# Development of an Energy Performance Benchmark Using Quantitative Analysis of Energy Consumption of Office Buildings

**HyeGi Kim – Ajou University – kimhyegi@ajou.ac.kr**
**SunSook Kim – Ajou University – kss@ajou.ac.kr**

## Abstract

Building energy benchmarking is a system to evaluate and compare the energy performance of a building over time, relatively to other similar buildings, or to a reference building, which can be used to continuously manage the energy performance of the building. An energy-benchmarking model is a mechanism to develop the benchmarks necessary for the benchmarking process. It should be selected appropriately considering the availability of building energy performance information and building specification data. The purpose of this study is to develop an energy performance-benchmarking model for existing office buildings by analysing energy consumption data from the national building energy consumption database (DB) in Korea. The results of this study can be used as the energy performance evaluation and diagnostic criteria for existing office buildings

## 1. Introduction

Building energy use benchmarking can help building owners and facility managers to assess building energy performance and to identify energy efficiency opportunities. With the advanced information technologies, many countries have provided databases, tools, and evaluation frameworks to assess energy performance as well as to compare buildings to standards or their peer group based on the real energy data collection. As a way to improve energy efficiency in the building sector, the Korean government developed a nation-wide integrated energy consumption DB with about 6.8 million building records and has operated an energy benchmarking system based on the DB. The current energy performance-benchmarking model uses the annual primary energy consumption of electricity and heat energy as a benchmark. The primary energy or $CO_2$ emissions are appropriate to compare national consumption of natural resources such as petroleum and coal, or to check implementation status on GHG reduction targets. However, stakeholders such as building owners and facility managers in individual buildings are less aware of the concept of primary energy. Therefore, it seems difficult to evaluate the heating and cooling energy consumption by the seasonal change thoroughly as well as to identify potential energy waste and the savings opportunities for improvement.

The purpose of this study is to improve the building energy benchmarking model for office buildings that can provide benchmarks with more detailed information to compare the energy performance of buildings. For this purpose, the building specification data and the final energy consumption data (end-use data) were collected from the Korean National Energy Performance Integrated Information System (EPIIS). By use of ASHRAE inverse modelling methods, parameterized models were derived from weather-dependent energy use and weather-independent use, and then an energy performance benchmarking model was developed by a more detailed analysis of the building information and energy use data.

## 2. Methods

To develop the energy performance-benchmarking model, building specifications, and energy consumption data of 4,304 office buildings were collected from the EPIIS. The monthly and annual electricity and heat energy consumption data for 36 months of the recent three years (2013–2015) were collected. Next, buildings with too high or low

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2018. Building simulation applications BSA 2017. bu,press.
https://doi.org/10.13124/9788860461360

energy consumption that could cause distortion in the analysis (399 office buildings) were excluded using the box-plot outlier removal method. To offer benchmarking information to energy consumers such as building owners and facility managers, we analyzed the energy consumption data of 3,905 buildings selected from the initial 4,304 buildings and developed the benchmarking model based on the following contents.

## 2.1 Energy Consumption by Usage

Different types of energy performance information were used as benchmarks to easily determine the current level of energy performance of the buildings. Energy performance indicators that are familiar to energy consumers include the final energy consumption by an energy source, such as electricity and gas, and energy performance according to the purpose of use. The final energy consumption is the energy sources provided to consumers to meet the energy demands for each purpose of use, such as heating and cooling, and it can be constructed easily based on the utility data. Accordingly, the energy consumption DB of each energy source can be used as a criterion to compare the performance level. However, in order for energy consumers to make retrofitting decisions to improve energy performance, the energy consumption for each purpose of use should be analyzed in detail.

