

Performance Evaluation of Hot Water Efficiency Plumbing System Using Thermal Valve

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ABSTRACT

In Korea two popular water distribution systems—the branch type and the separate type systems—have serious drawbacks. The branch type suffers from temperature instability while the separate type suffers from excessive piping. Neither of them re-circulates water. The system proposed in this paper utilizes a water-conserving piping system with a thermostat valve. This paper compares the proposed system with that of the separate type. Our findings show that the proposed system wastes less water. After re-circulating for 78-87 seconds, water is available at set point temperature (40°C). Also, when multiple water taps are in use, the average temperature deviation is less than 0.6°C. Moreover, the proposed system has 50% less flow rate than the separate type system.

Keywords: Water-conserving hot water piping system, Branch type hot water piping system, Separate type hot water piping system, Thermo controlled valve, Circulation, Mixing water pipe, Recirculation water pipe

INTRODUCTION

Background and Objectives

Finding ways to conserve energy while heating a building's water supply can be approached from a number of angles. Still in the literature hot water use in residential buildings, in terms of how much energy is consumed to maintain the hot water supply, has not attracted a great deal of research. Bujak⁽¹⁾ looked at seasonal variations in domestic hot water use at hospitals. Jacobs and Haarhoff⁽²⁾ came up with a residential end-use model to estimate hot-water use. The authors identified 79 parameters (over 12 months) that influence indoor and outdoor water demand. Cheng et al⁽³⁾ provided an empirical model that estimated heat loss from the conveyance of hot water to its consumption point. Sowmy and Prado⁽⁴⁾ evaluated the performance of electric storage water heaters, also taking into account dissipated heat while water is not being consumed.

In Korea research has centered on distribution systems within single dwelling residences. Currently, in Korean apartments there are basically two types of plumbing systems—the branch type system and the separate type system. The branch system, which has been used for decades, gets its name from its tree-like design with numerous branches coming off the main trunk.⁽⁵⁾ A single line, or “branch,” carries water from the main line to one consumption point. Hot water dispensed from that point affects the amount of hot water in the main line. Hence a person taking a shower becomes aware when another household member runs water from, say, a kitchen tap, a washing machine, or a toilet. The person in the shower will be scalded with hot water.

To solve this problem the separate type system was designed. The separate type system does away with the main branch. Every consumption point has a dedicated line. This way large fluctuations in water

temperature are avoided when more than one consumption point is running water at the same time.

The separate type system has, however, two main drawbacks: it consumes too much space and it's difficult to install. Another smaller problem is that when more than three water outlets are in use then the water temperature is no longer stable. Thus the showerhead requires a special thermal-controlled valve. Existing water plumbing systems whose supply of hot water comes from a boiler are controlled manually by the user. The heat dissipates from the water lying in the line between the boiler and the tap. Once the tap is opened hot water begins to flow from the boiler. There is thus a time lag from the time the hot water tap is turned on to the time hot water actually emerges. Hence this plumbing system's disadvantage is that so much water is wasted until the optimal tap temperature is reached.⁽⁶⁾ We tried to solve this problem by developing a water-saving hot water plumbing system that utilizes a thermo-controlled valve. The goal was to not allow this water to lie still in the lines but to circulate when starting to use the hot water. By circulating the water and using a temperature control system we were able to maintain a constant water temperature. This study of a water-conserving hot water piping system carried out three types of experiments: i) it compared the water-conserving system's quantity of water flow with that of the existing separate-type piping system, ii) it recorded the time interval for the system's circulated water to travel one loop as well as recording the time it took for the system's room temperature water to rise to set point temperature, and iii) it recorded each tap's rate of temperature change and fluctuations in flow rate when several taps—on a single system—ran water simultaneously.

Water-conserving Hot Water Piping System Overview

Figure 1 shows the water-conserving hot water

pipings systems. This system reheats the residual water lying in the pipe to set point temperature. A step motor is combined with a thermal control valve to produce a unit that achieves the set temperature. One unit controls the temperature at one tap, so that units can be added to a system to match the number of taps. Temperatures can be varied for each tap. To prevent scalding, this control box is installed next to the tap or to the entrance to the bathroom. The main digital control box can be controlled manually, allowing a person to start the circulation pump and thus circulation of the cooled water lying residually in the pipes. Because the water coming from the boiler is mixed with cold water (from the municipality) the resulting mixture is called “mixed water.” The unused water returning from the tap to the boiler is called “recirculated water.” The main control

box controls the distribution of water to every tap—Bathroom 1, Kitchen, Bathroom 2, and Laundry room. With each additional circulation loop, we are able to control the temperature at an additional tap. In this system there can be several circulation loops, with each loop supplying a set point temperature for the corresponding tap. This is the first merit to this system. Another merit is that this system greatly reduces the amount of piping that was used with the separate type hot water piping system. A third benefit is the prevention of thermal shock caused when a toilet is flushed while a person is in the shower. Finally, a fourth benefit is the conservation of water. With this system there is no need to run water while waiting for the hot water to arrive.

