Saving Water and Energy in Residential Hot Water Distribution Systems

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What Do You Want from your Hot Water System?

Safety

- Not too hot
- Not too cold
- No harmful bacteria or particulates

Convenience

- Adjustable temperature and flow
- Never run out
- Hot water right now
- Quiet

Do You Know Anyone Who Waits a Long Time to Get Hot Water Somewhere in their House?

- What is your “routine?”
- Where is the wait the longest?
- How long is the wait?
- How much water runs down the drain?
- Where is the wait the shortest?
- How far is the water heater from the furthest fixture?

Historical Overview

1940’s Development of the Plumbing Code

- Based on “fixture units” @ 7.5 gpm
- Greater distance and more fixtures = bigger diameter pipe

1960’s Beginning of large-scale development in the South and West

1990’s Energy Codes for water heaters and fixtures

- Fixture flow rates reduced to less than 2.5 gpm

Inadvertent Conflict Between Codes

1970 - Today

- Median US home increased from 1600 to 2400 square feet
- Distance to the furthest fixture increased from 30 to 80 feet
- Number of hot water fixtures increased from 6 to 12

Result - 18 times as long to get hot water

- Pipe area increased by 3, velocity reduced by 3
- Fixture flow rate reduced by 3, velocity reduced by 3
- Distance increased by at least 2, time increased by 2

Water and energy are wasted while waiting

How Much

- **Energy is Used** and
- **Water Runs Down the Drain**

While Waiting for the

Hot Water to Arrive?

Annual Water and Energy Use

	Natural Gas	Electricity
Gallons Per Day	64	
Gallons Per Year	23,360	
Energy into Water	17.5 Million Btu	
Efficiency	0.6	0.9
Cost per Unit	$0.70/therm	$0.07/kWh
Cost per Year	$200	$400

Assumes hot water is 90 degrees F above incoming cold water.
Cost per year has been rounded off.

Annual Water and Energy Waste

Annual Water Waste and Cost

(Combined water and sewer $0.01/gallon, rounded off)

	Water Waste	**Cost (Water and Sewer)**
5 Gallons Per Day (8%)	1825 gallons	$18
10 Gallons Per Day (16%)	3650 gallons	$36
20 Gallons Per Day (31%)	7300 gallons	$73

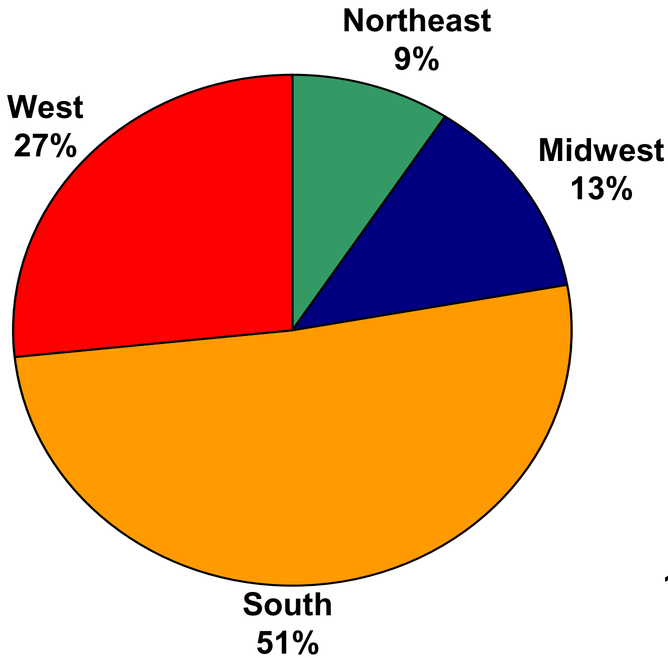
Annual Energy Cost (rounded off)

	Natural Gas	**Electricity**
5 Gallons Per Day	$15	$30
10 Gallons Per Day	$30	$60
20 Gallons Per Day	$60	$120

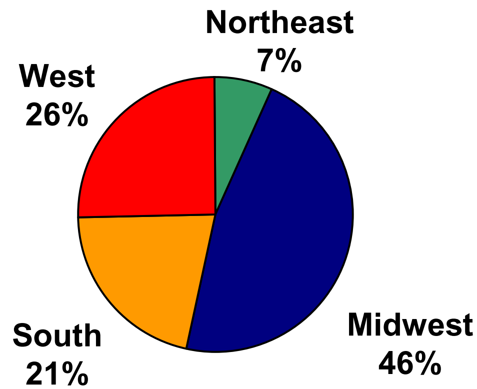
How Big is this Opportunity?

