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Field survey on the impact of window opening on indoor temperature and humidity during the heating season

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Abstract

This study evaluates thermal comfort in residential kitchens in Dhaka City, focusing on the influence of window opening behavior on indoor temperature and humidity under different weather conditions. The primary objectives were to analyze window opening patterns and their impact on indoor air conditions, identify architectural factors influencing thermal comfort, and recommend adaptive solutions for energy-efficient ventilation. An experimental-descriptive approach was used, encompassing real-time temperature and humidity measurements in six residential kitchens during May and June 2024. Measurements were recorded under three weather scenarios—sunny, cloudy, and rainy days—with windows fully closed and partially opened (1/4 opening). Results indicated minimal differences in indoor air conditions with closed windows, irrespective of weather. Opening windows to 1/6 proved optimal for balancing ventilation and comfort during sunny days, while prolonged window openings increased energy consumption. On rainy days, high humidity limited indoor comfort, making window opening less effective. Temperature fluctuations across different window opening ratios remained within 1°C, while humidity changes were limited to 0–5% RH. The findings suggest intermittent window openings of up to 8 hours as the most efficient ventilation strategy, while prolonged openings were inefficient. Additionally, adaptive air treatment processes were recommended to maintain desired thermal conditions. This research provides valuable insights for optimizing natural ventilation in residential kitchens, balancing indoor comfort and energy efficiency in tropical climates like Dhaka.

Keywords: Residential kitchen; Window opening; Temperature; Humidity; Heating-season

1. Introduction

The kitchen, often considered the heart of the home, is not only a place for food preparation but also functions as a space for recreation, family communication, and sometimes works. Cooking, a physically demanding daily activity can have significant physical, emotional, and cognitive effects on individuals (Banerjee et al., 2018). Factors such as temperature and humidity play a critical role in influencing quality of life and productivity, particularly for those spending long hours in the kitchen. According to Baruah et al. (2014), high temperatures and humidity have detrimental effects on work performance, with prolonged exposure leading to decreased efficiency and physical discomfort (Abdullah et al., 2021). Indoor air temperature in residential kitchens can rise by as much as 10.3°C above outdoor temperatures during cooking, further contributing to discomfort.

Indoor air quality in kitchens can deteriorate due to pollutants from gas stoves and other cooking sources, creating challenges in maintaining both thermal comfort and good air quality. Hailu et al. (2021) note that adaptive thermal comfort standards recommend indoor temperature zones for optimal comfort ranging from 24.7°C to 31.7°C. Khare

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(2014) found that humidity levels in kitchens typically ranged from 65-72%, whereas the comfortable humidity limits are usually between 40-50% in winter and 40-60% in summer. Adverse environmental conditions, including high temperatures and humidity, can negatively impact workers' performance and well-being (Khare, 2016).

Indoor environmental factors such as temperature and humidity are crucial to work performance. Prolonged exposure to unfavorable conditions can reduce efficiency and negatively impact workers' health. For women, who often balance work both inside and outside the home, maintaining a comfortable indoor environment is vital for their well-being (Cao et al., 2017; Grandjean, 1973). Women working in kitchens, in particular, are exposed to high temperatures and humidity, which adversely affect both their physical and mental well-being (Abdullah et al., 2021). Comfort in kitchen environments is largely influenced by temperature, humidity, and other environmental factors, such as lighting and noise, which can affect productivity and efficiency (Shobha et al., 2012).Effective management of climate variations is essential for maintaining comfort and reducing energy consumption (Li et al., 2021). In response to the increasing energy demands for cooling and improving indoor environments, strategies such as intermittent operation of systems can significantly reduce energy consumption (Li et al., 2021). Window-opening behavior plays a crucial role in influencing indoor thermal conditions, with factors such as window-opening ratios and durations affecting both air quality and comfort. Korsavi et al. (2018) found that outdoor humidity and temperature during non-heating periods were key predictors of window-opening behavior in classrooms. Similarly, Ekbatan et al. (2019) observed that window-opening behavior in offices was primarily influenced by indoor temperatures during winter and outdoor temperatures during summer.

