Linking Occupant Behavior and Window Design through Post-Occupancy Evaluation: Enhancing Natural Ventilation and Indoor Air Quality

Article

Linking Occupant Behavior and Window Design through Post-Occupancy Evaluation: Enhancing Natural Ventilation and Indoor Air Quality

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Abstract: This study investigates how window design features, such as size, placement, and orientation, might impact occupants' behavior related to natural ventilation in residential houses and how residents manage natural ventilation to affect indoor air quality (IAQ), comfort, and energy efficiency. By analyzing responses from a questionnaire distributed among 200 occupants, this article reveals that stuffy air, perceived outdoor pollutants, odors, and relative humidity, along with factors like inadequate ventilation, temperature fluctuations, and energy consumption concerns, emerge as primary issues affecting occupants' comfort and well-being. This study proposes design recommendations for enhancing IAQ, including optimal window placement for cross-ventilation, window-to-wall ratio (WWR) considerations, and the integration of smart window technologies. This research recognizes that window design is not just a technical matter but involves understanding social and behavioral factors as well. By analyzing occupant responses, it aims to provide insights into the socio-technical parameters that should be considered in window design. The findings offer valuable strategies for architects, designers, and homeowners to optimize natural ventilation and underscore the importance of an occupant-centered approach in sustainable building design.

Keywords: indoor air quality (IAQ); natural ventilation; window design; occupants' behavior; occupants' perceptions

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1. Introduction

Global energy consumption and its associated CO_2 emissions continue to rise, even with the pressing need to stop climate change [1]. In addressing climate change as a global challenge, the significant role of buildings in energy consumption and greenhouse gas emissions has come to the forefront [2]. Buildings account for over 30% of global energy use and around 26% of greenhouse gas emissions [3,4], a substantial portion of which (18%) is attributed to indirect emissions from electricity used for heating, cooling, and lighting. The energy intensity of heating, ventilation, and air conditioning (HVAC) systems, responsible for 40–60% of a building's energy consumption [5], particularly in the residential sector [6], highlight the urgency of adopting more energy-efficient practices in construction and design to mitigate environmental impacts.

Despite advancements in building design and construction codes and energy-efficient rating systems, such as the Australian Building Codes and NatHERS [7,8], there remains a gap between predicted and actual building energy performance [9,10]. This discrepancy often stems from the underestimated effects of occupant behavior on energy efficiency [11,12]. This highlights the need for a deeper understanding of how occupant behavior, influenced by cultural and social norms as well as individual habits and attitudes, impacts energy usage [13]. The literature shows that cultural and social norms and individual habits and attitudes significantly influence energy usage [14,15].

Studies have shown that occupants' window opening behavior, personal habits, and scheduling can significantly impact ventilation rates, heating system settings, and overall indoor air quality. For instance, occupants' decisions to open or close windows directly affect the amount of fresh air entering the building, which in turn influences CO_2 concentration levels and other IAQ parameters [16–18]. The COVID-19 pandemic has further highlighted the importance of occupant behavior, as changes in occupancy patterns due to remote working have impacted IAQ in residential buildings [16,19,20]. Additionally, IAQ measurements have been used as indicators for occupancy calculations or security access. These issues have gained significance in the context of the pandemic and the growing research on using IoT sensor grids for occupancy behavior and IAQ monitoring [21,22]. This insight into the importance of occupant behavior sets the stage for examining specific elements of building design that can either mitigate or exacerbate these challenges [23,24].

One of the elements that plays a key role in regulating indoor environments and energy consumption is the design of residential windows [25,26]. Effective window design, allowing for ease of operation and access, can lead to improved natural ventilation and light, better indoor air quality (IAQ), and reduced reliance on mechanical HVAC systems [27,28]. However, integrating occupant preferences and external conditions into window design to optimize energy efficiency while ensuring satisfaction remains a complex challenge, underscoring the necessity for further research [29–31]. The interaction between window design and occupant behavior exemplifies the broader issue of the gap between expected and actual energy performance. Addressing this requires a holistic approach that not only emphasizes technical solutions but also considers the user's role in energy efficiency [32,33], illustrating how detailed design choices like window configuration are intrinsically linked to the broader goals of reducing energy usage and enhancing sustainability in the built environment [34].

The literature has demonstrated that window design, encompassing shape, orientation, and size, significantly affects a building's energy performance, plays a critical role in a building's energy efficiency, and is influenced by occupants' preferences for larger windows and views, as well as demographic factors like age and gender [35–38]. Surveys conducted in different geographic regions highlight how outdoor conditions and personal concerns impact window usage, suggesting a need to align window design with natural ventilation and lighting to enhance energy efficiency and comfort [39–43]. However, while research has shown occupant behavior and spatial factors significantly influence the actual performance of windows and facades, this is not yet well reflected in practical design guidelines and tools, especially for the early stages [44–48]. More work is needed to translate these research insights into explicit guidance to help designers optimize window parameters around anticipated occupant usage patterns from the start of the design process.

Therefore, future research in this area may continue in order to aid the understanding of how window design parameters can be optimized to reduce energy consumption while maintaining occupants' satisfaction and to help designers and building professionals in designing windows that are more suited to the perception of occupants. To address these issues, the proposed study aimed to further investigate and characterize key elements of window design in the pre-design phase based on the preferences and behaviors of occupants to reduce the energy demand for NV.

This study adopted a user-centric approach by directly investigating how window design features influence occupant behavior related to natural ventilation usage, in contrast with many previous studies that have focused primarily on technical aspects without considering user preferences and behaviors. It recognized that window design is not just a technical matter, but involves understanding social and behavioral factors as well, aiming to provide insights into the socio-technical parameters that should be considered by analyzing occupant responses and identifying and characterizing the critical features of window design that influence occupants' preferences and behaviors related to natural ventilation and light usage.

This study also empirically investigated how window design affects occupant behavior and satisfaction, aiming to refine natural ventilation and lighting approaches to better predict building energy performance. The methodology used for data collection and data analysis is comprehensively presented in Section 2. Then, the results and discussion, Section 3 presents a thorough analysis that was conducted to identify the behavior trends of occupants and compare them with different window design parameters to determine whether there is a correlation or not. To aid in optimizing natural ventilation strategies, the conclusion provides a synthesis of the data, developing a framework for window design characteristics in residential contexts considering occupants' behavior patterns.

2. Methodology

In architecture, the term "occupants' behavior" refers to the choices, behaviors, and interactions of individuals occupying a certain building or area [49]. It includes aspects like:

- How do occupants move through and utilize the building?
- How do they interact with the various systems and features of the building?
- How do their presence and activities affect the overall performance and functionality of the structure?

The concept of occupant behavior, including people's actual physical interactions with the built environment and the symbolic meanings they attribute to it, is complex and varied [50]. Thus, comprehending the behavior of building occupants is essential for creating and overseeing structures that adapt to the requirements and inclinations of their users.

The present study is part of ongoing research to develop instructions that lead to a design guide to assist building designers in enhancing sustainability in residential houses. This study used a questionnaire to investigate how occupants' interactions with windows and the geometric characteristics of windows influence their decision to use natural ventilation and lighting in residential buildings in the Melbourne greater area. The questionnaire was designed to collect data on the following key areas:

- Occupants' preferences and behaviors related to window operation for natural ventilation, including factors like time of day that drive window opening and closing actions [51–53].
- Geometric characteristics of windows, such as window-to-wall ratio (WWR), window orientation, and placement, and their impact on energy performance [54–59].
- Occupants' thermal comfort and visual comfort in relation to window design and operation, considering factors like operative temperature, humidity, air velocity, and glare [52,60–62].

The collected questionnaire data was analyzed using the Coefficient of Correlation, which is a statistical measure that describes the strength and direction of a relationship between two variables, to identify the significant factors influencing occupants' decision to use natural ventilation and lighting [63]. The results provide insights into the key areas that can be improved in building design and operation to better align with occupants' needs and preferences. Figure 1 illustrates a flow diagram outlining the criteria used for the post-occupancy evaluation (POE).

Furthermore, the findings from the questionnaire study will inform the setup of configuration tests for future numerical studies, such as building energy simulations [64–66]. The identified significant factors and occupants' preferences can be used as input parameters for parametric simulations to optimize window design for natural ventilation and lighting while considering occupants' comfort and building energy efficiency.

Figure 1. Criteria used for the post-occupancy evaluation (POE).

By combining the questionnaire study with numerical simulations in the future stage of this study, this study aims to bridge the gap between designers and occupants and provide evidence-based recommendations for window design and operation in residential buildings in Melbourne. The holistic approach considering energy performance, thermal and visual comfort, and occupant behavior will contribute to creating sustainable and comfortable indoor environments.

The targeted participants will be introduced in Section 2.1. The stages involved in designing the survey and utilizing methods for analyzing the survey data are then explained in Section 2.2.

2.1. Targeted Participants

In conducting surveys, achieving valid and reliable results is essential. This emphasizes the selection of participant groups to ensure that the data collected accurately mirror the targeted demographic's opinions, experiences, or actions. This study focused on individuals aged 18 and above residing in Melbourne's residential buildings. Their living rooms had at least one window (a condition that aligned with the study's specific objectives). This enhanced the relevance and applicability of the findings to the intended group, reinforcing the study's validity and reliability.

Moreover, understanding the margin of error (MoE) in questionnaires is crucial for interpreting survey results accurately. This statistical measure, indicative of sampling errors, essentially informs us about the range within which the true opinions of the entire population are likely to fall. A common practice among survey researchers is to adopt an MoE ranging from 4% to 8% at a 95% confidence level. This standard reflects a balance, suggesting that if the survey was replicated multiple times, the results would consistently approximate the true population values within this error margin in 95 out of 100 instances. By combining strategic participant selection with a clear understanding of the MoE, the survey results analysis would reflect reliable insights into the population's opinions and behaviors.

This survey was distributed among 150 High Degree Research (HDR) students and staff via university administration channels and personal contacts. Using verified Victoria University (VU) email addresses and known personal connections mitigated concerns about malware or phishing and ensured the recipient's trust in the authenticity of the emails and their response to the questionnaire, which were important parts of ensuring their inclusion and respecting participants' privacy. This research was conducted with an 8% margin of error.

