PRELIMINARY IMPACT ANALYSIS

PROPOSAL: This proposal seeks to revise Australian Standard AS/NZS 3500.4:2018, *Heated water services* to include requirements for the metered delivery of heated water from centrally generated and circulated heated water systems to individual dwellings in multi-dwelling buildings or similar installations.

Responsible Technical committee: Australian Standard Committee WS-014, *Plumbing and Drainage*

NCC REFERENCE: For revisions or amendments to existing National Construction Code (NCC) referenced documents, provide additional information	**BCA Volume One:**	N/A
	BCA Volume Two:	N/A
	PCA Volume Three:	B2.2, B2.6, B2.7, B2.8 & B2.9

PROPONENT:	Nominating organisation:	The Institute of Plumbing Australia Inc
	Nominating individual:	Stephen Movley
	Position:	Secretary
	Contact email:	secretary@plumbing.org.au

DATE OF PIA: To differentiate between versions include the document date and/or version number	Date:	28/10/2019
	Version:	1.1
	Status:	DRAFT

NATURE AND EXTENT OF THE PROBLEM:

- The problem relates to AS/NZS3500.4:2018 not containing requirements for branches of centralised heated water systems in multi-dwelling buildings. In some cases, this is impacting on amenity and unnecessary loss of water and energy.

- Public comment to AS/NZS 3500.4:2018 revealed that some owners and occupiers of multi-dwelling buildings were not receiving an acceptable level of amenity due to inadequate and untimely supply of heated water. In reviewing the comments received and in consultation with the Hydraulic Consultants Association of Austrasia, Standards Australis WS-014 committee concluded that this was due to warm water being drawn from stagnant branches, resulting in a loss of water and energy (used to heat the water).
- Among other requirements, BP2.3 of the PCA requires that a heated water service must provide heated water at appropriate flow rates and temperatures for fixtures and appliances to function. BP2.5 and BP2.6 also require the management of legionella and water waste respectively.
- Following the public comment period for AS/NZS3500.4:2018, Standards Australia sought further information on the problem from stakeholders. This information can be found in Attachment B and was used in the development of this proposal.
- AS/NZS 3500.4:2015 previously only contained rudimentary information on Circulatory Heated Water systems, generally aimed at installations that did not require metered branches. In 2018, AS/NZS3500.4 for the first time included a separate section to cover sizing and installation of circulatory heated water reticulation. However, this revision was mainly centred on circulating pipework and did contain specific requirements for branches.
- This proposal will provide minimum requirements for compliance with the PCA BP2.5 (legionella control) and BP2.6 (energy use). Specifically, it will include requirements for branch layout and measurement restrictions from the centralised heating system to outlet points.

<u>Extent of the problem</u>

- Those affected by the problem include:
    - Suppliers and managers of centralised heated water systems;
    - Owners and occupiers of residential or commercial tenancies through loss of amenity and higher costs;
    - Strata management businesses can also be affected depending on who is responsible for the higher running and maintenance costs of centralised plant.
- The extent of the problem occurs daily in most multi-dwelling buildings as detailed in Attachment B and C.

<u>Consequence of no action</u>

The consequence of no action will be that the problem as described will continue to occur. That is, amenity of owners and occupiers of sole-occupancy units in apartment buildings will be impacted as a result of being supplied heated water at a temperature lower than desired. As a consequence, water and energy will be over consumed from occupants drawing-off cold or warm water before the desired water temperature at outlets is achieved.

OBJECTIVES:

The objective of this proposal is to ensure an adequate level of amenity, health and energy consumption is afforded to owners and occupiers of multi-dwelling buildings serviced by a metered heater water supply from a centralised and circulated heated water system. This objective corresponds to the Objectives of the PCA relating to the supply of heated water.

OPTIONS:

Options for analysis include:

Option 1: Retain the status quo

The status quo will be regarded as the baseline. Where the incremental impacts of other options result in a net cost, retaining the status quo will be recommended.

Option 2: Revise AS/NZS 3500.4:2018 to include requirements for metered branches

This option will result in a revision to AS/NZS3500.4:2018 to provide minimum appropriate requirements (and guidance) where metered branches are installed and connected from a centralised heated water system.

Note: A non-regulatory approach was considered and discontinued on the basis that the non-regulatory approach is considered status quo.

IMPACT ANALYSIS (OF ALL OPTIONS):

Option 1: Retain the status quo

Until the 2018 Standard circulation systems where only vaguely covered.

Under this option, AS/NZS 300.4 would continue to not provide any layout / design requirements for centralised heated water circulation with metred branches as distinct from a circulation system taken close to each outlet and the problem as described will continue to occur. That is, owners and occupiers of dwellings within multi-dwelling buildings will continue to receive inadequate amenity resulting in a loss of water and energy.

The current text of AS/NZS 3500.4 states:

> 10.9.2 Branch off-takes
>
> Circulatory piping shall be located so that dead leg branch off-takes are as close as practicable to the most frequently used outlet point or point's services by a branch.
>
> NOTE: See also Clause 4.12.1.

As the current standard provides a guidance approach which was intended to allow practitioners to determine the appropriate length based on the site specific conditions. This has proven to be difficult to regulate in that no indication of what is 'as close as practicable' is provided or what site conditions should be taken into consideration. This has resulted in the delivery of heated water temperatures being lower than desired at the outlet. As a consequence, water and energy will be continue to be over consumed from occupants drawing-off cold or warm water before the desired water temperature at outlets is achieved.

Option 2: Revise AS/NZS 3500.4:2018 to include requirements for metered branches

The proposed changes will apply the existing requirements for circulating heated water flow piping to be located close to outlet points and extend them to branches that require a flow meter by providing specific layout and measurement advice that, if adopted, will provide quantified Deemed-to-Satisfy provisions for plumbing practitioners and improved amenity for consumers.

As the existing Standard requires that heated water flow pipes be located as close as practicable to the frequently used outlets which is determined on-site based on the site specific conditions. This option propose to amend this to a specific measurement, which is not anticipated to increased installation costs or change industry practice who are currently undertaking this requirement based on the existing provisions.

Where change and potential increase in installation costs (additional pipework and labour) may occur is where practitioners and designers are not adhering to the current requirements. This may be caused by the unquantified nature of the requirement in its current form.

Under this option, change and industry practice and any increase in costs which would be associated with this change would only impact the designers and installers who are currently non-compliant under the current clause.

There are two primary benefits derived from implementing this option and including a quantified solution for plumbing practitioners. That is, the water saved from reducing water wastage from drawing-off warm water and the energy saved from avoiding wastage of heated water.

The energy savings associated with heating water is difficult to quantify. This is dependent on energy prices and how water was heated.

Water wastage is more quantifiable and is considered in the below example.

If one litre of water is saved per tap use, this could equate to

1 litre x 10 uses per day (2 persons per dwelling) x 7 days x 52 weeks x 24 dwellings in a building = 87,360 litres.

At 1.64c/l (Canstar Blue 2018) this could equate to $1,432.70 per annum, per building.

As the expected costs associated with the proposed amendment under this option is considered minimal and to only effect a small number of practitioners, it is considered that this option demonstrates a net benefit when compared to the status quo.

TRANSITIONAL MEASURES

The Standards Committee recommend that no transitional measures are required as a result of implementing Option 2. If changes are supported to AS/NZS 3500.4 they will take effect on 1 May 2022 through adoption of the PCA in each state and territory.

CONSULTATION:

- Public Comment on AS/NZS 3500.4 in 2018 revealed the nature of the problem.
- Standards Australia contacted the stakeholder and following discussion, a detailed email was provided. This information (attached) was used to scope this review.
- The WS-014 Technical Committee was consulted and decided that the points raised were of a serious nature and warranted a review of the current requirements. Subsequently a working group was reformed from the original heated water group, compromising of Standard Committee members and industry experts. (plumbing designers, consultants, installers, investigators, regulators, water heater and piping manufacturers, all with widespread industry knowledge)
- The WS-014 Technical Committee were then consulted during the review and have contributed to the final draft.
- One item that was considered and researched was the provision of a maximum wait time to receive water at a suitable temperature at a heated water outlet and although not received as a negative it was decided through consultation that it was difficult to include in a minimum standard and was deleted in favour of a more detailed description for designing and measuring a metered dead leg.
- Further consultation will occur during the Public Comment period associated with this revision.

CONCLUSION AND RECOMMENDED OPTION:

It is recommended that Option 2 is adopted as it provides a net benefit when compared with the status quo. This option will benefit all stakeholders impacted by the problem including designers and installers of plumbing systems and the owners/occupiers of individual dwellings in multi-dwelling buildings serviced by individually metered heated water supply systems.

IMPLEMENTATION AND REVIEW:

- Option 2 forms part of an overall review of the 3500 series of plumbing standards currently progressing through the standards approval system and aimed to be published for public comment early 2020 within the timeline for referencing in the NCC 2021.
- If implemented the changes will be included in a public comment draft to be issued for public comment early in 2020 and any comments will be reviewed by the working group and the technical committee.

LIST OF ATTACHMENTS:

Attachment:

A. Scheduled of major changes

B. Public comment email message
C. Hot Water Distribution Research by Gary Klein.
D. US EPA WaterSense New Home Specifications.

Attachment A: SCHEDULE OF MAJOR CHANGES

No.	Clause / Ref	Proposed Change	Justification / Reason for Change	Cost implications
1	Cl 1.9.4.2	Moved to Section 10	Causing misunderstanding in Industry as relates more specifically to Circulatory Pipe Systems	None
2	Cl 10.4.1	Changed and moved from Cl 1.9.4.2	As above	None
3	Cl 10.1 & 10.2	Add Notes relating to temperature and excluding warm water systems.	To make clear that this Section does not relate to "Warm Water Systems"	None
4	Cl 10.9.3	New clause to provide requirements for branches with flow meter from circulating heated water systems.	To provide missing information to overcome problems identified in Attachment B.	There are no cost implications for those installing systems to the intent of the Standard. Note existing Clause 10.9.2 and 4.12.1
5	Appendix Q	Insert a new Appendix to provide guidance for sizing branches from circulatory heated water systems	As reported in Attachment B there is currently no specific information for configuring branches from Circulatory Heated Water Flow, causing designers/installers to try and adopt (with poor results) an existing Table designed for Non-Circulatory Systems.	None

Attachment B: Public comment email message

The following is the text from an email sourced by Standards PM to expand on a Public Comment received. The highlighted areas were used in drafting the Scope for the Project.

It is becoming a more common place issue within apartments that a designer / plumber will push a design with a dead leg to a point where some occupiers of units are waiting over a minute for HW to arrive at the fixture. When I question them about the issue, the normal response is “the code does not mention dead leg lead times or distances to be run” (just the shortest possible which is open to a lot of conjecture). I find it frustrating that these designers are really only thinking about making the job cheaper for the plumber to build without any consideration to the next 50-100 years of occupants wasting energy costs as well as wasting our valuable water on HW lead times.

We have multiple sites where long lead times are causing numerous complaints from occupiers. The vast majority of these are where there is a riser cupboard on each floor and they run dead leg down the passage to the front door of the apartment. In some cases this can be 10-15m to the front door and then another 15-20m to the furthest fixture. Some being 20mm for a large portion of the distance with a low flow tap at the end.

In my company, we request a maximum of a 25-30 second lead time to the most disadvantaged fixture. We selected this time based on the low number of complaints from occupiers we receive on these type of sites (we still get a few). This sort of lead time forces designers to run HW branches down each floor and place a hatch in front of the door of the apartment and thus making the dead leg the shortest possible while allowing the meter to be serviceable without access to the apartment.

In saying this, many designers / D&C plumbers ignore this request and just say they are putting it in according to AS3500. It’s hard for us to fight this approach as our contract is with the developer and not the builder or plumber. In regards to pipe sizing, in many states, designers already step outside AS3500 and only design 10/12mm pipe work for the entire apartment.

With new low flow tapware being utilised in most apartments, they believe that while flow rates may be close to design limits within the code, the saving of water in dead leg lead times is more important. It helps serviced HW providers too.

