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Subjective and Objective Evaluation of Shading on Thermal, Visual, and Acoustic Properties of Indoor Environments

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Abstract: Through objective measurement, subjective measurement, and prioritization methods, this study evaluates the impacts of different shading facilities on the indoor environment of multi-story residential buildings, such as dormitories. The objective measurements mainly include the operative temperature, daylight factor, and sound pressure level. The subjective measurement is obtained from occupant votes regarding their satisfaction with the thermal uniformity, natural lighting, external noise, and the overall indoor environment. The results show that the subjective evaluations were significantly more reliable than the objective measurements for predicting indoor environmental satisfaction. The prioritization method of the ordered logistic regression was then used to evaluate the impact of perceived indoor environmental quality on overall satisfaction. The results show that the impact of the perceived indoor environmental quality on overall satisfaction varied with the shading facilities. In addition, the occupants commented on the function of items affecting their application preferences and provided recommendations for improving balconies and sunshades to provide occupants with better indoor environments.

Keywords: indoor environmental quality; occupant satisfaction; occupant surveys; shading

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1. Introduction

The increasingly prominent carbon emission-related problems have attracted progressively more attention to energy saving [1]. The shading of buildings has become a more significant consideration in China's hot summer and cold winter areas, together with occupants' increasing awareness of energy saving. The practice of building shading can effectively reduce direct sunlight in the summer and, therefore, the air conditioning cooling load [2–4], which plays a crucial role with respect to energy saving in buildings. The application of building shading is relatively common in new buildings. However, there are existing buildings that have not considered shading. Based on long-term practices, the different shading facilities have been applied in a manner that is dependent on the situation. The results of several investigations have truthfully reflected the current building-shading situation in Changsha. It was shown that even though the existing shading facilities are simple and low-cost, their use has still not been widely popularized. More importantly, the shading facilities have many other functions; sometimes, the shade function is not prioritized. In brief, there is still a large space for development with respect to building shading in Changsha.

Why do we need to evaluate the effects of different shading facilities on indoor environmental conditions? The window is a communication medium between humans and nature, and the shading facilities affect the indoor environment as the window's affiliate. Different shading facilities are usually applied in a manner dependent on the situation. How do different shading facilities affect the indoor environment? Xue et al. [5] conducted a questionnaire survey on the effect of balconies and sunshades on visual comfort for housing units to protect and improve the indoor environment. According to the World Health Organization, occupants' satisfaction and health are affected by many environmental factors, including indoor thermal, visual, and acoustic properties, as well as air quality [6,7]. However, not all environmental factors are equally important to an occupants' overall satisfaction. To meet the comfort requirements of the occupant, researchers typically analyze the top eight or more comfort factors [8–10]. For example, air-conditioned residential buildings are less affected by static, chemical, and microbial problems.

The shading facilities, associated with the presence of windows, affect the indoor thermal, visual, and acoustic conditions, as windows are not only the main pathway for solar radiation and natural light but the weak link for the sound insulation of buildings [11–13]. The current control temperature is often set at 18 °C in the winter and 26 °C in the summer for simplified design in HVAC systems [14]. Alone, this method of regulating indoor air temperature sometimes fails to meet human thermal comfort requirements [15,16]. The radiant asymmetry caused by solar radiation is largely regarded as the main cause of local discomfort in indoor environments [17]. A relevant study showed that the main parameters affecting indoor visual comfort include glare, the view, daylighting, illumination, uniformity, and privacy [18]. The literature summarizes visual comfort's composition and evaluation processes for building environmental performance evaluation tools and methods, especially investigating the parameters used in visual comfort evaluation tools (BREEAM, LEED, SBTool, and CASBEE) [19]. Strong noises have adverse effects on occupants' physiology and psychology. In daily work and living environments, noise can interfere with conversation, thinking, rest, sleep, and can even cause hearing loss. Occupants are mainly affected by external noise, as evidenced in Lai et al.'s [20] report that occupants are mainly disturbed by external noise compared to indoor noise.

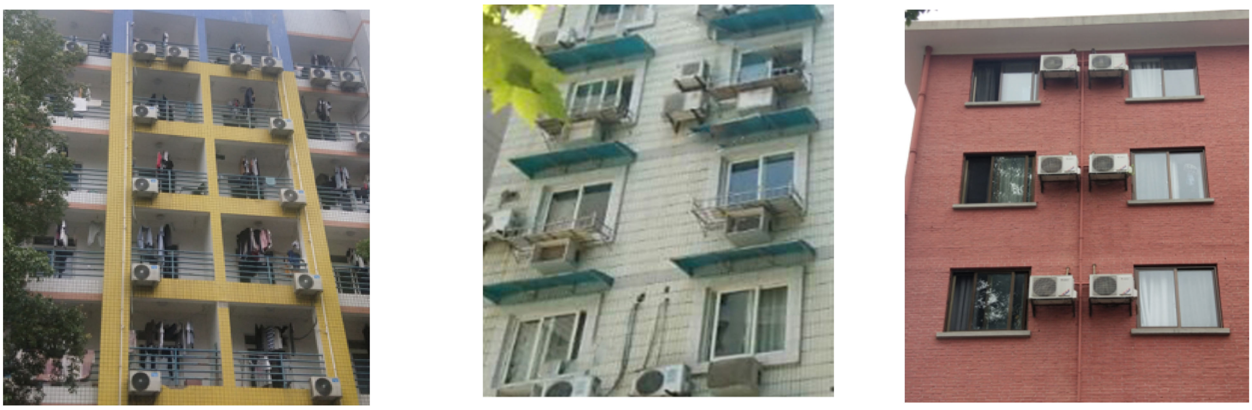
When identifying how satisfaction with different aspects of the indoor environment contributes to occupants' overall satisfaction, prioritization methods such as ordered logistic regression are used. Why is it important to prioritize the indoor environment? It is because this way, environmental problems that reduce occupants' overall indoor satisfaction can be identified. Once problems are recognized, architects can concentrate on exploring ways to optimize the design in the future or even make minor modifications to solve specific problems. It is also a way to assess the effect of a building's performance with respect to the satisfaction of its occupants. However, little is known about how occupants rank the effect of the perceived indoor environmental quality on overall satisfaction when a building adopts different shading facilities. This study compares the relative importance of the effect of the indoor physical environment on overall satisfaction when different shading facilities are applied to multi-story dormitories.

