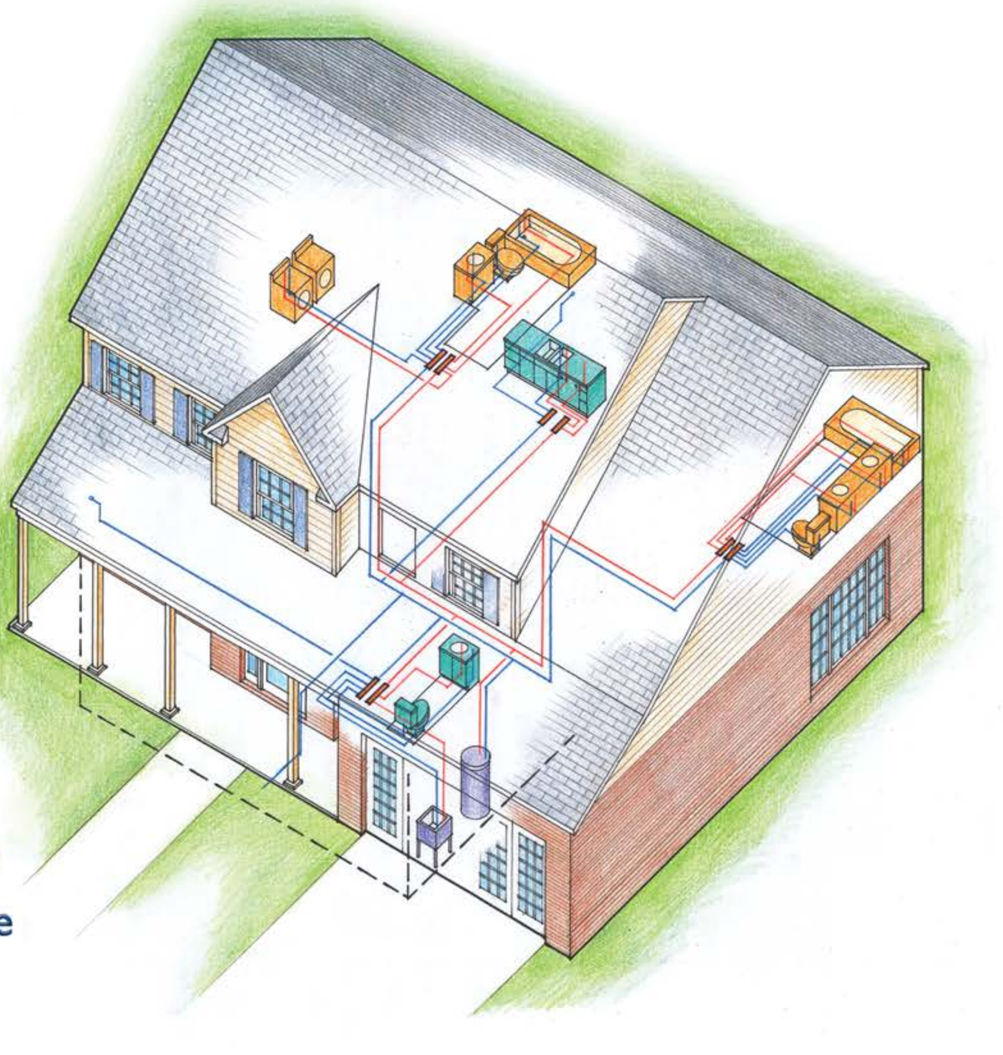
DESIGN GUIDE

Residential PEX Water Supply Plumbing Systems

Second Edition



Applications
Advantages
Material Properties
Joining Methods
Code Acceptance
System Design
Installation
and more

PPFA Plastic Pipe and Fittings Association

ICC ES PMG

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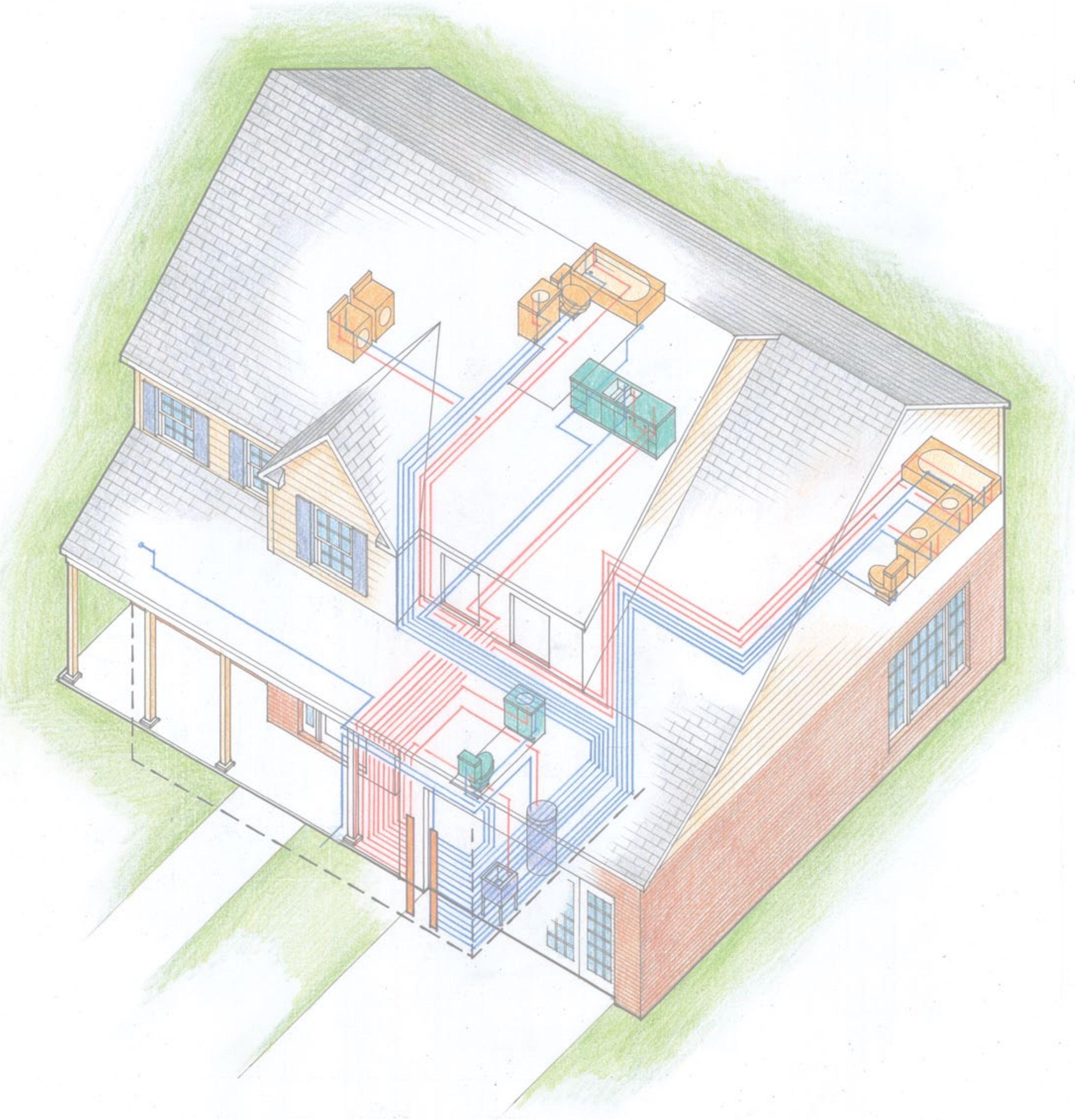

DESIGN GUIDE

Residential PEX Water Supply Plumbing Systems

Second Edition

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This document was developed as the result of a consensus process involving the Plastic Pipe Institute, the Plastic and Plastic Pipe and Fitting Association, and representatives from numerous piping and fitting manufacturers. It was prepared by the Home Innovation Research Labs.

