We will be starting soon!

Thanks for joining us

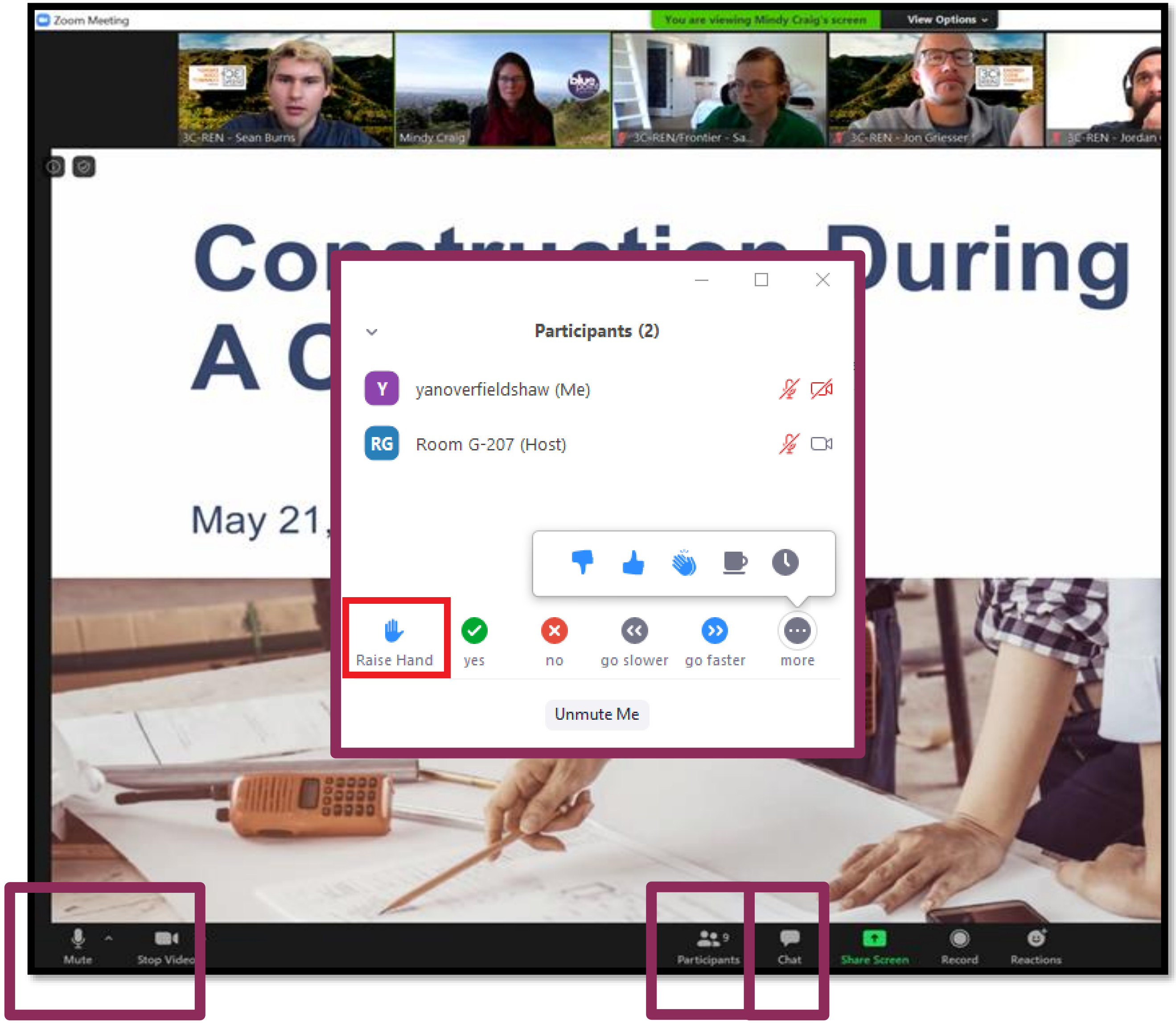
Best Practices for High-Performance Hot Water Systems

Gary Klein, Gary Klein Associates

October 4th, 2022

Zoom Orientation

- Please be sure your full name is displayed
- Please mute upon joining
- Use "Chat“ box to share questions or comments
- Under "Participant" select "Raise Hand" to share a question or comment verbally
- The session may be recorded and posted to 3C-REN's on-demand page. Feel free to ask questions via the chat and keep video off if you want to remain anonymous in the recording.



3C-REN: Tri-County Regional Energy Network

- Three counties working together to improve energy efficiency in the region
- Services for –
  - **Building Professionals:** industry events, training, and energy code compliance support
  - **Households:** free and discounted home upgrades
- Funded by ratepayer dollars that 3C-REN returns to the region

3C-REN
Staff Online

3C-REN ENERGY CODE CONNECT

3C-REN HOME ENERGY SAVINGS

3C-REN BUILDING PERFORMANCE TRAINING

3C-REN ENERGY CODE CONNECT

- Serves all building professionals
- Three services –
  - **Energy Code Coach**
  - **Training and Support**
  - **Regional Forums**
- Makes the Energy Code easy to follow

Energy Code Coach:
3c-ren.org/codes
805.220.9991

Event Registration:
3c-ren.org/events

3C-REN HOME ENERGY SAVINGS

Multifamily (5+ units)

- No cost technical assistance
- Rebates up to $750/apartment plus additional rebates for specialty measures like heat pumps

Single Family (up to 4 units)

- Sign up to participate!
- Get paid for the metered energy savings of your customers

3C-REN.org/home

3C-REN BUILDING PERFORMANCE TRAINING

- Serves current and prospective building professionals
- Expert instruction:
  - **Technical skills**
  - **Soft skills**
- Helps workers to thrive in an evolving industry

Event Registration:
3c-ren.org/events

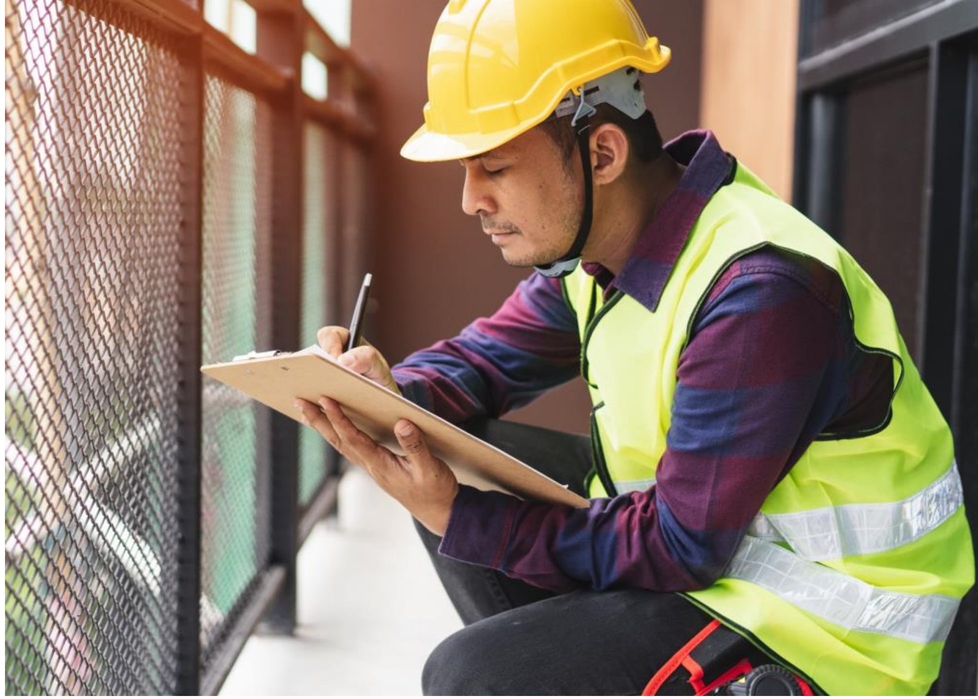
Introducing 3C-REN's new High-Performance Fundamentals (HPF) Program

Context

- “High performance” refers to buildings that are designed, built, and commissioned to achieve above-code, optimized performance.
- Specialized companies offering high-performance design and construction services in many parts of the State experience high demand, ongoing backlogs, and difficulty finding qualified new hires.

Goals

- Prepare aspiring building practitioners to for competitive job opportunities.
- For those in the industry, provide a refresher or supplement prior building science knowledge



Content

- Developed in consultation with dozens of national experts in high-performance building businesses
- Based on the foundational knowledge they are looking for in new hires
- Rooted in the fundamentals of building science and the design, construction, and business practices that distinguish high-performance practitioners from their conventionally-trained competitors

Classes

1. High-Performance Buildings and Careers: ~~June 21~~
2. The Role of Building Science in High-Performance Buildings: ~~May 17 & 19~~
3. Enclosure Best Practices: Air Sealing, Insulation, Testing & Metrics: ~~July 12~~
4. Heat Pump Fundamentals: Space Conditioning and Water Heating: ~~September 13~~
5. Water Heating Distribution Best Practices: ***This class!***
6. How To Assess a Home for Electrification: ***November 15***

Other HPF Program Elements

3C-REN's plans for further program development include:

- Formal certificate of completion
- Field-based, hands-on classes to complement initial series of lecture classes
- Mentorship and/or peer learning activities to support participants' learning process

Best Practices for High-Performance Hot Water Systems

3C-REN
October 4, 2022

Gary Klein

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916-549-7080

Today’s Topics

1. How things are now with hot water system design, and why that's not good enough.
2. Understanding the hot water use patterns for each occupancy.
3. Understanding the “service(s)” of hot water desired by these occupants.
4. Designing source(s) of hot water close to the uses in new construction & additions.
5. Minimizing pressure drop and optimizing velocity in the piping.
6. Insulating hot water piping.
7. Providing a method to prime trunk lines with hot water shortly before use in both new construction and existing buildings.
8. Selecting (hot) water-efficient fixtures, fittings, and appliances.
9. Capturing waste heat from hot water running down the drain and using it to preheat incoming cold water.
10. Selecting efficient, climate-friendly, water heaters matched to the uses and patterns.

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
- An even larger percentage in multi-family
    - Fewer exposed walls
    - More people per square foot
- How much do we spend on hot water?

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
  - 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.

Water Consumption 1980-2017

Water-using Fixture or Appliance	1980s Water Use (typical)	1990 Requirement (maximum)	EPAct 1992 Requirement (maximum)	2009 Baseline Plumbing Code (maximum)	"Green Code" Maximums (2017 CALGreen)	% Reduction in avg water use since 1980s
Residential Bathroom Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.2 gpm	66%
Showerhead	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	1.8 gpm	49%
Residential ("private") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Commercial ("public") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Urinal	1.5 to 3.0+ gpf	1.5 to 3.0+ gpf	1.0 gpf	1.0 gpf	0.125 gpf	**96%**
Commercial Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
Food Service Pre-Rinse Spray Valve	5.0+ gpm	No requirement	1.6 gpm *(EPAct 2005)*	No requirement	1.3 gpm	74%
Residential Clothes Washing Machine	51 gallons per load	No requirement	26 gallons per load *(2012 std)*	No requirement	12.6 gallons per load *(Energy Star)*	75%
Residential Dishwasher	14 gallons per cycle	No requirement	6.5 gallons per cycle *(2012 std)*	No requirement	3.5 gallons per cycle *(Energy Star)*	75%

From 1980 to 2017: Reductions range from 49 to 96%

Source: *The Drainline Transport of Solid Waste in Buildings*, PERC 1 Report - J. Koeller, P. DeMarco

Issues We Face

1. Flow rates have been reduced
2. Distances to fixtures have increased
3. Potential for simultaneous flow is generally overestimated
4. Code requirements for minimum pipe diameters have not been revised since before flow rates were reduced
5. Codes and efficiency and green programs generally focus on components, not the hot water system
6. 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 2 Key Services…

Hot Water Now = "Instantaneousness"

- Hot water available before the start of each draw
  - A tank with hot water
  - Heated pipes
- Source of hot water close to each fixture or appliance
- Point of use is not about water heater size, it's about location

Never Run Out in My Shower = "Continuousness"

- Large enough tank or large enough burner or element
- Or a modest amount of both

