ANALYSIS OF HOTEL FAÇADE AND COOLING ENERGY CONSUMPTION IN PENANG

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by

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ANALISIS FASAD HOTEL DAN PENGGUNAAN TENAGA PENYEJUKAN DI PULAU PINANG

ABSTRAK

Penyelidikan ini menyiasat prestasi termal fasad bangunan hotel bertingkat tinggi di kawasan panas dan lembap di George Town, Pulau Pinang. Penyelidikan ini telah mengenal pasti masalah reka bentuk fasad yang kurang efisien, sebagai penyumbang utama kepada penggunaan tenaga penyejukan penghawa dingin yang tinggi di hotel. Enam kajian kes hotel bandar bertingkat tinggi dipilih secara sistematik bagi mengukur prestasi termal fasad di bahagian barat. Tiga ukuran skala dicadangkan meliputi termografi inframerah bagi purata suhu permukaan, Nilai Keseluruhan Pemindahan Haba (OTTV) dan simulasi beban penyejukan ruang bilik tidur hotel bersama anggaran kos penggunaan tenaga. Hipotesis awal menjangkakan peningkatan purata suhu permukaan menyebabkan peningkatan nilai OTTV dan purata beban penyejukan. Hasil dapatan penyelidikan mendapati nilai purata suhu permukaan fasad bagi hotel yang terpilih merangkumi 33.3 ℃ hingga 35.9 ℃ dari bulan Januari hingga Jun 2019. Sementara itu, nilai OTTV untuk fasad di bahagian barat meliputi 38.6 Wm^{-2} ke 122.9 Wm^{-2}, dengan majoriti hotel tidak memenuhi purata wajaran pertambahan haba yang disyorkan oleh Malaysian Standards MS 1525 dengan nilai kurang daripada 50 Wm^{-2}. Manakala, nilai purata beban penyejukan bilik tetamu hotel terpilih mencatat angka antara 77.9 Wm^{-2} dan 131.2 Wm^{-2} bersamaan dengan kos penggunaan tenaga penyejukan tahunan antara RM 249/m^2 dan RM 357/m^2. Tambahan pula, kajian ini mendapati purata suhu permukaan menunjukkan perkaitan yang tidak signifikan dengan purata beban penyejukan sementara perkaitan linear yang kuat dapat dilihat antara OTTV dan purata beban penyejukan. Dapatan kajian bertentangan dengan hipotesis awal dan kesimpulan universal tidak dapat dicapai dalam kes fasad hotel bertingkat tinggi bagi iklim tropika di Pulau Pinang.

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ABSTRACT

The research investigates the thermal performance of building facade of high-rise hotels in the hot and humid climate of George Town, Penang. The research identifies the problem of inefficient facade design as main contributors to air conditioning high cooling energy consumption for hotels. In response, six case studies of high-rise hotels were systematically selected to measure the façade thermal performance on the west orientation. Three performance measurable scales proposed including the infrared thermography of average external surface temperature, the manual calculation of Overall Thermal Transfer Value (OTTV) and the guestroom space cooling load simulation alongside energy use cost estimation. Initial hypotheses predict the increase in average surface temperature corresponds to increase in OTTV and the average cooling load. The findings revealed the average surface temperature of the selected hotel facades ranging between 33.3 °C and 35.9 °C from January to June. While, the OTTV on the west facade ranges from 38.6 Wm^{-2} to 122.9 Wm^{-2} with a majority of the hotels have failed to meet the weighted average heat gain as recommended by Malaysian Standards MS1515 of less than 50 Wm^{-2}. While, the average guestroom cooling load of selected cases range between 77.9 Wm^{-2} and 131.2 Wm^{-2} equivalent to annual cooling energy consumption costs between RM 249/m^2 and RM 357/m^2. Additionally, the results of the research revealed the average surface temperature establishes an insignificant correlation with the average cooling load while a strong linear correlation is observed between OTTV and the average cooling load. The research findings contradict initial hypotheses and

a universal conclusion cannot be achieved in the case of high-rise hotel facade in the tropical climate of Penang.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter is an introductory chapter that intends to clarify the background of the study and discuss several related studies to identify the problem statement. Based on these discussions, the study determines the specific research problem. Accordingly, the research question, research objectives and initial hypothesis will be formulated. Finally, the chapter discloses the scope of the study, research framework, and the structure of the thesis organization.

1.2 Background of the Study

Sustainable architecture and green building design have become one of the most multifaceted areas of focus in the scholarly studies quintessentially touted to the built environment. The World Green Building Council noted that buildings are the single largest contributor to global warming accounting for one-third of global CO_2 emissions. In the 2015 Conference of Parties (COP21) which was held in France, Malaysia has expressed its commitment to mitigating temperature gains to below 2℃ by the end of the century and reduce greenhouse gas emission by 45% by 2030. Buildings are responsible for approximately 30 to 40% of total energy usage globally (Rahman & Rodzi, 2006) and recent statistics have anticipated the commercial sector electricity consumption in Malaysia tripling from 38.9 GWh in 2013 to 98.6 GWh in 2040 (Yong, Lesjak, Hor, Rowse & Tandon, 2017). In most developing countries including Malaysia, the commercial sector is accountable for the greatest fraction of total energy use. Since the 1980s economic boost in Malaysia, while a greater percentage of commercial buildings categories are made up of offices and retails, non-residential buildings such as hotels are dramatically growing in building stocks.

