildings	CO2 levels >1000 ppm led to discomfort and loss of productivity in office environments
Raouf et al. (2017)	Human respiration, ventilation systems	Monitoring in school buildings across Cairo	CO2 concentrations were higher in schools with poor ventilation, contributing to student fatigue and discomfort
Alshrefy et al. (2020)	Human respiration, HVAC systems	Field study in office buildings	Higher CO2 levels in offices with centralized HVAC systems led to complaints of discomfort and concentration issues
García et al. (2020)	Human respiration, ventilation	Case study in a school in Mexico City	CO2 concentrations of 1200 ppm were found in classrooms with poor ventilation, affecting students' health and academic performance
Melo et al. (2020)	Human respiration, building occupancy	Field measurement in an office complex	High CO2 levels in offices with high occupancy led to reduced work efficiency and increased complaints about indoor air quality
Zaman et al. (2021)	Human respiration, overcrowding	Field measurement in classrooms in Dhaka	CO2 concentrations in overcrowded classrooms ranged between 1200-1600 ppm, leading to discomfort and reduced cognitive performance in students

3. Methodology

3.1. Sampling Site Description and Measurement Period

This study focuses on analyzing the variability of CO_2 levels, indoor air temperature (T), and relative humidity (RH) in two elementary schools in Dhaka. Two sampling campaigns were conducted for each school over one week (working days only, from Sunday morning to Thursday evening). The first campaign took place during the summer season, between May and July 2023, while the second campaign was conducted in the winter season, from December 2023 to February 2024.

The investigation is based on an experimental-comparative approach. The city of Dhaka is located in the capital of Bangladesh shows table 2. According to the climatic parameters given by the metrological station of the city and the site (professional information about meteorological conditions in the world) during the period (2021-2023), Dhaka is characterized by a tropical climate, featuring hot, wet, and humid conditions. According to the Kop pen climate classification, the city exhibits a tropical wet and dry climate. Dhaka has a distinct monsoon season, with an annual average temperature of 25 °C (77°F). The temperature ranges from 18 °C (64 °F) in January to 29 °C (84°F) in August. The monsoon season, from May to September, contributes nearly 80% of the city's annual rainfall, totaling 1,854 millimeters (73.0 inches). This study evaluates the collective school in the Wari residential area. All selected schools were naturally ventilated, with air entering and exiting the classrooms through doors, windows, cracks, and other openings. The schools varied in terms of age, construction, and size. Table 2 provides the key parameters for each of the selected schools. Each classroom had one external wall, one wall in contact with an internal corridor, and the remaining two walls shared with adjacent classrooms.

3.2. Measuring Instruments

The CO_2 concentration levels were measured every 10 minutes using the HOBO Carbon Dioxide/Temperature/Relative Humidity Data Logger, which has a precision of 50 ppm and a range of 0-5000 ppm for indoor CO2 concentrations. Temperature and humidity measurements were taken using the Testo 445 device, which has a temperature range of 0 °C to 50 °C (32°F to 122°F) and the following specifications

- Accuracy: ±0.21 °C from 0°C to 50 °C (±0.38 °F from 32 °F to 122 °F)
- Resolution: 0.024 °C at 25 °C (0.04°F at 77°F)
- Drift: <0.1 °C per year (<0.18 °F per year)

The equipment was calibrated at the beginning of each measurement session. The CO_2 sampling device was positioned approximately one meter above the floor, away from doors and windows, to minimize potential disturbances from air currents.

Table 2 Observed school (source authors 2024)

Parameter	**School A**	**School B**
Location	Wari	Wari
Monitored Classrooms	A1, A2, A3	B1, B2, B3
Classroom Area (m^2)	62, 58, 62	56, 63, 64
Classroom Volume (m^3)	246, 252, 268	182, 205, 187
Average Occupation (pupils/classroom)	22, 26, 27	29, 18, 30
Location Type	residential	residential
School Working Hours (h)	8–15	8–15
Year of Construction	2002	1980
Type of Window	Aluminium-double glazing	Aluminium-double glazing
Type of Floor	Cement or lime concrete	Cement or lime concrete
Classroom Observations		
Window Types	Combination of top-hung windows, light windows, and jalousie windows positioned on the upper side.	
Window Height	The corridor window is located 1.20 meters above the floor; the opposite window is 0.90 meters above the floor.	
Total Opening Area	14.02 m^2 (31% of the classroom's total floor area).	
Effective Ventilation Area	Only 16.8 % of the total opening area was functioning as ventilation during the study.	