- At least 20 million existing homes
  - This is worth $1–2 billion per year in energy and water savings. Approximately 100 homes = 1 acre foot of water.
- More than 1 million new "problem homes" each year
  - This is worth $50–100 million per year in energy and water savings. Approximately 50 homes = 1 acre foot of water.
- Still more potential in commercial buildings

Where to Find the Houses

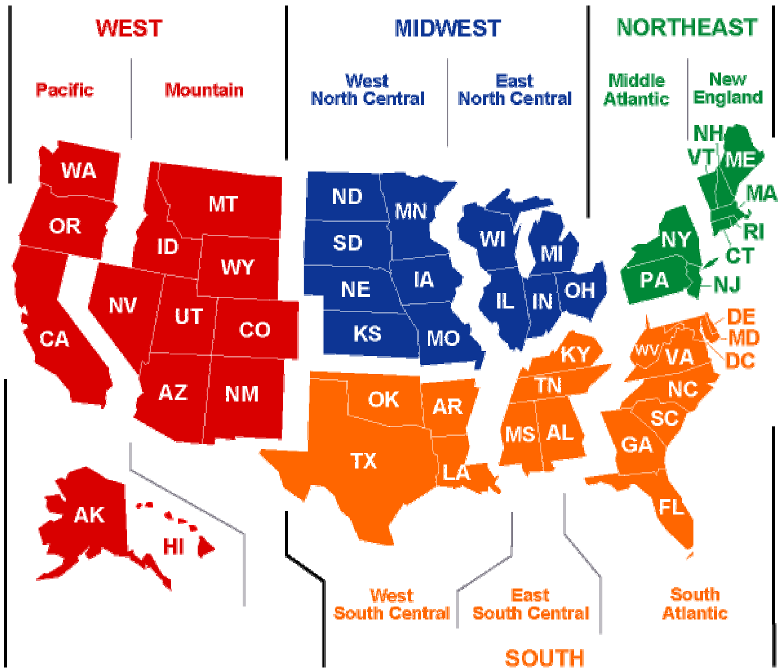


20 million Existing Homes



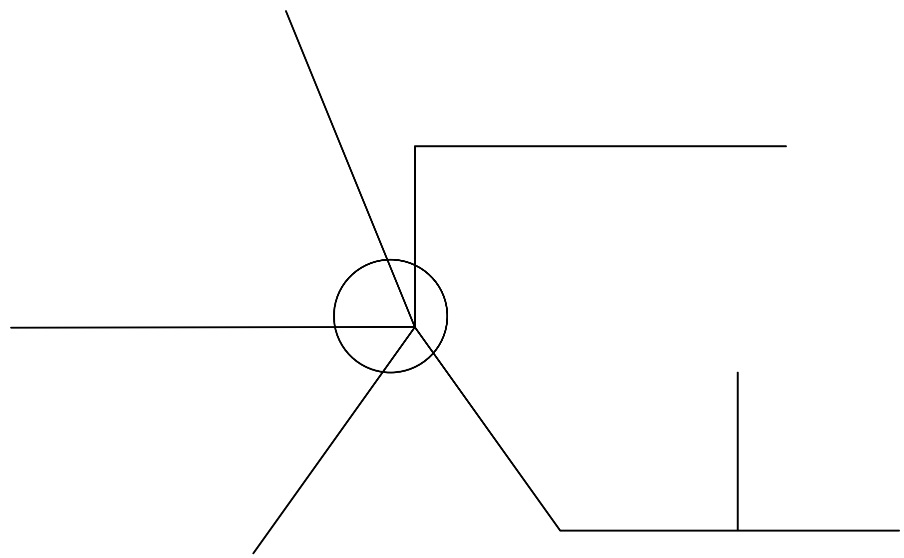
1 million New Homes Each Year

US Census Regions

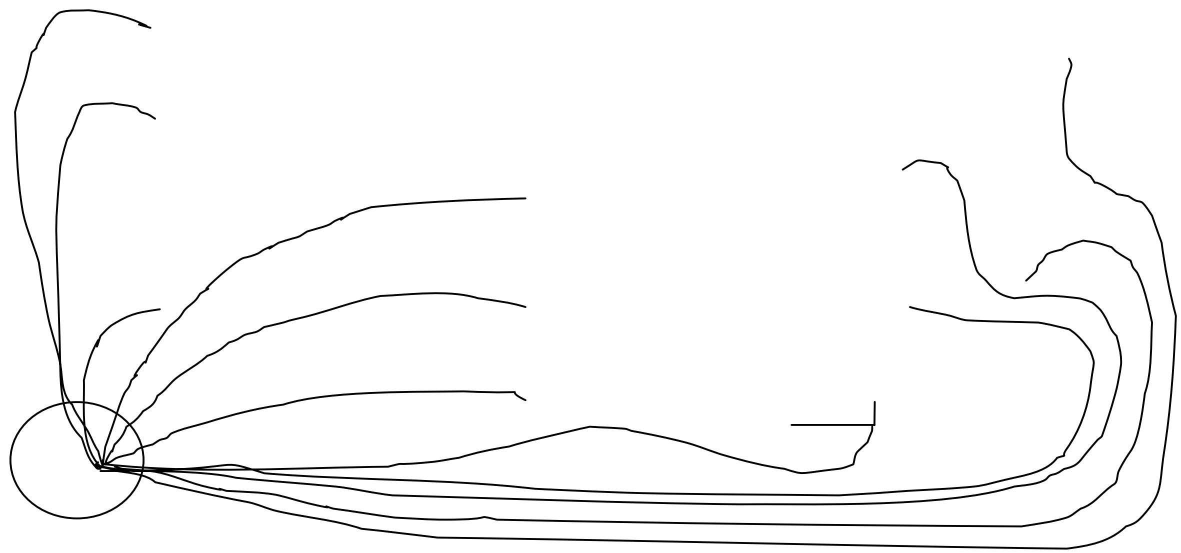


Which Distribution System is in Your House?

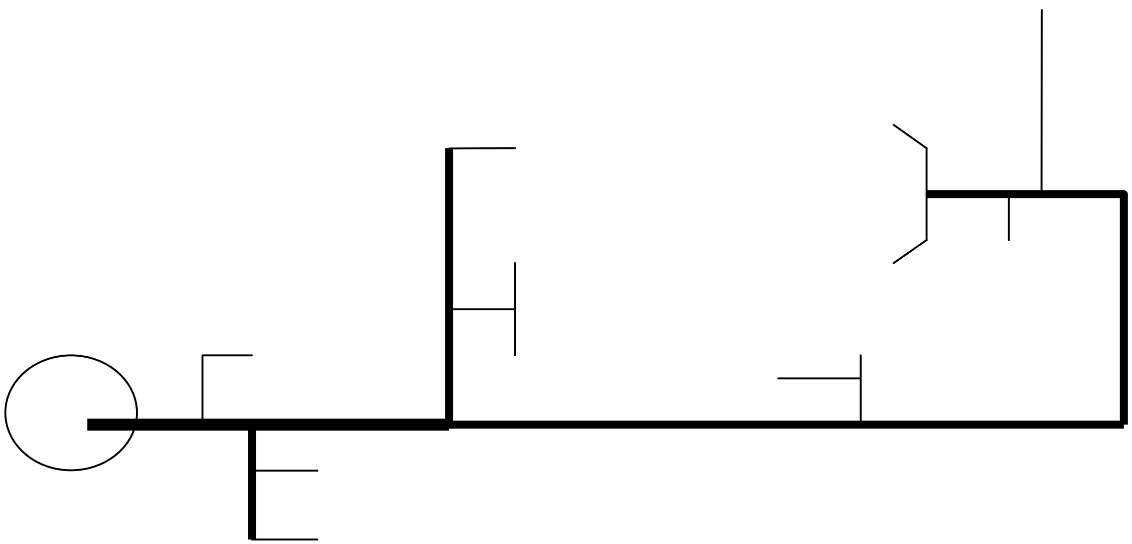
Radial, Manifold, Parallel Pipe-
Central Core



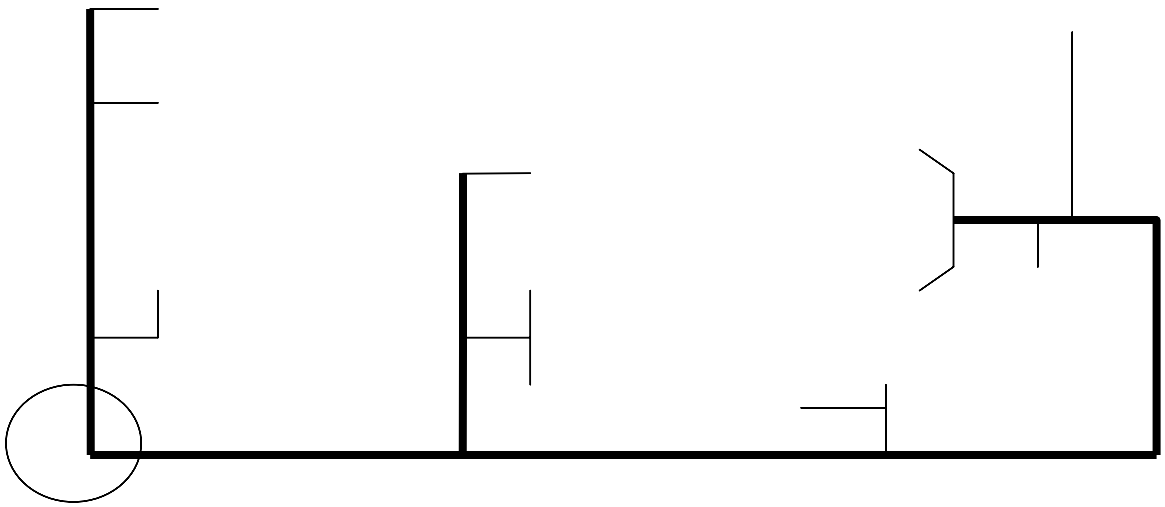
Radial, Manifold, Parallel Pipe-
Distributed