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Table of Contents

List of Figures

List of Tables

Appendix A

PERFORMANCE TEST SETUP AND DATA

Diagrams of piping layouts for different test runs.

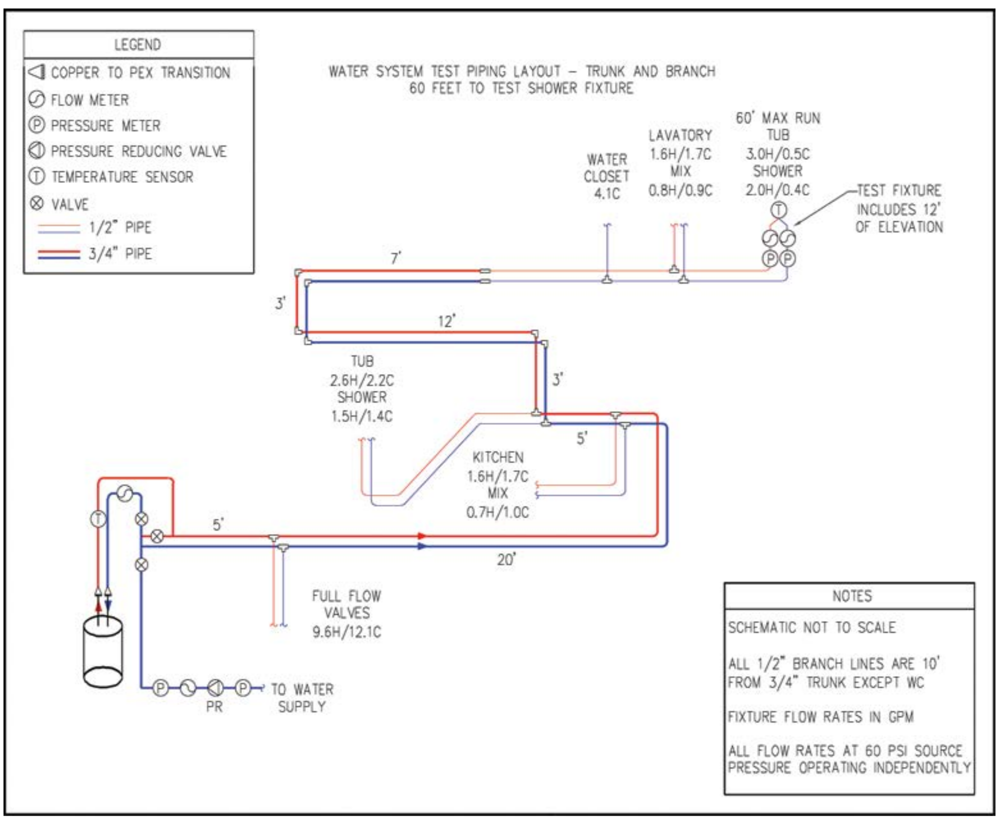

Figure A.1 – Water System Test Piping Layout – Trunk and Branch, 60' to TF

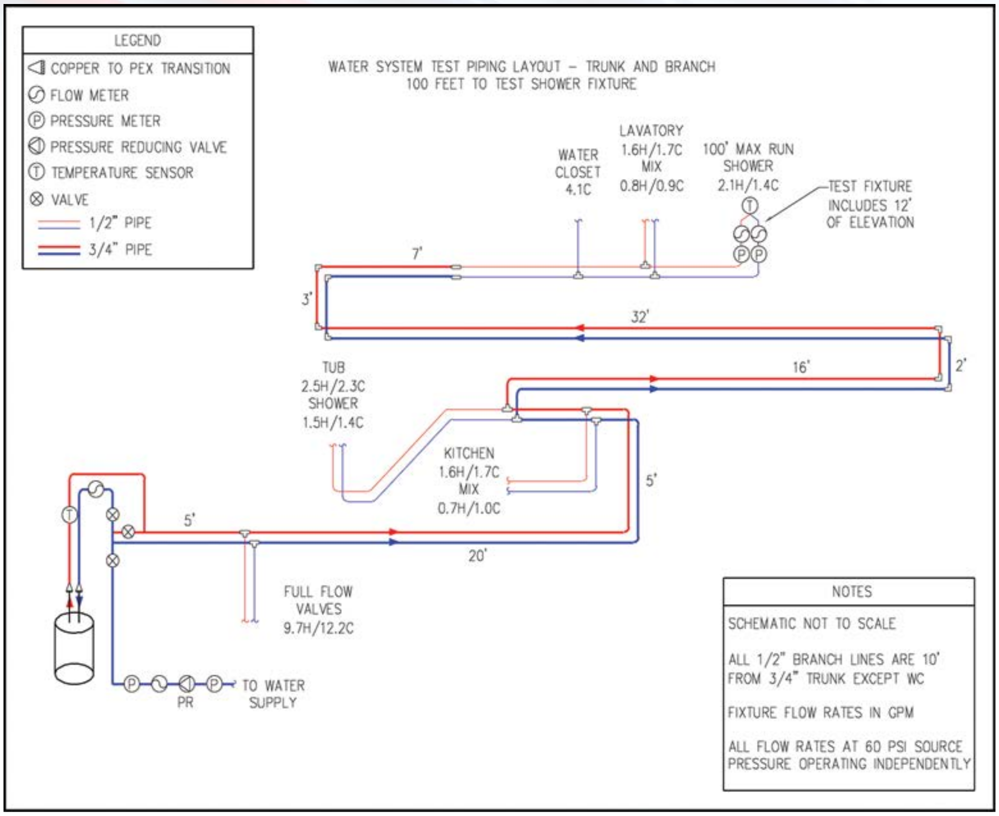

Figure A.2 – Water System Test Piping Layout – Trunk and Branch, 100' to TF

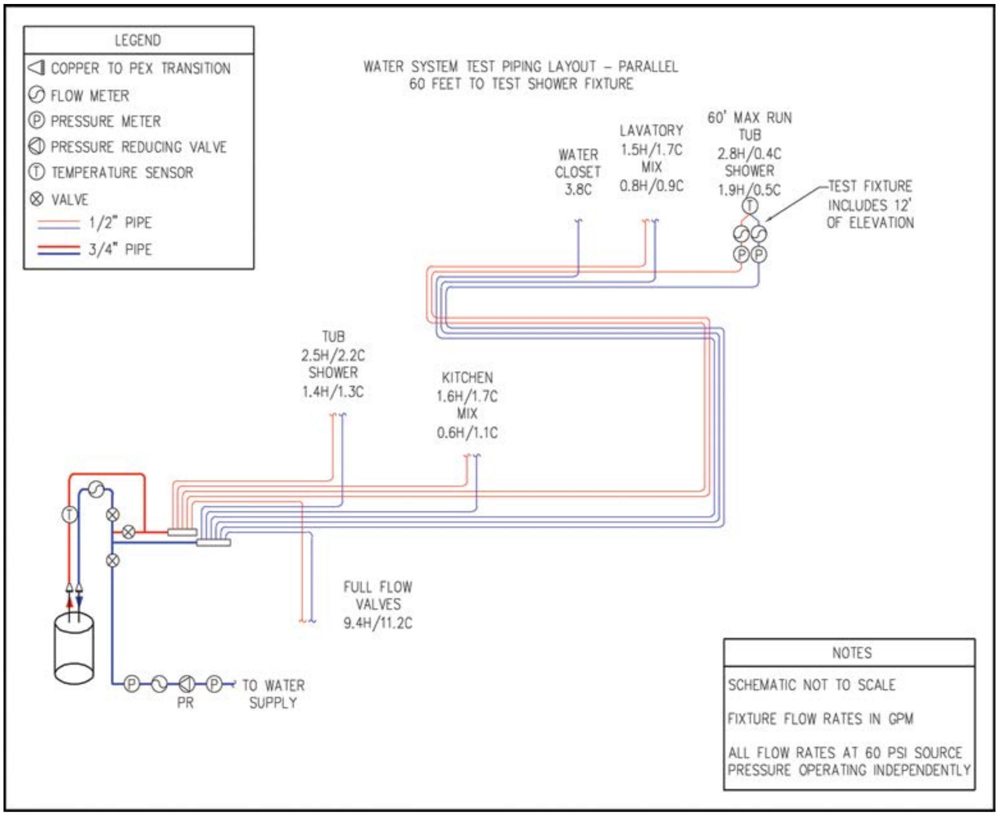

Figure A.3 – Water System Test Piping Layout – Parallel, 60' to TF

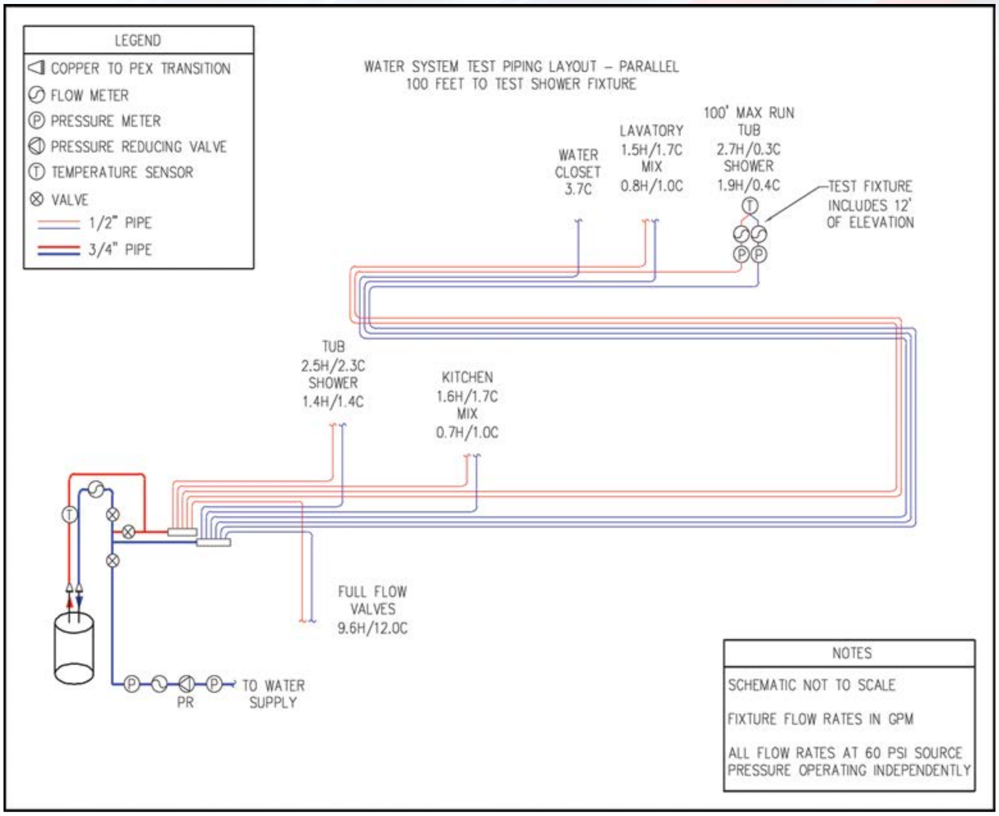

Figure A.4 – Water System Test Piping Layout – Parallel, 100' to TF

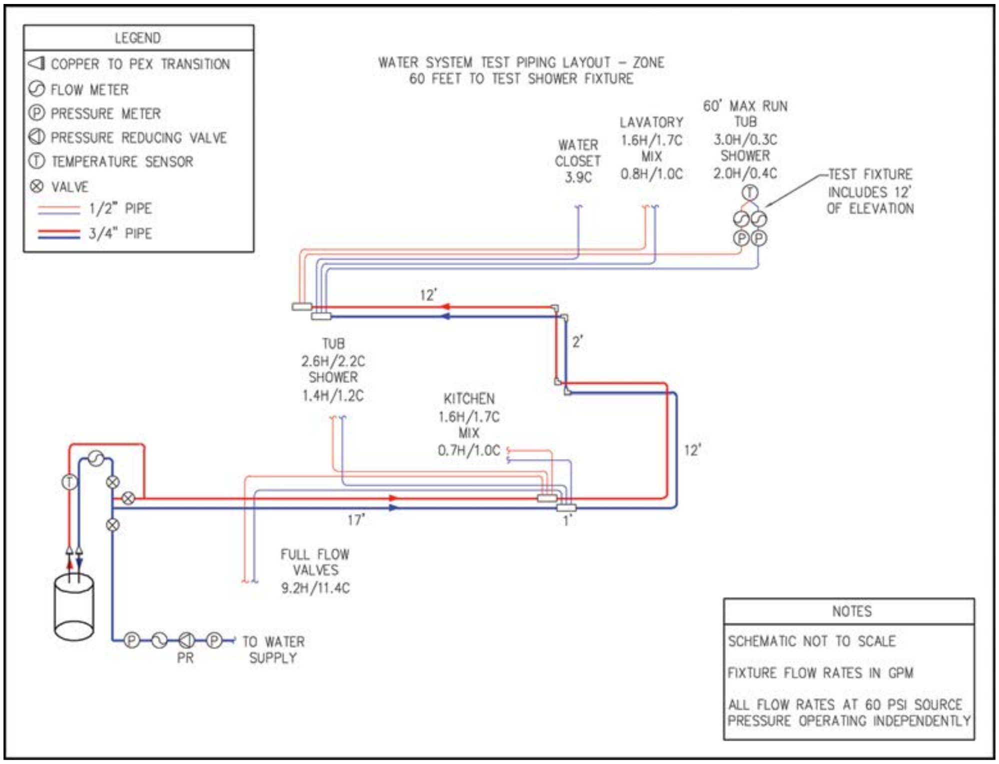

Figure A.5 – Water System Test Piping Layout – Zone, 60' to TF

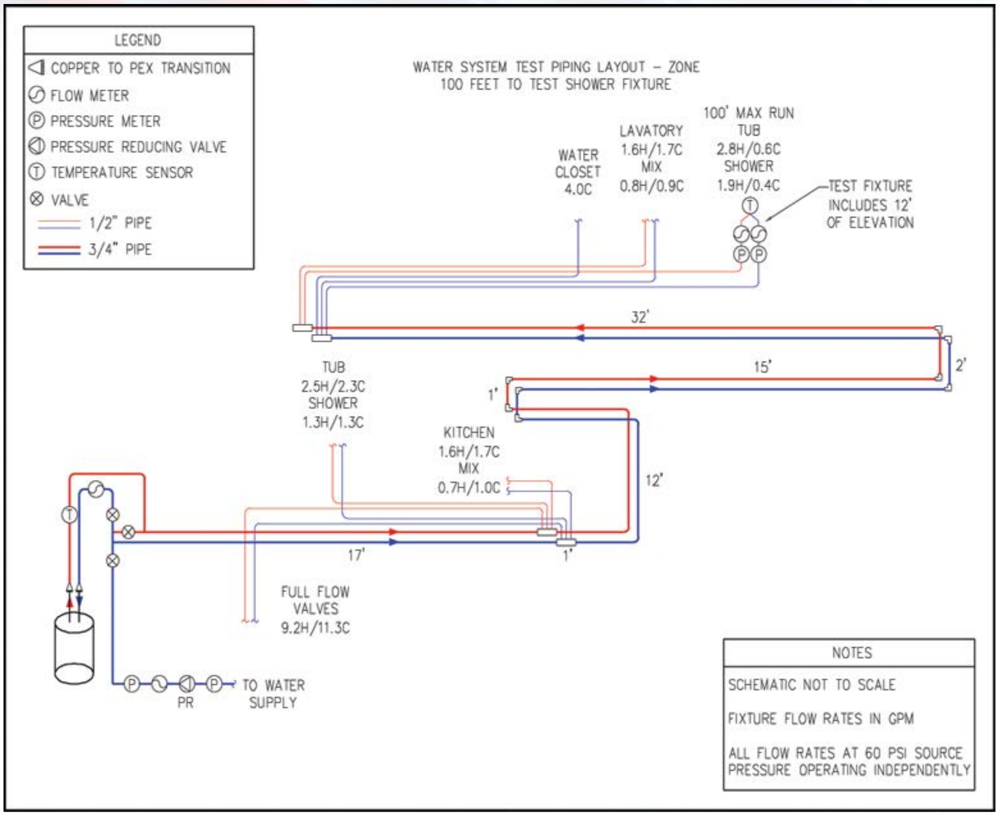

Figure A.6 – Water System Test Piping Layout – Zone, 100' to TF

Table A.1 – Simultaneous Flow Performance Data – 100' Maximum Length, 60 and 80 psi Source Pressure

