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Influence of Subjective Factors on Window Use in Maternity Hospitals in Spring

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Abstract: Poor indoor air quality in maternity hospitals can spread respiratory diseases; however, limited research exists on modifiable factors like occupant behavior. This study explores subjective drivers of window-opening in maternity wards, using surveys and on-site measurements. Results show 71.4% of respondents stay less than 14 days, leading to dynamic and irregular window behavior. Comfort, particularly thermal comfort, air quality, and circulation, is the main driver for window operations. Especially at low temperatures, pregnant women's comfort plays a critical role, while other factors increase in importance as temperatures rise. The results show that environmental factors drive window-opening, while indoor comfort drives closing. Occupants are more tolerant to humidity than thermal discomfort, but window adjustments are random. Moreover, respondents prioritize others' needs in closing windows, where outdoor noise often serves as a key factor. The time also had a greater impact on both window opening and closing decisions, while field measurements confirm that time influences window-opening more than closing. A Multivariate Analysis of Variance (MANOVA) analysis of the questionnaire data for 'comfortable sensation' showed that only 'air circulation' and 'air humidity' were correlated with comfort, whilst 'heat sensation' was the least correlated. The possible reason is that the questionnaire was conducted in the spring, when temperatures were within the comfort range, and therefore, occupants were more concerned with other factors. Window operations in maternity wards are a collective strategy for natural ventilation. This study shows that the factors affecting window use in maternity hospitals are different from other buildings, providing useful ideas for improving maternity ward design.

Keywords: window-opening behavior; influencing factors; maternity hospital; subjective survey; thermal comfort

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1. Introduction

In healthcare settings, poor indoor air quality (IAQ) could facilitate the spread of infectious respiratory disease and adversely affect occupants' health, while high ventilation rates have been shown to reduce cross-infection risks [1–3]. However, limited evidence was found on its potentially modifiable determinants such as occupants' behavior.

Occupant behaviors include occupancy [4,5], shading [6,7], lighting [8,9], window [10,11], and door [12] operations, as well as the use of a cooling/heating system [13,14]. Among the behaviors mentioned above, window-opening as one of the most influential and complex occupant behaviors is a common and convenient way to regulate indoor the thermal environment and air quality [11,15,16]. It can also maximize the use of natural ventilation to reduce the cooling load of the building thus influencing energy consumption [17].

We reviewed 694 papers related to human behavior from 1997 to 2024 and selected 117 of which focused on window-opening behavior and found this behavior exhibits significant variations across different building types and functions [11].

1.1. Window-Opening Behavior in Different Building Types

The characteristics of window-opening behavior vary considerably depending on the function of the buildings.

For office buildings, window operations can be an environmentally friendly and energy-efficient strategy to improve the indoor environment during transitional seasons [18,19]. The window opening and closing behaviors of indoor occupants are driven by a combination of thermal discomfort, habits (arrival and departure times), and daily routines (time of day) [20].

Indoor and outdoor temperatures, indoor PM2.5 concentrations, and hours of daylight have been proven to be the major influencing environmental factors on window opening. Other non-environmental factors such as time of day, season, daily activities, air-conditioning operating status, and window orientation have also been identified as possible motivators influencing occupants' window-opening behaviors [15,21–23].

Previous studies [24–26] pointed out that time of day played a prominent role in window status in office buildings; they concluded the possibility of completely open windows was virtually nil during the night. Also, they reported the time of arrival and departure significantly affects the window adjustments, which were found to mostly occur when occupants arrive. The reason is that window behaviors are affected by personal habits, daily routines, or state of mind rather than simple environmental responses.

A strong correlation was found between occupants' window behavior and seasons in office buildings [24,27]. The maximum window opening probability occurred in summer while the lowest was in winter, and intermediate in transition seasons. It is concluded that the window-opening behavior might be affected by long-term experience.

Similarly, Jones et al. [28] investigated the effect of season on window opening behavior in residential buildings and found that season affects both the drivers and frequency of bedroom window operation. The same simulation model can be used to predict window behavior both in spring and autumn.

In addition, in residential buildings, daily activities significantly influence window opening and closing. Specifically, cleaning, obtaining fresh air, and cooking contribute 40%, 33%, and 27% of the total openings, respectively [29]. Unlike office buildings, Barthelmes et al. [30] found that in residential buildings, the day of the week does not affect the window opening and closing. In contrast, the time of day was the most important variable, regardless of the day of the week, windows were opened or closed at specific times of the day (morning and late afternoon, respectively).

Most studies have proved that indoor and outdoor temperatures are normally the key environmental factors that affect the opening and closing of windows [10,29–32]. In addition, indoor CO_2 and PM2.5 concentrations have also been suggested as an important driver in window opening and closing behavior [30,33,34]. The effect of occupancy type on window opening status cannot be ignored. Shi et al. [35] indicated that occupant characteristics (i.e., floor location, dwelling size, decoration status, presence of elderly occupants, and smokers) have a greater influence on window opening status than environmental factors.

For the classroom buildings, Stazi et al. [16] pointed that compared to the need to improve indoor air quality, the need for thermal comfort tended to be the stronger driver for adjusting the windows [36]. Moreover, the daily routine seems to play an important role in window behavior and students operate the windows more frequently during break times [37].

Previous studies have proposed diverse approaches to elucidate how occupants' window behavior can be influenced by environmental, contextual, and other relevant drivers in office buildings and residential settings. However, there was limited research dedicated to specific building types, such as hospital buildings [38–40], or biophysical conditions, including the unique situation of pregnancy, which may influence occupants' window actions.

1.2. Window-Opening Behavior in Hospital Buildings

Compared to other building types, hospitals have unique functional requirements. The Chinese Building Design Standard strictly regulates indoor air temperature, humidity, air quality, ventilation, noise, and illumination for hospital buildings [41], exceeding those of residential [42], office [43], and school buildings [44,45]. Furthermore, hospitals serve as critical medical and nursing care facilities for treating injured and ill individuals, making indoor air quality of paramount importance due to potential exposure to various diseases and transmissible viruses.

Ventilation has been widely recognized as the fundamental approach to mitigate the risk of airborne infections within hospitals [46]. For example, Ibrahim, F. et al. [47] studied the link between IAQ and occupant behavior in six Malaysian hospitals' outpatient departments. They found that the increased activities worsened IAQ, though mostly within limitation. Temperature and air velocity were inadequate, but window ventilation significantly improved IAQ.

Research indicated that patients recover faster in controlled environments compared to uncontrolled ones [48,49]. The higher air exchange rates and specific requirements for IAQ in hospitals may lead to distinct window-opening behaviors compared to those in other building types. Furthermore, hospital wards are different from the rooms in residences, offices, and schools, as they are occupied by patients on a long-term basis. This perpetual occupancy stands in stark contrast to the transient nature of occupancy in other building types where occupants come and go for daily activities or during specific times. Consequently, the study of window-opening behaviors in hospital buildings merits further investigation.

The significance of natural ventilation in hospitals has been emphasized by previous studies [50]; however, the research on window-opening behavior in hospital wards remains constrained. Only Shi et al. [38] studied window behavior in Nanjing hospitals over a year, examining the effects of climate (indoor/outdoor temperature, indoor/outdoor relative humidity, rainfall, wind speed, and wind direction) and air quality (outdoor PM2.5 and indoor CO_2 concentration) on it. Key triggers were indoor temperature and humidity with seasonal variations: indoor humidity favored window openings in transition seasons but hindered them in cooling/heating seasons. In contrast, outdoor PM2.5 expressed no significant impact.

In addition, the comparison of the standard of prevention and control of healthcare-associated infection in labor and delivery units in healthcare facilities WS/T 823-2023 [51] and the General Hospital Building Design Code GB 51039-2014 [41] reveals that pregnant women and infants necessitate higher living environment standards concerning humidity and air quality. However, the research on window-opening behaviors specific to maternity hospitals remains limited.

For example, particulate matters (PM) are pointed to have an impact on hypertensive disorders of pregnancy [52–54], which could be a potentially significant factor for window operation models in maternity hospitals. The outdoor PM2.5 concentration has emerged as a crucial factor affecting window operations among Chinese occupants in residential [55,56] and office buildings [57,58] in recent years. However, Shi et al. [38] stated that outdoor PM2.5 had no significant impact on the window-opening behaviors in hospital wards in Nanjing, China. Therefore, further research is needed to investigate the effects of relevant parameters, particularly PM2.5 concentrations, on hospital window operations.

The only research on the window-opening behavior of maternity hospitals is conducted by Niu, B. et al. [39] in Beijing during the summer. They investigated the influence of environmental parameters on window-opening and used random forest models to predict the window states. Their findings revealed that outdoor PM2.5 concentration had the most significant impact on window states in both wards and doctors' offices, which is completely different from the findings of Shi et al. [38]. Moreover, they observed a distinct difference in hourly window opening probabilities between offices (approximately 70% open) and wards (fluctuating regularly from 10% to 65%). This discrepancy contrasts with the characteristics of window behavior in other types of buildings in Beijing during the summer season.

The analysis of window-opening behavior in maternity hospitals is meaningful but constrained by limited research. An existing study [39] indicated that window-opening behavior in maternity hospitals differs considerably from other building types. Furthermore, investigations on window-opening behavior in hospital buildings have not yet considered occupants' subjective tendencies in operating windows, and the underlying motivations for window opening remain unidentified.

1.3. Questionnaire Studies on Window-Opening Behavior

Previous studies [11,38,59,60] indicated that window-opening behavior is influenced by various environmental factors, including temperature, humidity, and air quality, and is also influenced by occupants' subjective perceptions and habits, rendering it stochastic in nature.

Most of the research on window behavior is aimed at establishing a model to predict the window state, with the data coming from field measurements. But fewer studies considered the impact of the occupants themselves on window-opening behavior, such as the type of occupant (e.g., age, pregnancy, or accompanying families) and subjective factors (e.g., window-opening habits, energy-related habits, environmental awareness, and temperature preferences) [55,56,61].

Questionnaires are usually employed to collect individuals' subjective intentions and complement field measurements. For example, Maier, T. et al. [62] discovered that besides good comfort and air quality perception with different ventilation systems, residents still preferred opening windows for adequate air change rates or thermal comfort. Lai, D. et al. [55] found the reasons for not using windows (noise, thermal discomfort, and outdoor pollution) and mechanical ventilation systems (insufficient performance, increased energy costs, thermal discomfort, and noise) through questionnaires.

