General-Purpose Building Energy Simulation Program 'BEST' for the Energy-Saving Standards in Japan

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ABSTRACT

The energy-saving standards in Japan will soon be revised. To achieve wide-scale energy savings, building owners are obligated to show their efforts toward energy conservation, building designers are oligated to design buildings efficiently, and administrative bodies are obligated to examine the energy performance of buildings. Although BEST ("the program") is a building energy simulation program that was developed in 2005 in Japan for demonstrating performance compliance with the Energy Conservation Law, it can also be used in the building design and operation phase for conducting whole-building life-cycle assessment. Since 2009, when the program was first used as a simulation software that corresponds to Japan's Energy Conservation Law, it has been downloaded more than 10,000 times. Between 2013 and now, the program has been further developed as a simulation software specifically for the revised Energy Conservation Law. In this paper, we will describe its features as a general-purpose building simulation program. In the program, building energy performance can be analyzed based on factors that include thermal insulation, building envelope, air conditioning, ventilation, lighting, hot water, elevator, etc. It is also possible to perform renewable energy-related analysis that take into account solar power generation, storage battery, solar hot water system, and cogeneration system. The program can generate results that include energy consumption, peak demand, and annual cooling/heating load. In general, since there is a wide range of input parameters, energy simulation programs can only be proficiently operated by skilled professionals. For the purpose of simplifying energy efficiency planning by using the program, a graphical user interface (GUI) was developed to make the software easier-to-use and to minimize input mistakes. Users can easily understand and learn to use the program through visual representation of building information inputs and graphical icons for complicated equipment. Simulation outputs include comparison between a standard building and a proposed building or between various design alternatives, list of input values, and various detailed analysis results. This simulation program is the first software developed in Japan that not only can accommodate local design codes, but also incorporates energy-efficient design strategies, technologies or building systems that are widely adopted in Japan but uncommon in other countries.

INTRODUCTION

In February 2016, the Japanese energy saving law was drastically revised for the first time in 15 years, due to the steady increase in energy consumption in Japan since 1990. While the energy consumption of manufacturing and transportation sectors has been decreasing, that of housing and commercial building sectors has been increasing. In

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response, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) enacted a law that illegalizes the construction of any buiding not meeting the new standards. Aside from such regulation, MLIT encourages building owners to further improve their energy efficiency by offering incentives like density bonus for buildings with 20% less energy consumption than a standard building, which must be proven using approved simulation tools like the program in this paper.

On the other hand, Japanese building professionals have long experienced difficulties in modeling their building using simulation programs, e.g., eQuest and EnergyPlus for international sustainable rating system like LEED. One reason is that Japanese design codes have rather different requirements for ventilation, energy recovery, etc. from international codes. Another reason is that energy-efficient design strategies commonly adopted by Japanese designers, e.g, air-to-air geoexchange system utilizing underground trenches, cannot be modeled in most overseas softwares. Such reasons prompted the need to develop an energy simulation program that can accommodate local design codes and practices, and the program in this paper is the first one developed in Japan that accomplishes that.

DESIGN PROCESS OF ENERGY CONSERVATION

The program is a useful life cycle tool in various design phases. Figure 1 shows what the program can be used for in many phases. In Concept Design phase, the program can be used to determine the energy-reduction goal and the optimum building form and geometry to achieve the desired goal. The program can be used to conduct sensitivity analysis to identify the optimum combination of technology, etc. Rough calculations can be made even if input information is limited. In Schematic Design phase, the program can assist in making decisions in preliminary design and equipment specifications, as well as performing energy consumption comparison. In Detailed Design phase, the peak load, annual load, annual energy consumption, and peak demand of a building can be estimated. In Japan, the building approval process usually starts at the end of this phase. Once the building is completed and moved into the operational phase, the program can be used to assist the commissioning of buiding services and systems by comparing the simulation results with operational performance. The impact of changes in operation schedule, optimization of preset temperature and illuminance, and partial renovation can also be estimated through program simulation.

