Scientific Research Journal,
Vol 22, special issue (2025) 189-205
https://doi.org/10.24191/srj.v22is.12788

Overall Thermal Transfer Value: A Preliminary Study of Residential Building in Hot-Humid Climate

Norasikin Hussin[1], Yusli Yaakob[1,*], Azli Abd Razak[2], Faizal Baharum[3]

[1]Centre of Mechanical Engineering Studies, Universiti Teknologi MARA Pulau Pinang Branch, 13100 Permatang Pauh, Pulau Pinang, Malaysia
[2]Centre of Mechanical Engineering Studies, Universiti Teknologi MARA Shah Alam 40450 Shah Alam, Selangor, Malaysia
[3]School of Building, Housing and Planning, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia

[*]Corresponding Author's E-mail: yusli662@uitm.edu.my

Received: 12 September 2024
Accepted: 26 September 2024
Online First: 25 January 2025

ABSTRACT

Malaysia buildings have high intensity of solar radiation and high daily air temperature. Due to excessive heat and high air temperature can cause discomfort, and the occupants need to use the air-conditioning system. The use of air-conditioning has influence to increasing the energy consumption in buildings. To tackle this issue, the Overall Thermal Transfer Value (OTTV) standard as an assessment tool is used to measure of heat gain in the building. OTTV standard is applicable to minimize energy consumption of air conditioning. This study aimed to investigate the OTTV in single terrace house. The method used in this study is by direct calculation. The OTTV was calculated for two cases, namely case study model A and model B. The study considered parameters of building envelope such as window-to-wall ratio. U value, glazing material, and fenestration orientation. Through OTTV calculation, the result for case study model B in the southeast direction is 53.51 W/m^2. Solar radiation through fenestration was contributor to the increasing of OTTV. Then, the total OTTV result for case study model A and model B was 22.86 W/m^2 and 23.26 W/m^2, respectively. The results showed that the building met the minimum requirements for the OTTV, less than 50W/m^2. This study shows that some design consideration in building envelope have influence on the OTTV.

Keywords: Overall Thermal Transfer Value; Building; Heat; Air-Conditioning; Energy

INTRODUCTION

The climate of Malaysia is tropical and humid climate. Malaysia has a mean temperature in the ranges between 22°C - 27°C (minimum) to 30°C - 34°C (minimum) [1]. The average annual relative humidity is between 70% and 90% and receive abundant rainfall throughout the year. Most of the Malaysian people likely to use the air-conditioning system for cooling purpose. The use of air conditioners in Malaysian residential buildings is increasing because almost all residential buildings have air conditioners (99%) and depend highly on it to keep indoor environments cool and comfortable [2]. Among the factors that determine the demand for cooling energy are operating hours, temperature settings and other operating parameters [3]. In addition, very low set-point temperature for air-conditioning practiced by the Malaysian residents was considered one of the important factors that increase the electricity consumption [2]. According to MS1525:2019, the indoor temperature should be within the range of 24°C to 26°C for the occupants feel comfortable [4]. However, in hottest day, the temperature outside is higher than inside the building. Thus, low set point temperature for air-conditioning is needed for comfort. The increased of indoor temperature is influenced by the increase in heat gain in the building caused by the heat conducted through the building envelope. Due to this problem, the building energy standard have been introduced to reduce building energy consumption while maintaining thermal comfort.

Most developed countries are implementing building energy standards to reduce building energy consumption and lead to energy efficient buildings. The Overall Transfer Thermal Value (OTTV) is one of the methods to measuring the thermal efficiency for building envelope. The OTTV concept and method was first introduced by the American Society of Heating, Refrigerating and Air-conditioning Engineers in 1975 [5]. In Malaysia, the government introduced the OTTV in Malaysia Standard, MS1525 to control energy use in the building envelope. In other words, the OTTV developed to measure the heat gain through the building envelope and hence reduce the cooling load of the air-conditioning.

The parameters of OTTV derived are based on heat gain in the building. Among the three components of heat again are considered conduction through opaque surface, conduction through glass and solar radiation through glass. The increasing of OTTV means that the heat gain inside the building has increasing. Meanwhile, the smaller OTTV means the smaller heat gain, and as a result lower cooling load [6]. Hence, less energy would be required for cooling. Cooling load due to heat gain through envelope is usually 10% - 20% of the total cooling load [6].

