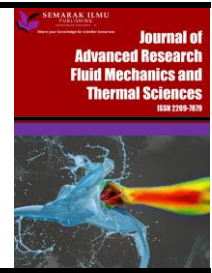




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OTTV'S Assessment on Thermal Performance of High-Rise Apartment Buildings in Penang

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ABSTRACT

This study evaluates the envelope thermal performance of high-rise apartment buildings in Malaysia, which are being largely dominated due to the high economic development and increased population. The evaluation was conducted using the Overall Thermal Transfer Value (OTTV), which is the key tool used in the Green Building Index to assess the Energy Efficiency of buildings. Different high-rise apartment buildings were selected with different architecture styles, to account for several periods of building construction. The OTTV value was calculated for the west-oriented façade of the selected buildings, which is considered as a critical orientation that receives high solar radiation. The results showed that four out of the five investigated buildings achieved the minimum requirements for the OTTV, i.e., less than 50 W/m². The maximum and minimum OTTV values with the buildings' original design were 82.60 W/m² and 41.54 W/m², respectively. However, one of the buildings achieved a lower OTTV value with the installation of shading devices by the owners, i.e., decreased from 48.39 W/m² to 37.60 W/m². The solar radiation penetration through the fenestration was found to be the major contributor to the total OTTV, while it can be controlled by the shading devices. Besides, using dark paints increased the heat conduction through the opaque walls by more than double compared to light paints. This study shows that some design considerations, such as paint colour, shading devices, and glazing material, can have a great influence on the heat gain in buildings.

1. Introduction

Worldwide, buildings consume around 40% of the global energy with as high as 60% goes for buildings cooling and/or heating [1,2]. In Malaysia, the electricity consumed by buildings in 2018 reached up to 49.5% of the total electricity consumption [3]. Since the largest part of the energy is produced from fossil fuels combustion, the energy sector is one of the major contributors to

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Greenhouse gas emissions, which have adverse impacts on the environment [4]. Therefore, actions are being taken in many countries to reduce energy requirements for buildings and mitigate the associated environmental impacts by applying strategies that support the use of renewable energy and energy efficiency technologies [1].

The Malaysian government has included manual energy efficiency usage in relation to the Ninth Malaysian Plan (2006-2009) in order to optimize energy usage in building design [5]. In addition, the Malaysian Board of Architects has enhanced green building designs by introducing the Green Building Index (GBI) as a guideline for green building designs. The GBI aims to assist the building sector to adhere to sustainable development. It evaluates the environmental design and performance of buildings based on six main criteria, namely 1) Energy Efficiency, 2) Indoor Environment Quality, 3) Sustainable Site Planning & Management, 4) Materials & Resources, 5) Water Efficiency, and 6) Innovation [6]. Energy efficiency in buildings is given 23 points out of the 100 points in the GBI. The envelope thermal performance is the main evaluated component of the energy efficiency, which receives 13 points and is assessed by the wall's Overall Thermal Transfer Value (OTTV) and the roof's U-value.

High-rise apartment buildings are being dominated in the majority of the cities in Southeast Asia countries due to the high economic development and the increased population. High-rise apartment buildings are classified under the tall buildings' category of the multi-story buildings, which are over 10 or 12 storeys and equipped with elevators [7–9]. The first high-rise building was the Home Insurance Building. It was built in the 1880s in Chicago in the United States of America. In Malaysia, the first high-rise apartment is Sulaiman Courts at Tunku Abdul Rahman Street in Kuala Lumpur as it was built before 1957 (Figure 1). The second high-rise building is a seventeen-storey building, Pekeliling Flats, which were built at Tun Abdul Razak Street in 1964. High-rise buildings in Malaysia were popularly in the 1970s [10].