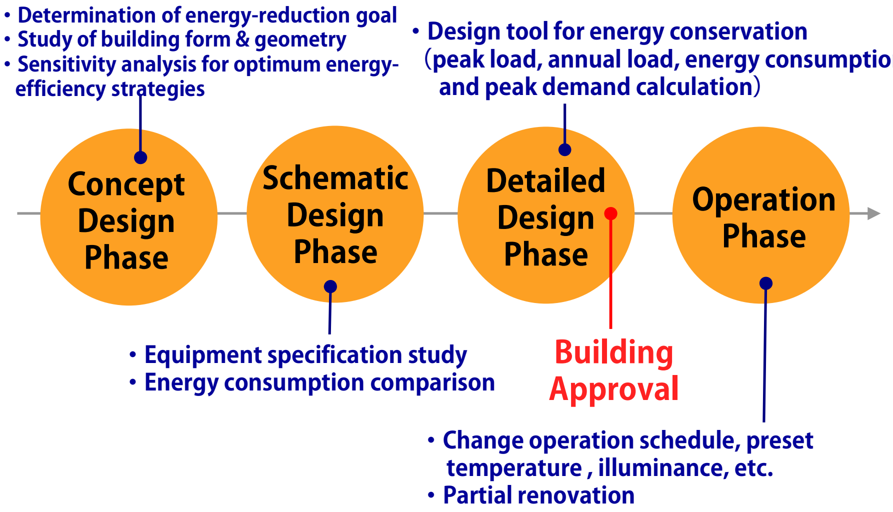


Figure 1 Utilization of the program during building design and operation phase

BASELINE BUILDING PERFORMANCE BASED ON ASHRAE STANDARD 90.1

Two methods can be used in the program for comparing the energy consumption of a baseline building with that of a proposed building. The first method is to compare a baseline value of energy consumption by building type (cap or benchmark) with a proposed value of energy consumption. The other method is by replacing the specifications of a proposed building and compare the resulted energy consumption to the building's energy consumption with the proposed specfications.

The program is mainly used for calculating the energy consumption of a proposed building. Based on the simulation requirements prescribed in ASHRAE Standard 90.1, the program can also be used for assessing the energy performance of design alternatives (by substituting the specifications of the proposed building). Table 1 compares the simulation capabilities of the program to the simulation requirements as described in ASHRAE Standard 90.1.

Table 1. Simulation General Requirements of ASHRAE Standard 90.1 and method of calculation by the program

	Simulation General Requirements of ASHRAE Standard 90.1 Appendix G	Simulation Capabilities of the program
a	8760 hours per year	5-minute computation time step for 365 days per year
b	hourly variation in occupancy, lighting power, miscellaneous equipment power, defined separately for each day of the week and holidays	Meet ASHRAE Std. 90.1 requirements
c	Thermal mass effects	Meet ASHRAE Std. 90.1 requirements
d	Ten or more thermal zones	Meet ASHRAE Std. 90.1 requirements
e	part-load performance curves for mechanical equipment	Meet ASHRAE Std. 90.1 requirements
f	Capacity and efficiency correction curves for mechanical heating and cooling equipment	Meet ASHRAE Std. 90.1 requirements
g	Air-side economizers with integrated control	Meet ASHRAE Std. 90.1 requirements
h	Baseline building design characteristics specified in Section G3: Calculation of the proposed and Baseline Building Performance	See note below

Note: Building site, geometry and orientation, exterior walls configuration, energy source of the equipment system and operation schedule are the same in both baseline and proposed buildings. In the baseline building, components such as window-wall-ratio by building type, window specification, thermal insulation, COP of refrigeration equipment, service hot water system, HVAC system, and lighting power density are defined per ASHRAE Standard 90.1 Appendix G. The proposed building performance is modeled with the proposed design specifications.

