Journal of Science and Technology in Civil Engineering, HUCE, 2026, 20 (2): 67–87

THERMAL-RELATED OCCUPANT BEHAVIORS IN HIGHRISE APARTMENTS: EVIDENCE FROM A LARGE SCALE SURVEY IN HANOI AND HO CHI MINH CITY

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Article history:
Received 13/4/2026, Revised 07/5/2026, Accepted 11/5/2026

Abstract

The rapid growth of air-conditioning use in Vietnamese metropolitan areas has become a major contributor to residential energy consumption and peak electricity demand. However, empirical studies focusing on actual user behavior in high-rise apartment remain limited. This study investigates air-conditioning usage patterns and related energy consumption behaviors through a large-scale residential survey conducted in Hanoi and Ho Chi Minh City. A total of 950 valid questionnaires were collected, covering occupants' characteristics, building's characteristic and air-conditioner ownership, operating habits, temperature settings, seasonal usage patterns. Quantitative statistical analysis was applied to examine differences in usage behavior across cities, seasons, and occupant characteristic groups. The results reveal distinct behavioral patterns in thermal comfort, especially in air-conditioning operation, variations in usage intensity between hot and transitional seasons. Occupants' characteristic differences were observed in specific behavior. The findings highlight the critical role of occupant behavior in residential energy consumption and demonstrate substantial potential for energy savings through behavioral adjustments and improved user awareness. This study provides empirical evidence to support energy-efficient building design, occupant centric energy strategies in rapidly urbanizing tropical cities.

Keywords: air-conditioning behavior; residential energy consumption; occupant behavior; high-rise apartment; Vietnam.

https://doi.org/10.31814/stce.huce2026-20(2)-06

1. Introduction

The building sector is widely recognized as one of the largest contributors to global energy consumption and greenhouse gas emissions. Residential buildings, in particular, account for a significant share of urban energy demand due to the increasing use of electrical appliances and mechanical cooling systems. In Southeast Asia, the demand for cooling energy has increased substantially over the past decade due to rising temperatures, economic growth, and substantial improvements in living standards [1]. Vietnam represents a notable example of this transition. With the rapid expansion of urban housing, especially in large metropolitan areas such as Hanoi and Ho Chi Minh City (HCMC), high-rise apartment buildings have become a dominant residential typology. Along with this transformation, the use of air-conditioning systems and other electrical appliances has increased significantly, contributing to a rapid rise in household electricity consumption. In many cases, the gap between predicted and actual building energy use can largely be attributed to behavioral factors. Understanding

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how occupants interact with building systems is therefore essential for developing effective strategies to improve energy efficiency in residential buildings [2, 3].

Despite the growing number of research on occupant behavior and building energy use, empirical studies focusing on residential cooling behavior in Vietnam remain limited. Hanoi and HCMC provide an interesting comparative context in this regard. While HCMC has a tropical climate characterized by relatively stable high temperatures throughout the year, Hanoi experiences a humid subtropical climate with four distinct seasons. These climatic differences may lead to different cooling practices, thermal comfort expectations, and operational behaviors among residents.

This study aims to investigate occupant cooling behavior and energy consumption patterns in high-rise residential buildings in these two major Vietnamese cities. Through a large-scale survey of apartment residents, the research examines household electricity consumption, appliance ownership, cooling device operation, and the use of natural ventilation strategies. The study also explores residents' perceptions of thermal comfort and their attitudes toward energy responsibility and energy-efficient technologies. By comparing behavioral patterns between Hanoi and , this research seeks to identify how climatic conditions, spatial functions within dwellings, and occupant preferences influence residential energy use. The findings are expected to contribute to a better understanding of occupant-centered energy behavior in high-rise housing and to provide insights for improving building design and energy management strategies in rapidly urbanizing cities. The study highlights the importance of integrating behavioral considerations into the design and operation of residential buildings. Architectural solutions that facilitate natural ventilation, support mixed-mode cooling strategies, and respond to local climatic conditions may help reduce dependence on mechanical cooling systems while maintaining acceptable levels of indoor thermal comfort. Such approaches are particularly relevant for developing countries where rapid urban growth and increasing energy demand pose significant challenges for sustainable building development.

This study focuses on the assessment of actual thermal comfort in high-rise apartments, approached through the lens of occupant behavior. Rather than relying solely on conventional comfort models, the research emphasizes how residents interact with their indoor environment, particularly through occupancy patterns and air-conditioning (AC) usage, as a direct reflection of their thermal preferences and adaptive strategies. Based on large-scale empirical data collected from apartments in Hanoi and Ho Chi Minh City, the objective of this study is to identify and characterize thermal-related occupant behaviors, thereby revealing common routines and behavioral patterns that shape real-world thermal comfort conditions. These findings aim to provide a more behaviorally grounded understanding of comfort, supporting the development of more accurate building performance simulations and occupant-centric design strategies.

2. Literature review

In the era of rapid urbanization and global climate change, achieving a balance between thermal comfort and energy conservation in residential sectors, particularly in tropical regions like Vietnam, Hong Kong [4] or in Nigeria [5], has become a significant academic and practical challenge [6, 7]. Current discourse on thermal comfort typically revolves around two primary frameworks: the steady-state model and the adaptive model [8, 9]. The adaptive approach is increasingly recognized as more appropriate for naturally ventilated buildings in hot-humid climates, as it emphasizes the capacity of occupants to adjust their behavior and expectations in response to the local thermal environment [3, 10].

Existing studies in Vietnam have historically focused on low-rise "shop-houses" due to their prevalence, noting that their narrow, tube-like geometry often hinders natural ventilation and complicates thermal management [11]. Simultaneously, the rise of high-density vertical developments has been shown to alter urban microclimates through the Urban Heat Island (UHI) effect and restricted airflow [12]. While passive design strategies and building envelope optimizations are effective, they frequently fall short during extreme summer peaks, necessitating the use of mechanical cooling systems [13]. The impact of fenestration and shading is critical, as approximately 86% of total heat gains are transmitted through windows, making effective shading strategies a key determinant of overall energy performance [14]. Accordingly, there is a study that highlights six core architectural strategies for energy-efficient buildings in Vietnam, with a primary focus on thermal insulation, solar shading, and optimized air-conditioning systems. Quantitative assessment of building energy savings should be conducted from the early design stage to ensure performance-driven decision-making [14]. A critical observation in recent research is that relying solely on international thermal standards that often derived from temperate climates or controlled office settings. This mismatch can lead to an overestimation of cooling needs, encourages excessive AC use and energy waste, as it fails to account for the actual thermal tolerance and habitual cooling patterns of tropical residents [6, 15].

However, a significant research gap persists regarding the specific behavioral patterns of residents in high-rise apartments. While energy simulations often focus on technical parameters, there is a shortage of empirical data derived from large-scale field surveys that clarify how occupants actually interact with their cooling systems. Specifically, there is limited understanding of AC usage trends, preferred cooling modes, and typical temperature set-points in the unique climatic contexts of Hanoi and HCMC. Addressing this gap by analyzing user-reported data is essential for developing realistic energy-efficient design guidelines and operational strategies for modern high-rise housing.

Passive design strategies, particularly natural ventilation and daylighting, remain fundamental to achieving thermal comfort in the subtropical climate of Hanoi. Historical precedents from Indochinese architecture demonstrate that adaptive building envelopes that utilizing dual-layered systems of internal glazing and external shutters, enable residents to regulate airflow effectively, harnessing cooling Southeast breezes in summer while mitigating cold winter winds. Such vernacular architectural solutions are instrumental in reducing the energy demand for both artificial lighting and HVAC systems [16].

However, recent studies indicate that occupant behavior exerts an influence on building energy performance that is comparable to, or even exceeds, that of technical specifications [17]. Interaction with the building envelope, specifically the frequency of opening windows and doors, directly dictates indoor air quality (IAQ). For instance, while sealing bedrooms at night may conserve thermal energy, it can lead to CO_2 concentrations exceeding 3,500 ppm, whereas even occasional ventilation can significantly enhance IAQ [17].

