ENVIRONMENTAL PERFORMANCE OF HIGH-RISE APARTMENT'S FAÇADE IN PENANG, MALAYSIA

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ENVIRONMENTAL PERFORMANCE OF HIGH-RISE APARTMENT'S FAÇADE IN PENANG, MALAYSIA

by

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PRESTASI PERSEKITARAN FASAD PANGSAPURI DI PULAU PINANG, MALAYSIA

ABSTRAK

Peningkatan jumlah penduduk di kawasan bandar besar sejak tahun 1950an menyebabkan permintaan yang tinggi terhadap unit perumahan. Kajian ini bertujuan meneliti impak perolehan haba (heat-gain) terhadap reka bentuk fasad bangunan pangsapuri berdasarkan piawaian Indeks Bangunan Hijau (GBI) di Malaysia. Kajian ini juga menganalisis prestasi reka bentuk teduhan yang direka bentuk pada fasad pangsapuri di Pulau Pinang, Malaysia. Enam bangunan yang mempunyai gaya seni bina yang berbeza bermula dari 1970an sehingga kini telah dipilih sebagai kajian kes; kesemuanya terletak di bahagian timur Pulau Pinang. Pangsapuri Halaman Kristal 5 dan Mutiara Idaman 1 dibina pada 1970an hingga 1990an memiliki gaya seni bina moden, Halaman Kristal 1 dan Mutiara Idaman 2, dibina sekitar tahun 1990an hingga 2010an, dan yang terakhir The Baystar dan The Light Linear yang dibina selepas tahun 2010. Kajian ini mengukur tiga (3) pembolehubah iaitu suhu permukaan fasad (°C) menggunakan *Fluke Ti20,* Nilai Pemindahan Termal Keseluruhan (OTTV) (W/m^2), dan prestasi pencapaian kadar penembusan cahaya matahari ke dalam bangunan menggunakan perisian simulasi komputer *SunTool* (mm). Dapatan kajian menunjukkan Halaman Kristal 1 (dengan reka bentuk fasad pasca moden) merekodkan bacaan suhu permukaan yang paling rendah, diikuti oleh The Light Linear, The Baystar (dengan gaya neo-minimalis), Mutiara Idaman 2 (gaya pasca moden), Mutiara Idaman 1 dan Halaman Kristal 5 (dengan gaya seni bina moden). Di samping itu, bacaan OTTV turut menunjukkan bahawa lima (5) bangunan kajian kes mempunyai

bacaan OTTV yang disarankan oleh GBI Malaysia (iaitu antara 31 ke 33 W/m^2), kecuali bacaan pada pangsapuri Mutiara Idaman 2, iaitu 60 W/m^2 yang melebihi bacaan piawaian yang boleh diterima oleh GBI. Bagi prestasi reka bentuk teduhan pula, gaya pasca moden mempunyai hasil terbaik kadar teduhan daripada penembusan cahaya matahari, diikuti oleh gaya neo-minimalis, dan akhirnya gaya seni bina moden. Kajian ini mengesyorkan bahawa dinding berserambi, anjung, reka bentuk peneduhan menegak, teduhan kekotak (*egg-crate*), dan warna adalah elemen-elemen penting yang mempengaruhi prestasi terma fasad bangunan.

ENVIRONMENTAL PERFORMANCE OF HIGH-RISE APARTMENT'S FAÇADE IN PENANG, MALAYSIA

ABSTRACT

Rapidly growing population in urban areas since the 1950s causes highly increasing demands for housing units. This study aims to investigate the heat gain of the apartments' façade design in line with the Green Building Index (GBI) standards in Malaysia. This study analyses the shading performance of high-rise apartments' façades in Penang, Malaysia as case studies. The analysis includes six residential buildings of different architectural periods of construction in the eastern part of Penang Island. The selected case studies are Halaman Kristal 5 and Mutiara Idaman 1 from 1970s to 1990s, Halaman Kristal 1 and Mutiara Idaman 2 from 1990s to 2010s, and Baystar and the Light Linear from 2010 to present. Three different variables were measured in this survey, the façade surface temperature (℃) using thermal imager Fluke Ti20, the Overall Thermal Transfer Value (OTTV) (W/m^2), and the extent of sunlight penetration (mm) using SunTool software for the computer simulation. The obtained results revealed that Halaman Kristal 1 façade design has the lowest surface temperature followed by The Light Linear, Baystar, Mutiara Idaman 2, Mutiara Idaman 1, and Halaman Kristal 5 of a modern façade architectural style. The OTTV results revealed that all case studies have an OTTV ranging from 31 to 33 W/m^2 which is accepted based on Malaysian standards except for Mutiara Idaman 2 with 60 W/m^2 above the acceptable standards. Regarding the shading performance, the post-modern architectural style achieved the best results of sunlight penetration followed by neo-minimalist and modern façade architectural styles. Therefore, it is recommended that

the recessed wall, balcony, vertical and eggcrate shading devices, and colour are regarded as the most important elements, which influence the thermal performance of high-rise apartments' façade design in Penang, Malaysia back in the 1970s until today.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter introduces the research topic and provides background information for the study. This study investigates the façade surface temperature, sunlight penetration, and the façade shading area of three different architectural styles of high-rise residential buildings in Penang, Malaysia. The chapter presents the problem of the study, the research objectives and questions, the significance of the study, its scope and limitations. The chapter concludes with the organization of thesis.