In recent years, most of the research has focused on the use of OTTV approaches in reducing energy consumption. The reduction in the energy consumption through OTTV approaches will not only minimize the heat gain of the building, but also decrease the cooling load, and then a proper sizing of air-conditioning system will be installed. Previous researcher detailed the OTTV of residential building. The study of Saidur *et. al* [7] reported the OTTV for residential building in Malaysia varied from 35 W/m² to 65 W/m² with a mean value of 41.7 W/m². The higher OTTV imposes more cooling load on the air conditioning system. Thus, the OTTV for residential in Malaysia should be designed not more than 45 W/m². Similarly, for the hot-humid climate of Indonesia, the OTTV must be designed less than 45W/m² [8]. In order to reduce the OTTV value and amount of energy needed for cooling, the selection of material for the building envelope must be made carefully to improve building energy efficiency. Also, to prevent excessive heat transmission in building envelope.

The thermal performance of building plays a fundamental role in energy consumption because a large amount of energy is required to balance the heat transfer that occurs through the envelope [9]. Thermal performance of a building is affected by total heat transfer through the building envelope. Heat transfer plays an important role in air-conditioning system. Understanding the principle of heat transfer through building envelope is essential for understanding how to reduce heat gain in the building. Heat transfer in building envelope involves convection, conduction and radiation. Heat conduction through building envelope (walls, roofs, floors) is the most important types of heat transfer in buildings. In a study conducted by Al-Ashwal and Hassan [10], the small WWR (5%-10%) and glazing with high visible transmittance can lead to highest decrease in energy consumption. Thus, most of the research in the residential building is focused on minimizing energy gain influenced by solar radiation [11]. In terms of energy efficiency and thermal performance of the building, less OTTV means less heat gain in the building. It is also impact to cooling load reduction and minimize energy consumption.

Objectives

This study investigates the heat gain and provides the calculation of OTTV (Overall Thermal Transfer Value) to single terrace house in Penang. This study focuses on orientation fenestration and impact on OTTV. The importance of analyzing and applying OTTV to building envelope can be used to design air-conditioning requirements. Therefore, the authors conducted a study entitled ‘A Preliminary Study of Overall Thermal Transfer Value in Residential Building’. The significance of this research is able to recognize the amount of heat gain in the building. Also, identify the OTTV of residential building met the MS1525 which is OTTV less than 50 W/m^2. However, if the OTTV is greater than the standard limit, the action of how to reduce the value is not discussed in this paper.

METHODOLOGY

The study methodology begins with identifying the building specification. Then proceeds to the mathematical calculation of thermal transmittance using OTTV standard. The OTTV was calculated for two cases, namely case study model A and model B. The equation of OTTV is referred to in Malaysia Standard, MS1525. The calculation of OTTV is to measure the heat gain through building envelope. Next, the OTTV of each case study was compared to MS1525.

Case Study Building

The location of the research study is Penang, Malaysia which is hot and humid climate, so that it is hot all year around. In this research, the analysis of OTTV was conducted on single terrace house. The details of the case study buildings are shown in Table 1. A single-storey residential building model with a floor area of 91.79 m^2 and a height of 3.0 m is developed in Figure 1(a). The indoor space layout of typical terraced houses is used in this model, which consists of three bedrooms, hall, dining area and kitchen as can be seen in Figure 1(b). The bedrooms consist of a master and two smaller bedrooms. The buildings were constructed with brick wall and equipped with glazing. Overall, the case study building consume energy for air-conditioning system, lighting system and home appliances. The case study buildings use electricity mainly supplied by the Tenaga Nasional Berhad (TNB).

Table 1: Details of the case study building

Description	Case Study
Name of building	Single terrace house
Location	Penang
Building type/function	Noncommercial building / Residential
Dimensions	6.7m x 13.7m x 3.0m
Floor area	91.79m^2
Air-conditioning system	Residential split unit system Set point temperature 18°C
Cooling schedule	1.00 am – 7.00 am, 7.00 pm – 12.00pm

Most of the residential turn on their air-conditioning at conditioning at night, especially from 7.00 pm to 7.00 am weekdays [12]. Thus, the daily operating hours for air conditioning system is 13 hours, and the annual demand hours is 4745 hours. In addition, most people turn of their air-conditioning during weekdays between 7.00 am and 8.00 am. About 92% of people more prefer setting the temperature of air conditioning between 16ºC to 28Cº [13]. In other studies, Kubota *et al.* [2] found that the occupants in Malaysia set the temperature between 20ºC to 21Cº.

