What Do Consumers Want from Their Hot Water Systems?

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS
PART ONE: CONSUMER EXPECTATIONS

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

Story by Gary Klein

Let's talk about high performance hot water systems. We'll discuss the mechanics of making the heat for hot water and how much of it we may need in a moment, but first we'd better figure out what customers actually care about. To provide context for this discussion, since the mid-1990s I have spoken with and interviewed more than 20,000 people from all walks of life throughout the United States and from many countries around the world to learn what they want and expect from their hot water systems. In this series, I will be sharing with you what I have learned from these hot water users and from research that has been conducted in the lab and in the field, and later how we can apply this knowledge to define the characteristics of high performance hot water systems.

What People Want and Expect

The first question we should ask any prospective client is "What do you want from your hot water system?" What they have told me they want are clean clothes, clean hands, dishes, body, relaxation, enjoyment — in other words, the service of the hot water. Well, these are the things that people actually want, in the simplest of terms: warm house, cold beer. They don't really care how the house gets warm or the beer gets cold, they just want it to be that way when they want it.

The next question we need to ask is, "What do you expect from your hot water system?" The customer expects safety, reliability and convenience.

- **SAFETY:** Customers expect the water to be neither too hot, nor too cold. They also expect it to contain no harmful bacteria or particulates, although quite a large number of people put up with hard water and other physical water issues. In food service and health services, customers expect sanitation.

- **RELIABILITY:** Customers expect that the entire hot water system will require little or no maintenance, that it will last forever and that it will be low in cost, both when they buy it and to run and maintain it over its operational life.

How many of you have a water heater in your facility or your home? Have you ever maintained the water heater in your facility? Drained it out, checked the anode, made sure that the temperate and pressure relief valves were working properly? You know, if you do that you can make a water heater last a really long time, but if you put the water heater in the back corner and ignore it, well, it probably won't last as long as you might like it to.

- **CONVENIENCE:** Customers also expect the ability to adjust both temperature and flow, although most showers only give the option of adjusting temperature. They expect that the system will be quiet — no water hammer, no sounds in the middle of the night from their recirculation system, no significant noise from a water heater (gurgling or fan noise from power vented systems). They also expect to


IF YOU HAVE A PROBLEM
DO NOT
RETURN THIS
WATER HEATER
TO THE PLACE OF PURCHASE.
Call 1-877-817-6770
For ALL installation, warranty and performance questions.
ENERGYGUIDE
Estimated Yearly Operating Cost
520
Cost Range of Similar Models
4879
Estimated Yearly Energy Use
Your cost will depend on your utility rates and use.
IMPORTANT
STATE OF CALIFORNIA NOTICE
DANGER
Water temperature over 125°F can cause severe burns instantly or death from scalds.
Children, disabled and elderly are at highest risk of being scalded.
See instruction manual before setting temperature at water heater.
Feel water before bathing or showering.
Temperature limiting valves are available. See manual.
HOT
BURN

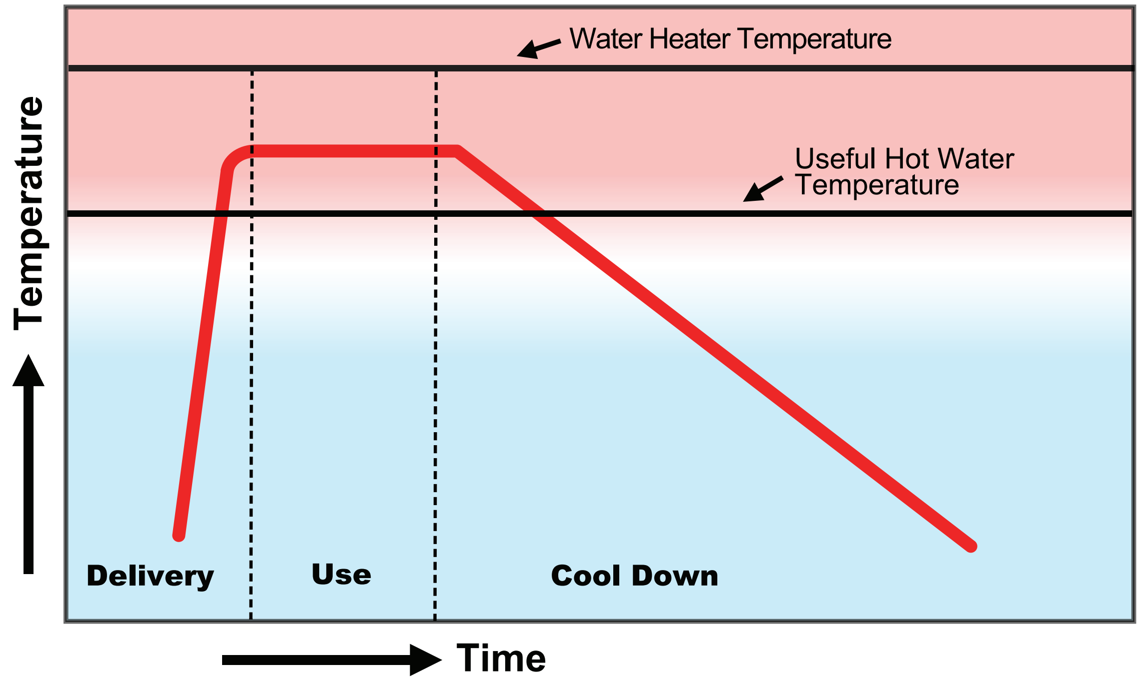

Figure A: Typical hot water event.