1.2 Background of the Study

This study investigates the façade thermal performance of high-rise residential buildings in Penang Island, Malaysia with reference to their level of exposure to solar radiation, sunlight penetration, and Overall Thermal Transfer Value (OTTV) for the most popular architectural styles in Penang. In other words, this study discusses the efficiency of high-rise residential buildings' façade design in terms of shading performance. Having a good façade shading design, which minimizes sunlight penetration into the apartment, helps categorize buildings under the Green Building Index (GBI) (Department of Statistics Malaysia, 2007). On the other hand, the building's façade, which does not consider passive designs, causes heat gain, as well as uncomfortable glare because of a large amount of sun exposure in the apartment's façade. In Malaysia, most of the low-cost and medium-cost apartments have poor shading façade designs with sun shading elements. Most of the residents of these buildings have low incomes and, therefore, they cannot afford high electrical bills for air conditioning systems.

The high-rise apartment is one of the most popular house types in Malaysia. This study focuses on investigating the surface thermal performance of the building's envelopes. The high-rise building system can provide suitable housing and meet the needs of the increasing population in Malaysia. Based on the Department of Statistics Malaysia (Department of Statistics Malaysia, 2011), the number of people in the urban areas has increased from (34% in 1980) to (51% in 1990), and to approximately 71% in 2010. This huge increasing in population caused a significant increase in demand of the housing units and high-rise buildings.

The findings of this study provided general useful guidelines to help designers and architects identify the best orientation and direction for the apartment façade. In addition, the findings helped in studying the façade shading elements in different architectural styles to achieve to the best shading performance during the daytime, especially when the façade is exposed to direct sunlight. Therefore, the proposed practical and useful guidelines of this study will help reduce and control global warming by reducing energy consumption if architects can design buildings with good passive façade designs to decrease the mechanical air conditioning systems' use.

High-rise apartments are classified under the tall buildings' category of the multi-story buildings of over 10 or 12 storeys, which are equipped with elevators (Cheung, Fuller, & Luther, 2005; Commission, 2003; Craighead, 2009). The first high-rise building was the Home Insurance Building. It was built in the 1880s in Chicago in the United States of America. In Malaysia, the first high-rise apartment is Sulaiman Courts at Tunku Abdul Rahman Street in Kuala Lumpur as it was built before 1957 (Figure 1). The second high-rise building is a seventeen-storey building. Pekeliling Flats were built at Tun Abdul Razak Street in 1964. In Malaysia, high-rise buildings were popularly built in the 1970s (Von Hoffman, 1996). while the first high-rise building in Penang was the 18-story The Rifle Range Flat that was built in 1965 in Ayer Itam (Figure 1.2)

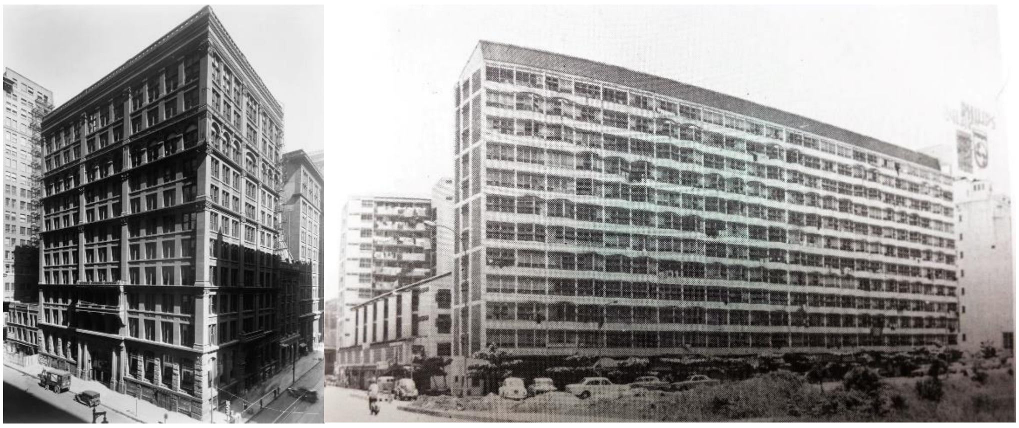

Figure 1.1 The Insurance Home building, Chicago (Left) Sulaiman Courts (Right)

Source: chicagology.com / Pertubuhan Akitek Malaysia

Figure 1.2 The Rifle Range apartment building in Penang.
Source: https://www.thestar.com.my/

Today, high-rise apartments are popularly built in urban areas, because they can provide many residential apartment units. The construction sector has solved the problem of land's scarcity in the urban areas to house the increasing city population. By 2000, about more than 2 million people were living in high-rise apartments in Malaysia. Figures 1.3 and 1.4 show the percentages of the apartments from a total of house types and the number of the apartment units (flat, apartment and condominium). Providing high-rise apartments is crucial as apartments in Putrajaya constitute the most popular house types representing 73% of the total house units (Department of Statistics Malaysia, 2011) Flats are categorized under low-income house types, apartments under middle-income house types, whereas condominiums are house types for high-income families.

