Pacific Northwest
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Domestic Hot Water Temperature Maintenance Technology Review

August 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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1.0 Overview

Domestic hot water temperature maintenance (HWTM) is an important topic in facility management, and there are often opportunities to optimize systems to achieve energy, water, and maintenance savings. The main purpose of a HWTM system is to provide reliable hot water at all fixtures with minimal wait time, saving both water and energy. This is done by reducing the length of hot water supply piping to the fixture and replacing heat losses during periods of low demand.

This document provides an overview of why the topic of HWTM is important, how to understand your building's system, considerations for occupant comfort, and comparison of typical and newly available technologies. The systems discussed in this report are applicable for both new construction and existing buildings.

This paper focuses on hot water temperature maintenance (HWTM) systems, not domestic hot water (DHW) generation systems, which are the primary source of heating incoming cold water supply.

2.0 Energy and Water Use

All piping in hot water systems is subject to heat transfer to the environment, called standby losses. Insulation reduces but does not eliminate standby losses. If standby losses are not thoroughly managed, energy and water are wasted while users wait for the desired water temperature to flow at the tap. The factors that impact wait time are the fixture flow rate, and the length and diameter of the "dead leg" branch (the last section of pipe to a fixture not served by the HWTM system).

According to the American Society of Plumbing Engineers (ASPE) Domestic Water Heating Design Manual, 2nd ed,[1] a reasonable wait time for delivery of hot water is 0-10 seconds from when the valve is opened. A delay of 11-30 seconds is possibly acceptable, and a delay over 30 seconds is considered unacceptable. Table 1 illustrates the estimated wait time for a given fixture flow rate and typical lengths of dead legs by diameter. For example, a fixture flow rate of 1.5 gpm (gallons per minute), a dead-leg length of 10 ft, and a pipe diameter of 3/4 in. will have an expected wait time of 16 seconds before hot water flows to the fixture at the proper temperature.

Table 1. Hot Water Delivery Wait Time in Seconds

Fixture Flowrate	0.5 gpm		1.5 gpm		2.5 gpm		4.0 gpm	
Length of dead leg	10 ft	25 ft	10 ft	25 ft	10 ft	25 ft	10 ft	25 ft
½-in. pipe diameter	25	63*	8	21	5	13	3	8
¾-in. pipe diameter	48*	119*	16	40*	10	24	6	15

*Wait time exceeds acceptable standards

The cooled hot water sitting in the dead leg branch is lost down the drain before the temperature is suitable for use. The cost associated with this wasted water includes the cost of delivering the potable water to the building, heating and maintaining the hot water, and the sewerage fees to remove the water. Figure 1 illustrates the volume of cooled hot water in a dead-leg segment that is lost down the drain during the wait times from Table 1.

[1] ASPE – American Society of Plumbing Engineers. *Domestic Water Heating Design Manual – 2nd Edition*. Available at https://www.aspe.org/product/domestic-water-heating-design-manual-2nd-edition/.