2.2. Survey Design and Analysis

It is evident from the literature that one of the most significant adaptive behaviors that can affect both building energy usage and the indoor atmosphere is the way that building occupants use windows [67]. Seasonal impacts, occupancy, time of day, and internal stimuli like temperature, humidity, and CO_2 can affect how occupants interact with building controls, such as opening or closing windows [68]. Therefore, while designing buildings for greater ventilation, it is crucial to consider both the design characteristics of windows and how occupants interact with them.

In the second phase of this study, a qualitative questionnaire was designed to gather feedback from participants in five categories: 1. Demographic Factors (DF), 2. Geometric and Building Features (GBF), 3. Behavior and Awareness (BA) of occupants, 4. Ventilation Options (VO), and 5. Thermal and Overall Comfort (TOC) of occupants.

A literature review revealed that previous studies investigating resident behavior employed questionnaires with different types of questions depending on the project's scope and elements under investigation [24,40,42]. A total of 250 distinct questions were gathered from previous surveys, with redundant questions yielding similar responses being removed. By comparing the factors examined in each project with those in the current study and identifying answer options that could provide more useful information, the researchers selected 60 relevant questions from the initial pool of 250. Additionally, 10 new questions were added to the questionnaire to meet the specific data requirements of the current research.

While designing this survey, it was crucial to ensure that all participants understood the survey questions in the same way, to ensure the validity of this study. This was important because variations in understanding lead to inconsistent results and affect a study's overall reliability. To tackle this issue, any phrasing that could potentially confuse or mislead respondents was revised or removed. When needed, clarifications or examples were included to help participants comprehend the purpose of each inquiry (Q. 8 in the Geometric and Building Features Section).

Before the commencement of the main study, a pilot test with a small, diverse group of participants who were representative of our target population was conducted. This pilot test served as a crucial step in identifying any questions that might be confusing or interpreted differently by different individuals. In addition, feedback was requested from respondents on the survey questions' comprehensibility and clarity during the pilot testing phase, which helped us smooth out any issues before the main study started. Based on the feedback received during the pilot test, several modifications were made to the survey questions to enhance clarity and comprehensibility. For instance, certain questions were rephrased to eliminate misunderstanding, additional instructions or examples were added where necessary (Q. 3 and 7 in the Geometric and Building Features Section), and any unnecessary items that did not appear to be significantly useful for the research objectives were removed.

Clear images were included before specific types of questions. For example, before questions related to specific window design parameters like orientation and size (WWR, Q. 8 and 9 in the Geometric and Building Features Section—Appendix A), a brief explanation of each parameter and its relevance to the study was provided, ensuring that participants were well-informed and able to provide accurate responses.

The use of a consistent question format aimed to minimize variability in participant responses and enhance the overall reliability of the study findings. Consistency in question format helps participants quickly become familiar with how to respond, reducing the cognitive load and potential for confusion. This was achieved by standardizing the wording and structure of the survey questions, ensuring uniformity across all items.

Table 1 summarizes the questions outlined in the questionnaire (refer to Appendix A), their categories, the reasons for the questions, and the relation between questions, as well as the required explanations. This preliminary study data will inform the development of the numerical analysis in phase three of the project. This survey was distributed to targeted participants over the age of 18 living in residential buildings in the greater Melbourne area.

Table 1. Survey questions mapping and rationale.

Section	Subject of Questions	Reason	Related Questions
General Demographics and Building Features	Age group and gender	The relationship between the age and gender of users and their usage pattern.	1, 2 in DF section
	Postal code	Find the nearest weather station and roughly guess the financial status.	1 in GBF section
	Type of building	This study only considers residential buildings.	4 in GBF section
	Ownership status, including bill and annual income	Compare NV usage patterns based on ownership and financial level. Find the impact of the included electricity bill on the NV usage pattern.	4, 6 in DF section, 13 in BA section
Geometric Factors	Number of bedrooms and living room area	Enhanced understanding of the layouts and a comparison of the area of rooms and the living room.	6, 7 in GBF section
	Size and orientation of windows	Investigate the WWR and determine the relationship between wind direction and NV usage pattern.	8 in GBF section
	Placement of windows (using picture)	Understand the relationship between NV usage patterns and placement.	9 in GBF section
	Dimensions of the living room (ceiling height, length, and width)	Understand the layout dimensions and NV performance pattern due to the number of windows and usage pattern.	2, 3 in GBF section
	Window and balcony options	Understand the residents' preferences and deeply understand their behaviors.	2, 3 in BA section
Behavior and Awareness	Availability of ventilation options and preferences in NV devices	Understand whether the usage pattern is due to their behavior or to the current situation. Understand what factors affect their behavior.	10, 11 in BA section and 1, 2, 3, 4 in VO section
	Window operation model	Opening time of windows means more NV usage even if they open them for other reasons.	5, 6, 12 in BA section
	Satisfaction level VS energy usage	Understand the occupant's beliefs and compare them with their behavior.	1 in BA section and 5 in DF section
Feeling and Comfort	Feeling and sensation of comfort	Understand the level of comfort using different cooling scenarios and their real feeling in their house due to the current situation.	1, 2 in TOC section and 1, 4, 7, 8, 14 in BA section
	The main reason for opening or closing windows	The main reasons for residents opening/closing windows and understanding their usage pattern regarding NV.	5, 8, 9, 12 in BA section

This survey introduced the research team, outlined the project's goals, and invited participants to contribute 15 min of their time voluntarily and anonymously. It clarified that while participants would not directly benefit, the findings could enhance the understanding of natural ventilation and potentially reduce energy costs. Privacy and confidentiality were assured from the start of the survey. Finally, participants were asked to confirm that they were over 18 and consent to participating in the survey. A total of 83 respondents answered all of the survey questions.

Several approaches were employed to characterize residential window design parameters based on occupants' preferences and behaviors, including sensor-based experiments, surveys, and simulation models. While each approach had its advantages and disadvantages, the survey approach provided valuable insights into occupants' preferences and behaviors, which were difficult to capture through other approaches [69]. Surveys have been used to investigate various aspects of window design, such as preferred window types, glazing properties, and shading devices [39]. These studies have highlighted the importance of considering the preferences and behaviors of occupants when designing windows to enhance the indoor environment and maximize energy efficiency. Our survey results will be used to define occupants' behavior, preferences, and usage patterns with critical design. Parameters of windows such as orientation, WWR, and position will be included in the numerical analysis.

Following the collection of the responses, it was necessary to analyze the behavior and preferences of the occupants based on their responses. Occupants' behavior can be deterministic or stochastic, and to describe it, both their stochastic behavior and their interaction with the building's elements need to be considered [70].

Firstly, to understand residents' needs and preferences, ten questions were selected from the behavior and awareness section of the survey to investigate occupant behavior. Selecting these ten questions strategically focused and analyzed understanding occupants' deterministic behaviors and offered a comprehensive view of how occupants interacted with their living environment. Table 2 summarizes the questions outlined in the selected questions (refer to Appendix B), their categories, the reasons for the questions, and the required explanation. This targeted approach not only shed light on the balance between comfort desires and energy-saving attitudes but also provided critical insights for stochastic behavior and related design architectural features in the next steps of our research to better meet occupants' needs and enhance natural ventilation.

Table 2. Explanations of the 10 selected questions from the questionnaire.

No.	Questions	Reason
1	If you were to improve your house's natural ventilation (save energy), which of the following solutions would you choose?	How would their NV preference affect any changes in their current situation?
2	In terms of natural ventilation, which one is your favorite?	The general view about NV preferences.
3	What is the most common adaptive behavior you use to make yourself comfortable?	Understanding the general adaptive behavior.
4	What is your preference?	Understanding the general preferences.
5, 6	Based on the time of day, you open and close your windows mostly for... (multi-choice accepted)	Understanding the time duration of using windows and background reasons.
7, 8	Which one do you have/prefer to have in your living room?	NV current situation/preferred situation.
9, 10	Which one best describes your window-opening/closing operation model?	What their opening/closing behaviors are and what factors affected their behaviors.

Then, to predict the probability of an action being taken by an occupant, the relationship between the potential action and the factors influencing its performance needed to be considered. Indoor and outdoor temperatures, as well as wind, all affect the likelihood of opening a window by an occupant [71].

To model occupants' behavior, the correlation coefficient is an effective method used to predict and model the behavior of responses based on occupant-related information [72]. Additionally, logistic regression can be employed to analyze occupant behavior and predict the likelihood of behavior based on various factors [73]. Modelling the occupancy and opening and closing window patterns is crucial in predicting occupants' behavior as they have a significant impact on NV and energy consumption in buildings. The steps in developing the survey questions are outlined in Figure 2.

Figure 2. Steps in developing the questionnaire.

Our strategy was to develop behavioral patterns based on the information collected through the questionnaire to model the behavior of occupants with windows concerning opening and closing actions. Developing these behavioral patterns created various scenarios that reflected a variety of occupant behaviors. These scenarios allowed us to consider several influencing factors, such as the residents' arrival time, the reasons why they open or close windows, and any potential building features, such as orientation, that may have effects on their behavior.

3. Results and Discussion

3.1. Occupants' Behavior

In this section, the behavior, needs, and preferences of occupants were analyzed using 83 responses gathered for the 10 selected questions from the original survey (shown in Appendix B). The rationale and relevance of each selected question are detailed in Table 2, and the general characteristics of the targeted residential buildings are summarized in Table 3.

Table 3. General characteristics of the targeted residential buildings.

No. of Eligible Respondents (Target Residential Buildings)	Average Residence Area	Average Living Room Area	Window on North Wall	Window on East Wall	Window on West Wall	Window on South Wall
83 (Out of 135)	196.7 m^2	33.5 m^2	79%	67%	58%	55%

The analysis of occupant behavior in residential settings indicates a pronounced preference for natural ventilation solutions, driven by factors such as cost-effectiveness, environmental awareness, and the desire for personalized control over indoor environments. This preference is reinforced by a notable tendency towards customizable window designs and the utilization of fans to increase airflow and enhance thermal comfort. Furthermore, the incorporation of both natural and mechanical ventilation methods demonstrates a nuanced approach towards attaining optimal living conditions, emphasizing adaptability and sustainability in residential design and management. Responses to the solutions for better natural ventilation (Q 1. Which of the following solutions would you prefer to do to have better natural ventilation (saving energy) in your house—Appendix B) highlight a preference for installing fans and customizing window sizes to enhance natural ventilation and comfort, as shown in Figure 3. The preference for fans may highlight their cost-effectiveness, low energy consumption, and flexibility, offering a simple yet effective means to elevate indoor air velocity and improve IAQ and thermal comfort. This trend also indicates a tendency to use low-energy ventilation facilities.

