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# Comparative analysis of conventional and modern high-rise hotels in Penang based on hourly simulation of cooling load performance using DesignBuilder

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**ABSTRACT**

The study examines the energy efficiency performance of hotel façades in relation to the annual cooling load simulation. In achieving the objective, two case studies of high-rise city hotels are selected within the locality of Penang, Malaysia. The case studies are selected based on the year of construction coupled with the architectural styles encompassing conventional and modern design of hotel facades. In traditional hotel facades, passive design elements, including proper window and wall materials selection alongside window-to-wall ratio (WWR), are less significant. Comparatively, elements of passive design in modern hotel facades are notable. In assessing the thermal performance of the hotel façade, a case study of the conventional and modern high-rise city hotels in Penang are selected to undergo hourly cooling load simulation in the hotel guestroom using the DesignBuilder simulation program in establishing the hotel's energy efficiency performance. The findings revealed the average annual cooling energy of the conventional and modern high-rise city hotel guestrooms is 553 kWh/m$^2$ and 538 kWh/m$^2$, respectively. The study concludes the elements of passive design, including WWR, window material selection, and external wall colour are crucial in determining energy-efficient hotel operations.

## 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 [1]. Since the 1980s economic boost in Malaysia,

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the country witnessed a dramatic proliferation in non-residential building stocks, including large hotels alongside the dominant commercial buildings categories, most notably offices and retail. A study by Ali *et al.,* [2] revealed an institutional building in Malaysia is found to contribute to monthly energy consumption ranging from 160 MWh to 250 MWh, which corresponds to 18% air conditioning energy consumption, 18% lighting energy and 10% energy used on electrical appliances [2]. Annually, the tourism sector is expanding rapidly in the local and global economy, with an estimated annual worldwide growth of 3.3% anticipated in 2030 [3]. The direct implication witnessed the development in the local tourism sector, culminating in a massive growth of tourist accommodations and services in Malaysia with special reference to large quality hotels. Generally, hotels in Malaysia can be categorized into three main categories: city or business hotels, resort hotels and service apartments [4].Among these categories the city hotel accounted for the majority of hotel stock especially in large cities nationwide.

In tropical climates, the ongoing conditions of prolonged and intense amounts of solar radiation invariably cause overheating of the building's external surfaces [5]. The overheated external walls, in return, will radiate the absorbed heat into the interior spaces in the hot and humid climate of Malaysia [4,5], resorting to a staggering increase in demand for indoor cooling [2]. The energy use intensity for hotels in the tropics is significantly larger than those in the temperate regions [6], accounting for energy intensity between 280 and 700 kWh/m$^2$/year [6]. At the same time, studies found that hotels in developing countries accounted for higher annual energy consumption intensity than those in developed countries possessing similar climate conditions [7].

Building energy use is intimately touted to the immediate ambient climate, and previous studies have anticipated that the cooling energy demands in the hot and humid climate will increase significantly with the future trend in climate change. The building cooling load prediction invariably acquires weather data and the conduction transient heat transfer analysis for specific facade construction [8]. Collectively, while building performance regulation, including the Overall Thermal Transfer Value (OTTV) has been made mandatory nationwide, most large hotels still need to undertake the OTTV performance evaluation [9]. It is apparent that a majority of large commercial hotels, regardless of categories, have not been properly assessed based on energy efficiency and certified as green hotels by the GBI [9]. 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 [9]. Clearly, a majority of local hotels have not undertaken the façade OTTV performance calculation. In consequence, the performance of hotel façades concerning energy efficiency is faintly established [8]. Therefore, it has become the premise of the study to firstly evaluate the thermal performance of the façade design of modern and conventional hotels based on the hourly space cooling load and the annual cooling energy consumption intensity of these hotel guestrooms and present a comparative analysis between the selected case studies to draw gain insights on the thermal performance of hotel façade design in the locality of George Town, Penang.

