

A Study on the Evaluation of Domestic Water and Gas Consumption through the Application of Hot Water Recirculation System in Residential Buildings

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ABSTRACT: In this study, recirculation system to individual hot water supply system is composed by scaled 1:1 model and the performance evaluation is executed in accordance with the standards of faucet usage schedule for 1 unit daily. Also, the application possibilities for recirculation system of individual hot water supply system in high-rise residential building is examined through the analysis of waiting time for hot water, quantity of wasted water and energy consumption quantity. The results of this study are as follows. The application plan of recirculation system shows that waiting time for hot water has not changed regardless of season and it can be reduced from about 72 to 85% compared to the prior plan. Also, the whole quantity of water wasted in a month is likely to be decreased approximately 74%. Gas consumption increasing rate is about 42% lower than that of the prior plan in comparison with spring/autumn and winter.

Keywords: recirculation system, hot water supply system, waiting time for hot water, residential buildings

1. INTRODUCTION

In modern residential buildings, the hot-water supply system consists of a boiler, pipelines, and faucets, which function as a single system. The hot water supply system is the second largest energy consumer, next to the HVAC system, for the creation of a sound temperature environment in a residential space, and the energy demand and water consumption for a hot water supply are increasing continuously with the improvement of residential environments.

There are two ways to save the energy consumed in the hot water supply system:

by increasing the efficiency of the hot water supply device and by increasing the efficiency of the hot-water-supply pipelines leading to the faucets.

The energy efficiency of the hot water supply device is increasing via the continuous technological development, and the central hot water supply system uses the waste heat recovery system to minimize the energy consumed by the hot-water supply. All the hot water supply pipelines in the residential buildings in Korea are open-circuited, however, so that the water is thrown away before hot water is obtained, which is tantamount to wasting energy and water.

According to a past study⁵, about 20% of the daily hot-water supply in a household is just thrown away. Korea imports most of the fossil fuel it uses and is classified as a water-stressed country by Population Action International. As such, there is an urgent need for a hot water supply design that will save energy and water.

Therefore, in this study, after the examination of the recirculation system in the hot water supply system, a pipeline structure was formed with a recirculation system for the individual hot water supply system, at a 1:1 scale, in a 105.6m² apartment, which is the typical size of the residential spaces in Korea.

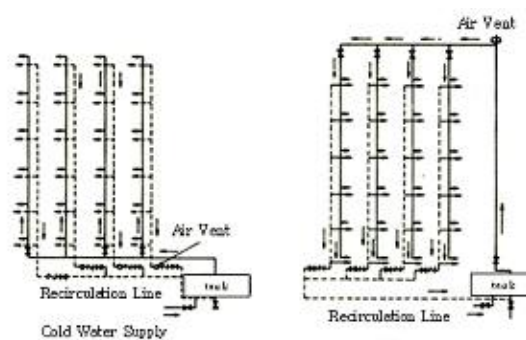
2. THE RECIRCULATION SYSTEM IN THE HOT WATER SUPPLY SYSTEM

2.1 Features of the recirculation system

The hot water supply method in a residential building is generally determined by the heating method and is classified into the individual hot water supply system and the central hot water supply system. The individual hot water supply system has small water heaters at those places where hot water is required, and the central hot water supply system has a large heater and a hot-water tank in the machinery room, for use in supplying hot water to those places in the whole building where hot water is required, through pipelines.

The central hot water supply system has recirculation pipelines, in which the hot water circulates to obtain the proper water temperature in a short time when the hot-water faucet is opened, as shown in Fig. 1. The individual hot water supply system, on the other hand, has a single pipe system. As such, the cold water in the pipe is discharged before hot water comes out, and it takes some time for the hot water to reach the proper temperature, which is not desirable as it is wasteful and inconvenient.

