D3/ The prediction method of supply water temperature for energy simulation of hot water supply system - Part2 Comparison between results of measurement and calculation of buildings in Kanagawa University

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Abstract

Supply water temperature is an important input condition to evaluate and predict energy consumption1). In small buildings such as detached houses, the city-pressure water supply system is employed and the supply water temperature is equal to the city water temperature. A break tank is used in general and the supply water temperature will be equal to the tank water temperature that is different from the city water temperature. Therefore, this study focuses on the supply water temperature in a building and shows the measurement and calculation results of supply water temperatures in buildings.

This paper describes the following:

(1) Summaries of measurements in three buildings by the building energy management system (BEMS) in Kanagawa University. The water temperatures and air temperatures around the pumps and/or break tanks and the pump running data are measured every minute. The water consumption volume of each building is recorded visually every month. This measurement is still ongoing and the measurement results from September 2017 to May 2018 are presented herein.

(2) The calculation method1) of city water and break tank water temperature is used.

(3) A comparison between the measurement and calculation results of water temperature is described.

The mean absolute temperature difference between the measurement and calculation results in Building C of Kanagawa University is less than 1.0 °C from September 2017 to May 2018. This paper shows that the calculation method is feasible for the estimation of supply water temperature in a hot water supply system.

Keywords

Hot water supply system; energy saving; city water temperature; tank water temperature.

1 / Introduction

The energy consumption of hot water supply systems is high in buildings such as dwellings, hotels, and hospitals. It can constitute up to 30% of a building's total energy consumption. The energy consumption of a hot water supply system is crucial in terms of energy saving in buildings. Moreover, it is affected by producing hot water, as well as heat loss due to piping and heat sources. Heat loss in heat sources is calculated from their efficiency. The heat loss in boilers is less affected by the supply water temperature; however, that in other heat source systems is sometimes affected by the supply water temperature. Therefore, the supply water temperature is an important input condition to evaluate and predict energy consumption. In small buildings, such as detached houses, a city-pressure water supply system is employed, and the water supply temperature is equal to the city water temperature. Generally, break tanks are used and the supply water temperature is equal to the tank water temperature, which is different from the city water temperature. Therefore, this study focuses on the supply water temperature in a building.

Iwamoto et al.1) showed an overview of the city water system and water supply system for building services in Japan, a calculation method of city water temperature from river water temperature as the water source, a calculation method of the break tank water temperature, and results of a case study for a business hotel on the energy consumption of a hot water supply system through simulations.

This paper describes the summaries of measurements in three buildings of Kanagawa University and the comparison between results of the measurement and calculation on the break tank water temperature in each building to show the validity of the aforementioned calculation method.

2 / Summaries of measurements

2.1 Measurement buildings

Measurements are conducted in three buildings, shown in Table 1, at Kanagawa University, Yokohama, Japan. The water supply systems in the buildings have break tanks and the water temperature, ambient air temperature, outdoor air temperature, signals of pump running, and water valve open/close are obtained by the building energy management system (BEMS). The Nishiya purification plant of the Yokohama Waterworks Bureau supplies the city water around the University.

Measurement site		Building A	Building B	Building C
Stories		eight stories and a basement	four stories	eight stories and two basements
Purpose of usa		Offices and Labolatories	Lecture rooms and Laboratories	Lecture rooms and Labolatories
water supply system		Break tank and booster pump system		Elevated tank system
Location of Break tank		Basement	Outdoor	2nd basement
Break tank size		3X7X2H	3X7X2H	4X6X3.5H
water supply quantity [m3]	Sep.2017	491	271	1,288
	Oct.2017	276	467	1,716
	Nov.2017	365	301	1,761
	Dec.2017	542	316	2,089
	Jan.2018	422	150	1,444
	Feb. 2018	535	76	1,678
	Mar. 2018	261	86	891
	Apr. 2018	483	259	1,131
	May 2018	328	388	1,258
	Total	3,703	2,314	13,256
daily number of water flow [cycle/day]	Max.	1,396	1,263	204
	Average	850	597	103
	Min.	24	39	10
Supply water flow rate [m3/min.]		0.0160	0.0142	0.4696
Makeup water flow rate [m3/min.]		0.5		0.1
Minimum / Maximum water volume in break tank [m3]		12.7 / 34		70 / 72

Tab. 1: Summary of the measurements at Kanagawa University.

