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Analysis of Hotel Façade Thermal Performance with a Special Reference to the City Hotels in George Town, Penang

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ABSTRACT

The present study identifies issues pertaining energy efficiency of high-rise city hotels in Malaysia and aims to examine the thermal performance of high-rise hotels with different façade design configurations. Large hotels in the tropics of Malaysia are found to be energy intensive among commercial building categories. The present study proposes two case studies of high-rise city hotels in George Town, Penang, with different façade configurations to determine their capability to comply the Overall Thermal Transfer Value (OTTV) requirements set by the Malaysian Standards MS 1525;14 and the Green Building Index (GBI). Utilizing the OTTV formula as stipulated in the MS 1525:14, the OTTV of each case study was manually calculated using the identified façade design parameters. Comparative analysis of the results indicate that each of the cases garnered OTTV which exceeded the recommended value of 50 Wm^{-2}. General guidelines and recommendations for improvement in the hotel façade design in the tropics are also included in the discussion.

1. Introduction

The rising awareness to achieve energy efficiency, especially pertaining to the commercial building sector, has emerged as one of the most multifaceted scopes of focus in the scholarly studies concerning the sustainable built environment globally. The building sector is among the major contributors to greenhouse gas emissions, with buildings consuming about 30% of the world's resources and around 40% of the world's energy [3]. The hotel industry has undergone a major competitive and technological transformation in recent decades. Hotels play a prominent role in Malaysian tourism, and the hospitality industry growth has continued magnificently in recent years.

In large hotels in the tropics, electricity is invariably recorded as the energy source with the highest consumption, and the average energy use intensity for hotels in the tropics is significantly higher than the ones in the temperate [10]. Hotel air-conditioning is variously estimated to account

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for 38.5% of the total building energy consumption [18], and 50 to 60 % of the overall power consumption in the air conditioning system is due to chillers [8]. The guestroom zone occupies the largest portion of a large hotel accommodating 65 to 85 percent of the total building volume. Accordingly, the hotel guestroom accounts for the most intensive annual energy consumption among the hotel building zones [19]. The annual electricity consumption of a hotel guestroom for hotels in the tropics can range between 11.43 MWh/room and 61.66 MWh/room [20]. On average, the daily energy use per guest in a hotel room ranges between 54.5 kWh and 61.9 kWh [21].

Additionally, while building performance measurement, including OTTV, has been made mandatory, most hotels have not undertaken the OTTV performance evaluation [8,22]. This is because most commercial hotels, regardless of category, have not been assessed and certified as green hotels by GBI [22,23]. Recent statistics published by the GBI revealed that out of 560 GBI-certified buildings nationwide, there was only 19 GBI-certified non-residential existing building and 291 under the new construction category circa September 2020 (GBI Projects Register, 2020). In fact, 2,264 hotels in Malaysia are registered under the Ministry of Tourism and Culture Malaysia (MOTAC) as star-rated hotels, amongst which only 20 are classified as green hotels [22]. This implies that most hotels across the country have not undertaken the OTTV energy efficiency assessment.

Having established these research problems, it has become the objective of the current study first to evaluate the thermal performance of the façade design of hotels based on the OTTV performance as stipulated in the Malaysian Standards 1525:14. The OTTV calculation is indicative of the energy used in air-conditioned hotel spaces thus, suggesting that the outcome of the study is critical in demonstrating the significance of the façade design configuration and its implication on the energy efficiency of buildings. Accordingly, a concise discussion on the ways to improve the design of hotel facades as a general guideline in response to the present needs for energy consumption mitigation strategies.

2. Literature Review

In examining the energy efficiency and thermal performance of hotel facades, it is noteworthy to include discussions on the concept of Green Hotel and Overall Thermal Transfer Value (OTTV).

