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RESEARCH

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Identification, prevention, and treatment of *Legionella* in bath facility water systems in South Korea

June Hae Lee[1], Sejin Lee[2] and Myoung-Souk Yeo[2*]

Abstract

Legionella bacteria infect people via aerosol transmission. These pathogens can meaningfully affect people with weak immune systems and the older adult population. *Legionella* proliferate in water systems at temperatures between 25 and 45 °C, the optimum range for bath facilities. Here, we discuss how and where water systems can be contaminated by *Legionella* in bath facility water systems in South Korea. An epidemiological investigation of *Legionella* detection data from the Korea Disease Control and Prevention Agency was conducted to understand the tendencies of general outbreaks of water system types in building groups. Onsite investigations were then conducted to identify the causes of contamination in water systems in actual *Legionella* detection cases. According to annual *Legionella* detection data, the highest rate of *Legionella* was detected in hot bathtub water. Onsite investigations revealed that sand filter circulation systems for bathtubs are susceptible to *Legionella* growth. Overall, this study examined the mechanisms of building water systems from a building engineering perspective in order to provide valuable information for future studies and strategies to control *Legionella* growth in bath facility water systems.

Keywords *Legionella*, Water systems in building, Bath house facility, Water circulation system, Disinfectant prevention

1 Introduction

Legionella are bacteria that are transmitted to individuals via inhalation of aerosols, and infected individuals manifest symptoms such as Pontiac fever or pneumonia, which is known as *Legionnaires*' disease [1]. The symptoms are insignificant for most healthy people; however, those with weak immune systems and older individuals may experience severe symptoms [2]. *Legionella* can be found anywhere where water exists, including artificial water systems and natural environmental systems, such as rivers, lakes, and soils [3]. These bacteria actively proliferate in water temperatures between 25 and 45 °C, in stagnant locations where water tends to accumulate and biofilm forms [4]. The growing conditions correspond to the water systems and water temperature range for bathing and showering in a building. Based on these characteristics, *Legionellosis* is classified as a representative Specific Building Related Illness (SBRI) [5, 6]. This infectious disease necessitates the establishment of a management system and collaboration among public health, architecture, and architectural engineering professionals.

Sporadic *Legionella* infection cases have been reported that were related to bathing systems. A newly opened hot spring facility in the Japanese city of Miyazaki resulted in 295 cases of *Legionellosis* and seven deaths [7]. A mass infection of *Legionellosis* occurred in the Ardennes, France, and an epidemiological investigation found that the infection originated from a whirlpool spa installed in a hotel room [8]. An epidemiological

*Correspondence:
Myoung-Souk Yeo
msyeo@snu.ac.kr
[1] Building Energy Research Department, Korea Institute of Civil Engineering and Building Technology, Goyang-Si, South Korea
[2] Department of Architecture and Architectural Engineering, College of Engineering, Seoul National University, Seoul, South Korea

investigation into a mass infection by *Legionella* in the Stoke-on-Trent area of the United Kingdom showed that an in-store spa pool display was the cause [9]. Bath-related facilities in South Korea are ranked as having the highest *Legionella* detection rate based on the Korea Disease Control and Prevention Agency (KDCA) reports from 2015 and 2018 [10, 11].

Older adults are at a high risk of *Legionella* infection; thus, *Legionella* detection in South Korean bathhouses is crucial for older individuals. Bathhouse facilities are common for leisure and public sanitation in South Korean cities. As bathhouses were developed during the era when residential buildings were not equipped with bathrooms, people regularly visited bathhouses for personal hygiene. Although most modern residential housings are equipped with fully functional sanitization, older adults continue to visit bathhouse facilities as a ritual. Therefore, *Legionella* detection in bathhouse facilities is a critical factor in the health of older people in South Korea. However, *Legionella* detection in bathhouse water systems has not been considered in terms of building engineering aspects. The objective of this study is to examine the causes of *Legionnaires'* disease in bathing facilities, which are susceptible to *Legionella* contamination, in order to establish architectural engineering-based guidelines for the development of management strategies to improve relevant laws and domestic conditions. This study diagnoses the cause of *Legionella* detection within the bathhouse facility water systems in South Korea via *Legionella* outbreak data from the KDCA.

