DOE Challenge Home

- Tech Training Webinar Series

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Efficient Hot Water Distribution II – How to Get it Right

U.S. DEPARTMENT OF ENERGY CHALLENGE HOME

The Home of the Future….Today

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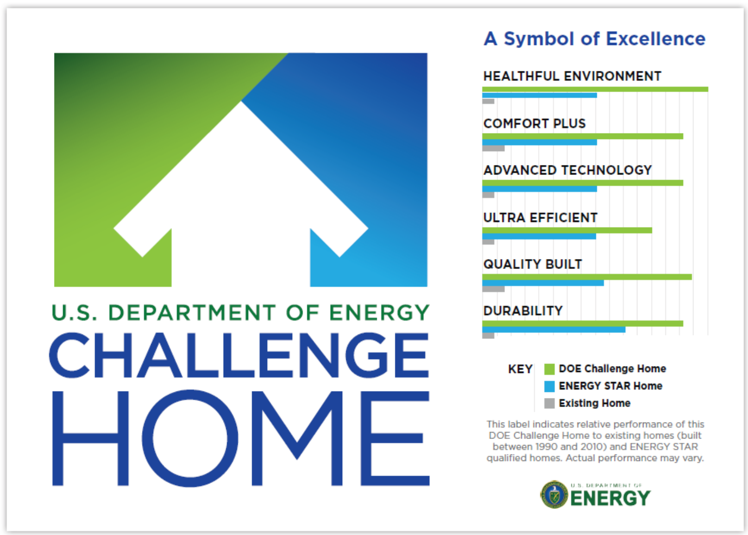
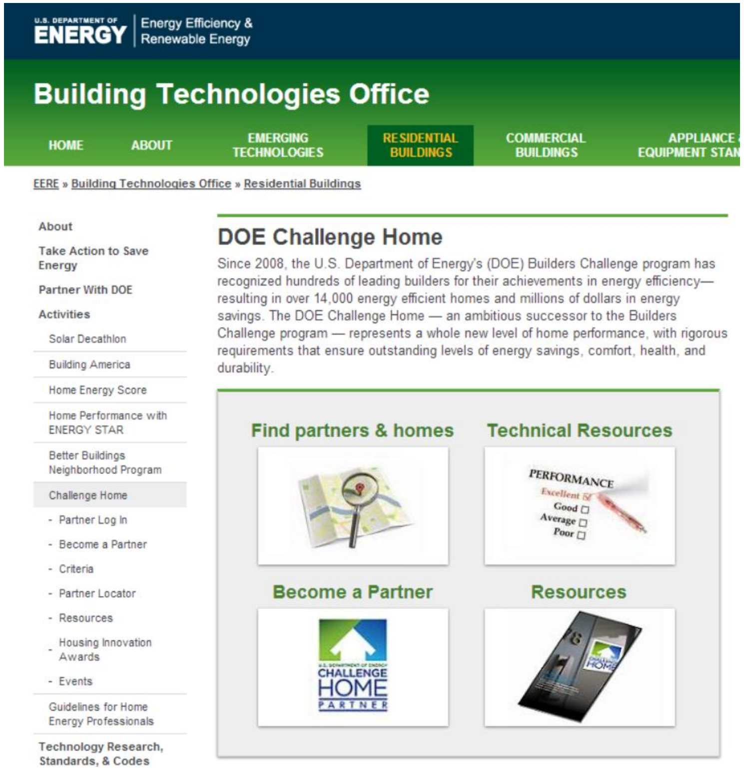


DOE Challenge Home Resources

Website

- www.buildings.energy.gov/challenge/
- Events:
  - Upcoming in-person ZERH Training
  - Technical Training webinars
- Partner Locator
- Program Specifications
- Webinar Recordings (coming soon)



Building America Solution Center

- http://basc.pnnl.gov/

DOE Challenge Home
- Efficient Hot Water Distribution

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Based on EPA WaterSense Specifications:
  - No more than 0.5 gallons of water in any piping/manifold between the hot water source and any hot water fixture.
  - No more than 0.6 gallons of water shall be collected from the hot water fixture before hot water delivered.
  - Recirculation systems based only on a timer or a temperature sensor don't qualify
- Water heater efficiency (ENERGY STAR Level) is addressed in the Target Home
- Performance and system efficiency involve the inter-related components of the water heater, the distribution system, and the flow rates….

Thank You

For More Information:

www.buildings.energy.gov/challenge/

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Efficient Hot Water Distribution Part 2 – How to Get it Right

DOE Challenge Home Tech Training Webinars

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Learning Objectives

1. Learn how to deliver hot water to every fixture, wasting less than one cup of water while waiting for the hot water to arrive, and wasting less energy than would have been wasted running the water down the drain.
2. Evaluate how the DOE Challenge Home/EPA WaterSense hot water distribution system requirements perform.
3. Understand how to integrate the components of a hot water system into a cost-effective high performance system that is water, energy and time efficient.
4. Develop a list of best practices that can be implemented immediately.

Integrating the Components into an Effective <u>System</u>

What Reduces Hot Water Use?

- Insulating hot water supply piping
- End uses closer to water heater(s)
- Lower flow rate plumbing fixtures
- Lower volume plumbing appliances
- Using waste heat running down the drain to preheat cold water
- Truly "Instantaneous" water heaters
- Warmer incoming cold water
- Anything else?

What Increases Hot Water Use?

- Uninsulated hot water supply piping
  - More uses start out with colder water
- End uses further from water heater(s)
  - More volume to clear
- Lower flow rate plumbing fixtures
  - Increases waste while waiting for hot water to arrive
- “Instantaneous” water heaters
  - Cold water runs through while ramping up to temp
- Colder incoming cold water
  - Increases the percent of hot water in the mix
- Anything else?

What Increases Customer Satisfaction?

- Instantaneousness
- Continuousness
- Hot water systems that are predictable and easy to “learn”
- Plumbing fixtures that provide rated flow even at low pressures
- Plumbing appliances that do their job with lower amounts of water.
- Lower energy bills for their hot water
- Anything else?

The Ideal
Hot Water Distribution System

- Has the smallest volume (length and smallest "possible" diameter) of pipe from the source of hot water to the hot water outlet.
- Sometimes the source of hot water is the water heater, sometimes a trunk line.
- For a given layout (floor plan) of hot water locations the system will have:
  - The shortest buildable trunk line
  - Few or no branches
  - The shortest buildable twigs
  - The fewest plumbing restrictions
  - Insulation on all hot water pipes, minimum R-4

The Challenge

Deliver **hot water**

to every hot water outlet

wasting no more energy

than we currently waste running water down the drain and

wasting no more than 1 cup

waiting for the hot water to arrive.

Question:

If you want to waste no more than 1 cup
while waiting for hot water to arrive,
what is the maximum amount of water
that can be in the pipe that is not usefully hot?

Answer:

1 cup = 8 ounces = 1/16th gallon = 0.0625 gallon

Question:

If you want to waste no more energy than you would have wasted waiting for hot water to arrive while running water down the drain, how much energy can any alternative consume?

Answer:

No more than was originally wasted!

Interactive Exercises

1. Demonstrate how hot water can be delivered to every fixture, wasting less than one cup of water while waiting for the hot water to arrive, and wasting less energy than would have been wasted running the water down the drain.
2. Evaluate the layout of a hot water distribution system without being able to see the piping.