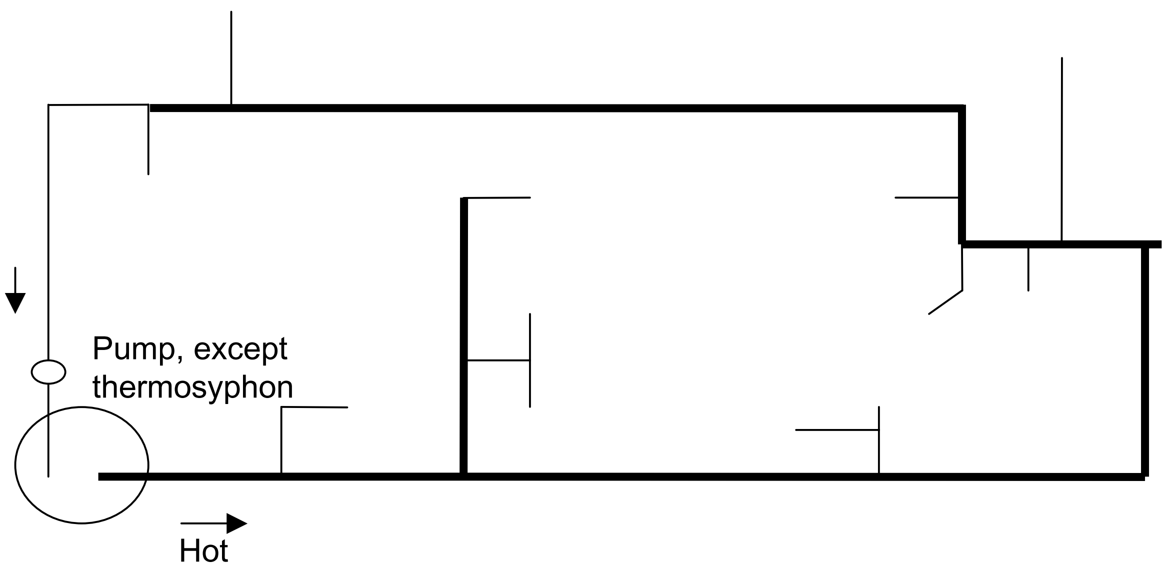
Single Trunk and Branch



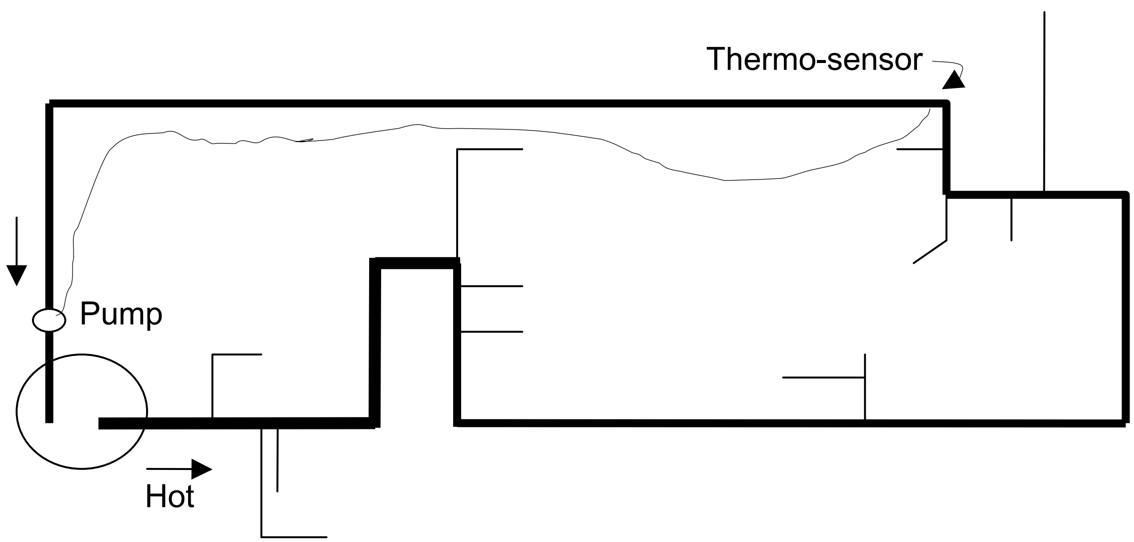
Multiple Trunk and Branch



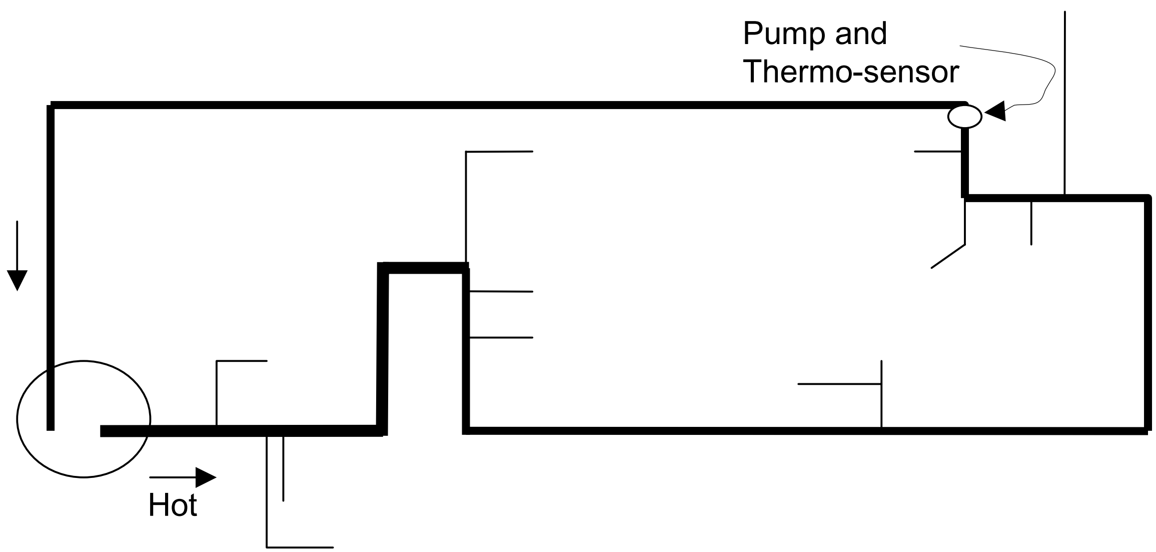
Full Loop Recirculation



Half Loop Recirculation
Pump Separated from Thermo-sensor



Half Loop Recirculation
Pump Located with Thermo-sensor



Guiding Principle

Provide People

What They Want...

(Safety and Convenience)

as Efficiently as Possible

The Challenge

Deliver hot water

to every fixture in the house

wasting no more energy

than we currently waste and

wasting no more than 1 cup

waiting for the hot water to arrive.

Possible Solutions

- Central plumbing core
- 1 water heater for every hot water fixture
- 2-3 water heaters per home
- Heat trace on the pipes
- Distribution system located within 1 cup of every hot water fixture

Five Important Questions

1. How many feet of pipe in 1 cup of water?
2. What capacity water heater is needed to supply 1 gpm?
3. What is the heat loss (gain) in the pipe under different conditions?
4. How does effective pipe length impact the delivery?