According to National Property Information Centre (NAPIC), hotels in Malaysia represent 2% of the total commercial buildings across the country (Yong et al., 2017). Although the hotel building categories represents a small percentage of the total building stock in Malaysia, recent decades have witnessed dramatic growth in the number of hotels nationwide. Statistically, the Gross Floor Area (GFA) of hotels in Malaysia has recorded a percentage increase of 37 % in a period just slightly over a decade amassing 2,259,096 sq.m. in 2002 to 3,100,000 sq.m in 2014 (Yong et al, 2017). In the period of 2016 to 2017, the hotel building stocks witnessed an increase in supply by 19 classified hotels to reach 4,980 hotels and 325,700 rooms nationwide (Kaliappen & Chee, 2018). Further, in May 2018 there is an additional 100 hotels recorded, with 25,589 classified rooms anticipated to be available for the period of 2018-2022 (Kaliappen & Chee, 2018; Chee, Bernhard & Teo, 2018). Figure 1.1 features the trend in hotel rooms supply for the period of 2015 to 2021 in Malaysia.

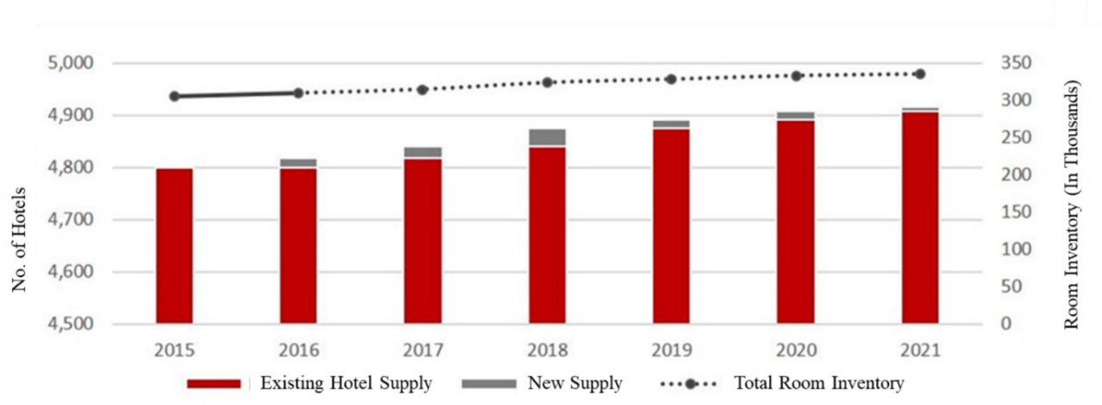

Figure 1. 1 The annual number of hotels and room inventory in Malaysia from 2015 to 2021

(Source : https://www.hvs.com/article/8008-in-focus-malaysia-a-rising-opportunity)

As a component of tourism industry, hotels play a prominent role in the Malaysia's economy and the hospitality growth continues magnificently undergoing a major competitive and technological transformation in recent decades (Mosbah & Saleh, 2014). Following the manufacturing sector, the tourism industry is one of the profound catalysts to the local economy accounting for at least about 8 to 10 percent of the annual GDP (Mosbah & Saleh, 2014). Tourism in essence garnered substantial revenues for governments (Salehudin, Prasad & Osmond, 2013) and the burgeoning growth of the Malaysian hospitality industry is evident in the proliferation new establishments including high-rise quality hotels in major cities Malaysia.

Overall, Sadom, Quoquab, Mohammad and Hussin (2020) reported that 643 hotel chains are operating in Malaysia with "three and above" in star ratings and 50% of the hotels in these categories nestled in the highly urbanized states across the country including Kuala Lumpur and Penang (Sadom et al., 2020). Large city hotels are dominant hotel category in major cities to accommodate the influx of tourist arrivals annually. The Penang Island being one of the most visited states in Malaysia has almost equally divided tourist arrivals between domestic and foreign as recorded in 2010 with just under six million hotel guests in difference (Ghaderi, Som & Henderson, 2012).

Despite the promising developments, the hotel industry is widely known one as among the most energy intensive sectors in the field of tourism and services. The energy consumption costs make up the largest constituent of the general operating costs of hotels. The main contributors of energy consumed by a large hotel in the tropics comprising of electricity from grid used to operate the air-conditioning, lighting, pumping, and vertical transport whilst gas and diesel for water heating (Priyadarsini Xuchao & Eang, 2009). In Malaysia, the estimated average annual electricity consumed for a high-rise hotel building is 2400 MWh/year with a majority of 882 hotels nationwide fall within this category (Yong et al., 2017). The value is equivalent to approximately double and half the amount of annual electricity consumed by purpose-built offices and shopping complexes as indicated in Figure 1.2.