I believe that with apartments not being the norm of design compared to a 3 bedroom lowset family home, that consideration of the reduction of the initial HW pipe size from 20mm to 12mm into the apartment should be considered. It is a different demographic of HW users. There is another issue involved in long lead times for apartments and that is balancing valves. On most medium size projects upwards where these valves get specified to balance flows across a series of risers, they are just installed and wound out to full flow and hoped the hot water fairy waves her magic wand and they control the flow as required.

On my last 7 projects, no-one has either commissioned these valves OR even knows how to go about it. My poor HW fairy is copping a flogging from consumers. Many have threatened to place her wand in some terrible places after we tell them that the system was installed to Australian Standards.

Poor to zero flows during low draw off times create risers with cooled down HW and thus long lead times (HW entering the system can create an illusion that the pipework is balanced). In my role of National Hot Water Manager for an embedded HW supplier, I think we need to;

1. Offer a smaller initial pipe size for units 3 bedrooms & under to assist in the above
2. Demand maximum lead times for dead legs to the most disadvantaged fixture in an
1. apartment
2. Demand compulsory lagging of all HW pipework wherever it is located in a building (I think
3. this is covered in the last update)
4. Demand specification of all Balancing valves flow rates in building drawings and demand
5. qualified personnel only work on them OR get TAFE / others to offer training on this process. Apparently no-one does for plumbers.

While I don't think we need to go down the path of regulating every aspect of our industry to allow some flexibility in design, I do believe that our bible of standards does need to have some loopholes closed.

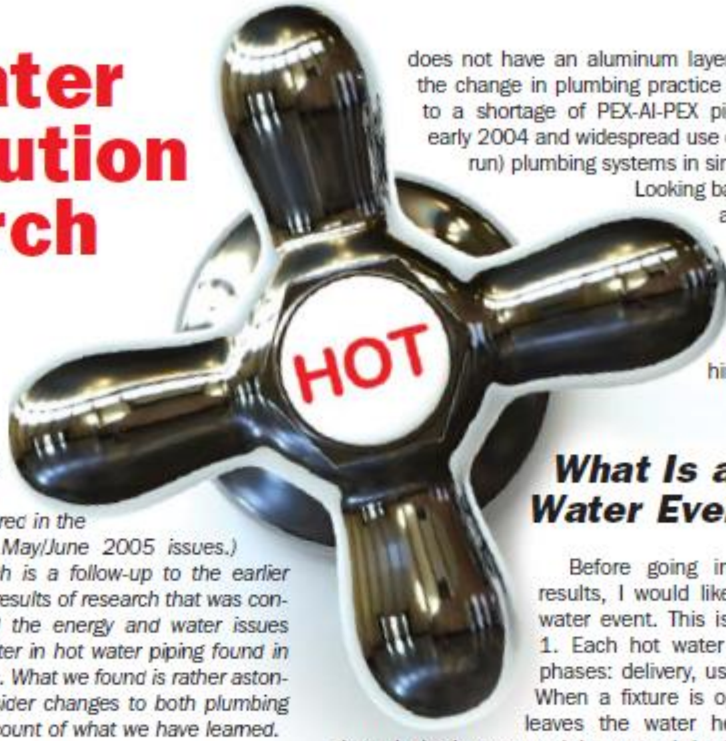
I would have to tell a plumber on a monthly basis that AS3500 is a minimum not an option and this is really starting to get me down. Especially in NSW where plumbing and building standards seem to be the lowest I have seen in my near 40 years in the industry. Maybe the Apartment tsunami has bought the worst out in some builders/ trades and it could be a good thing to see come to an end. I have seen some atrocious building work in the last few years and have wondered how there has not been more Opal towers come our way. I wouldn't buy a unit in some areas for anything.

I would love to have the backing of a new updated code & get support from all local plumbing jurisdictions when I find poor works that are completed and signed off. It seems they trades don't seem to worry about the compliance as much since self-certification has been introduced. "Bring back the biff" (I mean more plumbing inspectors).

Attachment C: Hot Water Distribution Research by Gary Klein

Hot Water Distribution Research

By Gary Klein



Starting in the January/February 2005 issue of Official, we ran a series of three articles on hot water distribution systems. (The other two articles appeared in the March/April 2005 and the May/June 2005 issues.) In the following article, which is a follow-up to the earlier series, we will document the results of research that was conducted to better understand the energy and water issues related to the flow of hot water in hot water piping found in typical residential applications. What we found is rather astonishing: we may want to consider changes to both plumbing and energy codes to take account of what we have learned.

Background

The California Energy Commission funded a project to study the performance of hot water distribution piping. That research was conducted by Dr. Carl Hiller, P.E., president of Applied Energy Technology.*

The purpose of the research was to compare the performance of hot water flowing through insulated and uninsulated pipes of various diameters. Before we began the tests we developed a matrix of test conditions that was quite large. We decided to start with 1/2- and 3/4-inch nominal diameter piping since our observation was that these two sizes were the most commonly used in single-family residences, both in California and around the country. These pipe diameters are also commonly found in multi-family, commercial and industrial applications and what we learned is applicable to these situations, too. The tests were to be conducted in air, with the temperature surrounding the pipes in the 65-70°F range.

We also decided to test copper and PEX-Aluminum-PEX (PEX-Al-PEX): copper because of its historically wide-spread use, and PEX-Al-PEX, because it was in common use in California at the time we began the tests. Since that time, we have seen a rapid shift to PEX piping that does not have an aluminum layer. The reasons for the change in plumbing practice appear to be due to a shortage of PEX-Al-PEX piping beginning in early 2004 and widespread use of manifold (home run) plumbing systems in single-family homes. Looking back, it would probably have made better sense to test PEX instead of PEX-Al-PEX; so much for 20/20 hindsight!

What Is a Hot Water Event?

Before going into the research results, I would like to define a hot water event. This is shown in Figure 1. Each hot water event has three phases: delivery, use and cool down. When a fixture is opened, hot water leaves the water heater and heads through the hot water piping toward the fixture. Ideally, we want this delivery time to be as short as possible. In practice there are probably two parts to the delivery phase. The first part is technical or structural and depends on: the plumbing system configuration; the location of the pipes; the volume of the water in the pipes between the water heater and the fixture; whether the piping is insulated; the fixture flow rate; the temperature of the water in the pipes compared to the temperature in the water heater, etc.

The second part is behavioral and depends on when the occupant decides the water is hot enough to use and "get in." As discussed in the first series, the behavioral waste can be significantly greater than the structural waste. The delivery phase may be short at some fixtures and long at others. It may be short or long at the same fixture, depending on when hot water was last needed somewhere else on the same line that serves the fixture. Some people hover near the fixture, checking to see when the water is hot enough, while others know from experience that it takes a long time, so they leave, returning when they are good and ready! From the occupant's point of view, this may appear to be totally random and hard to "learn," in which case I suspect their behavior defaults to the worst case condition at all fixtures.

In the articles that appeared in 2005, we showed how it is possible to deliver hot water, wasting no more than one cup. At flow rates between 0.5 and 2.5 gpm, this means the water will be delivered in 7.5 down to 1.5 seconds, which is pretty darned fast.

(*Hiller, Dr. Carl, P.E., 2005. Hot Water Distribution System Research – Phase 1, California Energy Commission, Sacramento, California, November 2005, CEC 500-2005-161. The full report can be found at: http://www.energy.ca .gov/pier/final_project_reports/CEC-500-2005-161.html)

The use phase needs to be whatever length it takes to perform the task for which hot water is desired. The cool down phase begins the moment the fixture is turned off. If the time until the next hot water event is short enough, the water in the pipes all the way back to the water heater will be hot enough to use. If it is too long, water coming from the water heater will be run down the drain until water hot enough to use arrives at the fixture.

At the fixture, hot water is generally mixed with cold water to reach the desired useful hot water temperature. The thermostat on the water heater needs to be set high enough to overcome the heat losses in the piping system and still provide water that is hot enough to be mixed at the farthest fixture with the highest desired useful hot water temperature. For purposes of our experiments, we selected 105°F as the nominal useful hot water temperature.

From our research, we have learned about all three phases of this process.

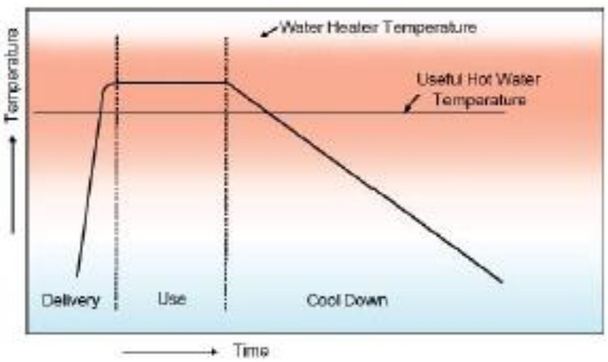


Figure 1. *Hot Water Event Schematic*

The Test Rig

We set up a test rig to measure the performance. This is shown schematically in Figure 2 and in pictures in Figures 3 and 4.

Calculations and observations helped us decide to test roughly 120 foot-long sections of pipe. Since our lab was only 40 feet long, we needed to create a serpentine piping layout. When we used hard copper pipe, the long legs were nominally 20 feet long (the pipe is actually a bit longer) and the short legs were roughly 18 inches long. Temperature sensors were located at the beginning and end of the serpentine shape and at the center of each short leg.

We thought these two layouts, one for hard pipe and one for flexible pipe, were essentially identical. It turns out that they weren't identical and we learned a great deal from this mistake.

Figure 2. *Serpentine Test Rig Schematic*

Figure 3. *Test Rig for Uninsulated (Top) and Insulated (Bottom) Copper Piping*

Figure 4. *Test Rig for Uninsulated PEX-Al-PEX*

The Delivery Phase

We learned three things from our research about the delivery phase:

1. During the delivery phase, hot water acts differently than cold water.

2. Low flow rates (< 1 gpm) waste much more water than high flow rates (> 4 gpm).

3. At typical fixture flow rates (1-3 gpm), sharp (standard) 90-degree elbows increase turbulence, heat loss and water waste.

Perhaps one of the most surprising things that we learned is that it is possible for significantly more water to come out of the pipe before hot water gets from the water heater to the fixture than is actually in the pipe. During the tests, our researcher found that the temperature sensor on the first turn was getting hot sooner than was theoretically possible assuming perfect plug flow. The difference in time was significant – otherwise he probably wouldn't have noticed it. To figure out what was going on, he used his hands to feel the pipe and found that there was a thin stream of hot water riding on top of the cold water that was running many feet ahead of the plug of hot water coming from the water heater. After some time, mixing would occur, but until that happened, there was a much greater surface area of hot water touching both the cold water and the relatively cold pipe than would normally have been expected.

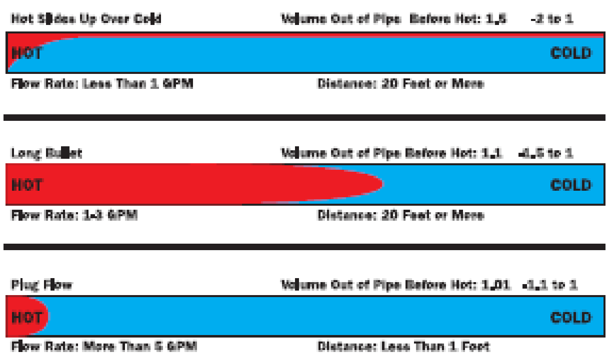


Figure 5. *Delivery Phase Schematics (drawings not to scale)*

This is depicted in the top portion of Figure 5. At the beginning of a hot water event, the cold water is much more viscous than the hot water. The length of the thin stream of hot water could be more than 20 feet long and would go around the elbows. The volume of water that would come out of the pipe (or past a given temperature sensor) before hot water arrived could be twice the volume that was in the pipe.

We found this condition most prevalent at flow rates less than 1 gpm. These flow rates are typical of commercial lavatory sinks, low flow showers and the hot water portion of the flow in a single lever sink when the valve is opened halfway between hot and cold.

