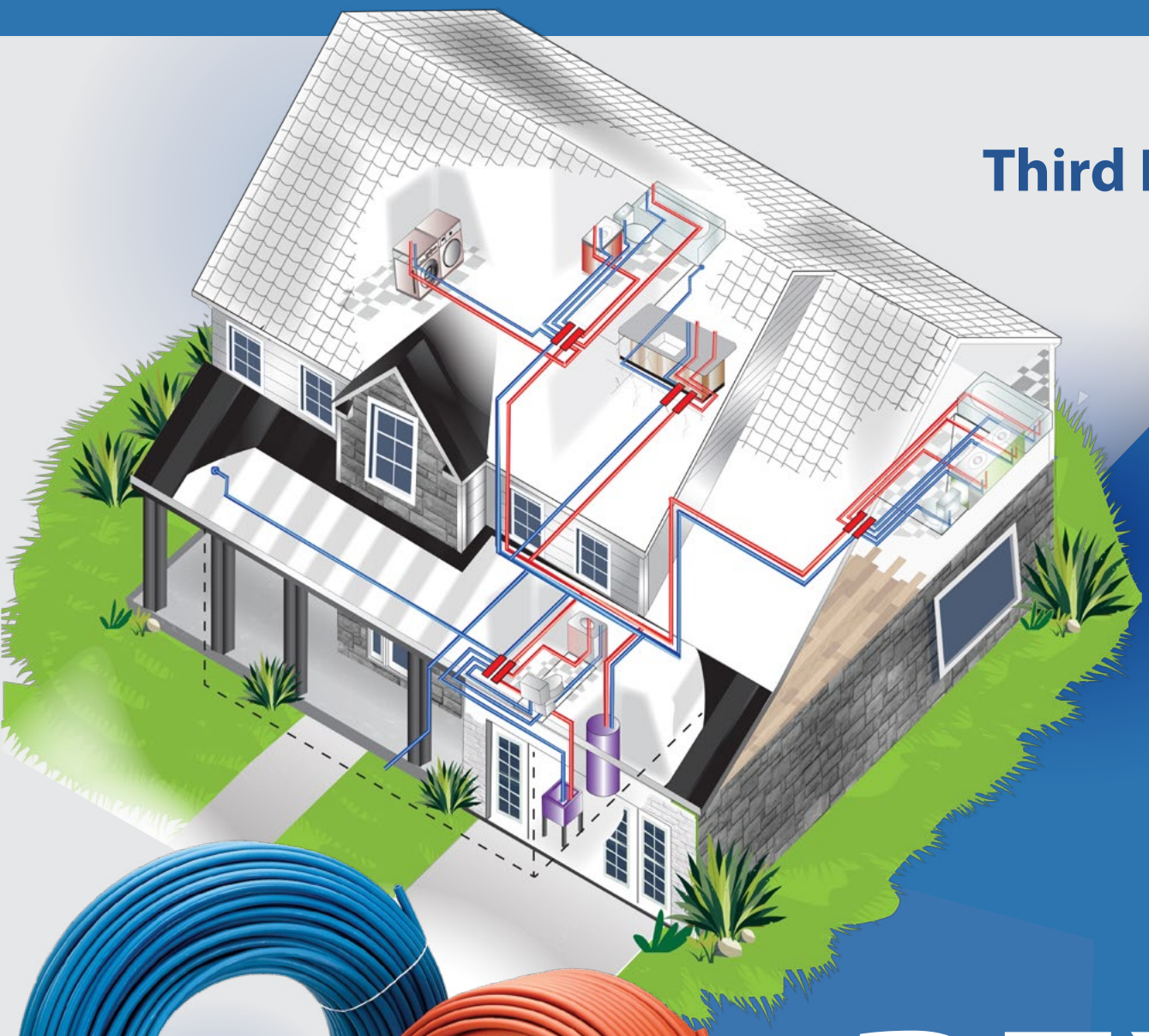
Third Edition



PEX

Plumbing Distribution Systems Design and Installation Guide

Advantages | Material Properties | Codes & Standards

Joining Methods | PEX Plumbing Layouts | Optimizing Design

Installation Guidelines | Water Service Line | Other Applications

IAPMO

PPI Plastics Pipe Institute The Voice of an Industry.

Home Innovation RESEARCH LABS™

PPFA Plastic Pipe and Fittings Association

ES ICC EVALUATION SERVICE®

PEX

Plumbing Distribution Systems Design and Installation Guide

Third Edition

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8 Performance Data

Following the introduction of PEX plumbing systems in North America in the 1980s and the rapid growth of its usage in the 1990s, a significant amount of research on the performance of PEX plumbing systems was conducted in the early 2000s with the objectives of determining the most efficient and effective plumbing designs for residential and light commercial applications.

For the reference of plumbing engineers and designers, installers, builders, and inspectors, this chapter is intended to present and summarize the foundational research which demonstrates the high levels of performance from various PEX plumbing designs and their suitability in distribution systems in a wide range of building types.

This chapter includes laboratory performance data on three common PEX plumbing layouts: trunk and branch, parallel, and zoned (i.e., remote manifold) – and provides both objective and subjective ratings of each of these designs for various type of residential and light commercial applications while considering numerous criteria.

