A simplified model of energy performance indicators for sustainable energy management

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Abstract. In international management, ISO 50001 has been widely applied in organisations across the world, including Thailand. The main objective of this standard is to continuously and sustainably improve the energy performance of the organisation in order to reduce energy consumption and costs, including alleviating environmental climate change impacts. This standard stipulates the measurement of energy performance improvement using energy performance indicators (EnPIs) and the energy baseline (EnB). This study proposes a simplified model of energy performance indicators (EnPIs), effective for ISO 50001 energy management at organisational level. Appropriate internal benchmarking is proposed for measuring three levels of energy performance, namely organisational, process, and main machine, through energy consumption, intensity, and efficiency. Multiple linear regression was selected to develop energy equations to express the relationship between energy consumption and significantly related variables such as service usage, operating hour, and CDD for business buildings, etc. The proposed EnPIs are applied to measure the energy performance of the case study of business buildings in Thailand complying with ISO 50001. This method can be effectively used to measure changes in the energy performance of the organisation as well as the processes and considered as a comparative alternative to public benchmarking, such as kWh/m². The findings of this study are considered to be beneficial for every organisation adopting the ISO 50001 system. This proposed method can be effectively used to monitor and measure the organisation's energy performance towards sustainable energy management. However, it still has certain limitations. In the case of energy consumption models that are related to non-linear related variables, it is necessary to conduct further studies to determine more appropriate EnPIs.

Keywords: Energy Performance Indicators, ISO 50001, Simplified Model, Sustainable Energy Management
1. Introduction
At the moment, sustainability and the impact of climate change are at the forefront of organisations around the world, with particular emphasis on activity collaboration between society and the environment [1]. Many agencies have created standards, criteria, and awards to support and encourage organisations to come together to create sustainability for future generations such as Carbon Trust [2], EarthCheck for hotels [3], UI green metric for green university [4] and LEED for green building [5]. These sustainability standards or criteria are important indicators of energy efficiency [2], [3], [4]. Energy efficiency directly affects the environment and sustainability [6]. The inefficient use of energy will lead to increased environmental problems, resulting in increased carbon dioxide emissions; the main cause of global warming [7], [8]. An important tool throughout the world for creating confidence in effective energy management is the Energy Management Standard such as ANSI/MSE 2000:2008 [9], EN16001 [10] and ISO 50001 [11], an international standard focusing on the continuous improvement of energy performance in organisations. To increase sustainability and reduce energy use and cost, including the mitigation of climate change and environment effects, there are more than 18,059 certificated around the world [12]. In Thailand, more than 260 sites have received ISO 500001 certification [12]. At present, the second edition of this standard is being implemented [13]. The ISO 50001 measures the effectiveness of energy management, continuous energy performance improvement, and EnMS. The standard specifies the measurement of energy performance improvement by comparing changes in energy performance indicators (EnPIs) with related energy baselines (EnBs) at organisational level, SEU level, and the major machinery involved [14], [15]. According to which form is appropriate, EnPIs may include energy consumption, energy intensity, or energy efficiency. In general, EnPIs consist of mathematical methods such as Simple Normalisation (Simple) used to sample of energy-consumption data and the floor area is MJ/m² for school buildings [16] and a commercial building [17]; Ordinary Least Squares (OLS) used a simple linear regression model to evaluate the energy performance of commercial building [18], Stochastic Frontier Analysis (SFA) [19], Data Envelopment Analysis (DEA) [20], the model-based method (Simulation) [21], and Artificial Neural Networks (ANNs) [22]. The most commonly used method is simple normalisation (Simple) in the form of public benchmarking [23], for example, kWh/m² for the building since this can be easily compared between organisations. In Thailand, there is a set of energy performance indicators for the energy management of buildings that operate in the form of simple normalisation (Simple), kWh/m², and MJ/m², mainly because of the many ideas presented in energy usage reports to government agencies. The disadvantage of this method is that it is not possible to accurately measure changes in the energy performance of buildings, since it cannot show the results of changes at different times, thereby affecting performance evaluation due to the lack of important factors influencing the energy consumption of buildings or relevant variables such as the volume of service usage and changes in outside air temperature which directly affect the working load of the air conditioning systems in Thailand. Moreover, the active area (m²) does not change, and this is defined as a static factor [15]. This study measures the change in energy performance in the form of energy consumption, considering the relevant factors or variables for a business building in Thailand that has implemented the international energy management standard ISO 50001 during 2017–2018. This paper proposes a development of simplified model of energy performance indicator to monitor the energy performance of the building that adopted energy management system. This will enable the managers to accurately monitor and evaluate the energy performance changes; bringing them to improve the sustainable energy management.