As the flow rate increased into the range typical of many sinks and showers (1-3 gpm), the thin stream gave way to a more normal mixing front, which we have depicted as a long bullet. The length of the bullet was several feet ahead of the hot water plug. The extra volume of water that came out of the pipe before hot water arrived was generally 10 to 50 percent more than the volume of water in the pipe. The waste was larger for a given flow rate in the hard-piped test rig that had standard elbows than it was in the flexible pipe test rig that used wide-radius bends in the pipe itself to make the 180-degree turns.

At higher flow rates, typical of those found in garden or Jacuzzi tubs, some laundry sinks, washing machines and dishwashers, we saw what looked like plug flow – the idealized type of flow I heard described in engineering school. In these cases, the length of the much shorter bullet was only a very short distance ahead of the hot water plug. The extra volume of water that came out of the pipe before hot water arrived was generally much less than ten percent more than the volume of water in the pipe. We found this condition some of the time at high flow rates in the hard-pipe test rig with hard elbows. We found it much more often and at lower flow rates in the flexible test rig with wide-radius bends.

If you recall from the first article in the series, I had delivery problems when I measured my house. Looking back, I had installed a low flow showerhead (1 gpm) specifically to save water. However, both the low flow rate and the elbows in the copper piping created conditions that wasted a significant amount of water before the hot water arrived (more than twice what was in the pipe). This was certainly an unintended consequence of my attempt to save water! The extra water that came out had to be heated by the water heater and so my energy consumption was increased during the delivery phase. As we will see in the next section, the low flow rate fixture also frustrated my attempt to save energy during the use phase, too.

The Use Phase

We learned four things about the use phase:

1. Uninsulated PEX-Al-PEX piping has a greater temperature drop at a given flow rate than does copper piping of the same nominal diameter. Insulating the pipes minimized the difference.

2. The temperature drop at a given flow rate is less in 1/2-inch piping than in 3/4-inch piping.

3. The temperature drop over a given distance is greater at low flow rates than at high flow rates. There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm.

4 Insulation decreases the temperature drop at a given flow rate.

Figure 6 shows the comparison between nominal 3/4-inch PEX-Al-PEX and 3/4-inch copper piping over a length of 100 feet. The figure is based on steady state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F. The water in the uninsulated PEX-Al-PEX pipe lost more temperature at the same flow rate than did the water in the copper pipe. We suspect that this additional heat loss is due to a combination of two effects: the nominal 3/4-inch PEX-Al-PEX pipe has a larger surface area than the nominal 3/4-inch copper pipe – once it is hot there is more surface area to lose heat; and because the PEX-Al-PEX has a larger internal diameter than the copper piping, the face velocity of the water in the PEX-Al-PEX is slower and the rate of heat loss is greater than it is in copper. Once the pipes were insulated, the difference in temperature drop essentially disappeared.

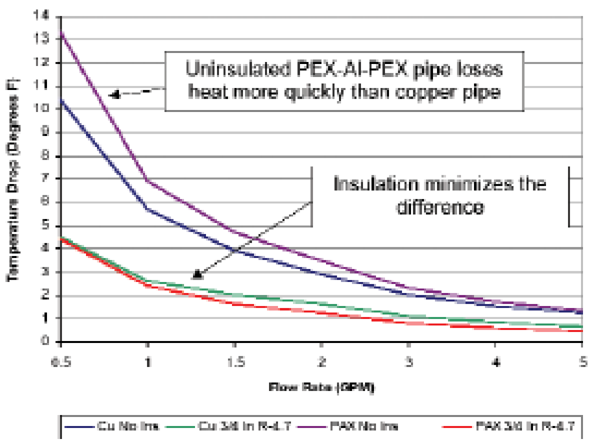


Figure 6. *Comparison of Nominal 3/4-Inch PEX-Al-PEX and 3/4-Inch Copper Piping*

We did not have enough funding to run tests on 1/2-inch PEX-Al-PEX. Based on the fact that uninsulated copper performed better than PEX-Al-PEX and, with insulation, the performance was very similar, we think we can use the performance of copper pipe at 1/2- and 3/4-inch, with and without insulation, as a reasonable first order proxy to better understand what generally happens in hot water piping.

Figure 7 compares the performance of nominal 1/2- and 3/4-inch diameter copper piping, both insulated and uninsulated. As in the prior figure, the graph is based on steady state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F over a length of 100 feet.

At a given flow rate, the temperature drop in 1/2-inch nominal piping is less than in 3/4-inch nominal piping. This is due to the increased face velocity of the water, which reduces the heat loss rate. While from a thermal perspective it is beneficial to use the smallest pipe diameter possible, frictional losses increase exponentially with increased face velocity and result in increased pressure drop over a given length. We did not measure pressure drop during the tests. Future tests should do this so as to better understand its impacts.

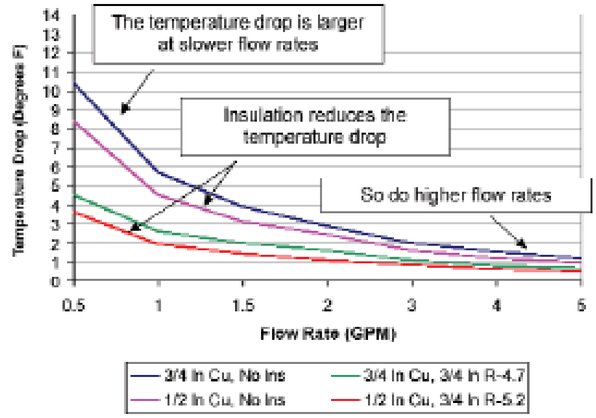


Figure 7. *Comparison of Nominal 1/2- and 3/4-Inch Copper Piping*

The temperature drop over a given distance is greater at low flow rates than at high flow rates. At 2.5 gpm, the highest flow rate allowed for showerheads, the temperature drop in uninsulated copper piping is between 2°F and 2.5°F. At 1 gpm, the temperature drop in uninsulated pipe climbs to between 4.5°F and 5.5°F. At 5 gpm, the temperature drop goes down to roughly 1°F, and the difference between 1/2- and 3/4-inch diameter goes away.

There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm. At 0.5 gpm, the temperature drop almost doubles. The curve will get even steeper if the flow rate is reduced still further and, for a given length at some low flow rate, hot water will never reach the fixture. The same thing would happen if length was increased while flow rate was held constant, or if the piping was located in a higher heat loss environment, say in damp soil under a slab or between buildings in a campus situation.

Insulation reduces the heat loss overall and, for a given flow rate, the temperature drop is cut roughly in half. Insulation also reduces the difference in temperature drop between 1/2- and 3/4-inch diameter piping.

The Cool Down Phase

We learned three things about the cool down phase:

1. If the time between hot water events is long enough, the pipes cool down to below the useful hot water temperature for the next hot water event.
2. Larger diameter pipes cool down more slowly than smaller diameter pipes.
3. Insulation extends the time it takes for the pipes to cool down to a given temperature.

The first point seems obvious, since if you wait long enough, the temperature of the water in the pipes will eventually reach equilibrium with the ambient temperature surrounding the pipes. The real question is: how long does it take to cool down to a non-useful hot water temperature? This depends upon the starting temperature of the water in the pipes, the diameter of the pipes, the amount of pipe insulation, the environmental conditions in which the pipes are located, and the temperature of water needed for the next hot water event.

Figure 8 compares how long it took for the water in 3/4-inch diameter copper pipes to cool down from a given starting temperature to 105°F. The ambient temperature surrounding the pipes was between 65°F and 70°F and the pipes were located in air. Without insulation, it took between 5 and 22 minutes for the temperature to reach 105°F. The hotter the water began, the longer it took.

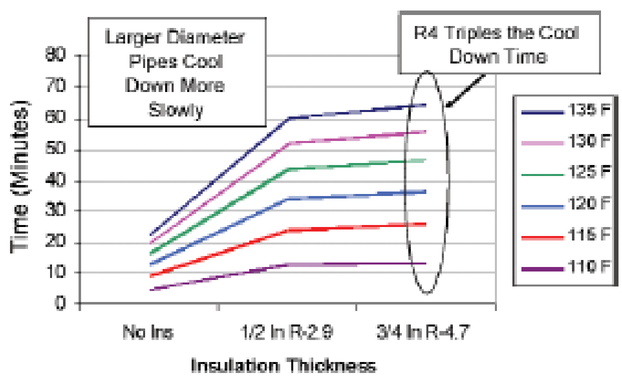


Figure 8. *Time Required for 3/4-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation*

When 1/2-inch wall thickness and 3/4-inch wall thickness insulation were added, it took significantly longer for the water to cool down to 105°F. Use of the 3/4-inch thick insulation (>R-4) roughly tripled the cool down time. The 1/2-inch wall thickness insulation did almost as well.

Figure 9 compares how long it took for the water in 1/2-inch diameter copper pipes to cool down from a given starting temperature to 105°F. As with the tests on 3/4-inch diameter pipe, the ambient temperature surrounding the pipes was between 65°F and 70°F and the pipes were located in air. Without insulation, it took between 5 and 20 minutes for the temperature to reach 105°F, almost exactly the same as for the uninsulated 3/4-inch piping. Use of the 3/4-inch thick insulation (>R-4) roughly doubled the cool down time. The 1/2-inch wall thickness insulation did almost as well.

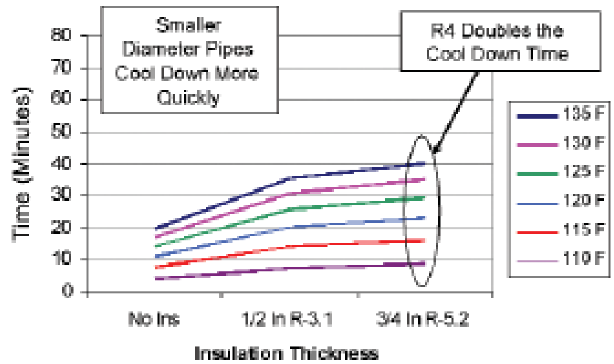


Figure 9. *Time Required for 1/2-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation*

Although the time it took the water in the uninsulated pipes to cool down was very similar for the 1/2-inch and 3/4-inch diameter pipes, when insulation was added, the water in the 3/4-inch pipes took roughly 1.5 times as long to reach the same temperature as the 1/2-inch pipes.

If the pipes were located in a colder environment, such as in a crawl space or an attic, used at night or early in the morning, or throughout much of the winter, they would have cooled down much more quickly. If the pipes were in a high heat loss environment, such as in the damp soil under a concrete slab, they would cool off even faster. If the ambient temperature were higher, such as in an attic in the middle of a summer afternoon, the pipes would take much longer to cool down. (On the other hand, the water in the cold water pipes might be too hot to use!)

In future articles in this series, we will apply the lessons learned to improving the performance of hot water distribution systems. We will also look at possible changes that might be made in plumbing and energy codes to take advantage of what we have learned and identify some additional research that should be done. Finally, we will look at the implications of making these improvements on the overall connection between water and energy use.

About the Author: Gary Klein

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. Gary has a passion for hot water: getting into it, getting out of it, and efficiently delivering it to meet customers' needs. He currently helps administer California's Public Interest Energy Research program and chairs the recently formed Task Force on Residential Hot Water Distribution Systems. He can be contacted at Gklein@energy.state.ca.us

Attachment D: US EPA WaterSense New Home Specifications.

Guide for Efficient Hot Water Delivery Systems

1.0 Introduction

This guide is designed to help builders better understand and meet the hot water delivery system criteria as specified in the *WaterSense® New Home Specification* (WaterSense new home specification). This guide offers a brief overview of and potential design considerations for hot water delivery systems, including example efficient plumbing design layouts. It also summarizes the hot water delivery system inspection process and provides tips for ensuring that the hot water delivery system will meet the WaterSense new home specification requirements. Lastly, this guide identifies potential options for correcting systems that do not initially meet the WaterSense new home specification requirements.

The WaterSense new home specification is not intended to replace or contravene state or local codes and requirements. All new homes are required to meet all applicable national, state, and local building codes and regulations. In addition, all plumbing system installers should meet all applicable state and local licensing requirements. WaterSense also recommends the use of qualified and experienced professionals to design and install the hot water delivery systems in WaterSense labeled new homes. Although guidance and options are provided, WaterSense does not make any specific recommendations about the type of material and hot water delivery systems that should be utilized and recommends that builders, designers, and plumbing professionals exercise their own professional judgment to select the most appropriate materials and hot water delivery system design.

