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Factor Impacts and Target Setting of Energy Consumption in Thailand's Hospital Building

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This article analysed the factor impacts on the energy usage of hospitals in Thailand by investigating on 14 hospitals, which were accountable for about 7 % of the energy usage of all hospitals in Thailand. Hospital buildings utilized electricity as high as 90 % of all the entire energy usage due to medical electric equipment and various electric systems in the hospitals. Multiple linear regression has been executed to find the relationship between electrical energy consumption and various essential variables. As a result, the developed model could be used to forecast energy consumption, and find which factor has the most impact on energy consumption in hospitals.

1. Introduction

Thailand has been increasing the energy use every year especially electrical energy usage. The business sector was accountable for about 34 % of all electricity use in Thailand (Department of Alternative Energy Development and Efficiency, 2016). The improvement of energy use in this particular sector was necessary and challenging for the investigation. The investigation focused on the energy baseline and target setting in hospital buildings which were estimated 11 % of the energy consumption and around 4 % of GDP from the total commercial sector in Thailand. The energy efficiency in Thailand generally focuses on energy conservation measures focusing particularly on energy management and replacing the old equipment with newly high energy efficient equipment. Specific energy consumption (SEC) is commonly used as a target setting of the energy use per product unit. For hospital buildings, SEC is normally defined as the energy use per unit area of indoor working space (both air-conditioning and non-air conditioning areas) or energy use per inpatient bed-day. Other factors, i.e., ambient temperature, relative humidity, numbers of staffs, have been seldom addressed in analysis of energy use consideration. A mathematical model for predicting building energy consumption based on the measured data had been developed through the multiple regression analysis for many commercial office buildings in Hong Kong (Jing et al., 2017). A benchmarking process for energy efficiency using multiple regression analysis of Energy Use Intensity (EUI) and related factors had been developed. The results from this model and the benchmarking system could be used in the policy analyses (Chung et al., 2006). From the energy consumption data of hospitals in Thailand, compared to other types of buildings, the 24 h scenario use of the healthcare buildings has a significant impact on the energy consumption in the hospitals (Sahamir et al., 2017). The study concentrated on factor impacts and target setting of energy consumption in Thailand's hospital building. Linear regression was used to analyze the electrical energy use and its related factors that might significantly affect the energy consumption. The results from the finding provided the baseline for the efficient energy use in hospital buildings in Thailand in the future (Thinate et al., 2017).

2. Background

Electrical energy is a primary source of energy used in the hospitals. Air conditioning and lighting systems takes the major portion of the electricity use in hospitals and most office buildings. Their high energy consumption is largely due to the use of very energy-intensive equipment such as air-conditioning, refrigerators and specialized medical equipment, as well as extended operating 24 h. The study focuses on 14 hospitals in Thailand with the

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total electrical energy consumption of 349.34 TJ. Figure 1 shows the portion of the energy consumption by engineering system. Air-conditioning system, lighting system and other system are accounts for 63 %, 15 % and 22 % of the total electrical energy consumption (Department of Alternative Energy Development and Efficiency, 2016).

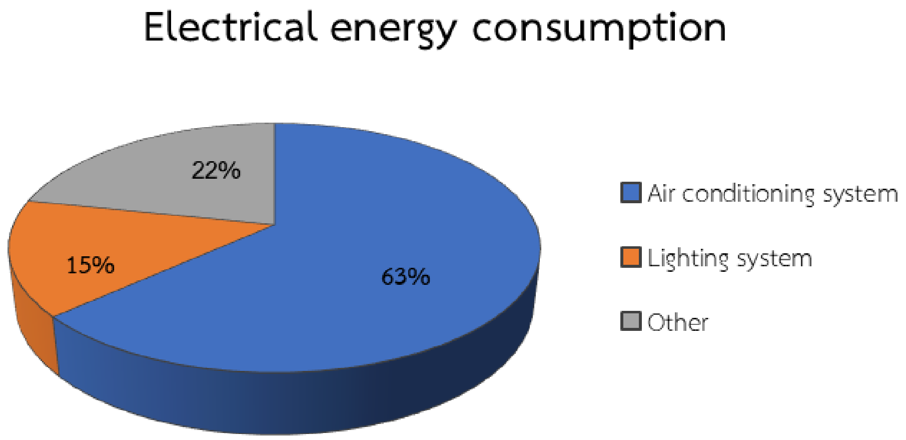


Figure 1: Portion of the energy consumption by engineering system.

