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Evaluation of Air Quality and Thermal Comfort in University Dormitories in China

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Abstract: Most studies on Chinese dormitories are carried out in summer, while few focus on a transition season or winter. This study evaluated the air quality of a student dormitory in a university in the Beijing area by using a questionnaire survey and on-site measurements. The CO_2 concentration was used as an indoor air quality evaluation index to characterize the freshness of the air, and different window opening conditions in the dormitory were simulated, with corresponding improvement plans proposed. The results of this study revealed that the air quality and thermal comfort of the student dormitories during a transition season and winter fell short of expectations. According to the survey, students who opened their windows frequently had a better subjective perception of the air quality. However, due to the large temperature difference between day and night, more than 80% of the students felt too cold when opening the windows. For daytime conditions, the area of unilateral ventilation window opening should not be less than 0.39 m^2, the area of bilateral ventilation window opening should not be less than 0.13 m^2, and the time taken to close the windows and doors should not exceed the maximum ventilation interval. Empirical equations were fitted for nighttime conditions based on the CO_2 concentration, number of people in the room, and window opening area, resulting in a reasonable window opening area of 0.349 m^2~0.457 m^2. In sum, this study assessed the air quality status within typical university dormitories across varying seasons, gaining a clear understanding of how different ventilation strategies and occupant densities influence air freshness and thermal comfort. Based on these insights, a practical and optimized window area recommendation was formulated to enhance the indoor environmental quality in these dormitories.

Keywords: college dormitory; air quality; natural ventilation; carbon dioxide concentration

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1. Introduction

Student dormitories are the main places for university students to rest, study and socialize, and their air quality has an important impact on students' health and academic performance, potentially causing allergies, headaches, respiratory diseases, and other health issues [1–4] and negatively impacting academic performance [5–8]. Amidst the ongoing COVID-19 pandemic, the significance of indoor air quality control has been realized, especially in enclosed spaces like university dormitories. These dormitories, with their limited floor areas, dense populations, and varying ventilation habits among residents, pose unique challenges in maintaining a sanitized and safe indoor atmosphere. Recognizing the heightened risk of virus transmission in such enclosed settings, it is imperative to prioritize the quality of air within dormitories, ensuring effective circulation of fresh air and minimizing the potential for the dissemination of airborne pathogens [9,10]. Furthermore, carbon dioxide, primarily emanating from human respiration, stands as one of the most prevalent sources of indoor air pollution in student dormitories. Although CO_2 is generally not toxic to the human body, it can cause harm if the concentration exceeds a certain threshold. For example, when CO_2 concentrations reach 0.3% to 0.4%, the depth of human respiration increases, resulting in symptoms such as a headache, ringing in the ears, slow pulse, and elevated blood pressure. Coley and Greeves' study [11] examined the effect of the ventilation rate on students' cognitive ability and discovered that elementary school children's attention span decreased by 5% as the CO_2 concentration increased from 690 ppm to 2909 ppm.

Indoor air pollution can be controlled using three main measures: source control, ventilation, and air purification [12]. Krzysztof et al. [13] developed a controller method for window opening to naturally ventilate a classroom with 30 occupants, and the results showed that natural ventilation significantly reduced the indoor CO_2 concentration and significantly improved the indoor environmental quality. Yang et al. [14] discussed the use of various window opening and closing strategies to reduce indoor pollutant levels during the summer vacation. Various window opening and closing strategies were used to reduce indoor pollutant levels during the summer vacation, and indoor and outdoor $PM_{2.5}$ and ozone concentrations were measured using various window patterns. Feng et al. [15] used the CFD method to simulate the ventilation effect of a typical dormitory in a university in Nanjing. They concluded that increasing the window area improves the ventilation effect very slowly when the window to floor area ratio is 0.114 or higher, but significantly when the window area is 0.114 or lower. However, in winter, buildings in the northern region mostly use central heating to ensure there is a sufficient indoor temperature. In order to maintain the indoor temperature of the building and reduce the heat loss of the indoor environment, people often reduce the frequency of opening windows, which leads to a reduction in fresh air generated by natural ventilation. The reduction in fresh air volume has an adverse effect on the dilution and diffusion of indoor air pollutants, resulting in the accumulation of air pollutants such as CO_2 produced by indoor sources in the room, and the decline of indoor air quality, which affects the work and learning efficiency and health of indoor personnel. Aurora et al. [16] conducted field measurements of indoor environments in nine schools in northern Spain, and the results showed that with natural ventilation, the CO_2 concentration in classrooms could be kept below 700 ppm, but natural ventilation lowered the indoor air temperature, causing students' thermal comfort to be compromised. Liu et al. [17] chose the dormitories of graduate students of various grades at a northern university and monitored the temperature, humidity, CO_2, and other parameters for two weeks during the seasonal changes of fall and winter. They discovered that the majority of the dormitories lacked natural ventilation, and the concentration of CO_2 during sleep was too high, affecting sleep quality and the mental state. Currently, research on air quality and thermal comfort in Chinese student dormitories focuses on the summer [18–22], with relatively few studies conducted during the transitional and winter seasons.

To gain a better understanding of the current state of air quality in dormitories during a transition season and winter, this study used the CO_2 concentration as an indirect indicator to assess the freshness level of indoor air and the ventilation capacity [23–26]. The experiments were designed using a combination of research and theoretical analysis, and the effects of various factors on air quality were thoroughly investigated via surveys, actual measurements, and numerical simulations. This methodology helps to gain a comprehensive understanding of the air quality problems in dormitories and provides a foundation for proposing scientific and effective improvement measures.

2. Research Methodology

2.1. Research Motivation

The test site was a dormitory building at a university in Beijing, built in 2005, with 12 floors above ground and 2 underground floors, each 3 m high, and an L-shaped top view of the building. The typical dormitory structure is a 6-person dormitory, with natural ventilation through windows and doors and no mechanical ventilation. When the doors and windows were closed, air leakage occurred. In the test, two rooms were randomly selected on each floor, for a total of 24 rooms. The area, layout, and occupant count of each dormitory are identical, while Figure 1 provides a comprehensive overview of the dormitory's dimensions, the positioning of doors and windows, and the arrangement of beds.