2.0 Background

Heating water is typically the second largest use of energy in a home (after space heating and cooling).[1] Despite its resource intensity, the hot water delivery system is seldom an area of significant focus when constructing a home. As a result, many homes today are built with poor performing, inefficient hot water delivery systems that take minutes to deliver hot water to the point of use and waste large amounts of energy and water in the process. Approximately 10 to 15 percent of the energy use associated with a hot water delivery system is wasted in distribution losses. Studies have shown that the average home wastes more than 3,650 gallons of water per year waiting for hot water to arrive at the point of use.[2]

How quickly and efficiently a hot water system can deliver appropriately heated water to the point of use depends on multiple factors that occur in three distinct phases:

1. **Generation:** How efficiently a water heater can convert electricity or natural gas (depending on the type of heater) into useful hot water has a major impact on the overall efficiency of the system. Hot water generation can be made more efficient by selecting a water heater with a higher energy factor (EF).

---

[1] Energy Information Administration, Office of Energy Consumption and Efficiency Statistics, 2009 Residential Energy Consumption Survey.

[2] Klein, Gary. "Hot-Water Distribution Systems Part 1." Plumbing Systems & Design. Mar/Apr 2004.

2. **Distribution:** Once heated, the hot water must be delivered to the intended point of use in the home. Several factors influence distribution efficiency and can play a role in a more efficient system. They include:

- Length of piping between the water heater and a given fixture
- Pipe diameter and materials
- Whether the piping is insulated

3. **Use:** Hot water is used by a variety of fixtures and appliances throughout the home (faucets, showerheads, clothes washers, and dishwashers). Using products such as WaterSense labeled faucets and showerheads that function at lower flow rates will increase the efficiency of the system.

Both generation and use of hot water can be reduced through simple product solutions. Using WaterSense labeled products adds to both the energy and water efficiency of the system by using less hot water at the point of use, while specifying water heaters with higher EFs reduces the energy needed to serve a home's hot water needs.

The length of piping between the water heater and each fixture, the pipe diameter, and the material from which the pipe is made can all have great impact on hot water delivery system efficiency, because those factors determine the volume of water stored within the delivery system. The volume of stored water affects how long it takes for hot water to reach each fixture and the temperature retention of the water as it is delivered. Systems with the least stored volume waste the least amount of water and energy.

Unlike generation and use, effective and efficient distribution of hot water requires a whole-system approach and can be challenging to many builders. However, considering the hot water delivery system early in the design phase and carefully following a plumbing design can deliver superior homes and reduced installation costs.

To address hot water delivery system water and energy waste, the WaterSense new home specification contains hot water delivery system requirements for both single- and multi-family homes as follows:

- No more than 0.5 gallons of water may be stored in any piping or manifold between the hot water source (i.e., water heater or recirculation loop) and any hot water fixture.
- To account for the additional water that must be removed from the system before hot water can be delivered (i.e., water stored in the fixture itself or water that cools off while moving from the heater to the point of use), no more than 0.6 gallons of water may be delivered to a fixture before the hot water arrives.
- Recirculation systems must be demand-initiated. They may not be solely timer- or temperature-based.

This document provides guidance specifically for minimizing stored water volume through efficient hot water delivery system design. WaterSense has also developed a simple, Excel-based calculator to help estimate the volume of water stored in a system based on the specified pipe types, diameter, and length.[3] For information about efficient water heaters or pipe insulation, review the *Resource Manual for Building WaterSense Labeled New Homes*.[4]

---

[3] EPA. Hot Water Volume Tool. http://epa.gov/watersense/excel/hw_volume_tool_v1.xlsm.

[4] U.S EPA's WaterSense Program. 2014. Resource Manual for Building WaterSense Labeled New Homes. http://www.epa.gov/watersense/docs/newhome_builder_resource_manual508.pdf.

3.0 Efficient Hot Water Delivery System Design

Efficient hot water delivery system design, which includes planning to minimize pipe run lengths and, to the extent possible, pipe diameters, can significantly reduce hot water delivery system water and energy waste and meet the WaterSense new home specification requirements. It also provides tangible benefits to both homeowners and builders. For homeowners, the convenience of drawing hot water from fixtures quickly is highly desirable, as are the reduced water and energy costs associated with an efficient hot water delivery system. For builders, an efficient hot water delivery system can reduce material and installation costs.

3.1 System Design Options

WaterSense developed a performance-based requirement for hot water delivery systems to allow builders to utilize the system design that best meets their project-specific needs while still meeting the WaterSense new home specification criteria. Although individual designs will vary by project, there are four basic hot water delivery system types that are used in single- and multi-family homes. These are:

- Trunk and branch systems
- Core systems
- Whole-house manifold systems
- Demand-initiated recirculation systems

To assist with planning and design selection, the following subsections provide a brief description of each system type and discussion of key considerations for system efficiency. In addition, Section 4.0 illustrates how to effectively implement each system type.

3.1.1 Trunk and Branch Systems

Trunk and branch systems are characterized by one long, large diameter main line (i.e., the “trunk”) that runs from the water heater to the farthest fixture in the house. As illustrated in Figure 1, along the way, “branches” from the main trunk supply hot water to various areas of the home, and smaller “twigs” branch off to supply hot water to individual fixtures. Typically, the main trunk uses larger diameter piping to ensure adequate flow, with smaller diameter piping branching off to individual fixtures.

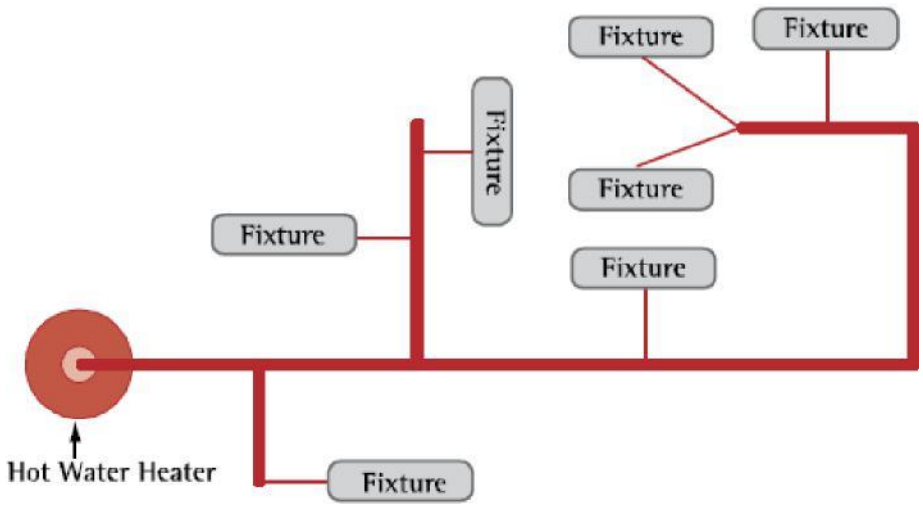


Figure 1. A General Configuration Typical of Trunk and Branch Systems

Trunk and branch systems are the most common type of hot water delivery system. They can be utilized in both single- and multi-family homes. In terms of maximizing hot water delivery system efficiency, trunk and branch systems are most suitable for smaller homes, homes with relatively few fixtures, or in multi-family housing if installed individually in each unit. It may be difficult to design an efficient trunk and branch system in larger homes with spacious layouts and a large number of fixtures. Of all of the hot water delivery systems presented in this guide, trunk and branch systems have the greatest potential to be inefficient, if care is not taken to centralize fixture placement and minimize pipe run lengths.

3.1.2 Core Systems

Core systems are a particular type of trunk and branch system. They warrant specific mention because they are, by design, generally more efficient than a traditional trunk and branch system. Core systems utilize a central plumbing core, where plumbing areas (i.e., kitchens, bathrooms, laundry rooms) are placed in close proximity to the water heater. Hot water is piped directly to each fixture or group of fixtures using smaller diameter piping when appropriate and as direct a path as possible. Figure 2 illustrates the main design principles of this configuration. As the figure shows, the relative proximity of the fixtures and direct horizontal runs minimizes the length of piping and the amount of time required for hot water to reach each fixture.

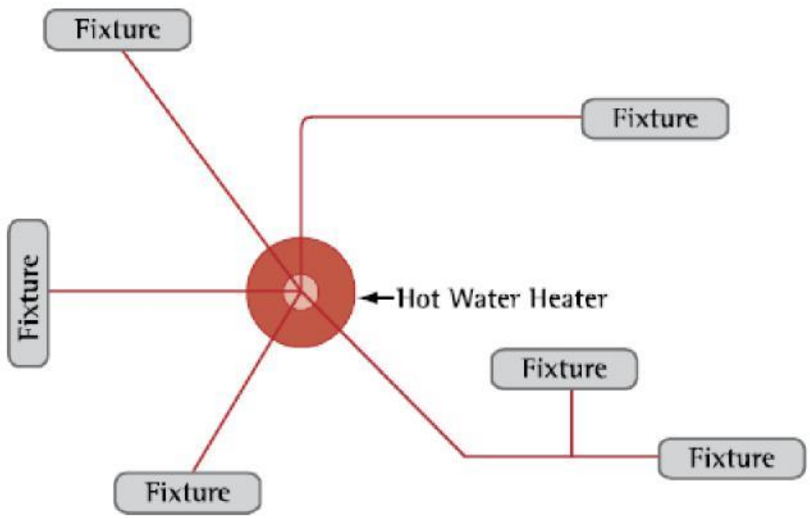


Figure 2. A General Configuration Typical of Core Systems

Because core systems use less—and smaller diameter—piping, they can significantly reduce conductive heat loss and the amount of water that users waste waiting for hot water to arrive at the fixtures. They can also be made with any type of piping (or multiple types if necessary); copper, CPVC, and cross-lined polyethylene (PEX) are the most commonly used types. As a result, core systems provide greater flexibility and can be less expensive and quicker to install relative to other system types.

Core systems can be utilized in both single- and multi-family homes. They are similar to trunk and branch systems in that they are most suitable for smaller homes or homes with relatively few fixtures. They might not be suitable for multi-family buildings if used as a building-wide hot water delivery system. It is also important to note that since core systems supply each fixture or point of use with their own line, they can be difficult to retrofit at a later time.

3.1.3 Whole-House Manifold Systems

Whole-house manifold systems, also called parallel pipe or home run systems, use small diameter, flexible piping (such as PEX) that run directly to each individual fixture from a central manifold. As shown in Figure 3, the central manifold is typically kept in close proximity to the water heater. The manifold may be constructed of wither plastic or metal.

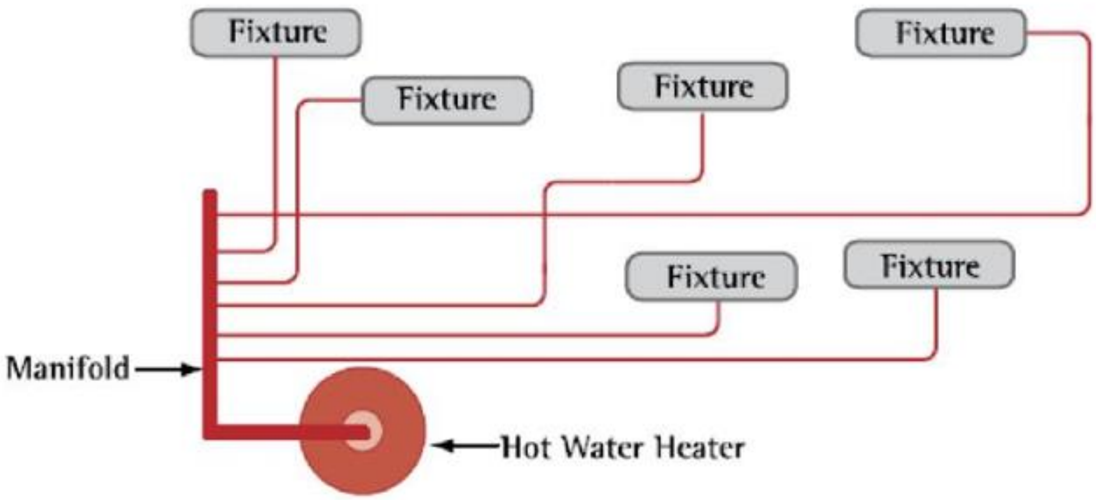


Figure 3. A General Configuration Typical of Whole-House Manifold Systems

The use of flexible piping allows these systems to be installed more quickly than rigid, non-flexible plumbing systems because fewer fittings are necessary during installation. Because the flexible piping is supplied as spools of continuous piping, plumbers can lay out relatively long piping runs without needing to install coupling fittings at regular intervals. Furthermore, by virtue of the piping's flexibility, it can be redirected as needed using continuous sweeping turns, eliminating the need for elbow fittings, which are time-consuming to install and contribute to the loss of pressure and heat as water moves through the system.