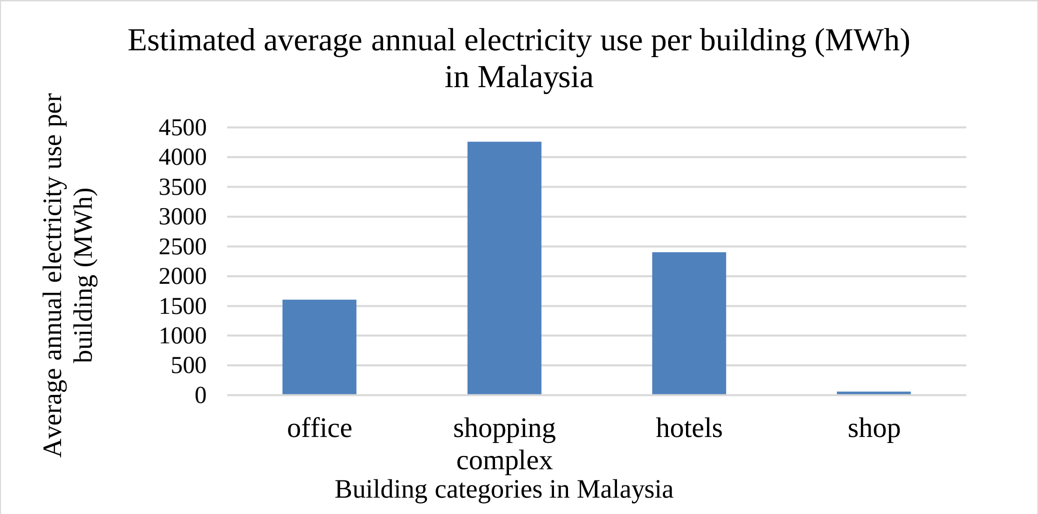

Figure 1. 2 Estimated average annual electricity use per building (MWh) in Malaysia.

(Source: Yong et al., 2017)

In the tropics, large city hotels are among the most energy intensive building categories (Ponniran, Mamat & Joret, 2012; Chirarattananon & Taweekun, 2003; Yamtraipat, Khedari, Hirunlabh & Kunchornrat, 2006; Kresteniti, 2017). Comparatively, the annual building energy intensity of hotel (BEI) is higher than most commercial buildings such as offices and retails ranging from 450 to 700 kWh/m^2/year (Casteleiro-Roca et al., 2019). The energy use intensity for hotels in the tropics are significantly larger than the hotels in the temperate regions (Dibene-

Arriola, Carrillo-González, Quijas & Rodríguez-Uribe, 2021). Large hotels in the tropics, accounts for energy intensity between 280 and 700 kWh/m^2/year (Priyadarsini et al., 2009; Wang, 2012; Dibene-Arriola et al., 2021). Figure 1.3 shows the comparative BEI of building categories in Malaysia and as shown the documented BEI of hotels are significantly larger as compared to the recommended energy intensity required to achieve a certified green hotel building with only 212 kWh/m^2/year (GBI, 2020).

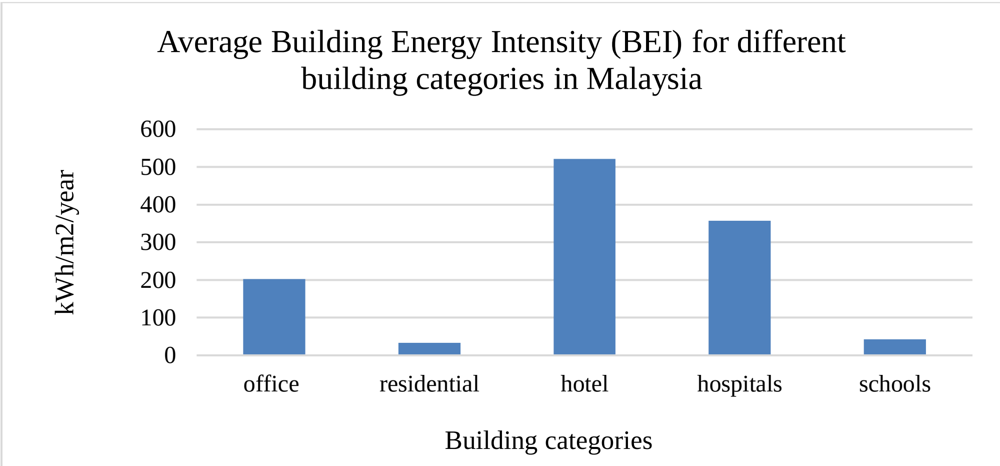

Figure 1. 3 Average building energy intensity (BEI) for building categories in Malaysia

(Lojuntin, 2014)

The energy consumption of hotels is intensive due to the unique nature of hotels which are generally embodying complex systems with individual modules, such as guestrooms, catering outlets, conference centres, combined into a greater whole (Bohdanowicz & Martinac, 2007; Lu, Wei, Zhang, Kong & Wu, 2013). In particular reference to the hotels, the physical and operational parameters are pivotal for the energy demand profiles and performance of a large hotel building (Bohdanowicz & Martinac, 2007). The physical parameters are common parameters including building dimensions, materials and design, climatic conditions, the energy systems installed (Bohdanowicz & Martinac, 2007; Lu et al., 2013). The operational parameters are predominantly associated with the resource use in hotels including different operating schedules for sub-facilities, services offered, fluctuations in room occupancy, customer preference and behaviour to indoor comfort (Bohdanowicz & Martinac, 2007).

In large hotels in the tropics, the 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 (Dibene-Arriola et al., 2021). The amount of electricity is predominantly consumed on air-conditioning and may reach up to 60.1% to total electricity consumption (Yong et al., 2017). Hotels air-conditioning variously estimated to account for 38.5% of the total building energy consumption (Yusoff & Mohamed, 2017) and 50 to 60 % of the overall power consumption in the air conditioning system is due to chillers (Chuan, 2017). Evidence that the hotel occupants tend to develop more extravagant patterns of energy consumption attesting to the reason to higher cooling energy intensity in hotels (Cadarso, Gómez, López & Tobarra, 2016). In fact, in some high-quality hotels the guestrooms' air-conditioning operate 24 hours daily (Priyadarsini et al., 2009) even when they are unoccupied to safeguard air circulation and removing undesirable odour for improved indoor quality (Priyadarsini et al., 2009). The continuous use in air-conditioning of hotel guestrooms rendered the hotels overconsumption in annual energy and cooling electricity costs (Wang, 2012).

