Journal of Climate Change
ISSN 2395-7611 Volume 11 (2025) No. 2. pp. 209–225

https://doi.org/10.70917/jcc-2025-015
Article

Assessing Thermal Comfort and Cooling Challenges for Women in Malaysian Households

Hasila Jarimi [1,4,*], Mirratul Mukminah Junedi [1], Nurfarhana Ahmad Affandi [1], Norasikin Ahmad Ludin [1], Emy Zairah Ahmad [2], Tajul Rosli Razak [3,4] and Saffa Riffat [4]

1 Solar Energy Research Institute, National University of Malaysia, Selangor 43800, Malaysia; sheekeen@ukm.edu.my (N.A.L.)
2 Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal Melaka 76100, Malaysia
3 Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, Selangor 40450, Malaysia
4 Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham, Nottingham NG7 2RD, UK
* Corresponding author: Hasila.jarimi@ukm.edu.my

Abstract: Access to adequate cooling is essential for health, well-being, and livelihoods. However, in Malaysia, there remains a significant gap in understanding cooling access and thermal comfort, particularly among women home-based workers and women who spend the majority of their time at home. Despite global recognition of cooling disparities, limited research has focused on this demographic. Addressing this gap is vital for promoting gender equality and enhancing quality of life for women, especially in rural and lower-income settings. This study investigates thermal comfort and access to cooling in villages across five Malaysian states: Selangor, Melaka, Perak, Kedah, and Perlis, where village houses represent over 50% of occupied housing. Semi-structured interviews were conducted with women who either work from home or spend most of their time at home, assessing their thermal comfort, daily cooling needs, and household practices. Findings reveal that thermal discomfort peaks between 2 PM and 5 PM, and while most households have access to cooling systems, 66% of respondents reported high electricity bills as the main reason for not using air-conditioning. An additional 29% cited financial inability to afford the system, indicating that cost-related factors are the dominant barriers to cooling access. A chi-square goodness-of-fit test focusing on village house respondents revealed that heat due to house structure was the statistically significant cause of discomfort ($\chi^2 = 27.91$ $p < 0.001$), suggesting structural issues such as poor insulation and solar heat gain as key contributors. To propose feasible solutions, TRNSYS simulations were conducted on a typical rural house model. Results showed that enhancing roof insulation was the most effective strategy, reducing cooling loads by approximately 10%, with an estimated load of 3.39 kWh. This study concludes that structural improvements, particularly roof insulation, are essential for reducing cooling needs and improving thermal comfort for women at home. Tackling both technical and financial barriers through affordable passive cooling strategies can significantly improve living conditions while enhancing women's health, productivity, and economic participation, contributing to a more inclusive and sustainable future.

Keywords: cooling; thermal comfort; residential; gender; women

1. Introduction

Access to cooling is a fundamental human need, one that directly impacts our health, well-being, and livelihoods. Globally, over 1 billion people residing in 54 severely affected countries face a dire challenge: they lack access to cooling that can safeguard them against the harsh effects of rising temperatures. Additionally, another 2.2 billion individuals find themselves in risky positions, relying on inefficient cooling solutions that barely offer relief from the heat. The consequences of this cooling inequality are complex, affecting various aspects of life, from health and economic prosperity to household dynamics and work environments. As reported in SEforALL(2021), the physical reactions of the human body to extreme heat are well documented. Numerous studies on the gendered effects of heat stress highlight that women recover from heat-related illnesses, such as heat rash, fatigue, or stroke, more slowly than men (Alele et al., 2020). In addition, research shows that, on average, women face significant barriers to accessing healthcare and nutritious diets, both of which rely on cooling. They face additional challenges in settings and regions where women have limited household decision-making power, lower literacy rates, restricted mobility, or face discrimination from healthcare providers (WHO, n.d.). Women are more vulnerable to heat stress during widespread extreme heat events due to the gendered nature of women's household responsibilities and cultural norms. Women are more vulnerable to heat stress during widespread extreme heat events due to gender-based household responsibilities and social norm (SEforALL, 2021),

It is also acknowledged that access to cooling has broad socioeconomic benefits, including contributing to poverty reduction, boosting children's academic success, and reducing health concerns related to indoor thermal stress (Mastrucci et al., 2022; Dabaieh et al., 2023; Mastrucci et al., 2019; Khosla et al., 2021). It is crucial to recognize that the impact of cooling is not uniform; it affects men and women differently. This disparity is especially pronounced when considering the domains of health, well-being, poverty, household dynamics, and the workplace. Women, who generally spend more time indoors than their male counterparts, are particularly vulnerable to inadequate cooling solutions.

In the case of Malaysia, with 15.9 million women, they make up 48% of the country's population. However, the women labour force participation rate in Malaysia only stands at 55.9% (Hassan, Ramli and Mat Desa, 2014). Those that did not fall into the labour force participation rate, include those that fell into unemployment, or part of the outside labour force (which includes housewives, students, retired, disabled, and uninterested in work). Access to better energy services, such as cooling options, has reportedly been shown to change women's social, economic, and political positions (SEforALL, 2021). However, no study has yet been conducted in Malaysia that investigates cooling access at the household and home-based worker. It is worth noting that this study not only highlights the urgent need for accessible cooling but also emphasizes the role of gender equality in achieving sustainable solutions. Sustainable Development Goal (SDG) 5, focused on gender equality, is deeply linked with the challenges of cooling access. Women, particularly those working from home in rural settings, are expected to face inadequate cooling systems. By addressing this inequality, we can contribute to both SDG 5 and broader sustainability goals, ensuring that women benefit from advancements in energy-efficient cooling technologies.

Gender Specific Analysis on Thermal Comfort Research

Research conducted in tropical climates, particularly in Indonesia and Malaysia, has uncovered variations in thermal comfort temperature and relative humidity within home environments. Field studies conducted in Malaysia, Indonesia, Singapore, and Japan during hot and humid seasons revealed that occupants in tropical office buildings could adapt to higher indoor temperatures than suggested by standards (Abass et al., 2021). Notably, in hot-humid climates, the comfort equation for naturally ventilated buildings is found to be influenced more by indoor air speed than indoor relative humidity (Esfandiari et al., 2021). Based on the study in Indonesia, the country lacks a reliable thermal comfort standard based on research. They found that thermal studies conducted in various Indonesian buildings indicated that the neutral (comfort) temperatures for subjects were around 27 to 28 °C, surpassing the values stated in the standard. Furthermore, research on thermal comfort conditions in traditional Bugis houses in South Sulawesi found influences from outside temperature, air humidity, and building materials (Latif et al., 2019).

Shifting the focus to gender-specific demands in terms of thermal comfort, studies indicate that women generally prefer higher relative humidity than men. Maykot, Rupp, and Ghisi (2018) observed a comfort temperature of 24.0 °C for women compared to 23.2 °C for men with additional support Lan et al. (2008) revealing that Chinese women are more sensitive to temperature and less sensitive to humidity than men.

Research on gender-specific aspects of thermal comfort has also provided several key findings. These findings align with the work of Haselsteiner (2021), who found that women perform better in warmer environments, while men perform better in colder temperatures. Delving into physiological differences between genders, Chaudhuri et al. (2018) developed a model to predict thermal state based on physiological parameters, and Thapa (2019) found that men generally have a lower comfort temperature. However, Zhang, Zhang and Jin (2017) found that rural participants, regardless of gender, had a wider acceptable temperature range, suggesting that cultural and environmental factors also play a role in thermal comfort. Despite global recognition of cooling inequalities, there remains a significant gap in understanding the specific challenges faced in Malaysia—particularly among women. While Malaysia, like many countries, is facing issues related to cooling access, research focused on thermal comfort and cooling access for the women population, especially home-based workers, is notably limited. Hence, this paper makes the following key contributions to address this gap.

First, this paper investigates the overlooked area of thermal comfort and cooling accessibility among women home-based workers in Malaysia, offering much-needed localised insight into this under-researched demographic. Second, thermal performance simulations using TRNSYS are employed to propose targeted strategies for improving thermal comfort. These simulations serve not only to justify the need for further research but also to identify practical, building-level interventions that can enhance the living and working conditions of women in similar contexts.

2. Methodology

2.1. Survey

In this study, we have employed the following methods to conduct the research.

Step 1: Questionnaire Development

In the initial phase of this study, we focused on developing comprehensive questionnaires to explore various dimensions of cooling access and its implications. These questionnaires were carefully designed to explore the following essential aspects: firstly, the awareness of different types of cooling energy; secondly, the perception of thermal stress and thermal comfort/satisfaction; and finally, the assessment of empowerment concerning decision-making on cooling.