Whole-house manifold systems also equalize pressure, and, therefore, several fixtures can be used simultaneously without dramatic changes in pressure or temperature. As noted above, the elimination of inline fittings also reduces pressure losses, allowing for the use of smaller 3/8 inch diameter piping. Reduced pipe diameters in turn deliver hot water to fixtures faster and with less water and energy waste than conventional piping systems.

Whole-house manifold systems can be utilized in either single- or multi-family homes. This system type is an ideal option for larger homes with more spacious layouts and multiple fixtures in which longer piping runs may be necessary. Like core systems, whole-house manifold systems supply each fixture with an independent line and can be difficult to retrofit.

3.1.4 Demand-Initiated Recirculation Systems

Recirculation systems consist of one continuous hot water supply loop that recirculates water throughout the home. As shown in Figure 4, a circulating pump draws hot water through the recirculation loop and returns to the water heater any ambient-temperature water residing within the loop. Alternately, the pump may return this water to the cold water line while simultaneously drawing hot water from the water heater. Utilizing the cold water line as the return is often a convenient solutions for inefficient distribution systems that are being retrofitted. Recirculation systems save water both because they can reduce the wait time for hot water to nearly nothing (thus eliminating the loss of water down the drain) and by returning ambient-temperature water stored in the piping is back to the heater. This decreases the work the heater must do to reach an acceptable temperature. In addition, the recirculation loop is typically located where it can be kept as short as possible and within 10 feet of every fixture.[5]

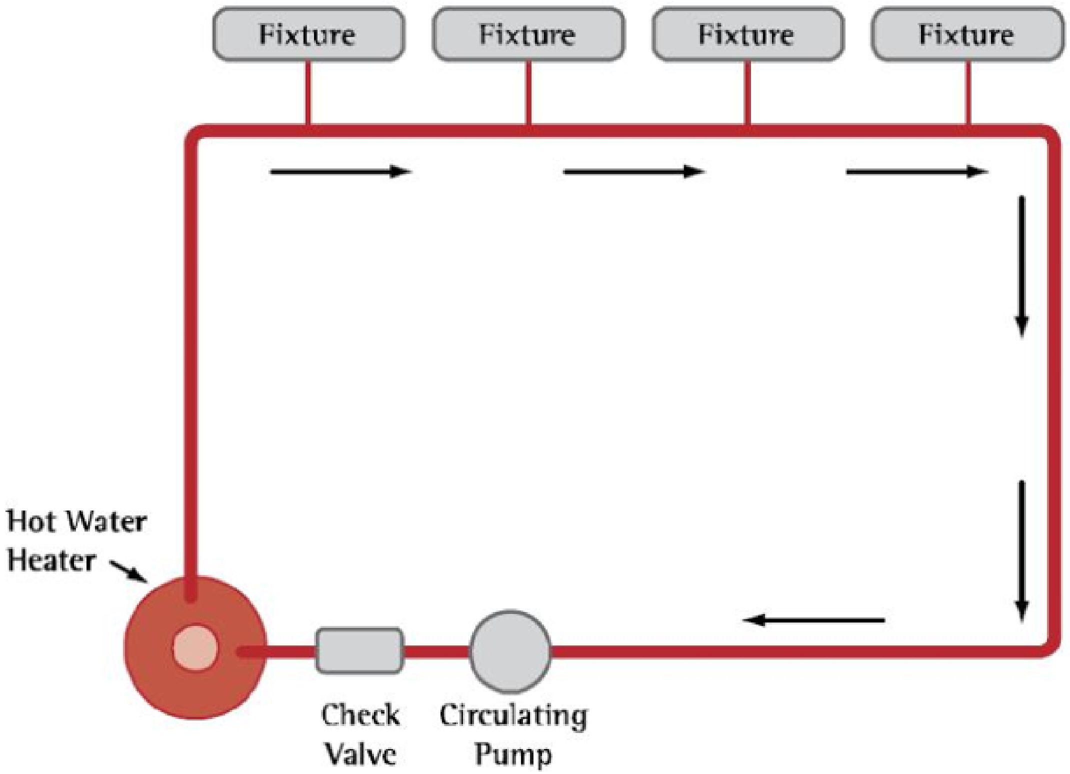


Figure 4. A General Configuration Typical of Demand-Initiated Recirculation Systems

Demand-initiated recirculation systems have been found to be more energy-efficient than other timer- or temperature-based recirculation systems, because hot water is only drawn into the recirculation loop when hot water is needed. Demand-initiated systems use sensor electronics installed at the fixtures to automatically adjust standing ambient temperatures in the hot water recirculation loop. When the user activates the pump by pushing a button, or via a motion sensor located near the hot-water fixture, the sensor measures temperature changes in the recirculation loop and activates the circulating pump until the water in the loop reaches a specified temperature, at which time the water is delivered to the fixture.

It is important to note that timer- and temperature-based recirculation systems may not be used to meet WaterSense new home specification criteria. Research indicates that these systems can use a large amount of energy to maintain the water temperature in the recirculation loop and are considered to be energy-inefficient.

Demand-initiated recirculation systems may offer builders with more flexibility than the other types of systems because they can allow for longer pipe runs and less centralized fixture placement. Although demand-initiated recirculation systems use energy in their operation, they can save energy in three ways:

- The water in the recirculation loop that is returned to the water heater is generally warmer than water coming into the house, and therefore, the water heater requires less energy to keep the water heated.

[5] Acker, L., G. Klein. “Benefits of Demand-Controlled Pumping.” Home Energy. 2006.

- Since hot water is distributed at a high flow rate to fixtures, significantly less heat is lost during distribution.
- The high distribution flow rate also allows hot water to reach the fixtures faster, and therefore, less hot water is needed to prime the recirculation loop.[6]

While the cost of the pump and wiring of the required sensors represent incremental costs, recirculation systems can be quicker to install and utilize less pipe than traditional distribution systems, which in turn can reduce installation costs.

Due to the energy required to recirculate the ambient-temperature water stored in the system, demand-initiated recirculation systems may not be suitable for larger homes, where large loops are necessary or where it is not practical to locate fixtures within ten feet of the loop. So while builders should weigh the water efficiency benefits against the potential energy-related drawbacks associated with the use of this type of system in large homes, the energy saved by reducing the amount of water that is heated and then run down the drain typically far outweighs the energy used to operate the pump.

3.2 Pipe Diameter and Materials of Construction

An efficient hot water delivery system design and layout will address water waste from long pipe runs, but as alluded to in the discussion above, pipe material and pipe diameter also impact system efficiency. For a given nominal diameter of pipe (where diameter is measured on the outside), the inside diameter will vary by material because the material has differing wall thicknesses. This means that identically designed hot water delivery systems, with exception to the type of material used, will store different volumes of hot water within the respective systems.

When designing hot water delivery systems, builders have several available choices regarding pipe material. Table 1 identifies some common types of pipe used for hot water delivery systems and lists the capacity of water that each type stores per foot of pipe for a given pipe diameter. It is important to note that the pipe material selection will to some extent be dictated by the type of hot water delivery system that will be installed in the home. For example:

- Trunk and branch and core systems can utilize any type of piping, although copper is traditionally used.
- Whole-house manifold systems typically utilize flexible piping such as PEX-Al-PEX, PE-AL-PE, or PEX CTS SDR 9 piping.
- Demand-initiated recirculation systems typically utilize copper or CPVC piping, but can also use PEX tubing

Builders should note that when using copper piping, there are three primary copper types that can be utilized: Type M, L, or K copper. Of the three, Type L and M are traditionally used in home plumbing systems, while Type K tubing, which is the thickest type of piping, is used primarily for main and underground water lines.

[6] Ibid.

Table 1.Internal Volume of Various Water Distribution Piping

Ounces of Water Per Foot of Hot Water Tubing								
Nominal Diameter in inches (in)	**Copper M**	**Copper L**	**Copper K**	**CPVC CTS SDR 11**	**CPVC SCH 40**	**PEX-AI-PEX ASTM F 1281**	**PE-AL-PE**	**PEX CTS SDR 9**
3/8	1.06	0.97	0.84	N/A	1.17	0.63	0.63	0.64
1/2	1.69	1.55	1.45	1.25	1.89	1.31	1.31	1.18
3/4	3.43	3.22	2.90	2.67	3.38	3.39	3.39	2.35
1	5.81	5.49	5.17	4.43	5.53	5.56	5.56	3.91
1 1/4	8.70	8.36	8.09	6.61	9.66	8.49	8.49	5.81
1 1/2	12.18	11.83	11.45	9.22	13.20	13.88	13.88	8.09
2	21.08	20.58	20.04	15.79	21.88	21.48	21.48	13.86

Source: Modified from *2009 International Plumbing Code Table E202.1. International Code Council. January.*

Conversions: 1 gallon (3.8 liters) = 128 ounces
1 ounce = 0.00781 gallons (0.0296 liters)
0.5 gallons (1.9 liters) = 64 ounces
0.6 gallons (2.3 liters) = 76.8 ounces

While builders are encouraged to consider how pipe material and associated diameters affect the efficiency of hot water delivery systems, the diameter should not be minimized to such an extent that it will compromise the system's operability. Pipe diameters should be sized according to the specific needs, design constraints, and applicable codes or standards. For example, main supply lines require larger diameters to ensure adequate water flow to each of the fixtures connected to that line. Smaller diameter piping may be acceptable to deliver water from the main supply line to the individual fixtures.

The use of pipe insulation can further improve the efficiency of the hot water delivery system, as it reduces the overall rate of heat loss from water stored in the hot water delivery system piping (both while the system is in standby mode and as hot water moves through the piping). Review the *Resource Manual for Building WaterSense Labeled New Homes*[7] for information about the efficient use of pipe insulation.

3.3 Summary of Key Considerations for Efficient Hot Water Delivery Systems

During the design phase of a new home, it is important to consider all project-specific needs or planning constraints in order to identify the hot water delivery system and material that will best serve the home. While each hot water delivery system type can be used efficiently in several settings, no system will suit the needs of every home. To assist builders with selecting the most appropriate system for their homes, Table 2 provides a summary of the key considerations for each type of hot water delivery system.

[7] U.S EPA's WaterSense Program. 2014. Resource Manual for Building WaterSense Labeled New Homes. http://www.epa.gov/watersense/docs/newhome_builder_resource_manual508.pdf.

