Development of an Integrated Energy Simulation Tool for Buildings and MEP Systems, the BEST (Part 3)

Outline of the Modeling Method of the Building and HVAC Systems

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1. Introduction

The simulation tool "BEST" is now under development. From the start of development, the developers have supported the following concept. "Currently, the most important thing is to develop flexible programs that can accept any change. In addition, close communication among developers is necessary, as is dealing with variable user-needs in order to flexibly develop programs that can be operated at anytime." In actual fact, the BEST developers have experienced many hardships. However, this report does not discuss these hardships, but rather the progress and future plans about a program for buildings and HVAC systems. Object-orientation, agile development and program flexibility are planned to be covered in future reports. Readers are especially expected to understand some of the novelty of this program for buildings and HVAC systems described in this report.

2. Calculation purpose in this program

Figure 1 is a mind map showing the calculation purposes of this program. The purposes can be divided into 4 groups: annual hourly calculation, design calculation, calculation supporting state energy strategies and calculation for specific purposes. The annual hourly calculation is the most general, which contains an evaluation of annual energy consumption, seasonal energy consumption, hourly values, etc. The design calculation is to obtain peak loads, to design equipment capacity and to conduct comparative studies on system performance, etc. Building designers consider the design calculation as a basic and important need. As for the calculation supporting state energy strategies, it is important to ensure its reliability as an objective evaluation tool for the energy-saving performance of architectural designs. Evaluation of energy-saving performance is the key to a larger political goal of global environmental load reduction. Considering usability for general building designers, it is essential to equip user-friendly input and output methods. Data on multipurpose buildings (e.g., residential and nonresidential) has to be entered reliably and simply. This program is designed so that the output contains data on dioxide emissions, energy and resource consumption, waste heat from buildings, indoor environmental quality and evaluation results from a life cycle viewpoint. The calculation for specific purposes contains an analytical evaluation, an overall evaluation and a control. BEST-Basic

