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Water Heating, Hot Water Distribution and Water Conservation

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Annual Energy Use for Heating Water

	Natural Gas	Electricity
Gallons Per Day	60	
Gallons Per Year	21,900	
Energy into Water	16.4 Million Btu	
Efficiency	0.6	0.9
Cost per Unit	$1.00/therm	$0.10/kWh
Cost per Year	$275	$535

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

Add about $110 per year for water and sewer (at $0.005 per gallon 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

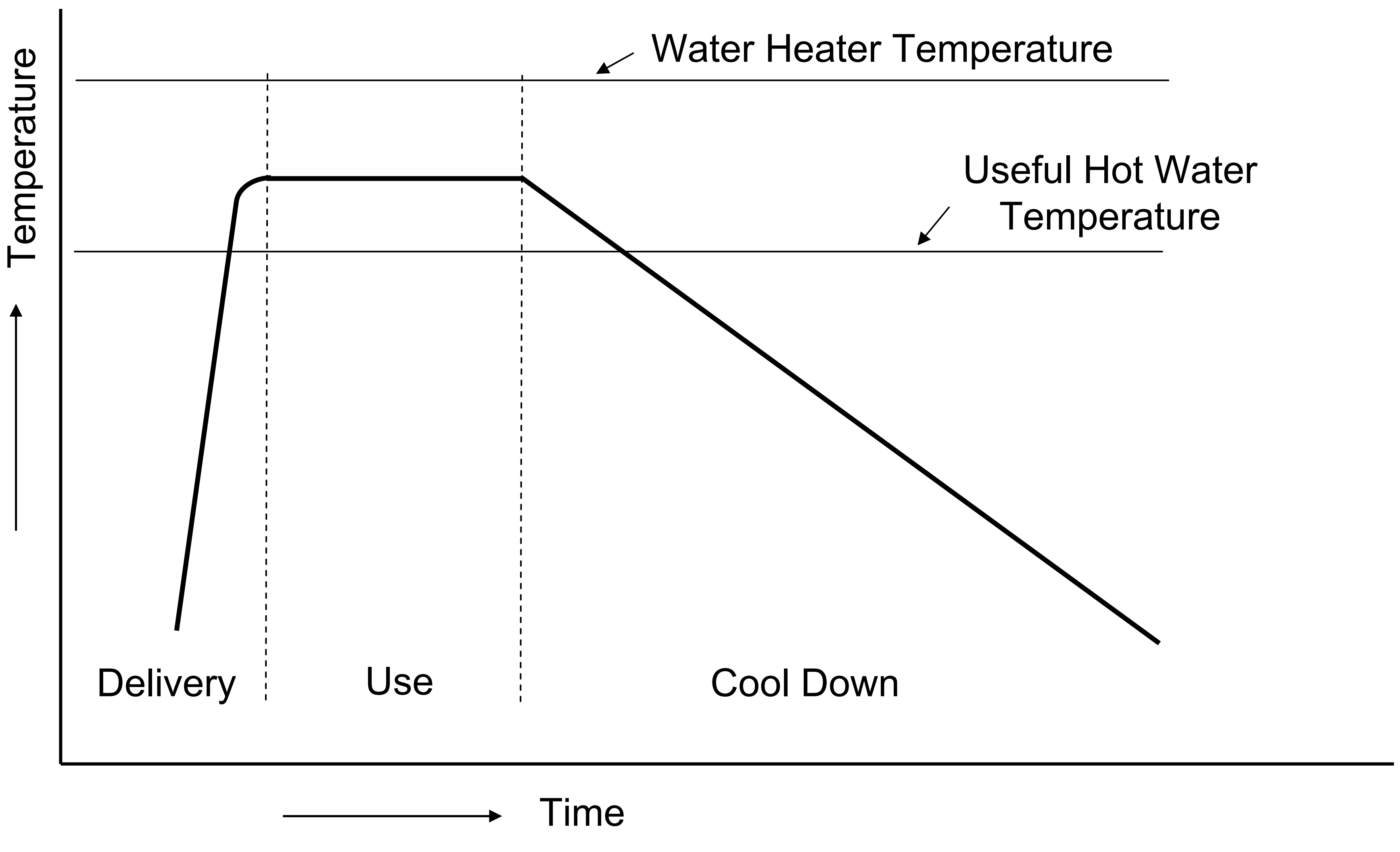
How does this compare to your:

- Cell phone bill?
- Internet bill?
- Cable or Satellite bill?
- Starbucks bill?

Do You Know:

- *Anyone who waits a long time to get hot water somewhere in their house? At their job? In their favorite restaurant?*
- Any Communities that have building or appliance energy standards or incentive programs? Green building programs?
- *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?*
- 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?