2 Guidelines for *Legionella* control for bath facilities

Maintaining the temperature of the system is the preferred method for managing *Legionella* growth [12, 13]. As *Legionella* grows rapidly at temperatures ≥ 25 or ≤ 50 °C [4], maintaining a certain temperature is essential. In most literature, it is recommended that both the storage water temperature and terminal temperature of the cold water supply should be maintained below 20 °C [14, 15]. For hot water, it is recommended that the storage temperature of the hot water tank be maintained at ≥ 60 °C and that of the hot water be ≥ 55 °C [14, 15]. The terminal portion of the hot water supply must be maintained at a minimum temperature of 50 °C. Therefore, the faucet-and-shower system at the bath facilities can apply a temperature control strategy to prevent *Legionella* growth.

The chlorine disinfection method is used for water quality management at bath facilities. Usually, a hot bathtub is operated using a water-circulation system after it is filled with water from a centralized hot water supply system. According to the WHO guidelines, when disinfectants are used in a circulation system, it is recommended that an automated device be used to inject the substance to maintain the proper concentration of disinfectant [1]. Moreover, it is recommended that such a disinfection device be installed in front of the filter to prevent microbial contamination and biofilm formation in the filter [14–16].

Table 1 shows the disinfectant concentration of the water in the bathtub during use and not in-use conditions. The recommended concentration of free residual chlorine in bathtub water in use is at least 1.0 mg/L and up to 5.0 mg/L. Periodic management suggests the application of chlorine shock treatment during the not in-use condition, and the concentration standard used for regular disinfection is typically 5.0 - 10.0 mg/L. Korea, France, and the European Union do not have regulations for chlorine shock treatment for *Legionella* control in circulation systems.

The standard for free residual chlorine concentration varies in different cultures. Korea and Japan have lower standards than other countries. The regulations limit the concentration of free residual chlorine to a minimum of 0.2 mg/L and a maximum of 1.0 mg/L, which is significantly lower than that of other countries. This is because the bath facility is used for hygiene and relaxation, and the scent of chlorine might disturb the relaxation of the Korean and Japanese bathing cultures.

3 Data analysis of *Legionella* inspection results

The *Legionella* test results for bathhouse facilities are based on water specimens collected from bathtubs, faucets, and showerheads. In South Korea, testing for *Legionella* bacteria in bathhouse building water

Table 1 Criteria for chlorine concentration in a circulation bathtub to prevent *Legionella* infection

Category		WHO [1]	KR [17]	JP [16]	US [14]	EU [18]	GB [19]	FR [20]	AU [21]
Free-residual chlorine [mg/L]	Routine	at least 1.0 2.0–3.0	0.2–1.0	at least 0.2–0.4 max 1.0	3.0–5.0	3.0–5.0	3.0–5.0	0.4–1.4 max 5.0	2.0–4.0
	Shock**	at least 5.0	-	5.0–10.0	10.0	-	10.0	-	10.0 × 1 h

** Water of bathtub: only circulation bathtubs are intended when the pH is approximately 7.0–7.8

** Shock: periodic management method for disinfectant shock in circulation systems. [free-residual chlorine concentration] × [contact time] systems is not a mandatory inspection item that needs to be performed on a regular basis. However, according to the Infectious Disease Prevention and Management Act, it is conducted at least once a year prior to the start of summer at local health centers in each province under the direction of the KDCA [11]. Among the 7989 test results submitted to the KDCA in 2016, 7802 cases with *Legionella* levels > 200 CFU/L were reported.

