Development of an Integrated Energy Simulation Tool for Buildings and MEP Systems, the BEST (Part 4)

Outline of Calculation Method for Plumbing Systems

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This study aims to develop a calculation tool, which is able to simulate overall energy consumption of air-conditioning systems, electric systems and plumbing systems for buildings. This paper outlines the framework and system that facilitate especially the development of a simulation tool, which enables the design of plumbing systems as well as calculating energy and water consumption spent on system operation while contributing to the conservation of energy and water sources.

Introduction

This study aims for the development and practical use of a simulation tool, "BEST," to calculate overall energy consumption in HVAC, electrical and plumbing systems in buildings to achieve the goal of preventing global warming. Previous reports [see References (1) and (2)] described the meanings and visions of the overall development of BEST, as well as the calculation framework regarding HVAC systems. In past studies, the most frequently reported simulation tools for estimating energy consumption in buildings were tools for HVAC systems. For plumbing systems, however, there are no applicable simulation tools to comprehensively calculate energy and water consumption in hot water supplies on a practical level.

More than one third of the primary energy consumption in hotels, offices and hospitals is due to hot water supply as shown in Figure 1. The energy-saving performance of central hot water supply systems has been evaluated using the CEC/HW index of the Energy Conservation Standards. In Japan, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) established a water conservation standard as an evaluation item for resources and materials. Europe and some countries in Asia (including China and Taiwan) have increasingly reported study results on the installation of water-saving equipment, rain water recycling systems and wastewater recycling systems for water resource conservation and water demand control in cities through CIB W062 (the International Council for Research and Innovation in Building and Constriction, Working Commission 062, Water Supply and Drainage for Buildings), which is an international research council. Considering the current situation, it is essential to develop simulation tools not only for HVAC systems, but also for plumbing systems, to calculate resources conserved, resource recyclability and energy consumption in water and hot water supply systems.

This report outlines this development project and the systematization of this calculation tool to design plumbing systems, to estimate prospective energy and water consumption if the created design is applied and to contribute to energy and resource conservation.

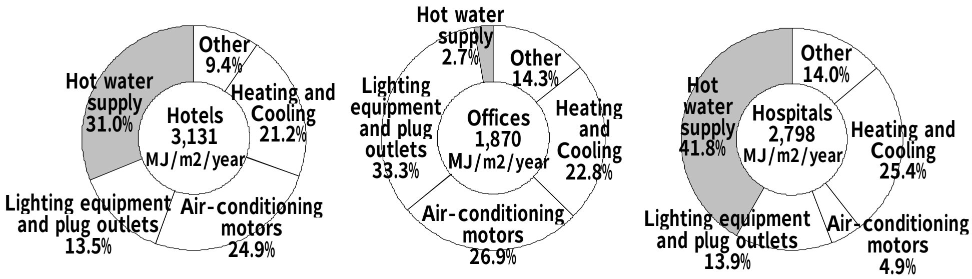


Figure 1 Percentage of primary energy consumption in each item for each specific building use [3)]

1. Outline and problems with existing calculation tools for plumbing systems

1.1 Outline of present load-calculation method for plumbing systems

-- Mainly for calculation of probable instantaneous water supply peak flow rate and for system calculation –

The Technical Outline of SHASE-S 206[4)] (SHASE: The Society of Heating, Air-Conditioning and Sanitary Engineering of Japan) and the Standards for Building Equipment are both systematized techniques for plumbing systems. In these guidelines, pipe diameter and equipment capacity are designed by calculating the load of each system (e.g., water supply, hot water supply, drainage and rain water recycling systems). Many existing studies focus on this point. As for water supply equipment, five load calculation methods based on the units of water supply fixtures are presented in the Outline. The main purpose of these methods is to calculate the probable instantaneous water supply peak flow rate as described above based on various basic data. As for hot water supply and drainage systems, the target fluids are different to that of water supply systems, but the purpose is nearly the same. For example, these methods have been used to calculate the hourly maximum hot water supply of hot water supply systems and to calculate the maximum drainage flow rate of drainage systems. One of the problems with these methods is that the calculated probable instantaneous water supply peak flow rates do not express dynamic load variation, which changes with time, but rather values at certain points in time. It is also a problem that these methods cannot estimate periodic load variation of systems in advance of practical operation of the designed system.

