

Performance of Thermal Comfort in Modern Glass Façade Building in Universiti Teknologi Malaysia Kuala Lumpur (UTM KL)

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DOI: <https://doi.org/10.30880/peat.2025.06.01.019>

Article Info

Received: 17 January 2025

Accepted: 05 February 2025

Available online: 30 April 2025

Keywords

Thermal comfort, modern glass facade, EnergyPlus simulation, window-to-wall ratio

Abstract

This study was conducted to determine the thermal comfort performance of modern glass facade building at Universiti Teknologi Malaysia (UTM) Kuala Lumpur, which is located in a tropical climate. Buildings with glass facade provide aesthetic appeal and help provide natural lighting. However, glass facade contribute to increased solar radiation, cooling demand and reduce occupant comfort. Using EnergyPlus simulation, this research aims to analyze thermal comfort parameters, including air temperature, mean radiant temperature, relative humidity, air velocity, Predicted Mean Vote (PMV), and Predicted Percentage Dissatisfaction (PPD) by studying the effects of window-to-wall ratio (WWR) and glass material on the building. The findings reveal that the selection of glass materials with optimized Solar Heat Gain Coefficient (SHGC), Visible Light Transmission (VLT) and U-values are important for achieving thermal comfort in tropical climates. In particular, SHGC values below 0.3 and U-values below 1.0 W/m²K reduce heat gain and maintain adequate natural lighting into the building. The WWR adjustment on the building facade plays an important role, proving the balance between natural lighting and thermal comfort. Other than that, this findings of this study follow practical design guidelines for integrating glass facades in the UTM KL building. The findings of the study prove the importance of balancing aesthetics, and occupant well-being in modern architectural design. The findings of this data are expected to influence future building designs, especially in educational institutions and urban high-rise developments.

1. Introduction

In recent decades, educational institutions built against beautiful landscapes have grown, with characteristic features and modern design elements such as glass facades becoming more prevalent (Prieto & Oldenhave, 2021). This feature is not only aesthetically pleasing but also works to take advantage of natural light, potentially reducing the need for artificial lighting and reducing energy consumption. However, the incorporation of extensive glass panels can also lead to higher energy consumption due to increased heat gain from solar radiation, especially in tropical climates such as Malaysia (Qahtan, 2024). The Universiti Teknologi Malaysia (UTM) Kuala Lumpur campus features several buildings with modern glass facades, making it an ideal case study to examine the implications of such architectural decisions on energy efficiency and thermal comfort. To preserve the environment, understanding the performance of buildings with existing energy efficiency and

occupant comfort is important for conducting academic research but also for practical implications in building design and architecture (Mitterer et al., 2012).

In the pursuit and fulfillment of thermal comfort in a modern glass facade building that represents a variety of factors associated with architectural design, engineering systems, occupant behavior and environmental factors. Thermal comfort defined as a state of mind that expresses satisfaction with the thermal environment is a critical aspect in building design and operation that affects various aspects such as occupant well-being, productivity and the overall experience in the interior of the building (Antoniadou & Papadopoulos, 2017). Although these modern glass facade buildings have been praised for their visual and dynamic impact, they also present complex challenges related to the building's energy performance and the building's internal thermal comfort (Mehaoued & Lartigue, 2019).

Universiti Teknologi Malaysia (UTM) Kuala Lumpur campus is home to several modern buildings, including a 15-story structure with glass window façade that is exposed to direct sunlight (Bulbaai & Halman, 2021). The process of incorporating glass facades in modern building design has been praised for its aesthetic appeal and criticized for the resulting energy performance, especially in tropical climates (Al-Kodmany, 2023). Glass is a material that acts and allows extensive natural light but is also a poor insulating agent compared to other building elements that are in contact with the outside air (Joseph Udi et al., 2023). Previous studies have proven that double glazing has advantages in terms of daylight use and has disadvantages in terms of heat gain and loss. In tropical climates, sunlight is more abundant and scorching affects the performance of buildings that have a lot of glass on the front (Sayed & Fikry, 2019). A study conducted by (Tsikaloudaki et al. 2012) studied the window-to-wall ratio that affects energy consumption in tropical climates, buildings with a high window-to-wall ratio experience increased cooling loads, further increasing energy consumption.

The extensive use of high window-to-wall ratio (WWR) and poorly insulated glass material in UTM KL façade design causing indoor temperature spike and thermal discomfort occupant. This has led to an over-reliance on heating ventilation air conditioning (HVAC) systems, while compromising occupant thermal comfort (Khosravi et al., 2023). Article from the book of Thermal comfort in Hot-Dry Climates said this mechanical cooling system will increase if the demand on energy use can also have an environmental impact such as greenhouse gas emissions and electricity demand. The aims of the study is to evaluate the thermal comfort performance of Universiti Teknologi Malaysia (UTM) Kuala Lumpur's building. The objectives of this study will be achieved by obtaining the following objectives such as to evaluate the current thermal comfort condition of the glass façade building of Universiti Teknologi Malaysia (UTM), Kuala Lumpur, to study the influence of window wall ratio on achieving thermal comfort in Universiti Teknologi Malaysia (UTM), Kuala Lumpur and to determine the type of glass for the wall to achieve thermal comfort in Universiti Teknologi Malaysia (UTM), Kuala Lumpur.