Typical Hot Water Event



What Do You Want from your Hot Water System?

- Clean clothes
- Clean dishes
- Clean hands
- Clean body
- Relaxation
- Enjoyment

The service of hot water

What Do You Expect from your Hot Water System?

Safety

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

Reliability

- Little or no maintenance
- Last forever
- Low cost

Convenience

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

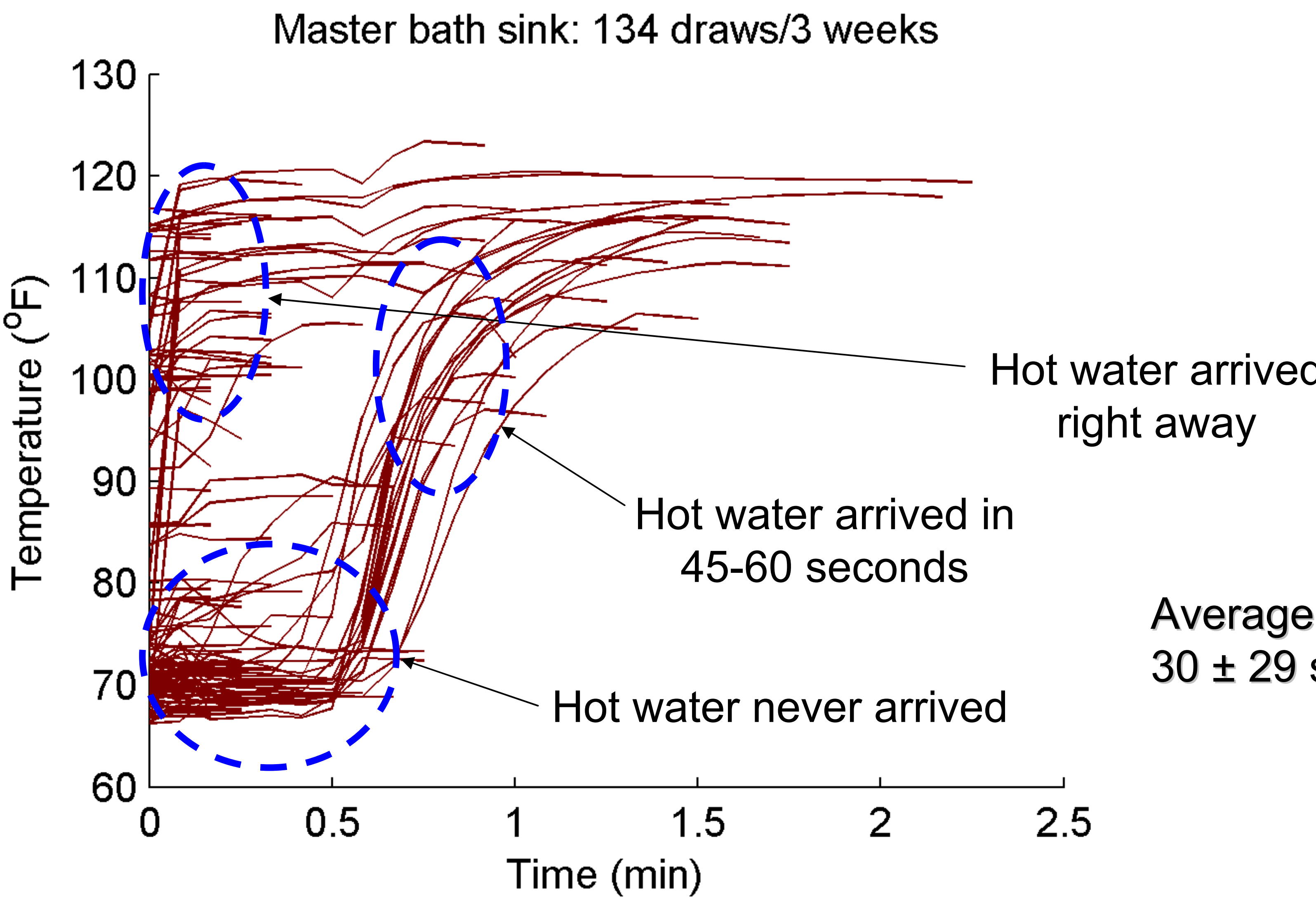
What are Your Hot Water Usage Patterns?

- Volume
- Flow Rate
- Duration
- Frequency of Use
- Number of Occupants
- Hot Water Fittings and Appliances
  - Number
  - Location

Have you ***measured*** the ***hot water*** demand in the facilities you are designing for lately?

How many hours a day do you ***use*** hot water?