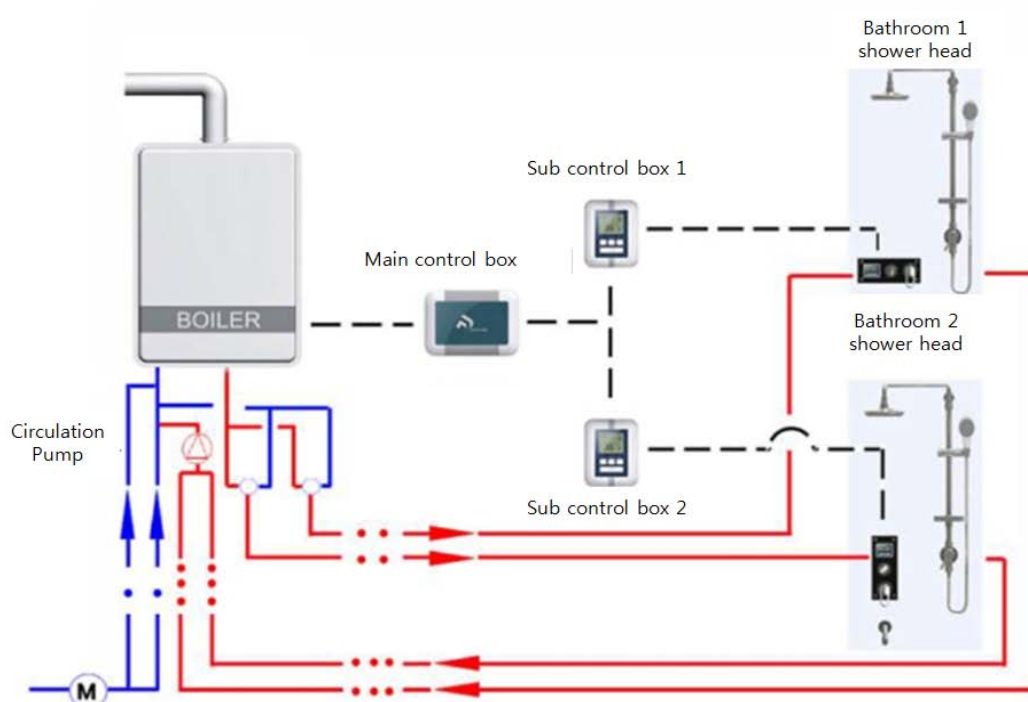


Figure 1. Schematic diagram of the water-conserving hot water piping system

EXPERIMENTAL APPARATUS AND METHOD

Experimental Apparatus

We selected a government-sponsored model home and installed the two types of plumbing systems to compare the performance results. In our laboratory we built a replica of the model home’s plumbing system. Figure 2 shows this plumbing system. As you can see from the figure, there were many points of data collection. We used a data logger (Data logger, Model: Agilent 34970A) to record, at one second intervals, the temperature, flow rate, and pressure. For the hot water supply we used a gas boiler (Model: Rinnai R112-20KF, heat output: 20,000 kcal/h) and the water supply was kept at a pressure of 2.8 kgf/cm².

