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Article

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Benchmarking the Energy Efficiency of Higher Educational Buildings: A Case Study Approach

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ABSTRACT

Previous studies have reported that buildings consume nearly 36% of the total energy used and contribute towards 30% of the total carbon dioxide (CO_2) emissions. Therefore, improving energy efficiency in buildings is essential to enhance a sustainable built environment. This research employed a case study approach with the Universiti Tun Hussein Onn Malaysia (UTHM) being selected as the case study. A number of buildings recorded high annual energy consumption (EC) data while others recorded low energy consumption. This was due to the absence of a benchmark line reference for campus buildings, thereby causing a significant difference in the energy consumption of each building. The study's aim was to develop an energy efficiency benchmark for university buildings by using statistical analysis. From statistical analysis, the standard practical range was between 72.5 and 141.0 kWh/m^2/year. Buildings with an energy consumption per unit area value below 72.5 kWh/m^2/year are regarded as best energy efficient buildings. In contrast, those above 141.0 kWh/m^2/year are considered poor energy efficient buildings. For recommendation, buildings that exceed the maximum value of this range require stricter supervision and monitoring by the university management.

Keywords: Building Energy Benchmarking, Energy Consumption, Energy Efficiency, Energy Saving, Higher Educational Buildings
JEL Classifications: C10, Q41

1. INTRODUCTION

Expansion of the building sector has affected the demand for energy resources and their uses. The government has come up with alternative plans to meet an increase in the energy demands of consumers while maintaining sustainability by reducing significant environmental impact. The Malaysian government has implemented various energy efficiency programs to ensure that the generation, transmission, distribution and consumption of energy is environmentally and economically sustainable. The Malaysian government has targeted a reduction in the intensity of electricity usage of 10% by 2025 and 15% by 2030 (KeTTHA, 2017).

According to an environmental report by the United Nations (UN) in 2018, as much as 36% of global final energy consumption and 39% of energy-related CO_2 emissions are contributed jointly by the building and construction sector (United Nations Environment Programme, 2018). Around 40% of the total energy consumed by buildings in Malaysia is expected to increase due to increments in building demand and construction (Energy, 2017). In 2011, energy consumption (EC) in Malaysia contributed substantially to greenhouse gas (GHG) emissions amounting to 218.9 $MtCO_2eq$. This was a rise of 31% relative to 2000 and has had a prominent effect on environmental quality (KeTTHA, 2017). Moreover, an increase in energy consumption affects not only the environment but the economy too.

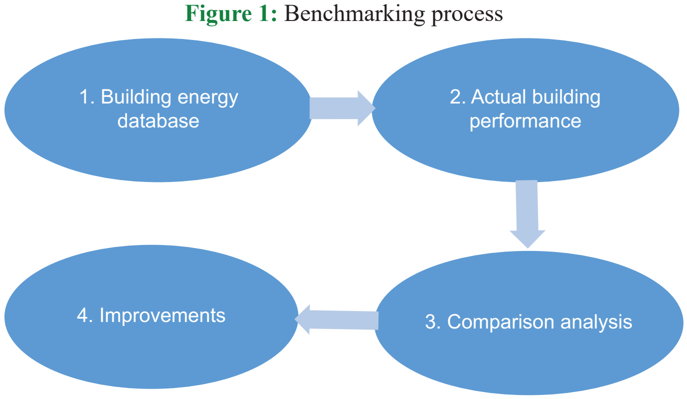
Globally, the number of large existing building stocks has increased. Therefore, due to a variety of building functions, they are among the largest contributors of energy consumption in the country. Building energy consumption in Spain, Japan, China, Brazil, Switzerland and Botswana is in the range of 23–50% of total energy consumption in their respective countries (Abu Bakar et al., 2015). Worldwide energy demand for buildings is expected to rise by around 45% from 2002 to 2025 (Abu Bakar et al., 2015).