2.2 Application of the recirculation system

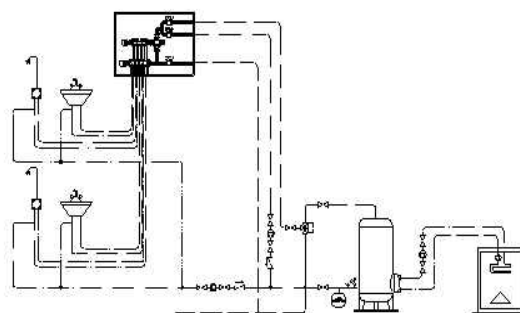


(a) Up-feed type

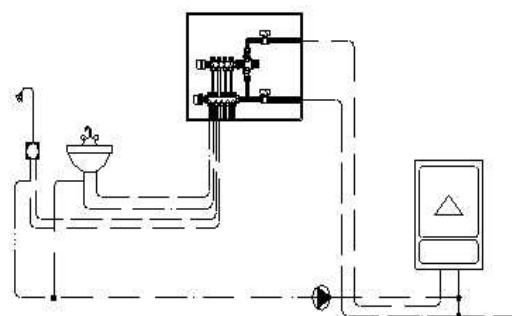
(b) Down-feed type

to the household by hot water supply system

Figure 1: Piping type of hot water supply system



(a) Recirculation system of central hot water supply system



(b) Recirculation system of individual hot water supply system

Figure 2: Recirculation system according to hot water supply system

There are two ways by which the recirculation system could be applied to the household: through the individual hot water supply system and through the central hot water supply system. Figure 2 (a) shows the recirculation pipelines that had been installed in the central hot-water-supply system. The recirculation pipelines connected to each faucet or heating header

and storage tank circulate the hot water continuously or upon the request of a user. What is different is that the recirculation pipelines are formed in the household as well as in the incoming section, which reduces the waiting time for hot water when hot-water faucets are opened. Figure 2 (b), on the other hand, shows the recirculation pipelines that had been installed in the individual hot water supply system. The recirculation pipelines are connected to each faucet or header and hot water tank, with the circulation pump circulating the hot water forcefully and continuously, or upon the request of a user. According to the examination of the circulation methods² that was conducted in the past studies, however, the continuous circulation of hot water can reduce the waiting time for it but creates heat loss from the hot-water-supply pipelines, which also leads to energy loss.

Therefore, in this study, the recirculation system was applied to the individual hot water supply system with circulation upon the request of a user.

3. MOCK-UP TEST METHOD AND PREPARATION

3.1 Mock-up test preparation

In this study, the lengths and diameters of the water/hot-water pipelines in a 32-pyeong apartment, which is the most typical residential space in Korea, were modeled so that a performance comparison test could be conducted on the current system and on the new system, to which the recirculation system had been applied (Figure 3). To obtain accurate test results, an inverter-type booster pump for controlling pressure was installed, and the water-supply pressure for the test was determined to be 0.25MPa, considering that the design pressure of a high-rise residential building is 0.15MPa and that the maximum allowable water-supply pressure is 0.3~0.4MPa. A gas boiler for both heating and hot water supply (instantaneous hot-water supply: 23.26kW)

was also installed in the household, 105.6m² residential building, as a reference.

The diameter of the pipelines for the water supply was 20mm from the booster pump to the water-supply branch pipeline and header, and 15mm for the pipelines after that. For the hot-water supply, the diameter of the pipelines was 20mm from the booster pump to the boiler, and 15mm for the pipelines after that. All the pipelines were made from polybutylene.

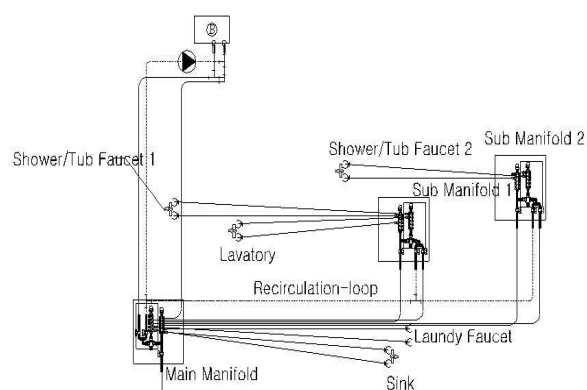


Figure 3: Mock-up test plan

3.2 The recirculation system for the individual hot water supply system

The recirculation system for the individual hot water supply system was installed at the header system and water supply pipelines of the boiler, as shown in Figure 4. A circulation pump and a thermostat were installed for hot water circulation and for the on/off control of the recirculation system, so that the circulation pump stops when the hot water temperature reaches 42°C. A flow rate control valve and a three-way mixing valve were also attached to maintain the required flow and temperature at each faucet in the header system, and the original design was not altered, except for the installation of the recirculation system, for comparison purposes.