In recognition of the excellent aesthetic appeal and increased utilization of natural sunlight, glass facades in architectural buildings become more common in the construction of most modern buildings. In addition, category of buildings has some considerable in terms of thermal comfort, which can be associated with high exposure to solar radiation, especially in tropical climate conditions like Malaysia. This normally would present a case of high dependence on heating, ventilation, and air conditioners to put up with the heightened energy consumption and its associated environmental vices.

2. Methodology

2.1 Introduction

Figure 2.1 show the case study that is the subject of this investigation is the result of the observation of high-rise buildings to study the effectiveness of buildings in the infrastructure of modern development models that use glass facades. on key aspects of thermal performance in glass facade buildings, including glazing material, shading devices and thermal comfort models.

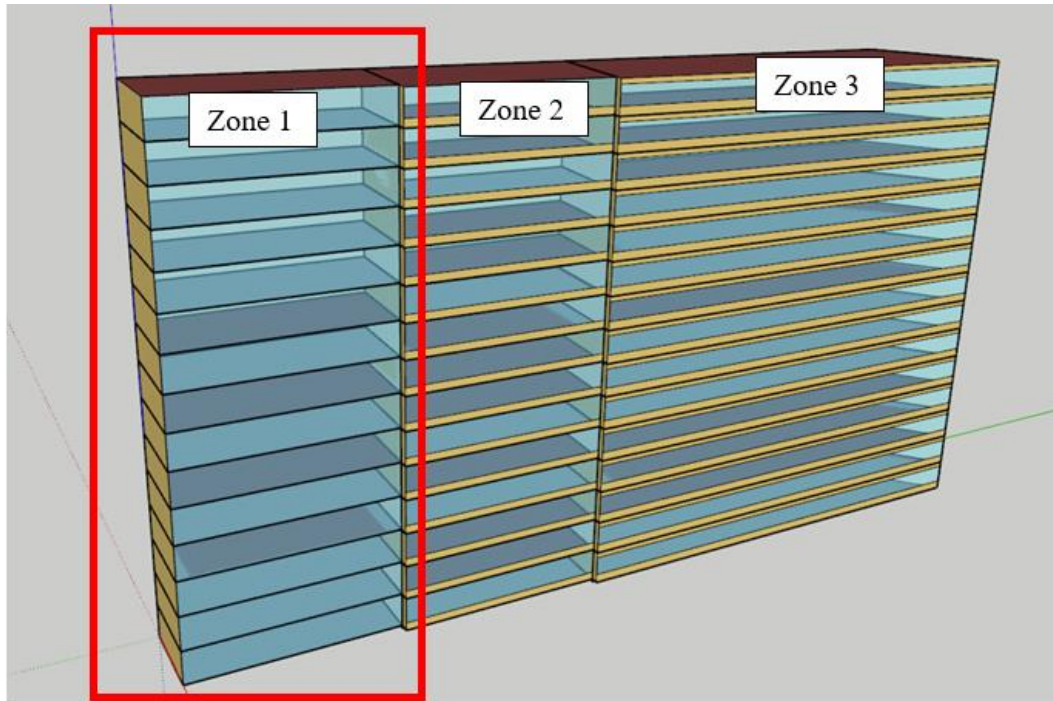


Fig. 2.1: Simulation building of Universiti Teknologi Malaysia (UTM) Kuala Lumpur

The building has 15 floors. All parts of the building are fully utilized. The simulation of this building is modified according to the study objectives to achieve thermal comfort in the building. Modifications to the window to wall ratio in zone 1 were done to test the level of thermal comfort that can be achieved.

2.2 Research Flow

This research process involves three stages, as illustrate in Figure 3.1

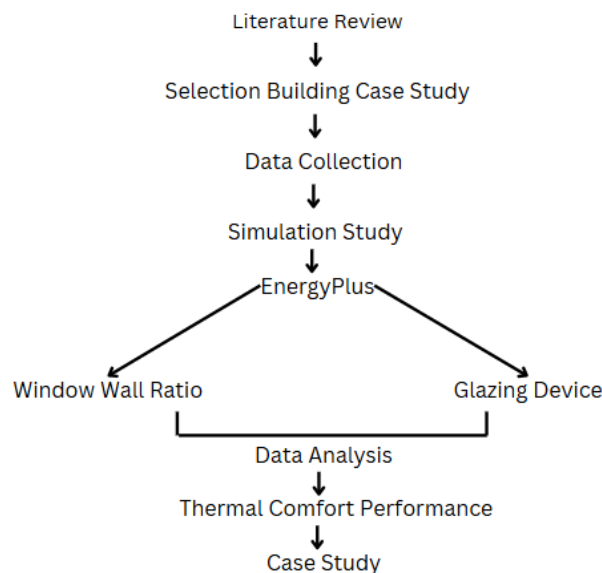


Fig. 2.2: Flowchart of Research Process

This building was selected because of its glass facade characteristics which reflected the main subject of the study. Initial data about the building was collected through observation, document analysis, and technical measurements on site. After that, the data obtained was then analyzed using a computer simulation approach. EnergyPlus software was used as the main simulation tool to evaluate thermal comfort performance. The two main parameters studied were the window wall ratio and the type of glazing device. This simulation process aimed to understand how the design of the glass facade affects the indoor temperature, and the comfort level of the building occupants.

