POTENTIALS OF ENERGY EFFICIENCY IN A PUBLIC HOSPITAL: A CASE STUDY IN HOSPITAL KAJANG

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A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
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JUNE 2022

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ACKNOWLEDGEMENT

"In the name of Allah, most Gracious, most Compassionate" Alhamdulillah. I am longing the felt of gratitude to those people who always provide and nurture their support, guidance and loves.

I would like to extend my deepest gratitude to my supervisor Dr. Mohd Faizal bin Mohideen Batcha for his lots of advice and guidance.

I would like to extend my appreciation to both my family, especially my wife and daughter for always supporting and motivating me during my studies.

I am also greatly thankful to the Director of Hospital Kajang and all the staff from the facility management unit, including staff from Radicare Sdn. Bhd. attached at Hospital Kajang for their technical support during energy audit and data collection at site. It has been very challenging during this pandemic and without all their help, this study may not be possible to be completed.

Finally, yet importantly, I also would like to thank all my friends and family who have been supporting me in my study.

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ABSTRACT

Hospitals are known to be one of the largest energy consumers as they continuously provide healthcare services to the community on a daily basis. This thesis reports a case study carried in one of the public hospitals in Malaysia - Hospital Kajang, as an effort to gather and disseminate more information regarding energy efficiency opportunities in hospitals which will benefit the hospital management as well as the public. The study was carried out via walk-through audit and desktop analysis, followed by a detailed energy audit to identify the electrical energy consumption pattern, factors that affect the energy usage and end-use energy analysis based on different categories namely air conditioning and mechanical ventilation system, lighting system, medical equipment, IT equipment and peripherals and other electrical equipment. Malaysian Standard MS 1525:2019 was used in this study for evaluating the indoor environment quality as well as lighting to ensure energy efficiency will not affect these requirements. From the study, it was found that the largest electrical energy end-user in Hospital Kajang is the air conditioning and mechanical ventilation system, which consumes approximately 78% of the total electrical energy. The building energy index calculation revealed that the hospital building has an index of 302.32 kWh/m^2/year for the year 2019 which is significantly higher than the benchmark value of 200 kWh/m^2/year for office buildings. A number of energy efficiency measures were proposed to reduce energy consumption in Hospital Kajang, together with their respective economic analysis.

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ABSTRAK

Hospital dimaklumi sebagai salah satu pengguna tenaga terbesar kerana hospital beroperasi secara berterusan setiap hari tanpa henti bagi menyediakan perkhidmatan kesihatan kepada masyarakat setempat. Tesis ini melaporkan kajian kes yang dijalankan di salah sebuah hospital awam di Malaysia iaitu Hospital Kajang. Kajian ini dijalankan sebagai salah satu usaha untuk mengumpul dan menyebarkan lebih banyak maklumat berkaitan peluang kecekapan tenaga di hospital yang akan memberi manfaat kepada pengurusan hospital dan masyarakay . Kajian ini telah dijalankan melalui audit *walk-through* diikuti analisis desktop, diikuti dengan audit tenaga terperinci untuk mengenal pasti corak penggunaan tenaga elektrik, faktor-faktor yang mempengaruhi penggunaan tenaga dan penggunaan tenaga akhir berdasarkan kategori berikut: sistem penyaman udara dan pengudaraan, sistem lampu, peralatan perubatan, peralatan teknologi maklumat dan peralatan elektrik lain. Piawaian Malaysia MS 1525:2019 telah digunakan dalam kajian ini memastikan cadangan-cadangan kecekapan tenaga yang dibuat tidak menjejaskan keperluan kualiti persekitaran dalaman dan pencahayaan di hospital. Hasil kajian mendapati pengguna tenaga elektrik terbesar di Hospital Kajang ialah sistem penyaman udara dan pengudaraan, yang merangkumi 78% daripada jumlah tenaga elektrik keseluruhan. Pengiraan indeks tenaga bangunan mendapati bangunan hospital mempunyai indeks 302.32 kWj/m^2/tahun bagi tahun 2019 iaitu jauh lebih tinggi daripada nilai penanda aras 200 kWj/m^2/tahun bagi bangunan pejabat seperti yang disarankan di dalam MS1525:2019. Beberapa langkah kecekapan tenaga telah dicadangkan untuk mengurangkan penggunaan tenaga di Hospital Kajang, beserta dengan analisis ekonomik yang berkaitan.

