Development of an Integrated Energy Simulation Tool for Buildings and MEP Systems, the BEST (Part 6)

Outline of the Modeling Method of Electrical Installation - Lighting Systems, Electrical Power Supply Systems, and Elevators

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This study aims to develop a calculation tool "BEST", which is able to simulate overall energy consumption of MEP systems. This paper presents the outline of the modeling method of electrical installation in BEST. Lighting systems, electrical power supply systems and elevators are the subject of electrical installation.

Introduction

This study aims for the development and practical use of the "BEST" simulation software to calculate overall energy consumption in MEP systems in buildings to achieve the goal of global environmental load reduction. The former reports described the framework and outline of the calculations regarding HVAC and plumbing systems as well as the meanings and visions of the entire BEST development project.

As for electrical installations, artificial lighting / daylighting simulation tools that focus mainly on visual environment analyses (e.g., lighting intensity and brightness) have been used frequently. Traffic simulation tools have also been used in elevator service studies.

Calculation methods and various coefficients for the energy consumption simulations are well maintained. For example, CEC/L (Coefficient of Energy Consumption for Lighting) and CEC/EV (Coefficient of Energy Consumption for Elevator) as defined in the Energy Consumption Law have been used. The CEC calculation system is designed so that the effects of installed effective energy-utilization systems (e.g., high-efficiency transformers, natural energy power generation systems and cogeneration systems) can be reflected on CEC. However, it seems that CECs are used less in the energy consumption calculations themselves. Not only that, there are many problems regarding the energy consumption calculations. For example, estimated energy consumption, Life Cycle CO2 (LCCO2) and LCCO2 (LCC) by the Research Committee on Electrical Installation Concerning the Global Environment at the Institute of Electrical Installation of Japan are just annual values. These values indicate the prospective effects that will result if the 14 techniques defined in the Environmental Load Reduction Method are applied to the building. Moreover, that data is not linked with weather data and does not contain synergic effects between the electrical installation and HVAC systems. Existing calculation tools for each power generation system (e.g., solar energy generation, wind power generation and cogeneration systems) have spread, but their calculation systems cannot handle an entire building.

BEST is a simulation tool to calculate energy consumption in office buildings and can contribute to energy conservation while taking advantage of the findings of existing studies. This report describes the development framework and outline of a program that is part of BEST and is for electrical installations. The "electrical installations" in this report refers to a group of power supply systems (including power generation equipment) to supply energy and lighting and elevator systems, etc., with energy.

1. Purposes of calculation program development for electrical installations

1.1 Comprehensive recognition of energy flow, especially electrical energy flow

This calculation program is designed so that users can comprehensively recognize energy flow in a building by defining various systems (e.g., HVAC, plumbing, lighting, elevator systems and plug outlets) as the load systems of power supply equipment to calculate the energy flow in the same framework. Consequently, users can also calculate power demand factors (the ratio of the maximum demand power and the capacity of the load equipment) of HVAC system partial load etc.

In addition, users can understand whether a buffer facility (e.g., electric power storage equipment) is necessary and estimate how large a capacity this buffer facility should have. Users can also estimate the behavior of these load systems and commercial power under the situation where a power generation system or cogeneration systems is installed.

1.2 Integration with building calculation and weather conditions

This program is designed so that users can concretely calculate energy consumption by using all of the following data: contribution of daylight to lighting systems, building types (e.g., rooms, windows and window-shades) and weather data (e.g., solar radiation) collected in part of this development project.

As for natural energy (e.g., solar, wind) power generation systems, this program can contribute to optimum system design by estimating the power to be generated based on the installation locations, hourly solar radiation, airflow rate, etc.

1.3 Recognition of equipment and system performance and relationship between use/operation pattern and energy consumption

Conventional HVAC simulation tools have used default load patterns for lighting systems and plug outlets as input data. In this program, however, users can use not only these default patterns but also more practical data, including equipment performance data, capacities and use/operation patterns of equipment and systems. This performance data can be entered by selecting a standard model (general model, energy-saving model or conventional model) without identifying the manufacturer of the equipment. Specific performance data can also be entered. Consequently, users can calculate energy loss in power supply systems through simulations for comparing the energy consumption of a conventional model (e.g., transformer introduced in the 1970's) and energy-saving models (e.g., top runner transformer or super high-efficiency transformer currently in use) under the current use/operation patterns.

