Hot-Water Distribution Systems – *Part II*

By Gary Klein

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In Part 1 of this article (see January/February 2005 – *Official*, pp. 19-22) we determined that waiting for hot water to arrive was a problem worthy of study, that it impacts a large number of homes, and that the related energy and water waste are significant. In this article we examine what people want from their hot water systems and, within this context, three possible solutions to reduce the waste and wait in existing homes and new construction.

What People Want

Several ideas have been proposed and tried in pursuit of solving this problem. As I learned about these ideas, I started asking people what they wanted from their hot water systems in order to provide me with a measure of determining how well each option met their desires. What I found was that people wanted many things—such as an endless shower, the ability to control the temperature, and an end to the "shower dance"—none of which included water or energy savings. Table 1 presents the results of several thousand informal surveys of what people want from their hot water systems. What people want generally falls into two categories, safety and convenience.

- **Safety**
  - Not too hot
  - Not too cold
  - No harmful bacteria or particulates
- **Convenience**
  - Adjustable temperature and flow
  - Never run out
  - Quiet
  - Hot water immediately

Source: Gary Klein

Table 1. *What People Want From Their Hot Water Systems*

Safety. Under safety, "not too hot" generally refers to the prevention of scalding young children when they draw a bath. It also refers to the uncomfortable experience of having to immediately dance around the shower to avoid getting burned after someone flushes a toilet.

"Not too cold" means that it must be hot enough for the task at hand, which is often a problem in homes with plumbing that runs below the slab. I have found many people who have turned up the temperature of their water heater in order to get hot water at distant fixtures more quickly. Turning up the temperature doesn't bring hot water more quickly, although it can help to overcome the problem of heat loss in the pipes. However, turning up the temperature increases the likelihood and severity of scalding, and increases the stand-by losses of the water heater, which means energy costs go up.

"No harmful bacteria or particulates" usually refers to hard water. However, in recent years we have seen concerns over Legionella, a.k.a. Legionnaire's disease. The most-often proposed solution for these problems is to raise the temperature of the water heater to kill the bacteria, although it increases the possibility of scalding and will cost more energy to do so.

Convenience. Under convenience, people want to be able to "adjust both temperature and flow." While this is possible at sinks and tubs, it no longer seems common in the single-lever fixtures installed for showers and tub-shower combination faucets.

It is annoying to run out of hot water while taking a shower. The strategies to "never run out" include turning up the temperature of the water heater, getting a larger water heater, limiting the time teenagers spend in the shower, and scheduling hot water use to accommodate the limitations of the water heater. Turning up the temperature of the water heater can help increase capacity by providing a higher starting point to mix with cold water at the fixtures. However, it does so at the expense of increased stand-by losses. Installing a larger tank-type water heater, if there is space, gives you additional hot water too, again at the expense of increased standby losses. A better alternative is to select a tank-type water heater with a larger-than-standard burner or element without increasing tank size. This keeps stand-by losses low while providing an increased recovery rate, but may require increasing the fuel capacities, e.g. gas pipe size or electrical breaker size.

Water heaters with essentially no tank and very large burners or elements look like tankless water heaters. As with all water heaters, tankless water heaters must be matched properly to the intended application. It is likely that some combination of a relatively small tank and a relatively larger burner or element will prove to be optimal, but that discussion is for another article.

Concerning "quiet," most of us remember pipes that tick as they warm up and knock when the faucet is shut off. Water hammer seems to have been solved, although you can still hear the pipes tick as the hot water arrives. Some people can hear the flow of water in recirculation systems particularly in the middle of the night (on evenings when they can't sleep), hence part of the need for timers to turn off the pump. This problem can also be reduced with careful selection of pipe materials, insulation and routing locations.

Reliability. Under reliability, people want their hot water system to work, "first time, every time" essentially forever, and without any maintenance. Unfortunately, while the basic hot water system is very reliable, water quality varies quite a bit and often interacts in ways to reduce the longevity of the water heater and sometimes the fixtures. Two of the most common problems are hard water and sediment, which result in deposits in both the water heater and in the fixtures. The proper selection of an anode rod and regular cleaning of the tank and checking the rate of decay of the anode rod can greatly improve the longevity of the typical tank water heater. However, this falls under the category of maintenance, which most people don't want to do!