The dormitories with and without common sunshade facilities (one with sunshades, one with balconies, and one without shading facilities) were selected from a Changsha university. The environmental parameters of the operative temperature, daylight factor, and sound pressure levels were measured correspondingly. The occupants' satisfaction with the thermal uniformity, natural lighting, and the external noise level were also evaluated. In the end, the prioritization methods indicate the contribution of different indoor environmental perceptions to occupants' overall satisfaction. In addition, the occupants' comments and suggestions regarding the application of shading facilities were investigated by a questionnaire to provide a reference for the optimization design.

2. Method

2.1. Research Buildings

The research buildings were three typical multi-story dormitories selected from a college in Changsha (i.e., 28°11′49″ N, 112°58′ 42″ E) according to the shading facilities, named D1 (balcony-shading facility), D2 (sunshade), and D3 (none), respectively, as shown in Figure 1. The characteristics of the research buildings are summarized in Table 1. The layouts were either a straight or folded line of dormitories with a large building density, and most of the rooms were arranged in the south and north directions, with only a few in the east and west directions. Additionally, the spatial layout of the rooms was hotel-style. For each dormitory, three rooms in different positions on the lower, middle, and upper floors with the same orientation were selected for measurement in a given week. Then, three rooms in different positions with other orientations were measured in succession.



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

Figure 1. The multi-story dormitories under study: (**a**) D1; (**b**) D2; (**c**) D3.

Table 1. Building characteristics inventory.

Building under Study	**D1**	**D2**	**D3**
Field measurement duration	2–16 July (2 Weeks)	17 July–7 August (3 Weeks)	8–29 August (3 Weeks)
Air-conditioning type	split air conditioning	split air conditioning	split air conditioning
Shading facilities	Balcony (RC structure)	Sunshade (PVC)	None
Shading facilities dimension	1.5 m×5.2 m	1 m×3 m	0
Shading Ratio	0.95	0.6; 0.7 (top floor)	0; 0.6 (top floor)
Room Orientation	North & South	West, North & South	East, North & South
Room Dimension	5.2 (w) × 7.5 (l) × 3 (h)	5 (w) × 7.2 (l) × 3 (h)	5.5 (w) × 6.5 (l) × 3 (h)
Room volume	117 m^3	108 m^3	108 m^3
Floor Area	39 m^2	36 m^2	36 m^2
Floor Level	5	5	3
Occupant per-room	Max.4	Max.4	Max.4
Window-to-Wall Ratio	0.6	0.45	0.3
Distance from highway	20 m (from the window)	70 m (from the window)	40 m (from the window)
Floor Reflectance factor	0.6 (Homogenous tiles)	0.6 (Homogenous tiles)	0.6 (Homogenous tiles)
Wall Reflectance factor	0.7 (white paint)	0.7 (beige paint)	0.7 (white paint)
Ceiling Reflectance factor	0.7 (white paint)	0.7 (beige paint)	0.7 (white paint)

2.2. Measured Environmental Parameters

The weather conditions during the experiment from 2 July to 29 August were observed and recorded with information from Changsha weather stations, including temperature, relative humidity, rainfall, and cloud cover. The recorded average minimum temperature was 28 °C, and the average maximum temperature was 35 °C. The average relative humidity was more than 80%. This area is frequently cloudy and rainy, and the average monthly rainfall recorded was 130.2 mm. The thermal, visual, and acoustic environmental parameters of relative importance were measured. Detailed information on the instruments is shown in Table 2. Thermal environmental parameters were measured, including air temperature, relative humidity, air velocity, and operative temperature. The air conditioning remained on, and the windows remained closed during the measurement. Multiple sensors were installed at a distance of 2.0 m from the windows shielded from direct sunlight, and the on-site measurement is shown in Figure 2. The data logger was set to take average readings at intervals of 10 min, so it obtained six readings in one hour.

Table 2. Instruments for physical measurement.

Physical Parameters	Instruments	Accuracy
Air temperature		±0.15 °C
Relative humidity	HD32.3TC thermal comfort data logger	±2%
Operative temperature		±0.15 °C
Air velocity	VELOCICALC-8347 air velocity meter	±3%
Illumination	UT382 lux meter	±(3.0% + 8)
Sound pressure level	UT352 sound pressure level meter	±1.5 dB

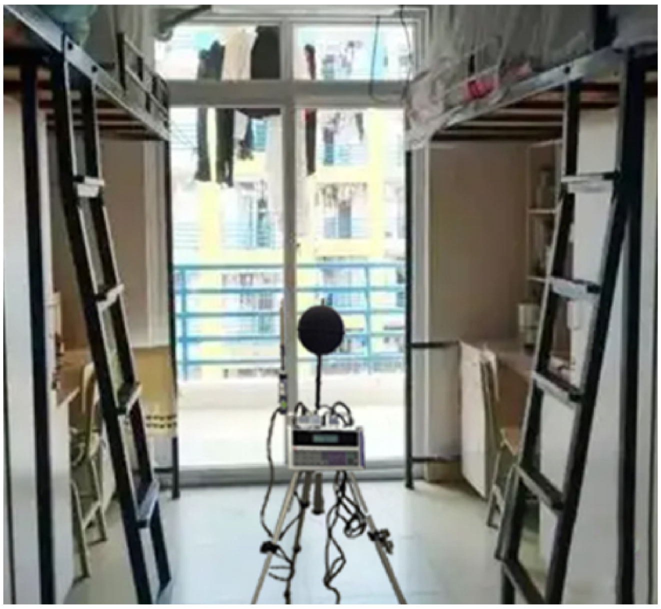


Figure 2. Field measurement for the indoor thermal environment.

The visual environmental parameter of the daylight factor was investigated. Two UT382 lux meters were used for outdoor and indoor measurements, respectively. The indoor lux meter was installed on a tripod at a distance of 2.0 m from the window and at a height of 0.75 m above the ground, and the curtain was opened to ensure full exposure of the window. A fisheye image was taken in an upward direction at a certain point in the room. At the same time, the outdoor lux meter was installed on a tripod at 1.5 m above the ground in the center of the space near the studied dormitory. In addition, the lux meters took data readings six times an hour, with a 15 min interval between the rooms with different heights.

The acoustic environmental parameter of sound pressure level (SPL) was measured. Sound pressure level refers to the logarithmic measure of effective sound pressure relative to a base value, using decibels (dB) to describe its relationship with the base value. The UT352 dB sound pressure level meter used in this investigation was installed 0.8 m above the ground. Its wind-proof capacitive microphone was pointed outdoors through a window. The measured SPL is expressed as L_{Aeq}, defined as the single SPL with a constant value duration of the measurement, i.e., over an hour, and the completion of a one-hour measurement is indicated by placing it in brackets, e.g., $L_{Aeq(1)}$. Similar to the measurement of the light environment, the measurement of the room's sound pressure level lasted for 1 h continuously, with a 15 min interval between the rooms with different levels. The sound pressure level was recorded from 8:00 to 18:00 (10 h) for three consecutive days. The external noise was assumed to be transmitted mainly from the road near the building.