Fixture Flow	Total System Flow	Cold Supply Flow	Hot Supply Flow	Main Pressure	Test Fixture (Shower)			
					Hot Flow	Hot Pres.	Cold Flow	Cold Pres.
	gpm	gpm	gpm	psi	gpm	psi	gpm	psi
Trunk and Branch 100' 60 psi Static	0.0	0.0	0.0	60.0	0.0	54.3	0.0	55.4
TF	2.5	0.5	2.1	60.0	2.2	50.0	0.3	55.2
TF+Lav	4.3	1.8	2.5	60.0	2.2	49.1	0.3	53.5
TF+WC	6.8	4.6	2.2	60.0	2.2	50.1	0.2	46.5
TF+Kit	4.3	1.5	2.8	60.0	2.2	49.2	0.3	54.9
TF+Sh2	5.2	1.6	3.6	60.0	2.1	47.9	0.3	54.8
TF+Sh2+Kit	6.9	2.7	4.2	60.0	2.1	47.4	0.3	54.5
TF+Sh2+Kit+Lav	8.6	4.2	4.4	60.0	2.1	47.1	0.3	52.1
TF+Sh2+Kit+Lav+WC	12.5	7.2	5.3	60.0	2.1	44.4	0.2	44.5

Table A.1 – Simultaneous Flow Performance Data – 100' Maximum Length, 60 and 80 psi Source Pressure *(continued)*

Fixture Flow	Total System Flow	Cold Supply Flow	Hot Supply Flow	Main Pressure	Test Fixture (Shower)			
					Hot Flow	Hot Pres.	Cold Flow	Cold Pres.
	gpm	gpm	gpm	psi	gpm	psi	gpm	psi
Zone 100' 60 psi Static	0.0	0.0	0.0	60.0	0.0	54.2	0.0	55.2
TF	2.5	0.5	2.1	60.0	2.2	49.7	0.3	54.9
TF+Lav	4.13	1.7	2.6	60.0	2.2	49.0	0.3	54.1
TF+WC	6.8	4.7	2.1	60.0	2.2	50.1	0.2	49.6