Several Solutions?

There are several techniques to get "hot water right now," and this article will cover three of them: multiple water heaters, heat trace, and manifold systems.

Multiple Water Heaters. Installing one or more additional water heaters at the problem locations is often the first solution that people think of to get hot water to each fixture quickly. If done to reduce the time waiting for hot water to arrive, installing more than one water heater should result in a house with more than one central core plumbing system, which is defined by short, small-diameter runs to each fixture. (See January/February 2005 *Official*, Figure 1, page 20.) If you don't end up with short, small-diameter runs, installing multiple water heaters won't reduce the wait. This is difficult and expensive to do in retrofit applications. In new construction, most builders and buyers don't want to give up the space or include the extra cost in the price of their homes.

Several factors need to be considered. First, there is the cost of running gas pipe or electrical wire to the additional water heater(s). This is almost always more expensive than the cost of running the equivalent length of hot water pipe. Second, there is the cost of installing the additional flue(s) if the water heater is gas-fired. Third, there is the cost of the additional water heater. Fourth, there is value of the space needed for the water heater. Assuming a tank-type heater, you need about 10 square feet of space. At sales prices of $100 to $200 per square foot, the value of the space inside the house is worth $1,000-$2,000. I suppose you could install the water heater in the attic, but have you ever tried to get a new one through the attic hatch? Fifth, there is the additional energy consumption of the additional water heater(s). Tankless water heaters don't have the stand-by losses that tank-type water heaters do, so they are a better alternative for energy reasons. They also take up much less space. Finally, there are the future costs of maintaining multiple water heaters.

Heat Trace. Installing heat trace on the pipes is another method that has been used to reduce the time to get hot water to fixtures. Heat trace is a thermostatically controlled resistance heater that is installed between the pipes and the pipe insulation. It is used to maintain the temperature of the water in pipes that have already been heated to the desired temperature. Assuming the heat trace draws 5 watts per foot, that there is only 100 feet of pipe to keep warm (very conservative), and it operates half the time or 12 hours per day, it will cost more than $190 per year to keep the pipes warm. Although heat trace will eliminate the time to get hot water if it has been installed all the way from the water heater to every fixture, it does so at a cost that far exceeds the cost of heating the water that currently runs down the drain.

Manifold Systems

Another alternative is to install manifold systems (also called parallel pipe or home run systems) with a dedicated line that goes from the manifold directly to each fixture. As with multiple water heaters, this is generally difficult and expensive to retrofit. We will consider them from the perspective of new construction.

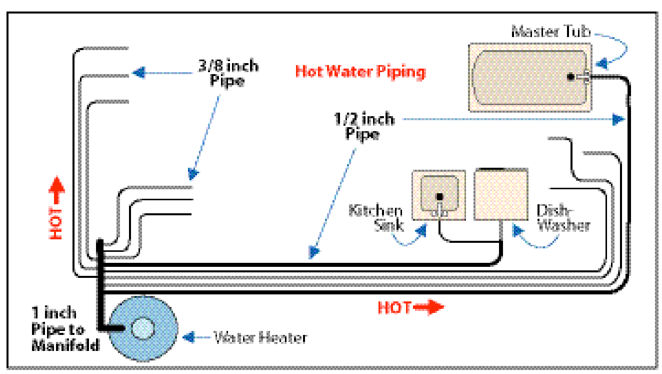

Figure 1. *Radial, Manifold, Parallel Pipe Plumbing (Distributed)*

Source: Gary Klein / Illustration: Jeff Ortiz

You can site-fabricate a manifold or you can purchase one that looks similar to an electrical circuit breaker box and is located near the water heater. Figure 1 shows a schematic of a manifold system in a 2400-square-foot, 2-story house with 12 hot water fixtures. There is a 1-inch pipe

Table 2. *Time for Water to Travel 50 Feet*

Type of Pipe	Time in Seconds at 1 GPM				Time in Seconds at 2 GPM				Time in Seconds at 3 GPM			
	3/8"	1/2"	3/4"	1"	3/8"	1/2"	3/4"	1"	3/8"	1/2"	3/4"	1"
"K" copper	20	34	68	121	10	17	34	61	7	11	23	40
"L" copper	24	36	75	129	12	18	38	64	8	12	25	43
"M" copper	25	40	80	136	12	20	40	68	8	13	27	45
CPVC	N/A	29	63	104	N/A	15	31	52	N/A	10	21	35
PEX	16	28	56	93	8	14	28	46	5	9	19	31