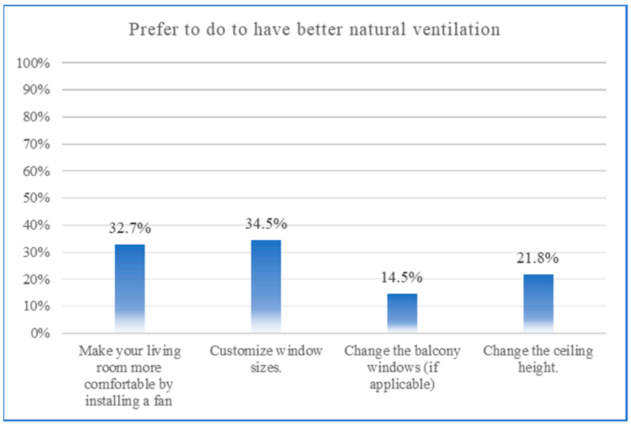

Figure 3. Preferences in changes for better natural ventilation.

The preference for customizing window sizes might reflect an understanding of the significant impact of window design on NV effectiveness and energy efficiency, driven by a desire for personal control and environmental awareness. Meanwhile, together, these preferences may underscore a growing trend towards sustainable living practices and the importance of adaptable, personalized solutions in residential settings.

The collected responses to the question about diverse behaviors (Q 3. Which of these adaptive behaviors do you usually use to make yourself comfortable?—Appendix B) highlight a strong inclination towards opening and closing windows, indicating a preference for cost-effective solutions, with 60% having selected the use of windows to reach thermal comfort (Figure 4), This indicates that when windows are designed based on occupants' behavior, they are more likely to be used for natural ventilation, resulting in less reliance on mechanical ventilation. This emphasizes the importance of prioritizing operable windows for natural ventilation, tailored to individual comfort needs and external conditions.

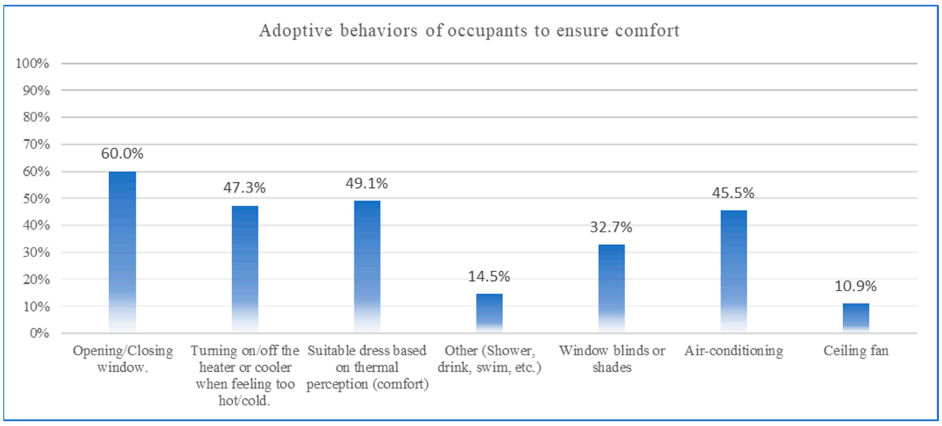

Figure 4. Preference in changes for better natural ventilation.

The motivations behind why residents choose to open windows are primarily centered on having fresh air as the results for this question (Q 5. Your window opening activity according to the time of the day is mostly for. . .—Appendix B) show that 85.5% of respondents open windows to get fresh air (Figure 5), which highlights the importance of the window design parameters (i.e., orientation, placement, and size) impact on NV usage. This further underscores the need to prioritize entering fresh air when designing windows. Several potential reasons could explain the observed patterns which link to specific window design:

- Window orientation and placement that maximizes natural ventilation potential while considering prevailing wind directions;
- Appropriate window-to-wall ratios that balance ventilation requirements; and

- Operable window configurations that allow occupants to control airflow as needed.

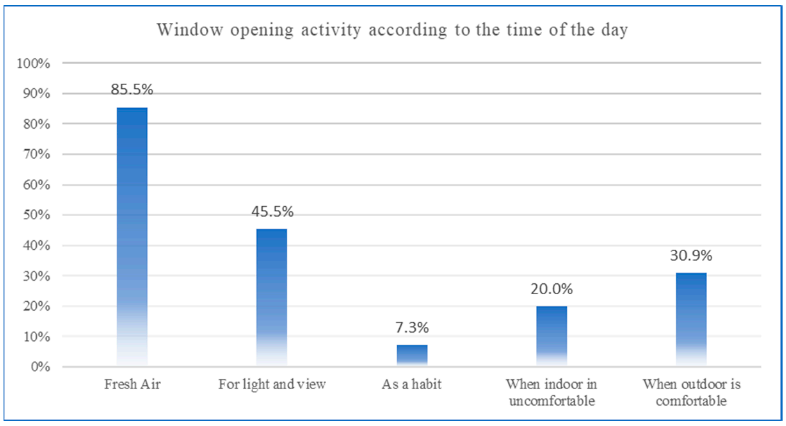

Figure 5. Occupants' opening activity according to the time of day.

The second most significant factor identified was the preference for open windows to enhance light and view, with 45.5% of respondents selecting this option. This could be related to the following potential links to window design:

- Appropriate window-to-wall ratios and glazing properties that prioritize daylight provision and visual connections;
- Window orientation and placement that enhances access to desirable views; and
- Integration of external shading devices or dynamic glazing to manage glare while maintaining the view.

Additionally, 30.9% said that they open windows when the outdoor climate is comfortable, which suggests that favorable weather can have a significant impact on indoor air quality. These key links could be related to window design considerations:

- Local climatic conditions to identify periods suitable for natural ventilation;
- Building orientation and window placement that enables effective cross-ventilation during favorable conditions; and
- Operable windows that are easily accessible for occupants to take advantage of pleasant outdoor air.

In conclusion, when designing windows, the primary objective should be allowing for fresh outdoor air, necessitating the optimal orientation, sizing, and placement of windows to maximize the natural ventilation potential. Enhancing daylighting and outdoor views is another critical consideration, requiring balancing between window-to-wall ratios, placement, and integrated shading systems. Moreover, occupants' willingness to open windows largely depends on comfortable outdoor conditions, indicating that designers must account for local climate patterns, facilitate cross-ventilation, and ensure easy window operability.

These figures demonstrate a clear preference for dynamic indoor environments, with active window management strategies that adapt to both internal sensations and external environmental conditions, highlighting the importance placed on dynamic, comfortable, and healthful living spaces.

Figure 6 indicates the main reasons that prevent occupants from using natural ventilation through windows, which were the concerns about insects, security, and privacy. (Q 6. Your window closing activity according to the time of the day is mostly for. . .—Appendix B). However, nearly half of the respondents (45.5%) also reported shutting windows when the outdoor temperature becomes uncomfortably hot. This behavior highlights the significant role windows play in regulating indoor climate and enhancing occupant comfort. This may indicate that while natural ventilation is essential for maintaining good IAQ, it sometimes becomes secondary to thermal comfort in conditions of high outdoor temperatures. This could have a strong correlation to a window parameter such as orientation to help reduce the heat gain. These results emphasize the importance of carefully considering window design and building orientation to balance natural ventilation with thermal comfort. Building orientation should maximize natural light exposure while minimizing heat gain, especially during hot weather. Properly oriented windows can also capture prevailing breezes, facilitating natural ventilation without compromising thermal comfort.

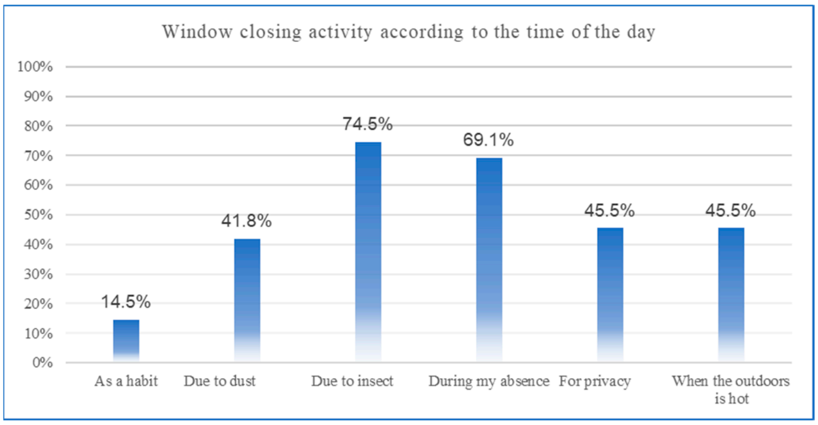

Figure 6. Occupants' windows closing activity according to the time of day.

The conclusions from analyzing occupant behavior regarding opening and closing windows according to the time of day (Figures 5 and 6) indicate that actions related to window operations, both opening for fresh air and closing for security or environmental control, are influenced by daily routines and external factors. The motivation to refresh indoor air when feeling stuffy or at the start of the day points to a proactive engagement with air quality. Conversely, closing windows before leaving or sleeping shows concerns over security and the maintenance of a comfortable indoor climate. These patterns underscore an overarching trend towards prioritizing natural ventilation while valuing the ability to adapt living spaces to personal and environmental needs for enhanced comfort and energy efficiency.

The analysis of occupant behavior highlights a distinct preference for natural ventilation and adaptive comfort strategies in residential settings. This preference underscores the crucial role of window design parameters, including orientation, placement, and size, in achieving desired comfort levels. The customization of window sizes, particularly favoring large operable windows, reflects occupants' desire for ventilation control and a stronger connection to the outdoors. Furthermore, observed adaptive behaviors, such as adjusting windows based on comfort and environmental conditions, indicate proactive indoor environment management. However, the preferences for both natural and mechanical ventilation methods suggest the need for a versatile approach to optimizing comfort, accommodating varying preferences and environmental factors. Overall, prioritizing these insights in residential window design is essential for fostering dynamic, comfortable living spaces that promote well-being and sustainability.

