ENERGY EFFICIENCY PERFORMANCE MODEL FOR OFFICE BUILDINGS IN MALAYSIA

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DEDICATION

This thesis is dedicated to my mother, wife and children.

Seeking knowledge is a duty upon every Muslim.

-Ibnu Majah

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ABSTRACT

Energy consumption in Malaysia has risen sharply and it is mostly contributed by commercial buildings. Energy benchmarking is necessary to improve the overall use of energy. This study aims to develop the baseline consumption and energy performance benchmark model through Building Energy Index (BEI). Energy audit reports from 25 office buildings in Malaysia were analysed to identify the factors that contribute to energy performance of office buildings. Regression analysis, via Ordinary Least Square (OLS) and Robust Least Trimmed Square (LTS) regression, was used to formulate baseline energy model and also Building Energy Index (BEI) model. Three other buildings were selected as samples for validation and verification of the model. The results showed Baseline Robust LTS model had the accuracy of 99.93%. This is followed by $BEI_{(GFA)}$ with accuracy of 68.64%, while $BEI_{(ACA)}$'s accuracy was recorded at 72.65%. These results showed that the model deducted from Robust LTS method for Baseline, $BEI_{(GFA)}$ and $BEI_{(ACA)}$ are applicable and feasible due to the accuracy. The validation showed that 6 from 9 cases were found to have less than 10% errors which is equivalent to 66.67%. This indicates that the model is applicable to predict energy efficiency in real situation for office buildings in Malaysia. This study established that Robust LTS models are able to predict the baseline and energy performance of office buildings by using single set of data, which is a holistic approach in determining the energy performance of office buildings.

ABSTRAK

Penggunaan tenaga di Malaysia semakin meningkat dengan ketara dan kebanyakannya terdiri daripada bangunan komersial. Penanda aras tenaga amat diperlukan untuk memperbaiki penggunaan keseluruhan tenaga. Kajian ini bertujuan untuk membangunkan model penggunaan garis pangkal dan model penanda aras prestasi tenaga melalui Indeks Tenaga Bangunan (BEI). Laporan audit tenaga daripada 25 bangunan pejabat di Malaysia dianalisis untuk mengenal pasti faktor-faktor yang menyumbang kepada prestasi tenaga bangunan pejabat. Analisis regresi, melalui Kuasa Dua Terkecil Biasa (OLS) dan regresi Kuasa Dua Trim Terkecil Teguh (LTS) digunakan untuk merumuskan model tenaga garis pangkal dan juga model Indeks Tenaga Bangunan (BEI). Tiga bangunan lain dipilih sebagai sampel untuk pengesahan model tersebut. Dapatan kajian menunjukkan model Garis Pangkal LTS Teguh mempunyai ketepatan 99.93%. Ini diikuti oleh $BEI_{(GFA)}$ dengan ketepatan 68.64%, manakala ketepatan $BEI_{(ACA)}$ direkodkan pada 72.65%. Dapatan kajian ini menunjukkan bahawa model yang diperoleh daripada kaedah LTS Teguh untuk garis pangkal, $BEI_{(GFA)}$ dan $BEI_{(ACA)}$ boleh diaplikasi dan dilaksanakan kerana ketepatannya. Pengesahan model menunjukkan bahawa enam daripada sembilan kes didapati mempunyai ralat kurang daripada 10% yang bersamaan dengan 66.67%. Ini menunjukkan bahawa model yang dibangunkan boleh diguna pakai untuk meramal situasi sebenar kecekapan tenaga bangunan pejabat di Malaysia. Kajian ini menegaskan bahawa model LTS Teguh dapat meramal garis pangkal dan tenaga bangunan pejabat dengan menggunakan satu set data yang merupakan pendekatan holistik dalam menentukan prestasi tenaga bangunan pejabat.