The Key Components of a Hot Water System

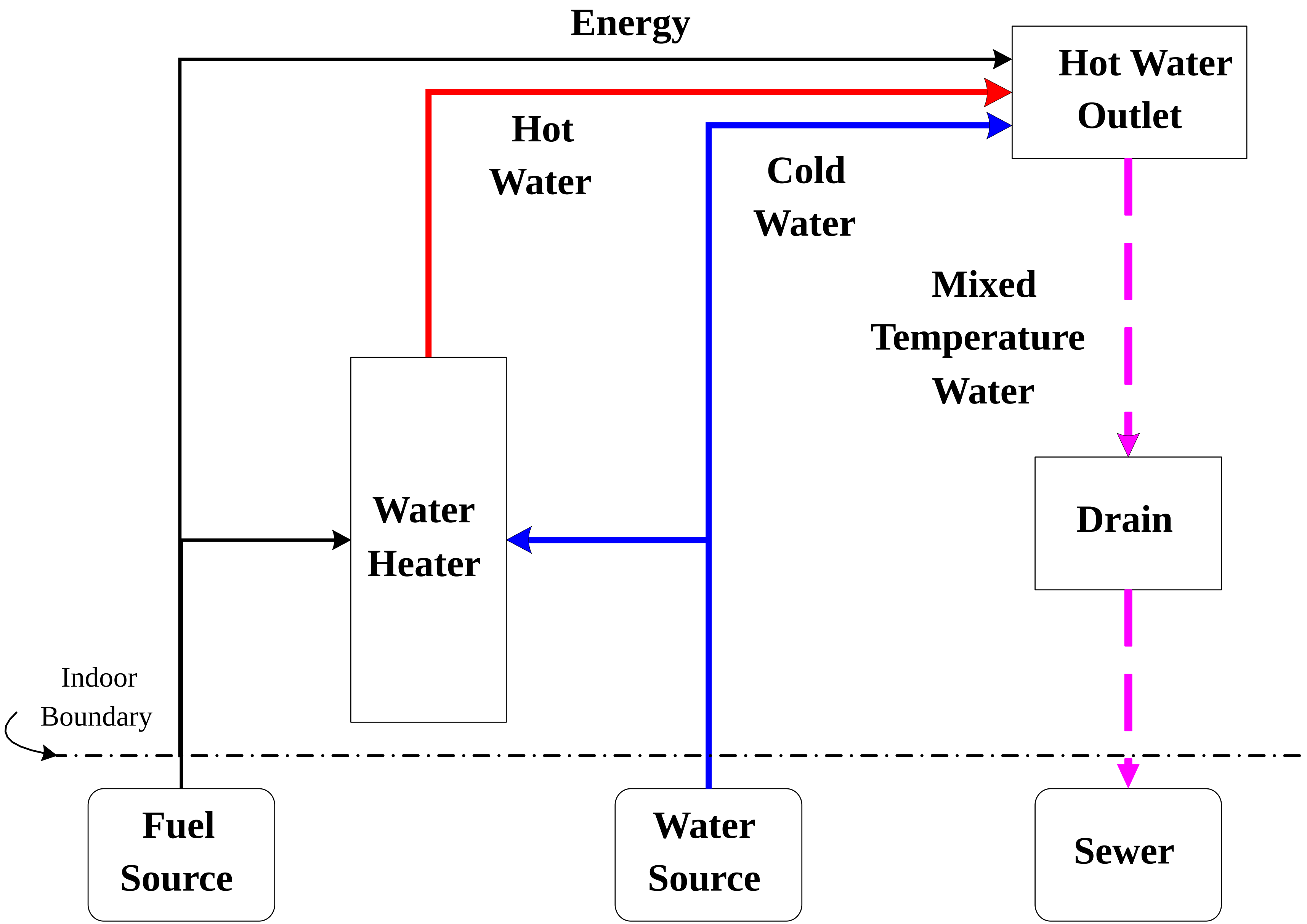
The Hot Water System

- 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

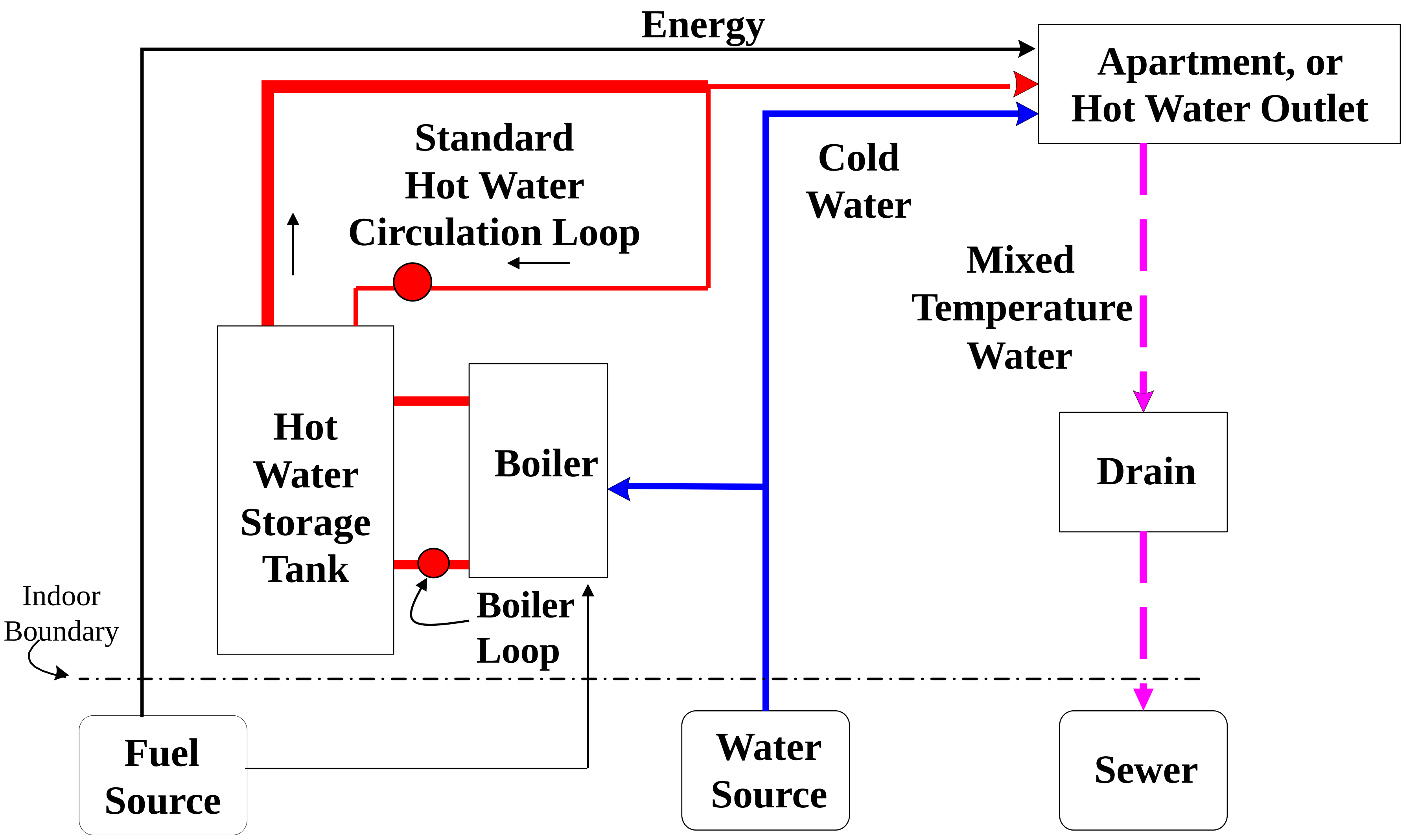
Which is the biggest ***variable*** in determining water and energy use?

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

Typical "Simple" Hot Water System



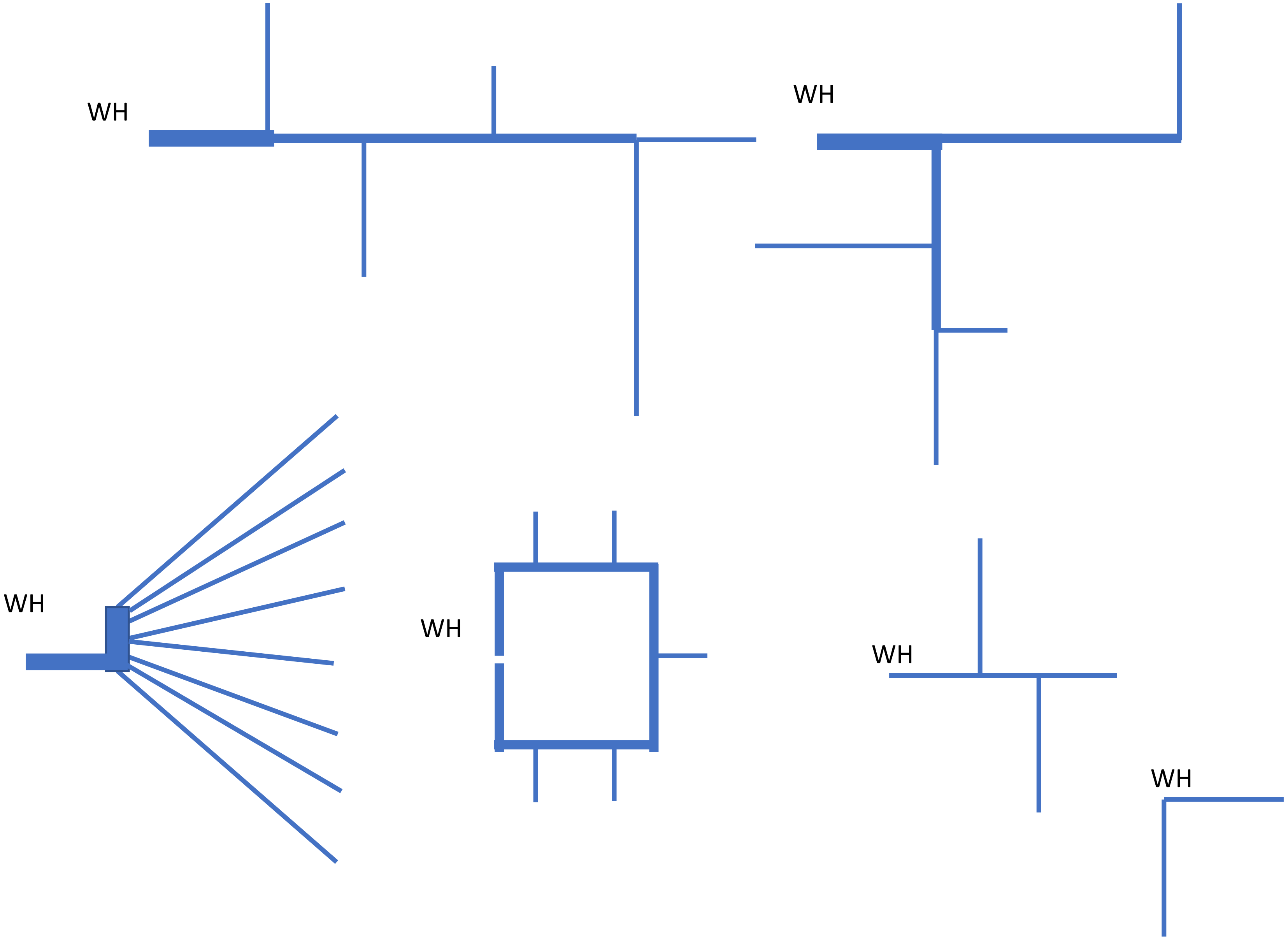
Typical Central Boiler Hot Water System



Definitions for Water Supply Piping

1. A **twig** line serves one outlet or appliance.
   - The twig diameter 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.

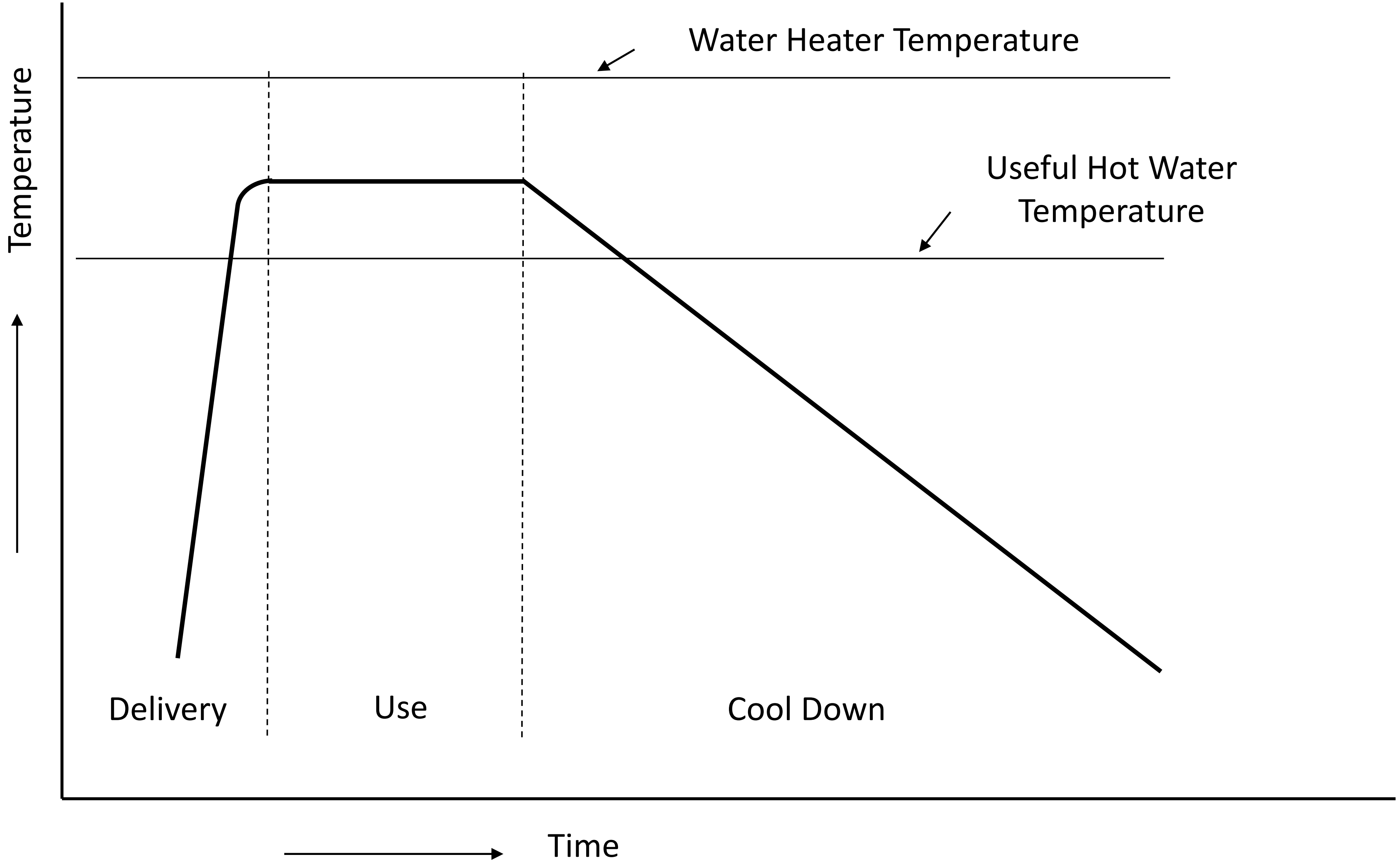
Layout Methods



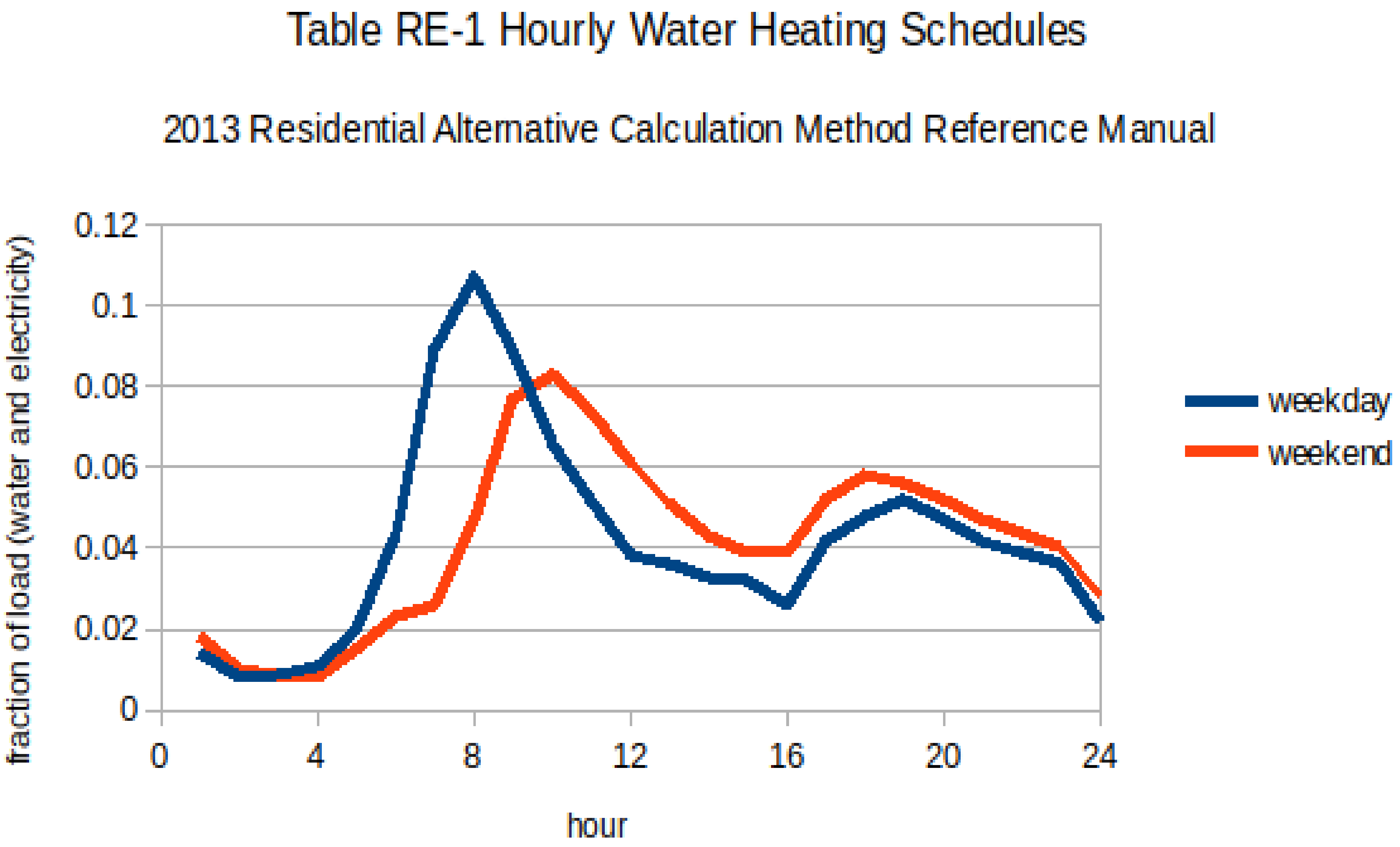
Do You Know:

- *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"?

