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Baseline building energy modeling of cluster inverse model by using daily energy consumption in office buildings

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ABSTRACT

Many retrofit projects are being carried out in existing buildings to reduce energy consumption. However, the energy consumptions before and after retrofit need to be known in order to evaluate such retrofit projects. Even though the energy consumption after retrofit can be determined through measurement, the energy consumption before retrofit cannot be known. This study is to more easily estimate energy usage prior to the retrofit. Generally, dynamic simulation or regression model should be used to estimate the energy consumption of buildings before retrofit. However, existing regression models have no way to calibrate the model if it is inaccurate. In this paper, we use a clustering technique to improve the accuracy of the regression model. The estimation of energy consumption before retrofit is referred to as "baseline model" and the inverse model is used to create this baseline model. The inverse model is created through monthly data, daily data, and other similar data. In this study, the inverse model was created through daily data and the baseline model was derived from it. The conventional change-point Model and the cluster inverse model presented in this paper were compared and evaluated with the criteria presented through M&V (Measurement and Verification). The results suggest that the cluster inverse model which reflects the characteristics of data is more appropriate when the baseline model is derived from daily data.

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1. Introduction

The building energy consumption has been continuously increasing in South Korea since the 1990s [1]. The energy consumption of office buildings increased by 12.8% of total energy between 2007 and 2010, and the electricity consumption increased by 22%. To reduce the increase rate of energy consumption in buildings, the Building Energy Efficiency Certification System for office buildings and public office buildings has been enforced as national policy since 2010. Various technologies are being introduced to reduce building energy from the design stage for new buildings. However, existing buildings have a limitation in that only simple retrofit projects can be performed [2]. Furthermore, it is a critical issue for existing buildings to evaluate the actually reduced amount of energy consumed by the building. This process is referred to as M&V (Measurement and Verification), which is illustrated in Fig. 1. To carry out M&V as shown in Fig. 1, the energy consumptions of the building before and after the retrofit are required. However, the energy consumption data of the building before the retrofit no longer exists after the retrofit. Therefore, the M&V must be conducted by estimating the building energy consumption before the retrofit [8,14,15]. The energy consumption before installing energy conservation measures (ECMs) is called the baseline model. To create this baseline model, dynamic simulation or inverse model is generally used.

Dong Seok Gong [3] proposed a method of creating a baseline model through the hourly data of BEMS and the dynamic simulation of EnergyPlus. Dynamic simulation requires calibration by comparing with the previous energy consumption. For input values, the current conditions and the data of design drawings of the target building were used. Incorrect input values were calibrated by performing a sensitivity analysis. The occupancy schedule of the target building was extracted from the electricity consumption data to represent the characteristics of each period. When compared with the measured energy consumptions, the baseline model created through calibrated simulation satisfied the tolerance for statistical error of the model presented by ASHRAE or FEMP. However, the creation of a baseline model through dynamic energy simulation requires a high level of expertise of the simulation user who must know a large amount of input data. Therefore, it is not easy for workers to actively use the baseline model. On the other hand, the inverse model can derive the baseline model through measured

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Nomenclature

$\vec{u}$	Centroid of cluster, average of pattern
$\vec{x}$	An element of a specific cluster, a specific pattern
ω	A group element of a specific cluster, a set of patterns
$C_i^{initial}$	Centroid of ith cluster
d_j	Distance between jth cluster and data
avgbig	Point of the largest average distance
C	Distance between the centroids of clusters
c_{avg}	Average distance between the centroids of clusters from c_1 to c_k
newDistAvg	Average distance between the centroid of a new cluster and data
oldDistAvg	Average distance between the centroid of an existing cluster and data
K	Number of the centroids of clusters
RSS_k	Residual sum of squares of the kth cluster
RSS	Residual sum of squares of all clusters
T_{OA}	Ambient temperature [°C]
B_1	Operating time of boiler no. 1 [min]
B_2	Operating time of boiler no. 2 [min]
B_3	Operating time of hot-water boiler [min]

data that has been collected and is likely to be actively used at the working level because it does not require a large amount of input data. Therefore, the baseline model was created through the inverse model in this study. In the dynamic simulation, it is possible to calibrate the error through input values. The inverse model also requires a calibration method like dynamic simulation. Yuna Zhang [4,16] compared daily energy data and hourly energy data through the change-point (CP), Gaussian process regression (GPR), Gaussian mixture regression (GMR), and artificial neural network (ANN) models, which are representative inverse models. The models based daily energy data satisfied the specified criteria for MBE and CV (RMSE), but showed very low accuracy for R^2. The models based on hourly energy data, however, exceeded all the specified criteria. Thus, this paper concluded that it was more rational to use the hourly data to predict the energy consumption of a building. However, there are practical problems such as cost and labor to acquire hourly data to use these models. In this study, therefore, the inverse model was developed to derive the baseline model that satisfies the tolerance for statistical error through daily data. However, the method of model presented in the paper is simply generated through the algorithm, and additional indicators are needed to calibrate the inverse model. Abhishek Srivastav [5] used the Gaussian mixture model to create a baseline model. In the Gaussian mixture model, the range of the dependent variable of Y-axis is determined as a normal distribution according to the independent variable of X-axis. In this paper, ambient temperature was used as the independent variable and electricity consumption as the dependent variable. However, using one independent variable in the Gaussian mixture model results in too broad a range of dependent variable. Therefore, the range of variables was narrowed by adding relative humidity and solar radiation to the dependent variables. Then the accuracy of the developed baseline of the Gaussian mixture model was compared with that of the baseline created through multiple regression analysis, and the accuracy of the former was higher. However, the data used to create this model was hourly data measured in 5 min intervals and only the coefficient of determination was used for model evaluation. The analysis of this paper determined that it was impossible to create a relatively accurate model with ambient temperature only. Therefore, such variables as relative humidity and solar radiation were added. Nevertheless, it is not easy to collect solar radiation data. In the present study, therefore, the model was calibrated through operating time recorded on the operation log of the heat source equipment in case the baseline model does not satisfy the tolerance. External environmental factors affecting building energy include relative humidity and solar radiation. However, the most important factor was the outside air temperature, and it was found that it is important to generate the model based on the outside air temperature. As mentioned in most literatures [2,6], the data that are typically used to evaluate energy reductions are monthly and hourly data, and the criteria for evaluating the baseline in ASHRAE and FEMP only include monthly and hourly data. However, there are only 12 monthly data in a year and the data have large errors [7,8]. Therefore, they cannot properly evaluate retrofit projects with small energy reductions. In the case of hourly data, 105,120 data are obtained if measured in 5 min intervals. However, a large number of sensors are required to collect hourly data, and operators are required to manage them, which makes it difficult to collect data. Daily data is recorded manually on operation log for building operation by building operators. There are 365 daily data collected for one year, and the baseline model created with daily data have smaller errors than monthly data and greater errors than hourly data due to the number of data. However, it is difficult to evaluate the model because ASRAE and FEMP do not present any criteria for evaluating the model.

In this study, the baseline model was created through daily data which is more accurate than monthly data and less accurate than the hourly data, but offers a lower cost burden. The characteristics of daily data were classified by clustering algorithm and a regression analysis was performed for the classification results before the baseline model was created [9,11]. However, because there were no criteria for evaluating the appropriateness of the model as mentioned above, the model was evaluated using the criteria adopted in existing literatures. If the model failed to satisfy the presented criteria, the baseline model was derived by analyzing the data using the multiple regression model with an additional independent variable [13,14]. Therefore, the purpose of this study was to create the base-

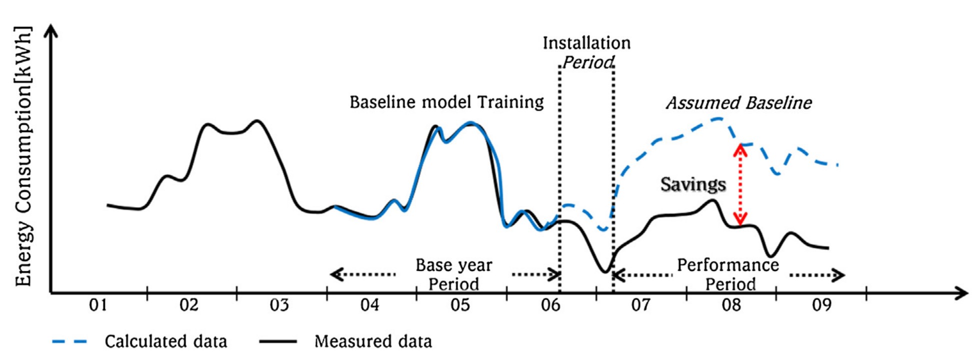

Fig. 1. Illustration of M&V for retrofit.

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