The results of this simulation were then subjected to an in-depth data analysis process, where quantitative data were compared with relevant thermal comfort standards. Since the research done is purely a building simulation without any comparison with real data, building case construction is using real building area data. For the weather data from Perian, the actual weather data is the verified one. Methodology explained further in the next section.

2.3 Data Collection

2.3.1 Case Study Building

The selected case study is a 15-story modern glass facade building at UTM Kuala Lumpur. The building features a full-glazed southwest-facing facade, making it a suitable model for analyzing thermal comfort performance in tropical climates. Key specifications of the building are provided in Table 2.1

Building Geometry	
Model dimension	70 m x 78 m x 8.92 m (B x L x H)
Building height	57 m
Total no. of floor	15
Floor area	700 m ²
Volume	49,000 m ³
Floor- to-floor height	3.0 m
Window-to- wall ratio	Full glazed (100%), South-West façade only
Building operation Details	
HVA System type	VRF system for all floor
Cooling set point	20 °C
Fresh air supply rate	10 L/s-person
Office equipment gain	7.64 W/m ² (ASHRAE 189.1)
Occupancy density	0.25 person/m ³
Operation schedule	All days: 08:00-17:00 hours
Thermal comfort parameters	Clothing insulation: 0.5 clo (warm period) Metabolic rate: 1.1 met (Office work)

Table 2.1: Building Geometry Details

The window ratio (WWR) of this case building is set to 100% only in zone 1. For the worst case scenario, a populated room with a space density of 4 m²/person (0.25 person/ m²) as stated in ASHRAE standard 189.1(2014) has been selected as a study guide setting. this building is simulated as part of a complete VRF system that follows the specified design guidelines. In addition, high wind speeds will occur on the Upper Floor. As this study only focuses on the effect of the full glass facade on the 7th floor of the building on thermal comfort on energy consumption, the design of window openings for natural ventilation interferes with the isolation of the full glass facade on the building of Universiti Teknologi Malaysia, Kuala Lumpur.

2.3.2 Building Inventory

Building inventory and geometry are two important aspects of building planning and analysis that play a role in determining the glass facade's efficiency and the room's overall performance at the Universiti Teknologi Malaysia (UTM) Kuala Lumpur. Figure 2.3 Campus (UTMKL) campus and the surrounding area, where numbers 1 to 10 describe the sections outside and inside the campus (Source: Google Earth Image), and Figure 2.4 show the location of Universiti Teknologi Malaysia, Kuala Lumpur, on maps topography.

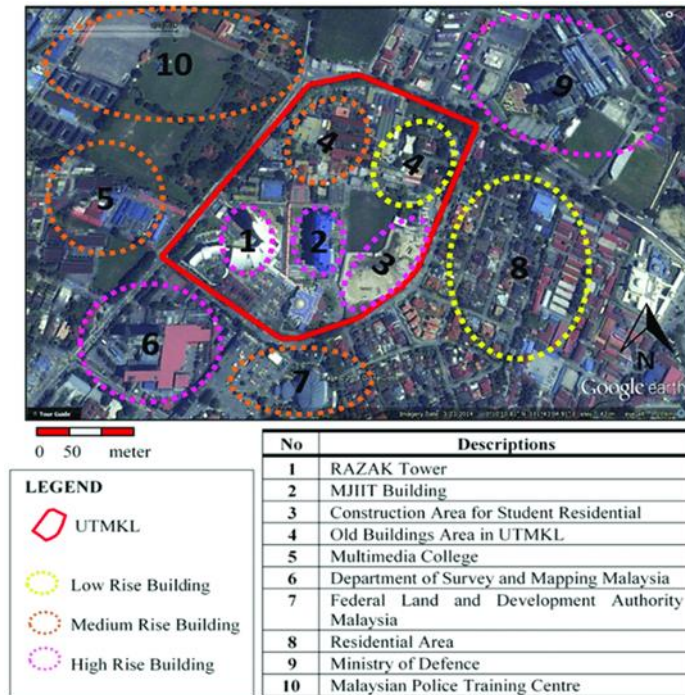


Fig. 2.3: Plan view of the Universiti Teknologi Malaysia Kuala Lumpur

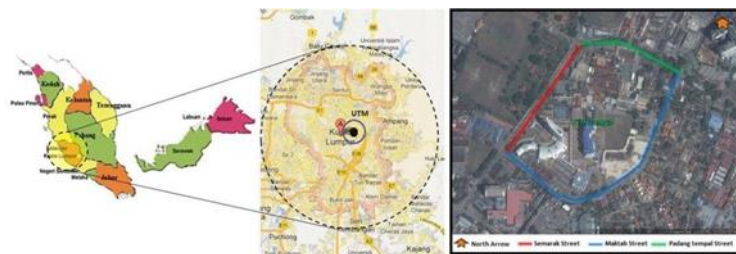


Fig. 2.4: Location UTM KL on maps topography

Besides, universities have a similar character to small cities in terms of population, their large size, and many different activities taking place on campuses, which have directly or indirectly impacted the environment.

3. Results and Discussion

Based on the finding that thermal comfort performance in recent modern glass façade buildings in Universiti Teknologi Malaysia (UTM) Kuala Lumpur needs further improvements to meet the established standards such as ASHRAE 55 these buildings offer modern, and attractive architectural features, that the indoor thermal environment normally has high solar heat gain, distribution of temperature and shading limitation.