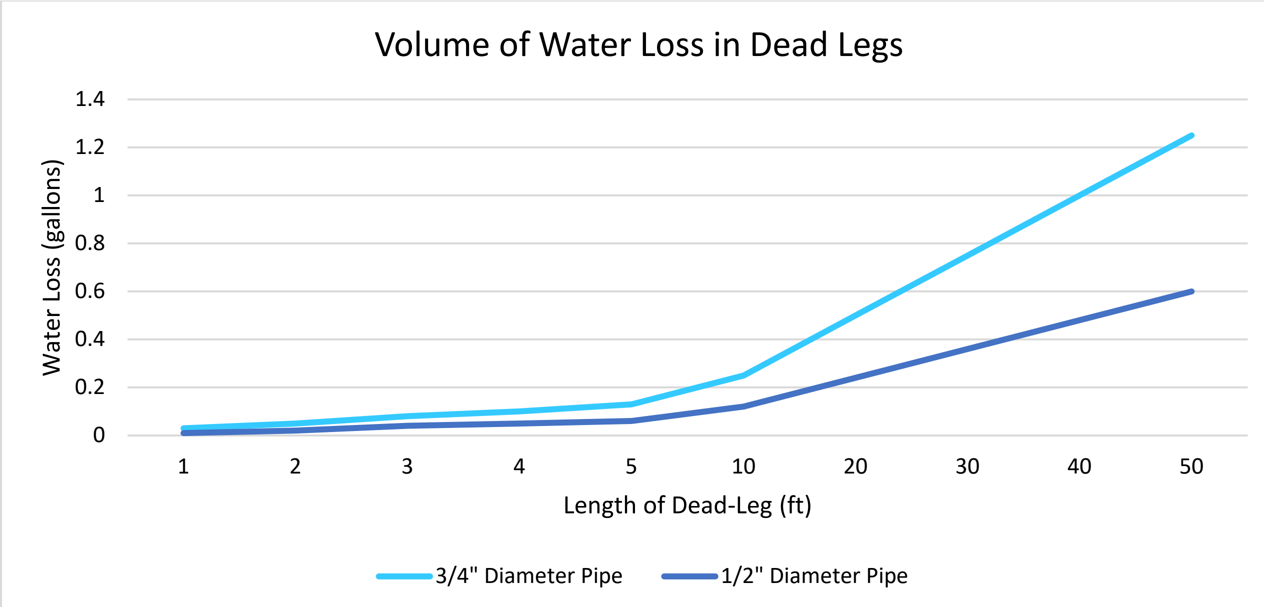

Figure 1. Water Loss per Foot of Dead Leg

Studies quantifying the energy and water use of DHW systems, including HWTM, are limited. Those few available are based on multifamily buildings on the West Coast and the Northeast[1,2,3] These studies indicate standby losses can be up to 30%-40% of the DHW energy load, which itself may be 10%-25% of the total building load. Water savings were not quantified in these studies, but the magnitude of savings can be approximated using Table 1 and Figure 1 and estimating the length of dead legs in the system.

This waste of energy and water can be minimized by proper design and installation, commissioning, maintenance and operation, and in some cases by adding appropriate retrofit solutions for HWTM.

2.1 Understanding Your Building's Hot Water System

A simple way to understand your water and energy savings potential is to consider how much water is wasted from taps before hot water arrives. Because energy and water savings are site specific, the guidelines below can help estimate the potential savings opportunities at your facility.

1. Measure the time it takes for water at a tap to reach the desired temperature. This should be done after a period of no water flow, such as the first use of a sink after an unoccupied weekend. Ideally, no fixture should take longer than 0-10 seconds to deliver hot water.

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[1] Heller J, S Oram, G Mugford, M Logsdon, and B Larson. 2017. *Multi-Family Hot Water Temperature Maintenance Study*. Prepared for Bonneville Power Administration. https://ecotope-publications-database.ecotope.com/2016_007_MultifamilyTemperatureMaintenanceStudyReport.pdf.

[2] Ayala GD and D Zobrist. 2012. Best Practices for Efficient Hot Water Distribution in Multifamily Buildings. In *2012 ACEEE Summer Study on Energy Efficiency in Buildings*. https://www.aceee.org/files/proceedings/2012/data/papers/0193-000030.pdf

[3] Skinner P and G Klein. 2020. Practically Perfect Plumbing In Multifamily. *PHCP Pros.* https://www.phcppros.com/articles/11971-practically-perfect-plumbing-in-multifamily

2. Identify the flow rates of the fixtures. Showerheads and faucets typically have them listed.
3. Estimate the amount of use the fixture gets. Ask questions like: Do occupants regularly use this shower? Do many occupants reside nearby that would use this specific sink? Or is it in a distant bathroom and used rarely?
4. Is the fixture in question far away from a recirculation loop (long dead-leg branch)? The plumbing plans for the building can help with determining this.
5. Check the recirculation pump. Does it operate 24/7? Is there a timer or thermostatic controls?

Based on the responses, it's possible to qualitatively assess the current operation of your DHW system and consider relatively low-cost solutions for "low-hanging fruit." The following are some considerations for simple improvement opportunities.

- Tepid water in a dead-leg section of pipe needs to be flushed before hot water arrives at the faucet. As such, it should be noted that installing low-flow faucet aerators and showerheads may increase the hot water delivery time. When showers take long to heat up, users tend to walk away to let water temper. Installing a shower stop device can limit the amount of water wasted from this user tendency.
- If a distant fixture sees little use, consider installing small point of use (POU) water heaters at the fixture, and valving off the hot water loop to reduce the amount of heat loss in pipes and associated pumping energy. Instantaneous heaters also have the advantage of significantly reducing time-to-tap.
- It is not always possible to access pipes inside walls, but insulation on all segments of hot water pipes should be added/repaired wherever possible. A DHW system with good insulation provides the opportunity to run a recirculation pump less often.