1.4 Larger integration with HVAC and plumbing systems

The integration of load systems (e.g., HVAC and plumbing systems) with power supply systems is described in Section 1.1. If this integration expands further, it will enable users to design and operate systems comprehensively. For example, it is planned that the effects of heat generation by lighting systems and plug outlets on HVAC systems and effects of load ratio on heat generation in transformers and HVAC systems (ventilation) will be integrated as well.

As for cogeneration systems that can comprehensively take advantage of power and heat, it is planned that control simulations for integrated HVAC, plumbing and power supply systems will be introduced to this program. As a result, data exchange among the simulations will be possible.

If integration with weather data or among systems is unnecessary, users can cancel this setting so that single system performance can be simulated.

2. Development framework

2.1 Macro design

Figure 1 is the electrical installation macro design that can lead to the goals described in Section 1. For example, lighting system simulations will be run through the following steps. Contribution of daylight to the room is calculated based on solar radiation data (weather data). Necessary actions (e.g., turning lights on and off and lighting control) for creating visual environments (e.g., necessary lighting intensity) are considered. Then, each component in the power supply system (e.g., transformer and main cable) requests the appropriate amount of electric power.

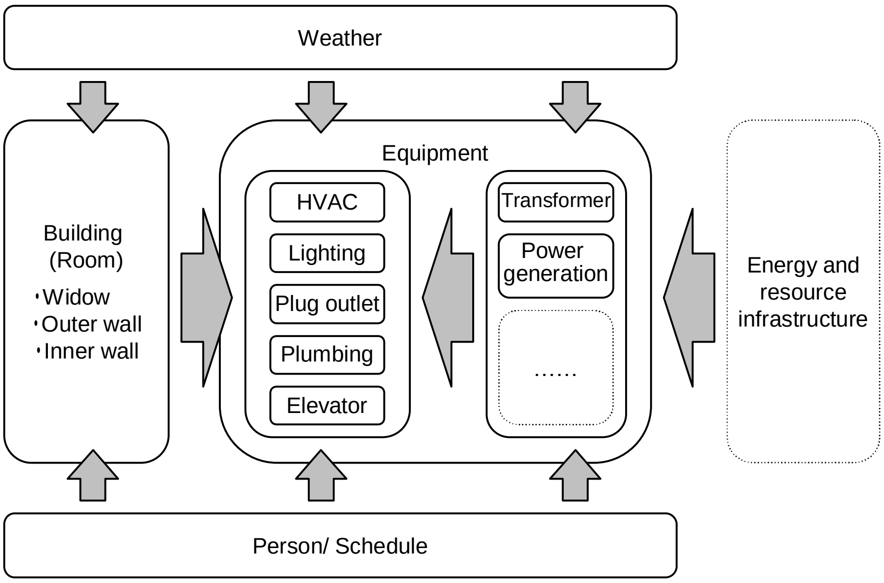

Figure1　Macro design of energy calculation for electrical installation

2.2 Mechanism for comprehensively recognizing energy consumption

A mechanism for comprehensively recognizing energy consumption (electric power, etc.,) is planned to be developed so that the power supply system performance can be allotted to the load equipment. The schematic view of this mechanism is given in Figure 2. On the GUI screen of this program, the power supply system (power board) will be connected to the load equipment by connectors (corresponding to the main cables and wires in Figure 2) to supply electric power.

A simple simulation method is also planned as a countermeasure for systems for which connection patterns may became complex. With this simple simulation method, the power supply system can be connected to the load equipment just by indicating whether the equipment needs single-phase (e.g., plug outlets for lighting) or 3-phase current (e.g., motors).

As for electric power consumption calculations, it is planned that the power factor and either of the power [kW] or the current [A] may be variable in order to study power consumption using active and reactive components comprehensively.