## 1. Literature Review

### *1.1 Space Cooling Load*

In hot and humid climates, air conditioning is the most paramount component of a hotel guestroom in providing ideal thermal comfort for the hotel occupants [10]. The main purpose of a cooling system is to maintain conditions that provide thermal comfort for the building occupants [11] and conditions required by the products and processes within the space [12]. During the air conditioning system operations in a hotel guestroom, the net rate of heat that must be removed from a space to keep the space at a comfortable level is called the cooling load [11]. Estimating the heat gain components is essential in calculating the cooling load to gauge the energy efficiency performance of building facades [13,14]. In principle, the cooling load of a space is a simple summation of all the heat generated internally and received from external sources for a space [15]. The concept of a design cooling load is quintessential to determining the HVAC system size, which presumably, under extreme conditions, will provide some specified condition within a thermal zone [16]. Space cooling load, a component of cooling coil load invariably known as the cooling load, is the rate at which heat must be removed from a conditioned space to maintain a constant temperature and acceptable relative humidity. Space cooling load represents the rate at which heat enters a conditioned space from an external source or is released from an internal source during a given time interval [28]. In the tropical climate of Malaysia, the cooling load design has to meet the requirements of the Malaysian Standards 1525:14 and MS 2680:17, particularly the ideal set point temperature for thermal comfort at 25℃ and the acceptable relative humidity of 50 % to 70 % (MS 1525, 2014) [18].

The space cooling load can generally be divided into two distinct categories comprising of internal and external cooling loads [19]. The internal cooling load includes all the latent heat gain components due to the convective sensible heat gains, infiltration sensible heat gain and sensible heat gains [20]. Typical indoor parameters for hotel guestrooms are invariably determined based on the stochastic method and details of indoor occupants' load [21]. According to [15] the typical value for the occupant load density of a hotel guestroom is with a typical occupancy density of 0.094 person/$m^2$. Conversely, the external cooling loads are loads that are formed due to heat gains in the conditioned space from external sources through the building envelope or building shell and the partition walls. The heat sources of external loads include the heat gain from the exterior walls, solar heat gain transmitted through the fenestrations, and conductive heat gain through the fenestrations [8].

### *1.2 Energy consumption of hotels*

According to the National Property Information Centre (NAPIC), hotels in Malaysia represent 2% of the total commercial buildings across the country [20]. In many tropical climate regions, hotels are among the most energy-intensive building categories [6,21]. Comparatively, the annual energy intensity of hotels is higher than the other building categories, recording an average energy intensity ranging from 450 to 700 kWh/m2 annually [22]. In Malaysia, the estimated average annual electricity used for a high-rise hotel building is 2400 MWh/year, and it is estimated that 882 of hotels in Malaysia fall within this category nationwide. Large hotels nationwide consume 2116800 Mwh of electricity annually [20], and more than 60% of the total electricity consumption is predominantly associated with indoor cooling. To date, the electricity consumption on air-conditioning for commercial buildings in Malaysia accounted for 60.1% [23] and the hotels air-conditioning is variously estimated to account for 38.5% of the total energy consumption [23]. In many cooling-dominated countries like Malaysia's tropical climate, air-conditioning is invariably declared the most dominant among the building's energy contributors.

## **2. Methodology**

The methodology begins with selecting case studies of conventional and modern designs of high-rise hotels selected within the locality of George Town, Penang. Then, the research methodology employs a simulation study involving the hourly space cooling load and annual cooling energy consumption using the software program DesignBuilder. A comparative analysis of façade energy efficiency performance will be undertaken to suggest a general guideline to designing high-rise hotels to ensure compliance to energy efficiency standards in Malaysia.

### *2.1 Selection of Case Studies*

The present study performs hourly cooling load simulation using DesignBuilder simulation program. Three case studies of high-rise hotel façades were selected to evaluate the thermal performance of the design elements on the façade. The case studies were selected within the locality of George Town, Penang as the city accounts for the highest distribution of hotels in Penang Island. These case studies include the Sunway Hotel and the Wembley A St Giles Hotel. The Sunway Hotel is built in 1994, comprising of 250 guestroom units, recreation facilities and meeting rooms. The Sunway Hotel represents the case study of conventional hotels in the present study.

