In Hot Water

Seventeenth Annual
Westford Symposium on Building Science
August 5-7, 2013

Gary Klein
Affiliated International Management, LLC.
P.O. Box 11752
Newport Beach, CA 92658-5040

Tel: 916-549-7080
Email: gary@aim4sustainability.com

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 water heaters and hot water distributions and fixture selection interact in terms of water, energy and time.
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.

Table of Contents

How Big is Hot Water?

Annual Energy Use for Hot Water?

Residential

- Single family or individual units in multi-family
  - 10-20 gallons per person per day
  - Large variations within and between households
- Annual costs for a US median household of 3:
  - Approximately $150-300 – natural gas
  - Approximately $500-1,000 – electric resistance or propane
    - Variations depend on temperature rise, water heater or boiler efficiency and fuel price
    - What would operating a heat pump water heater cost?
    - A condensing gas water heater or boiler?
  - Approximately $130 for water and sewer combined

How Big is Hot Water?

Water heating is the 1st or 2nd largest residential energy end-use: 15 – 30% of a house's total energy pie.

– What is number 1? Number 3?

– Percentage grows as houses and appliances get more efficient

How does this compare to your:

– Cell phone bill?

– Internet bill?

– Cable or Satellite bill?

– Designer coffee bill?

Why Do I Work on Hot Water?

- Energy Intensity of Indoor Cold Water
  - Range from 5 to 25 kWh per 1000 gallons
- Energy Intensity of Hot Water

	Electric		Natural Gas	
	Resistance (85 % Efficient)	Heat Pump (COP = 2)	(50% Efficient)	(95% Efficient)
kWh/1,000 Gallons	201	85	342	180
Relative Energy Intensity compared to 5 kWh/1,000 gallons	40	17	68	36

- Typically 40-68 times more energy intensive than indoor cold water.

The most valuable water to conserve
is hot water
at the top of the tallest building, with
the highest elevation,
in the area with the greatest
pressure drop.

Issues We Face

- Flow rates have been reduced
- Distances to fixtures have increased
- Potential for simultaneous flow is generally overestimated
- Code requirements for minimum pipe diameters have not been revised since before flow rates were reduced
- Codes and efficiency and green programs generally focus on components, not the hot water <u>system</u>
- Others?

Topics for Discussion

- Fixture fitting and appliance flow rates and fill volumes
- Pipe insulation
- Volume from source of hot water to uses
- Temperature maintenance systems
- Methods of controlling circulation loops
- Drain water heat recovery
- Water heater energy and water heater efficiency
- Vary requirements by type of occupancy
- Energy rating that takes into account reduced hot water use
- Others?

What Are We Aiming For?

- People want the service of hot water, as efficiently as possible.
- It does not make sense to discuss efficiency until the desired service has been provided.

The Key Components of a Hot Water System

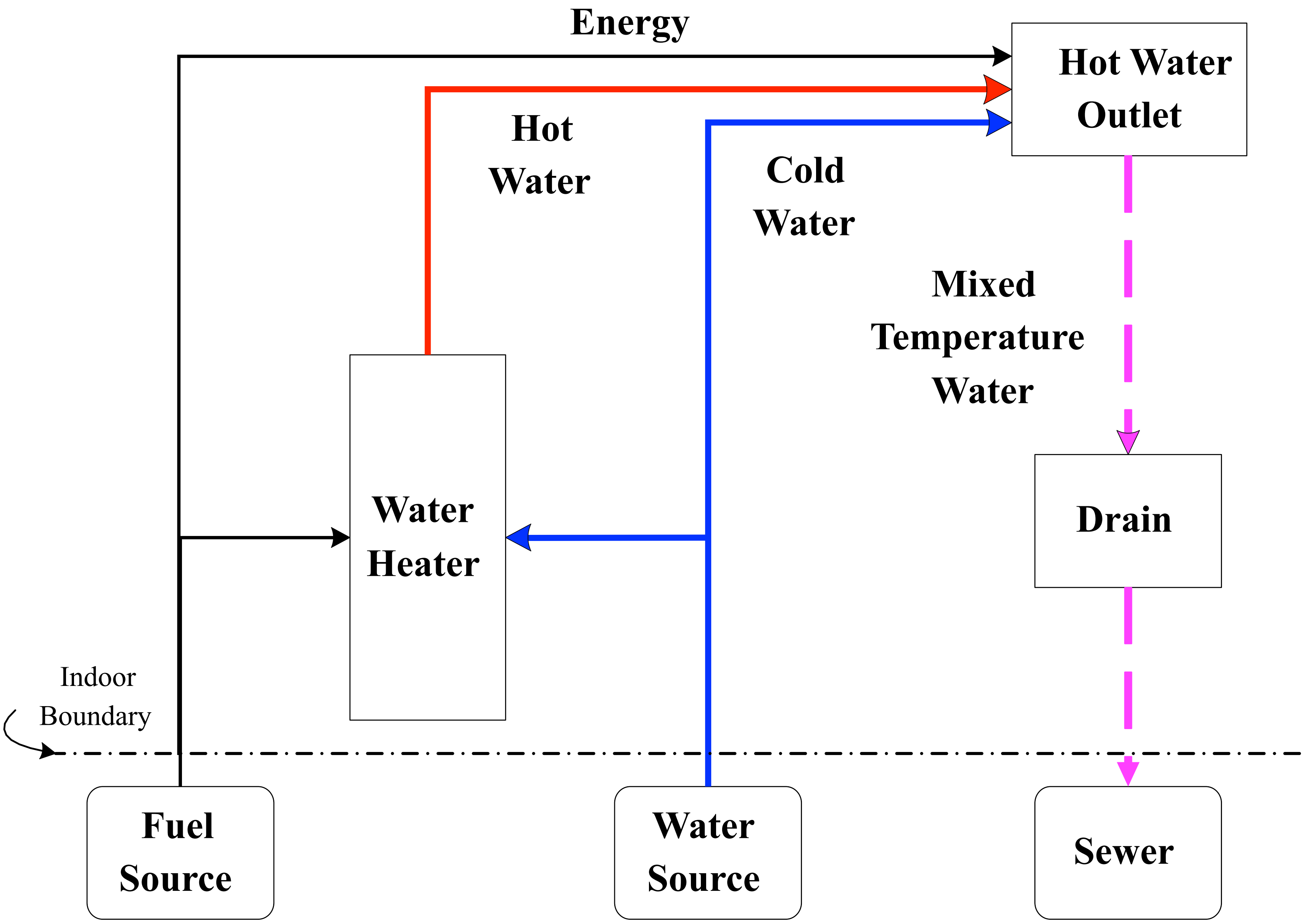
The Hot Water System

- Treatment and Delivery to the Building
- Use in the Building
  - Water Heater
  - Piping
  - Fixtures, Fittings and Appliances
  - Behavior
  - Water Down the Drain
- Waste Water Removal and Treatment

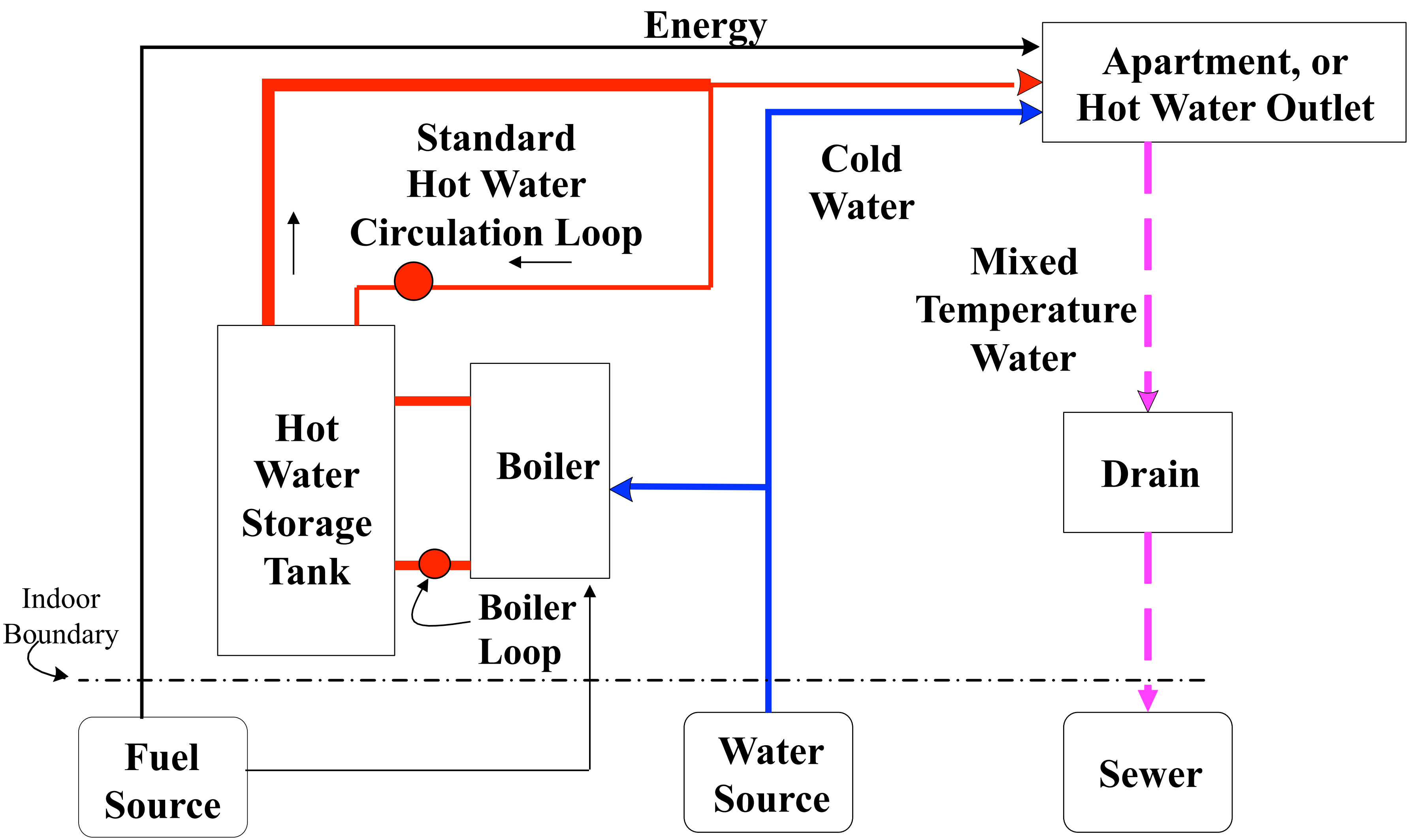
Which is the biggest ***variable*** in determining water and energy use?

How do the ***interactions*** among these components affect ***system*** performance?

Typical "Simple" Hot Water System



Typical Central Boiler Hot Water System



Definitions for Water Supply Piping

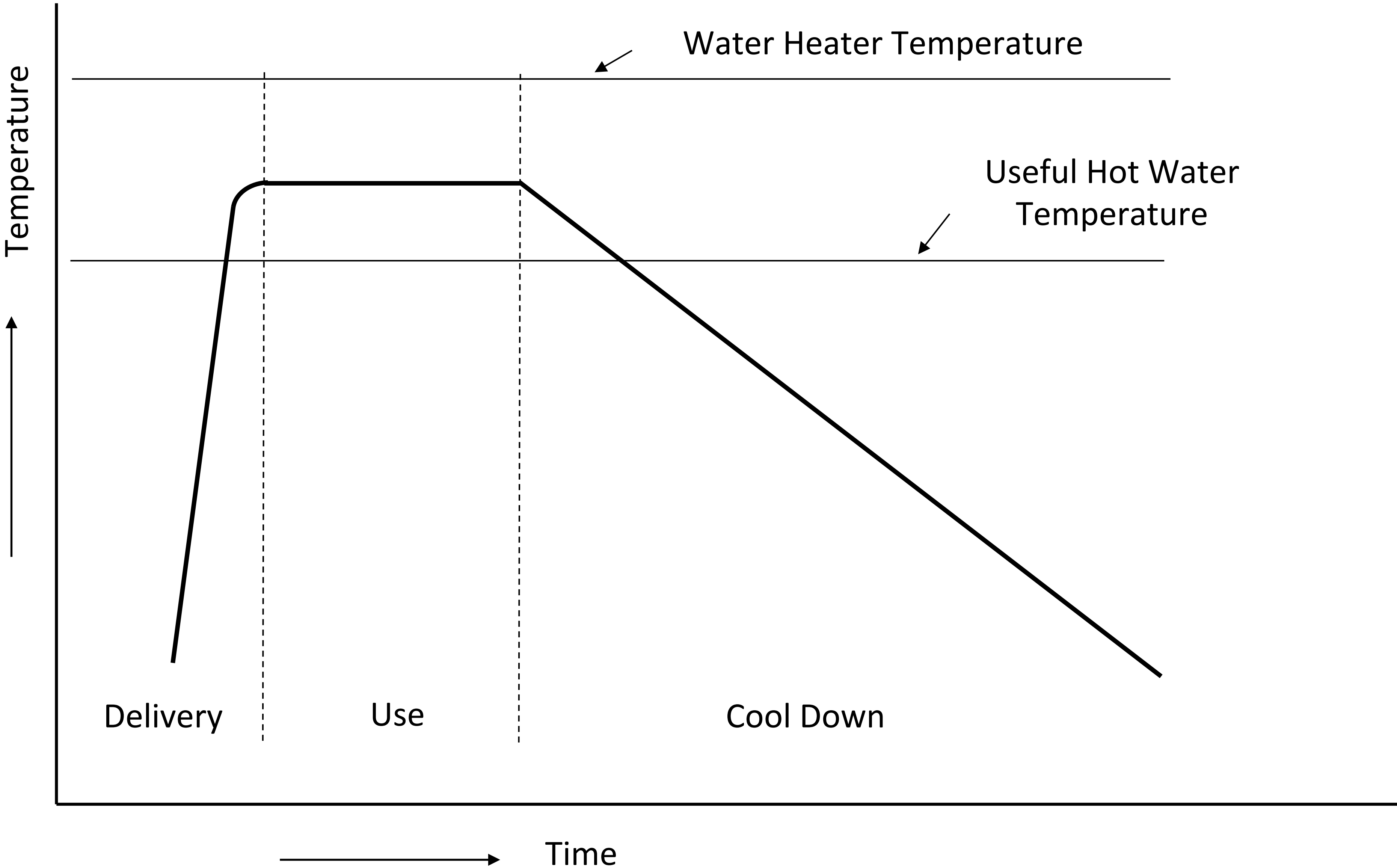
1. A Twig line serves one outlet or appliance.
   - The diameter of the twig should be determined by the flow rate of the outlet or appliance it serves and the pressure drop that will occur due to length, velocity and restrictions to flow (e.g. elbows and tees).
2. A Branch line serves more than one twig.
3. A Trunk line serves branches and twigs.
4. A Main line serves the building.
5. A hot water location contains one or more hot water outlets. Some cold ones too.