Fig. 1. First high-rise apartment in Malaysia; Sulaiman Courts [11]

High-rise apartments are popularly built in urban areas since they can provide many residential apartment units. The construction sector has solved the problem of land's scarcity in the urban areas to house the increasing city population. Figure 2 shows the percentage of apartment buildings compared to the landed houses for the main states of Malaysia. As can be seen, the apartment buildings represent up to 77% of the housing stock in Kuala Lumpur and Putrajaya and around half of the housing stock in Penang and Selangor [12]. Furthermore, the housing types are not evenly distributed and, therefore, some areas might get housing of the apartment type higher compared to the landed type. For instance, in Timur laut district (i.e., Northeast district) of Penang Island, the apartment buildings account for 85% of the housing stock compared to 15% for the landed houses [12].

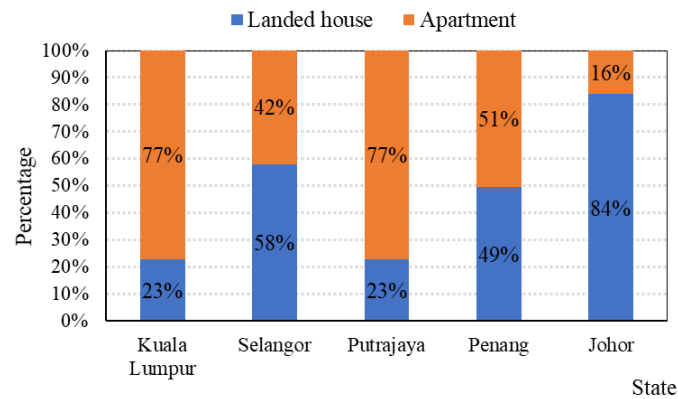


Fig. 2. Percentage of the apartment buildings compared to the landed houses as of 2019, Malaysia [12]

In high-rise apartment buildings, the majority of the indoor spaces are separated from the outdoor environment by the external walls, except for the spaces on the last floor. Therefore, the external walls become the main source for the external heat gain, which is being assessed in the GBI by the OTTV. The OTTV is a tool designed to measure the thermal efficiency of the envelope in air-conditioned buildings. It is defined as the average cooling load gained in a building due to the choice of its envelope (excluding the roof) based on the outside conditions (weather) and a typical inside condition in an office building [13]. The OTTV provides a simple method to estimate the total heat gain in buildings due to the heat conduction through its opaque walls and fenestration and due to the solar radiation penetration through its fenestration [13].

Various researchers and authorities have implemented many improvements to the OTTV calculation method. For instance, the OTTV calculation method was evaluated and revised to derive a set of correction factors to calculate OTTV for green roof integrated buildings and air-conditioned commercial buildings with naturally ventilated double-skin façade [14,15]. In Singapore, the OTTV calculation method was reviewed in early 2000 and was developed to Envelope Thermal Transfer Value (ETTV) and Roof Thermal Transfer Value (RTTV). Additionally, a new formula was formulated for the residential buildings to evaluate their envelope's thermal performance since they have different air-conditioning usage patterns. This formula was named Residential Envelope Transmittance Value (RETV) [16]. Tummur *et al.*, [17] formulated an OTTV to measure the performance of the building's envelope that enclosed bedroom space in Thailand. In Malaysia, the MS 1525, Energy efficiency and use of renewable energy for non-residential buildings - Code of practice, provides the method for the OTTV calculation in air-conditioned buildings. The standard indicates that the OTTV method is considered a useful tool to evaluate the thermal performance of non-air-conditioned buildings [18].

Due to the tropical climate in Malaysia, there is a high need for air-conditioning to improve the indoor thermal environment, which increases the energy consumption in buildings. To raise awareness and enhance sustainable development, it is a mandatory requirement that the OTTV should not exceed 50 W/m^2 for buildings with a total air-conditioned area of more than 1000m^2 [18,19]. However, a building with an OTTV of 50 W/m^2 can only score one point in the GBI assessment, while its score can be increased with lower OTTV values and can reach up to 10 points with OTTV of 30 W/m^2 or below [6].