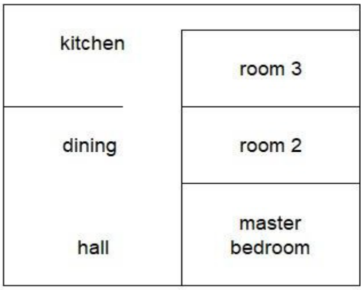
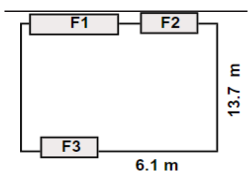
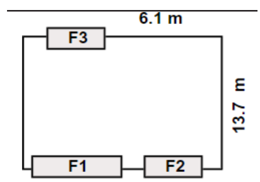


Figure 1: (a) case study building, single terrace house; (b) Indoor space layout of residential building

Table 2 shows the plan views for both case study, known as Case Study Model A and Case Study Model B. Therefore, the OTTV was calculated for two cases. Referring to the Table 2, the orientation of fenestration was different. Case study model A show that the fenestration (F1 and F2) in the northwest, and fenestration (F1 and F2) for case study model B in the southeast. The case study used 6 mm single glazing glass windows without any external shades or internal. The U-value of the fenestration is 6.4W/m²K. The shading devices can increase the size of the window, which is can reduce the heat gain [14]. However, in Malaysia, the common construction materials used for shading devices have minimal impact on improving energy efficiency and the installation of shading can increase the construction cost [15].

Table 2: Case study and glazing properties

Description	Case Study: Model A	Case Study: Model B
		
Fenestration types	Single glazing 6mm thick	Single glazing 6mm thick
Orientation	F1 and F2: northwest F3: southeast	F1 and F2: southeast F3: northwest
Fenestration size	F1:0.84m^2 (2.74mx0.31m) F2:1.78m^2 (1.22mx1.46m) F3:0.84m^2 (2.74mx0.31m)	F1:0.84m^2 (2.74mx0.31m) F2:1.78m^2 (1.22mx1.46m) F3: 0.84m^2 (2.74m 0.31m)
Visible transmittance, VT	0.88	0.88
Solar heat gain coefficient, SHGC	0.81	0.81
Shading coefficient, SC	0.95	0.95
U-value, m^2K/W	6.4	6.4

The thermal properties of the structural brick wall are given in Table 3. In calculating the OTTV, the thermal transmittance of opaque wall, Uw needs to be determined. The thermal conductivity, k-value of brick wall is 0.77 W/m/K. When the thickness of a wall material is known, the thermal resistance (R-value) can be calculated. The calculation of R-value is dividing wall thickness by its thermal conductivity. For example, the thermal resistance of brick wall is 0.148 m^2K/W where R = thickness of brick wall (mm)/thermal conductivity of brick wall (W/m/K). In this study, heat resistance on walls is thermal resistance, R-value (m^2K/W) and thermal transmittance, U-value (W/m^2K). The R-value and U-value are the mathematical reciprocals of each other. The R-value determines how a material resists the flow of heat and it is an inverse to the U-value where R=1/U. Thus, the U-value is the overall heat transfer coefficient and it is the converse of thermal resistance, U=1/R. Therefore, the total of thermal resistance (R-value) is 0.322 m^2K/W, then U-value is 3.1 W/m^2K.

Table 3: Thermal properties of the structural brick wall

Structural materials	Thickness,t (mm)	Thermal conductivity,k (W/m/K)	Thermal resistance, R (m^2K/W)	Thermal transmittance,U (W/m^2K)
External surface	-	-	0.040	3.10
External wall plaster	18	0.57	0.032	
Brick wall	114	0.77	0.148	
Internal wall plaster	18	0.57	0.032	
Internal surface	-	-	0.070	

OTTV Parameters

The calculation of OTTV was in accordance with Malaysia Standard MS2680:2017 on Energy Efficiency and Use of Renewable Energy for Residential Buildings – Code of Practices. In Malaysia, the OTTV is used for determining the envelope thermal performance of air conditioning buildings. The calculation of OTTV focuses on heat gain into a building through the building envelope [16]. OTTV requirements in considered simple without simulation process. Typically, the OTTV used manual calculation method and mostly calculated using excel spreadsheets. The OTTV has established to cut heat penetration over the exterior envelope, and hence decrease the electricity consumption for air conditioning [17]. Calculation of OTTV consists of three major components which is conduction through external wall, conduction through fenestration system, and solar radiation through fenestration system. The measuring OTTV relies on the parameters such as U-value, shading coefficient (SC), solar absorption (α), and window-to-wall ratio (WWR).