INPUT USER INTERFACE

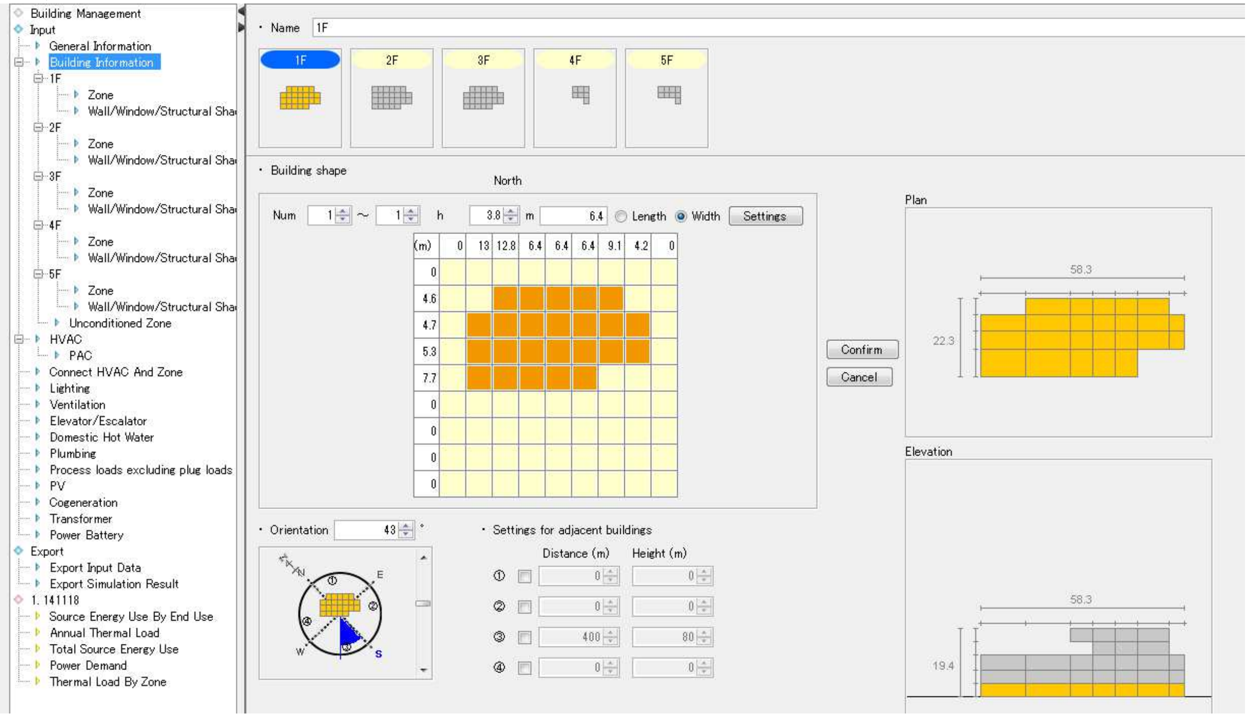
In general, since there is a wide range of input parametersenergy simulation programs can only be proficiently operated by skilled professionals. For the purpose of simplifying energy efficiency planning by using the program, a graphical user interface (GUI) was developed to make the software easier-to-use and to minimize input mistakes. Users can easily understand and learn to use the program through visual representation of building information inputs and graphical icons for complicated equipment, and therefore the program can be adopted as a general-purpose energy simulation program that can applied for any building size or use. In the near future, the program will become BIM-compatible; the program can import data from BIM to perform energy modeling.

Building Information Input

Figure 2 shows the building information input screen on which we can determine the volume and orientation of a building. On this screen, a building block plan can first be created based on the structural column layout of the building. Ignoring actual partitions and any uneven geometries, a rough outline of the building can be determined. Repeating this exercise floor-by-floor, the volume of the building can be completed. The building shape created in the block plan will automatically generateplan and elevation views with actual dimensions so that building proportions can be easily understood.

Figure 3 shows the screen for inputting space types, exterior walls, locations of windows, eaves (if used), and other detailed geometries. Based on the space type, the schedules for HVAC operation and internal heat load can be defined. Spaces are color-coded according to the designated space classification. Colored spaces are conditioned, and spaces shown as gray are unconditioned. Unconditioned spaces typically include elevator shafts, stairs, toilets, etc. We can also see the locations of exterior walls and windows, and window sizes. In this example, the northeastern side of the building has relatively low window-wall-ratio. As for the southwestern side, while it has high window proportion, eaves were used to block out the sunlight. In this figure, the actual outline of the exterior wall is drawn, and this wall line is broken into short sections to create an overall building geometry that more closely resembles the actual building as compared to that in the block plan.

Figure 4 shows the input screens for exterior walls. For each wall material, thermal resistance, thermal conductivity, specific heat, and density are already pre-defined. Therefore, users only have to input the construction layers of an exterior wall for the program to calculate the heat transfer coefficient (U-value) for the entire wall assembly.



・ Name 1F

・ Building shape

Num 1 ~ 1 h 3.8 m 6.4 ○ Length ● Width Settings

(m)	0	13	12.8	6.4	6.4	6.4	9.1	4.2	0
0									
4.6			🟧	🟧	🟧	🟧	🟧		
4.7		🟧	🟧	🟧	🟧	🟧	🟧	🟧	
5.3		🟧	🟧	🟧	🟧	🟧	🟧	🟧	
7.7		🟧	🟧	🟧	🟧	🟧			
0									
0									
0									
0									