GRAPHIC PROVIDED BY GARY KLEIN

never run out of hot water — a problem that many have experienced, but which actually seems to happen relatively infrequently. While it would be nice to have the ability to have several hot water devices operate simultaneously, this is not usually expressed as a big concern. They already have that ability, although tank volume and the burner or element capacity limits the duration of simultaneous events; and they generally schedule their hot water use so that big hot water uses do not overlap.

In addition, faucet, shower and appliance flow rates have been declining, effectively increasing the water heater's ability to sustain simultaneous events for a longer time.

Finally, they expect that hot water will arrive very quickly after they turn on a tap, although the vast majority complain about the length of the time-to-tap, which they describe as a random event, varying from 10-15 seconds at fixtures near the water heater to well more than two minutes at the fixture furthest from the water heater. Less than five percent of the people say they get hot water everywhere in less than five seconds after they turn on the tap. Most of these have a recirculation system; the others have a small house with a short distance from the water heater to the fixtures. In commercial buildings, such as restaurants, most people do not actually expect to get hot water in the public bathrooms, even though it is required by health codes!

Depending on the specific application, I suspect you and your customers want most, if not all, of these same services and have very similar expectations, too. Of all of the issues raised above, what the people I have interviewed want the most is to reduce the time-to-tap, followed by never running out in their shower — theirs, not their children's!

Typical Hot Water Event

Figure A shows a typical hot water event. There's a delivery phase, a use phase and a cool down phase. People would like the delivery phase to be short. According to those I have interviewed, a few want hot water to arrive immediately after they open the tap, which I explain is possible, but rather expensive. Well more than 90 percent say they want the time-to-tap to be between two and three seconds. We will see later on that this level of performance is achievable at reasonable costs.

The use phase is the use — washing dishes, taking showers, whatever it might be.

And then when you turn off the tap, the temperature of the water in the pipe starts to cool down, all the way from the water heater to the hot water outlet. It takes on the order of 10 to 15 minutes for the water in uninsulated pipes to cool from about 120° F down to 105° F when the pipes are located in air at a temperature between 65° F and 70° F, which is typical for most buildings. The water cools down more quickly when the surrounding temperature is colder, such as in a basement or a crawl space, or when the pipes are located under or in a concrete slab. The water cools down more slowly when the pipes are in a hot attic in mid-summer or when they are insulated. We will discuss this further later in this series.

The water heater temperature must be higher than the mix-point temperature you'd like to have, and the useful hot water temperature needs to be less than the point at which you mix it. Why? You need to have some head-room from the mixing point down to the useful hot water temperature point because of variations in desired temperature for any given application on any given day.

The Hot Water System

Now, let's talk about the hot water system. There are five components of hot water use in the building:

- Water heaters
- Pipes
- Faucets, showers, appliances and other fixture fittings
- Hot water running down the drain
- Behaviors

Which is the biggest variable in determining water and energy use? I ask this question of lots of people and get all sorts of answers, but the fact is behaviors are the single biggest variable and that is what's going to determine water and energy use.

How much do behaviors make a difference? Well, let's just pick on your home for a minute. Was today's hot water use *exactly* the same as yesterday's? Will it be *exactly* the same as tomorrow's? I get up at about the same time everyday, but I don't take a shower at exactly the same time, nor is it exactly the same length. I wonder if this happens to you in your home and in your facilities? I suspect it does.

Again, based on my large sample, there are probably an infinite number of hot water use behaviors and patterns. In homes, they often fall within "windows of opportunity" — morning rush hours and evening plateaus; and on weekends, all bets are off! The pattern varies depending on the facility you're in, but the concept of windows of opportunity still applies.

All of these behavior patterns boil down to two possible results: when you turn on the tap, either hot water comes out pretty darn quick or it doesn't. Which is it in your home, at your place of work, your favorite restaurants? I suspect for many of you and your customers, the answer is "it doesn't."

Another factor is how do the interactions among these components affect system performance? Imagine you have long uninsulated pipes between the source of hot water and the fixtures that are being used a lot. Do people wait a long time for hot water? What if you could move the water heater closer, make the pipes better insulated or deliver hot water quicker by use of a pump or electric heat trace? Do you think that that would improve system performance?