1.2 Problems with the equipment capacity calculation method for water supply and drainage systems

-- Acceptance of basic-unit variability and dynamic load --

The calculations described in Section 1.1 and equipment capacity design methods require various basic unit data. For example, the basic unit data such as "water consumption per person per day" contained in the SHASE Handbook of Air-Conditioning and Sanitary Engineering has been used in capacity design for pumps, receiving tanks and gravity tanks in water supply systems. The capacities of tanks in buildings are also defined in many standards by multiplying the daily water consumption in the building by a certain coefficient. However, there are many problems indicated. For example, the sources for the basic unit data, which are essential for the calculation, are uncertain and the basic unit data is unsuitable for multipurpose buildings and water-saving equipment. To solve these problems, new water load design methods and equipment design methods have been suggested [see References (5) and (6)]. The characteristic techniques of the new methods are segmentation of basic unit data and consideration for water for toilet flushing and the use times and frequency, etc., of plumbing fixtures. With these techniques, it is possible to accept changes in the purpose of a room and specific building uses and the renewal of plumbing fixtures. Moreover, these new methods indicate that start and stop patterns and operation patterns of equipment (e.g., pumps) can be estimated based on these techniques by using hourly use patterns in each day for each specific building use. In addition, these techniques are also applicable to the operation pattern selection to be applied to treatment equipment in digestion tanks of wastewater treatment facilities if there is little difference between the overall amount of water and hot water supply and that of wastewater. The concepts of dynamic load variation and of equipment capacity design using the dynamic load variation are very useful in the development of this program to simulate the equipment operation patterns suggested in this report.

1.3 Viewpoint regarding energy consumption and resource calculations

-- Development of calculation tool for CEC/HW and CASBEE --

According to the facts described in Sections 1.1 and 1.2, it is clear that a significant problem is the lack of simulation tools to calculate energy consumption in systems based on dynamic water-use patterns while integrating plumbing systems. Of course, there are useful indices to evaluate energy and resource-saving performance, such as the CEC/HW and CASBEE indices. However, these indices do not quantitatively express the energy or resources (e.g., water and hot water) that will be consumed or conserved if the equipment is operated.

1.4 Integration with HVAC system design methods and weather data

-- Simulation while integrating plumbing systems with other systems --

If water consumption in the entire building has to be simulated accurately, not only the consumption of water for daily necessities, but also that of makeup water in cooling towers for air-conditioning and water supply for humidification, etc., has to be taken into consideration. According to technical handbooks, makeup water systems in cooling towers have to be designed so that the amount of makeup water adequate for the chilling ability of the chiller or the amount of makeup water in proportion to a certain amount of circulating cooling water is included. However, there are no HVAC system design methods where water consumption estimated based on actual operation patterns is included. If solar thermal utilization is planned to be used for the hot water supply system, or if a rain water recycling system is planned, abundant data on weather variation patterns (solar radiation and rainfall) created with short observation intervals is required for the simulations. If waste heat from a cogeneration system has to be recycled effectively as heating energy for the hot water supply systems, integration of plumbing system design methods with HVAC system design methods is also essential.

2. Purpose of calculation program development for plumbing system

Figure 2 is a flow diagram showing the overall program development steps for plumbing systems. Figure 3 is an example calculation flow diagram for water supply systems. The key points of this development project are described below.