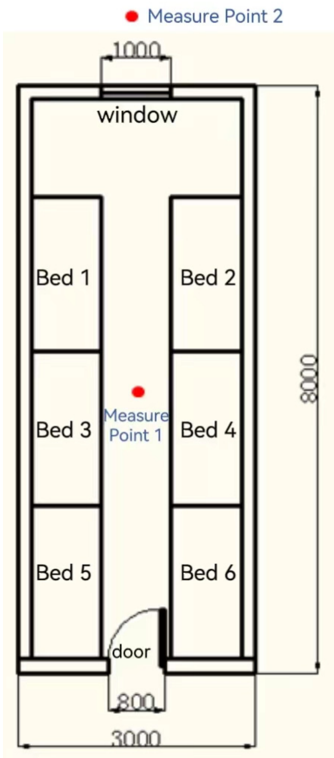


Figure 1. Test site and floor plan.

2.2. Questionnaire

The questionnaire was divided into three parts according to the recent ISO Standard 10551 [27]: the first part covered the basic information of the dormitory and individuals, including gender, school, the number of permanent residents in the dormitory, and the time spent in the dormitory every day; the second part of the questionnaire focused on the dormitory staff's ventilation habits, including the frequency of opening the windows every day, the length of time they were open, the reasons for opening them, whether or not they felt cold when they opened the windows, etc.; and the third part paid attention to the dormitory staff's subjective perception of and satisfaction with the thermal environment and air quality in the room [28,29]. The thermal environment evaluation followed the seven-level thermal sensation voting as defined by ASHRAE [30].

The questionnaire was primarily distributed online, with some offline distribution. The criterion for deeming a questionnaire invalid was a total of more than 15% of options or answers that did not provide a clear understanding of the respondents' perspectives on the issues. In our statistical analysis, SPSS software (version 29.0.2) was used to assess the effectiveness of the questionnaires, which resulted in 210 valid responses.

2.3. Test Configurations

The dormitory measures 8 m × 3 m × 3 m and has three beds on each side. It also has sliding windows that are 1.2 m from the ground, 1 m wide, and 1.3 m tall, and it has a 0.8 m wide and 2 m tall door. The measurement points in the indoor area are arranged in the center of the dormitory at a distance of 1.2 m from the ground (measurement point 1 in Figure 1), and the parameters of the measurements include the concentration of CO_2 and the temperature, determined using a US TSI7545 measurement instrument. The outdoor measurement points are arranged 1.5 m from the center of the window (measurement point 2 in Figure 1), and the measurement parameters used are wind speed and temperature, as measured by the US TSI9535 instrument. Table 1 provides the specific instrument accuracy and range information. The test times were set to 9:00–11:00 a.m. and 3:00–5:00 p.m., and each parameter measurement lasted two hours. The average value was obtained within two hours. In this paper, the standard limit value of indoor CO_2 concentration refers to the GB/T 18883-2022 "Indoor Air Quality Standard" [31], which specifies that the range of indoor CO_2 concentration is 1000 ppm; accordingly, this study used 1000 ppm as the standard limit value of indoor CO_2 concentration.

Table 1. Test instruments.

Instrument	Test Parameter	Measurement Range	Accuracy	Resolution
TSI7545	carbon dioxide (CO_2)	0~5000 ppm	±3.0% ± 50 ppm	1 ppm
	temperature	0~60 °C	±0.6 °C	0.1 °C
TSI9535	air velocity	0~30 m/s	±3% ± 0.015 m/s	0.01 m/s
	temperature	−17.8~93.3 °C	±0.3 °C	0.1 °C

2.4. Numerical Simulation

To simulate the change in CO_2 concentration in the dormitory, a model of the same size as the actual dormitory was created using CONTAM simulation software (Version 3.4.0.1), and the model was appropriately simplified (see Figure 2). CONTAM is a network modeling software developed by the Building and Fire Research Laboratory, a part of the National Institute of Standards and Technology (NIST) in the United States. It is used for multi-zone airflow simulation research. CONTAM is increasingly becoming an important tool for HVAC design and research professionals due to its reliability in algorithms, user-friendly graphical interface, extensive database, and robust data analysis and plotting capabilities. In the simulation, the initial indoor CO_2 concentration was set to 600 ppm, with a CO_2 production rate of 763 mg/min for an adult male sitting still, while the outdoor CO_2 concentration was around 400 ppm [32,33]. In the simulation process, the window width, the number of people in the room, whether to open the door, and other related parameters were changed to simulate different working conditions, to explore the influences of related parameters on the change in indoor CO_2 concentration. The numerical simulation allowed for a more comprehensive understanding of the trends in CO_2 concentrations in the dormitory.

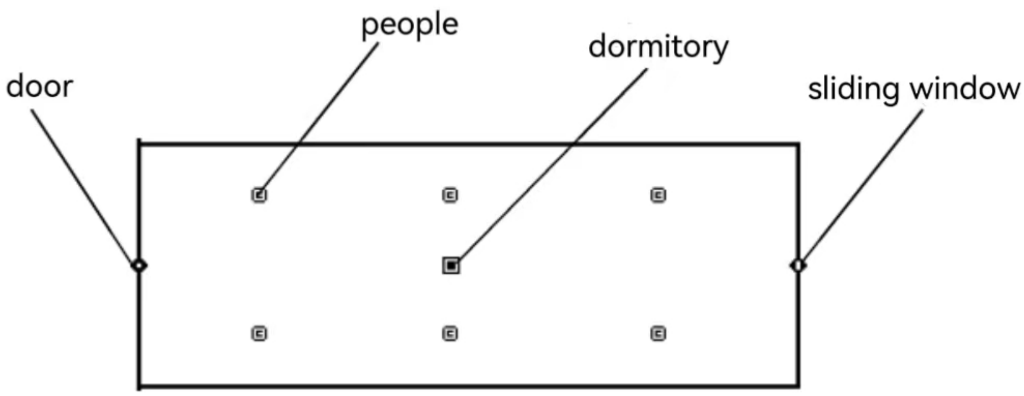


Figure 2. The simplified model.

3. Results

3.1. Survey Results

In the questionnaire, "very fresh" means the feeling of air in a forest; "fresh" means the feeling of air after rain; "general" means the feeling of air when outdoors; "not fresh" means the air outside in the evening; and "really not fresh" means that you may feel breathless. The results of the analysis of questionnaire statistics are shown in Figure 3. As the number of permanent residents in the dormitory rises, the proportion of people who perceive the indoor air as fresh or very fresh decreases. Simultaneously, students' satisfaction with the air quality also decreases with the increase in dormitory residents.