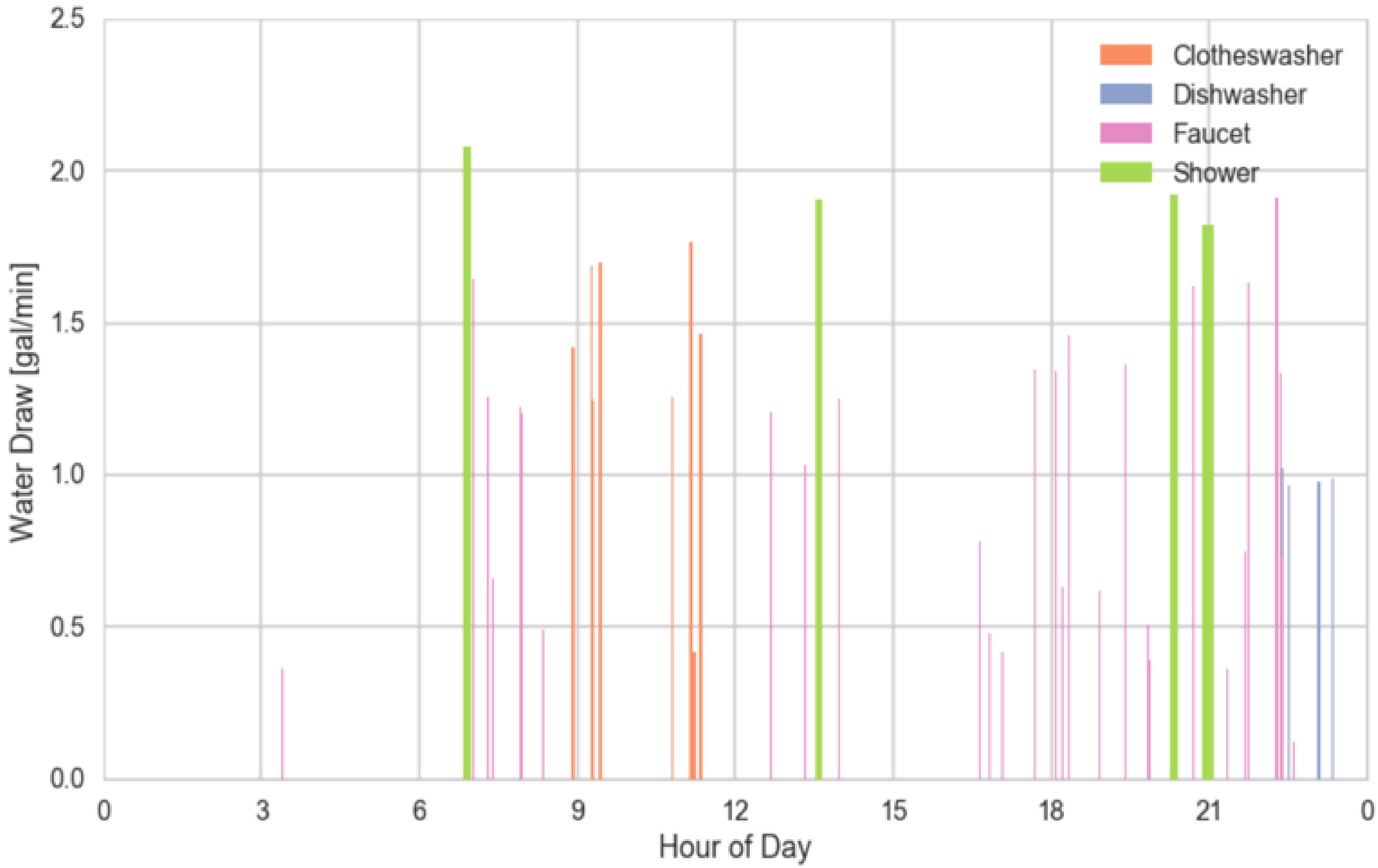
Typical Hot Water Event



Traditional Daily Hot Water Load



Actual Daily Hot Water Load



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

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

Research has shown there can only be about 1/2 cup!

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!

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

CTS = Copper Tube Size, same outside diameters.

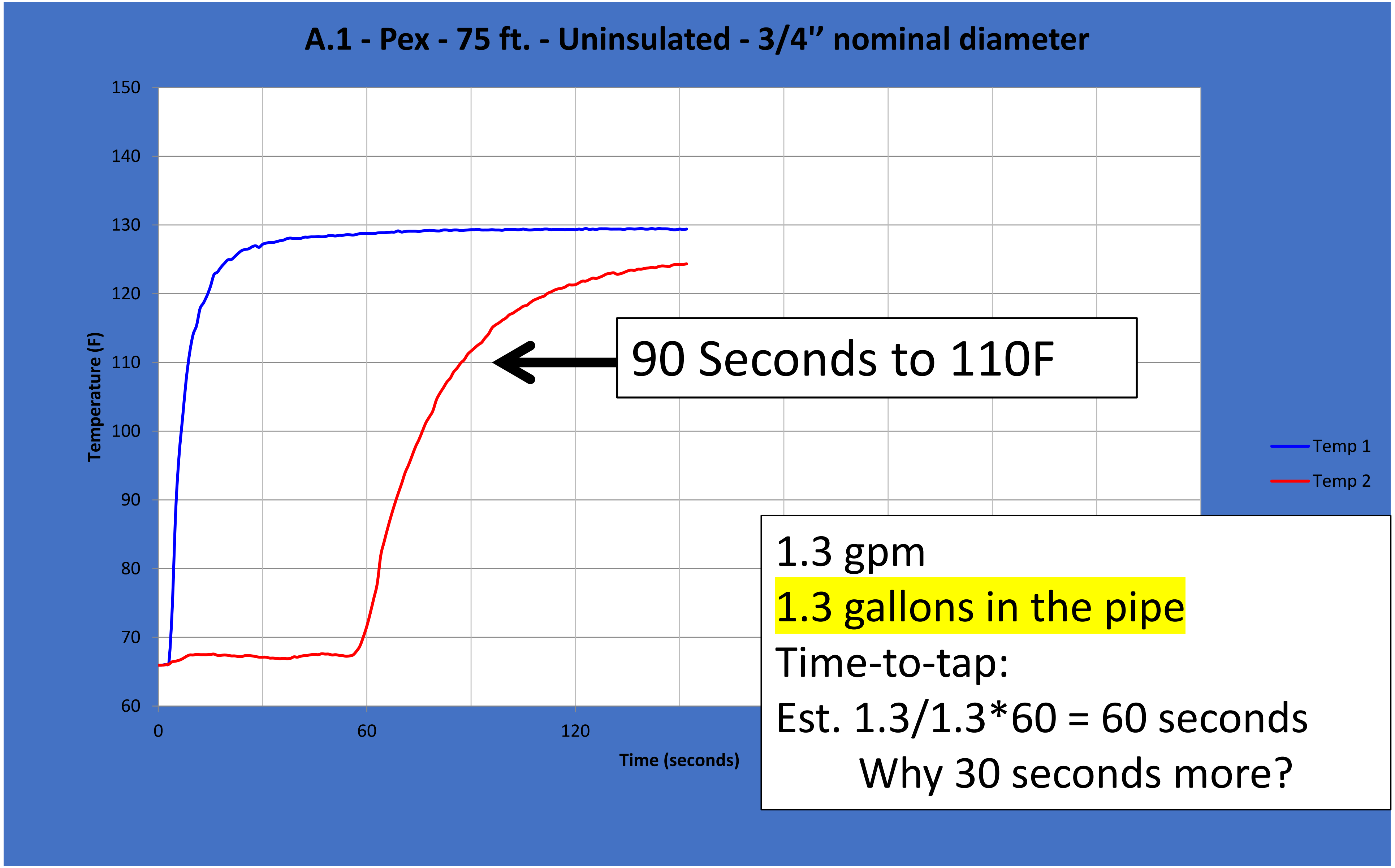
If You Were Plumbing, How Much Beer Would You Hold?
http://homeenergy.org/show/article/nav/hotwater/id/2271

Time-to-Tap and Volume-until-Hot

How Close Can We Get?

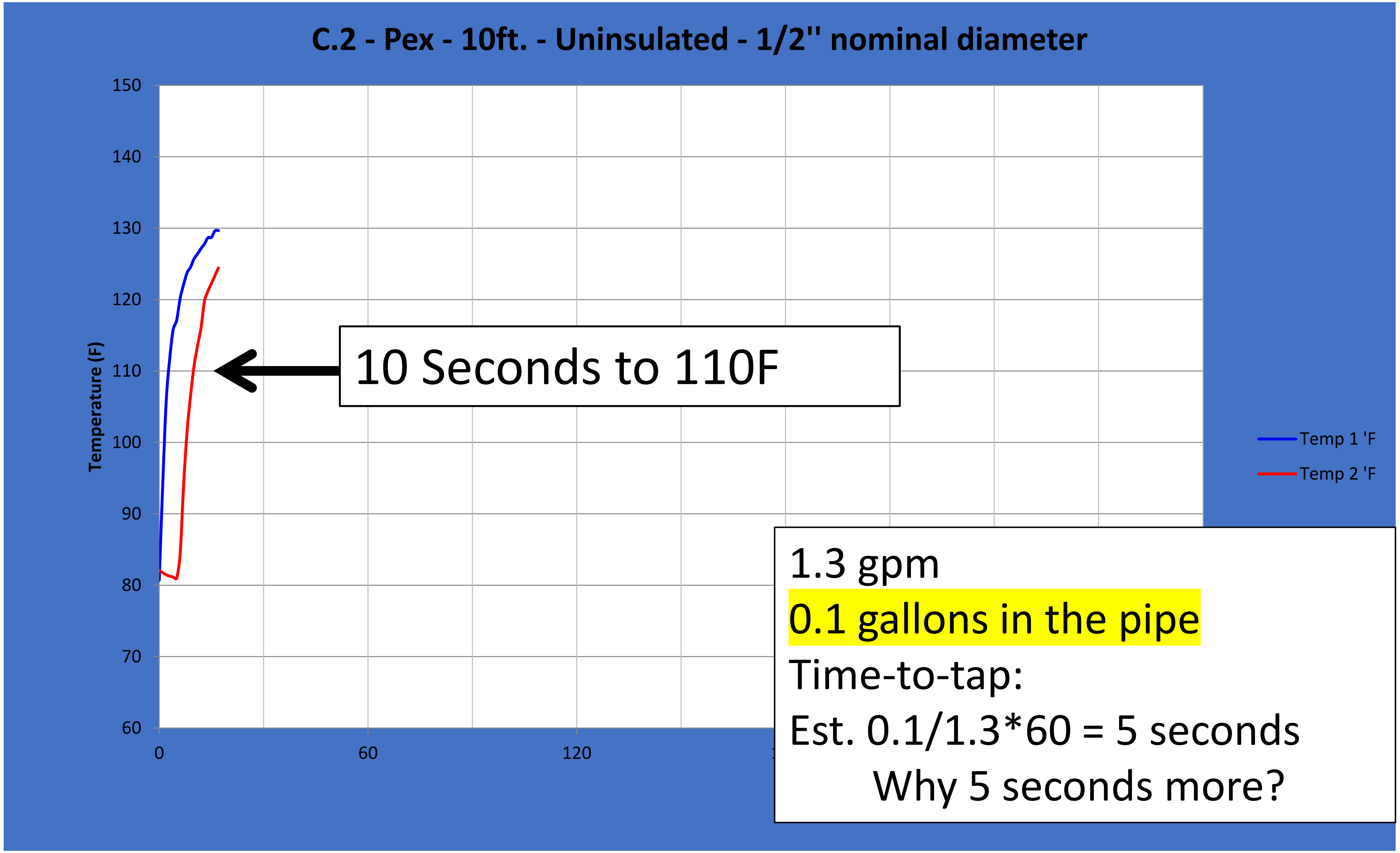
- Unless the heater is **in the fixture or appliance**, there will always be some volume in the pipe between the source and the use.
- It takes roughly 2x the volume in the pipe for hot water to come out the other end. (examples on next 2 slides)
- What is an "acceptable" **time-to-tap** or **volume-until-hot?** Work backwards to determine the maximum allowable in the pipe between source and use.
  - Plumbing up from below: **about 5 feet**
  - Plumbing down from above: **about 10 feet**

Demonstrating Performance-1



1.3 gpm
1.3 gallons in the pipe
Time-to-tap:
Est. 1.3/1.3*60 = 60 seconds
Why 30 seconds more?

Demonstrating Performance-2



1.3 gpm
0.1 gallons in the pipe
Time-to-tap:
Est. 0.1/1.3*60 = 5 seconds
Why 5 seconds more?

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

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~~ 1	4	1.9	0.9	0.6	0.5	0.4
~~4~~ 2	8	4	1.9	1.3	0.9	0.8
~~8~~ 4	15	8	4	2.5	1.9	1.5
~~16~~ 8	30	15	8	5	4	3
~~24~~ 12	45	23	11	8	6	5
~~32~~ 16	60	30	15	10	8	6
~~64~~ 32	120	60	30	20	15	12
~~128~~ 64	240	120	60	40	30	24

Cut the pipe volume in half to get these times

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

For volume per foot see 2018 UPC Table L 502.7 or 2018 IPC Table E 202.1

Calculating Time-to-Tap and Volume-to-Hot

Time-to-tap (seconds) = Feet * (Ounces/foot) *(1 gallon/128 ounces) / gpm * 1 minute/60 seconds

$$= \frac{\text{Feet} * 1\ \text{oz} * 1\ \text{gallon} * 1\ \text{minute} * 60\ \text{seconds}}{1\ \text{foot} * 128\ \text{oz} * 1\ \text{gallon} * 1\ \text{minute}}$$

= 0.46875 * Feet * ounces/foot * gallons per minute

Volume-to-Hot (gallons)

$$= \frac{\text{Feet} * 1\ \text{oz} * 1\ \text{gallon}}{1\ \text{foot} * 128\ \text{oz}}$$

Adjustment = Range of extra volume or time until hot is 1.5-2.5

≅ 2 * time in seconds based on pipe volume

≅ 2 * gallons in the pipe

How Do We Increase **Customer Satisfaction?**

1. Reduce the **Time-to-Tap**
   a) Reduce the Distance from the Source to the Use
   b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the **Pressure Drop**
   a) In the Pipe and Fittings
      1) Minimize the length
      2) Minimize the number of pressure-consuming fittings
   b) In the Faucets and Shower Valves
3. Install **Pressure-Independent Faucet Aerators and Showerheads**

1.a) Reduce the Distance from Source to Use

- The shorter the pipe, the less time it takes.
  - The smaller the pipe diameter, the less time it takes too!
- ***But***, the lower the flow rate, the longer it takes.
- How long is too long to wait?
  - 5 seconds? 10 seconds? Longer? Shorter?

Water-, energy-, and time-efficient hot water systems start with deciding how long we want people to wait.

The decision on the location of the wet-room(s) and the mechanical room(s) is made by the architect.

Better floor plans can lead to better hot water system performance.

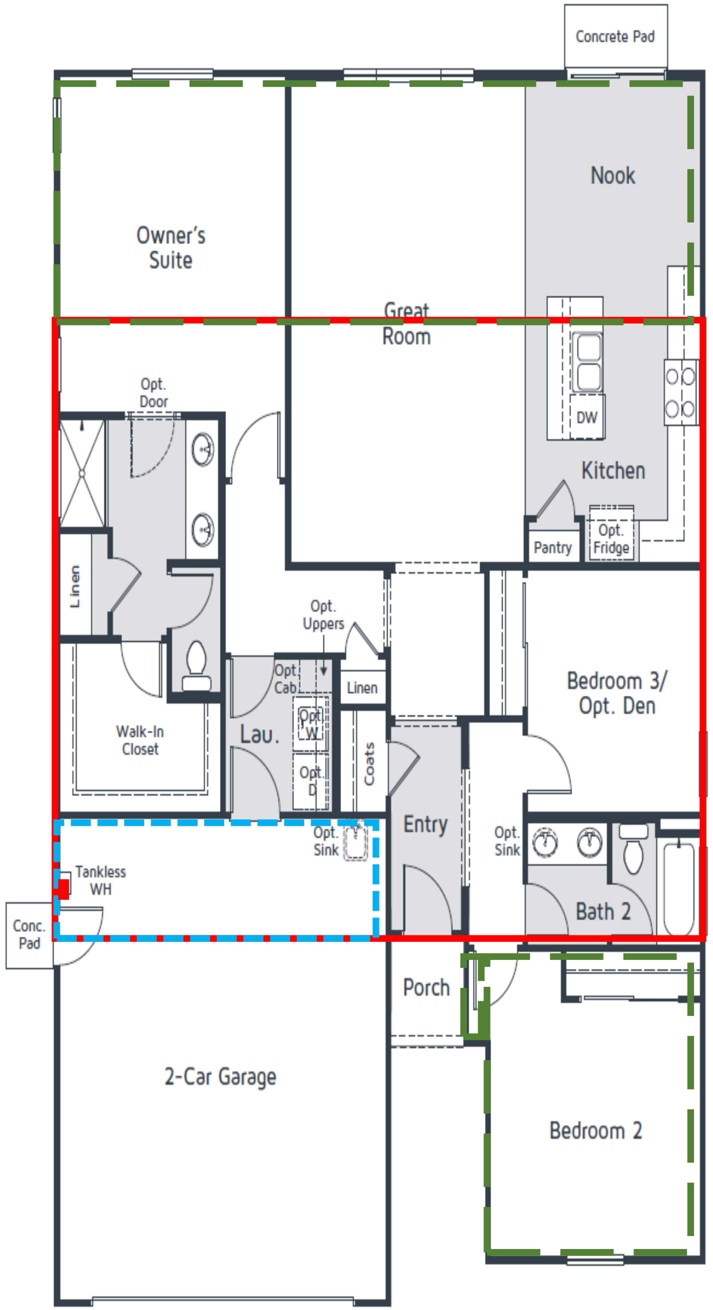
Better floor plans decrease the residence time in the premise plumbing system (hot and cold) too!