5. What is the actual flow rate from fixtures at different pressures?

Length of Pipe that Holds 8 oz of Water

	3/8" CTS			1/2" CTS			3/4" CTS			1" CTS		
	ID, in	gal/ft	ft/cup	ID, in	gal/ft	ft/cup	ID, in	gal/ft	ft/cup	ID, in	gal/ft	ft/cup
"K" copper	0.402	0.0066	9.48	0.527	0.0113	5.52	0.745	0.0226	2.76	0.995	0.0404	1.55
"L" copper	0.440	0.0079	7.92	0.545	0.0121	5.16	0.785	0.0251	2.49	1.025	0.0429	1.46
"M" copper	0.450	0.0083	7.57	0.569	0.0132	4.73	0.811	0.0268	2.33	1.055	0.0454	1.38
CPVC	N/A	N/A	N/A	0.489	0.0098	6.41	0.715	0.0209	3.00	0.921	0.0346	1.81
PEX	0.356	0.0052	12.09	0.481	0.0094	6.62	0.677	0.0187	3.34	0.871	0.0309	2.02

Ave	**8 feet**	**5 feet**	**2.5 feet**	**1.5 feet**

Relative Costs of Operation

Standard Distribution System	Natural Gas	Electricity
Annual Energy Cost	$200	$400
Annual Energy Waste	($50)	($100)
Useful Energy	$150	$300

Add the Energy Cost to Operate Recirculation System		
Thermosyphon	$250	$750
Continuous pump (24 hours per day)	$275	$775
Timer controlled pump (16 hours per day)	$180	$515
Temperature controlled pump	$135	$385
Timer and temperature controlled pump	$90	$255
Demand Controlled Pump	$10	$20