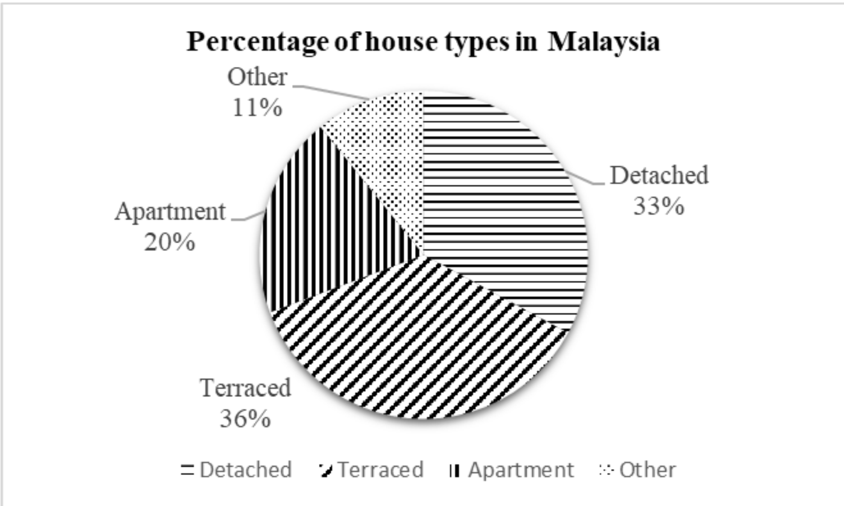

Figure 1.3 Apartments (apartment/flat/condo) percent 19.9% of the total house type

Figure 1.4 Apartment units' number by category of flat, apartment and condominium.

It is worth mentioning that the Rio Summit in 1992 emphasized raising the global awareness about sustainable development to reduce energy consumption and to focus on designing green buildings (Earth Summit, 1992). The Malaysian Board of Architects has enhanced green building designs by introducing the Green Building Index (GBI) rating as a guideline for green building designs, especially building designs for thermal comfort. The Malaysian government has also included manual energy efficiency usage in relation to the Ninth Malaysian Plan (2006-2009) in order to optimize energy usage in building design (Economic Planning Unit, 2006). Among the most critical tropics is the development of the apartment façade with an excellent performance against heat gain caused by solar radiation. Many steps can be taken for the ne constructions and buildings to comply with the Green Building Index or the Economic Planning Unit recommendations, as on the other hand, the study aims to focus on the existing building and recommend few steps to reduce the energy consumption due to the air-conditioning usage by applying recommending a guideline, which make it a necessity to conduct it as soon as possible.

1.3 Previous Related Studies

Heat gain through the building's façade is a global issue. It is concerned with sustainability and green building development to provide passive designs and increase awareness about other environmental issues to provide sustainable human comfort solutions for this generation and the coming generations as discussed by (Sawadisavi et al., 2008; Al-Tamimi & Fadzil, 2011).

To design a suitable building envelope that is environmentally and energy efficient, it is essential to comprehend tropical climate thermal comfort. Previous studies have investigated developing a thermal environment database. It is also important to study residents' responses in tropical climates. The temperature of 26℃ is given by ASHRAE standard 55 on "thermal environmental conditions for human occupancy" as the maximum temperature of a comfortable environment (ASHRAE, 2004). Nevertheless, it has been suggested that people, who live in hot and humid climates, are acclimatized to high temperature and humidity levels (Givoni, 1992; Busch, 1992; Feriadi, Wong, Chandra, & Cheong, 2003). The following sections provide an overview of previous studies on thermal comfort in tropical regions.

Abdul Shukor and Young (1993) conducted a controlled climate chamber study including 18-24-year-old students at university level. The participants experienced the light activity of 1.0 met and clothes of 0.5 Clo value, air velocity is 0.1 m/s and 50% relative humidity, and the neutrality temperature is 28.2°C. In the same vein, Sabarinah and Steven (2007) found that Malaysia comfort band including all types of buildings is between 23.6 and 28.6℃. The findings of another study by Zain et al. (2007) reported that thermal comfort below 28.69℃ can be obtained in

Malaysia. Based on a survey in which the indoor environmental parameters are measured. College students' comfort conditions in classrooms that are naturally ventilated in Shah Alam were investigated. The findings revealed that a mean temperature of 29.8°C and a mean air movement of 0.27 m/s were experienced by the survey respondents at 65% average humidity in addition to neutrality temperature of 27.4°C (Rahman & Ismail, 2008)

A study by Hassan and Hafeez (2016) investigated the impact of shading on Overall Thermal Transfer Value (OTTV) of early-modern residential apartment's façade in Kuala Lumpur, whereby special attention is directed to the modest mass-produced appearance characteristics for low-income families. Here, the focus is on the extended open-corridor system design as it has become the apex of solar shading manipulation on the apartment's façade. The study investigated Melati Apartment, located off the Loke Yew Street in Kuala Lumpur as a case study. The apartment's façade shading area amount (%) was simulated and systematically recorded throughout one day (from 8 am to 7 pm). Variations in the shading areas were recorded, together with time in response to length, width and height of the fenestrations and the open corridor. However, parameters like façade orientation, temperature difference, U-values, absorptive factor, and shading coefficient were found to be similar. OTTV was meticulously recorded as it was classified under two different façade conditions: fully-exposed façade and shaded façade. The subtraction method was used in the study, whereby the shaded façade OTTV is subtracted from the fully-exposed façade OTTV to obtain OTTV reduction. The findings concluded that during the period (from 11 am to 3 pm), the corridor provided the biggest shading area. This resulted in obtaining the lowest façade OTTV. During the early morning hours (from 8 am to 10 am) and late evening hours (from 5 pm to 7 pm), the OTTV of each façade reached its climax due to less shading percentages during morning hours.