Example:

1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA

Hot Water System Rectangle

~67% (1137 sq ft) of the floor area



Relationship between the Hot Water System and the Floor Area – The Logical Worst Case

Number of Stories	Hot Water System/ Floor Area (%)
1-story	100%
2-story	50%
3-story	33.3%
4-story	25%
5-story	20%

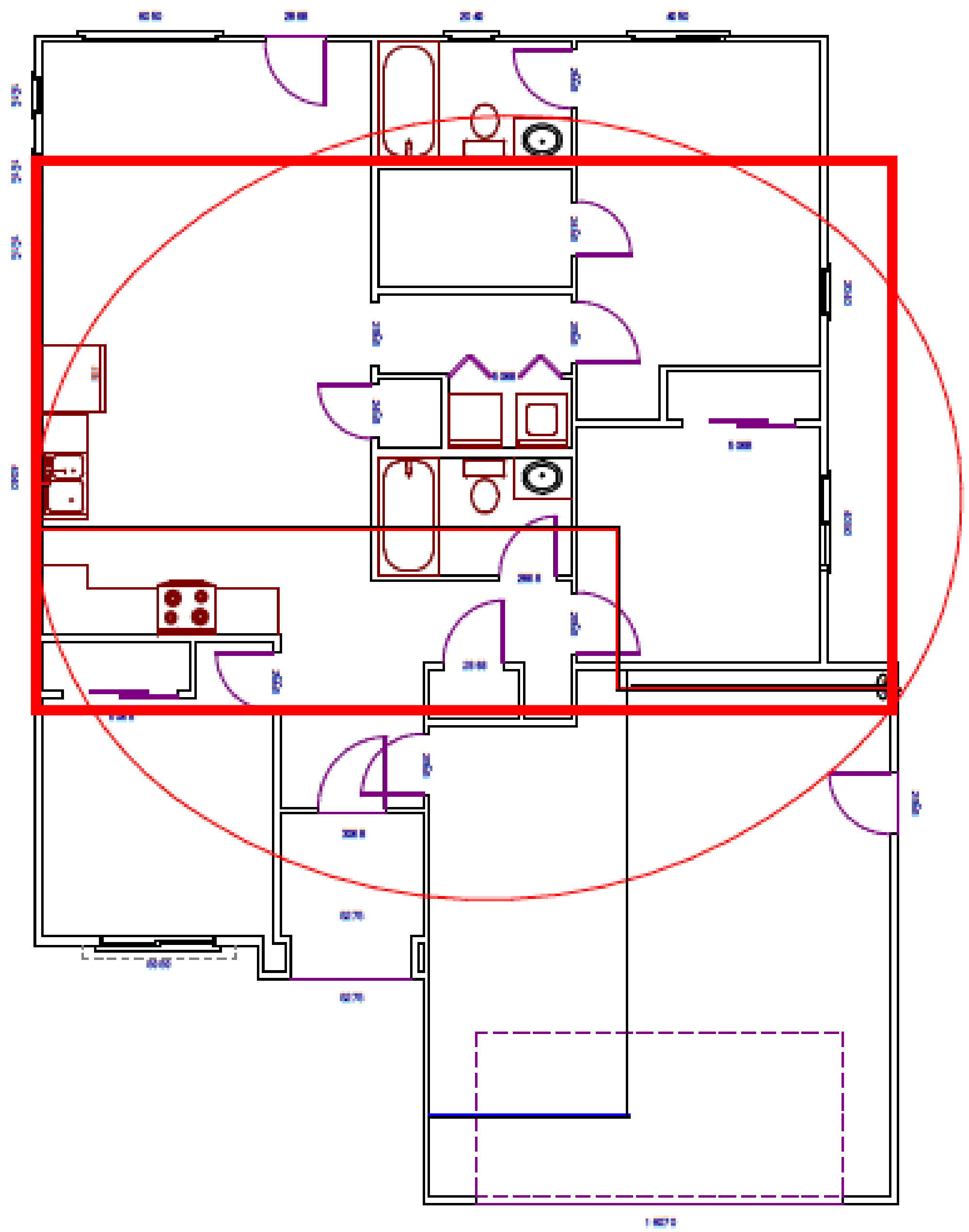
Basements count as stories if they contain wet rooms.

Best 1-Story So Far…

In the beginning:

1 Story
3 Br/2 Ba
1,619 sq ft
Stockton, CA

~79%
(1,279 sq ft)



1st iteration v1:

1 Story

3 Br/2 Ba

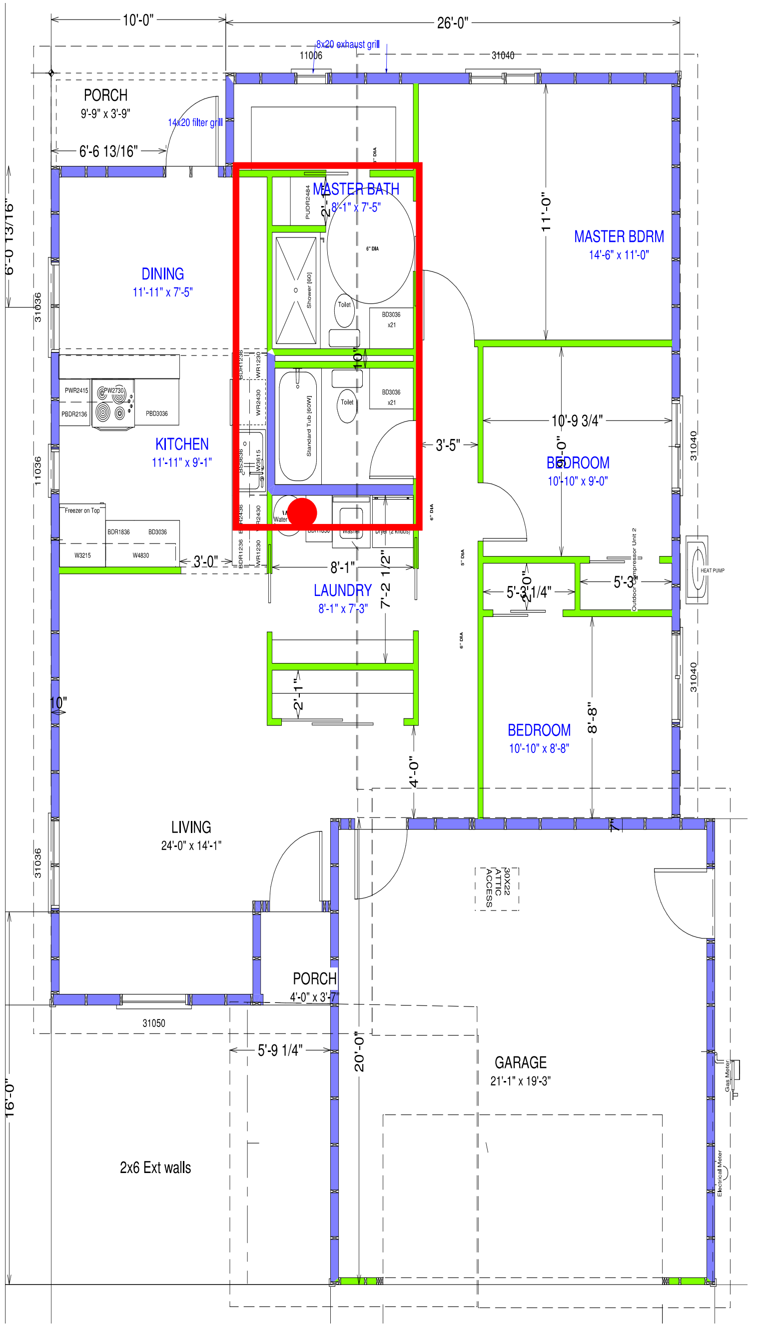
1,223 sq ft

Stockton, CA

~15%

(183 sq ft)

(when bounding the hot water plumbing fixtures and appliances)



1st iteration v2:

1 Story

3 Br/2 Ba

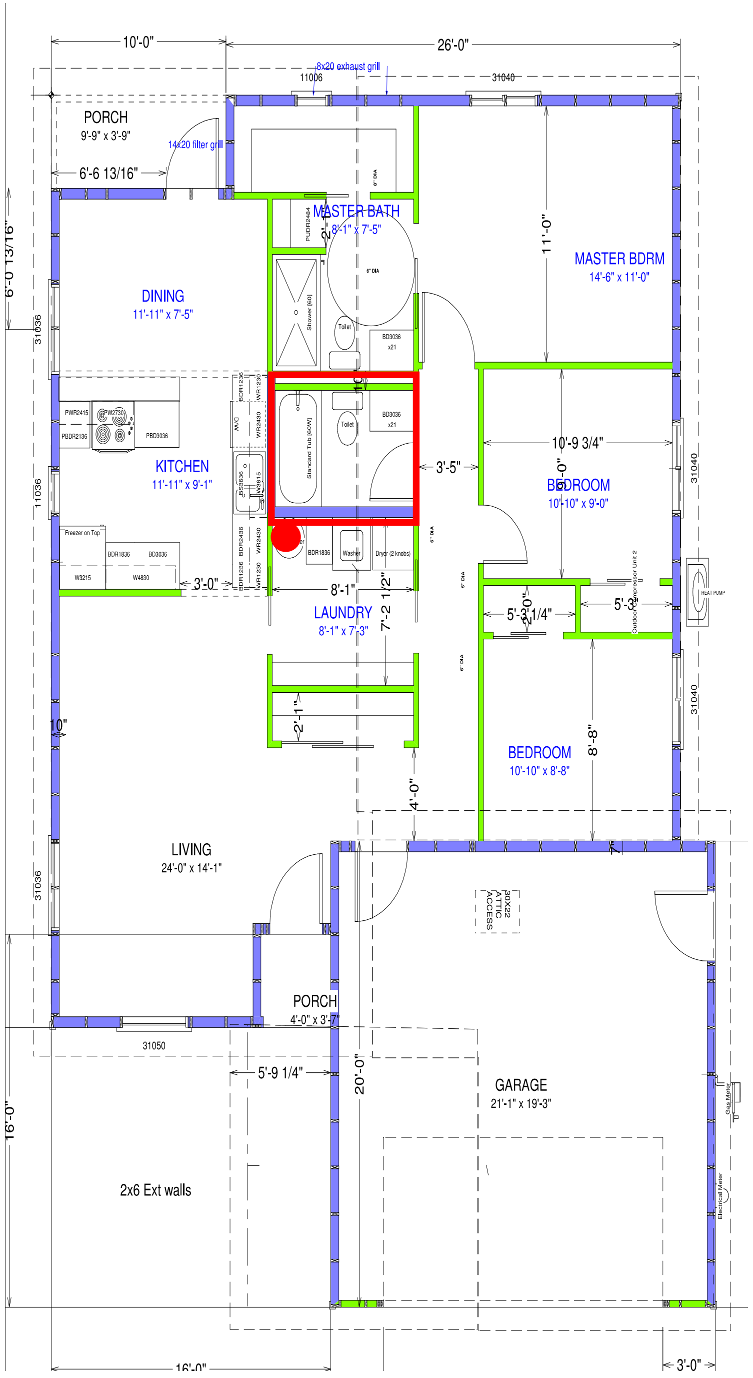
1,223 sq ft

Stockton, CA

~4%

(49 sq ft)

(when bounding the plumbing walls)



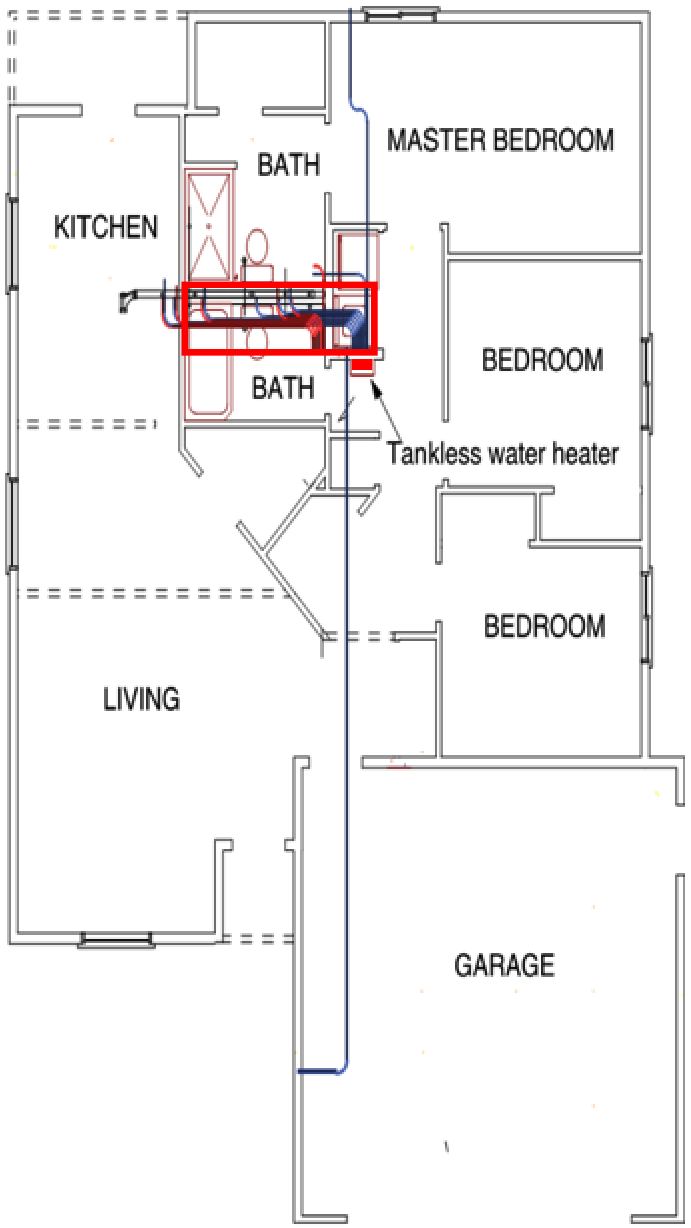
2nd iteration:

1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

~2.5%

(30 sq ft)

(when bounding the plumbing walls)



