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Energy Indexing for Different Type of Hospital Buildings in Malaysia

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Healthcare facilities are one of the major consumers of electricity, Building Energy Index (BEI) is an important tool that can assist healthcare facilities in monitoring and benchmarking their energy performance. There are many types of healthcare facilities, and a standardized form of BEI is not suitable to be used as it will result in a misleading interpretation of the energy performance. This article explains the study in developing an energy indexing where different hospital buildings in Malaysia can be benchmarked according to their specifications and needs. By monitoring and controlling the correct variables, energy indexing could be reduced by reducing the electrical energy cost through effective energy-saving measures. The aim of the study was achieved through the collection of 91 hospital data with pre-listed 33 potential variables, which were later reduced to 4 significant variables after evaluating minimum sample size, normalising data after considering parameters like R^2 (Coefficient of Determination), CV_{RMSE} (Coefficient of Variation - Root Mean Square Error), P-value, t-Stat, and multicollinearity using regression analysis. An energy indexing formula for different types of Malaysian hospital buildings was developed using a regression method to demonstrate the significant impact of independent variables on dependent electrical energy consumption. The energy indexing has been quantified for each category of hospitals and results obtained show Major Specialist Hospital has a mean of predicted energy indexing as high as 191, continued by General Hospital, which is 185.72, Minor Specialist Hospital with 173.24 and Non-Specialist Hospital with 147.81.

1. Introduction

The national sustainability goals to reduce carbon emissions have changed the way hospital managements plan their energy management system (Bernama, 2016). One of the energy management system's objectives is to monitor and evaluate the energy usage from time to time and, as an alternative, the Building Energy Index (BEI) has been introduced. Building energy efficiency and index evaluation system was not only the important key to determining whether a building was energy saving or not, but also the mechanism of the evaluation system's outcome (Xu et al., 2015). Common energy indexing is a standard tool widely used without considering factors attributing to energy usage-specific building operations. It is observed that the average common energy indexing reported for hospital building by other countries are United States which is 738.5 kWh/m^2 (Bawaneh et al., 2019), Greece is 700.3 kWh/m^2 (Droutsa et al., 2020), Spain is 270 kWh/m^2 (González et al., 2018) and China is 96.1 kWh/m^2 (Ji and Qu, 2019). Bawaneh et al. (2019) highlighted factors such as cultural differences and the level of sophistication in terms of the amount of equipment per facility might affect the energy consumption at a hospital building in the United States, which draws higher BEI in other countries. He also affirmed that a larger area or number of facilities alone does not necessarily increase energy consumption intensity. González et al. (2018) claimed that geographic location was seen to influence those BEI values directly. Ji and Qu (2019) also believed that different countries have different energy consumption characteristics and influence. Thus, when they investigated hospitals in China, the study highlighted the importance of hospital-grade distribution on the energy consumption per unit area in the different climatic zones. The current BEI needs to be improvised to suit the local climate and hospital building criteria by exploring the reliable factors of energy consumption other than Gross Floor Area (GFA) since the current BEI does not take the building's operation behaviours into account

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(González et al., 2018). A wide variety of building styles include healthcare facilities and hospitals, and they have different design specifications, equipment, occupancy rates, and operating schedules. As a result, buildings of this type differ significantly in their energy usage pattern when compared to common buildings. Most healthcare facilities studies are related to the evaluation of retrofitting techniques or the investigation of possible changes in energy usage primarily in heating, ventilation, and air-conditioning (HVAC) systems; often without taking into account the significance of typology of construction. Due to the variety of building typologies covered by this field, some studies highlight the average energy use difference across the healthcare sectors (Kolokotsa et al., 2012). Ahmed et al. (2015) have classified healthcare facilities into T1–T7; T1 (Hospital), T2 (Ambulatory/day surgery or procedure centre), T3 (Medical healthcare/centres), T4(Clinics), T5 (General practitioner and specialist), T6 (Rehabilitation palliative care) and T7 (Aged care/nursing homes). Healthcare services are offered over four phases of treatment: primary, secondary, tertiary and quaternary. Ahmed et al. (2015) also demonstrated the lack of a systematic instrument to measure and calculate healthcare facilities' energy efficiency. They emphasised that a significant step towards benchmarking energy efficiency is the proper classification of healthcare facilities. The description of the type of healthcare facility would help provide an accurate overview of energy use to promote practical steps and energy efficiency strategies (Ahmed et al., 2015). Hospital buildings usually consume more energy than other types of healthcare facilities due to the hospital's multi-service nature. Reddy et al. (2019) stated that hospital buildings' energy use has increased due to the integration of new equipment related to technology advancement. An example, a study in India found that the air quality control, high maintenance of sophisticated equipment, thorough sanitisation of premises, high patient load to doctor ratio are factors influencing energy usage, which is 1,596:1 compared to the 1,000:1 regulation recommended by the World Health Organization (WHO). Nearly 60 % of hospitals in India also cannot meet the minimum requirements of the Energy Efficiency Index (EEI), which is 200 kWh/m²/y (Reddy et al., 2019).