System Performance Comparison

Each of the three PEX plumbing layouts described in this guide can be installed in most homes and buildings, meeting the performance demands of the system, codes, and customer expectations. The different layouts and combinations thereof offer opportunities to optimize the performance of the plumbing system, reduce the installed cost, and increase overall customer satisfaction and acceptance.

To quantify the differences between PEX plumbing system designs, each system was tested in the laboratory to provide a similar set of conditions under which the systems are typically installed and operated. Actual residential plumbing fixtures, piping layouts with fittings, and elevation changes were included in these empirical tests.

This provided a consistent comparison between the performance of the three layouts, as well as an indication of the minimum performance characteristics of each system. PEX tubing was installed in each of the three layouts - trunk and branch, parallel, and zoned - with overall results showing that:

- All systems had similar flow characteristics at each of the fixtures when flowing independently

- All system designs responded in a similar manner to simultaneous flow events (more than one fixture flowing at once)
- Minor differences in the actual measured flow and pressure at a test fixture emerged when simultaneous flow events occurred

Test System Design and Set-up

Plumbing fixtures were installed in a laboratory setting to provide actual flow and pressure data during operation of the fixtures. The test system was constructed and reconfigured for each type of PEX plumbing design, including the standard trunk and branch (T&B), the parallel (HR), and the zoned system using remote manifolds (RM).

A primary Test Fixture (TF), represented by a tub/shower unit, was installed and instrumented to measure flow rate and flow pressure on the hot and cold lines, as well as mixed water temperature. **Figure 8.1** shows the laboratory system diagram for the T&B system. Other test system designs are shown in **Appendix A**.

The Test Fixture was positioned to be the farthest fixture from the water source and was operated in shower mode during all tests. The operating performance of this test fixture represents the "worst case" scenario of the full system, since all other fixtures were closer to the source. **Figure 8.2** shows the laboratory set-up configured with the fixtures and the T&B system design with 100-foot distance to the TF. **Figure 8.3** shows the TF with the sensors for pressure and flow installed.

The data provides assurance that the PEX plumbing system design is capable of supplying the required flow rates during operation of the fixtures. In addition, the test results provide assurance that the plumbing system design will supply adequate flow and pressure to a remote test fixture while other fixtures are operated simultaneously.