In the scale range of -0.5 to +0.5, it is a neutral or almost neutral condition, which means a thermally comfortable feeling in a room. In thermal comfort studies of modern glass façade buildings, data such as temperature, humidity, and air speed can be compared with the PMV value. If the PMV is mainly in the range of -0.5 to +0.5, the building achieves a good level of thermal comfort.

The aesthetic and functional values of glass façade in terms of increasing the potential thermal performance pose quite a huge challenge in design. A critical need to address challenges in holistic design. The use of advanced glass materials such as double-glazed or low-emissivity glass, can increase shading rates and optimize building orientation to reduce exposure to direct sunlight. In addition, the study conducted proves the importance of regular maintenance and upgrading the importance of HVAC systems to ensure that they function fully and efficiently in maintaining thermal comfort in the spaces involved. This study recommends the adoption of glazing material with SHGC values below 0.3 and U-values under 1.0 W/m²K to reduce solar heat gain and maintaining natural lighting. Additionally, optimizing WWR between 70-80% can achieve thermal comfort, especially in tropical educational buildings such as UTM KL

3.1 Characteristics of Environmental Parameters

3.1.1 Outdoor Environmental Parameters Pattern

Figure 3.1 illustrates the outdoor environmental parameters of dry-bulb temperature recorded throughout the day at UTM KL. From 8:00 AM to 12:00 PM, the temperature continuously increased due to the increasing solar radiation to the southwest façade. During the period of increasing temperature, the high SHGC glass materials transferred more heat into the building, which contributed to the increase in indoor temperature. With SHGC on the facade of the UTM KL building, it was able to effectively control the heat gain during critical periods, as well as maintain a more stable and comfortable indoor environment.

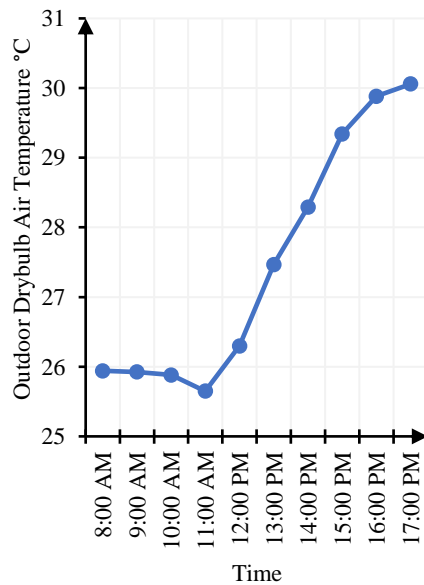


Fig. 3.1: Outdoor Temperature for UTM KL Building

This is likely due to the circulation of the sun's rays as the sun starts to move towards the horizon of the building. This change is normal and is influenced by the circulation of the sun and the current weather.

3.1.2 Indoor Environmental Parameters

Indoor conditions affect the level of thermal comfort, as shown in Figure 3.2, reflecting significant variations depending on the window-to-wall ratio in each zone of the building.

From 8:00 AM to 12:00 PM, the zones with higher WWR showed differences in indoor temperature due to the transmission of solar radiation. High SHGC of glass façade results in an increase of 3°C in indoor temperature at midday, the importance of using material with low SHGC values increase the comfort level of the occupants. However, a lower SHGC will maintain the conditions and comfort inside the building as less solar heat is absorbed and transmitted through the glass facade.

From 12:00 PM to 5:00 PM, the VLT value plays an important role in natural lighting and thermal comfort. Areas with moderate VLT values, sufficient daylighting will not cause glare or excessive heat gain, while zones with high VLT glass values experience overheating due to excessive light penetration from the glass facade.