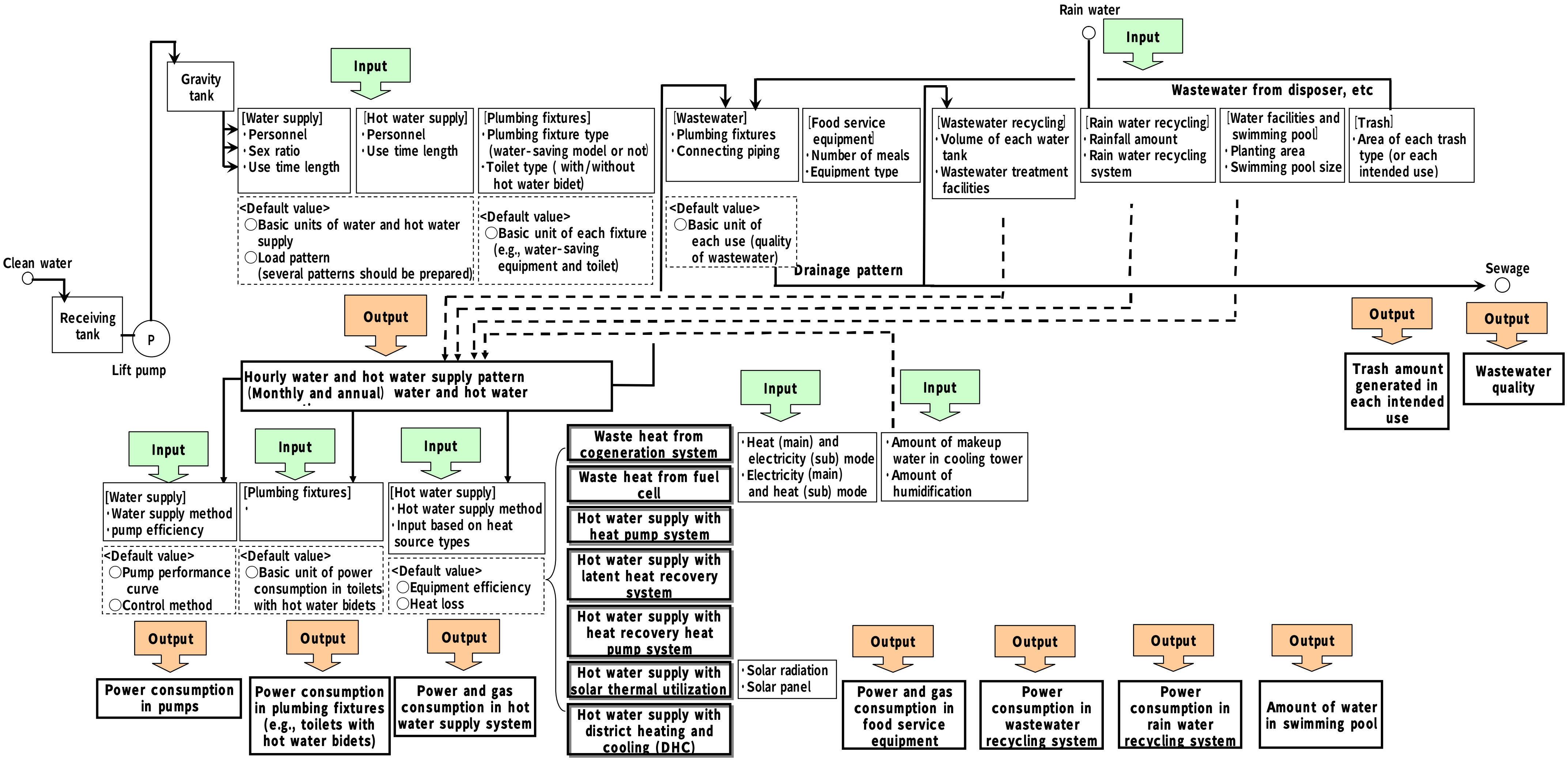
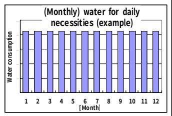


Figure 2 Flow diagram of overall program development for plumbing systems (focused on water supply systems)

<<Calculation of daily water supply load>>

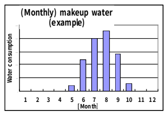
Basic unit of daily water consumption (liters/person/day)

<<Segmentation of basic unit>>



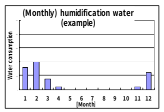
Calculation formula for makeup water consumption in cooling tower* (liters/day)

*: based on chilling capacity and operation time length



Calculation formula for humidification water consumption* (liters/day)

*: based on personnel and outdoor air temperature



×Multiplication by number of monthly operation days

Completion of annual water consumption calculation

(1) Segmentation of water consumption based on sex ratio and intended use (e.g., clean water and miscellaneous water)

		Designed water consumption for each intended use (liters/day)		
		Men	**Women**	composi-tion ratio Average
Perso-nnel	Composition ratio	0.62	0.38	
	Ratio of people in the roor	0.97	1.00	
Misc-ellan-eous water	Stall toilet (for men)	6.4		**24.1**
	Stall toilet (for women)		43.2	
	Urinal	6.3		(48%)
Clean water	Toilet with bidet	0.3	1.7	**26.4**
	Washbasin (for men)	5.5		
	Washbasin (for women)		17.7	
	Water heater	1.5	9.5	
	Cleanup	1.2	1.2	
	Other	10.0	10.0	(52%)
Total		**31.2**	**83.3**	**50.4**

Sex ratio can affect water consumption.

