

The Study of Window Size Variation Effects on CO₂ Concentration Level for Indoor Air Quality in Apartment Kitchens in Dhaka City

Farhana Ahmed¹; Rumana Rashid²

¹M. Arch Candidate; Department of Architecture Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh

²Professor; Department of Architecture Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh

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Abstract: Indoor air quality (IAQ) has become an important concern in residential building design because it directly affects occupants' health, comfort, and environmental performance. Among different indoor spaces, kitchens are considered one of the most critical zones influencing IAQ due to pollutant generation during cooking activities. Carbon dioxide (CO₂) concentration is widely used as an indicator of ventilation effectiveness and indoor air quality. However, many residential apartment kitchens in Dhaka are designed with limited façade exposure and small window openings, which may lead to inadequate natural ventilation and increased pollutant accumulation. The aim of this study is to evaluate the impact of window opening configuration and operable window area on indoor CO₂ concentration in naturally ventilated residential apartment kitchens in Dhaka City. The objectives include analysing CO₂ variation during different cooking phases, examining the influence of window opening conditions, evaluating the effect of kitchen orientation, and comparing seasonal differences in ventilation performance. A quantitative field-based research methodology was adopted. Field measurements were conducted in representative residential apartments using a HOBO CO₂ data logger and Testo instruments. Indoor CO₂ concentration was monitored at five-minute intervals during three cooking phases: before cooking, during cooking, and after cooking. The study analysed four window opening configurations (100% closed, 25% open, 50% open, and 100% open), four kitchen orientations, and two seasonal conditions (summer and winter). The results indicate that cooking activities significantly increase indoor CO₂ concentration, with peak levels reaching approximately 1850–2100 ppm under closed-window conditions. Increasing window opening area significantly improves ventilation performance and pollutant removal. Seasonal variation also affects pollutant behaviour, with winter conditions showing slower pollutant decay. The findings highlight the importance of operable window area in improving natural ventilation performance in residential kitchens. Adequate window design and effective ventilation strategies are therefore recommended to enhance indoor air quality in high-density residential environments.

Keywords: Indoor Air Quality, Carbon Dioxide (CO₂), Natural Ventilation, Residential Kitchens, Window Opening Configuration, Dhaka Apartments.

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I. INTRODUCTION

➤ Background

Indoor Air Quality (IAQ) has become an important concern in residential building design because it directly influences occupant health, comfort, and environmental quality. Among different indoor spaces, kitchens represent one of the most critical zones affecting IAQ because cooking activities generate various pollutants, including carbon dioxide (CO₂), particulate matter (PM_{2.5} and PM₁₀), volatile organic compounds (VOCs), and nitrogen dioxide (NO₂) (Feichtinger, 2022; Batagoda & Jayasinghe, 2010). When

these pollutants accumulate in poorly ventilated indoor environments, they may negatively affect residents' health and degrade indoor environmental condition

Carbon dioxide (CO₂) concentration is widely used as an indicator of ventilation effectiveness in indoor environments. Elevated indoor CO₂ levels generally indicate insufficient air exchange and inadequate ventilation performance (Kumar et al., 2022; Mandin, 2022). Previous studies have shown that prolonged exposure to elevated CO₂ concentrations may lead to respiratory discomfort, fatigue, and reduced cognitive performance (Heal et al., 2012; Kurmi

et al., 2022). Therefore, monitoring CO₂ concentration has become a reliable approach for assessing natural ventilation performance in residential spaces.

Rapid urbanisation in cities such as Dhaka has significantly increased the development of high-rise residential apartment buildings. However, these buildings often prioritise spatial efficiency and construction economy over environmental performance. As a result, kitchen spaces are frequently designed with limited façade exposure, small window openings, and restricted airflow pathways. Such design limitations can lead to inadequate natural ventilation and increased indoor pollutant accumulation during cooking activities. In many cases, kitchens are located within interior zones of apartment units where access to fresh outdoor air is limited, further aggravating indoor air quality problems.

Natural ventilation strategies play a crucial role in controlling indoor pollutants and maintaining acceptable indoor environmental conditions. Among different architectural design parameters, window size, opening configuration, and operability significantly influence ventilation performance and pollutant removal efficiency. Larger and operable windows can facilitate the movement of fresh outdoor air into indoor spaces while allowing polluted air to escape. In tropical climates such as Bangladesh, natural ventilation through windows provides an energy-efficient and sustainable strategy for maintaining acceptable indoor air quality without relying heavily on mechanical ventilation systems.

