Kasetsart J. (Nat. Sci.) 46 : 298 - 304 (2012)

Energy Utilization Index and Benchmarking for a Government Hospital

Sirinath Thongkaw and Kriengkrai Assawamartbunlue*

ABTRACT

The energy utilization index is a measure that can be used to identify whether energy is being efficiently used. Energy consumption in public buildings is extremely large and is difficult to control and monitor. An efficient index based on engineering principles and ease of use was developed to monitor the energy usage in a public building,—a hospital—as a prototype building. The index was calculated as the difference between the actual energy consumption and optimal energy consumption expressed as a ratio of the optimal energy consumption. Actual energy consumption was defined as the amount indicated on an energy invoice. Optimal energy consumption was derived based on several engineering standards and codes as a function of variables such as the number of officers, number of customers, operating hours and building areas, among other factors. The 'EnergyPlus' simulation program was used to analyze optimal energy consumption. Based on the results, the prototype hospital could save up to 15% on energy consumption if the building were improved to comply with standards and codes.

Keywords: 'EnergyPlus', energy utilization index, benchmarking, hospital building, energy standards and codes

INTRODUCTION

The current energy crisis has forced both the government and the private sector to determine energy conservation measures in order to lower their energy consumption. However, they are first confronted with the same simple questions: "Do we use energy efficiently nowadays?" and "How do we know whether we use energy efficiently?" The answers to such questions lead to different actions. An approach was used to develop an energy utilization index, using a hospital as a prototype building.

BACKGROUND

Sharp (1996) analyzed the energy intensities of office buildings and used a linear regression model to identify the strongest determinants of different intensities of office building energy use. The regression model showed that the most common and strongest indicators of the intensity of electricity use in a building corresponded to the logarithm of the number of workers per area, the category describing the number of personal computers in the building, the number of operating hours, the number of occupants, economizers and chillers. Murray *et al.* (2008) found that a benchmark of 0.2 $GJ.m^{-3}$ was suitable for Scottish healthcare buildings. Energy

Energy Technology Research Group, Department of Mechanical Engineering, Kasetsart University, Bangkok 10900, Thailand.
* Corresponding author, e-mail: fengkka@ku.ac.th

Received date : 06/08/11 Accepted date : 15/03/12

Policy and Planning (2007) developed an energy index for nine public buildings. Each building had different equations; for example, the equation for a hospital division was a function of occupancy number, total usage area, number of outpatients, length-of-stay of inpatients admitted into the hospital and ambient temperature. Department of Alternative Energy Development and Efficiency (2008) also developed energy indices for several other industries. For the steel industry, the energy index was 728 $kWh.t^{-1}$.

The work cited in the previous paragraph provides two common types of energy index. One is defined in terms of the specific energy consumption (SEC), while the other uses an energy utilization index (EUI). SEC is the ratio of the energy consumption divided by production. SEC is commonly used in industries utilizing products such as steel, wood and ceramics. The EUI is the ratio of actual energy consumption divided by optimal energy consumption. The actual energy consumption is the real energy consumption as indicated on an energy invoice. The EUI is commonly used, with examples being hospitals, schools and commercial buildings.

Benchmarking measures and compares the products and services of an individual organization with general corporate practices based on competitors in order to improve the products and services of the individual organization (Robear, 2000). Benchmarking is a popular tool nowadays used by many organizations because they can make substantial improvements and continue to expand. Generally, benchmarking is undertaken within the same or a similar industry with regard to products or services, such as steel, semiconductors, hotels, among others. One popular benchmark tool is to compare the SEC or the EUI. Although benchmarking is very useful, a disadvantage can be any differences in the corporate culture, so that this method is not suitable for every organization. In the current study, the EUI was used to compare the benchmark performance of the building. If the actual energy consumption (AEC) is greater than the optimal energy consumption (OEC), the EUI is negative and the building does not efficiently use energy. On the other hand, if the actual energy consumption (AEC) is less than the optimal energy consumption (OEC), the EUI is positive and the building uses energy efficiently.