These values can be calculated if collected rain water and/or waste water is (planned to be) recycled into raw water for miscellaneous water uses.

⇒Basic unit of daily water consumption (liters/person/day)

(2) Segmentation of water consumption based on fixture

	Fixture or intended use	Water consumption in each intended use	Water consumption of each fixture: **Wastewater for one time (liter/time)**	Number of operation times (time/day)	Number of use times (time/day)	Added amount for cleanup, etc. (time/day)	**Number of fixtures**	Remarks
Men	Stall Toilet (for men)	6.4	8.0	1.0	0.6	0.2		
	Urinal	6.3	1.5	1.0	4.0	0.2		
	Toilet with hot water bidet	0.3	0.5	1.0	0.6			
	Washbasin (for men)	5.5	1.0	1.0	5.3	0.2		
	Water heater	1.5	2.5	1.0	0.4	0.2		
	Cleanup	1.2						
	Other	10.0						Water spray and cleanup
	Total	**31.2**						

	Fixture or intended use	Water consumption in each intended use	Water consumption of each fixture: **Wastewater for one time (liter/time)**	Number of operation times (time/day)	Number of use times (time/day)	Added amount for cleanup, etc. (time/day)	**Number of fixtures**	Remarks
Women	Stall Toilet (for women)	43.2	8.0	1.5	3.4	0.2		
	Toilet with hot water bidet	1.7	0.5	1.0	3.4			
	Washbasin (for women)	17.7	1.1	1.0	15.9	0.2		
	Water heater	9.5	2.5	1.0	3.6	0.2		
	Cleanup	1.2						
	Other	10.0						
	Total	**83.3**						

Amount of water saved by each fixture can be calculated based on the water consumption of each fixture.

Instantaneous water supply load can be calculated by using the water supply load units of each fixture used in conventional design methods.

<<Selection of water supply method>>

①Gravity tank method

②Pressure feed pump method

③Booster feed pump method

<<Calculation of equipment capacity>>

- Calculation of receiving tank capacity
- Calculation of gravity tank capacity
- Calculation of lift pump capacity

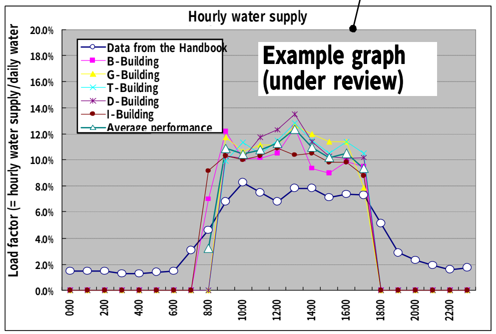
- Calculation of receiving tank capacity
- Calculation of pressure feed pump capacity

- Calculation of booster pump capacity

<<Calculation of hourly water supply load>>

Hourly water supply load pattern
Hourly load factor
(%)

* The hourly water supply load pattern is calculated by multiplying the hourly load factor by the daily water consumption.



<<Calculation of power consumption>>

Power consumption of feed pump (lift pump) (kWh/day)

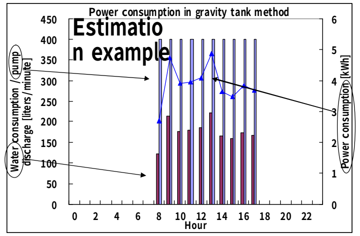
* Power consumption = daily operation time length × rated power consumption of pump

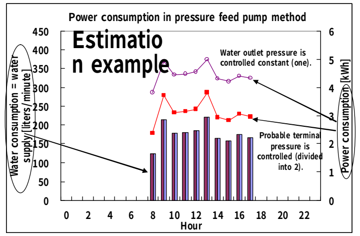
* Daily operation time length = daily water consumption × pump discharge

Power consumption of feed pump (pressure feed pump) (kWh/day)

* Power consumption = rated power consumption × (probable instantaneous pump head / designed pump head) $^{2/3}$

* Daily power consumption = Σ hourly power consumption





Toilet with hot water bidet
Basic unit: 0.343
(kWh/day/toilet)