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LIST OF SYMBOLS AND ABBREVIATIONS

AH	----	Absolute Humidity
AHU		Air Handling Unit
CHWP		Chilled Water Pump
CO_2		Carbon Dioxide
CWP	-	Cooling Water Pump
ECMs	-----------------	Energy Conservation Measures
GAI	-	Green Area Index
GIS	-	Geographic Information System
GPS		Global Positioning System
GWh		Giga Watt-hours
HID		High-Intensity Emission
Ktoe		Kilo tonne of oil equivalent
kW		Kilo Watt
LED		Light Emitting Diode
LNG		Liquid Natural Gas
MARDI		Malaysian Agricultural Research and Development
PF		Institute
PV		Plant Factory
RH		Photovoltaics

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RPM	Relative Humidity
SPAD	Revolutions Per Minute
TNB	Soil Plant Analysis Development
TOU	Tenaga Nasional Berhad
VPD	Time of Use
VRI	Vapour Pressure Deficit
	Variable Rate

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CHAPTER 1

INTRODUCTION

1.1 Background study

Energy is essential for human beings. In science, the law of conservation of energy states that energy cannot be created or destroyed. It can only be transformed from one form to another as well as transferred from one body to another but the total energy remains the same. With the population growth exceeding 7.8 billion in 2020 (*Current World Population*, n.d.), energy security has become one of the biggest challenges for mankind today. According to BP Energy Outlook 2019 (*World Energy Resources 2016 | World Energy Council*, n.d.), the world energy consumption can be divided into four important sectors: transportation, industry, buildings and non-combusted energy uses.

Being one of the largest energy consumers, building energy consumption has received great attention from engineers worldwide towards reducing energy consumption while coping with development and maintaining productivity. Increasing demand for energy particularly in the developing countries has prompted greater efforts by organizations to balance between energy generation and energy consumption. Significant amount of research works related to consumption of total energy in buildings have been carried out to share knowledge in energy efficiency and energy conservation initiatives (Sheng et al., 2018).

Malaysia, among other developing nations, has recorded a steady increase in energy demand since 1990 (*Malaysia Energy Statistics Handbook 2019*, 2020), and the figures were expected to further grow despite some hampering in the economic sector due to Covid-19 pandemic. It was estimated by (Marinosci et al., 2015) that

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the building sector's electrical energy consumption was up to 48% from the nation's overall electricity consumption. Hence for energy sustainability and conservation, the Malaysian government has outlined various initiatives, including the drafting of the Energy Efficiency and Conservation Act which is expected to be enacted this year, apart from encouraging research works in this area. In the building sector, there are a number of buildings which are known to consume relatively higher amounts of energy thus having higher energy intensity. Hospitals are known to be one of the high energy intensity facilities due to their 24 hours operation throughout the year.

As such, a case study on energy efficiency aspects was carried out in one of the government hospitals in Malaysia - Hospital Kajang. This case study involves both walk-through energy audit and detailed energy audit in Hospital Kajang, intended to investigate the electrical energy consumption characteristics by the hospital, followed by end-energy use breakdown and proposal for relevant energy efficiency measures. To ensure the feasibility of the energy efficiency measures, an economic assessment was also conducted in this study.