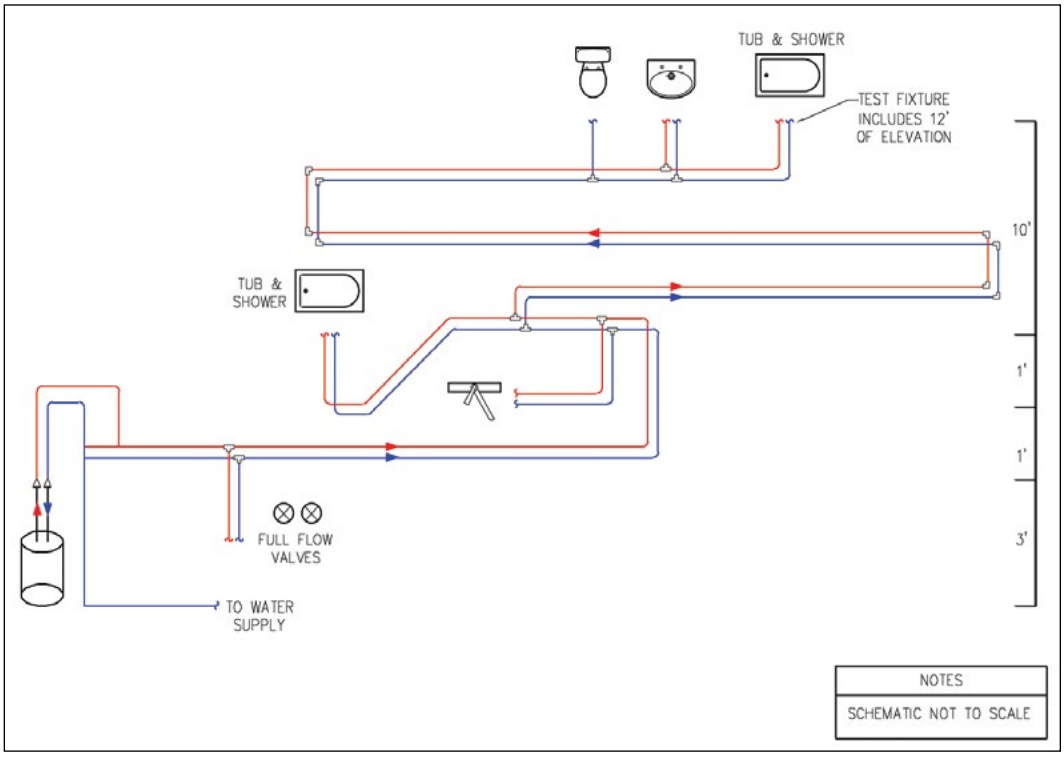

Figure 8.1 Fixture Layout for Laboratory Testing

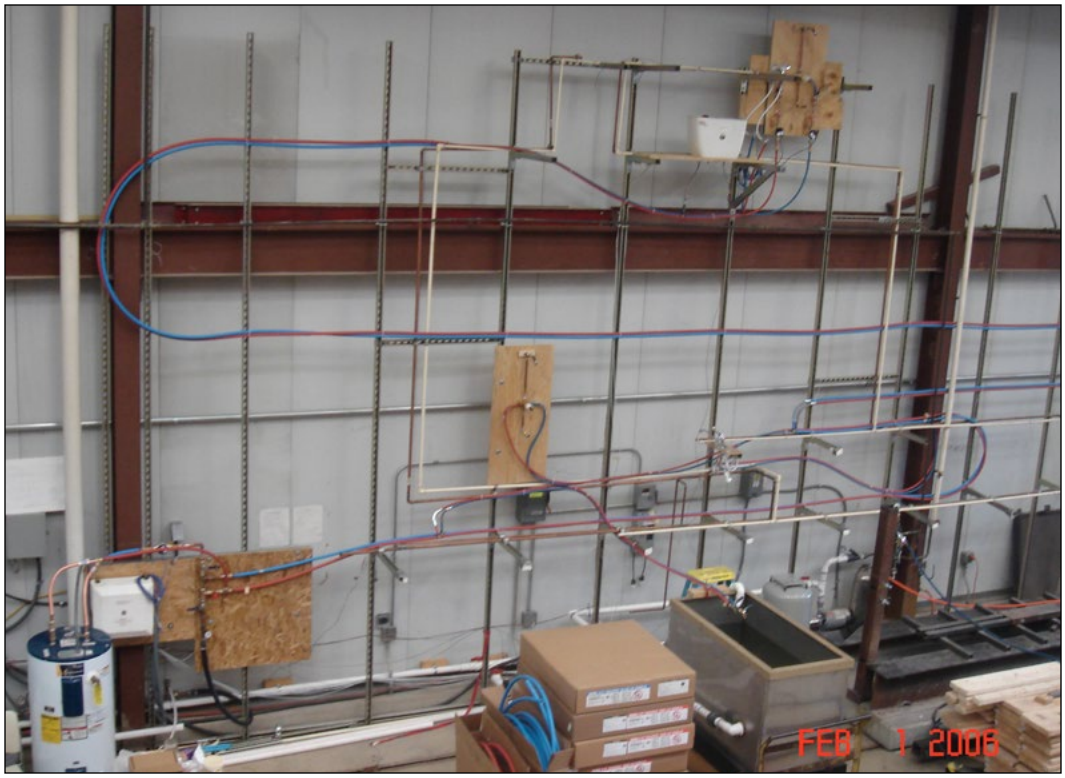

Figure 8.2 Laboratory Test Set-up with Hot Water Tank for T&B System

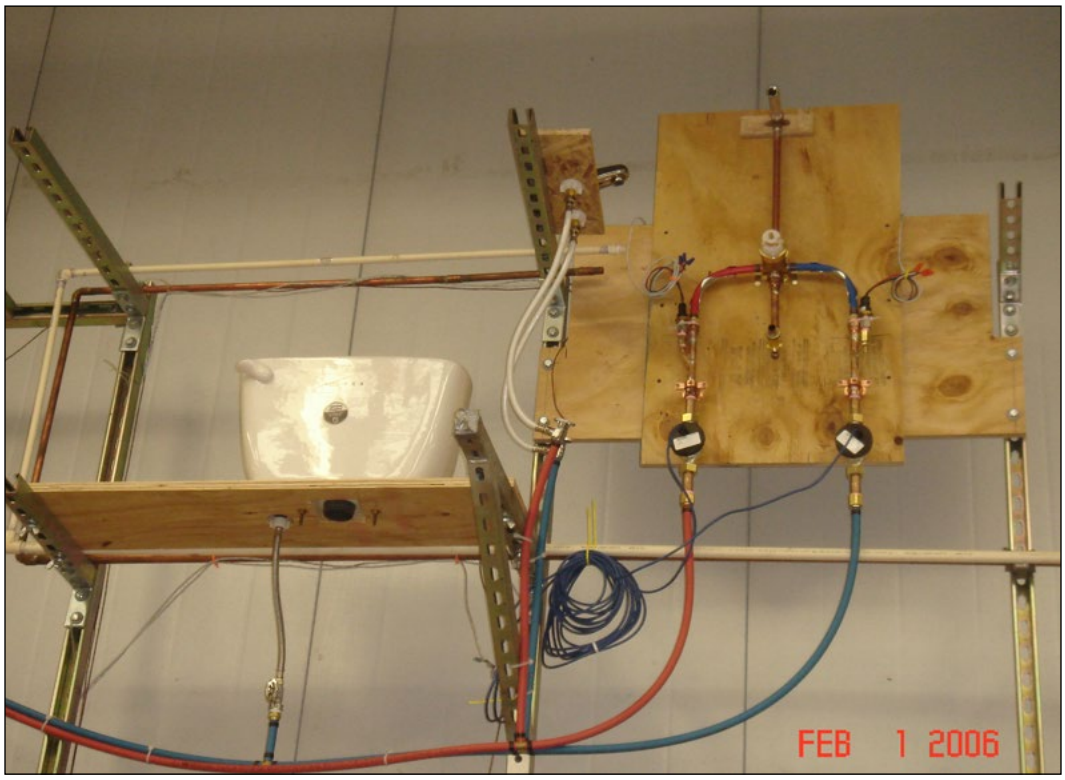

Figure 8.3 The Test Fixture (Shower) with Flow and Pressure Sensors Installed

Table 8.1 shows the set of plumbing fixtures installed to represent specific residential outlets. These fixtures were connected to each of the three different PEX plumbing configurations. Tests included using 100-foot and 60-foot total distances of pipe run to the farthest test fixture. The piping runs to the other fixtures were run in lengths that matched the type of piping system installed (i.e., if the HR system was being tested, all fixtures are plumbed with the HR system).