The House

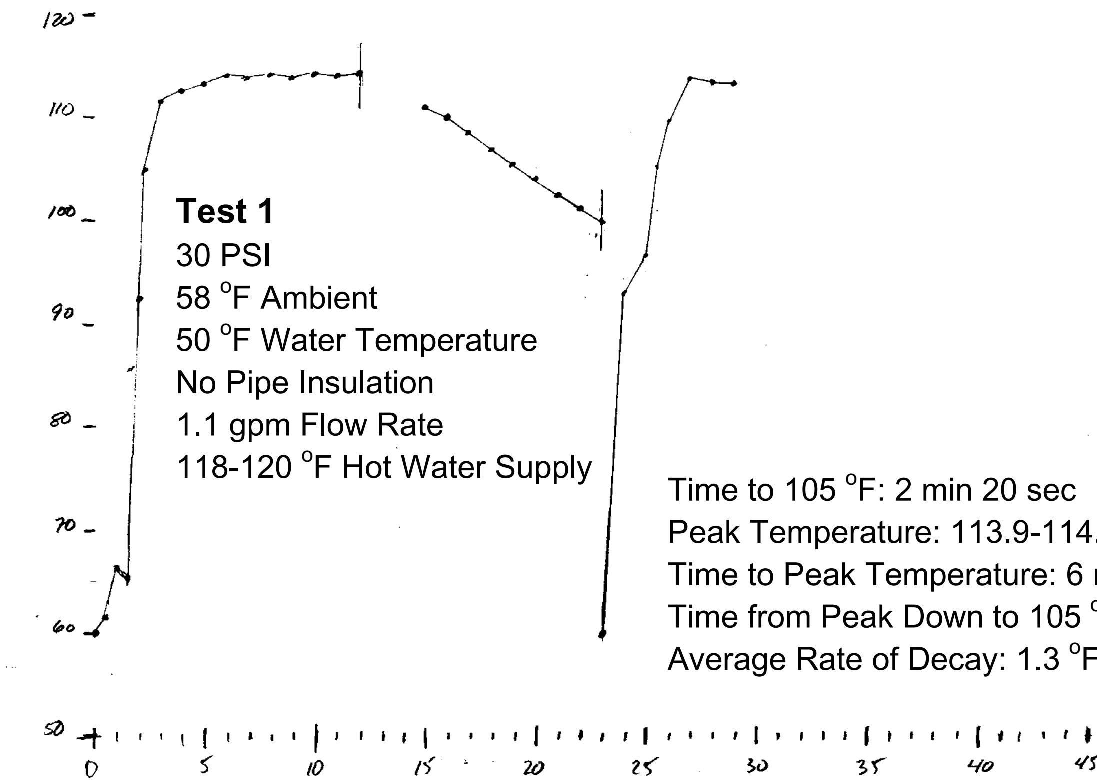
- 2400 square foot, 2-stories
- 3 full bathrooms, 13 hot water fixtures
- Water heater located on inside wall of garage
- Distance to the furthest fixture(s)
  - Kitchen sink and dishwasher
  - 77 feet ¾ inch trunk
  - 12 feet ½ inch branch

The Experiment

"Plumb" a house in a laboratory

- Distribution System
  - PEX pipe- ¾ inch trunk, ½ inch branches
  - Optimize for sinks and showers
  - Easy to repeat house after house
- Water heater
  - Tankless, natural gas, whole house
- Add 3/8 inch pipe insulation, R value=0.7
- Add Demand Controlled circulation system