The form of OTTV equation for each type of heat transmission shows in Table 4. Each of heat transmission type has calculated separately to shows the OTTV value. All the OTTV value for each heat transmission type has added together to produce the overall OTTV value.

Table 4: OTTV equation of heat transmission through building envelope [18]

Heat transmission methods	Calculation for OTTV
Heat conduction through external wall	$15.\alpha.(1-WWR).U_w$
Heat conduction through fenestration system	$6.(WWR).U_f$
Solar radiation through fenestration system	$194.OF.WWR.SC$

Then, according to Malaysia Standard MS1525, the total OTTV equation of any given wall orientation can be expressed based on Eq.(1) [18]:

$$OTTV_i = 15.\alpha.(1 - WWR).U_w + 6.(WWR).U_f + 194.OF.WWR.SC \quad (1)$$

Where;

WWR= Window-to-wall ratio (gross wall area) = A_f / A_i

A_f = Area of fenestration (m^2)

A_i = Gross area of the walls (m^2) = $A_w + A_f$

A_w = Area of opaque wall (m^2)

α = Solar absorptivity of wall

U_w = U value of the wall (W/m^2K)

U_f = U value of the fenestration (W/m^2K)

SC = Shading coefficient of fenestration (dimensionless) = SC_{win} x SSF

SC_{win}= Shading coefficient of window glass (dimensionless)

SSF = Solar shade factor of external shading devices (dimensionless)

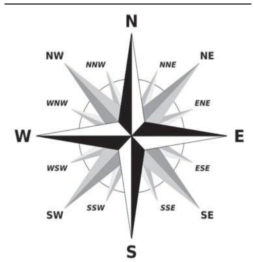
OF = Solar correction factor of fenestration (W/m²)

$$\text{OTTV} = \frac{(A_1.OTTV_1) + (A_2.OTTV_2) + \cdots + (A_n.OTTV_n)}{A_1 + A_1 + \cdots + A_n} \tag{2}$$

Eq. (2) shows the formula of total OTTV of the building. Referring Eq. (2), parameter A_1 is the gross exterior wall area for orientation 1 and the $OTTV_1$ means the overall thermal transfer value for orientation 1. To calculate the $OTTV_1$, the formula of calculation based on the Eq. (1).

As walls and windows at different orientations receive different amounts of solar radiations. The OTTV should be considered with solar radiation factor. Each of orientation receives different incident solar radiation. Table 5 shows solar correction factor of fenestration (OF) for eight primary orientations of the wall. In this study, the solar factor for solar heat gain through fenestration for both models is 1.09 for northeast, 1.13 for southeast, 0.90 for southwest and 0.90 for northwest.

Table 5: Solar correction factor of fenestration for different orientation

Orientation	Solar Correction Factor [18]	Orientation Direction [19]
North (N)	0.90	
Northeast (NE)	1.09	
East (E)	1.23	
Southeast (SE)	1.13	
South (S)	0.92	
Southwest (SW)	0.90	
West (W)	0.94	
Northwest (NW)	0.90	

In order to study the OTTV on the building envelope, the OTTV for each case study with different orientation needs to be calculated. Eq. (1) involves all the factors that determine the OTTV. Meanwhile, Eq. (2) is used to determine the total OTTV for each case study. Based on the equations, all parameters of the case study were substitute into equation set by the MS1525:2007. The OTTV of case study for both models are calculated and evaluated.

RESULT AND DISCUSSION

In this study, the calculation OTTV for both models has been calculated with different wall orientation. The purpose of OTTV calculation to investigate the heat gain in the building. The calculation begins with determining the window wall ratio. Solar absorptivity of the opaque wall with white gloss paint is 0.30. Each of orientation receives different incident solar radiation. Each parameter of the case studies is substituted into the OTTV equation by MS1525:2007. Results of the OTTV calculation with different orientation are illustrated in Table 6 – 9.