Gutierrez and Labaki (2007) investigated fixed exterior shading devices' thermal performance on the north and west orientation. The devices included horizontal louvers, vertical fins, as well as egg-crate typology made of concrete and wood. It was found that the horizontal concrete louver on the north façade achieved the best performance. Regarding building materials, it was found that the best results were obtained by concrete devices. It was also found that wood, when used as a building material, lowers the indoor air temperature even though the wood has good insulation properties. The findings of the study also revealed that the façade orientation has a huge impact on shading devices' performance.

Ghisi and Felipe Massignani (2007) investigated residential buildings' thermal performance. The researchers made a comparison between the thermal performances of eight vacant bedrooms with four different orientations. The researchers assessed the correlation between the indoor air temperature and thermal properties of the wall and the window and drawing the shading on the window. Both parameters obtained the best correlation with maximum air temperatures. In summer, the two parameters, i.e., the U-value and façade area should be lessened (minimized) to improve the indoor thermal condition. On the other hand, the two parameters, which obtained the best correlation in winter, are 1) thermal capacity and 2) thermal time lag. Therefore, they should be exploited (maximized) to boost the indoor thermal condition.

In another study by Sherif et al. (2012), the researchers investigated the impact of depth and perforation configuration of the external perforated window solar screens on the annual energy load. The study was carried out in Egypt's hot and dry climate. The findings of the study concluded that up to 30% of the total energy load is obtained by deep perforated solar screens to the south and west orientations and, therefore, 80% to 90% perforation and depth/opening width ratio of 1:1 are recommended.

The ideal window-to-wall ratios that are related to energy efficiency for insulated houses with manufactured 20 timber frames' structure was studies by Leskovar and Premrov (2012) . It was found that the obtained optimal windows' area for the lower U-values' walls is slightly smaller than the higher U-values' walls.

A comparison between external shading devices in residential houses investigating heating and cooling energy saving was carried out using energy simulations' programme IES-VE (Integrated Environmental Solution–Virtual Environment). The obtained findings demonstrated that the most efficient performance is achieved by the experimental shading device with adjustments of slat angle (Kim, Lim, Lim, Schaefer, & Kim, 2012).

The impact of the window-to-wall ratio (20%,a50%, 75%,wand1100%), multiple panes' window (single, duple, and triple), as well as south and west orientations on the tested the condition of thermal performance for the indoor atmosphere of the room are investigated by Haese (2010). The researcher compared the mentioned parameters. The study concluded that in case the building is south-oriented with 25% window-to-wall ratio, it is recommended that a single-pane glass window is used because there is no significant difference obtained between the three types (single, duple, and triple) based on the comparison made in the study.

In Bangkok, during the hot season in April and the rainy season in July, a survey was administered to more than 1100 office workers as questionnaire respondents. Offices with natural ventilation were compared with offices with air-conditioners. The findings revealed that people living in tropical regions can tolerate and adapt with warmer temperatures as opposed to comfort models and ASHRAE 55-1995 standards. The findings of the survey revealed that 80% of workers in Thailand live in a comfortable environment, whereas the maximum comfortable temperature is 28℃for the workers in air-conditioned offices, and 31℃in naturally ventilated offices(Busch, 1992).

1.4 Problem Statement

According to Leslie 2003, the apartment unit is designed to preserve energy and to create a comfortable environment for the residents. Comfortable temperature is maintained by a mixture of building envelop, orientation, insulation, and energy efficient façade design.

Heat gain through buildings' envelopes tends to be one of the main factors of increasing the indoor temperature and causing uncomfortable atmosphere leading to increase the usage of artificial cooling systems.

The energy consumption in residential building is considered as big sector (19% of overall energy consumption) due to the inefficient façade shading design, heat gain, and other reasons that lead to increase the usage of air-conditioning (Saidur et al., 2009). And 30% of the energy consumption in residential buildings occurred due to air conditioners (Varman, Masjuki and Mahlia, 2005). Fenestration and shading devices can contribute up to 22% of the energy consumption in residential buildings according to Al-Mofeez (2007) (Figures 1.5 & 1.6).