The water specimen from the hot bathtub had a high *Legionella* detection rate among all bath facilities, including large public bathhouses, Korean saunas, and hot springs, as shown in Fig. 1. Although there were fewer water samples from the bathtub than from the faucet or shower, the positive detection rate of bath water was 14.20%, while that from the faucet or shower was 9.06%, as shown in Table 2. Moreover, *Legionella* detection was higher in the hot water system than in the cold water system. The *Legionella* detection rate in hot water from both the faucet and bathtub was 16.02%, whereas the cold water detection rate was 6.48%. Therefore, the *Legionella* detection rate average was 21.79% for hot bathtub water from large public bathhouses (20.66%), Korean saunas (27.08%), and hot springs (17.14%).

4 Analysis of *Legionella* detected cases based on the Bathhouse water systems

The annual *Legionella* detection results inform us that *Legionella*-contaminated the water specimens were collected from bathtubs and hot water. In order to investigate the causes of *Legionella* growth in bathhouse water systems, we completed an onsite analysis. Three bathhouse facilities were examined to determine the cause of *Legionella* growth, as shown in Table 3. A *Legionella*-infected patient was reported at Bathhouse A. *Legionella* was detected through regular monitoring at Bathhouse B and C. Hot water tubs were identified as the most common location for *Legionella* detection in all three bathhouse facilities.

4.1 Investigation of *Legionnaires'* detected in Bathhouse A

A patient was confirmed to have *Legionellosis* at Bathhouse A, where *Legionella* was detected at approximately 24,000 CFU/L in water specimens collected from the hot bathtub of a male's bath facility. The buildings consisted of a basement level with four stories. Each story was equipped with a bathhouse for males and females, and the basement level contained a sauna and machine room. As depicted in Fig. 2, the building received potable water and groundwater stored in a

