CIB W062 Symposium 2017

Estimation of water supply loads for the company cafeteria, hot-water service rooms and restrooms in an office building

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1 Introduction

The authors have developed the dynamic calculation method for cold and hot water supply loads based on the data of water uses in the time series throughout the day by using a personal computer. The calculation method has been reported at the international symposium of CIB-W062 [1~7, 10. 11]. Now, the loads such as instantaneous flow rates, hourly and daily water supply consumption can be easily calculated by the developed simulation program that is called MSWC.

At the 42nd symposium of CIB-W062, the authors showed the water consumption that had been measured at each water usage by BEMS (Building Energy Measurement System) in an office building: T-building, and set up the models to estimate the water supply loads based on the analysis of hourly and daily data measured throughout the year. And, the calculated results using MSWC program were compared with the measured values in toilet flushing systems, and the accuracy was confirmed [12].

In this paper, for the same T-building, the authors show the calculation results of water supply loads for company cafeteria, hot water service rooms and restrooms where tap water is supplied in the office building. As for the calculation in the cafeteria, one unit model is set up as the whole based on the hourly measurement data by BEMS in T-building and the past research results. The models for other water supply systems are set up by the behavior of individual employee's water usage. Regarding the instantaneous flow rates in each use, the average values of 5, 10 and 60 seconds according to the statistics of each failure factor are discussed.

1 Introduction

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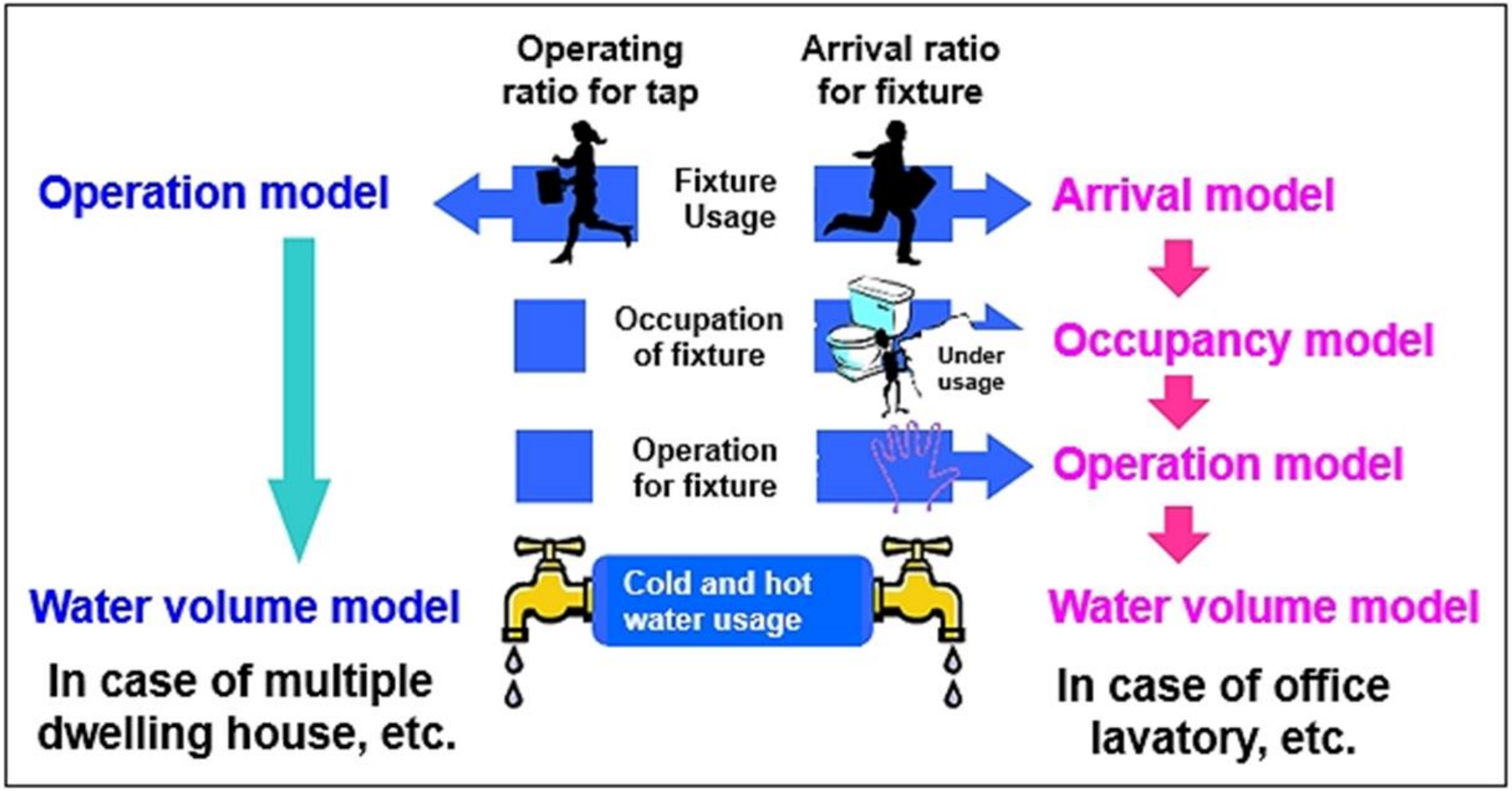

Outline of the dynamic calculation method for water supply demands

The water supply demands in buildings are caused by the people's behavior of water usage. The phenomena of fixture uses are occurred at random for setting time zone. The operating fixture for water discharge is controlled with occupancy or vacancy in the booth such as toilet. On the other hand, it is suitable to focus directly on the operating fixture in case of discharging water into the bathtub, laundry machine, etc.

2 Outline of the subject building

The outline of T-building is shown in Table 1. The T-building is an own office building located in Tokyo. The building is a relatively large. The total floor area is 29,747m^2 which have a convenience store, cafeteria and café for the employees. The employed enrollment is assumed about 1,900 people, and the ratio of the male and female is about 4:1.