Another application of the questionnaire is related to thermal comfort assessment. Rijal et al. [15] used surveys to obtain the data of window operations, and then quantified the operations' effect on comfort and energy use. Similarly, Haldy et al. [25] quantified the influences of adaptive behaviors (such as cold drinks, activities, clothing, as well as the operation of fans, blinds, doors, and windows) on thermal sensation in office buildings in Switzerland.

Usually, questionnaire results often serve as a supplement to empirical findings, as questionnaires and interviews often express a validation and interpretation effect on actual measurements. In addition, the questionnaire can also support the preliminary screening of environmental parameters, thus effectively helping eliminate unnecessary parameters [63]. For example, by combining the measurement and questionnaires, Andersen, R.V. et al. [64] identified factors influencing window behaviors including outdoor temperature, ownership conditions, floor area, solar radiation, gender, and environmental perception. Deme Belafi, Z. et al. [65] observed different drivers for window actions in two classrooms: one influenced by environmental parameters and the other by habits and time-dependent actions.

Surveys collecting occupants' information and subjective intentions have been mainly focused on residential and office buildings, with limited observations in other building types. Verbruggen et al. [61] suggested that the lack of window habit may lead to poor predictions of opening behavior, emphasizing the importance of accounting for occupants' subjective factors to achieve more reliable predictions.

1.4. Summary

Based on the literature review carried out, the research gaps on window-opening behavior in maternity hospitals were identified as follows:

- The investigations focused on maternity hospital buildings were unbalanced and limited, but the window-opening behavior observed in maternity hospitals exhibits significant disparities when compared to that of other building types [39].
- In recent years, the predominant approach in most studies concerning window opening behavior entailed predictions through factor analysis [10,28,29,31,57,66–68]; however, the quantitative descriptions often lacked precision and clarity.
- Occupants' information including occupant types and subjective factors have rarely been taken into consideration in the reported studies. More reliable predictions of window opening behavior could be achieved by accounting for occupants' subjective factors.
- The subjective determinants of window-opening behavior vary from different building types [55,64,65]. However, the majority of studies on subjective factors have predominantly examined residential buildings, with limited observation encompassing different building types [55,56,61].

Therefore, this research aims to understand the window behavior patterns and characteristics in a maternity hospital ward accommodating pregnant women. It provides insights into behavior specific to certain categories (e.g., children, pregnant women, elderly). The study can serve as a decision-making tool for enhancing hospital stay quality and exploring renovation options, fostering the development of more intelligent, energy-efficient, and healthier maternity hospitals.

Data collection for occupants' window behavior involves real-time field measurement and questionnaire surveys. These methods complement and contrast each other. Combining the questionnaire with field measurement addresses the limitations of questionnaire data accuracy and captures occupants' subjective tendencies. Additionally, comparing questionnaire and measurement results validates the questionnaire's accuracy.

Due to the privacy regulations of the maternity hospital, the questionnaire was only administered during the spring. Thus, this study was conducted only for the transition season, which is the season without air conditioning.

Furthermore, the implementation of the questionnaire survey depends on factors such as administrative and medical staff approval, ward decisions, and availability of target populations. These considerations aim to demonstrate the proposed methodology's validity and potential application in other case studies related to window-opening behavior in maternity hospitals, particularly concerning pregnant women and accompanying families. The goal is not generalization but rather providing guidance to researchers in the field.

2. Research Methods

2.1. Reference Building

This study investigated window-opening behaviors in Ningbo's largest maternity hospital, which annually provides 2.15 million outpatient services and over 12,000 births. The investigation focused on the maternity ward and involved pregnant women and accompanying family members as respondents. The inpatient department comprises fifteen floors, with the seventh floor dedicated to obstetrics, housing 40 rooms with 97 beds. Figure 1 shows the exterior view of the maternity hospital building.

The hospital is of the central corridor type, and four wards (wards 1 to 4), located in different directions of the corridor were selected as monitored rooms (shown in Figure 2). Wards 1 and 2 are located on the south side of the corridor, while wards 3 and 4 are on the opposite side.

Though all wards have identical dimensions (4.8 m $\times$ 3.5 m $\times$ 2.8 m) and amenities, the number of patients in different wards is different. The wards on the north side (wards 1 and 2) are triple rooms, while those on the other side are double rooms (wards 3 and 4). Thus, we chose both these two types of rooms as the test rooms.

Figure 1. Exterior view of the maternity hospital building (wards on the 7th floor were chosen for this investigation).

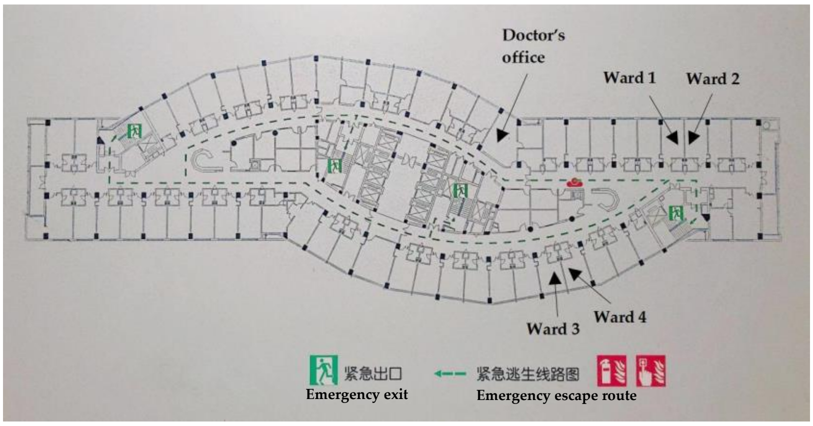


Figure 2. Floor plan of the 7th floor of inpatient department in Ningbo case study hospital.

Each ward is equipped with an internal bathroom and two top-hung windows facing either south or north. The wards are usually occupied by pregnant women accompanied by one or two family members. All wards are operated as usual during the measurement period.

For cooling and heating, the primary air fan-coil system (Figure 3), using lithium bromide as the refrigerant, serves the inpatient department. During transition seasons (Spring and Autumn), indoor temperature and humidity are adjusted through natural ventilation.

Figure 3. Photo of the primary air fan-coil system in Ningbo case study maternity hospital.

2.2. Questionnaire

The questionnaire aims to explore the potential relationship between subjective feelings and window-opening behavior in the maternity hospital wards and also to collect factors influencing window operations directly. To investigate the feelings about the indoor environment, the survey referred to the recommended thermal comfort questionnaire by ASHRAE 55 [69], ISO 10,551 [70], and Civil Building Indoor Thermal and Humidity Environmental Assessment Standards [71].

The questionnaire was conducted from 25 to 27 March 2019, between 10 a.m. and 5 p.m. Face-to-face questionnaires were administered on the 7th floor of the maternity hospital in spring 2019, with a total of 154 surveys completed and 147 effective questionnaires collected by the end of the study period.

It utilized simple random sampling for the sampling survey (consisting of 20 questions in total, with 12 single questions and 8 multiple questions, as shown in Table 1).

Table 1. The main information of the questionnaire survey.

Case Study Hospital	Location	Time	Target Population	Question Type	Number of Questions	Purpose	Collected Questionnaire	Sample Size
Ningbo case study maternity hospital	Obstetric ward	25 March–27 March 2019; 10:00 a.m.–5:00 pm.	Pregnant women and accompanying families	Single choice	4	(1) The respondents' basic information	154	3080
					6	(2) The respondents' feelings on the indoor environment in maternity hospital		
				Single choice and multiple-choice	10	(3) The respondents' habitual drivers and reasons for opening and closing windows in the hospital		

The contents have been divided into four main aspects according to the different aims:

1. Respondents' basic information: including age, gender, relationship with the pregnant women, and duration of their stay in the hospital.
2. Respondents' perceptions of the indoor environment: focusing on thermal conditions (air temperature and humidity), satisfaction with the indoor air quality, air circulation, and acceptability with the overall comfort. The used voting indicators are listed in Table 2.
3. Respondents' habitual drivers and reasons for opening and closing windows in the hospital.

Table 2. Scales used to assess subjective feelings in surveys.

Thermal Sensation	Humidity Sensation	Comfort Sensation	Air Quality Sensation	Air Circulation Sensation
cold (−3)	humid (−2)	very uncomfortable (−2)	low quality (−2)	stuff (−2)
cool (−2)	slightly humid (−1)	uncomfortable (−1)	relatively bad (−1)	slightly stuff (−1)
slightly cool (−1)	neutral (0)	neutral (0)	neutral (0)	neutral (0)
neutral (0)	slightly dry (+1)	comfortable (+1)	relatively good (+1)	relatively good (+1)
slightly warm (+1)	dry (+2)	very comfortable (+2)	high quality (+2)	good air circulation (+2)
warm (+2)				
hot (+3)				

The questionnaire was distributed to all occupants, including pregnant women who had given birth or not, and their accompanying families. To ensure the accuracy of the results, all participants were required to complete the questionnaire after the researchers had explained the contents.

Table 3 concludes the characteristics of the participants. The majority of pregnant women who participated in the survey were in the age range of 20 to 35 years old, with only 9 and 5 individuals below 25 and above 35 years old, respectively. In the obstetric ward, patients typically stayed for one week (arriving 2–3 days before the expected birth date and leaving 2–3 days after the birth). Most pregnant women were accompanied by their partners, and while some patients were in their rooms, some accompanying family members were in the corridor.

Table 3. Characteristics of the participants.

Parameter	Subjects	Under 25	25–35	35–45	45–55	Over 55
Age	Total (147)	14	104	13	13	3
	Males and non-pregnant female patients (81)	5	52	8	13	3
	Pregnant women (66)	9	52	5	-	-

2.3. Field Measurement

The field measurements were conducted at the largest maternity hospital in Ningbo City from 31 March 2019 to 30 December 2019. Since the questionnaire was administered in spring, the measured data used in this paper corresponds to the same spring period (31 March 2019 to 30 May 2019). The indoor and outdoor environmental factors and window status were recorded during the measurement. The detailed experimental instrument parameters are illustrated below in Table 4.

Table 4. Basic parameters of the experimental instrument.