Despite the recognised importance of window design for natural ventilation, many residential apartment kitchens in Dhaka still lack adequate window sizing and effective ventilation design. Existing building codes provide limited guidance regarding kitchen window dimensions or operable opening requirements. Consequently, a significant gap exists between design knowledge and actual building performance. Empirical research examining the relationship between window size variation and indoor CO₂ concentration in residential kitchens remains limited, particularly in the context of high-density tropical cities.

➤ *Aim and Objectives*

The main aim of this study is to evaluate the impact of window opening configuration and operable window area on indoor carbon dioxide (CO₂) concentration in naturally ventilated residential apartment kitchens in Dhaka City.

• *The Specific Objectives of this Research are:*

- ✓ To analyse the variation of indoor CO₂ concentration across different cooking phases (before, during, and after cooking).
- ✓ To examine the influence of different window opening conditions (100% closed, 25% open, 50% open, and 100% open) on indoor CO₂ concentration levels.
- ✓ To evaluate the effect of kitchen orientation on peak CO₂ accumulation and pollutant removal.
- ✓ To compare seasonal variations (summer and winter) in indoor CO₂ behaviour under similar ventilation conditions.
- ✓ To assess the relative importance of operable window area compared with geometric window size in determining natural ventilation effectiveness.

➤ *Research Questions*

- To what extent is indoor air quality, as reflected by indoor CO₂ concentration, considered in the design of residential apartment kitchens?
- How do existing kitchen layouts and window configurations influence natural ventilation performance and indoor CO₂ concentration levels in residential apartments?

➤ *Significance of the Research*

This research is significant as it addresses indoor air quality (IAQ) issues in residential apartment kitchens, a space where pollutant generation is high but often receives limited attention in architectural design. By focusing on indoor carbon dioxide (CO₂) concentration as an indicator of ventilation performance, the study provides quantitative evidence on how window size variation and kitchen design influence natural ventilation effectiveness in high-density residential buildings.

II. LITERATURE REVIEW

Table 1 Indoor CO₂ Concentration and Ventilation in Residential Kitchens

Year	Author / Study	Country	Research Focus	Key Findings
1954	Sterling	USA	Early IAQ assessment	Combustion stoves significantly increased indoor CO ₂ levels in residential buildings.
1973	Hodgson & Popp	USA	Residential combustion pollutants	Gas stoves were identified as major contributors to indoor CO ₂ accumulation; ventilation is essential.
1980	Jones et al.	UK	Indoor pollutants during cooking	CO ₂ concentration in kitchens was found to be 3–4 times higher than outdoor levels during cooking.
1990	Yamamoto et al.	Japan	IAQ in urban apartments	Small kitchens without proper ventilation recorded CO ₂ levels above 1500 ppm.
1993	Offermann	USA	Ventilation and CO ₂ peaks	Indoor CO ₂ exceeded 2000 ppm in poorly ventilated kitchens.
2001	Sherman	USA	Natural ventilation effectiveness	Opening windows reduced indoor CO ₂ concentration by approximately 45%.

2004	Yamamoto et al.	Japan	Cooking-related IAQ	Sealed kitchens experienced CO ₂ levels exceeding 2000 ppm during cooking activities.
2007	Kim et al.	South Korea	Kitchen ventilation strategies	Window ventilation reduced CO ₂ concentration from 1500 ppm to around 600 ppm.
2012	Liu & Zhang	China	Mechanical ventilation impact	Exhaust fans significantly reduced peak indoor CO ₂ levels.
2021	Patel et al.	India	Urban apartment ventilation	Cross-ventilation maintained indoor CO ₂ concentration below 1000 ppm.
2024	Xu et al.	China	Smart ventilation systems	Advanced ventilation systems maintained indoor CO ₂ below 900 ppm during cooking.

III. RESEARCH METHODOLOGY

This study adopts a quantitative field-based research approach to investigate the influence of architectural design parameters on indoor carbon dioxide (CO₂) concentration in residential apartment kitchens in Dhaka. Instead of relying on simulation or laboratory experiments, field measurements were conducted in occupied apartments in order to capture realistic cooking activities, occupant behaviour, and natural ventilation practices. This approach allows the research to represent actual indoor environmental conditions and provides practical insights for architectural design strategies related to indoor air quality. CO₂ concentration was selected as the primary indicator of ventilation performance and indoor air quality because it reflects the effectiveness of air exchange within indoor environments.