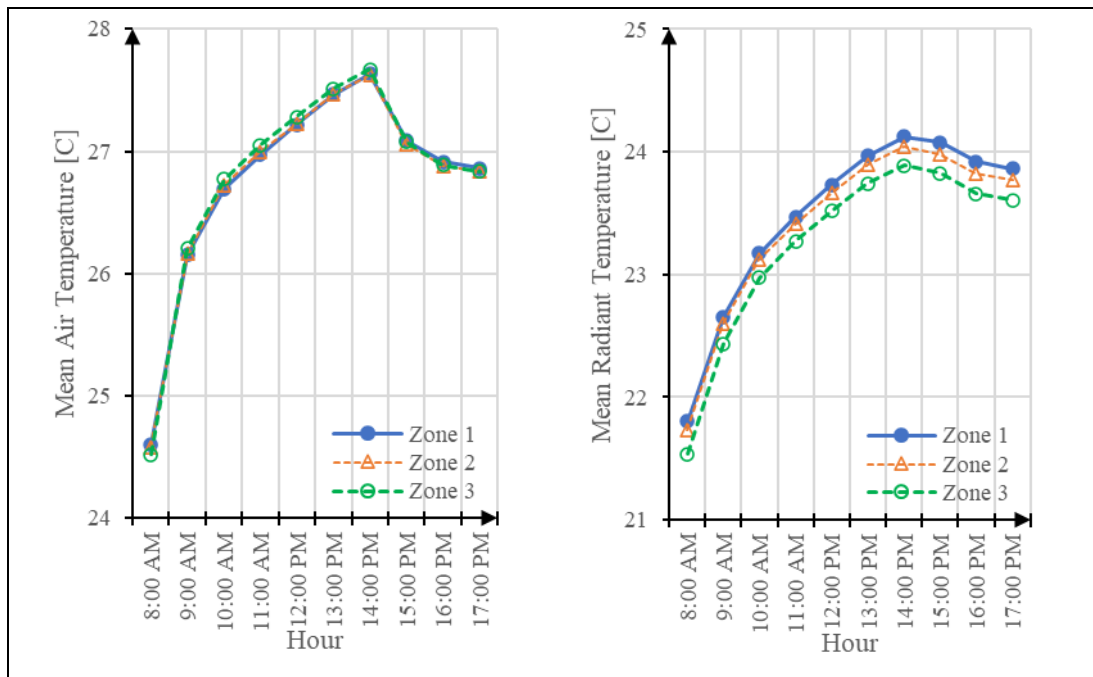


Fig. 3.2: Indoor Environmental Parameters

This also proves that the solar pattern found in the UTM KL building area is not protected from tall buildings around the area. To improve comfort levels, this analysis shows that the use of high-performance glass can influence temperatures at noon, when they reach maximum levels.

3.1.3 Thermal Comfort Performance

Figure 3.3 shows the PMV and PPD index values across different zones, as well as the thermal comfort levels throughout the day. The PMV values increase from 0.5 during peak hours from 8:00 AM to 12:00 PM, reflecting discomfort of glass façade with high WWR zones with high SHGC glass experience a significant increase in PMV values, an increase that affects occupant discomfort. From 12:00 PM to 5:00 PM, the VLT effect provides thermal comfort. VLT values minimize glare while allowing sufficient natural light, ensuring that PMV values remain stable. The low U-value maintains consistent PMV and PPD levels with low heat transfer from the hot exterior creating uncomfortable conditions for occupants inside the building.

In addition, the PPD value which is directly proportional to the PMV also showed the same pattern. The higher the PMV value, the more occupants felt uncomfortable especially at noon when the PPD was at its maximum. All three zones studied showed almost the same pattern of changes. This variation may be due to factors such as the orientation of the zones to sunlight, the nature of the glass facade materials, and the ventilation of each zone.

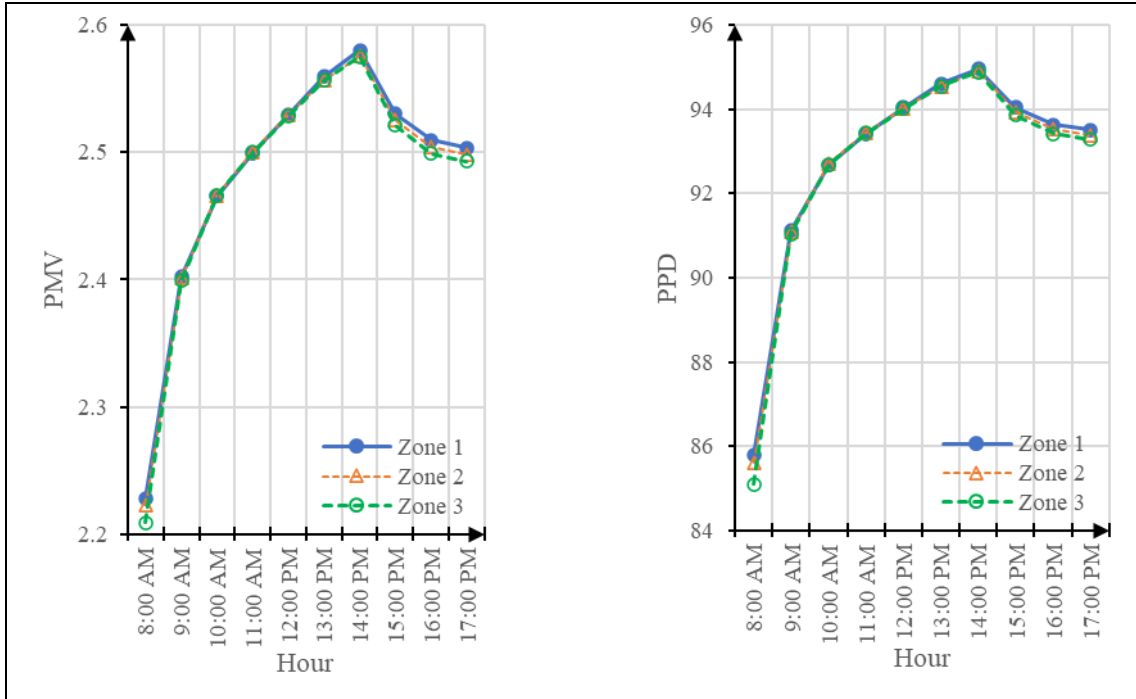
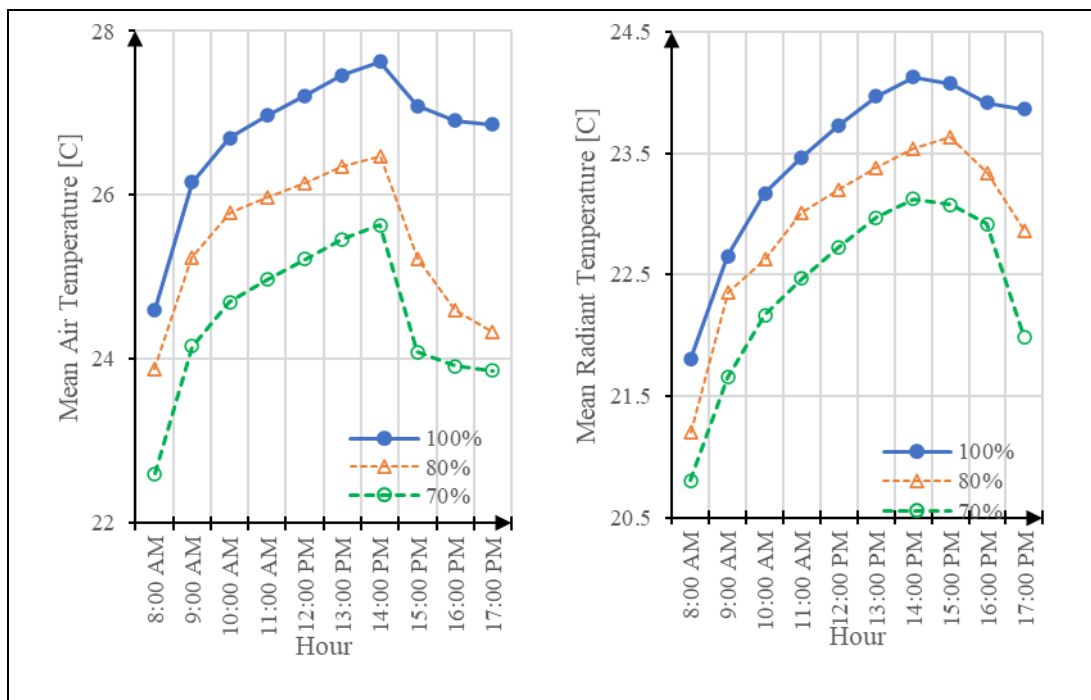