2.1 Green Hotel Façade and Energy Efficiency

The significance of passive façade design for building energy efficiency is highlighted in the Malaysian Standards MS 1525:14 and Green Building Index (GBI). The Department of Standards Malaysia introduced the concept of Overall Thermal Transfer Value in the Uniform Building By-Law (UBBL) with clause 38A [2]. The premise of OTTV is to estimate the amount of the external heat gain in air-conditioned spaces (Lam, 2000) based on the solar thermal load transmitted through the façade of commercial buildings in Malaysia (MS1525, 2014). The MS 1525:14 regulates the total OTTV to be less than 50 Wm^{-2}, where the smaller the OTTV corresponds to the lesser energy demand for indoor cooling [24]. Apparently, studies related to OTTV in Malaysia are extensive concerning the commercial offices alongside residential apartments, and little is known about the OTTV performance of hotels [8]. Thermal Transfer Value (OTTV) calculation as a façade thermal performance index for air-conditioned commercial hotels in Malaysia. The OTTV estimation has been made mandatory as a Malaysian Standards, MS1525:14 code of practice for Malaysian buildings following the adoption into the UBBL with clause 38A [2]. Studies related to OTTV in Malaysia are extensive concerning the commercial offices alongside residential apartments, and little is known about the OTTV performance of hotels [8].

2.2 Overall Thermal Transfer Value (OTTV)

In 1987, Malaysia adopted the Overall Thermal Transfer Value (OTTV) as a thermal performance index for building façade of commercial building energy standards [6]. Since then, the OTTV formula had undergone several amendments to meet a standard of local construction practices and tropical climatic conditions of Malaysia. The concept is incorporated into the Malaysian Standards MS1525, allowing for buildings with air-conditioned spaces of more than 1000 m^2 to be regulate with OTTV of less than or equal to 50Wm^{-2} [14].

OTTV is a performance-based evaluation method [5], and its output relies on the thermal building environment [1]. In the performance-based evaluation method, the emphasis is given to quantifying the total building performance. The word 'Overall' in OTTV refers to all the components of heat gain combined together into a single quantity known as OTTV, namely conduction through the opaque wall (Q_{wc}), conduction through the transparent glass (Q_{gc}) and solar radiation through a glass (Q_{gsol}) [17]. In Malaysia, study by Abdul Nasir and Hassan [16] suggested that, the heat conduction through opaque wall should be regulated between 0.2 to 5% from the calculated OTTV while the heat conduction through transparent windows account for 10 to 20% of the component of OTTV. The highest component in OTTV which is the solar radiation through glazing constituted 70 to 85% of the recommended OTTV. The formula for OTTV for a single fenestration (OTTVi) of a defined orientation given in MS 1525: 14 as follows:

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

where;
$\text{conduction through the opaque wall} = 15\alpha(1 - WWR)U_w$ (2)
conduction through the opaque wall, $Q_{wc} = 6WWRU_f$ (3)
conduction through the transparent glass, $Q_{gc} = 194 \times OF \times WWR \times SC$ (4)

From the above equation, WWR is the window-to-wall ratio for the orientation, α is the solar absorptivity of the opaque wall. The U_w and U_f is the thermal transmittance of opaque wall and the thermal transmittance of fenestration system respectively [9]. The OF represents the solar orientation factor while SC is the shading coefficient of the fenestration system. The OTTV calculation becomes the voluntary standard which has now been incorporated into the uniform building bye-Law (UBBL) with clause 38A under the amendment 2012 which means it is now a mandatory injunction for the building industry [2].

3. Method
3.1 Case Study:

Figure 1 illustrates the façade of the Wembley A St. Giles hotel. Located off Jalan Magazine, centrally nestled in the city of George Town. The hotel is rated a 4-star comprising of 415 guestrooms inclusive of Suites and Executive Rooms. The opaque façade of the hotel incorporates simplistic plain smooth plastered wall of designed with simple and unornamented surface subtly interlaced with continuous tinted glazed windows which amplifies the hotels functional and extreme simplicity. The opaque wall is constructed with plastered lightweight concrete with white paint external finishes while the transparent façade is made of single glazed tinted window.