Time and Temperature at the Master Bath Sink



Average draw is 30 ± 29 seconds

Source: National Renewable Energy Laboratory

What People Want

- Hot Water Now = “Instantaneousness”
  - Need hot water available before the start of each draw.
    - A tank with hot water
    - Heated pipes
  - Need the source of hot water close to each fixture or appliance
  - Point of Use is not about water heater size, its about location
- Never Run Out in My Shower = “Continousness”
  - Need a large enough tank or a large enough burner or element
  - Or, a modest amount of both

Waste versus Use

$$\frac{\text{Use + Waste}}{\text{Water Heater Efficiency}} = \text{Purchased Energy}$$

1. You cannot waste more than you purchase.
2. But you can waste more than you use.
3. Structural waste
4. Behavioral waste

Reduce the waste. Improve the use. Increase the efficiency.

Guiding Principle

Provide people what they want...

The Service of Hot Water

with what they expect…

Safety, Reliability and Convenience

as efficiently as possible

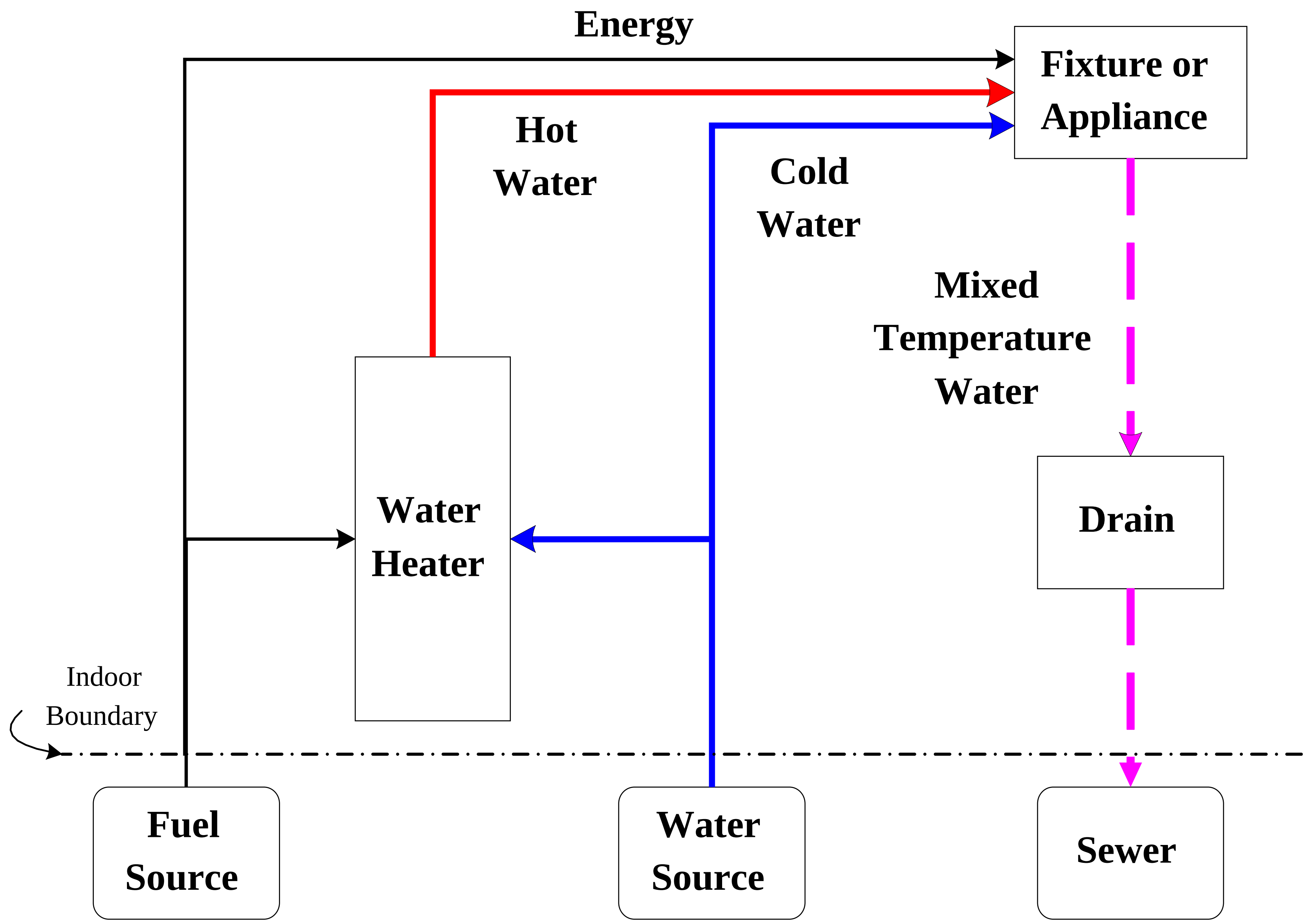
The Hot Water System

- 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



How Do We Conserve Hot Water?