On the other hand, the Wembley A St Giles Hotel adjacent to the Sunway Hotel represents the modern style hotel and was constructed fairly recently. The façade of the Wembley Hotel features the quality of contemporary architectural style befitting a modern 4-star hotel. The Wembley Hotel accommodates 415 guestrooms, inclusive of Suites and Executive Rooms. Figures 1 and 2 depict the floor-to-ceiling details of the hotel facades.

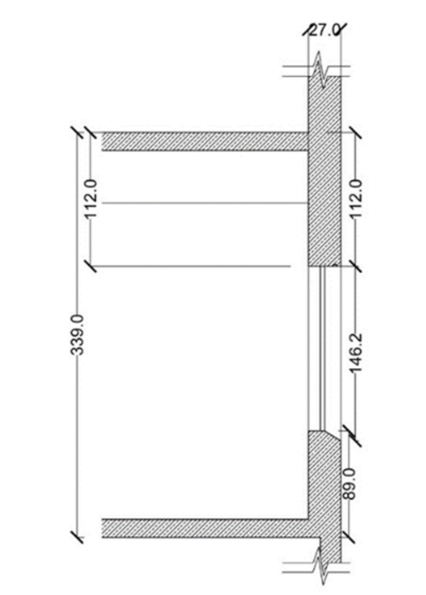


**Fig. 1.** Floor to ceiling of Sunway Hotel

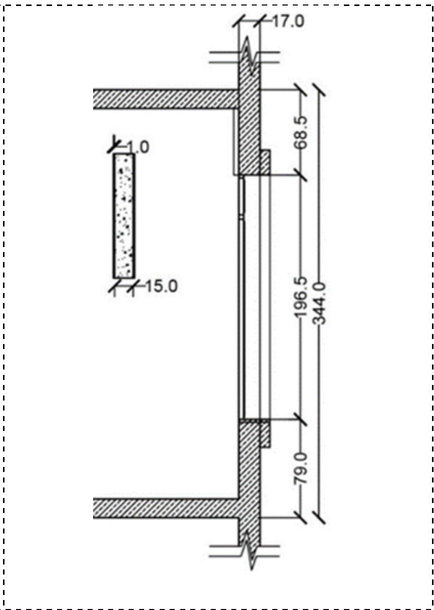


**Fig. 2.** Floor to ceiling of Wembley Hotel

Accordingly, based on the literature review, the façade parameters that affect the surface temperature measurement encompass the surface colour or solar absorptivity, wall constructional materials and thickness of the opaque wall. Table 1 summarizes the technical factors in consideration for each of the selected hotels. This is especially significant for comparative analysis between energy efficiency performances of the selected hotel facades.

**Table 1**
The physical characteristics of the guestroom façade of the case studies

| | Sunway Hotel | Wembley |
|---|---|---|
| Wall thickness (cm) | 24.0 | 17.0 |
| Wall construction | Full-Brick Wall Construction | Autoclaved Lightweight Concrete |
| External wall colour | Light brown finish | White plaster brick wall |
| Gross Window Area ($m^2$) | 627.8 | 296.3 |
| Window-to-wall ratio | 0.33 | 0.31 |
| Glazing type | Single glazed Tinted grey (dark grey) | Single glazed tinted |
| Shading device | - | - |
| Unit floor area ($m^2$) | 29.6 | 26.6 |

*2.3 Simulation of hourly cooling load*

The hotel guestroom is modelled in the DesignBuilder simulation program and these modelled guestrooms represent the typical rooms of each selected hotel. The DesignBuilder v6 offers several distinctive input options, each requiring different levels of details. Depending on the suitability and the scope of the study, the available skills, and the level of understanding of the subject, the DesignBuilder supports different levels of data input, ranging from simple to detail input simulation options, allowing more control and flexibility to the user. The study only focuses on the thermal performance of the façade on the west orientation of the hotels, and only the west façade is modelled in the simulation program [24]. The simple simulation option is selected in the model options as shown in Figure 3.