3.0 Occupant Safety and Comfort

Hot water is used in lavatories, showers, kitchens, sinks, tubs, appliances, and more. It provides a comfortable experience when used for hand washing or bathing. Hot water is known to be more effective than cold water at removing oils that can harbor bacteria in heavily soiled clothing or dishes. For these end uses, water needs to be supplied at hotter temperatures; however, care must be taken to avoid scalding occupants, which can occur in two seconds at 150°F, and in six seconds at 140°F. Anti-scald devices should be provided for lavatories and showers. Comfortable temperatures at lavatories and sinks (generally around 105°F) promote longer hand washing times, which improves hygiene.

Care should be taken to ensure water does not become stagnant for extended periods. Stagnant water allows free chlorine disinfectant levels to dissipate, which contributes to pathogen development and can also corrode metal pipes. Additionally, stagnant water at tepid temperatures (below 120°F) in piping or storage tanks can breed Legionella pneumophila, a bacterium that causes Legionnaire's disease when inhaled through spray or mist from a fixture. As such, DHW systems are subject to several important temperature criteria, and in general need to:

- Avoid stagnant water conditions
- Maintain water temperatures according to applicable plumbing codes and ASHRAE guidelines and standards to limit the growth of pathogens such as Legionella
- Provide comfortable temperatures for occupants while avoiding scalding
- Maintain ability to provide hot water for appliances with and without booster heaters

Table 2 shows typical hot water delivery temperatures for different types of fixtures and appliances.

Table 2. Domestic Hot Water Service and Delivery Temperatures

End Use	Recommended Minimum Stored Water Temp °F	Recommended Delivered Temp to Fixture °F
Showers	140	105-110
Lavatories	140	105-100
Residential Sinks and Dishwashers	140	120
Residential Clothes Washers	140	120
Commercial Clothes Washers	140	140-180
Commercial Sinks	140	140-160
Commercial Dishwashers with Internal Booster	140	140-160
Commercial Dishwashers without Internal Booster	180	180-195

Given the variety of temperatures to be managed based on end uses, it is clear why there can be conflicting guidance on setting appropriate temperatures for DHW systems. The most effective and efficient systems often benefit from robust design and operational principles in order to meet all these criteria. Certain facilities such as hospitals and clinics may have more stringent requirements per ASHRAE Guideline 12-2000, *Minimizing the Risk of Legionellosis Associated with Building Water Systems*.

4.0 Hot Water Temperature Maintenance System Options

HWTM systems are part of the design of a DHW system. All DHW systems include a primary heat source and supply piping to the hot water fixtures. Below, find a comparison of common HWTM systems along with a description of each HWTM system option type.

4.1 HWTM System Comparison

Table 3 ranks the most common alternative HWTM systems compared to a traditional HWR system for key attributes such as water savings potential and cost. This table is intended to provide facility managers with important information to understand the impact of existing HWTM systems to water and energy use, and when evaluating potential options. The table is based on input from several Pacific Northwest National Laboratory hot water system experts in engineering design and field surveys. Expand the headings below to find a description of a traditional HWR system and alternative technologies.

Table 3. Alternative Systems Comparison to Traditional HWR System

Measure	Self-Regulating Heat Trace	Point of Use	Internal Recirculation System	Flow Splitter System	Demand Recirculation
Energy Use*	Lower	Lower	Comparable	Comparable	Lower
Water Use	Lower	Lower	Comparable	Comparable	Lower
Operating Costs	Lower	Lower	Comparable	Comparable	Lower
Installation First Cost	Comparable	Lower	Higher	Higher	Lower
Ease of Retrofit	Higher	Higher	Lower	Lower	Higher
Improved Legionella Control	Lower	Higher	Comparable	Higher	Lower

* Does not include energy used to heat incoming cold water supply.

4.2 Traditional Hot Water Recirculation Systems

The most common service HWTM system is a “traditional” hot water recirculation (HWR) system, which moves hot water throughout the system and returns it to the hot water source to be reheated via a dedicated loop and pump. Because this is the most commonly used system in use, this section provides information on efficient pipe layout, balancing valves and pumps that should be considered for optimal design and operation.