4. Results and Discussion

Indoor Air Temperature: Over four days, the indoor temperature in the observation classrooms increased gradually, while the outdoor temperature fluctuated. The maximum indoor air temperature ranged between 30.3 °C and 32.5 °C, with relative humidity ranging from 91.7% to 94.6%.

Outdoor Air Temperature: The maximum outdoor temperature varied between 32.2 °C and 33.6 °C, with relative humidity between 95.9% and 98.5%.

Temperature Difference: The difference between the maximum indoor and outdoor temperatures ranged between 2.7 °C and 3.7 °C.

Relative Humidity: Indoor relative humidity ranged between 77.2% and 84.6%, while outdoor relative humidity was higher, between 95.9% and 98.5%.table summarizing the CO_2 concentration data for both indoor and outdoor environments:

Table 3 Indoor CO_2 Levels and Outdoor CO_2 Levels

Parameter	**Indoor CO_2 Levels**	**Outdoor CO_2 Levels**
Median CO_2 Concentration	602 ppm - 637 ppm	498 ppm - 520 ppm
Maximum CO_2 Concentration	Exceeded 1000 ppm (on occasion)	1893 ppm
Legal/Recommended Limit	1000 ppm (Health Standard)	400 ppm (ASHRAE Standard)
Implications	Occasional peaks over 1000 ppm	Consistent peaks at 1893 ppm
Ventilation Issues	Potential concern with limited ventilation causing peaks	Elevated outdoor levels could impact indoor quality

Results Shows table 4-7, monitoring data collected over four days revealed that indoor air temperatures in the classrooms increased gradually over time, as shown in Figure1-5. The CO_2 concentration in classrooms fluctuates based on the percentage of window closure. When windows are 75% closed, CO_2 levels tend to be higher compared to when they are 50% closed. This indicates that reduced ventilation (as seen with more closed windows) hinders the dispersion of CO_2, leading to its accumulation. The analysis of CO_2 levels across four days reveals clear patterns regarding ventilation and air quality in the classrooms. Higher CO_2 concentrations are consistently observed when windows are only 75% closed, highlighting the significant impact of limited ventilation on air quality. Block B classrooms exhibit consistently higher CO_2 levels than those in Block A, with Classroom B1 recording the highest concentrations across multiple days, reaching a peak of 2560 ppm. This suggests that factors such as room design, occupancy density, or ventilation inefficiencies might be contributing to the poor air quality in Block B classrooms. Meanwhile, Classroom A3 shows relatively lower CO_2 levels, indicating better ventilation or airflow.

Table 4 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 1

Day	**CLASS ROOMCO2**	**50%close window**	**75%close window**	**Average**
Day 1	CLASS ROOM A1	1367	2250	1808.5
Day 1	CLASS ROOM A2	1355	1780	1567.5
Day 1	CLASS ROOM A3	1340	1750	1545
Day 1	CLASS ROOM B1	1476	2378	1927
Day 1	CLASS ROOM B2	1420	2221	1820.5
Day 1	CLASSROOM B3	1418	2150	1784

