Designer's Guide

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Domestic Hot Water Recirculation Systems

Domestic hot water systems have been designed in buildings for many years dating back to ancient times. Recirculating hot water systems are not quite that old. I am not sure where the first recirculated hot water system was installed. I do know the industrialized cities, in the early years of the United States, had some domestic hot water systems that used gravity circulation in a vertical loop of piping. Hot water is less dense than cold water so naturally the hot water would rise and the cold water would fall back to the water heater in a return leg from the highest portion of the system back to the cold water inlet of the water heater. If the piping is installed properly without check valves and the heater is in a basement or on a lower floor, gravity circulation will occur naturally.

Many older buildings on the East Coast of the United States had hydronic heating systems and domestic hot water systems installed with gravity circulating systems before the advent of the circulating pump. These systems were generally limited to three floors or the slope of the hot water piping in the basement. Larger systems did not circulate well by gravity because the water in the pipe would cool off with inadequate insulation and cause the water to stop flowing as the hot water lost its buoyancy.

Large plumbing systems installed without domestic hot water recirculating pumps are notorious for causing time delays while allowing the cooled water in the domestic hot water piping to pour down the drain line while waiting for the warm water to get from the water heater to the farthest fixture. The water pouring down the drain had been previously heated and was a waste of energy and a cost to the owner for wasted fuel, water and sewer rates.

Modern systems

Since the advent of the circulator pump, several improvements have been made in the circulator pumps. Early pumps were the same ones used on hydronic systems. The pumps were made of ferrous metals with cast iron and steel parts and most of them suffered corrosion problems shortly after being installed in domestic hot water systems. Hydronic systems were closed systems with air eliminators to keep air and oxygen out of the piping circuit. Some hydronic systems use corrosion-inhibiting chemicals to help prevent corrosion of the ferrous metals. Oxygen contributes to the corrosion process and domestic water systems are open systems with air and oxygen entrained in the water flow. It is for this reason that hydronic pumps and piping can be ferrous metals while domestic hot water systems should be constructed of, and specified as, non-ferrous bronze or stainless steel parts with copper piping. Pump manufacturers have continually improved the materials, bearings, seals and efficiencies of the circulator pumps.

The domestic hot water system design guides from ASHRAE and ASPE indicated that it was acceptable to have a hot water system without recirculation as long as the distance from the water heater to the farthest fixture did not exceed 100 feet. This was only a suggested guideline for adding recirculating pumps to systems over 100 feet. This was a subjective number and since the advent of the Energy Policy Act of 1992 the flow from many plumbing fixtures has been significantly reduced. This was causing significant delays in getting hot water to some fixtures.

Consider the following example.

Given: A 50-gallon water heater with two showers and six lavatories located 100 feet away with a 1-inch hot water supply pipe with no hot water recirculation.

Prior to 1992:

The flow rate at a lavatory typically ranged from 3 to 5 gallons per minute (gpm) and the flow rate at the shower was typically 3 to 5 gpm with some models offering flow rates as high at 7 to 10 gpm.

Using a single 3 gpm lavatory in the morning, assuming the faucet is turned on to full hot water until the hot water gets to the faucet, the flow rate would be about 3 gpm through the 1-inch hot water main. The velocity of flow would be about 1.17 feet per second in a 1-inch type “L” copper pipe. In 1992, the person using the lavatory for the first draw of hot water would have to wait almost 85 seconds, or one minute and 25 seconds, before the hot water arrived at the fixture. During this time water that had been previously heated was pouring down the drain.

After 1992:

The Energy Policy Act of 1992 requires lavatory faucets to have a maximum of 2.5 gpm flow rate and many manufacturers offer 2 gpm, 1 gpm and 0.5 gpm flow restrictors on their faucets. Assuming we have a 2 gpm flow restrictor and the faucet is turned to full hot, the velocity of flow in the hot water pipe would be 0.78 feet per second. Taking into consideration the 100 feet of pipe from the heater to the faucet, it would now take more than 128 seconds to get hot water from the heater to the faucet. That is more than two minutes standing at the sink watching cooled hot water pour down the drain before the hot water arrives. Most people would not wait that long — they would simply wash their hands in the ambient temperature cool water and be on their way. What if we used the 0.5 gpm flow restrictor on the faucet in this example? The wait would be over 500 seconds, or more than eight and one-half minutes.