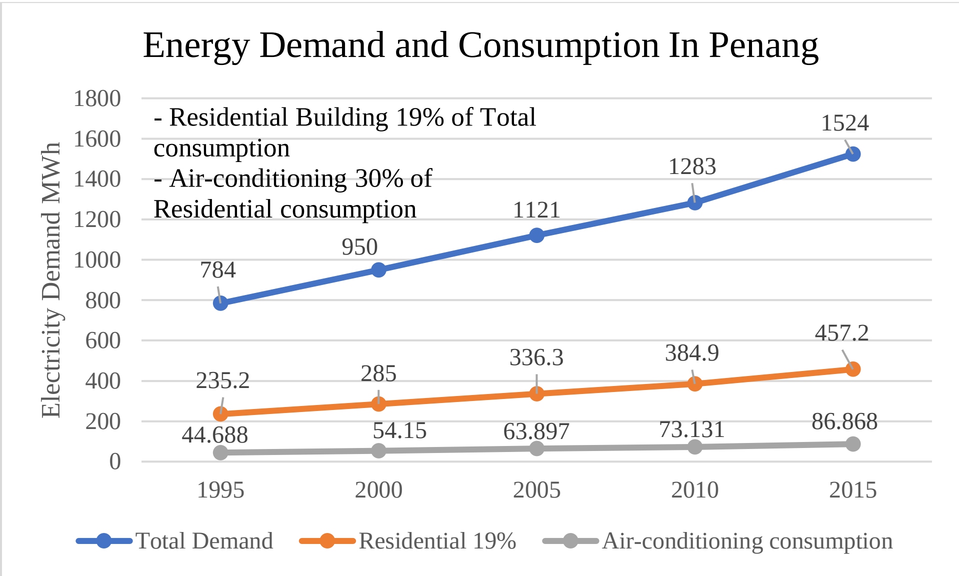

Figure 1.5 Energy demand and consumption in Penang

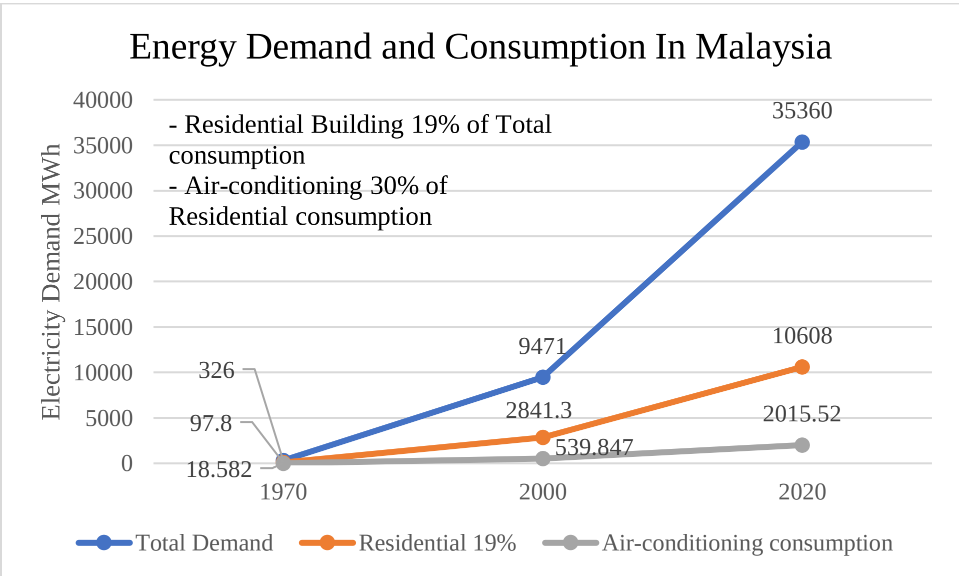

Figure 1.6 Energy demand and consumption in Malaysia

Residential high-rise building became a necessity to overcome the problem of high demand of housing units due to the immigration form rural area to the major cities and urban areas, the limitation on the land areas especially in places like Penang Island, and in addition to the huge increase in population since 1950s and 1970s until the present (DSM, 2015).

With the huge increase of the residential high-rise building's numbers (CETDEM, 2005), few studies found that the majority of these buildings have poor façade thermal performance due to their façade design and buildings envelops. Many studies have been carried out on commercial and governmental buildings but very few studies targeted the residential high-rise buildings.

- Lack of researches on the façade heat gain of residential high-rise apartment buildings
- Lack of researches on studying the overall thermal transfer value (OTTV) of residential high-rise buildings.
- Lack of researches which study the impact of buildings architectural design on the heat gain and the surface temperature.

Table 1.1 The population increasing in Malaysia and Penang in Million

Year	Malaysia	Penang
1970	10.91	0.78
1980	13.83	0.90
1991	18.1	1.06
2000	23.27	1.31
2010	28.4	1.57
2018	32.04	1.77

Heat gain and unnecessary sunlight without maintaining the indoor comfort temperature for the residential apartment building represent the most challenging issues facing researches, designers, and architects nowadays. Therefore, finding suitable solutions, providing guidelines for the best shading elements with the best building orientations, and providing the best comfort zone in the apartment building represent key issues of concern today. Accordingly, the findings of the study suggested that the application of the earlier mentioned factors along with useful guidelines for architects will surely raise more awareness about finding more sustainable solutions for a better sustainable development.

1.5 Research Questions

The research question of this study are as follows:

1. What is the average façade surface temperature of high-rise apartment building?
2. What is the most effective high-rise building architectural style which has better shading efficient façade designs?
3. What is the amount of heat gain transfer into the buildings through the façade envelop (Overall Thermal Transfer Value OTTV)?
4. What is the best existing high-rise architectural façade design in terms of shading performance and sunlight penetration?
5. What is the most efficient shading device for the residential high-rise apartment building's façade?