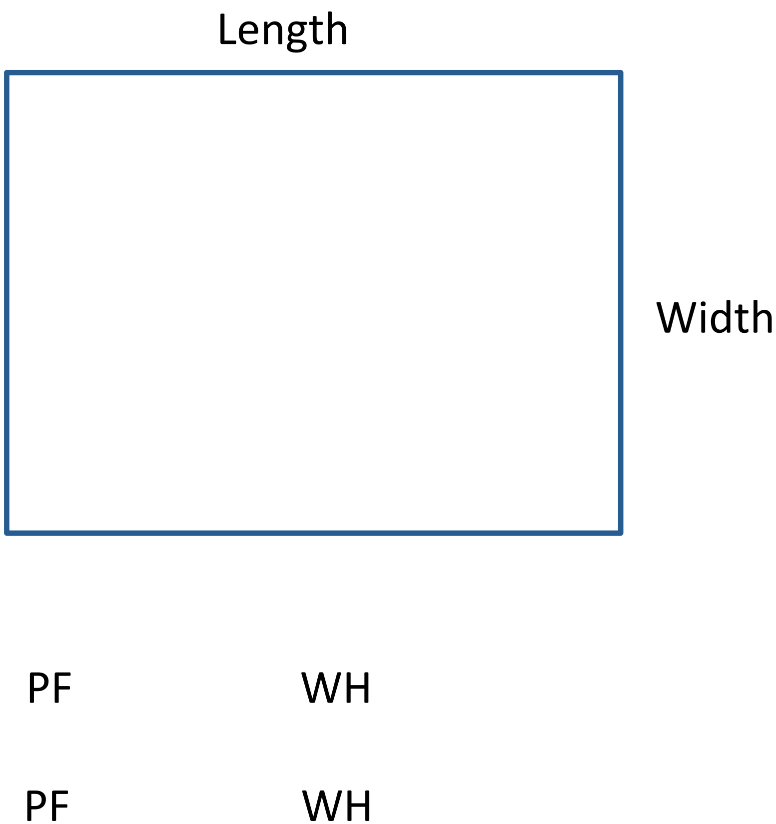
Maximum Allowable Volume Between Source and Use

DOE Challenge Home and EPA Water Sense: 0.5 Gallons from any source

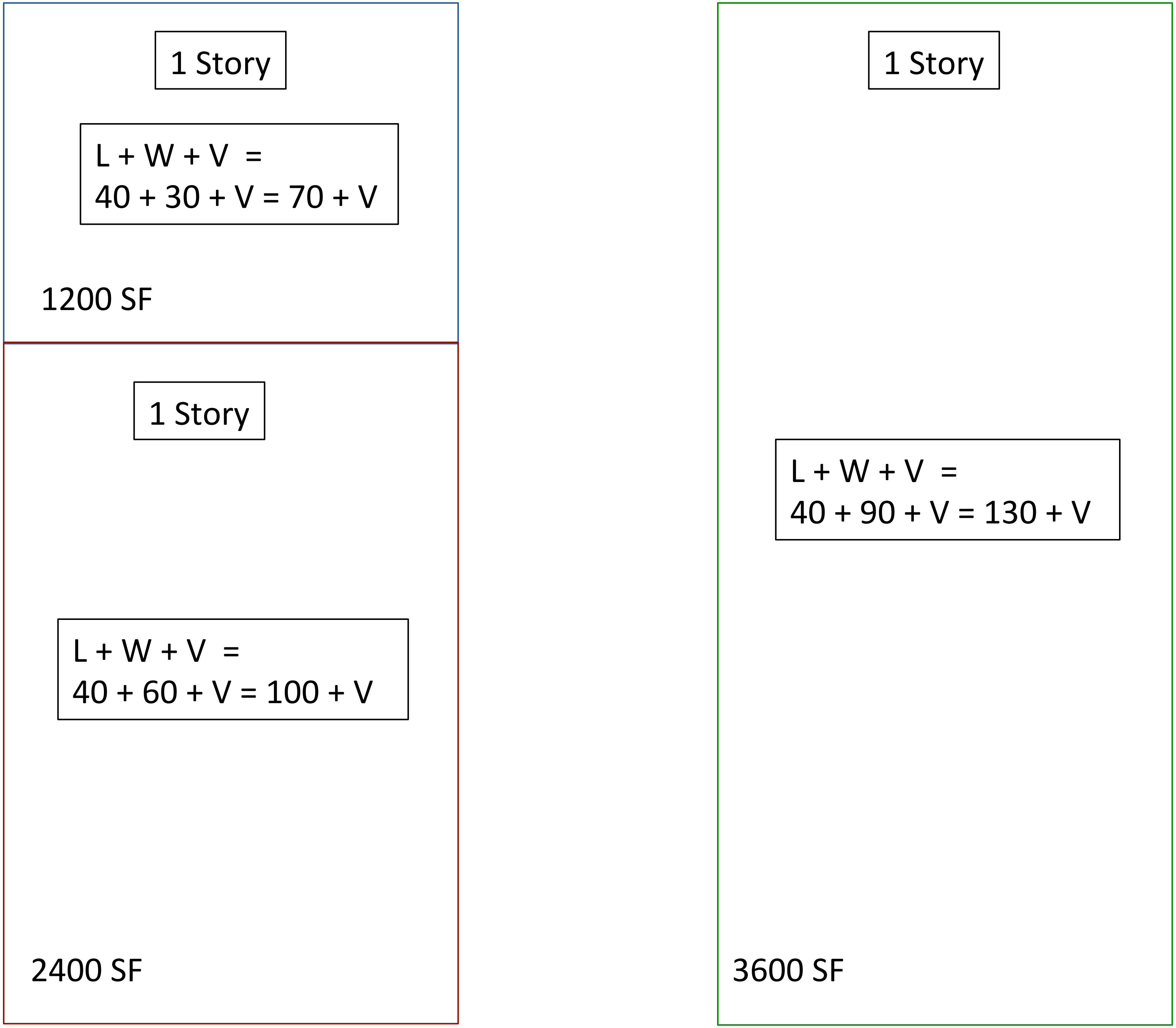
NOMINAL PIPE SIZE (inch)	VOLUME (liquid ounces per foot length)	MAXIMUM PIPING LENGTH (feet)	
		WATER FROM A WATER HEATER	WATER FROM A RECIRCULATION LOOP OR HEAT TRACED PIPE
1/4	0.33	50	50
5/16	0.5	50	48
3/8	0.75	50	32
1/2	1.5	43	16
5/8	2	32	12
3/4	3	21	8
7/8	4	16	6
1	5	13	5
1 ¼	8	8	3
1 ½	11	6	2
2 or larger	18	4	1

0.5 Gallons **0.19 Gallons**

The Logic of Plumbing



- Plumbing rarely runs diagonally
- What is the rectilinear path from the water heater to the plumbing fixtures and appliances?
- Length times diameter = volume
- How many paths or zones?