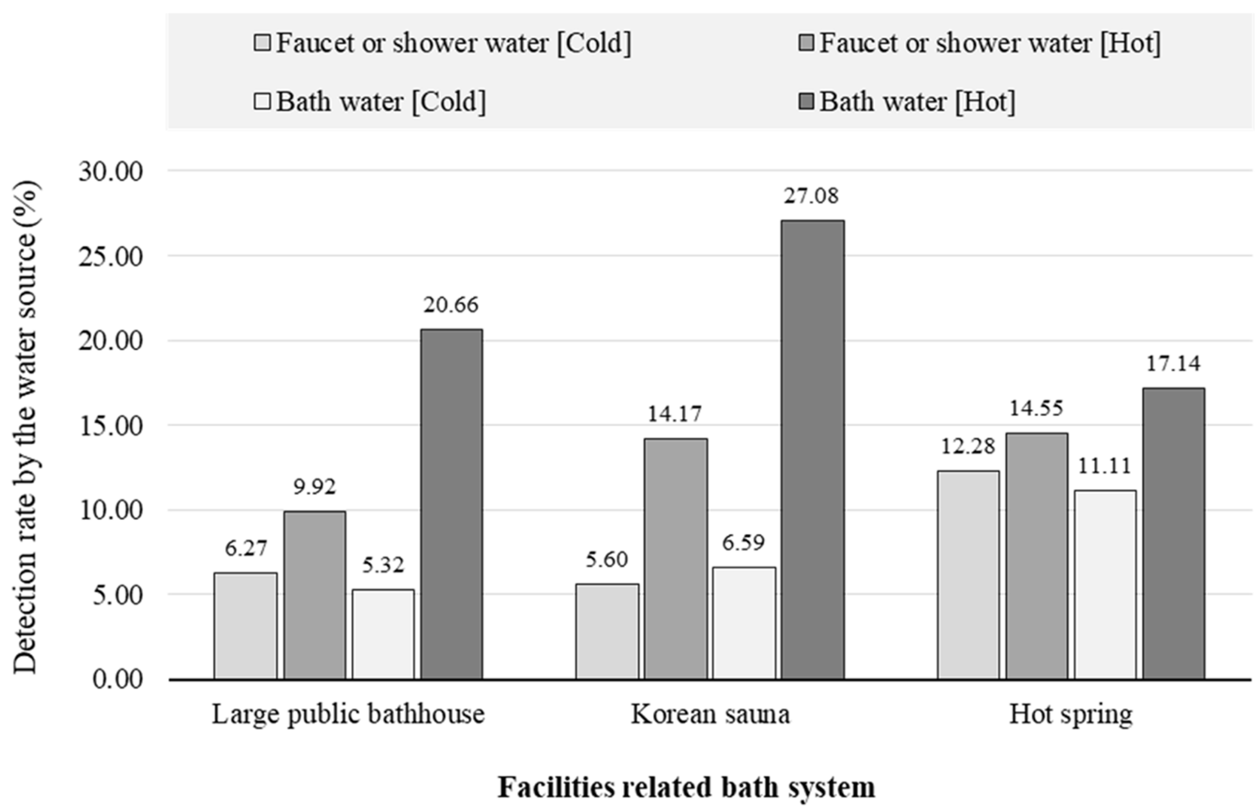

Fig. 1 *Legionella* detection related to bath systems

Table 2 Number of specimens, positive cases, and detection rates by sample location

Type of the facility	Faucet or shower water		Bath water		Total by water type	
	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water
Large public bathhouse						
Water specimen	351	363	282	305	633	668
Positive*	22	36	15	63	37	99
Detection rate	6.27%	9.92%	5.32%	20.66%	5.85%	14.82%
Korean sauna						
Water specimen	125	120	91	96	216	216
Positive*	7	17	6	26	13	43
Detection rate	5.60%	14.17%	6.59%	27.08%	6.02%	19.91%
Hot spring						
Water specimen	57	55	36	35	93	90
Positive*	7	8	4	6	11	14
Detection rate	12.28%	14.55%	11.11%	17.14%	11.83%	15.56%
Total						
Water specimen	533	538	409	436	942	974
Positive*	36	61	25	95	61	156
Detection rate	6.75%	11.34%	6.11%	21.79%	6.48%	16.02%
Total by water source						
Water specimen	1071		845			
Positive*	97		120			
Detection rate	9.06%		14.20%			

*Positive: 2.0×10^2 CFU/L or more

Table 3 Outline of site-visited Bathhouse facilities

	Bathhouse facility		
	A	B	C
Location (Province of S. Korea)	Chungcheongnam-do	Chungcheongnam-do	Chungcheongnam-do
Approval of building use	1982. 09	1998. 11	2015. 12
Symptom outbreak patient	1	0	0
Legionella detection location	Hot water bathtub	Hot water faucet Hot water bathtub	Hot water bathtub Cold water bathtub

feed cistern and sent to the hot water tank to produce hot water and directly supply cold water to the faucet, showerhead, and cold bathtub. Hot water was produced through heat exchange with a steam boiler and waste heat recovery heat pump in a hot water tank in the machine room.

Legionella was not detected in hot water faucets, hot water supply pipes, or hot water tanks, possibly because of the unfavorable operating temperatures for *Legionella* growth. The investigation determined that neither the central hot water supply system nor the system from the mixing valve to the terminal hot water supply were contaminated. Although there was temperature variation in the hot water tank, the maximum operating water temperature was 58°C. The temperature of the hot water supplied via a mixing valve with water from the feed cistern was approximately 55°C.

The water circulation system with its sand filter was the cause of *Legionella* proliferation in this facility. Cold water bathtubs were operated as non-circulation systems without *Legionella* detection, whereas hot water bathtubs were operated as circulation systems. The sand filter on the water temperature range of the circulation system was favorable for *Legionella* proliferation and accumulated micro-organisms such as shed skin cells