MATERIALS AND METHODS

The EUI was chosen for this research because of its flexibility and the variety of factors that affect the energy consumption of the selected building. EUI is defined by Equation 1:

$$EUI = \frac{OEC - AEC}{OEC} \quad (1)$$

where AEC is the actual energy consumption indicated on an energy invoice and OEC is the predicted optimal energy consumption based on several engineering standards, laws or recommendations developed by well-known energy institutes such as Thailand's Energy Conservation Promotion Act (Ministry of Energy, 2007), the Project Performance Improvement of Electrical Equipment (Electricity Generating Authority of Thailand, 2005) and the Energy Star Project (U.S. Environmental Protection Agency and the U.S. Department of Energy, 1995).

A difficulty in calculating the EUI is determining the OEC, which depends on several variables such as the number of staff, number of customers, number of operating hours and the size of air-conditioned areas, among others. The OEC should comply with several engineering standards and laws as indicated above. 'EnergyPlus' (U.S. Department of Energy, 2011) was used as a simulation tool to predict the optimal energy consumption. The program was first calibrated with the monthly actual energy consumption for 12 mth, based on building information and Thailand weather data (U.S. Department of Energy, 2011). Several parameters were adjusted so that the difference between the monthly actual and monthly predicted consumption was less than ±10%.

After calibration, standard criteria were applied to predict the monthly optimal energy consumption if the building had been modified to meet minimum energy requirements according to the applicable codes. Then 'EnergyPlus' was used to generate sets of data by varying factors, such as occupancy, outdoor temperature and other factors. These data were used to develop a regression model that could easily be used without requiring technical skills. Figure 1 shows the procedure in the study to determine the optimal energy consumption for a building.

This approach was chosen because 'EnergyPlus' is a sophisticated program that requires engineering skill and experience. It is not suitable for building technicians to directly implement the program if there are continual changes in the operating conditions, such as the number of outpatients and inpatients and the ambient temperature, among others. Thus, a regression model was developed using multi-linear regression techniques (Equation 2):

$$Y = B_0 + B_1 x_1 + B_2 x_2 + \ldots + B_k x_k \quad (2)$$

where the constants, $B_0, ..., B_k$, of the equation are determined using the basic principles of statistics and multi-linear regression, given the set of data generated by 'EnergyPlus'. If the equation has a high R^2 value, the equation can explain the relationship between the independent and dependent variables (Vanichbuncha, 2005). Hence, the OEC was determined and substituted into Equation 1 to determine whether or not the building efficiently used energy. If the EUI is positive, the building consumes less energy than the standard. However, if the EUI is negative, the building consumes more energy than the standard.

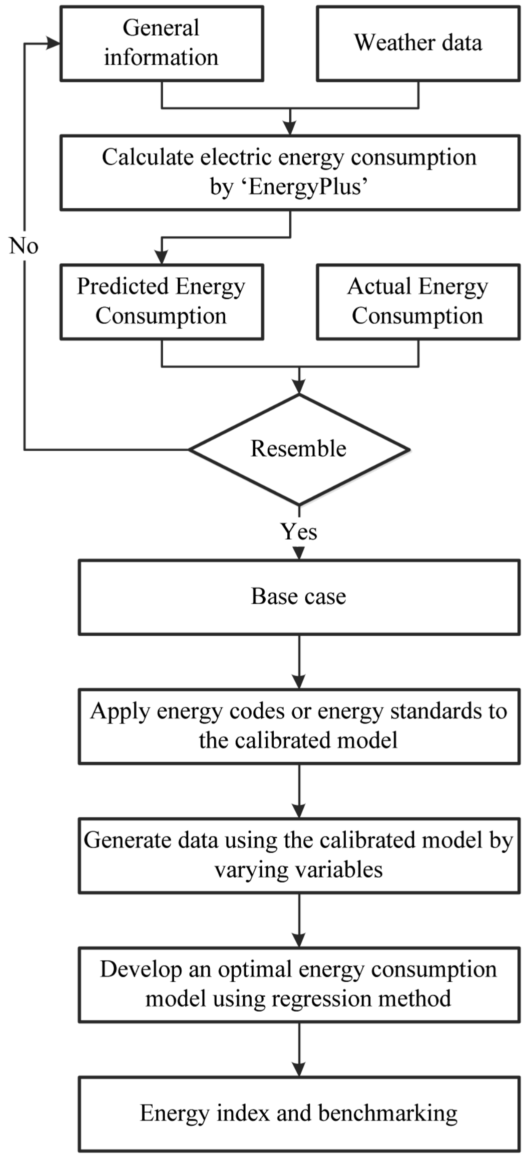

Figure 1 Research approach used in the study.

