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 *Version 1.1 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. For information about efficient water heaters or pipe insulation, review the *Resource Manual for Building WaterSense Labeled New Homes*.[3]

[3] U.S EPA's WaterSense Program. 2012. *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.

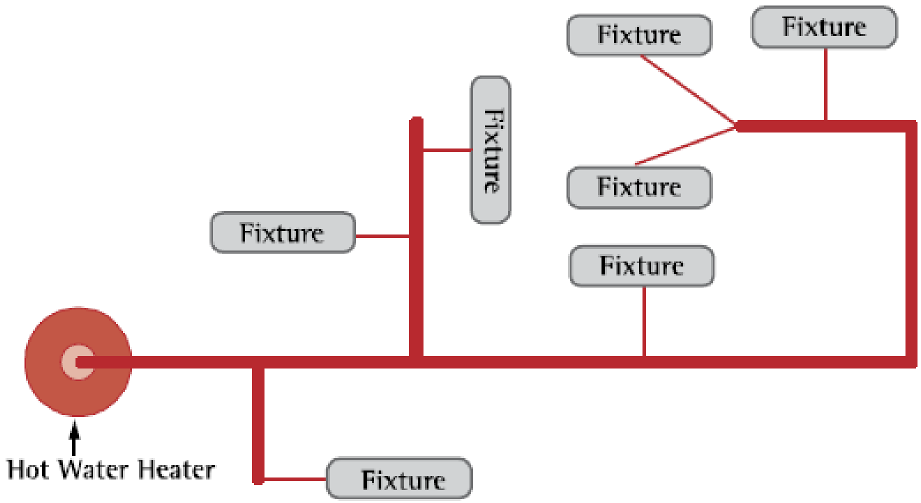


Figure 1. A General Configuration Typical of Trunk and Branch Systems

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.

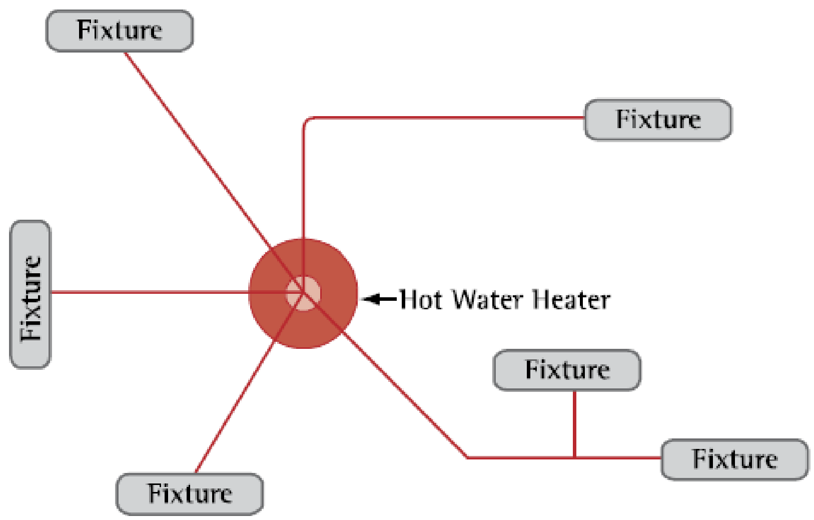


Figure 2. A General Configuration Typical of Core Systems

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 either plastic or metal.

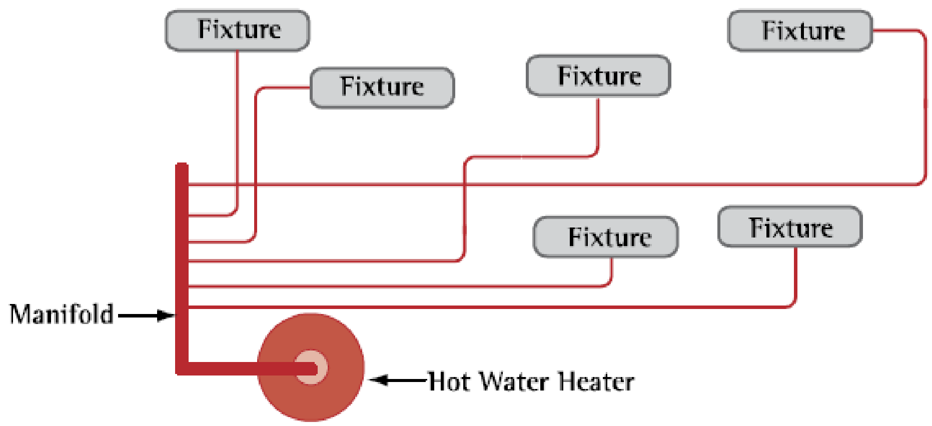


Figure 3. A General Configuration Typical of Whole-House Manifold Systems

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 that a water 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.[4]