Type of Pipe	Time in Seconds at 4 GPM				Time in Seconds at 5 GPM				Time in Seconds at 10 GPM			
	3/8"	1/2"	3/4"	1"	3/8"	1/2"	3/4"	1"	3/8"	1/2"	3/4"	1"
"K" copper	5	8	17	30	4	7	14	24	2	3	7	12
"L" copper	6	9	19	32	5	7	15	26	2	4	8	13
"M" copper	6	10	20	34	5	8	16	27	2	4	8	14
CPVC	N/A	7	16	26	N/A	6	13	21	N/A	3	6	10
PEX	4	7	14	23	3	6	11	19	2	3	6	9

Source: Gary Klein, based on gallons per foot from standard pipe tables

connecting the water heater to the manifold. This distance should be as short as possible, but given construction limitations, there is often ten or more plumbing feet between the water heater and the manifold. The drawing shows the use of 1/2-inch pipe to the master tub and to the split for the kitchen sink and dishwasher. There are 3/8-inch lines to all other fixtures. There are four 80-foot lengths of pipe to the farthest bathroom, in this case the master bath.

With these systems, the least wait and water and energy waste occurs when 3/8-inch-diameter pipe is used. While fixture flow rates, distance, applications and code restrictions sometimes make it possible to combine the lines serving more than one fixture—such as the kitchen sink and the dishwasher or the pair of sinks in a bathroom—doing so generally requires the use of 1/2-inch-diameter lines, thus increasing the wait and the water and energy waste.

Just how long you wait depends on the distance, pipe diameter, and fixture flow rate. Table 2 shows the time it takes for water to travel 50 feet in several diameters of pipe at representative residential fixture flow rates, assuming there are no pipe heat losses to overcome. The cells in red show the cases when the wait is longer than 15 seconds.

Compared to the time it takes hot water to arrive in 3/8-inch-diameter pipe at a given flow rate, it takes roughly 1.5 times as long in 1/2-inch-diameter pipe, three times as long in 3/4-inch-diameter pipe, and six times as long in 1-inch diameter pipe. If the pipe length is 25 feet, the time would be cut in half; if it is 100 feet, the time would double.

Regardless of the pipe length, if the wait is only 15 seconds, the waste of water waiting for hot water to arrive is one quart at 1 gpm, one-half gallon at 2 gpm, three-fourths gallon at 3 gpm, 1 gallon at 4 gpm, 1-1/4 gallons at 5 gpm, and 2-1/2 gallons at 10 gpm. If the wait is 30 seconds the amount of water waste doubles; if it is 1 minute, it doubles again. And there are all too many houses where the wait is longer than 2 minutes, which doubles the waste once again!

Some waste occurs at each fixture, every time it is turned on, until water of the desired temperature arrives. As pointed out in the first article, when all daily uses are accounted for, the total waste can be quite large. The actual wait and waste for 50-foot pipe runs are longer than those shown in the table due to three other factors:

(1) The human factor. If people have to wait, they often leave, returning when they are done with the intervening task. It is rare that they arrive just when the hot water arrives. Consequently, the waste and wait are often much larger and longer than we might calculate based on technical parameters alone.

(2) There are heat losses to consider. It takes energy to heat the pipe, which means that more water than is in the pipe must come out of the pipe before hot water arrives. It turns out that the amount of extra water is relatively large, often two to four times as much water as is in the pipe.

(3) The volume of water between the water heater and the manifold, and the volume of water in the manifold itself, also must be accounted for.