Higher educational buildings consume the most energy in this setup due to the number of occupants and the complexity and diversity of activities and functions (Ding et al., 2018; Dzulkefli, 2017). Higher educational buildings are distinguished by densely packed schedules, greater energy usage, diversified forms of equipment and higher electricity consumption per gross floor area (GFA) (Ding et al., 2018). Common systems in the building, such as heating, ventilation, and air conditioning (HVAC) and lighting, plug loads, lifts and other services, require energy usage for operation while maintaining comfort and health to facilitate the activity of users in the building (Fell, 2017).

Energy efficiency is a reduction in the quantity of energy used per unit service provided, energy saving is one way of maintain sustainability. Energy benchmarking is a tool used to promote energy efficiency. The benchmark supplies information targeted at changing energy usage by providing a baseline for energy saving, and efficiency and transparency of energy usage, which can help in the investigation of poor energy performance (Borgstein and Lambert, 2014; Khosbakht, 2018). One method that can be carried out to benchmark the performance of a building is to compare current energy usage with past usage. In addition, a comparison of case study buildings with reference buildings of identical function in a variety of organisations can be conducted in the benchmark study (Bernardo and Oliveira, 2018; Chung, 2011; Khosbakht, 2018). By simplifying an interpretation of the benchmarking system, Figure 1 demonstrates the process of energy benchmarking (Perez-Lombard et al., 2009). Consequently, the study aims to propose an energy efficiency benchmark for UTHM buildings.

Similarly, with regard to benchmarking the intensity of electricity consumption, previous studies indicated that higher education institutions benchmarked buildings. For example, in 2018, a case study in 13 complex campus buildings in China used a linear regression method and mean value as a benchmark (Ding et al., 2018). Chung and Rhee (2014) analysed the energy usage of a university in Korea and established that it had a potential of 6–30% energy conservation. In another study, conducted in higher education institutions in Portugal in 2018, an energy ranking

Figure 1: Benchmarking process



system and statistical analysis were used for benchmarking (Bernardo and Oliveira, 2018). Aziz et al. (2012) used a simple method of comparing the energy use intensity (EUI) with the recommended value of the EUI. Meanwhile, Sukri et al. (2012) compared building energy consumption with the previous year and found a reduction of almost 14%.

2. METHODOLOGY

UTHM, Batu Pahat campus was selected as the case study due to the availability of data and because the energy benchmarking focuses on campus buildings. A quantitative method of research design was used to collect and analyse data in this study. During the benchmarking process, data were collected from the relevant departments, analysed using a statistical analysis approach, and the building performance was determined. The building energy consumption data from 2019 was gathered from the Tenaga Nasional Berhad (TNB) monthly data bill and data logger. The building's basic information such as typology, GFA, age of building and number of floors were also collected in this study. Basic information data for each building was requested from the relevant offices.

In total, 13 campus buildings as shown in Table 1 met the criteria of data as stated above were involved in the study. Each building's energy consumption data were analysed using Microsoft Excel and IBM SPSS Statistic 22 software. A descriptive statistic was used to determine the average, maximum, minimum and percentage of the dataset.

Correlation analysis was established for the following dataset to measure the strength and direction of the linear relationship between two pairs of variables by defining the correlation coefficient. The range of correlation coefficient r was between +1 and –1. The closer the correlation coefficient, r value to ±1, the stronger the relationship between the variables. From the correlation analysis results, significant influencing factors in building energy consumption was used to normalise the EUI. The energy consumption was divided by significant building factors to determine the EUI for each building as in Eq. (2.1):