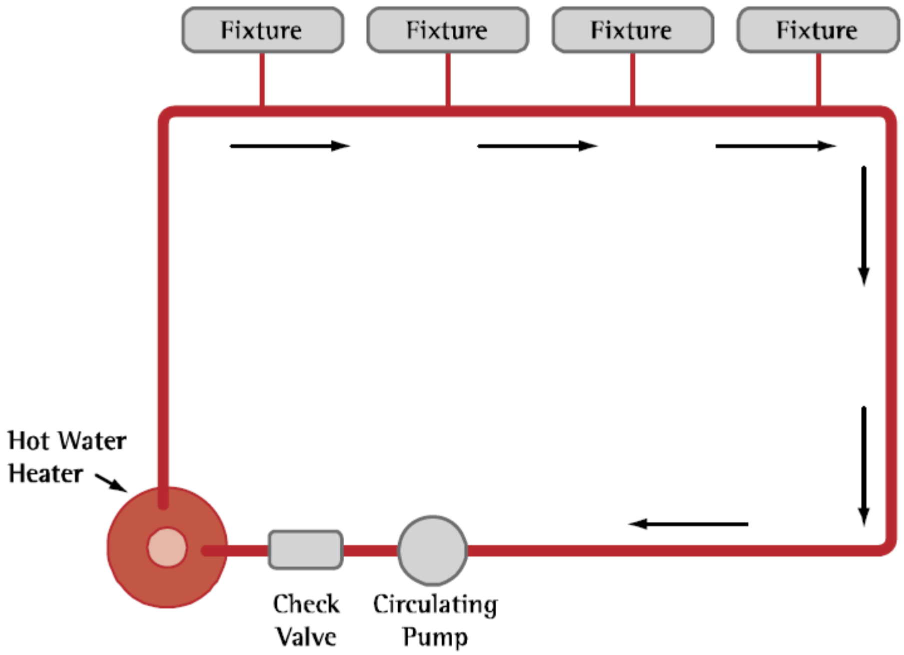


Figure 4. A General Configuration Typical of Demand-Initiated Recirculation Systems

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:

[4] Acker, L., G. Klein. "Benefits of Demand-Controlled Pumping." *Home Energy*. 2006.

- 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.
- 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.[5]

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.

[5] 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**
⅜	1.06	0.97	0.84	N/A	1.17	0.63	0.63	0.64
½	1.69	1.55	1.45	1.25	1.89	1.31	1.31	1.18
¾	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 ¼	8.70	8.36	8.09	6.61	9.66	8.49	8.49	5.81
1 ½	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*[6] 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.

[6] U.S EPA's WaterSense Program. 2012. *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

<table>
<tr><th rowspan="2">Consideration</th><th colspan="4">Hot Water Delivery System Type</th></tr>
<tr><th>Trunk and Branch</th><th>Core</th><th>Whole-House Manifold</th><th>Demand-Initiated Recirculation</th></tr>
<tr><td>Home Type Suitability</td><td>• Smaller homes
• Homes with relatively few fixtures
• Individual units of multi-family buildings</td><td>• Smaller homes
• Homes with relatively few fixtures
• Individual units of multi-family buildings</td><td>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</td><td>• 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</td></tr>
<tr><td>Layout and Design Strategy</td><td>• 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</td><td>• 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</td><td>• 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</td><td>• 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</td></tr>
</table>

Consideration	Hot Water Delivery System Type			
	Trunk and Branch	Core	Whole-House Manifold	Demand-Initiated Recirculation
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 water efficient 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 centrally 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