Use less water (volume) per event

- Begins with the water heater
- Passes through the hot water distribution system
- Discharges through the fixtures and appliances
- Total is due to a combination of structural and behavioral considerations.

The supply of hot water ends at the fixtures and appliances, not at the customer's meter,

- The future of water conservation programs depends on getting the structural considerations correct today.

Begin with the end in mind…

How much do you want to waste?

The Challenge

Deliver hot water
to every fitting or appliance
wasting no more energy
than we currently waste 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

Possible Solutions

A. Central plumbing core
   - Only if all fixtures are within 1 cup of one water heater. Unlikely without shift in perceptions of floor plans.

B. 1 water heater for every hot water fixture
   - More expensive to bring energy to the water heaters than it is to bring plumbing. Then you have the additional cost for the heaters, flues, and space. Not to mention the future maintenance.

C. 2-3 water heaters per home
   - Same as above. Might make sense in buildings with distant hot water locations and very intermittent uses.

D. Heat trace on the pipes
   - Long, skinny, under insulated water heater. Expensive to install. Great on water conservation. Competitive in certain applications, otherwise can be very be expensive on energy.

E. Circulation loop 1 cup from every hot water fixture
   - Most buildable option. All circulation systems can save water, only one can save energy.

To Improve the Delivery Phase:

Get hotter water sooner by
minimizing the waste of water, energy & time

- Reduce the volume of water in the pipe (smaller diameter, shorter length)
- Reduce the number of restrictions to flow (decrease “effective length”)
- Increase the flow rate (use a demand controlled pump)
- Insulate the pipe (becomes critical for very low flow rates and adverse environmental conditions)

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**

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

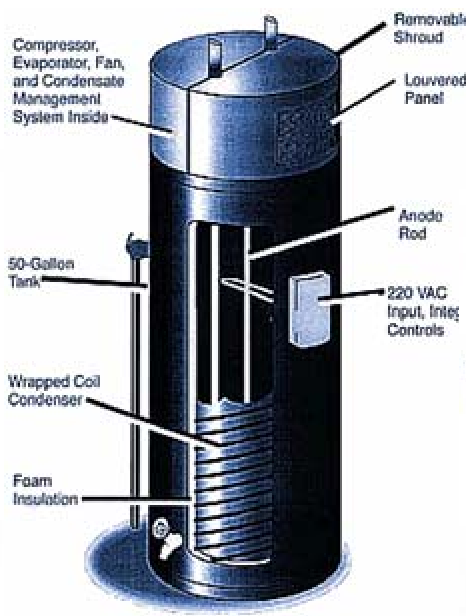
1 cup = 8 ounces = 1/16th gallon = 0.0625 gallon