4.2.1 Return Loop Layout

The pipe segments in a return loop are classified as:

1. **Mains**: Sections of hot water or return piping that are connected to the hot water generation system. These pipes are typically larger than branches or fixture supply pipes.
2. **Subloops**: Subloops maintain HWR in a zone by connecting to the hot water main with a balancing valve.
3. **Dead-Leg Branches**: Piping sections serving a fixture, or bank of fixtures, without a return to the main distribution system. Dead-leg branches are inevitable but their lengths should be limited to no more than 50 ft.

An efficient HWR system design has the return loop located as close to the hot water fixture(s) as possible (Figure 2). This layout reduces the number and length of dead legs, while optimizing routing of mains and subloops to reduce hot water wait times.

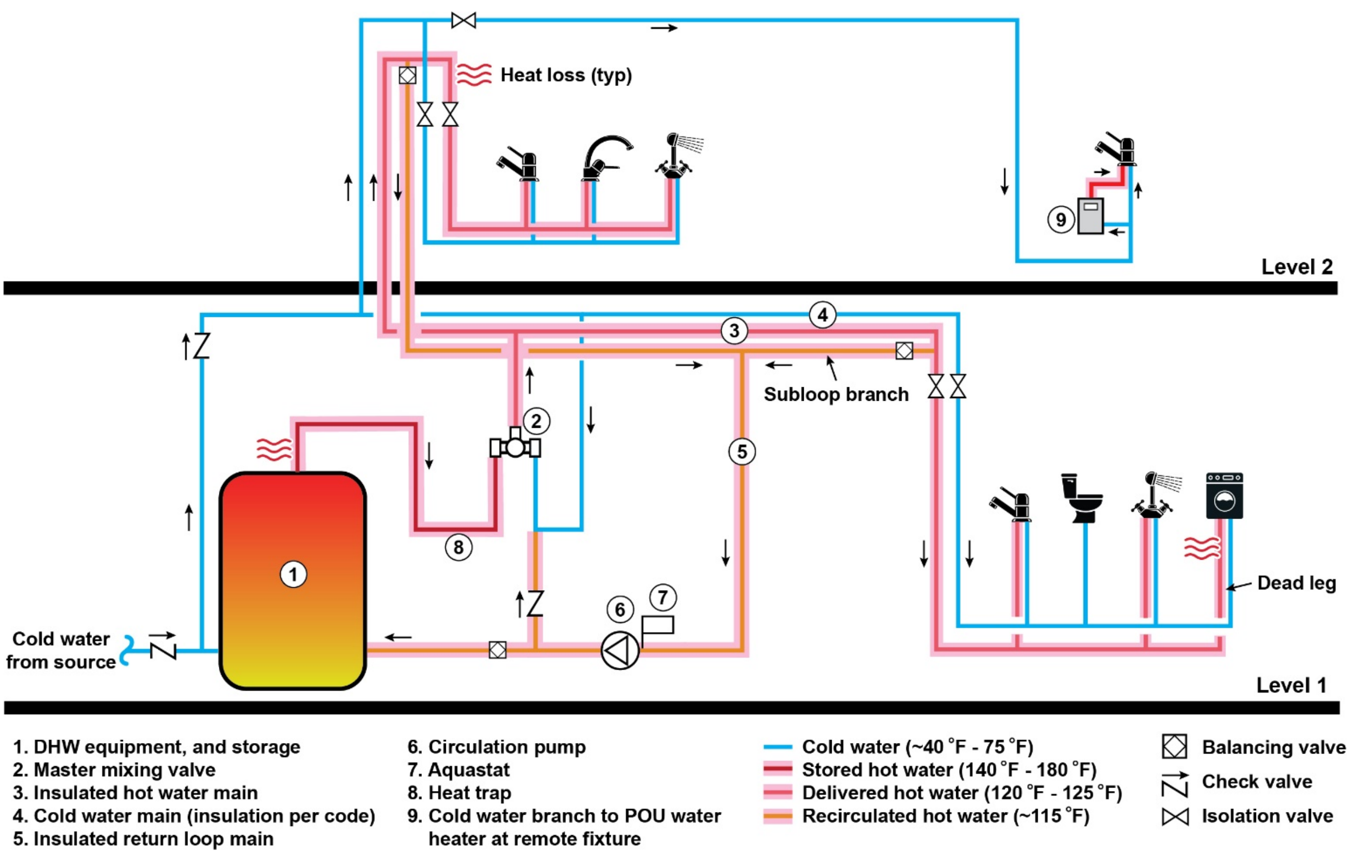

Figure 2. A recirculating hot water system

4.2.2 Balancing Valves

Because water flows through the path of least resistance, balancing valves are used to throttle hot water in the most remote segment of the return loop to balance out heat losses throughout the system. Three types of valves are typical in HWR systems: pressure dependent, fixed flow, and thermostatic valves. Recognizing the types of valves installed in your facility can help with troubleshooting and maintaining a system.