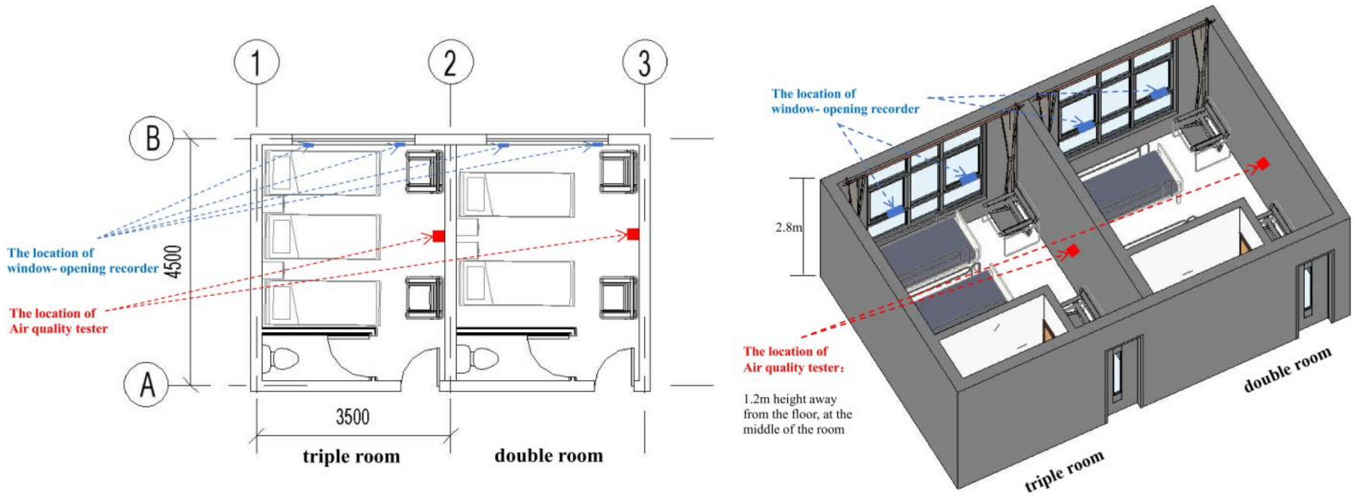
	Test Parameters	Instrument and Supplier	Test Range	Precision	Data Record Interval
Indoor parameters	Indoor temperature	Air quality tester (Hanwei Technology Group Co., Ltd., Zhengzhou, China)	−40~+85 °C	±0.3 °C	5 min
	Indoor relative humidity		0~100%	±2%	
	Indoor CO_2 concentration		0~5000 ppm	±5%	
	PM2.5		0~999 μg/m^3	±5%	
	Noise		30~110 dB	±5%	
Outdoor parameters	Outdoor temperature	FSR-4 portable weather station (Beijing Tianjian Huayi Technology Development Co., Ltd., Beijing, China)	−50~150 °C	±0.1 °C	1 min
	Outdoor relative humidity		0~100%	0.1%	
	PM2.5 concentration	Local meteorological station			1 h
State of the windows		Window-opening recorder (Xiaomi Technology Co., Ltd., Beijing, China)			real-time monitoring

All of the indoor factors were measured simultaneously by an air quality tester which has been installed at 1.2 m height away from the floor at the middle of the room, with a recording interval of 5 min. The outdoor environmental parameters were recorded by a portable weather station installed 1 km away from the hospital. The window status was monitored in real-time while the average outdoor PM2.5 concentration value was obtained hourly according to the nearest air quality monitoring station ('Ningbo Environmental Monitoring Center') of the test site [72], the linear distance is less than 1 km. Field installation of instruments are shown in Figure 4.

(**a**) Recorder of window status (**b**) Air quality tester (**c**) FSR-4 portable station

Figure 4. Photo of the experimental apparatus.

Figure 5 shows two-dimensional (2D) and three-dimensional (3D) drawings of the different types of wards in relation to the location of the windows, the people researched, the details of the window-opening recorders, the air quality testers, and the internal objects.



(**a**) 2D drawing (**b**) 3D drawing

Figure 5. Schematic diagram of the interior layout.

The results of the questionnaire survey and field measurement will be compared and analyzed in Section 3.3, including the factors related to time, thermal comfort, and indoor air quality. The combination of collected questionnaire results with real-time measurements will aid in comprehending the factors driving occupants' window behavior, considering both environmental and subjective aspects. These findings will be further explored in future studies.

3. Results and Discussion

3.1. Length of Hospitalisation

Personal information collected in the study includes respondents' age, relationship with the pregnant women, and the duration of their stay in the hospital.

Figure 6 presents a cross-analysis of the first two questions: the respondents' duration of stay in the hospital ('have spent') and their intended duration ('going to stay'). The 'Y' axis represents the number of days the respondents have already spent in the hospital, while the 'X' axis shows the overall percentage of each option for the planned duration. The different colors represent the various durations respondents intend to stay in the hospital. The numbers on the colors indicate the count of individuals who selected each corresponding option.

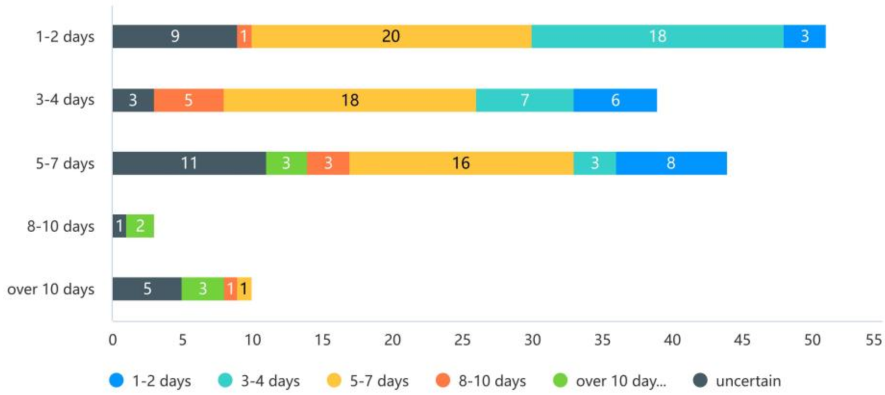


Figure 6. The association between the duration of respondents' past and future stay in the hospital.

The analysis indicates that the majority of respondents stayed in the hospital for relatively short durations, with 34.69%, 26.53%, and 29.93% reporting stays of '1–2 days', '3–4 days', and '5–7 days', respectively. Only a small fraction of respondents (13 out of 147) stayed in the hospital for more than seven days. As for the scheduled staying duration, 37.4% of respondents (55 out of 147) chose to stay for '5–7 days', followed by 'uncertain' (19.73%) and '3–4 days' (19.05%).

Notably, within a four-day period, 61.22% of respondents stayed in the hospital, of whom 73.89% intended to leave within a week. Furthermore, the majority of respondents (71.4%) were found to have a total stay in the hospital that did not exceed 14 days (as indicated in Figure 6, a group of respondents had a hospital stay of '1–2 days', '3–4 days' and '5–7 days' but simultaneously expressed their intent to leave within seven days), indicating a swift turnover of occupants.

This observation underscores the characteristic of maternity hospitals, where patient populations and accompanying family members exhibit significant fluctuations over short periods. Such variability in the patient population contributes to more complex window-opening behaviors compared to other building types, thereby adding intricacy to the study of window behavior.

3.2. Reasons for Opening/Closing the Windows

This section presents the analysis of respondents' reasons for window opening and closing in the hospital, consisting of eight multiple-choice and two single-choice questions. The multiple-choice questions in the second part of the questionnaire include inquiries about thermal senses triggering window actions, habits of window opening/closing, the timing of window operations, and factors influencing window actions. The last part features single-choice questions, asking participants to select the most significant factor affecting their window-opening behavior in the hospital.

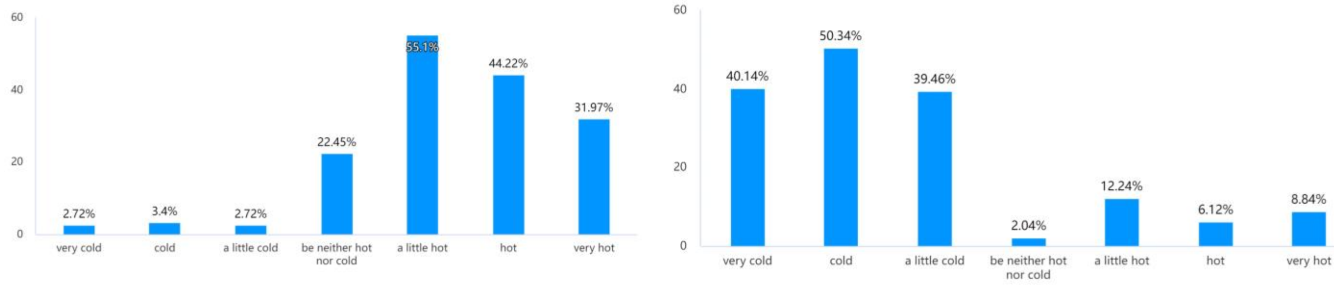
The analysis of multiple-choice questions involves descriptive and deductive statistics. Descriptive statistics, particularly frequency analysis, is widely used. It includes two essential indices: 'Percent of Cases' (percentage of individuals selecting a specific option among all respondents) and 'Percent of Responses' (percentage of times an option is selected in all choices made). The sum of the 'Percent of Responses' is 100%, while the 'Percent of Cases' may exceed 100%. Additionally, contingency table analysis is employed to explore the relationship between multiple-choice questions and other categorized variables.

Therefore, this part was conducted in two parts: frequency analysis and cross-sectional description.

3.2.1. Frequency Analysis

(1) Thermal sensation and window opening/closing behavior

Figure 7 illustrates the effects of thermal perceptions on occupants' window-opening and closing behavior, in relation to the question 'In which of the following thermal sensations would you open/close the window?'. The 'X' axis represents the percentage of occupants opening or closing the window, while the 'Y' axis represents respondents' thermal perception in the hospital during Spring.



(**a**) (**b**)

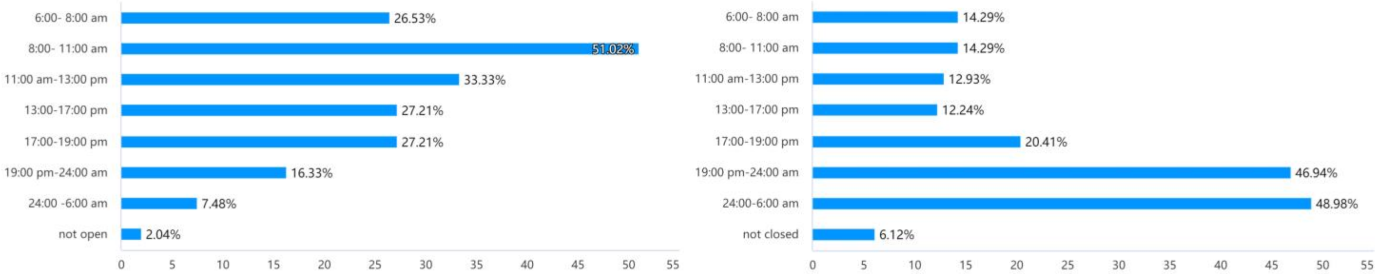
Figure 7. The distribution of respondents' window-opening behavior in response to different thermal sensations: (**a**) To open the window; (**b**) To close the window.

