REVIT SIMULATION APPLICATION IN EVALUATING FENESTRATION STRATEGIES TOWARDS ENERGY CONSERVATION IN MALAYSIAN INTERMEDIATE TERRACED HOUSES

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ABSTRACT

With Malaysia's population rising and rapid urbanisation, terraced houses were built to respond to new social and economic needs. The modern terraced house appeals to the demand for high-density development. However, with just two or three façades available for openings on the front and rear façades, these houses, particularly intermediate units, frequently lack natural ventilation, resulting in slow and inefficient air exchange throughout the house. As a result, adjustments on fenestration that functions as passive design solutions are necessary to increase internal thermal comfort and energy savings. This study aims to determine the various forms of fenestration placement in Malaysian terraced buildings and examine how these different types of fenestrations in terraced houses affect energy consumption and conservation. This study employs Revit modelling software to create a set of prototypes of intermediate terrace houses with different fenestration treatments. Building simulation is used to record findings of building energy performance based on the annual and monthly energy consumption of each prototype. This study found that the terraced home façade fenestration design significantly reduces energy consumption. It is anticipated that the finding of this study will benefit architects and designers better understand designing more ecologically conscious terraced houses by addressing internal thermal comfort through passive design.

Keywords: Fenestration, Building Simulation, Revit, Terraced Houses, Energy Conservation

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1. INTRODUCTION

A hot and humid climate distinguishes the tropical climatic zone. Malaysia is located in Southeast Asia, between 1° and 7° north of the equator, and has a hot, humid climate all year (Haw & Ashhar, 2022), where the average daily exposure to sunshine is six to eight hours. According to the American Society of Heating, Refrigerating and Air Conditioning Engineers ASHRAE, the optimal interior air temperature is between 22.5°C and 25.58°C. However, research findings have discovered that individuals living in hot, humid tropical regions described thermally comfortable temperatures of between 24.5°C to 28°C (Arminda & Kamaruddin, 2021).

With the rapid expansion of Malaysia's population and urbanisation, increasing the residential construction industry is vital to cater to the growing demand for residences, particularly in metropolitan areas (Weini et al., 2022). The terraced house is the product of the confluence of colonial history with traditional residential styles. These dwellings were built in the international functionalism style to meet new social and economic requirements (Johari & Said, 2021). Terraced houses require less land than similar numbers of other types of housing. As a result, they are the best type of housing for high-density development.

For ages, locals have developed traditional Malay houses in response to their environmental and cultural identity. Passive design strategies like fenestrations on all facades promote natural lighting and ventilation. A large roof overhang is another prominent architectural element that gives shade to walls and windows, reducing the impact of solar radiation (Nwalusi et al., 2022). These strategies have been tested and proven in a study conducted by Oleiwi and Mohamed (2021) in Malaysia. According to the study, an extended roof overhang reduces the indoor operative temperature of the house effectively by providing protection to the building's envelope against direct solar radiation. As a result, interior thermal comfort improves at lower energy consumption (Oleiwi & Mohamed, 2021).

Intermediate terraced residences in Malaysia often lack natural ventilation, with just two or three façades accessible for openings on the front and rear façades (Gunasagaran et al., 2022), causing sluggish, inefficient air exchange in the house and lack of natural lighting. On top of that, using artificial lighting raises the temperature within the house, affecting the indoor environment for the residents and reducing indoor thermal comfort (Yong et al., 2021). Optimal indoor comfort level in the city is essential, but urban terrace house design often overlooks implementing passive design strategies that allow natural daylight and ventilation (Oleiwi & Mohamed, 2021). Fenestration is an architectural terminology referring to the design of windows, doors or openings in a building façade. Indoor thermal comfort is highly influenced by air circulation, exterior and interior temperatures, fenestrations, and building materials (Othman et al., 2021). Air temperature in urban areas is greater than in the surrounding regions, especially at night, with indoor air temperature being higher than outdoor air temperature due to excess indoor heat content (Tong et al., 2019). A simulation model analysis found that the indoor air temperature of Malaysian houses was not within the permissible limit (Amir, 2019). Lower indoor air temperatures are necessary to provide occupants with optimum indoor thermal comfort. As a result, window design modifications and passive design strategies are required to enhance the habitability of the indoor thermal environment of these houses (Zakaria, 2017). Failure to do so will result in people having a worse quality of life in a thermally uncomfortable home (Amir, 2019).