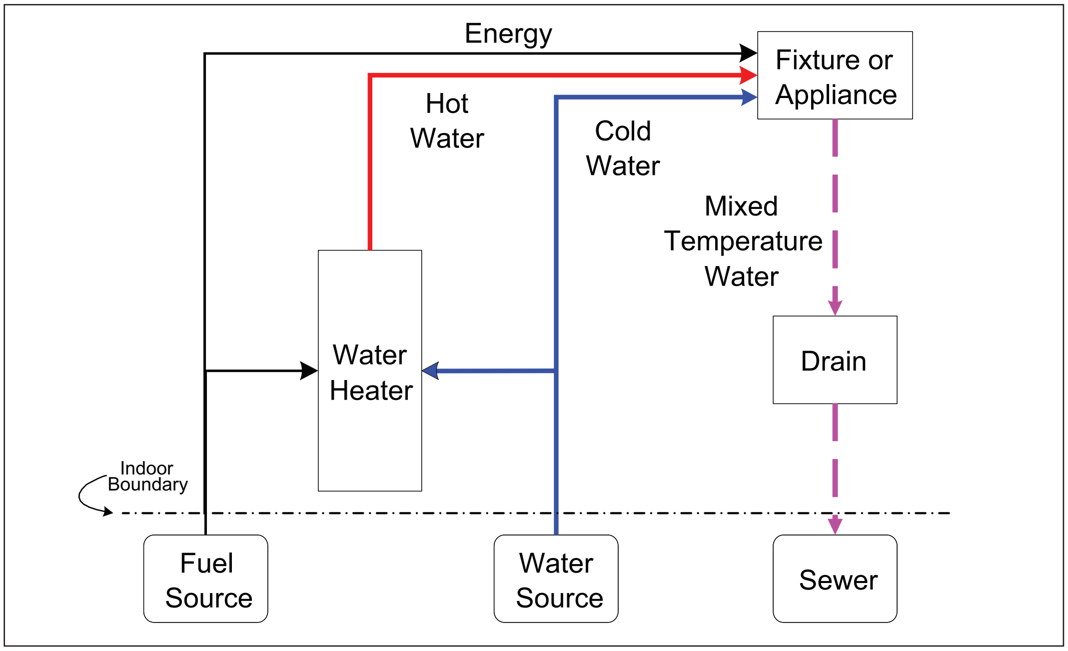

Figure B: Typical "simple" hot water system for single-family or single unit applications.

Fuel comes in, cold water comes in and it goes to a water heater. Hot water goes to fixtures or appliances; so does cold water. Some appliances use energy — dishwashers, washing machines — and there's mixed temperature water running down the drain, ultimately into the sewer.

(When I started doing these kinds of analyses I began asking people "Why do we run hot water down the drain?" I understand why we run the water down the drain, but why do we run it down the drain still hot? What if we could capture some of the waste heat? Wouldn't that be a good idea, too? We'll discuss how to do that later in this series.)

What about single lever valves on faucets or on showers where, when you turn on all hot, you actually get some hot and some cold? What if the valves performed differently so that when you wanted all hot water, you got all hot water? What about when you wanted cold water, you got all cold water? Well, all of these interactions affect the system's overall performance and you as a consumer pay for the system inefficiencies or, conversely, its efficiencies.

Figure B shows a typical simple hot water system. You see it in single-family housing, or single unit applications in multi-family buildings. You see it in commercial facilities.

Figure C is a typical central boiler hot water system. You generally see these in bigger buildings, whether they are residential or commercial. Often there is a boiler to make the heat, a hot water storage tank to store the heat for capacity and peaking, and then there's a circulation loop, most often using a 24/7 pump (sometimes controlled with a timer or an aquastat) to deliver hot water out to the far reaches of the building.

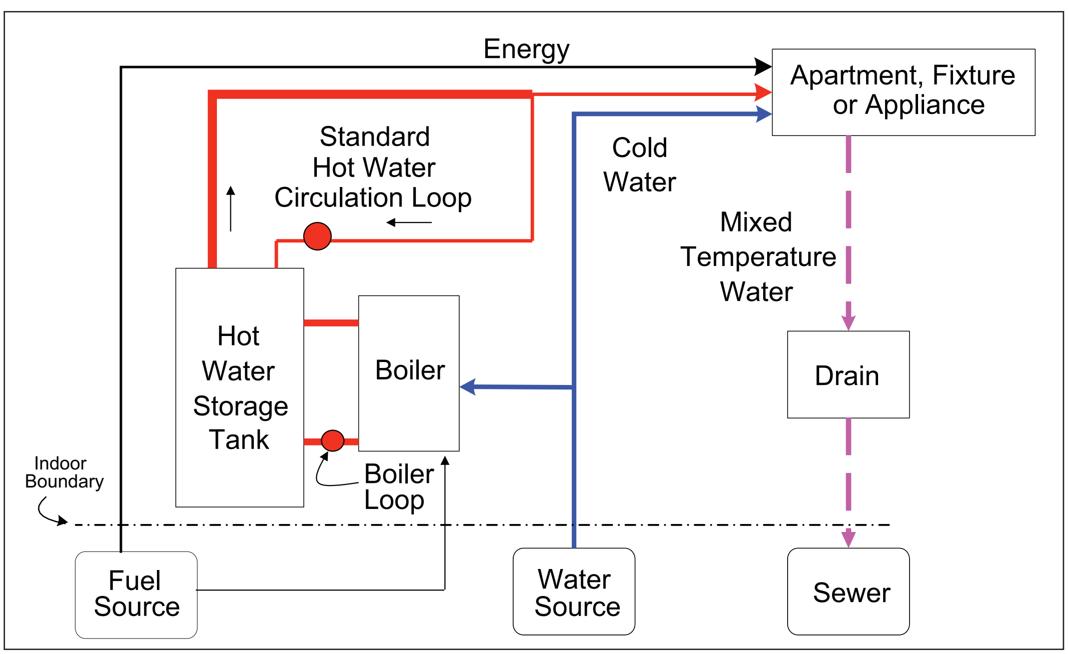

Figure C: Typical central boiler hot water system.