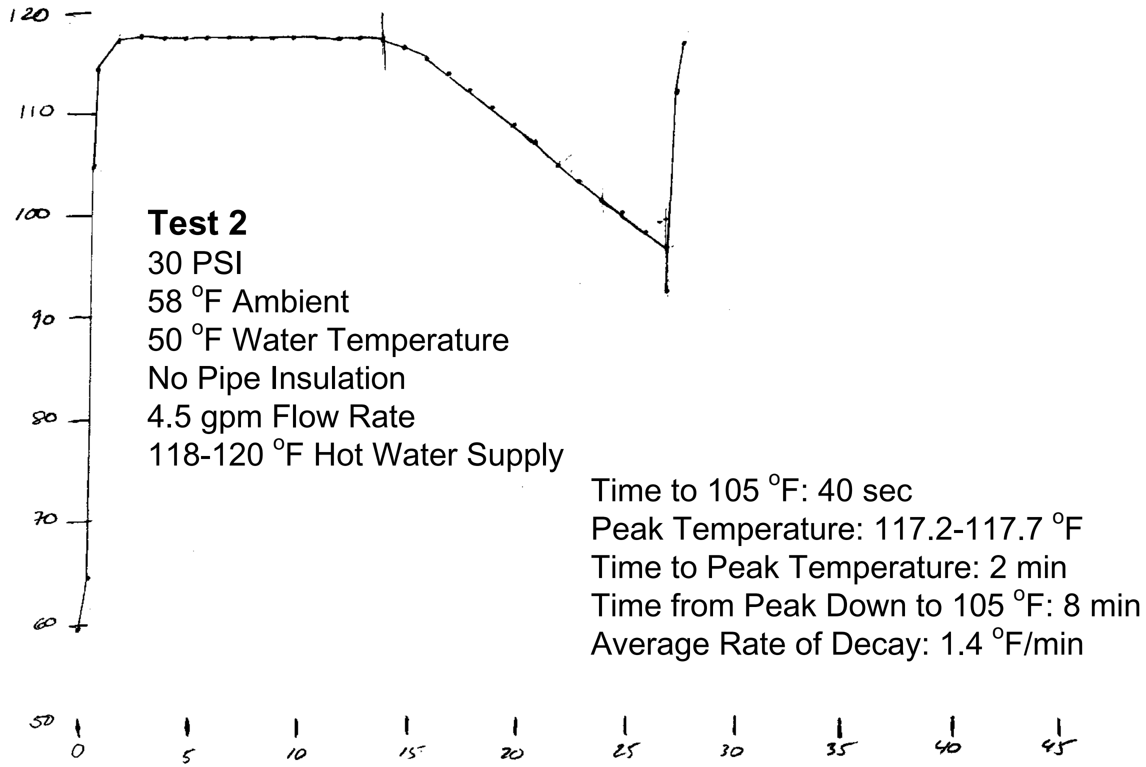
Low Flow Rate, No Insulation



Test 1
30 PSI
58 °F Ambient
50 °F Water Temperature
No Pipe Insulation
1.1 gpm Flow Rate
118-120 °F Hot Water Supply

Time to 105 °F: 2 min 20 sec
Peak Temperature: 113.9-114.2 °F
Time to Peak Temperature: 6 min
Time from Peak Down to 105 °F: 7 min
Average Rate of Decay: 1.3 °F/min