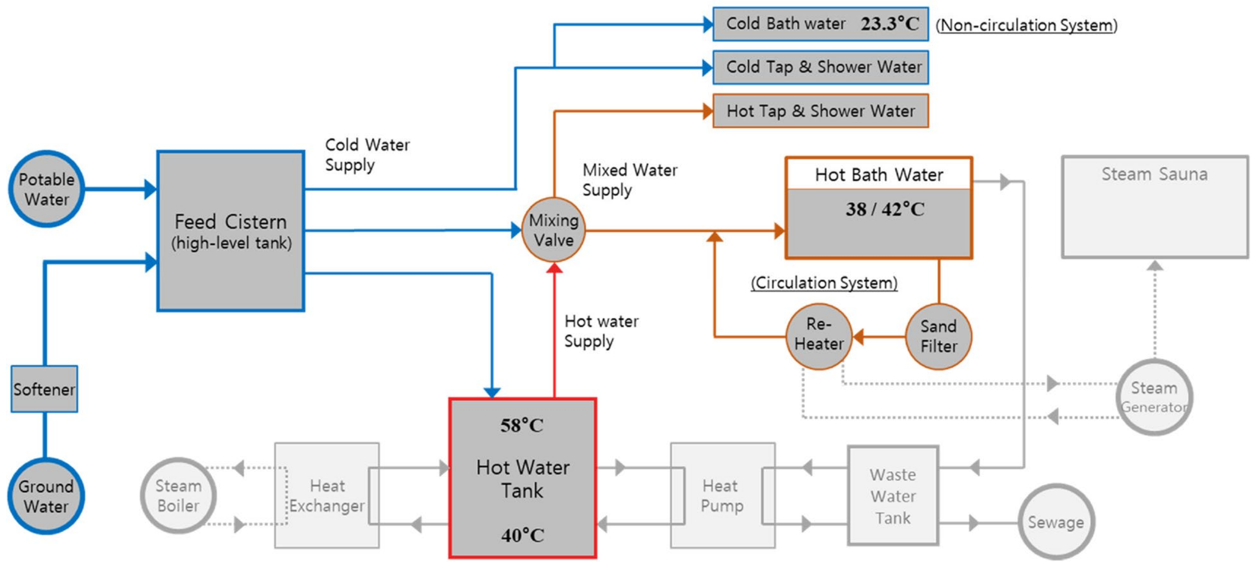

Fig. 2 Schematic diagram of the water system in Bathhouse A

Fig. 3 Sand filter and supply pipes for bathtub water in the basement machine room

from the human body. As illustrated in Fig. 3, the system recycled hot water for hot water bathtubs by filtering suspended matter through a sand filter.

4.2 Investigation of Legionnaires' detected in Bathhouse B

Regular specimen inspections at Bathhouse B revealed the presence of *Legionella* bacteria at 28,000 CFU/L in the hot water bathtub and 32,000 CFU/L in the hot water faucet. The building had two basement levels and four above-ground levels. The second basement floor consisted of a machine room (Fig. 4), and the spaces from the first basement to the third floor were used as a bathhouse and sauna. The fourth floor above the ground, as well as the rooftop, were used as the residence of the owner. As shown in Fig. 5, the facility was equipped with a system in which portable water was mixed with groundwater and stored in a feed cistern no. 1, from which water was sent to an elevated feed cistern no. 2 located on the roof of the building in order to supply water to each use point.

The risk of *Legionella* detection from the hot water faucet may have increased because of internal contamination in the pipe or a temperature drop by the time it reached hot water at the faucet. The bacteria may have grown because of contamination in the pipe supplied by