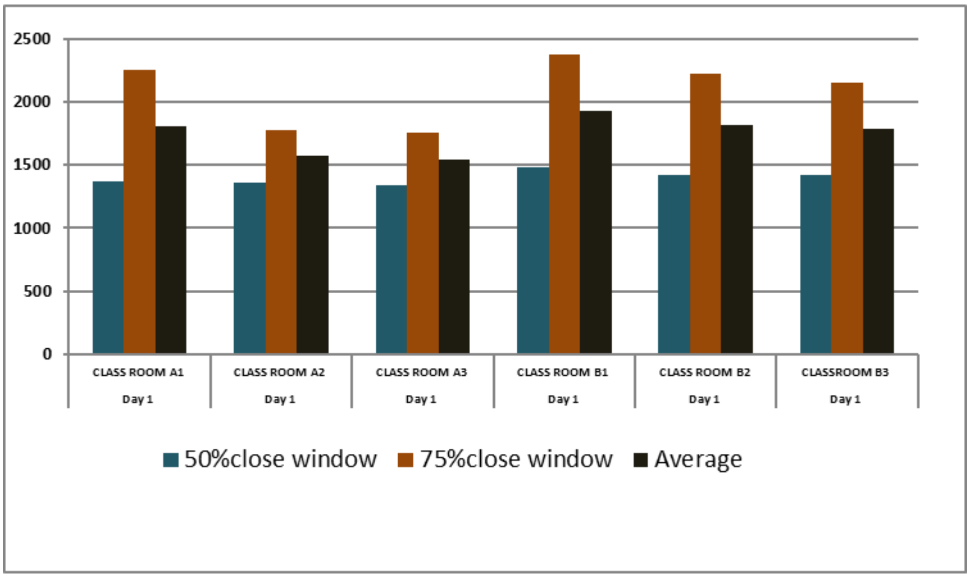

Figure 1 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 1

Table 5 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 2

Day	CLASS ROOM	50%close window	75%close window	Average
Day 2	CLASS ROOM A1	1465	2400	1932.5
Day 2	CLASS ROOM A2	1395	2276	1835.5
Day 2	CLASS ROOM A3	1405	2244	1824.5
Day 2	CLASS ROOM B1	1500	2560	2030
Day 2	CLASS ROOM B2	1455	2255	1855
Day 2	CLASS ROOM B3	1423	2210	1816.5

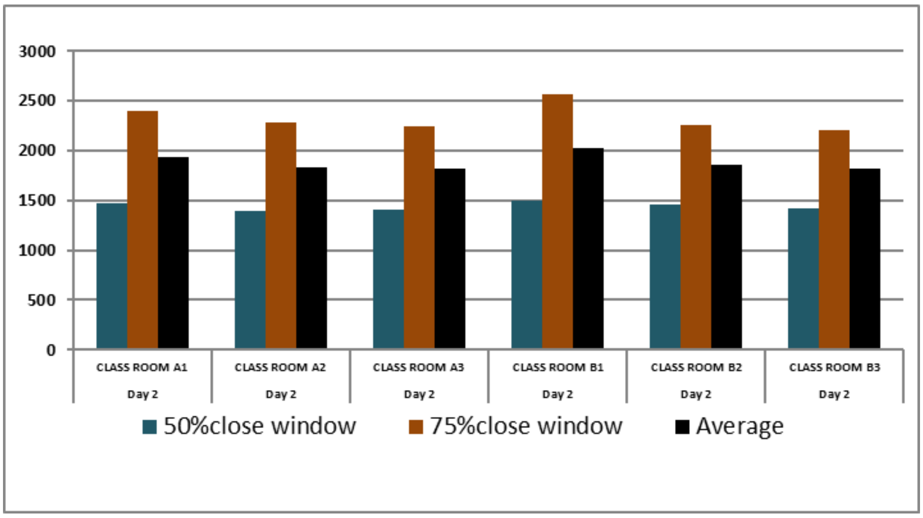

Figure 2 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 2

Table 6 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 3

Day	CLASS ROOMCO2	50%close window	75%close window	Average
Day 3	CLASS ROOM A1	1367	1176	1271.5
Day 3	CLASS ROOM A2	1467	1456	1461.5
Day 3	CLASS ROOM A3	1468	1460	1464
Day 3	CLASS ROOM B1	1476	1273	1293
Day 3	CLASS ROOM B2	1420	1476	1448
Day 3	CLASS ROOM B3	1189	1780	1484.5