What are Residential Hot Water Use Patterns?

Do You Know:

- *Anyone who waits a long time to get hot water somewhere in their house? At their job? In their favorite restaurant?*
- Someone who has ever run out of hot water?
- *Any Communities that have a "you can't build unless you can guarantee a long term supply of water" ordinance?*
- Someone who has a "routine"' that they do while waiting for hot water to arrive at their shower? At the kitchen sink? For the dishwasher?
- *Anyone who wants instantaneous hot water?*
- Someone who thinks that a tankless water heater is instantaneous?
- *Anyone who thinks that a whole-house manifold plumbing system will save water?*
- Someone who is confused about how to implement the LEED, NAHB, Water Sense, Build-it-Green or other hot water distribution system credits?
- *Anyone who would like to learn how to get hot water to every fixture wasting no more than 1 cup waiting for the hot water to arrive?*
- Someone who wants to know "the answer"?

Typical Hot Water Event



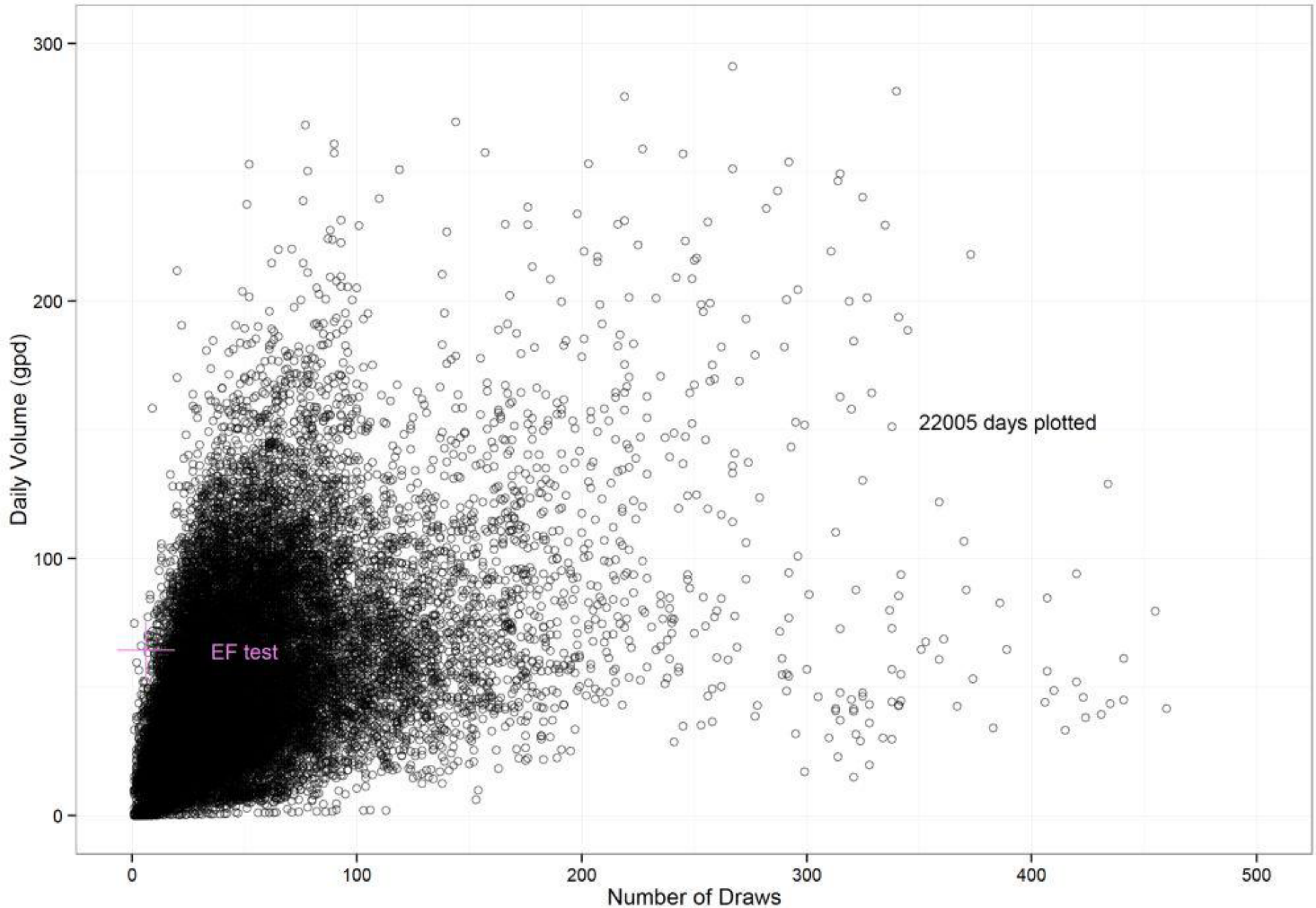
Field Studies of Hot Water Use

Summary of Field Studies

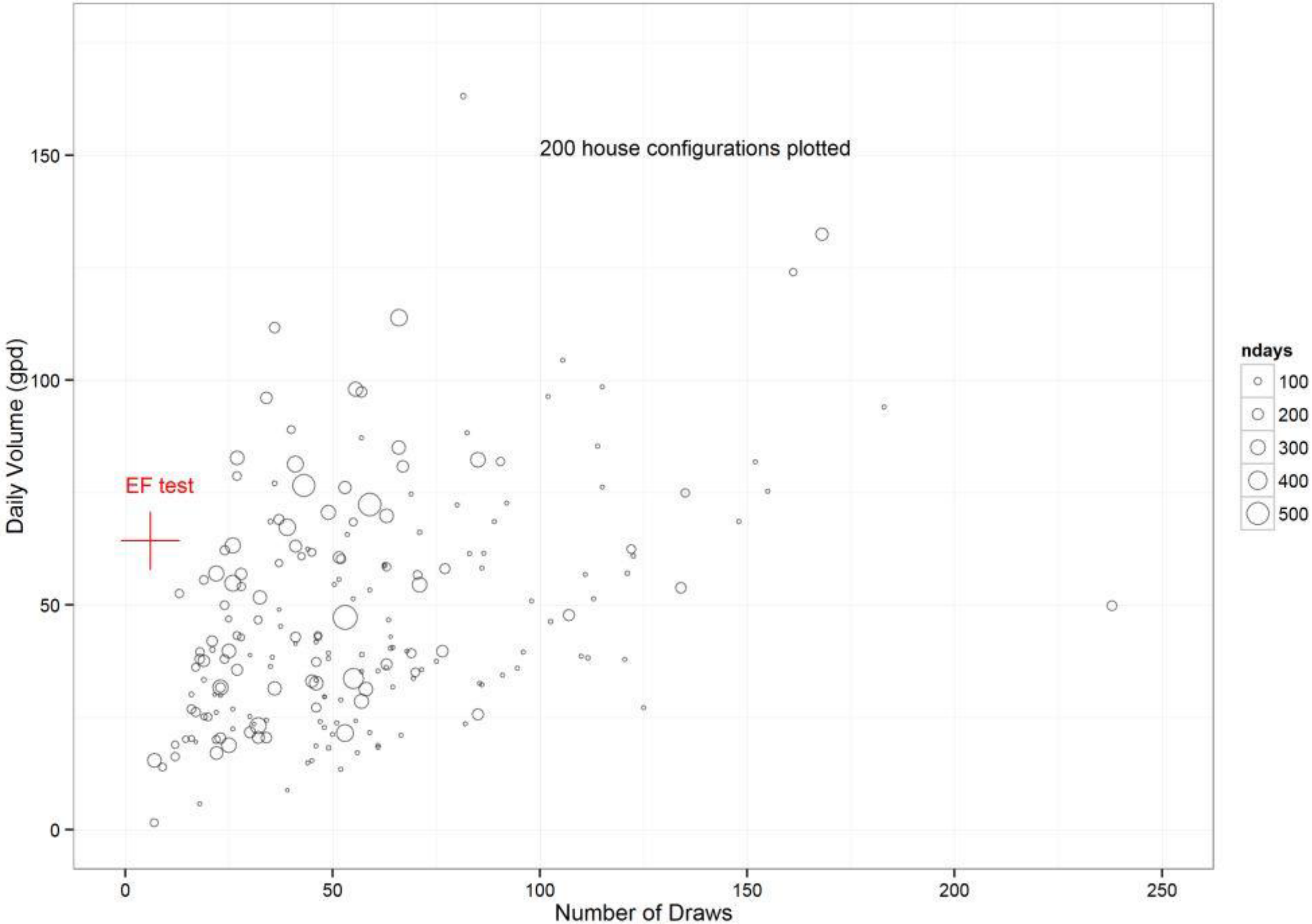
- 12 studies
- 159 monitored houses,
- 250 monitored configurations of water heaters and hot water end uses
- 22,902 days of monitoring
- 21,491 days that included inlet water temperature
- 1,679,668 hot water draws
- > 73 draws per day

Source: Jim Lutz and Moya Melody, Typical Hot Water Draw Patterns Based On Field Data, Lawrence Berkeley National Laboratory, November 2012