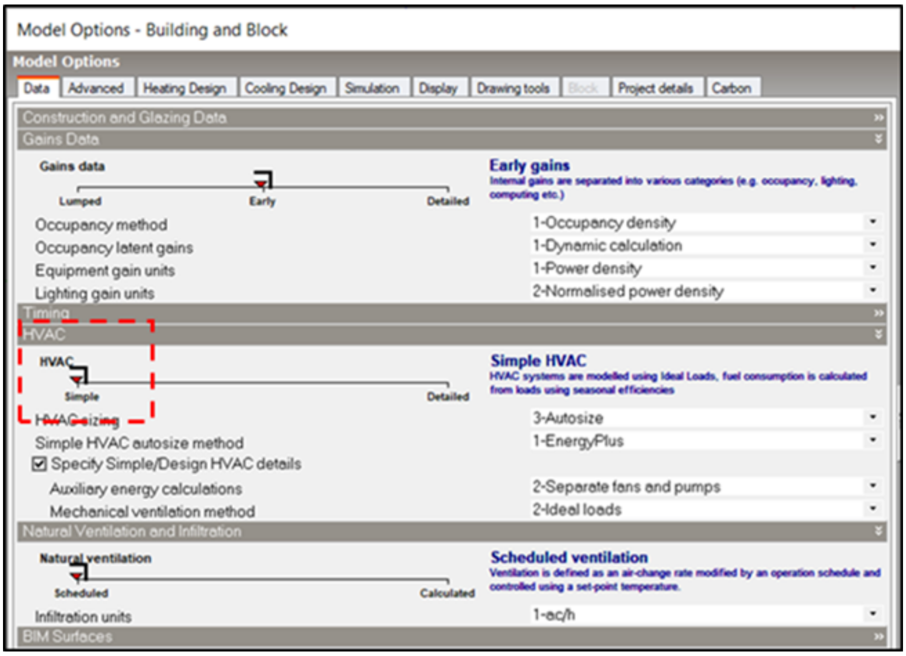

**Fig. 3.** Simple HVAC simulation selection in the model options

Each of the modelled guestrooms is assigned the 'en suite' in the activity tab to represent the activity of the hotel guestroom. In the activity template, the wide selection of building activity allows the users to manipulate the modelled indoor set-point temperature, external environment and parameters, including the room occupancy which can be referenced from the Malaysian Standards 1525:19 [25,27,28]. Table 2 summarizes the typical indoor design parameters for cooling load calculations in hotel guestrooms in Malaysia. Table 2 shows Typical indoor design parameters for cooling load calculations in the hotel guestroom.

**Table 2**
Typical indoor design parameters for hotel guestroom [4].

| Indoor design parameters | Value |
|---|---|
| Metabolic rate (W/person) | 104 |
| Room illuminance (lux) | 100 |
| Occupancy density (people/m$^2$) | 0.094 |
| General lighting loads (W/m$^2$) | 27 |
| Maximum lighting power density (W/m$^2$) | 5 |
| Recommended air movement (m/s) | 0.50 |
| Relative humidity (%) | 70 |
| Indoor setpoint temperature (°C) | 25 |

The program includes readily available and easily accessible updated hourly weather data of the Penang Island which is required in the simulation calculation of the space cooling load and the annual cooling energy consumption.

**Table 3**
Thermal properties of the opaque and transparent façades

| Case Studies | Type of wall | Wall U-value (W/m$^2$K) | Type of window | Window U-value (W/m$^2$K) |
|---|---|---|---|---|
| Sunway | Full-brick wall | 2.151 | Single glazed tinted grey (dark grey) | 6.31 |
| Wembley | Autoclave lightweight concrete | 1.013 | Single glazed tinted grey | 6.14 |

The simulation survey utilizes the Design Builder software which incorporates the EnergyPlus simulation engine to perform cooling load simulation based on the guestroom thermal zone. The simulation study defines the thermal zone as the typical hotel guestroom directly attached to the West orientation. The simulation procedure using thermal zoning provides estimations on the thermal load requirements that must be complied by an HVAC [26]. For the present study, the reference guestroom is created as depicted in Figure 4 for evaluating the cooling load to maintain occupants' thermal comfort for the worst scenario, which in the context of the study refers to the conditions that will cause the room to trigger the highest cooling load value.