Based on the utility data, we separated the energy performance by the purpose of usage for detailed analysis. For this separation, the change point method was applied among the ASHRAE inverse modelling techniques, which uses the point where the energy performance changes based on the ambient temperature. This method derives a regression equation for energy performance by climate in order to separate heating, cooling, and base load from final energy consumption. Therefore, this method requires monthly energy consumption of electricity and heat, and the dry bulb temperature. The EPIIS collected monthly and yearly electricity and heat consumption data in detail via a meter. However, these data were made from the measured values for the building own billing period and require correction for various periods. Thus, before separating energy consumption data by usage, the monthly mean dry bulb temperature data provided by the National Meteorological Administration were collected. Then, the monthly consumption data were corrected based on the collected billing periods information of the 3,905 buildings, and matched the temperature data and energy consumption data.

Fig. 1 shows the change point method that will derive five parameters according to the graph shapes, as follows:

| | |
|---|---|
| $b_0$ | Base-load (kWh/m²·monthly) |
| $b_1$ | Heating sensitivity (slope coefficient) |
| $b_2$ | Cooling sensitivity (slope coefficient) |
| $b_3$ | Heating start temperature (℃) |
| $b_4$ | Cooling start temperature (℃) |

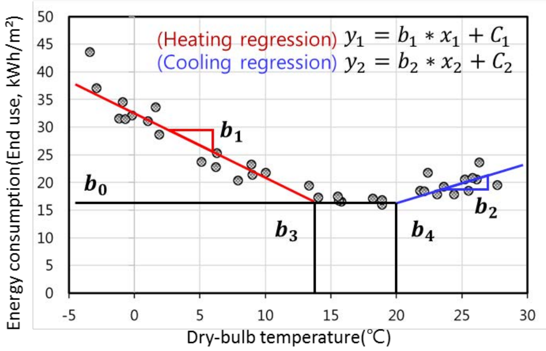


Fig. 1 – Five-Parameters of the cooling and heating models

Also, the following equations show a method to separate the heating and cooling energy consumption using a separated base-load.

***A* = *EC<sub></sub>*** 

$A = EC_M - b_0$

$B = EC_A - 12 \times b_0$

$C = \sum$(*$EC_{Ms}$ of the month which the T(℃) is lower than $b_3$*)

$D = \sum$(*$EC_{Ms}$ of the month which the T(℃) is higher than $b_4$*)

| | |
|---|---|
| $EC_M$ | Monthly final energy consumption(kWh/m²) |
| $EC_A$ | Annual final energy consumption(kWh/m²) |
| $A$ | Cooling and Heating $EC_M$ (kWh/m²) |
| $B$ | Cooling and Heating $EC_A$ (kWh/m²) |
| $C$ | Heating $EC_A$ (kWh/m²) |
| $D$ | Cooling $EC_A$ (kWh/m²) |

In this method, as a first step in separating energy performance, the amount of the base-load must be estimated in the total energy consumption. The base-load generally appeared in April-May and September-October every year. However, the base-load of each year is not the same, because the variables, exception made for temperature, influenced the base-load. Therefore, it is necessary to calculate the representative base-load of the building.

To calculate the representative base-load, two months were selected that showed the lowest energy consumption each year from 2013 to 2015. The use of the selected six energy consumptions set up the cases as shown in Table 1, and examined the cooling and heating energy regression models for each case.

Table 1 – Base-load calculation cases

| | Definition of cases |
|---|---|
| A | Selects the smallest value among the six energy consumptions as the representative base load. |
| B | Selects the second smallest value among the six energy consumptions as the representative base load. |
| C | Selects the third smallest value among the six energy consumptions as the representative base load. |
| D | Selects the fourth smallest value among the six energy consumptions as the representative base load. |
| E | Selects the fifth smallest value among the six energy consumptions as the representative base load. |
| F | Selects the largest value among the six energy consumptions as the representative base load. |

As a result, the number of buildings with high abnormal data and $R^2$ was examined and outlined in Table 2.