Table 8.1 Plumbing Fixtures Installed in the Test Plumbing System

Fixture	Length from Source (feet)	Elevation Above Source	Operation During Test
Tub/Shower TF	60 or 100	15	Full-On Shower
Lavatory	60 or 100	15	Intermittent
Water Closet (tank type)	55 or 95	15	Intermittent
Kitchen Faucet	Less than 40	5	Intermittent
Tub/Shower 2	Less than 40	6	Intermittent

Diagrams of all the test piping arrangements are shown in **Appendix A**.

Two sets of tests were performed for each plumbing system. One test recorded pressure and flow data at the test fixture while other fixtures were operated. A second set of tests was performed to measure the length of time it took for hot water to reach the test fixture. This test began after the piping was stabilized to the incoming water temperature.

Plumbing System Pressure and Flow Test Results

For all pressure and flow tests, the farthest shower Test Fixture (TF) was operated in the shower "full-on" mode. The flow pressure and flow rates for each of the hot- and cold-water supplies to the TF were recorded. During the operation of the TF, other simultaneous flows were added as described in **Table 8.2**. For this, the TF flow and pressure data were recorded as well as the total hot- and cold-water supply to the other fixtures and the pressure at the base of the riser.

Table 8.2 Pressure and Flow Test Regime

Test No.	Fixtures Operated	Nomenclature
1	Test Fixture (TF)	TF
2	TF and Lavatory	TF+Lav
3	TF and Water Closet	TF+WC
4	TF and Kitchen Faucet (mid-position)	TF+Kit
5	TF and 2nd Shower (full-on)	TF+Sh2
6	No. 5 and Kitchen	TF+Sh2+Kit
7	No. 6 and Lavatory	TF+Sh2+Kit+Lav
8	No. 7 and Water Closet	TF+Sh2+Kit+Lav+WC

Flow and pressure measurements were recorded for each of the tests and are recorded in **Table 8.3**. Each system was tested at three different static pressures measured at the base of the riser: 40, 60, and 80 psi. **Table 8.3** shows the results of the TF flowing with no simultaneous fixtures operating.

Table 8.3 TF Flow and Pressure Data for Each System

System Type, Distance to TF, Riser Pressure	Riser Pressure psi	TF Hot Valve Flow GPM	TF Hot Valve Pressure psi	TF Cold Valve Flow GPM	TF Cold Valve Pressure psi
T&B, 100', 40 psi	40.0	1.7	31.6	0.2	35.1
Zoned, 100', 40 psi	40.0	1.7	31.6	0.2	35.0
Parallel, 100', 40 psi	40.0	1.7	29.3	0.2	35.0
T&B, 100', 60 psi	60.0	2.2	50.0	0.3	55.2
Zoned, 100', 60 psi	60.0	2.2	49.7	0.3	54.9
Parallel, 100', 60 psi	60.0	2.1	46.4	0.3	54.8
T&B, 100', 80 psi	80.0	2.6	68.7	0.3	75.1
Zoned, 100', 80 psi	80.0	2.6	68.7	0.3	75.1
Parallel, 100', 80 psi	80.0	2.5	63.6	0.3	75.0
T&B, 60', 40 psi	40.0	1.8	32.0	0.2	35.1
Zoned, 60', 40 psi	40.0	1.8	32.1	0.2	35.0
Parallel, 60', 40 psi	40.0	1.7	30.8	0.2	35.0
T&B, 60', 60 psi	60.0	2.2	50.8	0.3	54.9
Zoned, 60', 60 psi	60.0	2.2	50.6	0.3	55.0
Parallel, 60', 60 psi	60.0	2.2	48.8	0.3	54.9
T&B, 60', 80 psi	80.0	2.6	69.9	0.3	75.2
Zoned, 60', 80 psi	80.0	2.6	70.2	0.3	75.1
Parallel, 60', 80 psi	80.0	2.5	66.9	0.3	75.1

Note 1: **T&B** = Trunk and Branch;
Note 2: Systems installed at either 100' or 60' to TF
Note 3: Nominal Pressures of 40, 60, and 80 psi are static pressures

The performance data for each of the three plumbing layouts shows very similar performance for both the 100-foot distance and the 60-foot distance to the Test Fixture. At 100 feet from the source, the TF flow rate on the hot side of the valve was the primary flow and was 1.5 GPM (US gallons per minute) at a low pressure of 40 psi (static). The flow rate at the valve increased to 2.4 GPM for the 60-foot distance with a riser pressure of 80 psi (static).