The research design focused on naturally ventilated kitchens, as natural ventilation remains the most common ventilation strategy in residential apartments in Dhaka. A comparative analytical framework was adopted to evaluate the influence of several variables on indoor CO₂ concentration. These variables included seasonal variation (summer and winter), kitchen orientation (north, south, east, and west), window opening configuration (100% closed, 25% open, 50% open, and 100% open), and cooking activity phases (before cooking, during cooking, and after cooking). By systematically varying one parameter while keeping others constant, the study was able to identify the individual influence of each variable on ventilation performance and indoor pollutant behaviour.

Field measurements were carried out in representative middle-income residential apartments in Dhaka to ensure that the selected kitchens reflected typical architectural characteristics found in urban housing. The monitored kitchens exhibited common spatial configurations with similar construction materials, floor-to-ceiling heights, and façade openings. The typical kitchen window measured approximately 1.066 m × 1.117 m, providing a geometric window area of approximately 2.30 m². However, the effective ventilation performance depended primarily on the operable portion of the window, which was varied according to the defined opening configurations during the experiment.

Indoor CO₂ concentration, temperature, and relative humidity were continuously recorded using a HOBO Carbon Dioxide/Temperature/Relative Humidity data logger with a measurement range of 0–5000 ppm and an accuracy of ±50 ppm. Additional environmental measurements were taken using a Testo instrument to verify temperature and humidity conditions. The monitoring device was positioned at approximately 1.0 m above the floor level within the kitchen, corresponding to the human breathing zone during cooking activities. Measurements were recorded at five-minute intervals to capture the dynamic changes in pollutant concentration associated with cooking activities.

Data collection followed a structured monitoring sequence covering three cooking phases: before cooking, during cooking, and after cooking. Each monitoring session lasted approximately 30 minutes and included baseline indoor air quality measurements prior to cooking, active pollutant generation during cooking, and post-cooking decay behaviour under controlled window opening conditions. Cooking activities represented typical Bangladeshi household practices, including frying, grilling, and boiling food items. These activities were selected to represent common pollutant generation scenarios observed in residential kitchens.

The collected CO₂ data were processed into day-wise average values to minimise short-term fluctuations and improve the reliability of the results. Comparative analysis was conducted to examine seasonal variation, orientation-based differences, and the influence of window opening configurations on indoor CO₂ concentration. Through this systematic methodology, the study provides empirical evidence on how architectural design parameters and natural ventilation conditions influence indoor air quality in residential apartment kitchens in Dhaka. Shown as figure 1.