TF+Kit	4.3	1.6	2.7	60.0	2.2	49.1	0.3	54.8
TF+Sh2	5.2	1.7	3.5	60.0	2.2	48.4	0.3	54.7
TF+Sh2+Kit	6.9	2.8	4.0	60.0	2.1	47.9	0.3	54.3
TF+Sh2+Kit+Lav	8.6	4.2	4.4	60.0	2.1	47.2	0.3	53.1
TF+Sh2+Kit+Lav+WC	12.5	7.4	5.1	60.0	2.1	46.3	0.2	47.8
Parallel 100' 60 psi Static	0.0	0.0	0.0	60.0	0.0	54.1	0.0	55.1
TF	2.5	0.5	2.1	60.0	2.1	46.4	0.3	54.8
TF+Lav	4.3	1.5	2.8	60.0	2.1	46.3	0.3	54.7
TF+WC	6.8	4.6	2.1	60.0	2.1	47.1	0.3	54.6
TF+Kit	4.3	1.4	2.9	60.0	2.1	46.2	0.3	54.7
TF+Sh2	5.2	1.7	3.5	60.0	2.1	45.7	0.3	54.7
TF+Sh2+Kit	6.9	2.7	4.1	60.0	2.1	45.3	0.3	54.6
TF+Sh2+Kit+Lav	8.6	3.9	4.7	60.0	2.1	45.0	0.3	54.4
TF+Sh2+Kit+Lav+WC	12.5	7.7	4.8	60.0	2.1	45.6	0.3	53.9
Trunk and Branch 100' 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.5	0.0	75.4
TF	2.9	0.4	2.5	80.0	2.6	68.7	0.3	75.1
TF+Lav	5.0	2.0	3.0	80.0	2.6	67.9	0.3	73.0
TF+WC	7.8	5.5	2.3	80.0	2.6	69.4	0.3	62.4
TF+Kit	5.0	1.7	3.3	80.0	2.6	68.5	0.3	75.0

Table A.1 – Simultaneous Flow Performance Data – 100’ Maximum Length, 60 and 80 psi Source Pressure *(continued)*