Once the baseline flow performance was verified for the TF, additional tests were performed adding simultaneous flows in conjunction with the TF flowing. The performance measure of the system capability to supply the farthest fixture is the flow and pressure data at the TF. **Table 8.4** shows the performance data for the 100-foot tests with a source pressure of 40 psi.

Table 8.4 Simultaneous Flow Performance Data – 100' Maximum Length, 40 psi Source Pressure

Fixture Flow	Total System Flow GPM	Cold Supply Flow GPM	Hot Supply Flow GPM	Main Pressure psi	Test Fixture (Shower) Hot Flow GPM	Hot Pressure psi	Cold Flow GPM	Cold Pressure psi
Trunk and Branch 100' 40 psi Static	0.0	0.0	0.0	40.0	0.0	34.0	0.0	35.2
TF	2.1	0.5	1.6	40.0	1.7	31.6	0.2	35.1
TF+Lav	3.5	1.6	1.9	40.0	1.7	31.2	0.2	34.2
TF+WC	5.5	3.9	1.6	40.0	1.7	31.9	0.2	29.5
TF+Kit	3.5	1.3	2.2	40.0	1.7	31.3	0.2	35.0
TF+Sh2	4.2	1.3	2.9	40.0	1.7	30.6	0.2	34.9
TF+Sh2+Kit	5.6	2.2	3.4	40.0	1.7	30.3	0.2	34.7
TF+Sh2+Kit+Lav	7.0	3.5	3.5	40.0	1.7	30.1	0.2	33.4
TF+Sh2+Kit+Lav+WC	10.2	5.9	4.3	40.0	1.7	28.6	0.2	29.3
Zone 100' 40 psi Static	0.0	0.0	0.0	40.0	0.0	33.9	0.0	35.2
TF	2.1	0.4	1.7	40.0	1.7	31.6	0.2	35.0
TF+Lav	3.5	1.4	2.1	40.0	1.7	31.1	0.2	34.6
TF+WC	5.5	3.9	1.6	40.0	1.8	32.0	0.2	31.8
TF+Kit	3.5	1.3	2.2	40.0	1.7	31.3	0.2	34.9
TF+Sh2	4.2	1.5	2.7	40.0	1.7	30.6	0.2	34.9
TF+Sh2+Kit	5.6	2.4	3.2	40.0	1.7	30.5	0.2	34.7
TF+Sh2+Kit+Lav	7.0	3.6	3.4	40.0	1.7	30.0	0.2	34.0
TF+Sh2+Kit+Lav+WC	10.2	6.2	4.0	40.0	1.7	29.8	0.2	30.8
Parallel 100' 40 psi Static	0.0	0.0	0.0	40.0	0.0	34.0	0.0	35.2
TF	2.1	0.4	1.7	40.0	1.7	29.3	0.2	35.0
TF+Lav	3.5	1.2	2.3	40.0	1.7	29.2	0.2	35.0
TF+WC	5.5	3.7	1.8	40.0	1.7	29.4	0.2	35.0
TF+Kit	3.5	1.2	2.3	40.0	1.7	29.0	0.2	35.0
TF+Sh2	4.2	1.5	2.8	40.0	1.7	28.6	0.2	35.0
TF+Sh2+Kit	5.6	2.3	3.3	40.0	1.7	28.6	0.2	34.9
TF+Sh2+Kit+Lav	7.0	3.3	3.7	40.0	1.7	28.4	0.2	34.8
TF+Sh2+Kit+Lav+WC	10.2	6.3	3.9	40.0	1.7	28.7	0.2	34.6

TF = Test Shower Fixture, 15' elevation; **Lav** = Lavatory, both valves open, 15' elevation;
WC = Water Closet, tank type, 15' elevation; **Kit** = Kitchen, mid-position, 4' elevation;
Sh2 = 2nd Shower, full open valve, 6' elevation

Based on the simultaneous flow performance data, all systems continued to supply adequate pressure and flow to the remote test fixture located 100 feet from the source. With the source pressure of just 40 psi, the maximum system flow rate was 8.0 GPM comprised of 5.0 GPM to the cold supply fixtures and 3.0 GPM to the hot supply fixtures. **Table 8.5** shows similar results with a system design of 60 feet to the TF.

Table 8.5 Simultaneous Flow Performance Data – 60' Maximum Length, 40 psi Source Pressure