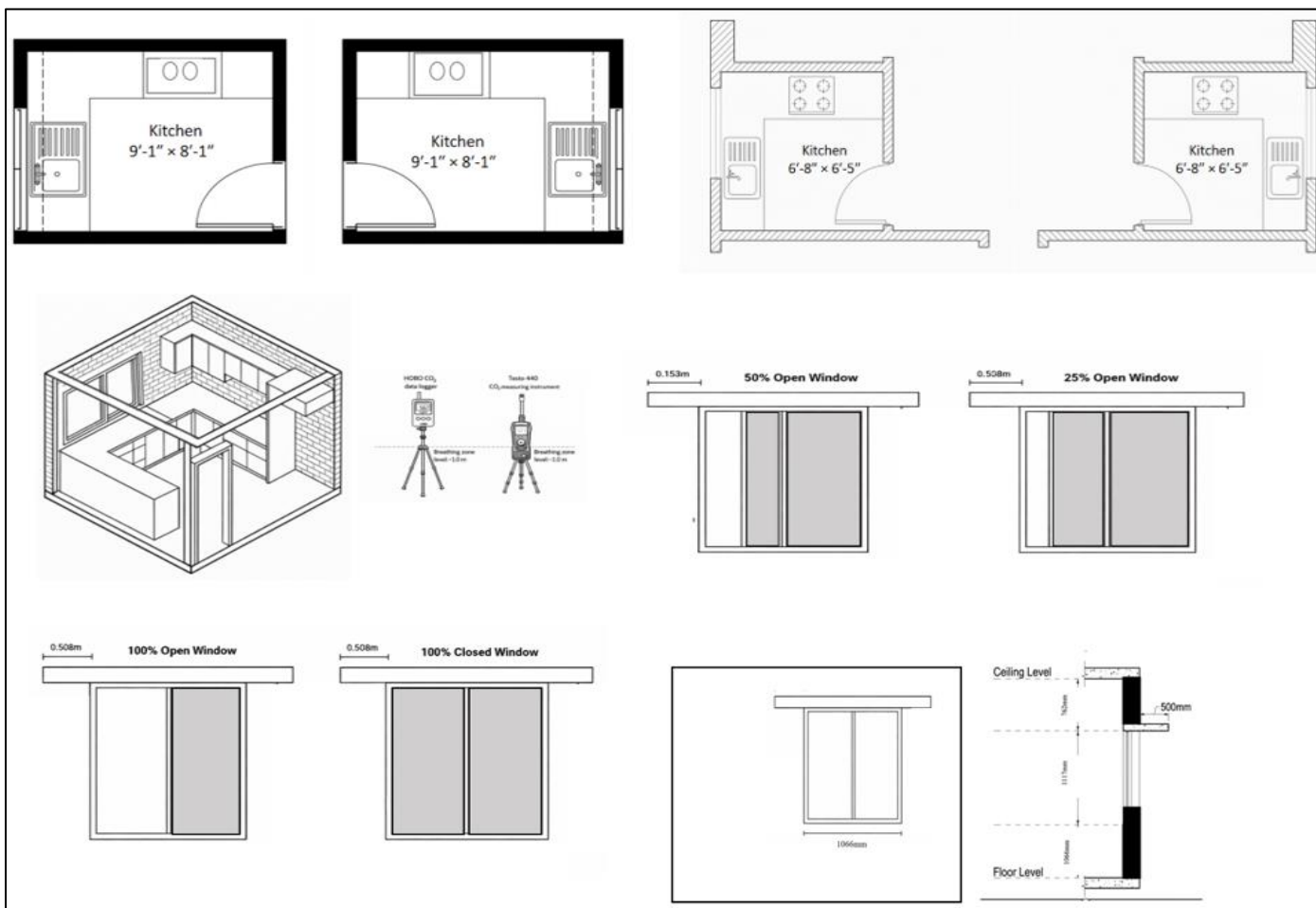


Fig 1 Research Methodology and Experimental Setup for Monitoring Indoor CO₂ Concentration in Residential Apartment Kitchens.

IV. RESULTS AND DISCUSSION

This study presents the analysis of indoor carbon dioxide (CO₂) concentration measured in residential apartment kitchens under different ventilation conditions. The collected data were analysed to evaluate how variations in window opening size, kitchen orientation, seasonal conditions, and cooking phases influence indoor air quality. Indoor CO₂ concentration was selected as the primary indicator of ventilation performance because it reflects the effectiveness of natural air exchange within indoor environments. The analysis focuses on identifying the patterns of pollutant generation during cooking activities and the subsequent decay behaviour under different natural ventilation scenarios.

The monitored kitchens represent typical residential apartment layouts commonly found in Dhaka. Data were collected over multiple monitoring sessions during both summer and winter seasons to capture seasonal variation in ventilation behaviour. Measurements were conducted at five-minute intervals, allowing detailed observation of CO₂ concentration changes before cooking, during cooking, and after cooking. The processed dataset was subsequently analysed using graphical and comparative methods to identify

the relationship between ventilation conditions and indoor CO₂ behaviour.

➤ *Seasonal Variation of Indoor CO₂ Concentration*

Seasonal variation significantly affects natural ventilation performance because outdoor climatic conditions influence airflow and window opening behaviour. The analysed data indicate that indoor CO₂ concentration levels varied between summer and winter seasons.

During the summer season, natural ventilation performance was generally higher due to increased airflow and a greater tendency for occupants to keep windows open. As a result, CO₂ concentration decreased more rapidly after cooking activities. Although peak CO₂ levels were still observed during cooking, pollutant decay occurred faster under summer ventilation conditions.

In contrast, winter conditions showed relatively higher indoor CO₂ concentration and slower decay patterns. This behaviour can be attributed to reduced airflow and limited window opening during colder periods. Consequently, pollutant accumulation remained longer in the indoor environment.