Table 1- Overview of the subject building

Building name	T-building
Building application	Office
Ownership form	Own Building
Completion	October 2014
Total floor area	29,747 m^2
Office area	24,269 m^2
Ratio of effective office area	81.6 %
Number of seats	2,347 seats
Employed enrollment	1,900 people (assumed value)
Gender ratio	Male : Female = 4 : 1
Construction	S and CFT structure
Scale	The ground 7th Floor, penthouse second floor
Water supply system	Receiving tank and booster pomp system, Rainwater harvesting system
Number of plumbing fixtures	Male's water closet : 41
	Urinal : 47
	Female's water closet (with device of imitative sounds) : 39
	Washbasin : 56
	Small washbasin for brushing teeth : 21
	Sink for cleaning : 16

2 Outline of the subject building

Figure 1 shows the water supply systems and measurement points of water consumption. The water supply system is a receiving tank and booster pumps. As the source of water for the toilet flushing systems, tap water and rain water are used. The tap water is also sent to the other water supply systems by booster pumps. The water consumption in the employee's cafeteria was measured at the point of M9 and M10 is analyzed.

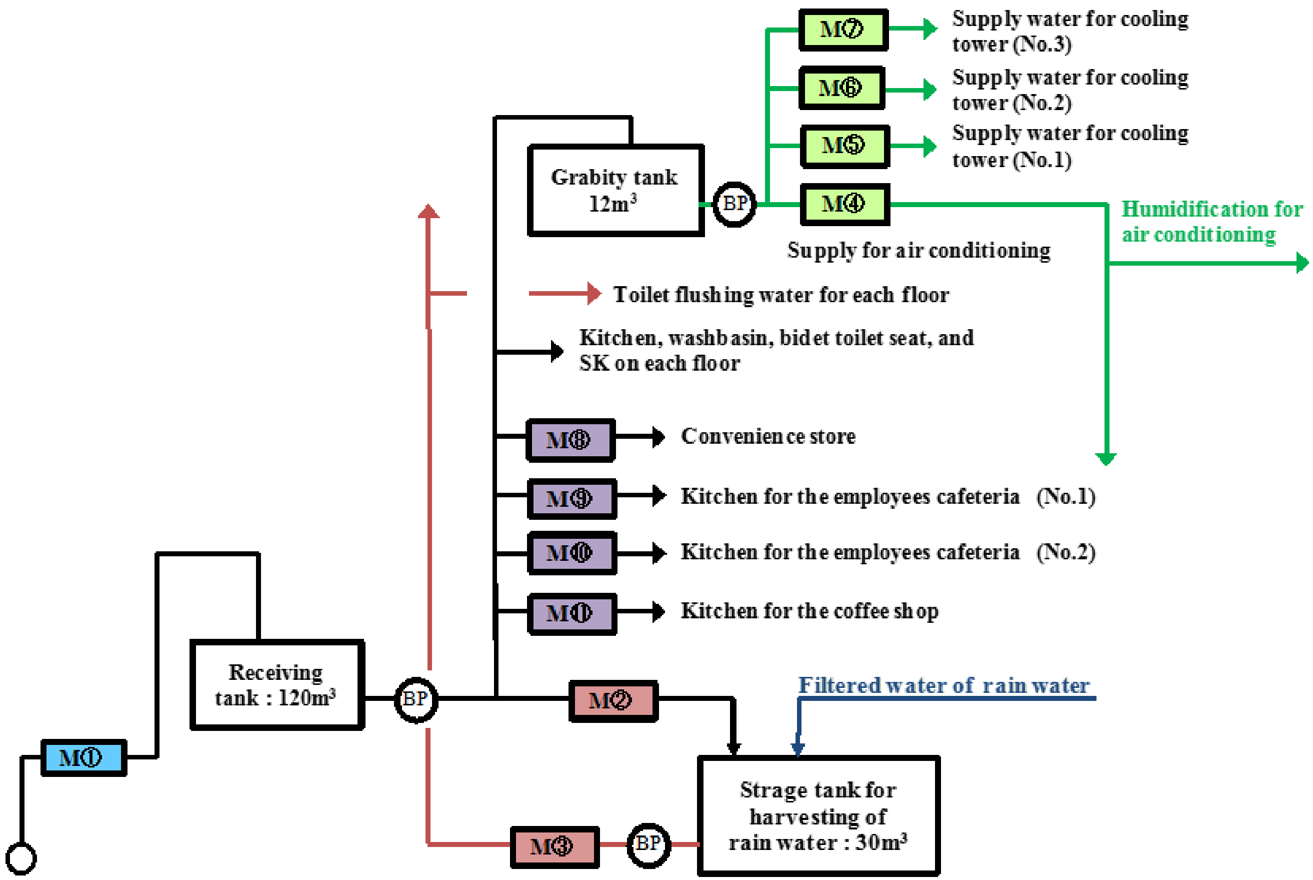

Figure 1 - Water supply systems and measurement points

3 Water consumption of tap water

Table 2 shows the statistical values of water consumption per day and per people in each water supply system. The values were analyzed with the cumulative value for 365 days per year, and 240 days on weekdays except Saturdays, Sundays and holidays which are working days of the building.

Table 2 – Statistics of water consumption per unit in each system

		Tap water systems in the office			Company cafeteria			Air conditioning systems			Toilet flushing systems						Total value		
											Tap water			Rain water					
		Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value
Daily water consumption (m^3/day)	Annual value (365 days)	85.99	40.79	13.79	34.01	27.00	15.20	58.01	36.80	10.87	63.99	59.00	34.24	47.99	20.01	5.05	169.99	154.00	79.15
	Value of working day (240 days)	69.01	43.00	19.80	34.01	28.01	22.61	58.01	40.05	12.90	63.99	60.06	50.69	47.99	25.99	6.69	169.99	157.00	112.69
Water consumption per people (L/people/day)	Annual value (365 days)	45.26	21.47	7.26	17.90	14.21	8.00	30.53	19.37	5.72	33.68	31.05	18.02	25.26	10.53	2.66	89.47	81.05	41.66
	Value of working day (240 days)	36.32	22.63	10.42	17.90	14.74	11.90	30.53	21.08	6.79	33.68	31.61	26.68	25.26	13.68	3.52	89.47	82.63	59.31

The average water consumption of the building as the whole is 112.69 [m^3/day] and 59.31 [L/people/day] for 240 days. The value for the latter 240 days corresponds the lowest value excluding the employee's cafeteria which is conventionally used in the practical design: 60~100 [L/people/day]. The average consumption of tap water is 19.80 [m^3/day] and 10.42 [L/people/day] for 240 days. The tap water include the consumption in the hot-water service rooms, washbasin and warm water washing toilet seat, cleaning water and sprinkling water.