Fig. 4 Machine room of Bathhouse B

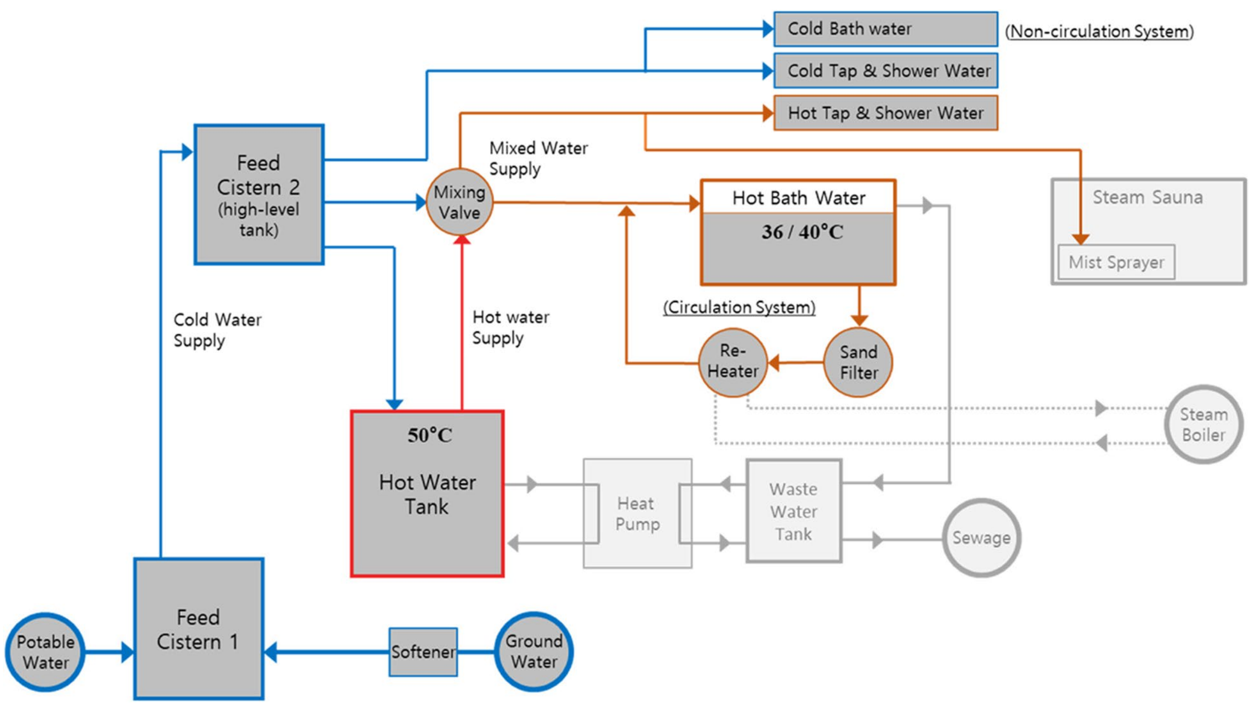

Fig. 5 Schematic diagram of the water system in Bathhouse B

the mixing valve; the supply temperature from the hot water tank was maintained at 50°C and was mixed with the potable water supply from feed cistern no. 2.

As in the case of Bathhouse A, the water temperature and sand filter in the hot water bathtub circulation system promoted the growth of *Legionella*. The temperature of the hot water circulating in the hot water bathtub ranged between 33°C and 40°C, and a sand filter captured the microorganisms to provide bacteria with nutrients. The re-heater on the water circulation system, which was heated by a steam boiler, was primarily used to adjust the temperature of the circulation hot water bathtub during winter. When the re-heater was not in use, the hot water was replenished via an auxiliary hot water pipe connected to a hot water tank.

4.3 Investigation of *Legionnaires'* detected in Bathhouse C

Regular specimen inspections detected *Legionella* bacteria at 34,000 CFU/L in the hot water bathtub and 800 CFU/L in the cold water bathtub at facility C.

This facility is a multi-purpose commercial building with three levels below ground and eight levels above ground. The bathhouse facility was located on the seventh floor and included spaces such as bathhouses, saunas, restaurants, and playrooms. The water supply machine room was located on the third basement level, the hot water supply machine room was on the first basement level, and the additional machine room with the sand filter circulation system was located on the seventh floor.

As illustrated in Fig. 6, hot water was generated via heat exchange with a vacuum hot water boiler and a waste heat recovery heat pump connected to a hot water tank located on the first basement level. A sand filter ciculation system applied to all bathtub water, including cold water bathtub. The groundwater supply of the facility was filtered and softened before being subsequently transferred to a groundwater storage tank on the third basement level, where it was introduced into a treatment tank. When the amount of groundwater was insufficient, the water supply was used to regulate the water level in the treatment tank.