Fig. 1. The Wembley A St. Giles Hotel

Fig. 2. The Berjaya Hotel

The Berjaya hotel is 4-star hotel which is centrally located in the capital city of Georgetown Penang. The hotel as shown in Figure 2 which was constructed in 1997 had undergone last renovation in 2013. The façade of the hotel is constructed of single brick wall with external surface finishes is plastered with brown paint. The transparent façade comprises of single glazed clear windows without shading devices. The hotel comprises of five different categories of guestrooms including the standard, the superior, the junior suite, the family room and the deluxe connecting room. Among the 320 rooms and suites provided in the hotel, the standard room is the typical guestroom type. The hotel comprises the horizontal podium and the vertical tower block. The exterior composition features Modern high-rise architecture with simple geometric façade elements with square shaped windows and rectilinear unornamented wall. The exterior façade is an amalgamation of opaque wall constructed with plastered brick with rough finishes while the guestroom windows is made up of standardized single clear glass. Table 1 itemizes the physical and thermal characteristics of the opaque façade of the case studies. These properties will be used in the comparative analysis to understand the impact of OTTV parameters in the thermal performance of each of the selected cases.

Table 1
Physical and thermal properties of opaque facade of the selected case studies

	Berjaya hotel	The Wembly hotel
Wall thickness (cm)	13.8	17
Wall construction	Single brick wall	Autoclave lightweight concrete
External wall colour	Dark brown finish	White plaster brick wall
Solar Absroptivity (α)	0.85	0.25
Wall U-Value (W/m^2K)	2.87	0.97

3.2 Overall Thermal Transfer Value (OTTV) Calculation

The research methodology employs two techniques involving the mathematical calculation of the Overall Thermal Transfer Value (OTTV) and the simulation study involving the hourly space cooling load and cooling energy consumption. The calculation of OTTV is conducted manually based on the formula given in the Malaysian Standards 1525:14 where the amount of heat transfer mechanism is individually quantified and combined. Three basic thermal transfer mechanisms in OTTV concept include heat conduction through opaque wall, heat conduction through glazing and solar radiation through glazing. In performing the OTTV calculation on the west orientation the scope of the calculation is limited to the façade of a single guestroom typical to the selected case studies. The OTTV (west) calculation based on the single guestroom method of calculation is adapted from previous research most notably by Abdul Nasir and Hassan [16] and Tummu *et al.*, [25]. In order to perform the OTTV (west) for the scale of a guestroom the following conditions must be met whereby, the selected guestroom must have at least a windowed façade that is exposed to outdoor conditions particularly on the west orientation as recommended by Tummu *et al.*, [25]. The subsequent phase in the research method involves the identification of the numerical values of each of the OTTV parameters for each of the façade construction as shown in Figures 3 and 4. Since the calculation of OTTV only considers the façade on the West orientation, the Orientation Factor (OF) of the façade is controlled to 0.94. Table 2 summarizes the physical and thermal characteristics of the opaque façade of the case studies.

Table 2
Façade glazing properties of the selected hotels

	Berjaya	The Wembley
Window to wall ratio (WWR)	0.50	0.31
Window type	Single glazed clear	Single glazed tinted grey
Window U-value (W/m^2K)	5.70	6.14
Window Shading Coefficient (SC)	0.96	0.71
Shading device	-	-
Shading Coefficient SC of shading device	1	1

Heat Conduction through wall, Q_{wc}
$= 15\alpha\,(1\text{-WWR})U_w$
$= 15(0.85)(0.5)(2.87) = 18.3\ Wm^{-2}$
Heat Conduction through windows, Q_{gc}
$= 6WWRU_f$
$= 6(0.50)(5.70) = 17.1\ Wm^{-2}$
Solar Radiation Through Glazing, Q_{gsol}
$= 194 \times OF \times WWR \times SC$

$= 194(0.94)(0.50)(0.96) = 87.5\ Wm^{-2}$
$OTTV_{west} = Q_{wc} + Q_{gc} + Q_{gsol} = 122.9\ Wm^{-2}$

