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Original Research Article

OVERALL THERMAL TRANSFER ANALYSIS OF GLAZING FACADE DESIGN FOR PASSIVE BUILDING ENERGY EFFICIENCY

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Abstract

The global warming incremental impacts such as temperature, precipitation, rise in sea level, and extreme weather events are indeed being observed globally. In recent decades, energy demand and greenhouse gas emissions have increased due to buildings being designed with active cooling and heating solutions, despite global attempts to reduce energy consumption. About 50 percent of all energy use is attributed to buildings. There has been a debate for Decades on building active and passive design, but very limited studies have been carried out to confirm the Overall Thermal Transfer Value (OTTV) during the operation phase of the building. This paper highlights the analysis of OTTV in the Passive Design Strategies using several conditions of glazing facades. The passive design of glazing facade strategies includes the variation in opaque wall Colour with different values of the coefficient of solar absorption, change in glazing type (U-Value and Shading Coefficient), and the decrease in the size of the openings. Building parameters were collected and OTTV was determined using the equation in Malaysian Standard MS 1525 for Energy Efficiency. The OTTV was then compared to the recommended value for Malaysia's tropical climate. Results showed that different paint Colours improved OTTV by up to 23.05%, changing glazing type reduced OTTV from 76.93 W/m² (Base case) to 64.12 W/m² (Double Low-E, e2=.1 Tint green), and reducing glass area by 10% lowered OTTV to 62.24 W/m².Whereas, by combining the Type of Glazing and White facade Colour the OTTV was reduced to 39.68%. It is concluded that this OTTV analysis enhances building energy efficiency and reduces cooling loads.

Keywords: glazing facade, passive design, overall thermal transfer value, energy efficiency, building

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1. INTRODUCTION

Since global warming has a detrimental impact on Earth's climate, it is the primary cause of climate change globally (Djamila et al., 2018). The global warming incremental impacts such as temperature, precipitation, rise in sea level, and extreme weather events are indeed being observed globally. Global recognition of the impact of greenhouse gas emissions has made it imperative to promote global efforts to control the use of primary energy (Sheng et al., 2020). In recent decades, energy demand and greenhouse gas (GHG) emissions have increased despite global attempts to reduce them (Simpeh et al., 2022). Urban Heat Island (UHI) is relative to outdoor temperature and penetrates buildings via openings and penetration through building materials. Cooling and heating a building are continuous demands for huge energy consumption that require power plants to produce energy supply to rapidly growing cities worldwide and increase the effects of global warming (Shah et al., 2023). As most of the energy at power generation plants is produced through the combustion of fossil fuels, therefore, it is one of the main producers of greenhouse gas emissions, which have a negative influence on the environment (Economic Planning Unit, 2020). Approximately 38% of the world's greenhouse gas emissions are attributed to buildings, primarily to the use of fossil fuels during construction to meet energy demands (Shah et al., 2023; Min et al., 2022). Being the main contributor to energy consumption, about 50 percent of Global Energy Consumption is attributed to buildings (Arab et al., 2023). Reducing energy use is one strategy to promote GHG reduction. Buildings are among the largest power users, and by designing them creatively, they can significantly lower greenhouse gas emissions and improve energy efficiency (Chan, 2021). Various actions have been taken including the policies implementation that encourage the use of renewable energy and energy-efficient technologies. Steps are being taken in many nations to lower the energy requirements for buildings and lessen the associated environmental implications (Mirrahimi et al., 2016).

The energy consumption of Malaysia has significantly increased with a surge of 26167 ktoe to 62489 ktoe from 1997 to 2017, due to its recent sustained high economic growth rates.(Energy Commission, 2019). This energy consumption was further increased up to 66483 ktoe in 2019 (Energy Commission, 2022). Up to 49.5 percent of Malaysia's total electricity consumption in 2018 was accounted for by building usage (Yasser Arab et al., 2023). Therefore, in Malaysia to evaluate the environmental design and building performance Energy Efficiency was included in all Malaysia Green Building Rating Tools including the Green Building Index (GBI) (Green Building Index, 2009), GreenRE (GreenRE, 2021), pHJKR (JKR, 2015), and Malaysia Carbon Reduction and Environmental Sustainability Tool (CIDB & JKR, 2015). For example, Energy Efficiency was included in six main criteria of the Green Building Index, along with Indoor Environment Quality, Sustainable Site Planning and Management, Materials and Resources, Water Efficiency, and Innovation. The GBI seeks to support the building industry's adherence to sustainable development (Green Building Index, 2009). During the hot days in Malaysia, air conditioning units consume a significant amount of electricity in residential and office buildings. Therefore, the designers face many challenges while designing the buildings by maintaining a comfortable environment with minimum utilization of Energy (Abass et al., 2020).

Building energy use is impacted by changes in the climatic system whereby Urban Heat Island (UHI) emerged from the effect of human activities that create global warming which the heat source is from sun radiation. This UHI is relative to outdoor temperature and penetrates to building via openings and penetration through building materials. The higher the outdoor heat penetrates the building envelope determines the higher the cooling loads. The higher cooling loads lead to higher energy demand and cumulatively impact to higher energy bills in building operation expenditure. Therefore, many countries around the world have implemented the indices regarding the energy consumption of buildings, to control the energy use of newly built buildings (Hwang et al., 2018). For that, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) introduced first the concept of Overall Thermal transfer Value in 1975 as an index to measure the thermal performance of buildings with air conditioning, which was defined as “The average heat gain of a building through its envelope” (ASHRAE, 2010). After that, it was developed and implemented in different countries, like Malaysia, Singapore, Hong Kong, and Thailand. In the case of Malaysia, the OTTV was incorporated into the Malaysian Building Regulations in 2001. Since the average heat conduction from the envelope of the building is estimated by its OTTV. Therefore, it can serve as a benchmark to evaluate how different buildings perform in heat conduction (Djamila et al., 2018). To standardize the technique of calculating the OTTV of air-conditioned buildings, MS 1525 provided a building code of practice in Malaysia named; “Energy Efficiency and Use of Renewable Energy for non-residential”. Using the OTTV index assessment, energy use in the building envelope is managed to minimise air conditioning energy use by lowering heat transfer through the building envelope and enhancing the building's overall energy efficiency. To put it in another way, OTTV is a tool for calculating the thermal performance of the air-conditioned building envelope (Department of Standards Malaysia, 2014). It provides an easy way to calculate the amount of heat that enters buildings from solar radiation entering via windows and conduction through walls and windows (Public Works Department Malaysia, 2013).