Step 2: Data Collection

To ensure the collection of relevant and representative data, our research encompassed villages in five states in Malaysia: Selangor, Melaka, Perak, Kedah, and Perlis. Within each of these states, we selected specific villages as focal points for data collection. The selection of these states and villages was purposeful, aiming to provide a diverse and comprehensive view of cooling access across different regions of the country. For this study, the participants were fully informed of the study's purpose, and consent was obtained prior to their involvement. In addition, no personal identification data such as national ID and names were collected during the survey and the questionnaire has been assessed by the funder.

Step 3: Data Analysis

The data collected underwent a rigorous quantitative analysis to draw meaningful conclusions. Our analytical approach comprises several key components. First, we conducted a quantitative assessment to measure the percentage of respondents concerning cooling access with the following parameters that were analysed:

i. The relationship between ownership of space cooling appliances with electricity bills.
ii. The trend in thermal sensation for the women at home.
iii. The relationship between cooling appliances and types of houses
iv. Reasons for thermal discomfort for the women and critical deduction

Furthermore, we look into an in-depth interpretation of the findings. This phase involved a thorough examination and interpretation of the data within the context of the survey. The aim was to provide a deeper understanding of the implications of the collected data, uncover notable patterns, and shed light on disparities related to cooling access. Lastly, we utilized our findings to make informed recommendations for further research in the field. These recommendations are intended to guide future studies and investigations, enabling a more comprehensive and insightful exploration of cooling access among women home-based workers in Malaysia.

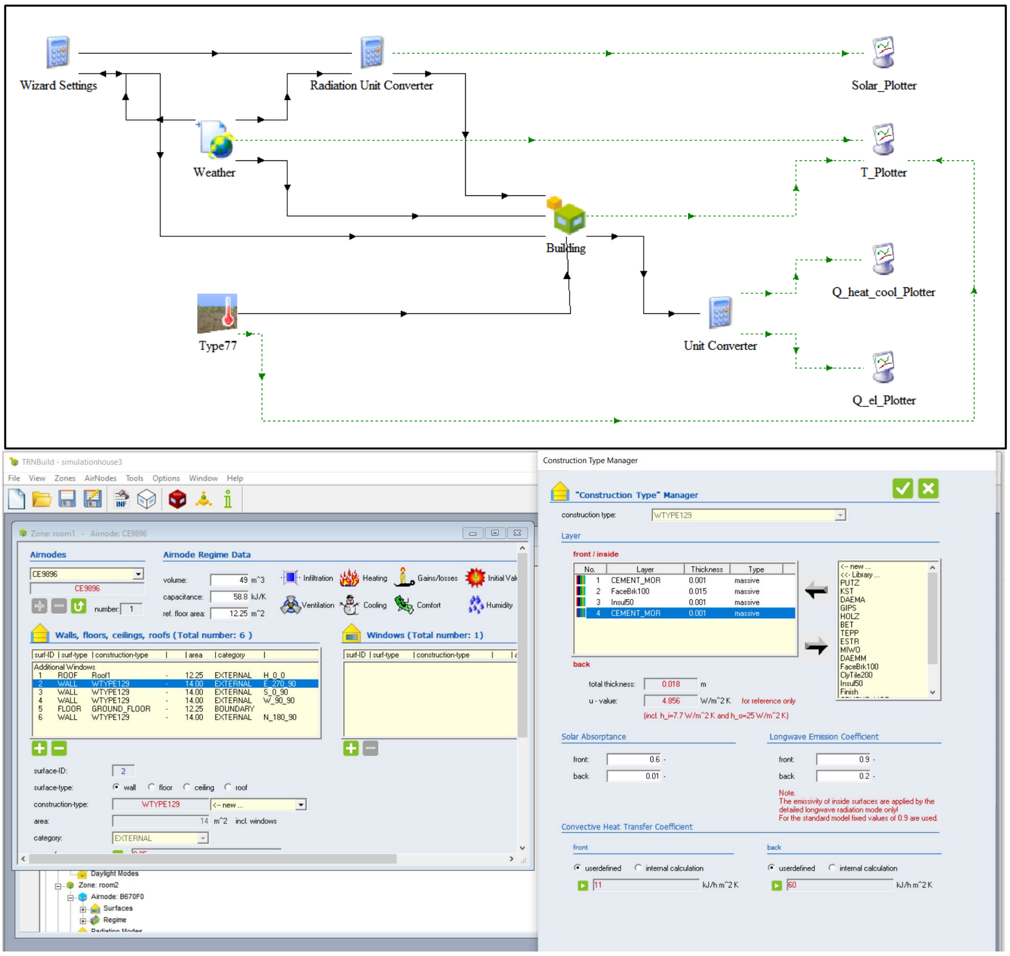
2.2. Building Simulation

Building simulations were carried out using TRNSYS 18 to evaluate the thermal performance of a typical house occupied by women home-based workers in the village in Malaysia. The simulations aimed to identify passive strategies to enhance thermal comfort by modifying the thermal transmittance (U-values) of key building envelope component such as walls, glazing, and roofs. A reference model was constructed based on actual house layouts commonly found in the surveyed village, with a floor area of 100 m² divided into a hall, kitchen, and two bedrooms. Weather data was input using the Meteonorm weather data for Kuala Lumpur, which closely represents the climate conditions of the study location. The interface of the TRNSYS simulation is shown in Figure 1a, whereby the U-value of different components of the house was modified accordingly as summarized in Figure 1b and Table 1. The boundary conditions and assumptions made in the simulation is the Internal gains assumed based on a single-family household and typical electrical appliances were considered. No mechanical ventilation or active cooling was simulated in the base cases, to reflect the reality of limited use of air conditioning. Natural ventilation was assumed with moderate air exchange (0.5 ACH). Initial indoor temperature: 29 °C (typical of non-cooled interiors in the tropics). Simulation timestep: 1 hour. Occupancy schedule: 8 a.m. to 10 p.m., based on reported activity patterns from women home-based workers. Meanwhile, five configurations (A–E) as Internal gains from occupants were developed to evaluate the impact of insulation upgrades:

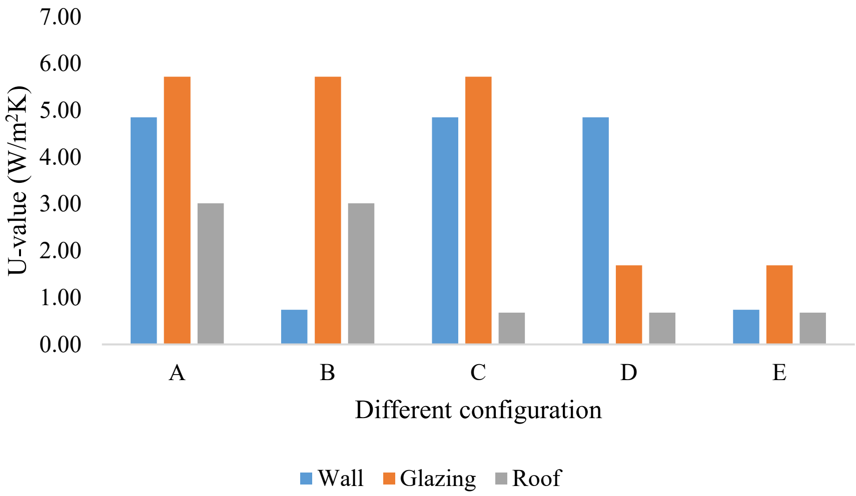
i. Baseline U-values (A) reflected typical Malaysian low-cost housing with no insulation (wall: 4.856 W/m²K, glazing: 5.72 W/m²K, roof: 3.015 W/m²K).

ii. Improved U-values in configurations B–E were selected based on affordable retrofit materials readily available in the local market (e.g., 5 cm EPS wall insulation, double glazing, rockwool roof insulation).

It is crucial to note that. the goal was to test practical, cost-sensitive solutions rather than idealized ones. The baseline simulation results were cross-checked against qualitative data from interviews and surveys, which indicated that peak discomfort periods occurred between 11 a.m. and 5 p.m., particularly in areas like the kitchen and hall.



(a)



(b)

Figure 1. (**a**) TRNSYS18 Layout and (**b**) Different configurations (A–E).

Table 1. Different categories/scenarios for U-value of the different part of the house.

Configu-ration	Wall - Plaster-bricks-plaster 4.856 W/m²K	Wall - Plaster-bricks-5cm insulation-plaster. 0.743 W/m²K	Glazing: Single glaze at 6 mm thick 5.72 W/m²K	Glazing: 1.69 W/m²K	Roof: Plaster and roof deck 3.015 W/m²K	Roof: Plaster - insulation - roof deck 0.68 W/m²K
A	x		x		x	
B		x	x		x	
C	x		x			x
D	x			x		x
E		x		x		x

3. Results and Discussion

3.1. Analysis of Preliminary Study

3.1.1. Ownership of Space Cooling Appliances

According to the results of our survey, Figure 2 illustrates that the majority of the respondents (women home-based workers) have access to cooling using electrical appliances such as standing fans, ceiling fans, and AC units. In addition, the majority also have control over AC usage decision-making. This indicates that women home-based workers may have gained economic independence, enabling them to afford electrical appliances such as standing fans, ceiling fans, and AC units.