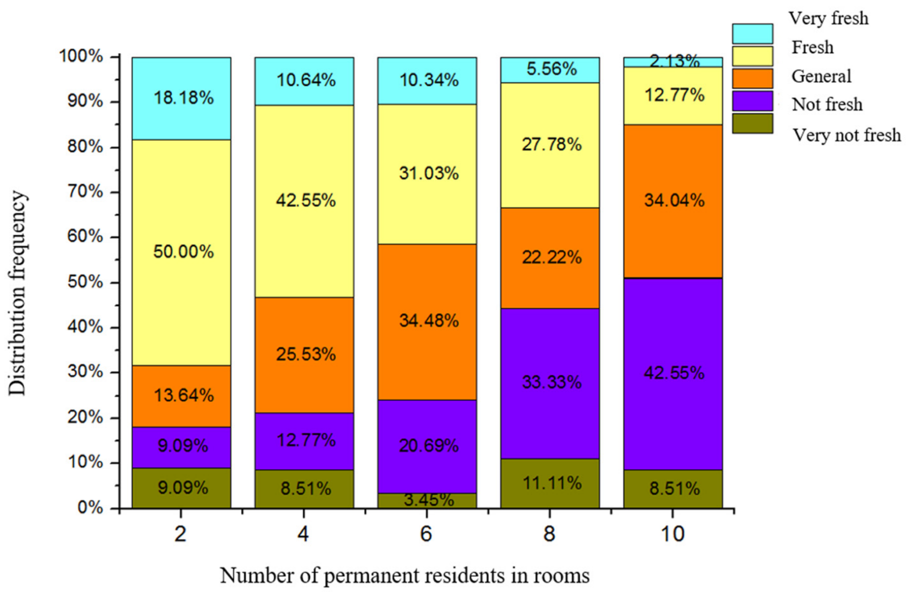


Figure 3. Perception of air freshness with different numbers of permanent residents in rooms.

Figure 4 illustrates the relationship between people's subjective perceptions of air quality and their ventilation habits. As the frequency of window opening increases, so do the number of people who feel the air is fresh and the proportion of those who feel it is extremely fresh. Intriguingly, relying solely on the indoor and outdoor environmental conditions to determine window opening and closing tendencies often leads to polarized subjective assessments of air freshness. Specifically, during periods of extreme outdoor temperatures, ventilation is often minimized for indoor insulation purposes, leading to reduced indoor air freshness. Conversely, when outdoor temperatures are moderate, ventilation is typically maximized, resulting in improved indoor air quality. Consequently, regulating ventilation based solely on environmental factors introduces a degree of uncertainty, necessitating a careful balance between thermal comfort and indoor air quality.

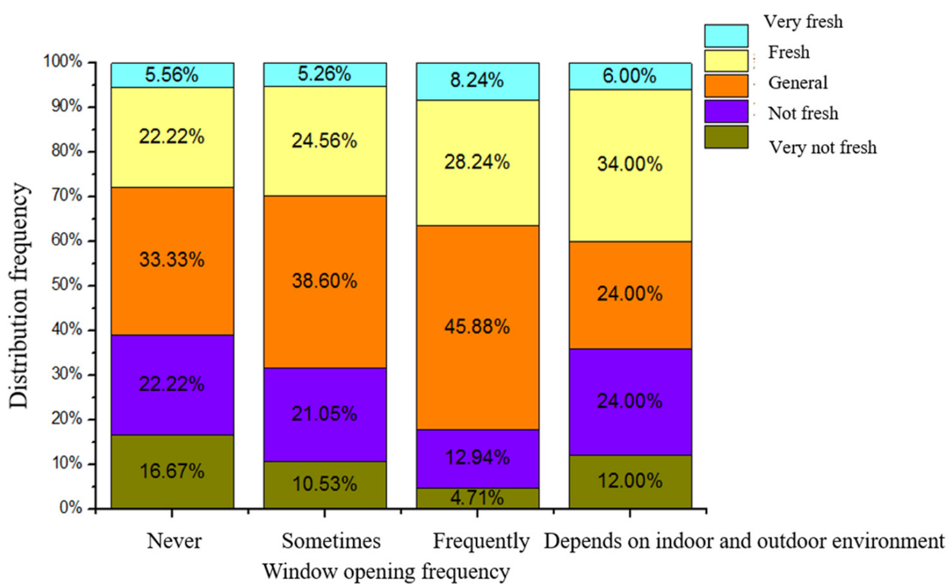


Figure 4. Perception of air freshness with different window opening frequencies.

Figure 5 suggests that window opening influences how people perceive indoor temperature. Although the majority of students do not feel cold when they open the windows, some do. As a result, when implementing measures to improve dormitory air quality, the combined effects of ventilation and thermal comfort must be taken into account. This ensures that students do not feel too cold while ventilating by opening the windows.

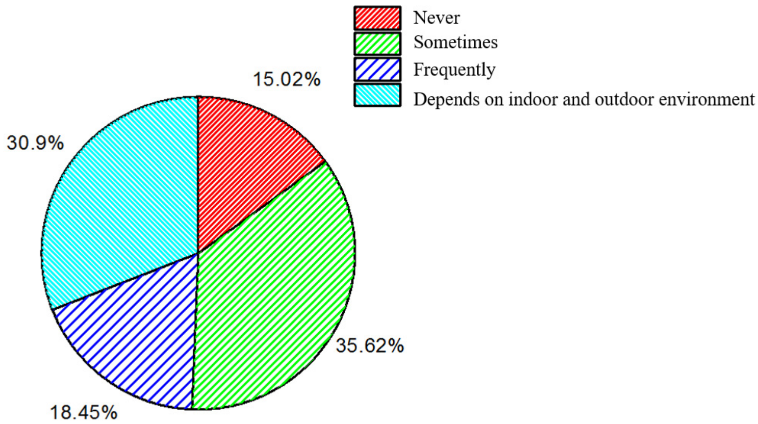
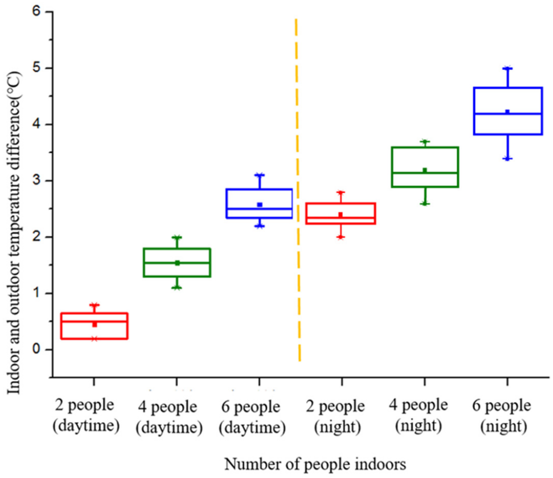


Figure 5. Frequency distribution of sensation of cold among dormitory residents when opening windows.