Fixture Flow	Total System Flow GPM	Cold Supply Flow GPM	Hot Supply Flow GPM	Main Pressure psi	Test Fixture (Shower) Hot Flow GPM	Hot Pressure psi	Cold Flow GPM	Cold Pressure psi
Trunk and Branch 60' 40 psi Static	0.0	0.0	0.0	40.0	0.0	34.1	0.0	35.2
TF	2.1	0.4	1.7	40.0	1.8	32.0	0.2	35.1
TF+Lav	3.5	1.4	2.1	40.0	1.7	31.6	0.2	34.5
TF+WC	5.5	3.9	1.7	40.0	1.8	32.1	0.2	31.2
TF+Kit	3.5	1.3	2.2	40.0	1.7	31.7	0.2	35.0
TF+Sh2	4.2	1.4	2.8	40.0	1.7	30.9	0.2	34.9
TF+Sh2+Kit	5.6	2.2	3.4	40.0	1.7	30.5	0.2	34.7
TF+Sh2+Kit+Lav	7.0	2.9	3.5	40.0	1.7	30.4	0.2	33.7
TF+Sh2+Kit+Lav+WC	10.2	6.0	4.2	40.0	1.7	29.2	0.2	30.0
Zone 60' 40 psi Static	0.0	0.0	0.0	40.0	0.0	34.0	0.0	35.2
TF	2.1	0.3	1.7	40.0	1.8	32.1	0.2	35.0
TF+Lav	3.5	1.3	2.2	40.0	1.7	31.7	0.2	34.8
TF+WC	5.5	3.9	1.6	40.0	1.8	32.3	0.2	33.1
TF+Kit	3.5	1.1	2.4	40.0	1.7	31.7	0.2	35.0
TF+Sh2	4.2	1.4	2.8	40.0	1.7	31.1	0.2	34.9
TF+Sh2+Kit	5.6	2.3	3.3	40.0	1.7	30.7	0.2	34.8
TF+Sh2+Kit+Lav	7.0	3.4	3.6	40.0	1.7	30.4	0.2	34.3
TF+Sh2+Kit+Lav+WC	10.2	6.2	4.0	40.0	1.7	30.4	0.2	32.0
Parallel 60' 40 psi Static	0.0	0.0	0.0	40.0	0.0	34.0	0.0	35.1
TF	2.1	0.4	1.7	40.0	1.7	30.8	0.2	35.0
TF+Lav	3.5	1.2	2.3	40.0	1.7	30.7	0.2	34.9
TF+WC	5.5	3.9	1.6	40.0	1.7	31.6	0.2	34.8
TF+Kit	3.5	1.4	2.2	40.0	1.7	30.6	0.2	34.9
TF+Sh2	4.2	1.4	2.8	40.0	1.7	30.2	0.2	34.9
TF+Sh2+Kit	5.6	2.3	3.3	40.0	1.7	30.0	0.2	34.8
TF+Sh2+Kit+Lav	7.0	3.3	3.7	40.0	1.7	29.8	0.2	34.8
TF+Sh2+Kit+Lav+WC	10.2	6.5	3.7	40.0	1.7	30.3	0.2	34.5

TF = Test Shower Fixture, 15' elevation; **Lav** = Lavatory, both valves open, 15' elevation;
WC = Water Closet, tank type, 15' elevation; **Kit** = Kitchen, mid-position, 4' elevation;
Sh2 = 2nd Shower, full open valve, 6' elevation

The system performance with simultaneous flows was very similar to the previous 100- foot test but with slightly lower pressure drops. A static pressure of 40 psi is considered to be a minimum supply pressure. A summary of the results for the simultaneous flow system performance at 60 and 80 psi source static pressure is shown in **Appendix A**.

Comparing the flow pressure and flow rate is a good way to determine the performance of a plumbing system. The limitation is that the pressure at the base of the riser is dependent on the size of the service line, meter, and water utility supply pressure. In order to describe and compare the performance of each type of system, the pressure drop from the base of the riser to the farthest outlet (including elevation losses) can be evaluated.

Figures 8.4 and **8.5** show the comparison of pressure drop based on various outlets in the system flowing with the resultant pressure drop at the farthest fixture. Both figures indicate that the parallel system, while having a higher pressure drop to the TF, has a more consistent pressure drop during simultaneous flow. The other systems, based on the trunk line feeding branch lines, continued to show increasing pressure drop as more fixtures were added to the system. In fact, when the full set of fixtures was operating simultaneously, the trunk and branch system pressure drop exceeded that of the parallel and the zone configurations. (The zone system is highly dependent on the system design, i.e., the location of the manifolds and the number of fixtures connected to the manifold).

