

B1) Calculation for the Cold and Hot water Demands in the Guest rooms of City Hotel

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Abstract

The authors are developing a calculation method for cold and hot water demands in the different types of buildings by the Monte Carlo Simulation technique. In this method, we suppose to calculate the instantaneous flow rates, hourly and daily demands in time series through a day by using a personal computer easily. So far in the CIB-W62 symposium, we have shown the calculation method applied to apartment houses, office buildings, restaurants and so on. However, when we apply the simulation technique, it is very important to grasp the water usage in each fixture or in each room unit.

In this paper, as a series of the developing study, we suggest the calculation method for cold and hot water demands in the guest rooms of city hotel.

Firstly, we show the cold and hot water consumption in the three guest rooms of a city hotel measured by interval of one minute through one year. We analyze the volume of cold and hot water consumption classified by the characteristics of the guests such as the number of people and the difference of male and female in a room. Also, we show the detailed fixture usage of cold and hot water measured by interval of five seconds. We analyze the frequency of fixture usage, duration time of pouring water and flow rates in each fixture, and the temperature of water uses. Based on these analyzed results, we propose the simulation models for calculation of cold and hot water demands. Lastly, we show an example of the calculation results for hot water demands carried out by the simulation models. And also, we analyze the relationship between the capacity of storage tank and the heating power on the basis of the simulation results for hot water demands.

Keywords

Cold Water Consumption, Hot Water Consumption, Hotel, Guest Room, Simulation

1. Introduction

We are now developing the calculation method for cold and hot water demands in the various types of buildings on the basis of fixture usage in the time series through a day. The method applies the Monte Carlo Simulation technique to calculate the instantaneous flow rate, hourly and daily water demands by a personal computer.

We had proposed the calculation method for apartment houses [1,2], office buildings [3,5,7], restaurants [4], etc. in the CIB-W62 Symposium.

Also, we showed the loads of hot water consumption in winter that were measured in the guest rooms of a city hotel [6].

In this paper, we propose the calculation models for cold and hot water demands on the basis of the measurement results in the same hotel through one year. With using the models, we estimate the cold and hot water demands in each scale of the number of guest rooms by the Monte Carlo Simulation. Moreover, we analyze the relationship between the capacity of storage tank and the heating power according to the calculation results of hot water demands in one minute interval through a day.

2. Outline of the investigation

2.1 Outline of the hotel and guest room

A city hotel, located in downtown Kyoto city, was chosen as the building of the measurement. The outline of the hotel is shown in Table 1. The hotel has 225 guestrooms, 2 banquet rooms, 3 restaurants, etc. Check in time is 13:00[h] and check out time is 12:00[h]. Not only business people but also tourists including foreigners use the hotel. And, it is expected the volumes of hot water consumption are large in the kitchens as well as the guest rooms

As an example of the plane, a guest room is shown in Figure 1. The guest room has popular two beds. But, it is possible to have accommodation for three persons with an extra-bed. The room has a combined bathroom and lavatory. The bathroom has a bathtub with two handle mixed faucet, and thermostat mixed shower. The toilet has a low down flush tank

Table 1 - Outline of the hotel

Name	N Hotel	Lot area	2,791.27 [m ²]
Location	Kyoto city, Kyoto, Japan	Building area	1,716.49 [m ²]
Building use	Hotel	Total floor area	21,773.00 [m ²]
Scale	14 stories, 2 basement, 2 penthouse	Structure	Steel-framed Reinforced Concrete structure
Facilities	225 guests rooms, 2 banquet rooms, 3 restaurants (Japanese, French, Chinese), 1 bar, 1 café Shops (Jewelry, Kyoto Specialties), Conference rooms, Wedding Reception, Wedding Chapels, Photo studio, Hairdressing & Esthetic salon, etc.		

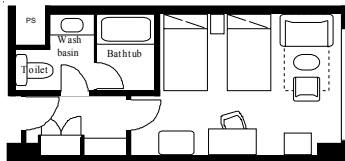


Figure 1 - Guest room plane

2.2 Outline of the measurements

Table 2 shows the outline of the measurement, and Figure 2 shows the schematic diagram of cold and hot water supply system in the guest room. Three guest rooms (A, B, C room) were chosen for the measurement of cold and hot water consumption.