Table 6 present the calculation of heat conduction through walls with different orientation for both models. The calculation begins by determining the thermal transmittance or U-value of wall (Table 2). The U-value of the building envelope is important factor in thermal performance and reducing energy consumption. Calculation of U-value for external walls depending on wall thickness. In this study, the U-value of walls is 3.1W/m²K.

Table 6: Heat conduction through walls

Wall orientation	Wall area (m²)	Constant	Solar absorption factor (α)	1-WWR	Uw value (W/m²K)	Heat conduction through walls (W/m²)
Heat conduction through external wall: 15 x α x (1-WWR) x U_w						
Case study: Model A						
Northeast	41.10	15	0.30	1	3.10	13.95
Southeast	18.29	15	0.30	0.89	3.10	12.42
Southwest	41.10	15	0.30	1	3.10	13.95
Northwest	18.29	15	0.30	0.83	3.10	11.58
Case study: Model B						
Northeast	41.10	15	0.30	1	3.10	13.95
Southeast	18.29	15	0.30	0.83	3.10	11.58
Southwest	41.10	15	0.30	1	3.10	13.95
Northwest	18.29	15	0.30	0.89	3.10	12.42

The heat conduction through fenestration was measured and results of the calculation are shown in Table 7. The calculation findings of each WWR are different depending on the orientation of the façade. For model A, the WWR calculation on the northwest façade is greater than southeast façade, which is 17% and 11% respectively. Meanwhile, the WWR of northwest façade is less than southeast façade for model B. The thermal condition of building can be affected by the WWR. When the value of WWR is larger, more energy is needed for indoor air conditioning. According to Abid *et al.* [20], the WWR has a significant impact on the building's need for cooling, thus the fenestration should be carefully considered in the future design of a residential building. It can be seen from Table 7 that the increase of WWR, the heat conduction through fenestration will increases.

The results highlighted that solar heat gain through fenestration contributes significantly to the OTTV for the southeast and northwest for both models, as shown in Table 8. The fenestration design in terms of WWR, solar factor and shading devices have a great impact on the calculation of solar heat gain. For this study, the value of shading coefficient is 0.95. From Table 8, the result showed that the solar factor has a larger impact on the solar heat gain through fenestration. It can be seen that the solar factor in southeast for model B has the largest solar heat gain compared to others. The largest solar heat gain through fenestration at 35.40W/m^2.

The heat entering in a building through a fenestration during the day depends on the size and area of fenestration. Therefore, solar heat gain from the fenestration is estimated to increase during the day due to exposure to solar radiation. The increasing of solar heat gain contributes to the increase cooling requirements and greater air-conditioning capacity for building.

Table 7: Heat conduction through fenestration

Wall orientation	Façade area (m²)	Constant	Window-to-wall ratio, WWR	Uf value (W/m²K)	Heat conduction through fenestration (W/m²)
Heat conduction through fenestration system: 6 x (WWR) x U_f					
Case study: Model A					
Northeast	0	6	0	6.40	0
Southeast	1.78	6	0.11	6.40	4.22
Southwest	0	6	0	6.40	0
Northwest	2.62	6	0.17	6.40	6.53
Case study: Model B					
Northeast	0	6	0	6.40	0
Southeast	2.62	6	0.17	6.40	6.53
Southwest	0	6	0	6.40	0
Northwest	1.78	6	0.11	6.40	4.22

Table 8: Solar heat gain through fenestration

Wall orientation	Façade area (m²)	Constant	Window-to-wall ratio, (WWR)	Solar factor (SF)	Shading coefficient, (SC)	Solar heat gain through fenestration (W/m²)
Solar radiation through fenestration system: 194 x WWR x SF x SC						
Case study: Model A						
Northeast	0	194	0	1.09	0.95	0
Southeast	1.78	194	0.11	1.13	0.95	22.91
Southwest	0	194	0	0.90	0.95	0
Northwest	2.62	194	0.17	0.90	0.95	28.20
Case study: Model B						
Northeast	0	194	0	1.09	0.95	0
Southeast	2.62	194	0.17	1.13	0.95	35.40
Southwest	0	194	0	0.90	0.95	0
Northwest	1.78	194	0.11	0.90	0.95	18.25

Calculation of the overall OTTV of each model with different orientation are shown in Table 9. According to Eq.(2), the total OTTV for model A is 22.86 W/m² and model B is 23.26 W/m². It can be seen that model B contributes the highest OTTV compared to model A. The result demonstrated that facing southeast orientation (model B) was significantly higher as the solar radiant compared to model A.