・ Orientation 43 °

・ Settings for adjacent buildings

		Distance (m)	Height (m)
①	☐	0	0
②	☐	0	0
③	☐	400	80
④	☐	0	0

Figure 2 A block plan on the building information input screen

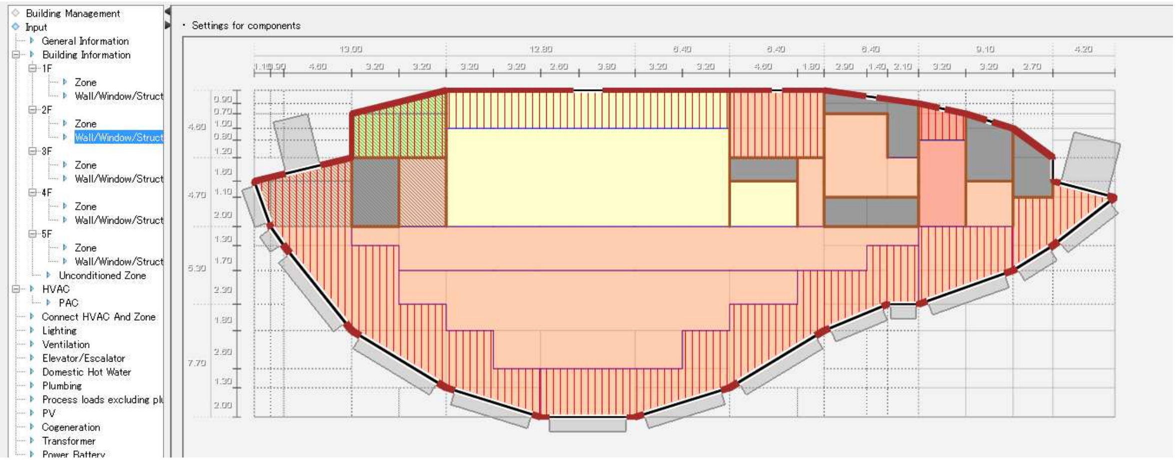
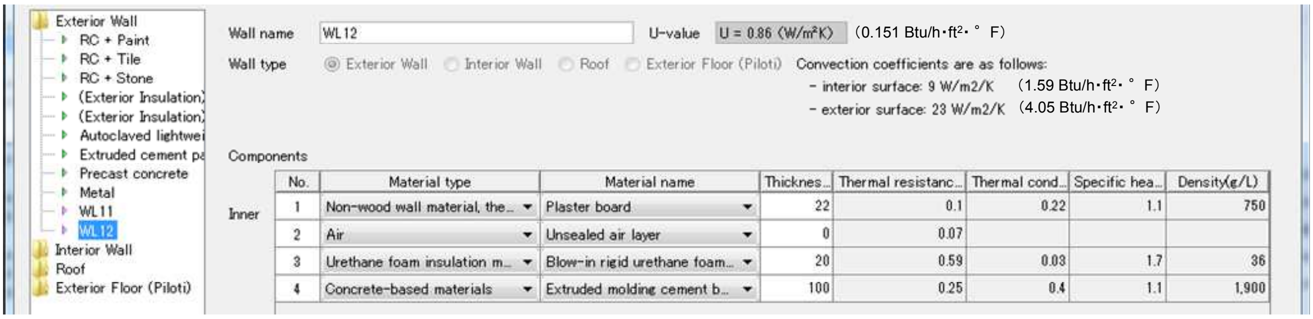


Figure 3 A detailed plan in the building information input screen showing exterior walls, window sizes and shading devices



Wall name: WL12

U-value: U = 0.86 (W/m²K) (0.151 Btu/h・ft²・° F)

Wall type: ◉ Exterior Wall ○ Interior Wall ○ Roof ○ Exterior Floor (Piloti)

Convection coefficients are as follows:
- interior surface: 9 W/m2/K (1.59 Btu/h・ft²・° F)
- exterior surface: 23 W/m2/K (4.05 Btu/h・ft²・° F)

Components

	No.	Material type	Material name	Thicknes...	Thermal resistanc...	Thermal cond...	Specific hea...	Density(g/L)
Inner	1	Non-wood wall material, the...	Plaster board	22	0.1	0.22	1.1	750
	2	Air	Unsealed air layer	0	0.07			
	3	Urethane foam insulation m...	Blow-in rigid urethane foam...	20	0.59	0.03	1.7	36
	4	Concrete-based materials	Extruded molding cement b...	100	0.25	0.4	1.1	1,900

Figure 4 An example of exterior wall composition and specifications on the building information input screen

HVAC System Input

In the HVAC system input screen, after selecting 'Central' or 'Split' type system, the user would select the quantity and equipment for the central plant (heat source) or HVAC equipment. Then, the detailed specifications (capacity, power consumption, and control method) for each piece of equipment can be entered. Finally, individual HVAC equipment would be linked to the space(s) that it is cooling or heating. When central air handling system is specified, VAV or CAV terminal units, and air outlets can be assigned to a specific space. In the case of split systems, the indoor unit can be assigned to a specific space.