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LIST OF ABBREVIATIONS

ACA	-	Air-Conditioning Area
ACMV	-	Air Conditioning and Mechanical Ventilation
AEI	-	Annual Energy-Intensity
ANN	-	Artificial Neural Network
BEI	-	Building Energy Index
BLC	-	Building Load Coefficient
CBECS	-	Collection based on a building energy consumption
EIA	-	International Energy Outlook
EPI	-	Energy Performance Indicator
ES	-	European Standards
EUI	-	Energy Use Index / Energy Use Intensity
GFA	-	Gross Floor Area
GHG	-	Green House Gas
HVAC	-	Heating, Ventilation and Air-conditioning
IMT	-	Inverse Modelling Toolkit
LEED	-	Leadership in Energy and Environmental Design
LTS	-	Least Trimmed Square
M&E	-	Mechanical and Electrical
MEIH	-	Malaysia Energy Information Hub
Mtoe	-	Million Tons of Oil Equivalent
O&M	-	Operation and Maintenance Manual
OECD	-	Organization for Economic Cooperation and Development
OLS	-	Ordinary Least Squares
PTM	-	Pusat Tenaga Malaysia
SSE	-	Sum Square Error
SSR	-	Sum Square Regression
SST	-	Total Sum of Squares
TNB	-	Tenaga Nasional Berhad
TQM	-	Total Quality Management
USEPA	-	United States Environmental Protection Agency

LIST OF SYMBOLS

n	-	Number of Observation
p	-	Number of Predictors or Independent Variables
β	-	Regression Coefficients
ε	-	Error
y_i	-	Sample Value of the Dependent Variable
$\hat{y}_i$	-	Corresponding Value Estimated from the Regression Equation
R^2	-	Coefficient of Determination

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Energy production is experiencing a depletion in the primary source which is oil (Hook & Tang, 2013). This threatens the global power generation industry and many countries are looking for alternative energy to generate power. Several studies have been conducted to analyse the sustainability and innovation in energy consumption and generation. However, the task is deemed to be a challenge because the demand for energy use is expected to increase along with global development (Woody, 2013). This is particularly observed in buildings that have high-tech automation system and services as their source of operation. Without proper energy management, it can lead to wastage of energy and bring negative impact to environment (Power-Star, 2015).

Asia is recorded to consume the highest level of energy (Lee, Park & Saunders, 2014). The total of world energy production is 12,800 Million Tons of Oil Equivalent (Mtoe) with share of energy consumption by Asia is 4,882 Mtoe. International Energy Outlook (EIA, 2015) has reported that energy used by developing countries which are mainly from Asian countries will out-consume the Organization for Economic Cooperation and Development (OECD) countries. OECD is a forum that consists of developed countries which has the aim of developing social and economic policy. China and India are two non-OECD countries that are forecast to consume almost half of the global energy generation and more than 40% of the energy consumed by OECD countries in 2040 (Conti, 2016).

The global electricity generation increases by around 60% between 2016 and 2040 (A View to 2040, 2018). The demand for electricity in the year 2020 in kilowatt hours (kWh) will be expected about 25.8 trillion kWh and the number will significantly increase to 36.5 trillion kWh in 2040 compared to only 21.6 trillion kWh in 2012 (Conti, 2016).

The growth in the global electricity demand is mainly due to lifestyle changes that are triggered by the use of new appliances and devices (Chen, 2017). In addition, the consumption increases in commercial buildings like hotels, hospitals, malls and sales outlets that is resulted from rise of population and growing product ranges. The contribution is higher by developing Asian countries than OECD countries which have a rise factor of just 2.5% due to their caution and also prevailing awareness scheme (S.V. Pisupati, 2016).

Other efforts to generate electricity from renewable sources are also given consideration to relief the current state. Apart from hydroelectricity, other renewable energy generation sources are also on the rise. EIA reported from 5% to 14% increment in the renewable electricity sources by the year 2040. The renewable energy generating process is estimated at 1.2% annually. Notwithstanding the above, coal fired power generation has been declining by 0.8% a year from 2.29% per year ever since 2012 (McCarthy, 2019).

On the other hand, the generation of nuclear power is expected to rise from 2.3 trillion in 2012 to 3.1 trillion in 2020 and 5.4 trillion in 2040. Figure 1.1 shows the different source of electricity generation from 2012 to 2040 (International Energy Outlook, 2016).