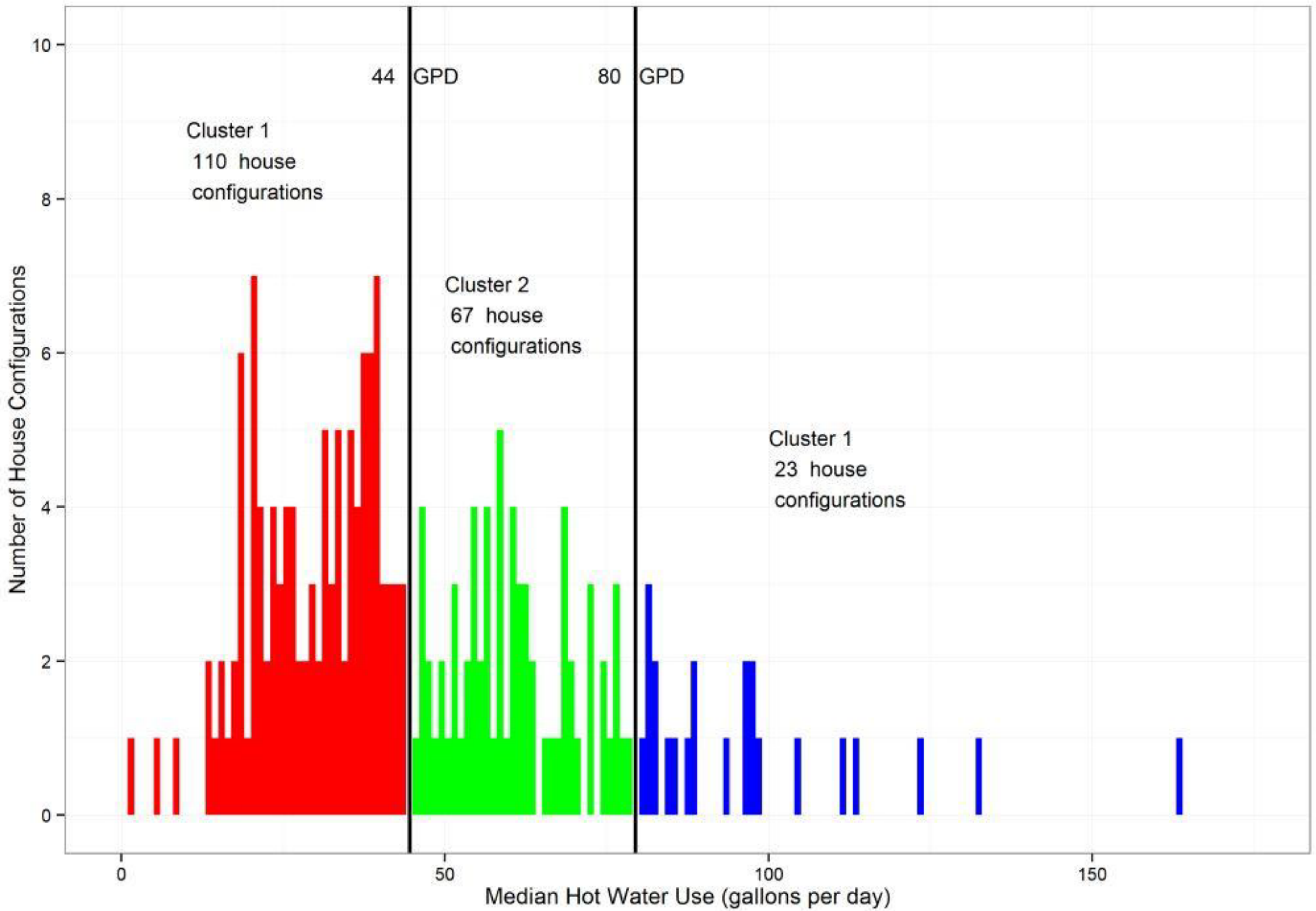
Daily Hot Water Use



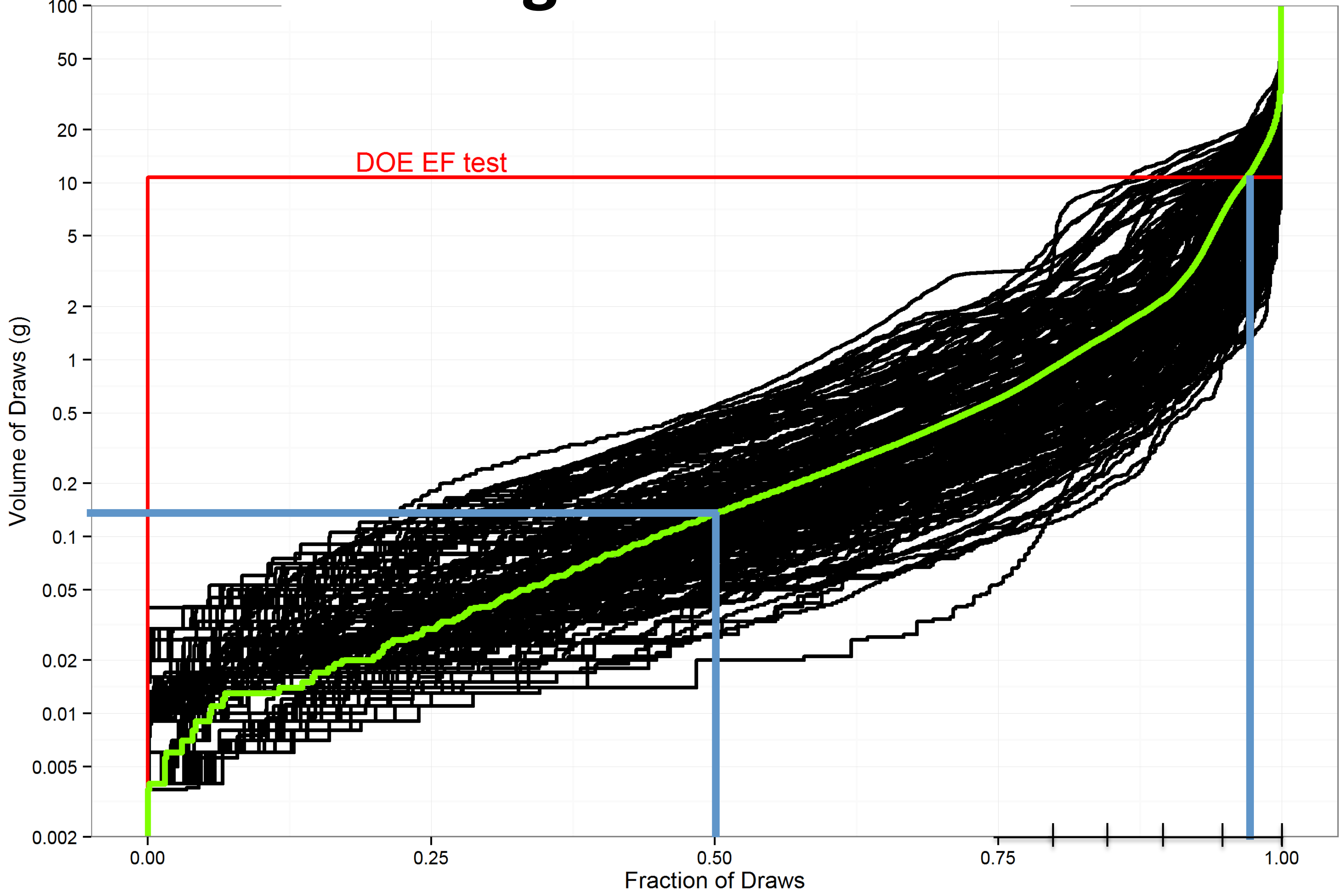
Median Daily Hot Water Use



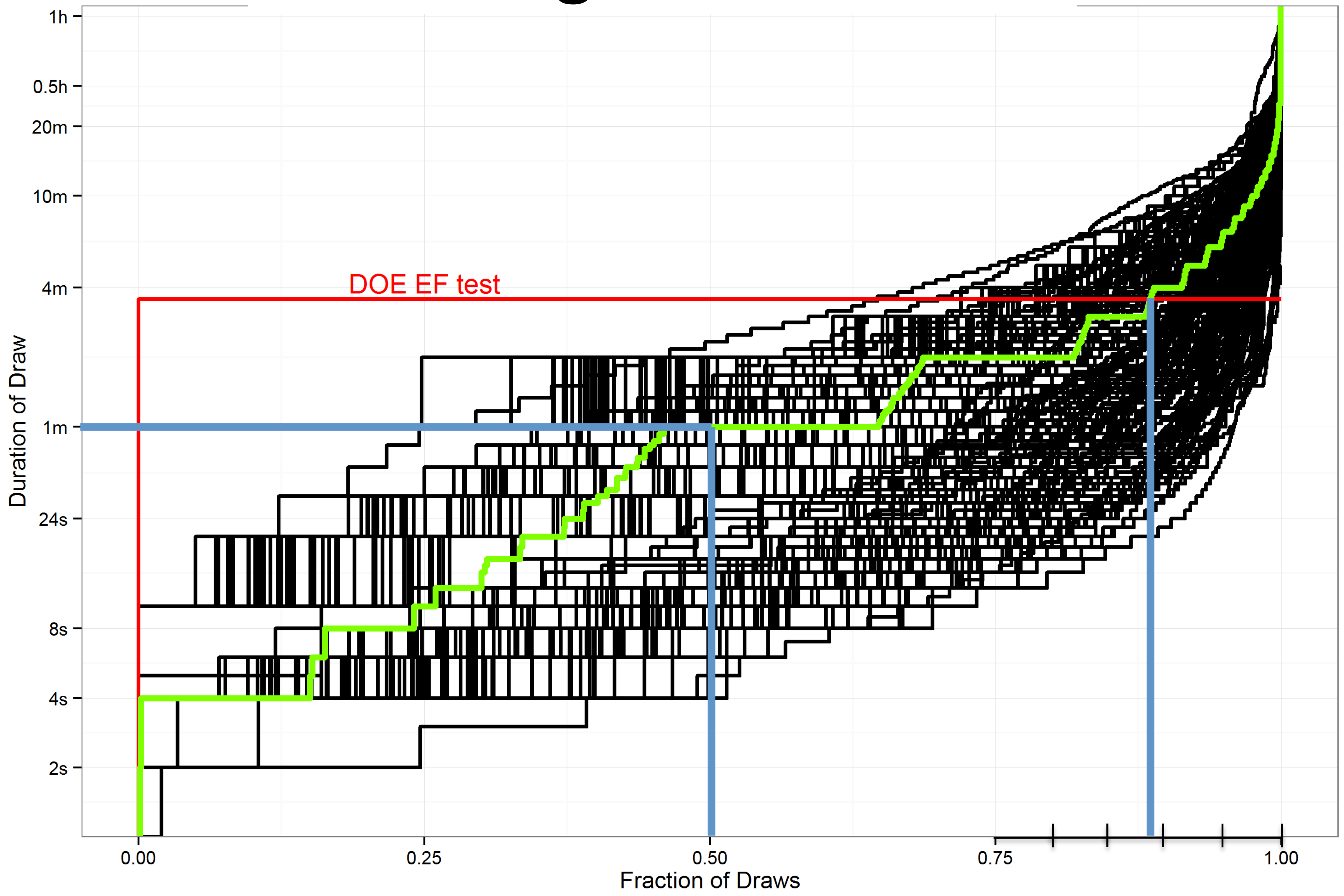
Clustered Median Daily Hot Water Use



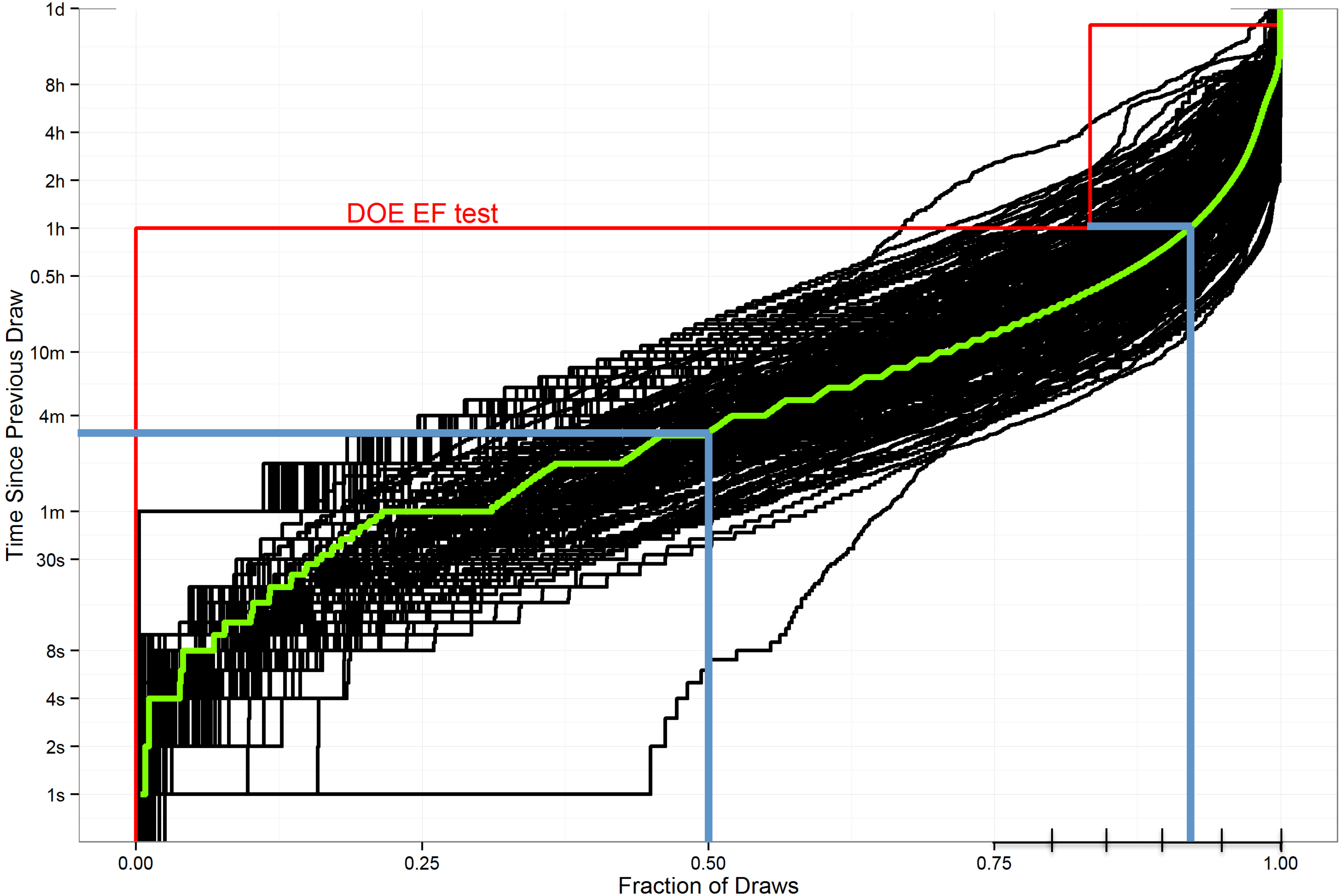
How Big are the Draws?



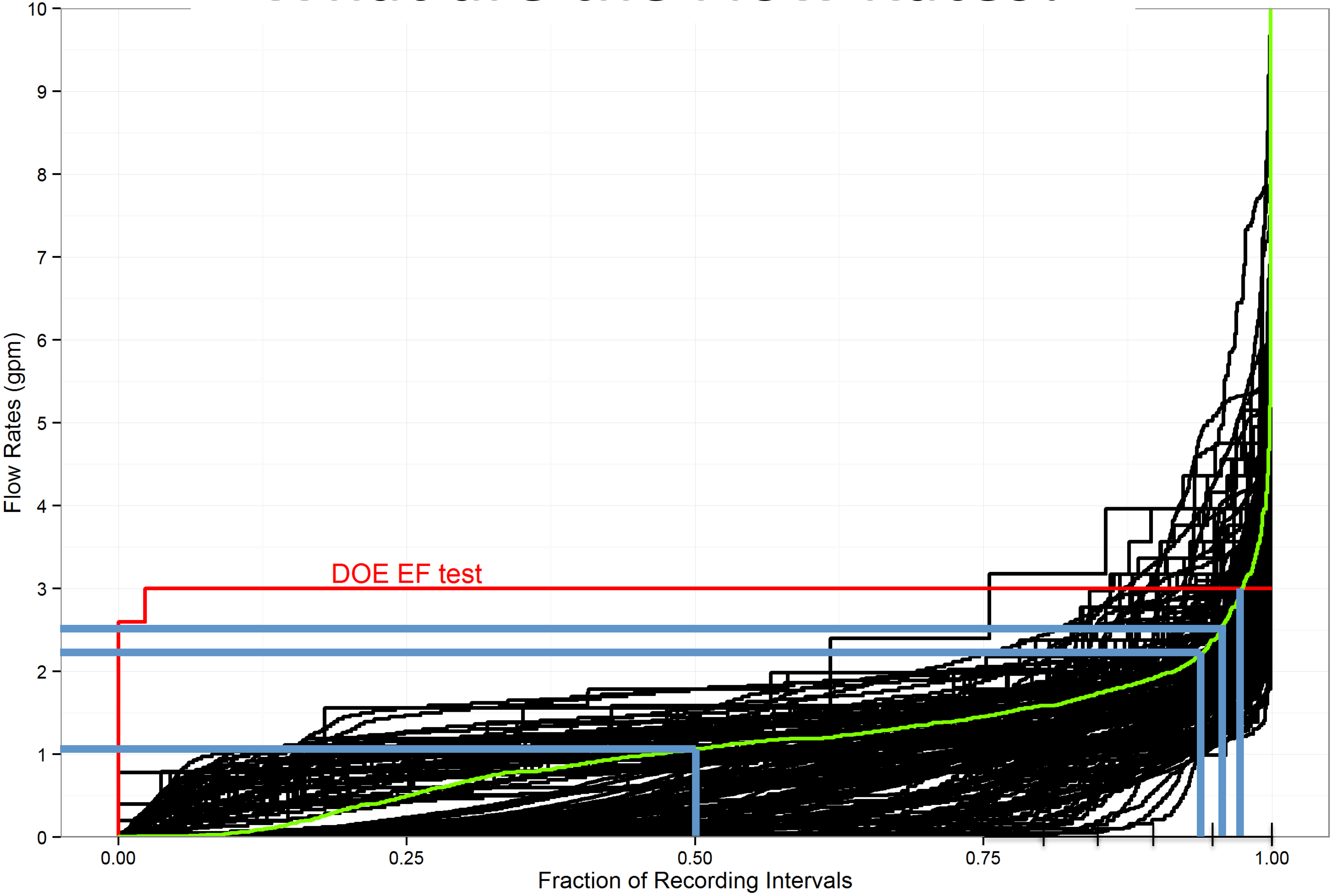
How Long is Each Draw?