Different researchers have studied the OTTV of various types of buildings. Saidur *et al.*, [19] conducted a study of the OTTV for 100 residential buildings in Malaysia. A survey was distributed firstly to collect the data required for OTTV calculation and to investigate the energy consumption of room air-conditioners. They found that the OTTV values ranged between 35 W/m^2 and 65 W/m^2 , and

was below 49 W/m^2 in 90% of the buildings. The low OTTV was attributed to the low window to wall ratio (WWR) of the residential buildings, i.e., 1 – 18 %. Ismail and Zainonabidin [20] utilized the OTTV tool to conducted an assessment for the envelope retrofitting of a 38-storey high-rise office building to improve its energy efficiency. Three variables were considered for the envelope retrofitting, namely U-Value, Shading Coefficient (SC), and WWR. This assessment showed that OTTV can be decreased from the original value of 77.43 W/m^2 to 28.43 W/m^2 .

In this study, the OTTV method was used to evaluate the envelope thermal performance for high-rise apartment buildings in Penang, Malaysia. The evaluation involved an assessment of the various methods of heat gain through the building's envelope, namely heat conduction through opaque walls, heat conduction through fenestration system, and solar radiation penetration through the fenestration system.

2. Methods

2.1 Case Study Buildings

Penang, which is the third most developed state in Malaysia, was selected as the area of the present study. It is located on the northwest coast of Peninsular Malaysia. It has two parts, namely Penang Island, where the capital city of George Town is located, and Seberang Perai (formerly Province Wellesley) on the Malay Peninsula. Penang Island has witnessed rapid economic developments over the last two decades. The studied buildings were selected on the eastern coastal line of Penang Island, which has witnessed huge and rapid developments with many residential construction and recreation projects. An investigation and observation were carried out by the researcher to select buildings with west or close to west facade orientation, which is considered as a critical orientation that receives high solar radiation. Furthermore, the studied buildings were selected from different architecture styles as follows

- i. Modern architectural style: Halaman Kristal 5.
- ii. Post-modern architectural style: Halaman Kristal 1 and Mutiara Idaman 2.
- iii. Neo-minimalist architectural style: Baystar and the Light Linear.

Halaman Kristal 5:

Halaman Kristal 5, Figure 3, is a twenty-one-floor apartment building. The first four floors are used for car park, while the fifth floor is occupied by the management and some facilities. Each floor, starting from the 6th floor, has fifteen residential units, which make a total number of 240 units. The building's architectural style is a simple design of straight lines, simple geometrics, and a flat roof. Common building materials were used in construction, such as brick walls and single clear glass for the fenestrations.



Fig. 3. Halaman Kristal 5, (a) external view and (b) the west façade of the selected apartment

Halaman Kristal 1:

Halaman Kristal 1 condominium, Figure 4 is a thirty-one-storey high-rise building. The first three storeys are allocated for the car parks, while the fourth storey is allocated for the management and facilities such as a swimming pool, a gym, a sauna, and a playground. The other twenty-seven storeys have a total of 360 units with 14 units per floor except for the last two floors, which consist of 12 and 10 units, respectively. The building represents the post-modern architectural style with the pitched roof and complex geometric form for the design. The designer used simplified colonial elements, like cornice, coping and pediment in the facade, which are usually used in the post-modern style with arches and triangular ends. The building materials include cement brick and cement plaster for the walls and aluminium frames with tinted single glazing for the fenestrations.

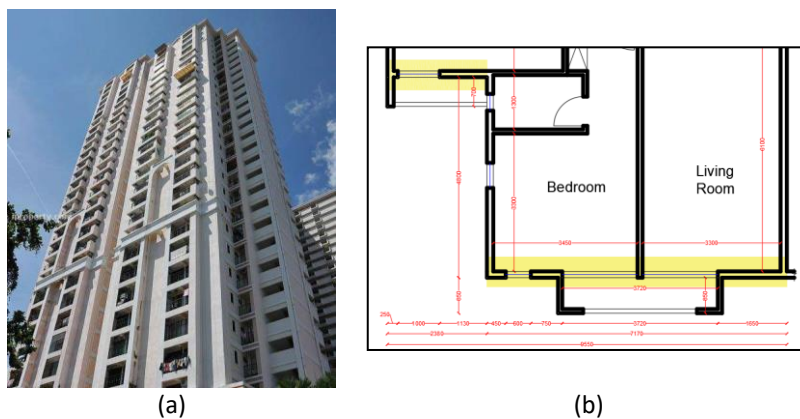


Fig. 4. Halaman Kristal 1, (a) external view and (b) the west façade of the selected apartment