1 Story
L + W + V =
40 + 30 + V = 70 + V
1200 SF
1 Story
L + W + V =
40 + 60 + V = 100 + V
2400 SF
1 Story
L + W + V =
40 + 90 + V = 130 + V
3600 SF

The Benefit of Multiple Stories

1 Story

L + W + V
= 70 + V

1200 SF

2 Story

L + W + V
= 70 + V

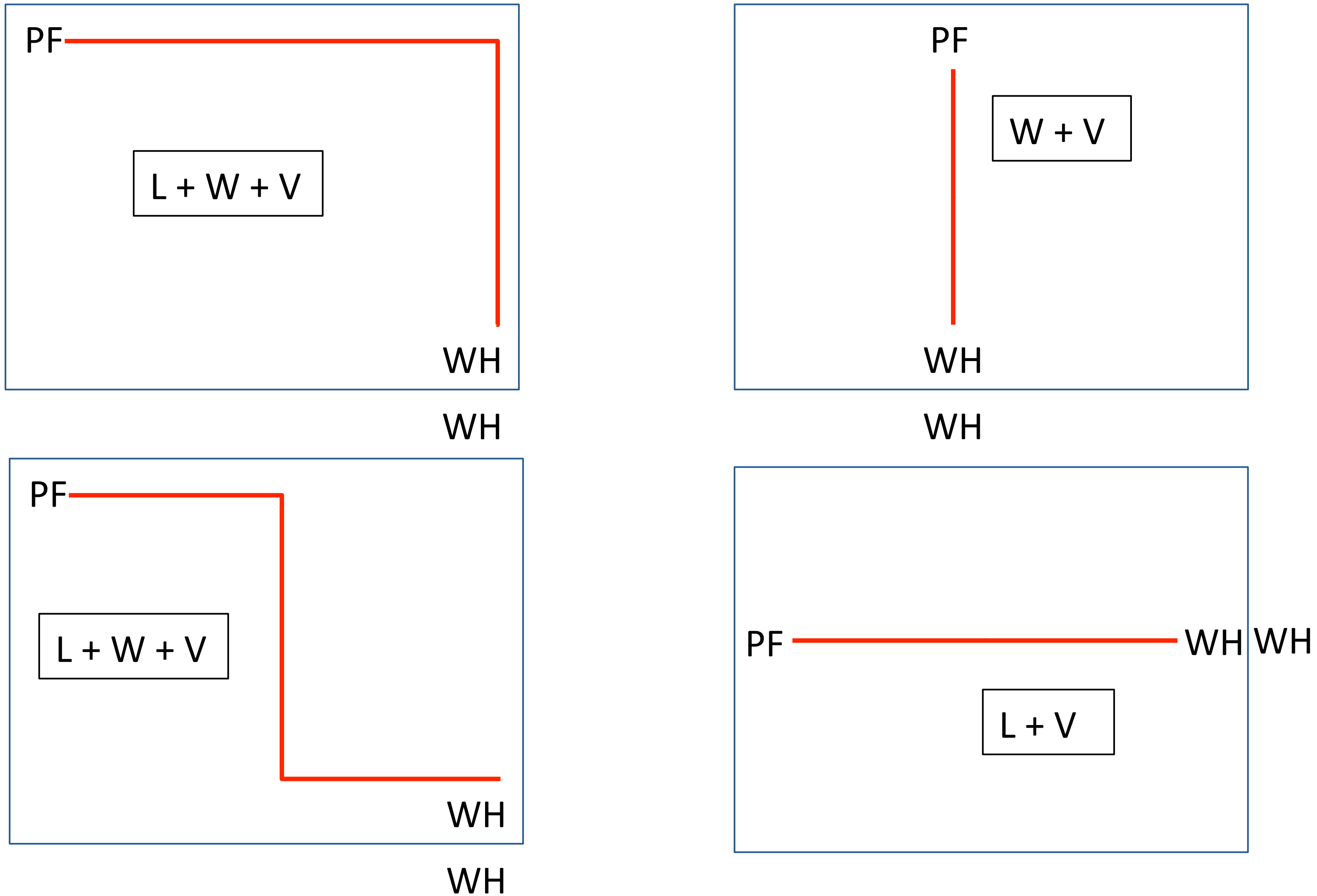
2400 SF

3 Story

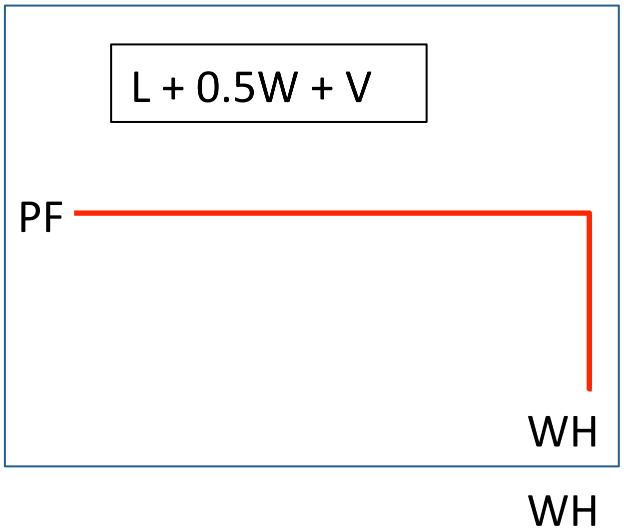
L + W + 2H
= 70 + 2H

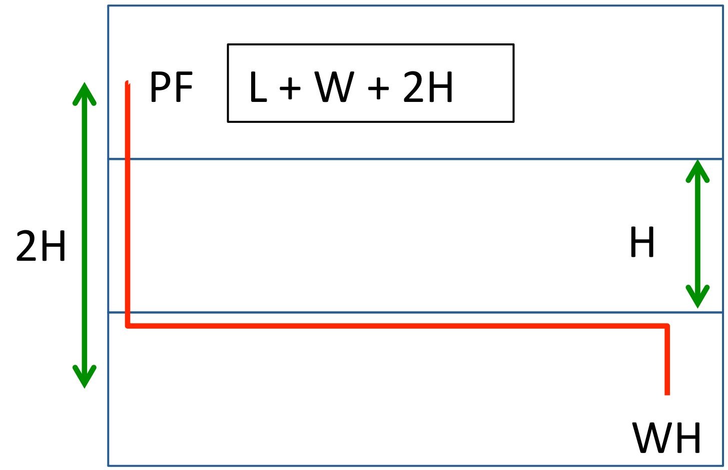
3600 SF

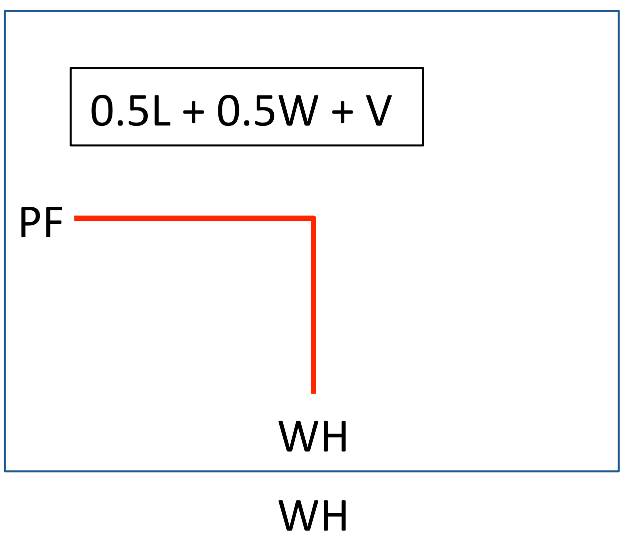
1-Zone Hot Water Distribution System

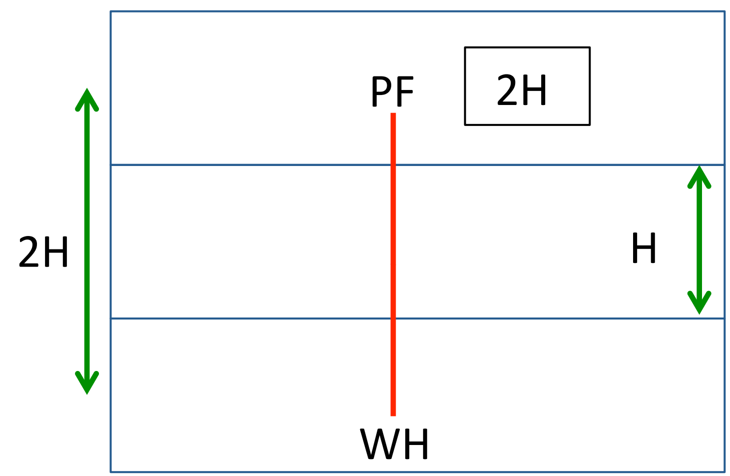


1-Zone Hot Water Distribution System

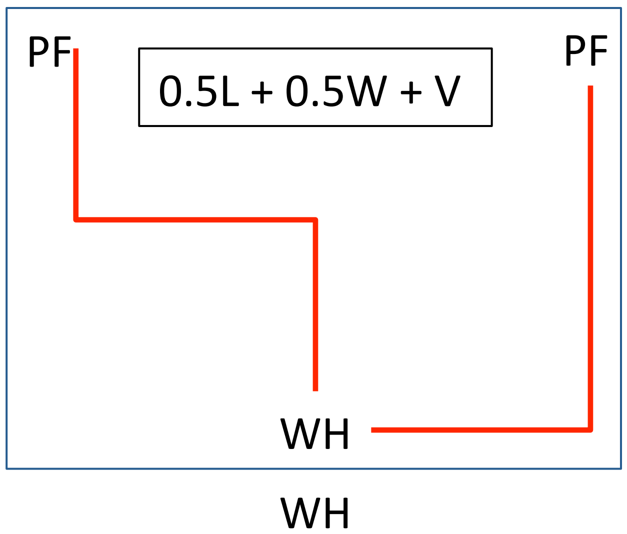


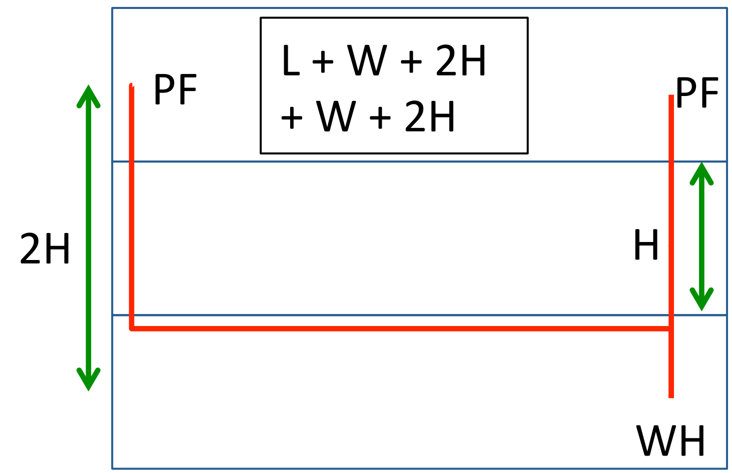


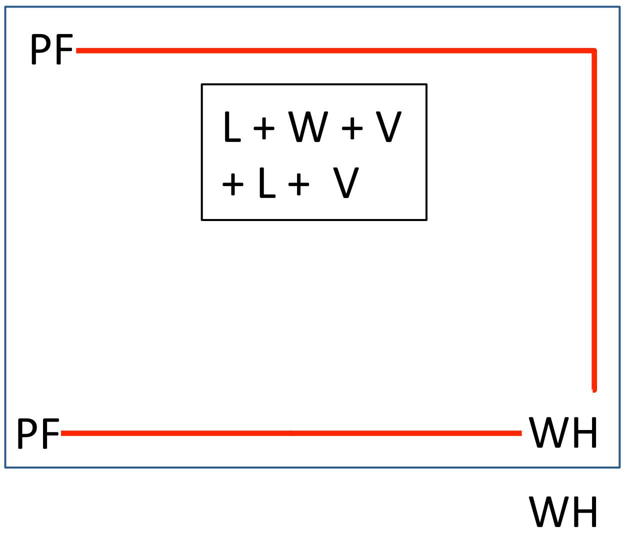


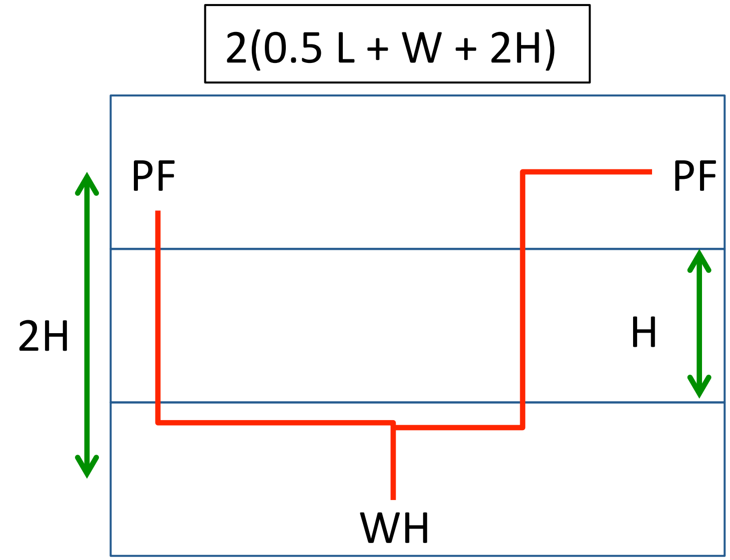


2-Zone Hot Water Distribution System

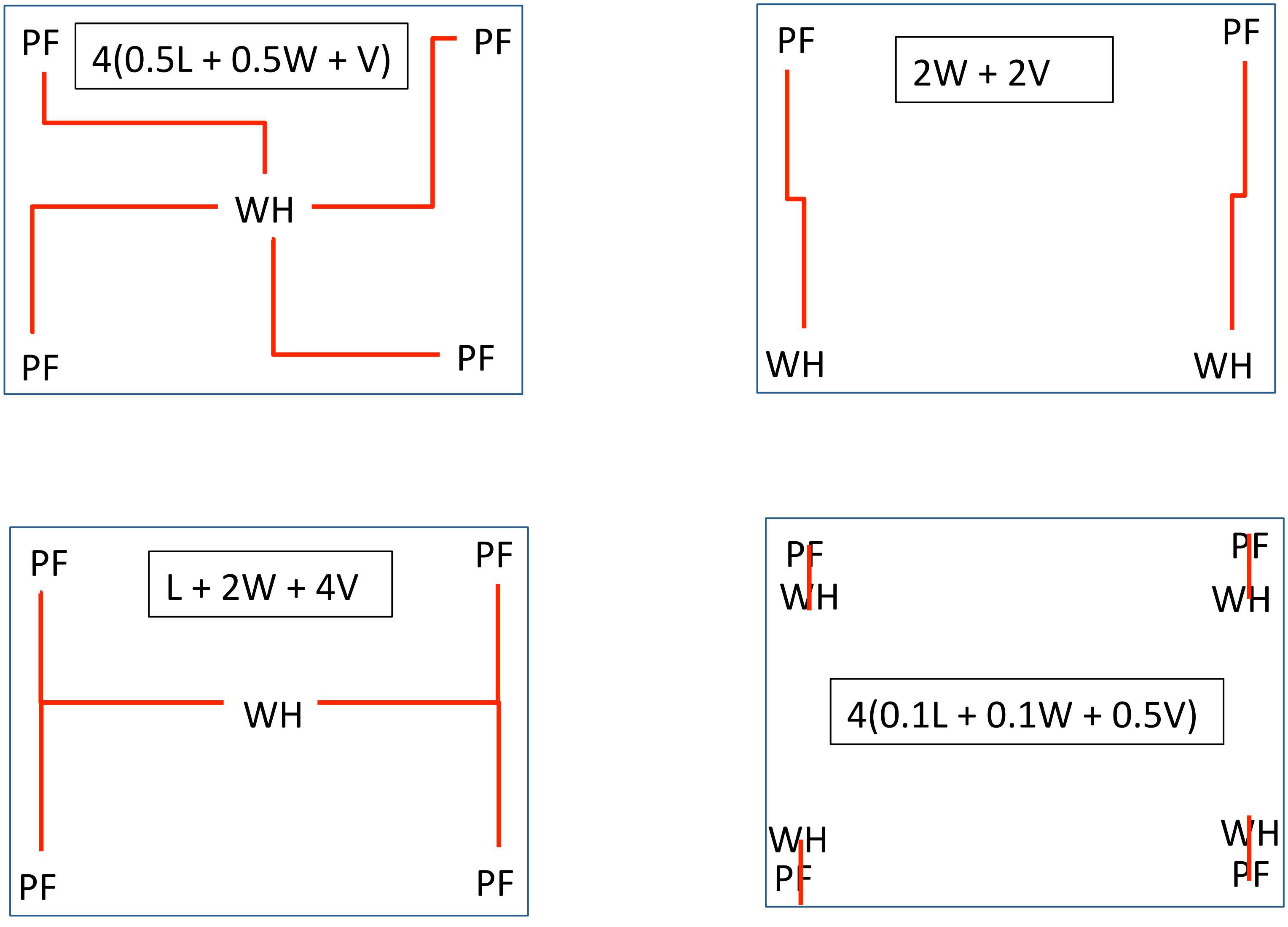




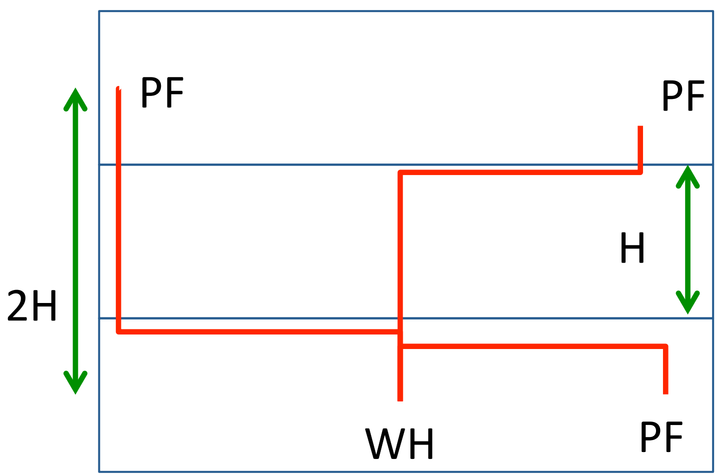




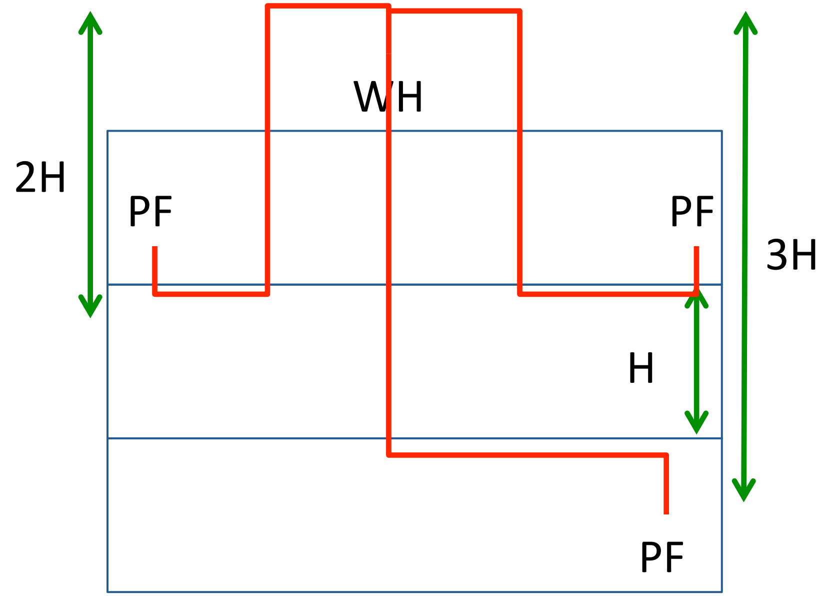
Multi – Zone Hot Water Distribution System