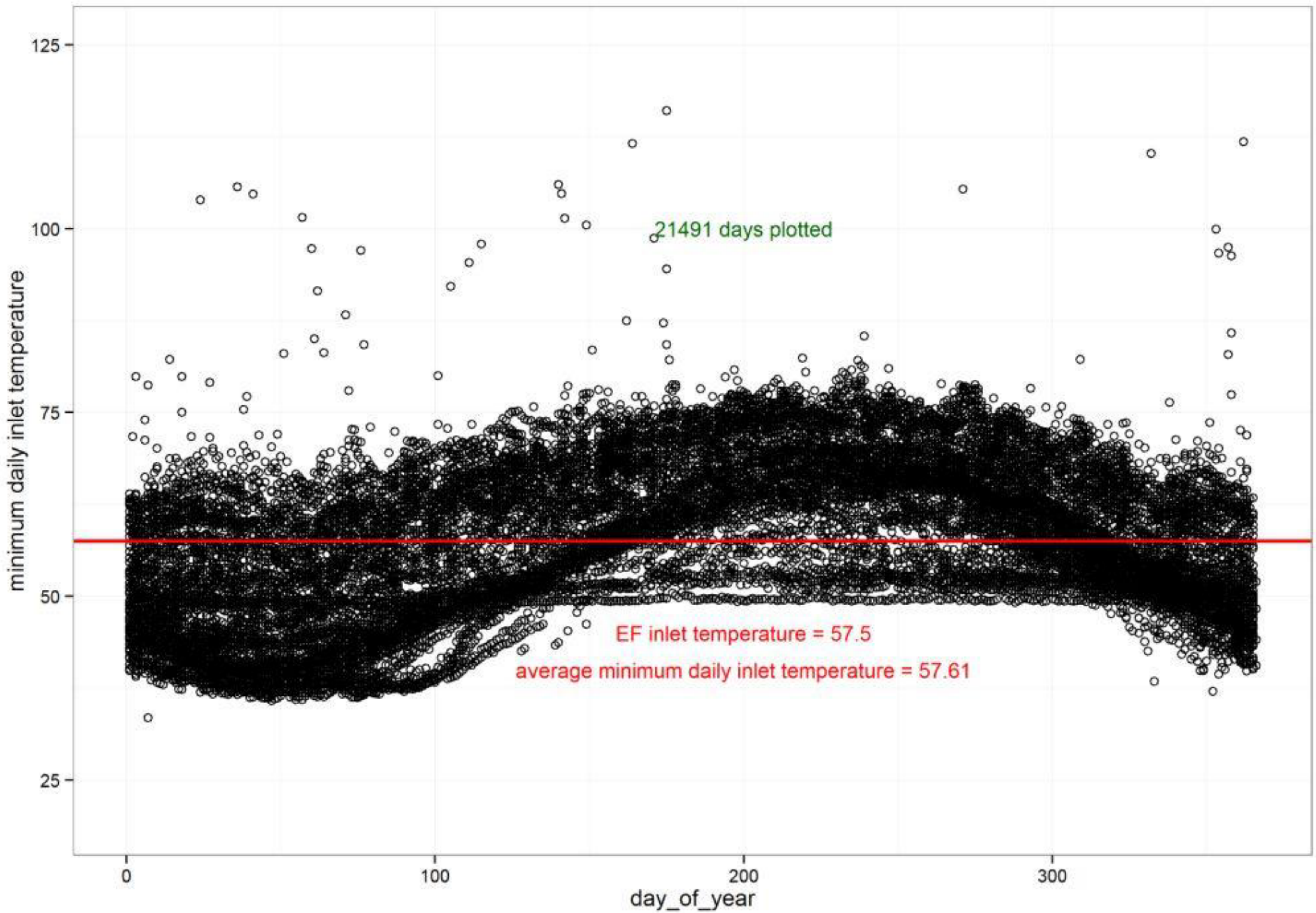
How Much Time Between Draws?



What are the Flow Rates?



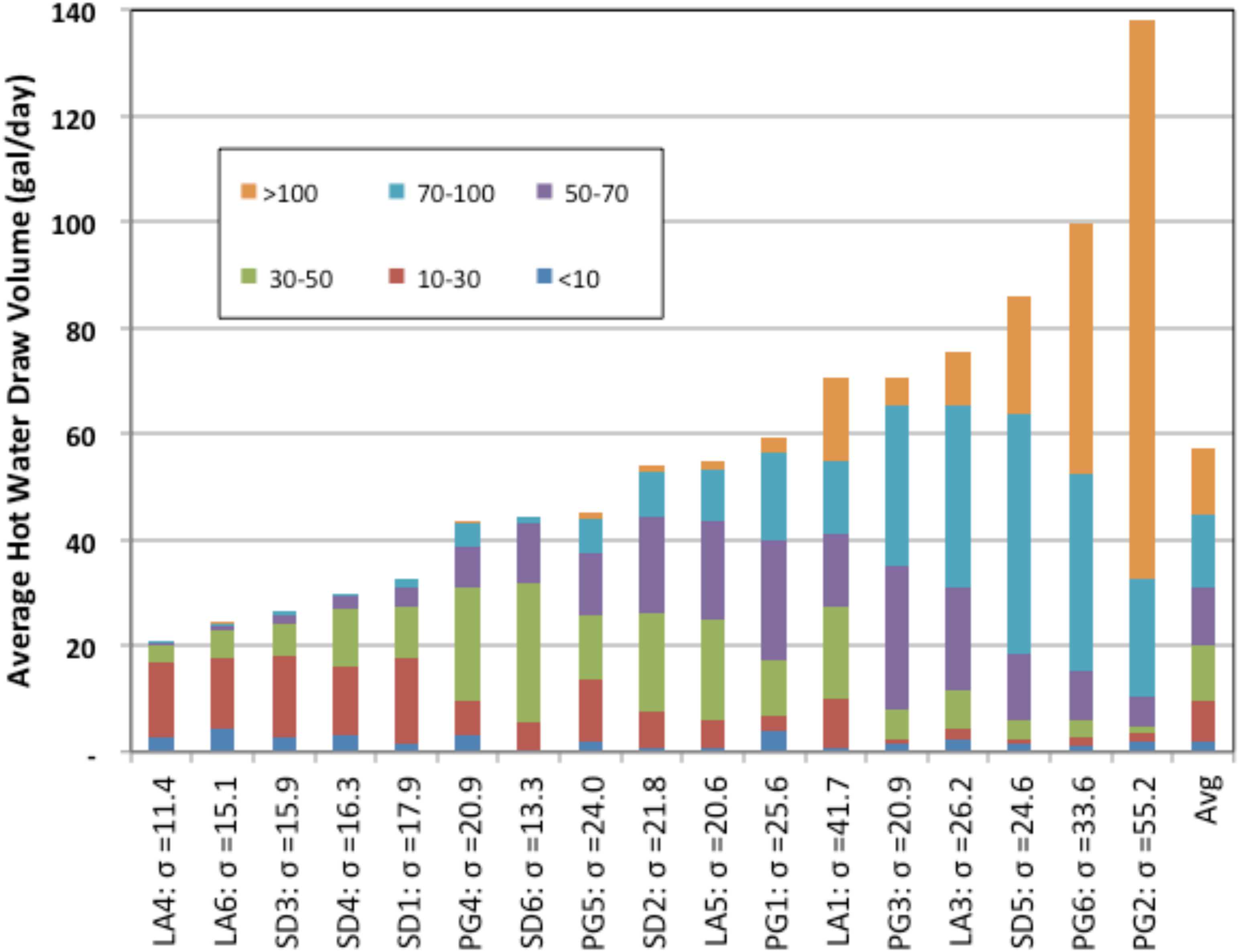
Inlet Water Temperatures



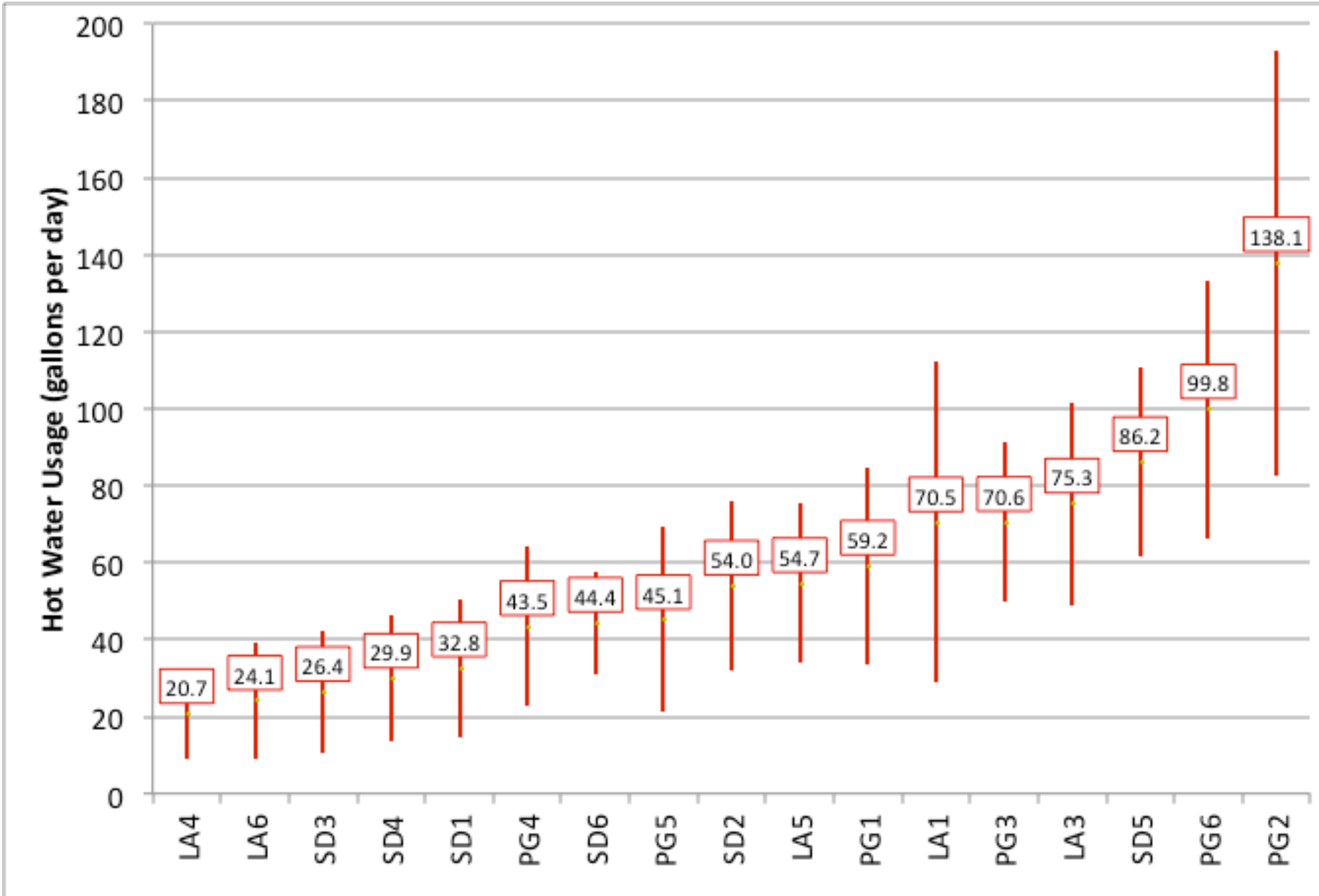
California Hot Water Research

- Residential Water Heating Program, Prime Contractor – Gas Technology Institute
- Funded by California Energy Commission, CEC 500-08-060
- 36 month study
- Field Studies – hot water use in 18 homes, distribution piping in 100 homes, surveys
- Laboratory Studies – water heaters, distribution piping

Daily Hot Water Use (Gallons)



Daily Hot Water Use (Gallons)

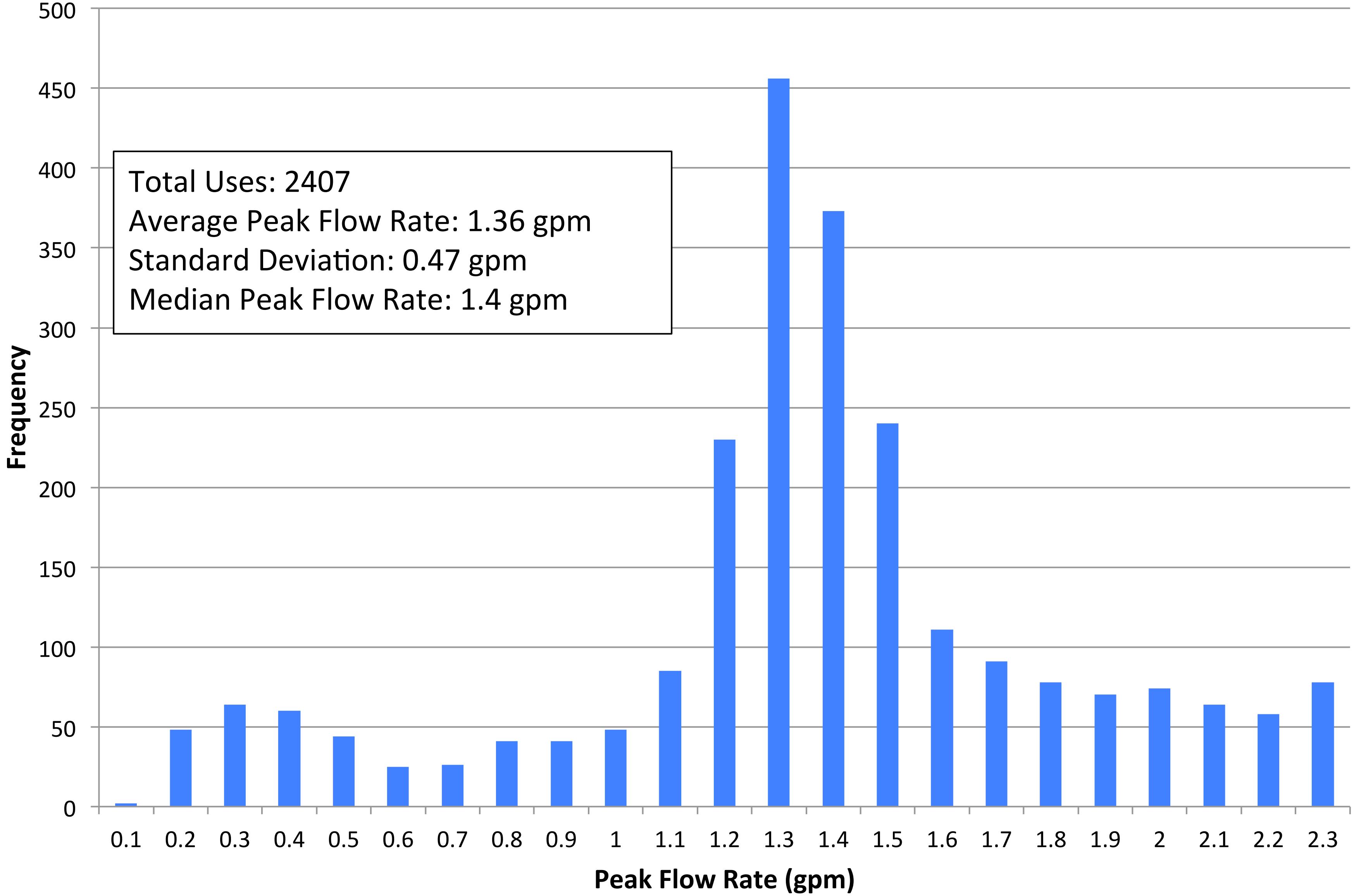


How do we use hot water?