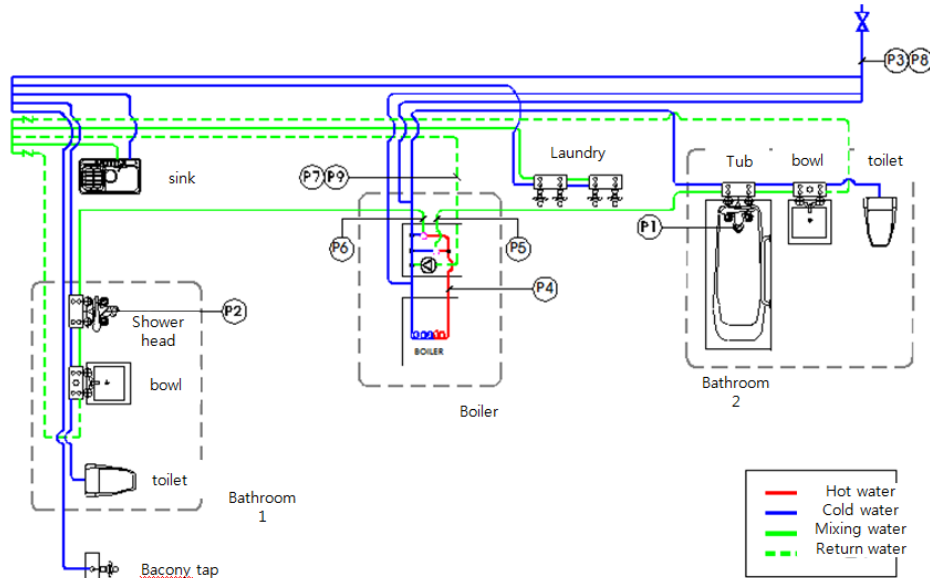
Experimental Method

Measurement of water savings.

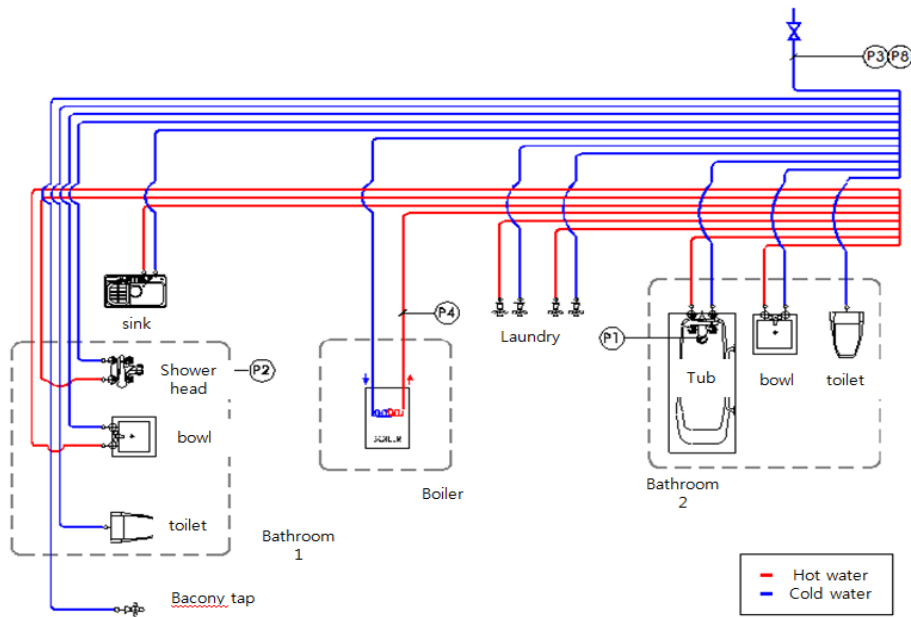
Because the water-conserving system recirculates the water, it can maintain water temperature at set point. By having instant hot water, the water that, in the previous system, would have cooled lying in the pipes is no longer wasted. If all households saved this amount of water, the cumulative effects would be felt at a national level. This saved water also saves municipalities on treatment costs. In this paper, to measure the amount of wasted water, we assumed that water used for personal hygiene purposes (washing the face, hands, and body) was at a temperature of 40-45°C^{(7), (8)}. Thus we established the set point temperature as 40°C. We selected two cases for the separate type plumbing system. The first case collected water solely from a hot water tap. The second case collected water half from the

hot water tap and half from the cold water tap. In this experiment we measured how long it took water from the tap to reach a temperature of 40°C as well as the flow rate of the wasted water. After repeating the

experiment three times, the results were averaged. We assumed that on average people would wait before getting in a shower until the water reached a temperature of 40°C.



(a)



(b)

Figure 2 Comparative diagrams of the two piping systems

- P1: temperature and flow rate sensor
- P2: temperature and flow rate sensor
- P3: temperature sensor
- P4: temperature sensor
- P5: temperature sensor

- P6: temperature sensor
- P7: temperature sensor
- P8: pressure sensor
- P9: pressure sensor

Time to reach set point temperature and circulation time.