3.2. Measurement of CO_2 Concentration in the Dormitory

3.2.1. The CO_2 Concentration in the Dormitory during Transitional Seasons

In the study of dormitory environmental conditions during transitional seasons, indoor occupancy was chosen as the independent variable, with the temperature difference between indoor and outdoor environments as the dependent variable. Measurements were taken in dormitories with two, four, and six occupants over a 24 h period. The testing period lasted two weeks and produced a total of 300 data points. Figure 6a shows the temperature differences between indoor and outdoor environments during transitional seasons, which are typically between 0 and 3 °C during the day. However, during the night, the temperature difference increased significantly, usually ranging from 2 to 5 °C. For both the daytime and night, the indoor/outdoor temperature difference increased when the number of occupants was higher. The reasons may be due to the small dormitory area, the increase in the number of indoor people, human body heat dissipation, and related indoor activities, such as an increased use of equipment. Those factors may lead the indoor and outdoor temperature difference to increase with the increase in the number of people in the dormitory. Figure 6b shows that outdoor wind speeds around the dormitories were predominantly less than 0.5 m/s. These measurements were obtained by placing the anemometer probe 1.5 m outside the window, with the wind direction parallel to the window. Specifically, measurement points with wind speeds less than 0.25 m/s accounted for 64.8%, those between 0.25 and 0.5 m/s for 22.5%, and measurement points with speeds greater than 0.5 m/s for 12.7%. As shown in Figure 6c, averaging CO_2 concentration measurements from 24 different dormitories revealed that only 4 of them had CO_2 concentrations below the permissible limit (1000 ppm), while the concentrations in the other dormitories exceeded the standard, with the highest reaching 2200 ppm. After further investigation, it was found that the four dormitories with indoor CO_2 concentrations lower than 1000 ppm had good ventilation habits, in that the students often opened the window when inside and they stayed in the dormitory for short times, while the dormitory with the highest indoor CO_2 concentration had two desktop computers inside and all six students often stayed in the dormitory. Generally, they did not open the window for ventilation and they closed the dormitory door.



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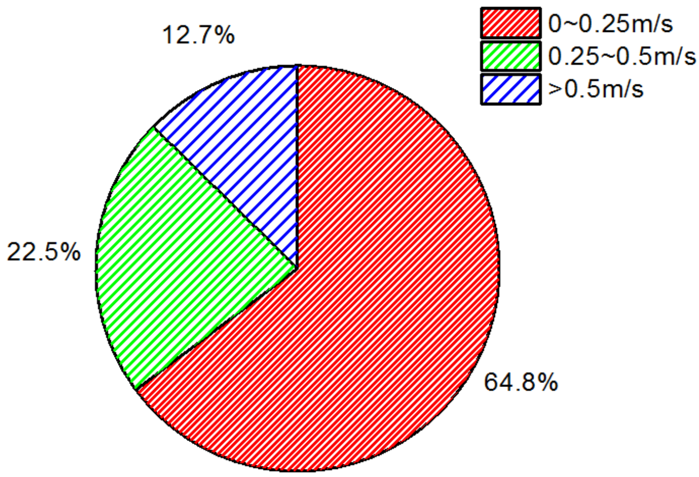

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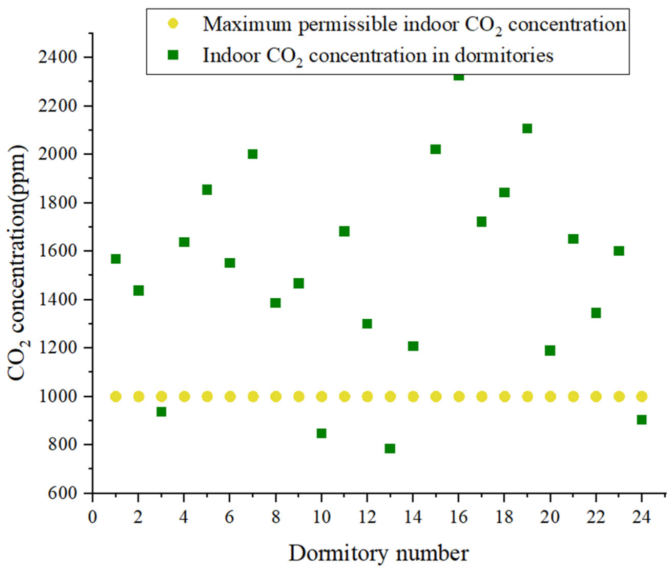

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Figure 6. Measurement of indoor and outdoor parameters of dormitory in transitional season. (**a**) Actual measurements of indoor and outdoor temperatures in a typical dormitory. (**b**) Actual measurements of outdoor wind speed around a typical dormitory. (**c**) Actual measurements of indoor CO_2 concentrations in different dormitories.

In response to the transitional season climate, the current ventilation modes in student dormitories are insufficient to meet air quality standards. Additionally, when opening windows to improve indoor air quality, thermal comfort must be considered. The appropriate window opening width should strike a balance between improving air quality and ensuring comfort. According to the research findings and practical considerations, the factors influencing dormitory air quality can be divided into three categories: number of people indoors, ventilation methods, and outdoor meteorological conditions.