1.2 Problem statement

Hospitals are usually made up of several buildings with a variety of functions namely patient's examination and consultation building, wards, operation theater area, administration office, cafeteria and many more. Each of these buildings have their unique operational characteristics which are proportional to their energy consumption profile. This provides a challenge to the facility management team to implement energy efficiency strategies without affecting the operation. Hospital Kajang has been chosen for this case study, as the hospital is relatively old and serves one of the most densely populated cities in Malaysia. Hence a detailed study is required to aid the hospital management towards energy efficient operation. The status quo of the present energy consumption by the hospital was analysed and compared with the recommended building energy index value of 200 kWh/m²/year in MS1525:2019 (*Malaysian Standards: (MS) 1525: 2019 – Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings – SEDA Malaysia*, n.d.).

In addition, the demand of electrical energy for heating purposes also requires evaluation as the potential to generate hot water via solar thermal system due to the

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increasing demand of hot water usage in hospitals, especially for cleaning and sanitation.

1.3 Objective

The objectives of this study are:

i. To analyze the energy consumption characteristics of Hospital Kajang
ii. To propose relevant energy efficiency measures for Hospital Kajang, and
iii. To evaluate the feasibility of integrating solar thermal system in Hospital Kajang.

1.4 Scope of study

There are several scopes of study to ensure the objectives can be achieved as following:

i. The case study is to be carried out in Hospital Kajang.
ii. Two types of energy audit to be carried out: walk through audit and detailed energy audit
iii. The electrical energy characteristics were based on annual energy consumption in 2019.
iv. Determination of building energy index (BEI) for Hospital Kajang and benchmarking with value proposed in MS1525:2019.
v. To design a solar thermal system for heating demand in Hospital Kajang.
vi. Economic analysis of solar thermal system based on simple payback period (SPP)

1.5 Significance of study

Among the significance of this study is to benchmark the present energy consumption in Hospital Kajang comprehensively to implement specific and relevant energy saving measures. Apart from that, the study may provide the vital information required to support our government’s ongoing initiative to establish energy profiles in various sectors including healthcare to facilitate the Building Energy Index

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Labeling (BIEL) program by the Energy Commission of Malaysia. The findings from this study may also benefits other hospitals in Malaysia towards becoming more energy efficient

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes an overview of the study on energy efficiency and energy consumption that has been carried out in the building. The main focus of this study is to gather information about electrical energy production, energy consumption, energy distribution and energy efficiency. Also, this chapter will explain about the current scenario of power generation and energy consumption in the world. It also describes previous statistical reports of energy consumption and the information was compared. Furthermore, information on the distribution of energy consumption in the building will be explained thoroughly in this chapter. At the end of this chapter will explain the energy efficiency of the building and solar thermal.

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2.2 World energy scenario

Energy in Malaysia essentially combines several energy resources such as oil, coal, natural gas from conventional sources to renewable energy sources such as solar energy, biomass and hydropower plants. In 1990 to 2017, more than 90% of the electricity in the peninsula was generated by fossil fuels (*Malaysia Energy Statistics Handbook 2019*, 2020). In 2016, 52% of the energy generation was from coal and 44% from natural gas. Figure 2.1 shows the total primary energy supply by fuel type in kilo tonne of oil equivalent (ktoe).