This research analyses the application of fenestration placement as a passive tropical design in Malaysian terraced houses for energy conservation. Understanding the significance of climate-responsive home designs is crucial for ensuring the indoor thermal comfort of Malaysian residents. Therefore, the aim of this research is supported by a series of objectives. First is to determine the type of fenestration commonly used in Malaysian terraced houses. Secondly, to determine how fenestration placement in terraced houses influences energy consumption and finally to establish the application of fenestration placement which improves energy efficiency by using Revit building simulation.

This study will help architects and designers better understand designing more ecologically conscious terraced houses by addressing internal thermal comfort through passive design. Additionally, developers will better understand potential consumers' preferences and offer a quality lifestyle that promotes passive design in the hope that both outcomes would contribute towards mitigating adverse environmental effects. This study would also help to establish the effectiveness of building simulation in assessing the thermal comfort performance of the building. Simulation and analysis capabilities incorporated into software like Revit allows researchers to provide prompt predictive results. Furthermore, the outcomes of simulation and analysis are directly proportionate by parametric building models, with can provide a broader range of variables for the study.

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2. LITERATURE REVIEW

Extreme heat exposure throughout the day and night in tropical countries causes urban buildings to overheat (Mohammad & Zulkifli, 2022). However, thermal comfort and energy efficiency can be achieved by the application of fenestration design as a passive design strategy to minimise indoor overheating in the present and future possibilities of warm tropical or subtropical climates (Gamero-Salinas et al., 2021).

According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures would rise by 1.5°C by 2050. The past century has seen a 0.7–0.8°C warming in the tropics (Fan et al., 2021). However, according to climate predictions, this area will warm another 1 to 2 degrees Celsius by 2050 (Gamero-Salinas et al., 2021). Consequently, marginalised people are far more at risk of experiencing severe climate consequences. As a result, tropical countries, where the world's poorest and most vulnerable people live, are in much more severe danger (Vaidya et al., 2019).

Buildings in tropical countries overheat due to the intense heat exposure day and night. However, thermal comfort can be achieved using these climatic zones' correct building design principles. However, very few studies particularly examine how passive design might reduce indoor overheating in the current environment and any future warm tropical or subtropical climates (Gamero-Salinas et al., 2021).

Increased nighttime ventilation rates have been shown in research from Myanmar to reduce uncomfortable indoor thermal environments significantly (Zune et al., 2020). Still, current ventilation techniques cannot provide thermal comfort throughout the average weather year and potential future climate change scenarios (Zune et al., 2020).

Natural ventilation was shown to be an efficient way to cool buildings in the warm, subtropical environment of Hong Kong. The most effective way to avoid overheating is sun protection since the cooling potential of the natural ventilation will eventually decline due to increase in outdoor temperature globally (Liu et al., 2020). Climate change will increase the world's hottest regions' need for cooling energy by 2100, necessitating the urgent implementation of construction industry mitigation plans while considering the challenges posed by the predicted rise in the demand for mechanical cooling and increased climate fragility (Gamero-Salinas et al., 2021).

2.1 Thermal Comfort in Malaysia House

According to the Malaysian Ministry of Energy, the residential sector is the leading electricity consumer, accounting for 21.6% of total annual energy consumption, with 11% used ~~only~~ for space cooling (Erixno et al., 2022). Thermal discomfort from high interior temperatures increases cooling demands from the residential sector, raising energy consumption.

Research conducted by Tuck et al. (2019) examined the internal thermal environment of a two-story corner terrace home in Malaysia and recorded the inside temperature in four ventilation modes: full ventilation, no ventilation, day ventilation, and night ventilation. The study indicates a peak interior temperature of 31.7C when a mechanical cooling device, including a fan and air conditioner, is in place and there is adequate natural ventilation. Malaysian residents use air conditioners for 7.6 hours daily, primarily at night, to reduce excessive heat and achieve thermal comfort (Tuck et al., 2019).