Controlling indoor temperature and humidity is crucial for ensuring comfort. Choi et al. (2020) found that fluctuations in humidity can significantly affect both energy consumption and air conditioning performance. As the demand for air conditioning increases during hot and humid summers, optimizing indoor thermal conditions becomes essential for reducing energy consumption. Karyono et al. (2019) recommended estimating indoor relative humidity to improve energy efficiency in buildings.

However temperature and humidity are key meteorological factors that influence human comfort and ecological conditions (Hamed et al., 2023; Huang et al., 2020). Fluctuations in these variables significantly affect well-being (Stull, 2011), and climate change, particularly temperature rise, has altered atmospheric conditions globally, impacting weather patterns and living conditions (Muslih & Błażejczyk, 2017; Parmesan et al., 2022). Higher temperatures have increased evaporation and specific humidity, affecting the air's moisture-holding capacity and relative humidity (RH), a vital factor for comfort (Vicente-Serrano et al., 2018; Yuan et al., 2020). Despite these changes, global RH remains stable, although there is significant spatial variability (Byrne & O'Gorman, 2018; Dai, 2006). Increased humidity disrupts heat transfer between the body and the atmosphere, leading to discomfort and strain (Desai & Dhorde, 2018; Kuchcik et al., 2021). This issue is especially pronounced in tropical regions like Bangladesh, where high temperature and humidity can cause severe heat stress, posing a health risk (Njoku & Daramola, 2019; Watanabe & Ishii, 2017). Bangladesh, with its tropical climate, experiences extreme heat and high humidity, particularly during the summer months, making daily activities uncomfortable (Shahid et al., 2016; Mortuza et al., 2014).

This study to explore the impact of kitchen window opening on indoor temperature and humidity. The findings will guide the development of effective kitchen design strategies and highlight areas for improvement. Practical recommendations will be provided for policymakers and designers to enhance indoor environmental quality and promote energy-efficient solutions in future residential buildings in Dhaka.

1.1. Aims and Objectives

The study aims to evaluate the rate of thermal comfort in residential Kitchens and its impact on architectural requirements in Dhaka City. Hence the objective of the study three fold:

- Assess window opening patterns and frequency during the heating season and their effects on indoor temperature and humidity.
- Identify architectural factors influencing temperature and humidity in kitchens.
- Recommend adaptive solutions to enhance kitchen ventilation while maintaining comfortable temperature and humidity levels.

Possible Outcomes: The research investigates innovative strategies and energy-efficient solutions for improving indoor temperature and humidity control in the design of modern residential kitchens.

Table 1 literature based

Aspect	Study/Author	Year	Methods	Key Findings
Impact of Window Opening on Indoor Temperature	Sepideh S. Korsavi et al.	2019	Field study in UK classrooms	Decisions influenced by outdoor humidity in winter and temperature during non-heating seasons.
	Schakib Ekbatan et al.	2018	Field study in German offices	Behavior linked to outdoor temperature in summer but driven by indoor temperature in winter.
	Stazi et al.	2015	Case study of adaptive thermal behavior	Indoor temperature was the primary determinant for window opening; outdoor factors were secondary.
Role of Humidity in Comfort	Chao Liu et al.	2017	Laboratory analysis and cognitive tests	Relative humidity (50–70%) impacts cognitive function and overall comfort.
	Xin Zhou et al.	2020	Field study of office buildings	Window-opening behavior followed polynomial patterns influenced by outdoor conditions and schedules.
Energy Efficiency	Xiaofang Shan et al.	2020	Simulation study	Intermittent operation mode reduced energy consumption by 11% compared to traditional systems.
	Liu Yang et al.	2018	Experimentation with advanced HVAC systems	New air conditioning systems improved indoor air quality and energy efficiency in humid climates.
Adaptation to Climate Change	Run Ming et al.	2020	Long-term field study	Highlighted dynamic adaptation strategies in extreme climates like hot summers and cold winters.
	Karyono et al.	2021	Evaluation of indoor environments	Emphasized humidity evaluation to enhance low-carbon energy efficiency.

2. Methodologies

This study aims to assess temperature and humidity levels in six residential kitchens. An experimental-descriptive approach was utilized, supported by a questionnaire distributed to six kitchens. Dhaka, the capital of Bangladesh, has a tropical wet and dry climate, as classified by the Köppen system. The city experiences hot, wet, and humid conditions, with an annual average temperature of 25°C (77°F). Seasonal variations range from 18°C (64°F) in January to 29°C (84°F) in August, with the monsoon season (May to September) contributing to 80% of the annual rainfall (1,854 mm or 73 inches). (Meteorological Department of Bangladesh, 2021–2024).