1.6 Research Objectives

The main objective of this study is to investigate and compare the high-rise building's façade design of different architectural styles in Penang, Malaysia to find out the best design in terms of façade surface temperature. The objectives of this research are as follows:

1. To investigate the façade surface temperature of different case studies from different duration of construction.
2. To measure the extent of sunlight penetration and compare the results of the selected case studies with different façade design.
3. To calculate and compare the Overall Thermal Transfer Value (OTTV) of the selected case studies.
4. To recommend efficient façade shading designs with general guidelines for apartment buildings.

1.7 Scope of the Study and Research Framework

This study investigates the shading performance of high-rise apartment's façade design in Penang, Malaysia. The study framework and the scope are illustrated in Figure 1.7, which presents the main three phases of this research: 1) the problem statement and literature review, 2) the research methodology, and 3) the analysis of results and discussion. The first phase consists of two parts. The first part provides key definitions of the terms in this study and summarizes the important related information from reliable sources such as books, journals, and theses in order to have a general, clear idea of the framework and how to accomplish the objectives of the study. The second part provides important information about the climate in the research area (a tropical region climate) and high-rise residential buildings, which represent the selected building types for the case studies of this research.

To investigate and understand façade shading and thermal performance in high-rise apartment buildings in Penang, the second phase (research methodology) explains the methods of survey, which were used in to obtain the results from the selected case studies of different architectural styles. The first step is to snap thermal images of the west façade of all the selected case studies using Fluke Ti20 thermal imager to measure the façade surface temperature and calculate the Overall Thermal Transfer Value (OTTV) of the west façade of the selected buildings. The researcher used a computer software to simulate the extent of sunlight penetration from the east and west façade of the selected buildings.

Finally, the last phase is the analysis of results and discussion. This part consists of three main sections. First, comparing the façade surface temperature and analyzing the effect of the architectural style and façade design on the façade surface temperature. Second, analyzing the OTTV of the buildings of different architectural styles so that useful suggestions are forwarded to improve the OTTV results in compliance with the Malaysian standards and requirements. The last part of this phase is to analyze the results of sunlight penetration and study the role of shading devises in each architectural style to prevent unnecessary sunlight from penetrating into the buildings from the fenestrations. The diagram below shows the research framework.