The measurements on the volumes and temperatures of cold and hot water consumption in the guest rooms were carried out as follows. The volumes of cold and hot water consumption were measured by setting up the water meters to the cold and hot water supply pipelines respectively. As for the cold water consumption, the volumes of the pipeline of toilet were measured in distribution from the pipeline to the wash basin and bathtub. The temperatures of cold and hot water were measured by thermistor in each supply pipeline individually (Figure 2). In addition, the data for the number and gender of guests in each room were provided by the management company.

The measurements were carried out from February 1st, 2005 to April 1st, 2006. These data were classified into three groups, winter season from December to March, summer season from June to September and middle season April, May, October and November.

The volumes and temperatures of cold and hot water consumption were recorded by one minute or three minutes interval. Furthermore, in the guest rooms, the volumes and temperatures of cold and hot water consumption were recorded by five seconds interval to clarify the water usage in detail. The detail measurements were carried out six times through 24 hours in each guest room as shown in Table 3. The table shows the number and gender of guests as well.

Table 2 - Outline of the measurements

Room	Point of measurement	Measuring instrument	Measurement item	Interval
3 Guest rooms A room B room C room	Cold water branch pipe (Wash basin and Bathing)	Water meter	Flow rate [L/min]	1 minute
	Cold water branch pipe (Toilet)	Water meter	Flow rate [L/min]	1 minute
	Cold water branch pipe	Thermistor	Cold water supply temperature [°C]	1 minute
	Hot water branch pipe	Water meter	Flow rate [L/min]	1 minute
	Hot water branch pipe	Thermistor	Hot water supply temperature [°C]	1 minute
	Guests	writing in	Number of guests and their gender	per day

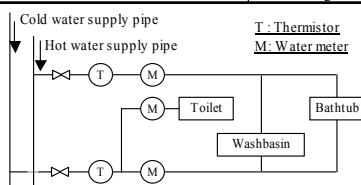


Figure 2 - Cold and hot water supply systems in the guest room

Table 3 - Detail measurement period by five seconds interval and the number of guests

Season	Measurement period	Number of guests [person]		
		A room	B room	C room
Winter	• 2005/03/05 14h • 03/06 10h	male 1 ♀female 1	male 1 ♀female 1	male 1 ♀female 1
Spring	• 2005/05/21 10h • 05/22 10h	male 1 ♀female 1	male 1 ♀female 0	male 1 ♀female 1
Summer	• 2005/08/06 10h • 08/07 10h	male 0 ♀female 3	male 1 ♀female 1	male 0 ♀female 1
Autumn	• 2005/11/26 10h • 11/27 10h	male 1 ♀female 1	male 1 ♀female 1	male 0 ♀female 2
Winter	• 2006/02/18 10h • 02/19 10h	male 2 ♀female 1	male 1 ♀female 1	male 0 ♀female 2*
Winter	• 2006/03/11 10h • 03/12 10h	male 1 ♀female 0	male 0 ♀female 1	male 0 ♀female 1

*Except the results with missing some of the temperature data

3. Number of guests

In case of this hotel, the number of guests was large in the Golden Week on the period between late April and early May, the time of the Bon Festival holidays, and the year-end and New Year holidays. The numbers of guests fluctuated periodically in one week.

Table 4 shows the statistics of the numbers of guests in each day of the week without consideration of special holidays. The numbers of guests were larger in Friday and Saturday than the other days of the week.

Figure 3 shows the number and gender of guests in the three rooms. The number of guests occupied by two persons of male and female showed the highest value in all season.

Table 4 - Number of guests depending on a day of the week

Day	Average value	Maximum value	Minimum value	Standard deviation	Number of days
Sun.	271	451	50	105.1	60
Mon.	227	440	52	107.1	60
Tue.	223	448	78	94.1	61
Wen.	219	435	61	94.7	61
Thu.	245	440	72	94.0	60
Fri.	322	470	172	80.3	60
Sat.	370	445	158	80.1	60

Unit: Number of guests [person/day] □ Number of days [days]