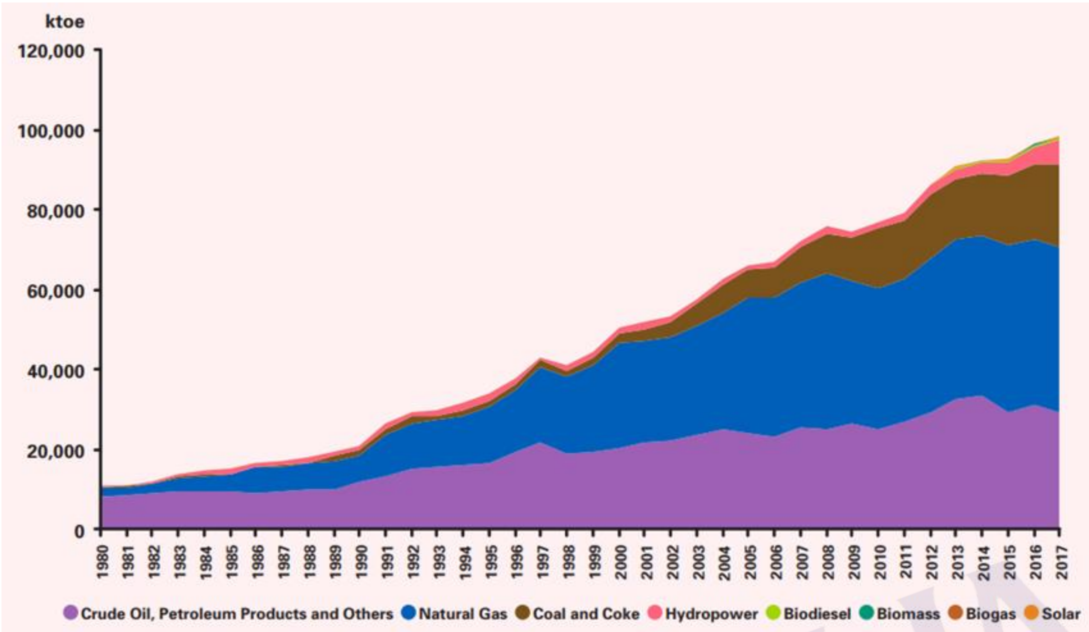

Figure 2.1: Energy source in Malaysia (*Malaysia Energy Statistics Handbook 2019*, 2020)

Figure 2.1 indicates that while petroleum products and natural gas have dominated as Malaysian primary fuel source for the last three decades, coal and coke has started to receive attention and its consumption as primary fuel rose significantly every year beginning 2001. This is due to the depleting local oil and gas resources while coal and coke are much cheaper on the global market. Apart from that, the advent of clean coal technologies enables sustainable power supply with reduced greenhouse gas emissions. It is also worth noting that hydropower and renewable resources such as biomass and solar have also made an impact with increasing production over the years.

The main challenge in Malaysian energy sources is to maintain the efficiency and reliability of the power plant in supplying sufficient energy with growing demands. Furthermore, studies and enhancements are continuously pursued to increase renewable energy use and ensure competitive supply to consumers is always affordable. In addition, the energy commission will continue to monitor progress and energy consumption development as well as promote energy conservation such as conducting energy audits, benchmarks and building energy index.

2.2.1 Types of energy

Energy can be produced from various natural resources in this world. Energy can be divided into two parts, renewable energy and non-renewable energy. Besides, the type of energy is divided into two parts, that is kinetic energy and potential energy. Potential energy is generating energy in a mass because of its position and condition such as chemicals and gravity energy. Kinetic energy is the energy generated in moving objects such as swinging pendulums and rotation of windmillsFigure 2.2 shows the division between potential energy and kinetic energy. Table 2.1 describes the type of energy.

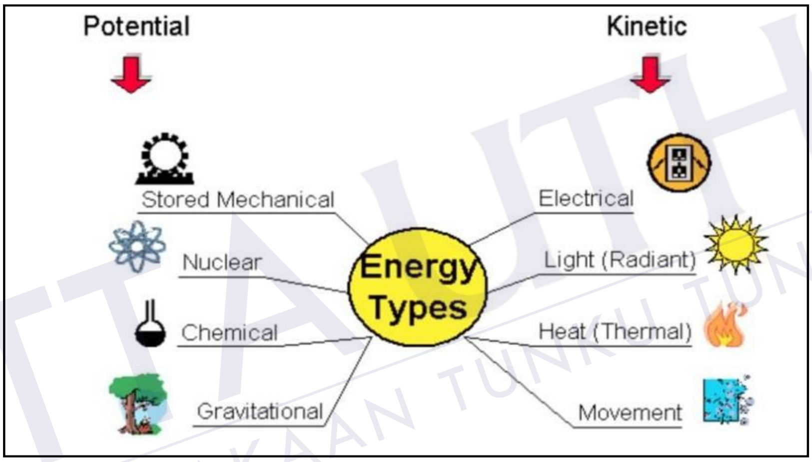

Figure 2.2: Types of Energy (*World Energy Resources 2016 | World Energy Council*, n.d.)