Mutiara Idaman 2:

Mutiara Idaman 2, Figure 5, is a twenty-one storeys high-rise building, which has 690 units divided into four blocks. The building implemented the maximum elements of the post-modern architectural style characteristics such as complicated shapes, triangular ends for the facades, and the pitched roof. Local materials were used in the building include cement bricks and plaster for the façade and clear single glazing for the fenestrations. The building's façade was painted with two colours; dark red colour for the lower floors and light beige colour for the upper floors.

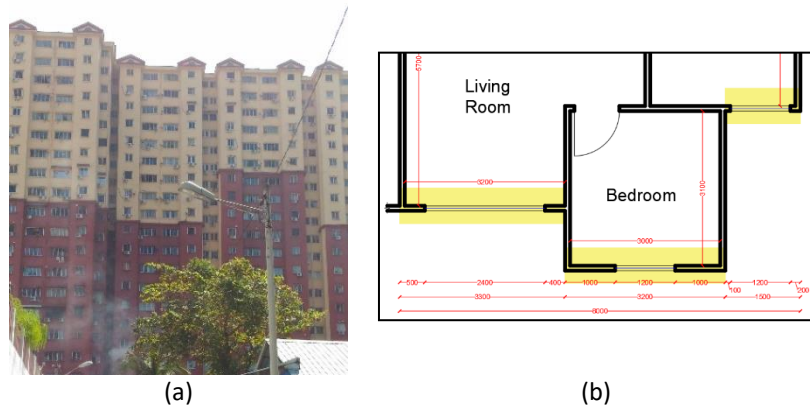


Fig. 5. Mutiara Idaman 2, (a) external view and (b) the west façade of the selected apartment

Baystar:

Baystar, Figure 6, is considered as a high-end residential building, which has 160 units divided into two blocks of eleven storeys. This building implemented the neo-minimalist style, which employs straight lines, simple shapes and a flat roof. Reinforced concrete and cement plaster were used as the building material with green-tinted single glazing for fenestration. The building façade was painted mainly with the white colour, while some areas have light grey paint.



Fig. 6. Baystar, (a) external view and (b) the west façade of the selected apartment

The Light Linear:

The Light Linear, Figure 7, is a two-block building with 17 floors and a total number of 328 units. The units were built in an area ranging between 1475 to 1560 square feet. This building was constructed for high-income families with a luxurious design. The neo-minimalist architectural style characteristics are represented in the Light Linear building such as the simplest and fewest possible lines in the facade and the flat roof. Reinforced concrete and cement plaster with white paint were used as building and finishing materials with aluminium frames and green-tinted single glass for fenestration.

Since the studied buildings are residential buildings and each apartment is isolated from the other apartments in terms of its indoor thermal environment and energy consumption, the OTTV calculation is carried out for the west-oriented façade of one corner apartment in each building.



Fig. 7. The Light Linear, (a) external view and (b) the west façade of the selected apartment

3. OTTV Calculation

The OTTV value represents the average heat that might transfer through the building’s envelope into the indoor environment. Building’s envelope consists of two main parts, namely opaque walls and fenestration systems. The later can be a glazing material, a shading device, and a combination of both. Therefore, the OTTV value combined three types of heat transmission, namely heat conduction through opaque walls, heat conduction through fenestration system, and solar radiation through fenestration system [18,21]. To calculate the OTTV, each of these components is calculated separately firstly and, then, they are added together to produce the overall OTTV. Table 1 presents the calculation of each type of heat transmission, while Eq. (1) shows the overall OTTV calculation.