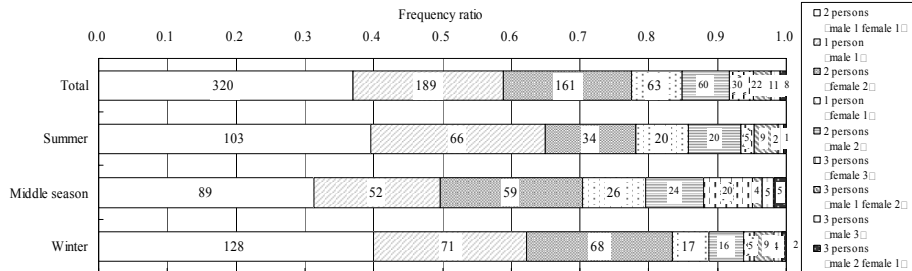


Figure 3 - Number and gender of guests in the three rooms

4. Cold and hot water consumption in the guest rooms

The average values of hot water supply temperature were 51.6 ~ 51.7[°C] in each season. It showed almost constant values through a year. However, the mean values of cold water temperature in winter, middle and summer season were 17.9[°C], 19.3[°C] and 21.4[°C] respectively. The difference of each season was small value because the city and well water were mixed. Therefore, we did not have the correction values for hot water supply temperature in this Chapter.

4.1 Daily consumption

As for the daily water consumption, the volumes of cold and hot water consumption per room are shown in Table 5, including the average number of guests per room. As the division of a day, it started at 13:00[h] that was the check-in time. The volume of hot

water consumption in winter was larger than that in summer. The volume of cold water consumption had the contrary tendency for the volume of hot water consumption in winter and summer.

Figure 4 shows the daily average volumes in each usage, which were grouped by season, a day of the week, and the number and gender of guests. There was little difference in each season and in a day of the week. The volumes of cold and hot water consumption per room were caused by the number of guests, the character of guests, the behavior of water usage, etc. When we compared with same number of guests, the volume of hot water consumption by female was larger than that by male.

Table 5 - Daily average volumes of cold and hot water consumption per room

Period	Statistics	Hot water	Cold water	Toilet	Total	Number of guests	
Total • 864•	Average	355.0	192.7	161.3	708.9	male	0.811
	S. D.	251.2	123.3	71.6	377.5	female	0.980
	Max.	3805.2	1338.0	565.5	4099.8	Total	1.792
Winter • 320•	Average	382.2	184.3	162.6	729.1	male	0.803
	S. D.	299.0	123.1	70.8	403.5	female	0.988
	Max.	3805.2	1338.0	420.6	4099.8	Total	1.791
Middle season (284)	Average	356.7	193.2	169.3	719.3	male	0.768
	S. D.	215.4	111.8	68.8	347.5	female	1.077
	Max.	1511.1	757.2	405.5	2482.1	Total	1.845
Summer • 260•	Average	319.4	202.4	150.9	672.6	male	0.870
	S. D.	217.2	134.8	74.4	374.6	female	0.862
	Max.	1426.9	902.6	565.5	2354.8	Total	1.732

Unit• Hot water • Total [L/room/day]• Number of Guests [person/room/day]• () is the number of samples in Period

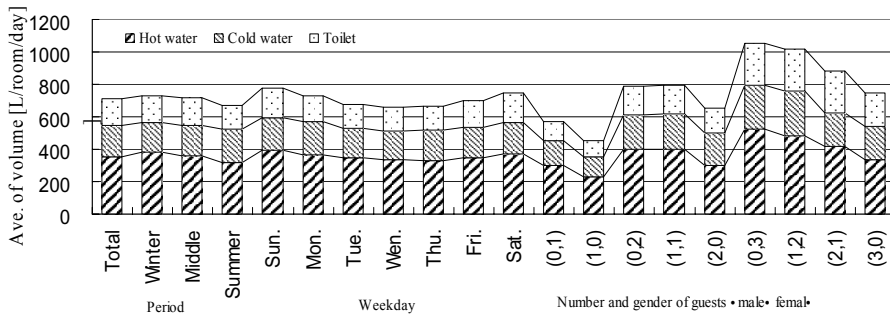


Figure 4 - Daily average volumes of cold and hot water consumption in period, weekday, number and gender of guests

4.2 Hourly consumption

Figure 5 shows the hourly average volumes of cold and hot water consumption that were grouped in a day of the week. The peak hours of cold, hot and total water consumption occurred at the time-zone of 21:00[h] and 22:00[h]. The peak hours of the consumption for toilet occurred at the time-zone of 7:00[h] and 8:00[h]. The night peaks on Friday and Saturday had tendency to get for late time-zone. The same observable fact occurred for male guests in comparison with female guests. The volumes of total water consumption were affected by the peak volumes of hot water consumption on taking a bath.