Another study by Yong et al. (2021) examined how Malaysia's public low-cost housing is perceived regarding thermal comfort. Thermal comfort with the thermal condition is characterised by satisfaction in the state of mind. Data analysis indicates that residents preferred mechanical cooling systems to attain thermal comfort, particularly in hot weather, despite this preference being first perceived as an emotional sensation. Many of the study's participants have installed air conditioners, and their primary concerns are the rising cost of electricity and its impact on the thermal comfort of their homes. This worry is extremely genuine because low-cost homes are tailored to low-income households (Yong et al., 2021).

These investigations have shown that Malaysian homes still have low interior thermal comfort. However, this research focuses only on Malaysia's two-storey corner terrace homes and low-cost high-rise residential structures' mechanical ventilation systems. In order to provide a thermally suitable indoor atmosphere in intermediate Malaysian terrace house units, this research will examine the relevance of fenestration as a passive design solution appropriate for the tropical climate.

2.2 Fenestration Effect on a Malaysian Terrace House

In Malaysia, there are many different types and sizes of terraced homes. Larger frontage houses are preferred due to their open floor plans which increase natural lighting design and offer better viewpoints through larger fenestration sizes (Othman et al., 2021). However, larger frontage residences may not always provide optimal indoor thermal comfort. Indoor thermal comfort is affected by various elements, including the size and type of fenestrations, the building material used and the ventilation system, the structure's orientation, and shading devices (Nasrollahzadeh, 2021). Othman et al. (2021) explored how the frontages of terraced houses impact internal thermal comfort. When addressing terraced structures with different orientations, one cannot simply assume that a more expansive frontage would provide more natural ventilation - assuming more fenestrations are available. Before making any deductions, it is crucial to consider the fenestration's design, size, location, and operation type - either fixed or adjustable. It is vital to note that a more expansive frontage may also pose a larger wall surface exposed to solar radiation, resulting in a higher thermal gain (Jankovic & Goia, 2021).

Timber doors, sliding doors, aluminium casement windows, aluminium jalousie windows, and skylights are the most popular fenestrations in Malaysian terraced houses (Oleiwi & Mohamed, 2021). Different terraced house frontages design poses different impact on indoor thermal comfort, with excellent indoor thermal comfort reported in a house frontage with the lowest window-to-wall ratio (WWR) (Othman et al., 2021). The average interior temperature decreases with decreasing WWR ratio, increasing occupants' indoor thermal comfort (Almhafdy, 2021). The evidence shows that a lower WWR reduces the amount of heat that is transmitted by solar radiation via the fenestrations. The study also revealed that the positioning of fenestration significantly reduces solar exposure of the house's facade as an effective passive design strategy to reduce solar radiation indoors in order to increase thermal comfort.

The scope of research conducted by Othman et al. (2021) aligns very similarly with this research. However, the previous research was only limited to the data gained from the study of indoor spaces with closed or fixed fenestrations. This research will further include the impact of openable fenestrations on natural ventilation to improve indoor thermal comfort.

2.3 Building Simulation Software in Measuring Building Performance

Research conducted by Al Doury et al. (2020) investigates how Revit software and its feature Insight 360 may enhance a building's thermal performance. Increasing a building's thermal performance reduces energy use and creates sustainable buildings (Abdullah Halim et al., 2021). According to the research, creating a new approach for a comprehensive analysis of the building is the first step towards achieving that goal. In the past, assessments have heavily depended on hand measurements, spreadsheets, building codes, and legally mandated national annexes. However, these analyses do not give the designers the adaptability they need to handle all analyses adequately. (Al Doury et al., 2020). Even though dynamic simulation software has been around since the 19th century, it is still not often used since it might be difficult to manually enter all the necessary data (Akkurt et al., 2020). On the other hand, Revit is a three-dimensional, real-time, and dynamic building modelling programme to increase the efficiency and accuracy of designers (Fateh and Aziz, 2021). Revit can address these issues, improve the input data's effectiveness, and boost existing data's reusability (Tao et al., 2021).