The discrepancy between predicted and operational energy performance is often exacerbated by forecasting inaccuracies regarding solar radiation and ambient temperatures. In high-temperature conditions, temperature forecast errors can result in an overestimation of cooling loads by 3.7% to 8.3% [18]. Integrating user-operated shading devices has been identified as a critical strategy to buffer these negative impacts. Ultimately, the adoption of such green solutions and energy-saving technologies is heavily moderated by socio-demographics [19]. A higher Willingness to Pay (WTP) is typically observed among cohorts with higher income and educational levels, particularly women with high environmental awareness. Moreover, household composition, specifically the presence of elderly residents and children who serves as a primary determinant in the selection of domestic thermal and energy management strategies [17].

3. Methodology

3.1. Sampling and data collection

This study employed a quantitative survey approach to investigate occupant behavior and energy use practices in high-rise residential buildings in Vietnam. The research was conducted in two major metropolitan areas, Hanoi and HCMC, which represent different climatic conditions and urban lifestyles within the country. The survey in this research were gathered within German government funded CAMaRSEC project on 2021-2023 [20]. A total of 950 questionnaires were distributed, with 475 surveys allocated to each city. The sample size was determined using the Cochran formula to ensure statistical representation of high-rise apartment residents (Eq. (1)). With a 99% confidence level and a 4.2% margin of error, the minimum required sample is approximately 950 respondents. This robust sample size provides the necessary statistical power for advanced multivariate analyses (Eq. (2)):

$$n = \frac{Z^2.p.(1-p)}{e^2} \tag{1}$$

where Z is the standard score; p is the estimated proportion; e is the margin of error.

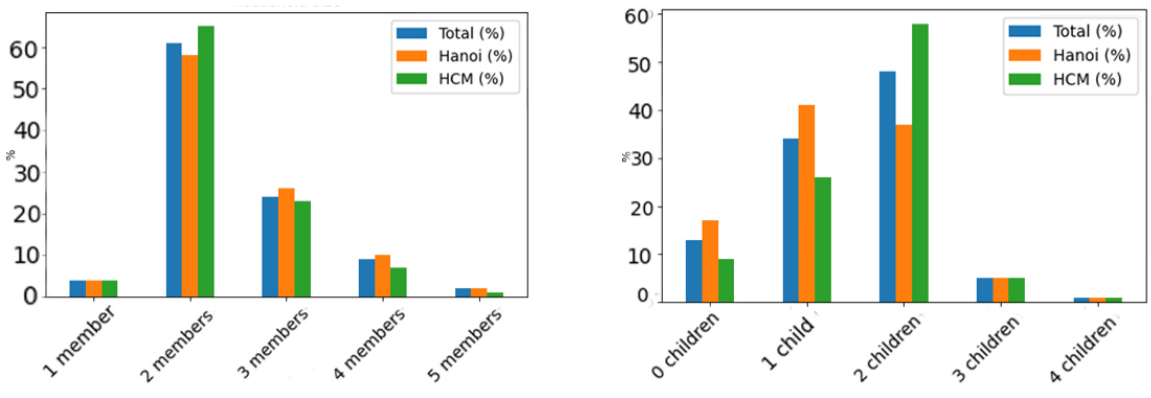
$$n = \frac{2.58^2.0.5.0.5}{0.042^2} = 944 \tag{2}$$

The determination of the sample size was guided by two primary criteria: minimizing sampling error via the Cochran formula, and satisfying the requirements for multivariate analysis [21]. The survey instrument consists of 35 primary variables and sub factors, categorized into specific branches tailored to two distinct region. The ideal ratio of observations to variables should range between 5:1 and 10:1 [18]. Even when analyzed independently by region, each subset of 475 responses maintains a ratio of 13.6:1, well above the recommended threshold. With a total of 950 valid responses, yielding an overall ratio of approximately 27:1. This study not only ensures the reliability of Exploratory Factor Analysis (EFA) but also enhances the validity of specialized statistical tests.

The target respondents comprised residents aged 18 years and above currently residing in high-rise apartment buildings within the urban areas of Hanoi and HCMC from 2012. The surveyed units were strategically selected to ensure a diverse representation of building conditions. This included an even distribution across four primary orientations (25% each for SW-S-SE, NW-N-NE, SW-W-NW, and SE-E-NE) and a stratified selection of floor levels: under 10 floors (30%), 10-15 floors (29%), 16-20 floors (26%), and above 20 floors (15%).

Furthermore, the survey covered a broad spectrum of housing typologies, ranging from social housing to luxury apartments, all constructed between 2010 until 2023. Respondents were further selected to ensure diversity in gender, age group, number of members (Fig. 1), income level (53% from 15.000.000 – 29.999.999 VND/ month, 29% from 30.000.000 - 44.999.999 VND/ month in Hanoi; and 32% from 15.000.000 – 29.999.999 VND/ month, 41% from 30.000.000 - 44.999.999 VND/ month in HCMC), occupantion various from big entrepreneur owner to unskilled worker (mostly are skilled worker and self-employed or small business owner), and educational background, thereby capturing a comprehensive representation of occupant characteristics and behavioral patterns. Although there is an income disparity between the two regions, their electricity bill payments are similar, ranging from 409,201 to 688,160 VND per month.

Data were collected using a combination of online and offline questionnaires. Participation was voluntary, and all personal information was anonymized to ensure privacy and confidentiality. After screening for completeness and consistency, valid responses were retained for analysis.



(a) Household size

(b) Number of children

Figure 1. Distribution of the collected responses

The questionnaire was structured into three main sections. The first section collected information on occupant characteristics, including demographic information, residential history, length of residence, and previous city of residence. These variables were included to examine whether individual background and regional cultural influences may affect household energy behavior and comfort preferences. The second section focused on building characteristics. Respondents were asked to provide information about their apartment conditions, including building orientation, window configuration, envelope materials, and the presence of issues such as moisture or mold. These factors were considered important in understanding the environmental conditions that may influence occupant thermal comfort and behavioral responses. The third section examined occupant operational behavior related to indoor thermal comfort. This section included questions regarding the use of air-conditioning systems, such as preferred temperature settings, operation modes, and duration of use. In addition, respondents were asked about the frequency and timing of natural ventilation practices, including window opening behavior.

3.2. Analytical framework

The survey dataset was first systematically cleaned and standardized using Python-based data processing workflows [22]. This included harmonizing categorical variables such as AC modes, room types, correcting inconsistent labels, and removing incomplete or anomalous responses. All frequency-based responses (Weight: Never: 0, Rarely: 0.25, Sometimes: 0.5, Often: 0.75, Always: 1) were converted into numerical scales and normalized to ensure probabilistic consistency. The collected data were statistically processed to convert qualitative responses into ratio scales and Likert scales, facilitating frequency analysis and data classification [23]. The survey specifically investigated mixed cooling strategies, such as the combined use of air-conditioning and natural ventilation, including the frequency, duration, and motivations behind these practices. Behavioral questions were quantified to determine precise response volumes, enabling correlation comparisons across different target groups. Behavioral variables related to cooling practices, such as AC modes, standalone fan usage, mixed-mode operation (AC and fan at the same time), and natural ventilation were then transformed into probabilistic behavior profiles. A weighted scoring system was applied to convert ordinal frequency responses into continuous values, where each response category was assigned a normalized weight (from 0 to 1) allowing the study to quantify patterns of cooling behavior and compare operational strategies across different seasons, spaces within the dwelling, and between the two climatic regions.

The study conducted a comparative analysis between empirical survey data and current standards, specifically TCVN 14214:2024 Residential and public buildings - Requirements for microclimate parameters in the room [24], to identify the gap between theoretical guidelines and actual usage. Distribution tables were established to determine the thermal comfort temperature threshold where the highest percentage of user satisfaction was achieved. Furthermore, variables regarding the quantity of electrical appliances and purchasing decision criteria, such as brand, price, and energy efficiency, were subjected to weight analysis to identify dominant factors.

The research also evaluated user trust in green certifications and the perceived responsibilities of various stakeholders, including developers, architects, and operators, in promoting green buildings. Overall, the survey design enabled the collection of comprehensive data on occupant characteristics, building conditions, and operational behaviors. This provides a practical basis for analyzing how climatic context and user behavior influence energy consumption patterns in high-rise residential buildings, serving as a foundation for design recommendations during the early stages of a project.