The research focuses on residential kitchens in Wari, a southern area of Dhaka. Case studies were conducted on six buildings, each containing a living room and three bedrooms. To understand respondents' perceptions of thermal comfort, the study was conducted during the summer season. The selected flat included a living room, kitchen, bathroom, toilet, and bedrooms, oriented along the north-south axis. The architectural design of the building follows a prototype layout, with rooms arranged around a central clearance space.

Real-time measurements of indoor air temperature and relative humidity were collected using the Rotronic Instruments Temperature Data Logger. The study incorporated both quantitative data and qualitative observations to analyze the impact of window openings on thermal conditions.

To analyze the effects of window opening on indoor air conditions, experiments were conducted based on the structure of indoor objects and typical window-opening habits. Two scenarios were measured: closed windows and partially opened windows (1/4 opening). The window opening area for the 1/4 condition. Continuous experimental measurements were carried out in Dhaka during May and June 2024, which are among the hottest months of summer. shows

2.1. Weather Conditions

- The study focused on three representative weather conditions:
- Sunny days: Defined as days with 0–30% cloud cover.
- Cloudy days: Days with 20–60% cloud cover.
- Rainy days: Categorized into:
- Showery cloudy days: Brief rain periods during certain times of the day.
- Continuous rainfall days: Persistent rain lasting more than 6 hours.

The local weather conditions and meteorological parameters were monitored and recorded daily using data from the official website of the Dhaka weather station. Table 1 summarizes the experimental scenario**s,** including window conditions, weather.

Table 2 experimental working condition

Case	Date	Window Condition	Weather
Case 1	10 May 2024	Windows closed	Sunny
Case 2	12 May 2024	Windows open 1/4	Sunny
Case 3	08May 2024	Windows closed	Cloudy
Case 4	23 June 2024	Windows open 1/4	Cloudy (High Humidity)
Case 5	27 May 2024	Windows closed	Rain (Showery)
Case 6	27 June 2024	Windows open 1/4	Rain (High Humidity)

2.2. Experimental Procedure

- Before starting the measurements, the indoor temperature and humidity were set to during cooking time
- Initial temperature: 29°C
- Initial relative humidity: 85% RH
- At 8:00 a.m., the cooking period, doors, and windows were closed tightly for the closed window condition.
- For the window opening 1/4 condition, one window was partially opened at 8:00 a.m., while the air conditioner was turned off.
- The experiments lasted for 8 hours, with measurements recorded until 4:00 p.m.

3. Results and Discussion

3.1. Indoor and Outdoor Air Temperature and Humidity Changes After Closing Windows

Figure 1 illustrates the changes in temperature and humidity inside and outside the room with windows closed under three summer weather conditions. Once the air conditioner, windows, and doors are closed, natural convection airflow ceases, leaving only hot air infiltration through window and door gaps. As a result, the indoor temperature rises steadily but slowly, with the slowest increase observed on rainy days. The experiment was conducted during the summer months of May and June 2024.

Due to the infiltration of hot outdoor air, the indoor temperature increases gradually, while the relative humidity also rises slowly. As solar radiation intensifies, the outdoor temperature increases, causing the outdoor relative humidity to decrease correspondingly.

On rainy days, depicted in Figure 1 the conditions began with morning showers, resulting in high outdoor humidity. During this time, indoor humidity increased slowly due to air infiltration through window gaps. As the rain stopped and the sky turned cloudy, the outdoor temperature rose, and outdoor humidity began to decline, no longer remaining excessively high. By the later stages of the rainy day scenario, the indoor humidity exceeded the outdoor humidity.

In all three weather conditions—Sunny, Cloudy, and Rainy—the indoor and outdoor humidity levels equalized at 152 minutes, 235 minutes, and 148 minutes, respectively. At the final measurement, the following conditions were recorded:

- On a sunny day: indoor temperature was 33.4°C, with relative humidity at 83.7% RH.
- On a cloudy day: indoor temperature was 31°C, with relative humidity at 76.7% RH.
- On a rainy day: indoor temperature was 30.3°C, with relative humidity at 78% RH.