There are few types of hospital building in Malaysia (Ministry of Health, 2016). State hospitals, hospitals with specialists, hospitals without experts, and special medical institutes are the four hospital structures in Malaysia. The central hospital for each state in Malaysia is the state hospital, which is the most extensive hospital with enormous bed capacity and offers various speciality services that may serve as a regional referral centre. The hospital with the specialist is further separated into major specialist and minor specialist hospitals only for administrative considerations. A minor specialist hospital that provides various specialised services may be elevated to a major specialist hospital if the state health department recommends it and the ministerial level agrees. The healthcare institution with a specific purpose for medical research and treatment falls under the special institution category. Since the hospital building itself has different types, it is crucial to study the specific hospital buildings' characteristics in order to benchmark the electrical energy consumption according to its type. According to Malaysia Energy Commission, any building including hospitals that consumes more than 3,000,000 kWh per month for six consequences months is enforced by the Energy Commission under Efficient Management of Electrical Energy Regulation 2008 (EMEER 2008) (Ludin et al., 2019). This regulation is applied to state hospitals and hospitals with specialists because they consume more electrical energy than hospitals without specialists and special medical institutions due to the location, number of beds and number of patients visited. Any medical buildings need to follow EMEER if their energy usage meets the term. For example, Institute Medical Research which falls under special institution is enforced under EMEER. The right of energy consumption criteria for each hospital buildings needs to be determined. It is also known that hospital building requires higher energy than similar Gross Floor Area of other commercial or non-residential buildings. Energy Commission (ST), as a regulatory body for energy, has announced the National Building Energy Intensity (BEI) Labelling for Government Buildings, specifically in office-type, which uses the typical indexing formula and not suitable for hospital building (Suruhanjaya Tenaga, 2019). The hospital building energy indexing needs to be standardised, and the best way is to categorise them accordingly. The energy indexing in Malaysia hospital's study showed that the BEI was 384 kWh/m²; the study was done for a selected large-scale hospital using total electricity and fuel energy consumption over-air-conditioned area as its energy indexing formula (Moghimi et al., 2014). Other variables had been explored using multiple regression analysis by other researchers. The regression techniques help researchers explicate the dynamics underlying a particular construct by finding which combination of variables gives a stronger association. Kamaluddin et al. (2016) suggested gross area per bed, number of beds, and a total number of assets to be added in their model as those data can be easily gathered. The final model explained 85 % of the annual energy consumption with a 90 % confidence interval in its prediction (Kamaluddin et al., 2016). Thinate et al. (2017) used six variables of the energy consumption's quantity of 45 large-scale hospital buildings with Multiple R equal to 0.6390. The variables are air-conditioning area (m²), non-air-conditioning area (m²), in-patient-department (bed-day), out-patient-department (person), staff member (person), and temperature (°C). It is vital to investigate the energy indexing for a different type of hospitals (Thinate et al., 2017). A national statistical investigation for each type of hospital's energy consumption and its potential significant variables needs to be explored. The standard Building Energy Index is not reliable tool for hospital buildings and could be replaced with a regression model for better monitoring and evaluating activity. This study aims to develop energy indexing using a regression formula and quantify energy benchmarking for different Malaysian hospital building types.