4.1 Setting up the calculation models

Figure 2 shows the model of occupied ratio to the number of workers in T-building. The ratios in the time zone from 7 o'clock to 8 o'clock were adjusted based on the standard model that was shown in the previous studies [6, 10], because the start time of work in T-building is about 30 minutes earlier than the general offices.

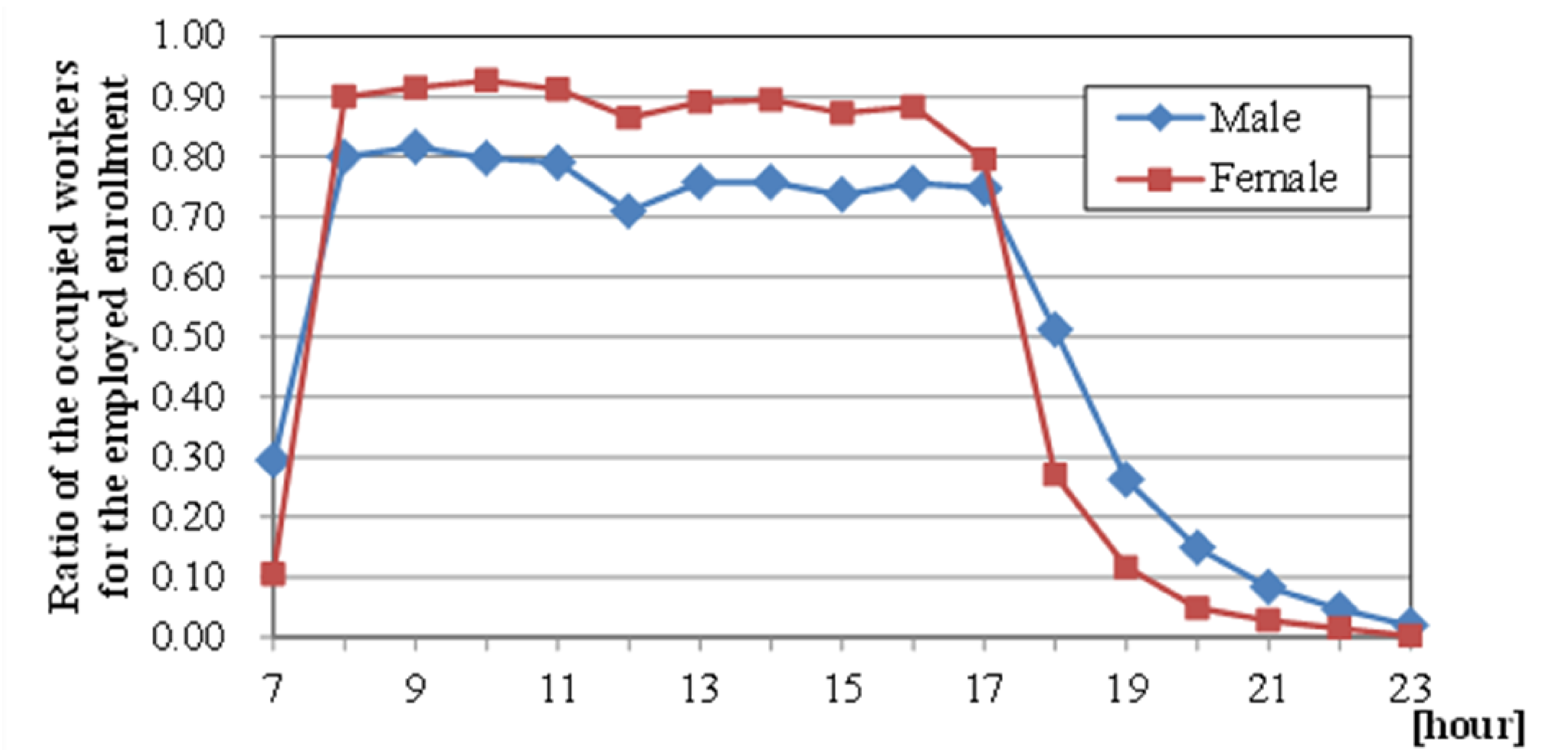

Figure 2 - Model of the occupied ratio of workers for the employed enrollment

4.1 Setting up the calculation models

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Figure 3 and Figure 4 show the frequencies of fixture usage per people and per hour for washbasin in the restrooms and hot-water service rooms, respectively. The frequencies of water usage of washbasin were adjusted by multiplying the values of the previous reports [6,10] by 0.9 to 1.25 times, which is the same way as treated in the toilet flushing system of T-building.