2. Methods
The purpose of using energy performance indicators for energy management according to ISO 50001 [13] is investigated in this research. The findings indicate that it is used to measure changes in the energy performance of buildings at different times following improvement according to established energy objectives and targets [15]. They are also used to monitor changes in energy performance each month. A business building is selected as a case study in this research.
2.1 Energy review for SEUs identification
An energy review is a procedure for analysing data on energy usage characteristics and past energy use to identify opportunities for improving the energy performance of buildings. The SEU accounts for substantial energy consumption and/or offering consideration of the energy performance improvement potential [13].

2.2 Determine relevant variables
A relevant variable is a quantifiable factor that significantly impacts on energy performance and routinely changes energy consumption in buildings [15]. It is necessary to determine the relevant variables affecting significant energy use characteristics based on monthly periods. Generally, more than one variable is used in the determination. The EnPIs data is normalised before comparison with EnB so that it can be compared equally.

2.3 Method selection
This study uses the multiple linear regression model to create the energy baseline equation to evaluate the energy performance of buildings [23]. By specifying that the independent variable is the relevant variable and Equation (1) represents the amount of energy consumption.

\[
Y = C_0 + C_1 x X_1 + C_2 x X_2 + \ldots + C_n x X_n
\]

where \( Y \) is Energy consumption
\( X_1, X_2, \ldots, X_n \) is the relevant variable 1, 2, \ldots, n
\( C_0 \) Coefficient values of intercept
\( C_1, C_2, \ldots, C_n \) Coefficient values of the relevant variable 1, 2, \ldots, n

2.4 Case study for validation
The method of the study is used to conduct an actual evaluation of the sample business building to monitor changes in energy performance of the building and the SEU arising from the implementation of energy conservation measures during 2017–2018.

3. Results
The case study involves a business building located near Bangkok, Thailand, with a usable area of approximately 34,850 m², open for 14 hours a day. Electricity is the main energy source.

3.1 Energy review for SEUs identification
The energy review shows the data for a business building during January–December 2017, including energy use and consumption as presented in Table 1.

### Table 1. Energy use and consumption for the business building in 2017

| No. | Energy use                          | Energy consumption (kWh/year) | Proportion (%) |
|-----|-------------------------------------|------------------------------|---------------|
| 1   | Central air conditioning system     | 10,328,395.06                | 63.92         |
| 2   | Lighting system                     | 2,749,836.13                 | 17.02         |
| 3   | Split-type air conditioning system  | 362,291.63                   | 2.24          |
| 4   | Sanitary system                     | 765,000.80                   | 4.73          |
| 5   | Elevators                           | 148,076.00                   | 0.92          |
| 6   | Waste water treatment system        | 305,532.00                   | 1.89          |
| 7   | Air ventilation system              | 827,487.85                   | 5.12          |
| 8   | Heat pump                           | 113,880.00                   | 0.70          |
| 9   | Other                               | 557,500.53                   | 3.45          |
|     | Total                               | 16,158,000.00                | 100.00        |

In Table 1, the SEU is determined by the use of Pareto analysis for establishing past energy consumption for a period of 12 months from January–December 2017. The central air conditioning and lighting
systems were selected as the top two SEU, accounting for over 80% of the total electrical energy consumption to meet the significance criteria.

3.2 Identify relevant variable
The relevant variable is identified by determining the factors affecting energy consumption or SEU characteristics of buildings by considering the quantitative relationships involved by applying the simple linear regression model. Table 2 shows the relevant variables: service usage (Person) \((R^2 = 0.23)\), cooling degree days (CDD) \([24](R^2 = 0.49)\), and operating hours \((R^2 = 0.35)\), respectively.