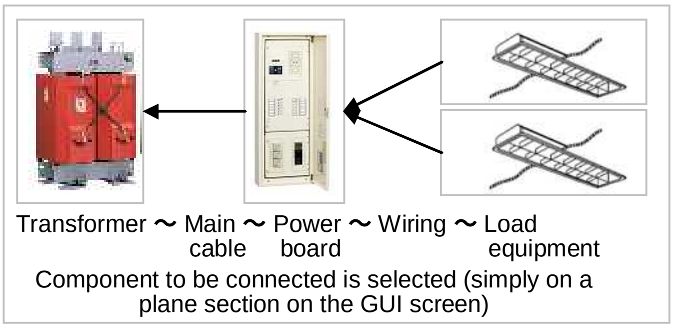

Figure2　Schematic view of mechanism for comprehensively recognizing power consumption

3. Usage and vision of this program

3.1 Using as design and operation guide for electrical installation

(1) Capacity design guide for transformers and main cables

Capacity design for transformers and main cables significantly depends on the demand factor, which varies with the load and operation patterns of the designed equipment. If the demand factor is unknown, the correction coefficient [(2)] defined in the design standards issued by the Ministry of Land, Infrastructure and Transport of Japan has often been used. However, the demand factor depends on the use and operation pattern of the equipment. In many cases, the capacities of electrical installations have been designed larger because of the synergistic effects produced by the following situations. That is, the capacities of electrical installations tend to be designed on the safe side in case of the future expansion of load equipment. The selected performance of electric power equipment is often larger than the safety factor if the equipment to be installed is undetermined, larger than the safety factor for the demand factor and larger than the necessary capacity. According to the Japan Electrical Manufacturers' Association (JEMA), the load factor of transformers (used by customers supplied with high-voltage) [(3)] is about 19% to 43%. The designed capacities of transformers and main cables may be reduced through analyses by BEST if the equipment performance and use and operation patterns can be predicted.

(2) Capacity design guide for power factor improvement capacitors

Capacity design for power factor correction capacitors to be installed at receiving points also significantly depends on the equipment load and especially on the power factor and demand factor of the equipment (before improvement). General machinery without capacitors in their control panels have a power factor of 0.80[(2)] before improvement. Nevertheless, this value may be reduced if the power factor of load equipment is provided (see the Table 1). Transformer performance is also essential in capacity design because the capacity of capacitors has to be designed so that the reactive power improvement value of the transformer is included. BEST will enable users to select appropriate equipment and examine the condenser capacities comprehensively.

Table1 Relation between load power factors of load and necessary capacity of capacitors

Power factors before improvement	Power factors after improvement $\cos\Theta$	
$\cos\Theta_0$	0.98	1.00
0.80	Qc=0.438P	Qc=0.600P
0.85	Qc=0.354P	Qc=0.526P
0.90	Qc=0.253P	Qc=0.436P
0.95	Qc=0.119P	Qc=0.312P

Note) Necessary capacitors capacity: Qc[k Var]=PcosΘ （tanΘ0-tanΘ）
P[kVA]; where the power factor of the load has to be improved.

(3) General design / operation guide for power supply equipment

BEST will enable users to calculate electrical energy consumption at various levels, i.e., hourly consumption, consumption at receiving point, consumption in transformers, main cables, wires, power boards and equipment. It will also be possible to select equipment in each subsystem. Accordingly, electrical installation designers can examine the approximate capacity of power supply equipment at an early design phase by entering the outline of the HVAC system (heat source equipment types, orientation of the main rooms, etc.).

If a design plan becomes definite, it will also be possible to estimate electrical demand based on the simulation results, to select the load equipment to be controlled and the control method to be applied and to conduct other studies for leveling the loads based on the duration curves, etc. Moreover, BEST will be used in examinations of transformer bank configurations with large seasonal load variations (e.g., schools with a summer vacation) and in examinations of ammeters and in looking at the necessary power for self-cooling equipment (e.g., heat source equipment and air conditioners). Such equipment is well known for exceeding its rated capacity if the outdoor air temperature is high.