Using Autodesk BIM, an energy study of a housing complex contributes to BIM's function in determining a building's sustainability level (Nordin, 2018). It is reported that Revit Architecture analysed challenging problems like daylight and solar access easier (Shivsharan et al., 2017). Furthermore, this programme is more accessible than ever thanks to the organisation of all details and their incorporation into the Revit Architecture. It enables simple access to tools that offer fast feedback on alternative design ideas (Lat et al., 2021).

Based on the research conducted by both Al Doury et al. (2020) and Shivsharan et al. (2017), building simulation software used in data collection is user-friendly and highly practical. Therefore, as a data collection and analysis technique, this research will also employ the Revit programme to model a few terrace houses included in the scope of the study. Consequently, it will be possible to accomplish this study on schedule and at the lowest possible cost.

2.4 Roof Design for Houses in the Tropical Climate Region

A house built in a tropical area might have a different indoor thermal environment depending on the type of roof design and material used. Hot air can rise far from the residences with a roof pitch between 30 and 45 degrees (Alqaed, 2022). Because of their porosity, traditional materials like thatch are ideal for an efficient cooling cycle. However, organic materials degrade more quickly than clay and cement roof tiles. Clay or cement roof tiles are more durable with less thermal conductivity. Thus, the best roof design in a tropical climate could be a hybrid of steep roof pitches and thermally insulating roof tiles.

Holder (2022) pointed out that a building roof is an integral part of the structure. It must thrive in a tropical climate with frequent and intense rainfall. In order to reduce heat gain, it must also be built to minimise solar heat exposure (Mohammad & Zulkifli, 2022). Pitch roofs are more prevalent in traditional and modern home designs in tropical countries. A gable roof creates a unique triangular form reminiscent of historic buildings in addition to the convenience of a pitched roof (Holder, 2022). Hot air may rise away from livable areas because of the high ceilings in the centre of a gable roof.

2.5 Malaysian House Fenestration Characteristics

Timber is Malaysia’s most popular door material because of its numerous advantages and abundant local resource. Timber is sturdy and long-lasting when properly treated. Timber is easy to work with and can be quickly adjusted in various sizes, shapes, and designs. It also has a thermal insulating property. Furthermore, timber doors can operate as a thermal barrier, keeping space at the ideal temperature (Raval, 2020).

Aluminium windows and doors are versatile house alternatives to wood and glass doors. Aluminium fenestrations are solid and long-lasting. Furthermore, it has a sleek profile that matches the design of modern Malaysian homes. Sliding doors take up less area than swing doors. As a result, it is ideal for making the most of limited space in smaller sizes. This fenestration works well in the living or dining room (Elements, 2021).

Ramli and Saji (2021) conducted research on the various forms of fenestrations found in the 30 houses in Kampung Morten. The study found that windows with basic shapes, such as casement windows, were excellent for classic and modern houses. According to the survey, 73.33% of residences have casement windows, with double casement windows coming in second at 13.33%. Finally, jalousie windows are used in 10% of the dwellings, whereas geometric windows are used in just 3.33%.

3. METHODOLOGY

The research examines the energy consumption in a typical Malaysian terraced house based on the different placement and types of fenestration. Relationships between the wall-to-window ratio and other passive design strategies will be assessed and analysed in the context of interior thermal comfort. The analysis is conducted by running a series of building simulations in Revit. Only two-story intermediate double-storey terraced houses with the pitched roof were chosen and modelled to represent comparable terraced houses throughout Malaysia in this study. The following are the limitation of the study.

i. The intervention of the variables is subjected to the implementation of fenestration, mainly on the front and rear facades and roof.
ii. Only two-storey terraced houses with comparable characteristics are analysed to prevent large data variance for a significant research outcome.
iii. Field surveys and site inspections of diverse housing types are not carried out per the pandemic standards due to more stringent Covid-19 rules that had to be put in place, including the Movement Control Order hence limiting the range of this research’s findings.