The energy performance of a hotel building is commonly assessed based on three distinct zones encompassing the guestroom zone, the public area and the service area (Ali, Mustafa, Al-Mashaqbah, Mashal & Mohsen, 2008; Deng & Burnett, 2000). The guestroom occupies the largest zone in a large hotel accommodating 65 to 85 percent of the total building volume (Deng & Burnett, 2000). The energy performance of the guestroom zone varies with occupancy (Lu et al, 2013). The energy performance of the public area which commonly incorporates the reception, banquet halls, pools and restaurants are determined based on the characteristics of the external heat gain and the internal loads (Ali et al., 2008). The service zones in a hotel include offices, kitchen, storage rooms and elevators (Ali et al., 2008). As these zones serve distinctly different functions, the level of energy performance in each zone is expected to vary differently (Ali et al., 2008).

Comparatively, the hotel guestroom accounts for the most intensive annual energy consumption among the aforementioned hotel building zones (Vujošević & Krstić-Furundžić, 2017). 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 (Priyadarsini et al., 2009; Wang, 2012). The daily energy use per guest in a hotel room on average range between 54.5 kWh and 61.9 kWh (Wang, 2012). The guestroom zone represents 35.4 % of total building energy consumption of hotels (Vujosevic & Furundzic, 2017). While data has shown that the remaining hotel zones including service zones and public areas account for 64 % in the hotel building energy use (Vujosevic & Furundzic, 2017).

The air-conditioning is invariably declared as the most dominant among the building's energy contributors (Yıldız & Arsan, 2011; Tang & Chin, 2013) due to issues of façade overheating (Santamouris, 2014). The electricity consumption by air-conditioning systems in tropical island hotels depends strongly on the weather conditions (Priyadarsini et al., 2009; Yao & Short, 2013) like temperature or humidity (Deng & Burnett, 2000; Eras et al., 2016). In the hot–humid tropical island like Penang characterized by uniformly high temperatures and humidity (Yau & Hasbi, 2017) alongside the constant exposure of solar radiation towards building surfaces resorting to high external surface temperature (Lara, Molina & Yanes, 2015). Collectively, these conditions triggering the demand for indoor cooling (Lara et al., 2015) and the ramification is significant rise in cooling energy consumption to maintain the guests' thermal comfort. Yet, prevailing studies on hotels cooling energy performance in Malaysia remained relatively nebulous (Chuan, 2017). It is intrinsic for hotels in the hot and humid climate with a year-round supply of air-conditioning in hotel guestrooms to undertake energy performance evaluation (Priyadarsini et al., 2009; Lara et al., 2015). The external building surfaces must be protected to minimize the façade heat gain (KiranKumar, Saboor & Babu, 2017) into the indoor spaces to reduce reliance on air-conditioning (Ariffin, 2014; Mirrahmi et al, 2016). Study by Tang and Chin (2013) revealed that solar heat gain the ranks the highest in energy contributor to indoor cooling with 25% the overall cooling energy constituents for a typical high-rise building in Malaysia.

The significance passive of 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 (OTTV) calculation as a façade thermal performance index for air-conditioned commercial buildings in Malaysia. The OTTV estimation (Sheng, Zhang & Ridley, 2020) has been made mandatory as a Malaysian Standards, MS1525:14 code of practice for Malaysian buildings following adoption into the uniform building by-Law (UBBL) with clause 38A (Ayegbusi, Ahmad & Lim, 2018). The premise of OTTV is to estimate the amount of the external heat gain into air-conditioned spaces (Lam, 2000) based on the solar thermal load transmitted through the façade of the 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 (Ayegbusi et al., 2018; Seghier, Lim, Ahmad & Samuel, 2017). Apparently, studies related to OTTV in Malaysia is extensive concerning the commercial offices alongside residential apartments, and little is known on the OTTV performance of hotels (Chuan, 2017).

The GBI certification promotes green building in Malaysia through voluntary rating tool adoption and tax incentive scheme in 2009 (Yong et al., 2017). The establishment of GBI supports Energy Efficiency (EE) Malaysia through benefits of tax exemption in the amount of additional green building costs and stamp duty exemption for GBI rated properties (Yong et al., 2017). The index assesses the buildings based on energy efficiency, indoor environmental quality, management of sustainable site, optimal use of materials and resources, water efficiency, and innovativeness (Yusof & Jamaludin, 2013). Among the assessment criteria for green building construction, the Energy Efficiency (EE) in the GBI rating system is the most profound and constitutes the greatest percentage accounting for 38% and 35% of the points for existing and newly-constructed hotels respectively (GBI, 2020). The OTTV concept as stipulated in MS 1525:14 becomes a minimum requirement in EE rating system. The anticipated benefit of GBI certification in newly constructed commercial buildings includes estimated energy savings with an average of 100 kWh/m^2/year alongside energy cost savings of about RM40/m^2 (Yong et al., 2017).