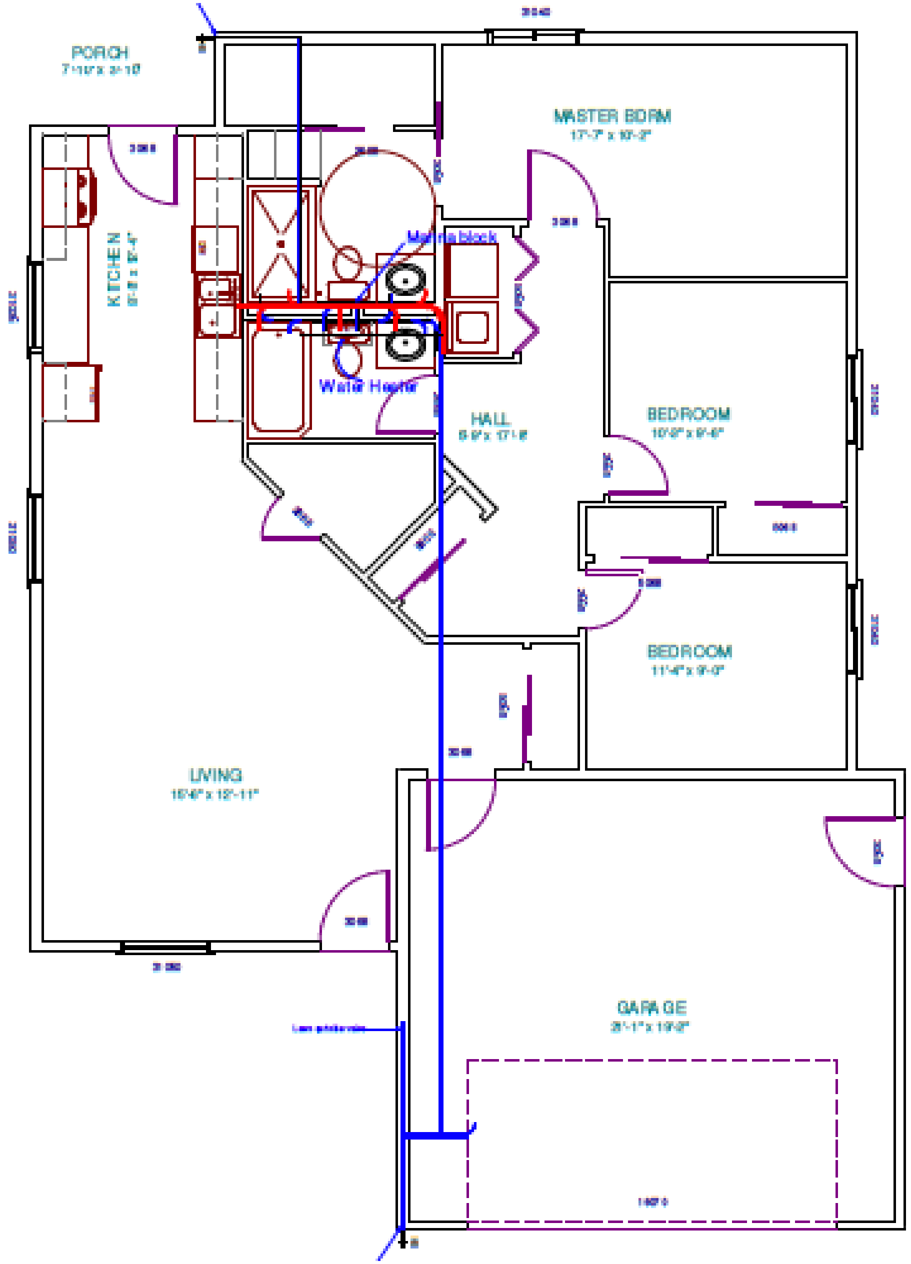
3rd iteration:

1 Story
3 Br/2 Ba
1,245 sq ft
Stockton, CA

~0.8%

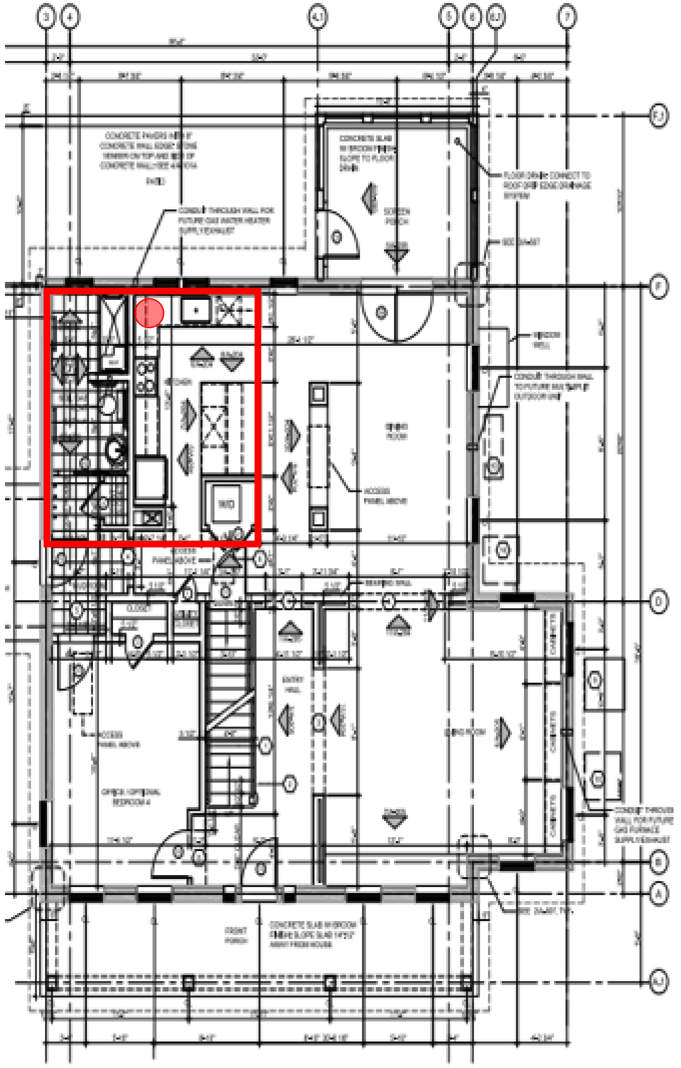
(< 10 sq ft)

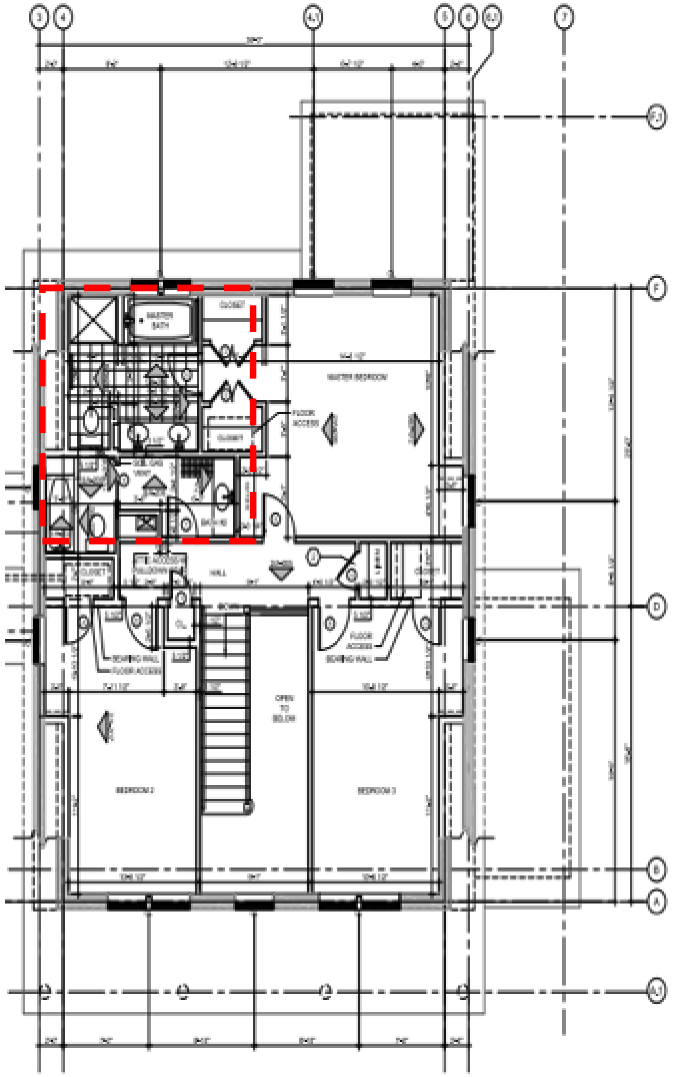
(1 short
plumbing wall)

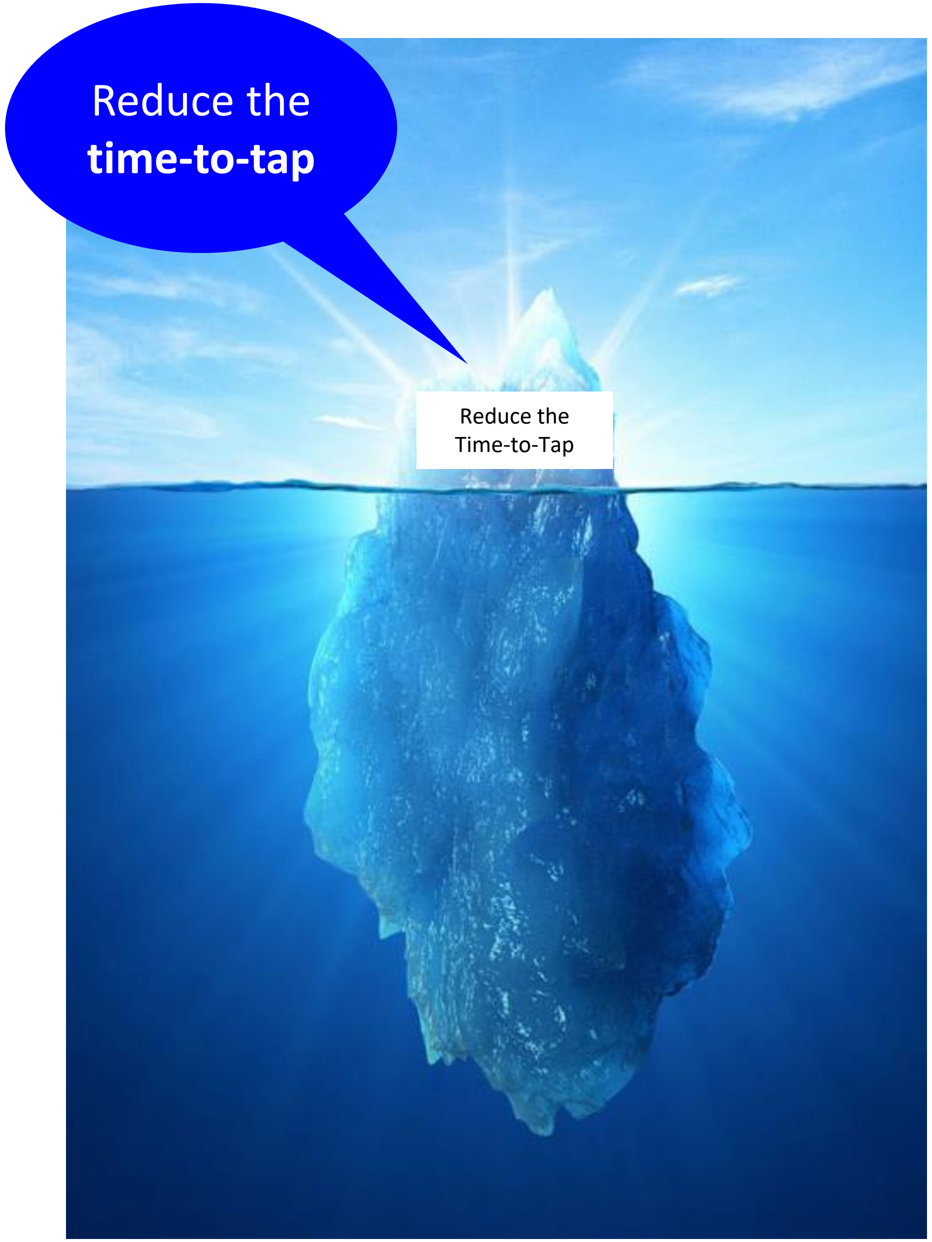


Best 2-Story So Far…

2 Story, 4Br / 3Ba, 2,709 sq ft
Gaithersburg, MD **~12%** (325 sq ft)







Increase Customer Satisfaction

Save money by:
Water efficient floor plans
Smaller diameter piping

Savings: ≈ $1,000-$2,000 per single-family dwelling

Code Changes and Implications of Residential Low-Flow Hot Water Fixtures CEC-500-2021-043
https://www.energy.ca.gov/publications/2021/code-changes-and-implications-residential-low-flow-hot-water-fixtures

1.b Right-Size the Plumbing

Which Pipe Sizing Method(s) do you use?

1. International Code Council (ICC)
   a. International Residential Code (IRC)
   b. International Plumbing Code (IPC)
   c. Local adoption as amended?
   d. NYS Stretch Code – IECC
2. International Association of Plumbing and Mechanical Officials (IAPMO)
   a. Uniform Plumbing Code (UPC)
   b. Local adoption as amended?
   c. **UPC Appendix M – Water Demand Calculator**
3. American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)
4. American Society of Plumbing Engineers (ASPE)
5. Others?

What is the Water Demand Calculator (WDC)?

An alternative method for **estimating the demand load for the building water supply** & principal branches for single- and multi-family dwellings

Water Demand Calculator (WDC v2.0)

PROJECT NAME : 6th Avenue

Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building→ 24

Total Apartments in this Calculation→ 24

Tuesday, July 27, 2021
6:24 PM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.54	5.5	5.5
	2	Bidet	0	0.60	2.0	2.0
	3	Combination Bath/Shower	24	2.08	5.5	5.5
	4	Faucet, Lavatory	24	1.37	1.5	1.5
	5	Shower, per head (no Bathtub)	0	1.42	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	0.60	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.36	1.3	1.3
	8	Faucet, Kitchen Sink	24	1.37	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	2	2.01	3.5	3.5
	10	Faucet, Laundry		1.37	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.37	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.00	0.0	6.0
	13	Fixture 2	0	0.00	0.0	6.0
	14	Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation	n = 74
99th Percentile Demand Flow	Q = 17.5 GPM
Hunter Number	H(n,p) = 1.20
Stagnation Probability	Pr[Zero Demand] = 30%

DOWNLOAD RESULT

RESET WDC

↓ Select Units for Water Demand ↓

RUN WDC

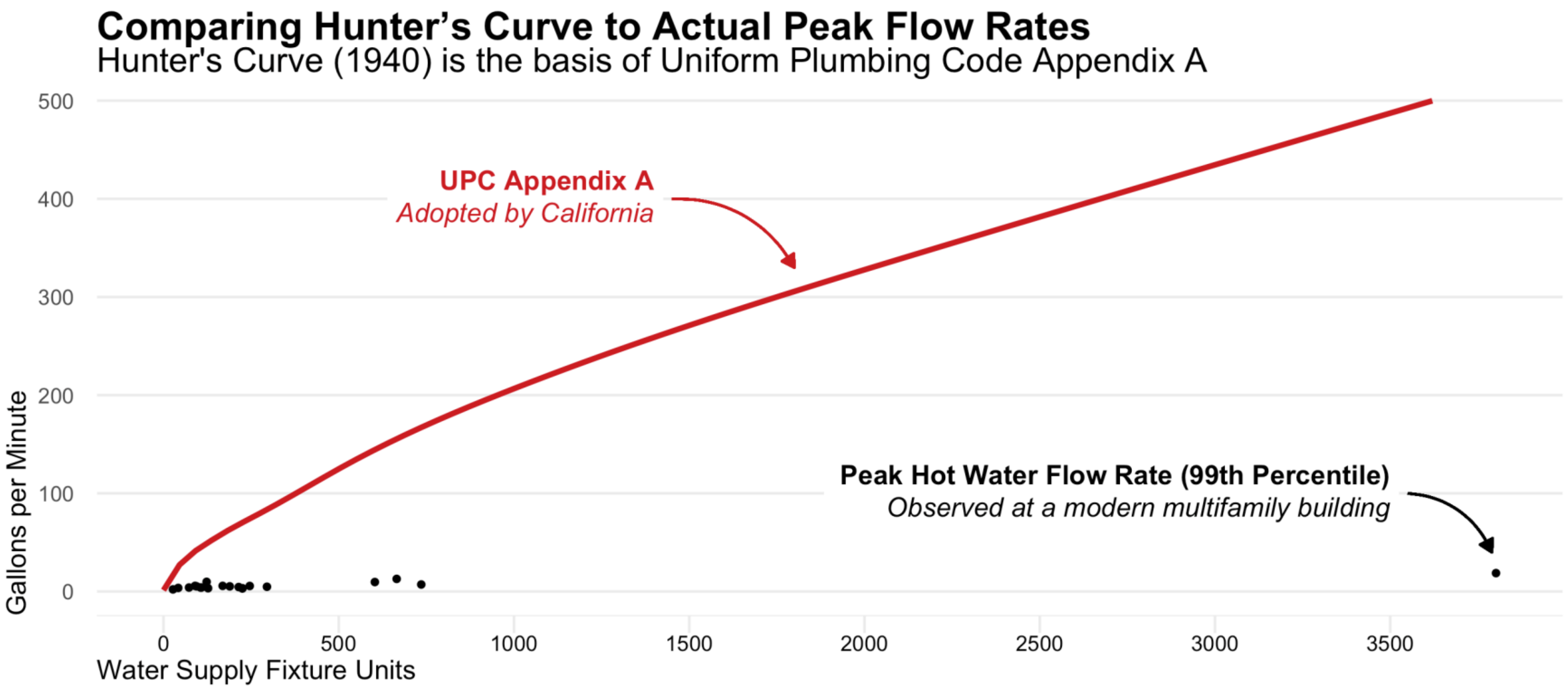
2021 UPC, Appendix M "Peak Water Demand Calculator" http://epubs.iapmo.org/2021/UPC/#p=453 and https://www.iapmo.org/water-demand-calculator
2017 Study on Peak Water Demand by S. Buchberger et al. (basis for Water Demand Calculator) https://www.iapmo.org/media/3857/peak-water-demand-study-executive-summary.pdf