It is evident that the sense of hotness (including 'a little cold', 'hot', and 'very hot') predominantly motivates occupants to open the window, while the sense of coldness (including 'cold', 'very cold', and 'a little cold') is the primary factor driving window closure. Among those, 'a little hot' and 'cold' are the most influential factors for window opening and closing, accounting for 55.10% and 50.43%, respectively. This suggests that respondents are more sensitive to higher temperatures during Spring.

Interestingly, under the condition of 'neither hot nor cold', 22.40% of respondents (33 out of 147) prefer to open the windows, while only 2.00% tend to close them. This indicates that occupants' window-opening behavior is driven by factors other than thermal sensation in the hospital, and occupants tend not to adjust the window under a comfortable indoor thermal environment. These findings align with previous studies by Rijal, H.B. et al. [15] and Roetzel, A. et al. [73].

(2) Time and window opening/closing behavior

Figure 8 illustrates the impact of time on window opening and closing behavior, corresponding to the questions 'When do you usually open/close the window in the hospital?'.



(**a**) (**b**)

Figure 8. Percent of Cases of window opening and closing at different time intervals: (**a**) The window-opening percent at different times; (**b**) The window-closing percent at different times.

The highest window opening percentage occurs between 8:00 and 11:00 (51.02%), decreasing notably during the nighttime hours (24:00 to 7:00) to 7.48%. Little change in window opening percentages is observed during the early morning (6:00–8:00) and afternoon periods (13:00–17:00 and 17:00–19:00), with values of 26.35%, 27.21%, and 27.21%, respectively. The lowest window-opening percentage of 7.48% is observed during the sleeping hours from 24:00 to 7:00.

Conversely, the highest and second-highest percentages for window closing are at the time periods of '24:00–07:00' and '19:00–24:00' (48.98% and 46.94%, respectively), followed by a significant decrease to 20.41% at the time period '17:00–19:00'. Additionally, except for the 'not closed', the window-closing percentage decreases slightly from the early morning (6:00–8:00) to the afternoon (13:00–17:00), from 14.29% to 12.24%. The lowest possibility for closing windows is during the time period '13:00–17:00'.

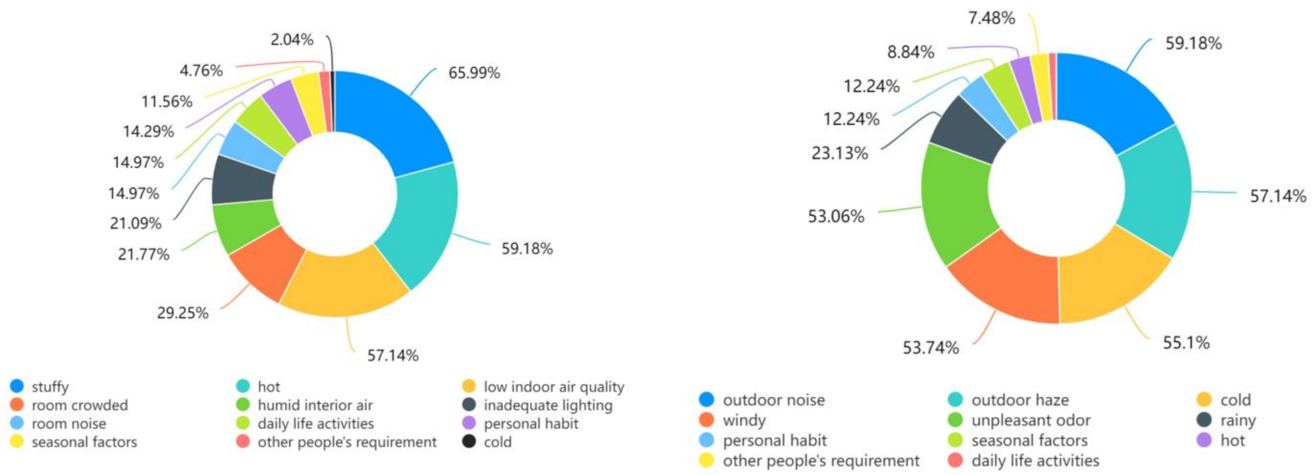
The percentage of window opening is more evenly distributed throughout different times, with a low point on evening periods (19:00–24:00 and 24:00–6:00), peaking between 8:00 and 11:00. The highest percentage of window closing and the lowest percentage of window opening occur during the same time period (24:00–6:00), indicating a preference for closed windows during sleep.

The total number of responses for window opening (281) is higher than that for window closing (259), suggesting a greater influence of time periods on window opening. Moreover, based on the face-to-face questionnaire, respondents chose 'not open' due to Chinese traditional practices where pregnant women in the ward are in a 'confined' period and avoid drafts. On the other hand, the choice of 'not closed' mainly reflects respondents' habits.

In conclusion, time periods significantly influence window-opening behavior other than closing, with preferences for open windows in the morning and during lunchtime, and closed windows in the evening. Furthermore, respondents tend to close windows during sleep.

(3) Various factors and window opening/closing behavior

Figure 9 presents the significance of various factors in driving respondents to open or close windows, corresponding to the questions 'Which of the following factors would cause you to open/close the window?'.



(**a**) (**b**)

Figure 9. Percent of Cases of different factors influencing respondents' decisions to open or close windows: (**a**) To open the window; (**b**) To close the window.

As shown in Figure 9a, the main drivers for window opening are the sensations of 'stuffy', 'hot', and 'low indoor air quality', accounting for close proportions of 65.99%, 59.18%, and 57.14%, respectively. Factors such as 'room crowded', 'humid interior air', and 'inadequate lighting' also influence window-opening behavior, with percentages of 29.25%, 21.77%, and 21.09%, respectively. However, factors like 'room noise', 'daily life activities', 'personal habits', and 'seasonal factors' have less impact on window opening, with the weakest factor being the sensation of 'cold' at 2.04%. The influence of 'other people's requirement' is also relatively small at 4.76%.

Regarding window closing, factors such as 'outdoor noise', 'outdoor haze', 'cold', 'windy', and 'unpleasant odor' have similar percentages ranging from 59.18% to 53.06%. Factors like 'personal habits', 'seasonal factors', 'hot', 'other people's requirement', and 'daily life activities' have marginal impacts, accounting for less than 13%.

The thermal sensations, either 'hot' or 'cold' play a significant role in opening and closing, respectively. Conversely, the percentages of the perception of indoor and outdoor noise differ when the window is opened or closed: 'outdoor noise' plays a significant role in window closing, while 'indoor noise' has a limited effect on window opening. Similarly, 'personal habits', 'seasonal factors', 'daily life activities', and 'other people's requirement' have fewer impacts on both window opening and closing. Furthermore, the total number of responses for factors affecting window closing is larger than that for window opening, with 508 responses compared to 466. This indicates that respondents consider window closing more thoughtfully than window opening.

In conclusion, the most effective driver for both opening and closing windows is the comfort requirement, including thermal and other comfort-related factors (e.g., air quality or air circulation). Occupants' tolerance to humidity is higher than thermal sense, with 21.09% compared to 59.18% ('humid interior air' to 'hot') for window opening, and 23.13% compared to 55.1% ('rainy' to 'cold') for window closing.

Despite various daily activities and potential noise in the hospital, these factors have minimal influence on window-opening operations. In contrast, 'outdoor noise', being related to human comfort, encourages occupants to close the windows. Personal habits and seasonal factors are of less concern to respondents in the maternity hospital, as their primary focus is on comfort.

(4) Respondent's habit and window opening/closing behavior

Figure 10 depicts the impact of respondents' habits on window opening and closing behavior, corresponding to the questions 'What are your habits of opening/closing windows in the hospital?'.

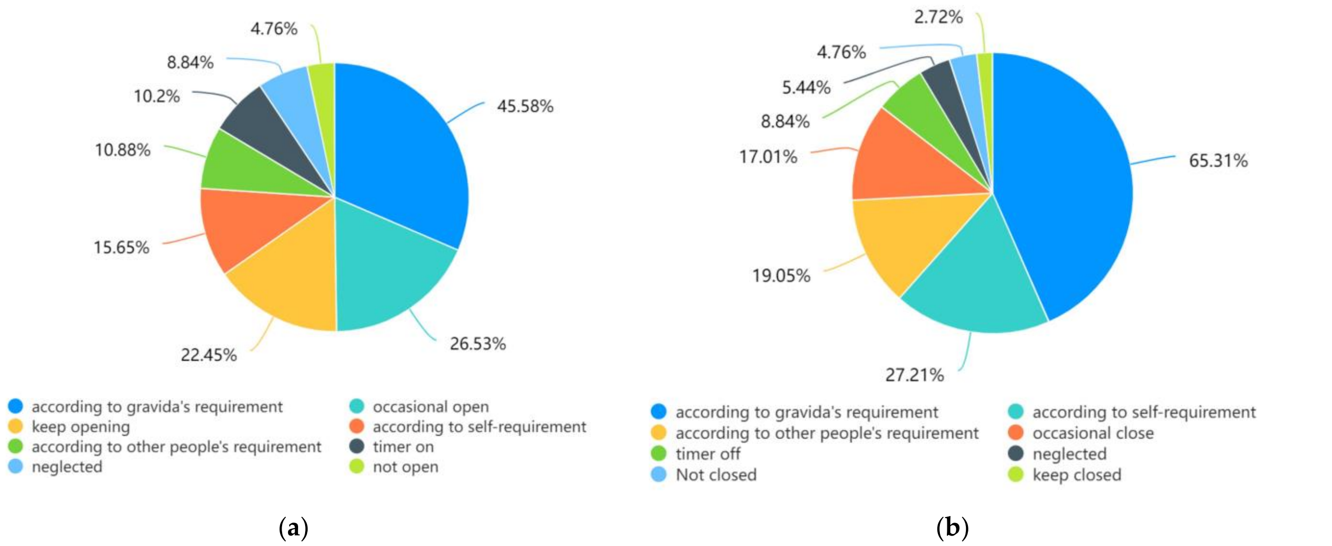


Figure 10. The impact of respondents' personal habits on window opening and closing behavior: (**a**) The window-opening percent with different habits; (**b**) The window-closing percent with different habits.