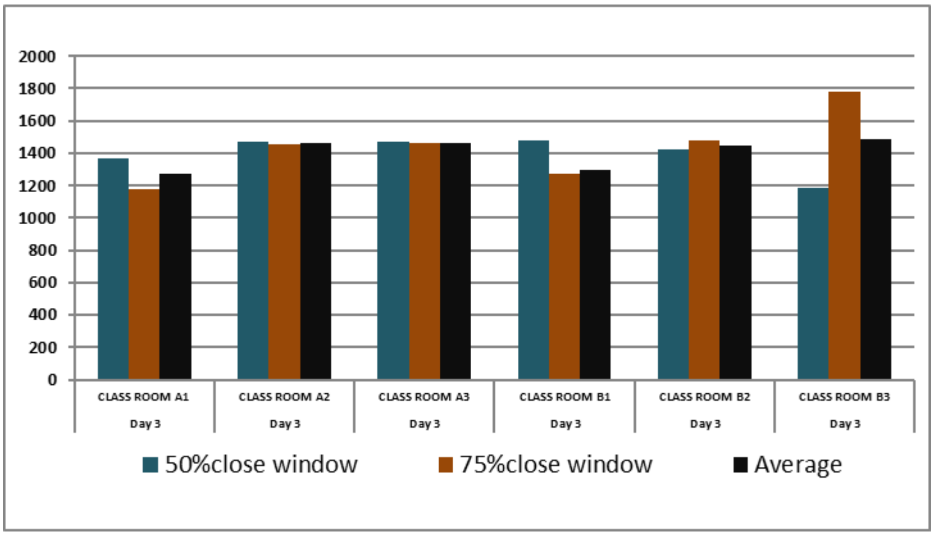

Figure 3 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 3

Table 7 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 4

Day	CLASS ROOM	50%close window	75%close window	Average
Day 4	CLASS ROOM A1	1486	2301	1893.5
Day 4	CLASS ROOM A2	1395	1893	1644
Day 4	CLASS ROOM A3	1567	2190	1878.5
Day 4	CLASS ROOM B1	1500	2276	1888
Day 4	CLASS ROOM B2	1256	2255	1755.5
Day 4	CLASS ROOM B3	1190	2210	1700

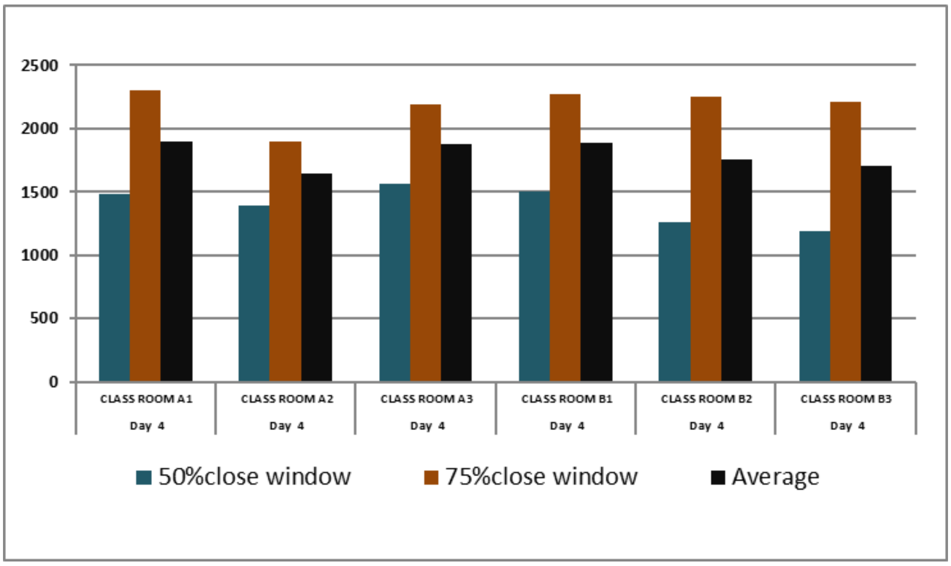

Figure 4 CO_2 Concentration Level opening window Class room A1, A2, A3 , B1, B2, B3 Day 4