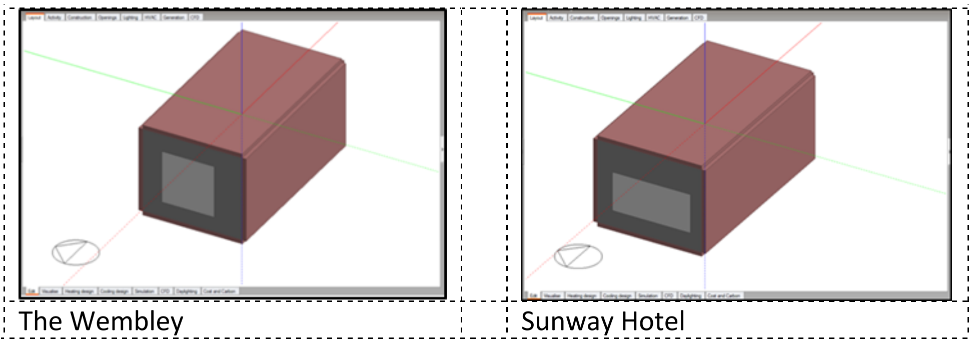


**Fig. 4.** Creation of 3D models of the typical guestroom

The outcome of the simulation will be compared to the recommended cooling load intensity as suggested by the MS 2680:17 to evaluate the level of compliance to the standards. Table 4 presents the cooling load intensity value for different room floor areas (m$^2$) as recommended in Malaysian Standards MS 2680:17.

**Table 4**
Typical indoor design parameters for hotel guestroom.

| Area to be cooled (m$^2$) | Cooling load (W) | Cooling load intensity (Wm$^{-2}$) |
|---|---|---|
| 17-24 | 2687 | 101.5-111.0 |
| 25-36 | 3956 | 101.5-111.0 |
| 33-48 | 5275 | 101.5-111.0 |
| 42-60 | 6594 | 101.5-111.0 |
| 60-72 | 7913 | 101.5-111.0 |

## 3. Results

### *3.1 Results of average hourly cooling load*

Figure 5 illustrates the total space cooling load taken on three days in January 2019. Overall trends depict a stable pattern in space cooling load where the acceleration in growth has been relatively small up to 1400 hour. Clearly the trend based on the monthly observation showcases marginal hourly load difference in from 1200 to 1400 before it continues to grow steadily before hitting a peak at 1800. Overall, the total average cooling of the Sunway Hotel implies higher hourly values than the the Wembley hotel accounting for a peak cooling load intensity of 97.6 Wm$^{-2}$ at 1800. As the MS 2680:17 regulates the maximum cooling load intensity of 111 Wm$^{-2}$, the hourly cooling load intensity for the three case studies are still in compliance to the requirement. The Wembley hotel accounted a lower cooling load intensity with 95.8 Wm$^{-2}$ as featured in the 1800 hour.

Accordingly, the average monthly total cooling for February 2019 is depicted in Figure 6 with overall trend for all cases on average exhibiting a significant rise in hourly total cooling for the month. Similar to the trend in previous month, the Sunway hotel records the highest values in hourly total cooling rising sharply from 1500 and culminating at 1800 with 105.0 Wm$^{-2}$. Comparatively, the peak cooling load for the Wembley hotel accounted for 103.2 Wm$^{-2}$ at 1800. This implies the hotels selected comply with the Standards MS2680:17. Dramatic surge in the hotels total cooling is identified from 1400 to 1500 with 7.7 Wm$^{-2}$ and 7.6 Wm$^{-2}$ for the Wembley and Sunway hotels respectively. At 1600 to 1800 hours, the hotels experience gradual reduction in hourly cooling load difference. In general, the rise in hourly cooling increment is greater in the case of the Wembley hotel than the Sunway hotel, with the highest increment of 8 Wm$^{-2}$ and 7.9 Wm$^{-2}$ respectively.