PROTOTYPE BUILDING

A 21-story hospital building with a total usable area of 55,836 m² was used as the prototype building. The air-conditioned area was approximately 51% of the total area. The walls and roof were made of common brick and cement and covered with a light-colored paint. Fenestrations were are made of 3mm-thick glass with a thermal barrier. The fenestrations accounted for 44% of the total exterior area. There were several types of rooms in the building; for example outpatient and inpatient departments, examination rooms, meeting rooms and offices. The prototype building was modeled by 'EnergyPlus'. There were 526 spilt-type air-conditioners, with an average energy efficiency rating (EER) lower than 7.6 BTU. $hr^{-1}.W^{-1}$ and 7 air-cooled chillers in the building. Typical lighting consisted of 18 W and 36 W fluorescent lamps with electromagnetic ballasts. Like other hospitals, there was a large amount of medical equipment, some of which required large amounts of power, such as X-ray machines and the blood freezer.

RESULTS AND DISCUSSION

Figure 2 illustrates the differences (less than ±10%) between the actual monthly energy consumption from the electricity bills and that predicted by 'EnergyPlus' after calibration. The energy standards and codes were implemented in 'EnergyPlus' to predict the optimal energy consumption under various operating conditions. The data from the predictions were then used to develop a regression model. The energy standards and codes are shown in Table 1.

The regression model was developed to predict the OEC and was based on statistical analysis. Four variables were considered—namely, the number of outpatients, inpatients, staff and the ambient temperature. These variables substantially affect the energy consumption of the building and have normally been recorded every month by building staff; thus, it was easy for them to retrieve these data for use in the developed model. A dataset for the regression was generated by varying these four variables using 'EnergyPlus' to represent various operating conditions. The regression model is shown in Equation 3 ($R^2 = 0.853$):

$$OEC = \exp[8.114 + 0.258\, ln(\text{outpatient}) + 0.486\, ln(\text{inpatient}) - 0.404\, ln(\text{staff}) + 0.552\, ln(\text{ambient temperature})] \quad (3)$$

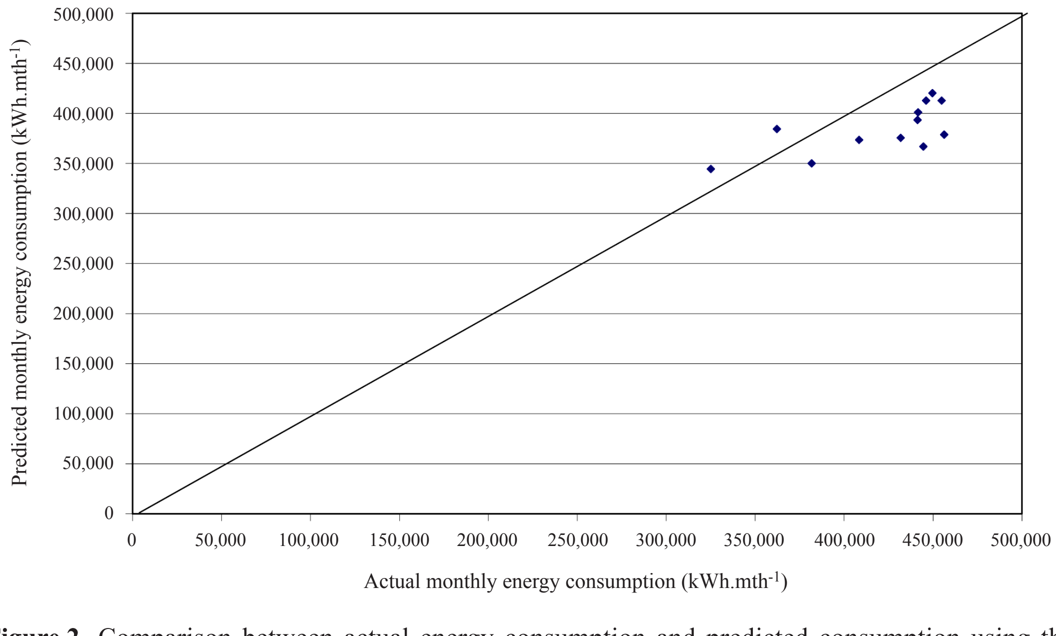

Figure 2 Comparison between actual energy consumption and predicted consumption using the calibrated 'EnergyPlus' model.