These weighted probabilities were aggregated to construct a Behavior Index (*BI*), representing the intensity of each cooling behavior under specific seasonal and spatial conditions.

$$BI = \sum_{i=1}^{n} (P_i.W_i) \tag{3}$$

where BI is the behavior index; P_i is the percentage of answers; W_i is the weight.

To enhance interpretability in the context of energy use, the BI was further extended into an Energy Behavior Index (EBI) by incorporating relative energy weights associated with each cooling mode, reflecting their operational energy intensity. This allowed differentiation between high-energy mechanical cooling such as cooling and heating modes, hybrid strategies (AC combined with fan), and low-energy or passive behaviors (fan-only and natural ventilation) to creating heat map between season and cooling mode.

$$EBI = BI.E_m \tag{4}$$

where EBI is the energy behavior index; BI is the behavior index; E_m is the energy weight of mode m.

Table 1. Cooling mode with energy weights and rationale

Mode	Energy Weight	Rationale
Cool / Heat	1.0	Highest intensity: Compressor operates at full capacity.
Auto	0.9	High
Dry	0.7	Moderate
Eco	0.6	Economical: Power-limited operation to reduce consumption.
AC fan mode	0.6	Using fan mode of AC only
AC + Fan	0.8	Hybrid intensity: Combines AC power with an external electric fan.
Fan only	0.3	Low: Only the standalone fan operates; low energy impact.
Window	0	Passive: Zero electrical energy consumption.

Statistical analyses, including descriptive statistics and comparative visualization, were conducted to examine seasonal variations, spatial differences (Hanoi vs. HHCMC), and behavioral patterns across household characteristics such as household size, income level. The resulting indices enabled a consistent comparison of occupant behavior across different contexts and were used to identify trends in thermal preference, cooling strategy selection, and energy-related attitudes. Furthermore, the framework supports distinguishing between adaptive behaviors and mechanically conditioned operation, providing a basis for linking occupant behavior to building energy performance.

4. Results

4.1. Occupant-preferred thermal comfort temperatures in residential buildings

Based on the collected survey responses, the air-conditioning set point temperatures selected by occupants under thermally comfortable conditions in Hanoi show an average deviation of approximately 1.22 to 3.72 °C, with the maximum recorded deviation reaching 4.36 °C. This indicates that the thermal comfort threshold in Hanoi tends to vary more significantly, likely due to the need to adapt to the city's four-season climate, whereas HCMC experiences two main seasons: the dry and rainy seasons.

With relatively high average temperatures throughout the year, the recorded thermal comfort threshold in HCMC is approximately 25.3 °C. In Hanoi, the tendency not to use air conditioning in bedrooms during spring, autumn, and winter is relatively high, reaching 85% in spring. Cases where AC is not used in living rooms were also recorded during autumn and winter, accounting for 66% and 82%, respectively.

These findings suggest that, due to the multi-generational living patterns commonly found in Vietnamese households, air conditioning in the living room in Hanoi is used more frequently, except during winter months, to maintain thermal comfort for the majority of household members. In contrast, the non-use rate of AC in bedrooms is higher, which can be attributed not only to occupant characteristics but also to the lower nighttime outdoor temperatures in Hanoi. Furthermore, bedroom temperatures tend to be higher than the AC set point temperatures in living rooms, as bedrooms are typically smaller, more enclosed spaces with lower occupancy levels compared to living rooms.

The experimental results of this study reveal several differences compared with previous research. Earlier studies based on regression models using Southeast Asian datasets, applied to Vietnam in naturally ventilated buildings, indicate that the comfort temperature range in Hanoi is approximately 24.4–28.8 °C, which is lower than that of HCMC (27.7–28.8 °C). This difference is commonly attributed to climatic characteristics: Hanoi experiences a cold winter, whereas HCMC has a more stable tropical climate [11].

However, when thermal comfort is examined under AC conditions, the comfort temperature tends to change. According to the Vietnamese standard TCVN 14214:2024: Residential and public buildings - Requirements for microclimate parameters in the room [24], thermal comfort temperatures are classified by season rather than by climatic region. Specifically, during the hot season, the recommended comfort temperature is 26 °C for both living rooms and bedrooms, while in the cold season the recommended value is 24.5 °C for these spaces. Nevertheless, the results obtained from the 950 survey responses in this study indicate noticeable deviations from these recommended values.

The findings suggest that geographical location and climatic conditions still influence the selected air-conditioning set point temperatures across different indoor spaces. In HCMC, the lowest recorded set point temperature is 16 °C. The temperature selections in bedrooms and living rooms are relatively similar. During the hot season, the most frequently selected temperature is 25 °C (accounting for approximately 23–26% of responses). During the rainy season, 28 °C represents 74% of the selections in living rooms, while 27 °C is the most common setting in bedrooms (27%). On average, the selected temperature in HCMC during the hot season is 23.77 °C for living rooms and 23.95 °C for bedrooms. In the rainy season, the average values increase to 27.25 °C in living rooms and 26.21 °C in bedrooms (Table 2).

In contrast, when air conditioning is used in Hanoi, the observed set point temperatures show a different pattern from that reported in previous studies. Instead of lower temperatures, as suggested by studies on naturally ventilated buildings, the average set point temperatures in Hanoi are relatively higher, ranging from 25.75 to 27.49 °C in living rooms and from 26.3 to 27.7 °C in bedrooms. This result suggests that thermal comfort preferences under air-conditioned conditions may not follow the same climatic patterns identified in naturally ventilated environments and may also be influenced by user behavior and adaptive practices.

Table 2. Average AC set point temperatures and selection rates by location, season, and room type

Location	Season	Room type	Average set-point temperature	Highest selection rate	Lowest selection rate
Hanoi	Spring	Living room	26.31 °C	23 °C: 85%	28 °C: 3%
		Bedroom	27.7 °C	No AC: 85%; 27 °C: 8%	25 °C: 1%
	Summer	Living room	25.75 °C	26 °C: 30%	29 °C: 2%
		Bedroom	26.3 °C	27 °C: 32%	22 °C: 2%
	Autumn	Living room	27.37 °C	No AC: 76%; 29 °C: 12%	24,25,26 °C: 1%
		Bedroom	27.78 °C	No AC: 66%; 28 °C: 17%	24 °C: 1%
	Winter	Living room	27.49 °C	No AC: 82%; 28 °C: 7%	24 °C: 1%
		Bedroom	28.31 °C	No AC: 79%; 28 °C: 11%	25,30 °C: 1%
HCM	Dry	Living room	23.77 °C	25 °C: 26%	16 °C: 1%
		Bedroom	23.95 °C	25 °C: 23%;	16 °C: 1%
	Rainy	Living room	27.25 °C	28 °C: 74%	23 °C: 1%
		Bedroom	26.21 °C	27 °C: 27%;	23, 30 °C: 2%

Overall, these findings suggest that geographical location and climatic conditions significantly influence occupants' behavior and perceived thermal comfort preferences.

4.2. *Occupant Attitudes Toward Energy Consumption, Appliance Use, and Green Buildings*

One important factor for understanding household energy consumption behavior in high-rise apartment buildings in Vietnam is the relationship between electricity consumption levels, appliance ownership, and the annual use patterns of cooling devices.

The survey results indicate that the average monthly electricity consumption of 450 apartments in Hanoi is 286.99 kWh, while the average consumption of 450 apartments in HCMC is 326.34 kWh. In both cities, the consumption range of 201–300 kWh per month represents the largest proportion of households, accounting for 39% in Hanoi and 29% in HCMC. To better understand whether the difference in electricity consumption between the two cities is related to household lifestyles or appliance ownership, the survey also examined the types and numbers of major electrical appliances used in each household (Fig. 2). The results show that households in Hanoi generally own a slightly higher number of major electricity-consuming appliances compared to those in HCMC. On average, households in Hanoi own 2.3 air conditioners, while the average in HCMC is 2.05 units. Similarly, the number of televisions per household is 1.54 in Hanoi, compared with 1.23 in HCMC.

These findings indicate that a higher number of appliances does not necessarily lead to higher electricity consumption. Instead, energy use appears to be more strongly influenced by occupant behavior and climatic conditions, particularly the seasonal temperature variations in Hanoi, where cooler autumn and winter seasons reduce the need for air-conditioning.