Building A contains office rooms and a few laboratories, and water is supplied using an optional usage system near the offices. Building B contains many lecture rooms and a few laboratories in the intensive usage system. Building C contains many experiment rooms, laboratories, and lecture rooms in both usage systems.
The break tank for Building A is set in a machine room on the basement floor and connected to a booster pump system.
The break tank for Building B is located outdoors in the shadow of other buildings and the booster pumps are set in a machine room on the ground floor.
The break tank for Building C is set in a machine room on the 2nd basement floor and the water supply system is an elevated tank system that easily measures the water supply schedule.

2.2 Methods of measurement

A summary of the measurement is shown in Figure 1. It is difficult to set the temperature sensor in the break tank; therefore, the sensor is set to the downstream side of the pump, as shown in Photo 1 of Figure 1, in each building. Its water temperature is a substitute for the water temperature in the break tank.

The ambient air temperature is measured with a thermostat used in air-conditioned rooms in each machine room where the pumps are located. The outdoor air temperature is measured at the top of the other building in the same campus.

All temperatures and signals of running pump are measured every minute by the BEMS. In Building C, the makeup water valve signal is measured from April 9, 2018. The used water volume is recorded in each tank by the facility staff of Kanagawa University by visually reading the water meter every month. The makeup water temperature is not measured and is set to the city water temperature, as will be described later.

2.3 Measurement results

The used water volume of each building is shown in Table 1. The used water volume of Building C is very large. The presentable day is set to December 7, when the used water volume is large in the three buildings, and the measurement results are shown in Figure 2. The running pump signal is shown as 0 or 1 in this figure.

In Building A, as shown in Figure 2(a), the pump runs frequently for the water pressure without flow and the

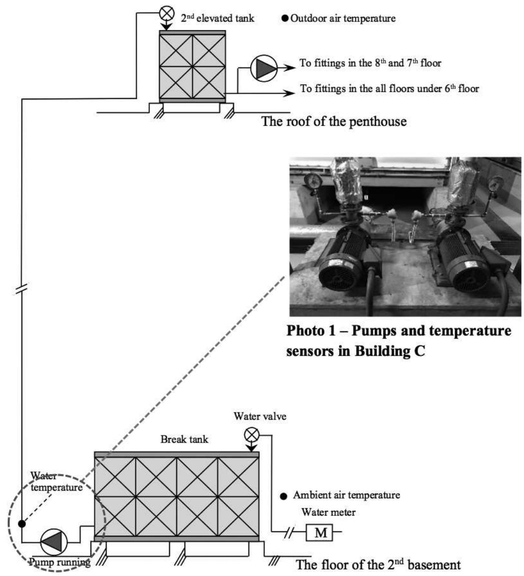


Fig. 1: Summary of measurement in Building C

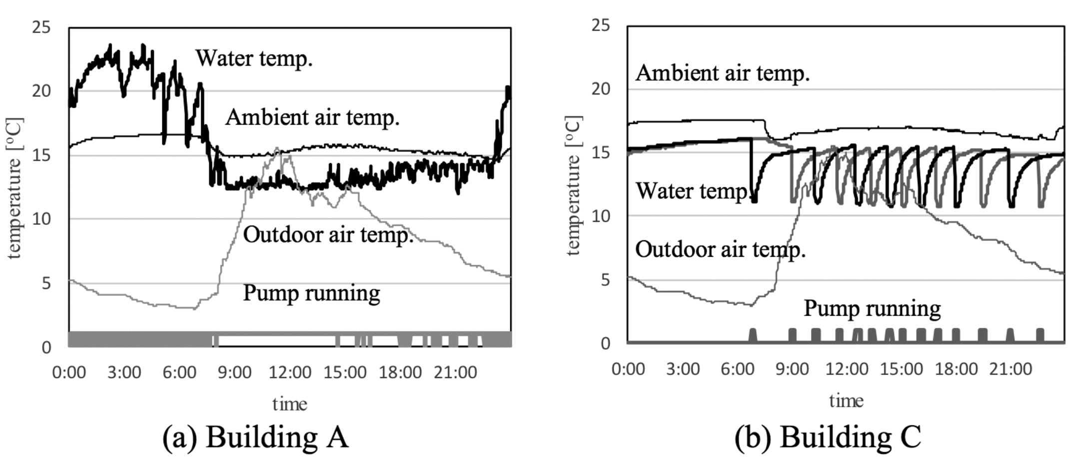


Fig. 2: Measurement results on December 7, 2017.

water temperature fluctuates significantly. It decreases by more than 5 °C when the water flows. Because it is difficult to determine the water flow by only the running pump signal, the water flow is determined using the water temperature drop.