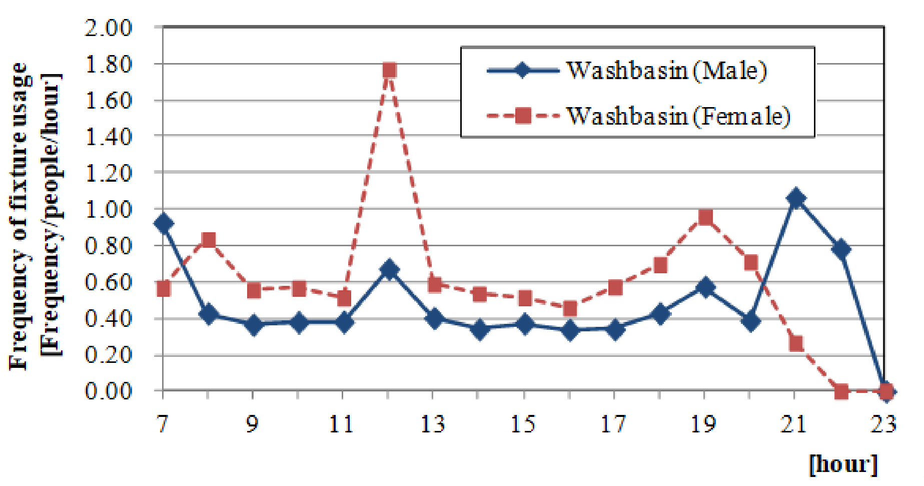

Figure 3 – Models of hourly frequencies of washbasin usage in the restrooms

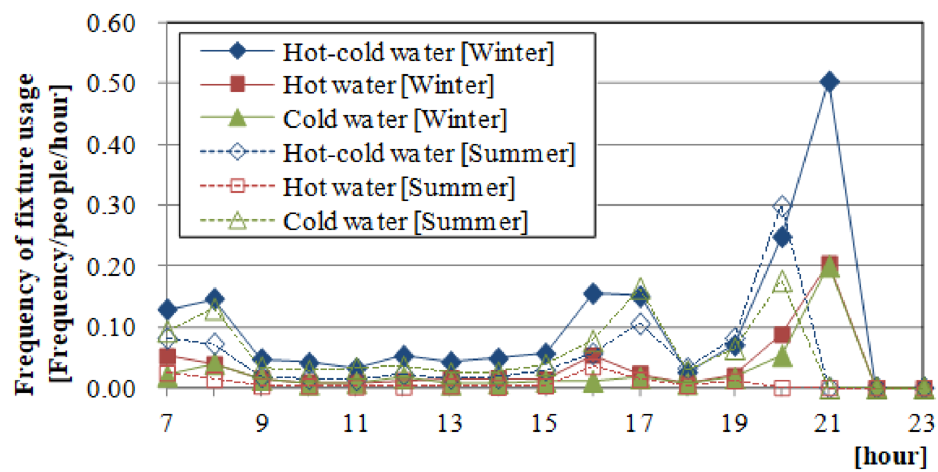

Figure 4 – Models of hourly frequencies of water usage in the hot-water service rooms

4.1 Setting up the calculation models

Table 3 shows the simulation models of each system installed in the hot-water service rooms and restrooms. In case of the hot-water service rooms, the models were set separately for summer and winter.

Table 3 – Simulation models to calculate the tap water supply loads

		Washbasin		Hot-water service room (summer)			Hot-water service room (winter)		
		Male	Female	Hot-cold water	Hot water	Cold water	Hot-cold water	Hot water	Cold water
Arrival model	Arrival interval distribution	Exponential distribution							
	Arrival ratio [people/min]	Setting in each time zone							
	Number of fixture	40	37	14	14	14	14	14	14
Occupancy model	Duration time of occupancy [sec]	12	17	45	16	14	35	10	5
	Distribution	Hyp.2	Hyp.2	Exp.	Exp.	Hyp.2	Hyp.2	Hyp.3	Hyp.2
Water volume model	Duration time of water discharge [sec]	6	11	45	16	14	35	10	5
	Distribution	Erl.3	Erl.3	Exp.	Exp.	Hyp.2	Hyp.2	Hyp.3	Hyp.2
	Flow rate [L/min]	5	5	10	8	10	10	8	10
	Distribution	Erl.10	Erl.10	Erl.3	Erl.4	Erl.3	Erl.3	Erl.4	Erl.3
Fixture operation model	Frequency of fixture operation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.2 Calculation results of the water supply loads by simulation technique

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4.2.1 Instantaneous water supply loads

In order to grasp the fluctuation of instantaneous flow rates, Figure 5 and Figure 6 show the examples of washbasin in the restrooms at the time zone of 12 o'clock and hot-water service rooms at the time zone of 8 o'clock, respectively as an example.