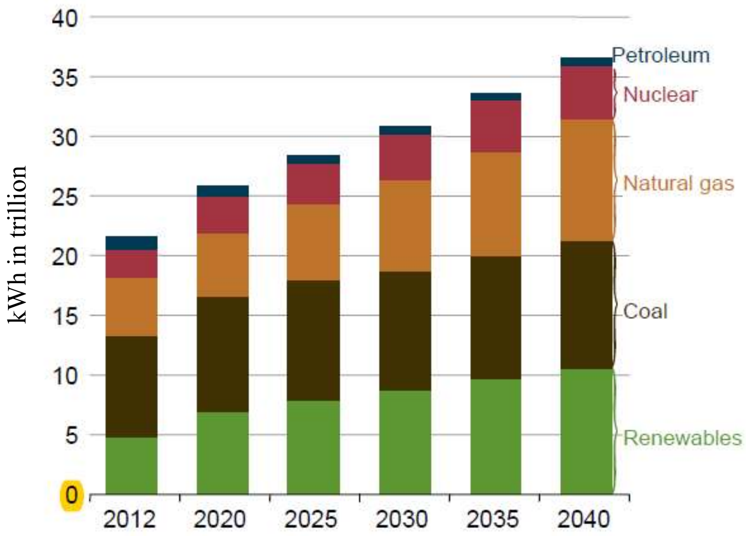

Figure 1.1 World Electricity Generation from 2012 – 2040 (International Energy Outlook, 2016)

Malaysia's energy consumption can be broadly divided into five areas namely industrial, transport, agricultural, commercial and residential and non-energy. According to Malaysia Energy Information Hub (MEIH), the country had produced 42,000 ktoe of energy in the year 2010 of which the transport sector was recorded to consume 41% of energy. This is followed by industrial (31%), commercial and residential buildings (16%), non-energy (9.4%) and agriculture (2.6%). In terms of year-to-year consumption, commercial and residential building is the highest energy consumer compare to other sectors. There has been an increase of 44% since the year 2000 (Chong *et al*, 2015). This sector includes hospitals, schools, office buildings, malls, supermarkets and all types of residential buildings. The commercial and residential building sector alone consumed 7,000 ktoe in the year 2010. At the rate of 5.6% average yearly rise in consumption, it is predicted that the total need by the residential and commercial building sector will lead to 12,000 ktoe by 2020 (Tan *et al*, 2013).

Even though Malaysia is an oil producing country and has abundant of energy reserves, sustaining the resources will be very expensive in future production cost (Ahmad & Abdul Ghani, 2011).

It is estimated that 40% of the energy generated is currently used for residential and commercial building (Hassan *et al*., 2014). According to Chong *et al*. (2015), the second largest energy consumers in Malaysia is government buildings and commercial office complexes. Generally, audit data showed that buildings consume the most energy in Malaysia. The use of electrical equipment within the premises of the buildings, over-sized buildings compared to the occupancy ratio, extended operational hours and very poor operation and control strategies for energy usage are several factors that contribute to high energy consumption.

Although electricity is considered to be cheap in Malaysia, the consumption volume is a major concern since the generation costs are expensive with consideration to external issues such as environmental impacts and ratified global agreements e.g. limits on carbon emissions. Eventually, a revamp on the energy policy is required to cater to one of the challenges which is demand management side (KeTTHA, 2017).

In 1989, the Ministry of Energy, Science, Technology, Environment & Climate Change (MESTECC) introduced the Guidelines for Energy Efficiency in Buildings. The Guidelines was developed as a Malaysian Standard, i.e. MS 1525 – Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings" in 2001. The code has been used as a guide in designing energy-efficient buildings in the country. The code was revised in 2007 and 2014 to incorporate the latest technological developments.

Surveys have shown that buildings in Malaysia consume an average energy around 230 kWh/m^2/year (Zainordin *et al*.,2012). At present the MS 1525:2014 is a voluntary code of practice and the choice to apply depends on the building owners

The following regulatory policies for energy consumption have been drafted (Hasan, 2016):

Under the Energy Consumption Act 2001 & Electricity Supply Act 1990, the following four sub-regulatory enactments have been implemented:

(a) Electricity Regulation 1994.

(b) Licensee Supply Regulation 1990.

(c) Electricity Supply (Compounding of Offences) Regulation 2001.

(d) Efficient Management of Electrical Energy Management 2008.

In addition to the electrical energy regulatory commissions instituted in the country, the government also included and introduced regulatory measures for the gas industry. The gas regulatory acts are:

(a) The Gas Supply Act 1993 (supported by sub-regulatory policies under

(b) Gas Supply Regulations, 1997, and

(c) Gas Supply Order (Compoundable Offences) 2006.

1.2 Problem Statement

Energy consumption in Malaysia has risen sharply and it is mostly contributed by office and commercial buildings (Tan *et al*., 2013). In line with country's development plan, the rapid growth of new building's energy consumption has become a concern where only 432 buildings fulfilled the requirement of green building index standard (Green Building Index, 2018). The remaining buildings are believed to have been constructed according to conventional method which energy efficiency were not taken into consideration.