2.3. Survey Development and Testing

The occupants' perceptions of the indoor environment with different shading facilities were collected by questionnaire. Thirty-five respondents were randomly selected for the originally designed questionnaire to conduct a predictive test. The subjects were asked to provide feedback on different aspects of the questions, such as each item's clarity, necessity, and rationality. We revised several questions based on the preliminary statistical analysis of survey results to make them more reasonable.

Only female students were surveyed. Male students were prohibited from entering female students' dormitories by the school rules. The students' age, height, weight, educational background, duration of stay, activities, and daily attire were investigated. This provided four age group options in the questionnaire, namely, 20 and under, 21–30, 31–40, and 41 years of age and above; two education background options, namely, undergraduate and postgraduate; and four stay duration options, i.e., less than one year, one year, two years, and three years and above. The Clo value ranged from 0.2 to 1.0 with respect to scores for occupants to choose from, calculated based on ISO7730 [21]. In addition, the occupants in the room were most likely to be sedentary. Occupants' perceptions of indoor thermal, visual, and acoustic parameters in the environment were evaluated based on three periods of daytime, namely, morning (8:00–11:59), afternoon (12:00–14:59), and evening (15:00–17:59). The specific questions are listed as follows, and the sensation scale is shown in the brackets behind the questions:

(1) How satisfied are you with the thermal uniformity? (Very satisfied: 1, very dissatisfied: 5)
(2) How satisfied are you with the natural lighting? (Very satisfied: 1, very dissatisfied: 5)
(3) How satisfied are you with the external noise level? (Very satisfied: 1, very dissatisfied: 5)

The question about occupants' overall satisfaction, tested through two groups of affected factors, was as follows:

(4) What is your overall indoor satisfaction with your room? (Very satisfied: 1, very dissatisfied: 5)

The occupants' overall satisfaction was tested through two building characteristics and indoor environment groups. The first group of factors include shade ratio, floor level, window–wall ratio, and room dimensions. The second group of factors refers to the occupants' satisfaction with the indoor thermal, visual, and acoustic environment.

The level of privacy protection of the student occupants could be examined through the use of curtains. The question for this purpose is as follows:

(5) Do you close the window curtains during the daytime? (Always: 1, never: 5)

The occupants' comments and suggestions regarding the application of shading facilities were investigated to provide a reference for the design optimization. The question for this purpose is as follows:

(6) How do you rate the following function of the balcony/sunshade? (Not important: 1, important: 5).

Functions: (1) Shade; (2) Block rain; (3) Close to nature; (4) Natural ventilation; (5) Provide privacy; (6) Beautify building; (7) Drying area.

2.4. Data Analysis

The data were analyzed using two statistical methods by SPSS version 19.0 (IBM, Armonk, NY, USA): repeated measure analysis of variance (ANOVA) with a two-tailed significance test and the Ordered Logistic Regression Model. Each statistical analysis method is introduced in detail under their respective subtitles.

2.4.1. ANOVA Repeated Measures

ANOVA is a hypothesis-testing method used to test for significant differences between the means of observational variables in two or more samples. The basic idea of ANOVA is to identify the influence of the control factor on testing results by analyzing the contribution of multiple factors' variation to total variation. Repeated measures ANOVA refers to the measurement of the same sample at different periods and is used to analyze the change characteristics of the observational variable at different periods. In scientific research, it is necessary not only to know whether a factor has a statistically significant effect but also to observe the size of the effect. Effect size is an indicator to measure the size of the difference caused by the factor. Unlike significance tests, the indicator is not affected by sample size. It represents the size difference between the sample means and can be compared between different studies. The effect size is also known as partial eta-squared. The partial eta-squared rather than the complete eta-squared is applied mainly to process the value with respect to the proportion of 0 to 1 for analysis. The partial eta-squared is also denoted as η_p^2, and its detailed calculation is shown in Equation (1).

$$\eta_{\mathrm{p}}^2 = SS_{treatment} / (SS_{treatment} + SS_{error}) \quad (1)$$

In the Equation, *SS treatment* is the variance of the control factor. *SS error* is the variance of the random factor. The general classification criteria for η_p^2 values are shown in Table 3 [22].

Table 3. Classification of effect size.

Partial Eta-Squared (η_p^2)	Size of Effect
$0.01 \leq \eta_p^2 \leq 0.06$	Small
$0.06 \leq \eta_p^2 \leq 0.14$	Medium
$\eta_p^2 \geq 0.14$	Large

2.4.2. Ordinal Logistic Regression

The prioritization method of ordered logistic regression is then used to evaluate the impact of perceived indoor environmental quality on overall satisfaction. Identifying the importance of the perception of the indoor environment to the occupant and combining them to produce overall satisfaction has proved to be a complex and difficult task [23]. The extensions of the current work should include a detailed analysis of the effect of various building design schemes on the occupants. Ordered logistic regression was chosen due to the characteristics of the data, that is, since the variables are ordered category data. Its purpose is to determine how satisfaction with different aspects of the indoor environment contributes to occupants' overall satisfaction. The occupants' satisfaction evaluation is based on a five-point ordinal scale from "very satisfied" (1) to "very dissatisfied" (5) [24]. Overall satisfaction is a five-level dependent variable, namely, ordinal category data. The traditional regression models cannot fit such a dependent variable but ordered logistic regression can solve this problem.

Based on the general expression of the ordinal logistic regression model, this research evaluates the importance of perceived indoor thermal, visual, and acoustic environmental quality to overall satisfaction with respect to different shading facilities and ranks these environmental conditions by odds ratio to show which should be given priority when attempting to optimize shading facilities. This paper proposes the occupants' perception mechanism of the indoor environment based on the relevant theory. Ordinal logistic regression can efficiently process ordinal category data and express the relationship between independent variables (e.g., thermal uniformity satisfaction) and dependent variables (e.g., overall indoor environmental satisfaction). According to the above literature research, the shading facilities' association with windows would also affect the indoor thermal, visual, and acoustic conditions. To further understand how satisfaction with the above aspects of the indoor environment impacts occupants' overall satisfaction with different shading facilities, the model employed is expressed as Equation (2):

$$\begin{aligned} Overall\ satisfaction\ &= \alpha_1(Thermal\ uniformity) \\ &+\alpha_2(Natural\ lighting) \\ &+\alpha_3(Outdoor\ noise) \end{aligned} \quad (2)$$

The study results are reported as odds ratio -α values and interpreted as the likelihood of a change in overall satisfaction if the predictor variable changes by one unit. In contrast, the other variables remain unchanged [25]. Odds ratios can also be used to rank the effects of the predictor variables on overall satisfaction [26]. In the model, the odds ratio is used to judge the influence of different independent variables on the dependent variable (overall satisfaction).