Fig. 3.3: Thermal Comfort Performance graph

In conclusion, the changes in the PMV and PPD values illustrated especially in zones with high WWR. The throughout the day showed that the thermal comfort in this glass facade building is directly influenced by the time and intensity of sunlight. At midday, thermal conditions are less comfortable, requiring mitigation strategies such as the use of high-performance glazing with optimized SHGC and U-values to ensure consistent indoor thermal comfort.

3.1.4 Modification to Window-to-Wall Ratio (WWR)

Figure 3.4 which shows the mean air temperature, mean radiant temperature and relationship between Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) on the 7th floor in Zone 1 of the UTM Kuala Lumpur building.



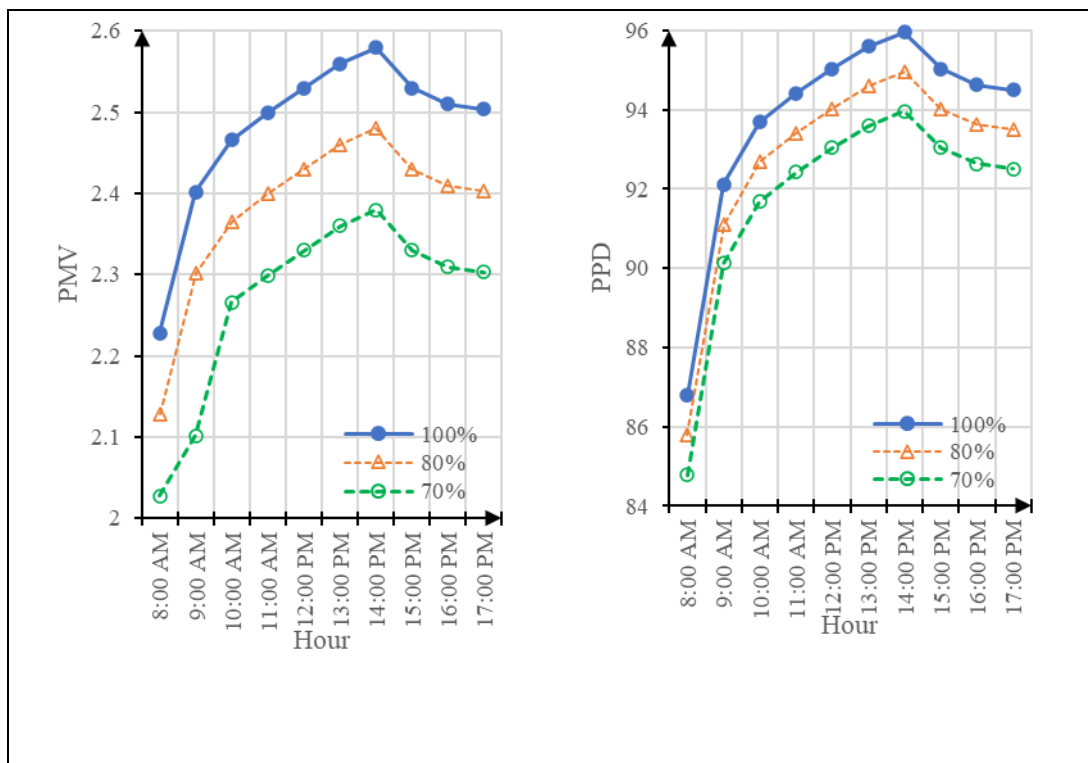


Fig. 3.4: Zone 1 Window-to-Wall ratio

PMV and PPD values show a slight difference for the modification of window to wall ratio for zone one with different window ratios. PMV values for WWR 100% show a lower comfort level from 8.00 am to 12.00 pm, while from 12.00 pm to 5.00 pm, the comfort level starts to increase due to the movement of the sun changing direction. However, WWR for 80% shows the different thermal comfort levels at 8.00 am to 12.00 pm, while from 12.00 pm to 5.00 pm, the comfort level starts to increase. WWR of 70% also shows the same proportion with a difference level of thermal comfort within 2.0 to 2.3 in the maximum comfort level due to the window modification ratio.