Energy use is expected to rapidly increase over time and therefore, the need to set a benchmark to identify the appropriate performance levels for the electricity use in each building is required. The benchmark will also help to monitor performance and efforts can be made to achieve reductions in future electricity consumption for the building.

The energy benchmarking refers to an assessment of the energy use performance of a building. Energy benchmarking assesses a building's energy performance without the need for going through a rigorous evaluation. It is a process of comparing the energy performance of a particular commercial building, i.e. an office building, to a range of energy-performance values of similar buildings. It helps to assess the energy use for the particular building and identifies opportunities for improvement through energy saving measures (ESM).

In Malaysia, there are limited studies and references on the development of building performance model and systems to follow in finding the energy performance of the building. Although there are several definitions in the Global Energy Use Index (EUI) applied in other countries, any of them seems to be difficult to standardise for Malaysia for a multitude of factors such as climate, building services system and policy. Lack of such studies has been described in this section as well as in the coming chapters.

1.3 Research Objectives

This study focus on to analyse and develop an end-use model energy benchmarking of office buildings in Malaysia. The study will enables to generate improvement plans on how to manage energy performance of current building stock.

Energy benchmarking becomes a threshold to obtain the energy use in comparison with other buildings. A major focus of this research is to develop and validate the benchmark model of the energy performance of an office building.

This study addresses the following research objectives:

(a) To identify factors contributing to the energy performance of office buildings in Malaysia.

(b) To develop a baseline model and energy performance benchmark for office buildings using the Building Energy Index (BEI) based on the factors identified in objective (a).

(c) To verify the baseline and performance of office buildings using the model obtained from objective (b).

1.4 Research Questions

This research aims to answer the following questions:

(a) What are the factors contributing to the energy performance of an office building?

(b) What is the baseline energy consumption model of an office building in Malaysia?

(c) What is the benchmark for the building energy index (BEI) model of an office building in Malaysia?

(d) How will the baseline and benchmark models obtained to be used to predict the energy performance for an office in Malaysia?

1.5 Scope

This study includes 25 office buildings in Malaysia that spanned across the country. This research work is carried out by including both private and public sectors buildings with the intention for future energy savings measures that would help reduce energy consumption of office buildings in Malaysia. The 25 office buildings' energy performance are examined based on several factors namely building age, building area distribution, occupancy, weather profile, monthly data consumption, baseline data and benchmark data. Other factors are not included in this study.

1.6 Significance of Research

Given the need for saving and efficiently utilising electrical energy, this work is considered significant for the following reasons:

(a) The work will enable office type buildings to identify their level of energy consumption and help to undertake conservation measures.

(b) This work will be of use when setting the optimal energy consumption reference indicator to set the baseline and benchmark for energy use in existing buildings.

(c) This study will identify factors contributing to the energy performance of office buildings.

1.7 Thesis Structure

The work of this thesis is arranged into five main chapters. Chapter 1 is an introductory chapter. The chapter presents the background of the research, its objectives and the scope and significance of the study.

Chapter 2 highlights a wide range of literature pertinent to current levels of energy performance in buildings across the world. Key factors related to energy performance are analysed and identify suitable set of factors for Malaysian office buildings. Then the explanation on descriptions of energy audit which form the base of the study and subsequently method used to benchmark energy efficiency in buildings.

Next, Chapter 3 introduces the methodological approach. The chapter starts by introducing the building data profile. This is followed by data collection procedures while analysis technique is given in the last part of the chapter.

Chapter 4 is dedicated to present the results and discussion. To address the objectives, three main sections are developed in the fourth chapter. First section explains the contributing factors for energy consumption by buildings. Second section details the development of baseline and benchmark model while final section shows the validation of the model.

Finally, chapter 5 concludes the thesis. Summary on findings obtained in this research is highlighted. Additionally, the research parameters and limitations are analysed for future works.

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Appendix A Regression Analysis Results From R Software

LIST OF PUBLICATIONS

1) Mohamad Hamzi Mohamad, Mohd Yusof Md Daud, Astuty Amrin, Noorlizawati Abd Rahim and Nurul Ain Mohd Yunos (2019). Energy Efficiency Benchmarking for Office Buildings in Malaysia. *Journal of Advanced Research in Applied Sciences and Engineering Technology (ISSN 2462-1943)*. Universiti Teknologi Malaysia. (In progress for publishing)