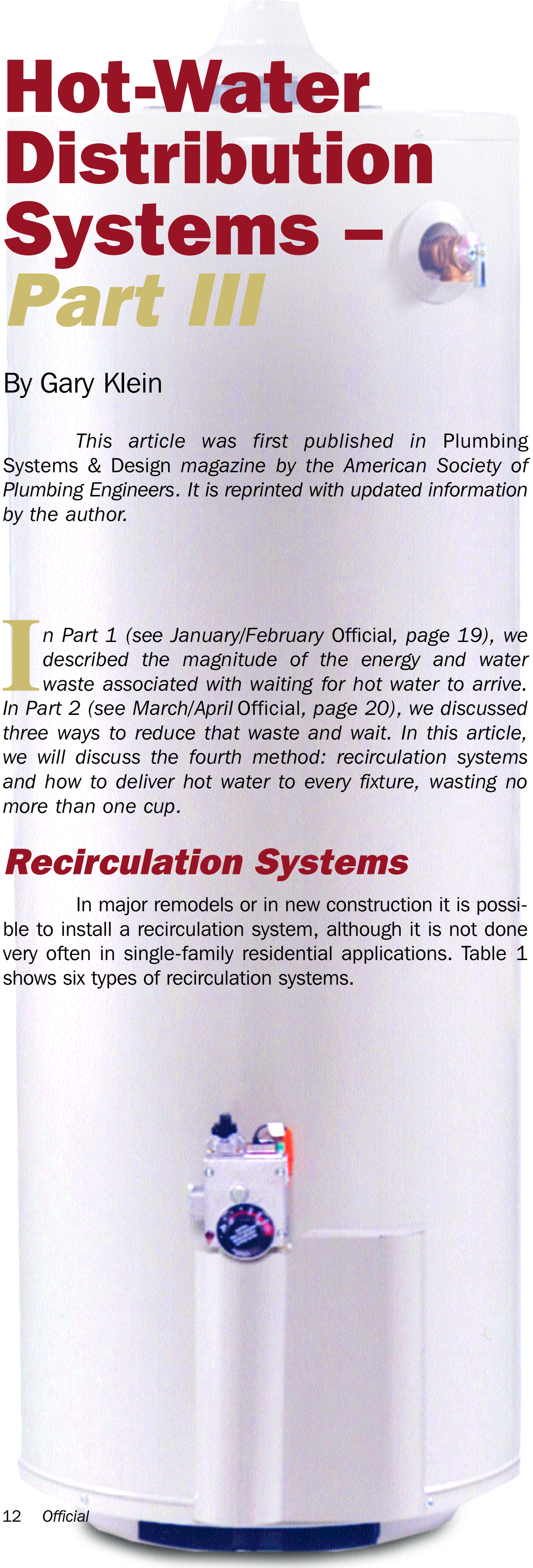


Hot-Water Distribution Systems – *Part III*

By Gary Klein

This article was first published in Plumbing Systems & Design *magazine by the American Society of Plumbing Engineers. It is reprinted with updated information by the author.*

In Part 1 (see January/February Official*, page 19), we described the magnitude of the energy and water waste associated with waiting for hot water to arrive. In Part 2 (see March/April* Official*, page 20), we discussed three ways to reduce that waste and wait. In this article, we will discuss the fourth method: recirculation systems and how to deliver hot water to every fixture, wasting no more than one cup.*

Recirculation Systems

In major remodels or in new construction it is possible to install a recirculation system, although it is not done very often in single-family residential applications. Table 1 shows six types of recirculation systems.

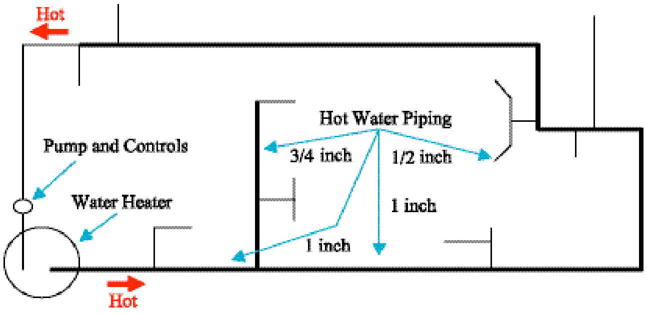
Table 1. *Types of Recirculation Systems*

Thermosyphon (24 hours per day, gravity)
Continuous Pump (24 hours per day)
Timer-Controlled Pump (16 hours per day)
Temperature-Controlled Pump (12 hours per day)
Time and Temperature-Controlled Pump (8 hours per day)
Demand-Controlled Pump (10 minutes per day)

Source: Gary Klein

All but the demand-controlled pump are what I call a full-loop recirculation system. A full-loop recirculation system (Figure 1) is characterized by fixtures located most of the way around the loop and the distance between the last fixture and the water heater is relatively short. Return lines, even in larger commercial installations are generally 1/2 inch diameter. It is necessary to heat the entire loop in these systems, because the controls and associated sensors are located at the pump.