Let's assume that there is a 1-inch-diameter pipe between the water heater and the manifold, and a 1-inch diameter manifold. The 1-inch pipe contains six times as much water per foot as the 3/8-inch pipe. So, assuming there is only eight feet of 1-inch pipe from the water heater to the far end of the manifold, and 48 feet of 3/8-inch pipe from the manifold to the fixture, this would double the time for the hot water to arrive. It would also double the water and energy waste. Figure 2 shows the relationship between the water heater and the manifold that was installed in a house in San Ramon, California, in early 2004. There are two runs to the kitchen of 100 feet and there are four runs to the master bath of 80 feet. The line serving the kitchen sink and dishwasher and the two lines serving the shower and the separate tub in the master bath are 1/2 inch diameter, which increases the wait and waste.

Photo by Carl Hiller

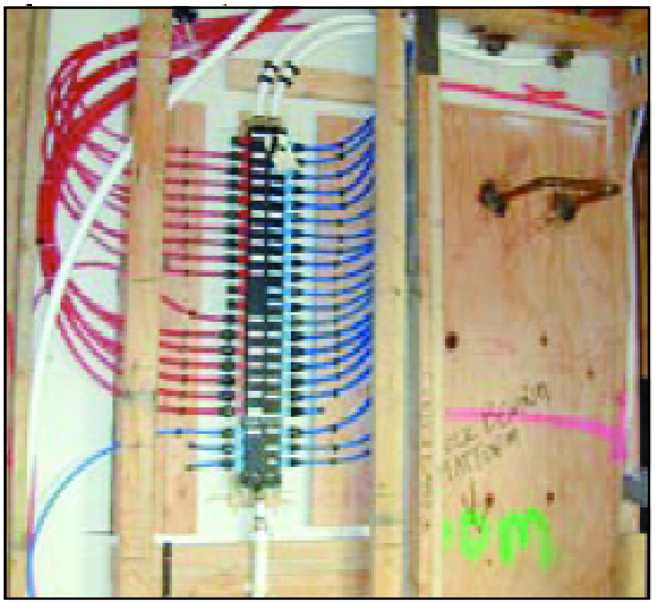

Figure 2. *Manifold system in home in San Ramon, CA*

Source: Gary Klein, based on gallons per foot from standard pipe tables

Type of Pipe	3/8″		1/2″		3/4″		1″	
	gal/ft	ft/gal	gal/ft	ft/gal	gal/ft	ft/gal	gal/ft	ft/gal
"K" copper	0.0066	152	0.0113	88	0.0226	44	0.0404	25
"L" copper	0.0079	127	0.0121	83	0.0251	40	0.0429	23
"M" copper	0.0083	121	0.0132	76	0.0268	37	0.0454	22
CPVC	N/A	N/A	0.0098	103	0.0209	48	0.0346	29
PEX	0.0052	193	0.0094	106	0.0187	53	0.0309	32

Table 3. *Gallons Per Foot and Feet Per Gallon*

Manifold systems are generally presented as water and energy savers compared to standard trunk and branch plumbing systems. However, let's consider the master bath in the San Ramon house with four hot water fixtures: Two sinks, a master tub, and a separate shower. In an idealized standard trunk and branch case, there would be 80 feet of 3/4-inch pipe between the water heater and the master bathroom and 10 feet of 1/2-inch branch line to each fixture. In a similarly idealized manifold case, there would be 10 feet from the water heater to the far end of the manifold and four 80-foot runs to the fixtures, one to each sink at 3/8-inch and the two to the master shower and the master tub at 1/2 inch. Table 3 presents the amount of water contained in different diameters and types of pipe.

Source: Gary Klein

	Trunk and Branch			Manifold		
	Feet	Diameter	Gallons	Feet	Diameter	Gallons
Trunk	80	3/4 in	1.50	10	1 in	0.31
Shower	10	1/2 in	0.09	80	3/8 in	0.41
1st Sink	10	1/2 in	0.09	80	3/8 in	0.41
2nd Sink	10	1/2 in	0.09	80	3/8 in	0.41
Master Tub	10	1/2 in	0.09	80	1/2 in	0.75
		Total	1.87		Total	2.00

Table 4. *Amount of Water Contained in Two Systems Serving a Master Bath*

For this example, we will assume that both systems use PEX piping. Table 4 shows the results of these calculations. The trunk and branch case contains 1.5 gallons in the main line and 0.09 gallons to each fixture. The manifold case contains 0.31 gallons in the 1-inch "trunk line" between the water heater and the manifold and 0.41 gallons in each of the 3/8-inch lines and 0.75 gallons in each of the 1/2-inch lines. There is more water in the pipes in the manifold system than in the trunk and branch system.