Table 2. Key Considerations for Hot Water Delivery Systems

Consideration	Hot Water Delivery System Type: Trunk and Branch	Core	Whole-House Manifold	Demand-Initiated Recirculation
Home Type Suitability	• Smaller homes • Homes with relatively few fixtures • Individual units of multi-family buildings	• Smaller homes • Homes with relatively few fixtures • Individual units of multi-family buildings	Can be used in any single-family or multi-family home, but suitable for: • Larger homes where long piping runs may be necessary • Homes that have a large number of fixtures • Multi-family buildings three stories or less with a centralized system supplying hot water to multiple units	• Smaller homes where fixtures are not centrally located near water heater • Individual units of multi-family buildings. • Larger homes with a large number of fixtures, provided a recirculation loop can be installed within 10 feet of each fixture
Layout and Design Strategy	• Locate fixtures in close proximity to water heater to minimize pipe run length to farthest fixture • One long main trunk supplies water to farther fixture, individual fixtures are connected to main trunk	• Locate fixtures in close proximity to water heater to minimize pipe run length to farthest fixture • Pipes run directly from water heater to individual fixtures	• Can be used with a less centralized layout where longer pipe runs are necessary • Piping runs from manifold to individual fixtures • Locate manifold in close proximity to the water heater	• Can be used with a less centralized layout where longer pipe runs would otherwise be necessary • Locate fixtures within 10 feet of loop and in relative proximity to minimize recirculation loop size • Piping runs directly from loop to individual fixtures
Materials and Pipe Diameter	• Any type of piping can be used, although copper is traditional • Requires larger piping on main trunk line, while smaller piping can be used to supply individual fixtures	• Any type of piping can be used and multiple types if necessary, although copper, CPVC, and PEX are common • Can use smaller diameter piping to run directly from water heater to individual fixtures	• Uses flexible piping such as PEX • Can use smaller pipe diameter running from manifold to individual fixtures; 3/8 inch diameter pipe is ideal	• Typically use copper of CPVC piping • Can use smaller pipe diameter to supply individual fixtures from the recirculation loop
Implementation	• Traditional system with which most plumbing professionals are familiar • Requires planning to centralize fixture placement and minimize pipe run lengths	• Requires significant planning to centralize fixture placement and minimize pipe run lengths • Provides flexibility in pipe material choice • Uses less material than trunk and branch and can be less expensive and quicker to install	• Can be installed more quickly than traditional rigid systems • Requires fewer fittings and installation is more flexible	• May be more expensive than other system types • Requires installation of pumps, switches or sensors and a significant amount of piping for the recirculation loop • May require homeowner training

Consideration	Hot Water Delivery System Type			
	Trunk and Branch	Core	Whole-House Manifold	Demand-Initiated Recirculation
Efficiency and Other Considerations	▫ Has the greatest potential for ▫ inefficiency May be the hardest type of system to use to meet the WaterSense new home specification requirements	• Smaller pipe diameters running directly to fixtures can reduce conductive heat loss compared to trunk and branch systems	• Equalizes pressure, allowing fixtures to be used simultaneously without pressure or temperature changes • Elimination of inline fittings reduces pressure loss and allows for even further reduction in pipe diameter over other systems • Reduced pipe diameter delivers hot water faster and with less water and energy waste	▫ If designed properly, can be the most waterefficient hot water delivery system

4.0 System Implementation

The following section provides examples and illustrations on how each of the four types of hot water delivery systems can be effectively implemented into a WaterSense labeled new home. This discussion includes sample layouts and supporting calculations showing the amount of hot water stored within each example system. For demonstration purposes, the same floor plan is used in each sample layout. Only the placement of the fixtures and water heater varies to show how each system type can be designed to meet the WaterSense new home specification criteria.

When designing the hot water delivery system layouts, builders should perform calculations such as those shown in the tables below to verify that no more than 0.5 gallons of water are stored between the water heater and each fixture. These preliminary calculations are necessary to ensure that the system can meet the WaterSense new home specification criteria before construction begins.

4.1 Trunk and Branch Systems

Figure 5 (on page 15) illustrates a plumbing layout that is representative of a traditional trunk and branch system. In this example, the main trunk extends from the water heater and supplies hot water to branches that run to the laundry, kitchen, and lower and upper level bathrooms. To reduce the total length of piping runs throughout the home (a key component of an efficient trunk and branch system), the floor plan is configured so that the bathrooms are stacked vertically between the lower and upper levels. Also, the laundry room is co-located with the lower level bathroom so that the water heater can be placed close to the bathrooms without sacrificing usable space in the lower level.

Note that, for the lower level bathroom, only twig lines run to the sink. Since this area has only one fixture, a larger diameter branch line is not necessary and would be less efficient than using the smaller diameter twig line.

Table 3 (on page 16) provides accompanying hot water volume calculations for each fixture as indicated in Figure 5. The calculations assume the use of Copper M piping. In this configuration, the farthest fixtures from the water heater (the dishwasher and upper level bathroom sinks) store approximately 0.48 gallons. Therefore, the trunk and branch system is able to meet the hot water delivery system requirements of the WaterSense new home specification.

4.2 Core Systems

Figure 6 (on page 18) illustrates a plumbing layout that is representative of a core system. The key distinctions for this core system include:

- Centralization of the water heater relative to the fixtures to minimize long pipe runs.
- Direct connection from the water heater to fixtures.
- Use of smaller diameter piping on direct connections from water heater to fixtures.

In comparing the core system layout to the trunk and branch system layout, note that the locations of the water heater and washer/dryer units are swapped so that the water heater is centerally located between the kitchen, laundry room, and lower and upper level bathrooms. The kitchen fixtures are also relocated to the wall closest to the water heater. For the upper level fixtures, the vertical branch line (i.e., pipe segment 10) is placed at the center of the upper level bathrooms to keep individual water heater-fixture distances to a minimum.

Table 4 (on page 19) provides accompanying hot water volume calculations for each fixture as indicated in Figure 6. The calculations assume the use of Copper M piping. In this configuration, the upstairs fixtures, which are the farthest from the water heater, store 0.42 gallons. Therefore, this core system is able to meet the hot water delivery system requirements of the WaterSense new home specification. Relative to the trunk and branch system, the lower level fixtures see a water volume reduction of up to 50 percent.

4.3 Whole-House Manifold Systems

Figure 7 (on page 21) provides a plumbing layout for a hot water delivery system that is representative of a whole-house manifold system. In this example, individual runs span from the manifold to each fixture, and the manifold is installed in close proximity to the water heater. The smaller pipe diameter and associated volume reductions compensate for the fact that the water heater is not in a centralized location relative to the fixtures.

Table 5 (on page 22) provides accompanying hot water volume calculations for each fixture as indicated in Figure 7. The calculations assume the use of PEX-AI-PEX tubing. For the lower level, the water volumes between the water heater and each fixture are comparable to that of the core plumbing system. Relative to the trunk and branch system, however, the whole-house manifold system reduces water volumes by roughly half. Table 5 shows that water volume reductions are also achieved at the upper level fixtures. In this case, the smaller diameter piping minimizes water volumes beyond what is achievable through core or trunk and branch systems. In fact, in this configuration, the farthest fixtures from the water heater (the upper level bathroom sinks) store approximately 0.27 gallons, approximately half the maximum volume allowed for in the WaterSense new home specification.

4.4 Demand-Initiated Recirculation Systems

Figure 8 (on page 24) illustrates a hot water delivery system that is representative of a demand-initiated recirculation system. In this example, a recirculation loop is installed over the kitchen, laundry, and bathrooms between the lower and upper levels, and is within 10 feet of each fixture. Note that the recirculation loop is considered to be the hot water source, and it does not count towards the 0.5 gallon water volume limit. As a result, the demand-initiated recirculation system is able to compensate for distances from the water heater that would exceed the WaterSense new home specification’s 0.5-gal requirement if using any of the other three system types.

Table 6 (on page 25) provides accompanying hot water volume calculations for each fixture as indicated in Figure 8. The calculations assume the use of CPVC SCH 40 Tubing. For the lower level fixtures, the calculations show that this system stores less water than each of the three systems previously shown.

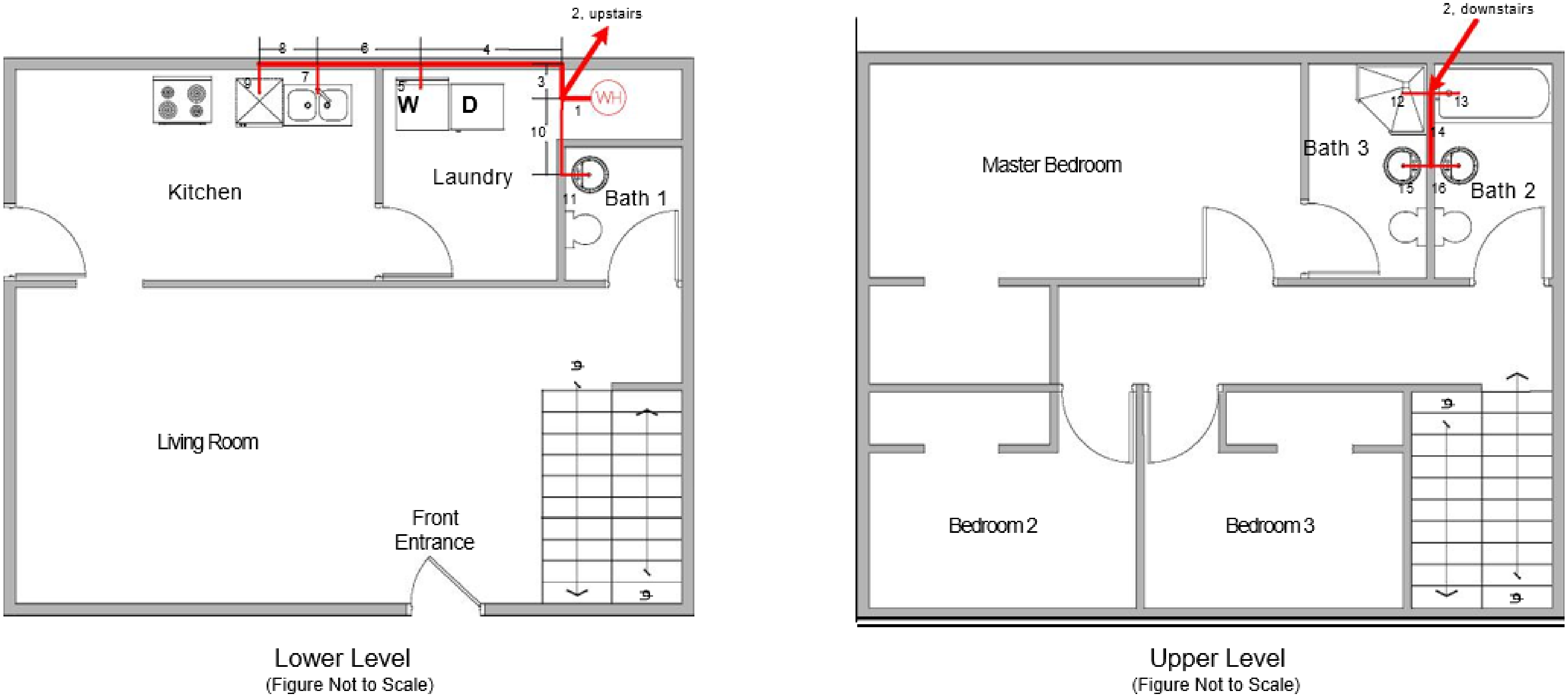


Figure 5. A Plumbing Layout Representative of a Trunk and Branch System[8]

---

[8] The numbering shown in the plumbing layout above enumerates individual pipe segments and not their individual lengths. Individual pipe lengths corresponding with the enumerated pipe segments are provided in Table 3.