Fixture Flow	Total System Flow	Cold Supply Flow	Hot Supply Flow	Main Pressure	Test Fixture (Shower)			
					Hot Flow	Hot Pres.	Cold Flow	Cold Pres.
	gpm	gpm	gpm	psi	gpm	psi	gpm	psi
TF+Sh2	6.0	1.8	4.1	80.0	2.6	67.9	0.3	74.8
TF+Sh2+Kit	7.9	2.9	5.0	80.0	2.5	66.3	0.3	74.3
TF+Sh2+Kit+Lav	9.9	4.8	5.2	80.0	2.5	65.2	0.3	71.3
TF+Sh2+Kit+Lav+WC	14.4	8.3	6.1	80.0	2.4	61.6	0.3	60.9
Zone 100’ 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.6	0.0	75.4
TF	2.9	0.5	2.4	80.0	2.6	68.7	0.3	75.1
TF+Lav	5.0	1.9	3.1	80.0	2.5	67.3	0.3	74.0
TF+WC	7.8	5.5	2.3	80.0	2.6	68.9	0.3	67.6
TF+Kit	5.0	1.7	3.2	80.0	2.6	68.2	0.3	74.8
TF+Sh2	6.0	1.8	4.1	80.0	2.5	67.2	0.3	74.8
TF+Sh2+Kit	7.9	34.1	4.8	80.0	2.5	65.9	0.3	74.5
TF+Sh2+Kit+Lav	9.9	4.8	5.1	80.0	2.5	65.0	0.3	72.7
TF+Sh2+Kit+Lav+WC	14.4	8.6	5.8	80.0	2.5	63.0	0.3	65.0
Parallel 100’ 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.5	0.0	75.3
TF	2.9	0.4	2.5	80.0	2.5	63.6	0.3	75.0
TF+Lav	5.0	1.7	3.3	80.0	2.5	63.3	0.3	74.8
TF+WC	7.8	5.3	2.6	80.0	2.5	64.4	0.3	74.6
TF+Kit	5.0	1.7	3.3	80.0	2.5	63.4	0.3	74.8
TF+Sh2	6.0	1.7	4.2	80.0	2.5	62.6	0.3	74.8
TF+Sh2+Kit	7.9	3.0	4.9	80.0	2.4	62.0	0.3	74.7
TF+Sh2+Kit+Lav	9.9	4.5	5.4	80.0	2.4	61.5	0.3	74.5
TF+Sh2+Kit+Lav+WC	14.4	8.9	5.5	80.0	2.4	62.0	0.3	73.8

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, 5’ elevation

Table A.2 – Simultaneous Flow Performance Data – 60' Maximum Length, 60 and 80 psi Source Pressure								
Fixture Flow	Total System Flow	Cold Supply Flow	Hot Supply Flow	Main Pressure	Test Fixture (Shower)			
					Hot Flow	Hot Pres.	Cold Flow	Cold Pres.
	gpm	gpm	gpm	psi	gpm	psi	gpm	psi
Trunk and Branch 60' 60 psi Static	0.0	0.0	0.0	60.0	0.0	54.2	0.0	55.1
TF	2.5	0.5	2.1	60.0	2.2	50.8	0.3	54.9
TF+Lav	4.3	1.8	2.5	60.0	2.2	49.9	0.3	53.7
TF+WC	6.8	4.7	2.1	60.0	2.2	50.8	0.2	46.5
TF+Kit	4.3	1.4	3.0	60.0	2.2	49.9	0.3	48.6
TF+Sh2	5.2	1.6	3.5	60.0	2.2	48.7	0.3	54.7
TF+Sh2+Kit	6.9	2.7	4.2	60.0	2.1	48.0	0.3	54.5
TF+Sh2+Kit+Lav	8.6	4.2	4.4	60.0	2.1	47.7	0.3	52.4
TF+Sh2+Kit+Lav+WC	12.5	7.3	5.2	60.0	2.1	46.0	0.2	46.5
Zone 60' 60 psi Static	0.0	0.0	0.0	60.0	0.0	54.0	0.0	55.2
TF	2.5	0.5	2.0	60.0	2.2	50.6	0.3	55.0
TF+Lav	4.3	1.7	2.6	60.0	2.2	50.1	0.3	54.5
TF+WC	6.8	4.7	2.1	60.0	2.2	50.9	0.3	51.7
TF+Kit	4.3	1.7	2.7	60.0	2.2	50.2	0.3	54.8
TF+Sh2	5.2	1.6	3.6	60.0	2.2	49.2	0.3	54.7
TF+Sh2+Kit	6.9	2.7	4.2	60.0	2.2	48.5	0.3	54.4
TF+Sh2+Kit+Lav	8.6	4.1	4.5	60.0	2.1	48.0	0.3	53.5
TF+Sh2+Kit+Lav+WC	12.5	7.5	5.0	60.0	2.1	47.4	0.2	49.7
Parallel 60' 60 psi Static	0.0	0.0	0.0	60.0	0.0	27.6	0.0	28.5
TF	2.5	0.5	2.0	60.0	2.2	48.8	0.3	54.9
TF+Lav	4.3	1.5	2.8	60.0	2.2	48.6	0.3	54.8
TF+WC	6.8	4.8	2.0	60.0	2.2	49.3	0.3	54.6

Table A.2 – Simultaneous Flow Performance Data – 60' Maximum Length, 60 and 80 psi Source Pressure *(continued)*

Fixture Flow	Total System Flow	Cold Supply Flow	Hot Supply Flow	Main Pressure	Test Fixture (Shower)			
					Hot Flow	Hot Pres.	Cold Flow	Cold Pres.
	gpm	gpm	gpm	psi	gpm	psi	gpm	psi
TF+Kit	4.3	1.7	2.7	60.0	2.2	48.5	0.3	54.8
TF+Sh2	5.2	1.7	3.5	60.0	2.1	47.8	0.3	54.8
TF+Sh2+Kit	6.9	2.7	4.2	60.0	2.1	47.3	0.3	54.6
TF+Sh2+Kit+Lav	8.6	4.0	4.6	60.0	2.1	46.9	0.3	54.5
TF+Sh2+Kit+Lav+WC	12.5	7.8	4.6	60.0	2.1	47.5	0.3	54.0
Trunk and Branch 60' 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.6	0.0	75.4
TF	2.9	0.4	2.5	80.0	2.6	69.9	0.3	75.2
TF+Lav	5.0	2.0	3.0	80.0	2.6	68.9	0.3	73.8
TF+WC	7.8	5.5	2.3	80.0	2.6	70.2	0.3	66.4
TF+Kit	5.0	1.7	3.3	80.0	2.6	69.4	0.3	75.0
TF+Sh2	6.0	1.8	4.2	80.0	2.6	68.2	0.3	75.1
TF+Sh2+Kit	7.9	2.9	5.0	80.0	2.5	66.9	0.3	74.7
TF+Sh2+Kit+Lav	9.9	4.7	5.2	80.0	2.5	66.1	0.3	72.1
TF+Sh2+Kit+Lav+WC	14.4	8.4	6.0	80.0	2.5	63.4	0.3	63.6
Zone 60' 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.5	0.0	75.3
TF	2.9	0.5	2.4	80.0	2.6	70.2	0.3	75.1
TF+Lav	5.0	1.8	3.1	80.0	2.6	69.0	0.3	74.4
TF+WC	7.8	5.6	2.2	80.0	2.6	70.2	0.3	69.9
TF+Kit	5.0	1.8	3.2	80.0	2.6	69.4	0.3	74.9
TF+Sh2	6.0	1.9	4.1	80.0	2.6	68.4	0.3	74.8
TF+Sh2+Kit	7.9	2.9	5.0	80.0	2.5	66.7	0.3	74.5
TF+Sh2+Kit+Lav	9.9	4.6	5.3	80.0	2.5	66.0	0.3	73.4
TF+Sh2+Kit+Lav+WC	14.4	8.7	5.7	80.0	2.5	64.5	0.3	67.7