To measure how long it takes the water lying in the pipe to reach the set point temperature, we first let it cool to the same temperature as the cold water supply. We then turned off the boiler, drained the hot water, and filled the pipes with water from the supply cold water supply. Then we turned on the boiler, heated the water to the set point (40°C) with the circulation pump and the boiler. When the temperature sensor detected water at 40°C, the main controller ordered the pump to stop. We could then measure the circulation time, meaning the time from when the pump started until it stopped. We repeated this procedure three times to measure the time elapsed in reaching set point temperature and the

water circulation time. After circulation was finished, we checked that the water flowing from the tap was still at the set point, as it was when we first opened the tap.

Variation in temperature and flow rate when taps used concurrently.

Typically, the proper water temperature and flow rate are the two most important considerations when taking a shower. We thus checked for variations in water temperature and flow rate at the shower head when other taps were running water. Table 1 shows seven cases of experiments conducted on both systems: the water-conserving hot water piping and separate line system.

Table 1 Experimental cases comparing effects of several taps being open

Alteration	Bathroom 1	Other location	Cases						
	Shower head target temp.	Opening status at other location tap	1	2	3	4	5	6	7
i	40°C	100% cold water supply*	○	○	○	○	○	○	○
ii	40°C	50% hot water supply**	○	○	-	○	○	○	-
explanation	<ul style="list-style-type: none"> · Case 1: shower head + sink tap · Case 2: shower head + laundry tap · Case 3: shower head + toilet flushing · Case 4: shower head + bowl tap · Case 5: shower head + sink tap + bowl tap · Case 6: shower head + sink tap + laundry tap · Case 7: shower head + sink tap + laundry tap 								

One asterisk (*) indicates the status when only the cold water tap was open. Two asterisks (**) indicate when the cold water supply and hot water supply were mixed to achieve set point temperature (40°C).

In the case of the water-conserving hot water piping system the water temperature was kept at 40°C. 50% hot water supply means opening only the hot water and mixing it with cold water. We conducted

experiments on seven cases. Initially we kept the shower head water temperature at 40°C for one minute and then opened another tap for two minutes. We logged data during the whole procedure. To determine the temperature variation we checked the maximum deviation from the average value. To determine the flow rate variation, we compared the average flow values of before and after the tap was opened.



Figure 3 Data acquisition system



Figure 4 Temperature control box



Figure 5 Pressure gauge



Figure 6 Thermal valve box



Figure 7 Pressure transducer



Figure 8 Flow meter



Figure 9 Temperature sensor

EXPERIMENTAL RESULTS AND DISCUSSION

Water Saving Effects

Table 2 shows that the separate type plumbing system can reduce wasted water from 14.9 liters to 4.3 liters. This calculation is based on the assumption that most people refuse to take a cold shower. If we assume that an ordinary four-member family takes

showers twice a day with the separate type plumbing system, the water wasted would amount to a minimum of 34.4 liters a day. The water-conserving hot water piping system is expected to prevent water being wasted at the beginning of a shower (as one waits for hot water to come from the shower head).

Table 2 Water wasted in the separate type plumbing system

Alteration	100% hot water supply		50% cold water supply	
	Bathroom 1	Bathroom 2	Bathroom 1	Bathroom 2
Approaching time (sec)*	28	40	58	76
Average flow rate (l/min)**	9.3	6.7	13.5	11.7
Wasted water (l)	4.3	4.5	13.1	14.9

Here the asterisk (*) indicates the time required in reaching the set point temperature $40\pm 0.5^{\circ}\text{C}$. Two asterisks (**) indicates the average flow rate while reaching set point temperature.

Results of the Circulation Time and the Time to Reach Set Point Temperature

The water-conserving hot water piping system controls the temperature constantly by circulating, via a digital device, the water lying in the pipe. So family members are able to use water at whatever temperature

they set it for before opening the tap. We conducted an experiment on how long the circulation time took and what the temperature of the water was when the tap was opened. Table 3 and Figure 10 show the results.