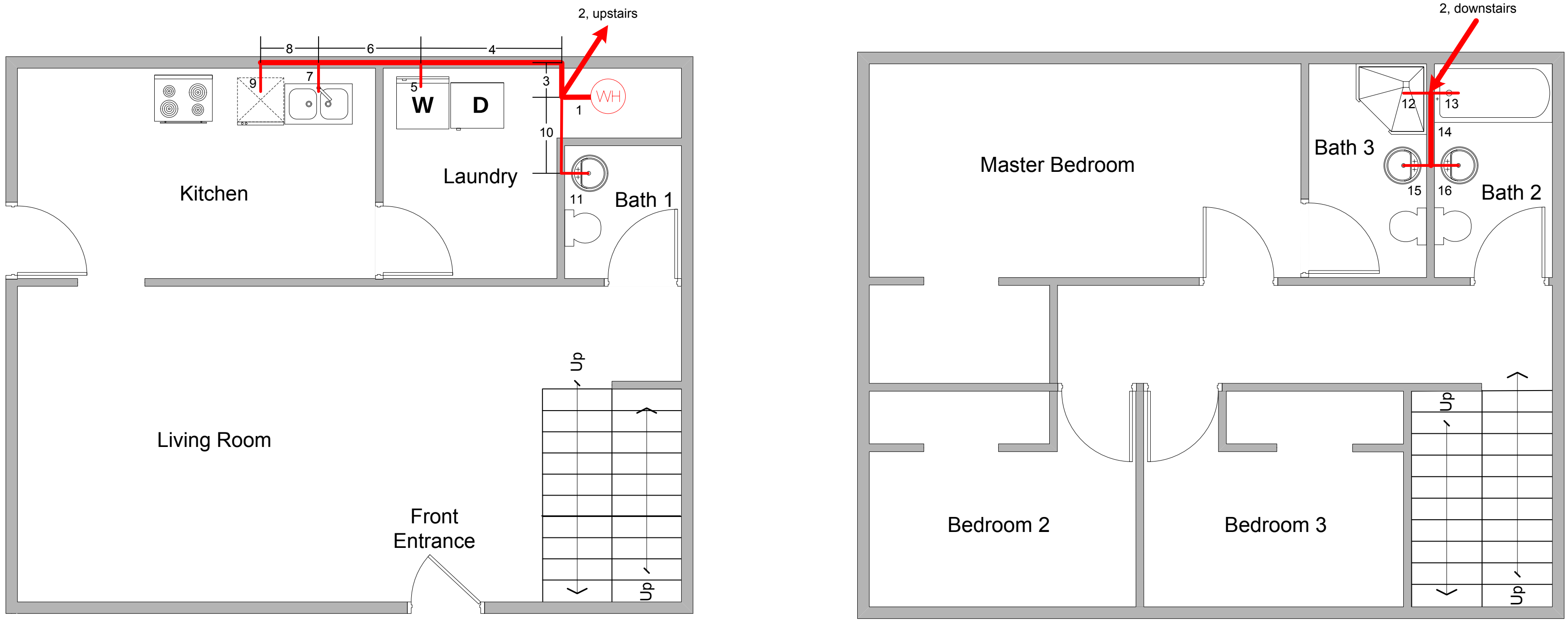
Figure 7 (on page 21) provides a plumbing layout for a hot water delivery system that is representative of a whole-house manifold system. In this example, individual runs span from the manifold to each fixture, and the manifold is installed in close proximity to the water heater. The smaller pipe diameter 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.



Lower Level
(Figure Not to Scale)

Upper Level
(Figure Not to Scale)

Figure 5. A Plumbing Layout Representative of a Trunk and Branch System[7]

[7] 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 ***Hot Water Wait Time[8]***	***0.40 gal*** ***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 ***Hot Water Wait Time[9]***	***0.12 gal*** ***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 ***Hot Water Wait Time[10]***	***0.48 gal*** ***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 ***Hot Water Wait Time[11]***	***0.40 gal*** ***12 sec***

[8] Assumes a kitchen faucet flow rate of 2.2 gpm.
[9] 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.
[10] Ibid.

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[12]	***19.2 sec***

[11] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.
[12] 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.

