Meeting the One-Cup Challenge

PART THREE: CENTRAL CORE PLUMBING

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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 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
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 showerhead 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 shower-head.

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...
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.

**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.