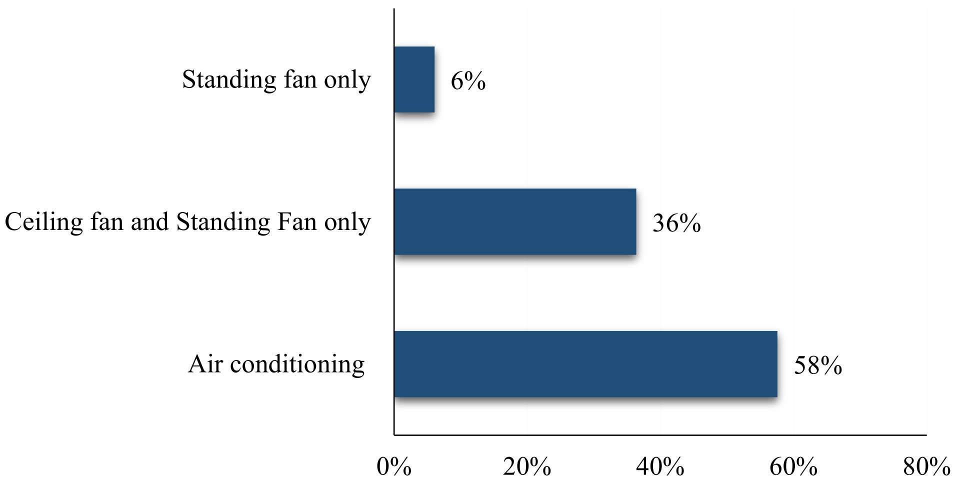


Figure 2. Ownership of space cooling appliances.

Next, to determine whether household income affects the monthly electricity bill, the results suggest that across all income levels, ranging from less than USD 535 (RM 2,500) to more than USD 3,210 (RM 15,000), the most common electricity bill paid falls in the range of USD 11–USD 21 (RM 51–RM 100), with 36% of the total respondents falling into this category. Likewise, the second highest range is USD 21–USD 42 (RM 101–RM 200), with 35% of the total respondents. Therefore, it can be assumed that the common household electricity bill in this study ranges from USD 11 to USD 42 (RM 51 to RM 200), covering 71% of the total respondents. Meanwhile, for electricity bills in the range of USD 42 to USD 106 (RM 201 to RM 500), 21% of households fall within this range, primarily from the income group USD 1,860 to USD 2,345 (RM 8,701 to RM 10,970).

These results may imply that there is no linear relationship between household income and monthly electricity bills, as across all income ranges, the bill of USD 11 to USD 42 (RM 51 to RM 200) is the most common value. However, as this study mapped out each income group corresponding with the bill they paid, a trend emerged that shows an influence of household income on monthly electricity bills, as shown in Figure 3 and simplified in Table 2.

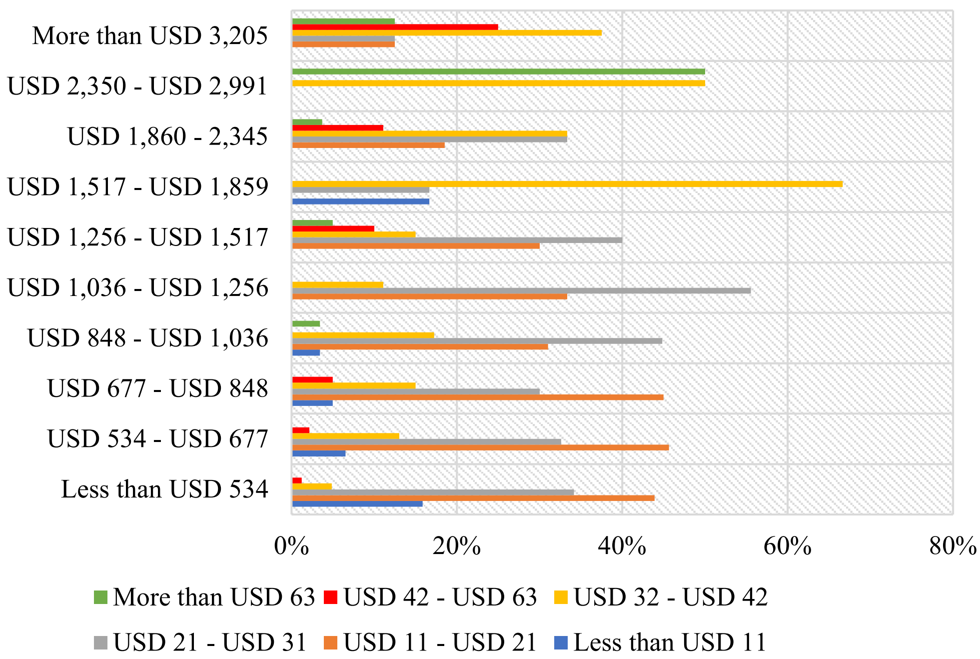


Figure 3. Household income impact on electricity bills.

Table 2. Mode of electricity bill based on income group range:

Income Group Range	Mode of Electricity Bill	Percentage Range
Less than **USD 535 to USD 850**	**USD 11–USD 21**	45% to 46%
USD 850 to USD 1,515	**USD 21–USD 42**	40% to 56%
USD 1,860 to more than USD 3,210	**USD 42–USD 63**	33% to 67%

For the income group USD 1,860–USD 2,345 (RM 8,701–RM 10,970) and USD 2,345–USD 3,000 (RM 11,000–RM 14,000), there are bimodal values (refer to Figure 2).

The comparative analysis of electricity bills based on income group, as depicted in Figure 3 and Table 2, suggests that the higher the income group, the higher the electricity bill, and vice versa. Additionally, it was observed in this study that the majority of respondents (94%), regardless of household income, paid less than USD 63 (RM 300) per month for their electricity consumption. This may suggest that respondents are highly aware of electricity-saving practices, as the previous section showed that most respondents installed cooling systems in their homes, specifically with 60% installing air-conditioning systems. However, does this mean that respondents paying more than USD 63 (RM 300) lack awareness, while those paying less than USD 11 (RM 51) are more aware? This implies that other factors, such as the number of household members, may impact total electricity consumption.

This study found that the number of household members impacts electricity consumption. Based on Figure 4, respondents with two, three, or four family members most commonly pay USD 11 to USD 21 (RM 51 to RM 100) per month, followed by USD 21 to USD 42 (RM 101 to RM 200). As the number of household members increases to five or more, the most common electricity bill is USD 21 to USD 42 (RM 101 to RM 200). Excluding respondents with only one household member, households with five or more members exhibit the highest percentage of paying more than USD 42 (RM 200) in electricity bills. This aligns with previous results, confirming that respondents in this study are likely to have a good understanding and awareness of energy-saving practices. Regardless of the number of household members, the majority of electricity bills are in the range of USD 21 to USD 42 (RM 101 to RM 200) and USD 11 to USD 21 (RM 51 to RM 100), respectively. For households paying more than USD 63 (RM 300), the data suggests that only a small percentage (2% to 6%) of respondents paid such amounts, and these households typically have three or more members, justifying the higher electricity consumption.

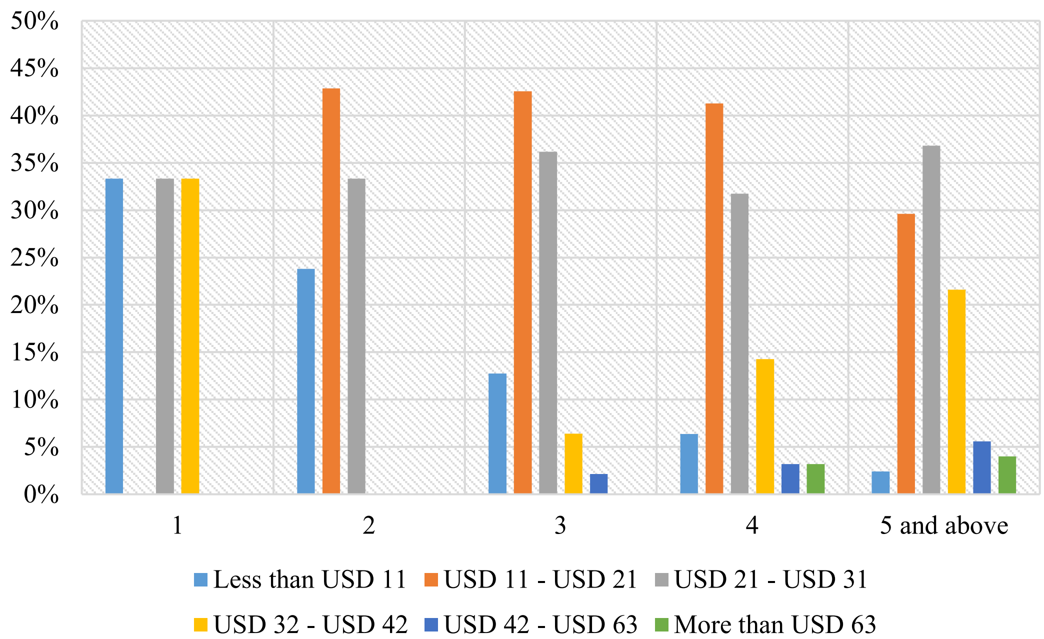


Figure 4. Number of household members' impact on electricity bills.