Let's look at a morning get-ready-for-work routine where the uses are close together. The first person gets up and takes a shower, then goes to the sink where he/she uses more hot water. The second person gets into the shower before the trunk line has cooled down (while the first person is at the sink) and when done, uses hot water at the other sink. The master bath is not used during this example. We will assume that the flow rate is 2 gpm for the sinks and the shower.

In the trunk and branch case, 1.59 gallons comes out of the pipe before hot water arrives for the first use. Since the first person started using the sink very shortly after leaving the shower, the temperature of the water in the main trunk line hasn't cooled down very much, so when he/she turns on the sink, it is only necessary to warm up the last 10 feet of 1/2-inch pipe. This means that only 0.09 gallons runs down the drain before the water is hot. In the meantime, the second person is using the shower, which means that the trunk and two branches are hot. When the second person goes to his/her sink, only the last branch needs to be heated, so only another 0.09 gallons runs down the drain.

In the manifold case, 1.06 gallons runs down the drain for the first shower. Once that person gets out, the temperature of the pipe begins to cool down. In fact, the long 1/2-inch branch line cools down more rapidly than the long 3/4-inch trunk line used in the previous example. This is due primarily to the smaller volume of water contained in the pipe; less mass means less ability to store heat. After several minutes, the 1-inch trunk line between the water heater and the manifold is still reasonably hot; however, the 3/8-inch pipe has cooled down to the point where the water temperature is unacceptable. This means that the second person will need to run 0.41 gallons down the drain before he/she gets hot water.

Meanwhile, the first person has moved over to his/her sink. The 1-inch line between the water heater and the manifold is still hot, but the 3/8-inch line to the first sink is cold so another 0.41 gallons of water will need to run down the drain before the hot water arrives. When the second person goes to his/her sink, the waste and wait is repeated once again.

Table 5 presents the water waste and wait for these two examples. Both the waste of water and the delay to get hot water is slightly less for the trunk and branch system when the uses are close-enough together so that the trunk line remains hot enough to use. It also shows the impact of taking a bath after using the other fixtures. The trunk and branch system's performance gets relatively better because there is a lot of water in the 1/2-inch pipe serving the master tub.

Source: Gary Klein

	Trunk and Branch		Manifold	
	Gallons	Seconds	Gallons	Seconds
1st Shower	1.59	48	1.06	32
1st Sink	0.09	3	0.41	12
2nd Shower	0.09	3	0.75	23
2nd Sink	0.09	3	0.41	12
Total	1.86	57	2.64	79
Master Tub	0.09	3	0.75	23
Total	1.96	60	3.39	102

Table 5. *Amount of Water Contained in Two Systems Serving a Master Bath*

Source: Gary Klein

	Trunk and Branch		Manifold	
	Gallons	Seconds	Gallons	Seconds
1st Shower	1.59	48	1.06	32
1st Sink	1.59	48	0.72	22
2nd Shower	1.59	48	1.06	32
2nd Sink	1.59	48	0.72	22
Total	6.36	192	2.96	108
Master Tub	1.59	48	1.06	32
Total	7.95	240	4.02	140

Table 6. *Waste and Wait When the Water in Pipes Has Cooled Down*

Table 6 shows how the two idealized systems perform when the pipes have cooled down completely before the next use. In this "cold start" example, the manifold system has approximately 54 percent less waste and wait than the trunk and branch system, before considering the use of the master tub. When the tub is added, the percent the manifold system is better declines to just under 50 percent.

As discussed earlier in this article, the actual waste and wait will be longer than in these idealized cases. Since smaller-diameter pipes cool down more quickly than larger-diameter pipes, pipe heat losses will impact manifold systems more severely because they are designed to have only a few feet of large-diameter trunk piping and many feet of small-diameter branches. In short, manifold systems cool down more quickly than trunk and branch systems.

Manifold systems help reduce the wait and the waste part of the time, but they aren't always better. Part 3 of this article will cover recirculation systems, whether or not to insulate hot water pipes, and discuss ways to deliver hot water to every fixture—wasting no more than one cup while waiting for the hot water to arrive.

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

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