3.2. Occupants' Behavior and Windows Design Parameters

Windows do more than just let in light and air; they shape how we experience our living spaces. This study closely examined how window design elements, such as placement, orientation, and size, influence occupants' actions and perceptions within their spaces.

Utilizing clear analysis from the results and real-life occupant feedback helped us to uncover the intricate correlation between window design parameters and occupants' daily behaviors. Understanding these correlations allowed for the formulation of hypotheses regarding window designs that cater to occupant behaviors, informing the next phase of this research. As established in the literature, window design factors such as orientation, placement, and size (window-to-wall ratio, or WWR) significantly impact a building's energy performance, which, in turn, influences occupants' behavior. Therefore, the analyses in this section focused on these key window design features.

These analyses were carried out using the Coefficient of Correlation, which is a statistical measure that describes the strength and direction of a relationship between two variables. It quantifies the degree to which changes in one variable are associated with changes in another variable. There are several types of correlation coefficients, but the most common is Pearson's correlation coefficient [74,75] (often denoted as "*r*") and it ranges from −1 to 1.

The selection of Pearson's correlation coefficient was based on its extensive use in the literature and its relevance to recent research findings, and it can be derived from the following formula:

$$r = \frac{\sum (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum (x_i - \overline{x})^2 \sum (y_i - \overline{y})^2}} \quad (1)$$

where r = correlation coefficient; x_i = values of x in a sample; $\overline{x}$ = mean of the values of the x; y_i = values of y in a sample; and $\overline{y}$ = mean of the values of the y.

Several methods have been proposed to categorize the correlation coefficient into descriptors such as a "weak", "moderate", or "strong" relationship. Although most researchers would likely agree that a coefficient of less than 0.1 signifies a negligible relationship and greater than 0.9 indicates a very strong relationship, the interpretation of values in between these remains debatable [76].

The *p*-value for each correlation was also examined, which represents the probability of obtaining test results at least as extreme as the result actually observed, assuming the null hypothesis is true.

A low *p*-value (typically $p \leq 0.05$) generally indicates strong evidence against the null hypothesis, suggesting that the correlation is statistically significant. Conversely, a high *p*-value suggests that the correlation is not statistically significant.

3.2.1. Window Orientation

Focusing on the link between occupant behavior, window orientation, and adaptive behaviors for comfort, the analysis of the survey data revealed insightful correlations that underscored the interplay between the built environment and human adaptive strategies. The strongest correlations observed offer a compelling narrative on the predominant role that north-facing windows play in influencing occupant behavior.

Figure 7 shows trends of adaptive behaviors (Q 4. Section Behavior and Awareness—Appendix A), and Figure 8 shows trends of window opening activities (Q 9. Section Behavior and Awareness—Appendix A) with different window orientations (Q 8. Geometric and Building Features—Appendix A); it should be noted that due to the limited number of respondents who had more than three windows in their living room, only the results of windows one to three are presented in the figures.

One of the most pronounced correlations was observed between north-facing windows and the act of opening and closing windows, which exhibited a strong positive correlation ($r = 0.37$, $p < 0.001$) with north-facing windows. This may be attributed to the prevailing northerly winds, which are by far the most frequent wind for the Melbourne region. Furthermore, Melbourne is known for having "four seasons in one day", which indicates a widely recognized characterization of Melbourne's climate, where the weather can change dramatically within a single day, and residents may adjust windows frequently to adapt to sudden changes in weather conditions, such as wind shifts or temperature drops. This behavior indicates a proactive engagement with the built environment, where occupants use natural ventilation as a primary method for moderating indoor conditions, and it reflects a dynamic interaction between the occupant and the north-facing windows, underscoring the importance of north window orientation in the design. However, the influence of prevailing wind direction and other climatic factors can vary significantly across different regions. Therefore, while these results provide insights, further studies are warranted to explore how window configurations and occupant behaviors interact in diverse environmental contexts.

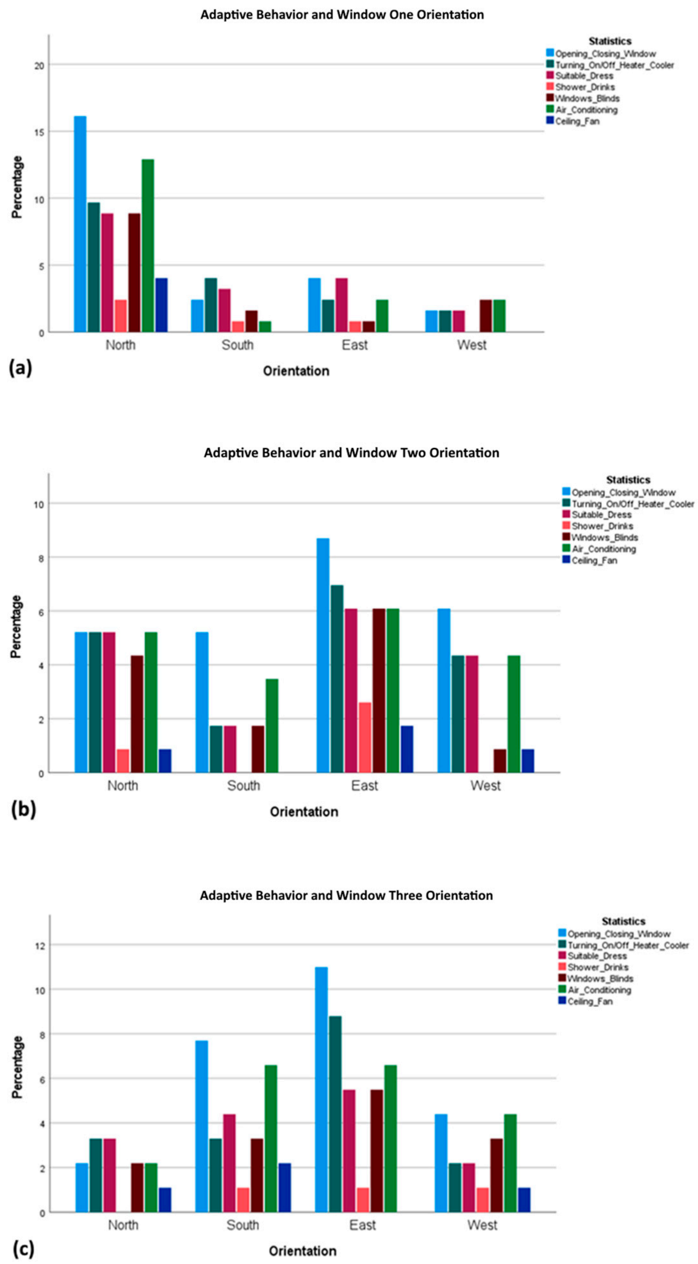

Figure 7. Adaptive behavior correlations with window orientation: (**a**) window one orientation; (**b**) window two orientation; (**c**) window three orientation.

The use of window blinds or shades also showed a positive but weak, less significant correlation with north-facing windows (r = 0.16, $p \simeq 0.15$), highlighting the role of shading devices in managing light and heat ingress, further contributing to indoor thermal comfort. Getting natural light is desirable but it could also lead to overheating, as north-facing windows in Melbourne (and in the Southern Hemisphere in general) can receive significant amounts of direct sunlight throughout the year compared to other orientations. The shades help to moderate this light and a positive correlation with the use of blinds or shades was noted, indicating that occupants may actively manage solar heat gain and light. By using shades, residents can control the amount of heat and sunlight entering the space, thus maintaining thermal comfort without necessarily resorting to mechanical cooling. It is also worth noting that designers should anticipate light ingress to customize shading solutions and/or implement smart technologies that adapt dynamically to changing light conditions. This approach optimizes both the benefits of natural light and thermal comfort.

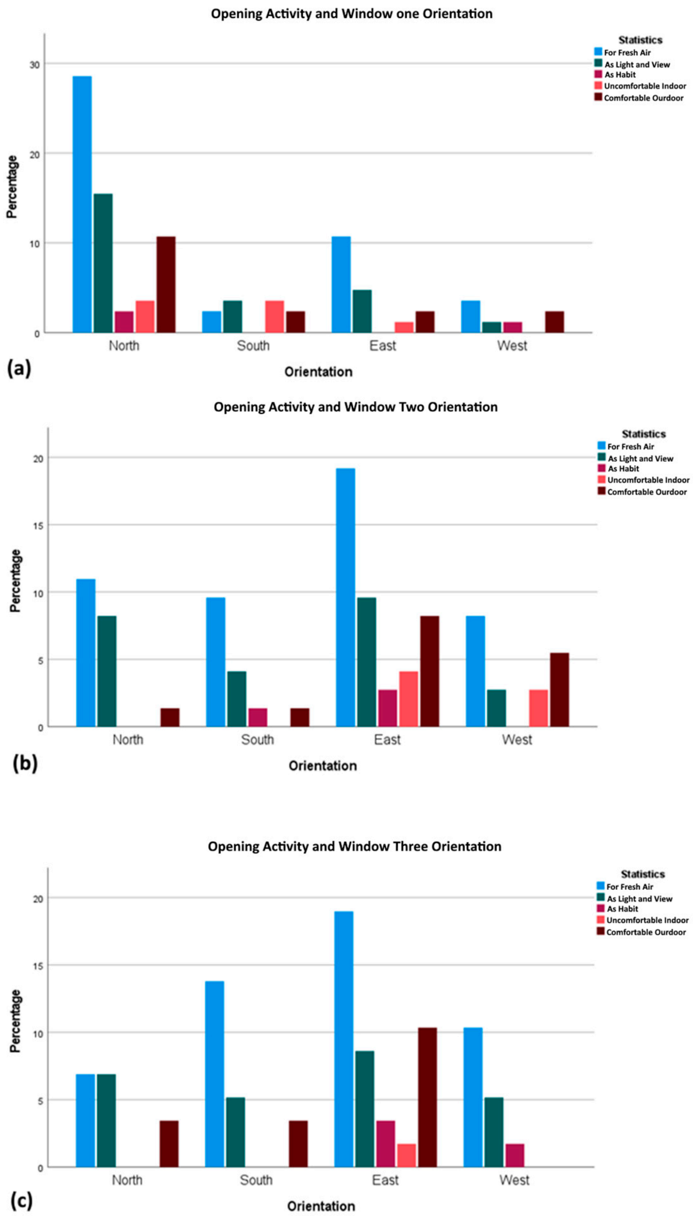

Figure 8. Window opening activity correlations with window orientation: (**a**) window one orientation; (**b**) window two orientation; (**c**) window three orientation.