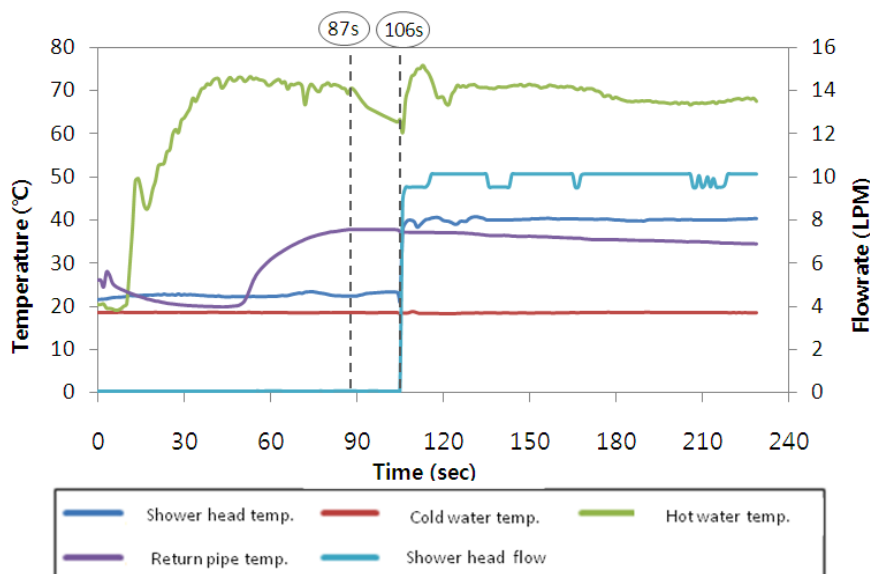


Figure 10. The circulation time and the reaching set point temperature time at shower head

Table 3. The measured circulation time in the water-saving hot water plumbing system

Alteration	Bathroom 1	Bathroom 2
The circulation time (sec)	87	78
the set point temperature approaching time (sec)*	1~2	1~2
Average temperature difference (°C)**	0.1	0.2
Maximum temperature difference(°C)***	1.2	1.7
Average flow rate(LPM)****	9.7	9.6

One asterisk (*) indicates the time required to reach set point temperature ($40 \pm 0.5^\circ\text{C}$). Two asterisks (**) indicate the average temperature difference for two minutes after reaching to the set point temperature. Three asterisks (***) indicates the maximum temperature difference for two minutes after reaching to the set point. Four asterisks (****) indicate the average flow rate difference for two minutes after reaching the set point temperature.

A user set the temperature at 40°C at the control box. He then pushed the start button to operate the circulation pump. The time it took the water temperature to reach set point temperature and stop the circulation pump was, for Bathroom 1, 87 seconds and, for Bathroom 2, 78 seconds. Circulation time can vary according to season. Other factors affecting it are the cold water supply temperature, the set point temperature, the interval between uses, and the performance of the pump. The cold water supply was at about $(19 \pm 1.0)^\circ\text{C}$. We set the temperature at 40°C . To raise the temperature 21°C , it took 78-87 seconds of circulation time. Figure 10 shows that after opening the tap, in 10 seconds a maximum variation of 1.7°C occurred for only 1-2 seconds. In a shower, such a perturbation is

unimportant. This occurred because the water flowing through the tap had been unaffected by the circulation. After the water reached set point temperature, in two seconds the average temperature deviation was 0.2°C , the average flow rate for Bathroom 1 was 9.7LPM and for Bathroom 2 9.6LPM.

Variation of Temperature and Flow Rate When Other Taps in Use

The experiments shown in Table 1 produced the results found in Table 4. Based on a water temperature of 40°C at the shower head, we show the temperature deviations when other taps were opened. The minus value indicates the water's temperature drop at the shower head.

Table 4 Temperature variation when multiple water-taps open

Case number	Type of the plumbing system	100% cold water supply		50% hot water supply	
		Average deviation	Maximum deviation	Average deviation	Maximum deviation
1	Water-conserving type	0.1	0.5	0.0	-0.7
	Separate type	1.4	2.3	-4.7	-5.1
2	Water-conserving type	0.2	0.7	-0.2	-1.0
	Separate type	1.9	3.6	-20.1	-21.2
3	Water-conserving type	0.5	0.9		
	Separate type	0.8	2.2		
4	Water-conserving type	-0.1	0.5	-0.1	-1.4
	Separate type	1.5	2.6	-4.1	-4.5
5	Water-conserving type	0.4	0.7	-0.4	-2.1
	Separate type	1.8	3.3	-7.5	-8.6
6	Water-conserving type	0.6	0.8	-0.3	-1.2
	Separate type	1.5	4.5	-19.6	-20.7
7	Water-conserving type	0.6	0.9		
	Separate type	1.0	3.9		