The passive design principles have received a lot of attention due to the enormous potential for energy efficiency in buildings. Natural ventilation, the use of external shading devices, window size and form, window glazing, sun path, building orientation, thermal insulation, thermal mass, building mass, and building location are some examples of passive design strategies. Particularly, in the building industry, passive design strategies encourage the use of renewable energy sources while lowering energy consumption to reach a low-energy and sustainable future. Passive buildings can minimise their energy use by regulating heat inflows and losses through the building's façade (Monis & Rastogi, 2022). This means that at periods of maximum temperature, thermal comfort can be sustained with very little energy inputs during the summer and very little during the winter. In the construction sector, employing passive techniques could be one way to increase building energy efficiency. Many passive design techniques exist for lowering the building’s energy use, including the use of renewable resources and consideration of the environment, especially in the selection of ventilation, heating, cooling, and lighting systems. It reduces the need for extra energy to keep the building comfortable (Monis & Rastogi, 2022). OTTV has emerged as one of the most crucial design parameters for new or existing building envelopes, particularly for office buildings, since it shows how much heat enters a building through its envelope and can be used to reduce heat gain and, consequently, the cooling load on the air conditioning system (Karim et al., 2019). In this scenario, by enhancing building envelope requirements, OTTV can be reduced using passive design techniques (Lakhiar et al., 2023). This passive design approach of OTTV can be simulated with the Building Information Modelling (BIM), even though the building is constructed. From the details of the building envelope given in Table 1, the Window-to-Wall Ratio is quite high in certain orientations of the building. The research on the passive design strategies including façade Colour, glazing type, and window-to-wall area must be considered to optimise the overall thermal transfer value of the existing building.

2. LITERATURE REVIEW

2.1. Passive Design Strategies

Passive Design Strategies play a vital role in converting the existing building into an energy-efficient building. This is particularly true for educational facilities, which have significant energy requirements because of their diverse room configurations, number of occupants, and operating requirements for heating and cooling. In addition, natural elements like aging and harsh weather will cause the buildings' energy performance to steadily decline (Sebayang et al., 2023). It has got a lot of research attention in the recent era.

For example, Bughio et al., (2021) used Passive Energy Efficiency Measures (PEEMs) to renovate an existing building and assessed the effects of using passive energy efficiency design methods. The effects of various building envelope composition options (modifications to the walls, roof, windows, doors, and sometimes even the entire building) on the amount of energy required for cooling were compared. It was suggested that the use of PEEMs could result in a significant 31.96 percent decrease in cooling energy consumption. Moni & Rastogi (2022) examined the effects of eight passive design strategies on building energy consumption, including thermal insulation, thermal mass, window size, shape, position, and glazing; external surface Colour; external shading devices; and building orientation and form. Most of these factors were considered in the design phase. It was found that passive design techniques, which maximise the use of renewable energy sources by reducing energy consumption, are widely acknowledged as the most significant approach for low energy and sustainable future in the construction business (Monis & Rastogi, 2022). Using Design-Builder software, Al-Saadi et al., (2017) created a simulation model of Oman's current residential buildings to examine the viability of energy-efficient retrofitting in the country's hot environment. It was discovered that combining the best strategies (improved air tightness of the home, AC efficiency, and usage of insulation for the walls and roof) from each category might reduce the building's yearly energy use by as much as 42.5% (Al-Saadi et al., 2017). Further, Mahar et al., (2020) conducted a pertinent study by performing a global sensitivity analysis on a typical residential building in the cold, semi-arid regions of Quetta, Pakistan. The investigation was done to find the most important design characteristics for thermal comfort and to look at how passive design elements affect adaptive comfort. According to this research, comfort levels can be increased without the use of mechanical solutions by utilizing passive design techniques including thermal management, passive solar heating, passive cooling, and solar radiation control (Mahar et al., 2020).

A simulation-based study was carried out by Mushtaha et al., (2021) to investigate how different realistic passive design strategies may be included in a typical dwelling. To reduce the building's cooling loads and increase thermal efficiency, the assessment was carried out using IESve and Climate Consultant software. The study found that by employing passive design elements such as natural ventilation, shading, thermal insulation, and small openings with a 15% WWR, 9.89 kW, or 59% of the building's overall energy use, could be decreased. Moreover, the findings imply that thermal insulation and shading devices can substantially lower total energy consumption by 19.8% and 53.5 percent, respectively (Mushtaha et al., 2021). To increase an educational building's energy performance by retrofitting with passive design techniques including adjustments to the shading and glazing characteristics, Sebayang et al., (2023) studied educational building façades. After implementing these passive design techniques together, it was found that the indoor temperature dropped by 0.835 °C, and the overall thermal transfer value decreased by 6.04 W/m2.