If real data obtained during operation is entered, users may verify the design values and obtain an indicator of operational improvement. BEST will also be used as a guide for determining [4] surplus power after equipment expansion and as a guide for power supply equipment renewal.

(4) Design / operation guide for measuring systems

An important part of environmental load reduction is the method of selecting the installation location of energy measuring equipment. As for watt-hour meters, the appropriate installation locations are compiled in the Reference (5). With BEST, users can detect noteworthy sections where capacities or loads vary significantly and where permanent equipment is not necessary because the load variation is small.

During under operation of the equipment, users may compare the real values to the design and estimated values, using BEST as a BEMS (Building Energy Management System).

3.2 Prediction of prospective energy conservation effect of installed high-efficiency equipment

Electrical installation efficiency has been upgraded significantly. For example, lighting equipment efficiency has increased by 1.7 times over 30 years (see Figure 3). Also, transformers and elevators are being upgraded, as is lighting equipment. BEST is designed so that users will quantitatively recognize the prospective energy conservation effects that will result if high-efficiency equipment is installed. Consequently, users can reflect the simulation results in life cycle evaluations. If equipment renewal is planned, users will be able to predict prospective energy conservation effects expressed in real load values.

Accordingly, BEST has high potential to contribute to the promotion of high-efficiency equipment installation. In addition, BEST will be used effectively to consistently recognize the effects of high-efficiency equipment installations if the upgrade of load system efficiency can contribute to the reduction of power supply system capacity.

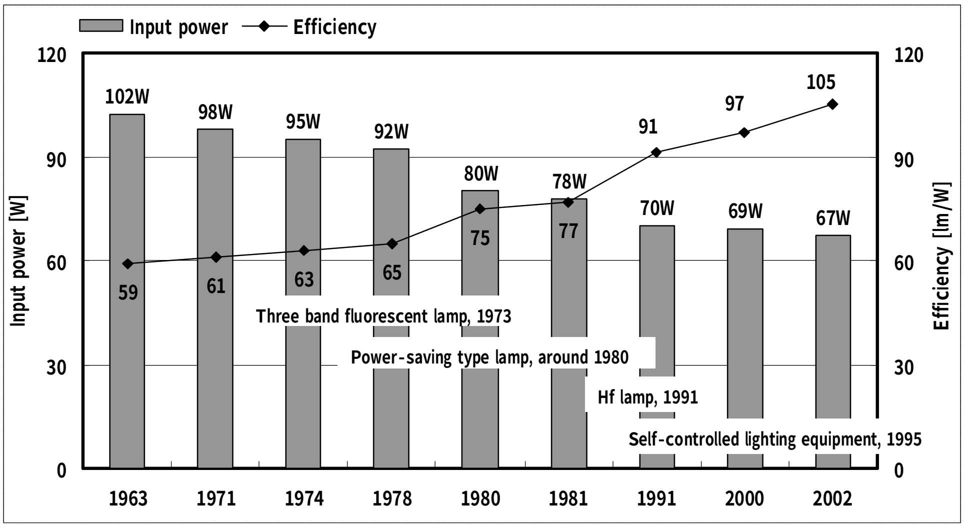

Figure3 Transition of lighting equipment efficiency upgrade [(6)]

3.3 Validation of the overall effects of lighting control systems

About one third of all building energy consumption is due to the electrical installation. About 90% of that is due to lighting (see Figure 4; note that plug outlets are excluded here). Energy conservation in lighting systems will be achieved if various control systems, as well as the high-efficiency equipment described in the preceding clause, are installed. There are several calculation methods (see Reference (7)) to predict the amount of energy to be saved by control systems. However, these are simplified prediction methods where the window size and performance, the locations of sensors and the ratio of people in the room are all fixed values. Contrary to these methods, it's not an exaggeration to say that BEST is the first overall-evaluation tool for various control systems, such as daylight-linked automatic lighting control systems, that link the building, weather data, human detection control systems and human detection sensors. BEST will also be used to examine in-depth examinations of the secondary effects, including examinations of the trade-off between light and heat to prevent thermal load increases by taking advantage of daylight. Currently, the use of multiple control systems for human detection sensors, light intensity sensors, cooperative control systems for lighting and HVAC systems and window shades have been increasing (see References (8) to (10)). Considering the current situation, BEST will become an effective design tool for control systems as well.