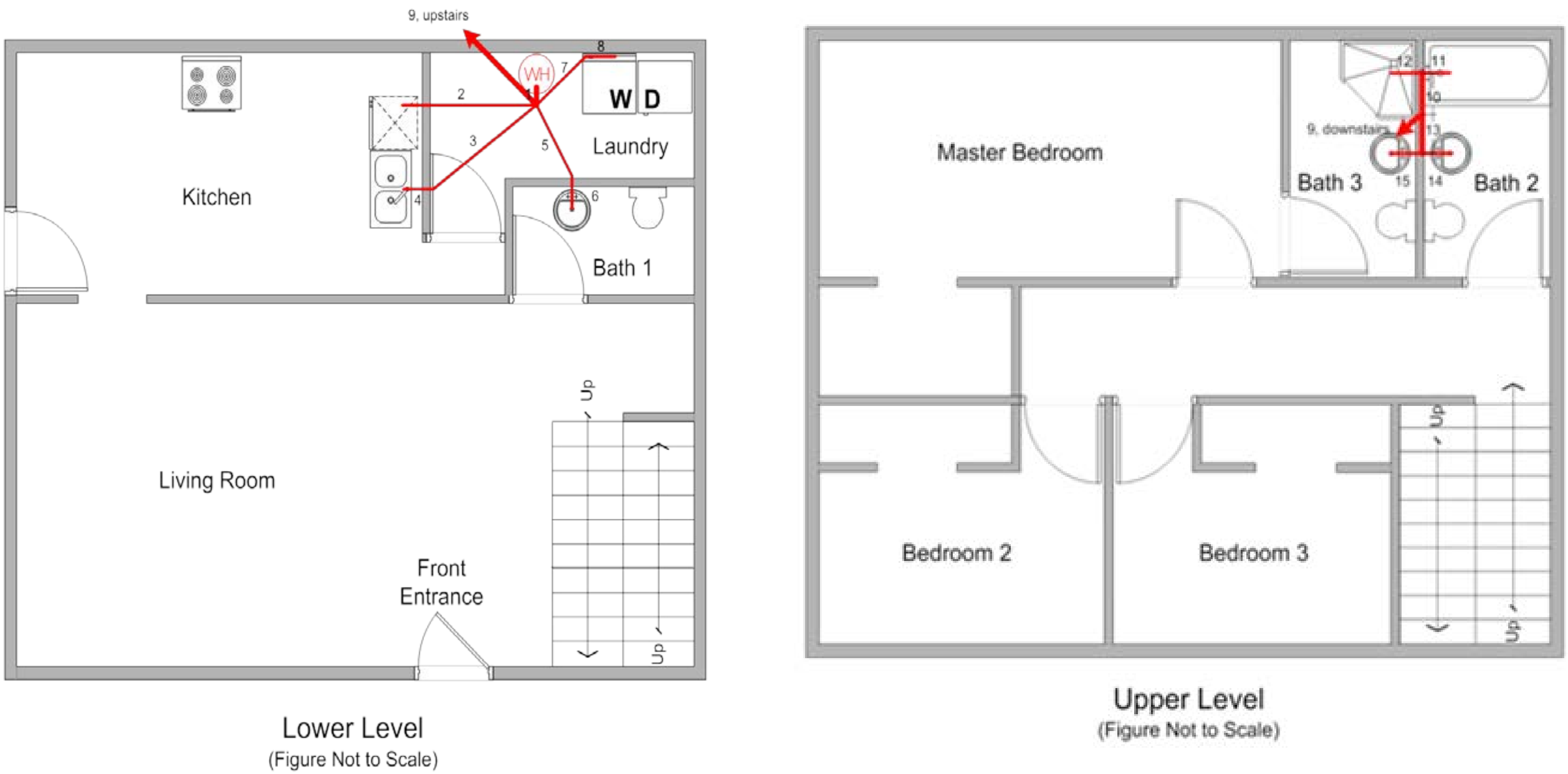


Figure 6. A Plumbing Layout Representative of a Core System[13]

[13] 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 ***Hot Water Wait Time***[14]	***0.21 gal*** ***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 ***Hot Water Wait Time***[15]	***0.14 gal*** ***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 ***Hot Water Wait Time***[16]	***0.42 gal*** ***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 ***Hot Water Wait Time***[17]	***0.42 gal*** ***12.6 sec***
Bath 3 Sink	1	3/4	3.43	1	0.03
	9	3/4	3.43	12	0.32

[14] Assumes a kitchen faucet flow rate of 2.2 gpm.
[15] 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.
[16] Ibid.
[17] Assumes a showerhead flow rate of 2.0 gpm (maximum flow rate for WaterSense labeled showerheads), as required in the specification.

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume (gal)
	13	3/4	3.43	1.5	0.04
	15	1/2	1.69	2	0.03
				Total Hot Water Volume	***0.42 gal***
				Hot Water Wait Time[18]	***16.8 sec***

[18] 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.