Benefits of Using the WDC

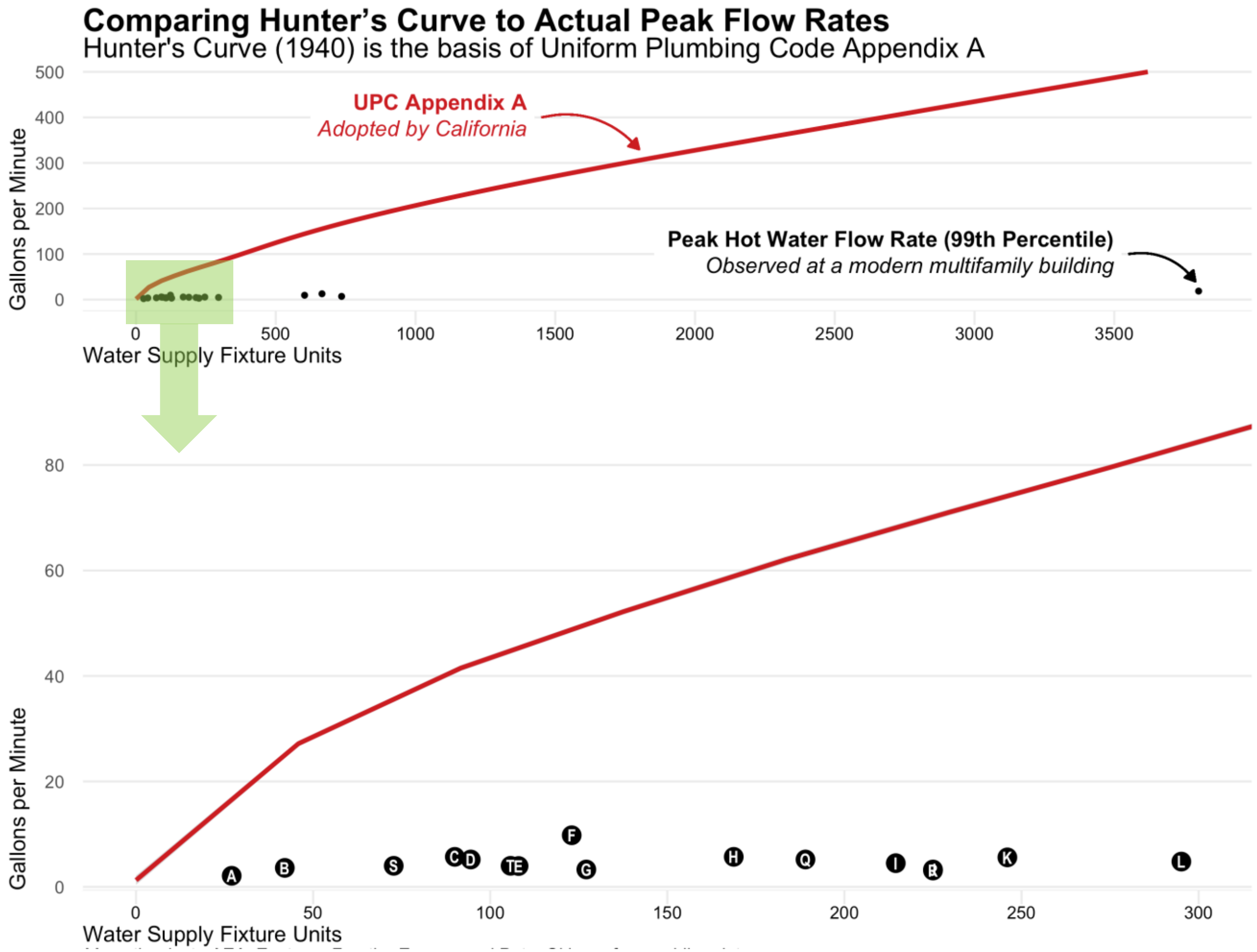
- **Water and embedded energy savings** due to faster hot water delivery times
- **Additional energy savings** due to decreased heat loss in distribution system, particularly in multifamily buildings with a recirculation system
- **Reduced public health and safety risk** and improved water quality due to shorter water dwell times in plumbing systems
- **Construction cost savings** due to smaller diameter pipes and fittings, less pipe insulation material, and reduced water service entrance size

2020 Study on Water Demand Calculator by Stantec (assessment of cost savings from using Water Demand Calculator)
https://www.iapmo.org/group/update/stantec-wdc-savings-study
2021 Report on Connection Fees and Service Charges by Meter Size by Alliance for Water Efficiency (assessment of cost savings from downsizing meters)
https://www.iapmo.org/media/25939/awe-meter-size-connection-fee-research.pdf

Standard Practice Overestimates Peak Flow Rates



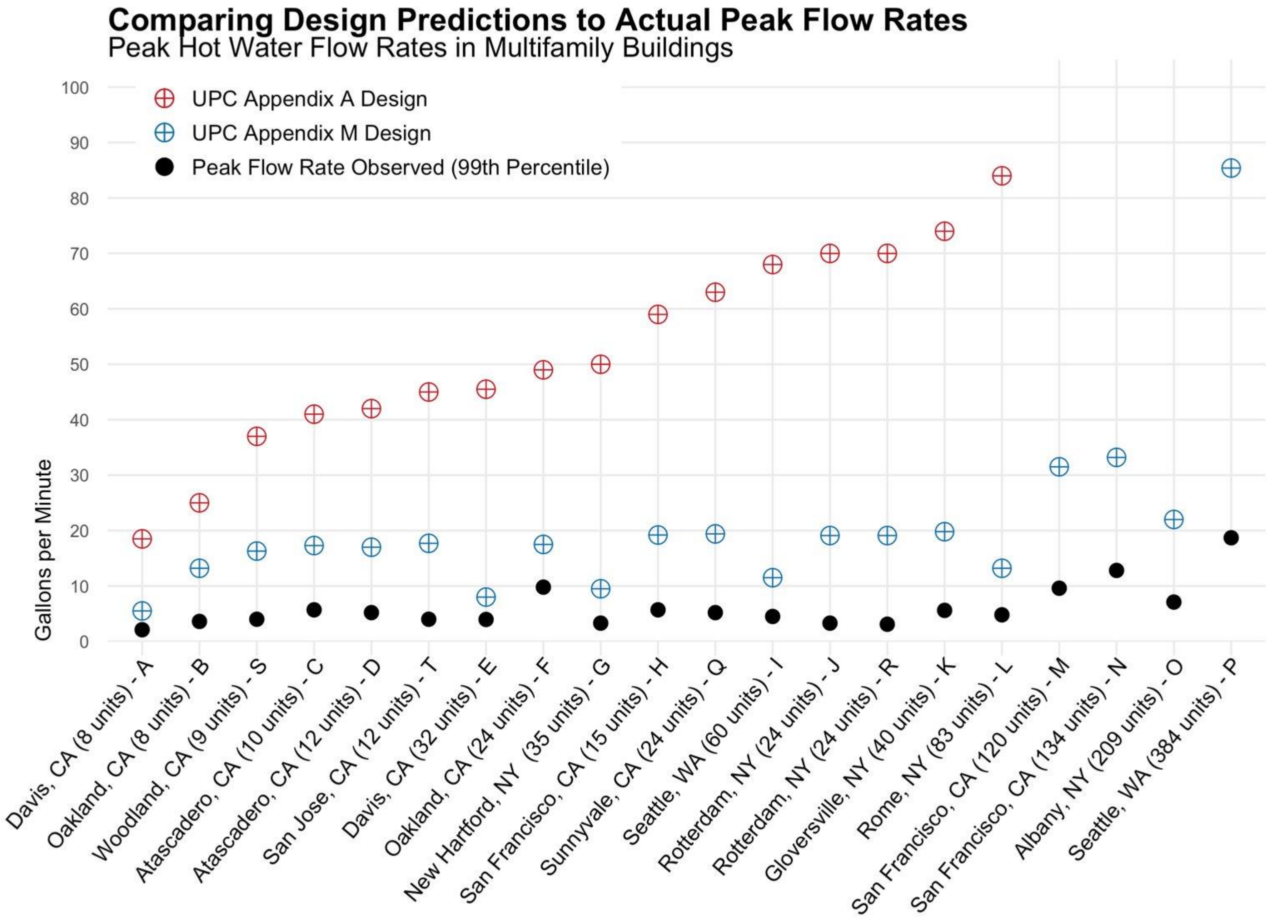
The Original Hunter Papers: The Foundation of Plumbing Engineering https://www.aspe.org/product/the-original-hunter-papers-the-foundation-of-plumbing-engineering/
2021 UPC, Appendix A "Recommended Rules for Sizing the Water Supply System" https://epubs.iapmo.org/2021/UPC/#p=326



Actual flow rates from **20 multifamily buildings** ranging from 8 to 384 apartments

Observed peak hot water flow rates 80-96% less than the peak predicted using UPC Appendix A (standard practice)

Many thanks to Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and UC Davis Western Cooling Efficiency Center for providing data.



UPC Appendix M design value is at least 1.8x the measured flow rates in multifamily buildings.

Monitoring period ranged from 9 days to over 2 years and logging interval ranged from 1 to 60 seconds depending on the building.
Out of order letters are for four buildings that were added after the submittal of the original 11/3/2021 petition to California state agencies.

Many thanks to Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and UC Davis Western Cooling Efficiency Center for providing data.

92-Unit Apartment Building	Savings
Time-to-Tap	Increased Satisfaction
Right Size Piping	$5,000
Right Size the Rest of the Plumbing	$5,000
Right Size the Water Heater	$30,000
Right Size the Water Meter	$16,000 – $68,000
Total First Cost Savings	**$58,000 – $108,000**
First Cost Savings/Apartment	**$600 – $1,200**
Annual Operational Savings (Does not include energy and sewer)	**$1,800 - $3,600**

How Do We Increase Customer Satisfaction?

1. Reduce the Time-to-Tap
    a) Reduce the Distance from the Source to the Use
    b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the Pressure Drop
    a) In the Pipe and Fittings
        1) Minimize the length
        2) Minimize the number of pressure-consuming fittings
    b) In the Faucets and Shower Valves
3. Install Pressure-Independent Faucet Aerators and Showerheads

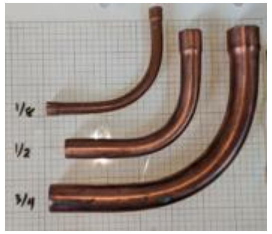
Measuring Pressure Drop in Modern Pipe and Fittings

Downey, CA

Arcata, CA

Pipe from ¼ inch to ¾ inch Nominal

Elbows – Copper Type-L

Technology (Copper)	**Image**
Elbow (tight inside corner)	
Long Radius Sweep	
Swoop®	

Also, copper tees and CPVC elbows and tees.

Elbows - PEX

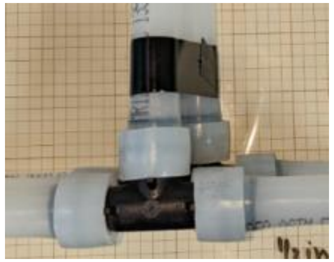
Technology (PEX)	Image
Poly Push to Connect Inner Seal ¾ in	 
Brass Push to Connect Outer Seal ¾ in	 
Brass Crimp ¾ in	
Poly Crimp ¾ in	

Technology (PEX)	Image
Brass Press ½ in	
Poly Press ½ in	
Bend Support	
Poly Expansion ¾ in	

Couplings

Technology (PEX)	Image
Poly Press ¾ in	
Brass Press ¾ in	
Poly Expansion ½ in	

Tees

Technology (PEX)	Image
Poly Press ½ in	
Brass Press ½ in	
Poly Expansion ½ in	

At 3 gpm, the pressure loss through 1/2 inch
Copper fittings is about 0.05 psi
CPVC fittings is about 0.2 psi
PEX fittings ranges from 0-2 psi

Pressure Drop Through Anti-Scald Tub/Shower and Shower Valves

At 1.8 gpm, the variation in pressure loss through the valves is 4-13 psi. How much is left for the shower head?

How Do We Increase Customer Satisfaction?

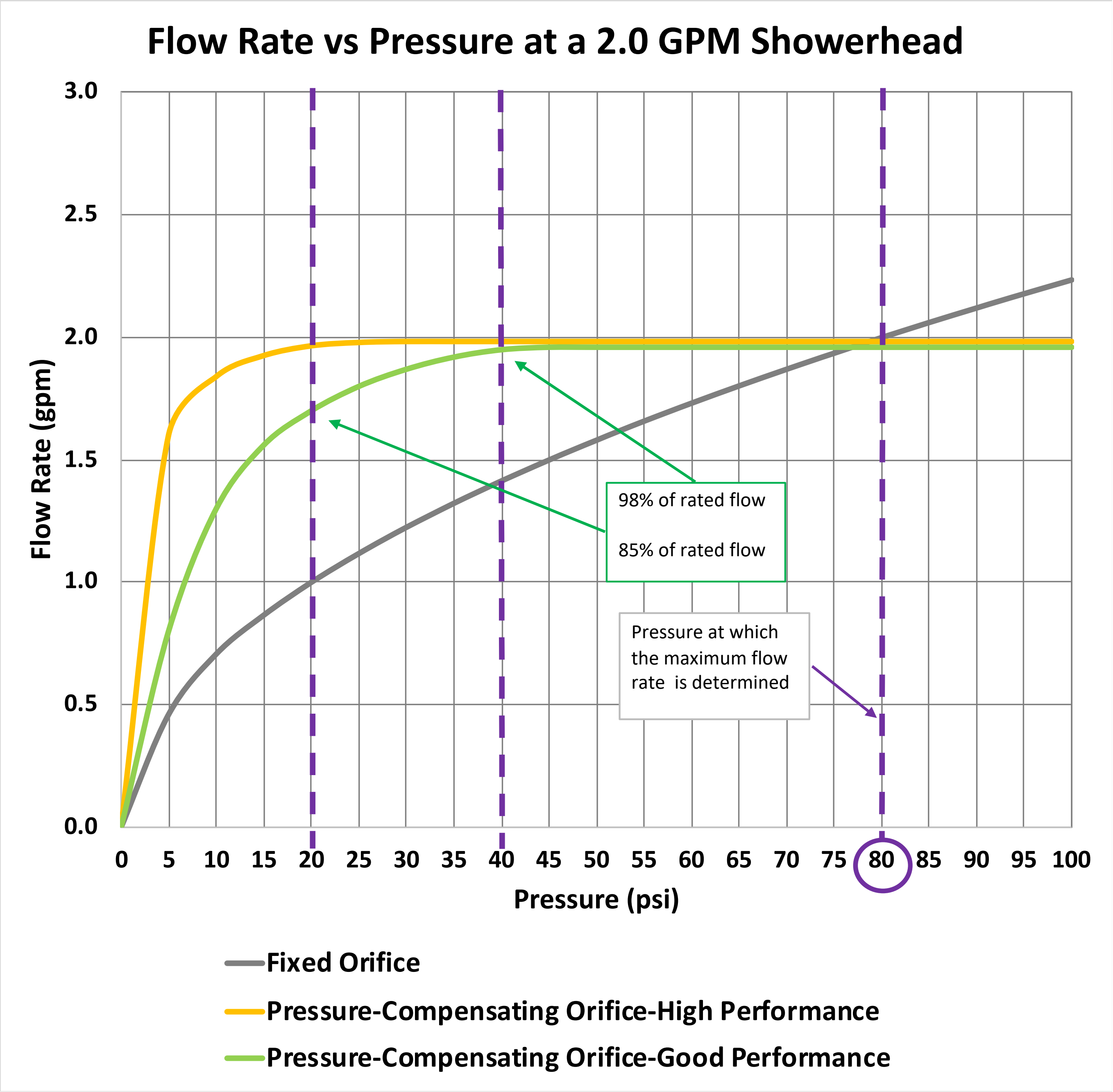
1. Reduce the Time-to-Tap
   a) Reduce the Distance from the Source to the Use
   b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the Pressure Drop
   a) In the Pipe and Fittings
      1) Minimize the length
      2) Minimize the number of pressure-consuming fittings
   b) In the Faucets and Shower Valves
3. Install Pressure-Independent Faucet Aerators and Showerheads