The 'requirement of pregnant women' is the most influential factor for both window opening and closing, with 26.53% of respondents occasionally opening the window and

22.45% keeping it open. The habit of 'self-requirement' follows closely, accounting for 15.65% of respondents. However, the consideration of other people's requirements and the use of timers have minimal influence on window opening in the hospital. The 'not open' option has the lowest percentage of 4.76%, and only 8.84% of respondents ignore their natural ventilation behavior.

Regarding window closing, the reasons are different. The second and third reasons are 'self-requirement' and 'other people's requirement' accounting for 27.21% and 19.05%, respectively, while the 'occasional close' only has a score of 8.84%. Similar to window opening, fewer respondents (8 out of 147) ignore their window-closing actions, with the 'keep closed' option having the lowest proportion of 2.72%.

Though the 'requirement of pregnant women' is the most significant factor both for window opening and closing, the number of respondents selected for window-closing is higher than that for opening, with 96 and 67 people, respectively. Similarly, more respondents were subjected to 'self-requirement' and 'other people's requirement' for window-closing than that for window-opening.

In summary, respondents are more concerned about indoor personal requirements (including 'requirement of pregnant women', 'self-requirement', and 'other people's requirement') when closing the windows than when opening them. The preference for window opening or closing is occasional, with fewer respondents using timers to control windows in the maternity hospital.

(5) Main factors for window opening/closing behavior

Figure 11 illustrates the paramount determinant influencing respondents' decisions to open or close the window, exhibiting trends consistent with those observed above. The comfort of pregnant women constitutes the most significant proportion for both window opening and closing, followed by 'environmental factors', 'personal comfort', and 'personal habit', while 'other people's requirement' exerts the least influence.

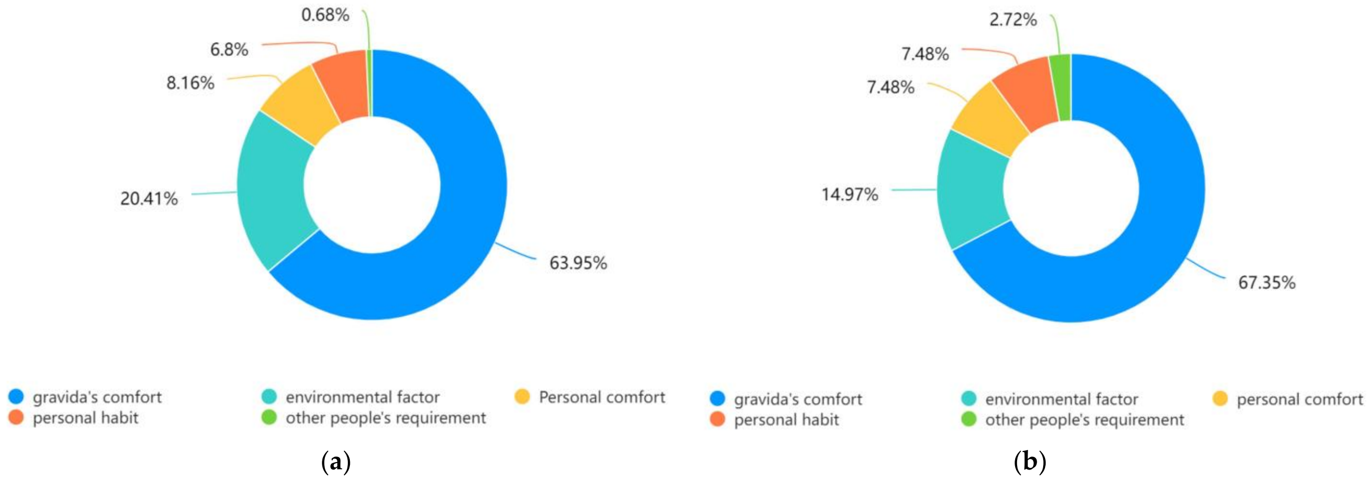


Figure 11. The paramount determinant influencing respondents' decision to open or close the windows: (**a**) To open the window; (**b**) To close the window.

Pregnant women's comfort holds a great impact on window closing (67.35%) compared to window opening (63.95%). Conversely, environmental factors play a more prominent role in window opening (20.41%) than in window closing (14.97%). This discrepancy can be attributed to the concern for the health and comfort of pregnant women in hospitals, where environmental variables significantly influence indoor air quality and thermal conditions.

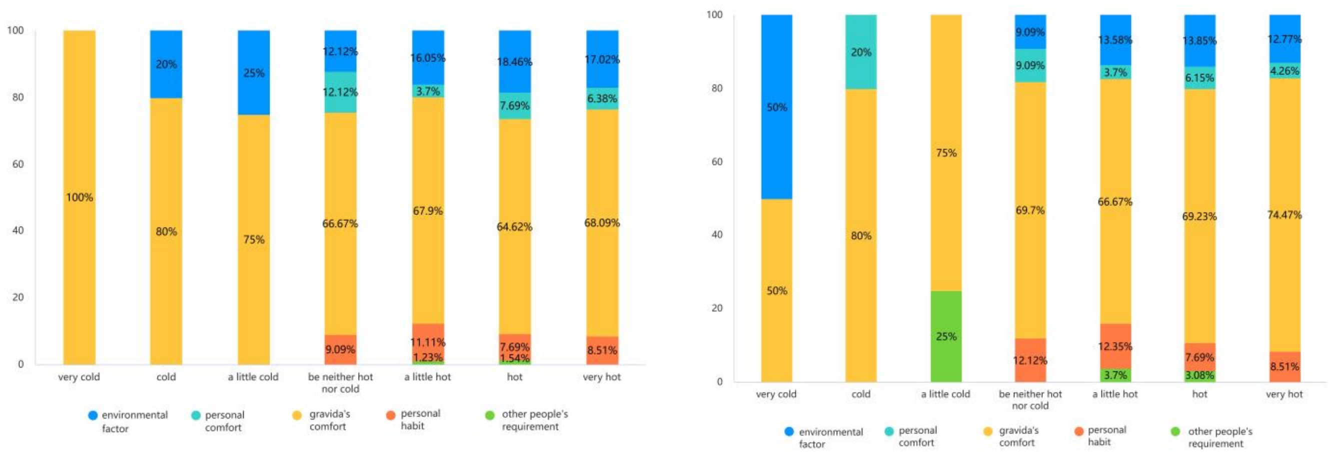
Moreover, the influence of personal comfort and habit on window opening and closing is less pronounced than the aforementioned main factors but still holds significance. Conversely, 'other people's requirement' has minimal impact on window opening (0.86%) while slightly affecting window closing (2.72%). These findings suggest that in public settings, window opening and closing behaviors are primarily driven by concerns related to pregnant women and respondents themselves.

3.2.2. Cross-Sectional Description

This section offers a cross-sectional analysis of multiple-choice questions.

(1) Cross-sectional analysis pertaining to the thermal sense and the paramount determinant influencing respondents' decision to open or close the windows

Figure 12 depicts the cross-sectional analysis of thermal sensation's influence and the primary determinants of window opening and closing. The 'X' axis represents respondents' thermal sensation, while the various colors represent different factors influencing window opening or closing. The 'Y' axis indicates the percentage of each option.



(**a**) (**b**)

Figure 12. The crosstabs analysis of the thermal sense and the most important factor to open/close the window: (**a**) To open the window; (**b**) To close the window.

Regarding window-opening behavior, as shown in Figure 12a, the impact of 'pregnant woman's comfort' follows a declining trend from 'very cold' to 'very hot', with the percentage decreasing from 100% to 68.09%. Conversely, Figure 12b shows no distinct trend, where 'pregnant woman's comfort' plays a dominant role (above 70%) for window-closing, except under the condition of 'neither hot nor cold', where other factors account for 66.7%.

In summary, the thermal comfort of pregnant women is the primary driver for window-opening, especially in colder indoor environments. As the indoor temperature increases, other factors become more influential. For window-closing, the thermal comfort of pregnant women remains the most significant factor, particularly in hotter indoor environments, compared to window-opening. Respondents prioritize their own comfort when they feel at ease, while the thermal comfort of pregnant women becomes the main consideration for window-closing under uncomfortable thermal conditions.

(2) Cross-sectional analysis pertaining to the window-opening/closing habits and the paramount determinant influencing respondents' decision to open or close the windows

Figures 13 and 14 present the crosstabs analysis of the most important influencing factors and respondents' window opening or closing habits, excluding the consideration of 'pregnant woman's comfort'. The 'X' axis represents respondents' window opening or closing habits, while the various colors indicate the different most important factors for window-opening or window-closing. The 'Y' axis represents the percentage of each option.

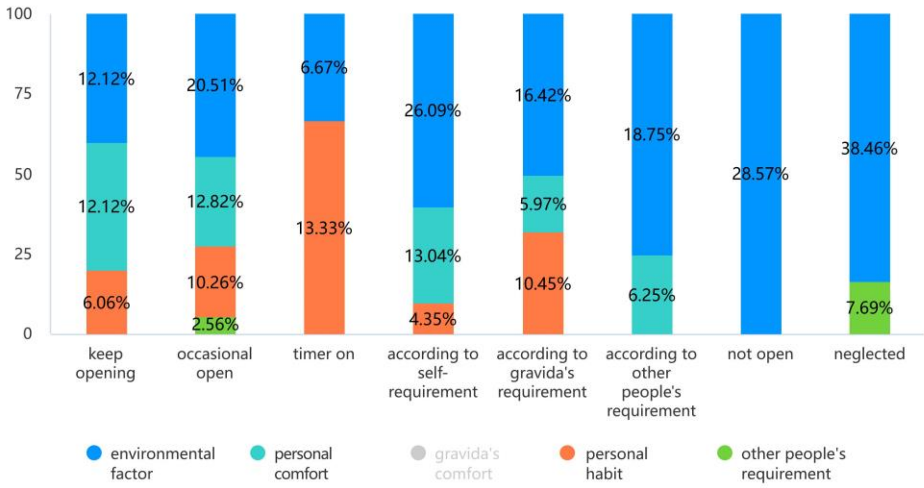


Figure 13. The crosstabs analysis of the respondents' window-opening habits and the most important influencing factor.