3. Methodology

3.1 Multi regression analysis

Mathematical regression analysis is normally used method for analysis of relationships between multiple variables. By identifying reasonable dependent relations between two or more variables, regression analysis helps in discovering the hidden rules from the data (Tian, 2016). Multiple linear regression analysis is an extension of the simple linear regression analysis. It is used to evaluate the relationship between two or more independent variables and a single continuous dependent variable. The multiple linear regression equation is as follows:

$$Y = b_0 + b_1(X_1) + b_2(X_2) + b_3(X_3) + \ldots + b_n(X_n) + \epsilon \quad (1)$$

Where Y is the predicted or expected value of the dependent variable, X_1 through X_n are n distinct independent or predictor variables, b_0 is the value of Y when all of the independent variables (X_1 through X_n) are equal to zero, and b_1 through b_n are the estimated regression coefficients (Yang et al., 2017). The residual ϵ is used to test the overall significance (F-test) of the equation. Another important indicator is the coefficient of determination, 2R, which not only indicates the goodness of fit, but also can be interpreted as the amount of variations of the dependent variables explained by the regression equation (Montgomery, 2006).

3.2 Energy baseline

One approach to obtain the energy baseline is to derive references or targets through benchmarking which is a well-established management tool (Moriarty, 2011). It is applied for the selection of the most appropriate pathway. The selected pathway will be employed to create a baseline sitting which is suitable for building control. To make baseline sitting, it requires considering the difference of variations in energy consumption and factors affecting the energy use, capacity in monitoring and report of building control (Thinate et al., 2017).

3.3 Target setting

The energy target-setting tool is designed to help in calculating incremental reduction targets, based on the assumption of a linear reduction trend. However, because reduction paths are not always linear, the incremental targets are intended to generally serve as a guide. It is essential to use this tool as a quick reference for incremental reduction targets that are necessary to progress toward the long-term goal (Wang et al., 2010).

4. Results and discussion

The regression model was developed from the involved energy variables from 14 hospitals from small to large hospitals. Thus, this model was served as a baseline sitting used to forecast the energy use in hospital buildings in the future. This section shows the quantity of the real energy use along with the quantity of the expected energy use obtained from the regression model. All variables used for constructing the regression model are illustrated in Table 1. Figure 2 shows relationships between electrical energy consumption and its related variables.

Table 1: Dependent variables (Y) and explanatory/independent variables (X)

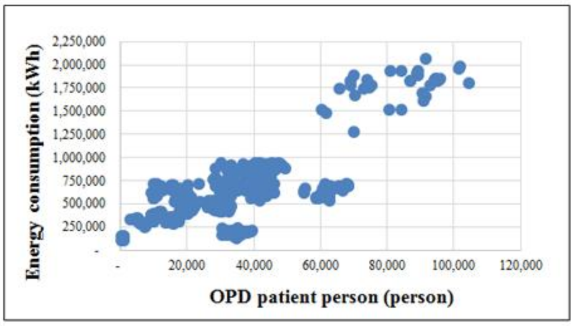
Variable	Description	Unit
Y	Electrical energy consumption	kWh
X_1	Out Patient Department (OPD) patient person	person
X_2	In Patient Department (IPD) service unit	bed-day
X_3	Number of staff member	person
X_4	Air-Conditioning Area	m^2
X_5	Non-Air-Conditioning Area	m^2
X_6	Parking spaces in the buildings	m^2
X_7	Ambient temperature	^oC
X_8	Average relative humidity	%

All variables shown in Table 1 were collected from real data. Out Patient Department (OPD) patient person, In Patient Department (IPD) service unit, number of staff members, air-conditioning area, non-air-conditioning area, parking spaces in the buildings were collected from surveyed data and from the hospital annual energy management report submitted to Department of Alternative Energy Development and Efficiency, Ministry of Energy of Thailand every year. The ambient temperature and relative humidity were obtained directly from the Thai Meteorological Department. This regression model was derived from a set of statistical processes for estimating the relationships among essential variables. As a result, the coefficient value of each of the independent variables were obtained as illustrated in Table 2.