Low-Flow and High-Efficiency Fixtures

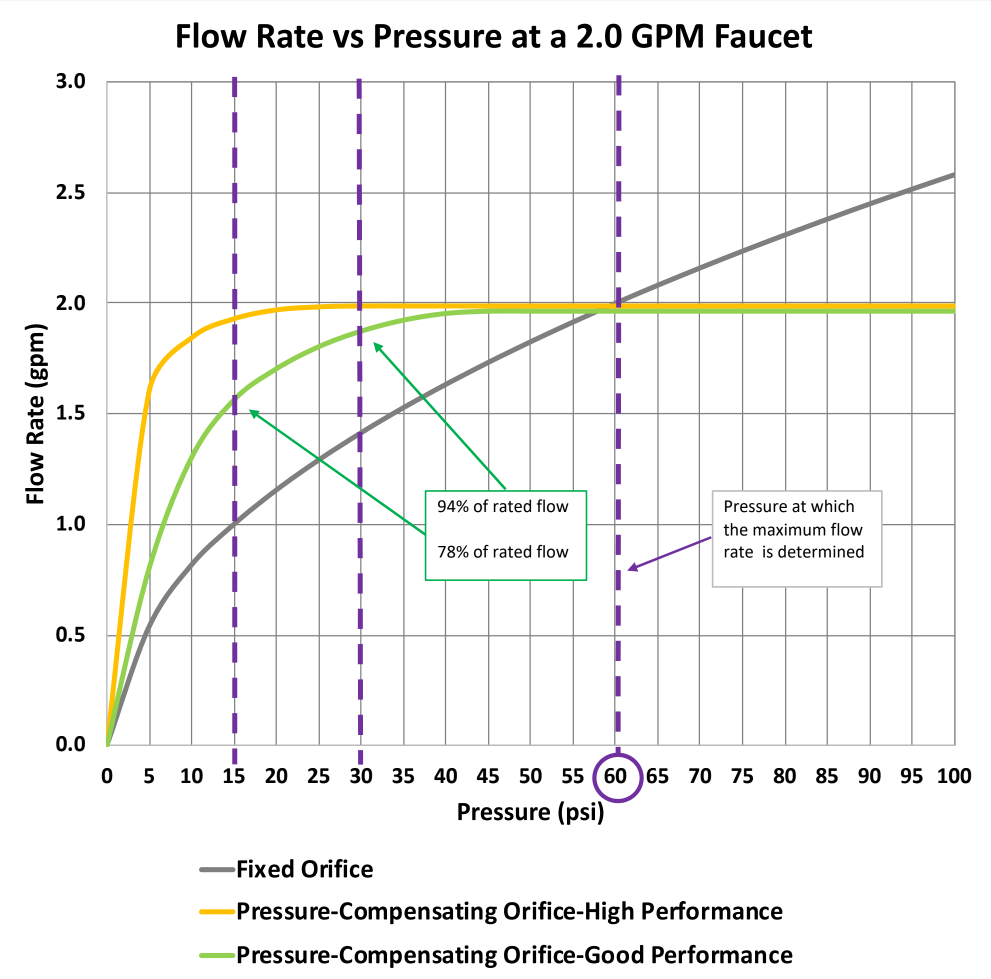
The current Federally required maximum flow rates are designated as "low-flow", whereas the lower volumes adopted by California and others are designated separately as "high-efficiency".

Hot water-using plumbing fixtures and fixture fittings	Maximum water consumption		
	Federal Standard	2016 CalGreen, Part 11 (mandatory)	Title 20, Article 4, Sections 1605.1 & 1605.3
Lavatory faucet-private	2.2 gpm	1.2 gpm	1.2 gpm
Lavatory faucet-public	2.2 gpm	0.5 gpm	0.5 gpm
Metering faucet-residential	0.25 gpc	0.25 gpc	0.25 gpc
Metering faucet-nonresidential		0.20 gpc	
Kitchen faucet	2.2 gpm	1.8 gpm	1.8 gpm
Showerheads	2.5 gpm	2.0 gpm	1.8 gpm

Which one do you want?



Which one do you want?



Select Good or High-Performance Faucet Aerators to Increase Customer Satisfaction.

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.

How many ways are there that reduce the energy needed to run the pump and also reduce the thermal losses of the loop by more than 80%?

The Theory

Operating Costs of Circulation Loops

- Pump
- Heat loss in the loop
- Maintenance
  - Failure of the pump
  - Incorrect control settings
  - Pipe leaks
- What percent of the energy costs are due to the pump? To losses in the loop?

Heat Loss in Circulation Loops – Calculation for Loop Losses Only

Sample Calculation: 1 gpm and 1°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°F = 500 Btu/hour/°F

Natural Gas Water Heater

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

Electric Water Heater

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

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 5°F

50-watt pump

Demand-Controlled Priming:

85-watt pump

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

The Practice

Control Strategies We Tested

The intent was to determine the energy it takes to provide hot water quickly anywhere, anytime, regardless of changing schedules

- Continuous Circulation
- Aquastat – Low, Medium and High Speed

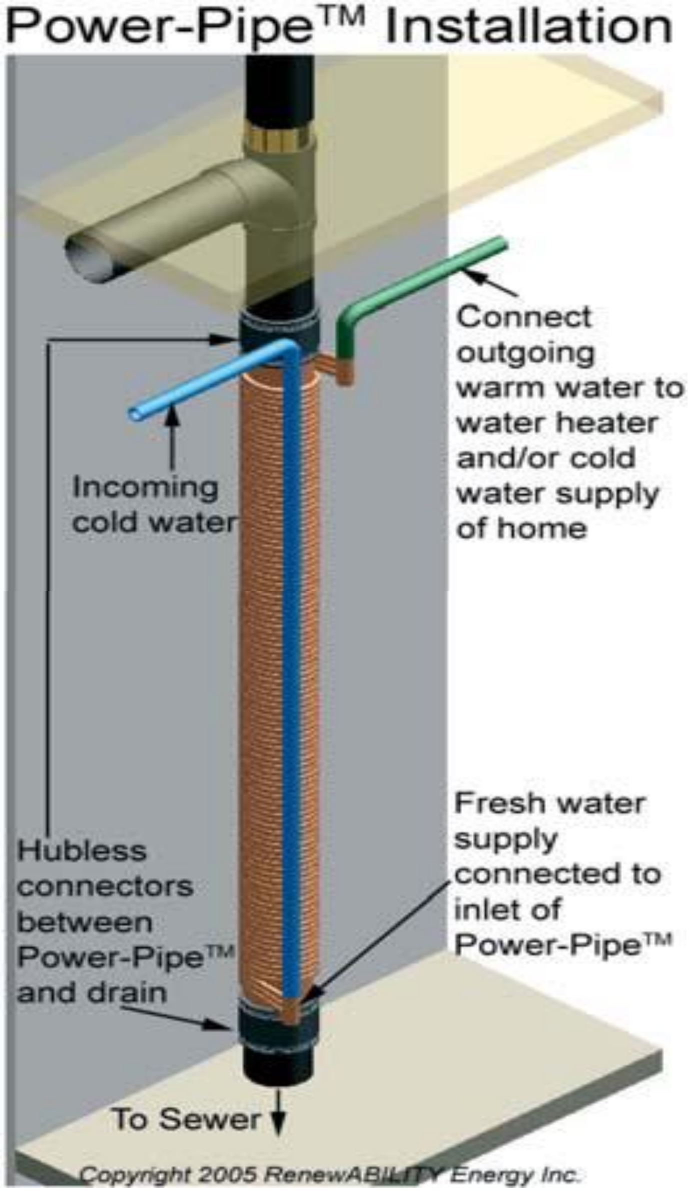
  – 85-105F, 105-115F
- Intermittent Pulsed Timer
- Demand Controlled
- Other – Aquastat and Timer, Memory

Energy Use of Circulation Controls

	Cycles				Pump		Energy		
	Delta-T	Length	Daily		Flow Rate	Watts	Annual (including Efficiency)		
	(F)	(Min)	Number	Hours	(GPM)		Loop		Pump
Strategy							BTU	Therms	kWh
Continuous Circulation									
Medium Speed	3.6	1440	1	24	1.2	25	25,218,708	252	219
Intermittent Pulsed Timer									
Medium Speed	36	5	20	1.7	1.2	25	17,512,99	175	15
Aquastat: Range 85-105F									
Medium Speed	24.3	7	25	2.9	1.2	25	20,687,22	207	27
High Speed	21.6	4.7	25	1.9	1.8	43	18,401,77	184	31
Aquastat: Range 105-115F									
Medium Speed	10.8	5	48	4.0	1.2	25	12,609,35	126	37
High Speed	19.8	3	48	2.4	1.8	43	20,805,43	208	38
Demand Control									
Button Activation	46.8	1.5	5	0.1	1.8	85	2,561,27	26	4

Many ways to reduce the energy needed to run the pump by more than 80%.
So far, only one way to reduce the thermal losses of the loop by more than 80%.

Drain Water Heat Recovery (DWHR)



How Much is Hot? How Much is Cold?

- $gpm_{mix} = gpm_{cold} + gpm_{hot}$
- $gpm_{cold} = gpm_{mix} * (T_{hot} - T_{mix})/(T_{hot} - T_{cold})$
- $gpm_{hot} = gpm_{mix} * (T_{mix} - T_{cold})/T_{hot} - T_{cold})$

Example:

- $gpm_{mix} = 2.0$
- $T_{cold} = 50F$
- $T_{hot} = 120F$
- $T_{mix} = 105F$
- gpm_{hot} = 2*(105-50)/(120-50) = 2*(55)/(70)
  = 1.57 gpm
- gpm_{cold} = 2.0 – 1.57 = 0.43

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%

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%
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	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 happens to the percentage of hot water:

As the hot water temperature increases? Decreases?

As the cold water temperature increases? Decreases?

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
  - Heat pump
- How does it impact temperature drop in the piping?

How Much is Hot? How Much is Cold? With DWHR?

		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%
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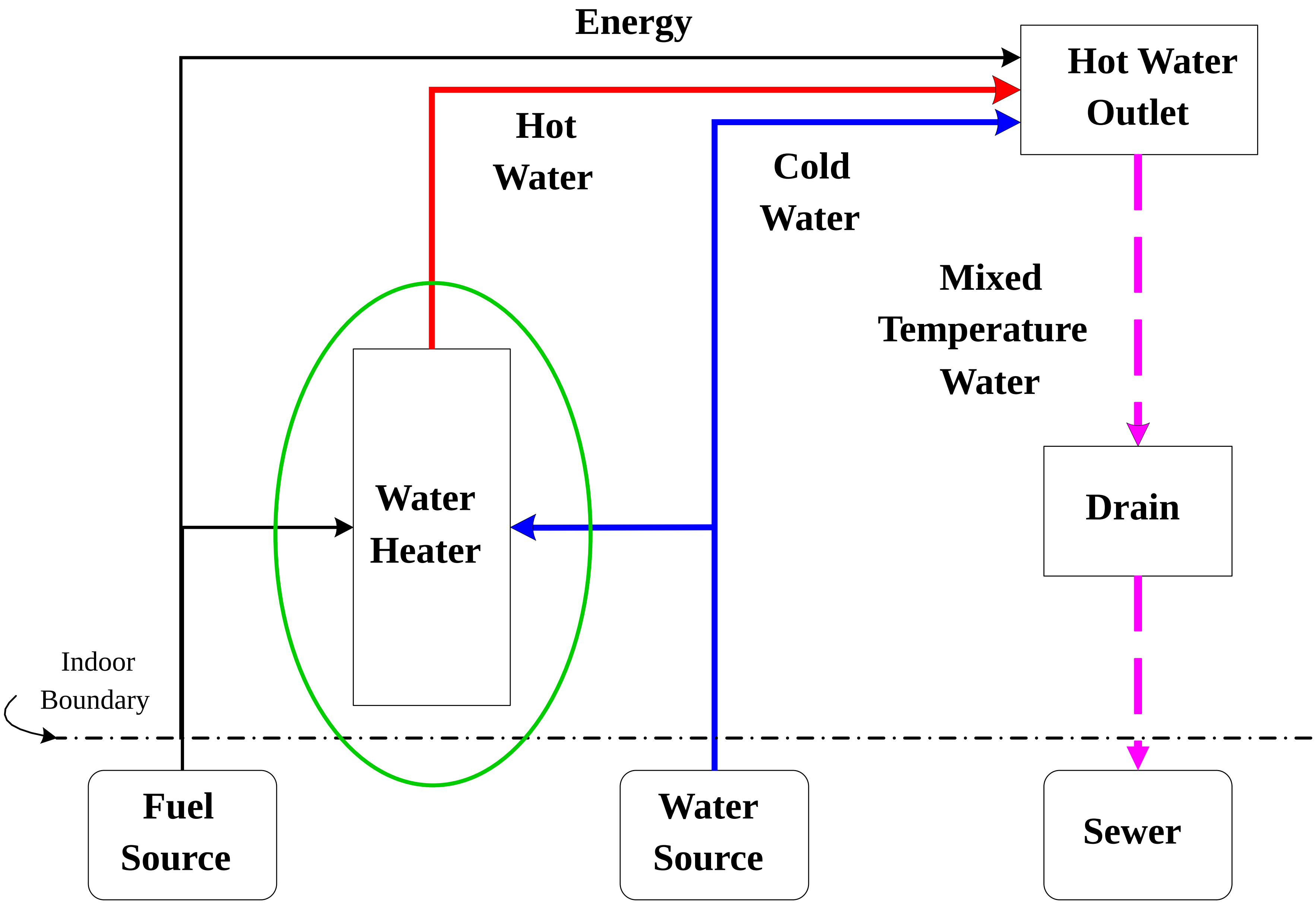
	50	92%	85%	79%	73%	69%	65%	61%	58%	55%	52%	50%
	55	91%	83%	77%	71%	67%	63%	59%	56%	53%	50%	48%
	60	90%	82%	75%	69%	64%	60%	56%	53%	50%	47%	45%
	65	89%	80%	73%	67%	62%	57%	53%	50%	47%	44%	42%
	70	88%	78%	70%	64%	58%	54%	50%	47%	44%	41%	39%
	75	86%	75%	67%	60%	55%	50%	46%	43%	40%	38%	35%
	80	83%	71%	63%	56%	50%	45%	42%	38%	36%	33%	31%