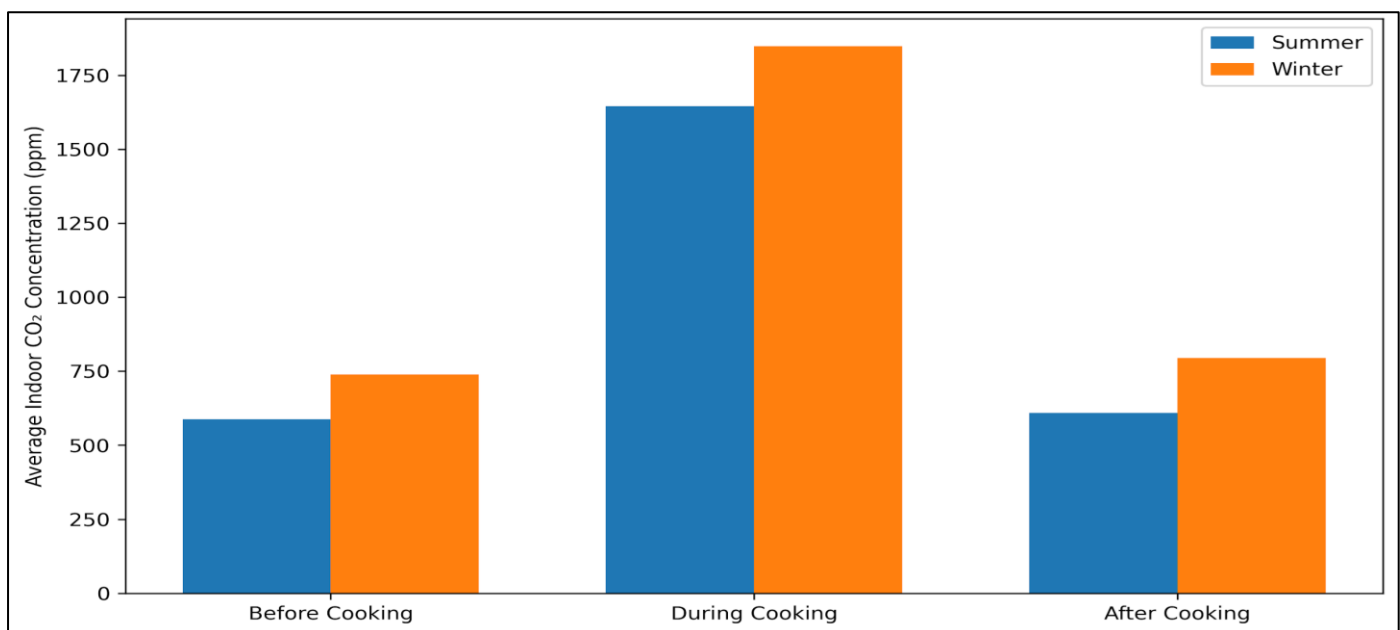


Fig 2 Seasonal Variation of Indoor CO₂ Concentration in Residential Apartment Kitchens (Summer vs Winter).

➤ *Effect of Window Opening Configuration*

Window opening configuration is one of the most significant parameters affecting natural ventilation performance. The study analysed four window opening conditions: fully closed (0%), 25% open, 50% open, and fully open (100%).

The results show that the highest CO₂ concentrations were observed when the window remained fully closed. Under this condition, air exchange was extremely limited and pollutants generated during cooking accumulated rapidly within the kitchen space.

When the window opening area increased to 25% and 50%, ventilation performance improved significantly. The increased operable window area allowed fresh outdoor air to enter the kitchen and diluted indoor pollutants. The lowest CO₂ concentration levels were observed when the window was fully open, indicating maximum ventilation performance.

These findings demonstrate that operable window area plays a critical role in controlling indoor pollutant concentration in naturally ventilated kitchens.