3.2.2. The CO_2 Concentration in a Dormitory during Winter

Figure 7 shows the winter testing results, with Figure 7a illustrating the temperature difference between indoor and outdoor environments in dormitories. Because of the heating in the dormitory, the temperature difference between indoor and outdoor areas is quite large. During winter, there is also a significant temperature difference between day and night, ranging from 2 to 5 °C. This suggests that indoor heating could have a significant impact on the dormitory's temperature, especially at night. Figure 7b shows that outdoor wind speeds around dormitories during the winter are typically less than 0.5 m/s. Outdoor wind speeds are generally more stable in winter than in other seasons, but some measurement points still have relatively high wind speeds. As shown in Figure 7c, averaging CO_2 concentration measurements from 24 different dormitories over the winter revealed that only four dormitories had CO_2 concentrations below the permissible limit (1000 ppm). Other dormitories had concentrations that exceeded the standard, with the highest at 9050 ppm. This suggests that during the winter, ventilation conditions in dormitories may require closer monitoring to ensure that CO_2 concentrations remain within safe limits.

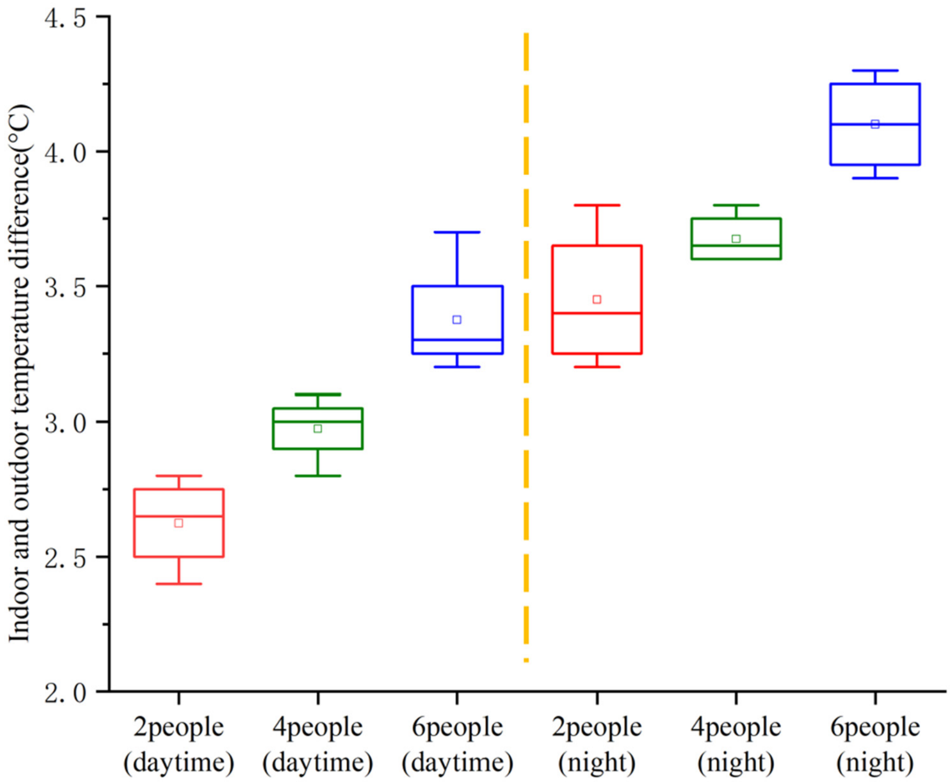

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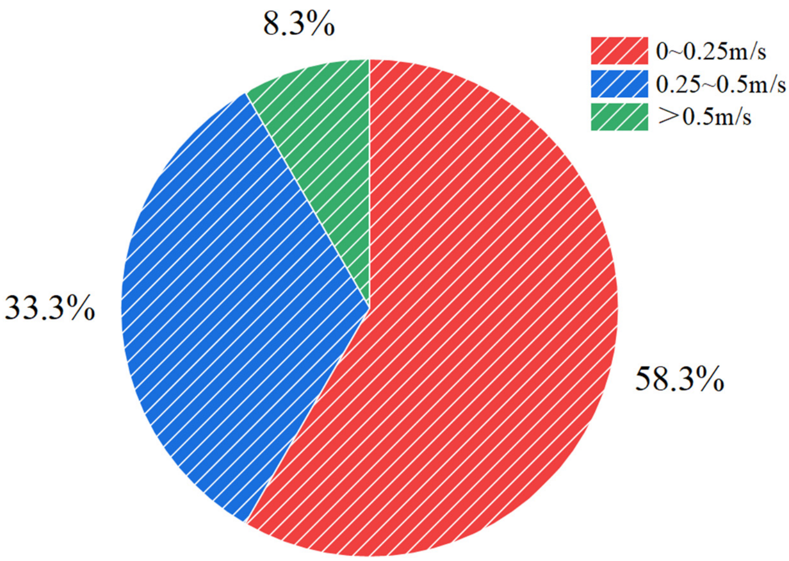
Figure 7. *Cont.*



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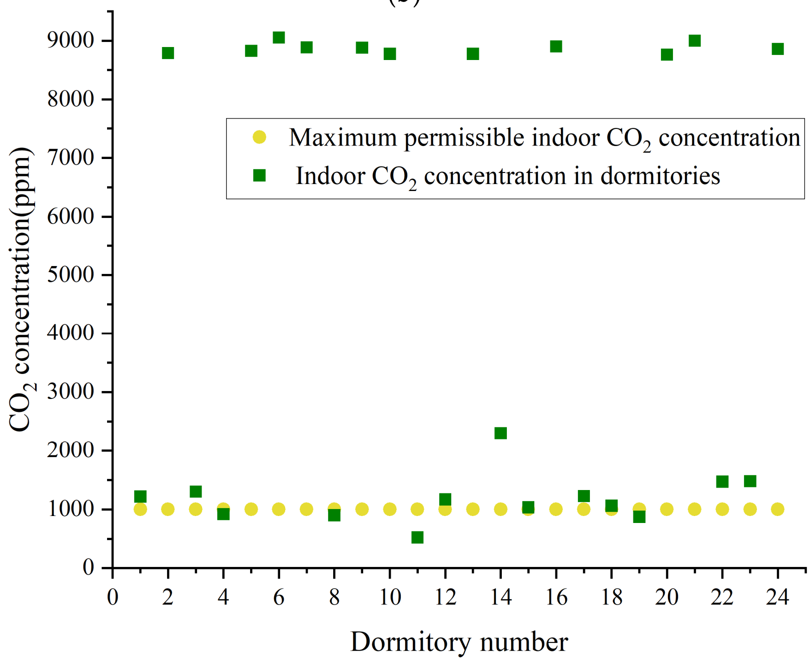

(**c**)

Figure 7. Actual measurements of indoor and outdoor parameters in dormitories during winter seasons. (**a**) Actual measurements of indoor and outdoor temperatures in a typical dormitory during winter. (**b**) Actual measurements of outdoor wind speed around a typical dormitory during winter. (**c**) Actual measurements of indoor CO_2 concentrations in different dormitories during winter.