This case demonstrated that *Legionella* proliferated in a sand-filtered circulation system. Both the cold and hot water bathtub utilized circulation systems. Additionally, water was replenished daily, and used water was circulated during business hours to collect nutrients for bacteria. The closed circulation system water temperature was maintained at a level favorable for *Legionella* proliferation. The temperature of the hot water supply was set at 50°C, and the temperatures of the four hot bathtubs were maintained between approximately 42°C and 48°C. The water temperature of the cold water bathtub was maintained above 20°C.

The detection rate in the water of the cold water bathtub was lower at 800 CFU/L than that at 34,000 CFU/L in the water of the hot water bathtub owing to the effect of residual chlorine in the potable water supply. As chlorinated potable water was used it may have been safe against *Legionella* growth if the operating temperature of cold water was maintained below 20°C. Because of water vapor, temperature, and individuals getting in and out of the bath, the temperature may have risen above 20 °C, which is within the range of *Legionella* growth.

5 Discussion on the *Legionella* management strategy for the investigated sites

The main problem common to the water systems of the bathhouse facilities was the sand filter circulation bathtub system, as shown in Table 4. Although the water circulation system was equipped with an auto-chlorine injection system, it was not used because of a lack of awareness about *Legionella* proliferation in the water system of the building. Several proprietors of private bathhouses erroneously believed that the sand filter could filter bacteria and that the disinfectant guideline was not an official regulation at the time. In such a system, the *Legionella* management method requires maintaining the proper concentration of disinfectant. The effectiveness of disinfection methods was proven with the