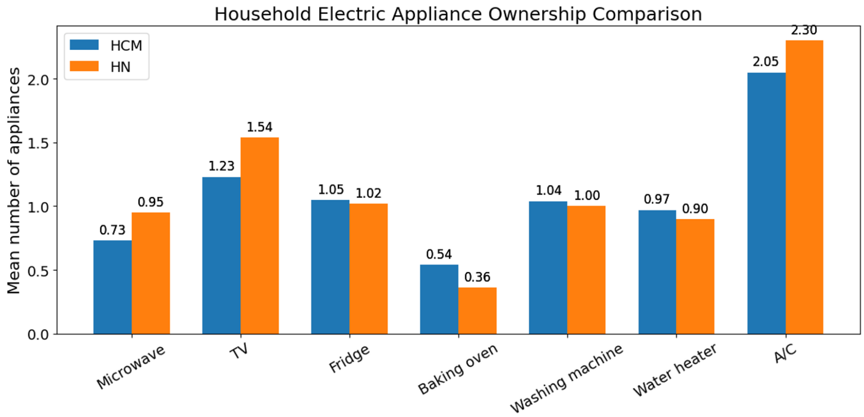


Figure 2. Average number of appliances per household

To further understand the factors that influence energy-related behavior, the survey also investigated whether price, brand, or energy efficiency labels affect household decisions when purchasing electrical appliances. The results show that price is the most influential factor for most respondents. In Hanoi, nearly 99% of participants considered price to be important or very important when selecting electrical appliances. In contrast, brand preference does not show a significant difference between Hanoi and HCMC. Among the three factors examined, energy efficiency labels were considered the least important factor influencing purchasing decisions (Fig. 3).

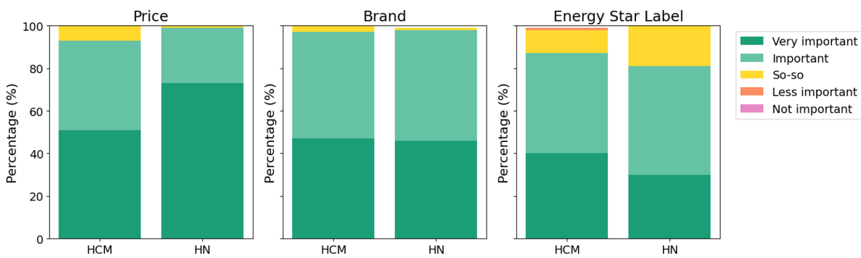


Figure 3. Importance of decision factors when purchasing electric appliances

To explore this issue further, respondents were asked about their level of interest in green building certifications and energy-saving solutions. The results reveal that residents in Hanoi generally show higher levels of interest compared to those in Ho Chi Minh City, with differences ranging from 8% to 20% depending on the indicator (Fig. 4). That difference between HN and HCMC might depend on different educational levels of the surveyed households. For example, approximately 89% of Hanoi residents expressed interest in learning more about energy-saving solutions, compared to about 80% in HCMC. In addition, around 60% of respondents in Hanoi expressed trust in energy efficiency labels, whereas the corresponding figure in HCMC is only 39%. These findings help explain why electricity consumption in Hanoi is lower than in HCMC despite the higher number of appliances. The difference may partly be attributed to higher awareness of energy-saving practices and seasonal climatic conditions that reduce cooling demand.

Although awareness of green building certification systems among surveyed residents is relatively limited, the survey results reveal an interesting contrast between awareness and trust. In Hanoi, approximately 86% of residents reported that they were not familiar with green building certification systems. Despite this limited awareness, respondents generally expressed a relatively high level of trust in such certifications. Nearly 50% of respondents indicated that they either strongly trust

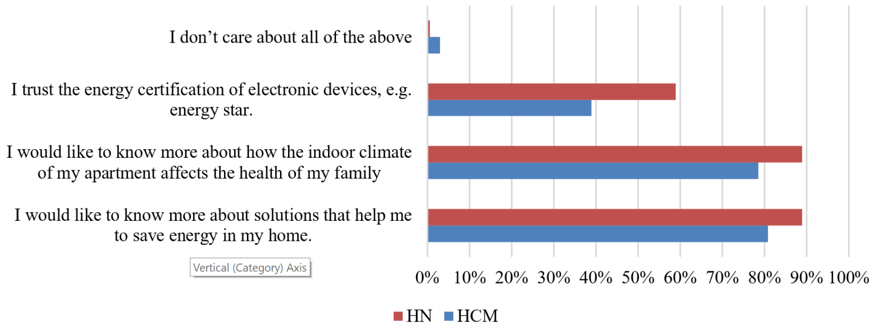


Figure 4. Respondents' interest in information on household energy-saving solutions

or highly trust green building certifications (Fig. 5). This finding suggests that even though public knowledge about green certification systems remains low, there is a generally positive perception of their credibility and potential benefits.

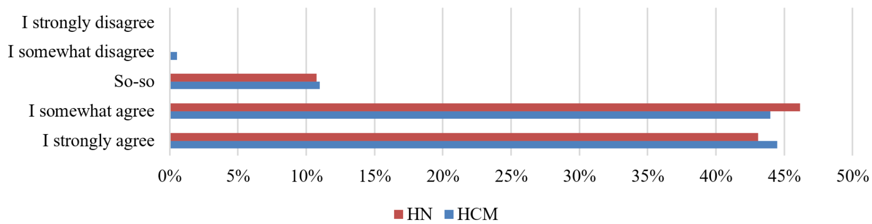


Figure 5. Respondents' trust in green building certifications

The survey also investigated respondents' perceptions regarding which stakeholders should bear primary responsibility for energy consumption in residential buildings. The results indicate that 35% to 60% of respondents believe that residents themselves are the primary actors responsible for building energy consumption. To quantify these perceptions, a Responsibility Score was calculated using a weighted Likert-scale approach. Responsibility Score (Eq. (5)):

$$RS = \frac{\sum_{i=1}^{n} (P_i.W_i)}{100} \tag{5}$$

where RS is the responsibility score, P_i is the percentage (%) of responses at each level and W_i is the weight assigned to that level [7].

The highest score was assigned to consumers or occupants ($RS = 4.56/5$), followed closely by architects ($RS = 4.47/5$). These results suggest that effective energy management in high-rise residential buildings requires collaboration between design professionals and occupants. In other words, architects and designers need to better understand actual occupant behaviors in order to develop building strategies that are both energy-efficient and practical for everyday use. In HCMC, 96% (from strongly agree to somewhat agree) of respondents believe that responsibility should primarily lie with building users, indicating a strong sense of personal responsibility. In contrast, respondents in Hanoi show greater expectations toward institutional actors, with 98% indicating that developers and government authorities should play a significant role in managing building energy consumption (Fig. 6).

Overall, these findings suggest that energy responsibility is perceived as a shared obligation among multiple stakeholders rather than being attributed to a single actor. Consequently, effective strategies for reducing energy consumption in high-rise housing should integrate behavioral considerations, design solutions, and policy support to ensure coordinated action among all stakeholders.

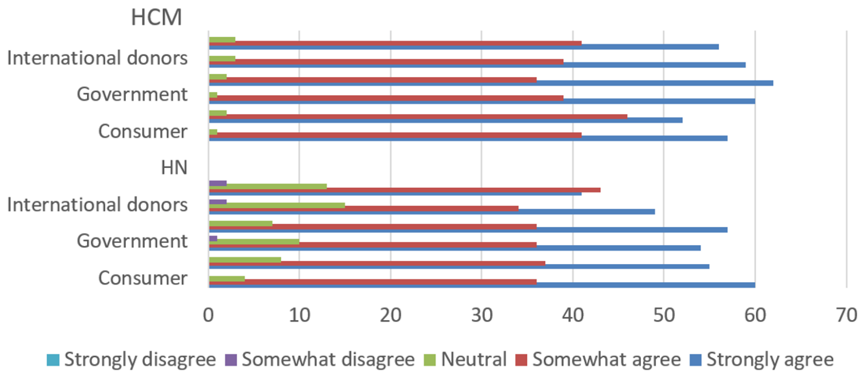


Figure 6. Perceived responsibility of different stakeholders in promoting energy-efficient buildings

The findings reveal an interesting paradox: occupant behavior and climatic conditions exert a stronger influence on energy consumption than the mere ownership of appliances. In appliance selection, cost emerges as the dominant factor, significantly outweighing energy labeling considerations. In the case of Hanoi, approximately 99% of respondents prioritize cost, while energy labels are ranked as the least important factor among the three key criteria (cost, brand, and energy labeling). A notable inconsistency is observed between high levels of energy-saving awareness and actual purchasing decisions, which tend to favor lower-cost options. This suggests that household energy-saving strategies are predominantly behavior-oriented rather than technology-oriented, relying more on adaptive usage practices than on investments in high-efficiency appliances.