Table 9: OTTV for each orientation

Wall orientation	Heat conduction through	Heat conduction through fenestration (W/m²)	Solar heat gain through fenestration (W/m²)	OTTV (W/m²)	Total OTTV (W/m²)
Case study: Model A					
Northeast	13.95	0	0	13.95	22.86
Southeast	12.42	4.22	22.91	39.55	
Southwest	13.95	0	0	13.95	
Northwest	11.58	6.53	28.20	46.30	
Case study: Model B					
Northeast	13.95	0	0	13.95	23.26
Southeast	11.58	6.53	35.40	53.51	
Southwest	13.95	0	0	13.95	
Northwest	12.42	4.22	18.25	34.89	

The OTTV value for each southeast and northwest for both models are shown in Figure 3. It can be seen that the southeast direction for model B has the biggest OTTV at 53.51 W/m², in comparison to the other directions, which are, respectively, 39.55 W/m², 46.30 W/m², and 34.89 W/m² in the southeast (model A), northwest (model A), and northwest (model B). It can be seen that the OTTV for Model B in the southeast has exceeded the OTTV limit, which is less than 50 W/m². The highest OTTV means more cooling load is required to reduce heat gain in the building. It is also to increase the energy consumption and impact on energy efficiency of building. Therefore, the energy efficiency strategy actions need to be taken in order to achieve the OTTV standard. However, the energy efficiency strategies are not discussed in this research paper.

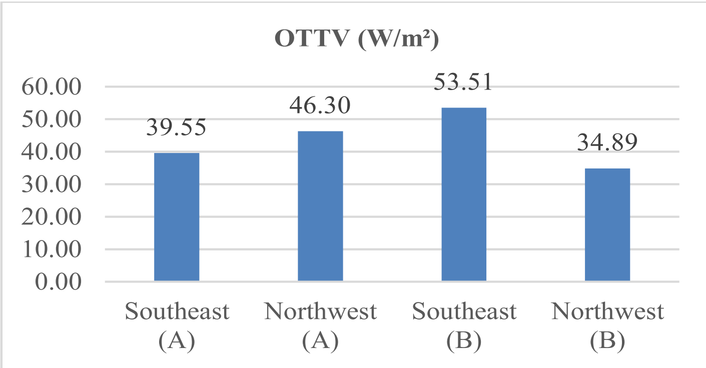


Figure 3: Comparison of OTTV value for each southeast and northwest for both models

CONCLUSION

The objective of this study is to identify and calculate the OTTV in single terrace house. The OTTV method is used to investigate the heat gain through building envelope. The calculation of OTTV was refer to MS1525:2007. The OTTV value was calculated for two cases, namely case study model A and case study model B. The total OTTV for the case study model A is 22.86 W/m^2 and model B is 23.26 W/m^2. The studied building met the minimum requirement for the OTTV. However, the calculation of OTTV for model B in the southeast direction is 53.51 W/m^2. It can be seen that the OTTV for Model B in the southeast has exceeded the OTTV limit, which is less than 50 W/m^2. Solar radiation through fenestration was contributor to the OTTV value. The different fenestration orientation lead to increase of OTTV. This study only calculates the OTTV with different case studies and there is no discussion of energy efficiency strategies to reduce the OTTV.

ACKNOWLEDGMENTS

Authors would like to express gratitude to Universiti Teknologi MARA for the support and facilities provided which made this research possible.

REFERENCES

[1] N. A. M. Al-Tamimi, and S. F. Syed Fadzil, 2011. Thermal Performance Analysis for Ventilated and Unventilated Glazed Rooms in Malaysia (Comparing Simulated and Field Data), *Indoor Built Environment,* 20 (5), 534–542.

[2] T. Kubota, G. Student, D. Hooi, and C. Toe, 2011. Energy Consumption and Air-Conditioning Usage in Residential Buildings of Malaysia, *Journal of International Development and Cooperation*, 17 (3), 61–69.

[3] M. Homes, M. F. Z. Bin Jaafar, and B. Croxford, 2010. Adapting To Technology: The Case Of Air Conditioning Use In Malaysian Homes, *Proceedings of Conference : Adapting to Change New Thinking on Comfort*, 9–11.