According to the research cited above, BIM can do OTTV analysis in a built building with the assistance of sensors and other Internet of Things (IoT) devices. Therefore, a proposal for retrofitting can be made via BIM simulation analysis. Retrofitting of High-Rise Residential Buildings was done by Arab et al., (2023) to improve energy efficiency by using Passive Design Strategies including changes in façade Colour, Different U-value and Glazing Systems, and External Shading Projection. Applications of these retrofitting techniques independently resulted in a 26% to 33.4% reduction in the OTTV. Whereas, by combining these measures, the OTTV was reduced by 75.6%. It was determined that by achieving such a significant reduction in OTTV, the building's energy efficiency might be enhanced as it would lessen the cooling load required for the air-conditioned structure. (Mughal et al., 2024) Performed BIM-based retrofitting of existing buildings in Pakistan to optimize energy consumption using different design alternatives. The results of the study revealed that the Energy consumption was optimized up to 46% using different design alternatives. Lakhiar et al., (2023) carried out retrofitting research employing various glazing systems to increase an office building's energy efficiency. The OTTV was found to have decreased from its initial value of 55.31 W/m2 to 45.34 W/m2. A thorough analysis of a passive office building is still necessary before implementing passive design techniques. A lot of studies have been done on the application of passive design techniques to improve the energy efficiency of already-existing buildings through retrofitting.

From the above-mentioned studies, it can be summarized that the Passive Design Strategies can improve the Energy Efficiency of buildings. The passive design strategies include the Facade Colour, Natural ventilation, thermal insulation, thermal mass, window shape, position, and glazing; external surface Colour; external shading devices; and building orientation and form. But very little attention has been paid to changing the Window-to-Wall Ratio (Size of Windows), therefore in this research study the variation in the size of windows is considered along with the Facade Colour, solar absorptivity, and Type of Glazing System to improve the Overall Thermal Transfer Value of an Air-Conditioned Office Building which turns to be the improvement in Energy Efficiency of that building.

2.2. Overall Thermal Transfer Value

The concept of Overall Thermal Transfer Value (OTTV) was initially introduced by ASHRAE in 1975. OTTV measures the quantity of heat that enters a building through its envelope. The Roof Thermal Transfer Value (RTTV) and the Envelope Thermal Transfer Value (ETTV) together constitute the Building Envelope, which is considered to be totally closed in accordance with the OTTV theory. Whereas the RTTV monitors heat transfer through the roof, the ETTV conducts heat transfer measurements through the walls or building exterior (Vijayalaxmi, 2010).

According to Vijayalaxmi, (2010), The primary goals of the OTTV are to: (i) develop and implement energy-efficient design protocols and pertinent design tools; (ii) set best practices and standards for energy management systems for different kinds of buildings; (iii) offer suggestions for boosting building energy efficiency; and (iv) promote climate-responsive building planning and design. Chow & Philip (2000), discovered four techniques to calculate the OTTV. These include applying the information from the computer simulation of TRACE 600, the Chow and Chan equation, the Hong Kong Code of Practice, and the ASHRAE90A-80 technique.

Controlling the OTTV is a key concept in building energy efficiency, as it regulates the amount of heat transferred from the building envelope. OTTV causes an increase in the quantity of heat gain through the building's envelope. Reduced heat gain allows the air conditioner to operate with less load, which lowers energy consumption overall (Vijayalaxmi, 2010). The OTTV Calculation is based on three main components: (1) conduction of heat from opaque walls, (2) conduction of heat from glass windows, and (3) conduction of heat due to solar radiation from glass windows (Seghier et al., 2022).

As per the standard 1975 ASHRAE 90A-1980, the general equation of OTTV is given below:

$$OTTVASHRAE1975 = TDeq\,(1 - WWR)\,Uw + \Delta T(WWR)\,Uf + SF(CF)(WWR)(SCf) \tag{2.1}$$

Where the weighted average OTTV (W/m2) is denoted by OTTV, SF is the solar factor (W/m2), TDeq is the equivalent temperature difference (0 K), Uf is the thermal transmittance of glass windows (W/m2 K), CF is the correction factor for solar heat gain through glass windows, SCf shading coefficient of glazing system, ΔT is difference in temperature of windows from outside and inside of the buildings (0 K), and WWR is ration of Window are to the wall area.
To lessen the complexity of the OTTV calculation, these parameters are replaced with numerical coefficients in the most recent OTTV formula developed by Malaysian Standards MS1525:14 defined as equation (2.2):

$$OTTVMS1525 = 15\,\alpha\,(1 - WWR)\,Uw + 6\,(WWR)\,Uf + 194\,(CF)(WWR)(SCf) \tag{2.2}$$

3. METHODOLOGY

This section illustrates the methodology used in this research study. Which includes the details of case study building, methods, and retrofitting measures used in this study.

1.1. Flow Chart of Research Methodology

To calculate the overall heat transfer value mathematically, the study approach starts with the problem formulation. Then defining the specifications of the building envelope, such as the type of materials used in walls, facade Colour, glass type, thickness, and properties. The three OTTV formula criteria are included in the calculation: i) Heat Gain through Opaque Walls, ii) Heat Gain through Glass Windows, and iii) Solar Radiation Heat Gain from the Glass Windows. The variables U-value, Shading Coefficient (SC), and Window-to-Wall Ratio will be used to determine these three criteria. The OTTV was compared with the Malaysian Standard 1525:2019, in which it is defined that, the OTTV of commercial buildings with a total air-conditioned area of 4000 square meters and above cannot be greater than 50 W/m2. Furthermore, Figure 1, illustrates the overall methodology adopted to conduct this study.