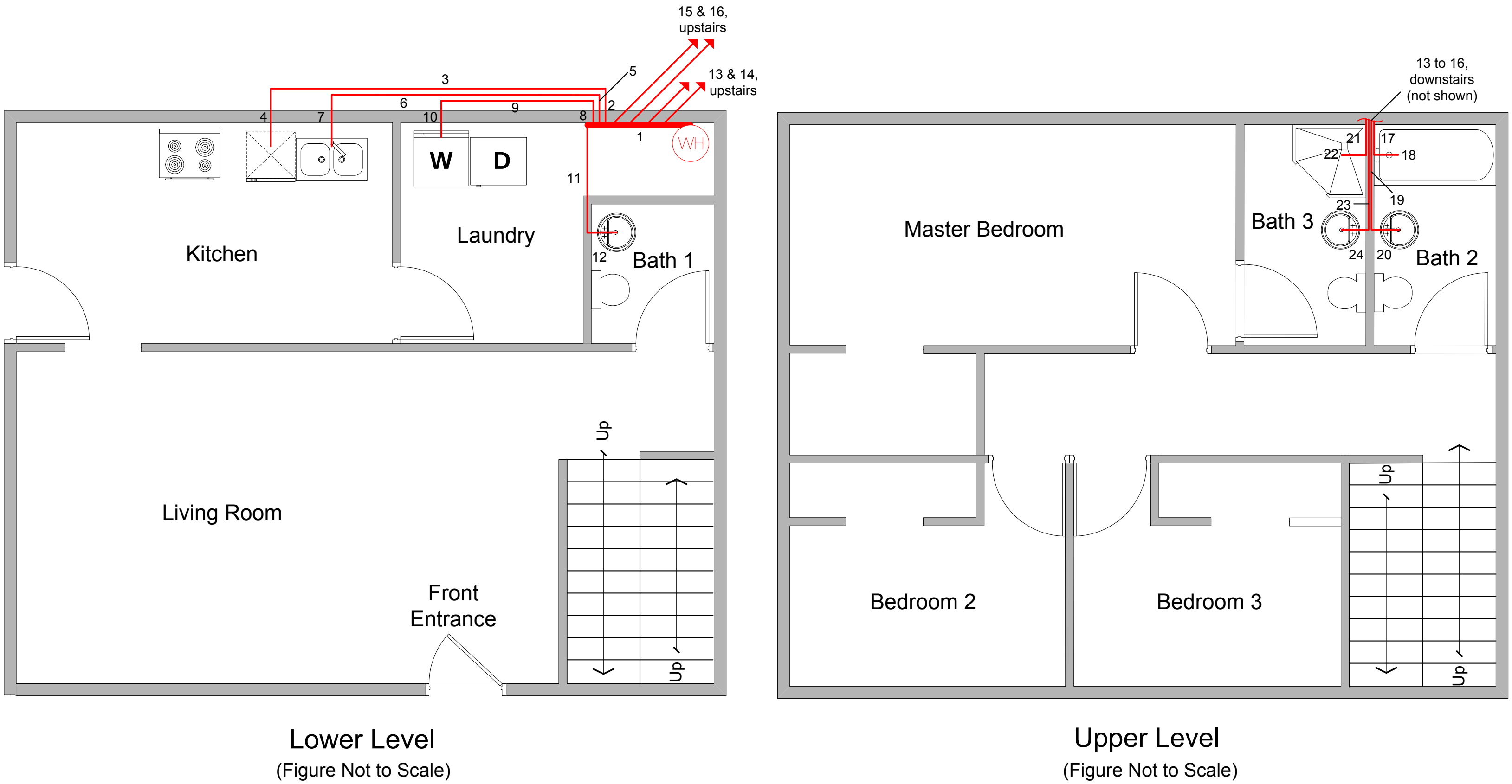


Figure 7. A Plumbing Layout Representative of a Whole-House Manifold System[19]

[19] 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-AI-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 ***Hot Water Wait Time***[20]	***0.24 gal*** ***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 ***Hot Water Wait Time***[21]	***0.21 gal*** ***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 ***Hot Water Wait Time***[22]	***0.27 gal*** ***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 ***Hot Water Wait Time***[23]	***0.25 gal*** ***7.5 sec***

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

Fixture	Pipe Segment	Pipe Diameter (in)	Water Capacity (oz/ft) (from Table 1)	Pipe Length (ft)	Water Volume (gal)
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[24]	***10.7 sec***