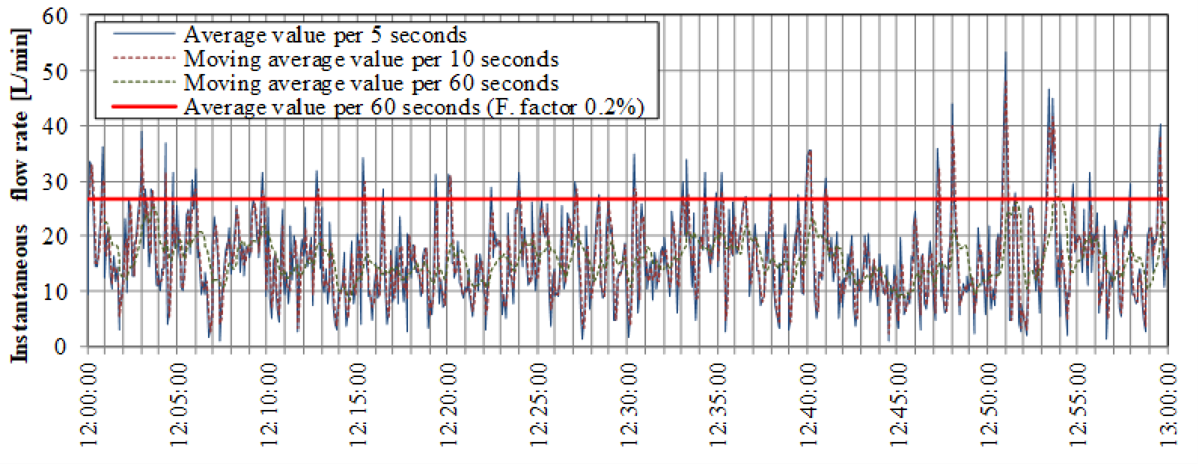

Figure 5 – Example of instantaneous flow rates for washbasin in the restrooms

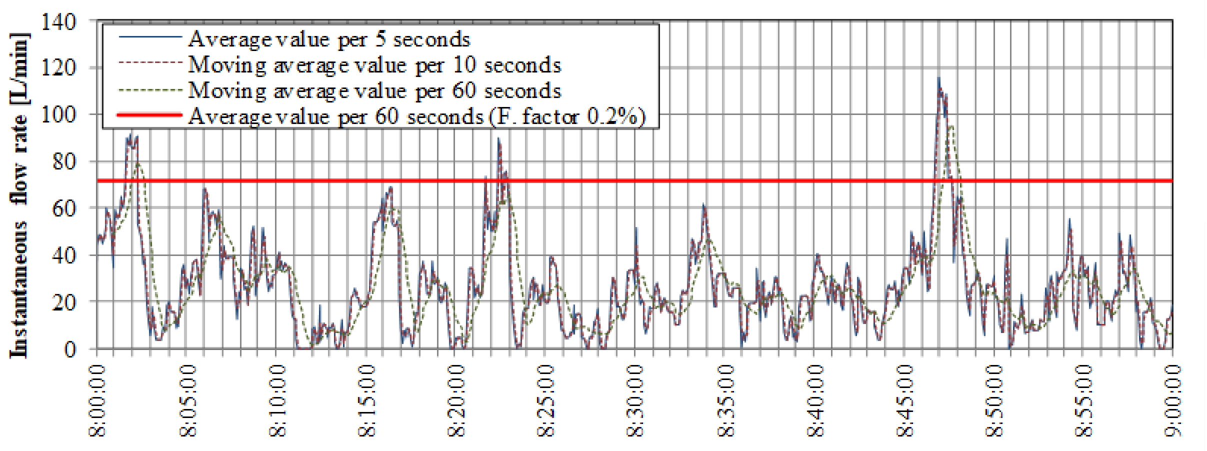

Figure 6 – Example of instantaneous flow rates for hot-water service rooms

4.2.1 Instantaneous water supply loads

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Table 4 shows the calculation results of the maximum and each failure factor for male, female and the whole washbasin in the restrooms. The analysis results are shown at the time zone of 12 o'clock when the peak value appears in the day.

For the instantaneous loads of washbasin system, there is no big difference between the 5 seconds value and the 10 seconds value. However, the 60 seconds value is averaged, and the maximum value is almost same as the failure factor 5% value of 5 seconds value. The calculation values of female washbasin show larger than the values of male washbasin, even though the number of fixtures is small, because the duration time of occupancy and water discharge is slightly longer than those of male.

Table 4 – Instantaneous water supply loads for washbasin in the restrooms

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
Washbasin (for male) [L/min]	Average value per 5 seconds	37.1	22.1	21.6	19.1	14.8	12.5	5.3
	Average value per 10 seconds	33.5	22.9	21.6	17.9	13.6	11.5	5.5
	Average value per 60 seconds	15.0	12.6	11.9	11.0	9.4	8.6	6.0
Washbasin (for female) [L/min]	Average value per 5 seconds	43.8	34.2	32.1	26.6	20.4	17.2	8.2
	Average value per 10 seconds	43.7	32.1	29.8	25.2	19.3	16.5	8.3
	Average value per 60 seconds	21.0	19.3	18.7	16.7	14.2	12.9	8.7
Washbasin (whole) [L/min]	Average value per 5 seconds	60.5	45.5	42.7	36.3	29.1	25.4	14.3
	Average value per 10 seconds	54.6	42.3	39.5	33.9	27.4	24.2	14.4
	Average value per 60 seconds	29.8	27.3	26.8	24.3	21.2	19.8	14.8

4.2.1 Instantaneous water supply loads

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Table 5 shows the calculation results of the hot-water service rooms in summer and winter, which are shown at the time zone of 17 o'clock and 8 o'clock.

Even in the hot-water service rooms, like washbasin in the restrooms, there is no big difference between the 5 seconds value and 10 seconds value. The maximum value of 60 seconds approximates to the failure factor 0.1% value of the 5 seconds value. The difference is small compared to the washbasin system.

Table 5 – Instantaneous water supply loads for hot-water service rooms

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
Hot-water service room (in summer) [L/min]	Average value per 5 seconds	135.4	103.0	96.1	78.6	61.4	52.9	26.4
	Average value per 10 seconds	128.5	100.2	93.4	77.2	60.4	52.1	26.3
	Average value per 60 seconds	102.0	84.8	81.0	66.6	53.5	47.3	26.8
Hot-water service room (in winter) [L/min]	Average value per 5 seconds	129.9	94.3	88.1	72.8	55.3	47.0	22.3
	Average value per 10 seconds	128.0	91.8	85.8	71.7	54.4	46.2	22.4
	Average value per 60 seconds	96.1	75.5	71.7	63.3	48.8	42.0	22.8

4.2.2 Hourly water supply loads

Figure 7 and Figure 8 show the hourly water supply loads for washbasin in the restrooms and hot-water service rooms, respectively. In case of the washbasin system, the failure factor 50% value at the time zone of 8 o'clock and the peak value at the time zone of 12 o'clock show about 530 [L/hour] and 900 [L/hour], respectively. At other working hours, the hourly values show about 400 [L/hour].

In case of the hot-water service rooms in winter, the failure factor 50% values at the peak time zones of 8 o'clock and 16 o'clock show about 1,500 [L/hour], and the average values for other working hours show about values of 400 [L/hour] to 500 [L/hour]. On summer season, the failure factor 50% value at peak time zone of 17 o'clock shows about 1,700 [L/hour].