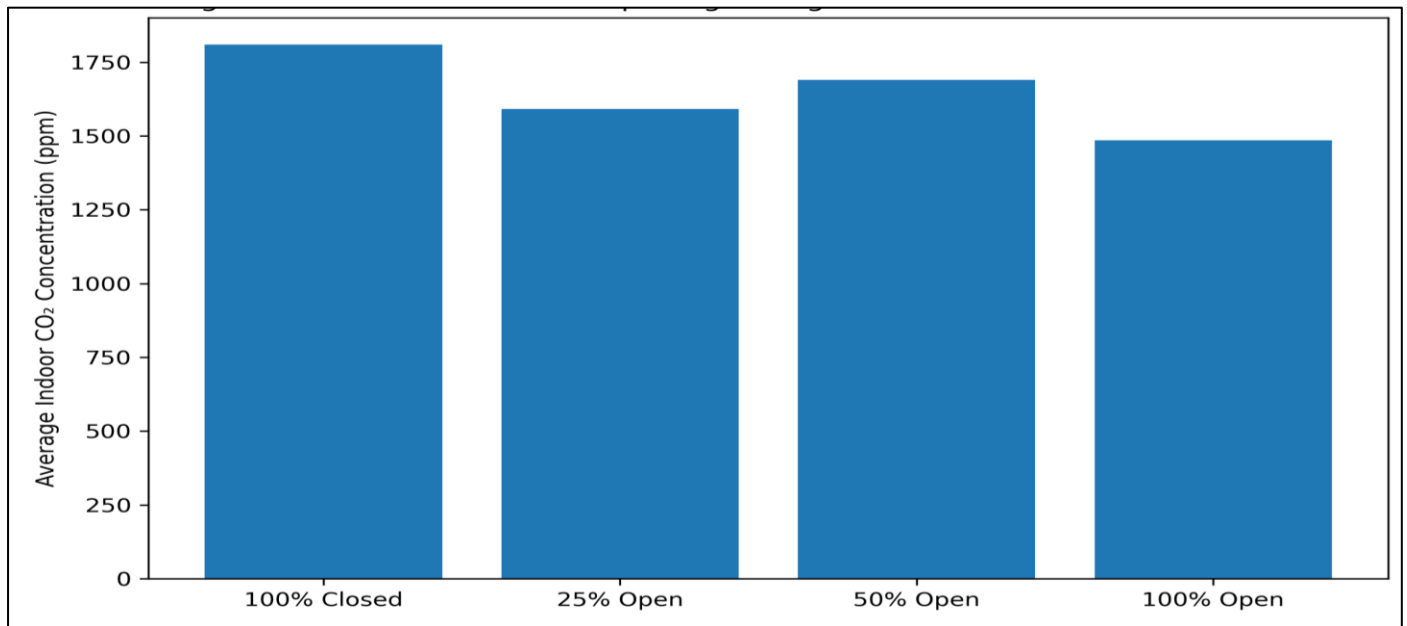


Fig 3 Effect of Window Opening Configuration (100% Closed, 25% Open, 50% Open, and 100% Open) on Indoor CO₂ Concentration in Residential Apartment Kitchens.

➤ *Influence of Kitchen Orientation*

Kitchen orientation also influences indoor CO₂ concentration because façade exposure affects airflow patterns and wind-driven ventilation. The study analysed kitchens facing four different orientations: north, south, east, and west.

The results indicate that kitchens with favourable airflow exposure generally experienced lower pollutant

accumulation. Certain orientations allowed better air movement through the kitchen window, resulting in improved ventilation performance.

Conversely, kitchens with limited airflow exposure experienced relatively higher CO₂ concentration levels during cooking activities. These results suggest that orientation plays an important role in determining the effectiveness of natural ventilation.