Table 2 – Analysis the results of regression of base-load cases

| CASE | | Case A | | Case B | | Case C | | Case D | | Case E | | Case F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Error case① | | 1,653 | | 924 | | 419 | | 178 | | 165 | | 216 | |
| Error case② | | 66 | | 85 | | 101 | | 102 | | 111 | | 179 | |
| Total | | 1,719 (44%) | | 1,009 (26%) | | 520 (13%) | | **280 (7%)** | | **276 (7%)** | | 395 (10%) | |
| Heating regression | $R^2<0.2$ | 2 | 0 % | 27 | 1 % | 55 | 1 % | 105 | 3% | 97 | 2 % | 88 | 2 % |
| | $R^2<0.3$ | 4 | 0 % | 11 | 0 % | 50 | 1 % | 62 | 2% | 66 | 2 % | 76 | 2 % |
| | $R^2<0.4$ | 10 | 0 % | 26 | 1 % | 48 | 1 % | 84 | 2% | 82 | 2 % | 105 | 3 % |
| | $R^2<0.5$ | 8 | 0 % | 25 | 1 % | 69 | 2 % | 99 | 3% | 123 | 3 % | 107 | 3 % |
| | $R^2<0.6$ | 33 | 1 % | 64 | 2 % | 105 | 3 % | 144 | 4% | 152 | 4 % | 159 | 4 % |
| | $R^2<0.7$ | 65 | 2 % | 147 | 4 % | 191 | 5 % | 230 | 6% | 224 | 6 % | 259 | 7 % |
| | $R^2<0.8$ | 170 | 4 % | 284 | 7 % | 406 | 10% | 431 | 11% | 458 | 12% | 448 | 11% |
| | $R^2\geq0.8$ | 1894 | 49% | 2312 | 59% | 2461 | 63% | 2470 | 63% | 2427 | 62% | 2268 | 58% |
| Total | | 2,186 (56%) | | 2,896 (74%) | | 3,385 (87%) | | 3,625 (93%) | | 3,629 (93%) | | 3,510 (90%) | |
| Cooling regression | $R^2<0.2$ | 8 | 0 % | 48 | 1 % | 165 | 4 % | 277 | 7% | 349 | 9 % | 359 | 9 % |
| | $R^2<0.3$ | 18 | 0 % | 43 | 1 % | 114 | 3 % | 164 | 4% | 174 | 4 % | 175 | 4 % |
| | $R^2<0.4$ | 29 | 1 % | 100 | 3 % | 155 | 4 % | 192 | 5% | 188 | 5 % | 202 | 5 % |
| | $R^2<0.5$ | 58 | 1 % | 118 | 3 % | 198 | 5 % | 223 | 6% | 244 | 6 % | 242 | 6 % |
| | $R^2<0.6$ | 116 | 3 % | 216 | 6 % | 278 | 7 % | 319 | 8% | 305 | 8 % | 309 | 8 % |
| | $R^2<0.7$ | 214 | 5 % | 340 | 9 % | 407 | 10% | 402 | 10% | 424 | 11% | 421 | 11% |
| | $R^2<0.8$ | 443 | 11% | 625 | 16% | 635 | 16% | 668 | 17% | 703 | 18% | 690 | 18% |
| | $R^2\geq0.8$ | 1300 | 33% | 1406 | 36% | 1433 | 37% | 1380 | 35% | 1242 | 32% | 1112 | 28% |
| Total | | 2,186 | | 2,896 | | 3,385 | | 3,625 | | 3,629 | | 3,510 | |

If the heating start temperature was higher than the cooling start temperature or the cooling and heating start temperatures did not correspond to the temperature category of the domestic climate, they were deemed abnormal data and removed. Next, the $R^2$ values of the cooling and heating regression equations of office buildings for which the abnormal data had been removed, were examined.

## 2.2 Analysis of Building and Energy Performance Information

Next, the building information was investigated and analysed. The building information and characteristics are outlined in Table 3.