GRAPHICS PROVIDED BY GARY KLEIN

What's Next:

In future installments, we will discuss the hot water distribution system: how to improve existing ones and how to build them more efficiently to begin with; the uses of hot water; drain water heat recovery; the ways to make hot water more efficiently and effectively; and how all of these components come together in a high performance hot water system.

Hot Water and How Best to Get It

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS

PART TWO: DISTRIBUTION

Story by Gary Klein

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

Originally published in OFFICIAL magazine, Winter Edition 2009 (www.eofficial.org); Reprinted with permission of THE IAPMO GROUP Copyright 2010. www.iapmo.org

Before we talk about hot water distribution systems, we need a few definitions.

A ***twig line*** serves one faucet, shower or appliance, either hot or cold water; the hot and cold water outlets. The diameter of the twig should be determined by the flow rate of the device it serves. For instance, a garden tub with a 10-gpm flow rate should have a larger diameter twig than a 0.5-gpm lavatory sink. By definition, there can be no simultaneity on a twig, as it serves only one device. (I have begun using "twig" to follow the tree analogy. My friend and colleague, Phil Campbell reminds me that the *Uniform Plumbing Code®* refers to these sections of pipe as fixture branches. Thank you, Phil!)

A ***branch line*** serves two or more twigs, a trunk line serves a combination of twigs and branches and the main line serves the building. The diameter of the branch, trunk and main lines should also be determined by the flow rate of the devices that they serve, coupled with an estimate of the likelihood of how many devices on the branch, trunk or main line would be operated simultaneously for any significant period of time.

In the previous paragraphs, I used the words "should be determined" when referring to the selection of pipe diameters. Flow rate isn't the only parameter, but it is a very important characteristic that should be more readily apparent when looking at pipes serving devices with widely varying flow rates. At the present time, the underlying mathematics behind Water Service Fixture Units (WSFU) and their implementation in various plumbing codes are being revisited to take into account the changes to flow rates that have occurred in the past 20 years and that are expected in the next 20. We will go into more detail on WSFU later in this series.

The ideal hot water distribution system would minimize the time-to-tap. To do this, it would have the smallest volume of water in the pipe from the source of hot water to the fixture. Sometimes the source of hot water is the water heater; sometimes it's a trunk line. In the ideal hot water distribution system, all the hot water outlets would be close to the water heater that serves them, and there might well be more than one water heater per building. For a given layout of hot water locations, the system will have the shortest buildable trunk line, few or no branches, the shortest buildable twigs and the fewest plumbing restrictions.

Whether the hot water pipes should be insulated and with how much insulation depends on several factors, including the location and length of the piping and the time between hot water events. Insulation makes a significant difference in reducing the time-to-tap when the time between hot water events on the same twig, branch or trunk is between 10 and 60 minutes for pipes from 3/8 to 1 inch in diameter. The time delay gets longer as the diameter of the pipe increases.

The need for insulation is understood when the pipe is installed in adverse environmental conditions, such as in the ground, under a slab or in a cold crawl space. But I would remind

"Here's the challenge: Deliver hot water to every fixture or appliance, wasting no more than one cup waiting for the hot water to arrive and wasting no more energy than we currently waste running water down the drain while we wait."

that normal room temperatures of roughly 70-degrees F are more than 35 degrees from a minimum acceptable hot water temperature. We insulate buildings for this temperature difference; we should do the same for our hot water piping. Oh, yes, all hot water piping, regardless of material (e.g. copper, steel or plastic), needs to be insulated.

High Performance Hot Water Systems

Now we're ready to talk about high performance hot water systems. Here's the challenge: Deliver hot water to every fixture or appliance, wasting no more than one cup waiting for the hot water to arrive and wasting no more energy than we currently waste running water down the drain while we wait.

Okay, you've thought about it a bit — how would you do it? Well, it turns out we have found five different ways to do this. I'll discuss them momentarily, but they all revolve around the answer to the following question: If you want to waste no more than one cup waiting for the hot water to arrive, what is the *maximum* amount of water that can be in the pipe that is not usefully hot? The *maximum* is one cup. In fact, it must be less than a cup because you do have to heat the pipe and there are some losses while you do it If you want to ensure that hot water will arrive before more than one cup runs down the drain, there can only be about 2/3 of a cup in the pipe.

The energy part of the challenge is perhaps less obvious. For this, we need to understand how much energy is wasted in typical hot water distribution systems while waiting for the hot water to arrive. It turns out there are two kinds of waste in the delivery phase. Structural waste is due to the volume of water between the source of hot water and the hot water outlets. Behavioral waste is what we do with it. The more volume, the longer it takes for hot water to arrive. The longer it takes, the more likely we are to give up (think waiting for hot water at a sink in a public restroom) or to leave and go do something else (Do you know anyone who, while waiting for the hot water to arrive at their shower, goes to the kitchen to make coffee, checks their email or texts their friends and returns when there is steam billowing out of the shower compartment?)

The actual wastefulness of a hot water distribution system is hard to determine since it is a combination of structural and behavioral considerations and you probably won't let me put a camera in the shower to let me know when you actually get in! The magnitude of this waste will be covered in the next article.