The above example illustrates the need for a hot water recirculating system or temperature maintenance heating cables. This article focuses on sizing recirculating pumps, so we will hold off on discussions about temperature maintenance heating cable for another time.

ASPE sizing recommendations

ASPE recently suggested changing from the 100 foot distance criteria to a time delay of 0 to 10 seconds from the time a faucet is turned on until hot water reaches the fixture for residential and office buildings. ASPE also recommends 11 to 30 seconds as marginally acceptable for other building types depending on the application. Any wait exceeding 30 seconds is considered to be unacceptable, according to the ASPE *Domestic Hot Water Heating Design Manual*.

Designing the domestic hot water recirculating system

Given the 10-second and 30-second criteria, there are a few considerations when piping the recirculated hot water return (HWR) piping.

1. **Routing.** Route hot water recirculation lines as close to fixtures as possible. The closer you can get the recirculated line to the fixture, the less time it will require to get hot water at the fixture.
2. **Balancing Valves.** If the building has multiple hot water mains, each branch should have a balancing valve and check valve before connecting to the hot water return main. This prevents short-cycling of the hot water through the closest circuit of piping or the path of least resistance.
3. **Minimum Pipe Size.** The minimum pipe size for the hot water return system piping should be 3/4-inch pipe. I often see 1/2-inch pipe installed and two things can occur. The smaller pipe coupled with too large of a recirculating pump causes high flow velocities and erosion of the inside wall of the HWR piping. There are some small systems where 1/2-inch HWR pipe will work, but on most commercial applications where the distance is greater than 50 feet it can cause pumping problems. Half-inch pipe flowing 3 gpm has a head loss of 16.48 feet of head per 100 feet of pipe. If the piping circuit is 300 feet long, the pump head required would be 49.44 feet. This would exceed the head on most small circulators. If a larger circulator is installed, the velocity increases and typically erosion of the inside of the pipe wall occurs.
4. **Piping Hot Water Returns in Systems with Mixing Valves**. When there is a mixing valve in the system, the Tempered Water Return (TWR) must split and be routed to the cold water side of the mixing valve and to the cold water inlet of the water heater. A balancing valve should be placed in the line going to the water heater and the mixing valve for flow adjustments if needed. If this is not done, the temperature of the tempered water system will rise to nearly the thermostat setting on the water heater.
5. **Sizing the circulator.** The ASPE *Data Book* has a precise way of selecting and sizing the circulating pump based on a 20-degree temperature loss from the water heater out to the farthest fixture and back to the circulator near the water heater. If the system has 140-degree water in the water heater, the sizing method maintains 130-degree hot water at the end of the system. Back at the cold water inlet to the water heater, the temperature would then be approximately 120 degrees. The calculation is based on heat loss in the hot water piping circuit. Table 2 in chapter 4 of the ASPE *Data Book* lists the British Thermal Unit per Hour (BTUH) losses for insulated and bare piping based on a 70-degree ambient temperature. A quick and simple way to estimate insulated pipe is to assume 25 to 30 gpm per linear foot, ignoring the hot water supply and return pipe size. This may simply result in a system where the temperature differential in most cases will be slightly less than 20 degrees. If you want to take the time to calculate the system exactly, use the Table 2 in the *Data Book* and the BTUH losses can be summed up for the various lengths of different pipe sizes and a total BTUH loss can be obtained. For a 20-degree temperature differential you would then divide by 10,000 to get the required flow rate. This is how the gpm is determined for the pump size. For the pump head requirement, the appropriate gpm is assigned to each section of pipe based on the BTUH loss requirements above and from pipe friction loss charts, and then a total feet of head or pressure drop in pounds per square inch (psi) can be determined. Remember when selecting pumps to convert from psi to feet of head. Most manufacturers list their pumps on curves listing feet of head vertically and gpm horizontally. Just remember: 1 psi = 2.31 feet of head, and 1 foot of head = 0.433 psi.