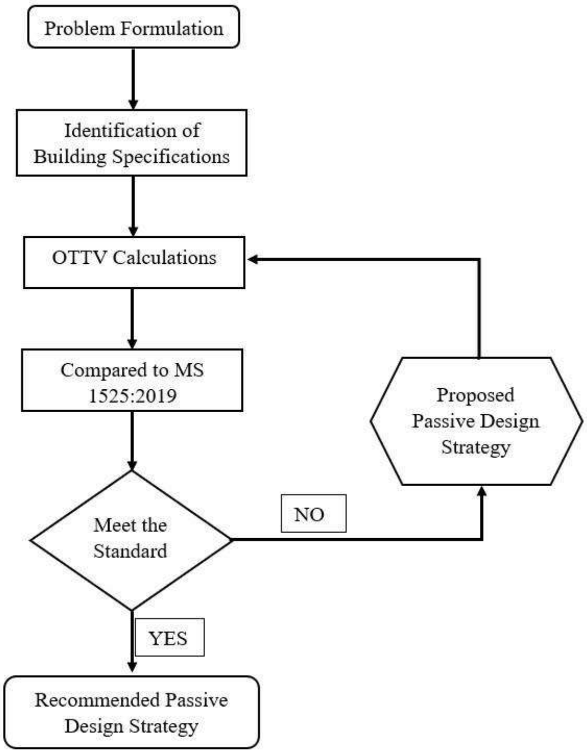

Fig. 1. Flow Chart of Research Methodology

1.2. Case Study Building

To prove the OTTV analysis in a constructed building, research is conducted to improve the energy efficiency of a passive office building of Universiti Teknologi Malaysia. In this study, an office building named UTM Eco-Home was selected. It was constructed by the collaboration of the students from UTM led by Prof. Dr. Muhd Zaimi Abd Majid and researchers of the Institute for Smart Infrastructure and Innovative Construction (ISIIC), UTM Construction Research Center (UTM-CRC), Malay World Architecture Study Center (KALAM) and Center of Electrical Energy Systems (CEES). With an approximate budget of RM 500,000, UTM Eco-Home was constructed over a year and occupies 1,450 square feet. As an extension of UTM's involvement in the Solar Decathlon China (SDC2013), which took place in Datong, China, the UTM Eco-Home project might serve as a venue for relevant UTM researchers to present their findings. The details of the UTM Eco-Home Building Envelope are given in Table 1.

Table 1. Data of UTM Eco-Home (Case Study Building)

Orientation of the Building	Gross Wall Area	Window Area	Window-to-Wall Ratio
North	25.682	5.15	0.200
South	57.005	27	0.473
East	70.313	16.801	0.238
West	55.297	32.739	0.592

1.3. Proposed Glazing Facades and Measures in UTM Eco-Home Building

As was previously stated, the three forms of heat gain in the buildings are considered by the OTTV. One of the primary forms of heat gain is conduction through opaque walls, that is determined by the Window to Wall Ratio, thermal transmittance value of the material (U-value), and external surface solar absorptivity. The WWR and the U-value of the glazing system affect the second type of heat conduction, which is heat conduction through the fenestration system. Sunlight entering the building through windows is the final form of heat gain. It is affected by window to wall ratio, the shading coefficient of the type of glazing, and the type and placement of the exterior shading system. Therefore, the proposed Retrofitting Measures that don't need any major renovation of the building are as under:

a) The Facade Colour (Opaque Wall Colour), Table 2
b) Type of Glazing system (U-value and SC Value of Fenestration), Table 3
c) The reduction in WWR (Proposed 5% and 10%)
d) White Facade Colour + Different Types of Glazing System

Table 2. Solar Absorptivity Coefficient for Different Facade Colours

Facade Colour (Paint Colour)	Absorptivity Coefficient
Flat Black	0.95
Dark Grey	0.91
Dark Brown	0.88
Medium-Light Brown	0.8
Medium Orange	0.58
Medium Blue	0.51
Light Green	0.47
Light Grey	0.4
Light Gloss	0.25

Table 3. Different Glazing Systems for OTTV Analysis

Type of Glazing System	U Value (W/m2 K)	SC Value
Double Tinted Green	2.72	0.57
Double Reflective-D Tint Green	3.179	0.41
Double Low-E (e2 = 0.1)	1.76	0.43

In this research, the reduction of Window size by 5% and 10% is assumed by following a research study conducted by R. Saidur et al., (2009), in which the authors mentioned the effect of different parameters including WWR, Shading Coefficient, U Value of wall, and Solar Absorptivity on OTTV. They checked the effect of WWR from 0.01 to 0.18 means 1% to 18% WWR and found significant variation in OTTV. Furthermore, it was mentioned that 6% WWR doesn't affect the OTTV as it is very low. But in this case study, the building is a Passive building that has a WWR of 0.200 for the North, 0.473 for the South, 0.238 for the East, and 0.592 for the West. Which shows quite a higher WWR for certain orientations. Moreover, it was considered due to the future recommendation of Shah et al., (2023), whereby the authors suggested that the impact of shading and glazing systems should be carried out with varying climates and varying WWR. Therefore, we assumed 5% as well as 10% to generalize the results.

4. RESULTS AND DISCUSSION

4.1 Mathematical Calculation of OTTV

The OTTV of the case study building was calculated using the formula defined in Malaysia Standard MS 1525 for Energy Efficiency of Buildings. The formula is:

$$OTTVMS1525 = 15\,\alpha\,(1 - WWR)\,Uw + 6\,(WWR)\,Uf + 194\,(CF)(WWR)(SCf) \quad (4.1)$$

Figure 2 given below shows the calculation of the Overall Thermal Transfer Value of the UTM Eco-Home building. This calculation is for the base case of the UTM Eco-Home Building. Generally, the OTTV consists of three major components: Heat Conduction through opaque walls, Heat Conduction through Glass Windows, and Solar Heat Gain through Glass Windows. The OTTV for each orientation was calculated separately and then averaged over the whole area of the building. From the calculation sheet, it can be seen that the major part to OTTV is being played by the Solar Heat Gain through Glass Windows. Hence, the Heat Gain through Glass Windows must be optimized to reduce the OTTV of a Passive Building. Due to this reason, in this study, the reduction in Window Size (WWR) is suggested as a retrofitting measure along with the solar absorptivity, Facade Colour, and Type of Glazing System.