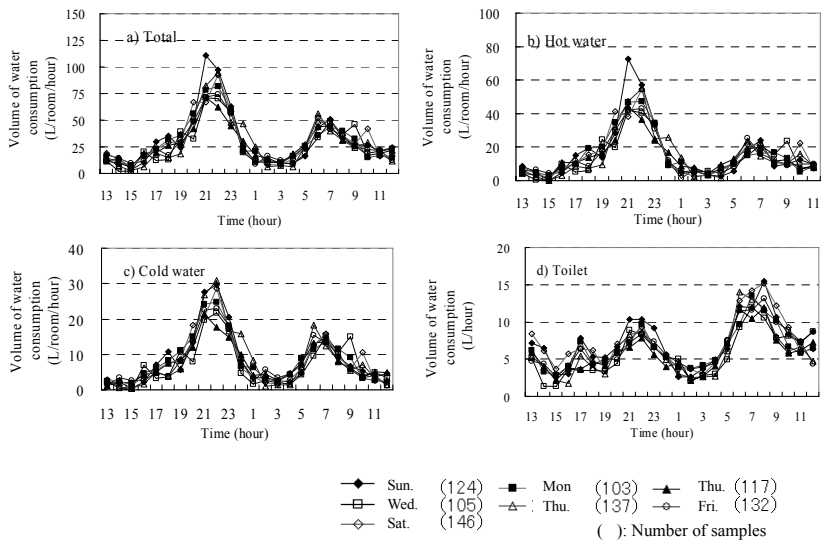


Figure 5 - Hourly average volumes of cold and hot water consumption in a day of the week

5. Fixture usage for cold and hot water demand

5.1 Applied data for analysis

The water usage in each fixture of the guest rooms was analyzed on the basis of the data measured by five seconds interval shown in Table 3.

As an example of the measurements, Figure 6 shows the water usage in each fixture that was grouped by the detection for values of flow rates, duration time of pouring water, volume of water consumption, and temperature of water usage.

The total 17 samples were analyzed as the three guest rooms put together. The average guest number per room was 1.824 [person/day]. The average volumes of cold, hot and total water consumption per room were 179.1, 278.7 and 160.2 [L/day] respectively.

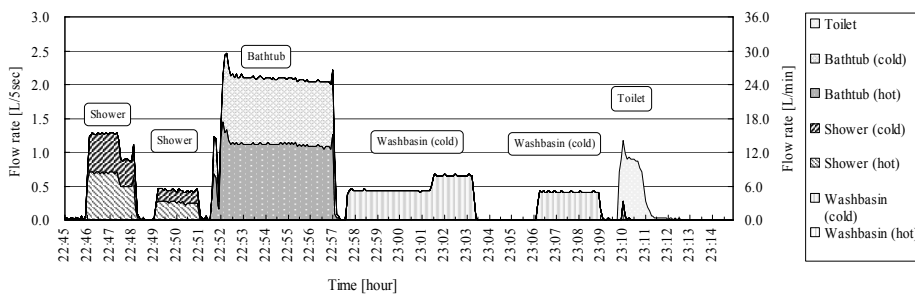


Figure 6 - Grouping for cold and hot water usage

5.2 Frequency of fixture usage

Table 6 shows the daily average frequencies and the hourly peak frequencies of fixture usage per room. The total frequencies of all fixtures usage per room were about 39 times. Figure 7 shows the ratios as the hourly average frequencies against the daily average frequencies for each fixture usage. The frequencies of hot water usage such as taking shower and bath were concentrated at the time-zone of 22:00[h] and 23:00[h]. On the other hand, the peak ratios for cold water usage were low, and occurred at the time-zone of 7:00[h]. However, the peak ratios showed a little high in comparison with the values which were analyzed by the measurement data for long term. Therefore, we had the leveling for hourly frequencies as the simulation models on the basis of the measurement results. The modeling will be shown at the next chapter.