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Table 2.1: Sources of Energy (*World Energy Resources 2016 | World Energy Council*, n.d.)

Energy	Description
Nuclear	Interactions with the neutrons and protons of an atom and thus relate to the strong force.
Chemical	Produced by or forming chemical or breaking bonds between atoms and molecules.
Mechanical	The kinetic energy and potential energy.
Gravitational	Dependent on the mass, distance and the gravitational constant.

Electrical	Movement of charged particles such as protons, ions and electrons.
Light	Photons are a form of energy.
Heat	Energy from the movement of atoms or molecules and considered as energy relating to temperature.

2.3 Building

The Malaysian energy commission has divided buildings in Malaysia into several categories according to its use and the characteristics of the occupants. Among the buildings in Malaysia is (*Malaysia Energy Statistics Handbook 2019*, 2020).

a) Agricultural building
b) Commercial building
c) Residential building
d) Educational building
e) Government building
f) Industrial building
g) Military building\

2.3.1 Commercial Building

A commercial building is buildings that are used for commercial purposes such as warehouses, office buildings, hospitals, retail buildings and hospitals. The energy consumption for each classification of buildings is different according to the tariff by the energy provider.

2.4 Energy Consumption Distribution in Building

Energy consumption in buildings is divided into several parts, such as cooling systems, power systems, IT equipment, lighting system and other equipment. Energy consumption in the building requires detailed information such as geographical

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location, operating schedule, building materials, air conditioning systems, energy supply, lighting system and climate. In Malaysia, for office and commercial buildings, the total electrical energy consumption is about 48% (*Malaysia Energy Statistics Handbook 2019*, 2020; Marinosci et al., 2015). Each building was constructed with various sizes, shapes, standards for specific purposes.

The difference in energy consumption is due to various factors such as operating time, weather conditions, occupancy schedules and equipment. A study of energy consumption has been conducted at a large hospital in Malaysia and it shows energy consumption is divided into several main parts (Moghimi et al., 2014), such as air-conditioning, medical equipment, lighting, ventilation and others. Figure 2. 3 shows the division of energy consumption of a building (Khoshbakht et al., 2018).

Table 2.2: Electricity consumption based on different sectors (Khoshbakht et al., 2018)

Sections		Consumptions (kW)		Percentage of total (%)	
Air conditioning	Main central systems (Chillers,pump, mini chillers)	19,323,977	25,663,203	46.7	62.0
	AHU	3,361,624		8.1	
	FCU	621,842		1.5	
	Split Unit	1,172,791		2.8	
	Ceiling Fan	30,660		0.1	
	Exhaust Fans	1,152,309		2.8	
Lifts		552,654		1.3	
Lighting		8,513,900		20.6	
Equipment and others		6,649,345		16.1	
Total		41,379,113		100	
AHU air handling unit, FCU fan coil unit					

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Table 2.2 shows the highest energy consumption in the building is the air-conditioning system. A study conducted in Canada states that environmental conditions and climate can affect energy consumption in the building (Rouleau et al., 2018). Besides that, the occupant behavior also affects energy consumption such as opening windows and doors while using the air conditioner. A study was conducted on three different types of buildings to investigate energy efficiency and the result was a difference in terms of energy consumption due to the variation in occupancy, building function as well as building design (Tahir et al., 2015). Malaysia is a temperate, tropical country. The percentage of high energy consumption is indicated by the air conditioning system and can be attributed to irresponsible attitude occupants. Heating, Ventilating, and Air- Conditioning are the systems that need to be installed in every building to provide comfort to users (Hassouneh et al., 2015). Figure 2.3 shows a breakdown of the HVAC system in the building.