OTTV Calculation

OTTV COMPONENT	Wall Location	A Wall Area (m^2)	B Constant	C Solar Absorption Factor (α)	D Window to Wall Ratio (WWR)	E (1-WWR)	F Wall Constr U-Value (Uw)	G Glass U-Value (Uf)	H Orientation Factor (OF)	K Shading Coefficient	L Wall OTTV (ie multiply all shaded cells in the same row)	% of OTTV
HEAT CONDUCTION THROUGH WALLS	North Wall	25.68	15	0.70	0.20	0.80	4.32	N/A	N/A	N/A	931.33	
	South Wall	57.01	15	0.70	0.47	0.53	4.32	N/A	N/A	N/A	1,361.03	
	East Wall	70.31	15	0.70	0.24	0.76	4.32	N/A	N/A	N/A	2,427.30	
	West Wall	55.30	15	0.70	0.59	0.41	4.32	N/A	N/A	N/A	1,023.23	
	∑ Wall Area	*208.30*	Equation for Heat Conduction Through Walls = 15 x α x (1 - WWR) Uw							∑	5,742.89	35.8%
HEAT CONDUCTION THROUGH WINDOWS	North Wall	25.68	6	N/A	0.20	N/A	N/A	2.72	N/A	N/A	84.05	
	South Wall	57.01	6	N/A	0.47	N/A	N/A	2.72	N/A	N/A	440.64	
	East Wall	70.31	6	N/A	0.24	N/A	N/A	2.72	N/A	N/A	274.19	
	West Wall	55.30	6	N/A	0.59	N/A	N/A	2.72	N/A	N/A	534.30	
			Equation for Heat Conduction Through Windows = 6 x WWR x Uf							∑	1,333.18	8.3%
SOLAR HEAT GAIN THROUGH WINDOWS	North Wall	26	194	N/A	0.20	N/A	N/A	N/A	0.90	0.5700	512.54	
	South Wall	57	194	N/A	0.47	N/A	N/A	N/A	0.92	0.5700	2,746.81	
	East Wall	70	194	N/A	0.24	N/A	N/A	N/A	1.23	0.5700	2,285.16	
	West Wall	55	194	N/A	0.59	N/A	N/A	N/A	0.94	0.5700	3,403.06	
			Equation for Solar Heat Gain Through Windows = 194 x WWR x OF x SC							∑	8,947.57	55.8%
										∑ WALL OTTV =	***16,023.64***	
										∑ WALL AREA =	***208.30***	
										OTTV =	***76.93***	

Fig. 2. OTTV Calculation

4.2 Effect of Facade Colour on OTTV

The OTTV of the case study building was calculated using different passive design strategies as retrofitting measures to make the building more energy efficient. The retrofitting measures included the Facade Colour, Types of Glazing System, and the Decrease in window-to-wall ratio (WWR). The base case (Natural Red Colour of Bricks) has an OTTV of 76.93 W/m2 which is exceeding the allowed limit of MS1525:2019 (50 W/m2). From the Figure 3, it is evident that, a substantial amount of OTTV can be reduced by using light Colour due to its low absorptivity coefficient (α). The OTTV was optimised by an amount of 23.05% by using a White Gloss Façade Colour, which is aligned with the results of (Arab et al., 2023) who discussed the role of Passive design approaches in optimizing the OTTV. Arab et al., (2023), optimized the OTTV using different façade colours by 26% from its original value. This significant reduction in OTTV shows the importance of Façade Colour in reducing the heat gain and improving the Energy efficiency of building. The highest OTTV value of 86.77 was with flat black façade paint and the lowest was 59.20 for the white Colour façade paint. The difference in OTTV between the base case and the white Colour (with absorptivity value = 0.25) was 17.73 W/m2. Because the absorptivity value of the Colour white is 0.25, whereas the basic case's value is 0.7. The OTTV was decreased by 11.82 W/m2 and 8.78 W/m2, respectively, with the use of alternative colours such as light grey and light green facade paints. In this way, the OTTV of the case study building can be reduced up to a considerable amount, thus suitable in the case of retrofitting the building. Moreover, other studies also support the influence of the facade Colour to reduced cooling loads as well as it is evident in the work by (Arab et al., 2023).