Table 1: Sample buildings

FKAAB	Faculty of Civil Engineering and Built Environment
FKMP	Faculty of Mechanical & Manufacturing Engineering
FKEE Q	Faculty of Electrical and Electronic Engineering, Block Q
FKEE G1	Faculty of Electrical and Electronic Engineering, Block G1
FSKTM	Faculty of Computer Science and Information Technology
FPTP	Faculty of Technology Management & Business
FPTV	Faculty of Technical and Vocational Education
PTTA	Tunku Tun Aminah Library
KKTF	Tun Fatimah Residential College
KKTDI	Tun Dr. Ismail Residential College
ORICC	Office for Research, Innovation, Commercialization and Consultancy Management
G3	Block G3
PPP	Development and Maintenance Office

$$EUI = \frac{Building\ Energy\ Consumption}{Building\ Factors} \quad (2.1)$$

The benchmarking process used statistical analyses such as mean index of total energy consumption (MITEC), mean of EUIs, quadratic average, median and percentile to determine the upper and lower range of EUI. The MITEC method defined the building energy consumption benchmark with the ratio of total energy consumption of all sample buildings, including the total area or the total number of floors. The calculation equation is shown in Eq. (2.2):

$$MITEC = \frac{\sum_{i=1}^{n} E_i}{\sum_{i=1}^{n} A_i} \quad (2.2)$$

Where E_i is the energy consumption in 1 year of sample buildings; A_i is the building area, the number of floors or other significant influencing factors.

The mean EUI method is obtained by averaging normalised energy using indexes from all sample buildings, and is another alternative for energy consumption benchmarking, as calculated in Eq. (2.3):

$$Mean\ of\ EUI = \frac{1}{n}\sum_{i=1}^{n} EUI_i \quad (2.3)$$

EUI_i is the energy use index of the sample buildings.

The application of this method in energy consumption benchmarking involves calculating the arithmetic mean of normalised energy using indexes, then averaging the normalised energy by using indexes of less than the arithmetic mean. Furthermore, defining the average of these two means is another option from the multiple choices available to build energy consumption benchmarking. The calculation is displayed in Eq. (2.4):

$$Quadratic\ average = \frac{\frac{1}{n}\sum_{i=1}^{n} EUI_i + \frac{1}{m}\sum_{j=1}^{m} EUI_j}{2} \quad (2.4)$$

Where EUI_i is the normalised energy use index of the sample buildings; EUI_j is the normalised energy use index of less than the arithmetic mean.

Additionally, the median of normalised energy use indexes of the sample buildings is another option for energy consumption benchmarking. A median is described as a numeric value separating the higher half of a sample from the lower half. The median of a finite list of numbers is identified by arranging all the observations from the lowest value to highest value and picking the middle one.

Building energy consumption benchmarks using the percentile method set the percentile value as a benchmark for the building to assess the level of building energy consumption. Past researchers applied the 25th and 75th percentile (AlFaris et al., 2016; Juaidi et al., 2016) and Xin et al. (2012) set the percentile according to the requirements stated by the country for energy consumption benchmarking. The 25th and 75th percentile were used for this case study.

3. RESULTS AND DISCUSSION

3.1. Building Data

From the collecting data process, basic information from the 13 sample buildings is presented in Table 2. Basic building information data, such as building typology, GFA, year of completion, building age and total number of floors, are listed below.

3.2. ECAnalysis

Table 3 presents the descriptive statistic results for energy consumption in 2019. The average energy consumption for 2019 in all sample buildings was 2,187,006 kWh. The maximum (max) energy consumption for 2019 was consumed by the PTTA building and the minimum (min) value of yearly energy consumption was utilised by the Blok G3 building.

3.3. Correlation Analysis

Figure 2 presents the scatterplot of energy consumption and building characteristics with their corresponding coefficient of correlation. Table 4 reveals the result of the correlation analysis between the buildings' energy consumption and characteristics. The number of floors indicated the weak positive relationship and was not significant with energy consumption. The age of the building had a very weak negative correlation (r = –0.264) with energy consumption, and there was no significant relationship. The GFA was the only variable that had a significant relationship and displayed a strong positive correlation (r = 0.789) with the energy consumption. Consequently, building energy consumption could be normalised by the GFA.

3.4. EUI Analysis

Table 5 displays the percentage of energy consumption, GFA and the EUI of the sample buildings. To establish the EUI, the energy consumption was divided by the GFA as it had a significant relationship with energy consumption from the correlation analysis. Researchers and engineers often use GFA as a factor to normalise the EUI in the analysis of building benchmarking.