More volume in the piping also means more energy that will be lost when the water in the pipes eventually cools down. In practice, this means that we need to make sure that the hot water piping is "right sized" taking into consideration flow rates, pressure drop, velocity, noise, water hammer and simultaneous uses on branch and trunk lines. Structural waste also includes the energy losses of the water heater, as well as letting the energy in hot water you have used run down the drain. These topics will be covered in future articles in this series.

Without further ado, here are the five possible solutions:

1. You could build every building with central core plumbing, such that all hot water fixtures in that building are within one cup of one water heater. It's technically possible to do, but it's not likely to be done in many buildings given the way our floor plans are laid out.

2. You could have one water heater for every hot water fixture. It's more expensive to bring energy to the water heaters than it is to bring plumbing, so that's one reason it's not done very often. You also have the additional costs for the water heaters, the

flues (if the water heaters are fossil fired) and the space, not to mention future maintenance. So, you want to be careful about putting in lots and lots of water heaters, but that's another way of getting the volume down to less than one cup of waste.

This method of improving the delivery phase of a hot water event is often called point-of-use. In most peoples' minds, point-of-use means a small water heater such as the ones found under the sink in a dentist's office. However, each point-of-use water heater needs to be sized for the intended use: a 0.5 gpm lavatory faucet needs a different water heater than a 2.5 gpm shower, a 70 gallon garden tub or a commercial dish machine. Point-of-use is really about location, not the capacity of the water heater.

3. You could put two to three water heaters per building or home. Implementing this solution depends on the clustering of hot water outlets, such as back-to-back or stacked bathrooms, or other hot water locations. It's the same idea as one water heater for every hot water fixture, but you're going to space them out a little bit farther apart. You still have some issues with the running of the power for the water heater, the power or the energy supply for the water heater, but none-theless it makes sense, particularly as buildings get bigger. Our estimates are that you ought to be putting in a second water heater when the distance between fixture groupings gets to be on the order of 75 feet.

A good example of using distributed water heating for clustered hot water outlets is for the supply of hot water to the sinks in public restrooms at hotels and airports. There are usually several sinks, all of which could be served by one water heater located under the sinks or elsewhere in or nearby the bathroom. Since the faucets all have 0.5 gpm aerators (federal law since the 1990s), the trunk line from the water heater only needs to be ½ inch diameter and the twigs need to be no larger than 3/8 inch. The short, small diameter, pipes will be insulated and once the first person draws hot water, everyone else will have hot water quickly throughout the day. You can make sure the trunk line is filled with hot water before anyone turns on the tap by using an on-demand pump to prime the line

with hot water triggered by a motion sensor when someone walks through the doorway to the restroom.

4. You could put heat trace on the pipes. Heat trace is electrical resistance heating elements that are strapped to the pipe and then insulation is wrapped around the entire combination. The electric resistance elements are self-regulating cables. It's a very sophisticated technology and you can have as many feet of heat trace pipe as you would like to have. Since you can run the heat trace very close to each hot water outlet, it can easily meet the water waste portion of the challenge. However, it is not clear that it will use less energy than is currently wasted while waiting for the hot water to arrive. Sometimes heat trace is used in combination with a circulation loop; the heat trace is used to maintain the temperature in the branches and twigs, and a pump is used to maintain the temperature in the trunk line. We're still investigating where it makes the most sense, but it looks competitive in certain applications, particularly where there would normally be very long return line runs found in large commercial buildings or multistory buildings.

5. And then finally you could put a circulation loop one cup from every hot water fixture. We have found this to be the most buildable option, and all circulations systems, how-ever their operation is controlled, can save water if the volume from the circulation loop to the hot water outlets are minimized. Only one that we have found can actually save energy.

In the next article, we will examine each of these hot water distribution strategies in detail.

Meeting the One-Cup Challenge

A SERIES ON HIGH PERFORMANCE HOT WATER SYSTEMS

PART THREE: CENTRAL CORE PLUMBING

Story by Gary Klein

About the Author:

Gary Klein has been intimately involved in energy efficiency and renewable energy since 1973. One fourth of his career was spent in the Kingdom of Lesotho, the rest in the United States. He has a passion for hot water: getting into it, getting out of it and efficiently delivering it to meet customer's needs. Recently completing 19 years with the California Energy Commission, his new firm, Affiliated International Management LLC, provides consulting on sustainability through their international team of affiliates. Klein received a BA from Cornell University in 1975 with an Independent Major in Technology and Society with an emphasis on energy conservation and renewable energy.

We concluded the last article of this series with a listing of five hot water distribution strategies that would be able to deliver hot water while running less than one cup down the drain after we turn on the tap. In this article, we will begin discussing each of these methods in some detail.

Central Core Plumbing

In the last article, we described a central core plumbing hot water distribution system that met our challenge as one in which all hot water fixtures in a building are within one cup of one water heater. While this is technically possible to do, it is not likely to be done in many buildings given the way the hot water locations are laid out. It gets more difficult to do as buildings get larger.

Figure 1 shows a plan view of a traditional central core plumbing system. There are two basic configurations used to pipe a central core hot water distribution system: Long Trunk-Short Twigs (figure 1) or Short Trunk-Long Twigs (figure 2). I think of both of these configurations as radiating out from the water heater and both are found in traditional hot water distribution systems. However, in recent years Short Trunk-Long Twigs has come to be referred to as "home-run manifold" or "parallel piping," terms that have been popularized by the manufacturers of valved manifolds. It is useful to think of a tee as a one-port manifold. Most tees do not have valves and they are not necessary for implementation of Central Core Plumbing systems. Using a non-valved manifold with several tees will work quite well. The key is to limit the volume between the water heater and the hot water outlets.