Meanwhile, the use of ceiling fans was marginally more common among occupants with north-facing windows ($r = 0.19$, $p \simeq 0.085$), suggesting a preference for passive cooling strategies in conjunction with natural ventilation.

The analysis revealed a similar weak but positive correlation between the presence of west-facing windows and the reported use of ceiling fans compared to other window orientations ($r = 0.19$, $p \simeq 0.085$). This finding aligns with the climatic patterns of Melbourne, where the western afternoon sun can contribute to increased heat gain through west-facing windows during the warmer months. In response, residents may turn to ceiling fans as an energy-efficient cooling measure to promote air circulation and offset the warmth from the intense late-day sun exposure.

However, it is essential to acknowledge that the observed correlation, though mildly suggestive, does not establish a definitive causal relationship. Various other factors, such as personal preferences, building design characteristics, and the specific size and shading conditions of windows, could also influence the use of ceiling fans as an adaptive behavior. This study aims to further analyze and validate these weak correlations using energy simulations in a later stage.

Another interesting trend in the results was the significant usage of east-facing windows for the second available windows, which may indicate that the morning sun has a compounding effect on thermal comfort, especially when more windows are involved; it also could help to warm the interior and create a natural convection current that draws in fresh outside air. This suggests that occupants are more actively managing east-facing windows as they become more impactful on the indoor environment. This trend underscores the importance of strategically orienting buildings to capitalize on morning sun exposure, especially in areas like bedrooms and morning-use spaces.

By incorporating both north-facing windows for natural ventilation and east-facing windows for daylighting and passive heating, architects can design spaces that closely align with observed occupant behavior and preferences. North-facing windows allow occupants to take advantage of cool breezes for natural ventilation, catering to their tendency to open and close windows to control indoor air quality and thermal comfort. Simultaneously, east-facing windows maximize the benefits of morning sunlight, providing ample daylighting to reduce reliance on artificial lighting while also enabling passive solar heating strategies. This integrated approach not only responds to occupants' desires for natural light, ventilation, and comfortable thermal conditions but also promotes energy efficiency and sustainable building practices. Crucially, the combination of north- and east-facing windows affords occupants greater control over their indoor environment, allowing them to actively manage ventilation, lighting, and thermal conditions according to their preferences and needs.

The overall pattern of adaptive behavior and window opening activities from window one through window three, concerning orientation, suggested a detailed approach by occupants to manage their environment. North-facing windows are used for immediate ventilation due to the prevailing northerly winds and variability of climate in Melbourne, while east-facing windows' usage ramps up, potentially due to the compounding effect of the morning sun that necessitates greater control of light and temperature. South-facing windows showed a consistent pattern due to less direct solar impact, and west-facing windows' adaptive behaviors did not show as much change, likely due to their less favorable afternoon sun exposure which may limit their use for natural ventilation. These outcomes show that the orientation of windows within a living space could influence the adaptive behaviors occupants employ to achieve comfort. These findings emphasize the role of architectural design, particularly north window orientation, in fostering environments that encourage energy-efficient and comfort-driven occupant behaviors.

3.2.2. Window Placement

The analysis drew an interesting line between the placement of windows and the likelihood of occupants engaging with these features to regulate their comfort. Figure 9 shows the trends of adaptive behaviors (Q.4, Section Behavior and Awareness—Appendix A), and Figure 10 shows trends of window opening activities (Q.9, Section Behavior and Awareness—Appendix A) with different window placements (Q.9, Geometric and Building Features—Appendix A).

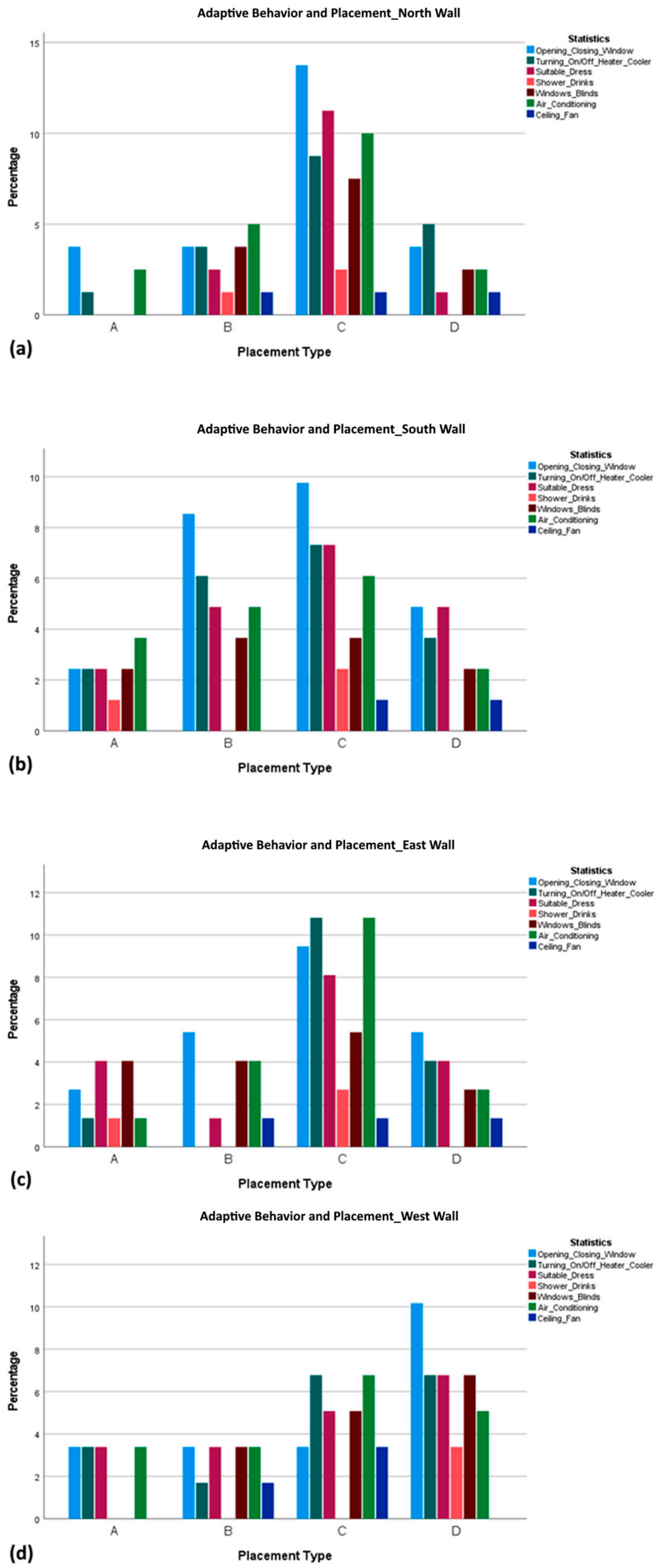

Figure 9. Adaptive behavior correlations with window placement: (**a**) north wall; (**b**) south wall; (**c**) east wall; (**d**) west wall.

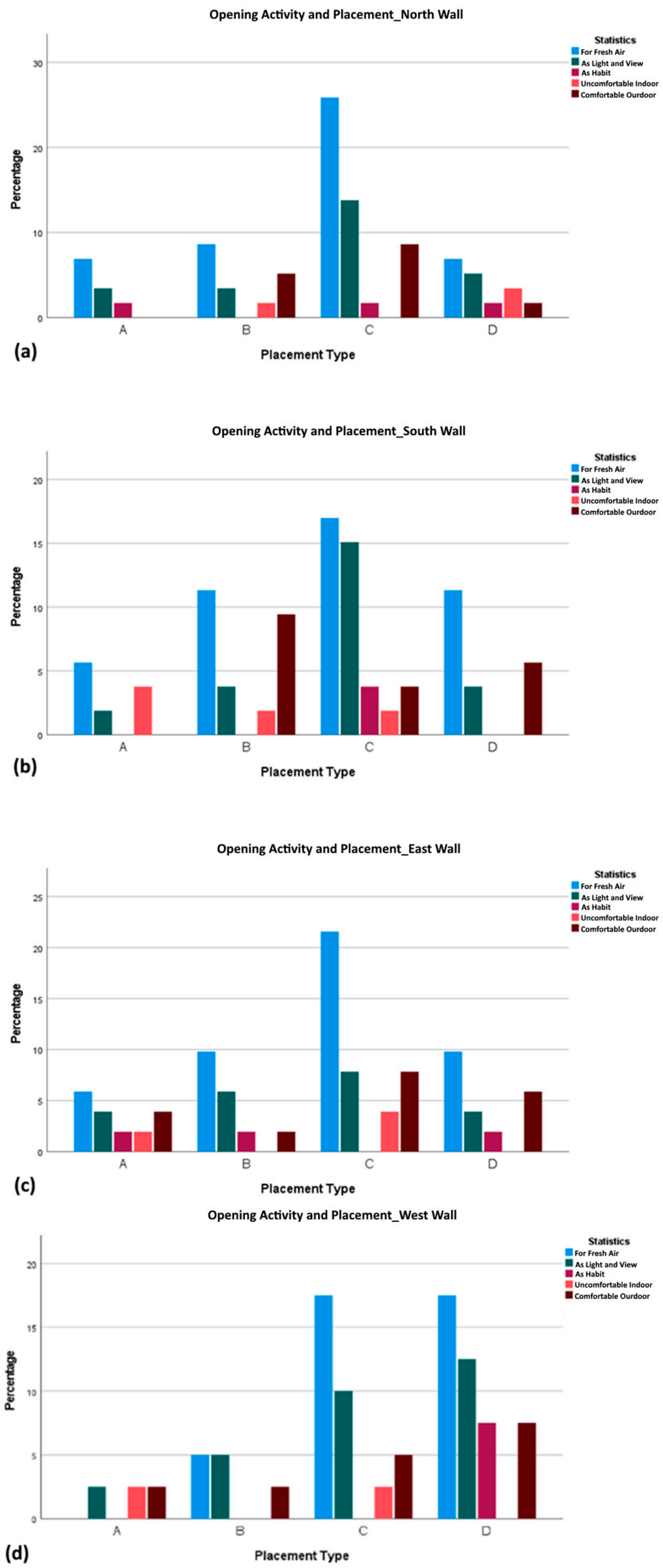

Figure 10. Window opening activity correlations with window placement: (**a**) north wall; (**b**) south wall; (**c**) east wall; (**d**) west wall.