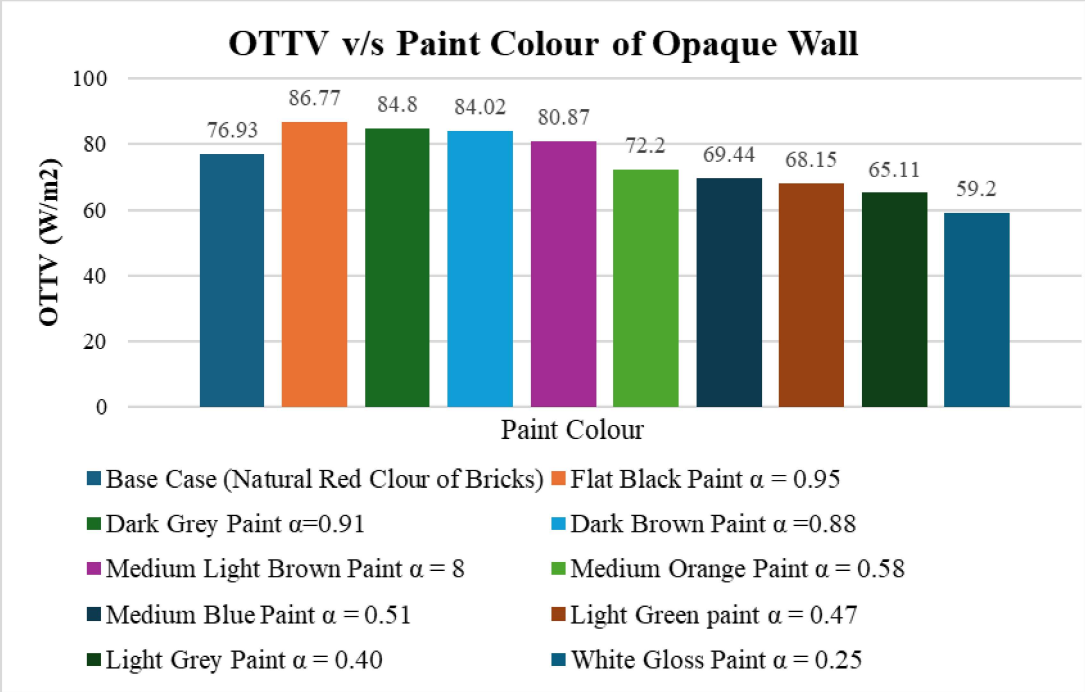

Fig. 3. Facade Colour vs OTTV

4.3 Effect of Using Different Types of Glazing Systems on OTTV

The effect of Glazing System on OTTV was examined using three different types such as Double Tinted Green (Base Case), Double Reflective-D Tinted Green, and Double Low-E (e2 = 0.1) Tinted Green. The OTTV of the case study building can be decreased by using the glazing system having a lower U-value and a lower shading coefficient value. Figure 4, given below illustrates the results of OTTV using three different types of Glazing Systems. The OTTV (76.93 W/m2) for the base case was decreased up to 14.26% by using a Double Reflective-D Tinted Green glazing system, and 16.65% by using a Double Low-E (e2 = 0.1) Tinted Green glazing system. Such reductions in OTTV emphasize on selection of Glazing system with Low Shading Co-efficient value and Lower U-Values. This result is aligned with the findings of (Lakhiar et al., 2023), in which they endorsed the role of the Glazing System in optimizing the building's energy efficiency. The authors demonstrated the role of different glazing types on OTTV and optimized the OTTV by 18%. The noted decreases provide additional evidence for the effectiveness of Low-E glazing systems in lowering OTTV and enhancing overall thermal performance. Which was supported by (Mirrahimi et al., 2016), who underscores the reliability of Glazing systems with High Performance in Hot-humid climates.

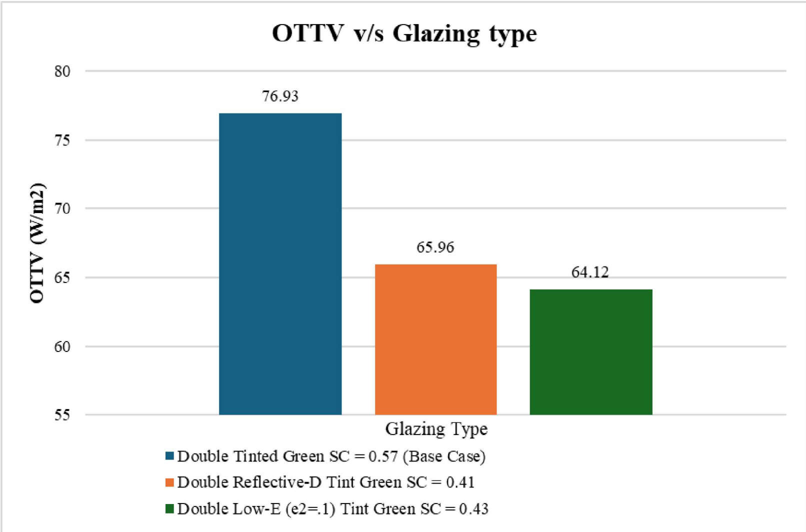

Fig. 4. Types of Glazing System vs OTTV

4.4 Effect of Decrease in Windows Glass Area by Percentage on OTTV

The decrease in window-to wall Area, was considered as significant passive design approach to reduce the OTTV by limiting the area available for solar heat gain. Which may be a little bit expensive as compared to the other glazing facade measures, but this cost can be overcome by its benefit. The OTTV of the selected building was calculated with a decrement of Windows Glass Area (WWR) by an amount of 5% and 10% along with the different types of glazing systems. This means that three types of glazing systems (Double Tinted Green, Double Reflective-D Tinted Green, and Double Low-E (e2 = 0.1) Tinted Green) were used with decrement in Glass Area (WWR). From Figure 5, it is evident that the OTTV was reduced by a maximum amount of 14.69 W/m2 (19.095%) with a Double Low-W Tint Green Glazing System plus a 10% decrease in the Windows Glass Area. These substantial decreases in OTTV offers the importance of balancing the window area (window size) with effective glazing system to reduce solar heat gain to improve the building's energy efficiency. The significant reduction in OTTV aligns with the conclusion of (Al-Saadi et al., 2017; Mahar et al., 2020), who discussed the role of Windows and Wall characteristics in improving indoor thermal comfort and decreasing cooling loads. Al-Saadi et al., (2017) claimed that the energy of a building can be saved up to 25.9% using their suggested different types of wall designs, roof designs, shading designs, and glazing designs.

4.5 Combined Effect of Using White Gloss Facade Colour and Type of Glazing System on OTTV

The last Glazing Facade measure employed in this study was the combination of White Facade Colour and Types of Glazing Systems to compute the OTTV of UTM Eco-Home. Figure 6 shows the results of OTTV with this retrofitting measure. The synergistic effect of these retrofitting measures demonstrates the holistic approach which can address multiple aspects of Thermal Transfer Performance through building envelope simultaneously. The OTTV was improved by an amount of 39.68% using white Colour as the paint of the Opaque Walls and Double Low-W Tint Green Glazing System with the lowest value of 46.39 W/m2 as compared to the base case OTTV was 76.930 W/m2. This Holistic Approach is supported by the findings of (Al-Saadi et al., 2017; Arab et al., 2023), who defined the role of integrated passive design approaches (Combination of Façade and Glazing Improvements) to reduce the OTTV.