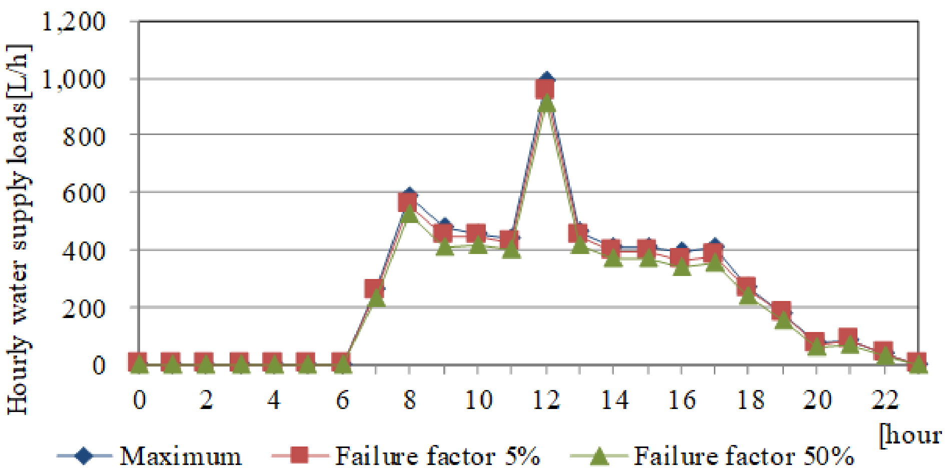

Figure 7 - Hourly water supply loads for washbasin system

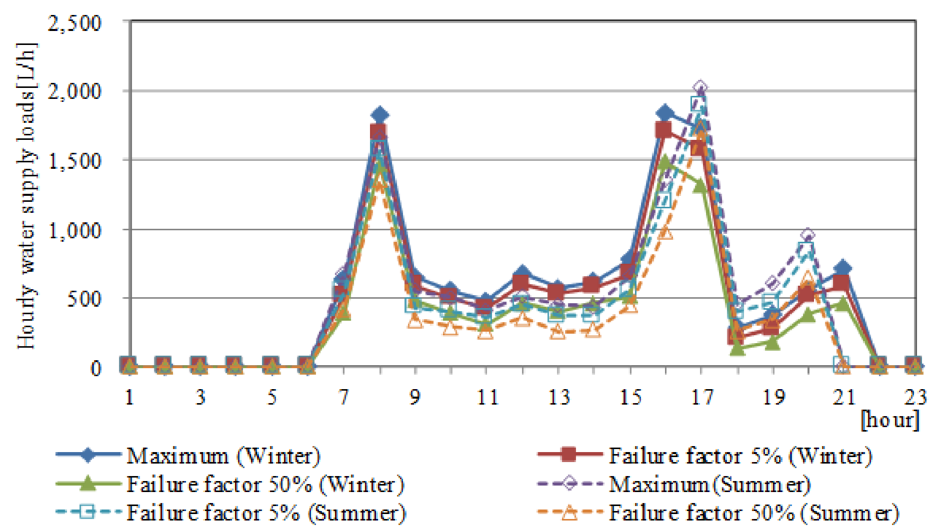

Figure 8 - Hourly water supply loads for hot-water service rooms

4.2.3 Discussion for the calculation results of water supply loads

Table 6 shows the water supply loads in each system, including daily loads. As for the instantaneous water supply loads, the whole value of washbasin system shows 39.5 [L/min], and the values for hot-water service rooms in summer and winter show 93.4 [L/min] and 86.0 [L/min], respectively. The values are slightly larger in summer.

When comparing these calculated values with the values according to the following formula used as a conventional calculation method.

Instantaneous load [L/min] = Average expected volume [L/hour] / 60 x (3~4)

The estimated load for the whole washbasin system is slightly smaller than the calculated value by the formula mentioned above. However, the estimated load for the hot-water service rooms is roughly equivalent to the calculated value.

Table 6 Calculation results of water supply loads in each system

		Washbasin			Hot-water service room	
		Male	Female	Whole	Summer	Winter
Instantaeous water supply loads [L/min] Average value of 10 seconds	F. factor 0.2%	21.6	29.8	39.5	93.4	86.0
Hourly water supply loads [L/hour]	Maximum	406	583	989	2,029	1,841
	F. factor 5%	391	575	951	1,887	1,708
	F. factor 50%	366	536	908	1,726	1,486
Daily water supply loads [m^3/day]	Maximum	3.1	2.4	5.4	8.6	9.6
	F. factor 5%	3.1	2.3	5.4	8.5	9.5
	F. factor 50%	3.0	2.3	5.3	8.0	8.9

4.2.3 Discussion for the calculation results of water supply loads

As for the estimated daily loads, the total load of washbasin system and hot-water service rooms is 13.3 ~ 14.2 [m^3/day]. The measurement data by BEMS show about 13.8 ~ 19.8 [m^3/day]. Since the measurement values include the consumption for cleaning system for office and water spraying system for planting, it seems that the results of simulation are showing reasonable values to represent the actual situation.

Table 6 Calculation results of water supply loads in each system

		Washbasin			Hot-water service room	
		Male	Female	Whole	Summer	Winter
Instantaeous water supply loads [L/min] Average value of 10 seconds	F. factor 0.2%	21.6	29.8	39.5	93.4	86.0
Hourly water supply loads [L/hour]	Maximum	406	583	989	2,029	1,841
	F. factor 5%	391	575	951	1,887	1,708
	F. factor 50%	366	536	908	1,726	1,486
Daily water supply loads [m^3/day]	Maximum	3.1	2.4	5.4	8.6	9.6
	F. factor 5%	3.1	2.3	5.4	8.5	9.5
	F. factor 50%	3.0	2.3	5.3	8.0	8.9

5 Estimation of tap water consumption for the company cafeteria

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5.1 Setting up simulation models for the company cafeteria

Table 7 shows the simulation models. In this paper, the average discharge flow rates and duration time for the whole kitchen as one unit were set up in three kinds of combination, which consist of 30 [L/min] and 60 seconds: A30, 25 [L/min] and 72 seconds: B25, 20 [L/min] and 90 seconds: C20, as the same amount of water consumption per one frequency.

Table 7 – Simulation models to calculate water supply loads for the cafeteria

		Company cafeteria (T-building)		
		A30	B25	C20
Water volume model	Duration time of water discharge [sec]	60	72	90
	Distribution	Hyp.20	Hyp.20	Hyp.20
	Flow rate [L/min]	30	25	20
	Distribution	Exp.	Exp.	Exp.
Frequency of fixture operation	Frequency per hour	Figure 11		
	Frequency per day (July)	780	780	780
	Frequency per day (Annual)	729.3	729.3	729.3

5.1 Setting up simulation models for the company cafeteria

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The hourly frequencies of water usage as one unit were calculated by dividing the water consumption per hour obtained from BEMS data by the water consumption amount per one time of fixture operation. As the two patterns of hourly frequency for simulation, the frequencies were calculated by the average values of weekdays on July and average annual values. Figure 11 shows the model of hourly frequency of water usage as the percentage of total frequency per day.