Generally, Configuration C (two windows placed side-by-side) consistently was the most common and showed the highest interaction by residents across all orientations. It is also interesting to note the behaviors associated with non-window actions, like adjusting blinds or turning on fans and air conditioning, which indicate other strategies occupants use to adapt to indoor conditions alongside window opening activity. For instance, on the west wall, air conditioning usage spikes, possibly due to the sun's path, which results in more direct sunlight on the west wall in the afternoon, especially during the summer. This increased solar radiation can elevate indoor temperatures, leading to a perceived increase in room temperature and prompting occupants to rely more heavily on air conditioning for thermal comfort. However, without considering the most common window placement, analysis of the survey responses indicates that a centrally placed window that extends to the ceiling (Configuration B) is more likely to be operated by the occupants, with a correlation coefficient of approximately 0.3 ($p \simeq 0.006$).

This suggests that such a design is not only visually appealing but also functionally inviting, encouraging interaction for better ventilation and light. This could be attributed to the extended windows reaching the ceiling, allowing for a more even distribution of natural light throughout the room, thereby reducing the reliance on artificial lighting.

The dual-window setup (Configuration C) shows a similar pattern of engagement with a correlation of 0.22 ($p \simeq 0.045$), hinting that having more than one window available does promote active use; this may be attributed to dual windows enhancing natural ventilation by facilitating better airflow and cross-ventilation in the living spaces.

Similar trends can be seen for adaptive behaviors, across all wall orientations; Configuration C consistently sees the highest window opening activity for fresh air, suggesting a strong preference for the benefits of having two windows, possibly for better control over airflow and temperature.

In contrast, the preference shifts towards Configurations B and D for light/view, possibly because these configurations provide a more balanced or controlled light, which is important in maintaining a comfortable indoor environment without excessive brightness or heat gain.

These results provide insights that can help window designers create more effective and user-friendly solutions. These findings highlight the preference for dual-window configurations for promoting natural ventilation and occupant interaction, as well as the benefits of centrally placed windows extending to the ceiling for better light distribution and user operation. Designers may also consider wall orientation, particularly the impact of solar radiation on west-facing walls and develop window solutions that mitigate heat gain and improve occupant comfort.

Furthermore, these results emphasize the significance of integrating window designs with non-window actions, such as adjusting blinds or using fans, to provide an approach to managing indoor comfort. By understanding occupants' preferences for fresh air (Configuration C) and light/view (Configurations B and D), designers can create innovative solutions that balance these needs. Ultimately, incorporating these data-driven insights into the design process can lead to more energy-efficient, user-friendly, and comfortable window solutions that enhance the overall occupant experience.

These analyses not only narrate a story of design influence on behavior but also serve as quantitative evidence of the importance of window placement in occupant-comfort interaction. Configuration C, with two windows side-by-side, was the most common and it promoted active use due to its benefits for natural ventilation. Configuration B, with a centrally placed window extending to the ceiling, was more likely to be operated by occupants for better light distribution and ventilation. Non-window actions, such as the use of blinds and air conditioning, also played a crucial role in maintaining indoor comfort, particularly in response to solar radiation on the west wall. These findings underscore the importance of thoughtful window design in enhancing occupant comfort and promoting energy-efficient behaviors.

3.2.3. Window-to-Wall Ratio (WWR)

In this study, the size of windows, as measured by the window-to-wall ratio (WWR), which influences how people adjust their surroundings to stay comfortable, was specifically analyzed.

Figure 11 shows the trends of adaptive behaviors (Q.4, Section Behavior and Awareness—Appendix A), and Figure 12 shows trends of window opening activities (Q.9, Section Behavior and Awareness—Appendix A) with different window sizes (Q.9, Geometric and Building Features—Appendix A); as was the case with window orientation, because of the limited number of respondents who had more than three windows in their living room, only the results of windows one to three are presented in the figures.

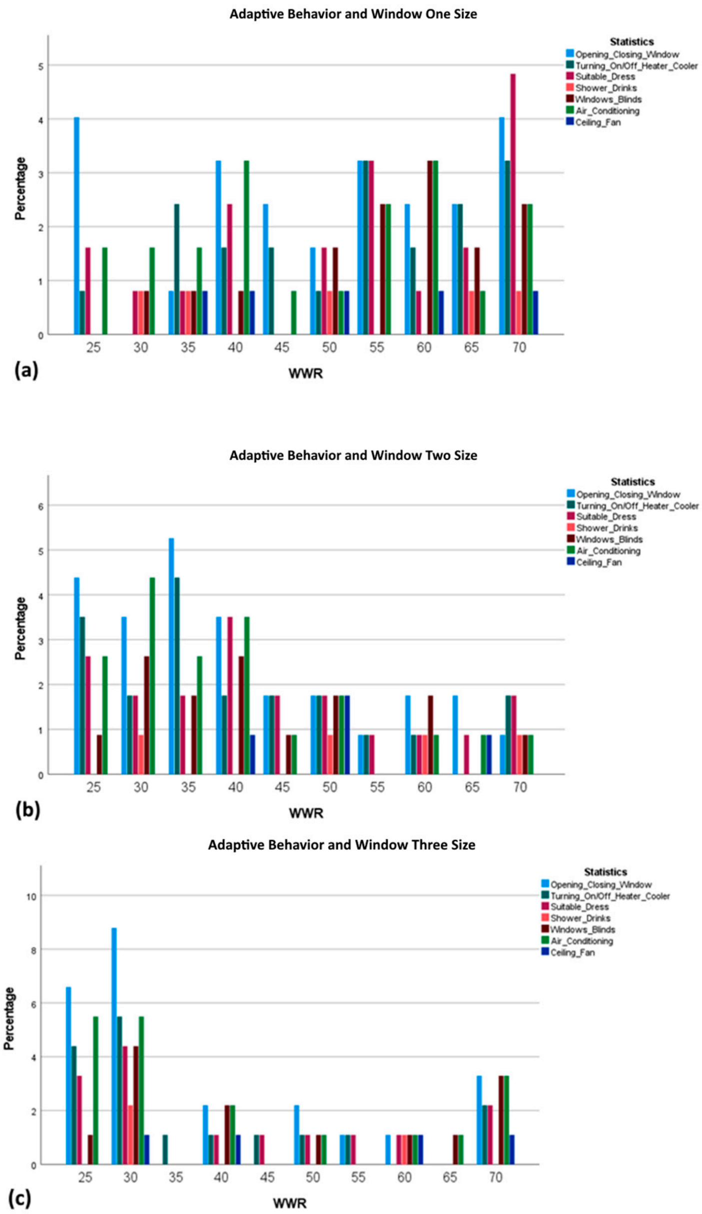

Figure 11. Adaptive behavior correlations with window size (WWR): (**a**) window one size; (**b**) windows two size; (**c**) window three size.

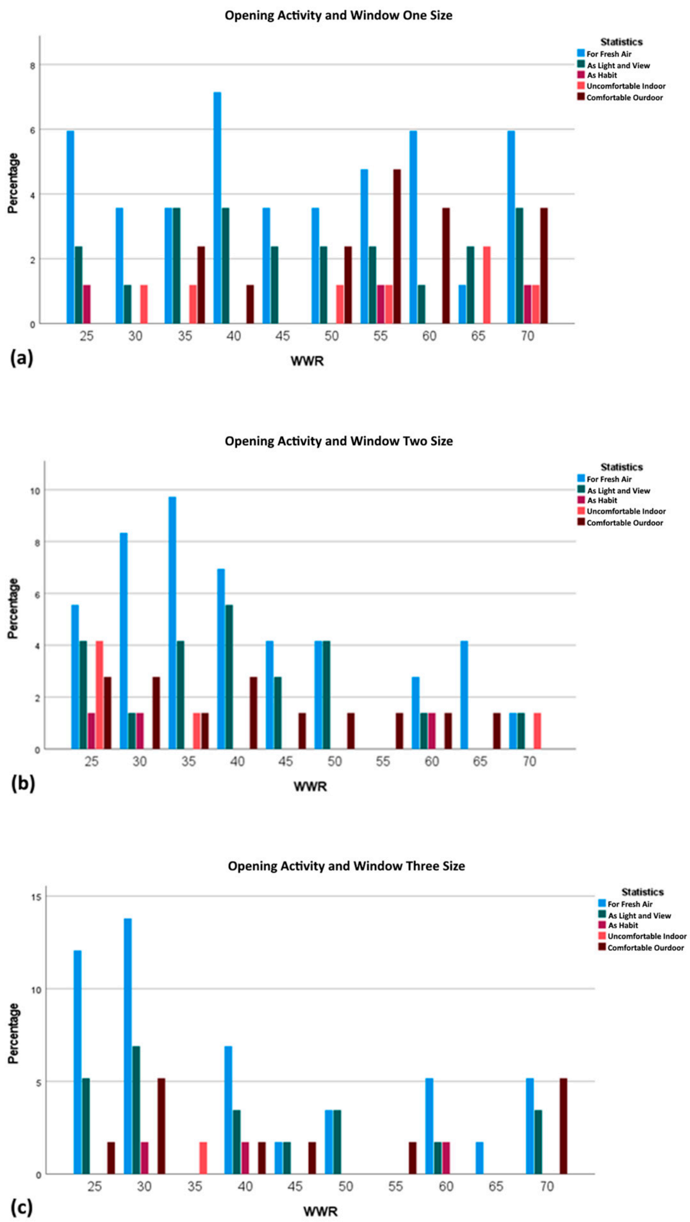

Figure 12. Window opening activity correlations with window size (WWR): (**a**) window one size; (**b**) windows two size; (**c**) window three size.