Table 1

Main methods of heat transmission through building envelop and their calculations for OTTV

Heat transmission type	OTTV Calculation
Heat conduction through opaque walls	$15\alpha (1 - WWR) U_w$
Heat conduction through fenestration system	$6 (WWR) U_f$
Solar radiation penetration through fenestration system	$194 \times OF \times WWR \times SC$

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

where WWR is the ratio of the windows’ area to the gross exterior wall area for the orientation under consideration, α is the solar absorptivity of the opaque wall, U_w is the thermal transmittance of the opaque wall ($W/m^2 K$), U_f is the thermal transmittance of fenestration system ($W/m^2 K$), OF is the solar correction factor for the orientation of the fenestration under consideration, and SC is the shading coefficient of the fenestration system. Since each wall with a different orientation receives different solar radiation, the OTTV calculation should be conducted for each orientation separately. This is achieved by selecting the required OF value for the orientation under consideration from Table 2 [18]. Finally, the total OTTV for the building, i.e., including all orientations, can be calculated based on Eq. (2).

Table 2

Main methods of heat transmission through building envelop and their calculations for OTTV

Orientation	OF	Orientation	OF
North	0.90	South	0.92
Northeast	1.09	Southeast	0.90
East	1.23	West	0.94
Southeast	1.13	Northwest	0.90

$$OTTV = \frac{(A_1 \times OTTV_1) + (A_2 \times OTTV_2) + (A_3 \times OTTV_3) + \dots + (A_i \times OTTV_i)}{A_1 + A_2 + A_3 + \dots + A_i} \quad (2)$$

where A_1 is the gross exterior wall area for orientation 1 and $OTTV_1$ is the OTTV value for orientation 1, which is obtained from Eq. (1). To calculate the OTTV value for the selected case studies, the solar absorptivity (α) for the white, light grey/beige, and dark red were taken as 0.25, 0.40, and 0.88, respectively [22]. The U_w for the walls was calculated based on the wall's materials and according to Building and Construction Authority Hong Kong [16], Table 3. Furthermore, The SC for the fenestration system is the product of the SC1 for the glazing multiplied by the SC2 for the shading. The U_f and SC1 for the glazing type were obtained from Table 4, while the SC2 was obtained from MS 1525 [18,23].

Table 3

Calculated U_w based on the walls' materials

Wall	U_w
0.1 m cement brick wall with 0.013 m cement plaster on both sides	2.97
0.15 m concrete wall with 0.013 m cement plaster on both sides	3.16

Table 4

Calculated U_w based on the walls' materials [23]

Glazing type	Thick	U-value	SC
Single clear float	4	5.88	0.98
Single Tented grey float	5	5.85	0.71

4. Results and Discussion

The building's façade is a combination of opaque walls and fenestrations. Since the fenestration has more influence on the internal environment (i.e., heat conduction and solar radiation), the WWR might have a great influence on the calculated OTTV. Figure 8 presents the WWR for the west-oriented façade of the case study buildings. The highest and lowest WWR were obtained with Halaman kristal 5 and Halaman kristal 1, respectively, (i.e., 33% and 18%), while the other three buildings have quite similar WWR, i.e., between 25 to 27%.