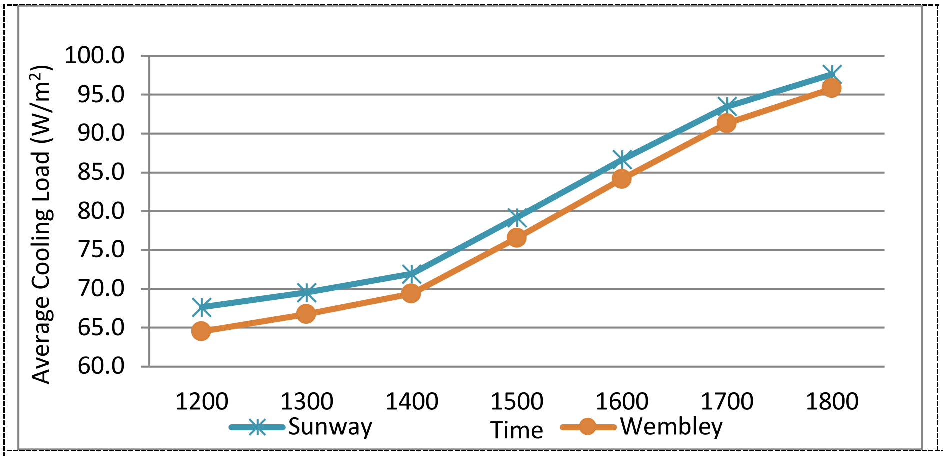


**Fig. 5.** Average Hourly Cooling Load January 2019

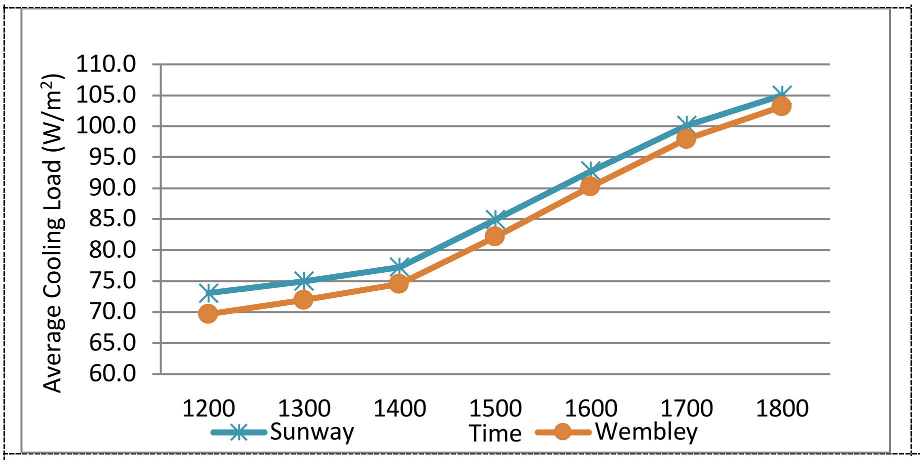


**Fig. 6.** Average Hourly Cooling Load February 2019

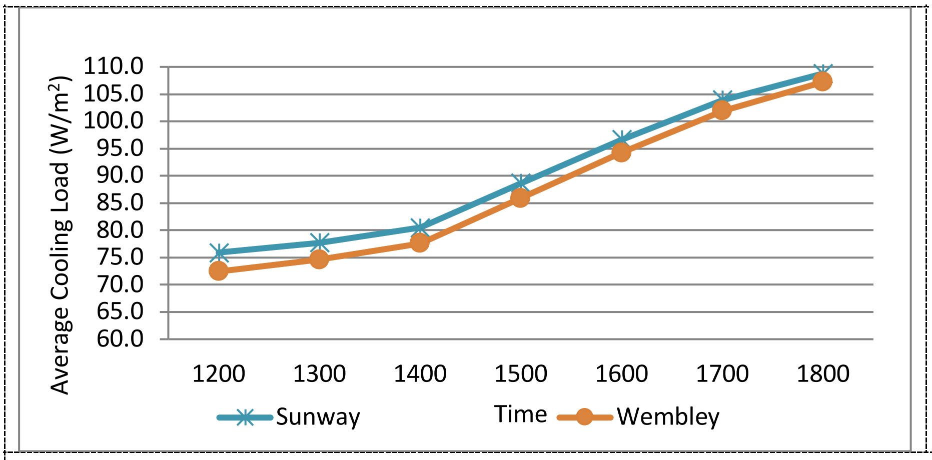


**Fig. 7.** Average Hourly Cooling Load March 2019

In March, the Sunway hotel remained the highest in the average hourly cooling with a peak of 108.8 $Wm^{-2}$ as depicted in Figure 7. Similar to the preceding months, a dramatic rise in the average cooling load can be observed from 1400 to 1800. The hotels experience none of the consecutive hours with an average cooling load exceeding 111 $Wm^{-2}$ in March, suggesting compliance to the standards MS 2680:17. The Sunway and the Wembley hotels have almost relatively similar figures in peak average hourly cooling load with 108.8 and 107.2 Wm$^{-2}$ respectively as registered in 1800 hour. Overall, the cooling load values of the Sunway hotel is higher than the Wembley and the values are higher than the cooling load values registered in February. However, the increase in hourly cooling load of the Wembley hotel is more significant than the Sunway hotel with the highest value registered of 8.3 Wm$^{-2}$ from 1400 to 1600 hours. In comparison, the Sunway hotel only registered the highest increment of 8.1 Wm$^{-2}$ from 1500 to 1600 hour. The increase in the cooling load values began to reduce steadily from 1600 to 1800 in both cases.