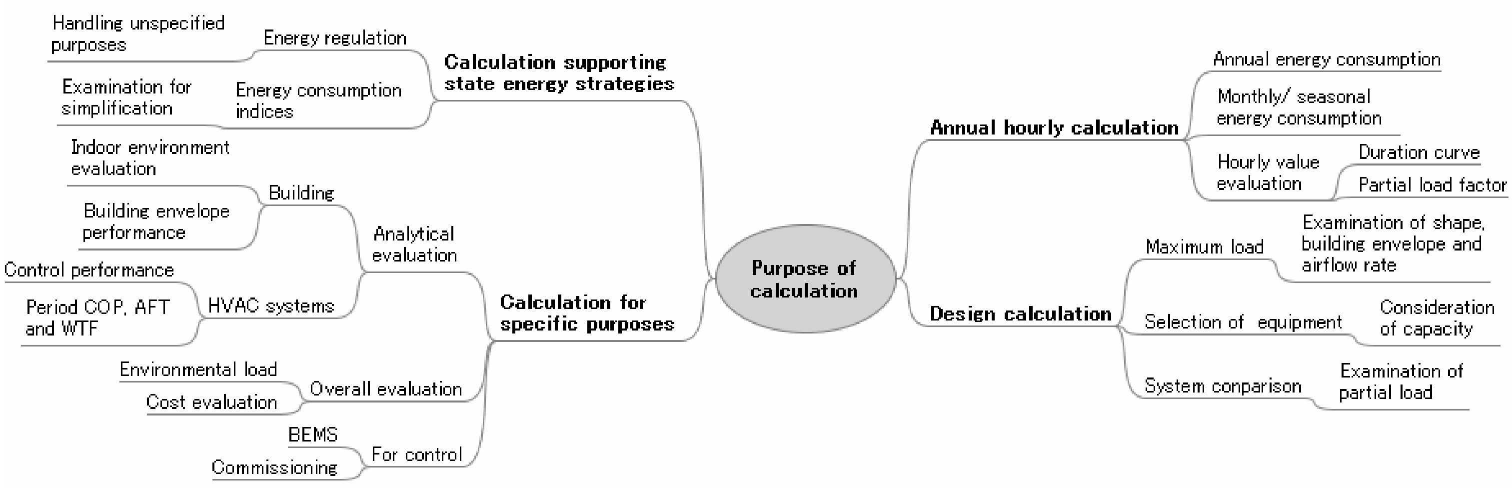

Figure 1: Purpose of calculation in BEST

Table 1: Comparison of integrated simulation methods for both buildings

Solving method	Outline	Advantages	Disadvantages
(1) Explicit solution	Phenomena are linearized and the established simultaneous equations are solved. The unknown number is the state value of the current time step. The unknown number and equations are searched and selected in each case so that convergent calculations become	The calculation time interval ΔT is not subject to the restriction of the solving method. Convergent calculation is unnecessary.	Unavailable if linearization is difficult. Repeated calculations are necessary to search the unknown number. The calculation procedures are complex.
(2) Iterative solution	Simultaneous equations containing nonlinear equations are solved by convergent calculations. The unknown number is the state value of the current time step.	ΔT is not subject to the restriction of the solving method.	Convergent solutions of discontinuous phenomena cannot be obtained.
(3) Implicit solution	The unknown number is the state value of the next time step. Simultaneous equations are not established. The operation rate of the system has to be decided in order to calculate the equilibrium state based on control theories (e.g., PID control).	It is unnecessary to solve simultaneous equations and make convergent calculations.	ΔT is rather short. Appropriate ΔT needs to be selected. A non-direct-feed through component is required for control stability.

will be used in the calculations supporting state energy strategies and BEST-Professional will be used in the annual hourly calculations and design calculations, etc., by general designers. BEST-Extended, which is planned for development in the future, will be used in a wide range of specific calculations.

3. Characteristics of calculations regarding buildings and HVAC systems

3.1 Integrated simulation method for buildings and HVAC systems

The basic principle of BEST is to enable the following 3 calculations: those regarding only buildings, those regarding only HVAC systems with the space thermal load as a given condition and those regarding integrated simulations for both buildings and HVAC systems. The issue facing integrated simulation methods is how to run the simulations. Table 1 shows existing main integrated simulation methods. As for buildings, the thermal equilibrium equation can be linearized. Then, the explicit solution (1) with a calculation time interval of about 1 hour is often applicable in the traditional manner. For HVAC systems, however, the explicit solution (1) is often unsuitable because many discontinuous nonlinear phenomena are associated with the systems. Therefore, an iterative solution (2) or an implicit solution (3) is rather practical. However, iterative solutions (2) have the problem of non-convergent solutions occurring. Therefore, implicit solutions (3) have been considered to be best choice because this program has to be applied to various HVAC systems to yield solutions without problems. In an implicit solution (3), shorter calculation time intervals are required to reduce errors. Moreover, it is important for an implicit solution (3) to contain a component with a delay response in order to maintain control stability. As for water-loops, using only the thermal capacity of the water may be sufficient in the calculations. As for air-loops, however, using only the thermal capacity of the air in the room may be insufficient as the space thermal capacity. Accordingly, the thermal capacity of furniture, etc., also has to be included.

3.2 Switch in calculation method

If an integration simulation for both buildings and HVAC systems is not required, appliance of the implicit solution to the building will result in a shortcoming. The implicit solution requires short calculation time intervals because of convenience. BEST can select the explicit solution if calculations regarding buildings have to be made independently. In BEST, the explicit solution was referred to as "backward method" and the implicit solution was named the "forward method" for differentiation. The selected calculation method can be switched depending on the time zone. For instance, the forward method, with its shorter time intervals, is selected for conditioning hours and the method can be switched to the backward method, with longer time intervals (about 1 hour traditionally), for unconditioning hours.

3.3 Calculation time interval

Short time intervals are sometimes required depending on the calculation purpose. Additionally, suitable time intervals are sometimes required on a case-by-case basis depending on the selected solving method. If variable calculation time intervals have to be applied, some issues occur. For instance, weather data has to be upgraded and interpolation methods have to be established. In addition, unsteady state heat transfer calculation method for walls, criteria for selecting the best calculation time interval and criteria for selecting the best calculation time interval based on the calculation must be studied. In BEST, Matsuo's common ratio method is selected as the calculation method for the irregular heat transfer of walls, because this method can deal with variable calculation time intervals. At the present stage, BEST is designed so that users can enter calculation time intervals by using schedule input functionality and can set the intervals depending on the time zones. Further study targets are the examination of automatic selection methods for the best calculation time intervals in the forward method and examinations of criteria for switching from one interval to another based on whether the calculation target is a building or HVAC system and whether there is wall heat transmission or heat absorption.