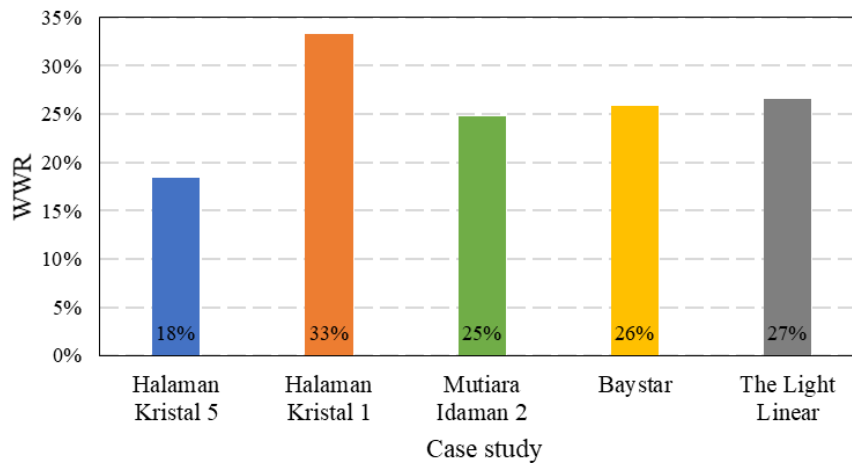


Fig. 8. WWR for the case study buildings

The OTTV value was calculated for each case study building. For the Halaman Kristal 5, all fenestration in the building were originally without shading devices. However, many of the owners have installed horizontal shading devices. Therefore, the OTTV was calculated for two cases, namely Case 1: without shading devices (No-Sh), and Case 2: with shading devices (W-Sh). Furthermore, Mutiara Idaman 2 has two different paint colours for its façade and, therefore, the OTTV was calculated for two cases, namely Case 1: using light paint (L-Paint), and Case 2: using dark paint (D-Paint). The results are illustrated in Figure 9.

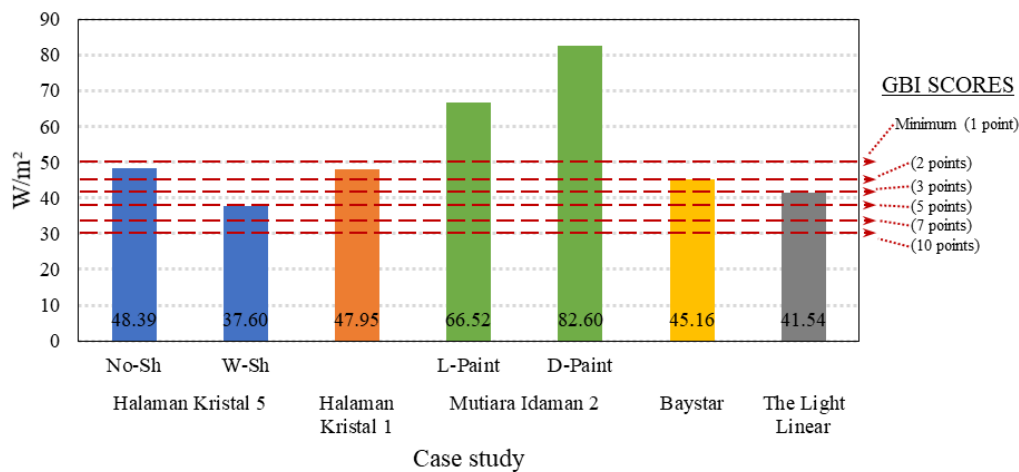


Fig. 9. OTTV for the case study buildings

From the five evaluated buildings, four buildings, namely Halaman Kristal 5, Halaman Kristal 1, Baystar, and The Light Linear, achieved the minimum requirements for the OTTV that was set by the GBI (i.e., 50 W/m^2) [6]. However, The Mutiara Idaman 2 achieved higher OTTV values at 66.52 W/m^2 and 82.60 W/m^2 for the L-Paint and D-paint, respectively. Furthermore, the figure shows that the installation of the shading devices by the owners for the case of Halaman Kristal 5 has improved the thermal performance of the façade and decreased the OTTV value by 10.80 W/m^2 . On the other hand, using dark paint, in the case of Mutiara Idaman 2, caused the OTTV value to increase by 16.07 W/m^2 . According to the GBI, the points are given according to the OTTV value and, therefore, Halaman Kristal 5 (W-Sh) will receive five points, followed by three points for The Light Linear, two points for Baystar, and one point for each of Halaman Kristal 5 (No-Sh) and Halaman Kristal 1.

For further evaluation, the OTTV value for each building was break-down into its components (i.e., heat conduction through opaque walls, heat conduction through fenestration system, and solar radiation through fenestration system). The results are illustrated in Figure 10. The figure clearly shows that penetration of the solar radiation through the buildings' fenestration is the major contributor to the total OTTV, i.e., account for 52% to 68%. The highest value was recorded with Mutiara Idaman 2 followed by Halaman Kristal 5 (No-Sh), which can be attributed to the absence of shading devices and the use of clear glass. However, when horizontal shading devices were installed by the owners of the Halaman Kristal 5, the building achieved the lowest solar radiation penetration through fenestration. Additionally, although Halaman kristal 1 has the highest WWR, it has lower solar radiation penetration through fenestration, which can be attributed to its shading system and the use of tinted glazing.