In their study, Al-Saadi et al., (2017), claimed that the annual energy consumption of a building can be reduced by an amount up to 42.5% using combined retrofitting measures. Whereas, Arab et al., (2023), found that the OTTV can be optimized up to 75.6% using the combination of different passive design strategies.

In previous studies, the decrease in WWR retrofitting measure was not considered. Therefore, it was added along with the Façade Colour and Glazing types in this study. From the results of this study, it is possible to say that the building equipped with the recommended alternatives can lower the OTTV by as much as 39.68 percent, which means that less heat gain will enter the interior of the building. By this way, the energy efficiency of buildings can be improved because it contributes to the reduced cooling load of air-conditioned buildings and for buildings without air conditioning, it offers a better interior thermal environment.

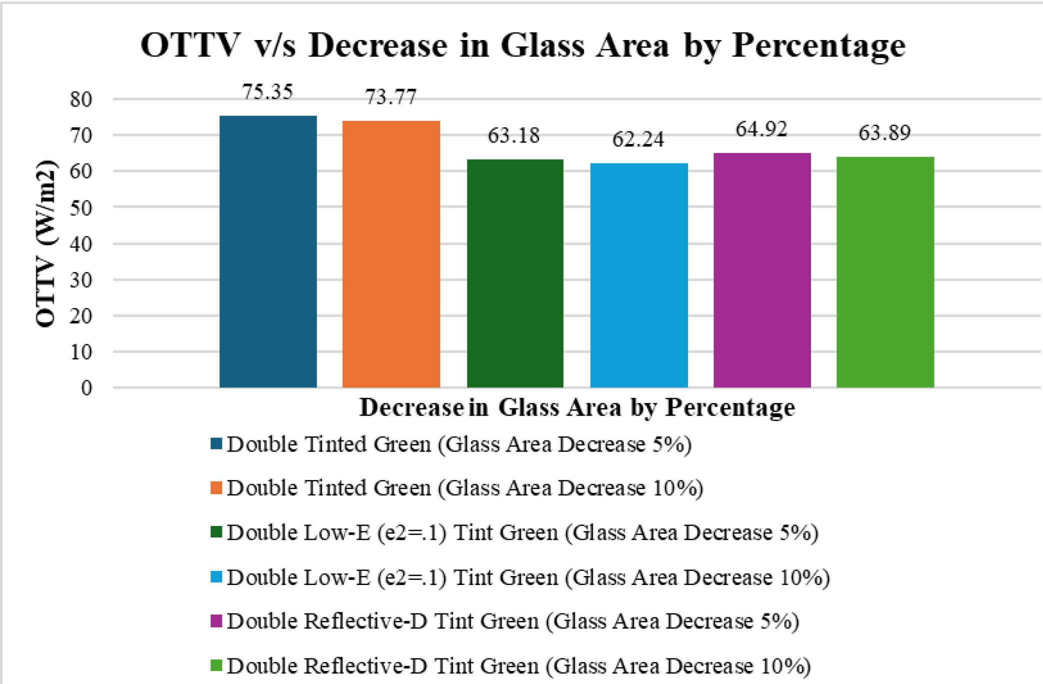

Fig. 5. Decrease in WWR + Types of Glazing System vs OTTV

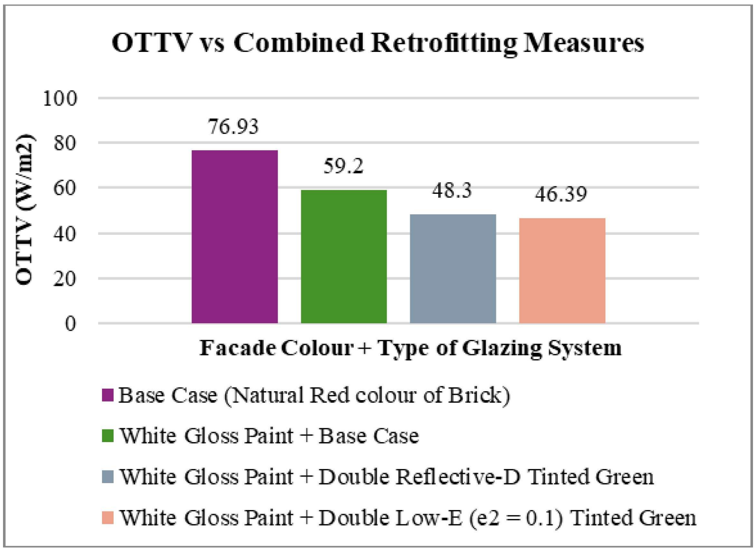

Fig. 6. The effect of different glazing techniques on white opaque walls.

The study clearly shows the reduction of OTTV of UTM Eco-Home Building using different passive design strategies such as Facade Colour, Type of Glazing System, and Reduction in WWR. This not only enhances the building's energy efficiency but also ensures the compliance of MS 1525 Malaysian Standard for Energy Efficiency of Buildings. The table 4, given below shows the effective findings of this study.