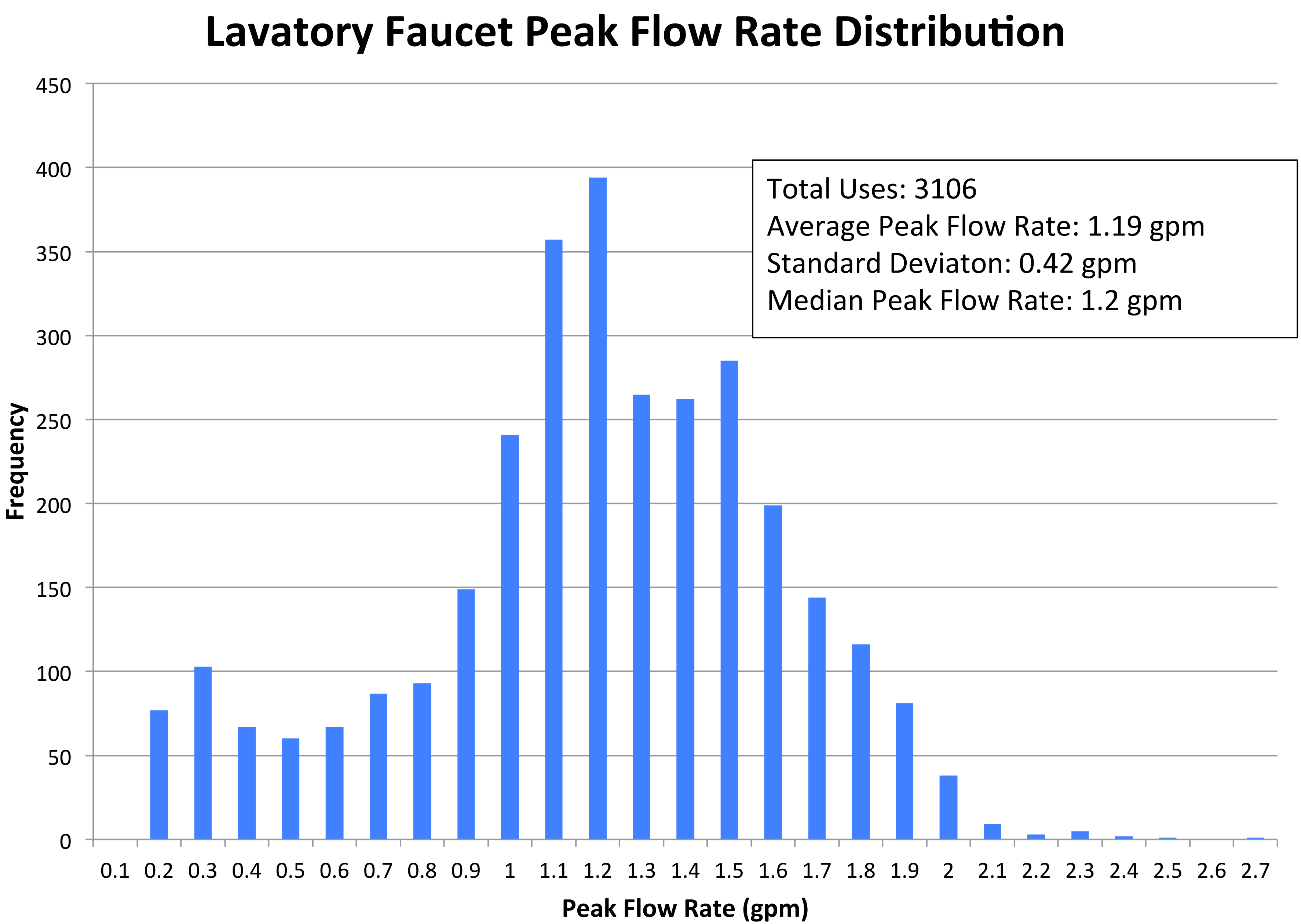
- Frequent short, low flow-rate draws
- Occasional long draws at low flow-rates
- High flow-rate and high volume draws are rare
- Draws are highly clustered

What We Have Learned About Flow Rates, Volume-until-Hot and Time-to-Tap

Kitchen Sink Peak Flow Rate Distribution

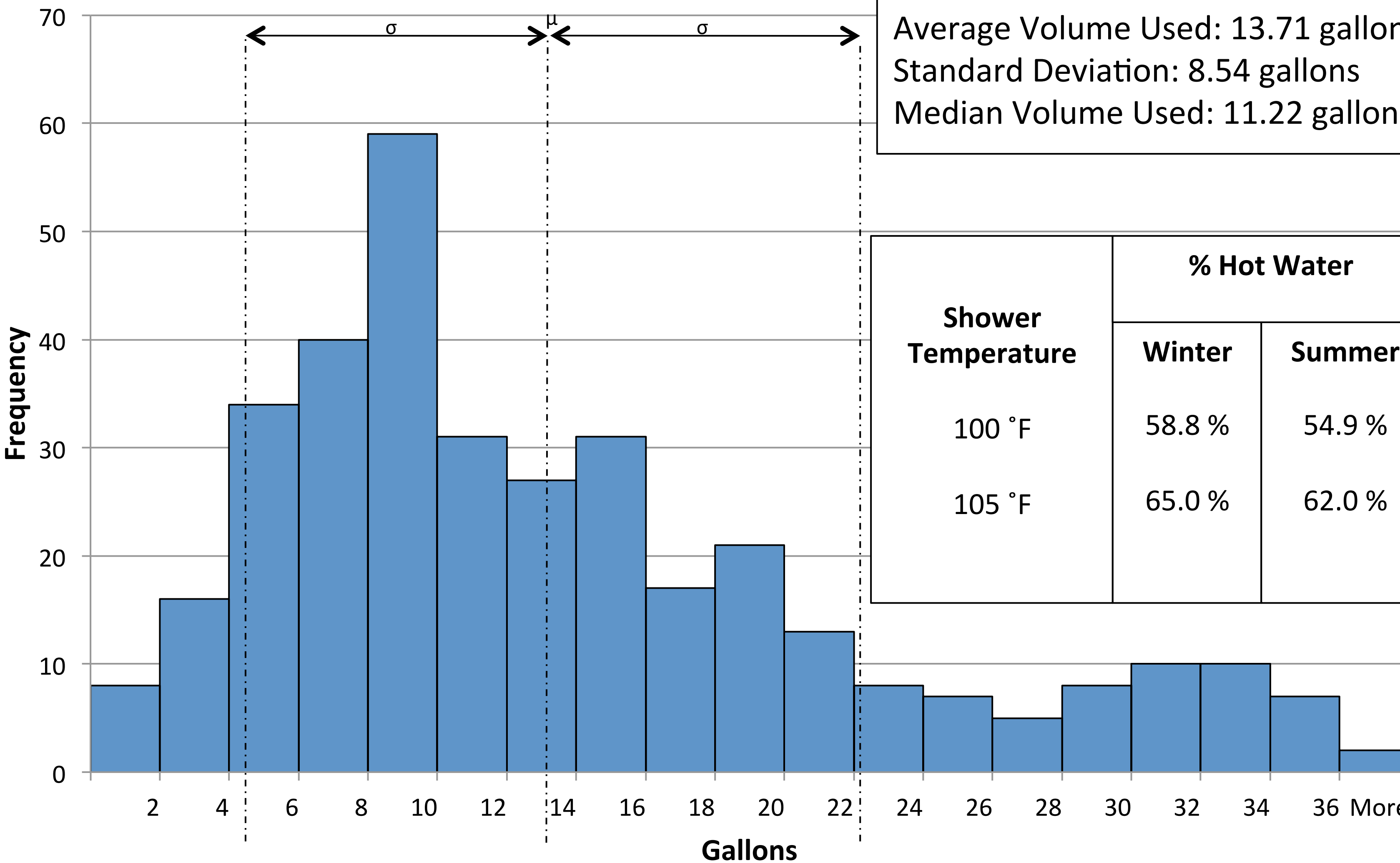


Source: Craig Selover, Masco



Source: Craig Selover, Masco

Shower Uses

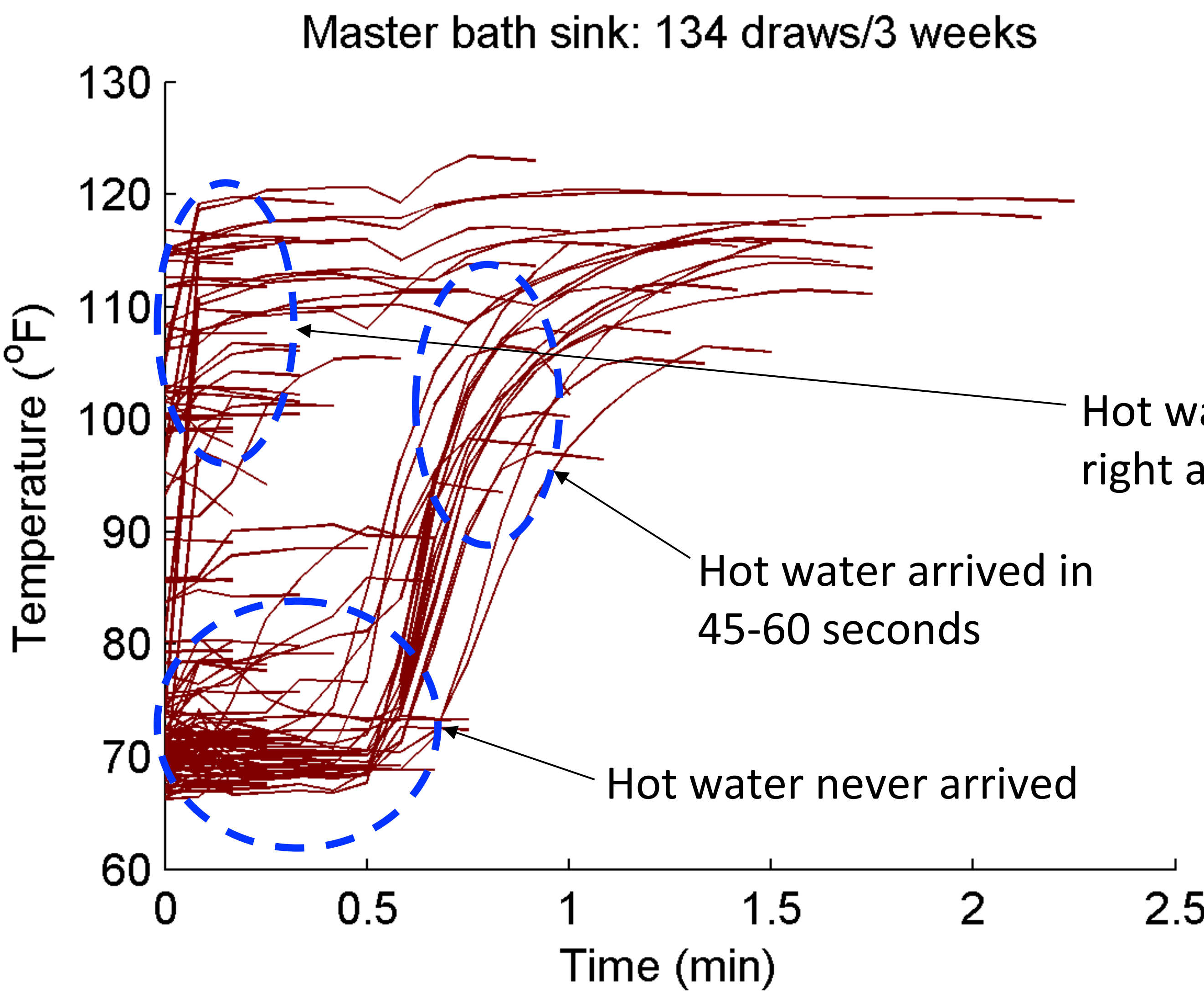


Total Uses: 354
Average Volume Used: 13.71 gallons
Standard Deviation: 8.54 gallons
Median Volume Used: 11.22 gallons

Shower Temperature	% Hot Water	
	Winter	Summer
100 ˚F	58.8 %	54.9 %
105 ˚F	65.0 %	62.0 %