Responsibility scores further reinforce this pattern, with the highest ratings attributed to users (4.56/5) and architects (4.47/5). This highlights that energy efficiency cannot be effectively achieved without the integration of design (architectural strategies) and operation (user behavior). When ranking the relative influence of key factors on energy performance within this study, the following hierarchy emerges:

- Occupant behavior and climate (most influential): These factors directly determine real-world energy consumption and can outweigh the impact of appliance ownership.
- Appliance cost: A critical determinant of household access to energy-efficient technologies.
- Coordinated responsibility (design–operation): A foundational factor for long-term energy optimization.

These factors operate synergistically rather than independently. A building may incorporate green design strategies and modern appliances, yet still exhibit high energy consumption if user behavior is not aligned or policy support is insufficient. However, in the short-term context of Vietnam, climate-adaptive behavior remains the most immediate and impactful driver of household electricity consumption.

4.3. Occupant behavior in different thermal mode

In addition to appliance ownership and purchasing preferences, occupant operational behavior plays a critical role in determining household energy consumption, particularly in the way residents respond to indoor thermal comfort needs. In high-rise residential buildings, thermal comfort is typically achieved through various adaptive strategies, including the use of AC, electric fans, natural ventilation through window opening, or combinations of these approaches. These behavioral choices directly influence the overall energy demand of the building. The survey results reveal notable differences between Hanoi and HCMC in the spatial distribution and usage of cooling devices. In Hanoi, air conditioners are installed in only about 50% of living rooms, whereas nearly 99% of bedrooms are equipped with AC units (Fig. 7). This pattern suggests that cooling devices in Hanoi are primarily prioritized for sleeping spaces rather than shared living areas. In contrast, the warmer year-round climate in HCMC leads to more consistent cooling demand across different indoor spaces. These differences can be explained not only by cultural habits and patterns of space usage, but also by Hanoi's four-season climate, particularly the relatively cold winter months, which significantly reduce the need for air conditioning in living rooms during certain periods of the year. Overall, the results indicate that air-conditioning combined with adaptive behaviors such as fan use and window opening forms the dominant strategy for achieving thermal comfort.

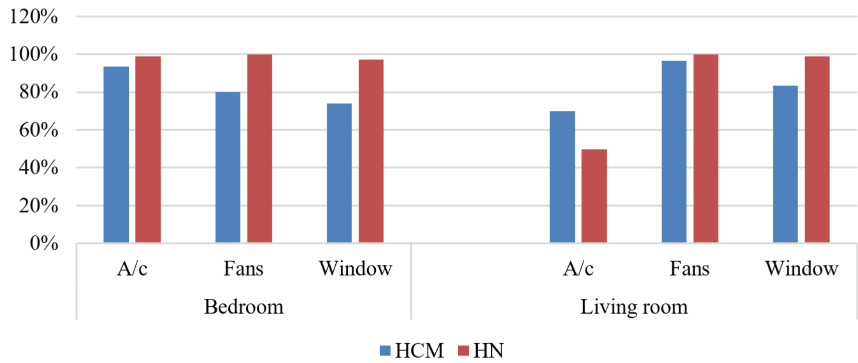


Figure 7. Ventilation ownership in bedroom and living room

During the dry season, cooling modes such as Auto and Cool are frequently used in bedroom in HCM. Approximately 70–80% of respondents reported using these modes often or always, suggesting that air-conditioning remains the primary cooling method in bedrooms. In contrast, the heating function is almost never used, with more than 65% reporting "never", which reflects the tropical climate conditions in HCMC where heating demand is practically nonexistent. Fan usage represents an important supplementary cooling strategy. Around 45–55% of respondents reported using fans often or always, while another significant proportion uses them occasionally. Similarly, eco mode is used by a notable proportion of households, indicating an increasing awareness of energy-saving settings during AC operation. A particularly significant behavioral pattern is the combined use of AC and fans. More than 50% of respondents reported using AC together with fans often or always, suggesting that occupants rely on air movement to enhance perceived cooling while potentially reducing AC intensity. Natural ventilation also remains relevant in bedroom cooling strategies. Approximately 40–60% of respondents reported opening windows sometimes or often, indicating that residents continue to incorporate passive cooling strategies even when mechanical cooling systems are available (Fig. 8).

During the rainy season the overall behavioral pattern remains largely consistent. Cooling modes such as Auto and Cool continue to dominate, with similar frequencies of use. However, fan usage and combined AC–fan operation slightly increase, reflecting the need for enhanced air movement to improve comfort under higher humidity conditions (Fig. 9).

However, cooling behavior in living rooms shows a somewhat different pattern compared with bedrooms, reflecting the different functional roles of the space and occupancy patterns.

During the dry season, the use of Auto and Cool modes remains common, although slightly less dominant compared with bedrooms. Approximately 60–70% of respondents reported using these modes often or always, suggesting that AC is still a primary cooling strategy in living rooms. Fan usage appears to be more prominent in this space. Around 60–70% of respondents reported using fans often or sometimes, indicating that fans play a larger role in living rooms compared with bed-

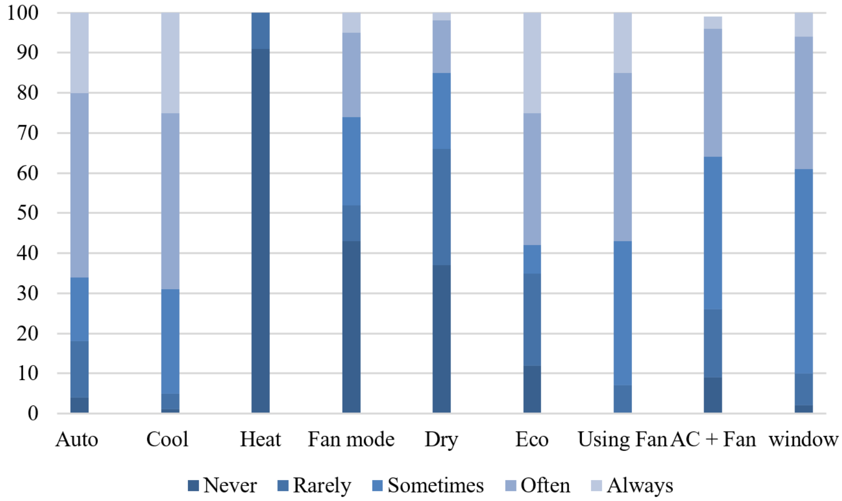


Figure 8. Frequency of cooling modes in living room during the dry season in HCMC

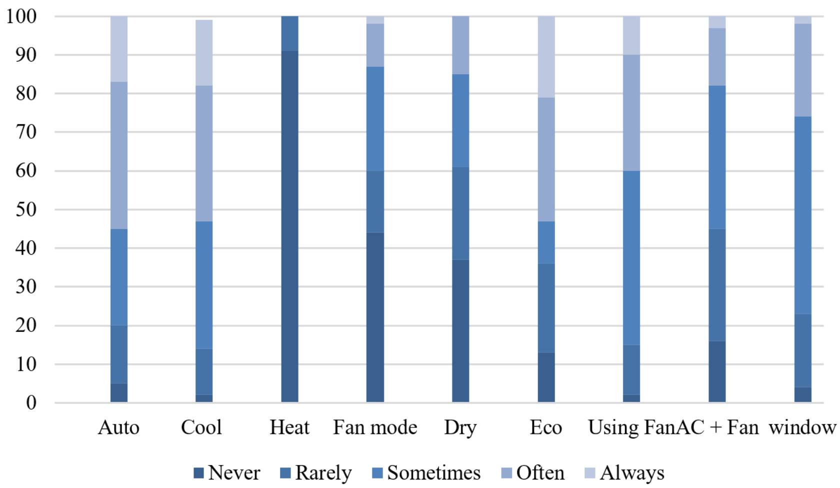


Figure 9. Frequency of cooling modes in living room during the rainy season in HCMC

rooms, possibly because these spaces are used more intermittently throughout the day and involve multiple occupants. Similar to bedroom behavior, heating functions are almost never used, reinforcing the climate-driven nature of appliance operation in HCMC. The combined use of AC and fans is also widely observed in living rooms, with a large proportion of respondents reporting frequent use. This combination likely reflects a strategy to improve thermal comfort while maintaining moderate AC settings. Window opening remains another common adaptive behavior. A significant share of respondents reported opening windows sometimes or often, demonstrating that natural ventilation is still integrated into daily cooling practices despite the availability of air conditioning (Fig. 10)

During the rainy season, several behavioral adjustments can be observed. Fan usage becomes even more prevalent, and the proportion of respondents using AC together with fans increases, suggesting that occupants respond to high humidity by increasing air circulation rather than relying solely on mechanical cooling. At the same time, window opening remains relatively frequent, indicating that residents continue to combine natural and mechanical cooling strategies depending on outdoor conditions (Fig. 11).