2. Methodology

Figure 1 illustrates the flow of the methodology framework. By using the minimum sampling method, the minimum sample size was determined (Louangrath, 2017). The data was collected from all hospitals with pre-listed 33 variables and checked if there were any unsatisfactory, missing, or unavailable result, of which were promptly corrected and completed. The variables are Gross Floor Area (m^2), Air-conditioned Area (m^2), Number of Operation Theatre Room (No.), Number of Major Operation Theatre Room (No.), Number of Minor Operation Theatre Room (No.), Number of Labour Room (No.), Number of Bed in ICU/CCU (No.), Number of Bed in HDU (No.), Accommodation Area (m^2), Operation Theatre Area (m^2), Maternity Area (m^2), Maternity Number of Bed (No.), Diagnostic & Imaging Department Area (m^2), Centralised Sterile Service Department (CSSD) Area (m^2), Accident & Emergency (A&E) Area (m^2), Laboratory Area (m^2), Mortuary Area (m^2), Non-Air-Conditioned Ward Area (m^2), Air-Conditioned Ward Area (m^2), Bed Capacity (No.), Average Annual Bed Occupancy Rate (BOR) (%), Occupied Bed Capacity (No.), Cooling Degree Days (CDD) (No.), Average Annual In-Patient (No.), Average Annual Day-Care Patient (No.), Average Annual Out-Patient (No.), Average accommodation energy usage (kWh), Total Design Cooling Load (RT), Total Number of Fixtures (No.), Total Installed Power (kW), Average Annual Total Lighting Energy Consumption (kWh), Total Number of Machines (No.) and Total Number of Machines Including Ultrasound (No.). CDD was Sum of Average Monthly Cooling Degree Days (CDD) using Base Temperature as 24 °C, while the Total Number of Machines was high energy consumption biomedical equipment (Cyclotron, Autoclave, MRI, Surgical gas, Linac, CT Scan, and PET Scan). After data checking and correction, 91 hospital buildings with 14 variable data satisfied the minimum sampling size needed. The data collected was varied in terms of unit and scale and to ensure the data's consistency and accuracy, it must be dimensionless and undergo a data normalisation method using multiple regression (Shalabh, 2008). For this study, the categorisation is divided into four (4) groups which are group A (state hospital and hospitals with specialist), group B (hospitals without specialist and special institution), group AB (all type of hospitals), and group C (all type of hospitals excluding special institution). By using Data Analysis Tool Pack in EXCEL, the analysis was conducted. The statistical method Single Linear Regression Analysis has been used. The variables are cutting down in each group where only the variables with a reasonable correlation above 75 % to electricity consumption are utilised to form the energy index formula. From there, the Multiple Linear Regression Analysis was performed with a 95 % confidence interval. The indicators set have been observed (Bender et al., 2007), as well as multicollinearity (Bremer, 2012), and the reliable variables have been compared between each group. The most reliable variables were selected in establishing the energy indexing formula. The variables were over Gross Floor Area (GFA) to match the output or the predicted annual electrical energy consumption over GFA. From the MLRA result, the energy indexing (EI) formula can be developed. The energy benchmark for each hospital building category was calculated using the developed EI formula. The calculated energy index's mean was reflected as an energy index's good practice for the respected type of hospital building.

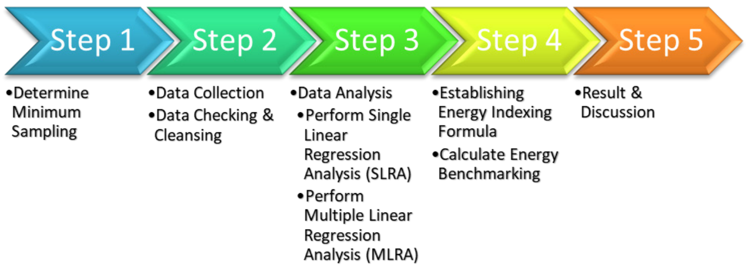

Figure 1: Energy indexing framework

3. Result and discussion

3.1 Single linear regression

Table 1 shows the single linear regression result for 14 variables. The variables which had a coefficient value of determination above 0.75 for Group A were Gross Floor Area (GFA), Number of OT Rooms (NOT), Bed Capacity (BC), and Annual Lighting Energy Consumption (LEC), for Group AB were GFA, Air-conditioned Area (ACA), NOT, and LEC, and Group C were GFA, ACA, NOT, BC, Occupied Bed Capacity and LEC. Variables in Group B showed a coefficient of determination below 0.65. Initially, the group created were group A, B, and AB.