This study reveals that 73% of respondents—women—are working, whether employed or self-employed (categorized as working from home). Illustrated in Figure 5, the percentage of male partners paying the bill is the highest, regardless of the wife's employment status. The wife also contributes to paying the bill in both categories. In the employed group, the wife's contribution is significant, with 16% paying the bill alone and 21% sharing the payment with the male partner. Even in cases where the wife is unemployed, she contributes to the bill in 1% of households, and in 19% of cases, both partners contribute. These results suggest that in most households in this cultural setting, the male partner plays the primary role as the head of the household, contributing the most to electricity payments, with the wife actively supporting. In other cases, unmarried respondents, widows, or children contribute to paying the bill.

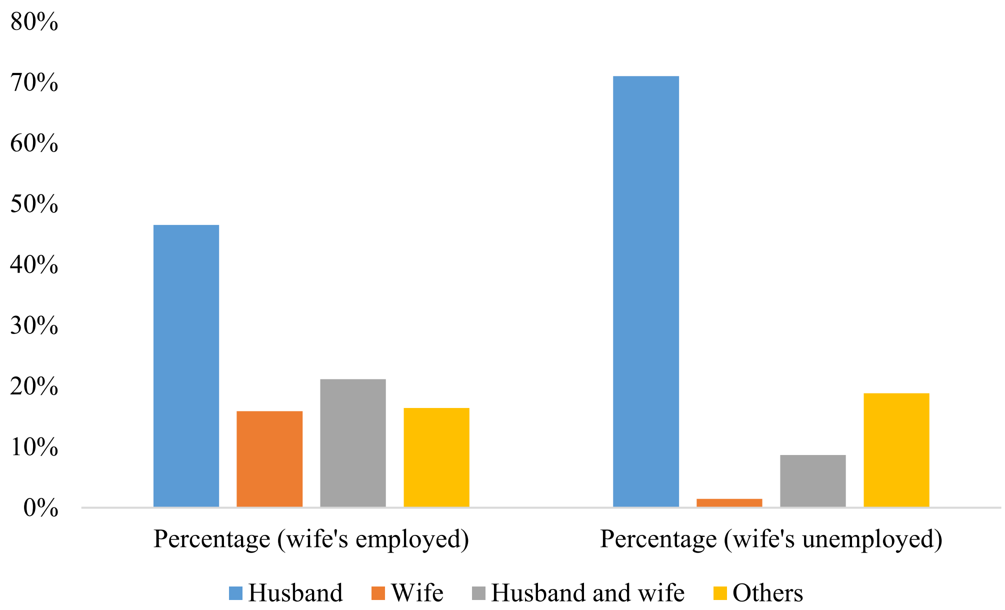


Figure 5. Electricity bill payer vs. wife's employment status.

3.1.2. Thermal Sensation

In accordance with the data presented in Figure 6 and Figure 7, a noteworthy observation whereby 94 % of the surveyed respondents expressed discomfort within their own homes. This discomfort can be attributed to a combination of various factors. One contributing factor to this discomfort is the high humidity in the region, which can lead to a hot and humid indoor environment, negatively impacting thermal comfort. Additionally, the financial burden of elevated electricity costs serves as a significant constraint for the extensive use of air conditioning, forcing many to endure unfavourable indoor temperatures. Furthermore, the placement of air conditioning units, predominantly within bedrooms, leads to ineffectiveness in cooling the entire living space. The concentration of cooling within the bedroom may leave other areas inadequately cooled, contributing to the overall discomfort experienced by the respondents.

The issue of house insulation also plays a key role. A considerable portion of the surveyed population resides in traditional Malaysian houses constructed primarily from wood or poorly insulated concrete, with inadequate to no roof insulation. These houses, due to their construction material and design, are susceptible to air leakage and have high heat gain. This leads to inefficient cooling, as the conditioned air escapes, and heat continuously infiltrates the living spaces. As a result, the majority of these households face a challenge to maintain thermal comfort within their homes. Also, the discomfort experienced by a vast majority of respondents in their homes is a non-straightforward issue influenced by factors such as humidity, high electricity expenses, air conditioning unit placement, and the challenges posed by traditional house construction. These interconnected factors highlight the root causes of thermal discomfort among surveyed households and highlight the need for strategies to improve thermal comfort and cooling access among women home-based workers in Malaysia.

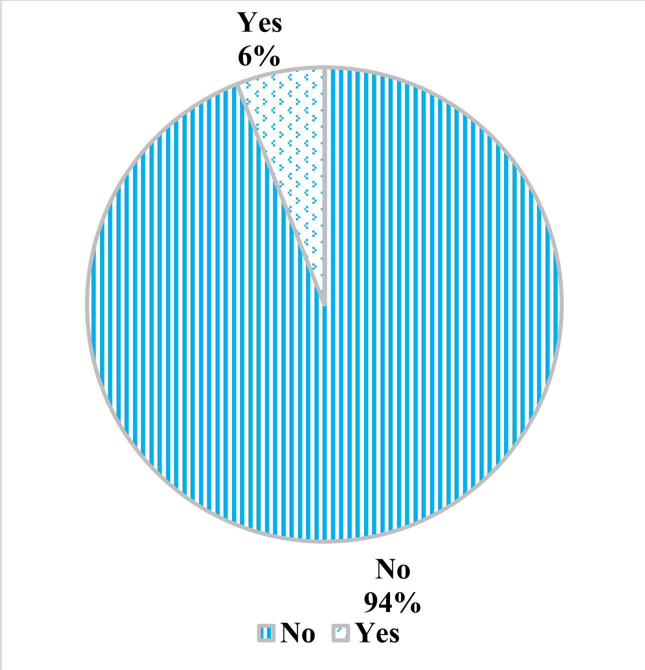


Figure 6. Percentage of thermal comfort.

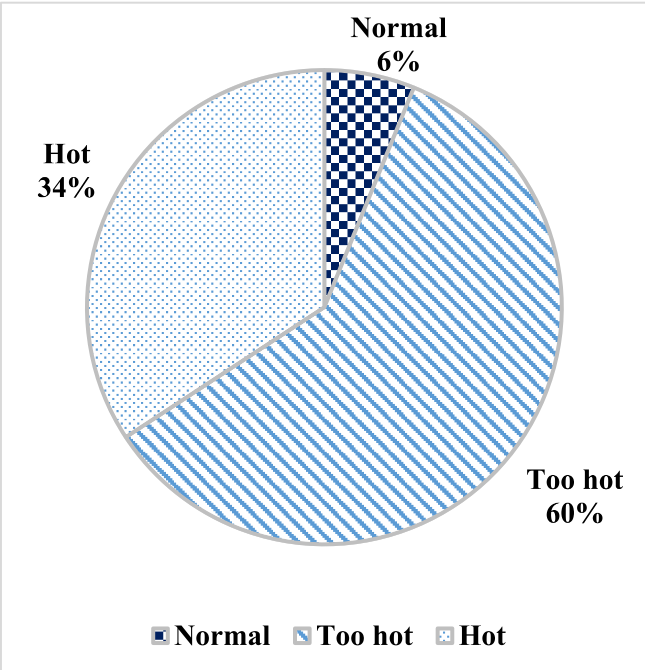


Figure 7. Percentage of the thermal sense and the condition in the house.