Table 5 displays data for the percentage of energy consumption used in each building from the total energy used at UTHM. The combination of other Pusat Tanggungjawab (PTj)s, which had a floor area of 47.5%, consumed as much as 29% of the total energy of UTHM. Both the FPTV and PTTA buildings consumed in total 14.6% of UTHM, Batu Pahat campus' total energy consumption, with GFAs using 5.1% and 9.3% respectively. The FKAAS

Table 2: Buildings' information data

Building	Typology	EC (kWh)	GFA	Year of completion	Building age	No of floors	Annual operating period
FKAAB	Faculty	2,443,027	23,795	2011	10	9	All year
FKMP	Faculty	1,641,663	10,786	2006	15	2	All year
FKEE Q	Faculty	872,552	10,522	2012	9	8	All year
FKEE G1	Faculty	991,905	11,160	2006	15	2	All year
FSKTM	Faculty	1,377,052	11,407	2011	10	8	All year
FPTP	Faculty	780,613	12,634	2011	10	9	All year
FPTV	Faculty	3,818,840	16,312	2011	10	6	All year
PTTA	Library	3,822,263	29,423	2010	11	6	All year
KKTF	Residential	1,014,440	10,094	2011	10	4	Semester period
KKTDI	Residential	930,186	10,371	2011	10	4	Semester period
ORICC	Office	432,278	2,842	2004	17	1	All year
G3	Teaching	386,353	15,103	2006	15	3	Semester period
PPP	Office	114,979	1,852	2011	10	1	All year
Other PTj	Mixed	7,617,922	150,691	-	-	-	
UTHM		26,244,073	316,994				

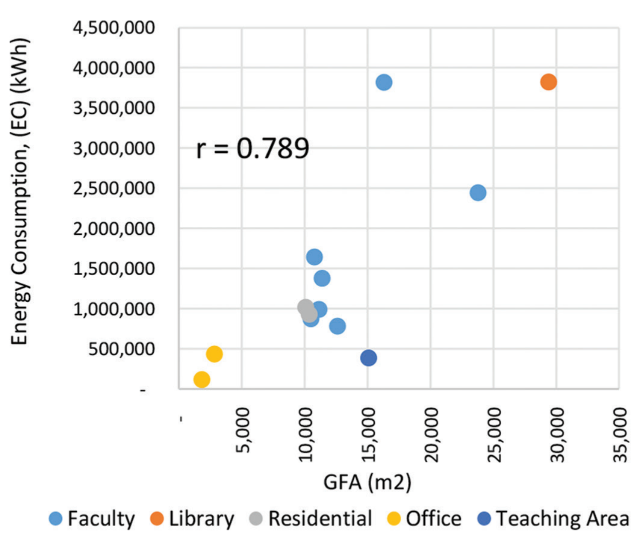
Table 3: Average energy consumption

Energy consumption (kWh)			
Average	Max	Min	Std Deviation
2,187,006	3,822,263	114,979	1,213,261

Table 4: Correlation analysis between energy consumption and building characteristics

	EC	GFA	AGE	FLOOR
EC				
Pearson Correlation	1	0.789**	–0.264	0.398
Sig. (2-tailed)		0.001	0.384	0.178