Figure 1. *Full-Loop Recirculation Systems*



Source: Gary Klein

Thermosyphon

Thermosyphon-based recirculation systems use the temperature difference between the hot and cold water and the height of the building to drive the water around the loop. They work because heat is lost from the time the water leaves the water heater until it returns at some colder temperature to the water heater. It takes energy to reheat the water; how much depends on the heat loss and the flow rate. Pipe insulation is often neglected, which means that there is significant heat loss as the water moves around the loop. Assuming that there is only a 5° F temperature drop as the water moves around the loop and that the water is flowing at 1 gpm, the energy cost to keep the loop warm 24 hours per day would be $336 per year with natural gas ($619 with electricity). (See the note in Table 2 for the prices.) This is significantly more than the cost of heating the water that is actually used in the home.

The costs to operate recirculation systems are proportional to both flow rate and temperature drop. If the temperature drop is larger–say 10° F–the costs to operate the loop would double. If the flow rate is lower–say 0.25 gpm–the costs would drop in half. The cost estimates in this article are based on a conservative combination of flow rate and temperature drop.

Continuous-Pump

A continuous-pump 24-hour recirculation system is thermally very much like a thermosyphon system, with the addition of a small pump. Assuming a 40-watt pump, this will add $30 per year to the cost.

Timer-Controlled Pump

Installing a timer to control the hours of operation of the pump has the effect of reducing the costs in proportion to reduced hours of operation. Assuming the timer is set for 16 hours per day, roughly the waking hours, the cost would be $244 per year.

Temperature-Controlled Pump

Another method of controlling the pump is to install an aquastat, which is a method of temperature control similar to that used in an automobile radiator. The aquastats that are often used in single family applications are set to open when the temperature drops to 95° F and to close when the temperature rises to 115° F—a 20° F bandwidth. Assuming that the minimum desired hot water temperature is 105° F, the temperature in the recirculation line is colder than desired at least half the time. A better choice from a water temperature perspective would be to use an aquastat with a minimum set point of more than 105° F. However, with a bandwidth of 20° F, the lowest water heater setting must be above 125° F, otherwise the pump will never shut off. An aquastat can be installed without a timer. For purposes of this article, we will assume that the pump will run half the time, or 12 hours per day, for an annual cost of $183.

Time- and Temperature Controlled Pump

Sometimes both a timer and an aquastat are used together. Assuming a 16-hour time clock, the aquastat will allow the pump to come on roughly half that time, or eight hours per day. This brings the annual cost down to $122, which is still more than the energy cost associated with the wasted water.

Demand-Controlled Pump

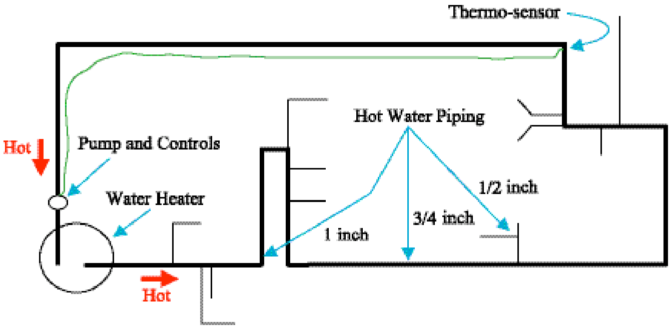
Demand control is the last method of operating a recirculation system. This system uses one or more consumer-activated devices (button, remote, flow switch, door switch, motion sensor)–located, where convenient, near the hot water fixtures–to tell the pump to come on. A thermo-sensor, looking for a small (5-10° F) rise in temperature above the ambient pipe temperature, tells the pump to shut off. There are two ways to install the pump and the thermo-sensor in what I am calling a half-loop recirculation system. (See Figures 2 and 3.)

A half-loop system differs from a full-loop system in two ways: (1) all of the fixtures are on the "supply" portion of the loop, and the distance from the last fixture to the water heater is large (one-third to one-half the loop length); and (2) the thermo-sensor is located just after the last fixture.

Locating the thermo-sensor just after the last fixture means that it is not necessary to heat half the loop, which reduces the heat loss from the pipes. In general, the return line should be no smaller than 3/4 inch. This is to accommodate the higher velocity found in demand pumps, since they are intended to "prime the line" quickly and then shut off.