3.4 Interaction among many zones

In this program, interaction among many zones can affect calculation results regarding buildings. The effect of adjacent zones is considered using inner wall heat transmission and air exchanged between the zones. Interaction between the interior zone and the perimeter zone can also be calculated. The calculation of multi-space in residential houses is also possible.

3.5 Handling various arrangements of HVAC system components

Various arrangements of HVAC system components are conceivable. Moreover, new systems and technologies will be developed in the future. Therefore, it is necessary to establish a calculation system that can accept flexible equipment configurations and has excellent scalability for future applications. At the same time, it is important to prevent the configuration input method from becoming complex. BEST is designed so that solving methods with high-versatility can be applied without being influenced by differences in the characteristics of various components. Moreover, the following principles have been complied with in the development of BEST: (1) modularization of the components and clarification of input and output (2) establishment of an object-oriented framework with Java and (3) definition and utilization of multiple connected components as one independent new module.

3.6 Indoor environment

The PMV thermal environmental index can also be calculated for comfort evaluation of the indoor environment as well as energy evaluation. The periodic input data for the calculation is clothing and metabolic rate, but air speeds are fixed. The AST of each zone is used as an alternative to MRT. In the future, a block model is planned for incorporation, as is integration of CFD. Consequently, evaluation of indoor temperature distribution will be possible.

4. Outline of calculation method for buildings

As described in the previous reports, calculations of building performance can be made by dividing a large space horizontally. In the future, vertical division will be possible if a block model, which can contain the effects of airflow along walls and jet flow from nozzles, is incorporated. As for heat convection and radiation, whether surface temperature should be handled as an unknown value or not, i.e., whether thermal equilibrium equations should be established while separating convection and radiation, were studied. According to the study results, BEST was designed so that convection and radiation are roughly separated. Complete separation is not practical, because the space radiant filed have to be calculated accurately and 3-D space information must be entered. As for calculations regarding irregular heat transfer, BEST is designed so that 1-D heat transfer and variable calculation time intervals are applied in principle. The response factor method adopted in HASP/ACLD cannot deal with variable calculation time intervals. The backward difference method, which is used frequently, has the shortcoming of increasing the unknown values. Meanwhile, the forward difference method has other shortcomings, such as restricting the calculation time interval and the wall division method. Therefore, Matsuo's common ratio method has been applied with a reduced number of roots. Table 2-1 shows the main calculation items and handling in BEST regarding buildings. As for windows, various calculation

Table 2-1: Calculation items and handling method and status of building and HVAC systems

Item	Handling method	Handling status
Various schedules	Calculations by using piecewise linear interpolation or step changes that are assumed by schedule input	○
Adjacent buildings	Calculations based on adjacent building heights and distances to them	○
	Consideration for more realistic effects of adjacent buildingss	B
Exterior window-shades	Vertical louvers and horizontal louvers	○
	Various shaped louvers	Extended version
Wall Furniture	Review and upgrade of physical properties on heat and humidity	A
	1-D heat transfer calculations (Matsuo's common ratio method)	○
	Application of heat absorption response from experiment data to office furniture	○
	Acceptance of rooftop gardening and underground walls	C
	Calculations of 2-D and 3-D heat transfer Calculation of heat absorption response	Extended version
Windows	Upgrade of thermal performance data of various windows	○
	Upgrade of visible performance data of various windows	A
	Interior window-shades, built-in type general windows and AFWs	○
	Use of solar heat gain coefficients and window U-factors. Use of incidence angle performance of a general window as a representative value	○
	Consideration of more accurate effects of incidence angles and profile angles	A
	Control of slat angles and PPWs	B
	Double skin (integration with air exchange calculation)	C
	Detailed calculation about heat and light	Extended version
Infiltration	Air exchange rate method	○
	Exterior wall area method for typical floors or window area method while using the assumed height of the neutral zone and outdoor wind pressure distribution	A
	Open entrances (integration with air exchange calculations)	C
Occupant	Application of Two-Node model	○
Lighting	Input of wattage Use of assumed heat convection and radiation ratios	○
	Upgrade of heat radiation performance data	A
	Lighting Control (integration with calculations relating to lighting and electric systems)	B
Equipment	Upgrade of heat generating equipment data	A
Space division	Horizontal division of zones	○
	Vertical division of zones (Block model)	A
Thermal comfort	Calculation of operative temperatures and PMV by using the AST of each zone	○
Integration with calculations of lighting and electricity performance	Simple calculation of daylight illuminance distribution and of lighting control	B
Integration with calculations of air movement	Calculation of natural ventilation (ignoring effects of HVAC and air exchange systems)	C
	Double skin	C
	Integration with CFD	C