* Value for family of four

→ **Power consumption of toilets with hot water bidets (kWh/day)**

Hand dryers
Basic unit: 0.0028
(kWh/time)

* Calculation formula: basic unit × number of washbasin use times

→ **Power consumption of hand dryers (kWh/day)**

Electric water heater
Basic unit: 0.0297
(kWh/m3)

* Calculation formula: basic unit × hot water used in washbasins × 1/3

\+

Standby power of electric water heater
Basic unit: 123.26
(kWh/year)

* Calculated by dividing by number of use days

→ **Power consumption of electric water heaters (kWh/day)**

×Multiplication by number of use days

Completion of annual power consumption calculation
<Compiled by the Working Group on Electrical Equipment>

Figure 3 Calculation flow diagram regarding water supply and drainage systems (Example focusing on water supply system)

2.1 Making it possible to consistently and consecutively calculate water supply load, drainage load and operation pattern of equipment systems

This program can calculate hourly water and hot water supply load patterns and calculate (monthly and annual) water and hot water consumption, if the types of plumbing fixtures, the water consumption per person per day, the hourly load patterns, the shape of the building, etc., are entered. By using both the calculated results and the equipment performance data (e.g., pumps and heat source equipment) of each water and hot water supply system, monthly and annual power consumption in pumps and plumbing fixtures, as well as power and gas consumption used in hot water supply, can be calculated consistently.

2.2 Making it possible to use data and study results available from study reports (e.g., basic unit data and load patterns) and to update the data in the future

This program can also simulate reduced consumption with water-saving equipment to be installed after the installation of conventional models. The simulated results can also be used as input for this program without using available pure basic unit data such as water and hot water consumption from the Handbook, etc. In other words, users can modify and update the entered data flexibly. Moreover, users can use not only the quantitative basic unit data that is being used now but also the load variation patterns of various equipment (if available) in each specific building use in the calculation.

2.3 Making it possible to calculate resource (water and resources) and energy consumption simultaneously

With considering Sections 2.1 and 2.2, this program can also simultaneously calculate resource amounts. For example, amounts of trash (general waste) and water consumption in a building as well as energy (power and gas) consumption in pumps, plumbing fixtures and hot water supply systems in the operation of the plumbing system can be also calculated.

2.4 Making it possible to make calculations while integrating components of plumbing systems, such as water supply, hot water supply, drainage and recycling systems

The calculation targets of this program are the various systems in a building, such as the water supply system, hot water supply system, plumbing fixtures, drainage system, food service equipment, wastewater recycling system, rain water recycling system, water facilities, the swimming pool and refuse disposal system. The input conditions for buildings are the data items described in Section 2.1 and those for weather include rainfall data, etc. The calculations are made by integrating the above systems. However, calculations regarding water supply and hot water supply systems, which are the most basic, will be made first.

2.5 Making it possible to perform calculations while integrating plumbing systems with the

building, HVAC systems and electrical equipment

The shape of a building affects the calculation results because this program designs piping routes during calculations of water and hot water supply systems. Moreover, there are many items to be noted regarding water and hot water supply systems. For example, the amount of makeup water in cooling towers for air-conditioning and the amount of water for humidification have to be considered in the calculations regarding plumbing systems. Similarly, whether or not waste heat from cogeneration systems will be effectively recycled as heating energy for the hot water supply system must be identified as described in Section 1.4. Therefore, calculations made while separating plumbing systems from other systems are inappropriate. This program is designed so that data can be exchanged among calculations regarding the building, HVAC and electrical systems and other related segments in order to make integrated simulations. Additionally, rainfall data is required for calculations regarding rain water recycling systems and solar radiation data is required for solar energy absorption systems. Accordingly, abundant weather data will be upgraded and used as part of this development project.

3. Concrete usage and future view of this program

3.1 Calculation of water consumption and of energy consumption in plumbing systems

If differences in energy consumption among various water supply systems can be identified through the simulations, designers can offer effective suggestions to clients. Figure 3 also shows a schematic view of a comparative study on power consumption using the gravity tank method and the booster pump water supply method. Figure 4 is a schematic view of the output of this program. With this program, values such as the amount of water supplied for each intended use and the energy consumption in each system can be displayed clearly.