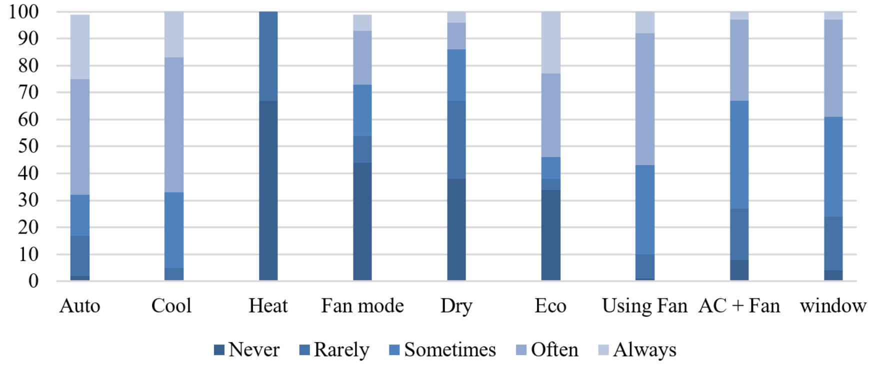


Figure 10. Frequency of cooling modes in bedroom during the dry season in HCMC

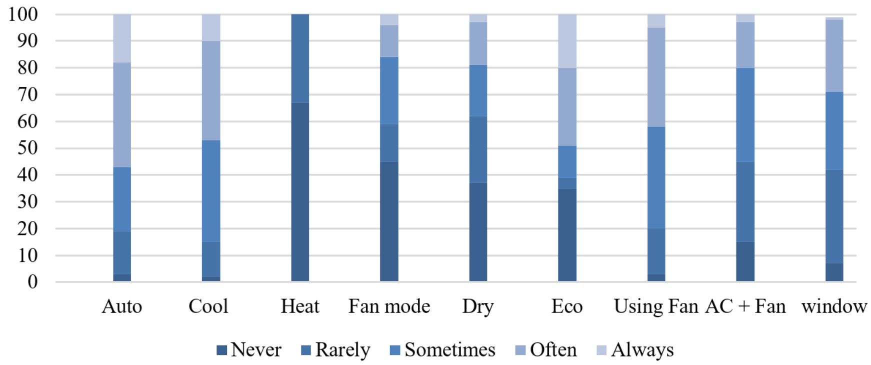


Figure 11. Frequency of cooling modes in bedroom during the rainy season in HCMC

A comparison between the two spaces reveals several important behavioral differences. Overall, living room cooling behavior in HCMC reflects a flexible and adaptive approach, with greater reliance on fans and mixed-mode cooling compared with bedrooms. First, AC usage is more concentrated in bedrooms than in living rooms. This pattern likely reflects the importance of maintaining thermal comfort during sleep, which leads households to prioritize cooling devices in sleeping areas. Second, fans play a more significant role in living rooms, where occupants appear more willing to rely on lower-energy cooling strategies. This behavior may be related to the shorter duration of occupancy and the more flexible comfort expectations in shared spaces. Third, mixed cooling strategies (AC + fan + window opening) are widely observed across both spaces, suggesting that occupants actively adjust their cooling behavior rather than relying exclusively on a single device. These findings highlight the importance of considering spatial usage patterns when analyzing household energy consumption behavior. Overall, the results suggest that seasonal differences influence the intensity of cooling strategies rather than the fundamental cooling behavior patterns of residents.

The survey results reveal clear seasonal variations in cooling behavior in bedrooms in Hanoi, reflecting the city's humid subtropical climate with distinct four seasons with temperature differences. During spring, the majority of respondents reported rarely or never using cooling modes such as Auto and Cool, indicating relatively moderate thermal conditions (Fig. 12). Instead, passive strategies and low-energy solutions play a larger role. Window opening and occasional fan use appear as the dominant behavioral responses for achieving thermal comfort. In summer, however, cooling behavior changes significantly. The use of AC modes such as Auto and Cool increases sharply, with a large proportion of respondents reporting frequent or constant operation. Fan use and the combined operation of AC and fans also increase, suggesting that residents adopt mixed cooling strategies to improve comfort during periods of high temperature and humidity. During autumn, cooling demand gradually decreases compared to summer. While AC is still used, the frequency of operation declines, and natural ventilation through window opening becomes more prominent. This transitional period reflects adaptive behavior where occupants rely less on mechanical cooling and more on passive strategies. In winter, mechanical cooling is rarely used. Most respondents reported never using cooling modes, while the heating function becomes more relevant, although still used by a relatively small proportion of households. Window opening and occasional fan use remain part of daily practices but at lower frequencies. Overall, bedroom cooling behavior in Hanoi is strongly influenced by seasonal climatic variation, with intensive AC usage during summer and predominantly passive or low-energy strategies during cooler seasons.

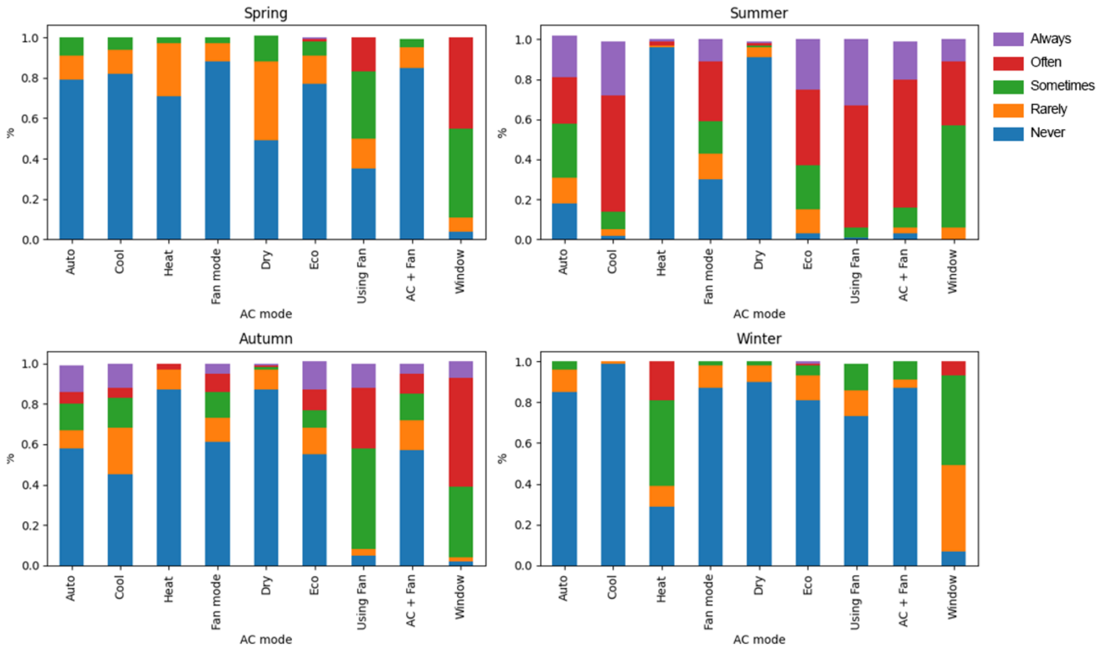


Figure 12. Frequency of cooling modes in bedroom in Hanoi

Cooling behavior in living rooms follows a similar seasonal pattern but with lower reliance on AC compared with bedrooms (Fig. 13). In spring, most respondents reported rarely using AC modes, while window opening and occasional fan use represent the dominant strategies for maintaining thermal comfort. The living room appears to rely more heavily on natural ventilation compared with bedrooms. During summer, the use of AC increases substantially. However, compared to bedrooms, the living room shows a higher proportion of fan use and mixed cooling strategies, such as combining AC with fans or natural ventilation. This behavior likely reflects the intermittent use of living rooms and the presence of multiple occupants. In autumn, mechanical cooling demand decreases again, and natural ventilation becomes a preferred strategy. Window opening shows a relatively high frequency of use, suggesting that residents take advantage of favorable outdoor conditions. In winter, air-conditioning for cooling is almost entirely absent in living rooms. Window opening remains relatively common during mild periods, while heating functions are occasionally used but still limited overall.