Central core hot water distribution systems were common in single family houses built before World War II. The reason? Single family houses were relatively small and most of the housing stock in the United States had been built in parts of the country where basements were the normal way to build a foundation. Water heaters were located in the basement, right next to the gravity furnace or the boiler. The number of hot water outlets was very limited as the house generally had 1-1.5 bathrooms, a kitchen and a laundry sink in the basement.

Even though multi-family buildings with a central water heating system could not meet the one-cup challenge, the hot water locations in each unit were even more limited than those in single family homes, typically one bathroom and a kitchen. The hot water locations were stacked and most buildings were not more than 4-5 stories since elevators were still not common or required. In general, commercial buildings also had fewer hot water locations than we see today and they had similar height restrictions.

The hot water distribution system was typically made from galvanized piping, which has a relatively small inside diameter for a given nominal pipe diameter when compared to copper, which become the most common hot water distribution system material in the last 40 years of the 20th century. This meant that for a given distance between the water heater

Figure 1 (right) illustrates an example of a central core plumbing schematic with long trunk-short twigs.

Figure 2 (far right) illustrates an example of a central core plumbing schematic with short trunk-long twigs

ILLUSTRATIONS BY ANNE HESS

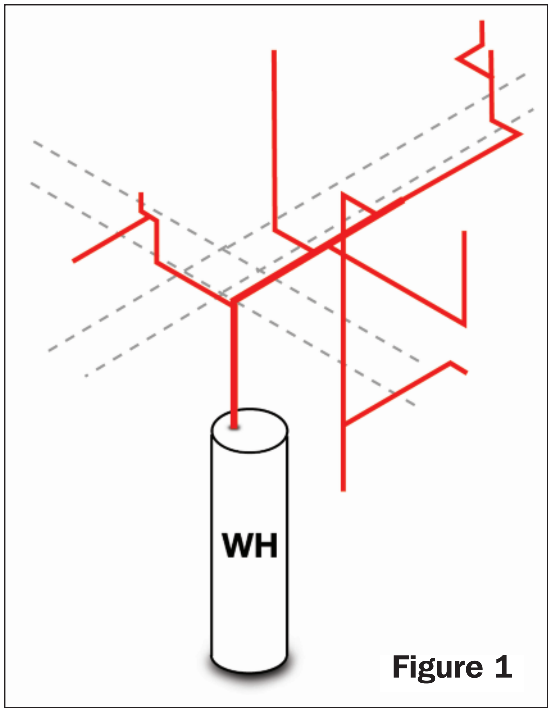

Figure 1

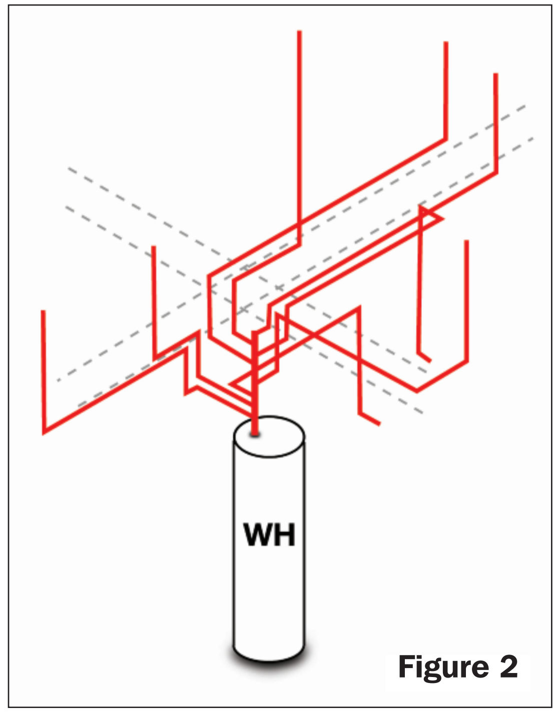

Figure 2

Table 1: Feet of Water Distribution Tubing that Contains One Cup of Water

Nominal Size (inch)	Copper Type M	Copper Type L	Copper Type K	CPVC CTS SDR 11	CPVC SCH 40	PEX AL-PEX ASTM F 1281	PEX CTS SDR 9
3/8”	7.5	8.2	9.5	NA	6.8	12.7	12.5
1/2”	4.7	5.2	5.5	6.4	4.2	6.1	6.8
3/4”	2.3	2.5	2.8	3.0	2.4	2.4	3.4
1”	1.4	1.5	1.5	1.8	1.4	1.4	2.0
1 1/4”	0.9	1.0	1.0	1.2	0.8	0.9	1.4
1 1/2”	0.7	0.7	0.7	0.9	0.6	0.6	1.0
2”	0.4	0.4	0.4	0.5	0.4	0.4	0.6

Table 1 (above) shows the number of feet per cup of water distribution materials that are in use today.

INFORMATION SOURCED FROM GARY KLEIN

and the hot water outlets the volume of water in the piping was relatively small.