Sizing example

Let's assume we have a building that is 400 feet long and 200 feet wide. The mechanical room is in the back, left corner of the building. There are restrooms throughout the facility and the front right corner has a restroom with four lavatories and a janitors closet. We route the hot water piping 400 feet along the back of the building and provide three 100-foot branches to various groups of fixtures in the center of the building. Then the pipe turns and runs 200 feet

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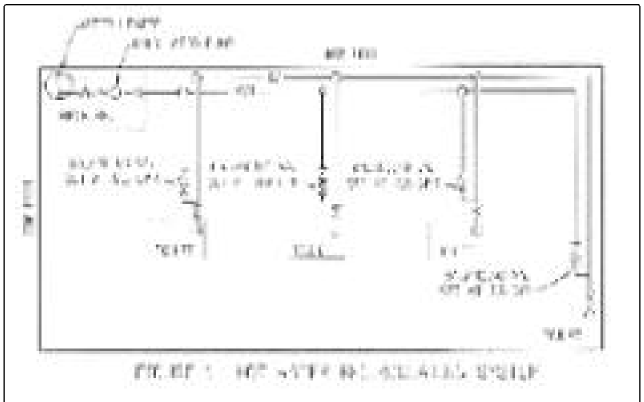
to the opposite corner, where the toilet room is located at the front, right corner of the building.

We will locate a tee for the hot water return as close to the drop into the plumbing chase as possible. In cases where 0.5 gpm flow restrictors are used on the lavatories, the designer should consider dropping the hot water into the plumbing chase and circulating through the chase and rising up on the other end of the chase with the HWR piping.



This piping circuit is 600 feet out and 600 feet back for a total of 1,200 feet. Multiplying that by 30 BTUH per foot yields 36,000 BTUH. We divide the total heat loss of 36,000 BTUH for the main by 10,000, for a required recirculation flow of 3.6 gpm for the main. A balancing valve and check valve could be placed at the end of the main with a note on the drawing to set the balancing valve at 3.6 gpm.

Along the back of the building, there were three branches 100 feet out and back with 200 feet in each circuit. Again multiplying times 30 BTUH per foot, the resulting loss is 6,000 BTUH. We divide the total loss of 6,000 for each branch by 10,000 to get 0.6 gpm for each branch.

Each hot water branch across the back of the building should have the hot water return pipe as close to the last fixtures as possible with a balancing valve and a check valve. The balancing valves should be labeled on the drawings to be set at 0.6 gpm each. (In some cases you could round this up to one gpm if there are not too many branches.)

Calculating the total recirculation flow required, 3.6 (main) plus 0.6 (branch 1) plus 0.6 (branch 2) plus 0.6 (branch 3) yields a total of 5.4 gpm.

Using the friction loss tables in Cameron Hydraulic or the ASPE *Data Book*, we can calculate the head requirements for the recirculated flow through the various pipe sizes in the system (see Table 1). Based on the assumptions shown, t he minimum pump selection for this example would be a 6 gpm pump with 16 feet of head. □

Table 1 — Head Requirement Calculations

100 ft. of 1 1/2 in. HW main at 5.4 gpm =	0.6 ft. of head
100 ft. of 1 1/4 in. HW main at 4.8 gpm =	0.7 ft. of head
100 ft. of 1 1/4 in. HW main at 4.2 gpm =	0.6 ft. of head
300 ft. of 1 in. HW main at 3.6 gpm =	3.75 ft. of head
300 ft. of 1 in. HWR piping at 3.6 gpm =	3.75 ft. of head
100 ft. of 1 in. HWR piping at 4.2 gpm =	1.40 ft. of head
100 ft. of 1 in. HWR piping at 4.8 gpm =	1.90 ft. of head
100 ft. of 1 in. HWR piping at 5.4 gpm =	2.50 ft. of head
Total ft. of head =	15.20 ft. of head