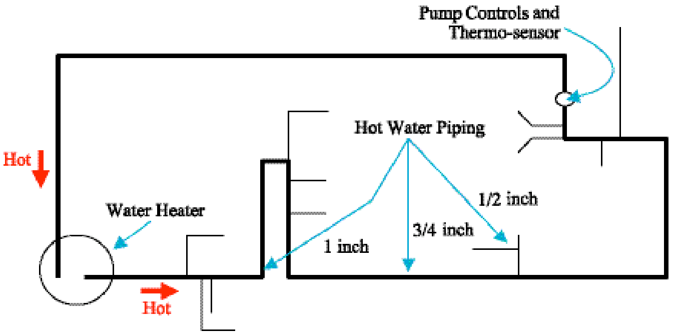
Both of these features reduce the cost of operating the half-loop system to less than $15 per year in either configuration.

Figure 2. *Half-Loop Recirculation System: Pump Separated from the Thermo-Sensor*



Source: Gary Klein

Figure 3. *Half-Loop Recirculation System: Pump Located with the Thermo-Sensor*



Source: Gary Klein

Table 2 compares the operating costs of each alternative discussed in this series to the costs of standard distribution systems. Standard distribution systems cost $116 for

Table 2. *Relative Costs of Operating Standard and Alternative Distribution Systems*

Standard Distribution System	**Water and Wastewater**	**Natural Gas**	**Electricity**
Total Annual Cost for Hot Water Including Waste	$116	$250	$465
Annual Cost Associated with the Wasted Water	($36)	($84)	($156)
Annual Cost Associated with Intended Water Use	$80	$166	$309
Additional Energy Costs to Operate Recirculation System			
Thermosyphon (24 hours per day, gravity, 5F temperature drop)		$336	$619
Continuous Pump (24 hours per day, 5F temperature drop)		$366	$649
Timer-Controlled Pump (16 hours per day, 5F temperature drop)		$244	$433
Temperature-Controlled Pump (12 hours per day, 5F temperature drop)		$183	$325
Timer and Temperature-Controlled Pump (8 hours per day, 5F temperature drop)		$122	$216
Demand-Controlled Pump (10 minutes per day)		$15	$27
Additional Costs Associated with Residual Wasted Water			
Manifold Systems (approximately 25% reduction)	$27	$63	$117
Heat Trace (approximately 90% reduction)	$4	$284	$284
All 6 Recirculation alternatives (approximately 80% reduction)	$7	$17	$31
Notes: Water and wastewater costs are $0.05 per gallon combined. Natural gas costs are $0.92 per therm. Electricity costs are $0.087 per kWh. Heat trace is only operated with electricity. The costs are the same whether the water heating fuel is natural gas or electricity.			

Source: Gary Klein

the water and wastewater and $250 for the natural gas to heat the water, for a total of $366 per year. We have assumed that in the standard system, 20 gallons are wasted every day waiting for the hot water to arrive at the fixtures. This means the "intended" hot water use is less than the total that was heated or brought into the house. For the standard system this lower number is a combined cost of $246 per year.

It is necessary to add the costs to operate each alternative to the costs associated with the "intended" hot water use to get the new total cost for reducing the waste of water and providing convenience. As discussed in Part 2, manifold systems are only better than standard distribution some of the time. Assuming that the average reduction in the waste and wait while waiting for the hot water to arrive is about 25 percent, the annual cost to operate manifold systems is $336 ($246 plus $27 for water and wastewater plus $63 for natural gas). This is less than the cost of operating a standard distribution system, but it is still relatively wasteful of hot water.

Heat trace can be installed on all trunk and branchlines and has the greatest potential to reduce waste and wait. However, it requires more electricity to operate than is associated with wasted water. Assuming that there is only 100 feet of hot water piping, which is very conservative, the annual cost to operate heat trace is $534 ($246 plus $4 plus $284).

Recirculation systems have the potential to reduce the waste and wait the same amount as heat trace. However, the branchlines still have water in them that must be run out of the pipe before hot water arrives, so we have assumed that there is more residual waste. The operating costs, assuming natural gas water heating, range from $636 ($246 plus $366 plus $7 plus $17) for the continuous pump down to $285 ($246 plus $15 plus $7 plus $17) for the demand-controlled pump.

Among all the alternatives we have examined, only manifold systems and demand-controlled recirculation systems cost less to operate than it costs to run water down the drain waiting for the hot water to arrive. Of these, demand recirculation systems are the most efficient, increasing convenience, minimizing the waste of water and consuming less energy for a combined savings of $81 ($366 - $285) per year compared to current practice. A reasonable marginal cost to install a demand-controlled recirculation in single-family new construction is roughly $500 including insulation for the circulation loop and the branchlines, the additional plug and the sensor and activation mechanisms. This makes it a very sensible investment, particularly when included in the mortgage where the monthly operational savings are greater than the increase in the monthly mortgage costs.