Table 2. Relevant variables and static factors in the energy consumption of the building in 2017

| Month | Energy consumption (kWh) | Relevant variables | Static factors | SEC |
|-------|--------------------------|--------------------|----------------|-----|
|       | Service usage (person)   | CDD                | Operating hours | Usage area (m²) | kWh/m² |
| Jan   | 1,286,000                | 427.225            | 86             | 434            | 34,850            | 36.90 |
| Feb   | 1,224,000                | 555.651            | 97             | 392            | 34,850            | 35.12 |
| Mar   | 1,407,000                | 713.504            | 143            | 434            | 34,850            | 40.37 |
| Apr   | 1,343,000                | 655.717            | 164            | 420            | 34,850            | 38.54 |
| May   | 1,436,000                | 647.159            | 149            | 434            | 34,850            | 41.21 |
| June  | 1,363,000                | 618.406            | 145            | 420            | 34,850            | 39.11 |
| July  | 1,378,000                | 693.240            | 109            | 434            | 34,850            | 39.54 |
| Aug   | 1,413,000                | 746.640            | 124            | 434            | 34,850            | 40.55 |
| Sep   | 1,375,000                | 611.684            | 133            | 420            | 34,850            | 39.45 |
| Oct   | 1,375,000                | 607.824            | 111            | 434            | 34,850            | 39.45 |
| Nov   | 1,289,000                | 684.718            | 90             | 420            | 34,850            | 36.99 |
| Dec   | 1,269,000                | 682.612            | 67             | 434            | 34,850            | 36.41 |
| Total | 16,158,000               | 7,644,380          | 1,418          | 5,110          | -                 | -     |

Note: CDD station ID: 48429 [24]

3.3 Energy Performance Indicator model
Since the energy consumption of a building depends on more than one relevant variable, the multiple linear regression model is used to create the 2017 energy baseline equation and energy performance indicators for measuring the change in energy efficiency of the building. The equation is considered as a normalisation.

In Table 3, the multiple linear regression analysis of energy consumption and relevant variables affecting energy consumption indicates that the multiple R is equal to 0.925, meaning that the level of service usage, CDD, and operating hours are correlated with energy consumption by up to 92.5%, with adjusted R square at 0.802. This shows that the level of service usage, CDD, and operating hours influence electricity consumption by up to 80.2% with a significance factor of 9.83E-04, which is much less than 0.05, and can create the equation for use as an indicator to measure the energy performance of buildings, for example, in the form of a statistical model.
Table 3. the result from multiple linear regression analysis

SUMMARY OUTPUT

Regression Statistics

|                  | Multiple R | R Square | Adjusted R Square | Standard Error | Observations |
|------------------|------------|----------|-------------------|----------------|--------------|
| Intercept        | 0.925442584 | 0.856443976 | 0.802610467 | 29032.8631 | 12 |

ANOVA

|                      | df   | SS             | MS             | F          | Significance F |
|----------------------|------|----------------|----------------|------------|----------------|
| Regression           | 3    | 4022974288     | 13409914294    | 15.909     | 0.000983237    |
| Residual             | 8    | 674325711      | 842907139.7    |            |                |
| Total                | 11   | 46973000000    |                |            |                |

Coefficients

|                          | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|--------------------------|----------------|--------|---------|-----------|-----------|-------------|-------------|
| Intercept                | -96147.151     | -0.322 | 0.755   | -783922.660 | 591628.358 | -783922.660 | 591628.358 |
| Service usage (Person)   | 0.126          | 1.123  | 0.294   | -0.132 | 0.383 | -0.132 | 0.383 |
| Cooling Degree Days      | 1437.531       | 4.685  | 0.002   | 730.009 | 2145.054 | 730.009 | 2145.054 |
| Operating hour           | 2801.079       | 3.882  | 0.005   | 1136.983 | 4465.175 | 1136.983 | 4465.175 |

Total energy consumption = -96,147.151 + 0.126 x service usage + 1,437.531 x cooling degree days + 2,801.079 x operating hours

Likewise, in the case of this building, where the SEU has a centralised air conditioning system, this time the above method is applied to the central air conditioning system (CH-01) of the building to create the following energy equations:

Energy consumption (kWh) = -164,620.08 + 0.112 x service usage + 483.17 x cooling degree days + 1,211.94 x operating hours

3.4 EnPIs monitoring

From 2017–2018, the building was measured to improve its energy performance as shown in Table 4. It is expected that, when completed, the energy usage will be reduced by 5.82% compared to 2017.