Digital sensors were attached to the front and rear of the booster pump and the pressure reducing valve, and faucet-end pipelines and turbine type flow meters were

attached to the faucet outlets for examination purposes. Temperature sensors were also installed at the faucet-end pipelines and outlets. Figure 5 shows the mock-up preparation, sensor attachment, and measuring process.

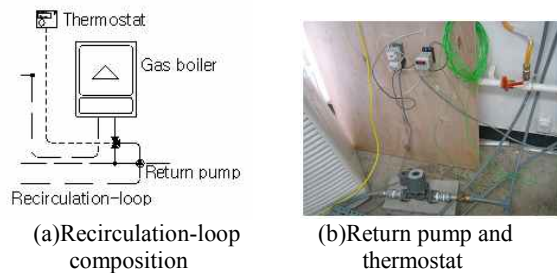


Figure 4: Figure of Recirculation-loop

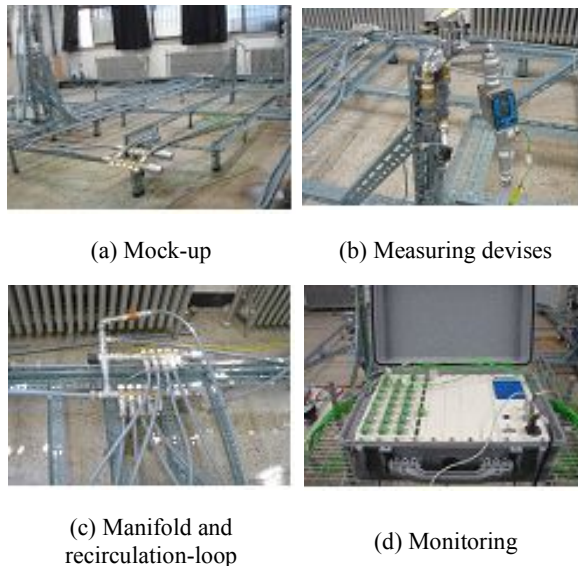


Figure 5: Figure of Mock-up test

3.3 Experiment method and details

As shown in Figure 6 and Table 1, according to the faucet-use schedule, the following were compared and analyzed in the mock-up test, by design: the waiting time for hot water; the water that is colder than the proper-temperature hot water, which was thrown away; and the energy consumption on a daily and monthly basis. The faucet-use schedule was decided on the basis of the past studies.^{2,5} It was assumed that in summer, hot water is used only for taking a shower or bath, but that in the transition period and winter, it is used for all purposes. Four-time bath and laundry per

month was assumed for the estimation of the gas consumption and the amount of wasted water.

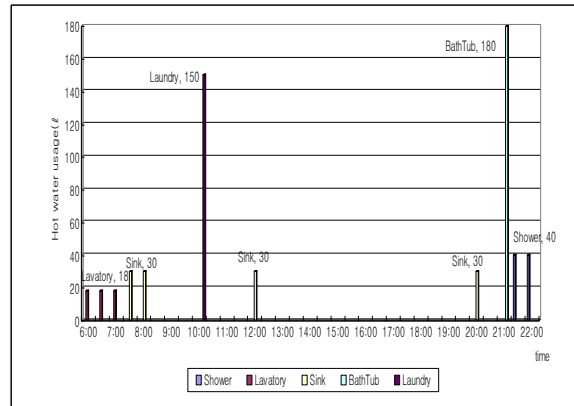


Figure 6: Usage schedule assumption of test cases

Table 1: Flow rate and water usage assumption

Division	Lavatory	Sink	Laundry	Shower	Tub
Flow rate (lpm)	6	6	8	8	8
Quantity of water usage(ℓ)	18	30	150	40	180

Table 2: Experiment condition

Division	Manifold system	Manifold system + Recirculation-loop
Cold water Supply temperature	Summer : 20 °C, Spring/Autumn : 15 °C, Winter : 10 °C	
Usage hot water temperature	Lavatory : 40 °C, Sink : 45 °C, Laundry : 40 °C, Shower/Tub : 42 °C	
Return pump Control	-	ON/OFF control (Off at 42 °C)
Measurement devise	Water pressure : Keller 21Pro Flow rate : turbine type flowmeter Temperature : thermocouple K type	

For the comparison and analysis of the waiting time for hot water and of the wasted water in the hot water supply, by design, the time spent before the proper hot water temperature is reached in each faucet was measured, and the discharged flow was assumed to be thrown away and not used.