Source: Craig Selover, Masco

Time and Temperature at the Master Bath Sink



Average draw is 30 ± 29 seconds

Source: National Renewable Energy Laboratory

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

(green)	**Acceptable Performance**	1 – 10 seconds
(orange)	**Marginal Performance**	11 – 30 seconds
(pink)	**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-to-Tap (Seconds)																								
	1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**
0.25	0.004	0.021	0.042	0.063	0.083	0.104	0.125	0.15	0.17	0.19	0.21	0.23	0.25	0.27	0.29	0.31	0.33	0.35	0.38	0.40	0.42	0.44	0.46	0.48	0.5
0.5	0.008	0.042	0.083	0.125	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.54	0.58	0.63	0.67	0.71	0.75	0.79	0.83	0.88	0.92	0.96	1.0
0.75	0.013	0.063	0.125	0.19	0.25	0.31	0.38	0.44	0.50	0.56	0.63	0.69	0.75	0.81	0.88	0.94	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5
1	0.017	0.083	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.0	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2.0
1.25	0.021	0.104	0.21	0.31	0.42	0.52	0.63	0.73	0.83	0.94	1.0	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
1.5	0.025	0.125	0.25	0.38	0.50	0.63	0.75	0.88	1.0	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2.0	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3.0
1.75	0.029	0.15	0.29	0.44	0.58	0.73	0.88	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.0	2.2	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.4	3.5
2	0.033	0.17	0.33	0.50	0.67	0.83	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.8	4.0
2.25	0.038	0.19	0.38	0.56	0.75	0.94	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.5
2.5	0.042	0.21	0.42	0.63	0.83	1.0	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8	4.0	4.2	4.4	4.6	4.8	5
3	0.05	0.25	0.50	0.75	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5	4.8	5.0	5.3	5.5	5.8	6
3.5	0.058	0.29	0.58	0.88	1.2	1.5	1.8	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.5	5.8	6.1	6.4	6.7	7
4	0.067	0.33	0.67	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.3	6.7	7.0	7.3	7.7	8
4.5	0.075	0.38	0.75	1.1	1.5	1.9	2.3	2.6	3.0	3.4	3.8	4.1	4.5	4.9	5.3	5.6	6.0	6.4	6.8	7.1	7.5	7.9	8.3	8.6	9
5	0.083	0.42	0.83	1.3	1.7	2.1	2.5	2.9	3.3	3.8	4.2	4.6	5.0	5.4	5.8	6.3	6.7	7.1	7.5	7.9	8.3	8.8	9.2	9.6	10
5.5	0.092	0.46	0.92	1.4	1.8	2.3	2.8	3.2	3.7	4.1	4.6	5.0	5.5	6.0	6.4	6.9	7.3	7.8	8.3	8.7	9.2	9.6	10.1	10.5	11
6	0.100	0.50	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12
6.5	0.108	0.54	1.1	1.6	2.2	2.7	3.3	3.8	4.3	4.9	5.4	6.0	6.5	7.0	7.6	8.1	8.7	9.2	9.8	10.3	10.8	11.4	11.9	12.5	13
7	0.117	0.58	1.2	1.8	2.3	2.9	3.5	4.1	4.7	5.3	5.8	6.4	7.0	7.6	8.2	8.8	9.3	9.9	10.5	11.1	11.7	12.3	12.8	13.4	14
7.5	0.125	0.63	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.6	6.3	6.9	7.5	8.1	8.8	9.4	10.0	10.6	11.3	11.9	12.5	13.1	13.8	14.4	15
8	0.13	0.67	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	8.7	9.3	10.0	10.7	11.3	12.0	12.7	13.3	14.0	14.7	15.3	16
8.5	0.14	0.71	1.4	2.1	2.8	3.5	4.3	5.0	5.7	6.4	7.1	7.8	8.5	9.2	9.9	10.6	11.3	12.0	12.8	13.5	14.2	14.9	15.6	16.3	17
9	0.15	0.75	1.5	2.3	3.0	3.8	4.5	5.3	6.0	6.8	7.5	8.3	9.0	9.8	10.5	11.3	12.0	12.8	13.5	14.3	15.0	15.8	16.5	17.3	18
9.5	0.16	0.79	1.6	2.4	3.2	4.0	4.8	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.1	11.9	12.7	13.5	14.3	15.0	15.8	16.6	17.4	18.2	19
10	0.17	0.83	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.17	10.0	10.8	11.7	12.5	13.3	14.2	15.0	15.8	16.7	17.5	18.3	19.2	20

Gallons Wasted as a Function of Time and Fixture Flow Rate

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

Time Until Hot Water Arrives (Seconds)

Flow Rate (GPM)	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

<u>Gallons</u> Wasted as a Function of Time and Fixture Flow Rate

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

Time Until Hot Water Arrives (Seconds)

Flow Rate (GPM)

	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	[illegible]	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	[illegible]	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	[illegible]	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	[illegible]	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

<u>Gallons</u> Wasted as a Function of Time and Fixture Flow Rate

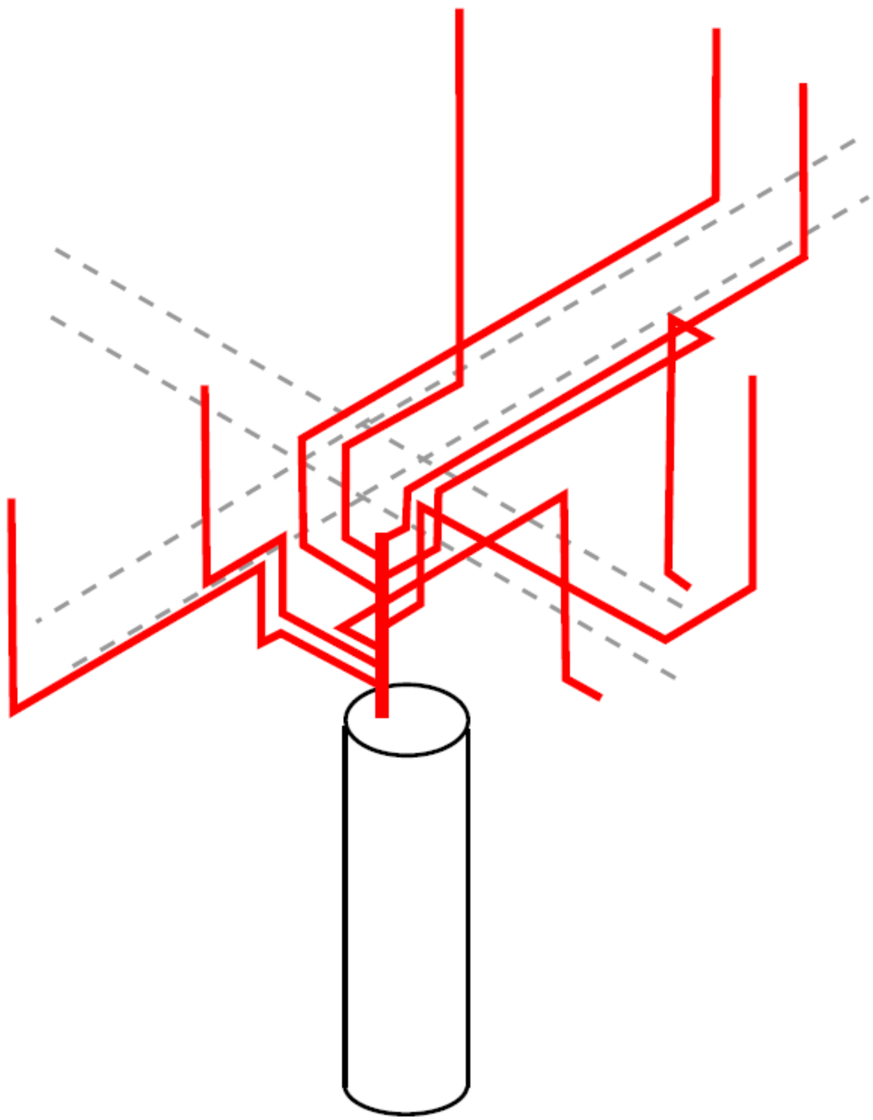
(Green < 2 cups), Red >1/2 Gallon)

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	[illegible]	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	[illegible]	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	[illegible]	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	[illegible]	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

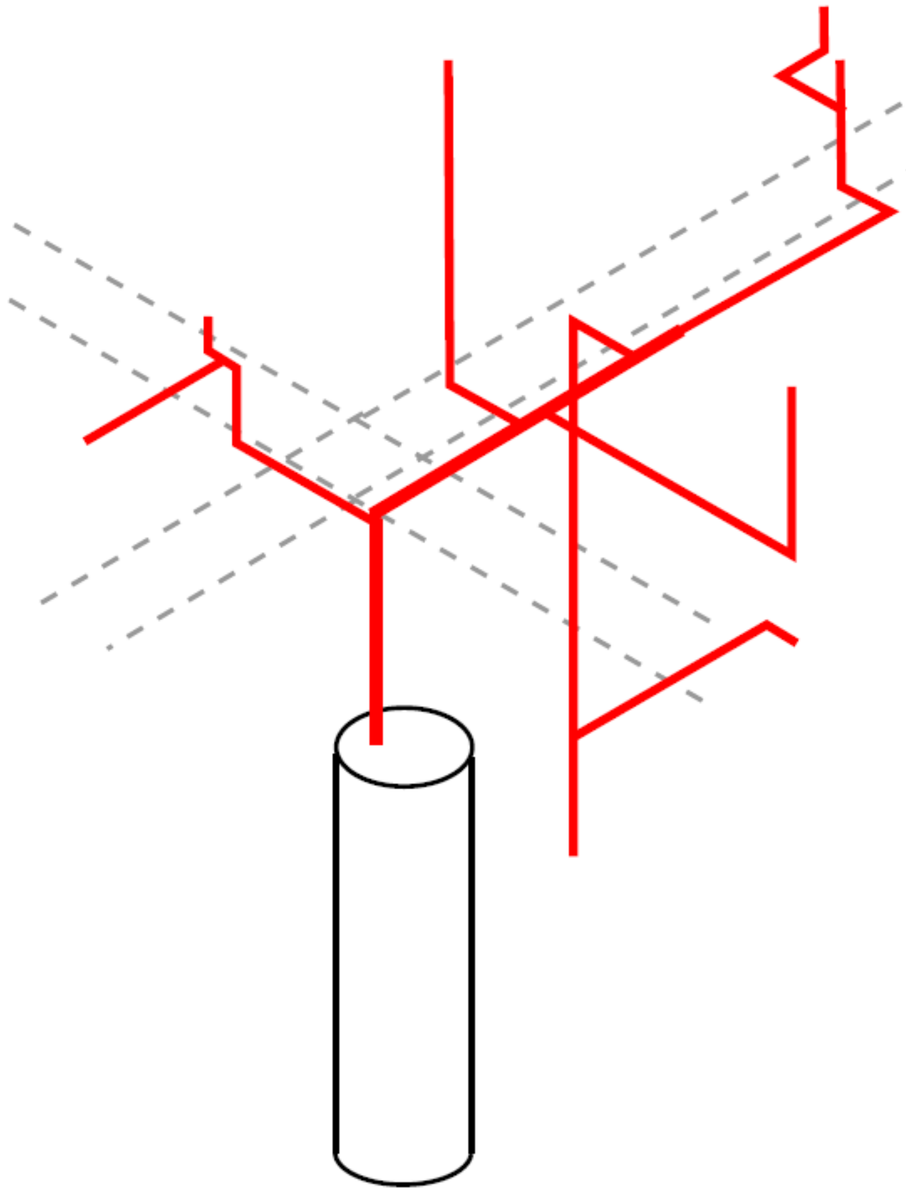
1- Quart Hot Water Distribution System

Short Trunk – Long Twig



1- Quart Hot Water Distribution System

Long Trunk – Short Twig



What is the Future of Flow Rates?

Kitchen sinks – 0.5 to 2 gpm (hot only to left, pot fill)

Lavatory sinks – 0.5 gpm (hot only to left)

Showers – 1.5 gpm (water down drain)

Showers – 15 gallons (maximum volume per event)

What impact will these flow rates have on system performance?

Given these flow rates, what impact will the interactions with the rest of the system have on customer satisfaction?

It’s All About the Feel!

Not the pressure or flow rate

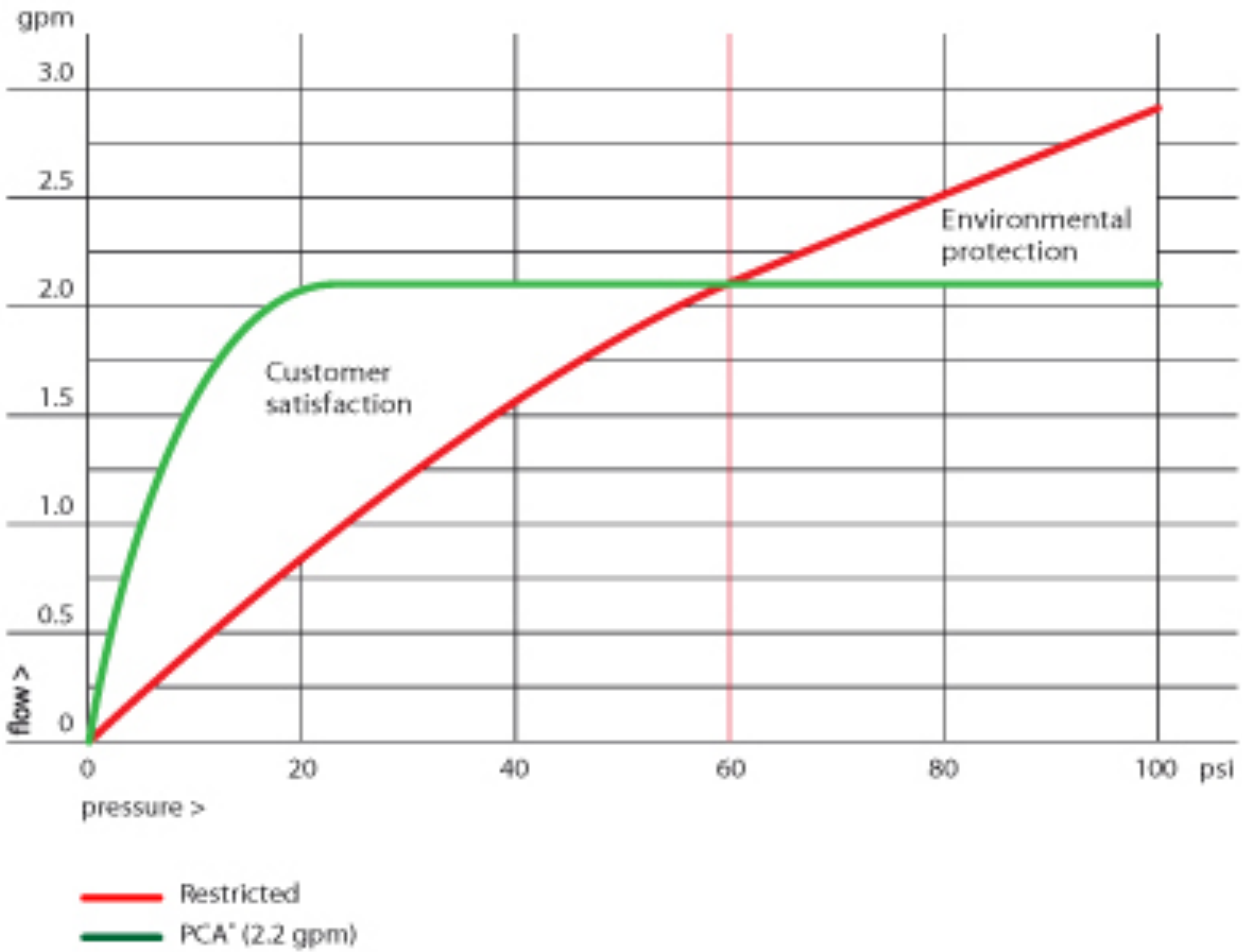
Lavatory Faucet Stream Patterns

Aerated stream
Aerators introduce air into the water stream to produce a larger and whiter stream soft to the touch and non-splashing. Aerators are the usual choice for residential faucet applications.