In the water-conserving type plumbing system, a shower showed a maximum temperature deviation range, with the other taps running 100% cold water supply, of $0.5\text{-}0.9^\circ\text{C}$. Generally speaking, the maximum temperature deviation appeared and disappeared, suddenly, after 4-5 seconds of the other taps being open. A shower user would feel little or no effect. In the case of the separate type plumbing system the average temperature deviation was $0.8\text{-}1.9^\circ\text{C}$. By virtue of the other location tap, the maximum temperature deviation was more than 2°C . In contrast to the water-conserving

type plumbing system, the separate type plumbing system revealed, until the other taps were turned off, a continuous temperature perturbation. As more taps were opened, the temperature deviation increased. In the water-conserving type plumbing system, the average temperature deviation remained below 0.6°C and the maximum temperature deviation under 1.0°C . When the hot water supply was at 50% and the other taps were open, the water-conserving type plumbing system showed results similar to the 100% cold water supply. For example, the average temperature difference was

less than 0.5°C. The separate type plumbing system, however, had a temperature drop from a minimum of 4°C to a maximum of 20°C. Hence when only one other tap is open, a shower user will feel significant effects. Table 5 shows the results from the seven case experiments on flow rate variation. At Bathroom 1 with only the shower head running, the flow rate of the water-conserving type plumbing system is 10.1 LPM. For the separate type plumbing system the flow rate was 14.2~15.0 LPM. When running one other tap with 100% cold water supply, the flow rate in the water-conserving type plumbing system drops from 11~17%. In the separate type water plumbing system, however, the flow rate drops from 29~52%, two to three

times that of the water-conserving type plumbing system. In the most severe case, three taps being open, the water-conserving type system's water reduction rate was still less than 40%. When taps were open simultaneously with the 50% hot water supply, the flow rate dropped even more than the 100% cold water supply. Case 2 shows a large drop in flow rate due to the laundry taps, which use hot and cold water separately. When two other taps were open the flow rate of the water-conserving type plumbing system was 42%. And in Case 6, the separate type plumbing system had a flow rate of under 2 LPM, making it impossible to use the system.

Table 5 Flow rate reduction rate in seven cases of the simultaneous other location taps open

alteration	Case number	Type of the plumbing system	Flow rate (LPM)		Reduction rate (%)
			Before opening tap	After opening tap	
100% cold water supply	1	Water-conserving type	10.1	9.0	11
		Separate type	14.4	10.1	30
	2	Water-conserving type	10.1	8.4	17
		Separate type	14.4	6.9	52
	3	Water-conserving type	10.1	8.7	14
		Separate type	14.5	10.3	29
	4	Water-conserving type	10.1	8.9	12
		Separate type	14.5	10.2	30
	5	Water-conserving type	9.9	7.5	24
		Separate type	14.8	8.4	43
	6	Water-conserving type	10.1	6.9	32
		Separate type	14.4	5.1	65
	7	Water-conserving type	10.1	6.0	40
		Separate type	14.5	4.2	71
50% hot water supply	1	Water-conserving type	10.1	8.5	16
		Separate type	14.2	9.6	32
	2	Water-conserving type	10.1	6.2	39
		Separate type	14.5	3.0	79
	3	Water-conserving type	/	/	/
		Separate type	/	/	/
	4	Water-conserving type	10.1	8.4	17
		Separate type	15.0	9.5	37
	5	Water-conserving type	10.1	5.9	42
		Separate type	14.8	7.6	49
	6	Water-conserving type	10.1	5.9	42
		Separate type	14.7	-	-
	7	Water-conserving type	/	/	/
		Separate type	/	/	/

The back slash (/) indicates it was not included in those cases. The minus sign (-) indicates that the measurement equipment could not pick up a measurement, namely out of range.

CONCLUSION

This paper experimentally compared two plumbing systems—the water-conserving and the separate type. The results led us to the following conclusions.

1) The water-conserving type system saved more water than the separate type. It can save from 4.3-14.9 liters per shower over the separate type system. In a family

of four that takes two showers a day, this savings can add up to 34.4 liters per day.

2) When the set point temperature is set at 40°C, the circulation time is 78-87 seconds. We can get set point water from the tap two seconds after opening. The standard deviation was 0.2°C, reflecting a stable hot water supply.

3) In the case of the 50% hot water supply, when three taps were opened simultaneously, the standard deviation for the water-conserving system was 0.6°C.

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