Multi – Zone Hot Water Distribution System



2(0.5L + 0.5W +2H)
+ (0.5L + 0.5W + H)



2(0.5L + 0.5W +2H)
+ (0.5L + 0.5W +3H)

Performance Metrics

- **Temperature**
  - ≥ 110F, hot enough to shower in
- **Volume-until-hot**
  - Goal is no more than 1 cup after opening tap
  - Settle for 2-3 cups, maybe 4
- **Time-to-tap**
  - Consistent and small
  - < 1 second, possible, but probably energy expensive
  - < 5 seconds, very buildable
  - < 10 seconds, “Acceptable” according to ASPE

How Does Challenge Home Compare?

- **Temperature**
  - 10F rise by 0.6 gallons, say 70 rises to 80F
  - This is not hot enough to shower in
  - Hot water is coming soon, probably
- **Volume-until-hot**
  - Maximum 0.5 gallons in pipe
  - Maximum 0.6 gallons until 10F rise
- **Time-to-tap**
  - Random depending on path
  - Possible exceptions: same volume twigs from circulation loop or heat traced trunk
  - 2 gpm = <u>minimum</u> 18 seconds
  - 1 gpm = <u>minimum</u> 36 seconds
  - 0.5 gpm = <u>minimum</u> 72 seconds

How Long Should We Wait?

Volume in the Pipe (ounces)	Minimum Time-to-Tap (seconds) at Selected Flow Rates					
	0.25 gpm	0.5 gpm	1 gpm	1.5 gpm	2 gpm	2.5 gpm
2	4	1.9	0.9	0.6	0.5	0.4
4	8	4	1.9	1.3	0.9	0.8
8	15	8	4	2.5	1.9	1.5
16	30	15	8	5	4	3
24	45	23	11	8	6	5
32	60	30	15	10	8	6
64	120	60	30	20	15	12
128	240	120	60	40	30	24

ASPE Time-to-Tap Performance Criteria

	Acceptable Performance	1 – 10 seconds
	Marginal Performance	11 – 30 seconds
	Unacceptable Performance	31+ seconds

Source: Domestic Water Heating Design Manual – 2nd Edition, ASPE, 2003, page 234

Water Waste as a Function of Flow Rate (Really Velocity)

Flow Rate	¾ inch Nominal Diameter Pipe	
	Relative Water Waste Percent	Approximate Velocity Feet per Second
Greater than 4 gpm	Just over 100%	Greater than 3
4 gpm	110%	2.65
3 gpm	120%	1.99
2 gpm	130%	1.33
1 gpm	150%	0.66
0.5 gpm	Roughly 200%	0.33
0.25 gpm	????	0.17