For PPD values, the change in discomfort shows that WWR 100% from 8.00 am to 12.00 pm show the increasing to maximum discomfort level at 96% and WWR 80% from 8.00 am to 12.00 pm it increases with a percentage value of 84% to 95%. From 12.00 pm to 5.00 pm, the discomfort level decreases due to the movement of sunlight absorbed by the glass facade. WWR for 70% shows a value that there is a significant difference in the level of discomfort of occupants in the UTM KL building.

Therefore, WWR at 70% is taken as a constant variable to be used as the WWR for determining glazing materials that can accommodate a comfortable proportion of PMV and PPD values. The changes in PMV and PPD values throughout the day indicate that the time and intensity of sunlight directly influence thermal comfort in glass facade buildings.

It was found that the PMV and PPD values changed throughout the day. The PMV value significantly increased from 8:00 am until reaching its peak around 12:00 noon to 3:00 pm. This increase reflected the decreasing thermal comfort conditions, especially due to the increase in outdoor temperature influenced by the intensity of sunlight at that time. After 3:00 pm, the PMV value began to decrease, indicating an increase in the level of thermal comfort as the outdoor temperature began to decrease.

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In addition, the PPD value directly proportional to the PMV also showed the same pattern. The higher the PMV value, the more occupants felt uncomfortable, especially at noon when the PPD was at its maximum. All three zones studied showed almost the same pattern of change, although there were slight variations in the absolute values. This variation is likely due to factors such as the orientation of the zones to sunlight, the nature of the glass facade materials, and the ventilation of each zone.

In addition, the PPD value which is directly proportional to the PMV also showed the same pattern. The higher the PMV value, the more occupants felt uncomfortable, especially at noon when the PPD was at its maximum. All three zones studied showed almost the same pattern of change, although there were slight

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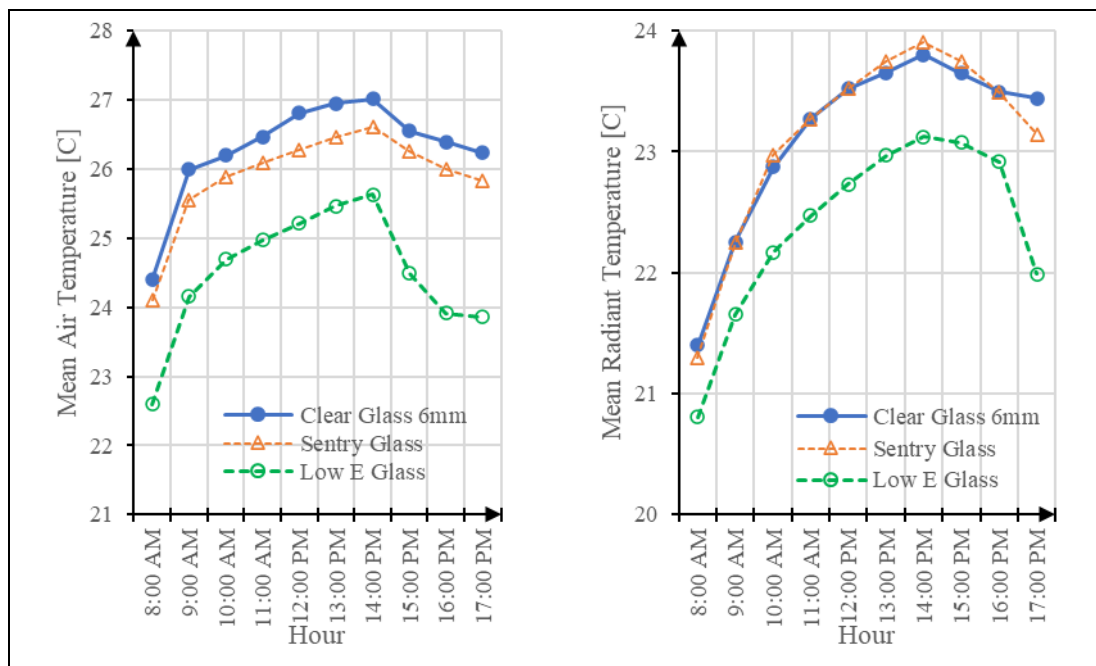
3.1.5 Modification WWR and Glazing Material

Figure 3.5 shows the difference between WWR and 70%, which is a significant difference. WWR 70% with clear glass 6mm air temperature value between 24°C to 27°C at (8.00 am to 12.00), which increases while (12.00 pm to 5.00 pm) decreases temperature. WWR 70% with sentry glass shows air temperature change between 24°C to 26°C at (8.00 am to 12.00 pm) while (12.00 pm-5.00 pm) shows a decrease in temperature. Other than that, WWR 70% of Low E glass show a decrease in air temperature between 22°C to 25°C at (8.00 am to 12.00 pm) while a decrease at (12.00 pm to 5.00 pm).