These results indicate minimal differences in indoor temperature and humidity across the three weather conditions at the final measurement, highlighting a weak correlation between changes in indoor air conditions and outdoor weather when windows are closed.

The graphs in Figure 1 are divided into two zones: the green zone represents the summer indoor comfort temperature range, while the tan zone represents the summer indoor comfort humidity range. Among the three weather conditions, the rate of indoor humidity increase was fastest on cloudy days, with the indoor comfortable humidity range lasting only 35 minutes. Without air conditioning, the duration of comfortable indoor temperature and humidity was limited in all weather scenarios. However, rainy days provided slightly longer comfort due to weaker solar radiation, which resulted in lower outdoor temperatures, reduced heat radiation on walls and windows, and weaker hot air infiltration compared to sunny and cloudy days.

Table 3 Indoor and Outdoor Air Temperature and Humidity Changes After Closing Windows

Weather Condition	Final Indoor Temperature (°C)	Final Indoor Humidity (%RH)	Time to Equalize Humidity (minutes)	Comfortable Humidity Duration (minutes)
Sunny	33.4	83.7	152	35
Cloudy	31	76.7	235	0
Rainy	30.3	78	148	45

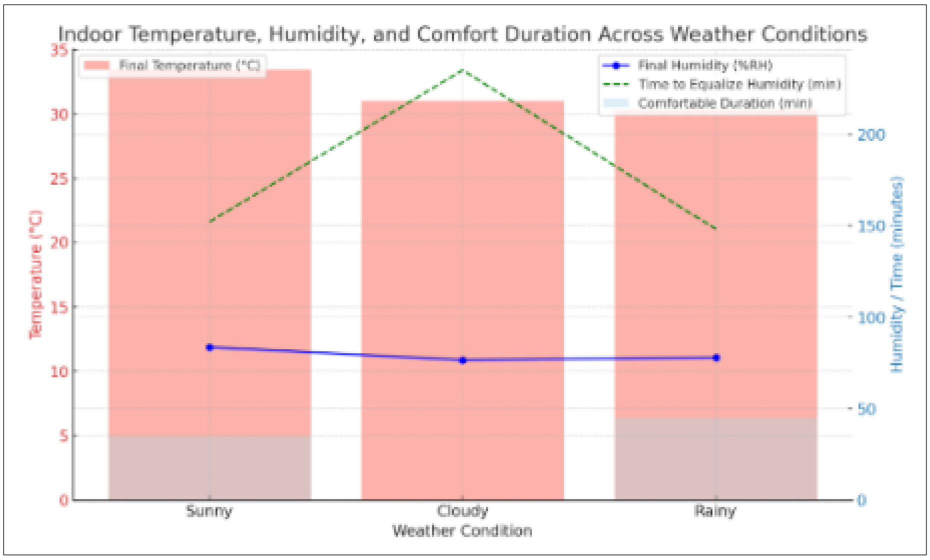

Figure 1 Indoor and Outdoor Air Temperature and Humidity Changes After Closing Windows

3.2. Temperature Change

Figure 2 illustrates the indoor temperature trends for different window opening ratios over five durations (4h, 6 h, 8 h, 10 h, and 12 h). The brown lines in the figure represent the final temperature points for each window opening duration.

In Figure 2 with windows closed, the indoor temperature rises gradually, with a maximum difference of 1.9°C compared to the 1/6 window opening condition. Due to the building's thermal storage capacity, a lower window opening ratio delays the peak indoor temperature. In Figure 2 on rainy days, the maximum difference in indoor temperature between closed windows and the 1/6 window opening condition is 1.3°C. The temperature peak occurs 1 hour earlier on rainy days than on sunny days due to lower outdoor temperatures.

The analysis shows that indoor temperature increases slightly with a larger window opening ratio. However, the temperature difference between various window opening ratios remains within 27°C for both weather conditions. While open windows have a significant impact on indoor temperature changes compared to closed windows, the specific percentage of open windows has a minimal effect on temperature variations. Instead, the window opening ratio primarily influences the rate of temperature change—larger openings result in faster temperature increases and decreases. The relationship between the window opening ratio and the rate of temperature response is positively correlated.