The velocity of 0.5 gpm in ¾ inch nominal pipe
is roughly equivalent to the velocity of
2 gpm in 1.5 inch nominal pipe

Gallons Wasted as a Function of Time and Fixture Flow Rate

(Green < 2 cups), Red >1/2 Gallon)

Flow Rate (GPM)	Time Until Hot Water Arrives (Seconds)															
	1	2	3	4	5	10	15	20	25	30	35	40	45	50	55	60
0.5	0.01	0.02	0.03	0.03	0.04	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50
1	0.02	0.03	0.05	0.07	0.08	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.00
1.5	0.03	0.05	0.08	0.10	0.13	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.13	1.25	1.38	1.50
2	0.03	0.07	0.10	0.13	0.17	0.33	0.50	0.67	0.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00
2.5	0.04	0.08	0.13	0.17	0.21	0.42	0.63	0.83	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50
3	0.05	0.10	0.15	0.20	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
3.5	0.06	0.12	0.18	0.23	0.29	0.58	0.88	1.17	1.46	1.75	2.04	2.33	2.63	2.92	3.21	3.50
4	0.07	0.13	0.20	0.27	0.33	0.67	1.00	1.33	1.67	2.00	2.33	2.67	3.00	3.33	3.67	4.00
4.5	0.08	0.15	0.23	0.30	0.38	0.75	1.13	1.50	1.88	2.25	2.63	3.00	3.38	3.75	4.13	4.50
5	0.08	0.17	0.25	0.33	0.42	0.83	1.25	1.67	2.08	2.50	2.92	3.33	3.75	4.17	4.58	5.00
5.5	0.09	0.18	0.28	0.37	0.46	0.92	1.38	1.83	2.29	2.75	3.21	3.67	4.13	4.58	5.04	5.50
6	0.10	0.20	0.30	0.40	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00
6.5	0.11	0.22	0.33	0.43	0.54	1.08	1.63	2.17	2.71	3.25	3.79	4.33	4.88	5.42	5.96	6.50
7	0.12	0.23	0.35	0.47	0.58	1.17	1.75	2.33	2.92	3.50	4.08	4.67	5.25	5.83	6.42	7.00
7.5	0.13	0.25	0.38	0.50	0.63	1.25	1.88	2.50	3.13	3.75	4.38	5.00	5.63	6.25	6.88	7.50
8	0.13	0.27	0.40	0.53	0.67	1.33	2.00	2.67	3.33	4.00	4.67	5.33	6.00	6.67	7.33	8.00
8.5	0.14	0.28	0.43	0.57	0.71	1.42	2.13	2.83	3.54	4.25	4.96	5.67	6.38	7.08	7.79	8.50
9	0.15	0.30	0.45	0.60	0.75	1.50	2.25	3.00	3.75	4.50	5.25	6.00	6.75	7.50	8.25	9.00
9.5	0.16	0.32	0.48	0.63	0.79	1.58	2.38	3.17	3.96	4.75	5.54	6.33	7.13	7.92	8.71	9.50
10	0.17	0.33	0.50	0.67	0.83	1.67	2.50	3.33	4.17	5.00	5.83	6.67	7.50	8.33	9.17	10.00

1 cup = 8 ounces = 1/16th gallon = 0.0625 gallon

SoCalGas Hot Water Demonstration Lab

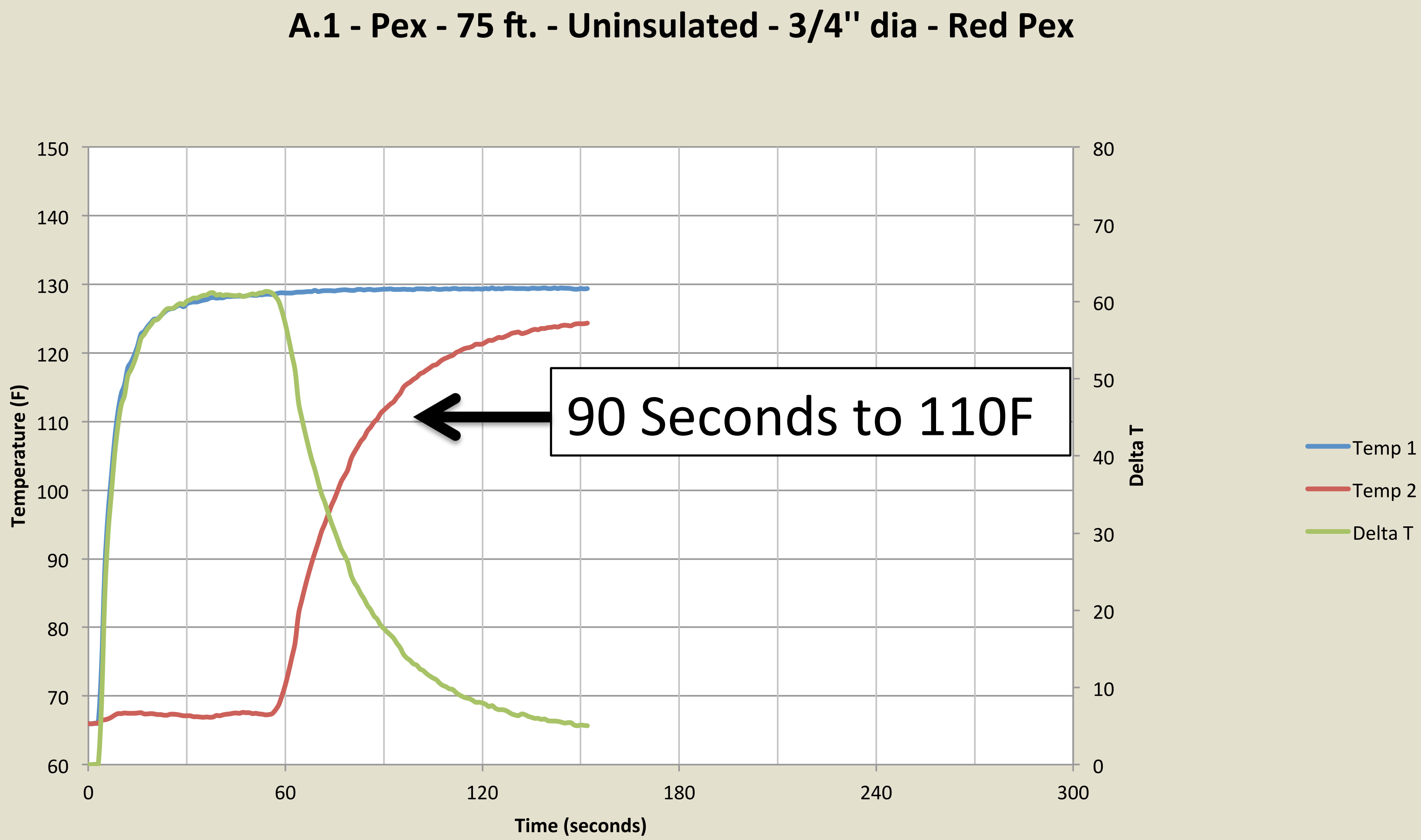
Entering Section of Experiment:

1. Flushing and Priming
2. Flow Rate
3. Pressure 1
4. Temperature 1

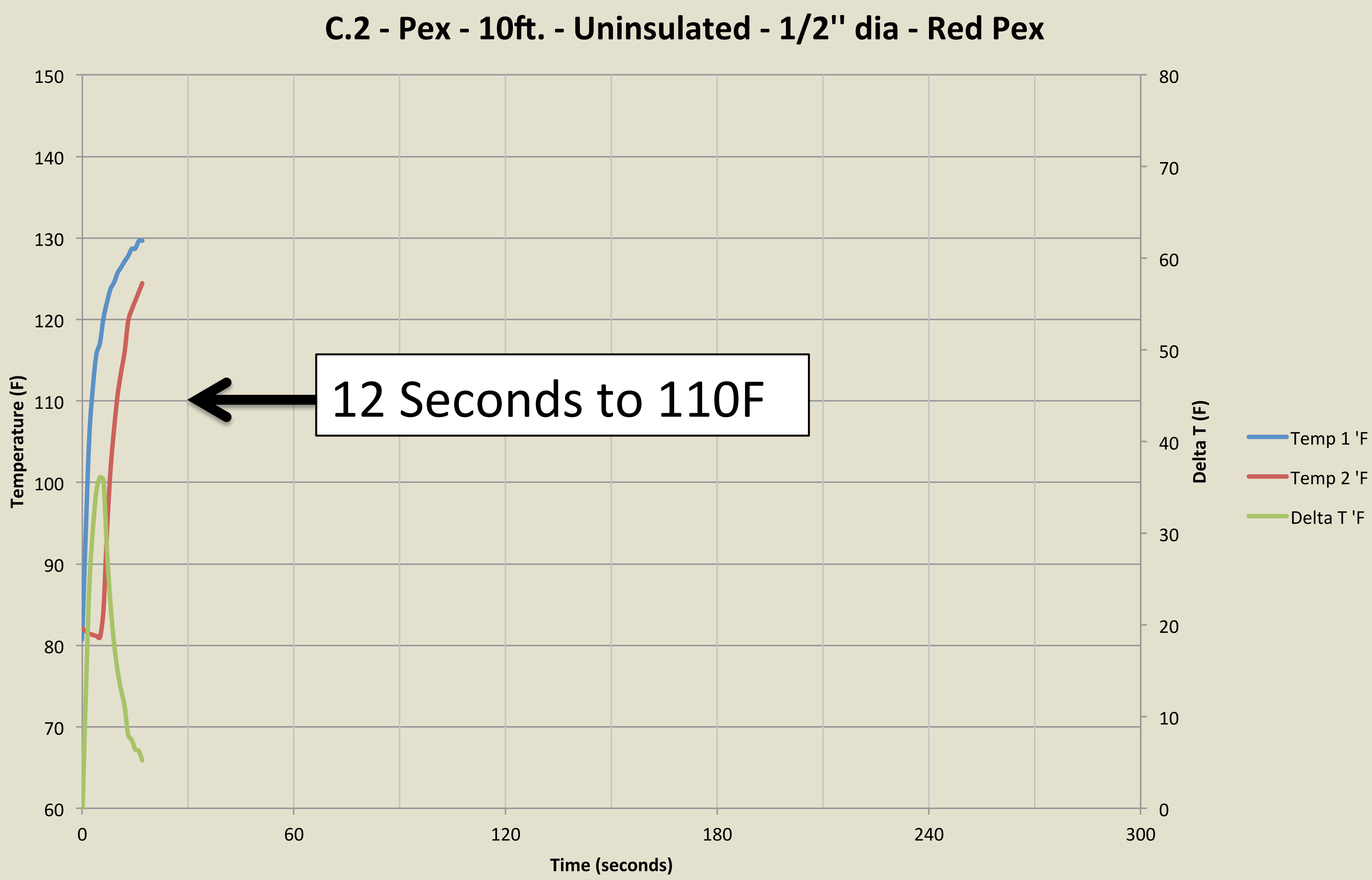
Exiting Section of Experiment:

1. Pressure 2
2. Temperature 2
3. Discharge through Plumbing Fixture

Demonstrating Performance



Demonstrating Performance



Hot Water Circulation Systems

There are six types of circulation systems:

- Thermosyphon (gravity convection with no pump),
- Continuously pumped systems,
- Timer controlled,
- Temperature controlled,
- Time and temperature controlled, and
- Demand controlled.

Given the same plumbing layout,
all of these systems will waste the same amount
of water at the beginning of a hot water event.

The difference in these systems
is in the ***energy*** it takes to keep the trunk line
primed with hot water.

Operating Costs of Circulation Loops

- Pump
- Heat loss in the loop
- Maintenance
  - Failure of the pump
  - Incorrect control settings
  - Pipe leaks
- 90 percent of the cost is from heat loss in the loop, 10 percent is from the pump operation

Determination of Heat Loss in Circulation Loops

- You could measure the pipe lengths, diameters, insulation and environmental conditions and calculate the heat loss, if you can get to all of it!

- Or you could measure flow rate and the difference in temperature between the water leaving from, and returning to the water heater.

Heat Loss in Circulation Loops –
Calculation for Loop Losses Only

Sample Calculation: 1 gpm and 1^{o}F temperature drop

- Energy = m* c_p* (T_{hot}-T_{return})=Btu
- 1 gpm * 8.33 pounds per gallon * 1 * 60 minutes per hour * 1^{o}F = 500 Btu/hour/^{o}F

Natural Gas Water Heater

- 500 ÷ 0.75 efficiency = 667 Btu/hour/^{o}F
- 667 ÷ 100,000 Btu/Therm = 0.00667 Therm/hour/^{o}F
- 0.00667 * $1.00/Therm = $0.00667/hour/^{o}F

Electric Water Heater

- 500 ÷ 0.98 efficiency = 510 Btu/hour/^{o}F
- 510 ÷ 3,412 Btu/kWh = 0.15 kWh/hour/^{o}F
- 0.15 * $0.10/kWh = $0.015/hour/^{o}F

Annual Energy Use for a Circulation System Attached to a Gas Water Heater (Therms)

Continuous Pumping at 1 Gallon Per Minute				
	Temperature Drop in ^{o}F			
Days	**1**	**5**	**10**	**20**
1	0.16	0.80	1.60	3.20
30	5	24	48	96
365	58	292	584	1,168
Pump Flow Rate in Gallons Per Minute				
1	58	292	584	1,168
5	292	1,460	2,920	5,840
10	584	2,920	5,840	11,680
Steady state heat transfer efficiency is assumed to be 75%.				

Electrical energy to operate the pump is additional

Annual Energy Use for a Circulation System Attached to an Electric Water Heater (kWh)

Continuous Pumping at 1 Gallon Per Minute				
	Temperature Drop in °F			
Days	**1**	**5**	**10**	**20**
1	3.60	18.00	36.00	72.00
30	105	525	1,050	2,100
365	1,278	6,388	12,775	25,550
Pump Flow Rate in Gallons Per Minute				
1	1,278	6,388	12,775	25,550
5	6,388	31,938	63,875	127,750
10	12,775	63,875	127,750	255,500
Steady state heat transfer efficiency is assumed to be 98%.				

Electrical energy to operate the pump is additional

When Do You Not Want to Operate a Hot Water Circulation Pump?

- When you don't need hot water
  - When you aren't there
  - When you are sleeping or doing something else
- When you are using hot water

The only time you want to operate the pump is just before you need hot water.

Use Demand Controlled Circulation

- The pump will run less than ½ hour per day
- The most energy efficient option.