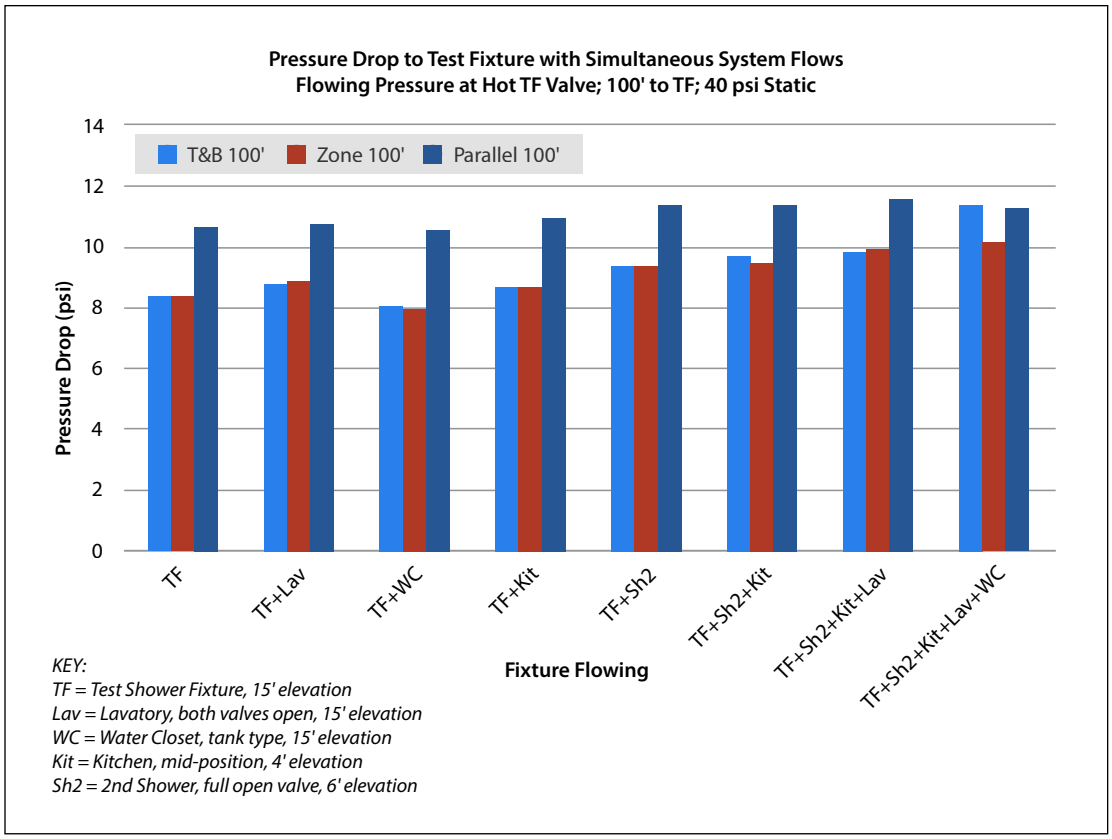

Figure 8.4 Pressure Drop Comparison, 100 ft. Distance to TF

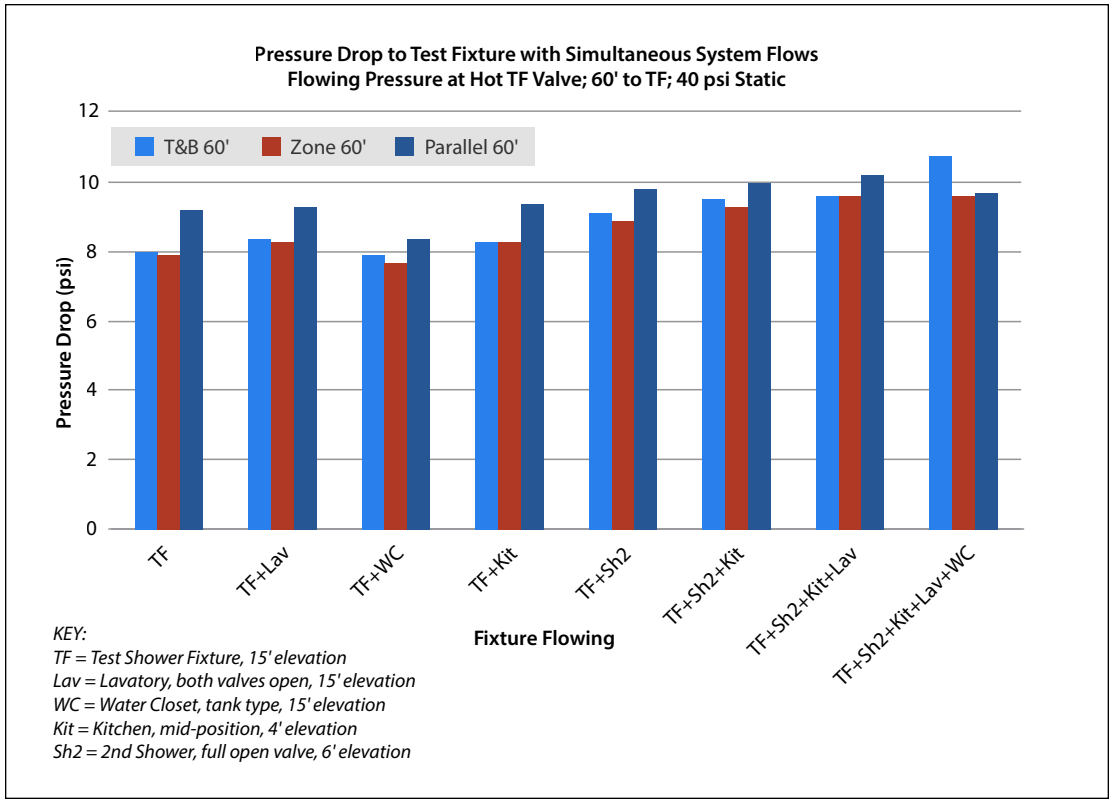

Figure 8.5 Pressure Drop Comparison, 60 ft. Distance to TF

Wait Time for Hot Water

A significant benefit of PEX piping systems is the opportunity to reduce water and energy waste by reducing the amount of time to deliver hot water from the water heater to the outlets.

Though hard to definitively quantify, there are indications that hundreds of gallons of water per year are wasted while waiting for hot water to reach outlet.

Tests were also performed on each of the three PEX system designs to compare the time it takes for hot water to be delivered to the test fixture (TF). **Figure 8.6** shows the results of delivering hot water to the shower fixture after the pipes were flushed with cold (city) water. The results were normalized to keep the flow rates and temperature from the hot water tank constant for all systems.