DWHR Applications

Water Heater Selection and Sizing

Typical "Simple" Hot Water System

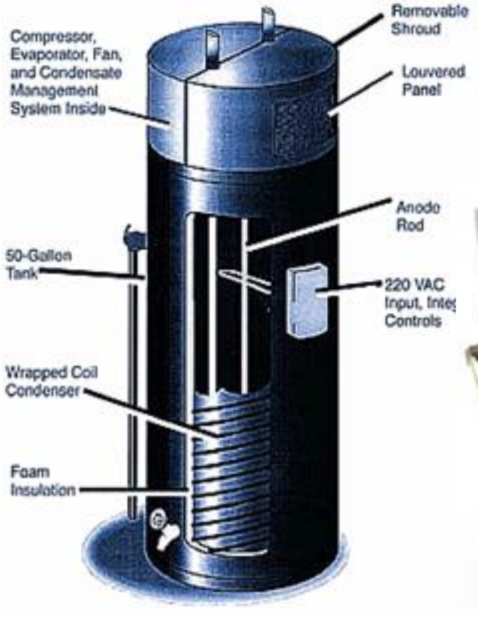


Water Heating Technologies

Electric





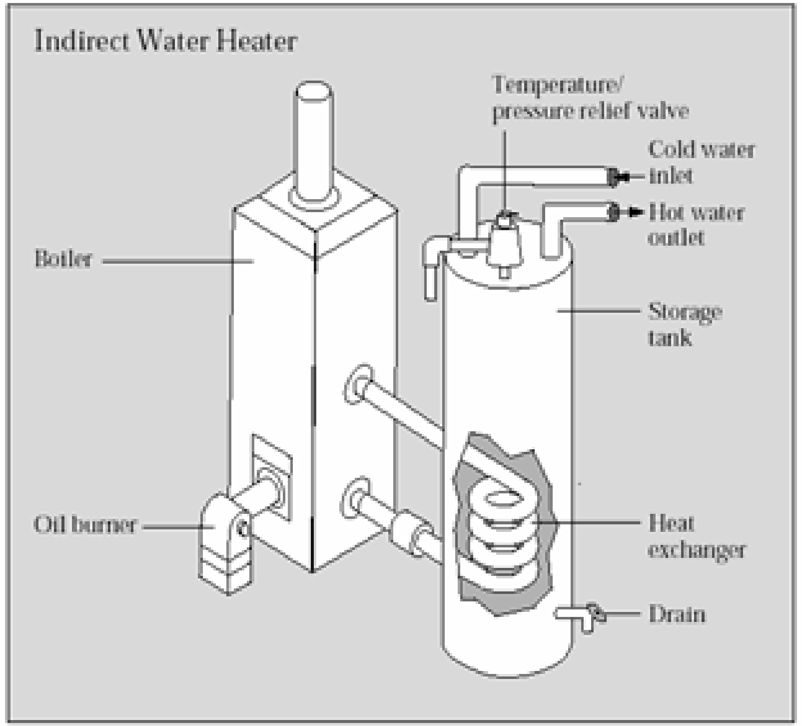



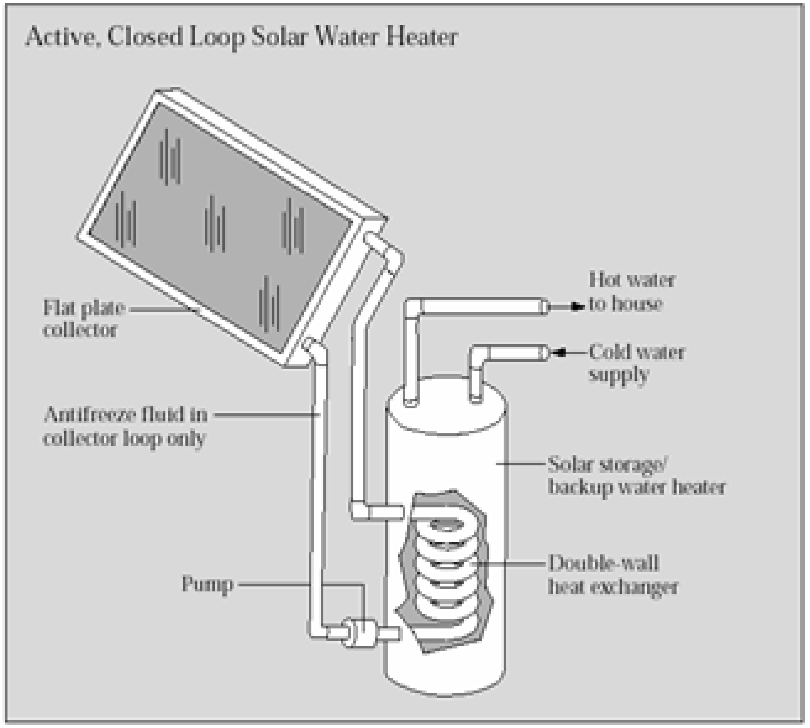
Gas



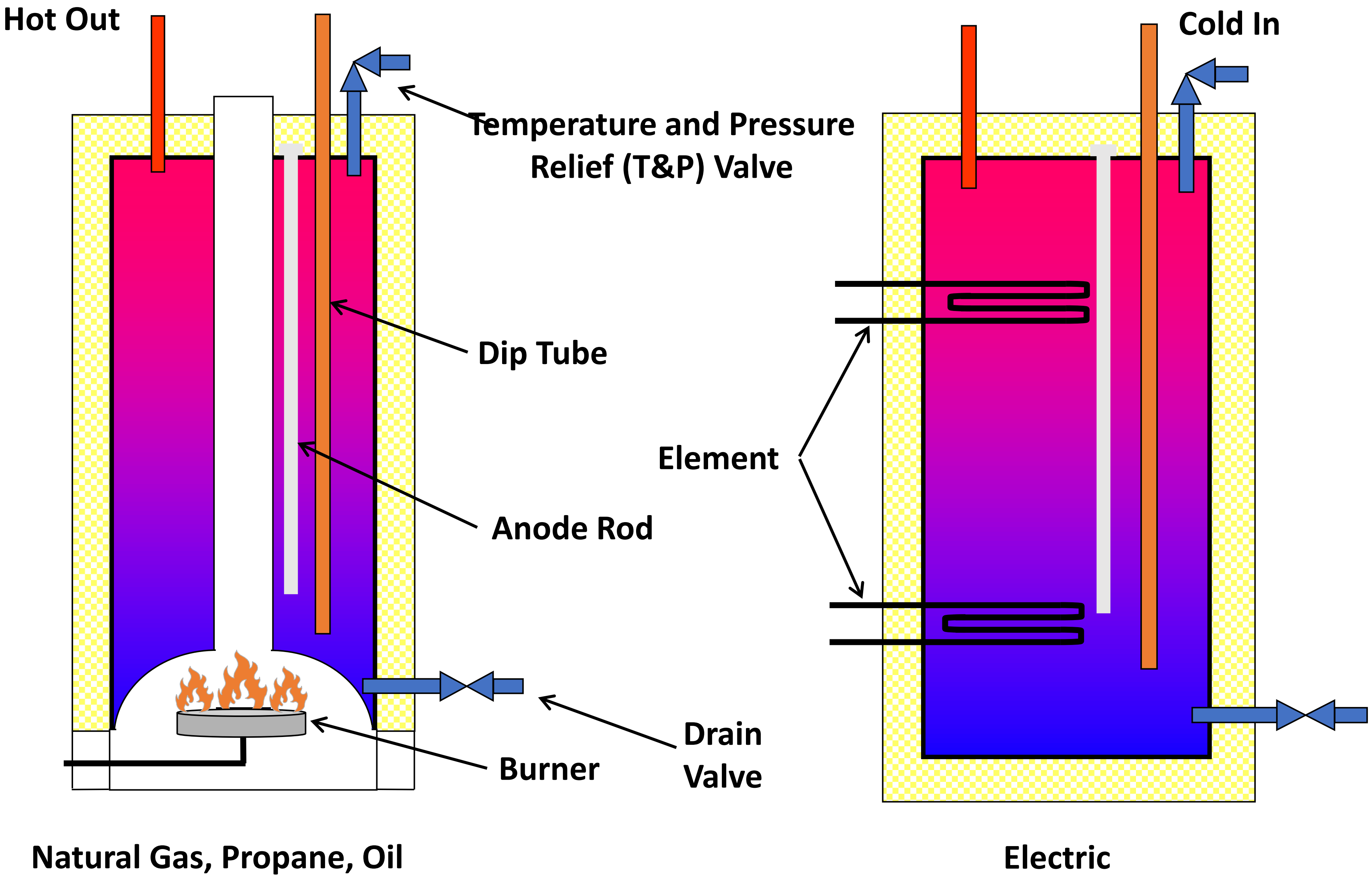



Still More Ways to Heat Water

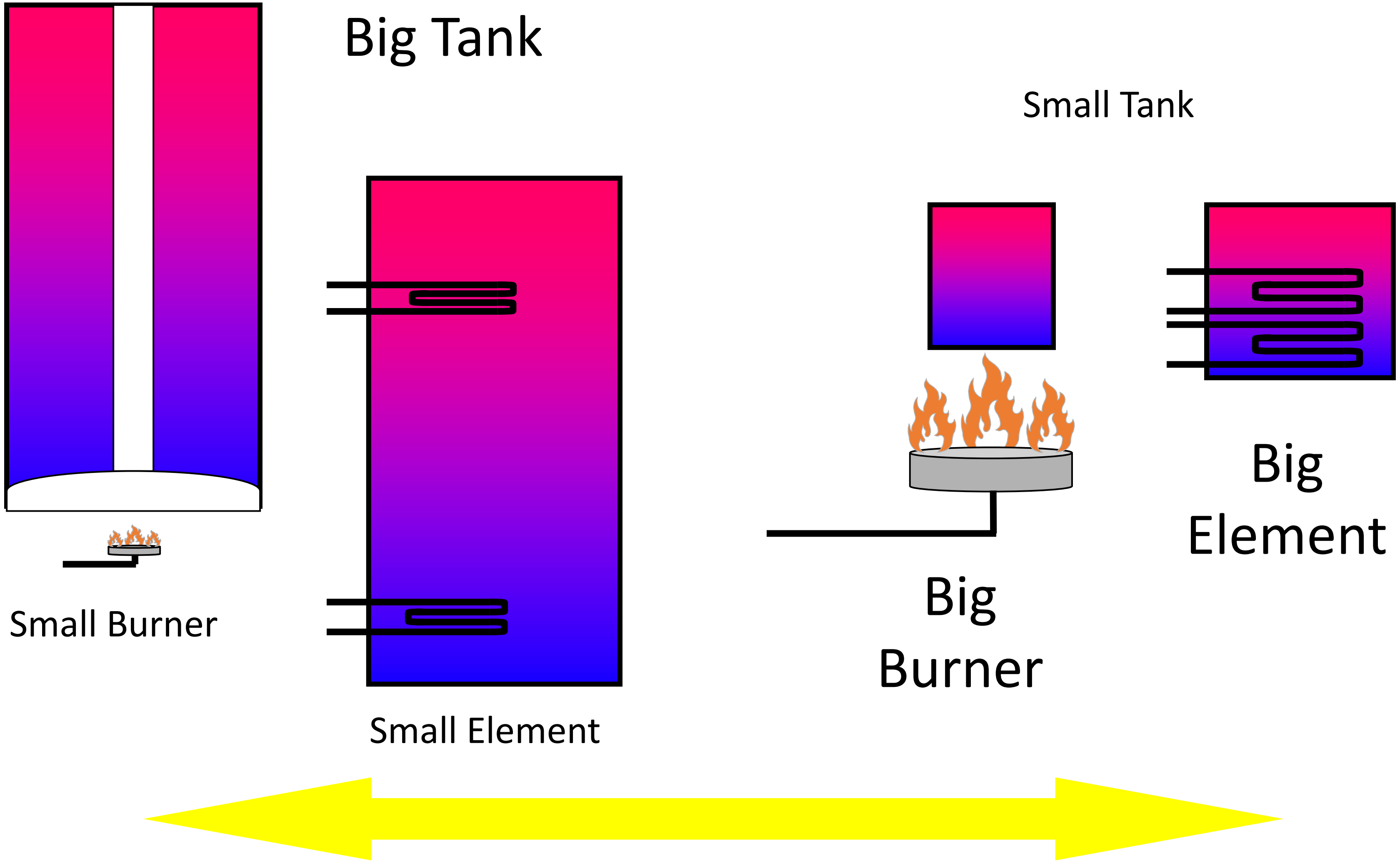




Inside a Storage Water Heater



The Essential Differences



Effective Capacity of Storage Water Heaters

50-gallon tank with 70% available volume (35 gal)

1 gpm =	35 minute shower
2 gpm =	17.5 minute shower
2.5 gpm =	14 minute shower
5 gpm =	7 minute shower
10 gpm =	3.5 minute shower
20 gpm =	1.5 minute shower

Typical heat rates:

- **Natural Gas** – 40,000 Btu, 75% thermal efficiency, 30,000 BTU/hour heat rate
- **Electric Resistance** – 4,500 watts in each of 2 elements, 98% thermal efficiency, 15,000 BTU/hour heat rate
- **Electric Heat Pump** – 350-400-watt compressor, 4,000-4,500 BTU/hour heat rate, hybrid mode 15,000 BTU/hour heat rate. Nominal 300% thermal efficiency

Effective Capacity of Tankless Water Heaters

Incoming cold water 50F. Hot output 120F.

Natural Gas			Electric
• 20,000 Btu =	0.5 gpm	=	5 kw
• 40,000 Btu =	1 gpm	=	10 kW
• 100,000 Btu =	2.5 gpm	=	25 kW
• 200,000 Btu =	5 gpm	=	50 kW
• 400,000 Btu =	10 gpm	=	100 kW
• 800,000 Btu =	20 gpm	=	200 kW

Natural Gas – nominal **75%** thermal efficiency

Electric Resistance – nominal **98%** thermal efficiency

How big does the pipe, wire or breaker need to be?

Neither Tank or Tankless is Necessarily the Answer

A combination of the two might be better:

- **Burner or element**
  - Sized for some amount of continuous use
  - Residential
    - Approximately 1.5-3 GPM
    - 60-120,000 Btu Natural Gas, 15-30 kW Electric
  - Commercial
- **Modest tank**
  - Hot water available at the beginning of every draw
  - Some volume for peak conditions
  - Enables a simpler burner control strategy
- **Possible in both gas, electric and electric heat pump**

How does the water heater interact with:
the fixtures?
circulation loops?

Electric Heat Pump Water Heaters: The Essentials

1. **HPWH are similar to, but different from your existing water heater**
2. **Heating (Recovery) Rate**
   - At present, most of the unitary models are about 1/3 that of electric resistance
   - It takes longer to heat the same volume of water
3. **Location, Location Location**
   - Residential unitary models want about 700 cubic feet of air in the space. If the air in the room gets too cold, the water heater will switch to resistance mode.
   - If you must install them in smaller spaces, watch this video first
   - https://register.gotowebinar.com/recording/6111602821382383631
   - The tanks for split systems can be installed in closets, if there is space for service
   - Where do you locate the heat pump in a split system?
4. **Installation**
   - The piping connections are not in standardized locations
   - There is an air filter on the unitary models. Need space to remove it for cleaning.
   - Air flow is critical, since that is the source of energy to heat the water. Not all units can be ducted. If needed, duct to-and-from outside or to-and-from inside
   - Need to make sure the condensate pan is set so the water can drain, and you need an additional drain-pipe
   - What about circulation pumps and controls?

Given human nature,

it is our job

to provide the infrastructure

that supports efficient behaviors.

Summary

1. How things are now with hot water system design, and why that's not good enough.
2. Understanding the hot water use patterns for each occupancy.
3. Understanding the "service(s)" of hot water desired by these occupants.
4. Designing source(s) of hot water close to the uses in new construction & additions.
5. Minimizing pressure drop and optimizing velocity in the piping.
6. Insulating hot water piping.
7. Providing a method to prime trunk lines with hot water shortly before use in both new construction and existing buildings.
8. Selecting (hot) water-efficient fixtures, fittings, and appliances.
9. Capturing waste heat from hot water running down the drain and using it to preheat incoming cold water.
10. Selecting efficient, climate-friendly, water heaters matched to the uses and patterns.

Possible Future Topics

- Architectural Compactness
- Right Sizing Pipe Based on Modern Materials and Flow Rates
- Pressure Drop in Modern Pipe and Fittings
- Cold Start Function Faucets
- To Insulate (or Not), That is the Question!
- Circulation and Heat Trace Control Strategies
- Drain Water Heat Recovery
- Anything Else?

Questions?

Thank you!

Closing

- Continuing Education Units Available
  - Contact shuskey@co.slo.ca.us for AIA LUs
- Coming to Your Inbox Soon!
  - Slides, Recording, & Survey – Please Take It and Help Us Out!
- **Upcoming HPF Courses:**
  - **How to Assess a Home for Electrification (11/15)**
- Regularly Scheduled Programming:
  - 2022 Energy Code: Existing Building, Additions, and Alterations (10/6)
  - Certified Passive House Tradesperson (10/10 – 10/14)
  - Carbon Free Homes: Features, Benefits, Valuation (10/17)
  - 2022 Energy Code: Accessory Dwelling Units (ADUs) (10/20)
  - HRVs and ERVs for Passive House Applications (10/25)
  - High Performance as the Baseline (11/8)

Thank you!

For more info:
3c-ren.org

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info@3c-ren.org

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TRI-COUNTY REGIONAL ENERGY NETWORK

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