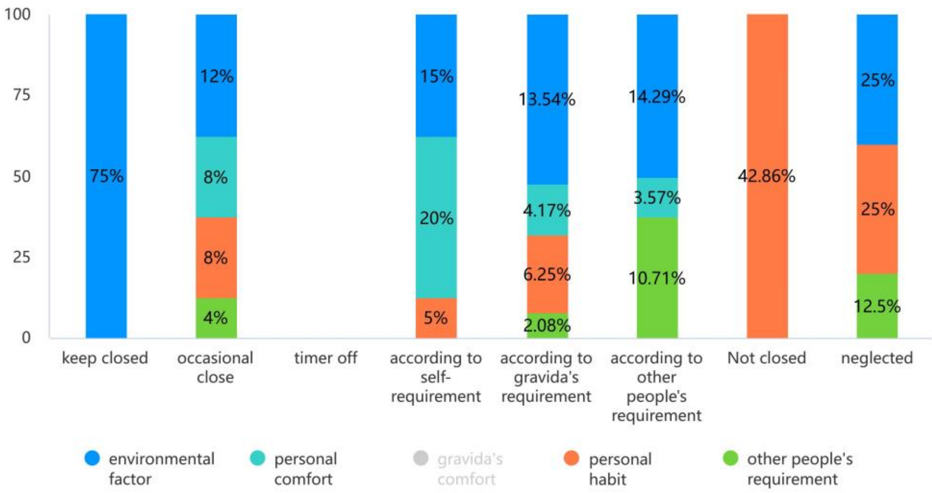


Figure 14. The crosstabs analysis of the respondents' window-closing habits and the most important influencing factor.

According to Figures 13 and 14, the 'environmental factor' emerges as the second strongest influencing factor for both window opening and closing, except for the influence of pregnant women's comfort. It significantly impacts the respondents' window-opening habits of 'neglected' (38.46%), 'not open' (28.57%), 'according to self-requirement' (comprising 18.75% of the total 25%), and 'according to self-requirement' (comprising 26.09% of the total 43.48%). Furthermore, it plays a dominant role in the window-closing habit of 'keep closed' with 75%. Notably, the empty 'time off' option in Figure 14 indicates this selection is 100% influenced by the comfort of pregnant women.

In comparison, 'personal comfort' and 'other people's requirement' only play marginal roles in window opening or closing behavior. However, the reason for 'personal habit' significantly influences respondents' window opening habit of 'time on' (accounting for 13.33% of the total 20%) and the closing habit of 'not closed' with 42.86%. Similarly, the selections of 'occasional open' and 'occasional close' (in window opening and closing, respectively) are influenced by a combination of complex factors, including 'environmental factor', 'personal comfort', 'personal habit', and 'other people's requirement'.

In conclusion, while the comfort of pregnant women remains the primary factor influencing window opening or closing in the maternity hospital, various window opening or closing habits are effectively influenced by different drivers, leading to increased complexity in occupants' window behavior. Comparatively, occupants' random actions, such as 'occasional open' or 'occasional close', are influenced by more intricate factors than other habits.

3.3. Comparison Between Questionnaire and Field Measurement Results

This section provides a comparative analysis of the questionnaire and field measurements, focusing on the factors related to time, thermal comfort, and indoor air quality.

3.3.1. Time of the Day

For field measurement, Figure 15 illustrates the relationship between the time of day and the probability of the window-opening state of all tested wards during the Spring. The statistics time interval is 1 h. The window-opening probabilities are calculated using the following formula:

$$Window - opening\ probability = \frac{the\ amount\ of\ window\ opening\ states}{the\ amount\ of\ \ total\ window\ states} \quad (1)$$

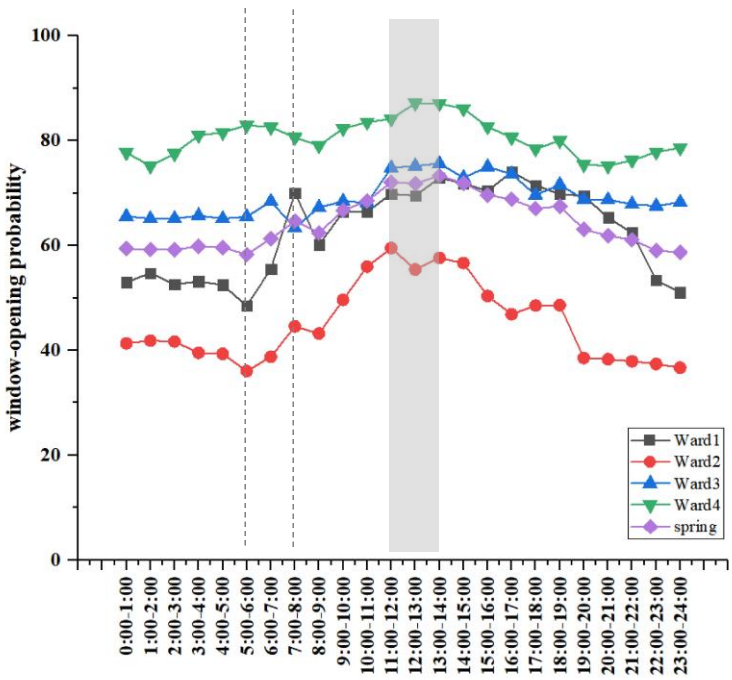
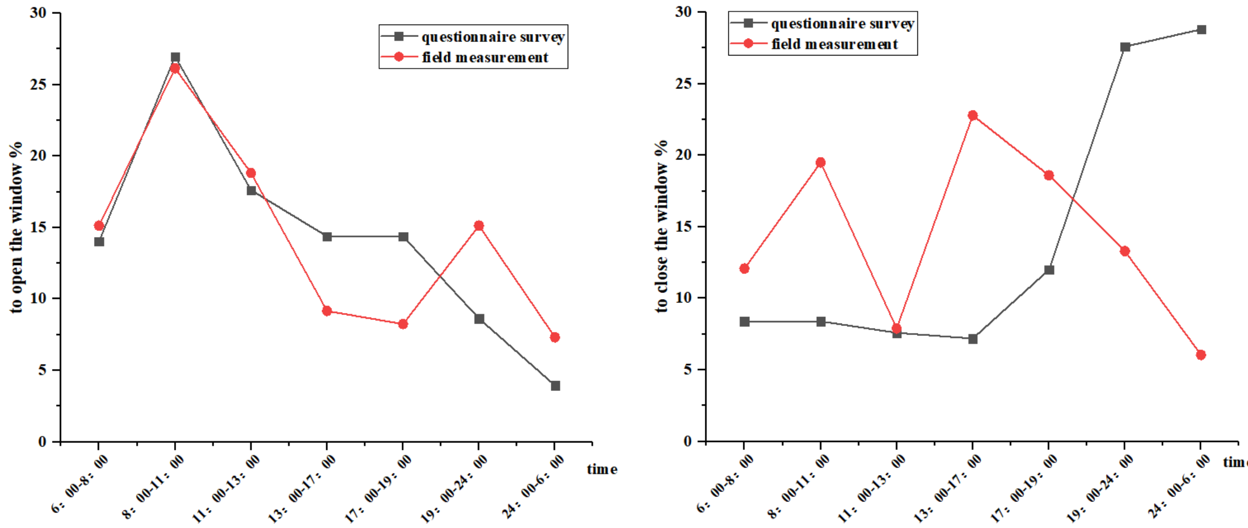


Figure 15. The variation of the correlation between time of the day and window-opening probability in different wards in spring.

In spring, the window-opening probability in wards 1 to 4 almost followed the same trend. A sudden increase is found around 5:00–6:00 while the window-opening probability keeps a gentle state before this point. The reason could be that in this maternity hospital, the ward-round time is 7:00, which provides a consistent wake-up time (at around 6:00) for all pregnant women and accompanying families. Then, the window-opening probability reaches a peak at 7:00–8:00, followed by a decrease from 8:00–9:00. After 10:00, the probability shows an upward trend, reaching its peak value at 11:00–13:00 (as shown as the gray area), then gradually decreases and remains stable during the sleeping hours (23:00 to 5:00). This figure strongly supports the conclusions drawn in Figure 8.

The questionnaire setting encompasses a categorization of the 24-h day into 7 periods aligned with the daily routines and activities of occupants within the maternity hospital wards. For example, the periods specialize the mealtime of breakfast (6:00–8:00), lunch (11:00–13:00), and dinner (17:00–19:00), respectively. As a comparison, this section presents the analysis of occupants' subjective answers to questions about window-opening and closing patterns and the reasons behind the behavior with time-related factors.

Figure 16 compares the tendency to open/close windows (obtained from the questionnaire) and the actual probability to open/close the window (field measurement) across different time periods of the day.



(**a**) To open the window (**b**) To close the window

Figure 16. Comparison of questionnaire and field measurement results of the probability of opening/closing the window within the different periods in spring.

The 'X' axis is time periods, and the 'Y' axis is the tendency/probability to open/close the window. For the field measurement, the probability of opening/closing the window is calculated using the following formula based on the actual data collected during the spring:

$$Probability\ to\ open/close\ the\ window = \frac{The\ actions\ to\ open/close\ the\ window\ in\ a\ certain\ bandwidth}{The\ total\ actions\ to\ open/close\ the\ window\ within\ the\ whole\ bandwidth} \quad (2)$$

The tendency of questionnaire results is derived from the data presented in Figure 8. The corresponding question for Figure 8 is a multiple-choice one, of which the percentage is calculated as follows:

$$\text{Percentageof}a\text{multiplechoiceoption} = \frac{Number\ of\ times\ the\ option\ is\ selected}{Number\ of\ valid\ responses} \quad (3)$$

This percentage represents the proportion of respondents who selected the particular option among all respondents. Thus, for multiple-choice questions, the sum of the percentages for different options can exceed 100%.

However, for field measurement, the sum of the window opening/closing probability across the entire time period is 100%. To compare the results of the questionnaire and field measurement, the probabilities derived from Figure 8 should be converted to a scenario where their total sum equals 100%, as Figure 16 shows.

For window-opening, a strong approximate similarity is observed between the questionnaire and field measurement analyses. Figure 16a illustrates that both the questionnaire and field measurement results show an uptrend in the probability of opening the window from 6:00–11:00, followed by a decrease. The highest probability is observed in 8:00–11:00, while the lowest value occurs during the range of 24:00–6:00. This suggests that occupants are more likely to open the windows in the morning and gradually reduce such actions throughout the day, with the lowest probability during the sleeping period from 24:00–6:00.

Conversely, for window-closing, contrasting trends are observed between the questionnaire and field measurement results. Except for the period of 11:00–13:00, which shows a low probability in both the questionnaire and field measurement, occupants subjectively prefer not to close the windows during daytime (6:00–19:00). However, the actual probability to close the window shows high values during both in 8:00–11:00 and 13:00–17:00 periods.