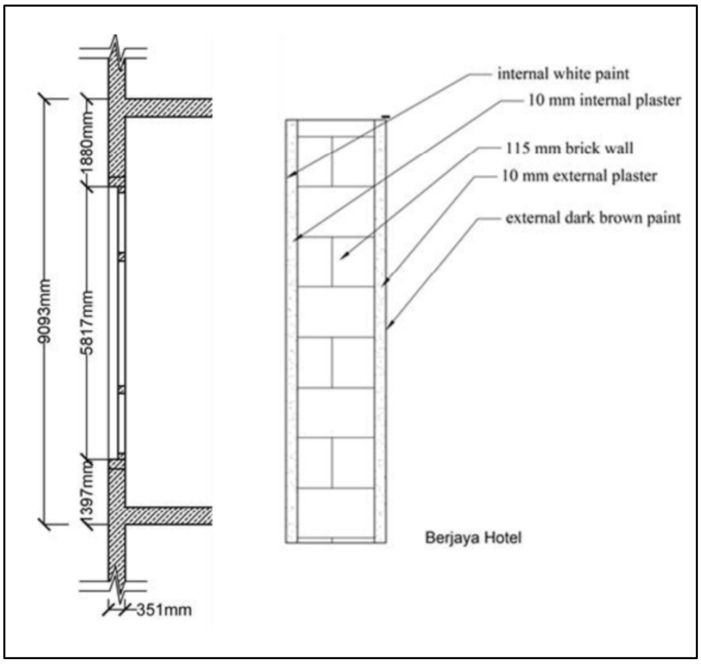

Fig. 3. Floor to ceiling of the Berjaya Hotel

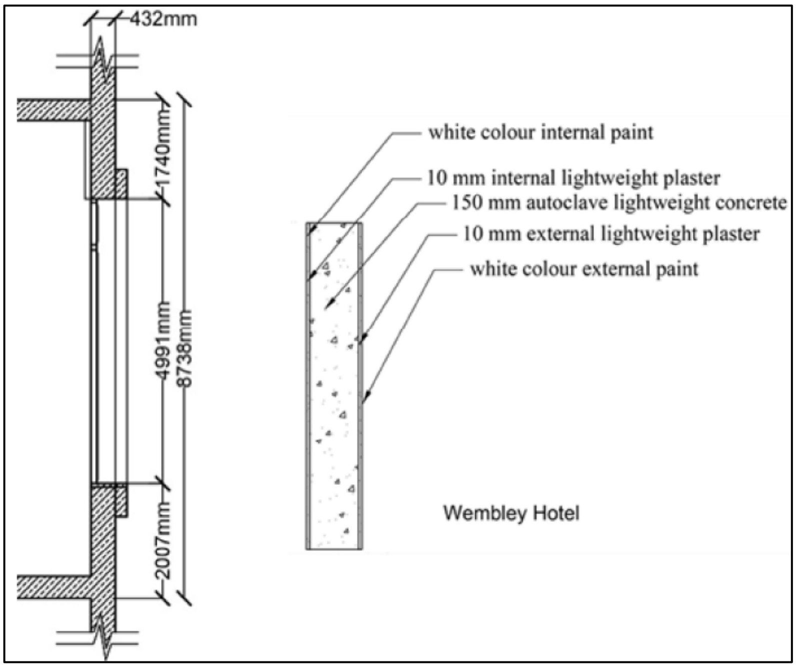

Fig. 4. Floor to ceiling of the Wembley Hotel

Heat Conduction through wall, Q_{wc}
$= 15\alpha\ (1\text{-}WWR)U_w$
$= 15(0.25)(0.69)(0.94) = 2.43\ Wm^{-2}$

Heat Conduction through windows, Q_{gc}
$= 6WWRU_f$
$= 6(0.31)(6.14) = 11.4\ Wm^{-2}$
Solar Radiation Through Glazing, Q_{gsol}
$= 194×OF×WWR×SC$
$= 194(0.94)(0.31)(0.71) = 40.1\ Wm^{-2}$
$OTTV_{west} = Q_{wc} + Q_{gc} + Q_{gsol} = 53.9\ Wm^{-2}$