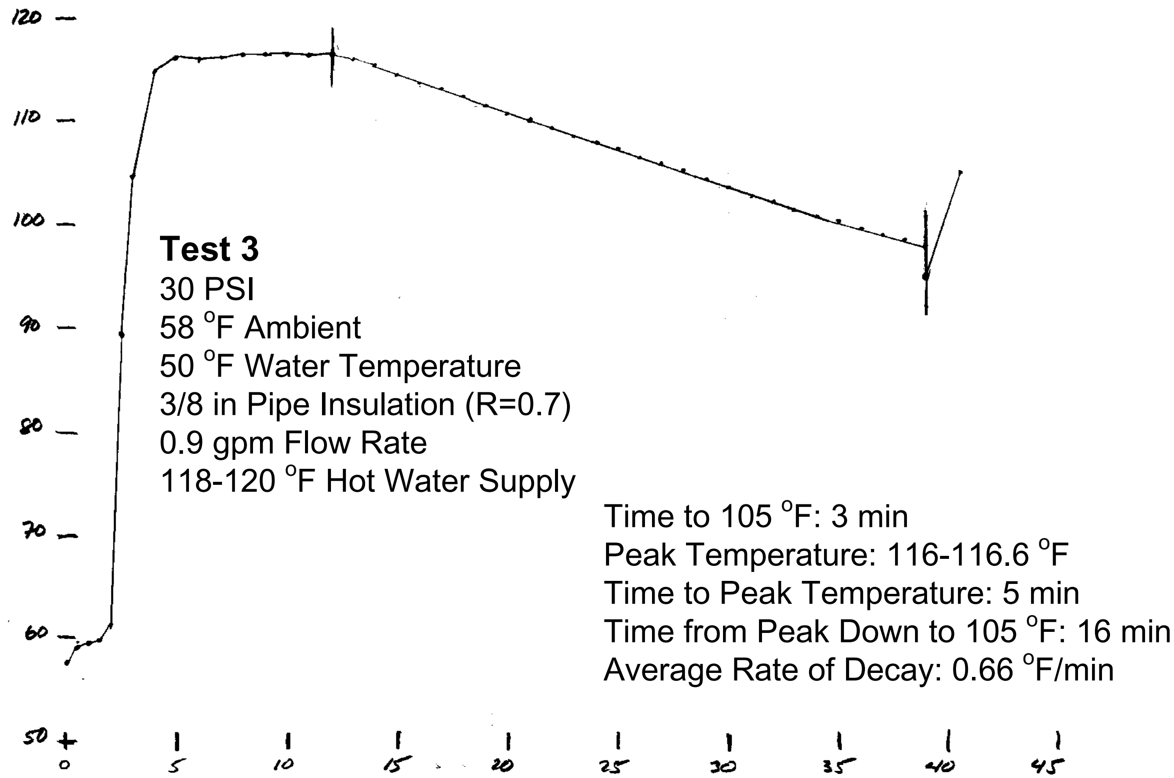
High Flow Rate, No Insulation



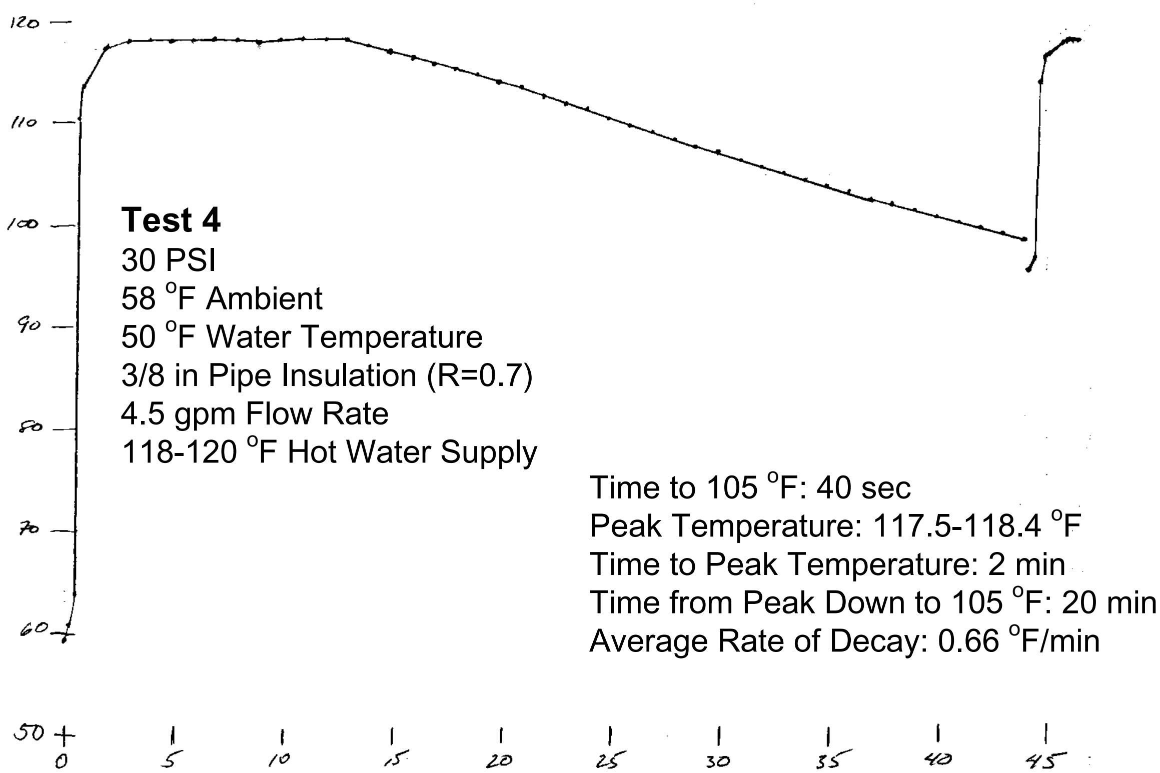
Test 2
30 PSI
58 °F Ambient
50 °F Water Temperature
No Pipe Insulation
4.5 gpm Flow Rate
118-120 °F Hot Water Supply

Time to 105 °F: 40 sec
Peak Temperature: 117.2-117.7 °F
Time to Peak Temperature: 2 min
Time from Peak Down to 105 °F: 8 min
Average Rate of Decay: 1.4 °F/min

Low Flow Rate, Insulation



High Flow Rate, Insulation



Test 4
30 PSI
58 °F Ambient
50 °F Water Temperature
3/8 in Pipe Insulation (R=0.7)
4.5 gpm Flow Rate
118-120 °F Hot Water Supply

Time to 105 °F: 40 sec
Peak Temperature: 117.5-118.4 °F
Time to Peak Temperature: 2 min
Time from Peak Down to 105 °F: 20 min
Average Rate of Decay: 0.66 °F/min

Experimental Conclusions

- Insulation improves performance during all 3 phases
  - Delivery, Use, Between Uses
- To waste no more than 1 cup while waiting
  - There must be less than ½ cup of water between the hot water source and the fixture
- “Prime the insulated line”, then shut off the pump
  - To optimize economics, water conservation and comfort
- Structured plumbing
  - Practical, cost-effective way to optimize the distribution system and provide what customers want (Half-Loop Recirculation)
- Multi-family and commercial buildings
  - Substantial water and energy savings benefits for these buildings too

Recommended Design Procedures

1. Determine how much water to waste at each fixture. Minimize the waste and wait at sinks and showers.
2. Plan to install pipe that contains less than ½ that volume between the fixture and the hot water loop.
3. Plan to insulate the loop and the branches.
4. Select one of the Structured Plumbing designs.
5. Design and build to code.
6. Verify that “as-built” performs “as designed”.

The Big Picture

Occupants

– Owners, Renters and Property Managers

Water Utilities

– Water supply, Wastewater treatment

Energy Utilities

– Electric Utilities

– Natural Gas Utilities

– Oil/Propane Suppliers

Regulators

– Energy and Environmental

– Building, Plumbing, Public Health

Contact Information

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