3.1.3. Types of Houses

Based on Figure 8, in the average of installed cooling appliances across house type, the percentage averages for ceiling fans, air conditioning and stand fans are 82%, 60% and 58%, respectively. For all types of houses, more than 50% of the respective house type owner installed ceiling fan, making the ceiling fan the most preferred cooling system. Meanwhile, for village houses and apartments, air-conditioning is the least preferred cooling system to be installed. In contrast with terrace houses and bungalows, air-conditioning system is the second preferred system after ceiling fan. From the analysis, it can be concluded that all types of houses have a moderate average percentage of installed stand fan and air-conditioning system with 60% and 58%, respectively. It implies that regardless of house types, on average, both systems are the least or second least preferred cooling system, suggesting that other factors may influence the choice which is not directly due to the type of house such as individual preference i.e., cost considerations.

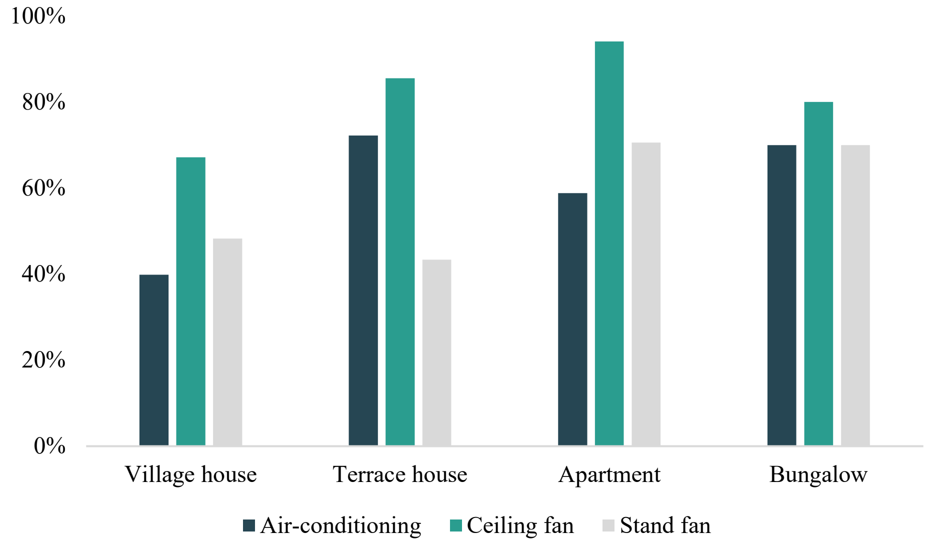


Figure 8. Influence of type house to the preferred type of cooling system.

3.1.4. Reasons of Thermal Discomfort

It is essential to consider multiple factors when evaluating thermal comfort and the use of air-conditioning systems in residential settings. These include the measured thermal comfort levels by house type, which are influenced by the structural materials and layout of the house, as well as household purchasing power, which can be assessed through monthly income levels, and individual or household preferences. In this study, particular attention was given to women respondents who do not have the autonomy to switch on the air-conditioning unit in their homes. As illustrated in Figure 9, the most frequently reported reason for not using the air-conditioning unit was the high electricity bill at 66%, followed closely by general financial constraints which are unable to afford the air conditioning unit itself. These two dominant reasons suggest that financial limitations are key contributors to the decision-making process related to the use or installation of cooling systems. This finding reinforces the need to consider affordability and economic impact when designing or recommending sustainable thermal comfort solutions, especially in households where control over appliance use may be limited due to social or cultural dynamics.

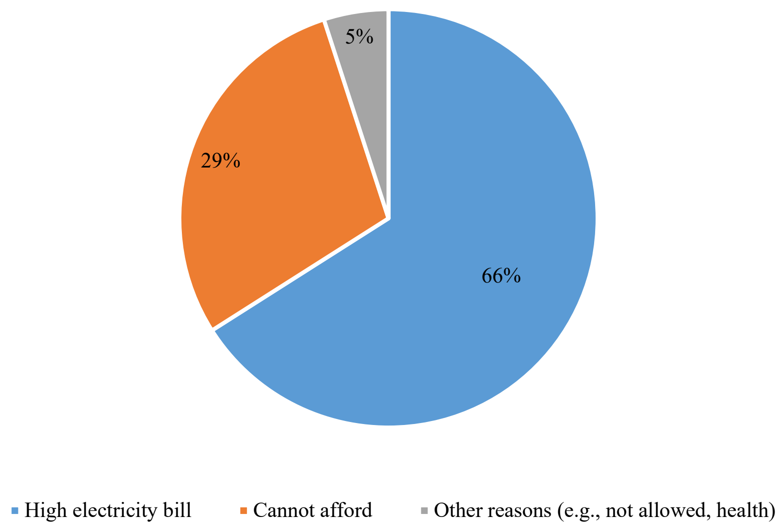


Figure 9. Reason for not switching on air -conditioning unit.

Consequently, based on Figure 10, the majority of respondents (60%) agreed that the house structure is the main reason why their house is uncomfortable due to the heat which then followed due to the reason of the sunlight penetration. These two major reasons imply that possible issues with the flooring material, window placements, and the overall building orientation. Meanwhile, a smaller percentage of 3% due to the longer time or no impact for air-cooling system suggest the needs to enhance the system's efficiency.

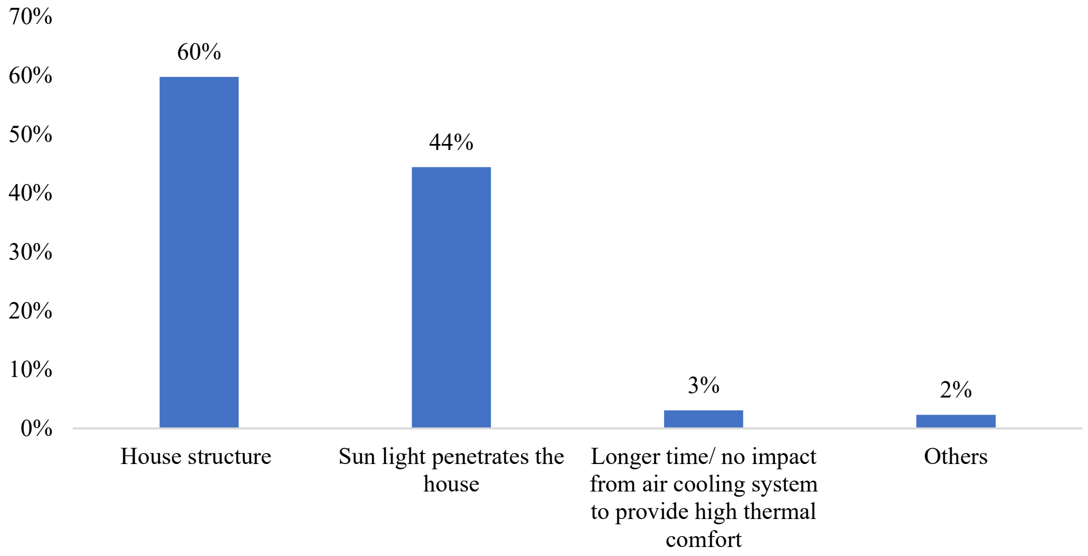


Figure 10. Reasons for thermal discomfort.

In addition, the area of discomfort analysis as depicted in Figure 11, shows that the highest percentage with 41% of discomfort in the kitchen suggests a critical area for improvement. This may be due to heat-generating appliances, insufficient ventilation, or poor insulation. Meanwhile, the second most discomfort area is the living room, suggesting that several issues should be addressed such as poor insulation, lack of proper heating or cooling systems, or inadequate ventilation.

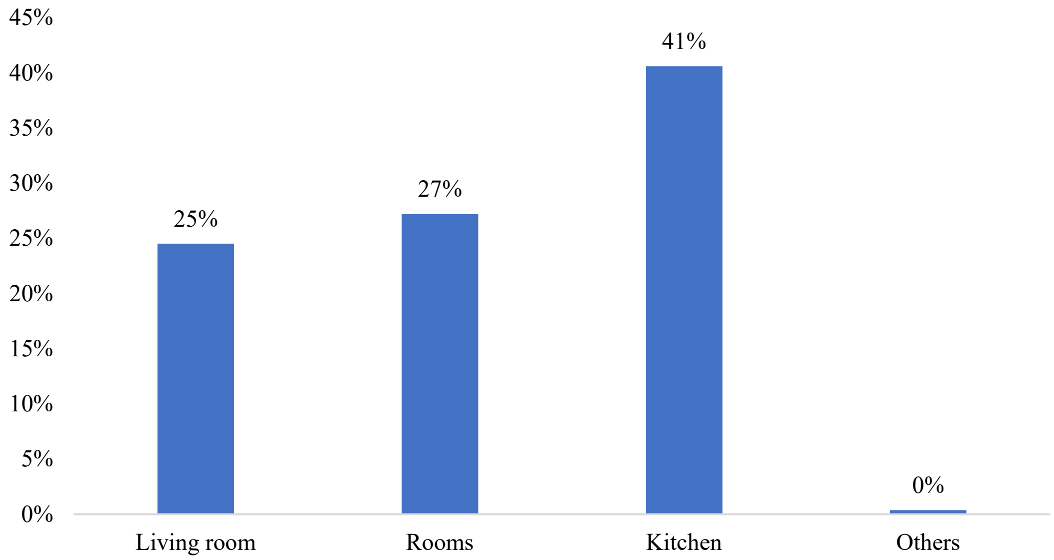


Figure 11. Area of discomfort in the house.