In the first stage, the model is applied to all questionnaire data. The main model aims to test whether multiple aspects of the thermal, visual, and acoustic conditions related to the shading facilities significantly impact the overall satisfaction of the occupants. Odds ratios rank the impact of predictor variables on the response variable.

In the second stage, the model is applied to different subgroups. As mentioned above, the paper mainly studies how occupants' satisfaction with different aspects of the indoor environment contributes to occupants' overall satisfaction with different shading facilities, creating subgroups based on the type of shading facility, namely, a balcony, sunshade, or a lack thereof. Odds ratios rank the impact of predictor variables on the response variable. The order is compared with the results of the main model.

The likelihood ratio test is required to evaluate the overall model to test whether the model performs better than an intercept-only model. The significance of the test results and the significance of individual predictor variables in the model are measured by calculating p-values. Analysis shows a rejection of the null hypothesis ($p = 0.000 < 0.05$). In the model, at least one of the independent variables is a significant correlation with the dependent variable, and the model fits well. In the test of parallel lines, the significance is greater than the test criterion ($p = 1.000 > 0.05$), which indicates that the ordered regression model can solve it, and the regression results are meaningful upon interpretation.

3. Result

3.1. Environmental Parameters

3.1.1. Operative Temperature Measurement

The operative temperatures in D1, D2, and D3 during three different periods were measured. The mean values, the standard deviations, and the ANOVA repeated measures results of the operative temperature are listed in Table 4. All the mean operative temperatures show a significant difference at $p < 0.01$ level with a large size effect ($\eta_p^2 > 0.14$). Based on each period (column of Table 4), The mean operative temperature differences among the three periods gradually increase from morning to night in D1, D2, and D3. This tendency suggests that the operative temperatures in all three dormitories were similar in the morning but gradually diverged as the day continued. However, it is worth noting that a lesser difference was not shown in the evening, as a relatively high mean operative temperature was measured in D3.

Table 4. ANOVA repeated measures of operative temperature during the different daytime periods in three buildings.

Building	**Mean Operative Temperature (C) for Different Periods**			
	Morning (8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1	25.8 (s.d = ±0.8)	26.7 (s.d = ±0.9)	26.2 (s.d = ±0.8)	0.24 ($p < 0.01$)
D2	26.4 (s.d = ±1.0)	27.5 (s.d = ±0.8)	26.9 (s.d = ±1.0)	0.26 ($p < 0.01$)
D3	26.7 (s.d = ±0.8)	28.1 (s.d = ±1.0)	28.7 (s.d = ±0.9)	0.64 ($p < 0.01$)
η_p^2 according to periods	0.23 ($p < 0.01$)	0.38 ($p < 0.01$)	0.63 ($p < 0.01$)	

Based on each study dormitory (row of Table 4), D3 rooms show the largest mean operative temperature difference in the three periods, followed by D2 and D1 rooms. D1 and D2 rooms show a lesser mean operative temperature difference among the three periods than D3 rooms, probably because the shading facilities of balconies and sunshades could effectively control indoor operative temperature fluctuations passively compared to no shading facilities. This suggests that the operative temperature in D3 was likely to rise in the evening, while the operative temperature in D1 and D2 tended to be more constant during the daytime. However, there is no significant difference in the mean operative temperatures for all 24 measured rooms, regardless of shade or its absence. In addition, orientation has almost no influence on the mean operative temperature.

3.1.2. Daylight Factor Measurement

The daylight factor (DF) of the room was calculated according to Equation (3):

$$\mathrm{DF} = \mathrm{En}/\mathrm{Ew} * 100\% \tag{3}$$

The daylight factor (DF), the most widely used index, is a static indicator of daylight performance. It defines the ratio of interior illuminance (En) on a horizontal surface to the exterior illuminance (Ew) under an overcast CIE sky. The larger the daylighting factor, the better the indoor daylighting effect [27]. Table 5 shows the mean daylight factor in D1, D2, and D3 during the three periods. For each period (column in Table 5), the mean daylight factor in D1, D2, and D3 show significant differences at the $p < 0.01$ level with a large size effect ($\eta_p^2 > 0.14$). The mean daylight factor difference among D1, D2, and D3 is largest in the morning, and the difference becomes smaller with the external illumination lessening in the evening. D1 rooms show the minimum daylight factor compared with D2 and D3 in the three periods (but the daylight factor still meets the needs). The daylight factors of most of the measured rooms met the minimum daylight factor provided by the code [28], i.e., more than 0.5% of the multi-purpose rooms. However, those rooms facing west in D2 were too bright, and the daylight factor was even more than 2% greater than that of the D3 rooms, which were unshaded.

Table 5. ANOVA repeated measures of daylight factor during the different daytime periods in three buildings.

Building	**Mean Daylight Factor (%) for Different Periods**			
	Morning (8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1	1.2 (s.d = ±0.8)	0.9 (s.d = ±0.6)	1.5 (s.d = ±1.0)	0.12 ($p < 0.01$)
D2	2.0 (s.d = ±1.3)	2.2 (s.d = ±1.6)	4.1 (s.d = ±3.2)	0.09 ($p < 0.01$)
D3	2.1 (s.d = ±1.8)	2.9 (s.d = ±2.1)	3.5 (s.d = ±1.2)	0.06 ($p < 0.01$)
η_p^2 according to periods	0.27 ($p < 0.01$)	0.24 ($p < 0.01$)	0.21 ($p < 0.01$)	

In each study dormitory (rows in Table 5), the difference in the mean daylight factor during the three periods with a medium size effect was detected in D1 and D2 ($\eta_p^2 < 0.14$), while an even smaller size effect was observed in D3 ($\eta_p^2 < 0.06$). This indicates that the mean daylight factor differs significantly in the three periods for each dormitory. Still, the variations in the daylight factor are small, and the daylight factor is greater in the evening due to the reduction in the dividend in Equation (2) (i.e., external illumination). Thus, it is proved to some extent that although the variations were observed during the three periods, the differences in the daylight factor may also be influenced by the shading ratio, window–wall ratio, and internal surface reflection factor.