Table A.2 – Simultaneous Flow Performance Data – 60’ Maximum Length, 60 and 80 psi Source Pressure *(continued)*								
Fixture Flow	**Total System Flow**	**Cold Supply Flow**	**Hot Supply Flow**	**Main Pressure**	**Test Fixture (Shower)**			
					Hot Flow	**Hot Pres.**	**Cold Flow**	**Cold Pres.**
	gpm	**gpm**	**gpm**	**psi**	**gpm**	**psi**	**gpm**	**psi**
Parallel 60’ 80 psi Static	0.0	0.0	0.0	80.0	0.0	74.5	0.0	75.3
TF	2.9	0.5	2.4	80.0	2.5	66.9	0.3	75.1
TF+Lav	5.0	1.6	3.4	80.0	2.5	66.3	0.3	75.0
TF+WC	7.8	5.4	2.5	80.0	2.5	67.3	0.3	74.7
TF+Kit	5.0	1.6	3.4	80.0	2.5	66.4	0.3	74.9
TF+Sh2	6.0	1.8	4.2	80.0	2.5	65.8	0.3	75.0
TF+Sh2+Kit	7.9	2.9	5.0	80.0	2.5	64.8	0.3	74.8
TF+Sh2+Kit+Lav	9.9	4.5	5.5	80.0	2.5	63.8	0.3	74.6
TF+Sh2+Kit+Lav+WC	14.4	9.0	5.4	80.0	2.5	64.2	0.3	73.9

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, 5’ elevation

Appendix B
INSTALLATION CHECKLIST

DESIGN

- ❑ Consult Local Codes
- ❑ Select Pipe and Joining System
- ❑ Design Piping System
  - ❑ Optimize Home Layout
  - ❑ Select Appropriate System
  - ❑ Plan Piping Routing
  - ❑ Plan Manifold and Valve Locations
- ❑ Estimate Material and Order

TRAINING

- ❑ Train piping installers on installation techniques and fittings
- ❑ Order or rent fitting tools

INSTALLATION

- ❑ Receive material and store as recommended by manufacturer
- ❑ Review piping plan with installers
- ❑ Ensure tools are calibrated/maintained
- ❑ Install per plan and manufacturer recommendations
- ❑ Pressure test per manufacturer recommendations and code requirements

FOLLOW UP

- ❑ Instruct homeowner on location and operation of manifold valves (if applicable)

Appendix C

RESOURCES

Articles and Reports

1. **Automated Builder Magazine, "PEX Pipe Gains Popularity for Practical Purposes."** April 2005, page 40. This article presents the multitude of advantages to using PEX plumbing water supply systems in residential construction, and discusses the standards and certifications required for PEX pipe and fittings. One home builder's experience with PEX and a manifold system is described.

2. **Couch, Toro, Oliphant and Vibien, *Chlorine Resistance Testing of UV Exposed Pipe,*** Jana Laboratories, Ontario, Canada, 2002. Chlorine Resistance (CR) testing is used to determine the impact of accelerated UV exposure on the oxidative resistance of cross-linked polyethylene (PEX) pipe. Following accelerated UV exposure, samples were tested to failure under accelerated test conditions to simulate chlorinated potable water. For the particular material examined, it was demonstrated that excellent retention of oxidative stability was achieved when suitable UV protection was employed.

3. **Kempton, William, "Residential Hot Water: A Behaviorally-Driven System," *Energy***, Volume 13, Number 1, January 1988, pages 107-114. This article reports on the results of monitoring the hot water use in seven homes over 7-18 months. The study shows the wide variation in hot water use among the different project participants. For instance, water consumption ranged from 44.5 liters per day per person to 126.4 liters per day per person. Bathing comprised the largest single water use in all homes but duration and volume varied significantly. The study points to the potential for water and energy savings through modification of behavior but also notes that habits related to hot water usage have deep roots in personal, social, and cultural values. The study also found that most of the participants had misperceptions related to the duration and amount of their water usage and did not have a firm understanding of the costs of hot water.

4. **Korman, Thomas M. et al, *Knowledge and Reasoning for MEP Coordination, Journal of Construction and Engineering Management,*** Volume 129 Number 6, November-December 2003, pp. 627-634. "Currently, designers and constructors use tailored CAD systems to design and fabricate MEP systems, but no knowledge-based computer technology exists to assist in the multidiscipline MEP coordination effort. The paper describes results from a research project to capture knowledge related to design criteria, construction, operations, and maintenance of MEP systems and apply this knowledge in a computer tool that can assist designers and builders in resolving coordination problems for multiple MEP systems." This work might provide background information relevant to developing a knowledge-based design tool for residential plumbing distribution systems.

5. **NSF International, *Frequently Asked Questions on Health Effects of PEX Tubing.*** This article explains who NSF International is, provides information on NSF Listed Products for potable water applications, and describes applicable NSF/ANSI standards for testing and evaluation of potable plumbing.

6. **Okajima, Toshio, Computerized Mechanical and Plumbing Design, *Actual Specifying Engineer,*** Volume 33 Number 6, June 1975, pp. 78-83. "Many mechanical and plumbing systems designs are based on the engineer's past experience or educated guesses. The author tells how one firm developed a computer program for plumbing and heating, ventilating, and air conditioning design."

7. **Orloski, M.J. and Wyly, R.S., *Performance Criteria and Plumbing System Design,*** National Engineering Lab, Washington, D.C., 1978. "An overview is presented indicating how the performance approach to plumbing system design can be used to extend traditional methods to innovative systems. …Some of the mathematical models now used for system design and pipe sizing in plumbing codes are reviewed in the context of performance-oriented research. … Conceivably the re-examination by plumbing designers of traditional design criteria against measured user needs could be beneficially extended to other areas of plumbing design such as water distribution, storm drainage, and plumbing fixtures. Beyond this, it has been recognized that uniform guidelines for evaluation of innovative systems, based on research findings, are essential for wide acceptance of performance methods, particularly by the regulatory community.

8. **Rubeiz, Camille, "Flexing Your PEX: Plumbing the Possibilities of Cross-linked Polyethylene Pipes," *Modern Materials,*** Vol. 2, No. 2, November 2004, pages 5-8. Properties of PEX pipe are described, as well as benefits of using PEX for potable water supply plumbing systems. Parallel piping and central manifold system installations are discussed. Real and misconceived limitations are also presented. In addition, other applications for PEX pipe systems, such as snow and ice melt and turf conditioning are mentioned.

9. **Rubeiz, Camille & Ball, Michael, "Warming Up to PEX Pipe Radiant Heating Systems," *Modern Materials,*** Vol. 2 No. 1, May 2004, pages 14-18. The article describes how radiant heating works, and compares the radiant heat distribution to traditional baseboard or forced air systems. There is a general description of the three methods of cross-linking polyethylene to form PEX piping (radiation, peroxide,

and silane processes). Applicable ASTM and CSA standard specifications for testing of PEX pipe and fittings are listed. Finally, the article briefly discusses the installation of PEX radiant heating systems in new residential construction or remodeling projects.

10. **Steele, Alfred, "Plumbing Design Has Major Impact on Energy Consumption,"** ***Specifying Engineer,*** Volume 45, Number 6, June 1981, pages 80-83. The paper discusses the potential energy savings that could result from low-flow fixtures, pipe insulation, and water heater temperature settings. The author emphasizes that significant water savings and therefore, energy savings as well could be achieved with no inconvenience to the end-user. It was not until 1994 that the first low-flow fixtures were introduced in the United States after being federally mandated.