Also, since the majority of the house owners are Village house type. Focusing more on this type of house, a statistical analysis using the chi-square goodness-of-fit test was conducted to determine whether the distribution of discomfort reasons among the residents was statistically significant. The null hypothesis stated that all reasons (heat due to structure, sunlight entering, and others) were equally likely, while the alternative hypothesis proposed that at least one reason was more prevalent. As summarized in Table 3, the test yielded a chi-square value of 27.91 with 2 degrees of freedom, and a *p*-value of 0.0000087. This value is far below the conventional significance threshold of 0.05, indicating strong evidence against the null hypothesis. Therefore, we conclude that the reasons for thermal discomfort in the traditional village house are not equally distributed. The analysis further confirms findings presented in Figure 10 that heat due to house structure is the primary and statistically significant reason for discomfort among respondents in this house type.

Table 3. Summary of Hypotheses and Chi-Square Goodness-of-Fit Test for Thermal Discomfort Reasons among.

Null Hypothesis (H_0)	The reasons for thermal discomfort are equally likely among residents
Alternative Hypothesis (H_1)	At least one reason for discomfort is significantly more common than the others
Observed Frequencies	Heat due to structure: 40 Sunlight entering 21 Other: 5
Expected frequencies	~33.33 for each category (assuming equal distribution)
Chi-square Value (χ^2)	27.909

Combining all the information above, several important insights into the relationship between thermal discomfort, financial constraints, and housing characteristics are deducted. Village houses, being the most commonly occupied type, exhibit structural limitations that result in poor thermal performance, making mechanical cooling systems like air conditioners less efficient. This inefficiency worsens the financial burden associated with cooling, reinforcing the conclusion that cost both in terms of electricity bills and affordability is a key reason for not using air-conditioning. Importantly, thermal discomfort is not solely due to financial limitations but also the result of poor building envelope performance, highlighting the potential impact of passive design improvements such as enhanced ventilation, insulation, and strategic window placement. The study also uncovers a gendered dimension, with some women respondents lacking autonomy in appliance usage, suggesting the influence of sociocultural dynamics on comfort-related decisions. Furthermore, discomfort is reported most frequently in the kitchen, a critical functional area, pointing to the need for targeted interventions in heat-intensive spaces. A smaller number of respondents cited ineffective or slow-performing cooling systems, indicating an opportunity for introducing energy-efficient and affordable alternatives. As whole, these deductions underscore the need for a holistic approach to improving thermal comfort, one that integrates structural design enhancements, social considerations, and access to more efficient cooling solutions.

3.2. Building Simulation Analysis for Thermal Comfort Based on U-Value Evaluation

Following the findings and discussion in Section 3.1, as illustrated in Figure 12, women who mainly spent time at home in a village with a potentially poor building envelope experienced peak discomfort periods between 2 PM and 5 PM, followed by 11 AM to 2 PM. This discomfort among these women correlates with sunlight penetration, suggesting that shading devices or adjusting curtain usage during these hours could significantly enhance comfort. Other than that, efforts to integrate enhanced U-value building structures would significantly improve thermal comfort for these women. This is in line with the findings of research whereby heat capacity has impact building energy performance and thermal discomfort (Muñoz et al., 2022). The issue is not just about whether they can afford air conditioning or cooling units, but more about how to first reduce the cooling load of the house via passive approach. By doing so, cooling consumption can be minimized, allowing electrical appliances to be used without placing too much strain on electricity bills, which are typically paid by the partner.

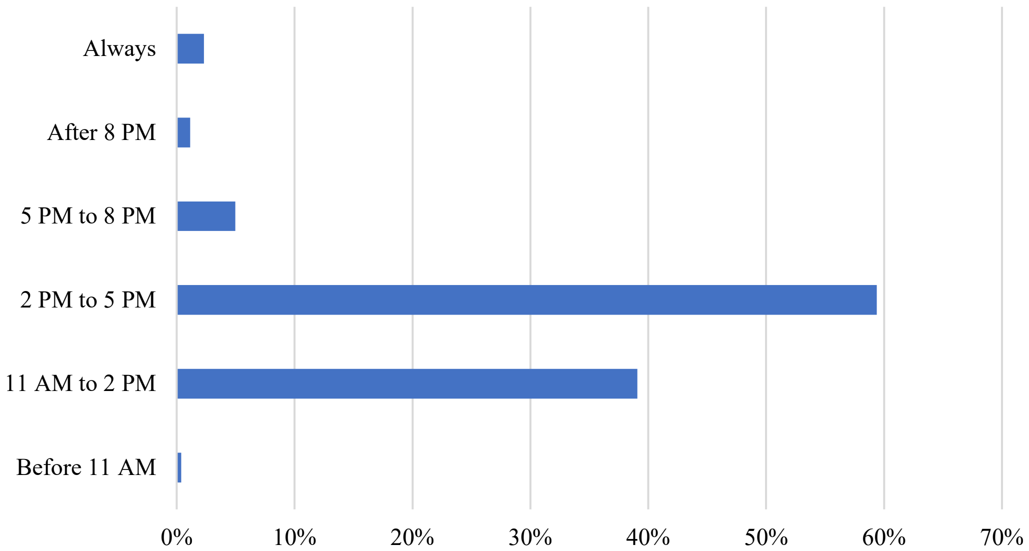


Figure 12. Timeframe of discomfort.

Key findings as illustrated in Figures 13 and 14 include high average temperatures in rooms, halls, and kitchen areas when air conditioning is off, particularly from 11 AM to 2 PM, due to heat gain through fenestration and electrical appliances. Among all the configurations, configuration B has an excellent wall insulation value reaching a peak of 39.8 °C. Meanwhile, in terms of the average space temperature, configuration E with the lowest overall U-value due to the excellent insulation introduced in the wall, roof and glazing showed the highest average temperature trend, indicating difficulty in heat escape. When cooling is introduced, as illustrated in Figure 15 on the contrary, lowest cooling load for configuration E was obtained due to its overall insulation level which indicates difficult for heat gained. However, it is worth noting that configurations C and D had similar average temperatures without cooling, with C slightly higher, suggesting the insulated roof has a greater effect than improved glazing. In addition, when evaluated in terms of its cooling load, among the different configurations tested, Configuration E—which included upgrades to wall, roof, and glazing insulation—achieved the lowest cooling load of 3.00 kWh, a significant reduction compared to the 3.82 kWh recorded in Configuration A. This represents an approximate 21.4% reduction, demonstrating the effectiveness of improved insulation in lowering energy consumption. Configurations C and D, which focused primarily on roof insulation, also showed notable reductions in cooling load (3.50 kWh and 3.39 kWh, respectively), further highlighting the importance of roof insulation in minimizing solar heat gain. Roof insulation is assumed to be the most affordable and practical option, followed by wall insulation and glazing improvements. This assumption is supported by existing literature and market trends (Akbari and Rose, 2008) which indicate that roof insulation typically requires less material and labour compared to wall and window insulation, making it a cost-effective solution for immediate implementation in low-income households. For instance, insulating an attic or roof space often involves adding insulation material over a straightforward and accessible area, whereas wall insulation may require more extensive work, such as drilling and filling cavities or adding insulation boards, and window upgrades can be costly due to the price of materials and installation labour. Thus, adding roof insulation is recommended for improved thermal comfort and reduced cooling load, as it is viable and has the lowest capital cost with similar impacts to wall and glazing insulation.