3.3. Simulation of Common Dormitory Conditions and Improvement Proposals

3.3.1. Daytime Conditions

The control factors for doors and windows, as well as the number of occupants, have a significant impact on indoor CO_2 levels. Most students spend more than four hours in the dormitory during the day and even longer on weekends. Furthermore, students have flexible control over the dormitory's doors and windows during the daytime.

(1) Ventilation interval

After thorough ventilation in the dormitory, indoor CO_2 concentrations approach outdoor levels. However, when external factors such as outdoor temperature, humidity, or noise cause the temporary closure of doors and windows to prevent ventilation, there is a ventilation interval before indoor CO_2 concentrations exceed the permissible limit (1000 ppm). The change in indoor CO_2 concentrations when doors and windows are closed was simulated using CONTAM simulation software for various occupant counts. With an initial indoor CO_2 concentration of 600 ppm, Figure 8 summarizes the time required for CO_2 concentrations to reach 1000 ppm under each condition. The ventilation intervals for various numbers of occupants (1 to 6 people) are 70 min, 35 min, 23 min, 17 min, 13 min, and 10 min. The ventilation interval decreases as the number of occupants decreases.

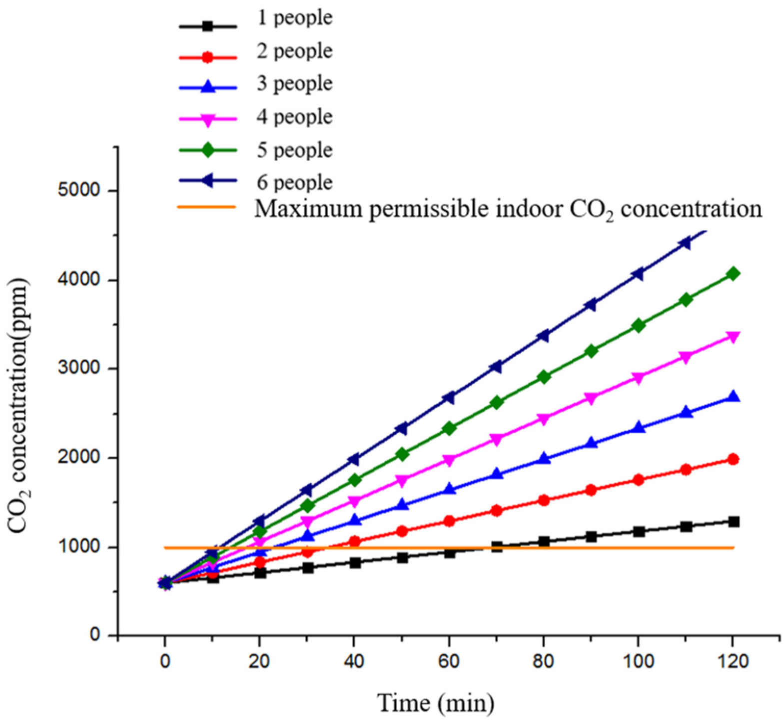

Figure 8. Changes in indoor CO_2 concentrations for different numbers of occupants when doors and windows are closed.

(2) Door and window opening control

Indoor CO_2 concentrations vary greatly due to the random number of occupants and control over doors and windows in the dormitory during the day. As a result, in order to control CO_2 concentrations, the final CO_2 concentration values after stabilization under typical conditions must be statistically analyzed. To eliminate other uncontrollable factors such as people moving and outdoor wind direction, numerical simulation methods are used. The outdoor wind speed is controlled at between 0 and 0.25 m/s, and an adequate ventilation time is considered essential for improving indoor air quality. Thus, in the simulation conditions, ventilation is continuous, and the ventilation time is equal to the simulation time. Table 2 lists the variables and levels for the simulation conditions.

Table 2. Variables chosen for simulations.

Independent Variables (Primary Influencing Factors)	Window Opening Area, Number of Occupants, and Door Opening
Window opening area (S)	0.065, 0.13, 0.195, 0.26, 0.325, 0.39 (window opening width K: 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm)
Number of occupants (N)	1, 2, 3, 4, 5, and 6
Door opening status (D)	Open, closed
Dependent variable	CO_2 concentration

Using CONTAM, the above conditions were simulated in 72 scenarios, and the stable CO_2 concentrations for each condition were statistically analyzed, as shown in Figure 9. Cross-ventilation (opening both doors and windows) significantly reduces CO_2 concentrations, with little effect of the number of occupants or window opening width. Cross-ventilation reduces CO_2 concentrations to less than 1000 ppm even with six people in the dormitory, when the window opening width is at least 15 cm. Larger window openings reduce CO_2 concentrations, but the effect diminishes as the window opening width increases. In closed-door conditions, increasing the window opening width from 5 cm to 25 cm has a significant impact on CO_2 concentrations. However, for cross-ventilation with both doors and windows open, except for increasing the window opening width from 5 cm to 10 cm, which results in a significant reduction in CO_2 concentration, increasing the window opening width has little effect. When the window opening width is equal to or greater than 30 cm, CO_2 concentrations under various occupant counts typically fall below 1000 ppm.

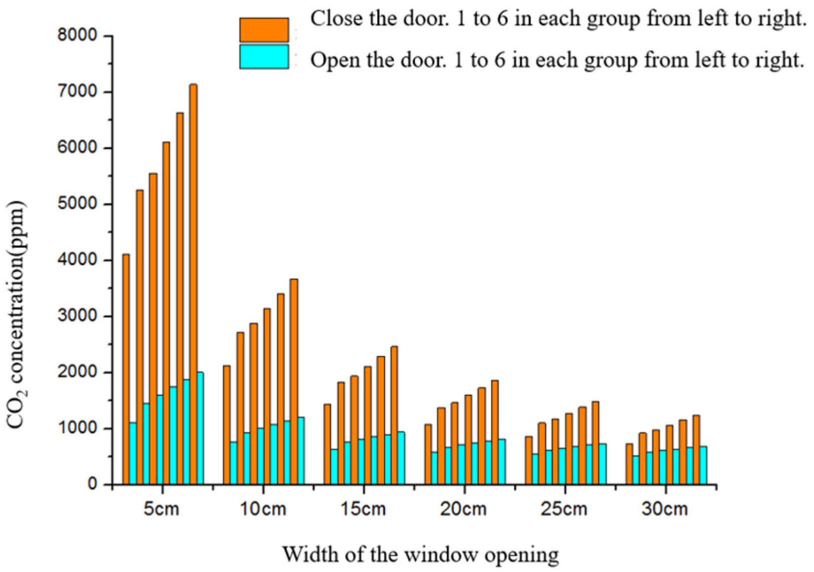

Figure 9. Simulation statistics of daytime working conditions in the dormitory. The X-axis means the opening width of the window, and the height of the window is always 1.3 m.