The mean radiant temperature shows the difference between clear glass, 6mm, and sentry glass, which increases at (8.00 am to 12.00) while (12.00 pm to 5.00 pm) shows a decrease in temperature. Low E glass shows the difference of temperature increase at (8.00 am to 12.00 pm) at 21°C to 23°C and decreases at (12.00 pm to 5.00 pm) at a temperature of 22.

PMV and PPD values show a slight difference in modifying the window-to-wall ratio of 70% for different types of glass. PMV for Low E glass shows the capacity reach to the thermal comfort performance between (-0.5 to +0.5) with the data below from (+0.5) while for the clear 6mm glass and sentry glass almost reached the thermal comfort performance in between (+3.0 to -3.0). PPD shows the graph of the Low E glass discomfort level of occupants in the building.

PPD values of WWR 70% show occupant discomfort in the building with three different glazing materials. For the glazing material, clear glass 6mm and sentry glass, the level of occupant discomfort in the building is very high at all times and exceeds the specified building comfort range of 15% to 35% in peak hours. However, for the glazing material Low E glass, during the peak hour at 11%, that caused several occupants in the building discomfort. This proves that the use of Low E glass can control the level of occupant discomfort in the building when WWR is increased with appropriate thermal comfort.



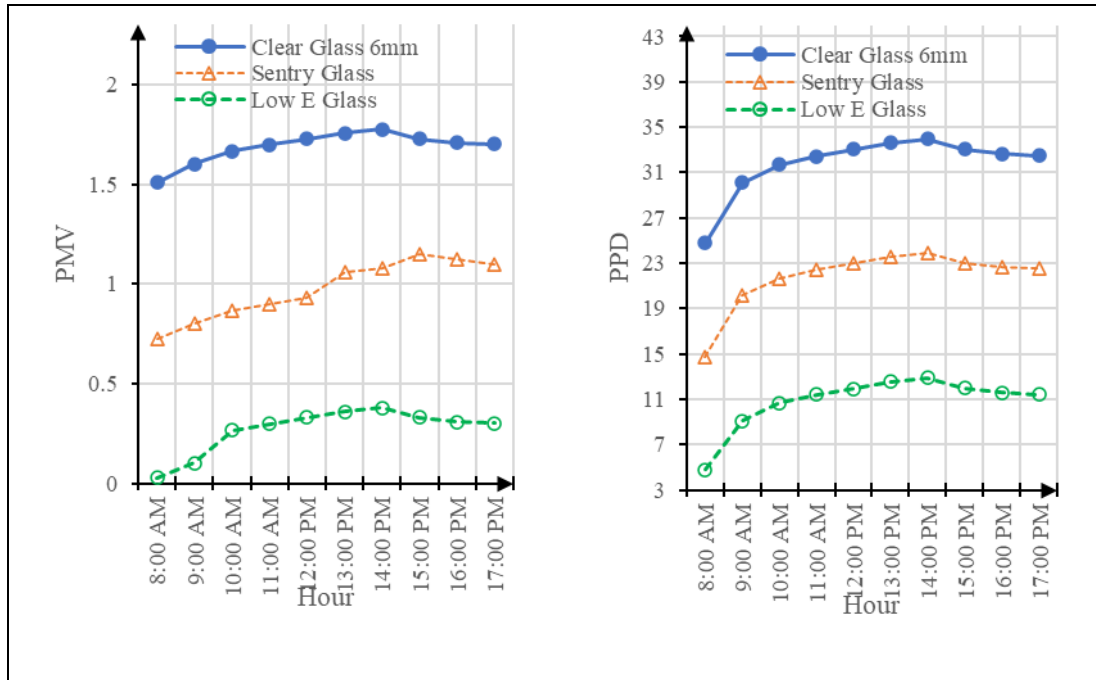


Fig. 3.5: Zone 1 with different type of glazing material

The changes in PMV and PPD values throughout the day indicate that the thermal comfort in this glass facade building is directly influenced by the time and intensity of sunlight. The values range (+3 to -3) is still within the tropical climate of Malaysia. At noon, the thermal conditions are less comfortable, requiring mitigation strategies such as the use of high-performance glass, and automatic blind control to maintain occupant comfort. The usual comfort range in the standard set by ASHRAE 55 is around <10% but the range for WWR modifications and glazing material types gives different influences and effects from the original building study conducted.

4. Conclusion

In conclusion, this modern glass façade building also represents an architectural solution that will be developed and adopted in the future, proving its performance to prevent occupant satisfaction without design modifications. The balance between aesthetic and functional values to ensure that this Universiti Teknologi Malaysia building provides a comfortable environment with visual appeal that is comparable with sustainable values and energy efficiency for occupants. The findings of this study serve as a guide for architects, engineers and building managers to improve thermal comfort rates in similar building designs.

The following is the numerical scale known as the PMV. The thermal comfort levels were referred to based on how much heat the body balanced. This goes in terms of :

Table 4.1: PMV Scale

Value	Sensation
3	Hot
2	War
1	Slightly warm
0	Comfortable
-1	Slightly cool
-2	Cool
-3	Cold

The indoor temperature, relative humidity, and wind speed greatly varied the building's glass façade design parameters. The data indicated that the temperature in several areas of the building was running above the comfort level set out by the ASHRAE 55 standard most of the time, particularly at midday. However, some zones with shading elements and good ventilation systems offered far better comfort. This may indicate the importance of both passive and active design integration for achieving optimal thermal comfort levels.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, University Tun Hussein Onn Malaysia for their support.

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