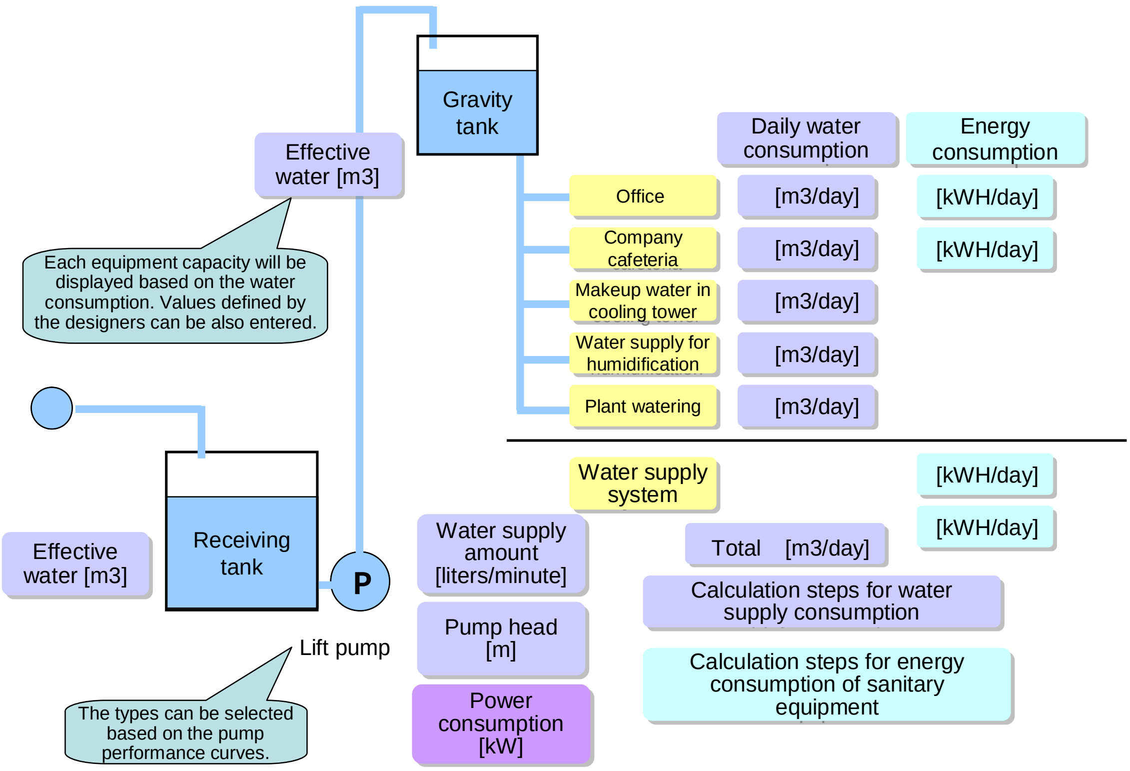


Figure 4 Calculation of water and energy consumption of each of water supply and drainage system

3.2 Calculation while considering load patterns and basic unit segmentation

An example of the water supply load variation patterns created from study reports is also shown in Figure 3. As is shown in Figure 3, users can easily calculate energy consumption load variation patterns by preparing hourly load factors (obtained by dividing the hourly water supply by the daily water supply) as default values. This program is designed so that users can also make calculations by segmenting the entire amount of water consumption into consumption for each plumbing fixture.

3.3 Calculation of the water-saving effect on the entire building while considering the characteristics of plumbing fixtures

If renewal of plumbing fixtures, such as changing conventional models to water-saving models, is required, users can calculate the prospective amount of water saved and the water-saving effect. As shown in Figure 5, the water-saving effect can be preliminarily estimated by comparing conventional models to the water-saving models to be installed during fixture repair work. This program is designed so that not only energy consumption in plumbing fixtures but also that of ancillary equipment (e.g., hand dryers, toilet hot water bidets and food service equipment) can be calculated while considering all of the water fixtures in the building.