During summer, when outdoor temperatures are high, opening windows for ventilation is essential to maintain indoor air quality. Among the different window opening ratios, opening windows to 1/6 provides the most favorable indoor temperature during the day, making it the optimal choice for balancing ventilation and comfort.

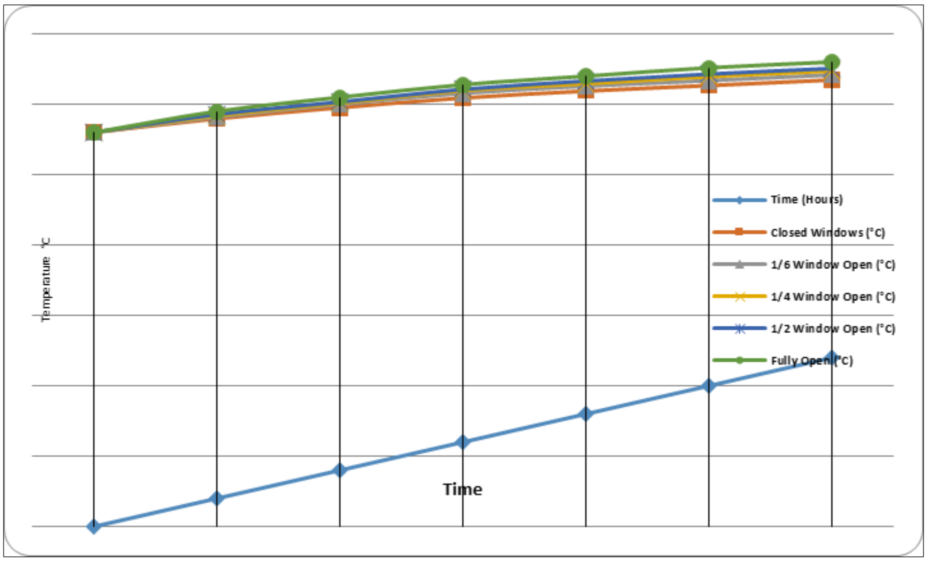

Figure 2 Indoor and outdoor temperature window opening condition.

3.3. Final Moment Humidity

Table 4 shows the humidity levels at the final moment across five window opening durations (4 h, 6 h, 8 h, 10 h, and 12h) on sunny days characterized by high temperatures and low humidity. Upon opening the windows, the indoor humidity quickly stabilized due to natural air intake, resulting in minimal subsequent fluctuations. With closed windows, indoor humidity remained steady regardless of the interval duration. After 10 hours, outdoor humidity increased gradually as the outdoor temperature decreased, causing a corresponding rise in indoor humidity when windows were open. Over time, the indoor humidity levels under different window opening conditions began to converge, with the difference in humidity at the final moment ranging from 0% to 5% RH across varying window opening ratios.the final moment humidity levels for various window opening durations on rainy days with low temperatures and high humidity, compared to outdoor humidity. On rainy days, due to extreme outdoor humidity, indoor humidity matched the outdoor levels after opening the windows. With closed windows, the indoor humidity remained 8%–12% RH lower than the outdoor humidity. The results indicate that, on sunny days, indoor humidity remains stable after opening windows but begins to rise after 8hours. On rainy days, window opening is not recommended due to persistently high indoor humidity levels. window opening ratio has a minimal impact on final indoor humidity levels. Prolonged window opening beyond 8hours results in unnecessary energy consumption for subsequent air treatment, making intermittent window opening of up to 8 hours the most efficient approach. On high-humidity rainy days, keeping windows closed is advisable to avoid excessive indoor humidity.

Table 4 Final Moment Humidity Levels across Different Window Opening Durations

Time (hours)	Sunny Days (Window Open)	Sunny Days (Window Closed)	Rainy Days (Window Open)	Rainy Days (Window Closed)
0	Initial Indoor Humidity	Initial Indoor Humidity	Initial Indoor Humidity	Initial Indoor Humidity
2	Stabilized (minimal fluctuation)	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity
4	Stabilized	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity
6	Stabilized	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity
8	Stabilized	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity
10	Begins to rise	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity
12	Begins to rise	Steady	Matched Outdoor Humidity	8%-12% lower than Outdoor Humidity

3.4. Air state point analysis

As the window opening duration increases, the indoor air temperature gradually decreases, while the relative humidity rises. To achieve the desired indoor temperature and humidity, two air treatment processes are recommended. Process A involves dehumidification through a solid hygroscopic agent (isenthalpic process), followed by cooling with an air cooler (iso-hygroscopic process). Process B employs dehumidification using an isothermal liquid spray (isothermal process) and subsequent cooling through an air cooler (isothermal process). These processes aim to optimize indoor air conditions effectively.