Laminar stream
Laminar stream straighteners produce a non-aerated water stream. Ideal for high flow applications or health care facilities (no mix water/air) laminar spout-end devices deliver a crystal clear and non-splashing stream.

Spray
When the flow rate is too low to produce an aerated or laminar stream, a spray device is used to produce a miniature shower pattern to provide full coverage of the hands during washing. Sprays are recommended for use in public lavatories.

Pressure Compensating Aerators



Integrating the Components into an Effective System

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.

Length of Pipe that Holds 8 oz of Water

	3/8" CTS	1/2" CTS	3/4" CTS	1" CTS
	ft/cup	ft/cup	ft/cup	ft/cup
"K" copper	9.48	5.52	2.76	1.55
"L" copper	7.92	5.16	2.49	1.46
"M" copper	7.57	4.73	2.33	1.38
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02
Ave	**8 feet**	**5 feet**	**2.5 feet**	**1.5 feet**

Uninsulated Pipe Heat Loss

	Heat Loss Factor - UA			
	No Flow	0.5 GPM	1 GPM	2 GPM
3/8 PEX - Air	0.345	0.355	0.368	0.368
1/2 Rigid Copper - Air	0.226	0.33	0.345	0.36
1/2 PEX - Air	0.438	0.438	0.438	0.438
1/2 PEX - Bundled - Air	0.7	0.7	0.7	0.7
3/4 Rigid Copper - Air	0.404	0.41	0.417	0.421
3/4 CPVC - Air	0.44	0.45	0.46	0.48
3/4 PEX - Air	0.535	0.54	0.545	0.555
3/4 PAX - Air	0.55	0.546	0.541	0.532
3/4 Roll Copper - Air	0.334	0.334	0.334	0.334
3/4 Roll Copper - Buried	1.2	1.8	2.1	2.4

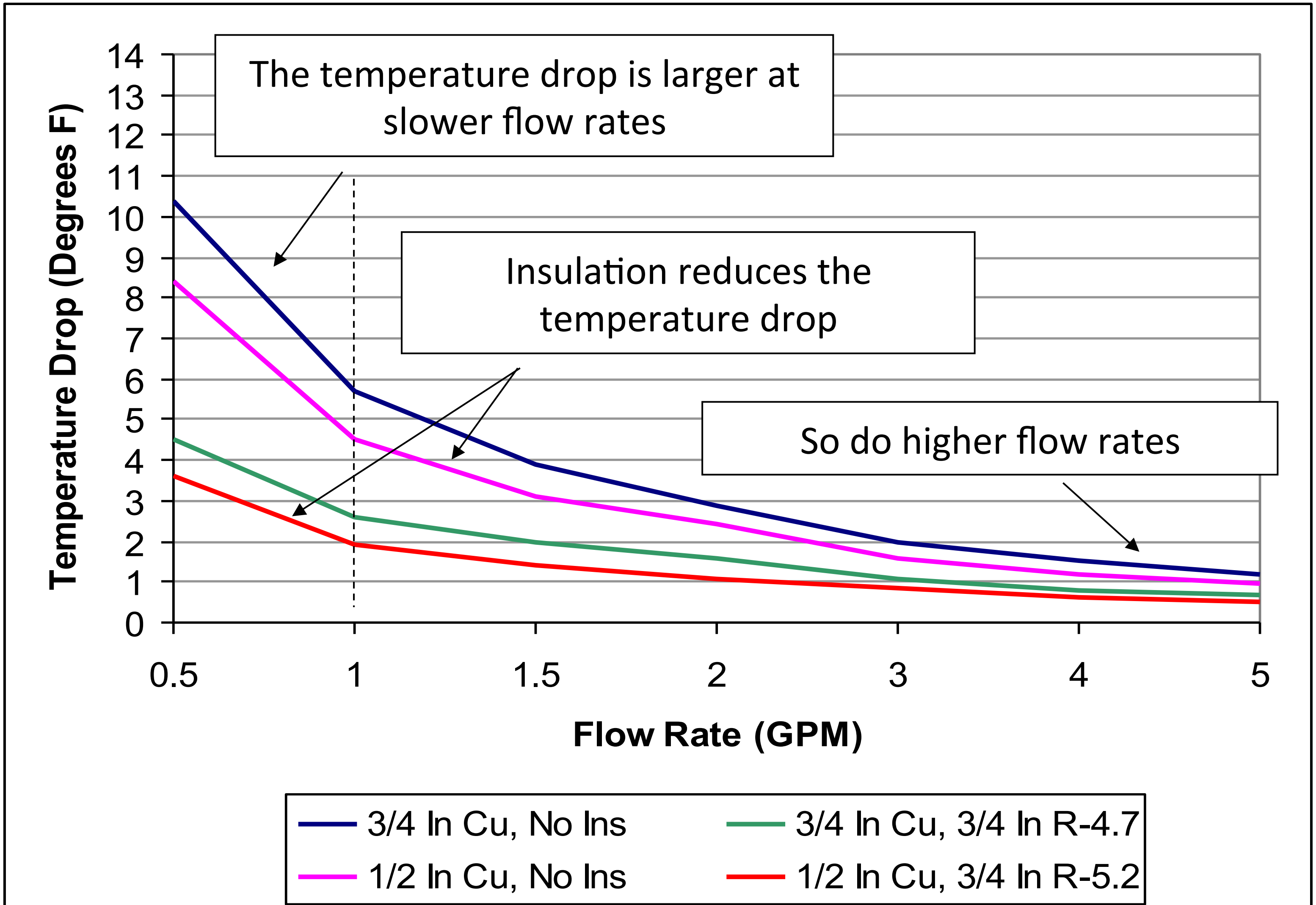
Pipe Insulation Benefits

- Reduces temperature drop during periods of flow
  - Reduces surface area losses
  - Allows using lower temperatures
- Slows cool-down rate
  - Reduces number of cold starts
  - Reduces volumetric losses

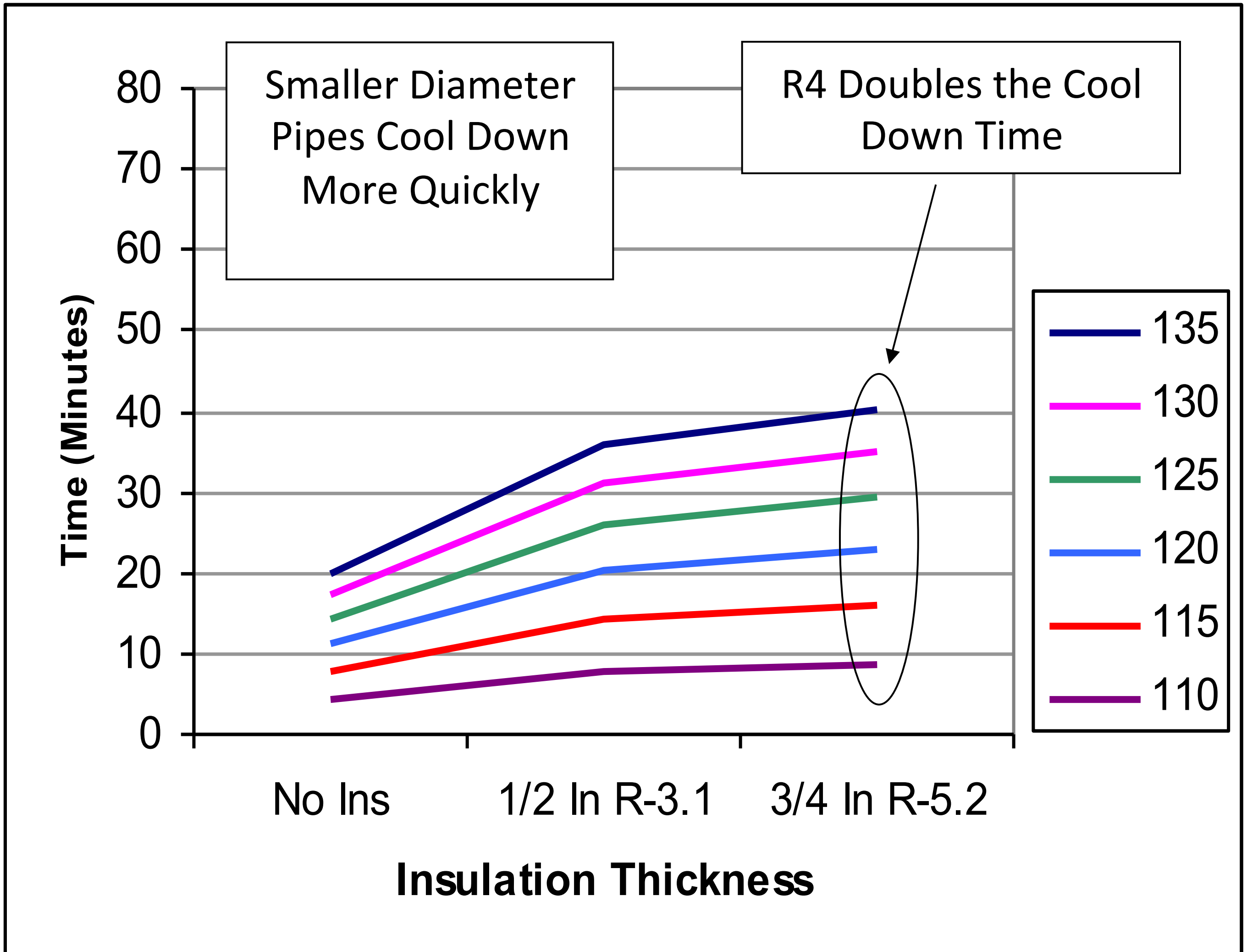
Steady-State Temperature Drop vs. Flow Rate

100 Feet of 1/2 & 3/4 inch Copper Pipe

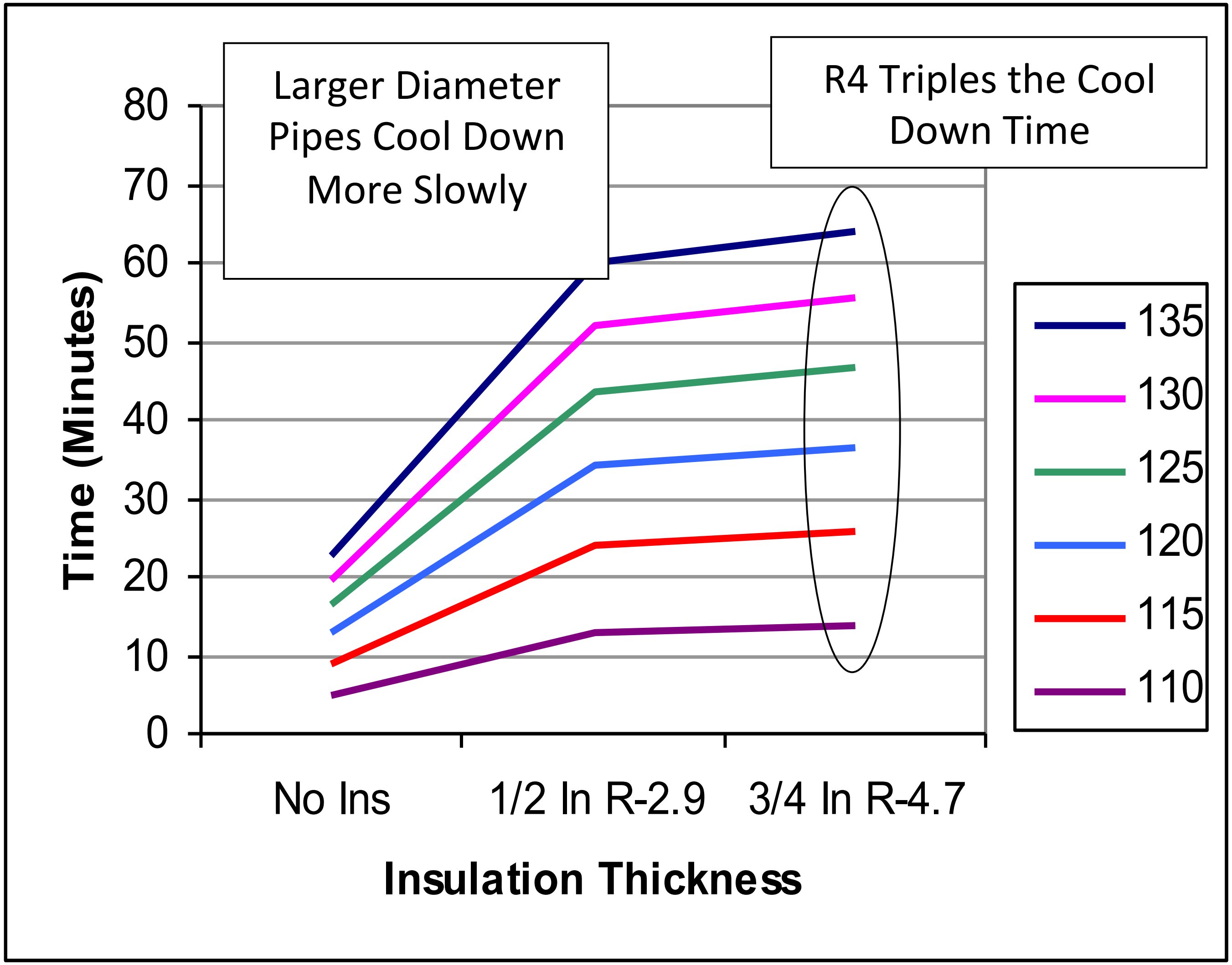
(Thot = 135 F, Tair = 67. 5 F)