3.1.3. Sound Pressure Level Measurement

The mean noise equivalent in D1, D2, and D3 during the three periods are recorded in Table 6. All of the mean sound pressure levels show significant differences. Based on each period (column of Table 6), the results show that the sound pressure levels increase from D1 to D3 and D2. Compared to D3, prominently disturbed by the road's noise, the D1 rooms—designed with balconies that provide noise shielding—can effectively reduce the noise disturbance from the road. While D2 was farthest from the road, which may indicate that external noise was mainly caused by the rainwater or condensation water dripping on the sunshade. However, based on each study dormitory (row of Table 6), there are small noise level variations throughout the day in D1, D2, and D3.

Table 6. ANOVA repeated measures of noise equivalents in one hour, $L_{Aeq(1)}$, during the different daytime periods in three buildings.

Building	$L_{Aeq(1)}$ for Different Periods			
	Morning (8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1	50.3 (s.d = ±5.2)	49.4 (s.d = ±5.8)	49.5 (s.d = ±4.6)	0.03 ($p < 0.05$)
D2	58.5 (s.d = ±5.7)	58.8 (s.d = ±5.8)	59.4 (s.d = ±5.2)	0.09 ($p < 0.01$)
D3	52.1 (s.d = ±4.8)	52.5 (s.d = ±4.9)	53.9 (s.d = ±5.6)	0.10 ($p < 0.01$)
η_p^2 according to periods	0.39 ($p < 0.01$)	0.43 ($p < 0.01$)	0.49 ($p < 0.01$)	

3.2. Subjective Measurement

3.2.1. Thermal, Visual, and Acoustic Environment Satisfaction Vote

Two hundred seventy-four female graduate students from three typical multi-story dormitories participated in the questionnaire survey. A total of 90% of the occupants surveyed were aged between 21 and 25. The occupants' height and weight (average ± standard deviation) were 162.0 ± 5.6 cm and 57.6 ± 6.4 kg, respectively. In addition, the mean Clo value was 0.4, indicating that the daily attire of student occupants indoors was short sleeves/underwear and apron/shorts. The heat production rate for student occupants was estimated to change from 60 W (i.e., while sleeping) to 140 W (i.e., while sitting or studying) [29].

Table 7 shows the thermal uniformity satisfaction mean votes during the three periods, i.e., in the morning (8:00–11:59), afternoon (12:00–14:59), and evening (15:00–17:59). Occupants' votes usually fall in between 'satisfied' and 'neutral' regarding the thermal uniformity of the rooms. Based on each period (column of Table 7), the votes in D1, D2, and D3 show significant differences at the $p < 0.01$ level with medium size effects ($\eta_p^2 < 0.14$) during each period. Among the three dormitories, D1 and D2 occupants were considered to have a higher satisfaction regarding thermal uniformity during the three periods, for the balconies/sunshade can effectively prevent solar radiation from entering the room.

Table 7. Occupants' thermal uniformity satisfaction votes during the different periods in three buildings, from Very satisfied (1) to Very dissatisfied (5).

Building	Mean Thermal Uniformity Satisfaction Votes for Different Periods			
	Morning (8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1 ($n = 82$)	1.6 (s.d = ±1.0)	2.5 (s.d = ±1.1)	2.1 (s.d = ±1.0)	0.20 ($p < 0.01$)
D2 ($n = 86$)	1.8 (s.d = ±1.1)	2.8 (s.d = ±1.1)	2.4 (s.d = ±1.2)	0.21 ($p < 0.01$)
D3 ($n = 106$)	2.2 (s.d = ±1.2)	2.9 (s.d = ±1.2)	3.1 (s.d = ±1.3)	0.24 ($p < 0.01$)
η_p^2 according to periods	0.09 ($p < 0.01$)	0.08 ($p < 0.01$)	0.11 ($p < 0.01$)	

Based on each study dormitory (row of Table 7), the thermal uniformity satisfaction votes show significant differences at the $p < 0.01$ level in the three periods, with large size effects ($\eta_p^2 > 0.14$). This can indicate that the occupants perceived the thermal uniformity to be in line with the objective measurements in the morning, afternoon, and evening. The objective measurements showed a basic rise in the operative temperature of about

1.0 °C from morning to afternoon in D1, D2, and D3. However, the change in operative temperatures from afternoon to evening differed in the three dormitories: it decreased by about 0.6 °C in D1 and D2 and increased by 0.6 °C in D3. Therefore, this tendency indicates that the occupants were slightly more satisfied with the thermal uniformity under shaded conditions.

The natural lighting satisfaction vote collected from the occupants in the three dormitories is shown in Table 8. D1 rooms had a larger window–wall ratio with balconies so that the uniformity would be improved compared to the D2 and D3 rooms. The occupants tended to be more satisfied with the natural lighting conditions. Based on each period (column of Table 8), the natural lighting satisfaction mean votes in D1, D2, and D3 only show a significant difference at the $p < 0.01$ level in the afternoon, indicating that the occupants were more susceptible to glare in the afternoon than in the morning and evening. This was because large amounts of sunlight (as observed in D3) usually appear on the rooms' floors in the afternoon, causing glare and nonuniformity. In contrast, D1 and D2 occupants were more satisfied with the natural lighting conditions, with the balcony/sunshade providing shade from the bright sunlight.

Table 8. Occupants' natural lighting satisfaction votes during the different periods in three buildings, from Very satisfied (1) to Very dissatisfied (5).

Building	**Mean Natural Lighting Satisfaction Votes for Different Periods**			
	(8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1 (n = 82)	2.3 (s.d = ±1.5)	1.8 (s.d = ±1.4)	2.4 (s.d = ±1.3)	0.09 ($p < 0.01$)
D2 (n = 86)	2.6 (s.d = ±1.6)	1.9 (s.d = ±1.1)	2.7 (s.d = ±1.4)	0.11 ($p < 0.01$)
D3 (n = 106)	2.6 (s.d = ±1.5)	2.3 (s.d = ±1.2)	2.8 (s.d = ±1.6)	0.10 ($p < 0.01$)
η_p^2 according to periods	0.01 (n.s)	0.05 ($p < 0.01$)	0.01 (n.s)	

Based on each study dormitory (rows in Table 8), the occupants voted to reveal their satisfaction with the natural lighting conditions from morning to evening. The results show similar degrees of natural lighting satisfaction for morning and evening regardless of the dormitory, which usually falls between the points 'satisfied' and 'neutral.' In the afternoon, especially in D1 and D2, the occupants felt more satisfied with the natural lighting conditions than in other periods, for the rooms were not only effective in daylighting but also in uniformity.