11. **Stewart, William E. et al,** ***Evaluation of Service Hot Water Distribution system Losses in Residential and Commercial Installations:*** Part 1 – Field/Laboratory Experiments and Simulation Model and Part 2 – Simulations and Design Practices, ASHRAE *Transactions,* Volume 105, 1999. The papers describe a numerical model developed to estimate the heat loss or gain from insulated and uninsulated, copper and steel hot water pipes. The authors contend that the simulation model is a more reliable and consistent method of estimating such losses due to the difficulty of accurately measuring small temperature differences in field and laboratory experiments. The results of the simulation model correlate closely with previously published data, specifically 1997 ASHRAE Handbook – Fundamentals and 1995 ASHRAE Handbook – HVAC Applications. The simulation results showed more than a 50 percent decrease in heat loss in hot water piping that was insulated within approximately three feet of the water heater and that increasing the length of pipe insulated does not significantly decrease heat loss further.

12. **Tao, William & Associates, "Plumbing System Design,"** ***Heating, Piping, & Air Conditioning,*** Volume 59 Number 3, March 1987, pp. 101-114. This article outlines the fundamental criteria to be considered in the design of a building plumbing system. These criteria include load calculations, system sizing, and special design applications. A procedure for plumbing system design is also introduced that may serve as a comprehensive basis for developing computer aided design programs.

13. **Vibien, Couch, Oliphant et al,** ***Assessing Material Performance in Chlorinated Potable Water Applications,*** Jana Laboratories, Ontario, Canada. In this study, the nature of the failure mechanism of cross-linked polyethylene (PEX) pipe material exposed in the laboratory to chlorinated potable water was examined. Based on this study, the PEX pipe material appears to have good resistance to chlorinated potable water.

14. **Wendt, R.L., Evelyn Baskin, David Durfee,** ***Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation,*** Buildings Technology Center, Oak Ridge National Laboratory for the California Energy Commission, Oak Ridge, TN, 2004. This study simulated and compared the energy and water performance, economics, and barriers to use of various domestic hot water distribution systems in California homes. Variation in systems included trunk and branch, manifold systems, copper pipe, CPVC pipe, PEX piping, insulated and uninsulated pipe, attic location, slab

location, demand recirculation, and continuous recirculation. Using a computer model, LabView, the following results were found for a clustered hot water usage pattern:

a. Demand recirculation systems, whether piping was copper or CPVC, wasted the least water and the least energy.

b. Whether copper or CPVC piping was used, the system with a centrally located water heater was second with respect to the least amount of energy wasted. However, almost twice as much water was wasted in comparison to the recirculation systems even though the water heater was centrally located.

c. In both groups, the CPVC systems were slightly better energy performers than their copper counterparts – about 4 to 14 percent better.

d. The parallel pipe configurations using PEX tubing wasted about 3 percent more energy than uninsulated copper pipe in an attic installation, but wasted 60 percent less energy than uninsulated copper installed in a slab. Insulating the sub-slab copper pipe brought its energy performance inline with the PEX system. With respect to water waste, the parallel system (attic installation) performed similarly to copper pipe installed in an attic.

e. Sub-slab installation without insulation compromised the energy and water performance of all the systems. However, the parallel system using PEX pipe suffered the least – an approximate 30 percent drop in performance compared to a fourfold decrease for the copper and CPVC systems.

f. Construction costs for the parallel system using PEX tubing were slightly lower than the trunk and branch system using copper, but higher than the CPVC systems.

While the study indicates that usage patterns have the most significant effect upon energy usage and water consumption in residential situations, it also postulates that "parallel pipe distribution systems may offer an attractive alternative for some house designs and distribution system layouts." The modeling showed very little difference in energy and water performance when clustered use was assumed but indicated that parallel systems outperform conventional trunk and branch systems when cold starts are typical.

15. Wiehagen, J. and Sikora, J. (March 2003). ***Performance Comparison of Residential Hot Water Systems,*** work performed by NAHB Research Center, Inc. for NREL. Using data from two research sites in Ohio and from weekly laboratory experimental data, a simulation model was developed to estimate annual energy consumption for several types of water-heating systems. Using the Transient Energy System Simulation Tool, TRNSYS, three types of systems were analyzed under high-usage (average 76 gallons per day) and low-usage conditions (average 28 gallons per day). The systems were 1) a standard electric storage tank water heater with a copper tree-configuration distribution system, 2) a central tankless water heater with a polyethylene (PEX) piping parallel distribution system, and 3) multiple point-of-use water heaters with a copper tree-type distribution system. The simulations showed a 12 percent increase in overall system efficiency for the tankless water heater with the PEX parallel piping system compared to the storage heater with the copper treed system under high usage conditions. For the low-use home, there was a 26 percent

increase in efficiency for the same system. The analysis also indicated energy savings for the PEX parallel piping configuration whether the water heating equipment was a conventional tank or a tankless system – 6 percent savings for the high-use home and 13 percent savings for the low-use home. Analysis of the tree-type system with multiple point-of-use heaters also showed improved energy performance in comparison to a similar treed distribution system with a storage tank water heater – a 50 percent reduction in energy consumption for the low-use condition and 28 percent reduction for the high-use home. In addition to the energy savings, an economic analysis showed a positive annual cash flow for the parallel distribution systems whether a tank or tankless heater was used compared to the standard tank/tree system. The analysis included estimates of installed cost, financing costs, and electricity costs.

16. **Wiehagen, J. and Sikora, J. (April, 2002). *Domestic Hot Water System Modeling for the Design of Energy Efficient Systems,*** work performed by NAHB Research Center, Inc. for NREL. Using data obtained from actual home sites, the researchers developed a computer simulation model to analyze typical residential plumbing systems. The evaluation compared demand water heating equipment in conjunction with various piping configurations to a standard tank heater with a tree delivery system. High- and low-usage patterns were considered. Maximum energy savings resulted from using a combination of a centrally located demand water heater with a parallel piping system. Annual energy savings were 17 percent for the high consumption home and 35 percent for the low use home. The demand system did show some hot water temperature degradation during periods of high flow rates.

17. **Wyly, R.S. et al, (May 1975). "Review of Standards and Other Information on Thermoplastic Piping in Residential Plumbing."** Sponsored by the U.S. Department of Housing and Urban Development, Washington, D.C. "The paper is a review of existing information on the physical characteristics of thermoplastic piping that are of particular interest in considering its potential for use in residential above-ground plumbing. The presentation is oriented to considerations of adequacy of functional performance of plumbing systems from the user's/owner's viewpoint in contrast with the typical product-specifications oriented format reflected in current standards. Not only are the physical characteristics emphasized that relate most directly to the determination of functional performance of installed systems, but the importance of design and installation detail in the context is discussed. In conclusion, this review indicates the need for better use of existing knowledge as well as for some research and test development work particularly in the areas of thermal properties, response to building fires, and resistance to water hammer."

Manufacturers' Information

1. **NIBCO, Inc. (2011)** ***NIBCO® PEX Piping Systems Installation Manual,*** Elkhart IN. The manual provides specific instructions to properly install NIBCO PEX plumbing systems and accessories. Also included are correct methods for making crimp, clamp, and sleeve connections with both metal and poly insert fittings. Definitions, tables, and warranty are included in the document as well.

2. **Uponor, Inc. (2011)** ***Uponor Professional Plumbing Installation Guide,*** Apple Valley, MN. Uponor's installation guide is published for building officials, plumbing professionals and contractors interested in Uponor professional plumbing systems. This manual describes general installation recommendations that use Uponor AquaPEX tubing products. Local code requirements should be followed.