[4] Department of Standards Malaysia., 2019. Malaysia Standard. MS1525:2019. Energy Efficiency And Use Of Renewable Energy For Non-Residential Buildings - *Code Of Practice* (Third revision).

[5] Department of Standards Malaysia., 2017. Malaysia Standard. MS2680:2017 Energy Energy Efficiency And Use Of Renewable Energy For Residential Buildings - *Code Of Practice.*

[6] J. C. Lam, S. C. M. Hui, and A. L. S. Chan, 1993. Overall Thermal Transfer Value Control of Building Envelope Design Part 2 - OTTV Parameters, *Hong Kong Engineer,* 21(9), 40–44.

[7] R. Saidur, M. Hasanuzzaman, M. M. Hasan, and H. H. Masjuki, 2009. Overall Thermal Transfer Value of Residential Buildings in Malaysia, *Journal of Applied Sciences,* 9 (11), 2130–2136.

[8] N. Nasrullah, R. Rahim, B. Hamzah, and R. Mulyadi, 2019. Energy Conservation Of The Air-Conditioning System Of Hotels Building In Makassar City, *International Journal of Civil Engineering and Technology,*.10 (10), 115–123.

[9] M. Carlini, E. Allegrini, D. Zilli, and S. Castellucci, 2014. Simulating Heat Transfers through the Building Envelope: A Useful Tool in the Economical Assessment Maurizio, *Energy Procedia*, 45, 395–404.

[10] N. T. Al-Ashwal, and A. S. Hassan, 2017. The Impact of Window to Wall Ratio (WWR) and Glazing Type on Energy Consumption in Air-Conditioned Office Buildings, International Transaction *Journal of Engineering Management & Applied Sciences & Sciences Technologies*, 8 (3), 197–207.

[11] Z. A. Rahim, and A. H. Hashim, 2012. Adapting to Terrace Housing Living in Malaysia, *Procedia - Social and Behavioral Sciences,* 36, 147–157.

[12] F. Basrawi, H. Ibrahim, M. Y. Taib, and G. C. Lee, 2013. Optimum Thickness of Wall Insulations and Their Thermal Performance for Buildings in Malaysian Climate, *International Journal of Automotive and Mechanical Engineering,* 8 (1), 1207–1217.

[13] N. Aqilah Hisham, S. Ahmad Zaki, A. Hagishima, and N. Md Yusoff, 2019. Load and Household Profiles Analysis for Air-Conditioning and Total Electricity in Malaysia, *KnE Social Sciences,* 773–786.

[14] B. Koo, K. Lee, Y. An, and K. Lee, 2018. Solar Heat Gain Reduction of Ventilated Double Skin Windows without a Shading Device, *Sustainability,* 10 (1), 1–18.

[15] J. Peng, T. I. S. T. Aziz, and P. C. Leng, 2023. The Exploration of Energy Efficient Material for Shading Devices in Tropical Climates, *Chemical Engineering Transaction,* 106,. 301–306.

[16] Y. Arab, A. S. Hassan, Z. A. Al-Absi, B. Witchayangkoon, and B. Qanaa, 2023. OTTV'S Assessment on Thermal Performance of High-Rise Apartment Buildings in Penang, *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 102 (2), 21–32.

[17] F. Abass, L. H. Ismail, I. A. Wahab, and A. A. Elgadi, 2020. Development of a Model for OTTV and RTTV based on BIMVPL to Optimize the Envelope Thermal Performance, *IOP Conference Series: Materials Science and Engineering.*, 713 (1), 012009

[18] Y. Arab, A. S. Hassan, Z. A. Al-Absi, H. Achour, B. Witchayangkoon, and B. Qanaa,2023. Retrofitting of a High-Rise Residential Building for Energy Efficiency with OTTV as an Assessment Tool, *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* 102 (2), 110–119.

[19] B. A. Rock, 2020. Comparing Building Surfaces' Orientations to Optimize Solar Energy Collection, *Journal of Green Building,* 15 (2), 3–28.

[20] M. R. S. Abid, A. Arshad, and M. Altaf, 2024. Studying the Impacts of Window to Wall Ratio (WWR) on the Energy Consumption in a Residential Unit Located in Bahria Town, Lahore, *Technical Journal.,* 29 (1), 1–6.