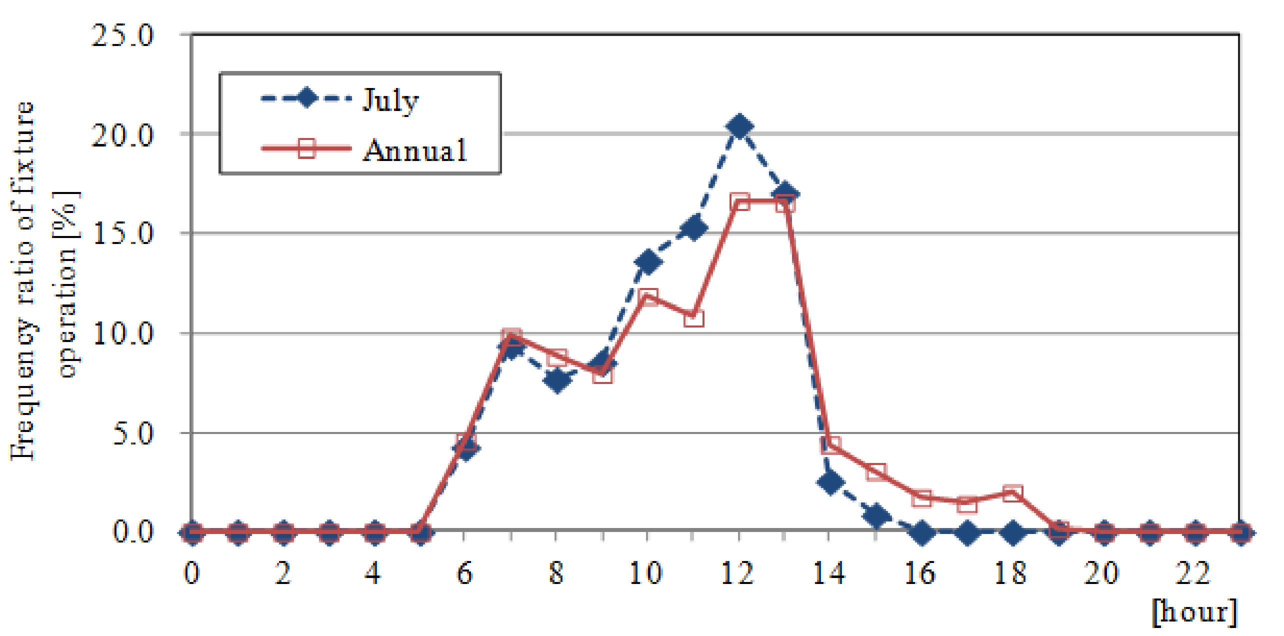


Figure 11 – Simulation models of hourly frequencies of water usage

5.2 Calculation results

5.2.1 Instantaneous water supply loads

Table 8 shows the calculated instantaneous water supply loads at the time zone of 12 o'clock showing the peak. As for the 5 seconds average value, there is no big difference from the 10 seconds average value. However, as the 60 seconds value is averaged, it becomes smaller than the other values of the 5 seconds and 10 seconds. Among the three kinds of calculation models, the values from maximum to failure factor 10 % for the case of A30 are larger than those of the case of A25 and A20, because the flow rate per time for the case of A30 is larger than those of the other cases. However, these differences become smaller as the value of the failure factor increases.

Table 8 – Statistics of instantaneous water supply loads for the three cases

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
A30	Average value per 5 seconds	486.9	361.3	329.5	269.6	197.8	164.4	68.0
	Average value per 10 seconds	473.6	352.8	326.4	267.3	196.3	162.9	68.1
	Average value per 60 seconds	370.0	314.8	289.5	241.2	181.6	151.8	69.2
B25	Average value per 5 seconds	402.3	334.8	310.3	257.3	187.3	157.1	70.0
	Average value per 10 seconds	394.0	336.8	305.9	254.5	185.9	156.4	70.2
	Average value per 60 seconds	343.8	315.0	293.2	237.8	173.9	149.4	70.7
C20	Average value per 5 seconds	390.8	315.2	292.2	231.9	174.3	148.3	74.7
	Average value per 10 seconds	377.1	313.9	291.3	230.7	173.7	147.7	74.7
	Average value per 60 seconds	332.8	294.1	277.6	215.9	165.8	142.2	75.0

5.2.2 Discussion for the calculation results in comparison with the measurement results

As the hourly and daily water consumption for the company cafeteria have been recorded throughout the year, the estimated water supply loads will be compared with those values and discussed for accuracy.

Figure 12 shows the hourly water supply loads by comparing the simulation results and measurement results. The simulation results show the values of the case A30. The failure factor 50% values on July and annual are almost same with the average values of measurement.