○: Already handled, A > B > C: order of priority

Table 2-2: Calculation items and handling method and status of building and HVAC systems

Item	Content	Handling status
(Unit type) Multi-unit	Calculation of cooling and heating by EHP and GHP Supply heat rate correction based on outdoor air temperature, returned air temperature, lengths of pipes and difference in elevations of pipes As for on-off control, the on-ratio is calculated while assuming that the air temperature is kept constant.	○
	Upgrade of equipment performance data	A
	Energy recovery operation for cooling and heating	B
(Central type) Basic component of primary system	Absorption chiller	○
	Boiler and electric heat pump chiller	A
	Open system cooling tower	○
	Closed type cooling tower and heating tower	B
	Upgrade of performance data of various types of equipment	A
	Various types of control methods	A
Extended system	Thermal storage system	B
	Cogeneration system	C
Basic component of heat delivery system	Pump (CWV) and fan (CAV)	○
	Pump (VWV) and fan (VAV)	A
	Confluence and bifurcation of pipes and ducts	○
	Pressure balance	Extended version
Secondary system	Chilled/hot water coils (wet surface coefficient method)	○
	Water humidifier	○
	Steam coils and other types of humidifiers	A
	Total heat exchanger, free cooling and other fresh-air-control methods	A
	Various types of control methods	B
BEMS	Detailed calculation using actual data	Extended version

methods can be applied and the calculation targets are planned to be expanded further in the future. The integration of this program with air exchange calculations and CFD is also planned.

5. Outline of calculation method for HVAC systems

If the calculation modules of HVAC system components (e.g., chillers and coils) are linked together, an HVAC system model can be established and calculated. A room is also considered to be one module. The calculation modules of HVAC system components (e.g. chillers, primary chilled-water pumps, cooling-water pumps and cooling towers) can be linked together in advance to be handled as one macro module. In the extended version of BEST, users can add modules. Calculations of HVAC system performance are always performed by the forward method. In BEST, calculation modules expressed by ordinary differential equations are solved by numerical integration using the fourth-order Runge-Kutta method. Equilibrium states of HVAC systems can be determined by incorporating a PID control module. Table 2-2 shows the calculation items regarding HVAC systems. Unit-type air conditioners can also be handled with a PID control module incorporated in advance regardless of whether with or without on-off control. Then the result is converted if an on-off operation is conducted.

6. Conclusion

The modeling method for buildings and HVAC systems is described in this report. Possible calculation items at the present stage and prospective items planned to be added in the future are also described.

Acknowledgment

This report describes some of the project achievements conducted by the “Study Group for the Development and Promotion of BEST (Chairperson: Shuzo Murakami)”, the Architecture Study Group (Chairperson: Yuzo Sakamoto), the Research Committee of Building and HVAC System (Chairperson: Hisaya Ishino) and the Class Concept Working Group (General Manager: Hisaya Ishino), which were established in the Institute for Building Environment and Energy Conservation (IBEC). These groups aim to develop a comprehensive tool to calculate building energy consumption 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.