**Correlation is significant at the 0.01 level (2-tailed).



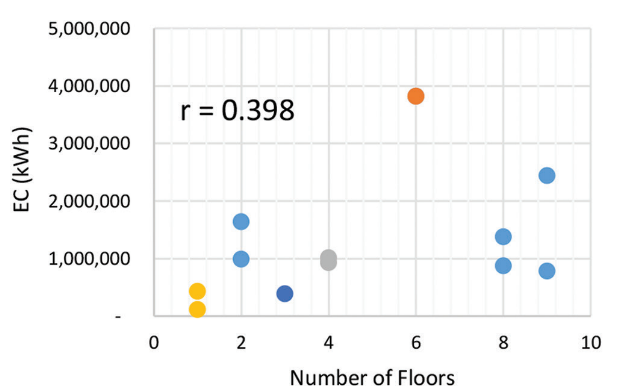
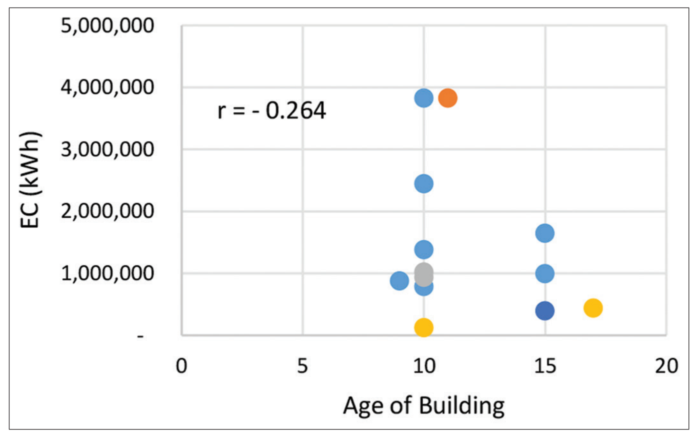


Figure 2: Scatter plots with their correspondent coefficient of correlation



building consumed around 9.3% of the total UTHM energy consumption.

The EUI presents the energy consumption per unit area of the building by calculation using Eq. (2.5). The EUI was calculated and is presented in the Table 5. The FPTV building, with 234.1 kWh/m^2/year, was the highest EUI among the sample buildings, followed by ORICC and PTTA with 129.9 kWh/m^2/year and 152.1 kWh/m^2/year respectively. The G3 building had the lowest EUI value with 50.6 kWh/m^2/year as displayed in the equation below:

$$EUI = \frac{Building\ Energy\ Consumption}{Building\ Factors} \quad (2.5)$$

3.5. Benchmarking Statistical Analysis

Various statistical analyses were used to benchmark the buildings at UTHM, such as MITEC, mean of EUIs, quadratic average, median and percentile. The results obtained from the different statistical analysis options by calculating the normalised EUI of sample buildings are summarised in Table 6.

The MITEC for the sample buildings was 112.0 kWh/m^2/year. Although this represented the overall energy consumption for

Table 5: Percentage of energy consumption, GFA and EUI

Building	Energy consumption (kWh)		GFA		EUI (kWh/m²/year)
	Total	%	Total	%	
FKAAB	2,443,027	9.3	23,795	7.5	102.7
FKMP G2	1,641,663	6.3	10,786	3.4	152.2
FKEE Q1	872,552	3.3	10,522	3.3	82.9
FKEE G1	991,905	3.8	11,160	3.5	88.9
FSKTM	1,377,052	5.2	11,407	3.6	120.7
FPTP	780,613	3.0	12,634	4.0	61.8
FPTV	3,818,840	14.6	16,312	5.1	234.1
PTTA	3,822,263	14.6	29,423	9.3	129.9
KKTF	1,014,440	3.9	10,094	3.2	100.5
KKTDI	930,186	3.5	10,371	3.3	89.7
ORICC	432,278	1.6	2,842	0.9	152.1
G3	386,353	1.5	15,103	4.8	25.6
PPP	114,979	0.4	1,852	0.6	62.1
Other PTj	7,617,922	29.0	150,691	47.5	50.6
UTHM	26,244,073	100.0	316,994	100.0	82.8

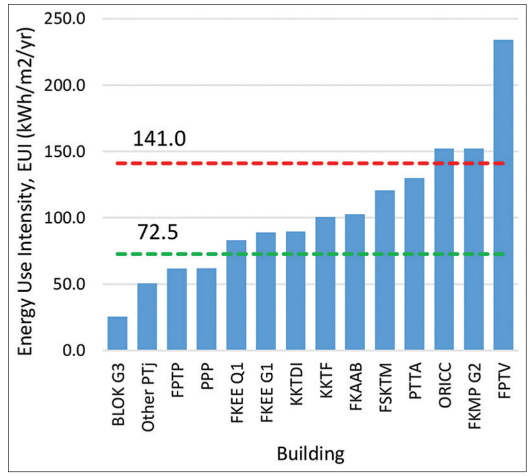
Table 6: Option of EUI by statistical analysis