Table 5 Air state point analysis

Window Opening Duration (hours)	Final Air Temperature (°C)	Final Air Humidity (%RH)
1	30.02	83.21
2	31	83.44
3	30.52	83.59
4	29.8	85.24
5	29.27	87.59

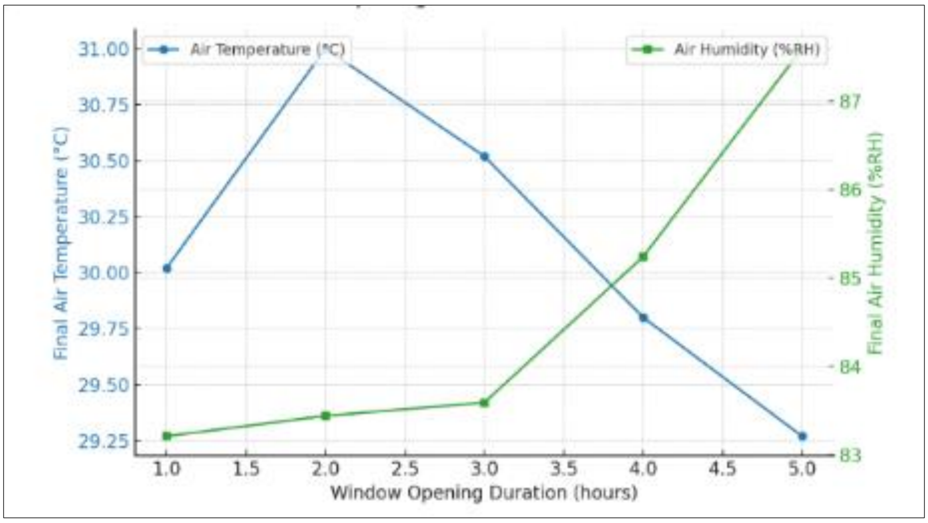

Figure 3 Air state point analysis

4. Conclusions and Recommendation

This study analyzes the variations in indoor temperature and humidity without air conditioning, focusing on the impact of window opening behavior under different weather conditions. Using field studies, the effects of various window opening ratios and durations were assessed. High-temperature, low-humidity sunny days and low-temperature, high-humidity rainy days were chosen as representative scenarios. The findings provide insights into strategies for reducing energy consumption through natural ventilation. The key conclusions are as follows:

Weather Conditions and Window Status

- Under closed-window conditions, indoor temperature and humidity differences across all weather scenarios were minimal.
- High outdoor temperatures and low humidity levels resulted in no significant correlation between weather conditions and the final indoor air conditions when windows were closed.
- With windows open, natural wind speed influenced the rate of temperature and humidity changes, although the overall impact on indoor temperature was small.

Outdoor Humidity and Window Opening Behavior

- Outdoor humidity levels determined the maximum indoor humidity under open-window conditions.
- High indoor humidity limited temperature increases, creating a hot and uncomfortable environment on rainy, humid days. This also increased energy consumption for subsequent air conditioning processes, making window opening unsuitable during such conditions.
- On sunny days with high temperatures and low humidity, opening approximately 1/6 of the windows proved to be the most effective.

Window Opening Ratios and Duration

- Indoor temperatures with closed windows were 0–3 °C lower than those observed with open windows.
- Temperature fluctuations between different window opening ratios remained within 1 °C, and humidity changes were within 0–5% relative humidity (RH). These variations were minor.
- Prolonged intermittent window opening increased energy demands for subsequent air treatment. Limiting window opening duration to less than 8 hours was identified as the most energy-efficient approach.

This research highlights the importance of optimizing window opening behaviors to balance indoor comfort and energy efficiency during natural ventilation.

Compliance with ethical standards

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Disclosure of conflict of interest

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

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