Table - 6 Daily average frequency and hourly peak frequency

Item	Frequency [times/day]		Frequency in peak time-zone [times/hour]	Peak time-zone [hour]	Peak ratio
	Average	S. D.			
Shower (cold & hot)	4.47	2.72	1.29	22	6.95
hot	3.53	4.98	0.65	22	4.40
Washbasin cold	13.06	7.80	1.82	7	3.35
cold & hot	3.41	2.98	0.65	7	4.55
Bathtub (cold & hot)	2.29	1.57	0.47	23	4.92
Toilet (cold)	12.24	5.68	1.59	7	3.12

Note : Peak ratios were calculated by dividing the volume of water consumption in peak time-zone with the average volume of water consumption per hour

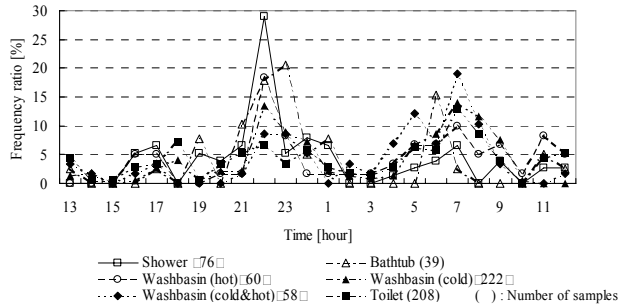


Figure 7 - Hourly frequency in each fixture usage

5.3 Duration time, flow rate and temperature in each fixture usage

Figure 8, Figure 9 and Figure 10 show the duration time of pouring water, flow rate and temperature in each fixture usage respectively as the cumulative frequency distributions, and show the approximate distributions by Erlang or Exponential distribution.

Average duration time and flow rate of pouring hot water into the bathtub; the capacity is about 200[L], were 315[sec] and 26[L/min] respectively. The guests sometimes operated the two handle mixed faucet with wide range; from 10[L/min] to 35[L/min].

Average duration time and flow rate for taking shower for one frequency were 154[sec] and 9.4[L/min] respectively. The duration times were some differences individually in comparison with the flow rates.

The temperature of water usage was calculated by the flow rates and temperatures of cold and hot water when the water demands were detected by the meters. The temperature distribution for water usage was approximated by the Erlang distribution with large phase.

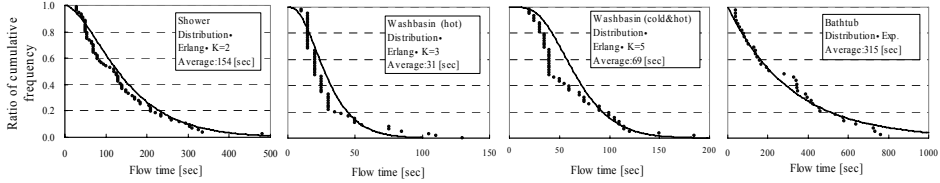


Figure 8 – Cumulative frequency distribution for duration time of pouring water

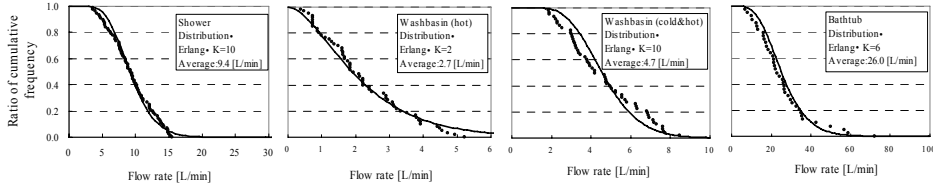


Figure 9 – Cumulative frequency distribution for flow rate

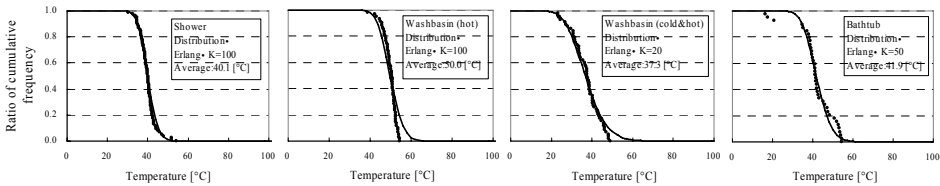


Figure 10 – Cumulative frequency distribution for temperature of water usage

6. Calculation of hot water demands and equipment capacity

6.1 Simulation model for calculation

Before the proposition of simulation model for calculation of cold and hot water demands in the guest rooms, we set up the three levels of unit value for cold and hot water consumption in the guest rooms occupied by two persons. By setting up the level, it is possible to choose the design values in accordance with the rank and scale of hotel.

Table 7 shows the three level values for cold and hot water consumption. As for the Level 1, we decided the values from the highest consumption used by two persons of male and female. The Level 3 showed the lowest consumption used by two persons of male. The Level 2 was set up by the mean values of Level 1 and Level 3. Also, this table shows two cases according to the difference of water supply temperature. The one case of 17[°C] was decided by measurement. The other case of 8[°C] was set up for the standard calculation model in winter. Besides, we set up 60[°C] for hot water supply temperature as the standard model.