The water supply temperature was determined considering the season, so that the waiting time for hot water, the amount of water that was thrown away, and the energy consumption could be measured. The general experiment conditions are shown in Table 2.

4. RESULTS OF THE MOCK-UP TEST AND THEIR ANALYSIS

4.1 Comparative analysis of the waiting time for hot water by design

The results of the analysis of the waiting time for hot water in each season, by design, show that in the original design, as shown in Table 3, the waiting time for hot water is longer in winter than in the transition period and summer. During winter, the maximum waiting time for hot water in the wash-up faucet, when hot water was used for the first time in a day, was 101 s; for the sink faucet, when hot water was used after 8 h, it was 77 s. In the case of the continuous hot-water supply, the waiting time for hot water was 36~47 s for the wash-up faucet, 24~32 s for the sink faucet, and 33~59 s for the shower faucet. The waiting time was about 10~15 s longer in winter than in the transition period and summer. The waiting time for hot water for bathing was found to be longer during summer than during the transition period and winter because in summer, the hot water was used for the first time in a day for bathing purposes.

Meanwhile, the waiting time for hot water was constant at about 10~17 s, regardless of the season and the daily hot-water-use schedule, in the design with the recirculation system. The design with the recirculation system reduced the waiting time for hot water in the existing design by about 72~85%, as shown in Figure 7.

4.2 Comparative analysis of the amount of wasted water by design

The results of the analysis of the amount of wasted water in each season, by design,

show that the amount of wasted water increased in winter compared to the transition period and summer in the original design, as shown in Table 4. The amount of wasted water before the proper hot water

Table 3: Wait time for hot water

Division		Summer (sec)	Spring/Autumn (sec)	Winter (sec)
Mani-fold system	Lavatory	-	36~83	47~101
	Sink	-	24~72	32~77
	Laundry	-	56	72
	Shower	34~36	33~44	49~58
	Bathtub	70	63	63
Recirculation system	Lavatory	-	10~13	12~15
	Sink	-	11~15	13~16
	Laundry	-	15	17
	Shower	11~15	12~16	14~16
	Bathtub	13	13	15

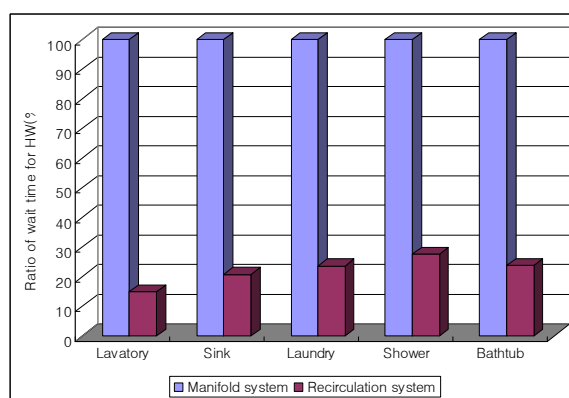


Figure 7: Comparison of ratio of wait time for hot water in winter

temperature was reached increased in proportion to the waiting time for hot water. The accumulated amount of wasted water in a month was 322.2 ℓ in summer, 1387.0 ℓ in the transition period, and 1686.0 ℓ in winter, with about 299.0 ℓ more in winter than in the transition period.

Meanwhile, the accumulated amount of wasted water in a month in the design with the recirculation system was 71.8 ℓ in summer, 375.2 ℓ in the transition period, and 431.2 ℓ in winter, showing no significant difference by season. The new design reduced the amount of wasted water by about 72~79% for each faucet, compared to the original design, and the accumulated

amount of wasted water in a month was about 74% smaller than that in the original design.

4.3 Comparative analysis of gas consumption by design

Table 4: Comparison of Water wasted

Division		Summer (ℓ)	Spring/Autumn (ℓ)	Winter (ℓ)
Mani-fold system	Lavatory	-	15.7	20.0
	Sink	-	18.1	19.6
	Laundry	-	7.5	9.6
	Shower	9.5	10.3	14.2
	Bathtub	9.3	8.5	8.4
	Daily total	18.8	60.1	71.8
	Monthly total	322.2	1,387.0	1,686.0
Recirculation system	Lavatory	-	3.5	4.1
	Sink	-	4.8	5.7
	Laundry	-	2.0	2.3
	Shower	3.5	3.7	4.0
	Bathtub	1.7	1.8	2.0
	Daily total	5.2	15.8	18.1
	Monthly total	71.8	375.2	431.2