3. **Viega LLC,** ***PEX Water Systems Installation Manual*** **(2012),** Bedford, MA. This manual provides detailed instructions for the installation of ViegaPEX, FostaPEX tubing and the ManaBloc parallel water distribution system. Included are design and layout strategies and pressure drop information that could be used to develop more specific design tools. Guidance given for parallel water distribution systems includes:
   - Typical supply line size per number of bathrooms;
   - Typical distribution line size per fixture flow requirement;
   - Use of multiple manifolds when the home is large or there are a large number of fixtures.

4. **Zurn, (2012)** ***Zurn PEX Plumbing Guide,*** Zurn Industries, Inc., Erie, PA. The Zurn Guide offers similar installation instructions to the other manufacturers. Each manufacturer recommends their specific crimp tool and gauge. In addition to guidance regarding thermal expansion, protection from damage, pressure drop, and flow rate, the Zurn manual also discusses sizing and locating manifolds for parallel piping distribution systems. While deferring to local code requirements, Zurn does recommend using 3/8-inch tubing for hot water lines whenever possible to reduce wait time, stating that 3/8-inch tubing is usually adequate for most sink, lavatory, and shower fixtures unless the distance is greater than 80 feet.

Plastics Pipe Institute (PPI) Technical Publications

1. **TN-17 (2013). "Crosslinked Polyethylene (PEX) Pipe and Tubing."** This technical note provides general information on cross-linked polyethylene (PEX), such as: "What is PEX?" and "How does PEX improve properties of PE?" Three methods of cross-linking polyethylene to form PEX, qualification standards, and certification requirement are presented. Finally, several applications for the use of PEX piping, and advantages of PEX pipe systems are listed.
2. **TN-26 (2005). "Erosion Study on Brass Insert Fittings Used in PEX Piping Systems."** The objective of this test program was to subject different brass insert fittings and different pipe diameters for PEX plumbing systems to flow rates that represented the maximums that could occur if a plumbing system was sized according to the 2000 Uniform Plumbing Code. Enough chlorinated water flowed through the pipe and fittings equivalent to 40 years of service in a typical single family residence. None of the brass fittings failed during the test. Weight losses were less than 3 percent for all fittings. A test procedure is appended to this Technical Note.
3. **TN-31 (2010). "Differences between PEX and PB Piping Systems for Potable Water Applications."** Several features and properties of PEX pipe are presented to differentiate between PEX and polybutylene (PB) systems. For instance, PEX is a crosslinked material, PEX pipes have 22% greater wall thickness, PEX pipes are tested to prove chlorine resistance, and PEX piping systems do not use polyacetal fittings."
4. **TN-32 (2010). "UV Labeling Guidelines for PEX Pipes."** These guidelines present recommendations for exposure and storage of PEX piping, and an example of a cautionary label to be applied to packaging to ensure that PEX is not over exposed to sunlight (UV radiation).
5. **TN-39 (2013). "Recommended Practices Regarding Application of Pesticides and Termiticides near PEX Pipes."** This Technical Note describes recommendations for correct installation of PEX water pipes for service line applications as well as hot- and cold-water distribution use. These recommendations are intended for the installing plumber, and will help to prevent misapplication of liquid pesticides/termiticides around PEX pipes.
6. **National Association of Home Builders (2008). "Fixture Flow Rate Comparison Cross-Linked Polyethylene (PEX) Piping and Copper Tubing."** This study was perfomed by NAHB-RC at the request of PPI to compare the volumetric flow rates of copper systems versus PEX systems, and the ability of each system to meet fixture demand requirements.
7. **PPI Statement A (2013). "Relative Oxidative Aggressiveness of Chloramines and Free Chlorine Disinfectants Used in Treated Potable Water on Cross-linked Polyethylene (PEX) Pipe."** This PPI statement examines the relative oxidative aggressiveness of the common potable water disinfectants free chlorine and chloramines on crosslinked polyethylene (PEX) pipes.

8. **PPI Statement Y (2008). "Taste and Odor Statement."** This PPI statement documents the history and requirements for the taste and odor and safety of plastic water pipes in North America including the mandatory test method/requirement in use in North America is the standard NSF/ANSI 61: Drinking Water System Components – Health Effects.

9. **AWWA recently published the 263 Committee Report: "Design and Installation of Crosslinked Polyethylene (PEX) Pipe in Accordance with AWWA C904."** This committee report has been issued to provide basic guidance and references on the design and installation of PEX piping manufactured in accordance with ANSI/AWWA C904, and includes information about temperature/pressure capabilities, flexibility, pressure surge dissipation, freeze-break resistance, chlorine resistance, corrosion resistance, chemical resistance, erosion, tuberculation and design.

10. **PPFA (2011). "PEER-REVIEWED LIFE CYCLE INVENTORY FOR THE PRODUCTION AND USE OF INSTALLED RESIDENTIAL PIPING SYSTEMS FOR THREE HOUSE LAYOUTS." Submitted to: Plastic Piping Education Foundation By: Franklin Associates, A Division of ERG.** The purpose of this study was to determine the baseline energy consumption and environmental releases associated with the production and use of residential pipe systems for three house layouts.

11. **TR-XX. "R-Value of PEX."** This report conveys the results of a test program to determine the R-Value of PEX (thermal conductivity). Samples of PEX and PERT were tested. This document has not received a final TR designation as of the printing of this guide.

GLOSSARY

ASTM: American Society for Testing and Materials

Corrosion: deterioration in metals caused by oxidation or chemical action

Crosslinked polyethylene: a polyethylene material which has undergone a change in molecular structure using a chemical or a physical process whereby the polymer chains are chemically linked. Crosslinking of polyethylene into PEX for pipes results in improved properties such as elevated temperature strength and performance, chemical resistance, and resistance to slow crack growth.

Elasticity: a measure of material stiffness or the ability of the material to stretch or deform temporarily under a load

Fitting: a device or connection that allows the PEX pipe to change direction or size, such as a tee, elbow, or coupling

Fixture: a device or appliance at the end of a water supply distribution pipe line. Example: lavatory, water closet, tub/shower, dishwasher

IAPMO: International Association of Plumbing and Mechanical Officials

ICC: International Code Council

IPC: International Plumbing Code

IRC: International Residential Code

Joint: the connection of the PEX pipe to a fitting, fixture, or manifold

Manifold: a device having a series of ports that are used to connect distribution lines for several fixtures

NSPC: National Standard Plumbing Code

Outlet: see fixture

Parallel: a plumbing design that utilizes a central manifold and distribution piping to each hot and cold water fixture

pH: a scale ranging from 0 to 14 that ranks how acidic or alkaline a liquid is; water with a pH below 7 is considered acidic and water with a pH above 7 is considered alkaline

PPFA: Plastic Pipe and Fittings Association

PPI: Plastics Pipe Institute

Scaling: process of mineral buildup on the interior of a pipe

Test fixture: the tub-shower unit farthest from the water source that was instrumented to measure flow rate, flowing pressure, and mixed water temperature in the lab tests

Thermoplastic: having the property of becoming soft when heated and hard when cooled

Thermoset: having the property of becoming permanently hard and rigid when heated or cured

Trunk and branch: a plumbing design that has a large main line that feeds smaller pipes to each fixture

Ultraviolet: high energy light waves found in sunlight that lead to the degradation of many plastics and materials (UV)

UPC: Uniform Plumbing Code

Wait time: the time it takes for hot water to be delivered to the Test Fixture; delivery time

Water hammer: a banging noise heard in a water pipe following an abrupt alteration of the flow with resultant pressure surges

Zone: a plumbing system that uses trunk lines from the water source to small manifolds at grouped fixtures, such as a bathroom; can be flow-through or closed end