Pressure Dependent - The most common type in traditional HWR systems, this type maintains a set pressure across the valve. These valves are field adjustable and require an iterative process to correctly balance the entire recirculation system. They typically have a minimum flow rate of 0.5 gpm.

Fixed Flow - This valve type is factory set to a specified flowrate. The valve has replaceable internal components for easy maintenance. They are prone to clogging due to the small orifice design. They are available down to a minimum flow rate of 0.33 gpm.

Thermostatic - A dynamic valve that opens automatically based on a set temperature at the connection to the return loop. While more expensive upfront, they eliminate the need for field adjustment, saving installation labor. The minimum flowrate is 0.1 gpm, which can better match the heat loss calculations to optimize pump sizing.

4.2.3 Pumps

Hot water circulation pumps serve an important role in a traditional HWR system by moving cooled hot water back to the water heater. This recirculation maintains the hot water supply in the distribution piping up to the desired temperature under conditions of low or no demand. As the HWR system is essentially a closed loop in conditions of low or no demand, the pump head is determined by the friction losses in the return pipe network. The pump flow capacity is a function of (a) the heat lost through insulation over a period of time and (b) the acceptable temperature drop at the balancing valves. Oversized pumps can induce high flow velocities that over time will erode the pipe wall, causing pinhole leaks that may be difficult to isolate and repair.

HWR pumps are typically small, in-line mounted, and constructed of bronze or stainless steel for corrosion resistance and to comply with lead-free requirements for potable water systems. They can operate at constant or variable speeds, with newer electronically commutated motor models having onboard controls to “learn” user demand patterns. Traditional HWR systems are typically controlled from a temperature sensor (called an aquastat) located upstream of the circulation pump. Some designs activate the circulation pump on a timer or a push button at the most remote fixture.

4.3 Alternative HWTM Systems

The two most common alternatives to a traditional HWR system are self-regulating heat trace (heat trace) and point-of-use (POU) systems. Recently, two innovative alternatives to traditional HWR have come on the North American market: internal recirculation and flow splitter systems. A hot water system design may incorporate a combination of these HWTM systems based on the building’s layout to minimize wait times and optimize water and energy savings. Any well, maintained and operated HWTM system will safely deliver hot water within a maximum wait period to save water and energy.

4.3.1 Self-Regulating Heat Trace System

An HWTM heat trace system is a series of cables installed along the hot water piping to replace standby losses (Figure 3). This system consists of specialized self-regulating cables, connection kits, and custom electronic controls (Figure 4). The cable is installed directly on the hot water supply pipes underneath the insulation, eliminating the need for a traditional recirculation system. The cable controls are set to the desired temperature to be maintained, and the cable adjusts its power output to replace heat loss through the insulation during periods of low demand. It is not intended to replace the primary domestic hot water generation system or to provide freeze protection.

A self-regulating heat trace system can use less energy than a traditional HWR system as it only heats the section of hot water pipe that needs it and does not require pumping hot water through the whole system in two sets of pipes.

If being installed as a retrofit, careful coordination with the building's electrical system is required during design to ensure required wiring, ground fault circuit interrupter breakers, local disconnects, and other associated components are provided and installed per the manufacturers' instructions for components in contact with potable water.