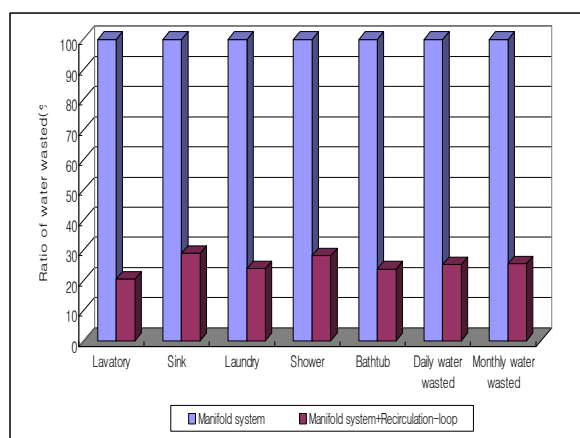


Figure 8: Comparison of ratio of water wasted in winter period

The results of the analysis of the gas consumption for the hot-water supply in each season, by design, showed that the gas consumption was greater in winter than in the transition period and summer in both designs, as shown in Table 5. The amount of

gas consumption was about 4.332 m³ greater in winter than in the transition period in the original design, and about 2.546 m³ greater in the design with the recirculation system, which shows that the gas consumption increase rate in the new design is about 42% lower than that in the original design. The design with the recirculation system, however, required a somewhat high gas consumption in the transition period and summer (not in winter). It seems that the recirculation system is connected to the incoming water-supply pipelines of the boiler, and that the influence of the water-supply pressure on the circulation pump reduces the circulation flow, leading to a longer heating time and lower recirculation efficiency. The use of a three-way valve to prevent the inflow of the water supply while the circulation pump is being operated may reduce the gas consumption.

Table 5: Comparison of gas usage quantity

Division		Summer (m ³)	Spring/Autumn (m ³)	Winter (m ³)
Mani-fold system	Lavatory	-	0.134	0.167
	Sink	-	0.255	0.307
	Laundry	-	0.227	0.241
	Shower	0.126	0.133	0.183
	Bathtub	0.238	0.264	0.312
	Daily total	0.364	1.012	1.210
	Monthly total	4.732	17.586	21.918
Recirculation system	Lavatory	-	0.141	0.158
	Sink	-	0.280	0.304
	Laundry	-	0.207	0.244
	Shower	0.140	0.142	0.174
	Bathtub	0.256	0.264	0.316
	Daily total	0.396	1.034	1.196
	Monthly total	5.223	18.774	21.320

5. CONCLUSION

In this study, the waiting time for hot water, the amount of wasted water, and the gas consumption in the original design of

the hot-water-supply system and in the design with a recirculation system, in residential building, were compared and analyzed, according to the daily hot-water-use schedule and the season, via a mock-up test, and the applicability of the recirculation system to the individual hot-water-supply system was examined.

The results of the study are as follows:

- (1) The results of the analysis of the waiting time for hot water in each season, by design, show that the waiting time for hot water is longer in winter than in the transition period and summer in the original design. Meanwhile, the waiting time for hot water was constant regardless of the season and the daily hot-water-use schedule in the design with the recirculation system. Such design reduced the waiting time for hot water by about 72~85% compared to the original design.
- (2) The results of the analysis of the amount of wasted water for each season, by design, show that the wasted water increased in winter compared to the transition period and summer in the original design, whereas the design with the recirculation system showed a relatively constant amount of wasted water, and the accumulated amount in a month was about 74% smaller than in the original design.
- (3) The results of the analysis of the gas consumption in each season, by design, show that the gas consumption increase rate in the new design was about 42% lower than in the original design in the transition period and winter.
- (4) The gas consumption was somewhat high because of the longer heating time that was needed to obtain the proper hot-water temperature, due to the decrease in the hot-water circulation flow rate as the circulation pump of the recirculation system was affected by the water-supply pressure. Therefore, the recirculation system can be

applied to the individual hot-water-supply system provided that the inflow of water will be prevented when the hot water is being circulated in the recirculation system.

ACKNOWLEDGEMENT

This work was supported by the Regional Research Centers Program (Bio-housing Research Institute), granted by the Korean Ministry of Education & Human Resources Development.

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