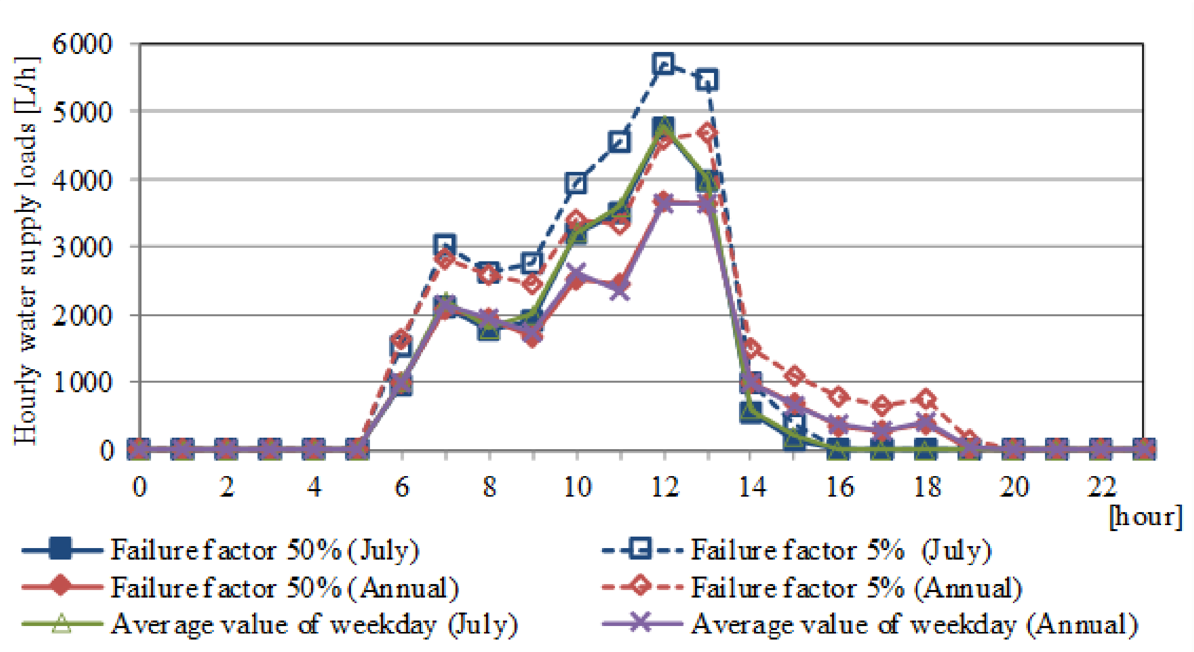
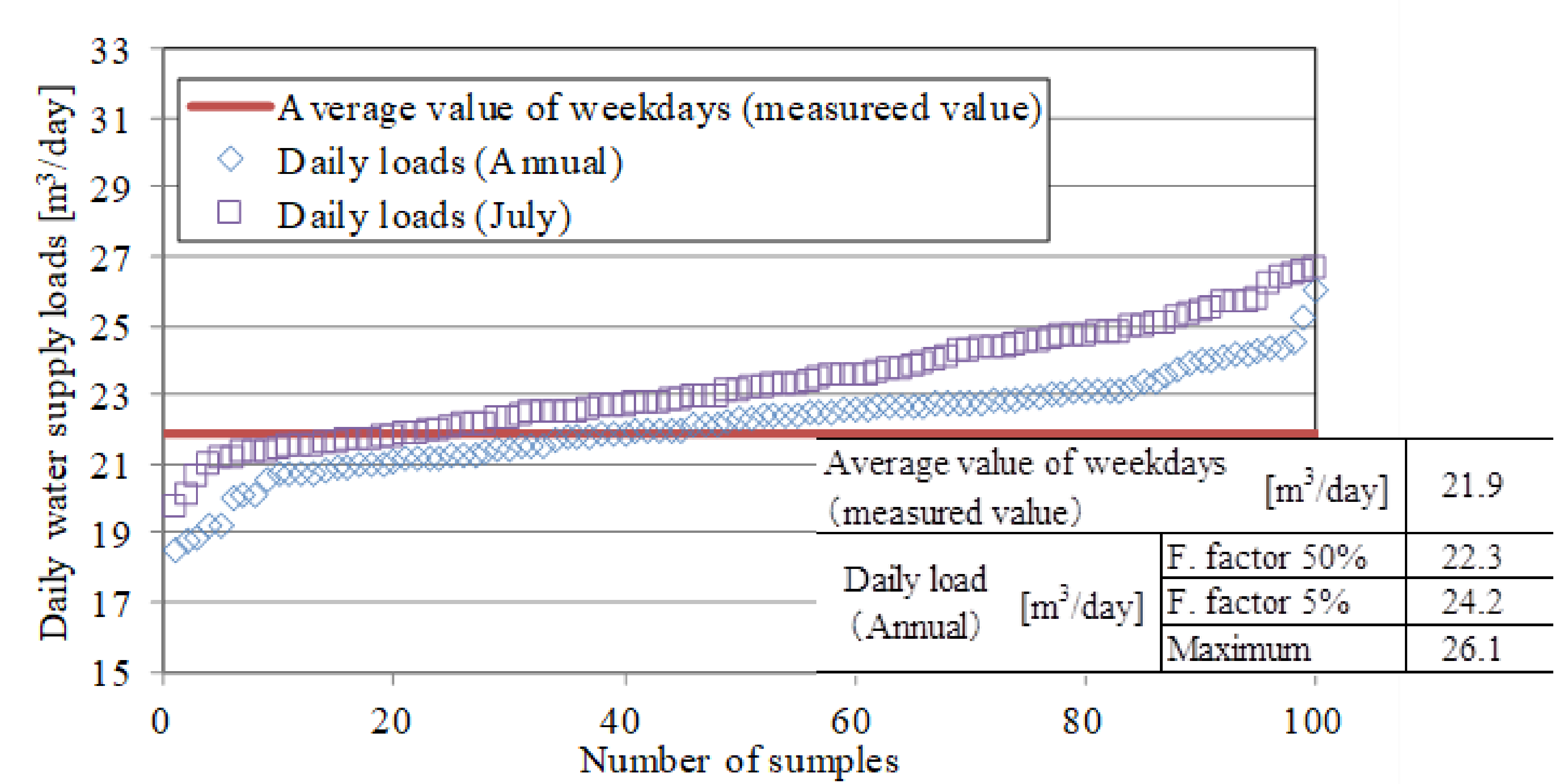


Figure 12 – Comparison of measured values and calculated values for water supply loads per hour

5.2.2 Discussion for the calculation results in comparison with the measurement results

Figure 13 shows the cumulative distributions of water supply loads per day for 100 trials by simulation. The failure factor 50% value by the annual simulation model is 22.3 [m^3/day], which approximates to the measured value of 21.9 [m^3/day].



Average value of weekdays (measured value)	[m^3/day]		21.9
Daily load (Annual)	[m^3/day]	F. factor 50%	22.3
		F. factor 5%	24.2
		Maximum	26.1

Figure 13 – Cumulative distribution of water supply loads per day by simulation and the average weekday measurement value per day

6 Conclusions

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It has been required to estimate the accurate water supply loads for water supply system with high energy saving. The authors have proposed the dynamic calculation method for the hot and cold water supply loads that can estimate from instantaneous flow rates to hourly and daily water consumption by using MSWC program.

In this paper, the tap water supply loads of washbasin in the restrooms, hot-water service rooms and company cafeteria in T-building were clarified by simulation technique. From these results, the following contents will be said:

When we grasp the instantaneous flow rates for design of the diameter of water supply pipes, pumping capacity of water supply systems, etc., it is important to consider the time interval to average the values of instantaneous flow rates. In case of the flushing system in toilet, it would be better to analyze the calculated results with shorter average time rather than with the 60 seconds average values. The instantaneous water supply loads depend on the characteristics of fixture usage such as the duration time of water discharge and flow rate per one time.

For setting up simulation models, the authors tried to use BEMS data in T-building. From the analysis of simulation results, it would be suggested that using BEMS data is a useful method for preparing the calculation models for various buildings applications. The authors have been studying to set up simulation models from the hourly data.

Thank you for your kind attention !

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