These results indicate that living room cooling behavior in Hanoi relies more heavily on adaptive strategies such as natural ventilation and fan use, while AC is prioritized primarily for bedrooms. First, AC use is highly seasonal, with peak operation occurring in summer and minimal use in winter.

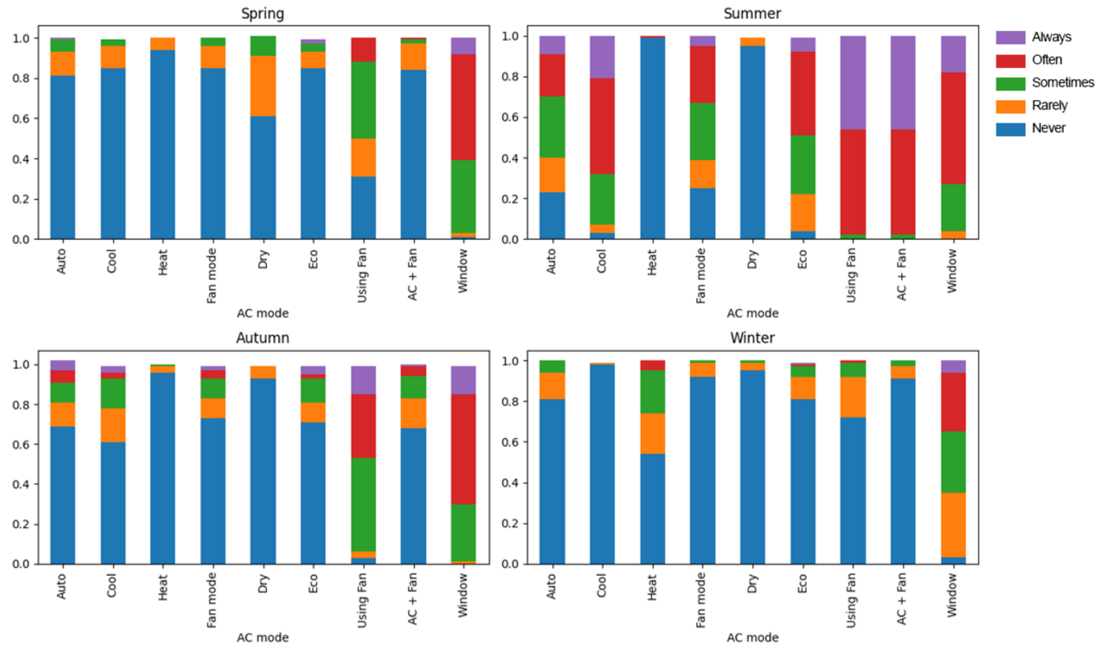


Figure 13. Frequency of cooling modes in living room in Hanoi

This pattern reflects the strong influence of Hanoi's seasonal climate. Second, mixed-mode cooling strategies are widely observed, particularly during the warmer seasons. Residents frequently combine AC with fans to enhance thermal comfort while potentially reducing energy consumption. Third, natural ventilation remains an important adaptive behavior throughout the year, particularly in spring and autumn when outdoor thermal conditions are favorable. Finally, space usage plays an important role in determining cooling behavior. Bedrooms consistently exhibit higher reliance on AC compared with living rooms, reflecting the importance of maintaining comfortable sleeping conditions.

A comparison between Hanoi and HCMC reveals important differences in the annual patterns of cooling behavior. In HCMC, where the climate remains consistently hot and humid throughout the year, cooling behavior is relatively stable across seasons. AC is frequently used in both bedrooms and living rooms, and the combined use of AC and fans represents a common strategy for improving indoor comfort. Seasonal differences mainly manifest in increased reliance on air movement during the rainy season rather than major changes in cooling technology.

In contrast, Hanoi exhibits strong seasonal variability in cooling behavior. AC usage peaks during summer but decreases significantly in spring and autumn and is almost absent during winter. As a result, residents rely more heavily on adaptive behaviors such as window opening and fan use during transitional seasons. Another important difference concerns spatial prioritization of cooling devices. In both cities, bedrooms show higher reliance on AC than living rooms. However, this contrast is more pronounced in Hanoi, where living rooms often rely on natural ventilation during cooler seasons. Overall, residents in HCMC display a more consistent reliance on mechanical cooling, whereas residents in Hanoi demonstrate more flexible and seasonally adaptive cooling behaviors.

When put all data from two big city together, the analysis of general cooling strategies reveals a sharp polarization in occupant behavior within Hanoi's four-season climate compared to the relative stability observed in HCMC. In Hanoi, the most intensive intervention occurs during the summer, where the AC and Fan index reaches a peak of 0.80, indicating a critical reliance on combined mechanical cooling to achieve thermal comfort during extreme heat. Conversely, a significant behavioral shift toward passive strategies is observed during autumn and spring, with Natural Ventilation indices rising to 0.68 and 0.62, respectively. In contrast, occupants in HCMC maintain a more consistent reliance on artificial cooling throughout both dry and rainy seasons. While Natural Ventilation remains a significant factor (ranging from 0.48 to 0.56), the steady indices for AC modes and AC + Fan combinations (hovering around 0.40 - 0.50) reflect a continuous need to mitigate the persistent tropical heat and humidity characteristic of the southern region (Fig. 14.)

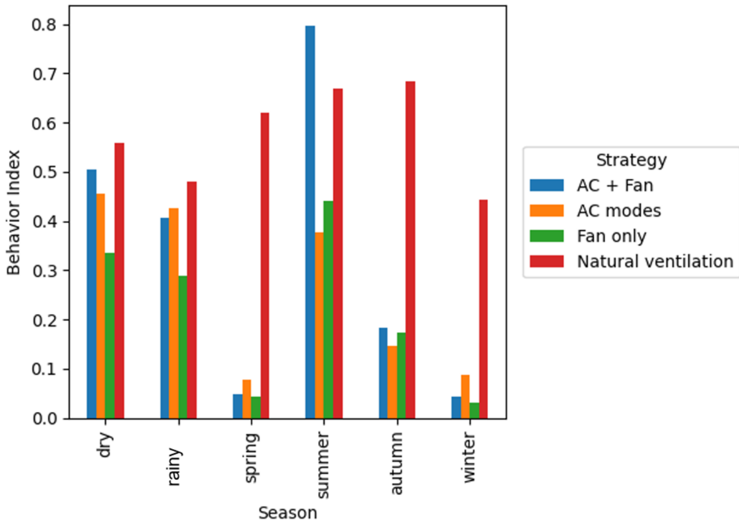


Figure 14. Cooling strategy by season

The fluctuation of the Behavior Index (*BI*) in the line graph provides a quantitative measure of occupant preference for specific thermal modes across different seasons. During periods of thermal extremity, such as Hanoi's summer, the *BI* for active cooling modes surges significantly; specifically, the Cool mode reaches approximately 0.73, while the AC + Fan combination nears 0.80. This pattern illustrates a systematic behavioral rule: when ambient heat exceeds natural endurance thresholds, the probability of occupants selecting technology-driven solutions (active cooling) becomes nearly absolute. Conversely, during transitional seasons like autumn, the *BI* for these AC-dependent modes plummets below 0.20, being overtaken by the *BI* for Open window and Fan only behaviors, which maintain high values between 0.60 and 0.85. This inversion of *BI* dominance demonstrates the "adaptive behavior" of occupants, as they actively recalibrate their cooling strategies based on external environmental cues.