Table 9 shows the external noise satisfaction votes collected from the occupants of the three dormitories with respect to the morning (8:00–11:59 am), afternoon (12:00–14:59), and evening (15:00–17:59). Based on each period (column of Table 9), the difference in the external noise satisfaction mean votes in D1, D2, and D3 had a large size effect ($\eta_p^2 > 0.14$). Compared to D3, prominently disturbed by the noise from the road, D1 occupants tended to feel more satisfied with the external noise level due to the screening effect of the balconies from external noise, which was mainly from the road. While D2's external noise was mainly caused by the rainwater or condensate water dripping on the sunshade, D2 occupants tended to feel that the external noise level was 'neutral'.

Based on each study dormitory (row of Table 9), there is no significant difference in the degree of external noise satisfaction during the three periods in D1, while there is a significant difference in external noise satisfaction during the three periods with a small size effect ($\eta_p^2 < 0.06$) in D2 and D3, indicating that the external noise satisfaction mean votes nearly the same throughout the day. From this finding, it can be assumed that the occupants were acclimated to the current noisy environment of the dormitories and thus felt that the rooms were neither quiet nor noisy during the day, although the records showed changes in noise levels.

Table 9. Occupants' external noise satisfaction votes in the different periods in three buildings, from Very satisfied (1) to Very dissatisfied (5).

Building	Mean External Noise Satisfaction Votes for Different Periods			
	Morning (8:00–11:59)	**Afternoon (12:00–14:59)**	**Evening (15:00–17:59)**	η_p^2 According to Dormitories
D1 (n = 82)	1.9 (s.d = ±1.7)	2.0 (s.d = ±1.5)	1.9 (s.d = ±1.6)	0.00 (n.s)
D2 (n = 86)	3.1 (s.d = ±1.8)	3.2 (s.d = ±1.6)	2.9 (s.d = ±1.5)	0.06 ($p < 0.01$)
D3 (n = 106)	2.5 (s.d = ±1.7)	2.7 (s.d = ±1.5)	2.4 (s.d = ±1.7)	0.05 ($p < 0.01$)
η_p^2 according to periods	0.26 ($p < 0.01$)	0.27 ($p < 0.01$)	0.25 ($p < 0.01$)	

3.2.2. Occupants' Overall Indoor Environment Satisfaction Votes

Table 10 provides the mean votes of the overall indoor environmental satisfaction. The occupants' votes are close to 'satisfied' in D1 (scoring: 2) and close to 'neutral' in D2 and D3 (scoring: 3). Combined with the subjective survey results of the three dormitories in terms of the thermal, visual, and acoustic environment, it can be seen that D1 occupants were considered to have the highest satisfaction with thermal uniformity in the three periods during the daytime due to the shading effect of the balconies. The rooms had a larger window–wall ratio with balconies in D1, so the occupants were more satisfied with the natural lighting conditions. Moreover, balconies can provide a screening effect on noise, which indicates that the popularity of balconies can improve the overall satisfaction of the indoor environment to a certain extent.

Table 10. Summary of the vote for overall indoor environmental satisfaction using ANOVA repeated measures, from Very satisfied (1) to Very dissatisfied (5).

	Mean Vote			η_p^2
	D1 (n = 80)	**D2 (n = 80)**	**D3 (n = 80)**	
Overall indoor environment satisfaction	1.9 (s.d = ±1.7)	2.7 (s.d = ±1.8)	2.8 (s.d = ±1.7)	0.25 ($p < 0.01$)

3.2.3. The Impact of Perceived Indoor Environmental Quality on Overall Satisfaction

This section contributes to the discussion on how satisfaction with different aspects of the indoor environment contributes to occupants' overall satisfaction. The three satisfaction factors of thermal uniformity, natural lighting, and external noise level satisfaction are independent variables. In contrast, the overall indoor environmental satisfaction is the dependent variable for the ordered logistic regression analysis, and the Probit connection function is used for its study. The analysis results show that the McFadden R^2 of the model is 0.345, indicating that thermal uniformity, natural lighting, and external noise level could explain 34.5% of the variation in overall satisfaction. Although the perceived indoor environmental quality related to shading facilities can influence overall satisfaction, other factors still influenced the occupants' satisfaction.

The odds ratio (OR) values are shown in both tables with their respective 95% confidence intervals. It can be seen that thermal uniformity, natural lighting, and noise level significantly positively affect overall satisfaction beyond the $p < 0.001$ level. The final analysis results (see Table 11) show that the odds ratio of thermal uniformity is 2.280, which has the greatest effect on overall satisfaction; should that change, there is a 2.280-fold greater likelihood that the overall satisfaction will change. The odds ratio of the external noise level is 1.912, which means that should the external noise level change, there is a 1.912-fold greater likelihood that the overall satisfaction will change. The odds ratio of natural lighting level is 1.810, which means that should the natural lighting level change, there is a 1.810-fold greater likelihood that the overall satisfaction will change.

Table 11. Satisfaction with IEQ impacts overall satisfaction (Main model).

IEQ	Odds Ratio-α Value	Confidence Intervals (95%)	
Thermal uniformity	2.280 *	1.836	2.833
External noise	1.912 *	1.589	2.300
Natural lighting	1.810 *	1.368	2.393

* $p \leq 0.001$.

The regression model was then applied to separate sub-groups based on the shading facilities to estimate how shading facilities impact occupants' comfort with respect to overall satisfaction. Odds ratios rank the impact of predictor variables on the response variable. The order is compared with the results of the main model. The influences of various environmental factors on the overall satisfaction of the indoor environment for buildings with different shading facilities were tested. The results show that the importance of multiple indoor factors to overall satisfaction varied with the shading facilities (Table 12). The significant factors that influence overall indoor environmental satisfaction have been considered. For D1, the parameter natural lighting has the greatest effect on overall satisfaction with the odds ratio α value of 3.453 (CI (95%) 1.264–9.434); however, thermal uniformity is the parameter by which the occupants are least affected. For D2, the external noise has the greatest effect on overall satisfaction with the odds ratio α value of 2.482 (CI (95%) 1.662–3.705), followed by natural lighting. For D3, thermal uniformity has the highest impact on overall satisfaction with the odds ratio α value of 3.379 (CI (95%) 2.250–5.074); however, external noise is the parameter by which the occupants are least affected.