Water Heating Technologies

Electric





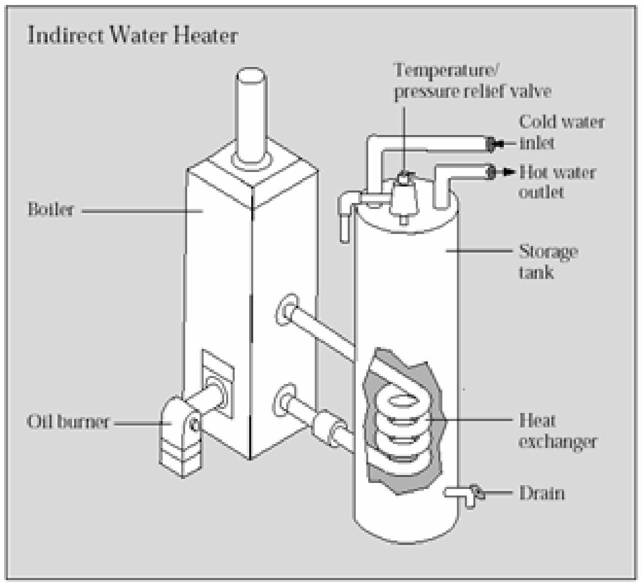



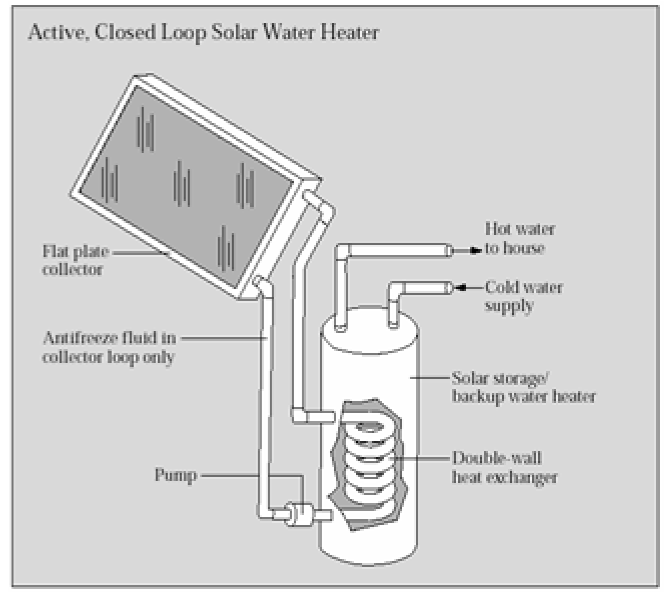
Gas






Still More Ways to Heat Water

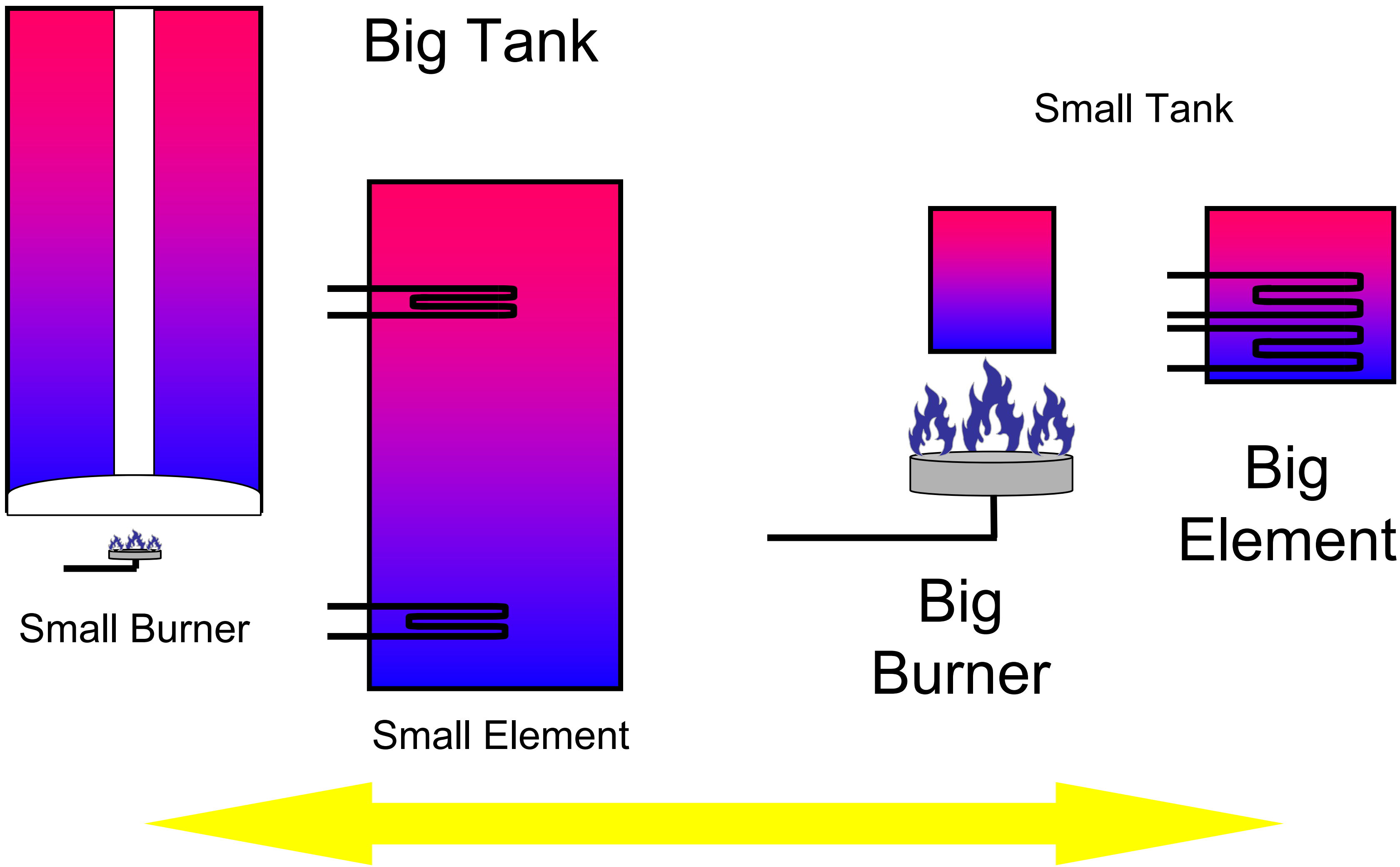




Comparing Tank and Tankless Water Heaters

1. Efficiency
   - Energy Factor or Thermal Efficiency
   - As compared to use pattern
2. Performance Characteristics
   - How does the water heater interact with the fixtures?
3. Ability to meet loads
   - Minimum, normal and maximum
   - Volume and flow rate
4. Installation
   - Size
   - Location
   - Bringing gas or electricity
   - Venting
   - Cost
5. Life Expectancy
6. Warranties