As for the simulation model of hourly frequency in each fixture usage, we applied the statistical technique of moving average to make smooth values in the time series

fluctuations of Figure 7. On the weighting values, we applied the value 0.5 for the concerned time-zone, and also applied the value 0.25 for the front and the rear time-zone.

Figure 11 shows the hourly frequencies in each fixture usage calculated by two times of moving average operation. We proposed the hourly frequencies as the simulation models to apply for the twin beds room.

We verified the accuracy of the cold and hot water demands calculated by using hourly frequencies shown in Figure 11. And we were satisfied with the calculation results in comparison with the hourly measurement results.

Table 8 shows the simulation models for calculation of cold and hot water demands in each fixture usage. We proposed the three levels calculation models by setting up the different frequencies per day.

Table 7 - Daily average water consumption for the three levels

Model		Cold water	Hot water	Toilet	Total
Temperature of water 17 [°C] (actual value)	Level 1	432.7	207.1	178.6	818.1
	Level 2	378.7	198.4	167.9	746.3
	Level 3	324.7	189.6	157.3	674.4
Temperature of water 8 [°C] (given value)	Level 1	396.9	242.9	178.6	818.4
	Level 2	358.0	219.1	167.9	744.9
	Level 3	319.0	195.2	157.3	671.5

Note: unit[L/room/day]. Given temperature of hot water is 60[°C].

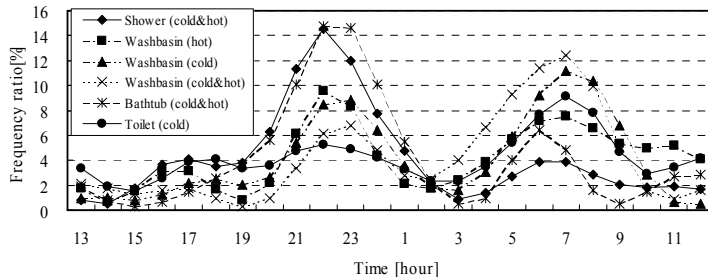


Figure 11 - Hourly frequency in each fixture usage as simulation model

Table 8 - Simulation model in each fixture usage

Fixture usage		Frequency of usage [times/day]			Duration time [sec]		Flow rate [L/min]		Temperature [°C]*	
		Level 1	Level 2	Level 3	Avg. value	Distribution	Avg. value	Distribution	Avg. value	Distribution
Shower	cold & hot	5.6	5.0	4.5	160	Erl. 2	10.0	Erl.10	41.5	Erl.100
	hot	3.9	3.5	3.1	35	Erl. 3	2.5	Erl. 2	60.0	Fixed value
Washbasin	cold	14.9	13.5	12.0	40	Erl. 2	3.0	Erl. 2	8.0	Fixed value
	cold & hot	4.3	3.9	3.5	70	Erl. 5	5.0	Erl.10	37.0	Erl. 20
Bath tub	cold & hot	3.2	2.8	2.5	315	Exp.	26.0	Erl. 6	42.0	Erl. 50
Toilet	cold	14.8	13.9	13.0	170	Erl.20	4.5	Erl.20	8.0	Fixed value

*Temperature is used for winter seasons.

6.2 Calculation of hot water demands

We carried out the calculation of hot water demands by using the Monte Carlo Simulation technique. On the basis of the fixture usage models as shown in Figure 11 and Table 8, the simulation was carried out 100 times with repetition to get the stability for the calculation. From these results, we grasped the fluctuation patterns of hot water demands in the time series through a day. And by using the statistical analysis, we

calculated the instantaneous maximum flow rates, hourly peak values and daily values of hot water demands.

In this study, we carried out the simulation by changing the scale of the number of guest rooms. We selected five kinds of scale that were 50, 100, 200, 300 and 500 guest rooms. These results for hot water demands are shown in Table 9.

The daily average hot water demands per room showed no difference in each scale of the number of guest rooms. These results showed nearly same values in Table 5. Therefore, we evaluated that the simulation was carried out suitably.

As for the hourly peak value of hot water demands, the ratios of peak values were changed within the values of 3.39 ~ 3.55. The ratios showed almost same values with the measurement results through a year.