Table 3. Sample Hot Water Volume Calculations for the Trunk and Branch System Using Copper M Piping

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity in ounces per feet (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume in gallons (gal)
Dishwasher	1	3/4	3.43	2	0.05
	3	3/4	3.43	2	0.05
	4	3/4	3.43	6	0.16
	6	3/4	3.43	4	0.11
	8	3/4	3.43	3	0.08
	9	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.48 gal***
Kitchen Sink	1	3/4	3.43	2	0.05
	3	3/4	3.43	2	0.05
	4	3/4	3.43	6	0.16
	6	3/4	3.43	4	0.11
	7	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.40 gal***
				Hot Water Wait Time[9]	***10.9 seconds (sec)***
Washer	1	3/4	3.43	2	0.05
	3	3/4	3.43	2	0.05
	4	3/4	3.43	6	0.16
	5	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.29 gal***
Bath 1 Sink	1	3/4	3.43	2	0.05
	10	1/2	1.69	3	0.04
	11	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.12 gal***
				Hot Water Wait Time[10]	***4.8 sec***
Bath 2 Tub	1	3/4	3.43	2	0.05
	2	3/4	3.43	12	0.32
	13	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.40 gal***
Bath 2 Sink	1	3/4	3.43	2	0.05
	2	3/4	3.43	12	0.32
	14	3/4	3.43	3	0.08
	16	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.48 gal***
				Hot Water Wait Time[11]	***19.2 sec***
Bath 3 Shower	1	3/4	3.43	2	0.05
	2	3/4	3.43	12	0.32
	12	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.40 gal***
				Hot Water Wait Time[12]	***12 sec***

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity in ounces per feet (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume in gallons (gal)
Bath 3 Sink	1	3/4	3.43	2	0.05
	2	3/4	3.43	12	0.32
	14	3/4	3.43	3	0.08
	15	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.48 gal***
				Hot Water Wait Time[13]	***19.2 sec***

[9] Assumes a kitchen faucet flow rate of 2.2 gpm.
[10] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.
[11] Ibid.
[12] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.
[13] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

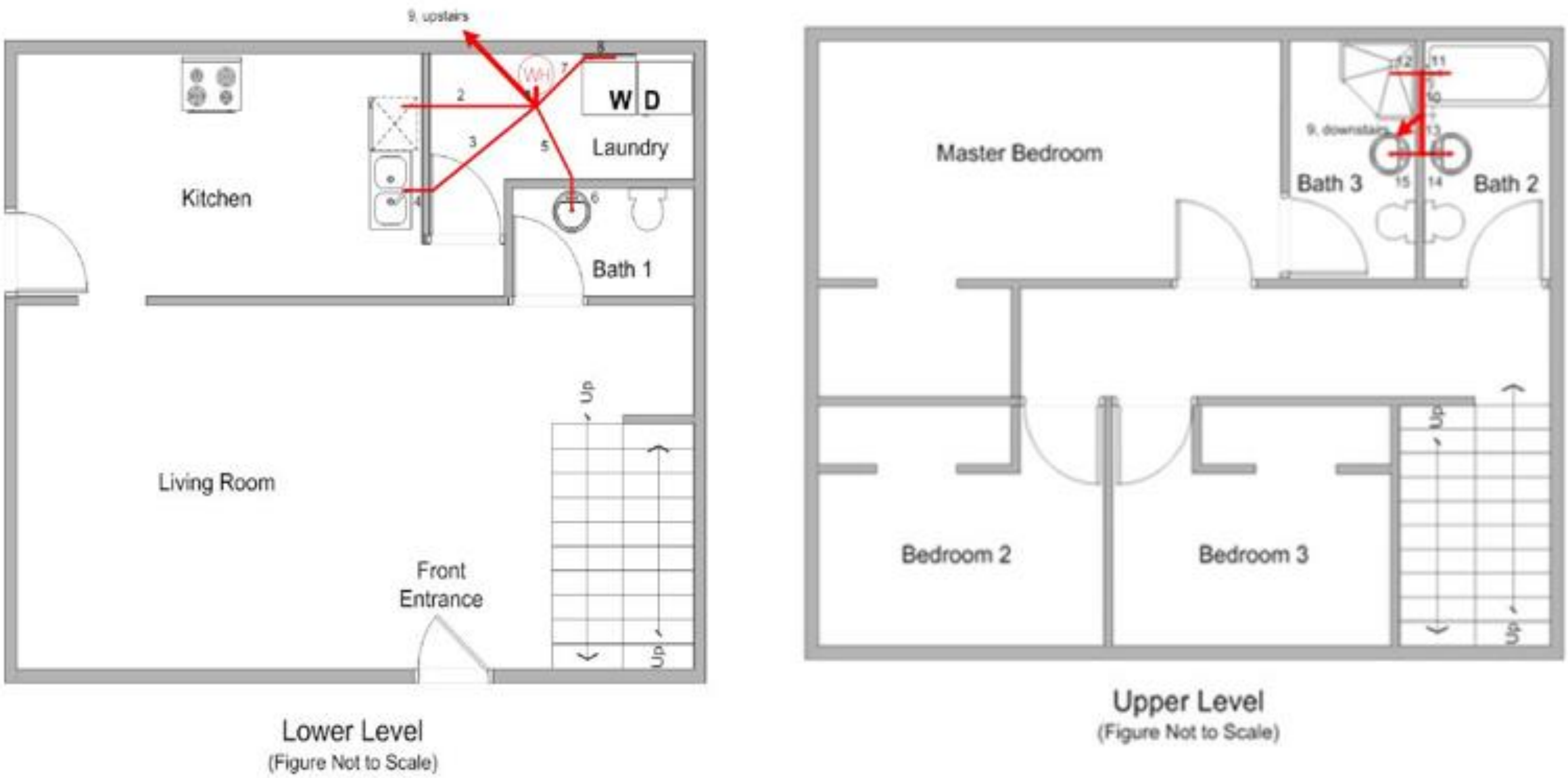


Figure 6. A Plumbing Layout Representative of a Core System[14]

[14] The numbering shown in the plumbing layout above enumerates individual pipe segments and not their individual lengths. Individual pipe lengths corresponding with the enumerated pipe segments are provided in Table 4.

Table 4. Sample Calculations for the Core System Using Copper M Piping

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume (gal)
Dishwasher	1	3/4	3.43	1	0.03
	2	1/2	1.69	11.5	0.15
				Total Hot Water Volume	***0.18 gal***
Kitchen Sink	1	3/4	3.43	1	0.03
	3	1/2	1.69	11	0.15
	4	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.21 gal***
				Hot Water Wait Time[15]	***5.7 sec***
Washer	1	3/4	3.43	1	0.03
	7	1/2	1.69	6	0.08
	8	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.14 gal***
Bath 1 Sink	1	3/4	3.43	1	0.03
	5	1/2	1.69	6	0.08
	6	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.14 gal***
				Hot Water Wait Time[16]	***5.6 sec***
Bath 2 Tub	1	3/4	3.43	1	0.03
	9	3/4	3.43	12	0.32
	10	3/4	3.43	1.5	0.04
	11	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.42 gal***
Bath 2 Sink	1	3/4	3.43	1	0.03
	9	3/4	3.43	12	0.32
	13	3/4	3.43	1.5	0.04
	14	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.42 gal***
				Hot Water Wait Time[17]	***16.8 sec***
Bath 3 Shower	1	3/4	3.43	1	0.03
	9	3/4	3.43	12	0.32
	10	3/4	3.43	1.5	0.04
	12	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.42 gal***
				Hot Water Wait Time[18]	***12.6 sec***
Bath 3 Sink	1	3/4	3.43	1	0.03
	9	3/4	3.43	12	0.32
	13	3/4	3.43	1.5	0.04
	15	1/2	1.69	2	0.03
		Pipe Diameter	Water Capacity	Pipe Length	Water Volume
				Total Hot Water Volume	***0.42 gal***
				Hot Water Wait Time[19]	***16.8 sec***

[15] Assumes a kitchen faucet flow rate of 2.2 gpm.

[16] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

[17] Ibid.

[18] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.

[19] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

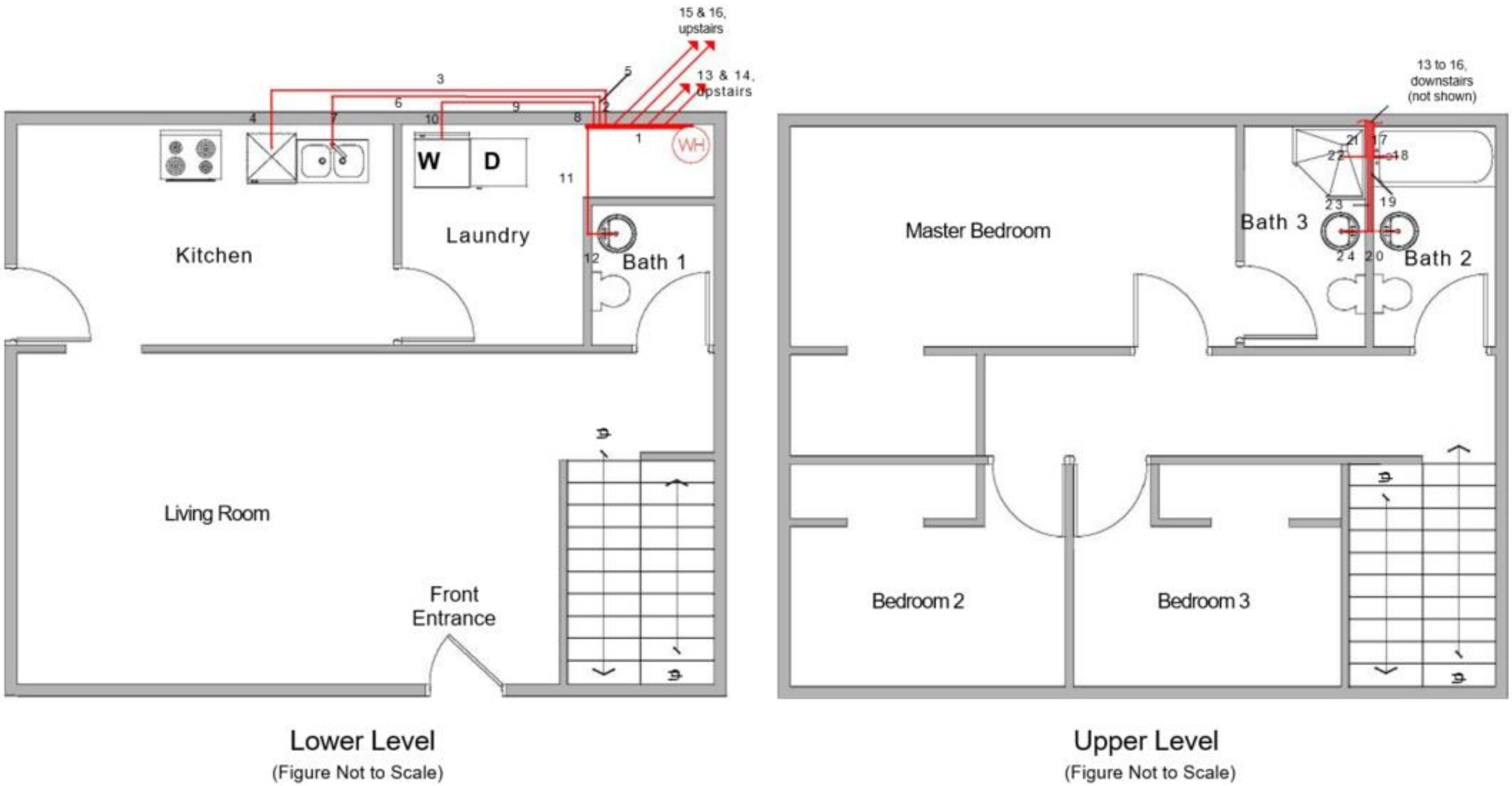


Figure 7. A Plumbing Layout Representative of a Whole-House Manifold System[20]

[20] The numbering shown in the plumbing layout above enumerates individual pipe segments and not their individual lengths. Individual pipe lengths corresponding with the enumerated pipe segments are provided in Table 5.

Table 5. Sample Calculations for the Whole-House Manifold System Using PEX-Al-PEX Tubing

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume (gal)
Dishwasher	1	1	5.56	4	0.17
	2	3/8	0.63	2	0.01
	3	3/8	0.63	13	0.06
	4	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.25 gal***
Kitchen Sink	1	1	5.56	4	0.17
	5	3/8	0.63	2	0.01
	6	3/8	0.63	10	0.05
	7	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.24 gal***
			Hot Water Wait Time[21]		***6.5 sec***
Washer	1	1	5.56	4	0.17
	8	3/8	0.63	2	0.01
	9	3/8	0.63	6	0.03
	10	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.22 gal***
Bath 1 Sink	1	1	5.56	4	0.17
	11	3/8	0.63	5.5	0.03
	12	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.21 gal***
			Hot Water Wait Time[22]		***8.4 sec***
Bath 2 Tub	1	1	5.56	4	0.17
	13	3/8	0.63	12	0.06
	17	3/8	0.63	2	0.01
	18	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.25 gal***
Bath 2 Sink	1	1	5.56	4	0.17
	15	3/8	0.63	12	0.06
	19	3/8	0.63	5	0.02
	20	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.27 gal***
			Hot Water Wait Time[23]		***10.7 sec***
Bath 3 Shower	1	1	5.56	4	0.17
	14	3/8	0.63	12	0.06
	21	3/8	0.63	2	0.01
	22	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.25 gal***
			Hot Water Wait Time[24]		***7.5 sec***
Bath 3 Sink	1	1	5.56	4	0.17
	16	3/8	0.63	12	0.06
	23	3/8	0.63	5	0.02
	24	3/8	0.63	2	0.01
			Total Hot Water Volume		***0.27 gal***
			Hot Water Wait Time[25]		***10.7 sec***

[21] Assumes a kitchen faucet flow rate of 2.2 gpm.