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 burner or element:

- Natural gas – 40,000 Btu, 75% thermal efficiency
- Electric – 4,500 watts in each of 2 elements, 98% 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 – nominal 98% thermal efficiency

A “Good” Water Heater

Residential

- Does not have to be large enough for extreme peak periods, but it must have a large enough burner or element to keep up with the hot water needed for one standard shower.
- Must be able to serve an infinite number of hot water use patterns
- Typical pattern: morning rush hour, evening plateau, weekends are spread out, lots of small draws

Commercial

- Serves the intended loads
- Meets the requirements of the applicable codes:
  - Health and Safety, Plumbing, Energy, Building, Green

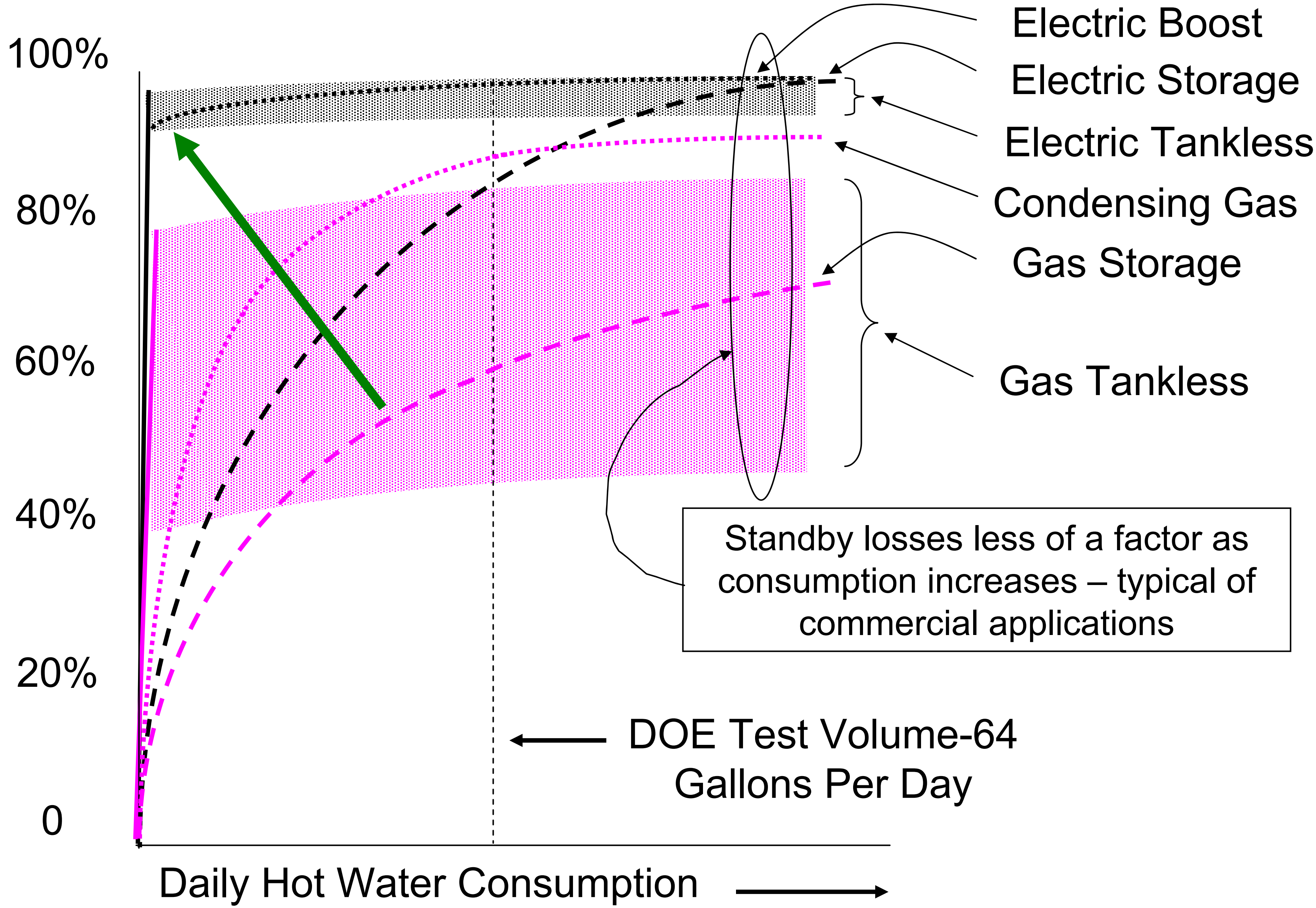
Neither Tank or Tankless is Necessarily the Answer