In Building C, as shown in Figure 2(b), the water usage is clear when the pump is running. The water temperature is steady at approximately 2 °C lower than the ambient air temperature, and the cause is still being investigated.

3 / Summaries of calculations

3.1 Calculation method for city water temperature

The makeup water temperature is equal to the city water temperature and is estimated by the calculation method of Iwamoto et al1). The city water at Kanagawa University is obtained from the Nishiya purification plant and the purified water temperature in 2016 and 2017 is provided by the Yokohama Waterworks Bureau2). A summary of the water temperature in the Nishiya purification plant is shown in Table 2, where the measurement was performed daily and approximately 240 days per year. The city water calculation uses the default values and the coefficient of friction d0 is 0.558 in 2016 and 1.03 in 2017. The calculation result is determined by the agreement of the average of source water temperature, as shown in Table 2. The average absolute temperature differences in 2016 and 2017 are 0.87 °C and 0.76 °C, respectively, which are within 1.0 °C. A calculation from Sep 2017 to May 2018 was conducted and the results are used for the following calculation.

3.2 Calculation method of water temperature in break tank

The calculation method1) of the water temperature in a break tank constitutes the following three steps:

Step 1: calculate the water volumes for use and makeup every minute

Step 2: calculate the initial temperature of the tank water

Step 3: calculate the temperature of the tank water with the overall heat transfer from/to the ambient environment

The input conditions required for this calculation in this study are shown in Table 3.

The water supply schedule is determined from the measurement results using the following conditions:

Step 1: daily minimum and maximum of supply water temperature are determined by the measurement result.

Step 2: the average of both temperatures is calculated.

Step 3: supply water flows when the supply water temperature is below the average.

Period	Item	Source water temperature			Purified water temperature		
		Max.	Ave.	Min.	Max.	Ave.	Min.
2016	Measurement	6.7	15.4	23.8	7.4	16.0	24.3
	Calculation	5.4	15.4	25.6	6.2	16.1	26.1
	Averaged error	0.98			0.87		
2017	Measurement	6.1	15.0	24.3	7.0	16.0	25.4
	Calculation	5.5	15.0	26.1	7.0	16.2	27.0
	Averaged error	0.99			0.76		
This period*	Calculation	5.0	15.0	25.5	6.5	16.2	26.4

* from September 2017 to May 2018

Tab. 2: Summary of measurement in Nishiya purification plant and city water calculation results.

Item	Application
Supply water flow rate	Setting constant values shown in Table 1
Water supply schedule	Estimated schedules with measurement results
Makeup water flow rate	Setting constatnt values shown in Table 1
Makeup water temperature	Calculated city water temperature in Nishiya purification plant
Ambient air temperature around break tank	Measurement values
Overall heat transfer coefficient of break tank panels [W/m^2K]	Setting values 1.99 attached to water, 1.32 attached air layer in machine room 2.99 to water, 1.32 to air layer outdoor
Water volume control in break tank	Maximum and minimum values setting in Table 1

Tab. 3: Input conditions for calculation.

Step 4: supply water stops when the supply water temperature is beyond 0.3 °C of the previous supply water temperature.

The estimated quantity of supply water flow are shown in Table 1 and the supply water flow rate is set to the water usage volume divided by the number of supply water.

All the break tanks are made of FRP panels and they are insulated to prevent dew condensation. The overall heat transfer coefficient of a panel is shown in the catalogue of tanks and measured in an experimental room. In this study, it is set to 1.99 W/m2K for the part attached to water, and 1.23 for the part attached to air in the machine room. It is set to 2.38 for water, and 1.34 for air where the break tank is located outdoors.

The makeup water flow rate is set as shown in Table 1. The measurement result on the makeup water valve shows that the valve is always opened. Thus, the flow rate is set to a small value and the minimum tank water volume is set to a large value.

3.3 Calculation results

3.3.1 Averaged absolute temperature difference between measurement and calculation results

The monthly average absolute water temperature difference between the measurement and calculation results of each building is shown in Table 4. For Building C, it is within approximately 1 °C, and is rather large for Buildings A and B.