Despite the commendable efforts made through the MS 1525:14 and GBI, the annual cooling energy use in hotel buildings continues to rise significantly even after a decade since the initial inception in 2009 (Yong et al., 2017). In practicality, there are several alternative strategies to safeguard cooling energy saving in large hotels most notably include adjustment of user behaviour (Wang, Xu, Wang & Li, 2019), the design of the HVAC System and passive design of building envelope (Acosta, González, Zamarreno, & Alvarez, 2016; Amirkhani, Bahadori-Jahromi, Mylona, Godfrey & Cook, 2020; Sozer, 2010). The passive façade design for large hotels is considered the best strategy from the spectrum of energy efficiency and long-term cost effectiveness (Chuan, 2017; Sozer; 2010). In the tropics, significant energy use reduction based on improved thermal performance of façade can contribute 20% in overall cooling energy reduction and 29 % energy consumption (Hassan & Al-Ashwal, 2015). In fact, the role of hotels is central to the guests' comfort and governing the behaviour of occupants to resort to energy-considerate options may not be a sustainably feasible strategy especially for quality hotels.

Passive façade design employs appropriate selection of facade materials, ideal window sizes, and shading devices (Egwunatum, Joseph-Akwara & Akaigwe, 2016; Mirrahimi et al., 2016) in minimizing heat gain into the interior, improves thermal comfort and reduces demand for indoor cooling (Sozer, 2010). The long-term ramification of passive façade design in tropical hotels entails significant reduction in building energy consumption particularly on cooling the indoor spaces (Pisello et al., 2014; Rao, 2012) and achieve cooling cost-efficiency (Egwunatum et al., 2016). In principle, the building façade acts as the external boundary that separates the building interior from the outdoor environments and the façade architectural design elements are responsible in regulating the amount of the external heat gain and improve facade thermal performance (Halawa et al., 2017). The thermal performance of a building façade can be referred to as the process of the heat transfer between a building facade and the surrounding (Bakar et al. 2015). Addressing the issues of cooling energy for hotels in the tropics acquires the in-depth understanding of the thermal performance of façade design elements most notably the configuration of the façade elements, thermophysical properties of materials, climatic factors and indoor conditions of a building (Gero, D'Cruz & Radford, 1983; Vijayalaxmi, 2010; Rao, 2012).

In essence, provided the aforementioned disclosure, it has become increasingly clear that a façade is the principal element in evaluating the building thermal and cooling energy efficiency performance. The dynamic relationship between the exterior surface and the impact on the interior cooling demand and thermal comfort conditions have been evidenced in numerous accounts (Cheung, Fuller & Luther, 2005). The idea of dissecting building façade design chronological stylistic narratives on the respective thermal performance is not relatively new in most developed western academia (Sozer, 2010). However, prevailing reports of similar literatures in the context of tropical climate Malaysia retrieved relatively nebulous outcomes considering the specific reference to the discourse of green architecture typical to high-rise city hotels (Chand, Basrawi, Ibrahim, Taib & Zulkepli, 2016; Chuan, 2017; Yusof & Jamaludin, 2013). Studies on cooling energy efficient facade for high-rise hotels is as equally important as other commercial building categories provided the increasing awareness for hotel buildings to be prudently managed and to improve the energy efficiency of building systems while maintaining thermal comfort to the occupants (Sadom et al., 2020). Nevertheless, it has become the central theme of this research to interrogate the thermal performance of building facades for cooling energy consumption and cost efficiency with special reference to the high-rise city hotels in the hot and humid tropical climate Malaysia.

1.3 Problem Statement

The problem with facade design of hotel is associated with lack of passive design elements where the typology of commonly multinational high-rise hotels is architecturally characterized by high window-to-wall ratio to allow full transparency and access to scenery aside from daylight (McNeill, 2008; Rao, 2012, Sozer, 2010). Another common view in high-rise hotel facade is the lack of shading design elements on the façade (Chuan, 2017; Foroughi, Asadi & Khazaeli, 2021; Alhuwayil, Mujeebu & Algarny, 2019). Passive façade design features have not become a priority to the local hotel design both conventional and contemporary predominantly (Eras et al., 2016) among multinational hotels in Malaysia (Chuan, 2017; Yusof & Jamaludin, 2013). These typical characteristics render the hotel facade to be directly exposed to high intensity solar radiation particularly on the west facade due to the tropical climatic conditions (Qahtan, 2019; Morris, Zakaria & Zain Ahmed, 2012). This can cause facade surface overheating (Lau, Salleh, Lim & Sulaiman, 2016; Santamouris, 2014) with continuous exposure to intense solar radiation (Mirrahimi et al., 2016; Lau et al., 2016). The repercussions can cause high peak external surface temperature on the façade (Hassan & Ali, 2019; Ahmad, Maslehuddin & Al-Hadhrami, 2014). Yet, concurrently, the extent of which the effects facade overheating due to effects of solar radiation has on the external surface temperatures of buildings in Malaysia is scarcely documented (Arab, 2018; Ahmed et al., 2015). Rising outdoor temperatures due to gradual changes in the local climate exacerbated the issues concerning the surface temperature of hotel facades. Study on surface temperature acquires profundity as the repercussions will not only a concern for indoor thermal comfort for hotel guestrooms but includes urban heat island mitigation effects (Arab, 2018; Din et al., 2012).