Notably, the *BI* for Dry mode maintains relative stability in HCMC (averaging around 0.30) but trends toward zero during Hanoi's winter. This indicates that the *BI* reflects not only thermal requirements but also behavioral sensitivity to atmospheric humidity. Furthermore, the fact that the Eco mode *BI* consistently tracks at a high level (above 0.50) during peak seasons reveals a shift in modern consumption habits: occupants no longer utilize appliances indiscriminately but instead aim to balance thermal comfort with economic efficiency. Overall, the divergence of *BI* curves on the graph portrays the complex interaction between regional climatic factors and the psychology of appliance interaction.

The longitudinal variation of specific AC modes demonstrates a strong positive correlation between ambient outdoor temperatures and the utilization of Cool and Auto settings. These modes reach their maximum threshold during Hanoi's summer, with the Cool mode index peaking at approximately 0.73. A distinct regional divergence is identified in the requirement for space heating; the Heat mode appears exclusively during Hanoi's winter with an index of 0.29, while remaining entirely absent in HCMC's data. Furthermore, the synchronous fluctuation of Fan only and Open window behaviors, both reaching peak values between 0.60 and 0.70 during autumn, confirms that during transitional weather periods, occupants prioritize mechanical or natural airflow as a complete substitute for compressor-based cooling to optimize energy efficiency (Fig. 15).

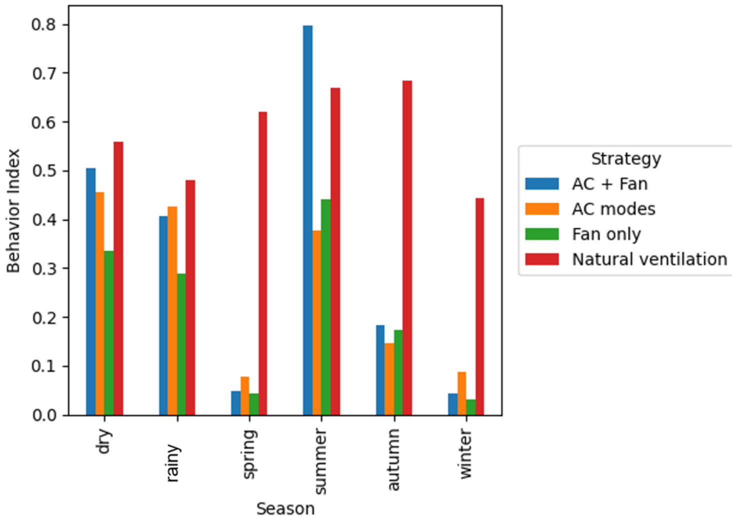


Figure 15. Seasonal variation of cooling behavior

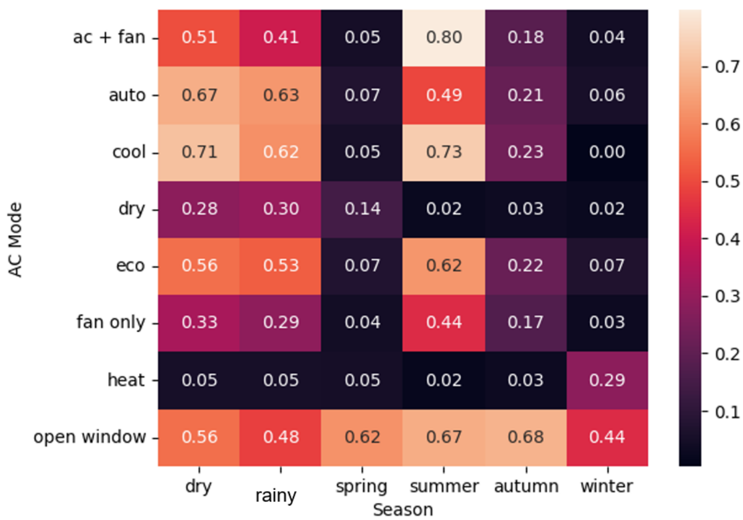


Figure 16. Heat map of cooling preference by season

Quantitative data from the seasonal heat map highlights the specialized role of humidity control in the southern climatic context. The Dry mode index is notably higher during HCMC's rainy (0.30) and dry (0.28) seasons, whereas it drops to a negligible 0.02 during Hanoi's summer, suggesting that southern occupants are more sensitive to latent heat regulation. Additionally, the Eco mode exhibits a consistent usage pattern, maintaining indices above 0.50 during peak cooling periods (dry, rainy, and summer), which reflects a conscious effort toward energy conservation during high-demand intervals.

Collectively, the heat map confirms that Open window behavior is the most pervasive and sustained strategy across most seasons, with indices consistently ranging from 0.44 to 0.68, only decreasing during periods of thermal extremity. (Fig. 16).

5. Discussions and conclusions

The findings of this study provide important insights into the relationships between climatic context, occupant behavior, and residential energy consumption in high-rise apartment buildings in Vietnam. The results indicate that geographical location and climatic conditions significantly influence both perceived thermal comfort and the behavioral strategies adopted by residents, it is not fixed as stated in the standard [24]. In HCMC, where high temperatures persist throughout the year, the recorded average thermal comfort threshold is approximately 25.3°C. In contrast, residents in Hanoi report a higher average comfort threshold of 27.13°C. This difference is also reflected in the average AC set point temperatures. In living rooms, the average cooling temperature is 26.73°C in Hanoi compared to 25.51°C in HCMC, while in bedrooms the average temperatures are 27.52°C and 25.08°C respectively. Overall, the average difference in thermal comfort thresholds between the two cities can reach 2.44°C, with the maximum observed difference reaching 4.36°C. Meanwhile, according to the standard, the climate is only divided into hot and cold seasons, and the temperature setpoints for different functional rooms are uniformly specified as 26°C for the hot season with air conditioning and below 30°C under natural conditions [24]. These results suggest that occupants adapt their thermal expectations according to local climatic conditions, demonstrating the role of adaptive comfort in residential environments.

The survey results also reveal that responsibility for improving building energy efficiency is perceived as a shared obligation among multiple stakeholders. A comparison between the two cities further highlights the influence of climatic conditions on occupant behavior. The results demonstrate that differences in residential energy consumption between Hanoi and HCMC are influenced more strongly by climatic conditions and occupant thermal behavior than by the number of electrical appliances owned. These findings underscore that optimizing building design and HVAC operations must integrate actual occupant behavior and local environmental cues to leverage passive solutions during transitional seasons, thereby effectively advancing energy reduction goals within the residential sector.

However, it is important to acknowledge a limitation related to the treatment of occupant characteristics. The reduction and simplification of these variables may not have fully captured all underlying socio-economic and housing-related factors. Consequently, some latent influences may not have been explicitly accounted for and could partially contribute to the observed regional differences. Hence, the results should be interpreted as reflecting a combined effect of climatic conditions and unobserved occupant-related factors.

This study contributes valuable insights into identifying the actual occupant behaviors within high-rise residential buildings. However, there are still limitations, these findings should be integrated with empirical measurement and simulation data in future research. Occupant behavior is inherently governed by underlying cultural factors and decision-making processes, which involve numerous stochastic variables that are difficult to quantify. Consequently, further specialized research is required to transition from qualitative assessments to quantitative modeling by establishing specific behavioral coefficients. While this study is limited by the lack of a fully integrated correlation between all observed factors to provide immediate architectural guidelines, it serves as a critical foundation for developing evidence-based design solutions for high-rise residential developments.

Acknowledgment

The authors would like to express their gratitude to the CAMaRSEC project (Climate-adapted Material Research for the Socio-economic Context in Vietnam), funded by the German Ministry of Education and Research (BMBF) for their support. Special thanks are extended to the Hanoi University of Civil Engineering (HUCE) for their essential partnership and collaboration during the data collection process. We also appreciate the contributions of all individuals and stakeholders who provided technical support and assistance throughout the development of this research. The authors would also like to thank Nguyen Thu Thuy, independent researcher from Hamburg for supporting the evaluation of the questionnaire at an early stage.

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