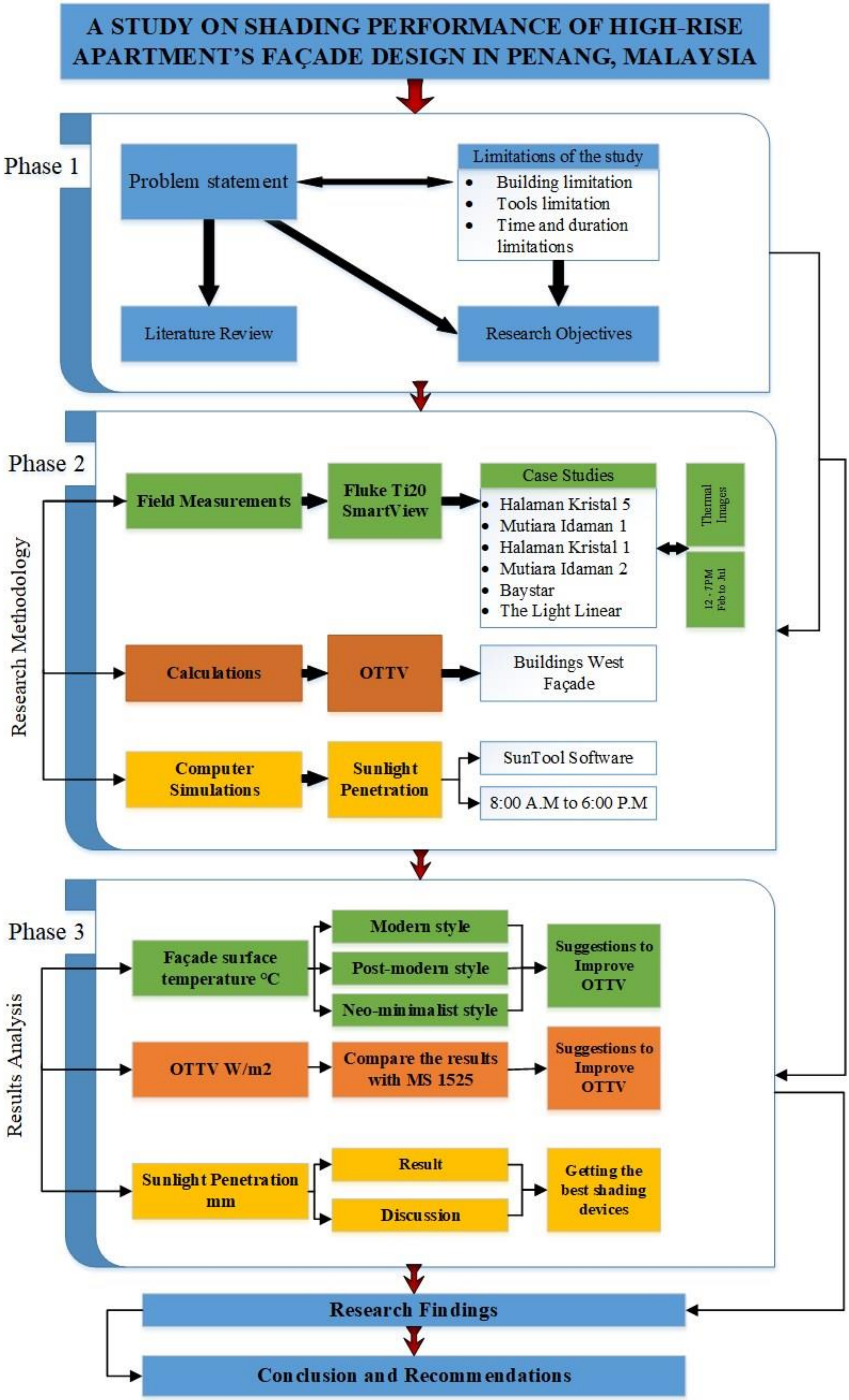

Figure 1.7 Research framework

1.8 Significant of the Study

Reducing heat gain and providing a good and comfortable atmosphere for residents are key points that should be taken into consideration by architects and designers. The extensive rural-to-urban migration has created a severe housing shortage and, therefore, high-rise buildings' type has become the main type of residential buildings, which provide the required housing. Based on (CETDEM, 2005), nearly half of the electrical energy in residential buildings is consumed by the air-conditioning system to achieve a suitable temperature. Thus, studying and investigating the thermal façade design and façade shading performance of high-rise residential buildings will help produce better façade designs. These improved designs will reduce heat gain and prevent unnecessary sunlight from penetrating into the indoor area.

Moreover, the Green Building Index (GBI) introduced designs along with suggestions for residential buildings to provide a good environment and reduce air-conditioning in residential buildings. Studies on high-rise residential buildings are scarce (GBI, 2013). Therefore, this study is significant research as it provides useful guidelines and directions for designers and proposes the best architectural style for high-rise buildings. The proposed guidelines aim to boost the façade shading performance, reduce the building's façade surface temperature, and as a result enhance the building's indoor atmosphere.

1.9 Limitations of the Study

While carrying out this study, there were a few limitations and obstacles that faced the researcher. The limitations can be divided into three categories: 1) the case study buildings' orientations, 2) tools and delay limitations, and 3) the duration of field measurements. This study investigated and analyzed six case studies. The selected case studies are located in different areas in Penang Island, Malaysia. This has led to the following limitations: 1) the study measured the façade surface temperature of different existing high-rise residential buildings. This has led the researcher to select a few case studies, but with some variation in the façade orientation, 2) the only tool, which is used by the researcher to measure the façade surface temperature, is Fluke Ti20 Infrared Thermal Imager. Finally, the measurements were limited to the time span of six months from February to July 2017.

1.10 Organization of Thesis

This study is organized into six chapters as follows:

Chapter 1 is the introduction of the study, which provides background information about the study, the problem statement, the research questions and objectives, limitations of the study, and the study framework.

Chapter 2 discusses the literature review, which covers thermal image, shading performance including shading area and sunlight penetration, Overall Thermal Transfer Value OTTV. It also discusses the tropical region's climate conditions and the high-rise residential buildings.

Chapter 3 discusses the development of high-rise building façade design in Malaysia from the 1950s until the present time. It presents the studied area and provides the architectural drawings of the selected case studies.

Chapter 4 describes the research methodology and presents the measurable factors and research variables. It presents and discusses the field measurements and computer simulation methods introducing the six selected case studies.

Chapter 5 analyses the results based on the field measurements and computer simulations during the study duration from February until July 2017 for the façade's thermal images, OTTV, and sunlight penetration.

Chapter 6 recaps the findings of the study and recommendations for further studies are advanced in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the previous related studies, which are related to the building surface temperature, thermal imaging, overall thermal transfer value, and sunlight penetration of high-rise buildings. The chapter aims to provide an overview of the study background. The chapter is divided into two sections. The first section defines the key terms that are used in the study. It provides a detailed discussion of the studied aspects of high-rise buildings in Penang, Malaysia. It also provides information on the regional climate and its factors, particularly the tropical climate in Malaysia. The second section focusses on the high-rise residential buildings including the low-income, high-rise residential buildings, as well as the studied apartments and condominiums.

2.2 Definitions of Terms

Definitions of the main terms and measurable factors in this study are presented in this section. The main four terms and factors are thermal images, surface temperature and overall thermal transfer value (OTTV), sunlight penetration, and shading performance.

2.2.1 Definition of Thermal Images and Surface Temperature

The aim of this study is to contribute to the thermal surface analysis of an apartment façade integrated with an on-field study using the thermal imager camera. The study findings provided data, which are helpful in guiding architects and those, who are involved in the building envelope design to tackle solar radiation on the building façades (Yasser Arab & Hassan, 2015). The collected data provided fundamental knowledge for designers to design building façades, which reduce solar radiation. The design has, therefore, reduced energy consumption on the mechanical cooling system inside the buildings. The study data also raised awareness regarding the model of the apartment façade design. The findings shed light on the importance of the building skin with minimum indoor heat gain problems through the utilization of the scientific know-how into practice (Arab, 2015; Prado & Ferreira, 2005).