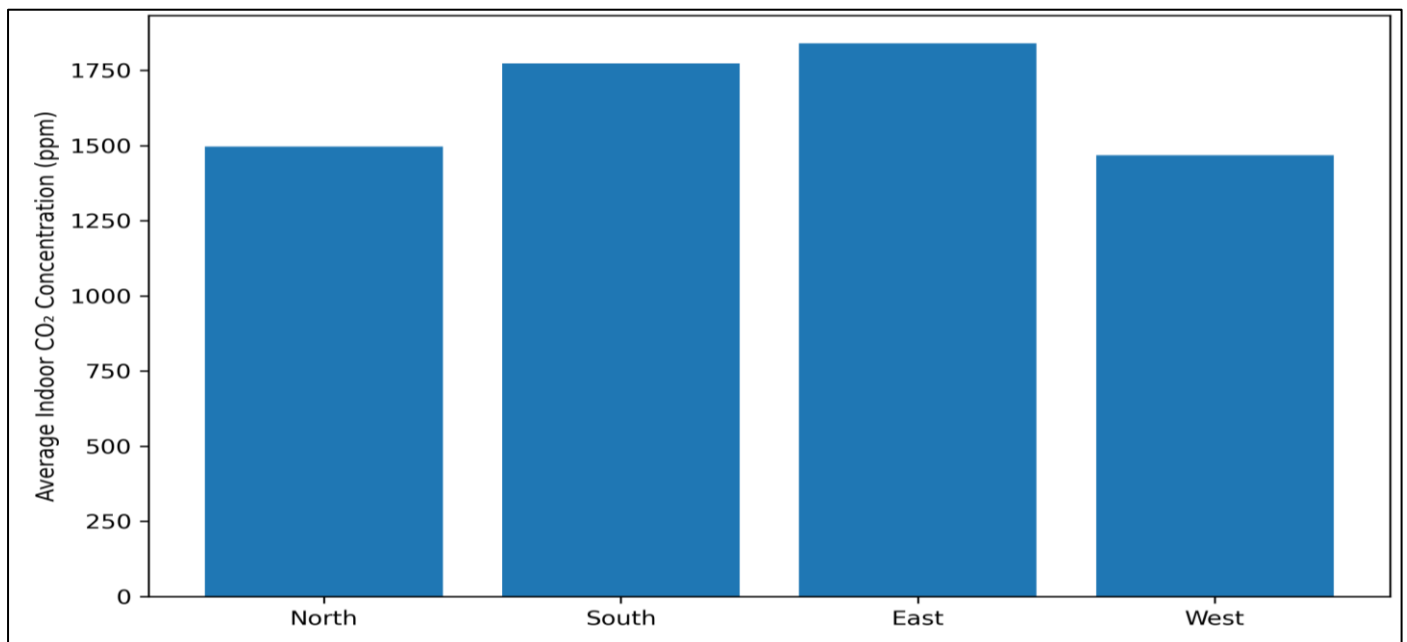


Fig 4 Comparison of Indoor CO₂ Concentration Across Different Kitchen Orientations (North, South, East, and West) in Residential Apartment Kitchens.

➤ *CO₂ Behaviour During Cooking Phases*

Indoor CO₂ concentration varies significantly across different cooking phases. To understand pollutant behaviour

in residential kitchens, the cooking cycle was divided into three stages: before cooking, during cooking, and after cooking.

Before cooking, baseline indoor CO₂ levels were recorded to represent the background indoor air quality condition. During cooking, CO₂ concentration increased rapidly due to combustion from gas burners and human activity. This stage represents the peak pollutant generation period.

After cooking, the decay behaviour of CO₂ concentration was analysed. Kitchens with larger window

opening areas showed faster pollutant removal, whereas kitchens with closed windows experienced slower recovery of indoor air quality.

This analysis highlights the importance of ventilation during cooking activities in order to reduce indoor pollutant accumulation.



Fig 5 Variation of Indoor CO₂ Concentration During Different Cooking Phases (before Cooking, During Cooking, and after Cooking) in Residential Apartment Kitchens.

➤ *Post-Cooking CO₂ Decay Pattern*

The decay pattern of indoor CO₂ concentration after cooking provides important information regarding ventilation efficiency. The analysis indicates that the rate of CO₂ reduction varies depending on window opening conditions.

Under fully open window conditions, pollutant removal occurred rapidly because natural airflow allowed effective

dilution of indoor pollutants. However, when the window remained partially open or closed, the decay rate was significantly slower.

This behaviour indicates that effective natural ventilation is essential for restoring indoor air quality after cooking activities. Increasing operable window area can significantly enhance pollutant removal efficiency.