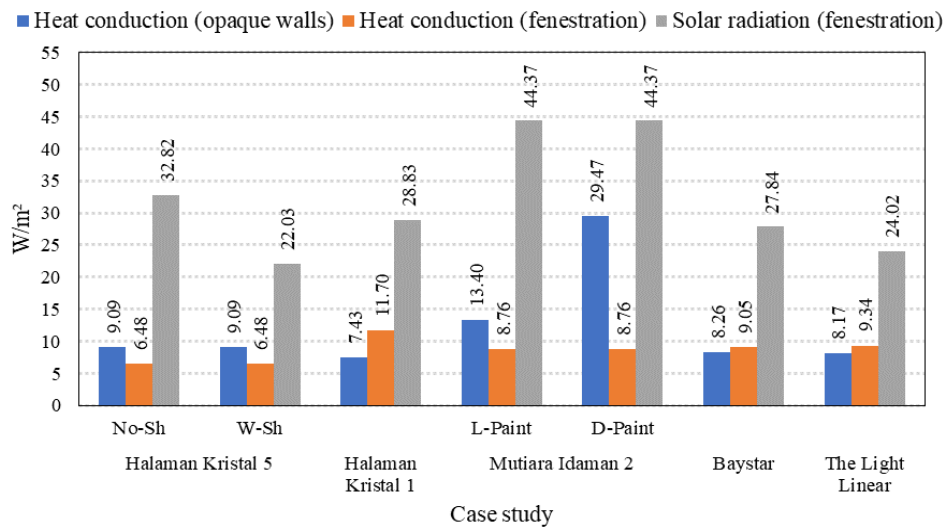


Fig. 10. Break down of the OTTV value for each building to its components (i.e., heat conduction through opaque walls, heat conduction through fenestration system, and solar radiation through fenestration system)

Furthermore, it is observed that Mutiara Idaman 2 followed by Halaman Kristal 5 have higher heat conduction through the opaque walls compared to the fenestration, while Halaman Kristal 1 has higher heat conduction through the fenestration compared to the opaque walls. The higher WWR for the Halaman Kristal 1 increases the heat conduction through the fenestration. However, the lower WWR of Halaman Kristal 5 decreases the heat conduction through the fenestration, while the higher solar absorptance of Mutiara Idaman 2 increases the heat conduction through the opaque walls. Moreover, the figure shows clearly that using the dark paint, in the case of the Mutiara Idaman 2, influenced only the heat conduction through the opaque wall, while installation of the shading devices, in the case of Halaman Kristal 5, influenced only the solar radiation penetration through the fenestration.

5. Conclusion

This study assessed the envelope thermal performance of high-rise apartment buildings in Penang, Malaysia. The assessment was performed using the OTTV method, which is being utilized by the Green Building Index rating system to assess the building's energy efficiency and the energy security target in Malaysia [24]. The assessment also explored the effects of the different methods of heat gain through the building envelope, namely heat conduction through opaque walls, heat

conduction through the fenestration system, and solar radiation penetration through the fenestration system. The following points can be concluded

- i. The WWR for the studied buildings ranged between 18% and 33%, which is quite high for residential buildings.
- ii. The OTTV for the studied buildings ranged between 37.60 W/m² and 82.60 W/m². Four out of the five studied buildings met the minimum requirement for the OTTV.
- iii. Solar radiation penetration through building fenestration was the major contributor to the total OTTV. Therefore, using shading devices and solar control glazing can reduce this type of heat gain.
- iv. Higher WWR can increase heat conduction through buildings' fenestration.
- v. Using dark colour paints for the opaque walls, i.e., high solar absorptance, can double the heat conduction through the opaque walls compared to using light colour paints.

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