where outpatient, inpatient and staff are parameters for the total monthly numbers of outpatients, inpatients and staff, respectively, and ambient temperature is the monthly average outdoor temperature.

Figure 3 shows the predictions from 'EnergyPlus' and from the regression model in Equation 3.

Figure 4 shows the monthly energy utilization index of the prototype building in 2008. Actual data (numbers of outpatients, inpatients, employees and ambient temperature) were retrieved from the hospital records and substituted into Equation 3 to predict the OEC. Then, the OEC and AEC from energy bills were substituted into Equation 1 to calculate the EUI.

Table 1 Implemented energy standards and codes.

Specification	Organization	Data source	Value
Efficiency of air conditioning	Ministry of Energy	Performance Improvement of Electrical Equipment project	11 $Btu.W^{-1}$
OTTV	Ministry of Energy	The Energy Conservation Promotion Act (2007)	30 $W.m^{-2}$
RTTV	Ministry of Energy	The Energy Conservation Promotion Act (2007)	10 $W.m^{-2}$
Power of lighting equipment	Ministry of Energy	The Energy Conservation Promotion Act (2007)	12 $W.m^{-2}$

OTTV = Overall thermal transfer value; RTTV = Roof thermal transfer value.

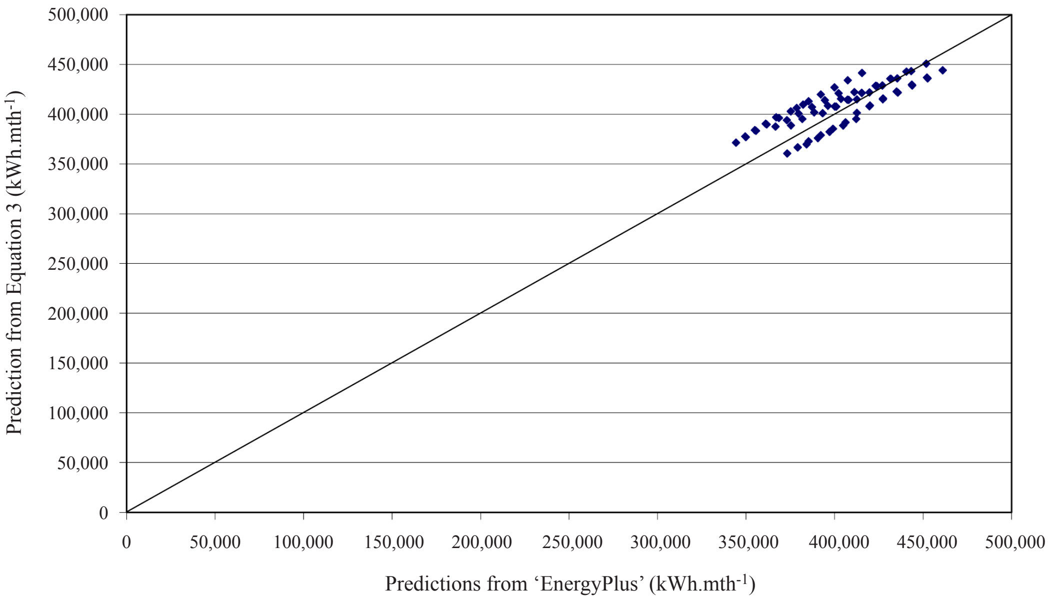

Figure 3 Predicted optimal energy consumption (OEC) from Equation 3 and the 'EnergyPlus' software.