4. Result and Discussion

The results of the OTTV calculation of each case studies will undergo comparative analysis to evaluate the performance based on the requirements of the Malaysian Standards 1525:14. Detailed examination on the amount of each component of heat transfer will be examined to evaluate each OTTV parameters on the components of heat transfer. Three components of heat transfer considered in OTTV calculation encompasses the heat conduction through walls Q_{wc} (Wm^{-2}), Heat conduction through transparent windows, Q_{gc} (Wm^{-2}) and Solar heat gain through transparent windows Q_{gsol} (Wm^{-2}). For the research, the results of the OTTV is based on the west orientation ($OTTV_{west}$) which will be compared to the OTTV requirements of the MS 1525:14. The standards regulates the average heat gain through the building envelope to be less than and equal to 50 Wm^{-2}. This means every square metre on the vertical façade regardless of orientation the maximum average heat gain is 50 Watt.

4.1 Results of Overall Thermal Transfer Value (OTTV)

Table 3 presents the results of the manual calculation of OTTV for the guest bedroom of selected case studies measuring each heat transfer mechanisms comprising of the heat conduction through opaque walls, heat conduction through transparent windows and solar heat gain through transparent windows. Overall, the Berjaya Hotel registers relatively high OTTV on the West orientation accounting for 122.9 Wm^{-2} which is considerably greater than double the mandatory requirement acquired by MS 1525:14 of 50 Wm^{-2}. While the calculated OTTV of Wembley hotel accounted for 53.90 Wm^{-2}.

Table 3
Façade window properties of the selected hotels

	MS1525	Berjaya hotel	The Wembley
Heat conduction through walls Qwc (Wm^{-2})	0.1 to 2.5	18.3	2.4
Heat conduction through transparent windows, Q_{gc} (Wm^{-2})	5 to 10	17.1	11.4
Solar heat gain through transparent windows Q_{gsol} (Wm^{-2})	35.0 to 42.5	87.5	40.1
$OTTV_{west}$ (Wm^{-2})	OTTV ≤ 50	122.9	53.9

In terms of the Heat Conduction through opaque walls, the recommended composition should represent 0.2 to 5% of the calculated OTTV [16,26] to fit the tropical climate of Malaysia. In order to achieve the maximum requirement of 50 Wm^{-2} the hotel façade should account for a value between 0.1 to 2.5 Wm^{-2} in heat conduction through opaque wall. In terms of the Heat Conduction through opaque walls, the Berjaya hotel registers 18.30 Wm^{-2} corresponding to 14.90% of OTTV. The Wembley hotel in contradiction, garnered only 2.40 Wm^{-2} accounting for 4.50% of the hotel's OTTV.

The recommended percentage of component of heat conduction through transparent windows is 10 to 20% of the OTTV. This is equivalent to 5 to 10 Wm^{-2} as expressed from the spectrum of maximum requirement of 50 Wm^{-2}. The Berjaya hotel registers the value with 17.10 Wm^{-2} in thermal conduction through windows an equivalent of 11.6% of the hotel's OTTV. The Wembley hotel represent the hotels with values closer to the recommended range with 11.4 Wm^{-2}.

Ultimately, the solar heat gain through windows which is the greatest contributor to the heat transfer through building facade in Malaysia should be regulated to be between 70 to 85% of the OTTV. To satisfy the maximum requirement of 50 Wm^{-2} the solar heat gain should be regulated between 35.0 to 42.5 Wm^{-2}. In essence, the Berjaya hotel records extremely high amount of solar heat gain with 87.50 Wm^{-2} and equivalent to 71.20% of the hotel's OTTV. The Wembley hotel yields 40.1 Wm^{-2} or 74.4% of the hotel's OTTV.