Moreover, the occupants' intention to close the windows increases with time after 17:00, while this trend differs in the measurement results. This is due to the fact that the data measured are the action of closing the windows, whereas the data from the questionnaire are the tendency to close the windows. The tendency encompasses the occupants' desire to close the windows or keep them closed.

Based on the questionnaire results, the majority of occupants in maternity hospital wards tend to close or maintain the window closed during the time range of 24:00–6:00. Similarly, comparing Figure 16a,b, this period exhibits minimal window opening and closing actions in field measurements. This can be attributed to the fact that 24:00–6:00 corresponds to the sleeping period of the indoor occupants, leading to reduced window operations.

This finding is also verified in Figure 15, which shows that the window-opening probability remains stable and tends to be minimal between 19:00 and 6:00. Thus, it can be demonstrated that windows tend to be closed during the night, which also validates the window-closing behavior in questionnaire data.

In summary, the results of the questionnaire and field measurement represent the occupants' preferences to act on the windows, and the actual window adjustment, respectively. The questionnaire findings indicate that respondents generally prefer to open the windows before lunchtime and close them before bedtime, maintaining them closed throughout the night. The field measurement results effectively corroborate these preferences. Additionally, the field measurement observations reveal that occupants are more inclined to adjust the windows (both open and close) during the morning hours (8:00–11:00) and tend to close the windows in the afternoon (13:00–17:00).

3.3.2. Factors Related to Comfort

Thermal perception is subjective, thus Thermal Sensation Vote (TSV) is used to compare different comfort levels and to provide a judging scale for thermal comfort for obtaining comparable and reliable data on subjective perception [69,70].

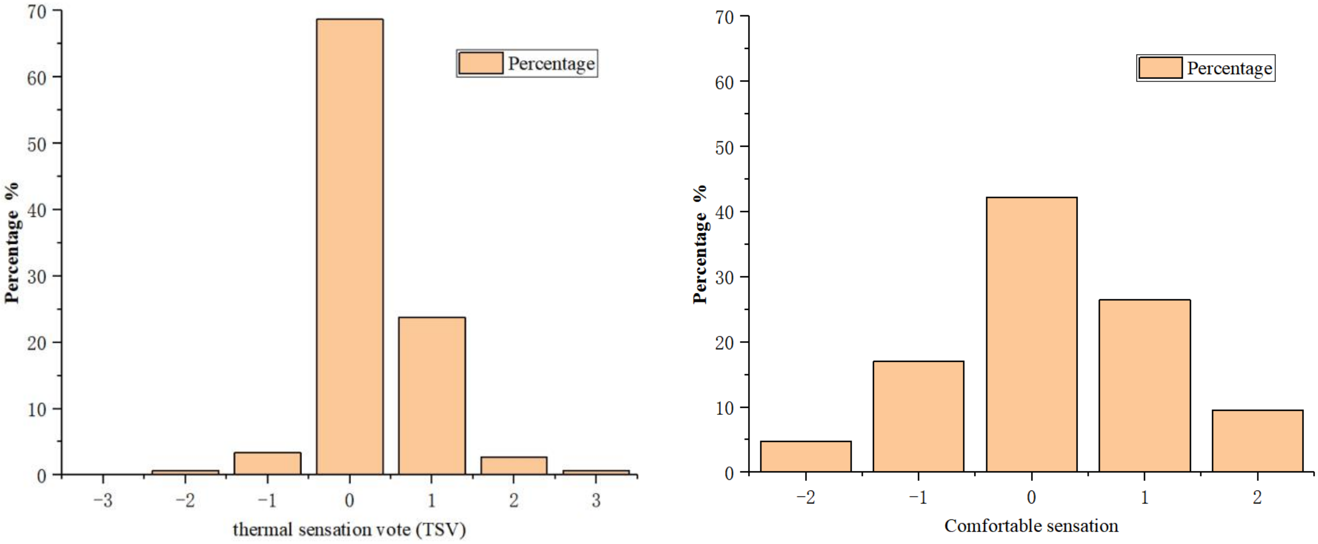
Figure 17 reports the frequencies with reference to the questions of the thermal and comfort sensation in the hospital. For thermal sensation (TSV), 'Neutral' accounted for 68.7% followed by 'Slightly warm' of 23.8%. Similarly, with the respondents dealing with comfort, the answer of 'Neutral' had the major frequency with 42.2% followed by 'Comfortable'(26.5%).

Table 5 concludes the results of the questions related to indoor comfort, along with the scope to translate the subjective perceptions into comparable and calculated measures (The complete data and calculation tables are illustrated in the Appendix A).

Table 5. The results of the questions related to thermal comfort.

Survey Question	Results
(1) the thermal perception in the hospital	+0.27 (TSV)
(2) the comfort sensation in the hospital	+0.19
(3) the humidity perception in the hospital	+0.05

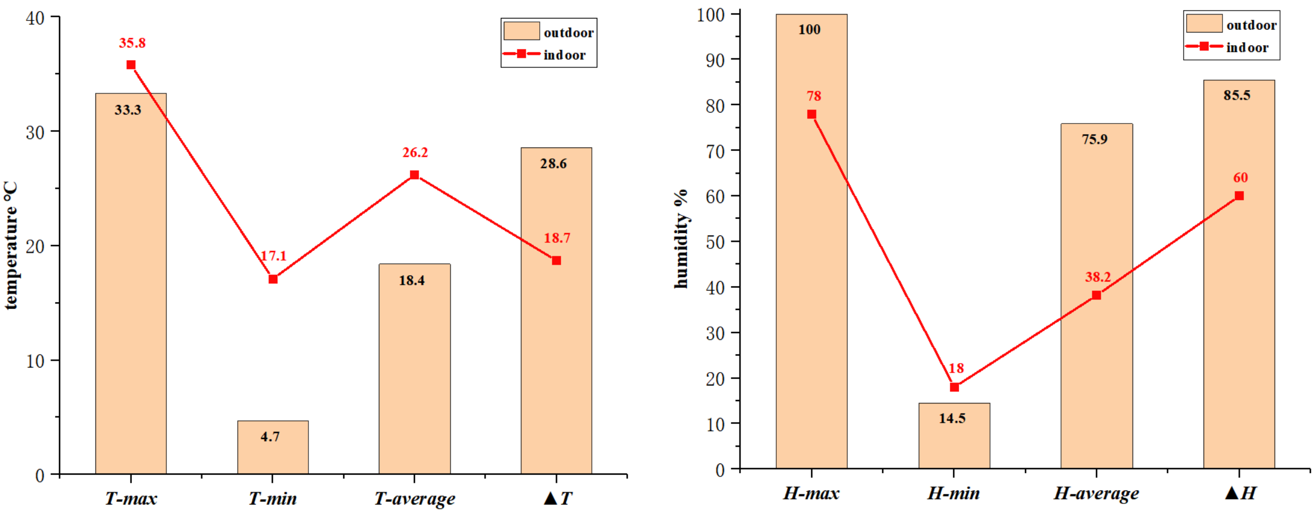
According to Table 5, the final TSV and comfortable sensation value were +0.27 and +0.19, respectively, with +0.05 for the humidity perception. This means in the maternity hospital, the respondents' perception of the indoor environment tends to be neutral in spring.



(**a**) Thermal Sensation Vote (TSV) (**b**) Comfortable sensation

Figure 17. Questionnaire results of TSV and Comfortable Sensation.

Figure 18 provides the measured data of indoor and outdoor temperature and humidity. The indoor temperature varied between 17.1 to 35.8 °C while the outdoor temperature changed from 4.7 to 33.3 °C during the spring. Though the maximum temperature achieved was about 33 °C, the average value was around 26 °C, within the comfort temperature zone (required 24–27 °C) of China's Code for Design of General Hospital (GB 51039-2014) [41]. This might be the reason that the overall thermal feeling is neutral.



(**a**) indoor and outdoor temperature (**b**) indoor and outdoor humidity

Figure 18. Variations of indoor and outdoor temperature/humidity during the measured periods.

For the humidity, in spring, the indoor and outdoor humidity ranged between 18–78% and 14.5–100%, respectively. Though the average outdoor humidity reached up to 75.9%, the average indoor humidity kept around 38%. It was a little lower than the recommended humidity comfort zone (between 40–50%). However, the humidity has less effect on the patient's thermal sensation, for example, the human body is not sensitive to a 2% change in humidity. That can be reflected in the humidity perception (Table 5) which is a neutral feeling.

3.3.3. Factors Related to Indoor Air Quality

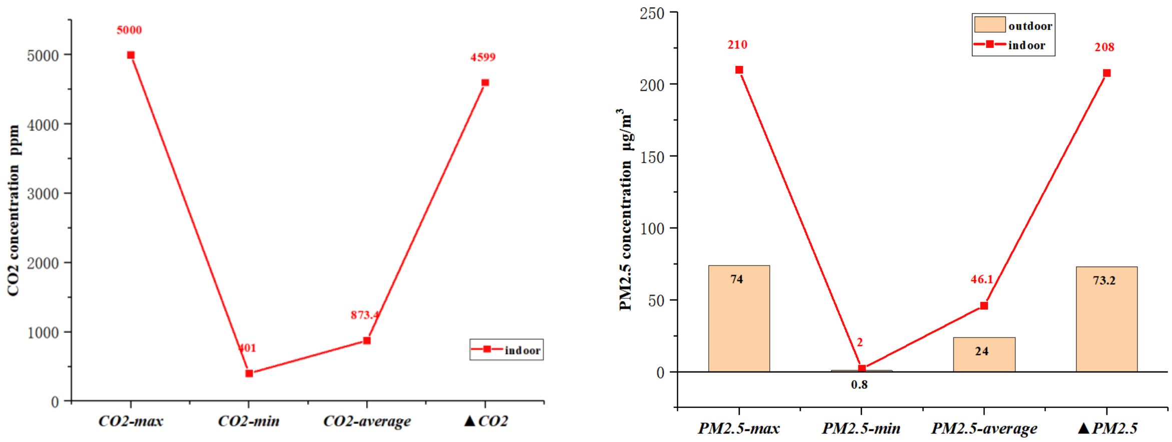
Table 6 shows the results of the questions related to indoor air quality, with the scope to translate the subjective perceptions into comparable and calculated measurements (the complete data and calculation tables are shown in the Appendix A).

Table 6. The results of the questions related to indoor air quality.