One of the most significant observations from this study was the relationship between large windows (a higher average WWR > 40%) and the use of window blinds or shades, showing a strong correlation of 0.34 ($p \simeq 0.002$), which suggests that the bigger the windows, the more likely people are to adjust their blinds or shades throughout the day. This behavior could be seen as a direct response to the challenges and opportunities presented by large windows, such as managing light and maintaining a comfortable indoor temperature.

Similarly, a positive correlation ($r = 0.28$, $p \simeq 0.01$) was found between larger windows and changing clothing for comfort. This indicates that people living in spaces with large windows often adapt their clothes to feel more comfortable, reflecting a personal and immediate way to control their thermal comfort.

Ceiling fans also correlated positively ($r = 0.21$, $p \simeq 0.057$) with larger windows. This finding is intriguing as it suggests that even with natural ventilation from windows, occupants still prefer the additional air movement provided by fans. It is a reminder of the nuanced needs for comfort beyond what natural ventilation can offer. The resemblance to the trends observed with north-facing windows suggests a potential avenue for further exploration in future research.

Moreover, the data suggest that there may be a threshold in window size (somewhere between 35% to 45% WWR) where the frequency of interaction with windows changes. This could be due to factors like physical ease of use or the perceived effectiveness of the window for ventilation and light. Regarding window opening activities, across all three situations, a clear trend was that occupants tend to use smaller windows more actively for ventilation purposes (fresh air). This might be due to the ease of operation, or the adequacy of airflow provided by smaller openings. As the number of windows increases, the opening activity does not increase proportionally with size for ventilation, suggesting that occupants may not feel the need to open larger windows as often if smaller windows can provide sufficient airflow.

For light/view, the behavior was more evenly spread across different WWRs, which may have been influenced by other factors like the position and the direction of the windows, which were explored in the previous sections. Understanding these patterns is important for architects and building designers to create environments that align with the natural tendencies and preferences of occupants, thus potentially enhancing comfort and reducing the reliance on mechanical systems.

These results indicate that designers could consider integrating effective shading solutions, such as built-in louvers or external shades, when incorporating large windows (WWR > 40%) to help occupants manage light and maintain a comfortable indoor temperature. The positive correlation between larger windows and the use of ceiling fans suggests that designers could consider integrating ceiling fans in spaces with large windows to provide additional air movement and enhance occupant comfort.

The potential threshold in window size (between 35% to 45% WWR) where the frequency of interaction with windows changes indicates that designers could consider the optimal window size for a given space, balancing factors such as ease of use, perceived effectiveness for ventilation and light, and energy efficiency.

The trend of occupants using smaller windows more actively for ventilation purposes suggests that designers could incorporate strategically placed smaller windows to facilitate natural ventilation, considering factors such as window position, direction, and the overall layout of the space.

Generally, this study revealed several insights into the relationship between window size and occupant behavior in residential buildings. Larger windows, particularly those with a window-to-wall ratio (WWR) above 40%, were associated with more frequent adjustments of blinds or shades, changes in clothing for comfort, and the use of ceiling fans. This suggests that occupants actively engage with their environment to maintain comfort, using a combination of personal adaptations and building features. These findings also indicated a potential threshold in window size (between 35% to 45% WWR) where the frequency of window interactions changes, with smaller windows being used more actively for ventilation purposes.

4. Limitations and Future Directions

One significant limitation of this study was the diversity of respondents' residential settings, including variations in ventilation systems, window designs, and other building characteristics. Evaluating multiple issues across such a heterogeneous sample may have introduced confounding factors, limiting the accuracy and generalizability of our findings. It would be more profitable to study larger homogeneous groups, such as inhabitants of residential developments with similar house designs, to minimize the influence of non-essential variables and facilitate more precise comparisons.

For future studies, a group of residential complexes with identical orientation, size, and design features could be targeted for a more detailed analysis, allowing for a controlled investigation of specific variables, such as window design parameters, framing materials, glazing types, and low-e coatings. This approach would enable a more thorough understanding of the combined effects of these elements on occupant behavior regarding natural ventilation, daylight distribution, and thermal performance.

Additionally, expanding the dataset by conducting similar studies in varied geographic locations and climates could yield valuable insights into how regional differences might influence occupant behaviors and preferences. Such comparative studies could help identify universal patterns as well as context-specific factors that shape occupant interactions with their living environments.

Finally, future studies can investigate how window design can be optimized to work in tandem with low-energy mechanical ventilation systems, such as ceiling fans, to enhance natural ventilation strategies. For instance, strategically placing ceiling fans near windows, considering their orientation and size, could significantly improve air circulation inside rooms. This setup would not only help in refreshing the indoor air when natural ventilation falls short but also assist in maintaining comfortable temperature levels throughout the living spaces. Exploring these combinations could lead to practical design solutions that balance energy efficiency with occupant comfort.

5. Conclusions

This study set out to investigate the relationship between window design characteristics and occupant behaviors in influencing natural ventilation and IAQ in residential buildings. The analysis of 83 responses to the questionnaire showed that there are correlations between window size, placement, orientation, and residents' perceptions of IAQ, comfort levels, and energy efficiency. The results identified several important insights into how window design factors like orientation, placement, and size (e.g., WWR) impact occupant behaviors and adaptive strategies for achieving indoor comfort and air quality.

For window orientation, north and east-facing windows are crucial in optimizing these aspects due to their ability to effectively harness wind and sunlight in Melbourne. North-facing windows demonstrated the strongest correlations with opening/closing windows (0.37), and the use of blinds/shades (0.16), suggesting occupants actively manage these windows to adapt to Melbourne's variable climate and prevailing winds. East-facing windows also showed increased usage patterns within the second or third available windows, reflecting their importance in capturing morning sunlight and influencing thermal comfort and air quality throughout the day.

Window placement significantly influences how occupants interact with their living spaces, with strategically placed windows enhancing both natural ventilation and occupant engagement. The analysis revealed that centrally placed, ceiling-height windows (Configuration B) were the most likely to be operated by occupants, showing a correlation coefficient of 0.3, which suggests that these windows not only provide superior natural ventilation but also encourage active use by residents seeking comfort and fresh air. Similarly, the dual side-by-side configuration (Configuration C) demonstrated consistently high levels of engagement across all orientations, indicating that multiple windows facilitate better airflow and more flexible environmental control by the occupants. This highlights the importance of considering window placement in residential design to maximize natural ventilation and occupant comfort, so contributing to a more sustainable and adaptive living environment.

Regarding window size (WWR), larger windows (>40% WWR) correlated with the use of blinds/shades (0.34) and changing clothes (0.28) as adaptive behaviors, and with ceiling fan usage (0.21). Despite this showing how larger window areas influence occupants' strategies to maintain comfort and manage indoor climate, smaller windows tended to be opened more frequently for ventilation purposes. Indeed, while larger windows enhance the visual appeal and increase natural light, they also require more active management of light and heat through adaptive behaviors, such as adjusting blinds and modifying attire to suit thermal comfort needs. On the other hand, smaller windows are effective in providing adequate airflow with less need for manual adjustments or reliance on mechanical systems.

This shows that the balance between window dimensions and occupants' comfort needs must be carefully managed to optimize both energy efficiency and livability.

These findings highlight how architectural decisions around window orientation, placement, and sizing can significantly influence occupant interactions and natural ventilation behaviors. Designing with these human–building interconnections in mind allows the creation of environments that promote desirable occupant-driven ventilation and comfort adaptation strategies while reducing reliance on mechanical systems. Future research should further explore the interaction between window design and placement and window orientation to optimize the interplay between natural forces and human comfort preferences, leading to buildings that are both energy-efficient and aligned with the needs of their users.

In the next stage of this study, the aim is to develop practical guidelines for window design and natural ventilation strategies by conducting a validated energy simulation that incorporates occupants' behavior patterns and interactions with windows. The simulation will focus on factors such as window-to-wall ratio (WWR), orientation, placement, and natural ventilation strategies. By considering these parameters and their impact on occupant comfort and building energy efficiency during the pre-design stage, this research could help bridge the gap between designers and occupants. The ultimate goal is to create sustainable, comfortable, and energy-efficient buildings through specific recommendations for window design and natural ventilation.

Author Contributions: M.P. methodology, formal analysis, validation, investigation, data curation, writing—original draft preparation, writing—review and editing, and visualization. N.I. conceptualization, methodology, writing—review and editing, formal analysis, supervision, and project administration. E.J. methodology, writing—review and editing, formal analysis, supervision. Z.V. writing—review and editing, supervision, and project administration. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Questionnaire

Demographic Factors (DF)

1. Please select your gender:
    - ○ Female
    - ○ Male
    - ○ Other
    - ○ I prefer not to answer.
2. Please select your age group:
    - ○ 18–25
    - ○ 25–35
    - ○ 35–45
    - ○ 45–55
    - ○ 55 and over
    - ○ I prefer not to answer.
3. Your current height and weight (for automatic BMI calculation)?
    - ○ Height . . .. . .
    - ○ Weight . . .. . .

- ○ Calculate (BMI)

4. What is the best way to describe your residency status?
   - ○ I am an owner-occupier.
   - ○ I am a tenant, and my electricity bill is included in my rent.
   - ○ I am a tenant, and my electricity bill is not included in my rent.
   - ○ I am a subtenant, and my electricity bill is included in my rent.
   - ○ I am a subtenant, and my electricity bill is not included in my rent.
   - ○ I prefer not to answer.
   - ○ Please specify if other
5. Based on the below scale (0–100), rate the importance of each of these factors when controlling your indoor environment:

Comfort Level **0** → **100**

Energy usage **0** → **100**

Electricity Bill (Cost) **0** → **100**

6. What is the total income of your family after taxes are deducted?
   - ○ Less than 45.000
   - ○ 45.000 to 89.000
   - ○ 89.000 to 120.000
   - ○ 120.000 to 180.000
   - ○ More than 180.000

Geometric and Building Features

1. What is your postcode: . . . .
2. What is the height of the ceiling in your house?
   - ○ 2.4–2.5 m
   - ○ 2.5–2.7 m
   - ○ 2.7–3.0 m
   - ○ More than 3.0 m
   - ○ I don't know.
3. The following image shows an example of how to measure a living room. What are the approximate dimensions of your living room?