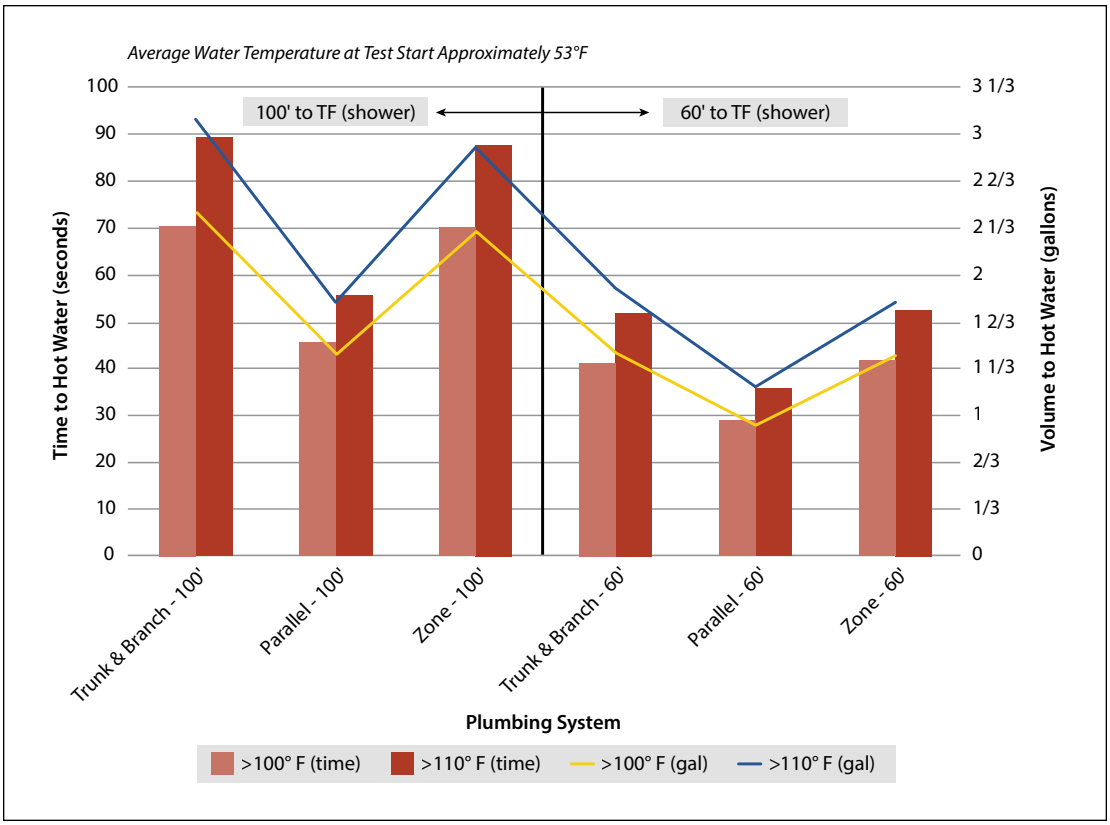

Figure 8.6 Comparison of Hot Water Delivery Time

Water and time savings of between 30% and 40% were identified based on this analysis of the parallel system over either the trunk and branch or zone system designs.

Test Summary

A summary of the performance characteristics of each system is shown in **Table 8.6**. The data indicates:

- Trunk and branch systems and zoned systems will supply a single fixture at a higher residual pressure than parallel systems, which utilize a dedicated supply line of smaller tubing
- Parallel (i.e., home-run) systems will supply more stable pressure to each fixture when operating simultaneous fixtures
- Parallel systems will deliver hot water to outlets quicker due to the smaller tubing
- Trunk and branch systems and zoned systems will deliver hot water quicker during sequential flows, because the trunk line is already charged with hot water when the second fixture is opened
- All three system designs will supply sufficient flow and pressure to fixtures even when the base riser (i.e., source) pressure is just 40 psi and the length to the farthest outlet is 100 feet

Table 8.6 Performance Summary, 100' Maximum Distance

System	Test Fixture Only		Test Fixture With Simultaneous		Test Fixture Only	
	Flow Rate Hot	Pressure Hot	Flow Rate Hot	Pressure Hot	Time to > 100°F Hot Water	Time to > 110°F Hot Water
	GPM	psi	GPM	psi	sec	sec
40 psi Static Pressure						
T&B - 100'	1.7	31.6	1.7	28.6		
Zone - 100'	1.7	31.6	1.7	29.8		
Parallel - 100'	1.7	29.3	1.7	28.7		
60 psi Static Pressure					**from 53°F**	
T&B - 100'	2.2	50.0	2.1	44.4	71.9	90.9
Zone - 100'	2.2	49.7	2.1	46.3	71.6	89.3
Parallel - 100'	2.1	46.4	2.1	45.6	46.3	56.8
80 psi Static Pressure						
T&B - 100'	2.6	68.7	2.4	61.6		
Zone - 100'	2.6	68.7	2.5	63.0		
Parallel - 100'	2.6	63.6	2.4	62.0		

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