Survey Question	Results
(1) how is the air quality?	+0.35
(2) how is the air circulation?	+0.28

Similar to the respondents' sensation of the indoor thermal environment, their sensation of air quality and air circulation level also lies between 'Neutral' and 'Relatively good'. It could be affected by the factors related to indoor air quality, such as CO_2 and PM2.5 concentration.

Figure 19 presents the changes in indoor CO_2 and PM2.5 concentration during the spring. The indoor CO_2 concentration ranged between 401 and 5000 ppm. According to the Chinese standards for indoor air quality (GB/T18883-2022) [74], the average indoor CO_2 concentration should be within 1000 ppm. During the measured periods, the average indoor CO_2 concentration met the requirement with the value of 873.4 ppm.



(**a**) indoor CO2 concentration (**b**) indoor and outdoor PM2.5 concentration

Figure 19. Variations of CO_2 and PM2.5 concentration during the measured periods.

As for the PM2.5 concentration, in spring, the indoor PM2.5 concentration ranged between 2 and 210 μg/m^3, with an average value of 46.1 μg/m^3 which is less than the recommended 24-h average limit, 50 μg/m^3 [74]. Furthermore, GB/T 18883-2022 points out, that with the absence of indoor sources, the indoor PM2.5 concentration should be lower than the outdoor concentration. However, the indoor concentrations are significantly higher than outdoor values, which indicates that the PM2.5 concentration is dominated by the indoor occupants.

3.3.4. Correlation Analysis Between Influential Parameters and Comfortable Sensation

The multi-factor analysis of variance (MANOVA) was adopted to investigate the relationship between influential parameters and comfortable sensation. MANOVA means the analysis of variance with two or more factors; it is used to investigate the independent influence of multiple factors on the observed variables, it can also be used to evaluate whether the interaction of multiple control factors would influence the distribution of the observed variable [75].

MANOVA is used to investigate the importance of the influencing factors on comfort sensation, including variables related to personal information, thermal sense, and indoor air quality evaluation. Table 7 shows the correlation analysis of the influential parameters and comfort sensation. The first line is 'Corrected Model' with a significance of 4.114×10^{-7} ($p < 0.05$ means the coefficient causes significant impacts [75]) and indicates the adopted model is statistically significant and could be used to determine whether the coefficients in the model reach the statistical significance. The R square of the model being 0.558 means this model can explain 55.8% of changing reasons for comfort sensation.

Table 7. Correlation analysis between influential parameters and comfortable sensation.

Dependent Variable: Comfortable					
Source	**Type III Sum of Squares**	**Degrees of Freedom (df)**	**Mean Square**	**F**	**Significance (*p*)**
Corrected Model	79.562 a	40	1.989	3.341	4.114×10^{-7}
air_circulation	8.091	4	2.023	3.398	0.012
air_humidity	7.945	4	1.986	3.336	0.013
noise_level	5.366	4	1.342	2.253	0.068
Relationship with pregnant women	4.064	6	0.677	1.138	0.346
days would stay	3.353	5	0.671	1.126	0.351
age	2.127	4	0.532	0.893	0.471
air_quality	1.965	4	0.491	0.825	0.512
days have stayed	1.808	4	0.452	0.759	0.554
thermal sense	1.677	4	0.419	0.704	0.591

a. R Square = 0.558 (Adjusted R Square = 0.531).

The table is arranged in the order of the significance value, and it can be observed that only the significance values of 'air circulation' and 'air humidity' are below 0.05 (0.012 and 0.013, respectively). It shows that 'air circulation' and 'air humidity' affect the comfortable sensation significantly while others have no significant effects. As window-opening dominates indoor ventilation in spring, it can be assumed it is closely correlated to indoor comfort in the maternity hospital.

In addition, among the existing research on indoor comfort and window behavior, noise was rarely considered as an influencing factor. However, from the results of the questionnaires, according to Table 5, noise is the third most important factor with a significance of 0.068 which means a weak correlation exists between noise level and comfortable sensation. Surprisingly, the 'thermal sense' has the largest *p*-value of 0.591, and this might be explained by the questionnaire being carried out in spring when the temperatures were within the comfortable range and occupants tended to be more concerned with other factors.

4. Conclusions

4.1. Conclusions

Based on the questionnaire results, most respondents stay in the maternity hospital wards for less than 14 days, indicating the dynamic nature of the patient and accompanying family population compared to general hospitals. This variability leads to more complex window behavior habits compared to other types of buildings, posing challenges for research in this area.

Regarding the reasons for window operations, the dominating driver for both opening and closing windows is the comfort requirement, primarily related to thermal comfort, air quality, and circulation. Occupants are more tolerant to humidity than thermal discomfort when deciding to open or close windows.

Pregnant women's comfort plays the leading role both in window-opening and closing, particularly in colder indoor environments. The influence of other factors on window-opening increases with the temperature rises, while window-closing shows significance only when respondents feel neither hot nor cold.

Other than that, environmental factors are more important for opening, but the respondents exhibit a stronger focus on indoor individuals' requirements for closing windows rather than opening them. Their window behavior tends to be more random, with a preference for occasional window openings or closings, and fewer individuals adhering to regular patterns.

Moreover, window-opening behavior is influenced by time periods, with preferences for openness in the morning and lunchtime, while windows are generally closed in the evening and during sleep. While daily activities and hospital noise have minimal impact on window opening, outdoor noise related to human comfort encourages window closing.

In addition, the field measurement results effectively corroborate the conclusions drawn from the questionnaire, supporting the finding that the impact of time periods on window opening is higher than on window closing. Respondents tend to adjust windows during the morning and lunchtime, while they prefer to close windows in the evening, especially during sleeping hours.

The subjective evaluations of the indoor environment (both thermal comfort and indoor air quality) by indoor occupants are around neutral values. Comparison of the parameters with the measured data showed that the average values of the parameters related to indoor thermal comfort (temperature and humidity) and air quality (CO_2 and PM2.5 concentration) were within the range specified by the national standards during the test period in spring.

However, a MANOVA analysis of the questionnaire data for 'comfortable sensation' showed that only 'air circulation' and 'air humidity' were correlated with comfort, whilst 'heat sensation' was least correlated. This is possibly due to the fact that the questionnaire was conducted in the spring, when temperatures were within the comfort range, and therefore occupants were more concerned with other factors.

The window operations in maternity hospital wards are the result of collective action, acting as the main strategy of natural ventilation to create a comfortable and healthy environment. This study emphasizes that the factors influencing window adjustments in maternity hospitals significantly differ from those in other building types, providing important insights for optimizing maternity facility design.

As an important place to protect the health of women and children, the quality of the indoor environment of the building in maternity hospitals has an important impact on the recovery of patients and the efficiency of staff. The window actions, as an important method to regulate the indoor environment, functions to improve the air quality, regulate light, temperature, and humidity, and thus can promote the sustainable development of hospitals to a certain extent, including improving the quality of the indoor environment, enhancing patient comfort, and reducing air-conditioning energy consumption through natural ventilation.

4.2. Limitation

The study was conducted with a limited number of participants in a single test bed, which could be enhanced with a larger sample size. The data collection process resulted in 147 valid questionnaires out of a total of 154, involving pregnant women and their accompanying families from Ningbo's largest maternity hospital. Although the sample size (154 subjects) may be considered a limitation, considering the circumstances and the restrictions given by the hospital administration, the pool is acceptable. Similar pioneering studies in the literature, such as Liu, Zhou [76] with 30 subjects and Fabbri, Gaspari [77] with 55 subjects, have also employed relatively small samples from hospitals.

Additionally, the questionnaire survey was specific to a Ningbo maternity hospital and conducted during the spring season. As the questionnaire did not explore regional influences on window-opening behaviors, it was not deemed critical or necessary to conduct it across different regions.

Combining real-time field measurements with questionnaire survey analysis allows for an understanding of the correlation between influencing factors and occupants' window-opening behavior. However, this study only compares the impacts of the time of the day on window-opening/closing behavior from the questionnaire and the measured results. An in-depth investigation into the comparison of other factors will be conducted in our next research.

Author Contributions: M.X.: Writing—original draft, Investigation, Data curation; W.D.: Writing—review & editing, Investigation, Resources; H.M.: Resources, Project administration; J.W.: Methodology, Data curation; T.Z.: Writing—review and editing; J.Z.: Supervision, Conceptualization; Y.W.: Formal Analysis; S.P.: Writing—review and editing, Supervision, Resources; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: Manxuan Xiao and Haipeng Ma were employed by Tongzhou International Engineering Management Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A

Survey results tables, in which the 'Value' equal to (number of answers) × (standard grade), the 'Final value' equal to (Total value)/(Total number of answers)

(1) Comfortable sensation

Comfortable Sensation	Standard Grade	Number of Answers	Value
very uncomfortable (−2)	−2	7	(14.00)
uncomfortable (−1)	−1	25	(25.00)
neutral (0)	0	62	0.00
comfortable (+1)	+1	39	39.00
very comfortable (+2)	+2	14	28.00
Total		147	28.00
Final value			**0.19**

(2) Thermal sensation vote (TSV)

Thermal Sensation Vote (TSV)	Standard Grade	Number of Answers	Value
cold (−3)	−3	0	0.00
cool (−2)	−2	1	(2.00)
slightly cool (−1)	−1	5	(5.00)
neutral (0)	0	101	0.00
slightly warm (+1)	+1	35	35.00
warm (+2)	+2	4	8.00
hot (+3)	+3	1	3.00
Total		147	39.00
Final value			**0.27**

(3) The perception of indoor humidity

Perception of Humidity	Standard Grade	Number of Answers	Value
humid (−2)	−2	3	(6.00)
slightly humid (−1)	−1	11	(11.00)
neutral (0)	0	110	0.00
slightly dry (+ 1)	+1	22	22.00
dry (+2)	+2	1	2.00
Total		147	7.00
Final value			**0.05**

(4) The perception of indoor air quality

Perception of Air Quality	Standard Grade	Number of Answers	Value
low quality (−2)	−2	9	(18.00)
relatively bad (−1)	−1	21	(21.00)
neutral (0)	0	48	0.00
relatively good (+1)	+1	48	48.00
high quality (+2)	+2	21	42.00
Total		147	51.00
Final value			**0.35**

(5) The perception of indoor air circulation

Perception of Air Circulation	Standard Grade	Number of Answers	Value
stuff (−2)	−2	8	(16.00)
slightly stuff (−1)	−1	27	(27.00)
neutral (0)	0	48	0.00
relatively good (+1)	+1	44	44.00
good air circulation (+2)	+2	20	40.00
Total		147	41.00
Final value			**0.28**

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