Reference

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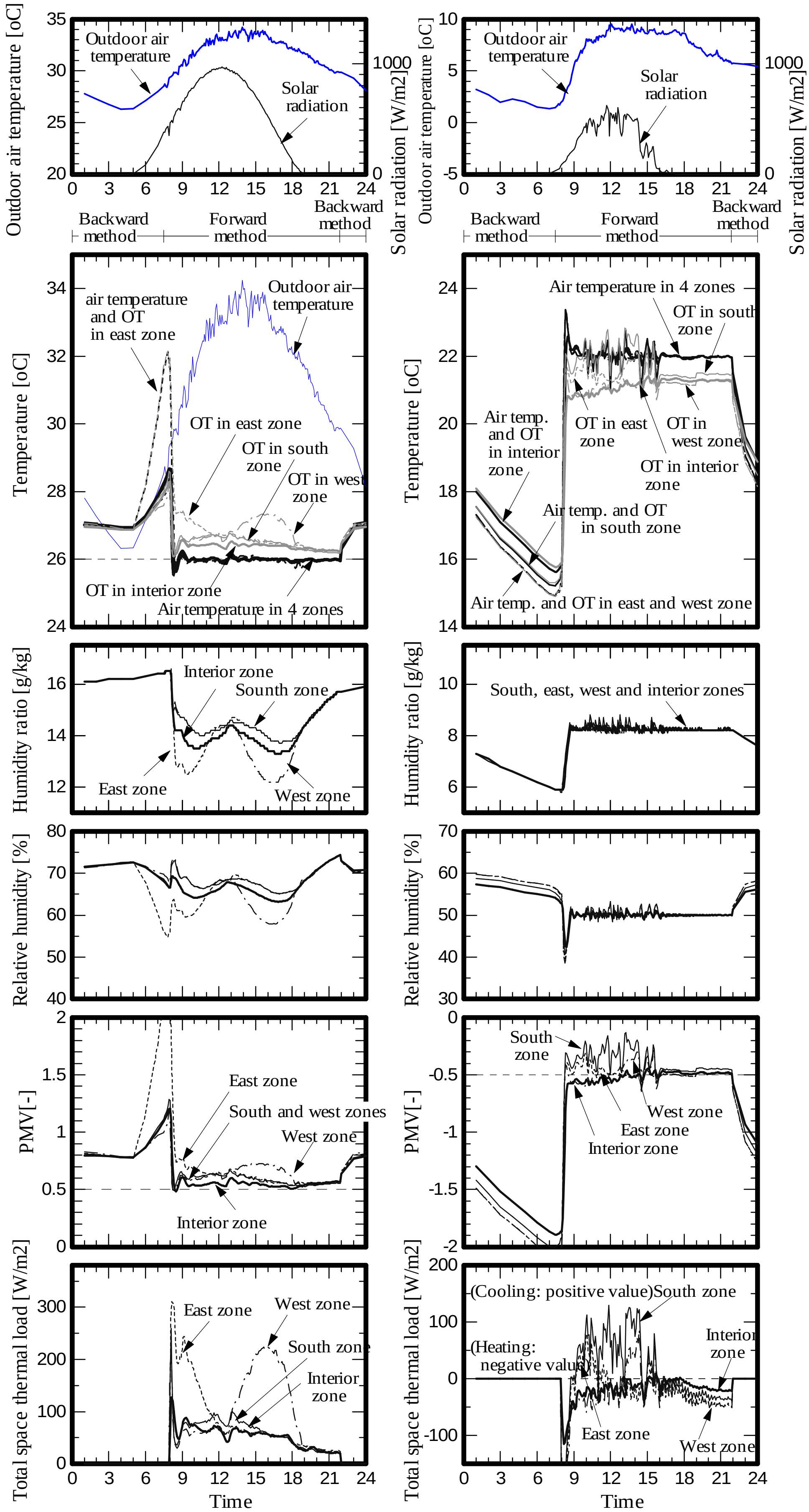

(a) Typical day in summer (July 28 (Fri.))   (b) Typical day in winter (Jan. 27 (Fri.))

Figure 2: Hourly variations of indoor environment and space load on representative days (Osaka, Japan; 2006)

Note

The graphs show the calculation results in an office in a building under standard conditions (see the report Part 14). One-minute interval weather data for Osaka, Japan is used. The displayed values are indoor environments and the loads of half of the south area of the room on a typical floor, which is divided into 4 zones: south, east, west and interior zones.

Windows: 2.6 m height low-e double glass with neutral-colored window-shades, without exterior window-shades;
Infiltration rate: 0.2 times/hour;
air exchange between zones: 200 CMH/m;
internal heat generation (peak value): 20 W/m^2 from lighting, 15 W/m^2 from equipment and 0.15 person/ m^2 from personnel;
heating and air-conditioning system: interior AHU (CAV); airflow rate: 7 times/h (fresh air rate contains air supply for the perimeter zone); FCU for perimeter zone; air-conditioning time zone: 8:00 to 22:00;
room set point temperature: 26 ºC for cooling and 22 ºC for heating;
room set point humidity: 50%;
primary system: only chilled water supply during cooling operation and only hot water supply during heating operation; and
calculation time intervals: 5 minutes during 7:30 to 22:00, 60 minutes during 22:00 to 7:00 and 30 minutes during 7:00 to 7:30.