For the instantaneous flow rates, we showed the values of maximum and failure factor 0.2, 1.0 and 5.0[%]. From the comparison with the measurement results, we suggest to choice the values of failure factor 0.2[%] as the maximum flow rates for practical design.

Figure 12 shows the instantaneous flow rates in each scale of the number of guest rooms. The figure shows the changes of flow rates affected by the number of guest rooms and the values of failure factor as the ratios against to the values of 50 guest rooms. Referring to the declining tendency of the ratios, the more the failure factor is small, the more the decline is large.

Table 9 - Calculation results for hot water demands

Number of rooms	Hot water [L/day]			Thermal value			Hot water [L/h]			Thermal value [MJ/h]		Instantaneous value [L/min]					
	Avg. per room	Max.	S.D.	Avg. [MJ/day]			Avg.	Peak time	Peak ratio	Avg.	Peak time	(at 22:00 - 23:00 hours)					
50	404.5	23880	1586	4403	843	2892	3.43	183.5	629.4	179.1	147.9	123.8	96.0	48.2			
100	406.5	47335	2056	8849	1694	5874	3.47	368.7	1278.6	267.5	218.1	189.5	158.8	97.9			
200	403.4	89118	3385	17560	3361	11528	3.43	731.7	2509.4	382.0	341.8	312.0	277.3	192.1			
300	402.5	130818	3787	26286	5032	17140	3.41	1095.3	3730.9	486.8	461.8	430.3	385.9	285.7			
500	404.7	214895	4522	44045	8431	28999	3.44	1835.2	6312.4	859.2	739.0	680.9	616.3	483.3			
50	355.5	21142	1448	3869	741	2527	3.41	161.2	550.1	139.1	124.2	110.6	88.2	42.1			
100	359.4	40647	1811	7824	1498	5206	3.48	326.0	1133.3	251.7	206.5	178.4	149.6	86.8			
200	359.3	78779	2720	15640	2994	10210	3.41	651.7	2222.5	446.2	347.6	303.0	257.6	170.2			
300	357.1	115461	3420	23322	4464	15135	3.39	971.8	3294.5	518.4	432.7	392.3	351.1	252.2			
500	356.9	192673	4478	38845	7436	25605	3.44	1618.5	5573.5	734.9	668.0	619.3	560.3	426.7			
50	316.8	19098	1512	3447	660	2342	3.55	143.6	509.8	155.3	129.0	105.0	81.8	39.0			
100	320.4	36661	1936	6974	1335	4592	3.44	290.6	999.5	216.6	192.0	162.3	133.2	76.5			
200	317.6	70129	2362	13825	2646	9047	3.42	576.0	1969.2	349.8	309.4	271.1	230.5	150.8			
300	320.2	104144	3200	20909	4002	13809	3.45	871.2	3006.0	470.3	416.3	377.0	327.1	230.2			
500	319.9	170464	3582	34819	6665	22953	3.44	1450.8	4996.3	656.2	607.7	565.2	506.1	382.6			

Note: Each value is 100 trials average value by the results of simulation

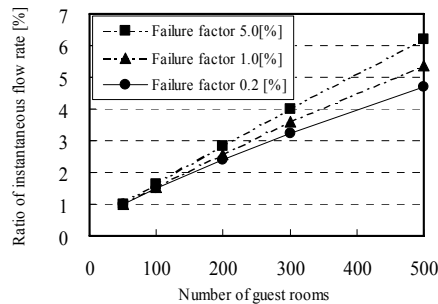


Figure 12 – Relationship between the number of guest rooms and instantaneous flow rates in each failure factor (In case of Level 3)

6.3 Calculation of equipment capacity

As for the analysis on the capacity of hot water storage tank, the basic approach way is as follows.

When the hot water demands exceed the heating power, the shortage volumes that are calculated from the difference values between the heating power and hot water demands are accumulated. Moreover, the maximum value of the cumulative shortage volumes that are calculated through a day is decided as the minimum capacity of storage tank.

Based on the consideration, we carried out the simulation according to the calculation results for hot water demands in each scale of the number of guest rooms. The simulation was tried for 100 times with using the hot water demands calculated by one minute interval. Among the results of 100 trials, we chose the maximum capacity of storage tank and heating power at that trial.

The calculation results are shown in Figure 13. Upper values of each curve satisfy the sufficient demands for the capacity of storage tank and heating power. The existing design value described in the handbook of SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) is excessive in comparison with the our results.