In a tropical region like Malaysia, the apartment façade design, which prevents the building from the solar radiation is crucial. The apartment façade is exposed to direct sunlight and this causes the problem of solar radiation to the indoor area and the façade's surface temperature (Omer, 2008). The solar energy, which radiates the heat from the outside wall, is transmitted into the interior of the house. It generates heat gains inside the house, which creates heat gain to the room air temperature. This causes an uncomfortable thermal condition to the occupants (Cena & Clark, 1978b, 1978a). The problem is that most apartment buildings have a poor façade design with sun shading elements (S. Hassan, Arab, Salem, & Bakhlah, 2015). Most medium-income families cannot afford to install an air conditioning system in all the rooms in the apartment and if so, they have to pay high electric bills. The sun shading elements determine the intensity level of the solar radiation striking on various surfaces of the apartment façades (Arab & Hassan, 2015; A. S. Hassan & Arab, 2014).

The study survey included the studied apartments' façades and it was conducted on site. The surface thermal temperature of the apartments' façades was obtained using the thermal imager device 'Fluke Ti20'. It is a camera with a thermal surface detector.

The surface temperature of the apartments' west façades was exposed to direct sunlight was measured. The apartments' façades are relatively perpendicular to the evening sun path. As a result, these façades were investigated to conduct the comparative analysis. The measurements were conducted at hourly intervals from 1.00 pm to 6.00 pm. Fluke Ti20 produced a series of digital surface temperature photo images detected using an infrared lens, which indicated the amount of heat cast at the façades' surface. There is a grid reference, which is used as an indicator to carry out to analyze the data (Bezbabicheva, O. I. Bilchenko & Kyslov, 2010).

2.2.2 Overall Thermal Transfer Value

Energy is one of the indispensable factors for development and economic growth; energy consumption has rapidly increased. Residential energy consumption is one of the major energy consumption sectors (Hui, 1997). Overall Thermal Transfer Value (OTTV) measures the envelope thermal performance of air-conditioned buildings based on energy efficiency standards. Yik & Wan (2005) stated that the OTTV is an appropriate building envelope energy performance index for use in regulatory control. Based on the climatic parameters, OTTV is calculated for residential building envelope designs in Malaysia. In order to standardize the residential energy consumption, researchers have investigated many parameters. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers introduced OTTV, which measures heat transfer from outside to inside the building. Moreover, Lam, 2000 stated that there are three components of heat transfer from outside to inside the building such as conduction through the opaque surface, conduction through the glass, and solar radiation through the glass (Li, Lam, & Wong, 2002).

OTTV for the walls: The surfaces of an opaque wall, solar, and thermal radiation together with convection heat transfer causes a net conduction heat flow into the wall material. Hui 1997 clarified that walls at different orientations receive different amounts of solar radiation. The general procedure is to calculate the OTTV of individual walls with a similar orientation. It is calculated by the weighted average of these values.

In 1975, the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) proposed OTTV, which is a measure of the average heat gain into a building through the building envelope indicating its thermal performance (L. P. Wang, 2006). OTTV according to the Malaysian Standard 1525 is a design parameter, which refers to the solar thermal load that is transmitted through the building envelope excluding the roof The accepted value of OTTV according to the MS1525 standard is $50W/m^2$ (Department of Statistics Malaysia, 2007). OTTV is one aspect of energy conservation for the design and planning of energy-efficient buildings. It measures the energy consumption of a building envelope (Hanna, 2004). According to the Malaysian Standard 1525, OTTV aims at achieving the design of the building envelope to reduce external heat gain and, therefore, reduces the cooling load of the air-conditioning system. It can be applied to air-conditioned buildings only based on the assumption that the envelope of a building is completely enclosed (Vijayalaxmi, 2010).

2.2.3 Definition of The Sunlight Penetration and Shading Performance

The main aim of this study is to analyze the extent of sunlight penetration to the indoor area in order to achieve a better understanding of the façade shading performance of the colonial and neo-minimalist apartment buildings. SunTool is computer simulation software, which was used to obtain the extent of sunlight penetration at the east and west façades of the case studies (Y. Arab, Hassan, & Qanaa, 2017b). The simulations were conducted during hourly intervals when the apartments' façades were exposed to direct sunlight from 8:00 am until 7:00 pm. Penang is located close to the equator, which has almost the same duration of daytime and night time. Normally, the sunrise time is at 7:00 am and the sunset time is at 7.30 pm. The simulation was conducted based on the sun's orientation and azimuth data, where the sun rays were perpendicular to the building's façade at the east façade in the morning and at the west façade in the evening (A. S. Hassan & Mazloomi, 2010; Mazloomi, Hassan, Bagherpour, & Ismail, 2010). In order to obtain reliable simulation results, this study was limited to the sun path at perpendicular sunlight rays either to the east façade (90°) or to the west façade (270°) (Arab, Y. Hassan, 2012; A. S. Hassan & Bakhlah, 2013; S. Hassan et al., 2015) as shown in Table 1 and Figure 3. The simulation was limited to the perpendicular direct sunlight exposure, which takes place on certain dates and times throughout the year. However, the limitation of this survey is that on these dates and times, there are azimuths of the sun rays that cannot be exactly 90° or 270°. As an alternative, the simulation used the closest azimuth to 90° and 270° in the morning and evening hours, respectively (Figure 2.1) (Arab & Hassan, 2013).