The monthly EUI was negative because approximately 74% of the existing equipment and air conditioners were classified as low-performance based on field measurements. The existing overall thermal transfer value (OTTV) and roof thermal transfer value (RTTV) of the building were 51.67 and 21.49 $W.m^{-2}$, respectively, which are above the energy standards shown in Table 1. The prototype hospital could save approximately 15% on energy consumption costs if the building were improved to conform to the standards. The OEC was derived from the energy standards and codes already mentioned. To have a positive EUI, the equipment and building must be improved to meet the energy standards and codes; for example, by installing exterior or interior shading to reduce the solar heat load or by replacing existing clear glass with double low E glass. Such changes would contribute greatly to a reduction in the OTTV but would require a large capital investment. Roof insulation could be installed to reduce thermal transfer through the roof and reduce the RTTV. Air conditioners could be changed to ones with a higher performance rating (EER > 11) and office appliances could be replaced with those meeting the 'Energy Star' standards.

According to the Energy Conservation Promotion Act (Ministry of Energy, 2007), all commercial and industrial buildings must have an energy management team to manage the use of energy within the facility. The EUI can be used as a performance index for the energy management team as well as for their energy conservation measures. Required data could be recorded and used to calculate the EUI to assess their performance each month.

The method can also be used for economic analysis. If the prototype building were improved to the energy standards, the building would consume less energy (approximately 457,457 $kWh.yr^{-1}$) with an estimated value of THB 1.6 million annually. This amount is simply calculated from the difference between the actual energy consumption and the optimal energy consumption. While this estimate may not be accurate, it is useful for a preliminary assessment and economic analysis of the measures which can be presented to the board of directors. Although it may require time and money to improve a building's energy usage, the energy management team could use the EUI to develop a plan for implementing energy saving measures.

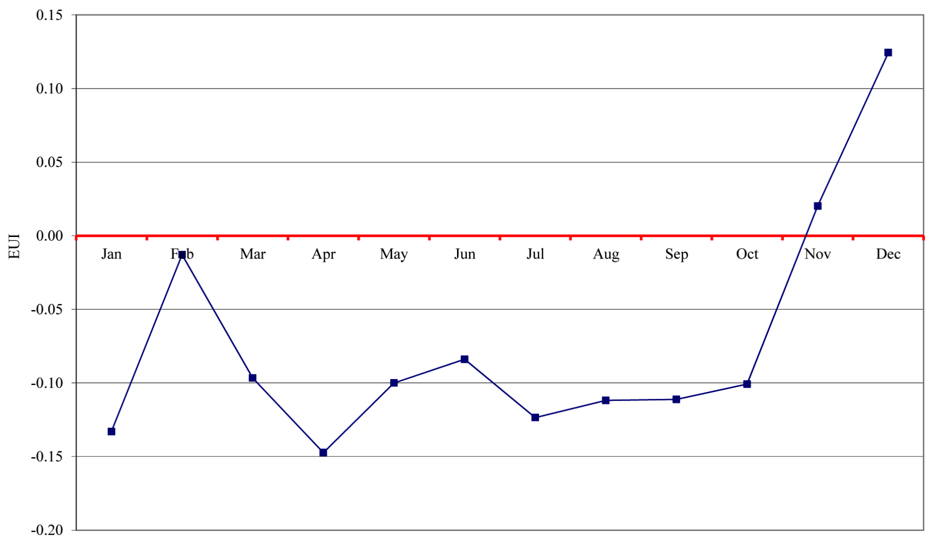

Figure 4 Energy utilization index (EUI) analysis by month for the prototype hospital.

CONCLUSION

The energy utilization index is a measure that can be used to identify whether energy is being efficiently used, compared with energy standards and codes. It also provides a means to estimate the monetary value of energy costs and potential saving that the energy management team can use to make investment decisions and facilitate retrofitting work. The approach proposed to determine the EUI of a building was based on energy simulation and energy codes. The approach has limitations which may cause prediction errors such as where a building is modified, for example, by increasing the air-conditioned area, increasing the amount of equipment or changing the function of an area. Such limitations are due to the simplicity of the regression model which was designed for ease of use by non-technical persons. When a building is modified, a new regression model must be developed that can accurately predict the optimal energy consumption under the new operating conditions. Thus, Equation 3 may need to be revised every 3–5 years, or when the function of the building or the amount of equipment changes noticeably.

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