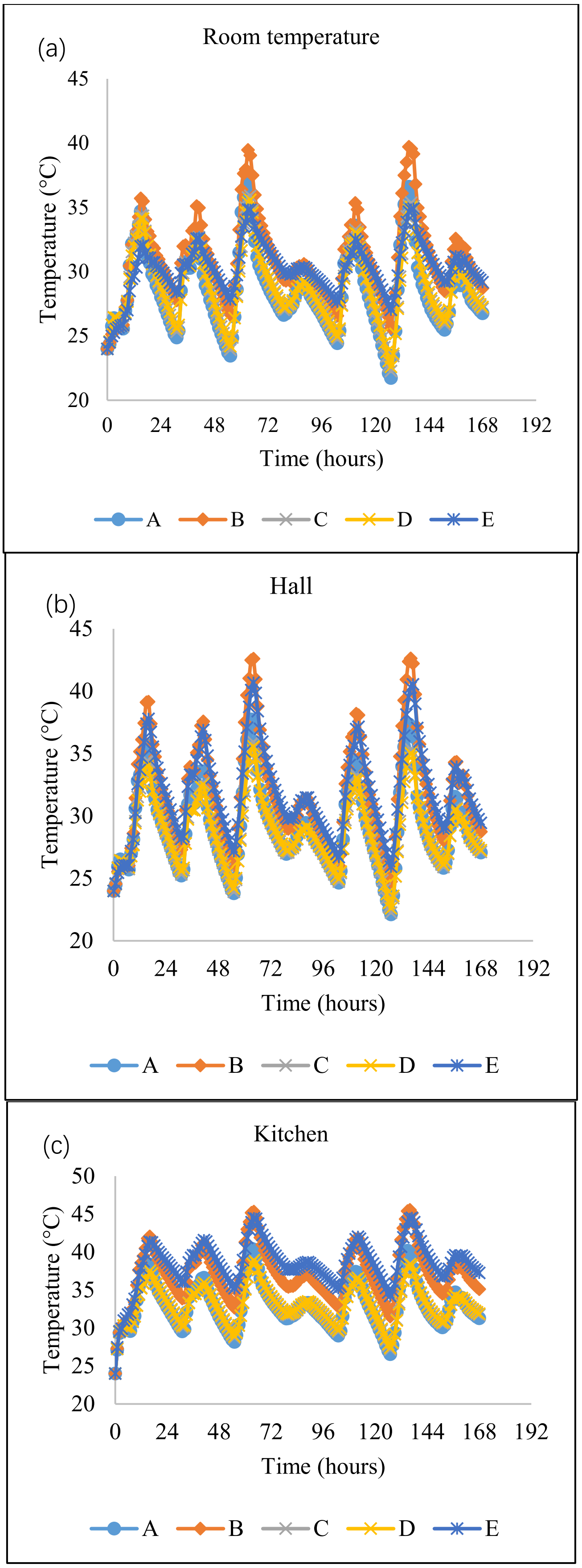


Figure 13. The temperature variation with the time of the day for 7 days of simulation at three different spaces in the house: (**a**) Room, (**b**) Hall, and (**c**) Kitchen.

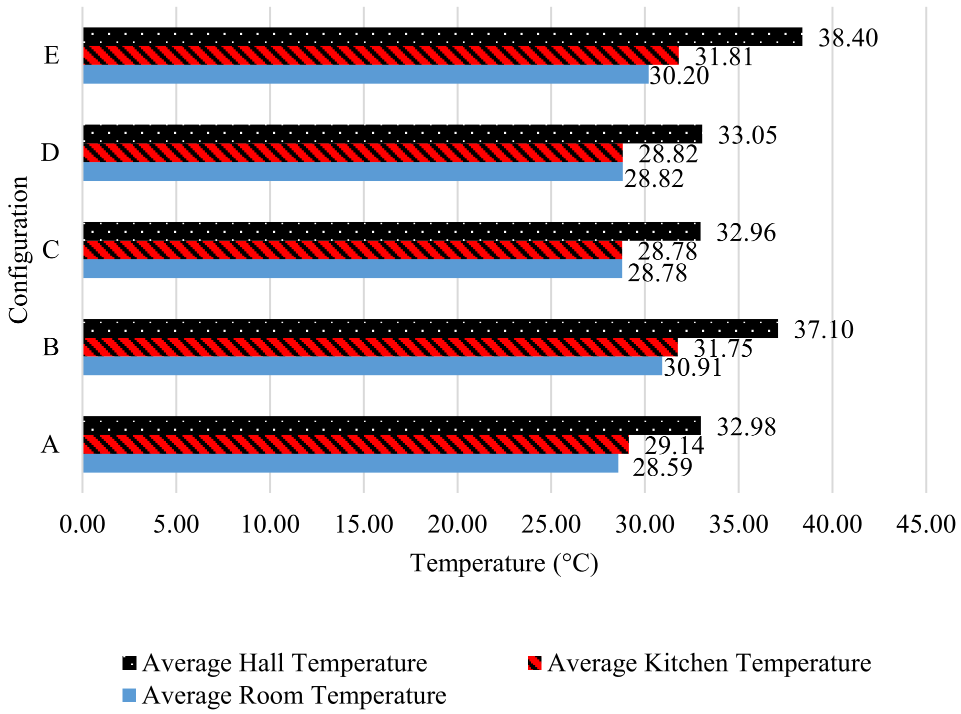


Figure 14. Average space temperature without cooling.

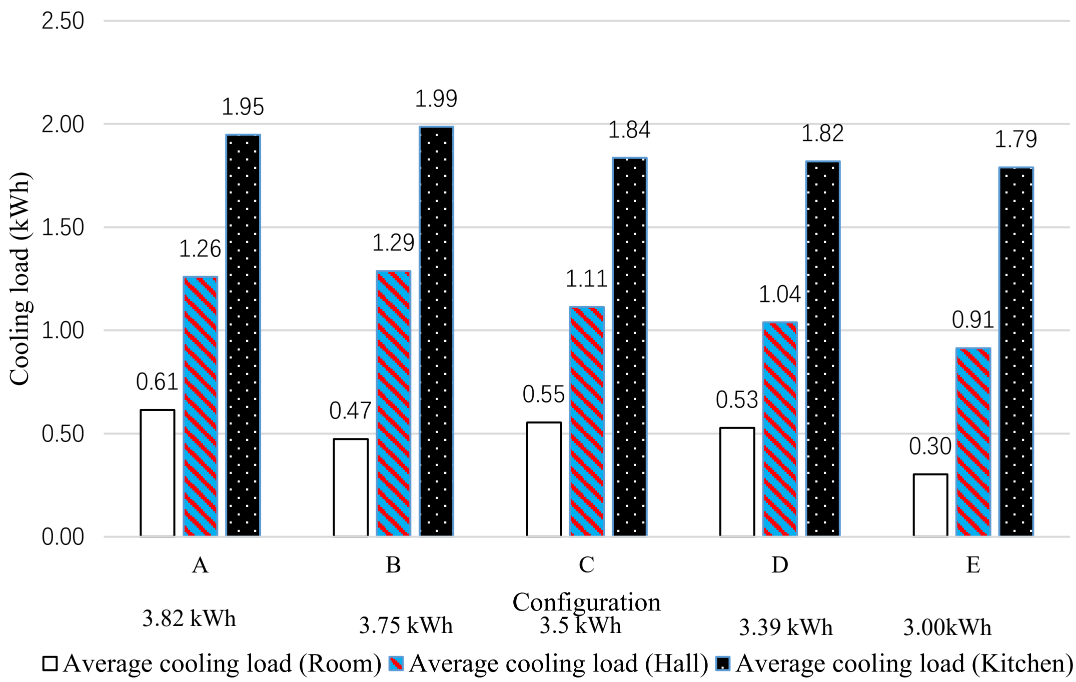


Figure 15. Average cooling load in kWh.

3.2. Recommended Strategies in Addressing SDG 5 Cooling Access for Women Home-Based Workers

Based on the analysis of the survey and the simulation study, we propose several strategies that may be implemented to accelerate the impact of introducing insulation into underserved communities. In strengthening the connection to SDG 5 (Gender Equality), this study offers practical policy recommendations grounded in the findings. First, government-supported insulation programs should be introduced to subsidize retrofitting costs for low-income households, particularly those headed by women or with women working from home. As demonstrated in the simulation case study, enhancing the roof insulation and wall insulation can significantly reduce thermal discomfort and energy consumption. With that being said, this may be achievable if financial support or subsidies are given. Second, from the activities that the researchers have conducted during data collection, clearly public awareness campaigns and knowledge-sharing initiatives which targeted at the community level rather than academic circles are essential to promote simple energy-saving strategies through using shading devices, proper curtain usage during peak hours, natural ventilation, and the selection of affordable insulation materials. These strategies are especially beneficial in rural areas where access to and affordability of active cooling technologies like air conditioning units, as well as the ability to cover ongoing electricity costs, are major concerns. Third, gender-sensitive energy policies should be integrated into national development plans to ensure that the thermal comfort needs of women who typically spend more time at home are explicitly addressed. This is supported by our survey findings, which revealed that 94% of women home-based workers reported experiencing thermal discomfort at home. Finally, improvements in insulation and access to cooling should be embedded within broader rural development and poverty alleviation initiatives, ensuring that efforts to enhance building performance also contribute to long-term women's empowerment and wellbeing.