Statistical Analysis	Parameter	EUI (kWh/m²/year)
Mean Index of Total Energy Consumption	MITEC	112.0
Mean of EUIs	Mean	107.9
Median	EUI 7th	100.5
Quadratic Average	Average EUI of less than the arithmetic mean	87.7
	Quadratic average	97.8
Percentile		
	EUI 25th	72.5
	EUI 50th	100.5
	EUI 75th	141.0

UTHM, Batu Pahat buildings, it cannot accurately report on individual building energy consumption. The average EUI is 107.9 kWh/m²/year is among the results of statistical analysis. Another average that is demonstrated through the statistical method is the quadratic average of normalised energy use index, which is an advanced average energy performance. The average the normalised energy use indexes of less than the arithmetic mean were 87.7 kWh/m²/year and the quadratic average value was 97.8 kWh/m²/year. Building energy benchmarking based on the quadratic average method stands for an energy consumption level that lies between average and advanced level (Juaidi et al., 2016).

The median value was 100.5 kWh/m²/year and was the seventh value according to the sequence of building sample data ranging from low to high data. The median is the separator between the high and low halves, and unlike mean value, it is not affected by extreme values in the dataset. Following in the footsteps of past researchers, the 25th, 50th and 75th percentiles were used (AlFaris et al., 2016; Juaidi et al., 2016). The EUI was found to be the minimum value from the 25th percentile and the maximum value from the 75th percentile calculations. Thus any building with a normalised EUI between the ranges of 72.5–141.0 kWh/m²/year had standard building energy performance efficiency at UTHM as shown in Figure 3. Those with an EUI value below this range were considered the best energy efficient buildings. By contrast, those above this range were considered poor energy efficient buildings.

Figure 3: EUI building with range of normal practice for UTHM Batu Pahat Campus



4. CONCLUSION

A case study was conducted at the UTHM, Batu Pahat campus to benchmark energy consumption. A total of 13 buildings were identified by using the annual use data and characteristics of buildings from 2019.

As a result, FPTP and PTTA were among the buildings using the highest annual amount of energy compared to the other sample buildings in the study. Correlation analysis indicated a significant positive relationship between energy consumption and the floor area of the building, confirming that energy consumption increases if the floor area increases. The EUI analysis was calculated by dividing the building energy consumption with GFA, the significant factor from the correlation analysis. The FPTP building was the only building with an EUI exceeding the value of 200 kWh/m²/year with the additional buildings remaining below 160 kWh/m²/year.

Building benchmarking at UTHM, Batu Pahat campus used the statistical analysis method to establish that normal use range value for the buildings on campus was between 72.5 and 141.0 kWh/m²/year. Buildings below the value of 72.5 kWh/m²/year were energy efficient within their own building area. In ORICC and FKMP G2 buildings where the EUI value slightly exceeds the maximum value range of 141.0 kWh/m²/year, the building occupants should be encouraged and made aware to use energy efficiently. Meanwhile, in the FPTP building stricter supervision and observation by the university management should be conducted to identify potential problems and to address excessive energy consumption per unit area.

Encouragement and reminders from university management to the building occupants should be offered periodically using various methods such as campaigns or seminars on energy management efficiency. Other initiatives include providing awards or appreciation to the energy efficient building with the lowest monthly or annual energy consumption rate. The simplest implementation would be for the university management to remind building occupants to switch off electrical equipment when it is not in use. Maintenance of electrical equipment, according to the set schedule, must be completed to ensure that it is in good working order.

Benchmarking is one of the methods for improving efficient use of energy. This study provided a direct evaluation based on the value of EUI obtained from study results for the reference of university management for the purpose of evaluating the performance of buildings in the UTHM, Batu Pahat campus.

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