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

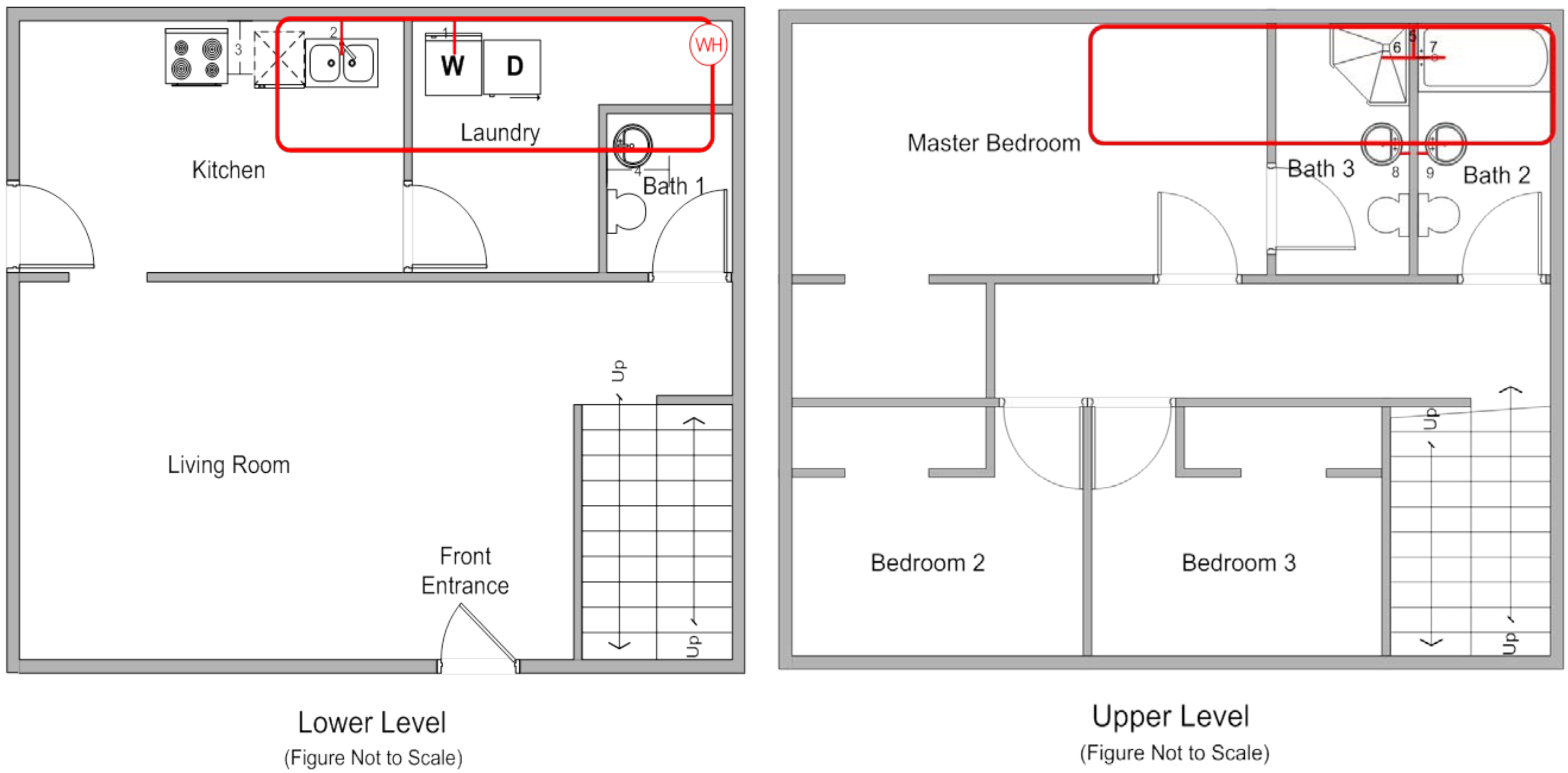


Figure 8. A Plumbing Layout Representative of a Demand-Initiated Recirculation System[25]

[25] 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***[26]	***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***[27]	***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***[28]	***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***[29]	***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***[30]	***0.10 gal*** ***4.0 sec***

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

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.[32] 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°F.

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.

[31] U.S. EPA's WaterSense program. 2012. Inspection and Verification Guidance for WaterSense Labeled New Homes. <http://www.epa.gov/watersense/docs/home_inspection-guidelines508.pdf>.
[32] U.S. EPA's WaterSense program. 2012. WaterSense Labeled New Home Inspection Checklist, Version 1.1. <http://www.epa.gov/watersense/new_homes/cert_new_homes.html>.

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.

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*[33], 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 reinspected.

If the hot water delivery system fails to meet the WaterSense new home specification requirements, the builder may 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.

[33] US EPA's WaterSense program. 2012. Inspection and Verification Guidance for WaterSense Labeled New Homes. <http://www.epa.gov/watersense/docs/home_inspection-guidelines508.pdf>.