Energy to Operate a Circulation Loop

	Recirculation						Demand Controlled Priming
	Daily Hours of Operation						
	24	12	8	6	4	2	0.25
Loop Heat Losses							
Natural Gas (therms)	292	146	97	73	49	24	3
Electric (kWh)	6,388	3,194	2,129	1,597	1,065	532	67
Pump Energy(kWh)	438	219	146	110	73	37	8

Loop is assumed to be 100 feet long.

- 50 feet supply, 50 feet return

Recirculation:

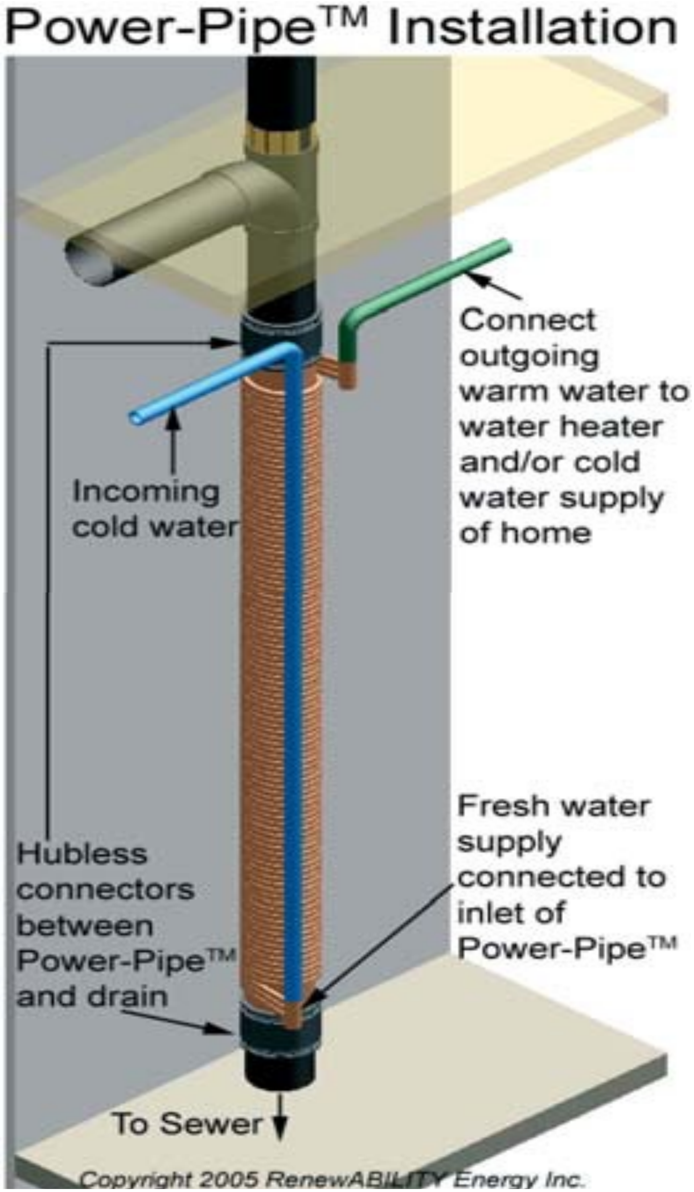
- Flow rate is 1 gpm
- Temperature drop is 5F
- 50 watt pump

Demand Controlled Priming:

- 85 watt pump

Drain Water Heat Recovery

Drain Water Heat Recovery (DWHR)



DWHR Applications

Drain Water Heat Recovery (DWHR)

Balanced Flow – Preheat the cold water entering the water heater and the shower

Unequal Flow – Preheat the cold water entering the shower or the water heater

Potential Savings

- Captures 40-80 % of the temperature drop
- Balanced Flow saves more than Unequal Flow

Impacts

- How does this affect the operation of the water heater?
  - Tank versus tankless
- How does it impact temperature drop in the piping?

Send in Your Questions

Incorporating High Performance Hot Water Systems into Our Buildings

Given What We Have Learned....

- What best practices can you come up with?
- What should become code?
  - IPC
  - IECC
  - IRC
  - UPC
  - Other?
- What should be included into HERS, Energy Star, LEED?

Best Practices

- Understand the hot water use patterns for each occupancy.
  - The key is that hot water use is generally extremely variable within and among households.
  - Hot water events are clustered together within windows of opportunity based on the schedules of the occupants.
  - Flow rates are generally low and simultaneity is much smaller than assumed in current plumbing codes
- Understand the “service(s)” of hot water desired by these occupants
  - People want Instantaneousness and Continuousness. They expect safety and reliability.
  - Provide these services in the most water and energy efficient way

Best Practices

- Locate source(s) of hot water close to the uses
  – Sometimes the source of hot water is a water heater or boiler, sometimes it is the trunk line or the supply portion of a circulation loop or a heat traced pipe.
  – Sometimes more than one water heater or more than one hot water distribution system is needed. Sometimes both.
- Keep the volume from the source(s) to the uses small
  – This is critical when the volume per event is small and time between events is long; for example hand washing in restrooms in office buildings.
  – New washing machines and dishwashers have flow rates while filling of less than 1.5 gpm, so they are similar to faucets and showers.
  – Fixture branch piping (twigs) should contain less than 2 cups from the trunk line to the fixture fittings or appliances.
- Minimize pressure drop and optimize velocity in the piping
  – Size fixture branch piping (twigs) in accordance with the flow rate of the fixture fitting or appliance that it serves.
  – Use wide radius sweeps or bend the pipe into “swoops” instead of using hard 90-degree elbows wherever possible.

Best Practices

- Insulate hot water piping
  - Insulate all of it because the patterns of use are so variable and likely to change over the life of the piping within the building.
- Provide a method to prime trunk lines with hot water shortly before use
  - Demand controlled pumping systems are the most energy efficient way to accomplish this.
  - They can be installed in a circulation loop with a dedicated return pipe or they can be installed to use the cold water line as a temporary return.
- Utilize (hot) water use efficient fixture fittings and appliances
  - Lower flow rate faucets and showers and lower fill volume washing machines and dishwashers will be more satisfactory to consumers when installed in conjunction with the hot water distribution system described above.
  - In areas with low pressure, specify pressure compensating aerators, particularly for showers.

Best Practices

- Capture waste heat from hot water running down the drain and use it to preheat incoming cold water
  - Preheat the cold water going to the water heater(s)
  - Preheat the cold water going to the shower(s)
  - Preheat the cold water going to both the water heater(s) and the shower(s)
- Combine energy requirements for water heating and space heating into one thermal engine.
  - In thermally efficient housing, which can be found in all climate zones, the emphasis should be on the water heating load
  - It is likely to be necessary to help justify the higher cost of more efficient water heating.
- Select water heaters (or boilers) matched to these uses and patterns
  - Pay attention to the lowest flow rates and the smallest volumes – which happen with great frequency – as well as to the peaks – which happen much less often.
  - Maintain this water heater so it lasts a very long time.

Getting Better at What We Do

- Technical skills
- How to Win Friends and Influence People
  - Dale Carnegie, 1936
- How I Raised Myself from Failure to Success in Selling
  - Frank Bettger 1947
- Personality Plus-Florence Littauer 1983
- Personality Puzzle-Florence and Marita Littauer 1992
- The Great Connection- Arnie Warren 1997
- The Go-Getter-Peter Kyne 1921
- The Richest Man in Babylon-George Clason 1926

Summary – Part 2

- Review
- Any additional questions?

Given human nature,
it is our job
to provide the infrastructure
that supports efficient behaviors.

Thank You!

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