[22] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

[23] Ibid.

[24] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.

[25] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

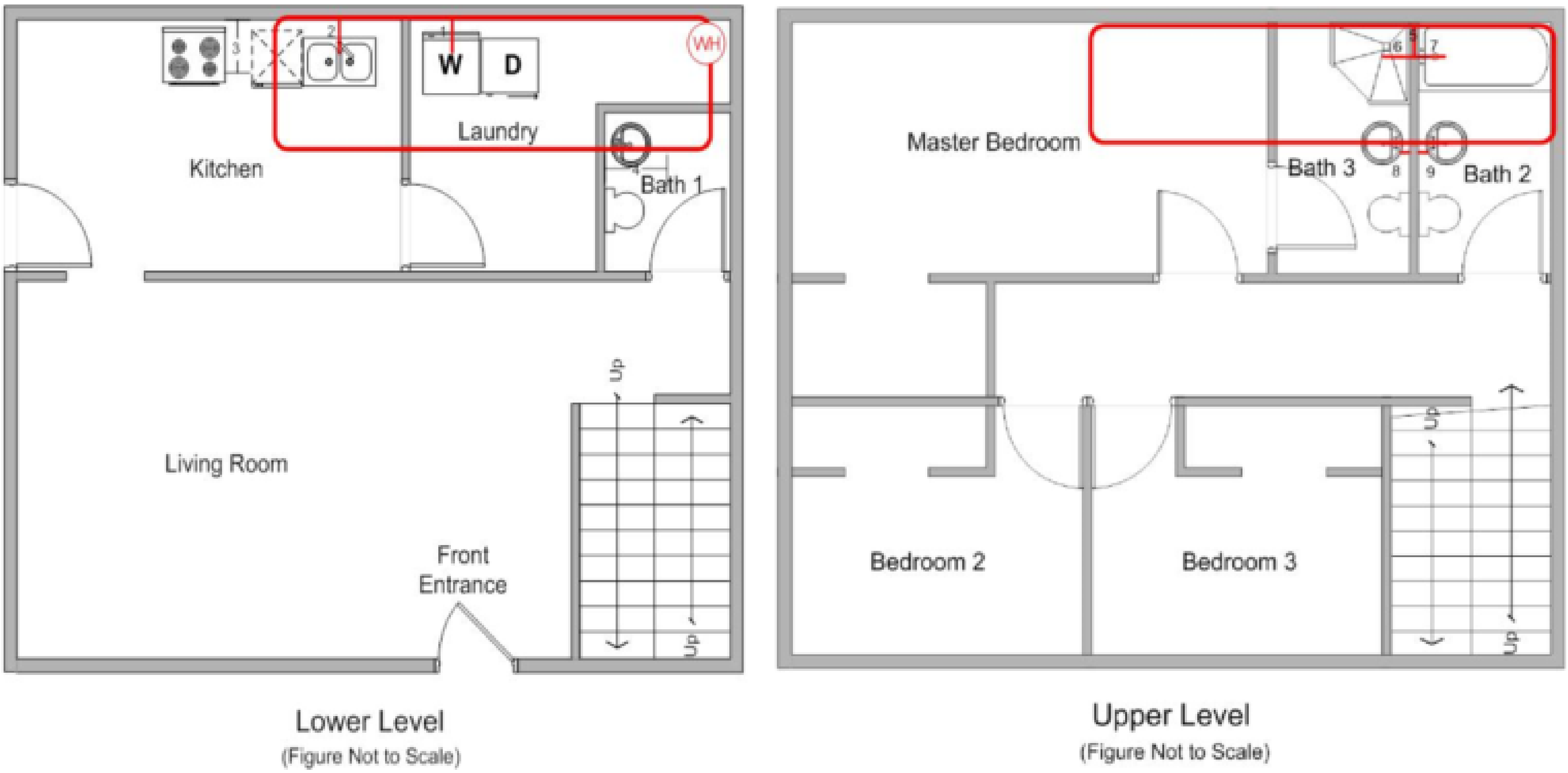


***Figure 8. A Plumbing Layout Representative of a Demand-Initiated Recirculation System*[26]**

---

[26] The numbering shown in the plumbing layout above enumerates individual pipe segments and not their individual lengths. Individual pipe lengths corresponding with the enumerated pipe segments are provided in Table 6.

Table 6. Sample Calculations for the Demand-Initiated System Using CPVC SCH 40 Tubing

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume (gal)
Dishwasher	Drop from Loop	1/2	1.89	7	0.10
	3	1/2	1.89	2	0.03
				Total Hot Water Volume	*0.13*
Kitchen Sink	Drop from Loop	1/2	1.89	7	0.10
	2	1/2	1.89	2	0.03
				Total Hot Water Volume *Hot Water Wait Time*[27]	*0.13 gal* *3.5 sec*
Washer	Drop from Loop	1/2	1.89	7	0.10
	1	1/2	1.89	2	0.03
				Total Hot Water Volume	*0.13 gal*
Bath 1 Sink	Drop from Loop	1/2	1.89	7	0.10
	4	1/2	1.89	2	0.03
				Total Hot Water Volume *Hot Water Wait Time*[28]	*0.13 gal* *5.2 sec*
Bath 2 Tub	Drop from Loop	1/2	1.89	5	0.07
	5	3/4	3.38	2	0.05
	7	1/2	1.89	2	0.03
				Total Hot Water Volume	*0.15 gal*
Bath 2 Sink	Drop from Loop	1/2	1.89	5	0.07
	9	1/2	1.89	2	0.03
				Total Hot Water Volume *Hot Water Wait Time*[29]	*0.10 gal* *4.0 sec*
Bath 3 Shower	Drop from Loop	1/2	1.89	5	0.07
	5	3/4	3.38	2	0.05
	6	1/2	1.89	2	0.03
				Total Hot Water Volume *Hot Water Wait Time*[30]	*0.15 gal* *4.5 sec*
Bath 3 Sink	Drop from Loop	1/2	1.89	5	0.07
	8	1/2	1.89	2	0.03
				Total Hot Water Volume *Hot Water Wait Time*[31]	*0.10 gal* *4.0 sec*

[27] Assumes a kitchen faucet flow rate of 2.2 gpm, as required in the specification.
[28] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.
[29] Ibid.
[30] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.
[31] Assumes a bathroom sink faucet flow rate of 1.5 gpm (maximum flow rate for WaterSense labeled bathroom sink faucets and accessories), as required in the specification.

5.0 System Inspection

Once the hot water delivery system and associated fixtures have been installed, the home can be inspected to ensure that the system meets the WaterSense new homes specification criteria. The following subsections discuss the inspection protocol that is used to test the performance of the hot water delivery system and what measures a builder can take to ensure compliance with WaterSense new home specification requirements either before the inspection or after, if any deficiencies are identified by the inspector. For more detailed information on the inspection process, review the *Inspection and Verification Guidance for WaterSense Labeled New Homes*[32].

If possible, builders should consider having their hot water delivery systems inspected before putting up any interior walls. Doing so will allow for any potential adjustments to be made without the need for cutting out or removing wall sections. This approach also will ensure that inspection can occur with minimal disruptions to project schedules or budgets.

5.1 Inspection Protocol

An inspector will test all hot water delivery systems to ensure compliance with the WaterSense new home specification's requirements and document the results using an inspection checklist[33]. Note that the hot water delivery system should not be used for several hours prior to the inspection, because it must be completely cool prior to testing.

During the inspection, the inspector will:

- Identify the fixture farthest from the hot water source.
- Place a bucket or a flow measuring bag (pre-marked for 0.6 gallons or 2.3 liters) underneath the hot water fixture. *Note that for inspection purposes, the WaterSense new home specification accounts for an additional 0.1 gallons of water above the 0.5 gallon requirement that must be removed from the system before hot water can be delivered.*
- Turn the hot water completely on, place a digital thermometer in the stream of water, and record the starting temperature.
- Once the water meets the pre-marked line (approximately 24 seconds for a lavatory faucet), record the ending temperature.
- Note the temperature increase. The hot water delivery system meets the WaterSense new home specification criteria if the temperature increases by at least 10 degrees Fahrenheit.

Builders will be given an opportunity to correct systems that do not initially pass. However, the inspection cannot be performed again until the system completely cools down.

5.2 Ensuring and Verifying Compliance Prior to Inspection

WaterSense encourages builders to work with their plumbing professionals throughout the design and installation of the hot water delivery systems to ensure that the as-built system will meet all criteria of the WaterSense new home specification. It is also good practice for builders to verify compliance with WaterSense new home specification criteria prior to the inspection, to ensure that the hot water delivery system will pass and that construction can continue without costly delays and work-arounds.

---

[32] U.S. EPA's WaterSense program. 2014. Inspection and Verification Guidance for WaterSense Labeled New Homes. http://www.epa.gov/watersense/docs/home_inspection-guidelines508.pdf.

[33] U.S. EPA's WaterSense program. 2014. WaterSense Labeled New Home Inspection Checklist. http://www.epa.gov/watersense/new_homes/cert_new_homes.html.

5.2.1 Design Stage Check

During the design stage, builders should determine the theoretical volume of water stored between the water heater and the farthest fixtures, to ensure that the system can meet the 0.5 gallon requirement.

To determine the volume of water stored in the hot water delivery system:

1. Obtain copies of the plumbing layouts, similar to those shown in Figures 5 through 8.
2. Identify the type of piping that will be used (e.g., Copper M, CPVC, PEX);
3. Identify the hot water fixtures farthest from the water heater and note:
    a. Nominal diameter of each individual pipe segment between the water heater and the fixture.
    b. Length of each pipe segment running from the water heater to the fixture.
4. Using the piping volumes provided in Table 1, calculate the volume of water stored in each pipe segment.
5. Total the volume of water stored in all pipe segments running from the water heater to the fixture. The total should be less than 0.5 gallons if the design meets the WaterSense new home specification criteria.

5.2.2 Installation Stage Check

Once the hot water delivery system is installed, builders should visually inspect the system to ensure that the as-built system is identical to the planned design. If any changes are made between the designed and as-built system, it may be necessary to recalculate the volume of stored water per the steps outlined above to ensure that the system is still able to meet the WaterSense new home specification requirements.

5.2.3 Pre-Inspection Check

Builders should also test the farthest fixtures prior to inspection to ensure that no more than 0.6 gallons of water is delivered before hot water arrives at the fixture. Builders can test fixtures by following the inspection protocol outlined in Section 5.1 above.

5.3 Troubleshooting

Per the *Inspection and Verification Guidance for WaterSense Labeled New Homes*[34], the inspector will notify the builder of any deficiencies and the builder will be given an opportunity to correct them. The home can then be re-inspected.

If the hot water delivery system fails to meet the WaterSense new home specification requirements, the builder can consider the following modifications. Note that the specific course of action to fix a system that does not pass the inspection is up to the builder.

- Reconfigure hot water piping so that the distance between the furthest hot water fixture and the water heater is reduced to an acceptable level.
- Add additional water heaters to ensure hot water will reach the affected fixtures sooner.
- Retrofit the hot water distribution system with a demand-based hot water recirculation system.

[34] US EPA's WaterSense program. 2014. Inspection and Verification Guidance for WaterSense Labeled New Homes. <http://www.epa.gov/watersense/docs/home_inspection-guidelines508.pdf>.