3.3.2 Supply water temperature of measurement and calculation results

The supply water temperatures of the measurement and calculation results for Buildings A and C on December 7, 2017 are shown in Figure 3. Figure 4 shows the results on February 25, 2018 when the water usage is low. The measurement value is set to zero when water is not used.

For Building A, calculation values do not agree with the measurement values sufficiently. However, the calculation values agree with the measurement values sufficiently for Building C. This shows that this calculation method is feasible when the calculation conditions shown in Table 3 are sufficient.

Month	Water temperature difference			Daily minimum water temperature difference		
	Building A	Building B	Building C	Building A	Building B	Building C
Sep.	1.18	3.07	0.99	0.64	1.42	1.03
Oct.	1.98	2.64	0.74	0.80	0.69	0.70
Nov.	2.09	3.14	0.84	0.71	1.09	0.76
Dec.	2.35	4.69	0.79	1.27	2.42	0.44
Jan.	1.75	4.66	1.22	0.68	2.40	1.08
Feb.	2.03	4.59	0.90	0.68	1.51	0.67
Mar.	2.08	4.12	0.84	0.71	0.84	0.67
Apr.	2.40	2.69	0.81	0.52	1.25	0.66
May	1.88	2.25	0.95	0.88	1.32	0.84
ALL	1.94	3.51	0.90	0.77	1.44	0.76

Tab. 4: Average absolute difference of supply water temperature for each month and each building.

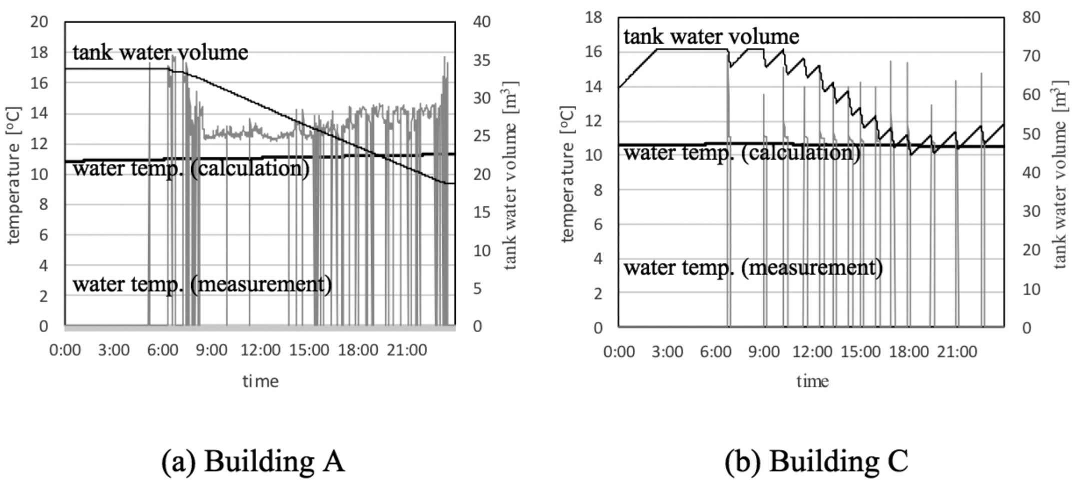
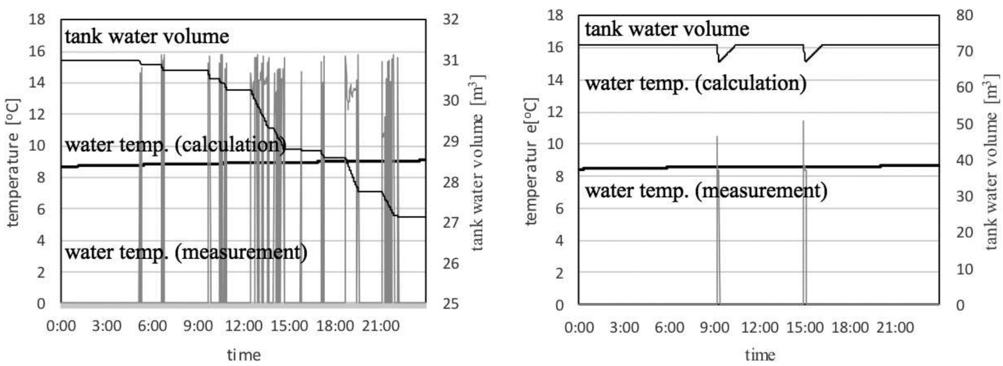


Fig. 3: Water temperature of measurement and calculation on Dec. 7, 2017.