Figure 5 shows an example of a complicated four-pipe central plant system. The information of central plant equipment are represented by graphical icons making it easy to visualize the complete system. Since all primary equipment (e.g., chiller, boiler), pumps, and auxiliary equipment are presented on a single screen, the connection between each systems and equipement can be easily imagined, which could minimize input errors.

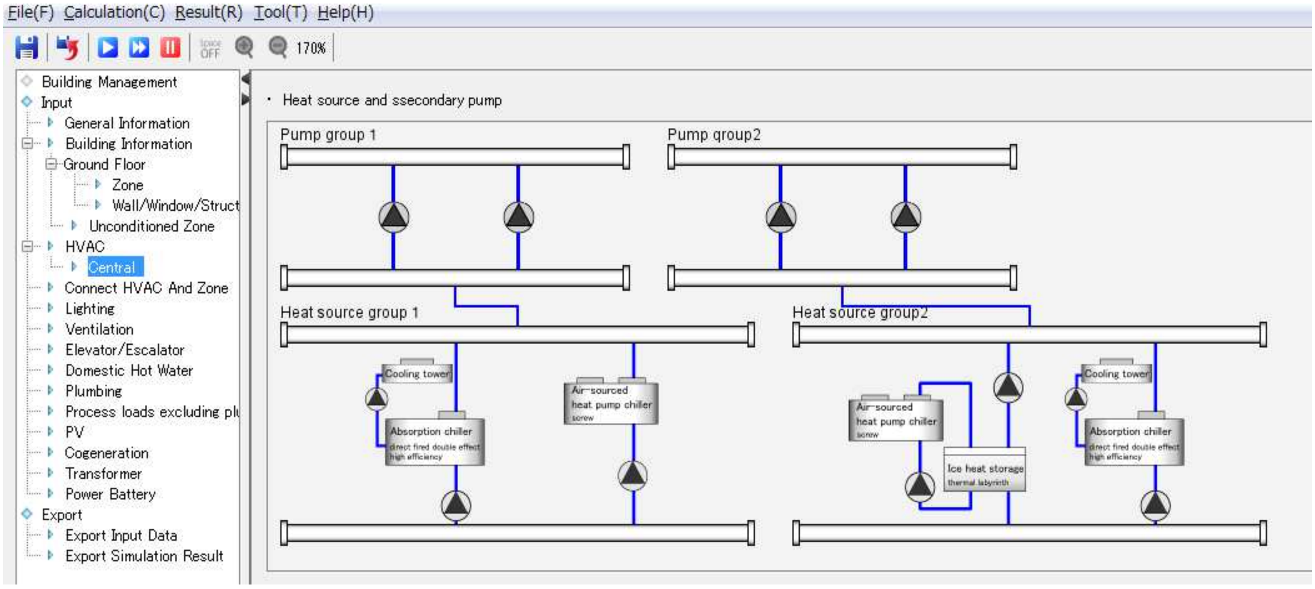


Figure 5 An example of a complicated four-pipe central plant system on the HVAC system input screen

Ventilation System Input

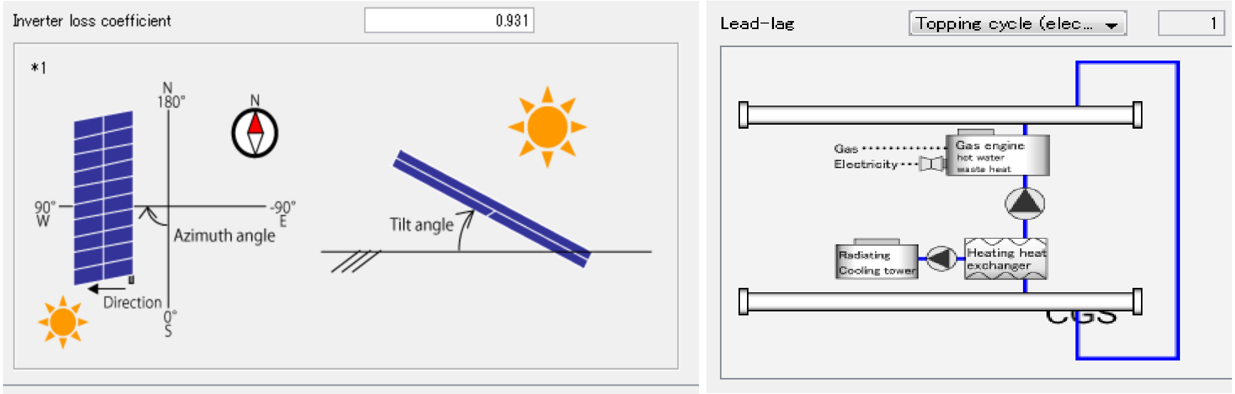
The ventilation system input section is applicable to unconditioned spaces such as parking lots, machine rooms, electrical rooms, toilets, etc. By inputting fan type, air volume, and static pressure, the power consumption of a ventilation can be calculated. Option for ventilation control for energy-saving operationsinclude the following: VAV, demand-based (CO or CO_2), and temperature setpoint.