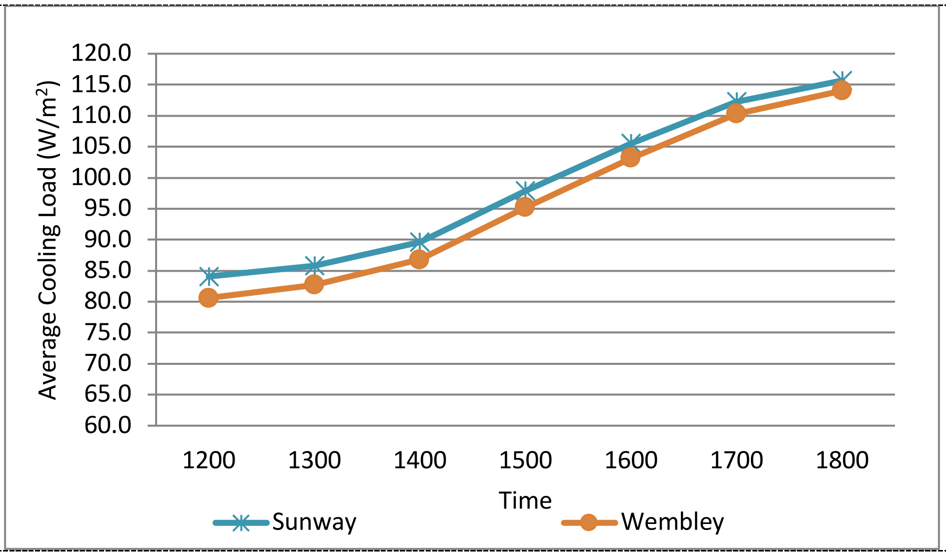


**Fig. 8.** Average Hourly Cooling Load April 2019

The trend in the average cooling load in April is illustrated in Figure 8 where the cases witness significantly higher increment than previous months with the Sunway hotel dominating the selected cases accounting for peak total cooling of 115.7 Wm$^{-2}$. It is worth noting that the hotel room undergoes two consecutive hours of total cooling exceeding the maximum recommended capacity for efficiency of 111 Wm$^{-2}$ as seen in the case of Sunway hotel from 1700 to 1800 hours. While the hourly cooling load values indicate a significant rise than previous months, the average maximum increment in the Wembley hotel shows a significant peak of 114 Wm$^{-2}$ registered at 1800. The figure shows half of the cases underwent abrupt surge in values from 1400 to 1500 with the Wembley hotel demonstrating the highest cooling load hourly increment of 8.4 Wm$^{-2}$ as compared to only 8.3 Wm$^{-2}$ in the case of Sunway hotel. The Wembley hotel experiences an hour of cooling load value exceeding the recommended maximum capacity at 1800 with 114.0 Wm$^{-2}$. Overall, it can be deduced that for April, the Wembley hotel features smaller values of average cooling load than the Sunway hotel. However, the changes in hourly increment in the case of Wembley Hotel is greater than the conventional style Sunway Hotel.