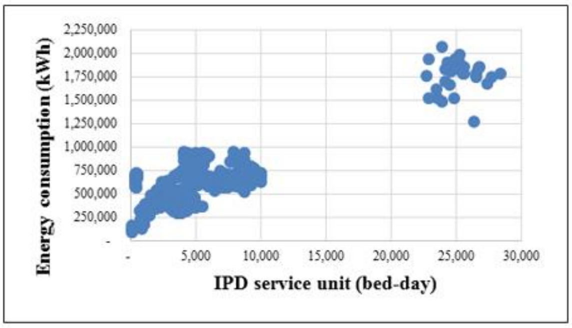
Table 2: Coefficient values of independent variables (X)

Variable	Description	Coefficient value
X_1	Out Patient Department (OPD) patient person	-1.507
X_2	In Patient Department (IPD) service unit	15.918
X_3	Number of staff member	132.720
X_4	Air-Conditioning Area	9.653
X_5	Non-Air-Conditioning Area	0.040
X_6	Parking spaces in the buildings	6.211
X_7	Ambient temperature	13,469.937
X_8	Average relative humidity	-3,922.397

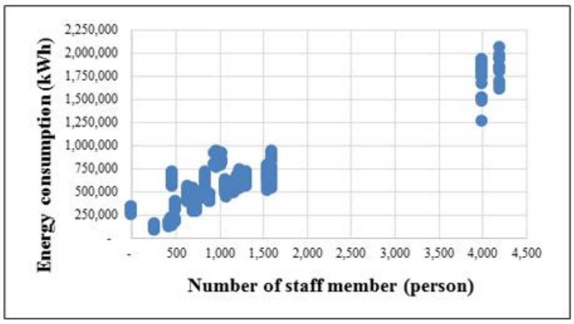
Regression analysis showed that non-air-conditioning area (X_5) had insignificant impact on the electrical energy consumption (Y) due to a very small coefficient value with p-value greater than 0.05, non-air-conditioning area would be neglected. Other variables that had impact on electrical energy consumption were OPD patient person, IPD service unit, number of staff member, air-conditioning area, parking spaces in the buildings, ambient temperature and average relative humidity. It was observed from Figure 2 that OPD patient person (X_1), IPD service unit (X_2) were the most impact factors among all variables. Even though the coefficient value of OPD patient person was small in compared with the one of IPD service unit, however, there were great numbers of patients and their relatives using the OPD service unit all day. The electrical energy consumption changed substantially in proportional to the change in numbers of OPD patient persons and IPD service unit. The results matched the nature of the hospital business, since the OPD and IPD units were mostly crowded areas in the hospital. Even though the graphs showed that the electrical energy consumption changed in response to the changes in the number of staff members (X_3) and air-conditioning area (X_4), this was because the data were collected from many hospitals that had different air-conditioning area and numbers of staff members. In fact, the numbers of staff members do not change very much, so that it should not affect the change in electricity use in the hospital. Similarly, the air-conditioning area does not change very often, therefore, it should not really affect the change in electricity use in the hospital as well. Parking spaces (X_6) had small impact on the change in electrical energy use since the numbers of lighting, CCTV, and other systems used in the parking area were usually unchanged. Ambient temperature (X_7) usually influenced the electrical energy use in air-conditioning system. Since the coefficient value of ambient temperature was so high, it really did affect the amount of electrical energy consumption of the hospitals even with small changes in the ambient temperature. To reduce



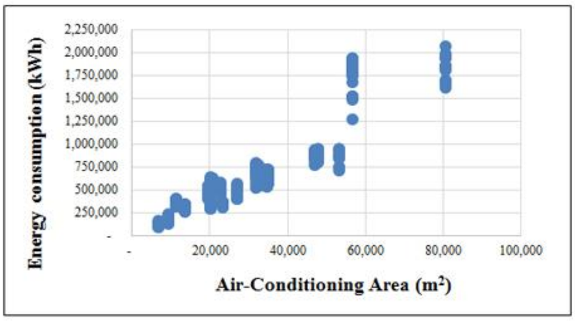
(a) The relationship between energy consumption with OPD patient person