Building simulation using Revit is chosen as the data collection method. Five models of intermediate unit double-storey Malaysian terraced houses with pitched roofs at 27º degrees with a 600mm overhang and similar designs are chosen as the sample in this research and modelled in Revit. The terraced house for this simulation is modelled based on typical Malaysian intermediate terraced houses which comprises three bedrooms and three bathrooms, complemented by two living spaces and a flexible room designated as a study area in this research. The floor plan is kept constant with dimension of 6100mm x 21000mm and total of 27100mm floor base area to reflect the typical intermediate Malaysian terraced houses layout, base model height of 3000mm for both ground floor and first floor height, and size of windows and doors are kept constant in this research as a controlled variable. All prototypes are simulated based on the setting of Malaysian coordinate of 4.2105° N, 101.9758° E. The construction materials adhere to the Malaysia Standard Energy Efficiency and Use of Renewable Energy for Residential Buildings – Code of Practice (2017). This code of practice provides guidance for design, material selection, and electrical appliance choices, focusing on energy efficiency and incorporating renewable energy solutions in both new and existing residential buildings. These models are incorporated with different fenestrations that differ in placement and type on the front and rear façade. The fenestration chosen for this study is timber doors, sliding doors, aluminium casement windows, aluminium jalousie windows and aluminium skylights to represent the typical design of Malaysian terraced houses' fenestrations.

As shown in Figure 1, Model A acts as a control prototype by default design of casement windows and single-leaf timber door. Model B (shown in Figure 2) differs from Model A by application of a louvred glass window as a façade treatment replacing the casement window while retaining single leaf timber door. Model C shares the same type of window which is casement window while changing the single-leaf timber door to a glass sliding door. Model D differs from Model A with the addition of a skylight on the roof. Model E replaces the casement window in Model A with empty openings. The difference between each model is shown as follows:

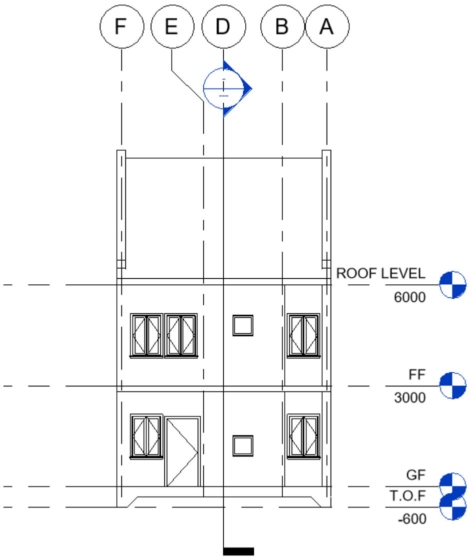

Figure 1: Model A: Casement window and single-leaf timber door

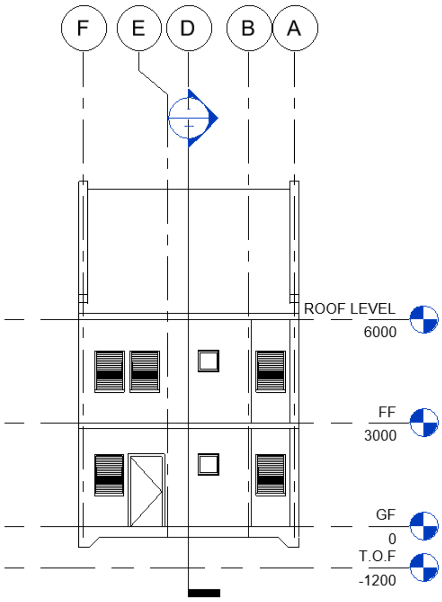

Figure 2: Model B: Louvred glass window and single-leaf timber door

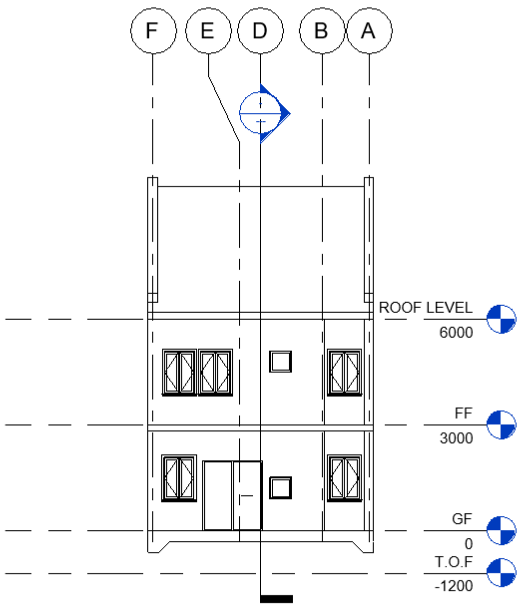

Figure 3: Model C: Casement window and sliding door

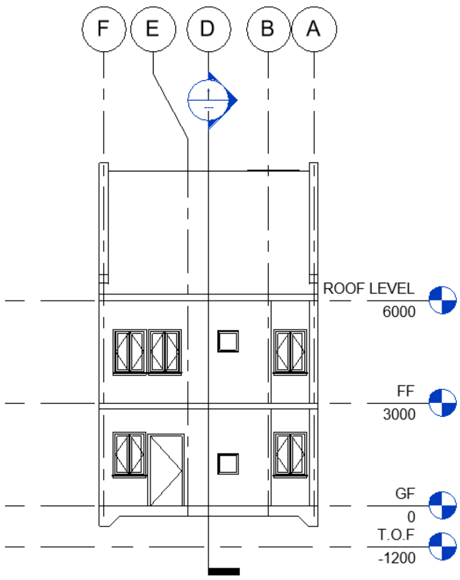

Figure 4. Model D: Casement window, single-leaf timber door and skylight.

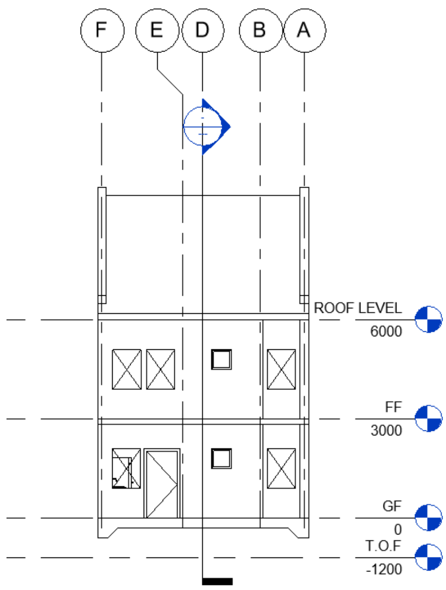

Figure 5: Model E: Empty openings and single-leaf timber door

Then, Green Building Studio – a plug-in for Revit that measures thermal properties – will simulate the indoor thermal environment of the house. The data collected from the Revit simulation is compiled and examined to provide a comparative analysis that answers the research questions and fulfils the research aims. After collecting data from Revit, the data are tabulated and compared to provide a comparative analysis. Building simulation data collection can provide quantitative data in a short time frame that fits the schedule of this project.

4. RESULTS AND DISCUSSION

The data collected from Revit Energy Analysis shows that in the Malaysian tropical climate, a typical terraced house requires an average of 5252.25 kWh to keep an indoor temperature of 26^0 C with the aid of mechanical ventilation such as fan and air-conditioner. More annual consumption suggests lesser efficiency of the fenestration as the use of mechanical ventilation is needed to maintain indoor thermal comfort.

Table 1: Simulated Annual Energy Usage of Malaysia Terraced House

Model	Fenestration	Annual Consumption (kWh)	Monthly Consumption (kWh)
A	Casement window and single-leaf timber door	63,375	5,281.25
B	Louvred glass window and single-leaf timber door	63,650	5,304.17
C	Casement window and glass sliding door	62,530	5,210.83
D	Casement window, single-leaf timber door and skylight.	63,865	5,307.08
E	Empty openings and single-leaf timber door	61,895	5,157.92
		Average	5,252.25