### *3.1 Results of Annual Cooling Load Intensity*

In order to estimate the cost of annual cooling energy consumption of the selected case studies, further simulation of annual cooling energy consumption is undertaken and as depicted in Table 5 demonstrates the annual cooling energy consumption costs measured in RM for each of the selected hotels. Table presents the annual cooling energy intensity of the Sunway and the Wembley hotels accounting for 553.65 kWh/m$^2$ and 538.55 kWh/m$^2$ respectively.

**Table 5**
Typical indoor design parameters for hotel guestroom.

| Case Study | Annual cooling energy intensity (kWh/m$^2$) |
|---|---|
| Sunway | 553.65 |
| Wembley | 538.55 |

### *3.3 Comparative analysis of hotel façade and cooling load performance*

In evaluating the performance of the average cooling load intensity of the selected hotels, it is worth examining the relationship between the hotel façade design and the magnitude of the cooling load. These determinants include the physical and thermophysical properties of the façade elements [3]. The parameters include the opaque and transparent facade materials, external surface colour, WWR and shading devices. The opaque wall construction of the hotel façades is responsible for the varying magnitudes of the cooling load performance. The prominent effect of the external wall colour on the cooling load performance is established with the hotels with darker colour feature high cooling load than those with a lighter colour. This is due to the increased solar absorptivity of the wall and among both of the hotels, the Sunway hotel with light brown wall finish executes a higher average cooling load as compared to the Wembley hotel. Apart from the surface color, the types of wall materials affect the surface temperatures through the amount of specific heat capacity or thermal mass properties. The thermal property of brick wall features higher thermal mass and specific heat capacity than lightweight concrete wall, thus, reinforcing the research findings.

Additionally, the outcomes demonstrate that the hotel façade with high average and peak cooling loads embodies a higher WWR. The Wembley hotel has a WWR of 0.31, which is smaller than the Sunway Hotel with WWR of 0.33. The WWR of a façade on the west orientation should be kept minimal to reduce the solar heat gain due to the absence of shading devices on the façade of both hotels. Lastly, the average cooling load and peak cooling for all the cases are affected by the thermophysical performance of window materials. The use of single glazed tinted dark grey window with U-value of 6.31 W/m$^2$K in the case of Sunway as compared to 6.14 W/m$^2$K in the case of the Wembley hotel contributes to higher amount of conduction heat gain through transparent fenestration in the case of the Wembley hotel.

## 4. Conclusions

Concurrently, research on the thermal performance of the external façade design with specific reference to high-rise city hotels and the effects on the cooling energy consumption and annual cooling cost estimation is at the nascent stage, acquiring serious profundity. In addressing the aforementioned issues related to the discourse, the research seeks to evaluate the performance of hotel facades which has been designed differently based on conventional and modern high-rise hotel typologies. In essence, the study's outcome suggests the following guidelines in response to improving the thermal performance of façade design for tropical high rise city hotels for energy and cost-efficient cooling energy consumption. The external surface of high-rise city hotels in tropical climate Malaysia should be designed with materials of low thermal absorptivity through light colour external finishes. The diurnal variation in the average cooling load of the selected cases with white finishing was more gradual than that of the model with slightly darker brown finishing. The external opaque façade should be constructed from autoclaved lightweight concrete wall, ideal for facades on the west orientation. Simultaneously, the WWR should be kept minimal to mitigate the amount of the incident solar radiation admitted through the transparent glazing, as hotel facades are designed without external shading devices. Future studies can be conducted to evaluate the space cooling load for different spaces in the hotel to determine the amount of cooling energy consumption for a hotel in the tropics. The space cooling load calculation can be improved by utilizing realistic occupancy data to reflect a more accurate evaluation on cooling energy consumption of hotel spaces.

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