Table 4. Energy conservation measure for the building during 2018

| no | Energy conservation measure                          | Energy saving (kWh/year) | Total energy consumption saving in 2018 (%) |
|----|------------------------------------------------------|--------------------------|---------------------------------------------|
| 1  | LED Lighting replacement                            | 167,622.72               | 1.04                                        |
| 2  | iCEE system for central air conditioning system      | 576,253.35               | 3.57                                        |
| 3  | OZONE system for cooling tower                       | 196,465.40               | 1.22                                        |
| 3  | Total                                                | 16,158,000               | 940,341.47                                 | 5.82 |

The energy efficiency improvement measures performed on the building directly affect its energy performance and central air conditioning system (CH-01) according to the energy performance data shown in Table 5 and Figures 1 and 2, respectively.
Table 5. Energy consumption of the business building in 2018 and monitoring of the building’s energy performance

| Month | Actual energy consumption (kWh) | EnB 2017 energy consumption (kWh) E=f(x) | % Diff from EnB CUSUM | Energy saving CUSUM | Relevant variables | Static factors | SEC |
|-------|---------------------------------|----------------------------------------|-----------------------|---------------------|-------------------|---------------|------|
| Jan   | 1,311,000                       | 1,328,001                              | -1,28 -17,001         | 663,122             | 84                | 434           | 34,850 | 37.62 |
| Feb   | 1,212,000                       | 1,189,021                              | 1.93 5,979            | 647,241             | 71                | 392           | 34,850 | 34.78 |
| Mar   | 1,383,000                       | 1,407,610                              | -1.75 -18,631         | 704,774             | 134               | 434           | 34,850 | 39.68 |
| April | 1,321,000                       | 1,345,836                              | 1.85 -43,468          | 667,379             | 122               | 420           | 34,850 | 37.91 |
| May   | 1,348,000                       | 1,394,969                              | 3.37 -90,437          | 592,650             | 135               | 434           | 34,850 | 38.68 |
| June  | 1,339,000                       | 1,344,855                              | 0.44 -96,292          | 470,739             | 138               | 420           | 34,850 | 38.42 |
| July  | 1,321,000                       | 1,362,116                              | 3.02 137,408          | 449,938             | 125               | 434           | 34,850 | 37.91 |
| Aug   | 1,285,000                       | 1,337,883                              | 3.95 190,291          | 411,059             | 112               | 434           | 34,850 | 36.87 |
| Sep   | 1,235,000                       | 1,283,570                              | 3.78 238,861          | 303,040             | 111               | 420           | 34,850 | 35.44 |
| Oct   | 1,278,000                       | 1,346,999                              | 5.12 307,860          | 436,194             | 116               | 434           | 34,850 | 36.67 |
| Nov   | 1,232,000                       | 1,300,122                              | 5.24 375,982          | 469,813             | 108               | 420           | 34,850 | 35.35 |
| Dec   | 1,279,000                       | 1,340,358                              | 4.58 437,340          | 595,950             | 98                | 434           | 34,850 | 36.70 |

Note: CDD station ID: 48429 [24]

Figure 1. Energy performance changes in the Building during 2018
Figure 2. Energy performance changes in the central air conditioning system (CH-01) during 2018

4. Discussion

The data presented in Table 5 and Figure 1 compares the EnPI of an organisation using the simplified statistical model to measure energy performance in the form of energy consumption resulting from the relationships of significant relevant variables. The efficiency of surveillance applications and changes in the organisation’s energy performance, including SEU, are shown in Figure 2. This effectively enables organisations to monitor the progress of energy performance improvement resulting from the implementation of energy conservation measures, especially in relation to those applying the ISO 50001 standard compared to energy performance measurements involving intensity (specific energy consumption (SEC) kWh/m²). Consequently, energy performance measurements based on SEC values are unable to indicate whether energy performance values have changed each month as in February 2018 the SEC value is 34.78 kWh/m² indicated in the best performance of the year but in actually it was the worst performance of the year, which may result in inefficient energy management, and sustainability of the system in the long term.

The results of this study will be useful for all organisations applying the ISO 50001 standard. The proposed method can be used to efficiently monitor and measure an organisation’s energy performance that changes according to the energy performance indicator. This indicator proposed here is better than the energy intensity model such as kWh/m²/month to achieve sustainable energy management. However, certain limitations remain. In the case of the power patterns of unrelated variables in a straight line, further studies are needed to determine more appropriate EnPIs.

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