Even with all of these considerations, the volume of water in the piping was rarely as small as one cup. A ¾-inch riser came out of the water heater. Branches and twigs came from this riser and were generally ½-inch nominal piping. Roughly 3 feet of ¾-inch or 6 feet of ½-inch galvanized pipe contains one cup of water. So, if the riser was 3 feet and the longest branch and twig combination was 30 feet, the combined volume of water in the pipe would have been 6 cups.

Table 1 shows the number of feet per cup of water distribution materials that are in use today. For each nominal pipe diameter, copper has the largest internal diameter of these materials and therefore has the fewest feet per cup. PEX has the smallest internal diameter (with the exception of 3/8-inch PEX-AL-PEX) and has the most feet per cup.

The central core systems shown in Figures 1 and 2 shows a maximum volume between the water heater and the valve or angle stop of the outlets that is greater than one cup. In these drawings, we have allowed the volume to be a maximum of four cups on any path from the water heater to a hot water outlet. This is admittedly difficult to do, but still possible to build given the current requirements in the plumbing code. To meet the four-cup limit, it will be necessary to locate all of the hot water outlets very close to each other and to the water heater. To be completely accurate, we really should be accounting for the volume between the valve or angle stop and the faucet, shower, tub or appliance, too. The volume from the angle stop to the sinks is very small; on the order of 1/10th of a cup since it is often a ¼-inch nominal diameter tube approximately two feet long.

On the other hand, the volume from the shower or tub/shower valve to the shower-head is on the order of one cup and when we are limiting the volume to the valve to four cups an additional cup increases the volume by 25 percent. This suggests that showers and tub/shower combos need to be located closer to the water heater so that the volume can be less than four cups all the way to the showerhead.

How close? Based on the *2009 Uniform Plumbing Code* and common plumbing practices, the riser out of the water heater and the rest of the trunk line will be ¾-inch nominal diameter and the branches and twigs will be ½-inch. (SEE RELATED INFO. ON PAGE 47) Let's see how this plays out for both configurations.

Long Trunk-Short Twigs: If the riser contains three cups, there is only one cup left to get to the outlets. Using the numbers in Table 1, the riser will be 6.9-10.2 feet long and the sum in any branch and twig combination will be 4.7-6.8 feet.

The hot water outlets will need to be closer to the water heater if copper tubing is used. PEX gives the greatest flexibility in locating the hot water outlets. If 3/8-inch nominal tubing was used for the twigs and any applicable branch and twig combinations, the length from the riser would increase to 7.5-12.7 feet. This would give still more flexibility for all piping materials.

Short Trunk-Long Twigs: Assuming that the riser contains one cup, this leaves three cups to get to the furthest hot water outlet. Using the numbers in Table 1, the riser will be 2.3-3.4 feet long and the sum in any branch and twig combination will be 14.1-20.4 feet.

The hot water outlets will need to be closer to the water heater if copper tubing is used. PEX gives the greatest flexibility in locating the hot water outlets. If 3/8-inch nominal tubing was used for the twigs and any applicable branch and twig combinations, the length from the riser would increase to 22.5-38.1 feet. This would give still more flexibility for all piping materials.

Figure 3 is a photo of a Short Trunk-Long Twig central core plumbing system, showing a copper manifold and PEX (cross-linked polyethylene) twigs. The copper manifold is connected right to the top of the water heater and each of the PEX twigs has its own valve so it can be separately turned off if you want to do any maintenance. You'll notice that the twigs are 3/8-inch diameter nominal pipes (the system was engineered and approved by the local jurisdiction). The twigs are shown in PEX, but they could be of any approved plumbing material.

In general, it is easiest to visualize how to keep the volume to less than four cups if the water heater is located below the hot water outlets, such as when it is installed in a basement. The Short Trunk-Long Twig option gives the most flexibility in the distance between the water heater and the hot water outlets.

If the Long Trunk-Short Twig option is chosen, the hot water outlets will need to be in rooms directly above or right next to the water heater and the twigs will probably need to go horizontally within the walls. Remember that if we put a tee 2/3 of the way up the three-cup trunk, we gain another cup of volume from the trunk line (4.7-6.8 feet in ½-inch nominal pipe, or 7.5-12.7 feet in 3/8-inch nominal pipe). If we put a tee 1/3 of the way up the three-cup trunk, we gain two cups and twice as much additional distance, but the system then begins to look and perform like the Short Trunk-Long Twig option.

All of the hot water distribution piping should be insulated. The new IAPMO *Green Plumbing and Mechanical Code Supplement* will have a section that requires that hot water distribution piping be insulated using a strategy that aims for equal heat loss per foot. For a given insulating value of the insulation (k-factor), this can be achieved by using pipe insulation with a wall thickness equal to the nominal pipe diameter. This means that ½-inch nominal piping will have ½-inch wall thickness pipe insulation, ¾-inch will have ¾-inch, 1-inch will have 1-inch, etcetera, up to 2-inch nominal pipe diameters. After 2-inch nominal pipe, the wall thickness can be maintained at 2 inches. (The German energy

Water Heating Design, Equipment and Installation are also covered in Chapter 6 of the new *2010 Green Plumbing and Mechanical Code Supplement,* to help better achieve maximum water efficency.