4. Conclusion

This study emphasizes the critical role of gender equality in the pursuit of sustainable cooling. The findings are significant as they provide insights into cooling access, specifically addressing women home-based workers in Malaysia, while also highlighting factors that may limit the use of cooling appliances. The survey results indicate that although systems such as air conditioning units and fans are widely available, their usage is constrained by the high cost of electricity. Additionally, inefficient cooling may result from poor insulation, as suggested by the housing types common in these areas. Building simulations using TRNSYS revealed that improving insulation plays a crucial role in reducing cooling loads and enhancing thermal comfort. Key findings that can be drawn from the paper are as follows:

i. 94% of surveyed women home-based workers reported thermal discomfort in their homes with the kitchen and hall were identified as the most uncomfortable spaces during the day.
ii. Configuration E, which featured upgraded wall, roof, and glazing insulation, achieved the lowest cooling load at 3.00 kWh—a 21.4% reduction compared to Configuration A (3.82 kWh). Configurations C and D, focusing mainly on roof insulation, also reduced cooling loads to 3.50 kWh and 3.39 kWh, respectively, emphasizing the significant role of roof insulation in reducing solar heat gain.
iii. Electricity cost was the main barrier to the use of cooling appliances, even when available.
iv. The traditional village houses where women home based workers mainly spent their time at commonly lacked proper insulation, contributing to internal heat buildup.
v. TRNSYS simulations confirmed that:
   a. Roof insulation had the most significant effect on reducing cooling loads at the lowest cost.
   b. Full insulation (roof, wall, glazing) provided the greatest energy savings.
   c. Roof-only insulation achieved nearly similar thermal performance as full insulation, making it a practical first step for low-income households.

Worth highlighting that the scope of this study is limited to villages in Malaysia, which may affect the generalizability of the findings to other regions with different climatic, socio-economic, or cultural contexts. Additionally, the proposed strategies for improving thermal comfort are confined to passive approaches, specifically through modifications to building insulation properties. This study is also limited to a technical perspective, with key assumptions made regarding the cost-effectiveness of retrofitting interventions. With that being said, future research may extend geographical coverage and explore the integration of both passive and active cooling solutions to provide a more comprehensive understanding and set of recommendations

Finally, the results emphasize that while comprehensive insulation upgrades (as seen in Configuration E) provide the most significant reductions in cooling load, roof insulation alone can deliver substantial energy savings at a lower cost. Therefore, future research should focus on implementing these findings in real-world building retrofits and assessing the long-term financial benefits for women home-based workers. Moreover, although this research aligns with SDG 5 by empowering women through improved working environments and reduced energy costs, its full impact will only be realized if future studies include policy recommendations and the development of a suitable framework to support scalable and sustainable implementation.

Acknowledgement
The authors would like to thank Dana Padanan Kolaborasi (DPK) Geran Padanan Universiti Kebangsaan Malaysia with research grant DPK-2022-008. Also, this research is part of the "A novel solar desiccant dehumidification and cooling technology using porous aluminosilicate foam-PCM panels for building cooling and indoor air quality (CoolAQ) Project", supported by a Research Environment Links grant from the British Council and Malaysian Industry-Government Group for High Technology, as part of the British Council's Going Global Partnerships program. The main author, Hasila Jarimi, would also like to thank UKRI for the Marie Skłodowska-Curie Actions (MSCA) Postdoctoral Fellowship Guarantee Funding (Ref: 101151868), which enabled her to complete this paper during her fellowship.

References

Abass, F., Ismail, L.H., Wahab, I.A., Mabrouk, W.A. and Kabrein, H. (2021) 'Indoor thermal comfort assessment in office buildings in hot-humid climate', *IOP Conference Series: Materials Science and Engineering*, 1144(1), p. 012029. https://doi.org/10.1088/1757-899X/1144/1/012029.

Akbari, H. and Rose, L.S. (2008) 'Urban surfaces and heat island mitigation potentials', *Journal of Human–Environment System*, 11(2), pp. 85–101.

Alele, F., Malau-Aduli, B., Malau-Aduli, A. and Crowe, M. (2020) 'Systematic review of gender differences in the epidemiology and risk factors of exertional heat illness and heat tolerance in the armed forces', *BMJ Open*. Available at: https://bmjopen.bmj.com/content/10/4/e031825 [Accessed 1 April 2025].

Chaudhuri, T., Zhai, D., Soh, Y.C., Li, H. and Xie, L. (2018) 'Random Forest based thermal comfort prediction from gender-specific physiological parameters using wearable sensing technology', *Energy and Buildings*, 166, pp. 391–406. https://doi.org/10.1016/j.enbuild.2018.02.035.

Dabaieh, M., Bendixsen, A.F. and Laursen, L.N. (2023) 'How to Stay Cool Without Fossil Fuel: A Passive Low-Tech Cooler for Extreme Climates', in Faircloth, B., Pedersen Zari, M., Thomsen, M.R. and Tamke, M. (eds) *Design for Climate Adaptation*, Cham: Springer, pp. 733–743.

Esfandiari, M., Zaid, S.M., Ismail, M.A., Hafezi, M.R., Asadi, I. and Mohammadi, S. (2021) 'A Field Study on Thermal Comfort and Cooling Load Demand Optimization in a Tropical Climate', *Sustainability*, 13(22), p. 12425. https://doi.org/10.3390/su132212425.

Haselsteiner, E. (2021) 'Gender Matters! Thermal Comfort and Individual Perception of Indoor Environmental Quality: A Literature Review', in *Gender and Energy Research*, pp. 169–200. https://doi.org/10.1007/978-3-030-71819-0_9.

Hassan, F., Ramli, A. and Mat Desa, N. (2014) 'Rural Women Entrepreneurs in Malaysia: What Drives Their Success?', *International Journal of Business and Management*, 9(4), pp. 10–21. https://doi.org/10.5539/ijbm.v9n4p10.

Khosla, R., Somanathan, E., Sethi, T., Singhal, R., Chaturvedi, V. and Shah, N. (2021) 'Cooling for sustainable development', *Nature Sustainability*, 4(3), pp. 201–208. https://doi.org/10.1038/s41893-020-00627-w.

Lan, L., Lian, Z., Liu, W. and Liu, Y. (2008) 'Investigation of gender difference in thermal comfort for Chinese people', *European Journal of Applied Physiology*, 102(4), pp. 471–480. https://doi.org/10.1007/s00421-007-0609-2.

Latif, S., Hamzah, B., Rahim, M.R., Mulyadi, R. and Idrus, I. (2019) 'Thermal investigation on the attics of buginese traditional houses in South Sulawesi', *IOP Conference Series: Earth and Environmental Science*, 382(1), p. 012024. https://doi.org/10.1088/1755-1315/382/1/012024.

Mastrucci, A., Byers, E., Pachauri, S., Rao, N. and van Ruijven, B. (2022) 'Cooling access and energy requirements for adaptation to heat stress in megacities', *Mitigation and Adaptation Strategies for Global Change*, 27(8), p. 59. https://doi.org/10.1007/s11027-022-10032-7.

Mastrucci, A., Byers, E., Pachauri, S. and Rao, N.D. (2019) 'Improving the SDG energy poverty targets: Residential cooling needs in the Global South', *Energy and Buildings*, 186, pp. 405–415. https://doi.org/10.1016/j.enbuild.2019.01.015.

Maykot, J.K., Rupp, R.F. and Ghisi, E. (2018) 'A field study about gender and thermal comfort temperatures in office buildings', *Energy and Buildings*, 178, pp. 254–264. https://doi.org/10.1016/j.enbuild.2018.08.033.

Muñoz, P., González, C., Recio, R. and Gencel, O. (2022) 'The role of specific heat capacity on building energy performance and thermal discomfort', *Case Studies in Construction Materials*, 17, p. e01423. https://doi.org/10.1016/j.cscm.2022.e01423.

SEforALL (2021) *Chilling Prospects: Tracking Sustainable Cooling for All*. [online] Sustainable Energy for All. Available at: https://www.seforall.org/system/files/2021-05/Chilling-Prospects-21-SEforALL.pdf [Accessed 1 April 2025].

Thapa, S. (2019) 'Insights into the thermal comfort of different naturally ventilated buildings of Darjeeling, India– Effect of gender, age and BMI', *Energy and Buildings*, 193, pp. 267–288. https://doi.org/110.1016/j.enbuild.2019.04.003.

WHO (n.d.) *Gender and Health*. [online] World Health Organization. Available at: https://www.who.int/health-topics/gender [Accessed 1 April 2025].

Zhang, Z., Zhang, Y. and Jin, L. (2017) 'Thermal comfort of rural residents in a hot–humid area', *Building Research & Information*, 45(1–2), pp. 209–221. https://doi.org/110.1080/09613218.2017.1246003.