Lighting System Input

While the lighting power consumption and quantity of lighting fixtures are being entered for each space, referring to an input screen of a drawing, the lighting power density will be shown. Daylighting system can also be applied by inputting window area, window direction, daylighting depth, and target illuminance. As lighting level changes responding to daylight variations, a space's internal heat gain would also be affected, impacting the sizing of the HVAC system. The decrease in air-conditioning load due to lighting power reduction can be automatically simulated in the program. The other options for lighting control are occupancy sensor control or dimming control.

Renewable Energy System Input

This input section accepts renewable energy systems (solar power generation, and solar hot water system) and untapped energy systems (air-to-air geoexchange system utilizing underground trenches, thermal energy from river water, and exhaust heat from cogeneration system). Figure 6 shows the input screen for solar power generation (left) and cogeneration system (right). In the calculations of solar power generation and solar hot water supply, we determine an azimuth angle and a tilt angle, and calculate electric power generation and thermal energy collection in accordance with the amount of insolation by time unit at a site. For the cogeneration system, we can now calculate energy consumption of the gas engine system. We can choose the type of cogeneration operating system from the following methods: electricity generation-oriented operation, heat generation-oriented operation, or constant power generating operation. Since the program is capable of studying the balance between electricity generation and exhaust heat utilization according to the characteristics and needs of a building, it can be used for determining the optimum capacity of a cogeneration system.


Inverter loss coefficient 0.931

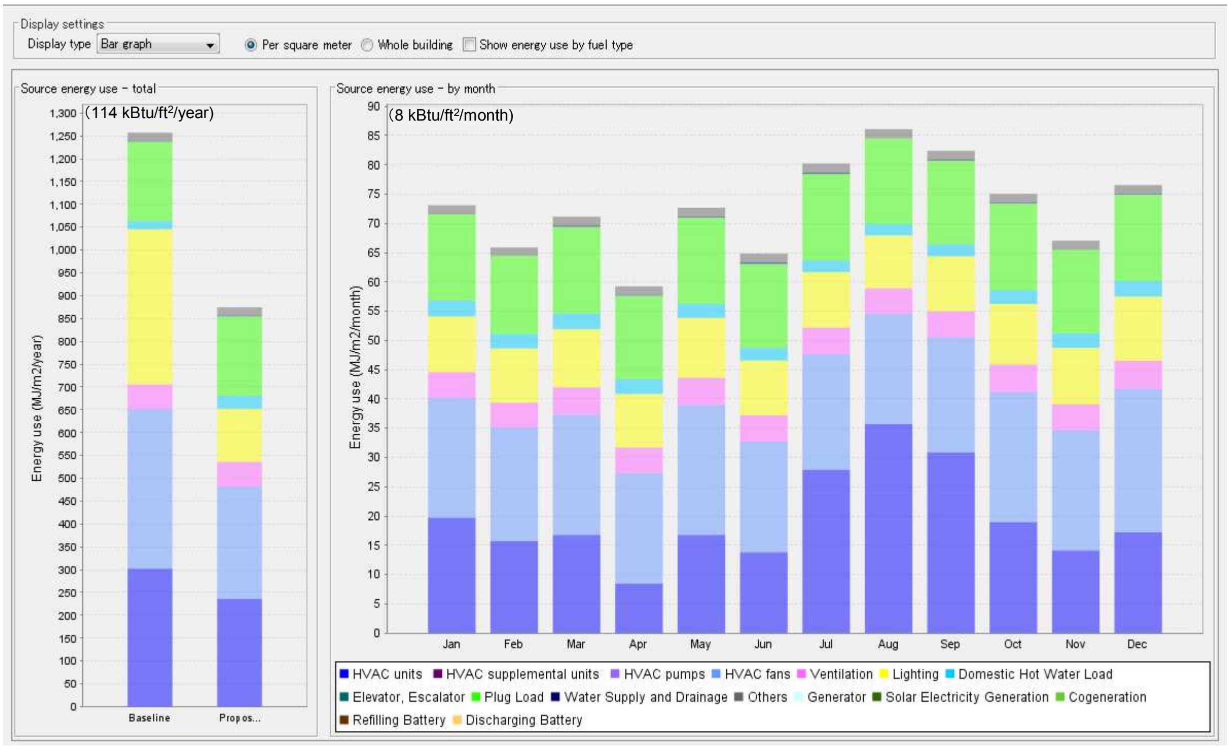
Lead-lag Topping cycle (elec... 1

Figure 6 Input screen for solar energy system (left) and cogeneration system (right)