Table 3 – The building information of office buildings

| Variable type | Variable | Group classification criteria | | | Frequency |
|---|---|---|---|---|---|
| Discrete variable | Region | - | | | 16 |
| | Structure | - | | | 9 |
| | Roof type | - | | | 4 |
| Continuous variable | Gross area (m²) | 1 | 0~25% | 3000 ~ 3968 m² | 4 |
| | | 2 | 25~50% | 3968~5334 m² | |
| | | 3 | 50~75% | 5334~9483 m² | |
| | | 4 | 75~100% | More than 9483 m² | |
| | Floor area (m²) | 1 | 0~25% | Less than 3004 m² | 4 |
| | | 2 | 25~50% | 3004~4047 m² | |
| | | 3 | 50~75% | 4047~6623 m² | |
| | | 4 | 75~100% | More than 6623m² | |
| | Period (years) | 1 | 0~25% | Less than 14years | 4 |
| | | 2 | 25~50% | 14~21years | |
| | | 3 | 50~75% | 21~26yeras | |
| | | 4 | 75~100% | More than 26year | |
| | Ratio of the floors (Aboveground) | 1 | 0~25% | Less than 0.75 | 4 |
| | | 2 | 25~50% | 0.75~0.8 | |
| | | 3 | 50~75% | 0.8~0.83 | |
| | | 4 | 75~100% | More than 0.83 | |
| | Building height (m) | 1 | 0~25% | Less than 17m | 4 |
| | | 2 | 25~50% | 17~27m | |
| | | 3 | 50~75% | 27~40m | |
| | | 4 | 75~100% | More than 40m | |

Most of this information affects energy performance, but it was difficult or impossible to regard these items as energy conservation measures (ECM). Furthermore, when the building information was a nominal variable, the number of office buildings was greatly different by group. This implies that there is a high possibility of error in the statistical results. Thus, selected the building information corresponding to a continuous variable as peer groups, it was divided according to the quartiles. The quartiles of a ranked set of data values are the three points that divide the data set into four equal groups, each group comprising a quarter of the data.

The first quartile (Q1) is defined as the middle number between the smallest number and the median of the data set. The second quartile (Q2) is the median of the data. The third quartile (Q3) is the middle value between the median and the highest value of the data set.

However, classifying all building data into peer groups may result in a large number of inefficient groups, or derive the insignificant statistical benchmarks. Thus, we analysed the building information to verify the building information that can classify meaningful peer groups. For the analysis methods, a statistical technique to test the quantitative differences of the data and a practical significance test to professionally review the possibility that such differences can occur practically were applied. Performing signification statistics test on a statistical technique can show whether the analysis result for a sample reached a statistical probability that can be regarded as an actual characteristic of the population. In general, the comparison of the representative values of the group tests the difference, and if the significance probability (p) is lower than the specified significance level, the difference can be declared statistically significant. However, even if statistically significant results are obtained, expert review is required regarding the cause(s) of differences in performance.

Therefore, the Kruskal-Wallis statistical method was applied to analyse the difference in energy performance according to building information. As a result, the gross area was found to generate significant differences in performance for all energy parameters, and the gross area was set as the classification criterion for peer groups.

## 2.3 Derivation of Benchmarks

Generally, statistical techniques are used to reflect the attributes of samples and to calculate them as the representative values of the samples. Examples of such statistical techniques include regression analysis and the representative value calculation methods. Regression analysis is a suitable method to calculate the benchmarks that reflects the characteristics of the individual buildings because it derives a value reflecting the characteristics of individual samples. However, as has already been shown, the current building data has limitations. Thus, in this study, we used the representative value calculation methods.

The representative value calculation methods include the median, mean, and mode calculation methods, with the appropriate method chosen according to the data distribution of the sample. Thus, the distribution of energy performance by total area section was analysed using the Kolmogorov-Smirnov and Shapiro-Wilk tests to test, according to the p value, the hypothesis that states that the distribution of data corresponding to the sample group follows the normal distribution. The analysis result showed that the energy performance data did not follow the normal distribution in all sections. The reason for this result seems to be due to the energy characteristics of buildings where excessive use of energy frequently occurs. Consequently, the median calculation method was applied in this analysis to determine the representative value of each peer group.

## 3. Results and Discussion

Table 4 is a benchmark table of office buildings to compare the energy performance level of each gross area group, and the benchmarks in this table correspond to the median of each gross area group.