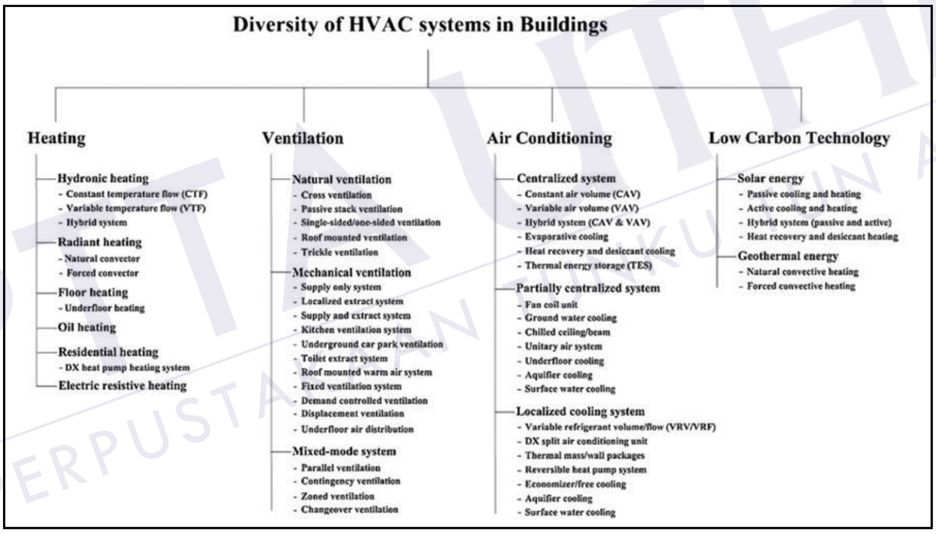

Figure 2.3: HVAC systems in buildings (Hassouneh et al., 2015)

Other than air conditioning systems, IT equipment and lighting systems also use most of the energy consumption in buildings (Roth & Rajagopal, 2018). The percentage of energy consumption is different for each building. If energy consumption information is studied in detail, there are many effects that can cause increased energy consumption, such as other equipment, elevators, etc. (Xin & Rao, 2013). But in performing significant improvements in energy consumption, the highest percentage of energy consumption should be reviewed and controlled.

2.5 Energy Efficiency

Energy efficiency in the buildings refers to the total energy consumption per square meter of floor area of the building (Syed Yahya et al., 2015). Energy efficiency can also be determined by measuring the energy consumption before and after the implementation of energy efficiency improvement measures. This energy efficiency is also coordinated under local climate conditions to adjust the energy efficiency. Malaysia, especially in the the state of Sabah and Sarawak, also relies on hydropower as a major source, the risk of drought will lead to a major source of electricity losing much of its energy generation capabilities (Dwaikat & Ali, 2018). Hence, the importance of every development sector to carry out improvement in terms of energy efficiency. In India, the implementation of energy efficiency policies has been carried out through a study and shows that in the year 2050, 20% of energy consumption can be reduced compared to previous energy efficiency (Kluczek & Olszewski, 2017).

There are several steps that can be taken to improve energy efficiency, among which is to conduct energy consumption audits. Energy audits are to conduct continuous observations in addition to collecting information about energy consumption in the building. In addition, a benchmark for the energy consumption of the building by comparing the actual performance of energy usage in the previous year through the building energy index is done.

2.5.1 Energy Audit

An energy audit is being conducted to collect and analyze information on the characteristics of energy consumption in the buildings. This process is the first step in identifying the measures to reduce energy consumption, especially for the commercial and industrial sectors. In conducting energy audits, the use of professional equipment such as a weather meter, lux meter, digital clamp meter and infrared camera is required. A study conducted in Germany shows that energy audits can increase energy efficiency in buildings (Yung et al., 2013). In a study carried out in Brazil, industry also argued that energy audits could help to increase energy efficiency (González et al., 2011). This energy audit process can be carried out either

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in the industrial sector or in small scale buildings such as residential houses. An energy audit is closely related to the cost of bill payments, consumer comfort and energy efficiency. Based on previous research, it can be ascertained that the energy audit can increase the energy efficiency of the building.