The number of bed capacity's coefficient of determination Group A is highest, but it gave lower value in Group B and AB. Group C was created to exclude the Special Institution type. The Special Institution might consist of facilities with non-routine procedures compared to typical hospital work. For example, Hospital Bahagia Ulu Kinta and Pusat Darah Negara. It may interfere with the analysis because of routine inequalities in the hospital's operation. After creating Group C, we found that the number of bed capacity's coefficient of determination for group C is highest, 0.9088 compared to other groups. It indicates that although the number of beds is high in some Special Institution building, it does not mean that the energy consumption in the building is high. Another thing we found was that the number of machines that consist of higher energy consumers (Cyclotron, Autoclave, MRI, Surgical gas, Linac, CT Scan, PET Scan) showed a coefficient of determination below 0.5 in all groups. When the number of ultrasounds was included, the R^2 value increased up to above 0.7. Ultrasound has usually been used for Obstetrics & Gynaecology (O&G) services. Although it consumes small energy, this machine's number is quite large. Almost all hospitals have an ultrasound, reflecting those O&G services are there in almost all hospitals. Not only the ultrasound, other biomedical machines and the number of the labour room, for example, might contribute as essential variables that can be explored in future.

Table 1: Single linear regression analysis

Variables	Unit	Group A	Group B	Group AB	Group C
Gross Floor Area (GFA)	m^2	0.9288	0.5316	0.9153	0.952
Air-conditioned Area (ACA)	m^2	0.7279	0.3478	0.8058	0.8179
Operation Theatre (OT) Area (OTA)	m^2	0.5429	0.0005	0.6333	0.632
Number of OT Rooms (NOT)	Number	0.8482	0.0564	0.8779	0.8918
Bed Capacity (BC)	Number	0.8638	0.1991	0.7189	0.9088
Bed Occupancy Rate (BOR)	%	0.0044	0.0177	0.0489	0.041
Occupied Bed Capacity (No.)	%	0.6882	0.1811	0.6248	0.7899
Sum of Average Monthly Cooling Degree Days (CDD)*	Number	0.01	0.0055	0.0278	0.0406
Annual Out-Patient (AOP)	Number	0.2633	0.1382	0.4581	0.4596
Total Design Cooling Load (RT)	RT	0.675	0.0545	0.7141	0.7146
Total Number of Machines (NOM)**	Number	0.282	0.2676	0.4462	0.4882
Total Number of Lighting Fixtures (NOL)	Number	0.4919	0.2085	0.5262	0.5293
Annual Lighting Energy Consumption (LEC)	kWh	0.7805	0.6381	0.8422	0.8456
Total Number of Machines Including Ultrasound (NOMU)***	Number	0.5714	0.2698	0.7096	0.7127

*Sum of Average Monthly Cooling Degree Days (CDD) using Base Temperature as 24 °C.
**The Total Number of Machines was high energy consumed biomedical equipment (Cyclotron, Autoclave, MRI, Surgical gas, Linac, CT Scan, and PET Scan).
***The Total Number of Machines, Including Ultrasound, was (Cyclotron, Autoclave, MRI, Surgical gas, Linac, CT Scan, PET Scan, and Ultrasound).

3.2 Multiple linear regression

Based on the single regression analysis result, as Group B did not meet the R-square requirement, it had been removed from the multiple linear regression analysis. Multiple Linear Regression analysis was done for Group A, AB, and C. For Group C, although the coefficient of determination for Occupied Bed Capacity is above 75% for SLRA, when this variable is related to other variables in Group C, this variable cannot give a good relationship between variables to the output. The Occupied Bed Capacity was then eliminated. The multiple R and R-square for all these groups were above 0.9, as shown in Table 2. By referring to Table 2, from 4 variables in Group A, the bed capacity number's t-Stat and P-value were out of acceptance value. The t-Stat and P-value for the 4 variables in Group AB were within the acceptance range. Group C has 5 variables (GFA, ACA, NOT, BC, and LEC) which also its t-Stat and P-value were in the acceptance range. Overall, Group C had the highest Multiple R and R-square which were 0.9859 and 0.9720. It means that the model fitness has been tested telling 97.20 % of the variability in annual electricity consumption explained by the model variables in Group C. Figure 2 shows the normal probability plot for the final model.