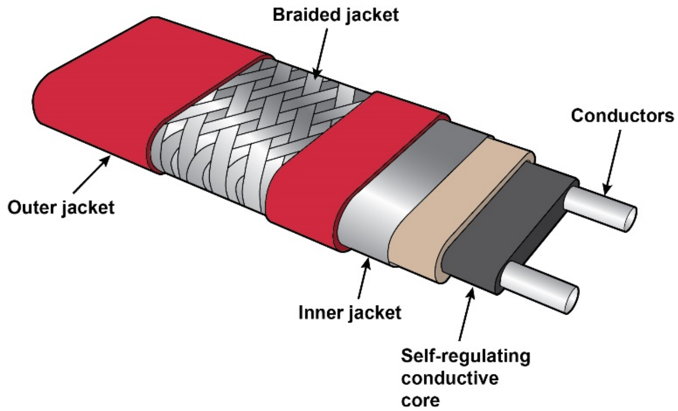

Figure 3. Self-Regulating Heat Trace Cable

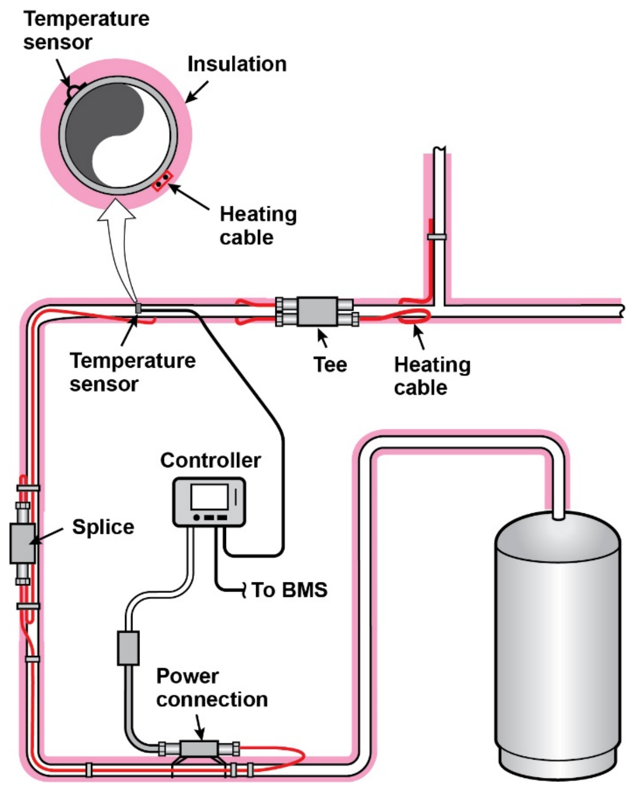

Figure 4. Self-Regulating Heat Trace System Components

4.3.2 Point-of-Use System

Small POU systems are supplied by a cold water connection only to eliminate the need for hot water temperature maintenance. Options are typically between instantaneous water heaters and small storage tanks (2-10 gallons) (Figure 5). Instantaneous water heaters powered by electricity draw larger current than a small storage tank type model. Instantaneous gas water heaters are typically larger and applicable to high-volume demands such as showers, commercial kitchens and laundry. An inefficient architectural layout may be better served with several smaller, centralized DHW systems (generation and recirculation) for higher-demand fixture banks (showers, commercial kitchens) and distributed POU water heaters at remote fixtures.

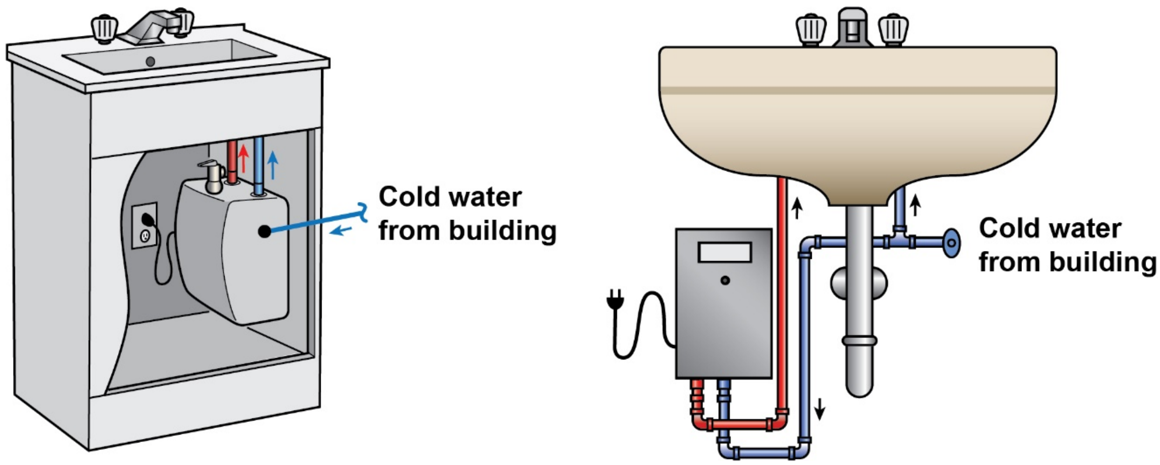

Figure 5. Instantaneous POU Electric Water Heater (left), Small Tank POU Water Heater (right)