   X: . . . . Y: . . . .

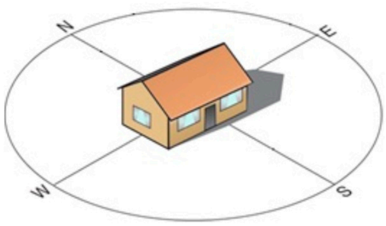
4. What kind of residence do you live in?
   - ○ Apartment or Unit
   - ○ House
   - ○ Townhouse
   - ○ Villa
   - ○ Retirement Living
   - ○ Other (i.e., Block of Units, Acreage, Rural, etc.)
5. What is the number of occupants in your home?

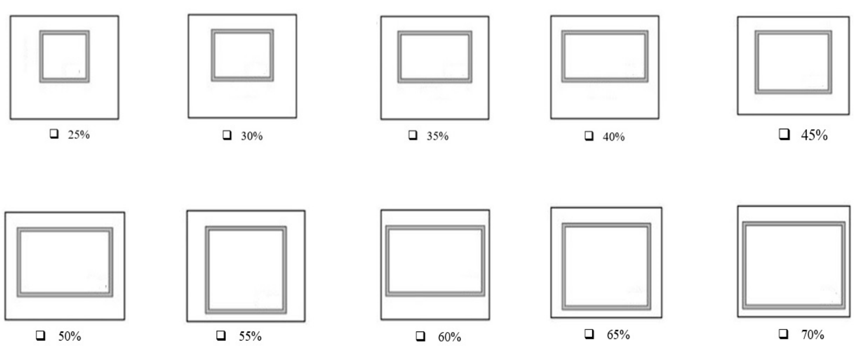
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5 or more

6. What is the number of rooms in your house?
   - ○ 1
   - ○ 2
   - ○ 3
   - ○ 4
   - ○ 5 or more
7. How many square meters (m^2) is the approximate area of your residence?
   The internal areas of the house include the living rooms, bedrooms, and laundry room, but do not include the garage, the outdoor veranda, etc. (see the example image below).
   - Residence area is . . . . m^2

8. What is the orientation (direction) and size of the windows in your living room?
   For example, Window 1: N—35%
   Below is an example image showing the orientation and overall size estimate.

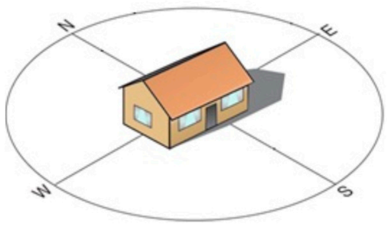
- ○ Window 1
- ○ Window 2
- ○ Window 3
- ○ Window 4
- ○ Window 5
- ○ Window 6

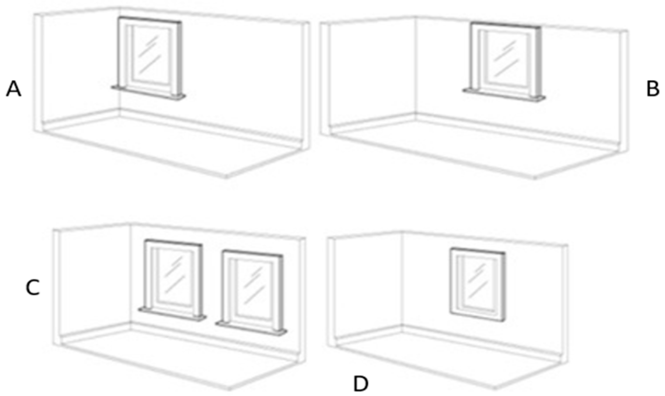




9. Which photo best depicts the placement of the windows on the walls? For reference, please see the image below.

- North Wall
- South Wall
- East Wall
- West Wall





10. During these periods, where do you usually spend your time?

○ From 8 am to 1 pm ☐ Living Room ☐ Bedroom ☐ Kitchen ☐
○ From 1 pm to 7 pm ☐ Living Room ☐ Bedroom ☐ Kitchen ☐
○ From 7 pm to 12 pm ☐ Living Room ☐ Bedroom ☐ Kitchen ☐

<u>Behavior and Awareness</u>

1. How satisfied are you with your building's energy expenditures/costs?
   ○ Very satisfied
   ○ Satisfied
   ○ Neutral
   ○ Dissatisfied
   ○ Very dissatisfied
2. If you were to improve your house's natural ventilation (save energy), which of the following solutions would you choose?
   ○ Make your living room more comfortable by installing a fan (if it does not have one already).
   ○ Customize window sizes.
   ○ Change the balcony windows (if applicable).
   ○ Change the ceiling height.
3. In terms of natural ventilation, which one is your favorite?
   ○ Big operable windows
   ○ Balcony
4. What is the most common adaptive behavior you use to make yourself comfortable?
   ○ Opening/closing window
   ○ Turning on/off the heater or cooler when feeling too hot/cold
   ○ Suitable dress based on thermal perception (comfort)
   ○ Other (shower, drink, swim, etc.)
   ○ Window blinds or shades

- ○ Air-conditioning
- ○ Ceiling fan

5. What is your preference?
    - ○ I prefer windows to be closed most of the time.
    - ○ I prefer to change the status of the windows frequently.
    - ○ I prefer to open my windows most of the time.
6. When it comes to saving energy, what is the extent to which you are willing to [not] use windows? Scale (0–10) . . ..
7. You will be more comfortable when the environment of your house is. . .

    Temperature: o Colder o A bit colder o Same o A bit hotter o Hotter
    Breeze (indoor air movement): o Slower o A bit lower o Same o A bit higher o Higher
    Humidity: o Drier o A bit drier o Same o A bit wetter o Wetter
8. What is your typical experience with the breeze airflow (air movement) in your home?
    - ○ Completely not acceptable
    - ○ Not acceptable
    - ○ Slightly not acceptable
    - ○ Slightly acceptable
    - ○ Acceptable
    - ○ Perfectly acceptable
9. Based on the time of day, you open and close your windows mostly for. . .. . . (multi-choice accepted)
    - **Opening**
        - ○ Fresh air
        - ○ For light and view
        - ○ As a habit
        - ○ When indoors is uncomfortable
        - ○ When outdoors is comfortable
    - Closing
        - ○ As a habit
        - ○ Due to dust
        - ○ Due to insect
        - ○ During my absence
        - ○ For privacy
        - ○ When outdoors is hot
10. In your living room, which one do you have?
    o Window o AC o Fan o All
11. In your living room, which one do you prefer?
    o Window o AC o Fan o All
12. Which of the following best describes how you operate your windows?
    - Opening:
        - ○ Open as long as possible when no other trigger affects the status.
        - ○ Open when feeling stuffy.
        - ○ Open after getting up in the morning.
    - Closing:
        - ○ Never close if no other trigger affects the open status.
        - ○ Close before sleeping.
        - ○ Close before leaving.
13. How much is your monthly electricity bill? . . ..
14. How do you use AC in your house's living room?
    - ○ Comfortable based
    - ○ Schedule based
    - ○ Mixed

Ventilation Options (VO)

1. Heating system
   - ○ Centralized
   - ○ Autonomous
2. Heat source type
   - ○ Traditional boiler
   - ○ Condensing boiler
   - ○ Heat pump
3. Cooling system
   - ○ Electric air conditioner
   - ○ Fans
4. What is the most common type of energy used in your home? (one option or more)
   - ○ Electricity
   - ○ Gas
   - ○ Solar
   - ○ Other (i.e., coal, wood, LPG, Paraffin, etc.)

Thermal and Overall Comfort (C)

1. What is the main reason you [if] feel uncomfortable about Indoor Air Quality?
   - ○ Stuffy air
   - ○ Bad/strong offensive odors
   - ○ Outdoor air
   - ○ Relative humidity
   - ○ N/A
2. During hot weather, how do you feel if one of the following cooling devices or strategies is your only option for cooling? (please select the relevant option)

(a) Airstream (AS) via openable balconies' doors

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

(b) Airstream (AS) via openable windows' doors

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

(c) Ceiling Fan

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

(d) Combination of Fan and AS

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

(e) Air-conditioning (AC)

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

(f) Combination of AC and air stream

COLD	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot
I Don't Use						

Appendix B. Occupants' Behavior Analysis Questions

1. Which of the following solutions would you prefer to do to have better natural ventilation (saving energy) in your house?
    - A. Make your living room more comfortable by installing a fan (if it does not have one already).
    - B. Customize window sizes.
    - C. Change the balcony windows (if applicable).
    - D. Change the ceiling height.
2. Which one do you prefer to have by natural ventilation?
    - A. Big operable windows
    - B. Balcony
3. Which of these adaptive behaviors do you usually use to make yourself comfortable?
    - A. Opening/closing window.
    - B. Turning on/off the heater or cooler when feeling too hot/cold.
    - C. Suitable dress based on thermal perception (comfort).
    - D. Other (shower, drink, swim, etc.).
    - E. Window blinds or shades.
    - F. Air-conditioning.
    - G. Ceiling fan.
4. How would you describe your preference?
    - A. Prefer windows to be closed most of the time.
    - B. Prefer to change the windows' status frequently.
    - C. Prefer to open windows most of the time.
5. Your window opening activity according to the time of the day is mostly for… (multi-choice accepted)
    - A. Fresh air.
    - B. For light and view.
    - C. As a habit.
    - D. When indoors is uncomfortable.
    - E. When outdoors is comfortable.
6. Your window closing activity according to the time of the day is mostly for… (multi-choice accepted)
    - A. As a habit.
    - B. Due to dust.
    - C. Due to insect.
    - D. During my absence.
    - E. For privacy.
    - F. When the outdoors is hot.
7. Which one do you have in your living room?
    A. Window B. AC C. Fan D. All
8. Which one do you prefer to use in your living room:
    A. Window B. AC C. Fan D. All
9. Which one best describes your window opening operation model?
    - A. Open as long as possible when no other trigger affects the status.
    - B. Open when feeling stuffy.
    - C. Open after getting up in the morning.
10. Which one best describes your window closing operation model?
    - A. Never close if no other trigger affects the open status.
    - B. Close before sleeping.
    - C. Close before leaving.

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