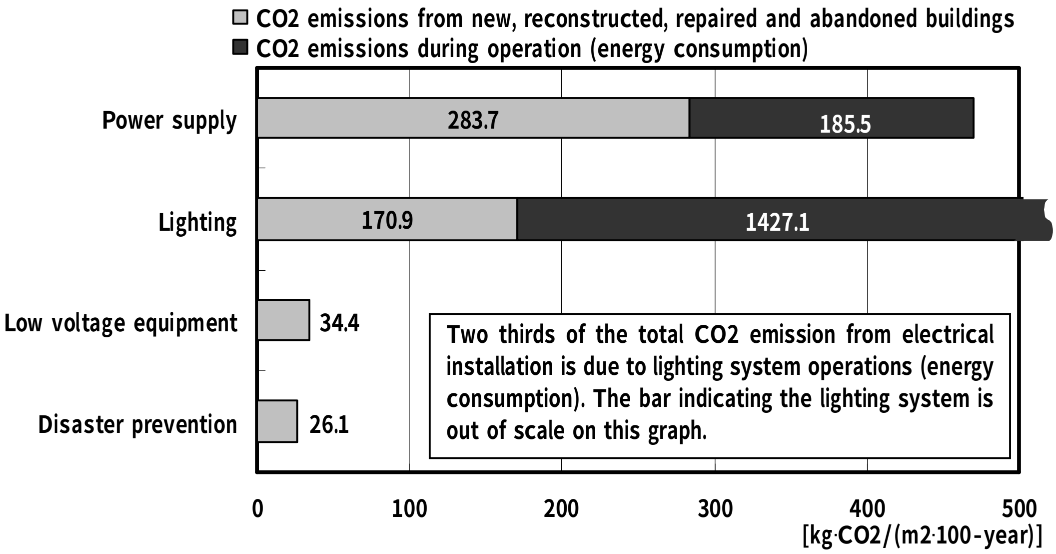

Figure4 Estimation examples of LCCO2 emissions due to electrical installation

3.4 Use of weather data for optimum design of natural energy power generation

Generally, converted weather data has been used in studies on natural energy power generation systems. For example, monthly solar radiation data has been used in studies on solar energy generation systems. Contrary to that, BEST uses a significant amount of weather data. As a result, BEST will become an effective tool in examinations of hourly power generation by solar or wind energy power generation systems, of power interchange and of interconnection with commercial power generation systems (with/without reverse power flow and the amount). Moreover, BEST will be used to evaluate the performance of solar energy power generation systems operated under poor conditions (e.g., continuing low solar radiation). Consequently, examinations of the backup period of storage batteries under the individual operation conditions will also be possible.

3.5 Others

It is often difficult to detect the small capacity power supplies of an entire building (e.g., standby power), because it may be included in the measurement error margin [11] depending on the installation locations of the measuring equipment. However, BEST can estimate such small values because the error margin can be set to zero in the calculations.

Conclusion

The development framework and outline of this program, which is part of the integrated energy simulation tool "BEST" and is for electrical installations, are described in this paper. BEST may calculate values that are equivalent to CEC (Coefficient of Energy Consumption). This will be examined further. BEST will become an effective design tool for electrical installations and may well change the ideal situation of electrical installation design. This will also be examined further in future.

Acknowledgement

This report describes some of the project achievements conducted by the Study Group for Development and Promotion of BEST (Chairperson: Shuzo Murakami), the Architecture Study Group (Chairperson: Yuzo Sakamoto) and the Working Group on Electrical Installation (Chairperson: So Takizawa). These Study Groups and this Working Group, which are part of the Institute for Building Environment and Energy Conservation (IBEC), aim to develop an integrated energy simulation tool for buildings for the purpose of environmental load reduction, in collaboration with industry, government and academia. We would like to express our gratitude to all of the parties involved.

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