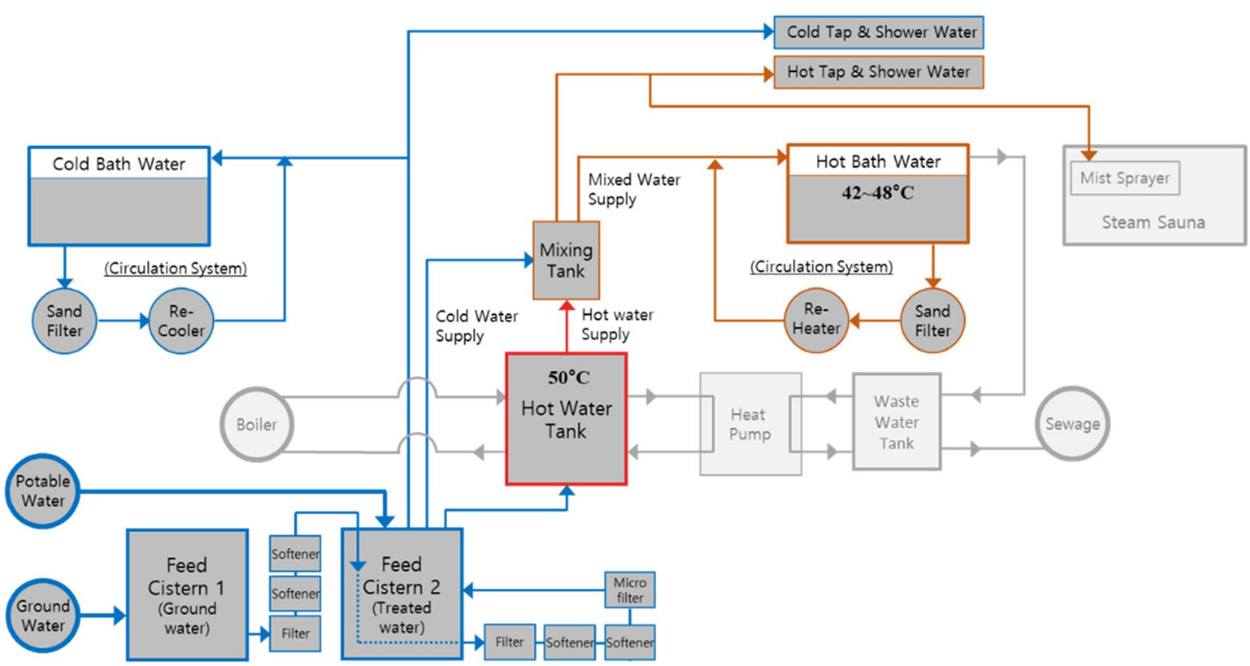

Fig. 6 Schematic diagram of the water system in Bathhouse C

Table 4 Summary of *Legionella* detection in visited bathhouse facilities

	Bathhouse facility		
	A	**B**	**C**
Legionella detection location and rate (CFU/L)	Hot water bathtub (24,000)	Hot water faucet (32,000) Hot water bathtub (28,000)	Hot water bathtub (34,000) Cold water bathtub (800)
Building water system	Central supply	Central supply	Central supply
Facility features	Filter circulation system (hot bathtub)	Filter circulation system (hot bathtub)	Filter circulation system (hot and cold bathtub)
Hot water storage temperature (°C)	unidentified	50	50
Terminal hot water temperature (°C)	38–42	36–40	32–48

cold water bathtub. The detection rate of the cold water bathtub with the circulation system in Bathhouse C was 800 CFU/L, which was a substantially lower detection rate than that of the hot bath tub. The cold water bathtub uses potable water with residual chlorine, which may affect the efficacy of the disinfectant.

Temperature control was essential for the hot water supply of the water system. *Legionella* bacteria were detected in the hot water faucets of Bathhouse B (Table 4). Guidelines suggest that the supply temperature of hot-water systems should be maintained within the range of 55–60°C and below 20°C. The hot water tank was operated at a temperature of approximately 50°C; however, the temperature had decreased by the time the hot water reached the faucet. In addition, hot water at a temperature of 50°C was mixed with the potable water supply, and internal contamination in the pipe may have increased the risk of detection from the hot water faucet. Therefore, it is necessary to shorten the pipeline after mixing points for hot and cold water and to maintain a water system temperature above 50°C and below 20°C.

6 Conclusion

This study aimed to determine how and where *Legionella* contamination occurs in bathhouse water systems in South Korea by analyzing water specimen data and epidemiological survey cases. *Legionella* bacteria can grow and be detected when optimum temperature and nutrient conditions are met and can readily occur in artificial water systems. In particular, the number of causes is critical for bathhouse facilities. However, there is no investigation on the correlation between bathhouse water systems and *Legionella* growth aspects as it relates to building engineering. It can be difficult to identify the cause of contamination at building sites with complex water piping systems solely based on the sample location where direct contact occurs with humans at the terminal.

Based on collected sampling data from 2016 in South Korea, the sample locations with the highest amounts of *Legionella* detected in bathhouse facilities were as follows: hot water from bathtubs, hot water from faucets, cold water from bathtubs, and cold water from faucets. Site investigations confirmed that *Legionella* proliferated where optimum temperatures occurred in the systems. In the case of a system used in a hot water bathtub, the sand filter circulation system created a high risk of *Legionella* contamination owing to the presence of ideal temperatures and the inflow of organic matter from human bodies.

In this study, we diagnosed predictable issues for bathhouse water systems. A limitation is that improvements facilitated by the reduction in bacteria were not recorded or confirmed. Regarding the effectiveness and performance of disinfectants, we concluded that standards differ based on specific regulations and that the effects vary depending on the specific site. Future research on these results and the consequences of practical bacterial reduction is necessary. Despite these limitations, this study improves our understanding of *Legionella* contamination pathways in building systems.

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Authors' contributions
The author(s) read and approved the final manuscript

Availability of data and materials
The data that support the findings of this study are available from Korea Disease Control and Prevention Agency (KDCA) but restrictions apply to the availability of these data, which were used under license for the current study and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of KDCA.

Declarations

Competing interests
The authors declare no competing interests.

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