Table 12. Satisfaction with IEQ impacts overall satisfaction applied to subgroups.

IEQ	Main Model	D1 (Balcony)	D2 (Sunshade)	D3 (None)
Thermal uniformity	2.280 * [1.836–2.833]	2.910 ** [1.354–6.253]	1.441 (*n*) [0.820–2.534]	3.379 * [2.250–5.074]
External noise	1.912 * [1.589–2.300]	3.046 ** [1.490–6.227]	2.482 * [1.662–3.705]	1.720 * [1.293–2.288]
Natural lighting	1.810 * [1.368–2.393]	3.453 *** [1.264–9.434]	1.640 *** [0.920–2.925]	1.805 *** [1.065–3.057]

* $p \leq 0.001$; ** $p \leq 0.01$; *** $p \leq 0.05$; (*n*) $p > 0.05$.

For further study, it should be noted that the impact of the perceived indoor environmental quality on overall satisfaction is different with different shading facilities. The application preferences regarding shading facilities and the functional items affecting the preferences also require study.

3.3. Occupants' Comments and Recommendations Regarding Shading Facilities

This section collects occupants' comments regarding the functional items affecting the application preferences of different shading facilities, thus providing a reference for the optimization design of shading facilities. Seven related functions of the shading facilities sunshades/balconies were organized and graded by the occupants living in the dormitories. Figure 3 shows the result of the evaluation of different functions of the sunshades/balconies. It can be seen that sunshades have a plurality of functions: their primary purpose is to block rain, and the shade function sometimes takes a back seat. The result also suggests that sunshades could be more useful than balconies in providing privacy. As urbanization accelerates, balconies in residential buildings are replacing courtyards and gardens as the ideal private outdoor space close to nature [30]. Moreover, the balconies have advantages with respect to providing shade, enhancing natural ventilation, drying clothes, and beautifying the building.

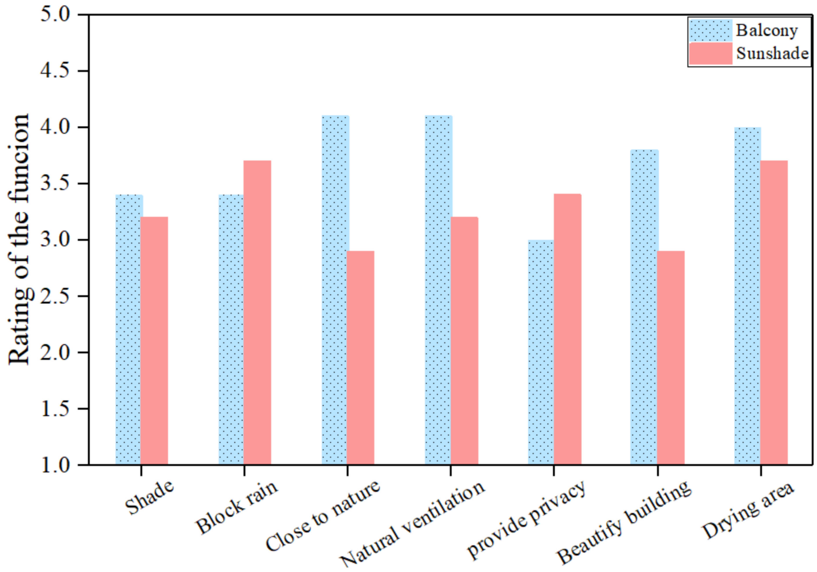


Figure 3. Subjective ratings of occupants concerning the functions of sunshades and balconies. (Not important: 1, to important: 5.)

Balconies have a great integrated advantage in many respects, except for their disadvantage in providing privacy. Privacy protection of the student occupants can be observed through the use of curtains. A descriptive analysis was used to identify the central tendency in the frequency of curtains usage during the daytime. As seen in Figure 4, the trend line on the left of the axis of the balcony is flat, so the occupants living in dormitories with balconies tended to use curtains more often during the daytime. Curtains can not only protect privacy but also reduce glare effects, which provokes the occupants living in dormitories with balconies to use artificial lighting more often, resulting in the daylighting feature becoming less functionally important than expected.

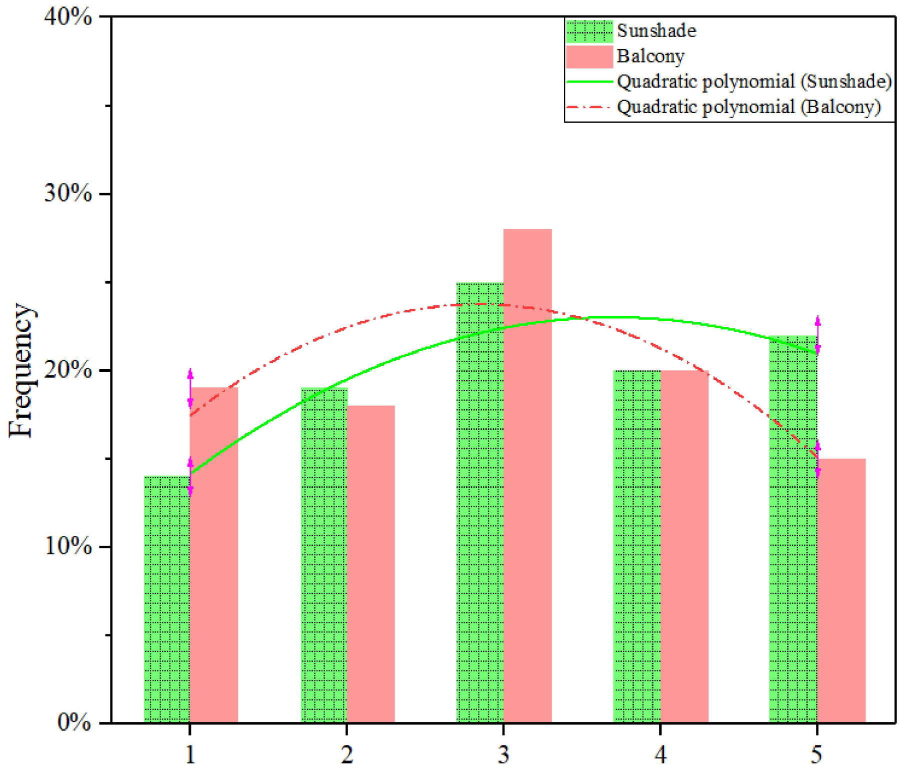


Figure 4. Do you close the window curtains during the daytime? (Always: 1, to never: 5).