Table 4. Effective Findings on OTTV Reduction

Parameter	Variation	OTTV (W/m^2)	Reduction in OTTV	Observation
Change in Facade Colour	Natural Red (Base Case) White Light Grey Light Green	76.93 59.20 65.11 68.15	Base Case 23.05% 15.6% 11.41%	Changing the facade Colour to white led to the most significant reduction in OTTV (23.05%), demonstrating that lower solar absorptivity significantly reduces heat gain.
Glazing Type	Double Tinted Green (Base Case) Double Reflective-D Tinted Green Double Low-E (e2 = 0.1) Tinted Green	76.93 65.96 64.12	Base Case 14.26% 16.65%	The Double Low-E (e2 = 0.1) Tinted Green glazing resulted in a 16.65% OTTV reduction, validating the effectiveness of low-emissivity glazing in minimizing solar heat gain.
Reduction in Window-to-Wall Ratio (WWR)	Base Case Decrease in WWR by 5% with	76.93	Base Case	Reducing the WWR to 5% achieved a 28.43% OTTV reduction, emphasizing the

	Double Low-E (e2 = 0.1) Tinted Green Decrease in WWR by 10% with Double Low-E (e2 = 0.1) Tinted Green	63.18 62.24	14.16% 28.43%	importance of optimizing window size for energy efficiency.
Combined Retrofitting of Glazing Type, Decrease in WWR, and Facade Colour	Double Low-E (e2 = 0.1) Tinted Green, Decrease of 10% in WWR & White Gloss	46.39	39.68%	Combined Passive Design Strategies like using Double Low-E (e2 = 0.1) Tinted Green glazing type, reduction of WWR to 10%, and using White Façade Colour can reduce OTTV by an amount of 39.68%, emphasizing the importance of passive design strategies for energy efficiency.

Since the selected case study building is passive and has a higher window-to-wall ratio for different orientations. The WWR has a great influence on the OTTV Calculation due to the fact that the building fenestration plays an important role in the OTTV of a building because it influences the indoor environment (i.e. Heat conduction and Solar Radiation). To understand the effect of building fenestration on OTTV, the calculation of OTTV is divided into three parts (Heat Conduction through Opaque Walls, Heat Conduction through building Glass Windows, and Solar Heat Gain through Glass Windows. The figure illustrates the OTTV Calculation, and it shows that a major part of OTTV goes with the building fenestration as the OTTV calculation for building fenestration accounts for more than 50% of the OTTV. Generally, the results of this study can be compared to that of Arab et al., (2023). In which the OTTV was improved by an amount of 26% to 33.4% by using individual retrofitting measures whereas for this study it is 23.05%. Also, the same was optimized up to 75.6% by combining the retrofitting measures whereas in this study this value is up to 39.68%. The major difference is the retrofitting measures whereby the change in the size of the windows or in other words, the change in the Window-to-Wall ratio was not considered, which is considered in this study.

5. CONCLUSIONS

This work aims to present a detailed evaluation of how passive design strategies could be employed to minimize the OTTV of a building in a tropical climate like Malaysia. From the analysis, it was found that the design of UTM Eco-Home presented an average OTTV value of more than 50W/m² of MS 1525; therefore, the improvements with passive design strategies contributed to the enhancements for compliance with the mentioned criteria. These strategies included the Façade Colour (Colour of the Opaque Wall i.e. Solar Absorptivity), the Type of Glazing system (U-value and SC Value of Fenestration), and the reduction in the window-to-wall Area (WWR) collectively showed that they have the potential to improve energy efficiency, Indoor Environment Quality, and building performance.
The findings demonstrate the efficacy of these measures as follows:

Change in Colour of Facade: The use of a white facade decreased the OTTV by 23.05%, illustrating the important role that low absorptivity has in reducing heat input. This result is aligned with the findings of Arab et al., (2023), in which the authors found the effect of facade Colour on the OTTV of the Building and claimed a reduction in OTTV by 26%.

Type of Glazing: When Double Low-E (e2 = 0.1) Tinted Green glazing was used, the amount of solar heat gain was reduced by 16.65%, demonstrating the efficiency of modern glazing technologies. The result is aligned with a similar study conducted by (Lakhiar et al., 2023) to check the effect of Different Glazing Systems on OTTV and improved the OTTV by 18%.

Combined Retrofitting of Glazing System, Facade Colour, and Reduction in Window-to-wall Ratio: When optimal glazing was paired with a 10% decrease in WWR, the OTTV was further reduced by 39.68% (46.39 W/m2). It ensures the results of a study conducted by (Al-Saadi et al., 2017) whereby the authors said that buildings can achieve up to 42.5% energy reduction by applying a combination of passive design strategies.

The general conclusion drawn from this study is that it is worthwhile to pursue reductions to bring a building's OTTV below the permissible level when it does not match current standards. The results imply that comparable passive design techniques can be successfully used in various building types and climates, especially in areas where solar heat gain is a major concern. According to the findings of R. Saidur et al., (2009) the OTTV can serve as the Parameter for reducing cooling load and can provide a better indoor environment for non-air-conditioned buildings (Arab et al., 2023). Therefore, it was presumed that this retrofitting could increase building energy efficiency by reducing the cooling load in air-conditioned buildings and providing a better indoor atmosphere in non-air-conditioned buildings.

6. LIMITATIONS AND FUTURE RECOMMENDATIONS

This study was conducted on the UTM Eco-Home Building of University Teknologi Malaysia. Due to its focus on a specific building, the results may not be directly applicable to all types of buildings. Different buildings may have unique characteristics that affect the effectiveness of the proposed measures. The findings are based on the climate conditions of the study location. The effectiveness of the glazing facade measures may vary in different climatic regions, limiting the generalizability of the results. While the study shows significant potential improvements, the cost of implementing the recommended measures in existing buildings was not fully explored. Further investigation is needed to assess the economic and logistical aspects of retrofitting measures. It is imperative to do an investigation of the durability and long-term performance of the suggested glazing façade measures. Subsequent investigations ought to concentrate on the long-term efficacy of these strategies and their influence on building maintenance expenses.

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