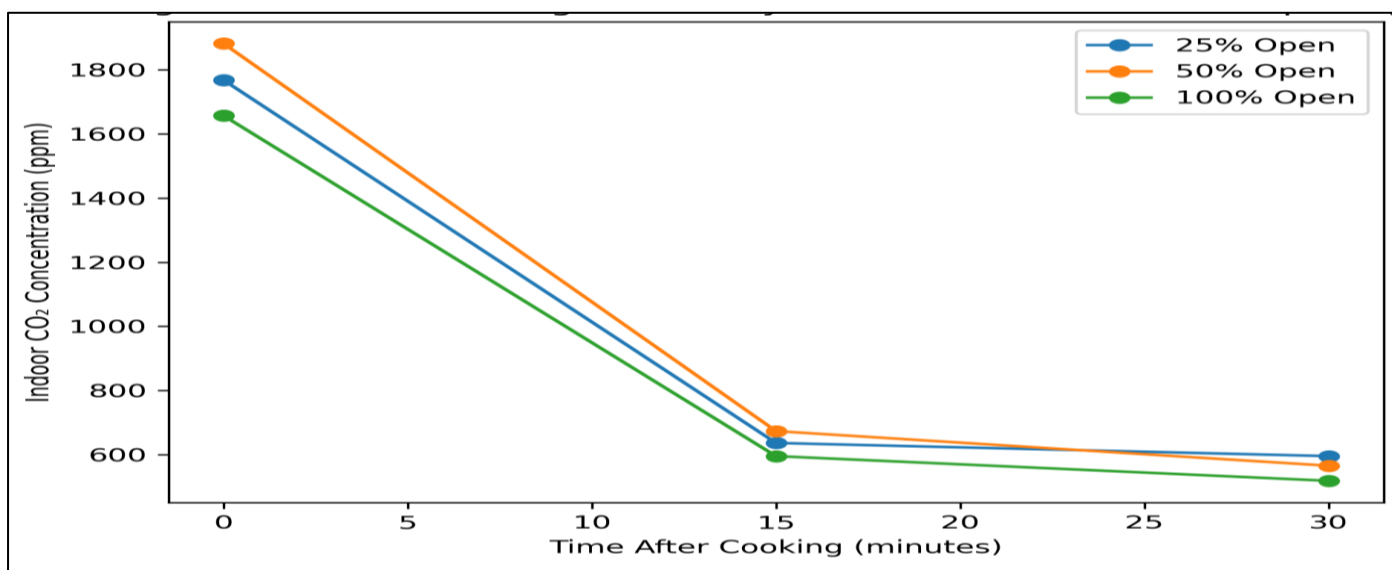


Fig 6 Post-Cooking Decay Pattern of Indoor CO₂ Concentration Under Different Window Opening Conditions.

Table 2 Summary of Key Findings on Window Opening, Orientation, and Seasonal Effects on Indoor CO₂ Concentration

	Condition	Key Observation (Data-Based)	Quantitative Evidence
Window Opening	100% Closed	Worst ventilation performance	Peak CO ₂ ≈ 1850–2100 ppm
	25% Open	Minor improvement	≈ 5–7% peak reduction
	50% Open	Significant improvement	≈ 13–15.5% peak reduction
	100% Open	Best recovery performance	Lowest after-cooking CO ₂ ≈ 545–700 ppm
Orientation	Summer	South highest, West lowest	≈ 17% peak variation
	Winter	Reduced orientation effect	≈ 10% variation
Seasonal Effect	Seasonal sensitivity	West most sensitive	≈ 16% winter increase
	Winter vs Summer (Peak)	Winter consistently higher	≈ 9–16% increase
	Winter vs Summer (After)	Slower decay in winter	≈ 14–21% increase
Window Size & Ratio	WWR	High façade openness	≈ 39%
	WFR	Large floor-based ratio	≈ 58%
Operable Area	0% Open	No effective ventilation	0.00 m ² (0%)
	25% Open	Minor airflow gain	0.58 m ² (14.5%)
	50% Open	Strong performance improvement	1.15 m ² (29%)
	100% Open	Maximum potential utilised	2.30 m ² (58%)

V. CONCLUSION

This study investigated the behaviour of indoor carbon dioxide (CO₂) concentration in naturally ventilated residential apartment kitchens in Dhaka. The results indicate that cooking activities significantly increase indoor CO₂ levels, with the highest concentrations occurring during active cooking periods.

The analysis shows that operable window area is a key factor influencing ventilation performance. Kitchens with larger window openings demonstrated lower CO₂ concentrations and faster pollutant removal after cooking. In contrast, closed or partially opened windows resulted in higher pollutant accumulation and slower recovery of indoor air quality.

Seasonal variation also influenced ventilation effectiveness. Winter conditions generally produced higher indoor CO₂ concentrations and slower pollutant decay compared to summer. Orientation differences were observed; however, their influence was less significant than window opening configuration and seasonal airflow conditions.

Overall, the findings highlight that effective natural ventilation in residential kitchens depends primarily on adequate operable window area and appropriate ventilation strategies to maintain acceptable indoor air quality.

RECOMMENDATIONS

Based on the findings of this study, several recommendations can be proposed to improve natural ventilation performance in residential apartment kitchens. First, sufficient operable window area should be provided to enhance air exchange and reduce indoor CO₂ accumulation during cooking. Second, window design should emphasize

functional operability rather than relying only on large geometric window size. Third, additional ventilation support such as exhaust fans or cross-ventilation strategies may be considered to improve pollutant removal, particularly during winter conditions when natural airflow is reduced. Finally, kitchen orientation and surrounding urban density should be considered in residential building design to ensure adequate airflow access and better indoor air quality.

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