Secondly, while building performance measurement including OTTV has been made mandatory a majority of hotels have not undertaken the OTTV performance evaluation (Chuan, 2017; Sadom et al., 2020). This is due to the fact that a majority of commercial hotels regardless of categories have not been assessed and certified as green hotels by GBI (Abdulaali, Hanafiah, Usman, Nizam & Abdulhasan, 2020; Sadom et al., 2020). 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 new construction category circa September 2020 (GBI Projects Register, 2020). In fact, there are 2,264 hotels in Malaysia registered under the Ministry of Tourism and Culture Malaysia (MOTAC) as star-rated hotels amongst which only 20 of these hotels are classified as green hotels (Sadom et al., 2020). This indicates that a majority of hotels have not undertaken the façade OTTV performance calculation. Consequently, the performance of hotel façade in relation to energy efficiency is faintly established (Chuan, 2017; Sozer, 2010). Presently, the available research on the facade OTTV performance of high-rise hotels both domestic and multinational owned is relatively nebulous when compared to similar studies on other building categories including offices and residential apartments (Chuan, 2017; Yusof & Jamaludin, 2013).

Thirdly, the extent contribution of façade heat gain on cooling load of hotel guestrooms alongside cooling consumption costs is rarely documented in the tropical climate regions (Chuan, 2017; Lara et al., 2015). In understanding the hotel façade performance on cooling energy load and costs acquires a proper cooling load calculation (Chuan, 2017; Rotimi, Bahadori-Jahromi, Mylona, Godfrey & Cook, 2017) and relying on OTTV alone is inadequate (Lam, 2000; Lee, Kim, Kim, Song & Jeong, 2018; Hwang et al., 2018). In achieving more accurate estimation of cooling loads has to take into account not only the thermal gains of the external walls but also all the internal heat sources on the guestroom units scale as it is attached directly to the façade (Hwang et al., 2018; Alhuwayil et al., 2019; Vujošević & Krstić-Furundžić, 2017). This is because a hotel building is made up of rooms with different functions (Udawatta & Witharana, 2010; Deng & Burnett, 2000) and each room embodies its own unique characteristics (Eras et al., 2016) in terms of its indoor conditions (Eras et al., 2016; Sozer, 2010). The space cooling load of guestrooms attached to the façade which are the dominant space in a hotel should be separately evaluated (Priyadarsini et al., 2009; Deng & Burnett, 2000) to understand the façade performance (Musa, Lawal, Yusuf & Almustapha, 2018).

Collectively, in Malaysia lacks framework for driving building sector energy efficiency for high-rise hotels (Yong et al., 2017) and new guidelines especially on energy-efficient façade design for high-rise hotels becomes increasingly critical (Chuan, 2017). While there is a growing body of knowledge of passive facade design for energy efficient hotels in the cold climates (Huang & Niu, 2016) the search for similar studies in the context of the hot and humid climate Malaysia retrieved relatively nebulous outcome (Chuan, 2017, Chand et al., 2016). There is a gap in prevailing research on the potential combination of passive façade design elements on cooling energy consumption in the tropical climate Malaysia (Chand et al., 2016; Chuan, 2010, Sadom et al., 2020).

1.4 Research Questions

Question 1-What is the average surface temperature of different hotel facades in George Town, Penang?

Question 2-What is the level of performance of façade design on the Overall Thermal Transfer Value (OTTV) for hotels in George Town, Penang?

Question 3- What is the average cooling load for a hotel guestroom with different façade design in George Town, Penang?

Question 4-What is the cost of annual cooling energy consumption for a hotel guestroom with different façade design in George Town, Penang?

Question 5-What is the best combination of façade design elements for energy efficient hotel design in George Town, Penang?

Question 6-Which of the hotel façade design gives the best performance in average external surface temperature, the OTTV and the guestroom average cooling load?

1.5 Research Objectives

Followings are the research objectives based on research questions.

Objective 1-To determine the average external surface temperatures of hotel buildings with different façade design

Objective 2- To calculate the Overall Thermal Transfer Value (OTTV) of hotel buildings with different façade design

Objective 3-To evaluate the average cooling load and the cost of annual cooling energy consumption for a hotel guestroom unit of different façade design.

Objective 4-To contribute a general guideline on passive design strategies for energy efficient hotel façade relative to the hot and humid climate in George Town Penang

1.6 Research Hypothesis

The hypothesis of this study anticipates that energy efficiency of hotels in the hot and humid climate of George Town, Penang can be achieved through passive façade design for improved thermal performance and energy efficient cooling energy consumption of hotel guestrooms. The assumption is that when the building façade on the west orientation is efficiently designed, it will result in less dependency on the indoor air-conditioning systems. Therefore, the research hypothesizes that:

- Average surface temperature of hotel facades establishes a significant relationship with average cooling load of hotel guestrooms suggesting that increase in the average surface temperature of high-rise hotel façade on the west orientation corresponds to increase in average cooling load of the hotel guestroom.

- The condition of high external surface temperature of hotel façade contributes to the significant amount of heat gain through the façade. Therefore, it is expected that the OTTV for the west façade is high for façade conditions with high facade surface temperature.
- The cooling load of a space establishes a proportional relationship with OTTV and increase in OTTV results in accumulation of the average external heat gain and eventually the space cooling load.
- Collectively, increase in the average external surface temperature of building façade has a highly significant causal impact on cooling energy consumption in hotels and high average surface temperature of hotel facades correspond to high cooling energy consumption and cost.