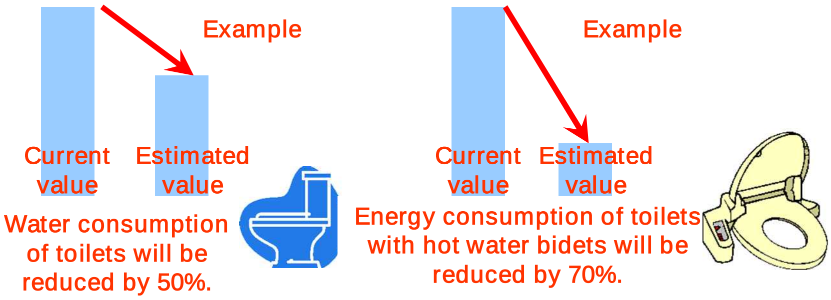


Figure 5 Water-saving and energy-saving effects estimated before equipment renewal

3.4. Integrated calculation method for resource and energy consumption

As shown in Figure 6, this program is designed so that users can calculate energy consumption in various hot water supply systems if hot water load patterns, areas of solar panels and weather data are entered. As shown in Figure 7, if a rain water recycling system is planned to be installed, users will also be able to estimate the prospective amount of clean water to be saved by the recycling system by using abundant rainfall data.

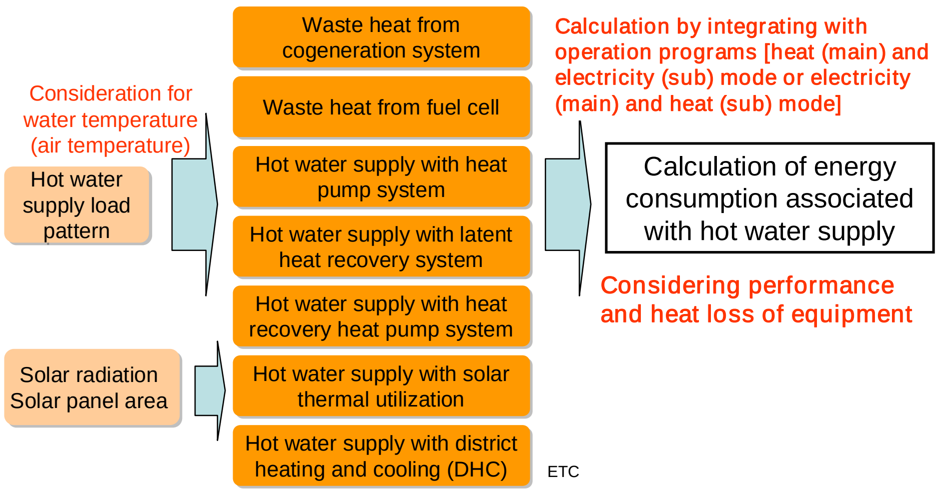


Figure 6 Response to calculations regarding hot water supply systems

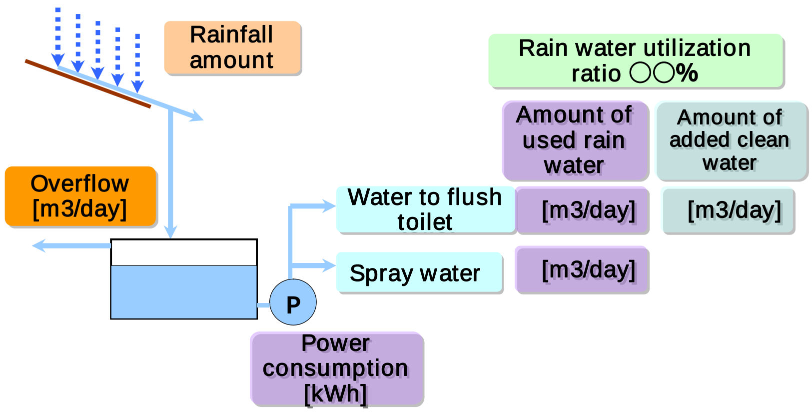


Figure 7 Calculation of rain water recycling system performance

4. Future tasks

There are future tasks regarding calculation methods for energy consumption in hot water supply systems where thermal loss from pipes and equipment are considered. For example, simple calculation methods to obtain CEC/HW while integrating the plumbing system with the building have to be examined. Also, calculation methods to obtain water outlet pressure while considering friction loss in pipes also have to be examined.

Acknowledgement

This report is describes some of the project achievements conducted by the "Study Group for the Development and Promotion of BEST (Chairperson: Shuzo Murakami)" and the Working Group on Health. The Study Group and the Working Group, which are part of the Institute for Building Environment and Energy Conservation (IBEC), 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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