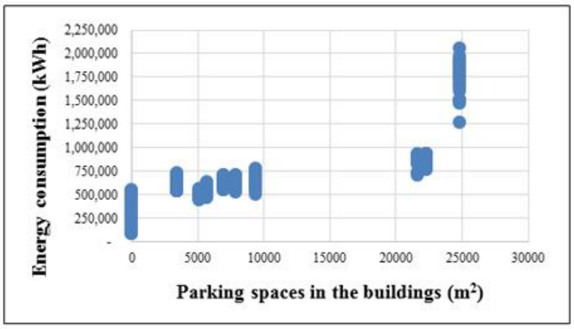
(b) The relationship between energy consumption with IPD service unit



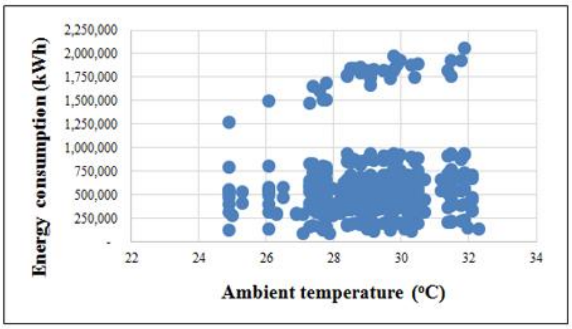
(c) The relationship between energy consumption with number of staff member



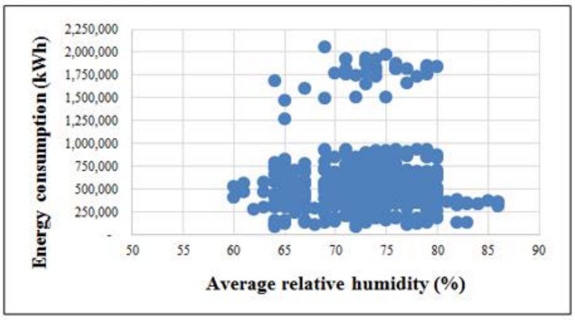
(d) The relationship between energy consumption with air-conditioning area



(e) The relationship between energy consumption with parking spaces in the buildings



(f) The relationship between energy consumption with ambient temperature



(g) The relationship between energy consumption with average relative humidity

Figure 2: Relationships between electrical energy consumption and related variables.

the effect of heat loads from outside temperature, well designed building and energy management must be achieved. The forecast model of the electrical energy consumption (Y) with respect to all independent variables is given by Eq(2).

$$Y = -1.507(X_1) + 15.918(X_2) + 132.720(X_3) + 9.653(X_4) + 6.211(X_6) + 13469.937(X_7) - 3922.397(X_8) \quad (2)$$

Figure 3 shows the electrical energy consumption obtained from the multiple regression model and the collected actual data in the hospitals over 3 y period from 2015 to 2017. The energy consumption obtained from the forecast model follows closely to energy consumption from the actual collected data. The energy consumption from the forecast model is approximately 4.4 % different from the energy consumption from the actual data. Therefore, this regression model can be used to forecast the electrical energy consumption in hospitals. Furthermore, this model can be used as a tool to analyse energy consumption, in which what variables play major contribution to the increase in the electrical energy consumption in the hospitals. At present there may be some models forecasting the energy consumption in hospitals, however, it often involves with only a few variables such as indoor working area and IPD service unit. Since there has not been models for forecasting the energy consumption with respect to numerous variables at the same time. This work could help in making the target setting of the reduction of the energy use in hospitals. Moreover, it could also help in the decision making for separating the hospitals with high potential energy efficiency from the low potential one.