1.7 Research Framework and Methodology

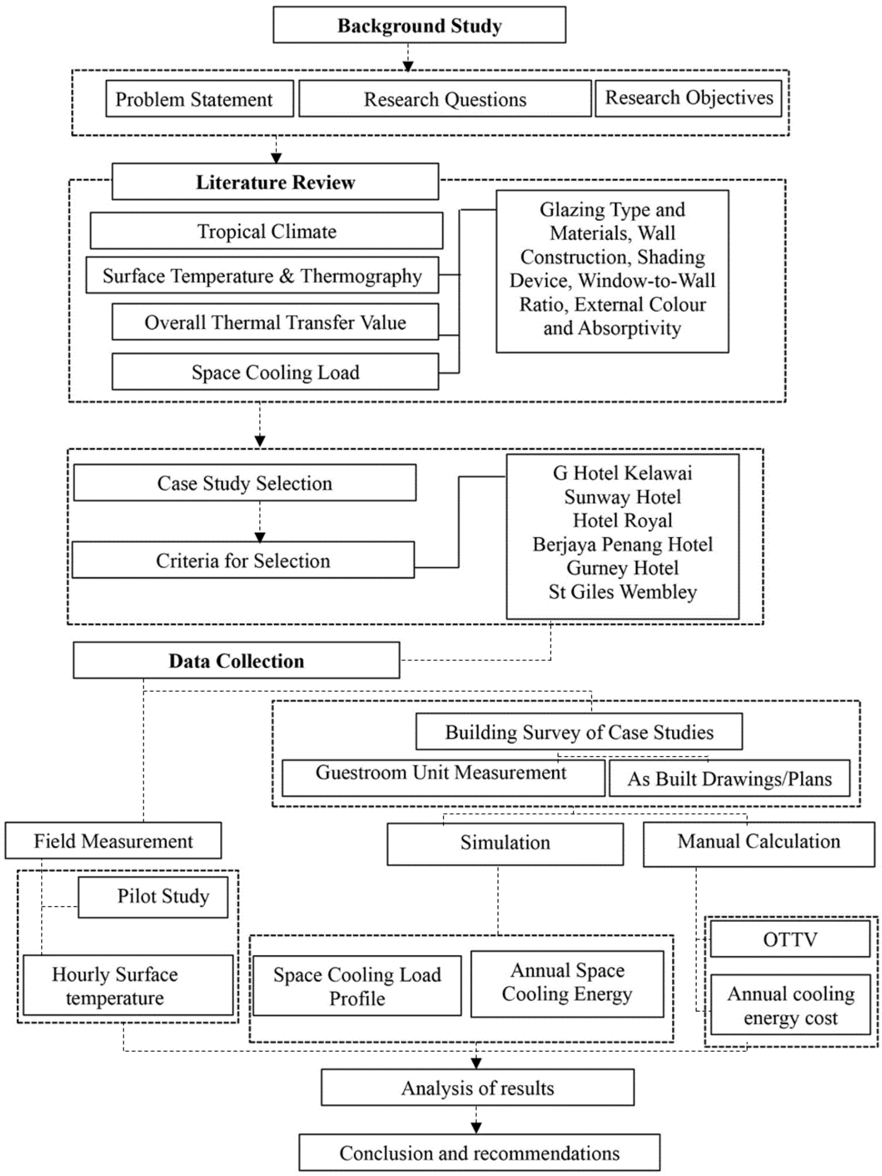

Figure 1. 4 Research framework and methodology

The research framework and methodology is used to navigate the researcher through the different phases of the research, providing clear workflow, steps and methods in conducting the research and achieving the research objectives. Figure 1.4 illustrates the research framework and methodology of the research. The scope of the study as represented in the research framework can be organised into three main phases encompassing the background study, research methodology and ultimately research analysis and discussion. In the first phase which embodies the problem statement, research questions, and research objectives is considered the initial phase where during this stage different sources of information relevant to the research title were identified. Among the notable sources used as references for previous studies are books, journals and theses which assist in identification of problem statement, research questions coupled with the objectives. The first phase ends with the research framework providing a clear workflow and scope of the study.

The second phase of the research entails the methodology which comprises of three measurable methods in evaluating the performance of façade in relation to cooling energy performance and cost. Following the identification of the ideal case studies, the methodology is proposed based on literature review and emphasises the profound influence of three measurable scales including the average surface temperature, the Overall Thermal Transfer Value (OTTV) and average space cooling load. The methodology used in the research is generally divided into three elements through execution of field measurement, manual calculation, and the computer simulation. In the field measurement, the data on each façade configurations will be collected from varying sources including on-site survey and external references. The drawings of hotel facades and floor plans of each case studies will be used for calculation of OTTV and simulation of space cooling load.

The outcome of each research undertaking will undergo comparative analysis which leads to the third and final stage in the research framework. In this phase, the findings of the research will be analysed individually based on the measurable scales to draw relevant relationship with the façade design elements in suggesting the thermal performance and cooling energy performance of each case studies. Then, the research will proceed with the analysis on the relationship between the three measurable scales to provide understanding on the effects of each measurable scale on hotel façade thermal performance. Subsequently, the research phase ends with conclusion and recommendations where suggestions on improved and ideal façade design for the energy efficient cooling energy for high rise city hotels in the tropical climate Malaysia will be rigorously discussed. Table 1.1 shows the relationship between problem statement, research questions, research objectives and research methods use in the research.

Table 1.1 The relationship between research problem, research questions, research objectives and research methods.