A combination of the two might be better:

- **Burner or element**
  - Sized for some amount of continuous use
  - Residential
    - Approximately 2-3 GPM
    - 80-120,000 Btu Natural Gas, 20-30 kW Electric
  - Commercial
- **Modest tank**
  - Some volume for peak conditions
  - Hot water available at the beginning of every draw
  - Enables a simpler burner control strategy
- **Possible in both gas and electric**

How does the water heater interact with the fixtures?

Relative Efficiency of Water Heaters



Hot Water Distribution Systems

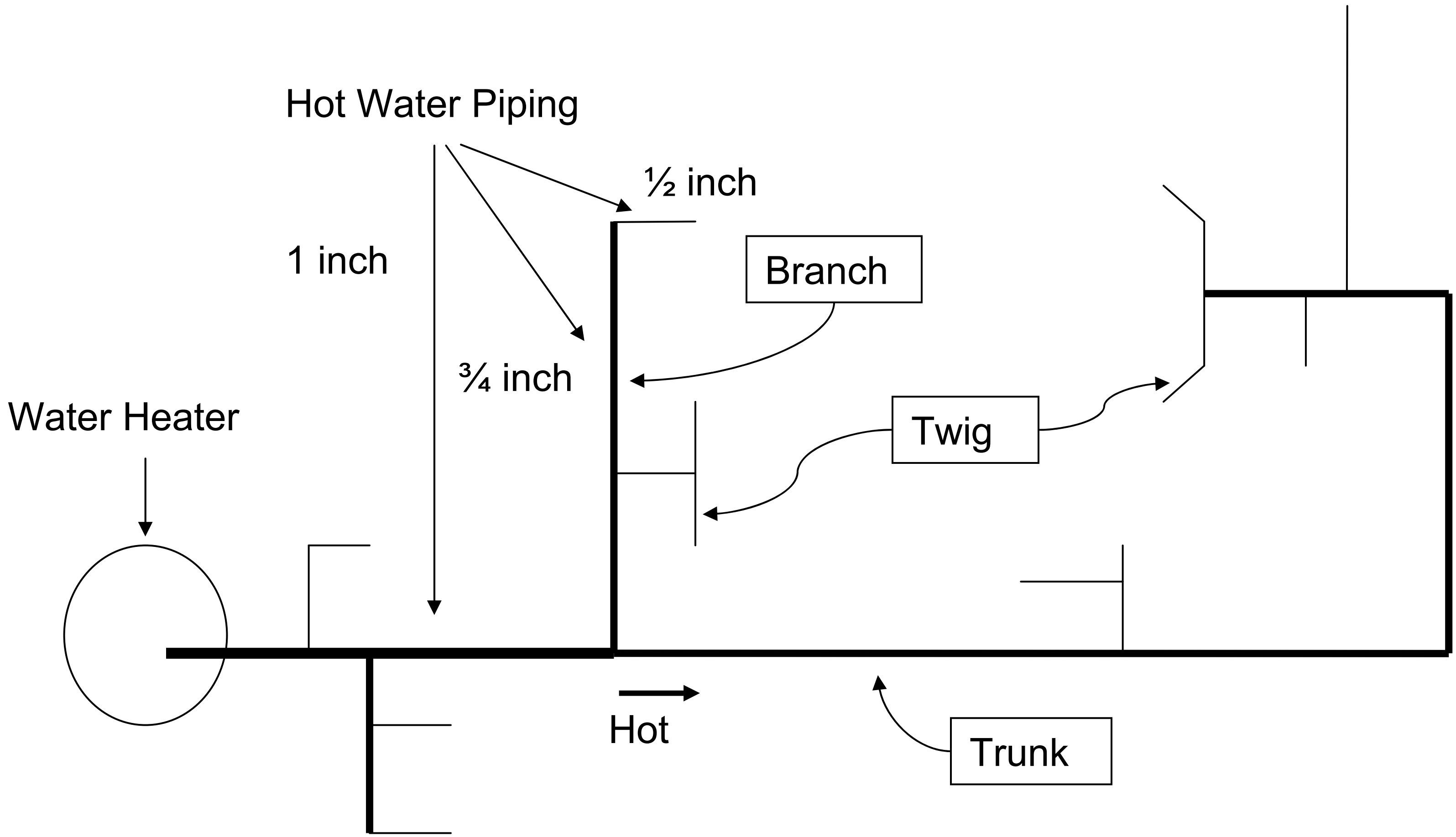
Definitions

1. A Twig line serves one fitting, fixture or appliance.
2. A Branch line serves more than one.
3. A Trunk line serves many.
4. A Main line serves the house.