Time for Temperature to Drop to 105 °F in 1/2 Inch Copper Pipe



Time for Temperature to Drop to 105 ºF in 3/4 Inch Copper Pipe



The Importance of Minimizing Pipe Volume

			Volume in Pipe That Cools Down							
		Gallons	0.0625	0.125	0.25	0.5	0.75	1	1.5	2
		Cups	1	2	4	8	12	16	24	32
Heat Loss										
Btu/Year	**Btu/Day**		**Number of Times Per Day that Water in Pipe Cools Down**							
500,000	1,370		53	26	13	7	4.4	3.3	2.2	1.6
1,000,000	2,740		105	53	26	13	9	7	4.4	3.3
1,500,000	4,110		158	79	39	20	13	10	7	5
2,000,000	5,479		210	105	53	26	18	13	9	7
2,500,000	6,849		263	132	66	33	22	16	11	8
3,000,000	8,219		316	158	79	39	26	20	13	10
3,500,000	9,589		368	184	92	46	31	23	15	12
4,000,000	10,959		421	210	105	53	35	26	18	13
4,500,000	12,329		474	237	118	59	39	30	20	15
5,000,000	13,699		526	263	132	66	44	33	22	16
5,500,000	15,068		579	289	145	72	48	36	24	18
6,000,000	16,438		631	316	158	79	53	39	26	20

The Importance of Minimizing Pipe Volume

Heat Loss			Volume in Pipe That Cools Down							
		Gallons	0.0625	0.125	0.25	0.5	0.75	1	1.5	2
		Cups	1	2	4	8	12	16	24	32
Btu/Year	Btu/Day		Number of Times Per Day that Water in Pipe Cools Down							
500,000	1,370		53	26	13	7	4.4	3.3	2.2	1.6
1,000,000	2,740		105	53	26	13	9	7	4.4	3.3
1,500,000	4,110		158	79	39	20	13	10	7	5
2,000,000	5,479		210	105	53	26	18	13	[illegible]	7
2,500,000	6,849		263	132	66	33	22	16	[illegible]	8
3,000,000	8,219		316	158	79	39	26	20	13	10
3,500,000	9,589		368	184	92	46	31	23	15	12
4,000,000	10,959		421	210	105	53	35	26	18	13
4,500,000	12,329		474	237	118	59	39	30	20	15
5,000,000	13,699		526	263	132	66	44	33	22	16
5,500,000	15,068		579	289	145	72	48	36	24	18
6,000,000	16,438		631	316	158	79	53	39	26	20

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^oF temperature drop

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

Natural Gas Water Heater

- 500 ÷ 0.75 efficiency = 667 Btu/hour/^oF
- 667 ÷ 100,000 Btu/Therm = 0.00667 Therm/hour/^oF
- 0.00667 * $1.00/Therm = $0.00667/hour/$^oF$

Electric Water Heater

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

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

Continuous Pumping at 1 Gallon Per Minute				
	Temperature Drop in °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

Energy to Operate Heat Trace

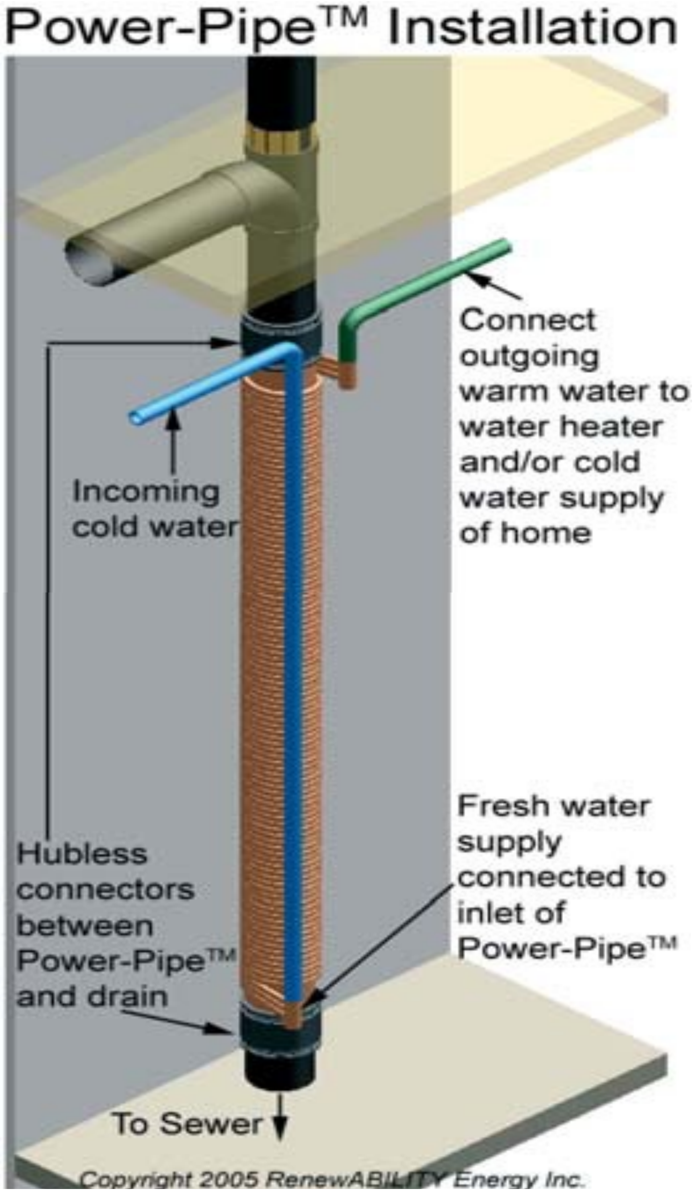
		Heat Trace		
		(kWh per year)		
		Trunk	Br	T-Br
Loop Heat Losses	**Supply Heat Losses**			
Natural Gas (therms)	High Temp	197	276	473
Electric (kWh)	Economy Temp	460	644	1,104
Pump Energy(kWh)	**Total Electricity**	657	920	1,577

A timeclock is programmed to maintain regular and economy temperature settings

50	feet
115	F temperature maintenance setpoint
1.8	watts per foot
6	hours per day
105	F temperature maintenance setpoint, economy
1.4	watts per foot
18	hours per day

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

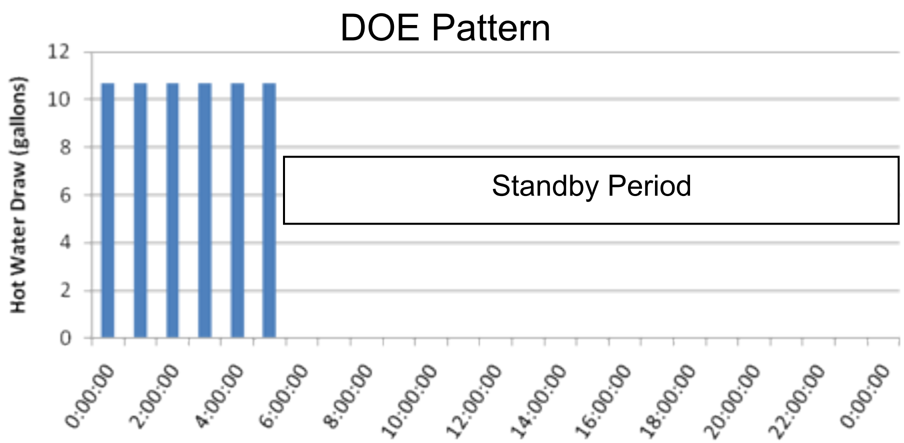
- How does this affect the operation of the water heater?
  - Tank versus tankless
- How does it impact temperature drop in the piping?

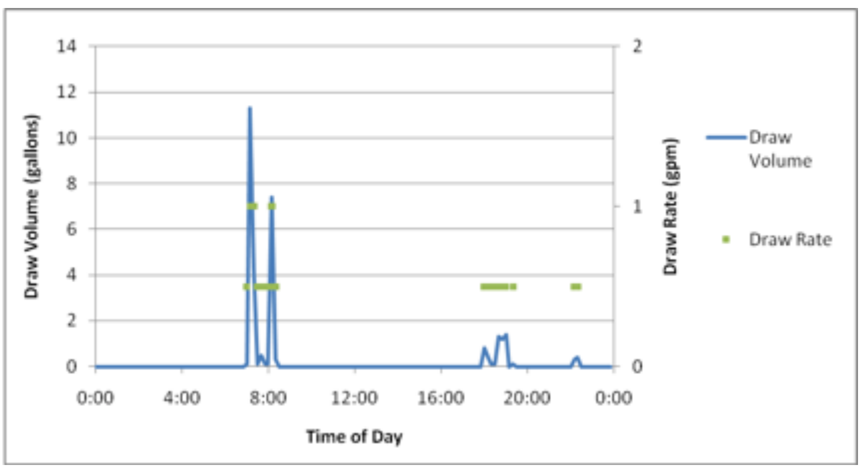
How Much is Hot? How Much is Cold?

		Percent of Mixed Temperature Water (105F) that is Hot										
		Hot Water Temperature (F)										
		110	115	120	125	130	135	140	145	150	155	160
Cold Water Temperature (F)	35	93%	88%	82%	78%	74%	70%	67%	64%	61%	58%	56%
	40	93%	87%	81%	76%	72%	68%	65%	62%	59%	57%	54%
	45	92%	86%	80%	75%	71%	67%	63%	60%	57%	55%	52%
	50	92%	85%	79%	73%	69%	65%	61%	58%	55%	52%	50%
	55	91%	83%	77%	71%	67%	63%	59%	56%	53%	50%	48%
	60	90%	82%	75%	69%	64%	60%	56%	53%	50%	47%	45%
	65	89%	80%	73%	67%	62%	57%	53%	50%	47%	44%	42%
	70	88%	78%	70%	64%	58%	54%	50%	47%	44%	41%	39%
	75	86%	75%	67%	60%	55%	50%	46%	43%	40%	38%	35%
	80	83%	71%	63%	56%	50%	45%	42%	38%	36%	33%	31%

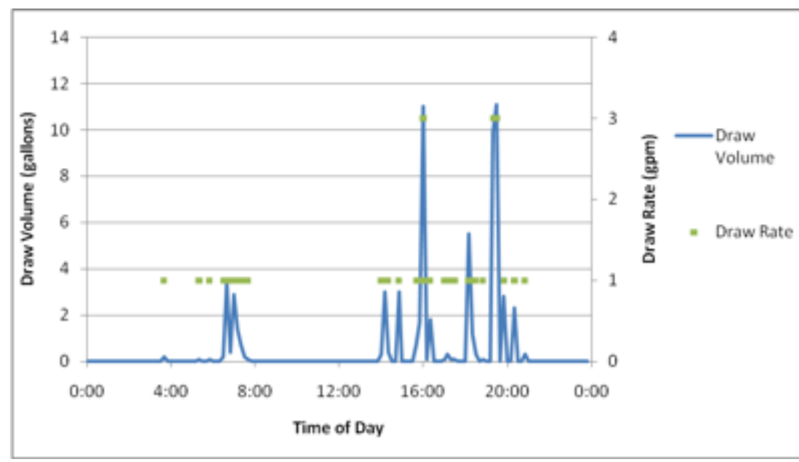
What We Have Learned About Water Heaters

Draw Patterns for Water Heater Tests





GTI Low Use Pattern (30 gal/day)



GTI Mid Use Pattern (64 gal/day)

Storage Water Heater Results

Operating Costs

2010 Mid CA Electricity Price	0.1575	$/kWh
2010 Average CA Natural Gas Price	0.9688	$/therm

		15 year old water heater	0.62 EF Atmos	0.67 EF Atmos/ Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/Fan Boost	Hybrid	Condensing Storage
Estimated Annual Operating Cost	DOE Standard EF	$239.74	$231.25	$229.17	$219.74	$236.53	$194.31	$208.69	$194.01
	GTI Mid Draw	$246.81	$246.10	$255.53	$244.03	$245.71	$242.43	$226.91	$206.41
	GTI Low Draw	$141.08	$136.13	$144.06	$129.85	$134.35	$136.18	$132.16	$103.31
Gas Consumed (therms)	DOE Standard EF	0.678	0.654	0.624	0.574	0.631	0.515	0.529	0.528
	GTI Mid Draw	0.698	0.696	0.699	0.637	0.655	0.650	0.573	0.562
	GTI Low Draw	0.399	0.385	0.384	0.338	0.357	0.352	0.319	0.280
Electricity Consumed (Whs)	DOE Standard EF	0	0	148.4	291.8	233.3	212.4	376.4	127.2
	GTI Mid Draw	0	0	145.5	326.9	245.3	219.0	422.7	133.7
	GTI Low Draw	0	0	144.0	179.8	141.2	203.8	336.8	74.8

Tankless Water Heater Results

Operating Costs

2010 Mid CA Electricity Price	0.1575	$/kWh
2010 Average CA Natural Gas Price	0.9688	$/therm

		Non-condensing	Condensing 1	Condensing with Buffer Tank (24 hr*)	Condensing with Buffer Tank (Inactive*)
Estimated Annual Operating Cost	DOE Standard EF	$201.74	$157.49	Not tested	
	GTI Mid Draw	$178.11	$168.47	$243.59	$170.29
	GTI Low Draw	$100.72	$84.03	Not tested	
Gas Consumed (therms)	DOE Standard EF	0.500	0.394		
	GTI Mid Draw	0.451	0.431	0.544	0.403
	GTI Low Draw	0.236	0.198	Not tested	
Electricity Consumed (Whs)	DOE Standard EF	433.9	313.6		
	GTI Mid Draw	322.9	278.8	889.3	485.5
	GTI Low Draw	300.5	245.0	Not tested	

*Indicates scheduling of internal recirculation pump

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.

Summary

- Review
- Any additional questions?

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

Thank You!

Gary Klein
Affiliated International Management, LLC.
P.O. Box 11752
Newport Beach, CA 92658-5040

Tel: 916-549-7080
Email: gary@aim4sustainability.com