Hot Water, Wasting Less Than One Cup

The key to delivering hot water to a fixture while wasting less than one cup waiting for it to arrive is that there cannot be more than one cup of water in the branchline between the fixture and the source of hot water (see Table 3).

Table 3. *Number of Feet Containing One Cup of Water*

	Feet per Cup			
Type of Pipe	**3/8"**	**1/2"**	**3/4"**	**1"**
"K" Copper	9.48	5.52	2.76	1.55
"L" Copper	7.92	5.16	2.49	1.46
"M" Copper	7.57	4.73	2.33	1.38
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02

Source: Gary Klein

In fact, because it takes energy to heat the pipe, there must be less than one cup in the branchline. For short branchlines, a good estimate is to assume that 1.5 to 2 times the volume of water that is in the pipe must come out of the pipe before hot water gets from the source of hot water to the fixture. Practically speaking, this means that 1/2 inch copper branchlines need to be less than 3 feet long and 3/8 inch branchlines need to be less than 5 feet long. If you use PEX, the length increases slightly to 4 and 8 feet respectively. These are tight but buildable constraints whenever it is possible to plumb up from the floor below, for example, in single-story houses over a basement or between the first and second floor of a two-story house. It is still possible to get close to this when plumbing from above, but unless the circulation loop is brought down into the wall, it is more practical to expect the waste will be closer to 2 cups.

The source of hot water can either be a water heater or a circulation loop. The analysis presented in this series has shown that the most energy-efficient and cost-effective alternative is a circulation loop with a demand-controlled pump, so it makes sense to combine the demand-controlled circulation system with small volume branchlines.

To provide the best system for your customers, the circulation loop and the branchlines to each fixture need to be insulated. The major benefit of insulation is that the hot water lines will stay hot longer between uses. Selecting the R value so that the temperature stays above 105° F for 45-60 minutes will generally cover the delay between uses during the morning and evening peak periods. The effective pipe length of the circulation loop should be kept to a minimum. This reduces the pressure loss in the loop and minimizes the time it takes for the demand-controlled pump to prime the loop with hot water.

If the waste is limited to one cup, at a flow rate of one gpm, it will take less than four seconds for the hot water to arrive. At two gpm it will take less than two seconds. Even if the waste is closer to two cups, the time will still be less than eight seconds at one gpm. Given that many people wait more than 90 seconds, this system will provide hot water at least ten times faster, a significant improvement over current practice. At these short delays, many people will feel that their convenience desire for "hot water immediately" (see Part 2, page 20 in *Official,* March/April 2005) will have been met.

The data presented in Table 2 assumed that all recirculation systems reduced the waste of water by 80%. Assuming that the typical waste per event is 0.5 to 1 gallon, this translates into a residual waste of 1.6 to 3.2 cups per event. Limiting the waste of water to one cup increases the efficiency to an average of 90%, roughly halving the water and energy costs associated with the wasted water shown in Table 2. This reduces the operating costs by $3.50 per year for the water and waste water and $8.50 per year for the natural gas, bringing the combined cost of operating a demand-controlled circulation system down to $273 per year, a savings of $93 per year.

Conclusions and Observations

This series of articles has shown that there is a significant amount of water and energy wasted while waiting for hot water to arrive. The focus has been on the costs to the consumer. There are additional savings that will accrue to the water and wastewater utilities, including reductions in energy consumption and chemical use due to the reduced throughput of water.

A circulation system with a demand-controlled pump has been shown to use the least energy, waste the least water and do so the most cost-effectively of all alternatives examined. If designed and installed correctly, in new construction it is possible to reduce the waste and wait by more than 90 percent compared to standard practice. It is also possible to retrofit demand-controlled circulation systems. The savings will still be significant, particularly in homes with single trunk and branch systems.

Demand-controlled circulation systems are also relatively resource efficient during construction. In Part 2, we discussed a manifold system installed in a 3000-square-foot home in San Ramon, California. There were more than 900 linear feet of hot water pipe in the house. The same home with a demand-controlled circulation system would use fewer than 300 linear feet.

Although single-family homes were used for the examples in this series, the same principles apply to multi-family and commercial buildings. As we learn more about how they perform in these installations, we will share our findings.

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in Lesotho, the rest in the USA. Currently, he is an Energy Specialist at the California Energy Commission and is the chair of the recently formed Task Force on Residential Hot-Water-Distribution Systems. He can be contacted at Gklein@energy.state.ca.us