4.2 Recommendations for Energy Efficient Hotel Façade

Based on the results indicated in Table 3 it can be deduced that demonstrably failed to meet the requirement of OTTV less than 50 Wm^{-2}. However, the OTTV performance of the Wembley hotel can be considered as considerably better than the Berjaya hotel. This indicates the façade design of the Wembley hotel is more energy efficient for indoor air-conditioning than the Berjaya hotel. Close examination revealed that the Wembley hotel meets the requirement for Q_{wc} and Q_{sol}. In contradictory, the Berjaya hotel does not meet the requirements as stipulated in MS 1525:14 for all the heat transfer mechanisms. In comparison between the selected cases, the Wembley hotel meets the requirement for Q_{wc} and Q_{sol}. While the façade design of the Berjaya hotel does not meet the requirements as stipulated in MS 1525:14 for all the heat transfer mechanisms. It is worth noting that, one of the major factors that contributes to the high OTTV is due to absence of shading devices in the design of both of the hotel facades. The incorporation of shading devices can effectively reduce the solar heat gain on the façade up to 80% of OTTV [26]. The direct solar radiation impinges on the hotel facades contribute to large solar heat gain into the hotel guestroom, thus induce the reliance on air-conditioning and increases the cooling load.

In order to reduce Q_{wc}, it is worth examining the physical and thermal parameters that constitute to its magnitude. The profound parameters as identified previously include solar absorptivity (α), wall U-values (U_w) and the wall thickness. The Berjaya hotel embodies a relatively high thermal conduction due to the darker wall surface colour which affects the solar absorptivity, α. A façade with a darker surface colour absorbs heat generated by the solar energy more easily than the façade with a brighter surface colour which tends to reflect the solar heat gain. In fact, the lower thickness of the single brick wall of the Berjaya hotel provides less insulation allowing for the heat energy to be conducted more easily as compared to the higher wall thickness of the autoclave lightweight concrete wall of the Wembley hotel. This corresponds to the high U-value of the single brick wall of the Berjaya hotel as compared to lower U-value of the autoclave lightweight concrete of the Wembley hotel.

The higher WWR and SC in the case of the Berjaya hotel justifies the higher amount of Q_{gc} and Q_{gsol} as compared to the Wembley hotel. In terms of the design of the transparent glazing, the Berjaya hotel has a high WWR (50%) which allows for high amount of solar heat gain as compared to the Wembley hotel with a relatively lower WWR. In the tropics, the optimum WWR for the design of glazing on the West façade is 25% regardless of the glazing materials [27]. High WWR allows for greater solar radiation penetration into the transparent façade [28]. Another important factor in determining the solar heat gain performance of glazing is the SC. High SC corresponds to greater heat gain through the glazing as the shading performance is reduced with increasing SC. The Berjaya hotel is made up of low performance single glazed clear glass with high SC as compared to grey tinted single glass window of the Wembley hotel with slightly lower SC. Eventually, the value of SC of a glazing can be reduced by replacement with coated or tinted materials [28]. In the tropics, the optimum SC for controlling the solar heat gain is between 0. 25 and 0.75 [27].

5. Conclusion

The research identifies the issues in façade design of high-rise city hotels characterized by inefficient design of wall assembly and solar geometry in the hot and humid climate of George Town, Penang. Subsequently, a methodology to evaluate the façade thermal performance of high-rise hotels in the locality of hot and humid climate of George Town Penang is included in the present study using manual calculation of OTTV based on MS1525:14. The outcome of the study highlights the importance of facade design in safeguarding energy efficient hotel guestroom operations, underscoring the significance of passive facade elements in regulating the amount of solar heat gain which is the main contributor to space cooling load. Among the energy efficient façade design initiatives available the element of shading device is the most critical especially to protect the façade against direct solar radiation on the west orientation. As the design of hotels in the tropics commonly undermine the importance of shading devices for energy efficient hotel operations, the intensity of cooling energy use for large hotels continue to grow significantly every year as a result of façade's surface overheating. Previous studies have demonstrated that large hotels in the tropics consume relatively higher amount of energy annually as compared to similar hotels on the temperate climatic regions. High-rise city hotels constitute the highest portion among the varying types of temporary accommodation categories in Malaysia and only a small percentage have been certified as green hotels.

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