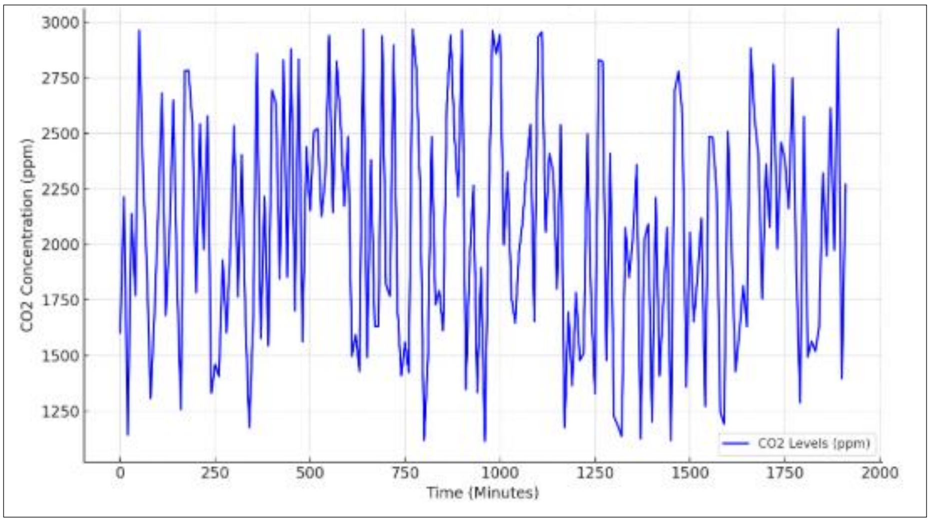

Figure 5 CO2 Concentration Level opening window every 10 minutes day1,2,3,4

These findings underscore the urgent need for improved ventilation strategies to enhance indoor air quality. Opening windows beyond 50% closure could help reduce CO^2 levels significantly. Additionally, targeted investigations should be conducted in Block B classrooms to identify and address specific ventilation shortcomings. Implementing regular monitoring and maintenance of ventilation systems is essential to ensure CO2 levels remain below the recommended threshold of 1000 ppm, promoting healthier and more conducive learning environments.

5. Conclusion

This study highlights the critical role of effective ventilation in maintaining indoor air quality (IAQ) in classrooms, particularly in Dhaka's tropical climate. The observed trends in CO_2 concentrations and indoor temperature fluctuations reveal the direct impact of window design and ventilation practices on air quality. Key findings include:

- Indoor temperatures showed a gradual increase; while outdoor temperatures fluctuated, with indoor relative humidity remaining lower than outdoor humidity. The temperature difference between indoor and outdoor spaces was consistently between 2.7 °C and 3.7 °C, indicating the influence of ventilation on heat buildup within classrooms.

- The concentration of CO_2 in classrooms increased significantly with reduced window openings, particularly when windows were 75% closed. This pattern demonstrates that limiting natural ventilation leads to the accumulation of CO_2, which can negatively affect IAQ. The CO_2 levels peaked at 2560 ppm in some classrooms, well above the recommended threshold of 1000 ppm, particularly in Block B classrooms, which displayed consistently higher concentrations compared to Block A classrooms.
- The study found significant variability between classrooms in terms of CO_2 levels, with Classroom B1 consistently exhibiting the highest CO_2 concentrations. This suggests that factors such as room design, occupancy density, and ventilation inefficiencies contribute to the observed discrepancies in air quality.
- The findings underscore the importance of optimizing window openings for natural ventilation to reduce CO_2 levels. Ensuring windows are open beyond 50% can significantly improve air quality. Regular monitoring, maintenance, and assessment of ventilation systems, especially in schools like those in Block B, are essential to keep CO_2 concentrations within healthy limits.

Overall, this research emphasizes the need for improved building designs and ventilation strategies to enhance IAQ in classrooms. It calls for further investigation into the design and functioning of ventilation systems, particularly in schools with suboptimal air quality, to create healthier learning environments for students.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare that there are no competing interests.

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