3.3 Energy indexing formula

Group C has been chosen and used to set up the linear equation. Since the standard energy indexing is total energy consumption over the GFA, all the variables were also over the GFA. The multicollinearity also has been observed, which is around 1. The energy indexing (EI) formula utilising a quantitative strategy with a certainty level of 95 % could be written in a regression formula as shown in Eq(1).

$$Y = 80.21\ X1 + 217493.03\ X2 + 2.06\ X3 + 3118.17\ X4 + 23.75 \quad (1)$$

where Y is Annual Electricity Consumption/GFA (kWh/m^2), X1 is ACA/GFA (m^2/m^2), X2 is No. of OT Rooms/GFA (No./m^2), X3 is Annual Lighting Energy Consumption/GFA (kWh/m^2) and X4 is Bed Capacity/GFA (No./m^2).

Table 2: Multiple R, R-Square Value, T Stat and P-Value

Variables	Group A		Group AB		Group C	
Multiple R	0.9759		0.9821		0.9859	
R-Square	0.9524		0.9645		0.9720	
T Stat and P-Value	T Stat	P-value	T Stat	P-value	T Stat	P-value
Gross Floor Area (GFA)	4.3084	0.0001	3.8466	0.0002	3.1147	0.0026
Air-conditioned Area (ACA)	-	-	4.3853	3.26E-05	3.3062	0.0014
Number of OT Rooms (NOT)	2.5857	0.0137	7.6295	2.95E-11	4.0223	0.0001
Bed Capacity (BC)	1.0938	0.2809	-	-	2.1827	0.0321
Annual Lighting Energy Consumption (LEC)	2.3393	0.0247	4.6488	1.20E-05	3.9674	0.0002

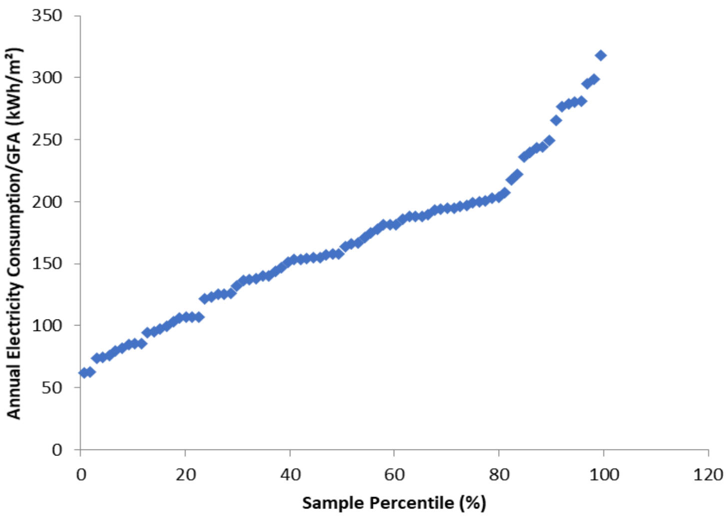

Figure 2: Normal probability plot for final model

3.4 Energy benchmarking for different type of hospital building

Using standard EI formula, which is total energy consumption over the GFA, the mean of EI for each type of hospital building is calculated using collected data and tabulated in Table 3 and marked as Common EI. The mean of EI using EI formula in Eq(1) as multiple regression model is also been calculated and shown as Proposed EI in Table 3. Major Specialist Hospital had higher proposed energy indexing, which was 191, continued by state/general hospital (185.92) and minor specialist hospital (173.24). The non-specialist hospital had the least energy indexing, which is 147.81. It was also proven that different type of hospital has a different range of proposed energy index as can be seen in Table 3. Special Institution is proposed to have their independent energy indexing specifically to its represented building.

Table 3: Proposed energy index

Type of Hospital	Common EI	Proposed EI	Proposed EI Range
State/General	201.45	185.72	135.66 - 231.23
Major Specialist	218.93	191.00	135.79 - 283.06
Minor Specialist	196.74	173.24	131.09 - 247.33
Non-Specialist	122.16	147.81	77.51 - 267.54

4. Conclusion

By using the multiple regression linear analysis, an energy indexing formula has been developed with 95 % certainty to explain the significant independent variables for different type of hospitals in Malaysia. The mean of energy indexing for Major Specialist Hospital is 191, which is the highest, continued by General Hospital (185.72), Minor Specialist Hospital (173.24), and Non-Specialist Hospital (147.81). This energy indexing can be used as a good practice benchmark for hospitals. It is important to differentiate hospital buildings by type as their BEI alone can be misleading due to their different specification and needs. Other potential significant variable like Total Number of Machine could be explored in future.

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