4.3.3 Internal Recirculation System

This “pipe in a pipe” system has the recirculation loop main installed inside the hot water supply riser, eliminating a separate insulated return riser and replacing heat losses via the hot water supply temperature (Figure 6). It is best suited for multi-story buildings with higher hot water demands as the hot water riser pipe size needs to account for the internal return pipe diameter. As in a traditional HWR system, care must be taken to reduce the quantity and length of dead legs to reduce delay in hot water delivery time.

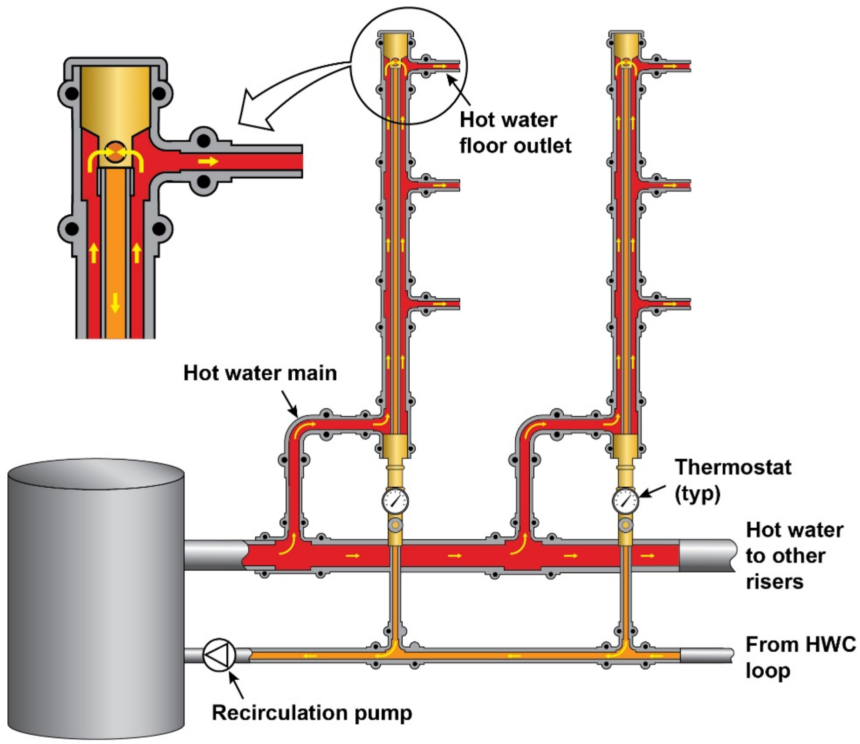

Figure 6. Internal Recirculation System

4.3.4 Flow Splitter System

A flow splitter valve has an internal Venturi nozzle which creates a small pressure differential to direct water flow through a branch subloop (Figure 7). The valve maintains a minimum open position, allowing full flow through the main loop at peak demand conditions. During low demand, the flow is directed through the subloop, thus reducing stagnation.

A flow splitter system requires careful planning of the piping network to create branch subloops to the hot water fixtures, reducing the size of (and possible need for) a traditional HWR system. Use of this system is best suited for new construction and retrofit of facilities that may encounter stagnant water due to low occupancy, or that require a high level of hygiene such as hospitals and clinics.