Model A serves as a prototype control. Model C and Model E consumed 5,210.83 kWh and 5,157.92 kWh, less than the average monthly consumption of 5,252.25 kWh, indicating that both façade treatments, namely glass sliding doors and empty openings, reduce energy consumption effectively. Model B with louvred glass windows recorded higher annual energy consumption than Model A control prototype, implying that they are ineffective in lowering energy consumption in terraced houses. This is due to the characteristic of louvered windows, which are constructed with multiple slats or glass panels, and they typically lack the same level of airtight sealing found in the solid, single-pane structure of casement windows. This absence of a secure seal can lead to air infiltration, permitting outdoor air to enter and conditioned indoor air to exit. Consequently, the heating and cooling systems in a home must exert greater effort to sustain a stable indoor temperature. On the other hand, the addition of a skylight leads to the highest energy usage, yet only marginally more than a louvred glass window. Model D, which has a timber door, casement windows, and a skylight, allows more light into the building but uses the most energy to cool down (63,865 kWh). This is because a skylight admits a large quantity of heat acquired from solar radiation, increasing the WWR ratio and resulting in a greater indoor temperature in the house. Model B with louvred glass windows had a significantly lower yearly usage of 63,650 kWh compared to model D. The reduction can be explained by lower admittance of daylight with the absence of skylight, reduced WWR ratio, and hence a smaller quantity of heat from solar radiation. Both Model C and Model E recorded lower annual energy consumption as both demonstrated passive design strategies in improving indoor thermal comfort although in different approach. Model C tackles the issue of indoor thermal comfort by providing airtight sealing that helps to retain indoor temperature while Model E benefits from natural air ventilation through empty opening. Due to the larger WWR ratio from the glass sliding door, Model C had a higher yearly usage of 62,530 kWh than Model E as larger WWR ratio allows daylight penetration that permits heat penetration into the building. The Model E with the wall opening consumed the least energy to cool, at 61,895 kWh per year. The opening in the wall of model E demonstrated how effective building fenestration contributes to energy saving by permitting direct natural ventilation and adequate shade due to reduced solar heat gain. This contrast shows the restriction of airflow and lack of ventilation affects the indoor thermal comfort.

5. CONCLUSION

According to research, conventional Malaysian terraced housing façade designs cannot provide an appropriate thermal environment without mechanical cooling equipment. Most of the residents of these terraced houses cannot live comfortably without ASHRAE Standard 55 compliance and without the integration of mechanical ventilation or cooling equipment. Solar radiation and fenestrations cause a portion of the building's façade surface area to generate heat due to direct exposure to sunlight. (Othman et al., 2021). The heat gained from solar radiation rises as the surface area exposed to sunshine increases. Lengthy sunlight exposure to the Malaysian tropical climate during the day leads to a large quantity of solar heat gain. As a result, adapting some passive design strategies, such as selecting the appropriate type of fenestration, helps reduce the amount of solar heat gain (Oleiwi & Mohamed, 2021). Glazing with low thermal conductivity absorbs less heat. Sun shading devices can provide shade to reduce heat gain near fenestration. Understanding the principles of WWR helps ensure that fenestration with large surface surfaces, such as glass sliding doors and casement windows, can be modified to promote natural ventilation and daylighting, resulting in indoor thermal comfort with minimal heat gain.

The five prototype models simulated using Revit can provide comparable results of annual energy consumption from one another. It also emphasises how the effective placement of modern Malaysian terraced house façade fenestration can improve the indoor thermal environment through natural ventilation and daylight. Based on the simulation results, this study concludes that the modest aperture of model E with a single door is the most appropriate type of fenestration. It provides the building with cross-ventilation and natural daylighting, which improves heat exchange more effectively than louvred glass windows and timber doors.

The materials and treatment of the fenestrations determine the influence of the indoor thermal environment. Effective fenestrations may control lighting and ventilation, affecting the indoor thermal environment based on understanding the principle of balancing natural ventilation and adequate shade. The application of Revit simulation helps inform the designer on the efficacy of the fenestration design as a passive design strategy in a terraced house design. Therefore, careful consideration by the designer of making informed decisions based on the simulation outcome can help improve indoor thermal comfort in intermediate terraced houses design. Future research can further investigate the impact of fenestration material, the size of fenestration, and the influence on the internal thermal environment through natural ventilation and lighting. This recommended future study may employ Revit simulation as a reliable analysis method in analysing the energy performance of other building types.

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