CALCULATION RESULTS

The program can generate easy-to-understand results in graphic form. The results include primary energy consumption, annual cooling and heating loads, hourly power consumption during peak use days, etc. These results are shown in graphs and tables, so they can be easily exported to some other programs or software tools to be further analyzed. By using the program, both result data and input data can be shared with administrative bodies responsible for examining the energy performance of buildings, and the industry peers.

Figure 7 presents an example of calculated primary energy consumption. The left graph compares the annual primary energy consumption between a baseline and proposed building; the proposed building consumes about 30% less energy than the baseline building. The right graph shows the monthly primary energy consumption of the proposed building from January to December. Both annual and monthly graphs show the breakdown of energy end-use, which includes the following categories: HVAC equipment, HVAC fans, ventilation, lighting, domestic hot water, plug load, etc.



Display settings

Display type: Bar graph ● Per square meter ○ Whole building ☐ Show energy use by fuel type

Figure 7 Simulation results comparing primary energy consumption of baseline and proposed buildings

Figure 8 shows the simulation results of Figure 7 in a pie graph form. Seeing the pie graph, we can find the distribution ratio of annual energy consumption, and know which end-use category consumes more energy. In this building, more than half of the total energy is used for HVAC, which means that we can still strive to reduce energy consumption related to the HVAC system.

Table 2 shows the energy consumption and peak demand by end-use for both baseline building and proposed building. By comparing end-use categories ‘HVAC equipment’ with ‘HVAC fans’, we can see that while their energy consumption is nearly equal, their peak demand is quite different. This suggests that we need to take energy-saving measures not only to reduce the HVAC load but also to shorten the operating time of HVAC fans.

The left panel of Figure 9 displays the annual cooling and heating loads; the top graph presents the monthly load and the bottom graph presents the hourly loads in descending order. In this figure, we can find the ratio of cooling to heating load of a building and the occurrence frequency of the peak load. Such results are useful when, for example, a design engineer tries to introduce a system with high partial-load efficiency or can reduce the peak building load.

Figure 9 presents the daily fluctuations of power demand, which allows the user to examine closely the demand that occur on peak summer days. In this graph, the fluctuations of power demand throughout a day and the ratio of daytime and nighttime consumption can be easily understood. This is helpful when studying the impact of peak demand reduction on the regional power grid.

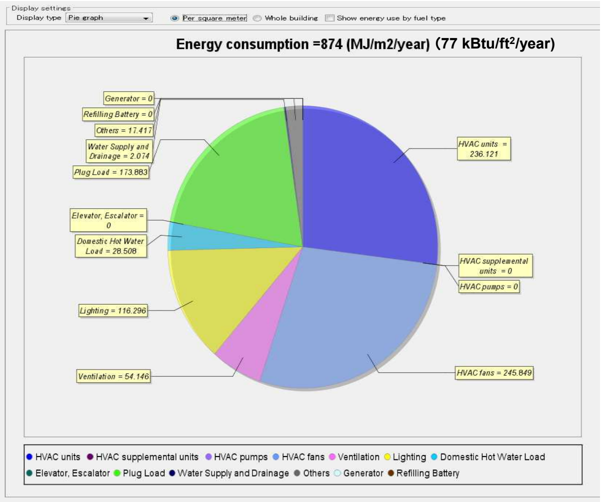
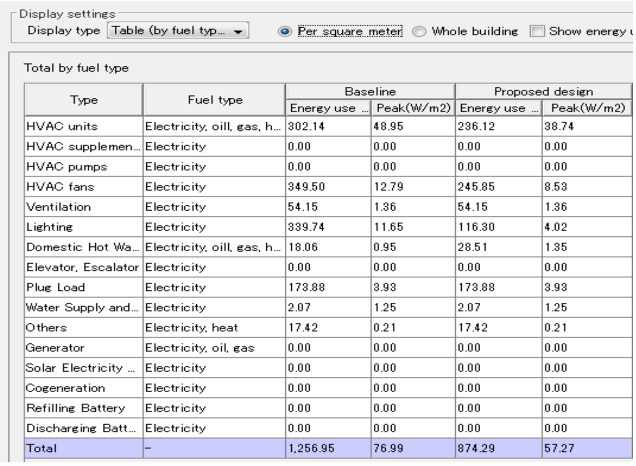