WWW.IAPMOGREEN.ORG

Figure 3 is an a example of Figure 2 with a Short Trunk (Copper) and Long Twigs (PEX).

PHOTO COURTESY OF GARY KLEIN

code continues the wall thickness equal to the nominal pipe diameter pattern up to 4-inch nominal pipe diameters. This seems like a smart idea if there is the space to do so.)

Pipe insulation should completely surround the pipe and be as continuous as possible. It is not necessary to insulate the piping as it passes through the building framing, nor is it necessary to insulate the piping exposed under typical lavatory and kitchen sinks. A later article in this series will go into insulation in more depth.

Performance

How well will these two configurations perform in terms of water, energy and time? All of the hot water piping has been insulated, which results in doubling the cool down time in the ½-inch piping (increasing it from roughly 10 up to 20 minutes) and tripling the cool down time in the ¾-inch piping (increasing it from roughly 15 to 45 minutes). In both configurations, it is necessary to clear out the four cups of cold water in the hot water distribution system. At two gallons per minute, it will take approximately 10 seconds to get hot water to the first fixture that is turned on, which is admittedly quite good. However, after that the two configurations perform differently.

The reason has to do with the different volume in the twigs. In Long Trunk-Short Twig, the second and subsequent events only need to clear out a maximum of one cup. In Short Trunk-Long Twig, it is necessary to clear out a maximum of three cups.

Think of two of the pairs of hot water outlets shown in Figure 1 as a bathroom (sink and tub/shower combo) and another pair as the kitchen (sink and dishwasher). Since the piping is insulated, it will stay hot 20 minutes in the ½-inch nominal twigs and 45 minutes in the ¾-inch nominal trunk. This allows for a relatively long time between hot water events on any one twig; good for people sharing the same bathroom who need their privacy and it gives plenty of time to get to the kitchen and make breakfast before the trunk line will have cooled off. Now, let's go through morning "rush hour" where everyone has to get up and out of the house on the way to work and school.

Long Trunk-Short Twig: The first person would run a minimum of four cups down the drain at the shower. This primes the entire trunk line so that one cup will come out any time another tap is opened. At 2 gpm this will take an additional two seconds. Assuming that one person uses the sink and the tub/shower combo in each bathroom and the kitchen sink is used to make breakfast, the waste of water will be four cups (first draw) plus four cups (one to clear out the cold water in each twig). This is a total of eight cups of water and 18 seconds. The eight cups of water will cool down by the time they return from work and school and the energy in it will have been dissipated, sometimes beneficially, sometimes not.

Short Trunk-Long Twig: Again, the first person would run a minimum of four cups down the drain at the shower. This also primes the entire trunk line, but since it is only a cup long, three cups will come out any time another tap is opened. At 2 gpm this will take an additional six seconds. Assuming that one person uses the sink and the tub/shower combo in each bathroom and the kitchen sink is used to make breakfast, the waste of water will be four cups (first draw) plus 12 cups (three to clear out the cold water in each twig). This is a total of 16 cups of water and 28 seconds. The 16 cups will cool down by the time they return from work and school and the energy in it will have been dissipated, sometimes beneficially, sometimes not.

Both of these examples are for a house with the same use patterns, so we are comparing the wastefulness of each configuration. (The location of the hot water outlets relative to each other and to the water heater is more limited in the Long Trunk-Short Twig configuration, but still buildable).

Since both configurations have the same maximum volume in the piping between the water heater and the hot water outlets, cold starts (first thing in the morning or any use after the piping has cooled down) will have the same waste of water energy and time. The difference comes during hot starts, which occur after the trunk line is filled with hot water. Over the life of the building, there will be a combination of hot and cold starts and during the hot starts the Long Trunk-Short Twig configuration outperforms the Short Trunk-Long Twig in terms of water (eight cups versus 16 cups, a savings of 50 percent), energy (also a savings of 50 percent) and time (18 seconds versus 28 seconds or a savings of 36 percent).

In the next article, we will continue the discussion of the five hot water distribution strategies that would be able to deliver hot water while running less than one cup down the drain after we turn on the tap.

RELATED INFO

Some Things Never Change… but Should They?

These are the same nominal diameters used more than 60 years ago. This seems a bit odd to me since flow rates for faucets and showers — and fill volumes and flow rates for appliances such as dishwashers and washing machines — are significantly lower than they were then and they appear to be getting even smaller in the future. The diameter of the twigs should be based on the flow rate of the outlet and the pressure drop in the piping. The diameter of the branches and the trunk should also be based on the flow rate of the devices that they serve, but primarily on an estimate of the likelihood of how many devices on the branch and trunk line will be operated simultaneously for any significant period of time.

Since the central core system limits the length, there should be relatively few fittings, so the pressure drop in the piping should be relatively small to begin with. Flow rates are lower, so pressure drop to velocity is lower, too. For twigs serving outlets with less than 2 gpm, the diameter could be no larger than 3/8-inch. This diameter also applies to branches serving a group of outlets with a combined simultaneous flow rate of 2 gpm. The trunk line could be ½-inch nominal for simultaneous flow rates up to 3.5 gpm in copper and 5.5 gpm in PEX.

A longer discussion of this topic can be found in Residential Hot Water Distribution System Research Suggests Important Code Changes, G. Klein and R. Wendt, which appeared in Official's January/February 2007 issue.