All respondents were invited to provide additional recommendations for improving shading facilities in residential buildings. Regarding sunshades, the respondents generally suggested addressing the noise problem by employing ideal materials that can effectively insulate sound. In addition, the survey results show transparent sunshades in certain low levels of rooms that were often blocked by nearby buildings and trees, etc. Transparent sunshades were adopted because they could block rain and provide enough lighting. The respondents proposed that the sunshade's functional design and system control should be more efficient and intelligent. For instance, the sunshade can be tilted upwards when needed so that it does not obscure views and block sunlight to some extent. Furthermore, the transparent sunshade could be better decorated with a curtain inside to provide enough sunlight via automatic adjustment while blocking rain.

The survey shows that some balconies of the lower level rooms should be enclosed due to safety concerns. Likewise, the rooms of the lower levels were often blocked by nearby buildings, trees, etc. As a consequence, the shading function of the balcony became meaningless. So, it is necessary to determine the appropriate floor level above which a balcony should be constructed for a residential building under the shading effect of adjacent buildings. Some occupants believed the buildings were too close to each other, obscuring views and blocking sunlight. In addition, the adjacent buildings sometimes resulted in poor ventilation and uncomfortable reflected glare. In particular, the balconies may cause occupants privacy problems, forcing them to use curtains and artificial lighting more frequently.

4. Discussion and Findings

Through objective and subjective measurements, this paper successfully evaluated the indoor thermal, visual, and acoustic environmental properties with different shading facilities of three dormitories in a college in Changsha. The research site was restricted to a tropical area, and the research result represents the hot weather conditions. In the thermal environment, the air conditioning was kept on and the windows closed during the measurement; the airflow was between 0.02 m/s and 0.03 m/s, and the relative humidity was between 40% and 60%. The occupants felt that the airflow was moderate (neither strong nor weak), and that the indoor humidity was neutral. The data show that airflow and humidity were not the main factors affecting the subjective thermal response. The operative temperature reflects the comprehensive effect of the air temperature and mean radiant temperature. The indoor air temperature was constant at 26 °C when the air conditioner was turned on. The shading facilities of balconies and sunshades could control the indoor operative temperature fluctuations passively compared to those rooms without shading facilities. This phenomenon suggests that the operative temperature in D3 was likely to rise in the evening, while the operative temperature in D1 and D2 tended to be more constant during the daytime.

The D1 rooms show the minimum daylight factor compared with D2 and D3 in three periods (but the daylight factor still meets the needs). The daylight factors of most of the measured rooms met the minimum daylight factor provided by the code, i.e., more than 0.5%. The natural lighting satisfaction mean votes in D1, D2, and D3 only show a significant difference at the $p < 0.01$ level in the afternoon, indicating that the occupants were more susceptible to glare in the afternoon than in the morning and evening. This tendency was because large amounts of sunlight (as observed in D3) usually appear on the rooms' floors in the afternoon, causing glare and nonuniformity. D1 and D2 occupants were more satisfied with the natural lighting conditions as the balcony/sunshade shaded the room from the bright sunlight.

The D2 external noise was mainly caused by rainwater or condensation water dripping on the sunshade. Compared to D3, prominently disturbed by the noise from the road, D1 occupants tended to feel more satisfied with the external noise level due to the screening effect provided by the balconies against external noise, which was mainly from the road. The literature [31,32] also mentioned that the balcony has a positive effect on reducing indoor noise. The survey results show that the occupants had adapted to the current noisy environment of the dormitories and felt that the rooms were neither noisy nor quiet during the day, despite the records showing changes in noise levels.

The prioritization results show that the importance of multiple indoor factors to overall satisfaction varied with the shading facilities. The significant factors that influence overall indoor environmental satisfaction have been considered. For D1, the parameter natural lighting has the greatest effect on overall satisfaction with the odds ratio α value of 3.453 (CI (95%) 1.264–9.434); however, thermal uniformity is the parameter by which the occupants are least affected. For D2, the external noise has the greatest effect on overall satisfaction with the odds ratio α value of 2.482 (CI (95%) 1.662–3.705), followed by natural lighting. For D3, thermal uniformity has the highest impact on overall satisfaction with the odds ratio α value of 3.379 (CI (95%) 2.250–5.074); however, external noise is the parameter by which the occupants are least affected.

From the satisfaction votes of the indoor environment, it can also be inferred that dormitory students have connatural expectations of indoor thermal, visual, and acoustic conditions. It can be detected that the satisfaction votes changed as the daytime periods changed, thus indicating that the external environments, such as that resulting from the shading effect, varied with the daytime, which could affect the occupants' satisfaction to some extent. This result corresponds to the findings from Effting et al. [33]. The occupants hope that the shading facilities could be more efficient and intelligent. The quality of the design and control lie in the ability of the built conditions to adapt to immediate environmental performance requirements, which is a looming challenge for future standardization. Respect for interdependence in human-built environmental systems is essential. This view is also similar to Šujanov et al. [34]. It can be found that nearby buildings, trees, etc., often block rooms on low levels, and a report [35] indicates that increasing buildings' density can reduce the indoor temperature. In addition, correlational studies [36–38] certify that vegetation can significantly regulate microclimates through shading and evapotranspiration processes. The vegetation can cool a building's surface to protect it from surplus radiation and asymmetry, which is very useful for improving the indoor comfort of a building.

5. Conclusions

Through observation, the occupants' satisfaction with the indoor environment has been the reference for evaluating the indoor physical environmental quality with different shading facilities via the perception of thermal, visual, and acoustic environmental attributes. In addition, subjective evaluations can be considered the more reliable basis for the optimal design of shading facilities to create a more comfortable environment. This evaluative method can also be applied to other shading facilities. In addition, the prioritization methods' results show that the impact of the perceived indoor environmental quality on overall satisfaction differs with different shading facilities. The shading facilities have many other functions, and the balconies have a great integrated advantage in many respects except for their disadvantage in providing privacy; the sunshades' primary purpose is to block rain, and the shade function is sometimes relegated. The occupants hope the sunshade's functional design could be more efficient and system control could be more intelligent. As for balconies, they should be considered and constructed with respect to the appropriate floor level above, for the rooms on the lower levels are often blocked by nearby buildings, trees, etc. The application of building shading in Changsha is still at a low level, without standardization and systematization. The survey results may help the government understand the status quo, establish appropriate guidelines, and help researchers and architects improve shading facilities, which could provide occupants with better indoor environments.

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