With fewer occupants, the CO_2 concentration is lower; however, as the width of the window opening increases, the impact on CO_2 concentration decreases. For a closed door, the effect on CO_2 concentration becomes more pronounced as the window opening width increases from 5 cm to 20 cm, and further increasing the window opening width has a diminishing effect. Except for a notable reduction in CO_2 concentration when the window opening width is 5 cm, the impact on other window opening widths is minimal.

Thus, our recommendations for improving indoor air quality during daytime conditions are as follows: Students in dormitories should open the doors for bilateral ventilation as much as possible to significantly reduce indoor CO_2 concentrations and improve indoor air freshness. When using bilateral ventilation with open doors, the window opening width should be no smaller than 10 cm. Furthermore, reasonably scheduling students' time in the dormitory during the day, that is, staggering the time periods for individual students in the dormitory as much as possible to reduce the number of occupants, is a viable solution for improving indoor air quality without modifying dormitory hardware facilities. Moreover, while ensuring comfort, the window opening width should not be too small, especially when using single-sided ventilation. Increased the window opening width can significantly improve indoor air quality. When using single-sided ventilation, the window opening width should be no smaller than 30 cm. Table 3 shows our significance analysis of various influencing factors discussed earlier, as well as the improvement measures corresponding to each dormitory condition. These measures can effectively improve indoor air quality, and the numbers indicate their priority order.

Table 3. Viable measures to improve indoor air quality in dormitories under different window widths and numbers of people.

Indoor Occupant Number	Window Width		
	10 cm	20 cm	30 cm
1~2 people	① Bilateral ventilation (open doors and windows) ② Increase the window area	① Bilateral ventilation	① Ensure the window opening time
3~4 people	① Bilateral ventilation ② Increase the area of windows ③ Reduce the number of people indoors	① Bilateral ventilation ② Increase the window area	① Ensure the window opening time
5~6 people	① Bilateral ventilation ② Increase the area of windows ③ Reduce the number of people indoors	① Bilateral ventilation ② Increase the window area	① Ensure the window opening time ② Bilateral ventilation

3.3.2. Nighttime Conditions

The nighttime covers a range of conditions. In the nighttime when people are sleeping and in the daytime when the room doors are closed, the number of people, the time of window opening, and the width of the window opening are all fixed and unchanged. At night, the number of occupants in the dormitory is fixed, the door is closed, and the weather outside is uncertain. To improve indoor air quality, the width of window openings may be controlled. To derive a more accurate window opening width, we simulated changes in the indoor CO_2 concentration under typical conditions and developed an empirical formula. To make the empirical formula more adaptable to different window sizes, we used the window opening area rather than window opening width, and the formula was then validated using experiments. To eliminate the influence of outdoor meteorological conditions, the wind speed was set to be static. Table 4 lists the variables and levels for the simulated conditions.

Table 4. Variables chosen for simulations.

Independent Variables (Main Influencing Factors)	Values
Window opening area, S	0.065 m^2, 0.13 m^2, 0.195 m^2, 0.26 m^2, 0.325 m^2, and 0.39 m^2 (corresponding to window opening widths, K: 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, and 30 cm)
Number of occupants, N	1, 2, 3, 4, 5, and 6 occupants

A total of 36 conditions were taken into account when using CONTAM to simulate the conditions listed above. The CO_2 concentration after stabilization for each condition was statistically analyzed, and a linear fit was performed using the least-squares method, yielding the curve equation shown in Equation (1):

$$C = 233.789N - 13075.895S + 4582.288 \quad (1)$$

where C represents the indoor CO_2 concentration at equilibrium in ppm; N represents the number of occupants indoors; and S represents the window opening area in m^2.

The correlation coefficient is 0.87. The static wind speed is fixed at a low value of between 0 and 0.25 m/s, so the formula only applies to low speeds at the window.

To experimentally validate the simulated empirical formula, the indoor CO_2 concentration was set to the permissible value of 1000 ppm. The number of occupants ranged from one to six, yielding six sets of window opening areas. These were then converted into window opening widths, and six sets of validation tests were carried out. Table 5 details the specific experimental conditions.

Table 5. Experiment to verify the empirical formula of window width (test object: CO_2 concentration; test time: 2 h).

Group Count	Outdoor Wind Speed	Indoor Occupant Number	Width of Window Opening
1	0~0.25 m/s	1	22.4 cm
2	0~0.25 m/s	2	23.8 cm
3	0~0.25 m/s	3	25.2 cm
4	0~0.25 m/s	4	26.6 cm
5	0~0.25 m/s	5	28.0 cm
6	0~0.25 m/s	6	29.3 cm

Figure 10 depicts the experimental results, which show that if CO_2 concentrations remain below the starting point concentration for half an hour, the indoor environment has reached concentration equilibrium. Figure 10 is mainly used to demonstrate the change in CO_2 concentration over time; since the process is dynamic, it is difficult to take multiple measurements at the same time point and under the same condition. In order to smooth the fluctuations and make the trend of the graph more obvious, each data point in the graph is taken as the average value within 10 min, rather than the value at the current time. The CO_2 concentration curves for all six scenarios are approximately 1000 ppm. In the scenario with four occupants, the CO_2 concentration slightly exceeds 1000 ppm but remains within the permissible limit. As a result, this empirical formula can be used to guide window opening strategies at night.