2.5.2 Building Energy Index

The building energy index (BEI) is a globally accepted performance criterion which is used to measure energy usage intensity in buildings. A variety of BEI values were proposed and utilized in many worldwide. The initiative of energy performance of buildings was reported to begin as early as the 1970s, motivated by the energy crisis which occurred then. Among the earliest energy indices were proposed by Yannas (Krawietz, 2007), known as the 'Energy Index (EI)', and other pioneering works such as by Silpasastra in India (Acharya, 1995) and Morgan in Rome (Vitruvius & Morgan, 2019) focused on design models based on climate types. A comprehensive review on BEI has been done by (Abu Bakar et al., 2015). The energy index allows a proper benchmarking of the energy consumed by the building over a period of time, which helps towards continuous improvement.

Recently, the Energy Commission of Malaysia introduced the building energy index labeling program for government building (*NATIONAL BUILDING ENERGY INTENSITY (BEI) LABELLING FOR GOVERNMENT BUILDINGS*, n.d.). The aim of the program is to encourage government staff to improve the energy intensity of their respective buildings. At the moment, the program has enrolled government office buildings in Putrajaya, several public hospitals, public universities, schools and aims to involve other premises in the future. The range of BEI values are shown in Figure 2.4, whereby a 5-star rating is given to buildings achieving a BEI value less than 100 indicating the most energy efficient building.

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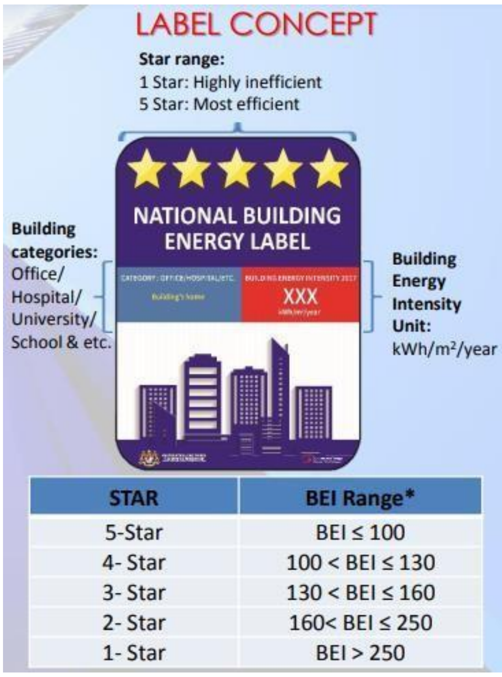

Figure 2.4: Building energy index labelling (*Malaysia Energy Statistics Handbook 2019*, 2020)

While the BEI labeling program by the Energy Commission focuses on government buildings, the building energy indexing in the private sector began much earlier. Among the established building energy indexing is the one by Green Building (GBI) which offers a variety of assessment tools which covers other aspects of the building apart from energy such as water and material consumption. For energy consumption, GBI recommends an index of 150-180 kWh/ m2/year for existing buildings where GBI divides their green rating into platinum, gold, silver, and certified, indicating the best to the worst in terms of green rating points (Moghimi et al., 2014). Among the buildings in Malaysia which was awarded the platinum GBI rating was the Public Works Department's tower in Kuala Lumpur in 2016.

2.6 Solar Thermal Application

Solar heaters, or solar thermal systems, provide environmentally friendly heat for household water heating, space heating, and the heating of swimming pools. Such systems collect the sun's energy to heat a fluid. The fluid then transfers solar heat directly or indirectly to the home, water, or pool to be utilized.

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