Problem Statement	Research Objectives	Research Questions	Research Method
Façade made with lighter materials, large glazing and no shading device on façade. Direct exposure cause surface overheating and high surface temperature.	Objective 1-To determine the average external surface temperatures of hotel buildings with different façade design	Question 1- What is the average surface temperature of different hotel facades in George Town, Penang?	Quantitative method Field measurement and thermographic survey of façade external surface temperature.
Many hotels are not certified by GBI means majority have not undertaken the OTTV calculation	Objective 2- To calculate the Overall Thermal Transfer Value (OTTV) of hotel buildings with different façade design	Question 2- What is the level of performance of façade design on the Overall Thermal Transfer Value (OTTV) for hotels in George Town, Penang?	Quantitative method Manual calculation of Overall Thermal Transfer Value (OTTV) based on the formula given in MS 1525:14

Cooling load calculation and cost estimation for hotel guestroom is necessary to include indoor conditions to represent the energy efficiency performance of hotel facade	Objective 3- To evaluate the average cooling load and the cost of annual cooling energy consumption for a hotel guestroom unit of different façade design.	Question 3- What is the average cooling load for a hotel guestroom with different façade design in George Town, Penang? Question 4- What is the cost of annual cooling energy consumption for a hotel guestroom with different façade design in George Town, Penang?	Quantitative method Simulation of space cooling load and annual cooling energy consumption. Manual calculation of annual cooling energy cost using the electricity tariffs
In Malaysia, recent study on passive façade thermal performance of hotels for cooling energy consumption and costs is relatively nebulous.	Objective 4- To contribute a general guideline on passive design strategies for energy efficient hotel façade relative to the hot and humid climate in George Town Penang	Question 5- What is the best combination of façade design elements for energy efficient hotel design in George Town, Penang? Question 6- Which of the hotel façade design gives the best performance in average external surface temperature, the OTTV and the guestroom average cooling load?	Quantitative method Comparative analysis of results from the field measurement, manual calculation of OTTV, cooling load simulation and annual cooling energy consumption cost.

1.8 Research Scope

The research identifies the following scope of research:

- The study limits the scope to evaluating the cooling energy performance of high-rise city hotels only and not inclusive of other types of temporary accommodation like resort hotels and service apartments. The primarily characterized by façade without shading and without atrium.

- The research is conducted in the city of George Town on the Penang Island entitled to the tropical climate of Malaysia with specific reference to the climatic conditions for the locality of George Town, Penang.
- The scope of the study focuses on the effect of surface temperature and heat gain on the west façade orientation only and investigation is conducted in limited hourly interval between from 12 p.m. to 7 p.m.
- The research is related to the performance of the west façade of high-rise hotels and only the hotel guestroom unit attached to the perimeter of the west wall will used to define the thermal zone for cooling energy performance simulation. The rest of the indoor building zones of the selected hotels will not be considered in the research.

1.9 Research Limitations

In conducting the research there are three general research limitations encountered comprising of building selection limitations, technical limitations and limitations due to time and access to selected buildings.

1.9.1 Building Sample Limitations

In the selection of case studies, the hotels that were selected as case studies have slight variation in the façade architectural design (wall assembly, solar geometry) due to constraints of in number of building available in the city of George Town. However, the variation is sufficient to undertake analysis as upon close inspection technical parameters including wall material and thickness vary between the selected hotels.

Since the study only emphasizes on the façade on the west orientation selection of case studies pose a constraint as it is found that a majority of the hotels are not oriented towards the west orientation and only the available hotels that embodies significant façade area oriented to the cardinal west were selected. Overall, only six hotels out of 49 registered hotels across the state were selected to represent the façade design typical hotel façade design in the locality of Penang.

1.9.2 Technical Limitations

In performing the OTTV calculation and cooling simulation the materials of the façade have to be initially determined and the common method in used research is by acquiring the technical and detail drawings of the façade from the architects or local council. In the research, the detail drawings for each hotel façade are unavailable for access and cannot be retrieved from the local council.

Another limitation is inability to obtain the data on actual building energy consumption of each of the case studies. This data is necessary to validate the result of annual cooling energy simulation. In fact, in the data of annual energy consumption (i.e. monthly electricity bill) is not available based on the single guestroom which is befitting the scope of the research.

1.9.3 Time and Access Limitations

In performing the field measurement, the surface temperatures of the external façade of the selected hotels have to be taken within an hourly interval from 1200 to 1800 hours. The time allocated for measuring the temperature of each of the case studies in each hourly interval is limited. The researcher has to consider the traffic condition in the city to ensure the field measurement for each case studies is collected in each hour.

1.10 Significance of the study

The significance of the study are as enlisted:

- The results of the research could be useful for façade designers, architects, engineers to fully understand energy saving opportunities in hotel buildings through passive design of façade in the context of the tropical climate Malaysia.
- The outcome can provide useful information to local Administrations, for example the municipalities, to carry out approximate assessments of the energy quality of existing buildings or to make preliminary checks on the application of the rules and regulations.
- The results of this study could serve as a useful reference for hotel managers, operators and investors interested in hotel construction, retrofitting and to further employ proper energy saving measures to enhance cooling energy efficiency and conservation particularly in high-rise hotel buildings.
- The results of the study serve as a guideline for local government authorities in preparation to establish energy-efficient façade design and retrofitting strategies through energy-efficient façade design for both domestic and multinational high-rise hotels in Malaysia.

1.11 Summary of Chapter

The proposed research is organized and the overview of each chapter is as enlisted below: