An Energy Management Process and Prediction of Energy Use in an Office Building

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Abstract
The purpose of this study was to propose a building energy management process, verify the proposed model by applying energy management techniques in a real office building, and develop an empirical approach for predicting building energy use with regression analysis. This study proposed the four major energy management steps: energy audit, energy analysis, identifying and evaluating the energy saving opportunities, and retrofit implementation and follow-through. For the prediction of energy use, simple regression models were developed based on historical energy consumption data as a function of daily outside temperatures, while the predicting equations were derived for different operational modes and day types. By selecting a real building as a case study, the feasibilities of the building energy management process and the empirical approach for predicting building energy use have been examined.

Keywords: energy management; process model; regression analysis; empirical method

1. Introduction
Building energy management involves several management steps which are identically applied to all buildings, however the details vary according to the building types. Predicting building energy use means calculating the needed energy consumption or the required energy use in a given period in order to maintain an indoor environment appropriate to the function of a building. These calculations are an important element for the evaluation of building energy performance.

Usually, facility managers determine building energy consumption peculiarities or analyze the consumption patterns by auditing and measuring building energy use, and they not only make use of the results as a means of building energy performance evaluation but also continuously try to save energy in buildings by predicting energy use in advance, finding out the components of abnormal energy consumption or waste of energy, and positively reflecting them in building operation.1,2)

Accordingly, the purposes of this study were to propose a comprehensive energy management process and to develop an energy use prediction technique in an office building. This study has been conducted as follows: a building energy management process was defined, a subject building was selected, and the proposed energy management technique was validated through a real application in an office building.

Also, a technique for predicting building energy use through regression analysis of an empirical approach was developed. By applying this to predict the energy use of an existing building, a real building was chosen, data were collected, and the results were examined through the energy management process.

2. Building Energy Management Process
2.1 Steps and flow of the process model
The building energy management process is composed of four major steps, and the unit work in each step is composed of a main process and various input and output information.

The 4-step process of building energy management establishes the purposes of the project according to the time flow consisting of the following steps: the building energy audit step, in which the architectural design, building services and operational peculiarities of a subject building are audited; the building energy analysis step, in which energy saving opportunities are drawn through the analysis based on the audited data; the energy savings opportunity evaluation and decision of retrofit priority step, in which the architectural design, building services and operational peculiarities of a subject building are audited; the building energy analysis step, in which energy saving opportunities are evaluated from diverse viewpoints and the retrofit priority is determined; the retrofit and follow-through step, in which the building is retrofitted according to the determined retrofit priority and the retrofitted building is managed for its optimum energy performance. Here, the detailed processes of the unit work of inputting the necessary information according to the contents and outputting the proper information based on the input, complete the whole process. At this time, the input-output information is prepared by feeding back the newly collected information and the output drawn from the previous work.

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Because each detailed process is logically connected and the outcome from a previous step greatly influences the next step, the process should be carried out synthetically and in an orderly manner according to the time and work flow, and to enhance the correctness and credibility of the overall work, each unit work should be carried out in balance with the others. Also, since the output information itself can be very useful for building energy management, it should be systematically arranged.

2.2 Building energy audit

The first step in the building energy audit process is to collect all the available information regarding the energy systems and energy use patterns of the building, and then divide it into walk-through audit and detailed audit. In the walk-through audit, by investigating the general operation and management conditions, the patterns of energy use, the indoor environment status, and the general conditions of a building through interviews with the building manager and users, the building becomes familiar, its energy performance can be predicted, and its occupants’ comfort level assessed.

In the detailed audit, various data relating to building energy performance are thoroughly collected from all kinds of drawings, records and on-site visits, by surveying the indoor environmental conditions, the weather data, the general information of the building, the outdoor conditions, building envelope, structures and conditions of the rooms, equipment properties and operation schedules, energy use and so on to understand the features of building energy use, peak demand and energy cost.

2.3 Building energy analysis

In this step, various analyses concerning the building energy are made to evaluate the saving opportunities exactly. It is the step in which the energy performance data collected in the energy audit step is enlarged. In this step, detailed and exact information affecting building energy performance such as weather effect, building operation and their patterns of energy use, energy cost, as well as overall energy use is necessary, as is the ability to mathematically quantify and analyze the information of the equipment efficiencies and the system responses and building operations.

2.4 Evaluating the opportunities

In this step, the energy saving opportunities drawn in the energy analysis step are evaluated, and the priority of the retrofit is determined based on the evaluation. This step includes the evaluation of savings opportunity, identification of the final inventory and examination process. In the savings opportunity evaluation process, comparative priority of the saving opportunities is drawn through the sensitivity and life-cycle cost analyses, the saving opportunities are again evaluated in the last inventory and examination process, and it systematically arranges and ultimately determines the priority for retrofit.

2.5 Retrofit and follow-through

The main purpose of this step is to continuously maintain the building so that the improved functions and energy performance can continue stably after the retrofit. The retrofit process includes the manual preparation for the successful retrofit according to the drawings, the specifications, and the operation and use of the building after the retrofit; the follow-through process includes a performance check to confirm if the retrofits were made according to the manuals, the work of effectively managing and maintaining the energy savings after the retrofits, and of monitoring the building regularly and continuously to maintain maximum energy performance.

3. Application of Management Process Model

3.1 Synopsis of the Building

![Fig.1. Façade of Case Study Building](image)

Table 1. Synopsis of the K-building

| Synopsis       | Contents                  |
|----------------|---------------------------|
| Site Area      | 2,477 m²                  |
| Ground floor area | 908.87 m²                |
| Total floor area | 11,637.27 m²             |
| Ground floor/site area | 36.40%               |
| Total floor/site area | 295%                   |
| Stories        | B1-3, 1-9                 |
| Plant          | Boiler 1EA                | Hot water/humidification |
| (LNG)          | Chiller/Heater (S)        | Dining Room/Kitchen      |
|                | Chiller/Heater (L)        | Cooling/Heating          |
|                | Cooling Tower 2EA         | Counter flow-Type        |
| HVAC           | VAV                       | Interior Zone            |
|                | FCU                       | Perimeter Zone (229EA)   |
|                | Fan                       | Supply/Exhaust (30EA)    |

This study examined the validity of efficient energy management in a subject building by applying the proposed management process model to a real building. The K-building in Seoul was selected as the subject building. The building stands with its long side facing north and south, and its entrance, located at the southeast side of the building, stands on a main street. The building is nine stories above the ground, five stories are used for office rental, three stories are used by a training institute, and the top floor contains mechanical equipment and a water tank room.

The K-building synopsis is shown in Fig.1. and Table 1.
3.2 Energy audit of the K-building

For the energy audit of the subject building, first, a walk-through survey of the building was carried out. Using a worksheet for walk-through audit prepared in advance, general information about the operation and management of the building and the system, on-site conditions, the building envelope, lighting on each floor, ventilation, cooling and heating conditions, and other general patterns of energy use were investigated. Second, a detailed audit was conducted to collect the necessary information for the building energy analysis using a simulation program based on the information obtained from drawings and on-site survey.

Also, historical data regarding energy consumption were used to understand the overall energy performance of K-building and analyze the improvement opportunities. The energy source types used in K-building were divided into electricity and LNG.

Electricity consumption accounts for 43.2% of the whole energy consumption and LNG 56.8%. Dividing consumption again by end uses, electricity is used as energy source for parking equipment, elevators, HVAC and other power plants; LNG is used as energy source for cooling and heating, hot water, and cooking.

Among them, cooling and heating use the most energy, occupying 45.5% of the total energy consumption, while the others come in the following order: power plants 25.7%, lighting appliances 17.5%, cooking 6.7%, and hot water 4.6%.

3.3 Energy performance analysis of K-building

The energy performance of K-building was analyzed using the DOE-2.1E building energy simulation program. First, the base-case model was prepared, establishing the year 1996 as the base year and relevant weather data file for the DOE-2.1E simulation, to calculate the energy consumption and compare the results with actual consumption data. In both electricity and LNG, the errors between the simulation values of the base-case model and actual energy use in the building were shown to be less than 10%, confirming that the base-case model had been drawn up properly for numerous parametric studies for further analyses.

The load peculiarities of K-building were examined based on the simulation results of the base-case model. The maximum cooling load occurred at 5 p.m. on August 1\textsuperscript{st}, and the order of components influencing the cooling load was as follows: infiltration, solar radiation, conduction through windows, lighting, and internal heat gain from occupants.

The component ratio of the maximum cooling load is shown in Fig.2.

On the other hand, the maximum heating load occurred at 7 a.m. on December 1\textsuperscript{st}. In the case of maximum heating load, the order of the components influencing the load was as follows: infiltration, conduction through windows, and conduction through walls.

Fig.3. shows the component ratio of the maximum heating load.

Also, the degree of influence that each load component had on the energy consumption was evaluated through sensitivity analysis using the base-case model.

The energy saving opportunities were then identified based on the relative importance of each load component influencing the energy consumption. Thus, the opportunities for improving the energy performance could have been identified through the analysis of energy audit data and the calculated energy consumption data from DOE-2.1E simulation.

Table 2. shows the relationship between load components and energy consumption in the building; the numbers are the relative percentages of total energy consumption in the building and the shaded parts identify the top-3 components that have the most influence on energy consumption in the space categories.

In Table 2., it is shown that the building envelope does not affect electricity consumption much, however, it does have a big influence on LNG consumption, which is mostly influenced by windows and infiltration. Therefore, it is found that windows and infiltration mainly influence the heating and cooling energy consumption, and accordingly the LNG consumption.

Regarding the internal heat gain and electricity consumption, there are 5 top-3 items, and all of them are related to lighting. Consequently, lighting significantly influences the electricity consumption.

Concerning LNG, there are only 2 top-3 items and all of them come from the occupants. From this fact, it can be said that sensible and latent heat from the occupants significantly influences the cooling energy consumption.

In the case of outdoor air, all the items are within the top-3 regarding LNG consumption. Therefore, it
can be concluded that the introduction of outdoor air for ventilation significantly influences the building's heating and cooling energy consumption.

The transport equipment, the fan, the pump and the cooling tower also significantly influence electricity consumption.

3.4 Evaluating the energy saving opportunities

The K-building is relatively new, only 3 years old, and its energy consumption per unit area is generally less than that of other existing buildings. The selected retrofit plans were drawn up through partial renovation plans or new operation method of the service systems. The building and the service components of the retrofit plans were arranged based on the results of energy audits and measurement of indoor conditions, and are shown in Tables 3 and 4.

Table 3. Building Components of the Retrofit Plans

| Retrofit Strategy | Retrofit Contents |
|-------------------|-------------------|
| Infiltration      | Vestibule, Entrance improvement |
|                   | Turnstile, Entrance improvement |
|                   | Air tightness, 1.2F windows & frames |
| Shading devices   | Automatic control |
| Lighting system   | Control wiring in a row from the window side |
|                   | Highly efficient lighting fixture |

Table 4. Service Components of the Retrofit Plans

| Retrofit Strategy | Retrofit Contents |
|-------------------|-------------------|
| System            | Evaporative cooling in addition to VAV |
|                   | Dehumidification in addition to VAV |
|                   | Heat recovery in addition to VAV |
| Control           | Economizer cycle Free cooling |
|                   | VAV fan Variable speed motor |
|                   | Night purge Mass cooling |

3.5 Priority decision for retrofits

The energy saving opportunities of the performance retrofit plans shown above were analyzed through DOE-2.1E computer simulation. As the building components of the retrofit plans were applied for the simulation, 6 strategies were selected relating to infiltration, shading and lighting.

For the service components of the retrofit plans, 6 strategies were chosen relating to the existing VAV system and its control.

Table 5. Energy Savings by Retrofits

| Rank | Retrofit Strategy | Retrofit Plan | Electricity savings (MWH) | LNG savings (MWH) | Total (MWH) |
|------|------------------|---------------|---------------------------|-------------------|-------------|
| 1    | System           | Heat recovery | -10.5                     | -173.5            | -184.0      |
| 2    | Dehumidification| +52.2         | -160.4                    | -108.2            | -109.4      |
| 3    | Evaporative cooling | +0.2      | 0                         | -0.2              | -0.2        |
| 4    | VAV fan          | -28.8         | -48.3                     | -77.1             | -77.1       |
| 5    | Night purge      | +0.9          | -0.8                      | +0.1              | +0.1        |
| 6    | Economizer cycle | +6.9          | -3.5                      | +3.4              | +3.4        |
| 7    | Shading device   | -7.5          | -33.3                     | -40.8             | -40.8       |
| 8    | Highly efficient lighting fixture | -15.135 | -1.3                      | -16.435           | -16.435     |
| 9    | Switching system | -11.704      | -1.9                      | -13.604           | -13.604     |
| 10   | Infiltration     | Vestibule     | -0.9                      | -3.8              | -4.7        |
| 11   | Air tightness    | -0.8          | -3.8                      | -4.6              | -4.6        |
| 12   | Turnstile        | -0.2          | -1.8                      | -2.0              | -2.0        |

In the case of the building components, the results were not so good since changes in building configuration are not possible in existing buildings and retrofit is restricted to partial replacement only, however, they were generally effective in LNG savings. In terms of lighting, the electricity saving was very effective, by accompanying reduction in heating loads leading to energy saving opportunities for LNG.

Energy savings by service components were excellent considering the investment cost and effort for retrofit, however, careful consideration will be needed in conducting a computer simulation or in actual retrofit because its effect is very complex.

The simulation results of the anticipated energy saving effects on the building are shown in Table 5. However, the anticipated energy savings are not very meaningful in real application because the energy performance of K-building is generally excellent to begin with, and the possible energy savings through its
partial retrofit are, therefore, much smaller than that of other buildings that consume much more energy.

Nevertheless, these results are expected to be used as a reference in helping in the decision-making process concerning building energy management, by enabling calculation of the energy saving differences according to the retrofit plans, and establishment of retrofit priorities.

3.6 Retrofit and follow-through

Because the K-building did not undergo a retrofitting, the effects of such retrofit and follow-through cannot be judged.

It is expected, however, that a study regarding this will be carried out in the future, that more results will be produced, and that these cases will become source data.

4. An Empirical Approach by Regression Analysis

Engineering calculation needs a lot of time and effort because preparing the input data is very difficult and the analysis process is complicated.4) A new approach therefore, which can act as a substitute and draw credible results, the input-output of which is relatively easy, is required. In this section, a prediction method with simple regression analysis was used as an empirical approach for predicting K-building energy use. The cooling and heating energy consumption of a building has close correlations with the thermal characteristics of a building, the use and operation modes of that building and the outside weather conditions. Therefore, if the change of daily outside air mean temperature is taken as an independent variable, it shows a constant correlation with daily energy consumption according to the types of building use. Here, the empirical approach is meant to be a technique that can predict the building energy use based on those types after drawing a linear correlation or functional relation between the independent and dependent variables by using the simple regression analysis model based on past building management records or its energy use data. At this time, to minimize the difference between the actual energy consumption data and the predicted value by the regression analysis, correlation coefficients are derived and used. When the absolute value of the correlation coefficient is less than 0.2, it means there is no correlation and it can be ignored; when the absolute value is 0.4 or less, it means weak correlation; and when the absolute value is 0.6 or more, it means strong correlation.5)

4.1 Application of regression analysis

As a building is composed of complicated systems, it is difficult to predict its performance exactly. To analyze building performance and enhance the correctness of prediction, base-case models should be developed through reasonable hypotheses, while comparative analyses of actual use should be continuously executed. Here, the influence of energy use factors removed through rational hypothesis are judged to be negligible when the structural aspects of the base-case model are considered.6)

(1) External variable selection

In the application of the regression analysis technique for building energy performance analysis, the first step is to select the factor having the maximum influence among the building energy consumption factors. For this, the correctness of data and the degree of difficulty in collecting them, as well as their influence should be considered at the same time. In this study, assuming that external variables such as wind velocity and solar radiation are relatively less important, but that temperature has the maximum influence, only daily mean outdoor air temperature was selected as the independent variable.

(2) Removal of Outlier

The regression analysis, a kind of statistical analysis technique, can compare the correctness of analyses by utilizing the least square method; The least square method assumes a regression equation in which the sum of the squares of the differences (residuals) between actual values and values predicted by the regression equation becomes the least, which becomes the base-case for determining the exactness of a predicting equation.

At this time, the bigger the number of the actual value becomes, the more exact the prediction becomes. If this actual value is abnormal, it may lower the exactness of the regression equation; it is called “outlier” and can be excluded.7) In other words, it is assumed that the special energy use resulting from changes in building use or exceptional building operations will not be considered. In the evaluation step, the outlier's influence is evaluated by confirming it. Accordingly, the followings were excluded in this study: weekdays or Saturdays without energy use and days with abnormal energy use due to repairs or test operations of the system.

(3) Internal variable selection

In addition to external variables, internal variables also influence building energy use. There is no energy use on Sundays when the building is not used, even if the outdoor air temperature becomes very high or low. Therefore, the building occupancy types according to weekdays, Saturdays and Sundays/holidays that most significantly influence the building energy use based on occupancy schedule, machinery use schedule and other variables, were considered together with the building energy use in relation to the daily mean outside air temperature. Accordingly, considering that building energy use primarily has a correlation with the outdoor air temperature and secondarily with the day-types, the predicting equations for electricity and LNG use have been derived separately for the heating period, the cooling period, and the mid-term period by establishing the daily mean outdoor air temperature and the building energy use data for electricity and LNG of the year 1996 as the independent and the dependent variables, dividing the week into weekdays, Saturdays and Sundays/holidays, and executing the simple regression analysis. By using these equations, the building energy use of the year 1997 was predicted.8) Here, in the case of LNG, only the energy used in the heating and cooling system and hot water was considered. (The energy use in cooking was excluded.)
4.2 Predicting equations by operational modes

After dividing the year into the heating, cooling and mid-term periods in consideration of the energy use modes by day-types of the week, the predicting equations were drawn separately for the heating, cooling, and mid-term periods. At this time, to find out the operational modes of heating, cooling and mid-term periods, the balance point temperatures, which are the outside air temperatures when the heating and/or cooling starts, become fixed, and the interval between the balance point temperatures of heating and cooling is assumed to be the temperature of the mid-term period. The mid-term period was determined through the following process.9)

(1) Determining the mid-term period

To determine the mid-term period, the temperatures that begin heating and/or cooling should be set. Here, the trial and error technique is needed to some degree, and in this study, by establishing 6°C as the mid-term range based on the graph analyzed above, and adjusting the balance point temperatures at an interval of 1°C, the equations were drawn through the least square method. Here, some assumptions are needed due to the technical nature of the subject: it is not permitted that the straight-line slope of the cooling term be negative (-) or that of the heating term be positive (+). This restriction does not apply to the mid-term period.

(2) Setting up the balance point temperatures

In this study, through the above process, the temperature at which the correlation coefficient (R value) becomes the maximum is found based on the trial and error technique, changing the balance point temperature several times, and finally the balance point temperatures for heating and cooling are established. Consequently, 20°C (x intercept of predicting equation for the cooling period) and 13°C (x intercept of predicting equation for the heating period) were differently fixed as the balance point temperatures of the heating and cooling (Table.6).

In Fig.4., the predicting equations for LNG use drawn through this process are seen separately by operational modes on weekdays.

In the case of Saturdays, only the predicting equations of the heating and cooling periods were drawn; the predicting equations of the mid-term for Saturdays were excepted because there was no LNG use. Likewise, in the case of Sundays, the predicting equations of the mid-term were excluded because there was no LNG use, except for test operations and/or repairs regardless of the outdoor air temperature.

Since electricity always showed basic level energy consumption due to the power requirement of lighting, machinery etc, its predicting equations for Sundays and holidays could be drawn.

The predicting equations of LNG and electricity use by occupancy patterns and building operational modes are shown in Tables 7 and 8.

| Mid-term range | Predicting equations | Decision factor |
|----------------|----------------------|----------------|
| 12-18°C Heating y=-33.974x+452.51 0.7337 |
| 12-18°C Cooling y=83.455x+1665.4 0.7226 |
| 12-18°C Mid-term y=-9.1028x+230.29 0.0544 |

| Mid-term range | Predicting equations | Decision factor |
|----------------|----------------------|----------------|
| 13-19°C Heating y=-34.15x+457.77 0.7676 |
| 13-19°C Cooling y=89.573x+1819.4 0.7491 |
| 13-19°C Mid-term y=14.731x-157.12 0.1853 |

| Mid-term range | Predicting equations | Decision factor |
|----------------|----------------------|----------------|
| 14-20°C Heating y=-33.215x+452.9 0.7416 |
| 14-20°C Cooling y=89.577x-1822.1 0.7466 |
| 14-20°C Mid-term y=8.4712x-33.312 0.0375 |

Here, another assumption is necessary: it is supposed that the electricity use also changes on the basis of 20°C and 13°C just as the LNG use does. Heating and cooling influence the electricity use, but do not show the definite relationship that LNG use does because of its base load such as lights and machinery. However, because light and machinery show relatively constant load patterns throughout the year, plant power use due to the heating and cooling system operation, leads to the increasing trend of electricity use for defined operational modes of heating, cooling and mid-term periods.
5. Prediction of Energy Use

By applying the daily mean outside air temperature drawn from the 1997 weather data to the 14 predicting equations, derived based on occupancy patterns and operational modes, the energy use of the year 1997 was predicted. The results shown in Fig.5. indicate that the LNG and electricity consumption estimated as a function of the outside temperature by using the predicting equations; in the case of electricity, it is spread somewhat wider compared to the actual consumption, and the electricity consumption is somewhat under-estimated.

The monthly comparison of LNG and electricity use prediction with the actual consumption data for the year 1997 are shown in Fig.6. The results show that predicting equations estimated the monthly LNG and electricity use fairly closely to the actual consumption data with a mean error of less than 10%. In the case of electricity, however, the predicted value appeared to be less than the actual consumption. As previously stated, this is due to the fact that the electricity consumption, especially the basic level of electricity consumption in 1997, increased compared to that of 1996. Taking into consideration the fact that LNG consumption did not increase compared to that of the previous year, the increase in electricity is assumed to come not from consumption in relation to the changing outdoor air temperature but from a general increase in basic demand for electricity.

6. Conclusions

This study, as a technique enabling comprehensive energy planning and management for an office building, proposes a 4-step building energy management process model. Through the actual application of the process model, energy performance retrofit plans were drawn up for the subject building, and energy saving opportunities evaluated. The results were based on a computer simulation, so more careful attention would need to be paid before applying the results to a real project. Therefore, in the future, the priority of applicable retrofit plans is expected to be determined after additional validity analyses and economical efficiency evaluations have been carried out, by collecting more concrete cases and related data for energy retrofits.
Building energy use prediction using regression analysis, when compared with the engineering approach such as DOE-2, is evaluated to be simple, relatively good and reasonable. Therefore, the possibility of its being used as a means of building energy performance evaluation in the future is judged to be very high. In carrying out building energy retrofit especially, this technique can be used to analyze the actual energy savings after the retrofit. In addition, by analyzing the patterns of energy use on the basis of data not only from one year but from several years, more accurate predictions of building energy consumption will be possible.

The simplicity and exactness of the application is not withstanding, the following defects are also seen: if there are no consumption data following a real retrofit, it is impossible to make a comparison, and the application’s dependence on only a few variables in predicting energy use limits it in making flexible predictions.

In addition, because the building energy use prediction technique is based on the existing energy consumption data of a specified building, it has the following limitations: the technique cannot be generalized and applied to all buildings, and in the case of energy performance improvement by retrofitting, supplemental regression equations must be developed continuously.

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