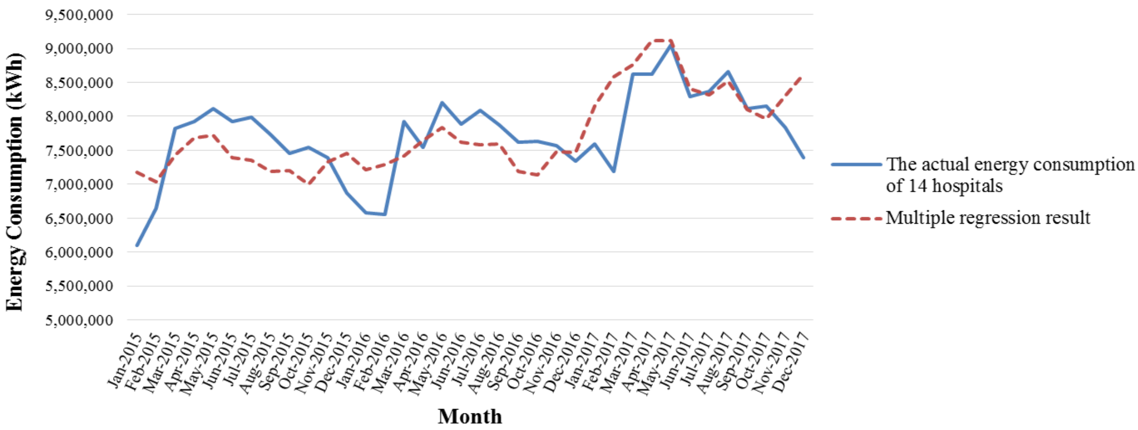


Figure 3: Energy consumption from regression model and actual data

Eq(2) can only be used to forecast the electrical energy consumption of 14 hospitals all together. It is suitable and very beneficial for the government to see the energy consumption in a big picture for the hospital sector in Thailand. However, if one wants to evaluate the electrical energy consumption in a particular hospital, Eq(2) may not be suitable for this job. Air-conditioning area, non-air conditioning area, and parking spaces in the buildings are usually constant for each hospital. In fact, there will not be any significant changes in these areas very often. Numbers of staff members are generally the same for each hospital as well. With these reasons, the new regression model of the electrical energy consumption needs to be derived solely for each hospital. Only OPD patient person, IPD service unit, ambient temperature, and relative humidity are significantly accountable for the variations of the electrical energy consumption in each hospital. As a result, the regression model for each hospital can be reduced to Eq(3).

$$Y = b_1(X_1) + b_2(X_2) + b_7(X_7) + b_8(X_8) \quad (3)$$

Further investigation on electrical energy consumption based on size of the hospitals can be performed by separating hospitals into two groups, i.e., large and small hospitals. It is clearly seen in Figure 2(b) that large hospitals have over 20,000 bed-day with the amount of electrical energy consumption more than 1,500,000 kWh. On the other hand, the small hospitals have less than 10,000 bed-day with the amount of electrical energy consumption less than 1,000,000 kWh. Even the numbers of staff members increase from less than 1,500 persons for small hospitals to more than 4,000 persons for large hospitals. These surely affect the amount of energy consumption in hospitals as well. By grouping hospitals into large and small sizes, this can certainly help in achieving a more useful and accurate multiple linear regression model on electrical energy consumption for hospitals in Thailand. However, there may be some limitations to obtain a good regression model for smaller hospitals as a result of lack of personnel, equipment and financial resources.

5. Conclusions

This paper presents relevant factor impacts and target setting of energy consumption in Thailand's hospital building. Multiple linear regression has been developed to find the electrical energy consumption with respect to various variables, i.e., OPD patient person, IPD service unit, numbers of staff members, air-conditioning area, parking spaces in the buildings, ambient temperature and average relative humidity. The study demonstrates the comparison of the real electrical energy use and the forecasted electrical energy use from the regression model. The difference between the energy consumption from the forecast model and the energy consumption from the real data is approximately 4.4 %. The developed regression model can be served as a baseline sitting used to forecast the energy consumption in the hospitals. Therefore, the quality and amount of data are the most dominant factor that determines the performance of a regression model. A good regression model may not be obtained for smaller hospitals, where most data are not well organized and recorded due to a lack of personnel, equipment and financial resources. For large hospitals, there are many departments and large scale medical equipment, investigation on the electrical energy consumption and operation time in these particular areas can be the future challenge to learn how these factors impact the electrical energy consumption in the hospitals.

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