Table 5 shows the criteria and indicators to diagnose energy consumption based on the information in the benchmark table.

We compared the values for the same cumulative percentages from Group 1 to Group 4. From Group 1 to Group 4, the value equivalent to the same percentile gradually increased or decreased. That is, the increasing gross area appeared to influence the energy performance per unit area. The increasing trend of energy consumption per unit area with the increase in gross area was different from the relationship between the energy performance and the gross area of residential buildings. The number of household members is limited even if the area of a residential building increases, so the energy consumption and area do not increase proportionally. However, as the area increases, the energy also increases, because the characteristics of the office where the number of necessary manpower and equipment increases proportionally.

Table 4 – Benchmark Table of existing office buildings

| Cumulative percentages of gross area(m²) | | Benchmark Table of office building (Energy performance comparison/diagnosis table) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $b_0$ | $b_1$ | $b_3$ | $b_2$ | $b_4$ | $EC_M$(Monthly energy consumption) | | | | | | | | | | | | $EC_A$(Annual ) | | |
| | | | | | | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | H + C | Heating | Cooling |
| Group 1 (~25 %) | 10% | 4.85 | -1.37 | 11.63 | 0.16 | 16.29 | 3.50 | 2.44 | 0.88 | Replaced with base-load benchmark | | 0.01 | 0.88 | 1.00 | Replaced with base-load benchmark | | 0.43 | 2.53 | 16.92 | 11.77 | 2.29 |
| | 25% | 6.71 | -1.03 | 13.14 | 0.28 | 17.24 | 5.80 | 4.05 | 1.91 | | | 0.61 | 1.89 | 1.89 | | | 1.25 | 4.21 | 25.98 | 19.09 | 4.71 |
| | **50%** | **9.30** | **-0.61** | **14.47** | **0.45** | **18.50** | **10.23** | **7.21** | **3.77** | | | **1.53** | **3.28** | **3.22** | | | **2.59** | **7.94** | **44.68** | **33.33** | **8.65** |
| | 75% | 12.99 | -0.35 | 15.87 | 0.78 | 20.13 | 17.47 | 13.28 | 7.58 | | | 3.19 | 6.23 | 6.13 | | | 4.73 | 14.58 | 80.01 | 60.28 | 17.38 |
| | 90% | 17.09 | -0.22 | 17.03 | 1.69 | 21.92 | 23.03 | 18.04 | 10.67 | | | 8.64 | 14.85 | 14.26 | | | 7.27 | 20.34 | 117.98 | 80.53 | 42.35 |
| Group 2 (25~50 %) | 10% | 5.18 | -1.42 | 11.45 | 0.20 | 16.17 | 3.48 | 2.29 | 0.85 | | | 0.13 | 1.24 | 1.25 | | | 0.47 | 2.45 | 16.87 | 10.75 | 3.29 |
| | 25% | 6.89 | -1.12 | 12.89 | 0.32 | 17.10 | 6.13 | 4.29 | 2.01 | | | 0.72 | 2.19 | 2.27 | | | 1.20 | 4.53 | 28.64 | 19.53 | 5.74 |
| | **50%** | **9.60** | **-0.74** | **14.46** | **0.52** | **18.39** | **12.47** | **9.31** | **4.93** | | | **2.03** | **4.21** | **4.17** | | | **2.82** | **9.79** | **55.59** | **42.06** | **11.52** |
| | 75% | 13.38 | -0.40 | 15.65 | 1.12 | 19.73 | 18.47 | 14.16 | 8.29 | | | 4.47 | 9.23 | 9.25 | | | 5.39 | 16.07 | 91.73 | 64.34 | 25.74 |
| | 90% | 18.01 | -0.23 | 16.58 | 1.85 | 21.23 | 23.99 | 18.32 | 11.01 | | | 10.01 | 16.51 | 16.33 | | | 7.55 | 21.21 | 126.23 | 85.07 | 47.63 |
| Group 3 (50~75 %) | 10% | 5.49 | -1.46 | 11.38 | 0.25 | 15.90 | 4.55 | 3.00 | 1.25 | | | 0.27 | 1.60 | 1.62 | | | 0.50 | 3.26 | 22.31 | 14.86 | 3.96 |
| | 25% | 7.58 | -1.19 | 12.71 | 0.42 | 16.82 | 7.92 | 5.53 | 2.49 | | | 1.05 | 3.01 | 3.05 | | | 1.44 | 6.32 | 37.32 | 25.50 | 7.96 |
| | **50%** | **10.30** | **-0.85** | **14.09** | **0.77** | **17.97** | **13.38** | **10.18** | **5.26** | | | **2.77** | **6.41** | **6.38** | | | **2.93** | **11.26** | **67.27** | **46.18** | **17.10** |
| | 75% | 14.50 | -0.49 | 15.63 | 1.52 | 19.36 | 19.13 | 14.30 | 8.33 | | | 7.47 | 13.15 | 12.64 | | | 5.05 | 16.60 | 103.16 | 66.73 | 37.77 |
| | 90% | 18.56 | -0.30 | 16.77 | 2.05 | 20.77 | 23.91 | 18.01 | 11.12 | | | 11.70 | 18.48 | 18.60 | | | 7.56 | 20.99 | 133.22 | 84.42 | 53.75 |
| Group 4 (75 %~) | 10% | 6.73 | -1.44 | 10.10 | 0.42 | 15.48 | 5.89 | 3.30 | 1.25 | | | 0.79 | 3.19 | 3.19 | | | 0.00 | 4.49 | 33.47 | 18.92 | 8.31 |
| | 25% | 8.87 | -1.20 | 11.62 | 0.67 | 16.26 | 9.99 | 6.41 | 3.00 | | | 2.21 | 5.85 | 5.43 | | | 0.74 | 8.20 | 54.84 | 31.98 | 15.22 |
| | **50%** | **12.43** | **-0.94** | **13.11** | **1.16** | **17.44** | **14.22** | **9.52** | **5.14** | | | **5.13** | **10.34** | **9.93** | | | **2.36** | **12.29** | **78.98** | **47.34** | **28.91** |
| | 75% | 17.14 | -0.69 | 14.45 | 1.66 | 18.62 | 17.92 | 12.76 | 7.50 | | | 9.23 | 16.01 | 15.45 | | | 3.99 | 16.34 | 103.58 | 61.33 | 46.36 |
| | 90% | 22.49 | -0.40 | 15.87 | 2.13 | 19.87 | 22.12 | 16.17 | 10.03 | | | 12.99 | 20.30 | 19.75 | | | 6.14 | 20.59 | 127.74 | 75.77 | 60.01 |

Table 5 – Energy performance diagnostic indicators

| Indicator | Range of cumulative percentages | |
|---|---|---|
| | $b_1, b_4$ | Others |
| ★★★ | More than 90 % | Less than 10 % |
| ★★☆ | 75 % ~ 90 % | 10 % ~ 25 % |
| ★★ | 50 % ~ 75 % | 25 % ~ 50 % |
| ★☆ | 25 % ~ 50 % | 50 % ~ 75 % |
| ★ | 10 % ~ 25 % | 75 % ~ 90 % |
| ☆ | Less than 10 % | More than 90 % |

Next, to examine the validity of the benchmarking model, the energy performance evaluation of the energy consumption of 3,625 office buildings was performed by using the benchmarks, and the results were analysed. This was performed with the following Equation:

$$Energy\ Efficiency\ Ratio = \frac{Building\ energy\ use}{benchmark}$$

The Energy Efficiency Ratio (EER) approaches 1 if the building has the same performance as the benchmark. On the other hand, as the energy efficiency increases or decreases, the EER of the building will deviate from 1. The accumulation of EER scores for individual buildings can be used to obtain the cumulative frequency of buildings according to the EER. If the building group that is closest to the benchmark is located at the center of the distribution, it can be said that the representative nature of the benchmark has been satisfied.

Table 6 shows the evaluation results of the energy performance of five parameters for 3,625 office buildings using the derived benchmark. For all the energy performance information, the EER was close to 1 when the cumulative distribution of data was 50 %. Furthermore, in the cases of cooling sensitivity, the corresponding EER score was much higher than the one for other energy performance data when the cumulative frequency distribution was 90 %. In other words, even though buildings with extremely high cooling sensitivity distorted the data distribution, as the benchmark using the median calculation method was derived, the EER scores of buildings with extreme performance data were very high and the distribution of the building group corresponding to the score of 1 was concentrated in the median.

Table 6 – the EER evaluation results of the five parameters

| Cumulative percentages (%) | Energy Efficiency Ratio (EER) | | | | |
|---|---|---|---|---|---|
| | $b_0$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
| 10 % | 0.56 | 0.35 | 0.76 | 0.44 | 0.86 |
| 25 % | 0.77 | 0.60 | 0.87 | 0.71 | 0.92 |
| **50 %** | **1.07** | **1.08** | **0.97** | **1.29** | **0.98** |
| 75 % | 1.51 | 1.55 | 1.07 | 2.72 | 1.06 |
| 90 % | 2.02 | 1.93 | 1.15 | 3.77 | 1.15 |

Fig. 2 shows the energy performance diagnosis result of a randomly selected building. The energy performance of the parameters is diagnosed using the energy performance diagnostic indicators in Table 5 and EER results. The energy performance of the parameters is diagnosed as the caution level if we judged that an energy performance improvement is necessary only in energy efficiency diagnosis indicators, or only in EER evaluation results. If both indicators and EER results indicate that energy efficiency is required, the diagnostic results are presented according to the indicators and EER result levels.

| Cumulative percentages of gross area(m²) | Star | Energy performance compare/diagnosis table | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Base-load (kWh/m²) | Heating Sensitivity | Heating Start T(℃) | Cooling Sensitivity | Cooling Start T(℃) | Annual energy consumption(kWh/m²) | | |
| | | | | | | | H+C | Heating | Cooling |
| Group 3 | ★★★ | Less than 5.49 | More than -0.30 | Less than 11.38 | Less than 0.25 | More than 20.77 | Less than 22.31 | Less than 14.86 | Less than 3.96 |
| | ★★☆ | 5.49 ~7.58 | -0.30~ -0.49 | 11.38 ~12.71 | 0.25 ~0.42 | 20.77 ~19.36 | 22.31 ~37.32 | 14.86 ~25.50 | 3.96 ~7.96 |
| | ★★ | 7.58 ~10.30 | -0.49~ -0.85 | 12.71 ~14.09 | 0.42 ~0.77 | 19.36 ~17.97 | 37.32 ~67.27 | 25.50 ~46.18 | 7.96 ~17.10 |
| | ★☆ | 10.30 ~14.50 | -0.85~ -1.19 | 14.09 ~15.63 | 0.77 ~1.52 | 17.97 ~16.82 | 67.27 ~103.16 | 46.18 ~66.73 | 17.10 ~37.77 |
| | ★ | 14.50 ~18.56 | -1.19~ -1.46 | 15.63 ~16.77 | 1.52 ~2.05 | 16.82 ~15.90 | 103.16 ~133.22 | 66.73 ~84.42 | 37.77 ~53.75 |
| | ☆ | More than 18.56 | Less than -1.46 | More than 16.77 | More than 2.05 | Less than 15.09 | More than 133.22 | More than 84.42 | More than 53.75 |
| EER | | $Energy\ Efficiency\ Ratio = \frac{Building\ energy\ use}{benchmark}$ | | | | | | | |

| Gross area of your building (m²) | | 7421.5 | | |
|---|---|---|---|---|
| Evaluation contents | | Value | STAR | EER |
| Base-load (kWh/m²) | | 15.59 | ★ | 1.62 |
| Annual heating and cooling energy consumption (kWh/m²) | | 33.61 | ★★☆ | 0.6 |
| Heating | Annual energy Consumption(kWh/m²) | 20.94 | ★★☆ | 0.5 |
| | Sensitivity | -0.46 | ★★☆ | 0.62 |
| | Start T(℃) | 12.81 | ★★ | 0.89 |
| Cooling | Annual energy consumption(kWh/m²) | 14.00 | ★★ | 1.22 |
| | Sensitivity | 0.66 | ★★ | 1.27 |
| | Start T(℃) | 18.80 | ★★ | 1.02 |

| | |
|---|---|
| Caution level | Star rating is between ★★ and ★★★, but EER is greater than 1 or Star rating is between ☆ and ★☆, but EER is lower than 1 |
| Improvement is recommended. | ★☆ |
| Improvement is needed | ★ |
| Must be improved ! | ☆ |

| | |
|---|---|
| Diagnostic results | **Improvement of base-load is needed !**<br>• Reduce equipment schedules<br>• Eliminate any electric heating<br>• Reduce lighting load<br>• Reduce plug loads<br>• Check fossil fuel baseload |
| | **• Be careful about using cooling energy** |

Fig. 2 – Diagnosis result using developed benchmarking model

## 4. Conclusion

In this study, we developed a benchmarking model that can provide benchmarks of existing office buildings to compare the energy performance of a building and to provide understandable information to building owners and operators at the early stage of office building retrofitting. The results of this study are summarized as follows.

(1) To develop the benchmarking model, we analysed the DB of EPIIS. The information such as gross area, period, and height of the building, etc. was collected, but information related to energy performance such as window U-value, SHGC or envelope information was not collected.

(2) In order to provide easy-to-understand energy performance information to energy consumers, the heating, cooling, and base loads were separated from the final energy consumption DB. To do this, it was necessary to collect monthly temperature information and to correct the monthly energy performance.

(3) Since various kinds of building information were not built in EPIIS, we set up a peer-group based on gross area and benchmarks that were calculated by applying the method of the calculating median.

(4) The results of this study can be used as the energy performance evaluation and diagnostic criteria for existing office buildings by providing useful energy performance information based on the actual energy consumption. However, to improve and manage the energy of buildings in the future, it is necessary to collect the related building information to improve energy such as the u-value of walls and windows, SHGC of windows, and equipments, etc.

## Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NO. 2014R1A2A2A01007405)

## References

Donnelly, M., J. Kummer, K. Drees. 2013. *LEAN Energy Analysis: Using Regression Analysis to Assess Building Energy Performance.* Washington, U.S.A.: Jonson Controls.

Energy in Buildings and Communities Programme (EBC). 2013. *Total energy use in buildings (Annex 53): Analysis and evaluation methods.* Tokyo, Japan: Institute for Building Environment and Energy.

Energy in Buildings and Communities Programme (EBC). 2013. *Statistical analysis and prediction methods (Annex 53): Separate Document Volume V.* Tokyo, Japan: Institute for Building Environment and Energy.

Environmental Protection Agency (EPA). ENERGY STAR Portfolio manager(ESPM). "Technical Reference." http://www.energystar.gov/

Kissock, J.K., J.S. Harberl, D.E. Claridge. 2002. *Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models: ASHRAE Research Project 1050-RP.* Tokyo, Japan: Institute for Building Environment and Energy; and Atlanta, U.S.A.: ASHRAE.

National Institute of Standards and Technology. 2013. *e-Handbook of Statistical Methods*. http://www.itl.nist.gov/div898/handbook/

Shengwei, W., T. Chengchu, X. Fu. 2012. "Quantitative energy performance assessment methods for existing buildings". *Energy and Buildings* 55: 873-888. doi:10.1016/j.enbuild.2012.08.037

Si-Won, Y., K. Sun-Sook. 2014. "Improvement of operation rating method in building energy performance disclosure system". *Journal of the architectural institute of Korea planning and design* 30(12): 307–314. doi:10.5659/JAIK_PD.2014.30.12.307