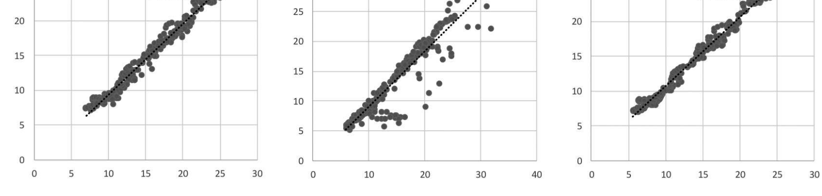
(a) Building A (b) Building C

Fig. 4: Water temperature of measurement and calculation on Feb. 25, 2018

3.3.3 Daily minimum water temperature

The daily minimum water temperature is important for the calculation of energy consumption of a hot water supply system. Figure 5 shows the comparisons between the measurement and calculation of the daily minimum water temperature for Building C. The R2 value is close to 1.0 and the calculation results agree with the measurement results except for a few points for Building B.

Figure 6 shows the daily minimum water temperature of the measurement and calculation from September 2017 to May 2018. The calculation results agree with the measurement results for the daily minimum water temperature; this calculation method is useful to determine the energy consumption for a hot water supply system. However, the difference between measurement and calculation is beyond 1 °C at times, even for Building C. Moreover, the calculation temperature is always greater than the measured temperature. The causes are still being investigated and other calculation methods of city water temperature such as the Blokker and Pieterse–Quirijns3) should be considered.



(a) Building A (b) Building B (c) Building C

Fig. 5: Comparisons of daily minimum water temperature between measurement and calculation; the x-axis represents the measurement and the y-axis represents the calculation.

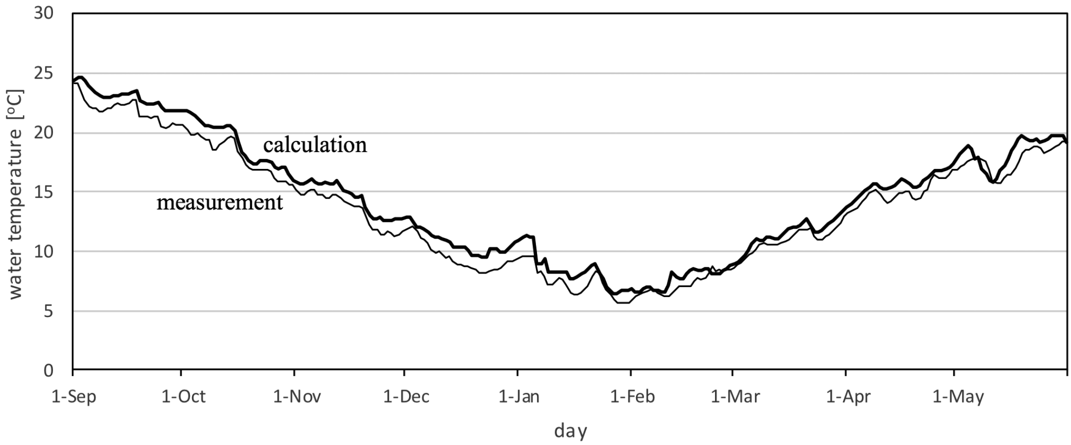


Fig. 6: Daily minimum water temperature of measurement and calculation for Building C.

4 / Conclusion

The conclusions of this study are as follows:

(1) The supply water temperature was measured from September 2017 to May 2018, and the validity of the calculation method was shown by comparing the measurement and calculation results of three buildings.

(2) For Buildings A and B, the average absolute water temperature difference between the measurement and calculation results was beyond 1 °C. However, for Building C, it was within 1 °C. This calculation method appears to be feasible when the calculation conditions shown in Table 3 are sufficient.

(3) A comparison of the daily minimum water temperature between the measurement and calculation for each building shows a good agreement, and this calculation method is useful to obtain the daily minimum water temperature for the evaluation of energy consumption in a hot water supply system.

We plan to measure the supply water temperature for more than a year within the forthcoming June, July, and August and show the energy consumption of a hot water supply system using this supply water temperature.

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