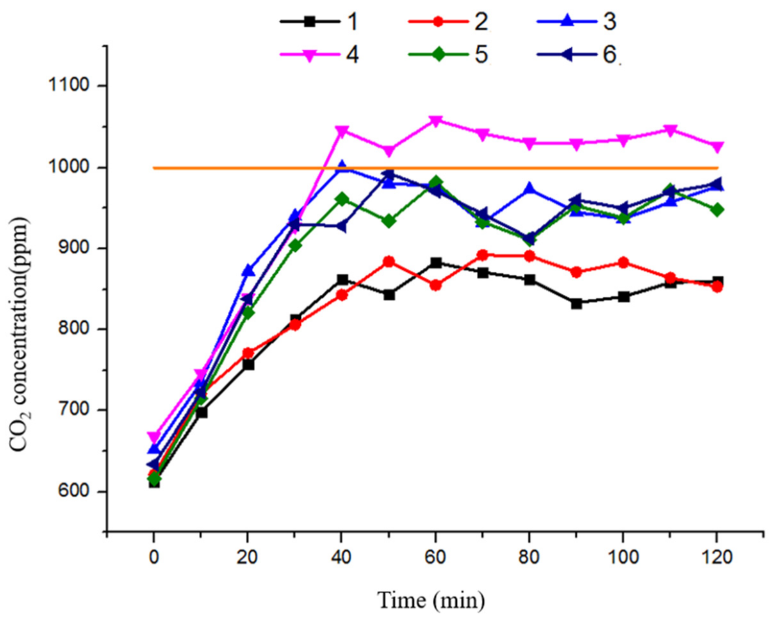

Figure 10. The experimental results.

However, the formula may not provide universally applicable window opening widths due to the variability inherent in actual conditions. In order to maintain a CO_2 concentration below 1000 ppm for varying occupant counts, the window opening areas were computed via an empirical formula and subsequently multiplied by a safety factor of 1.2 to account for diverse circumstances. The findings are displayed in Table 6.

Table 6. The window opening areas that correspond to the different numbers of people after multiplying by the safety factor of 1.2.

Number of People	1	2	3	4	5	6
Open window area (m^2)	0.349	0.371	0.393	0.415	0.437	0.457
Window width (cm)	26.9	28.6	30.2	31.9	33.6	35.2

Experiments were carried out in three different six-person dormitories to ensure that the window opening area was valid. A subjective survey of dormitory residents was also conducted to ensure that both air quality and thermal comfort were met simultaneously. Each dormitory tested the indoor CO_2 concentration for a variety of occupant counts, yielding stable results for a total of 18 experimental sets. The window opening width for each experimental set was adjusted in accordance with Table 6. Following each experimental set, a subjective survey of the dormitory residents was conducted, which included assessments of thermal comfort and air quality. This experiment was conducted over six days, with one person in each of the three rooms on the first day, adjusting the area of the open windows and waiting until the indoor parameters stabilized and the personnel were surveyed; two people in each room on the second day; and so on. The subjective survey results for each experimental set are the average values reported by all participants in the experiment. Tables 7–9 present the results of each experiment as well as the subjective survey.

Table 7. The CO_2 concentration in each room with different numbers of occupants. Unit: ppm.

Occupant Number	1	2	3	4	5	6
Room 1007	809	841	834	813	796	886
Room 1105	822	773	812	860	839	870
Room 909	828	786	811	824	818	815
Average	819.7	800.0	819.0	832.3	817.7	857.0

Table 8. Air freshness in each room with different numbers of occupants. −2 means really not fresh, −1 means not fresh, 0 means general, 1 means fresh, and 2 means very fresh.

Occupant Number	1	2	3	4	5	6
Room 1007	1.00	0.00	1.00	0.75	0.60	0.50
Room 1105	1.00	1.00	0.67	0.25	0.40	0.00
Room 909	2.00	1.00	0.00	0.25	0.40	0.33
Average	1.33	0.67	0.56	0.42	0.47	0.28

Table 9. Thermal sensation vote scores in each room with different numbers of occupants. −3 means very cold, −2 means cold, −1 means a little cold, 1 means a little hot, 2 means hot, 3 means very hot, 0 means normal.

Occupant Number	1	2	3	4	5	6
Room 1007	0.00	1.00	1.00	0.50	−0.60	−0.83
Room 1105	1.00	0.50	0.00	−0.25	−0.40	0.00
Room 909	0.00	0.00	−0.33	0.25	0.40	0.33
Average	0.33	0.50	0.22	0.17	−0.20	−0.17

Table 7 shows that the CO_2 concentrations in each room under different conditions are stable and less than 1000 ppm, indicating that the measured air quality meets the standards. Table 8 shows that the subjective assessment of air freshness in different rooms for various occupancy levels is generally positive, with the majority of students believing the indoor air is relatively fresh, which is consistent with the measured findings. Table 9 shows the subjective assessment of thermal comfort in different rooms at various occupancy levels.

The closer the value of thermal comfort is to 0, the greater the proportion of people satisfied with the thermal environment. The average thermal comfort results for different occupancy levels in each room fall between −0.5 and +0.5, indicating that the majority of students are comfortable. In conclusion, the window opening area scheme shown in Table 6 can be used as a reference for six-person dormitories at night.

4. Conclusions

This study assessed the air quality of university dormitories in Beijing during transitional and winter seasons. The findings showed significant deficiencies in thermal comfort and air quality in dormitories during both seasons, particularly in winter, when indoor CO_2 concentrations were significantly higher than in the transitional season. While natural ventilation is an effective way to improve air quality, it has a negative impact on thermal comfort. As a result, specific improvement strategies were proposed using numerical simulations for various scenarios. The recommendation for daytime conditions in dormitories is to use cross-ventilation, as opening doors for ventilation reduces indoor CO_2 concentrations and improves air quality. In this case, the window area should be at least 0.13 m^2. To ensure comfort in the case of single-sided ventilation, the window width should not be too small; increasing the window width effectively improves indoor air quality. In this case, the window area should be at least 0.39 m^2. Regarding nighttime conditions in dormitories, given that window opening is the only controllable factor and should not have a significant impact on thermal comfort, an empirical formula was developed by fitting the relationship between indoor CO_2 concentration, occupant count, and ventilation area. The formula suggests that the window area should be between 0.349 m^2 and 0.45 m^2. Experimental verification confirmed that window areas in this range meet both indoor air quality and thermal comfort standards. In sum, this study comprehensively evaluated the air quality of typical university student dormitories across various operational scenarios, utilizing simulation methods to devise an optimized window opening plan that serves as an economical and energy-saving reference for similar dormitory settings.

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