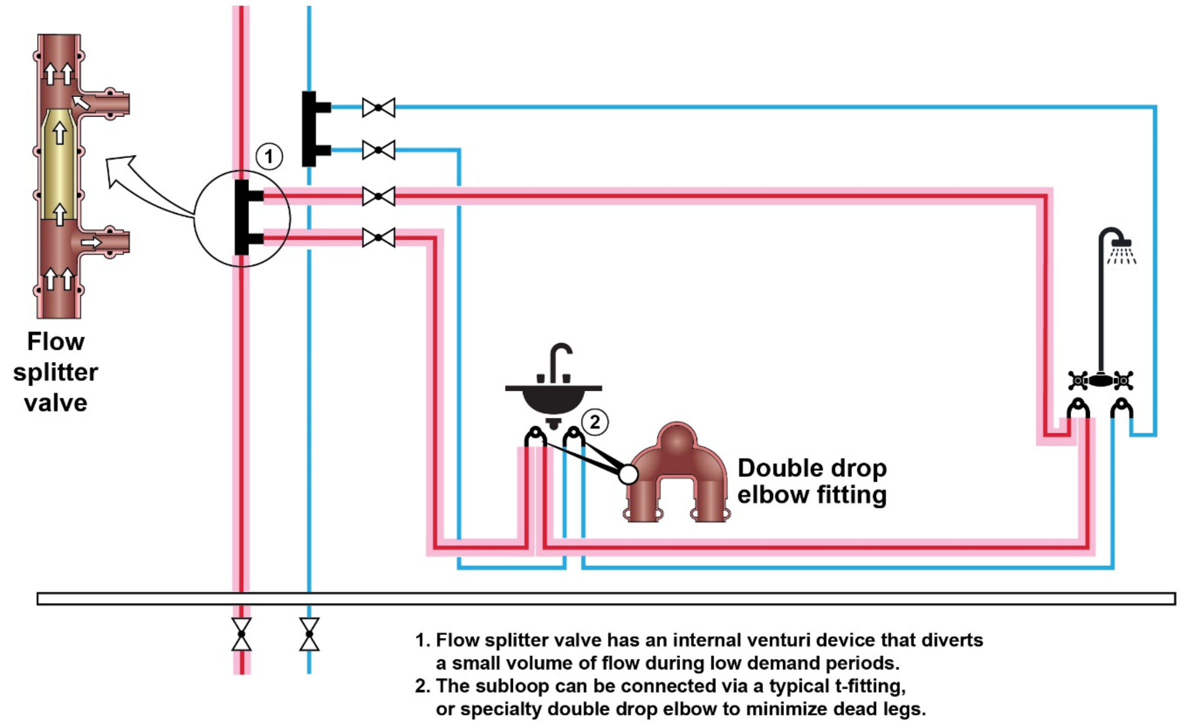

Figure 7. Flow Splitter System

4.3.5 Demand Recirculation

Small "demand" recirculation systems circulate water to the furthest fixture when called, either by an occupancy sensor or push button (Figure 8). Although allowed by recent code updates, these systems are not recommended for commercial applications as they connect the hot water supply pipe to a small pump at the furthest fixture, allowing tepid water to flow into the domestic cold water supply pipes. This configuration could contribute to Legionella growth, introduction of dissolved metals from the hot water heater into the cold water supply, and potential scalding if thermostats are not correctly set.

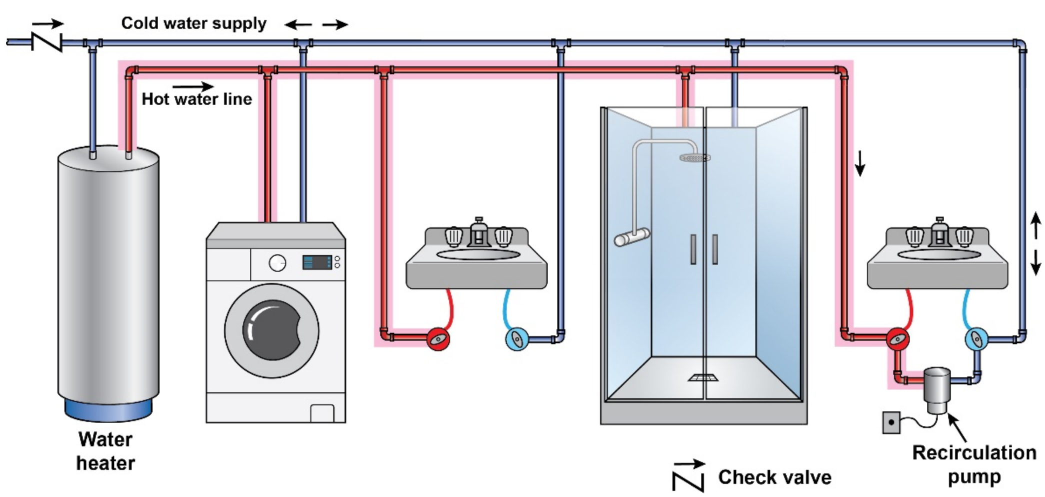

Figure 8. Demand Recirculating System

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