Figure 14 shows the relationship between the heating power and the minimum capacity of storage tank in each scale of the number of guest rooms. Now, the heating power [%] shows the hourly hot water supply volumes against to the daily values, and the minimum capacity of storage tank [%] shows the ratio for the daily hot water supply volumes. On this figure, if we set 20[%] value for the minimum capacity of storage tank against to the daily hot water supply volume, the minimum heating power is about 8~12[%] value in the range from 50 guest rooms to 500 guest rooms. The existing design value by the handbook of SHASE shows 14.3[%] value.

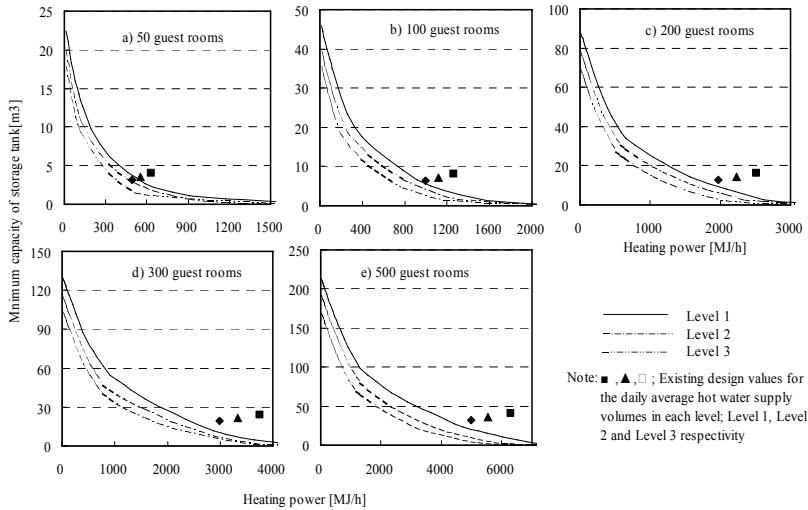


Figure 13 – Relationship between the heating power and the minimum capacity of storage tank

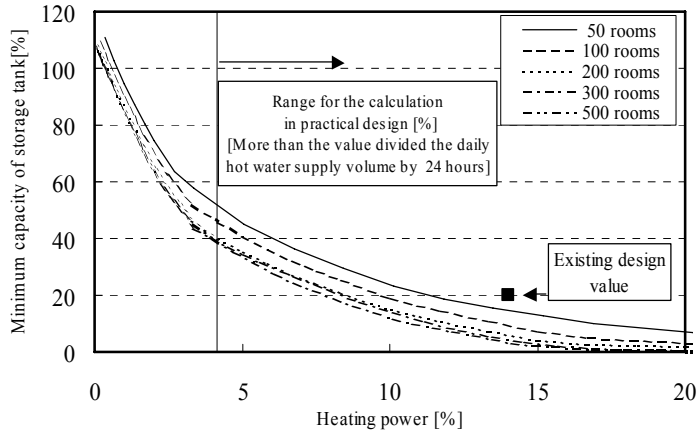


Figure 14 - Relationship between the heating power and the minimum capacity of storage tank (In case of Level 2)

7. Conclusion

We carried out the measurements for water usage in three guest rooms of a city hotel to get the basic data for setting up the simulation models to calculate the cold and hot water demands.

From the measurement results of one minute interval through a year, we clarified the volumes of cold and hot water consumption in the guest rooms on the basis of the analysis for the number and gender of guests in each season.

Furthermore, we clarified the detailed water usage about each fixture with the measurement of five seconds interval in the guest rooms. The frequency of fixture usage, duration time of pouring water, flow rate and temperature of using water were analyzed for setting up the simulation models. As for the model on the frequency of each fixture usage, the hourly patterns modulated by using the moving average method were presented.

The validity of the simulation technique was confirmed with measurement results. We calculated the hot water demands in winter season in each scale of the number of guest rooms; 50, 100, 200, 300 and 500 rooms. We clarified that instantaneous maximum flow rates per minute and per guest rooms were reduced on the increase of the number of guest rooms.

Also, we clarified the relationship between heating power and capacity of storage tank on the basis of the calculation results of hot water demands every one minute through a day. From these results, we showed that the simulation method was very useful to promote energy conservation for planning of hot water supply system.

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Main author presentation

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