Display settings
Display type: Pie graph
● Per square meter ○ Whole building ☐ Show energy use by fuel type

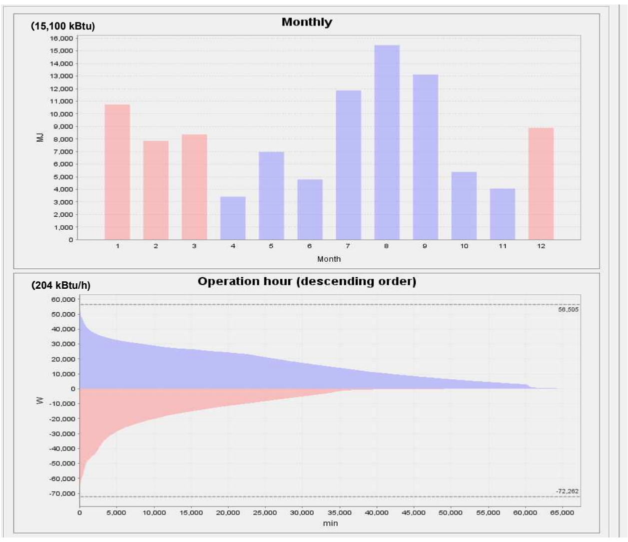
Figure 8 Energy consumption by end-use shown in pie graph

Table 2 Energy consumption and peak demand of baseline and proposed design building


Display settings
Display type: Table (by fuel typ...
● Per square meter ○ Whole building ☐ Show energy u

Total by fuel type

Type	Fuel type	Baseline		Proposed design	
		Energy use ...	Peak(W/m2)	Energy use ...	Peak(W/m2)
HVAC units	Electricity, oill, gas, h...	302.14	48.95	236.12	38.74
HVAC supplemen...	Electricity	0.00	0.00	0.00	0.00
HVAC pumps	Electricity	0.00	0.00	0.00	0.00
HVAC fans	Electricity	349.50	12.79	245.85	8.53
Ventilation	Electricity	54.15	1.36	54.15	1.36
Lighting	Electricity	339.74	11.65	116.30	4.02
Domestic Hot Wa...	Electricity, oill, gas, h...	18.06	0.95	28.51	1.35
Elevator, Escalator	Electricity	0.00	0.00	0.00	0.00
Plug Load	Electricity	173.88	3.93	173.88	3.93
Water Supply and...	Electricity	2.07	1.25	2.07	1.25
Others	Electricity, heat	17.42	0.21	17.42	0.21
Generator	Electricity, oil, gas	0.00	0.00	0.00	0.00
Solar Electricity ...	Electricity	0.00	0.00	0.00	0.00
Cogeneration	Electricity	0.00	0.00	0.00	0.00
Refilling Battery	Electricity	0.00	0.00	0.00	0.00
Discharging Batt...	Electricity	0.00	0.00	0.00	0.00
Total	–	1,256.95	76.99	874.29	57.27



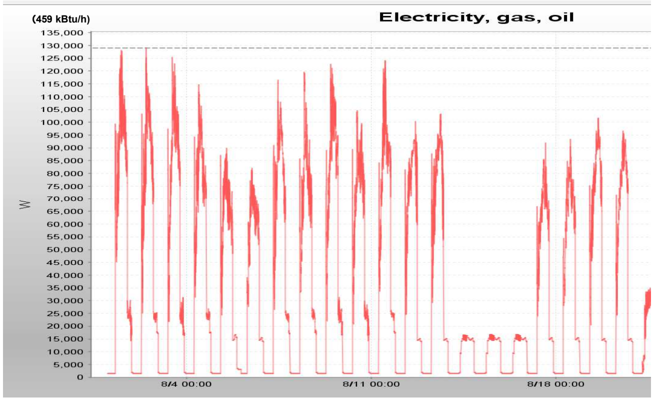


Figure 9 Monthly cooling and heating load, and hourly loads in descending order (left). Daily fluctuations of electricity demand on peak summer days (right)

CONCLUSION

In this paper, we described what the program 'BEST' is, how it can be utilized, and how easy-to-use its graphical interface can be easily used. This simulation program is the first software developed in Japan that not only can accommodate local design codes, but also incorporates energy-efficient design strategies or building systems that are widely adopted in Japan but uncommon in other countries. Although this program is already familiar to Japanese building professionals, we hope to introduce it to practitioners in the international building and construction community.

ACKNOWLEDGMENTS

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