The Ideal
Hot Water Distribution System

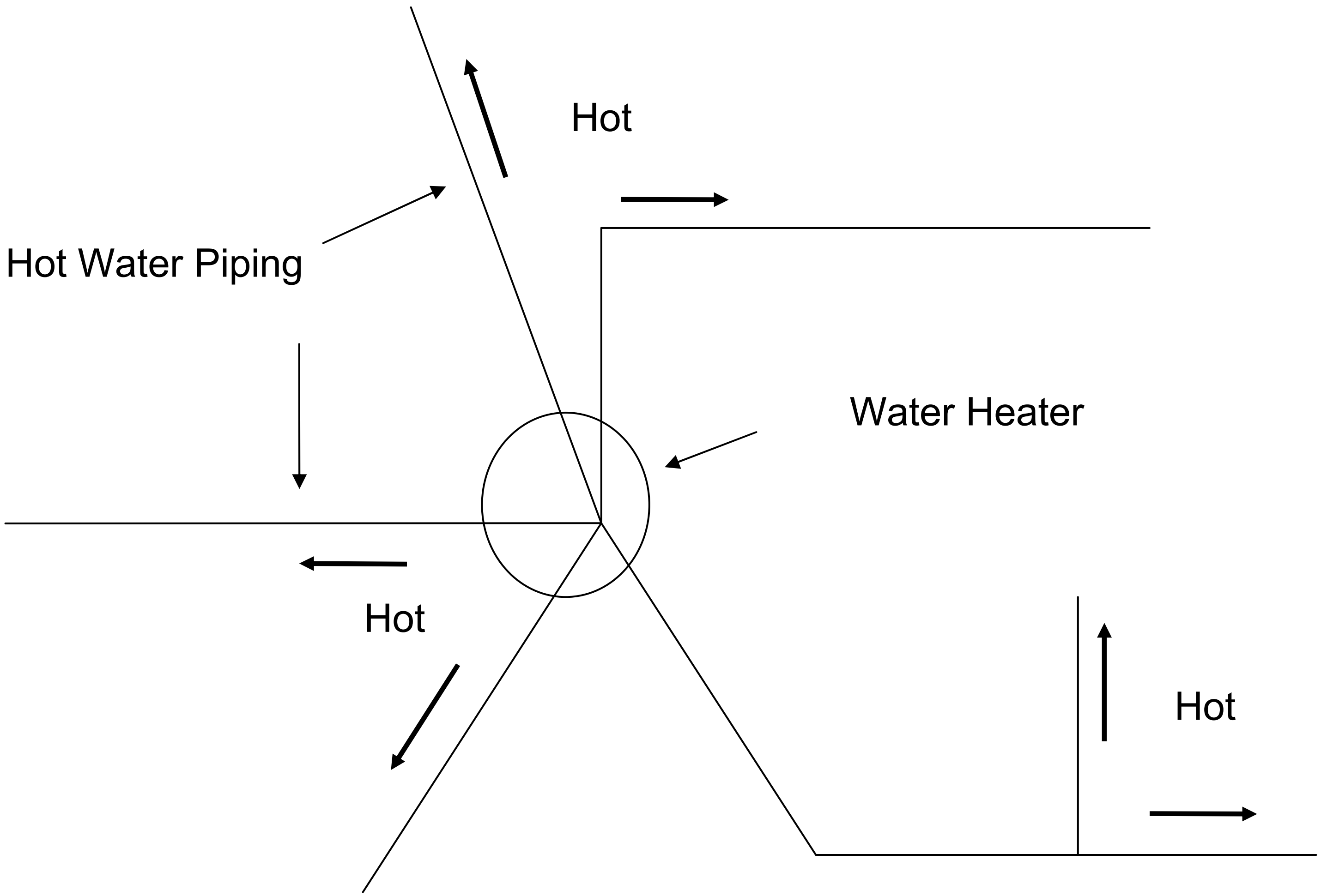
- Has the smallest volume (length and smallest “possible” diameter) of pipe from the source of hot water to the fitting.
- Sometimes the source of hot water is the water heater, sometimes a trunk line.
- For a given layout (floor plan) of hot water locations the system will have:
  - The shortest buildable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

Single Trunk, Branch and Twig

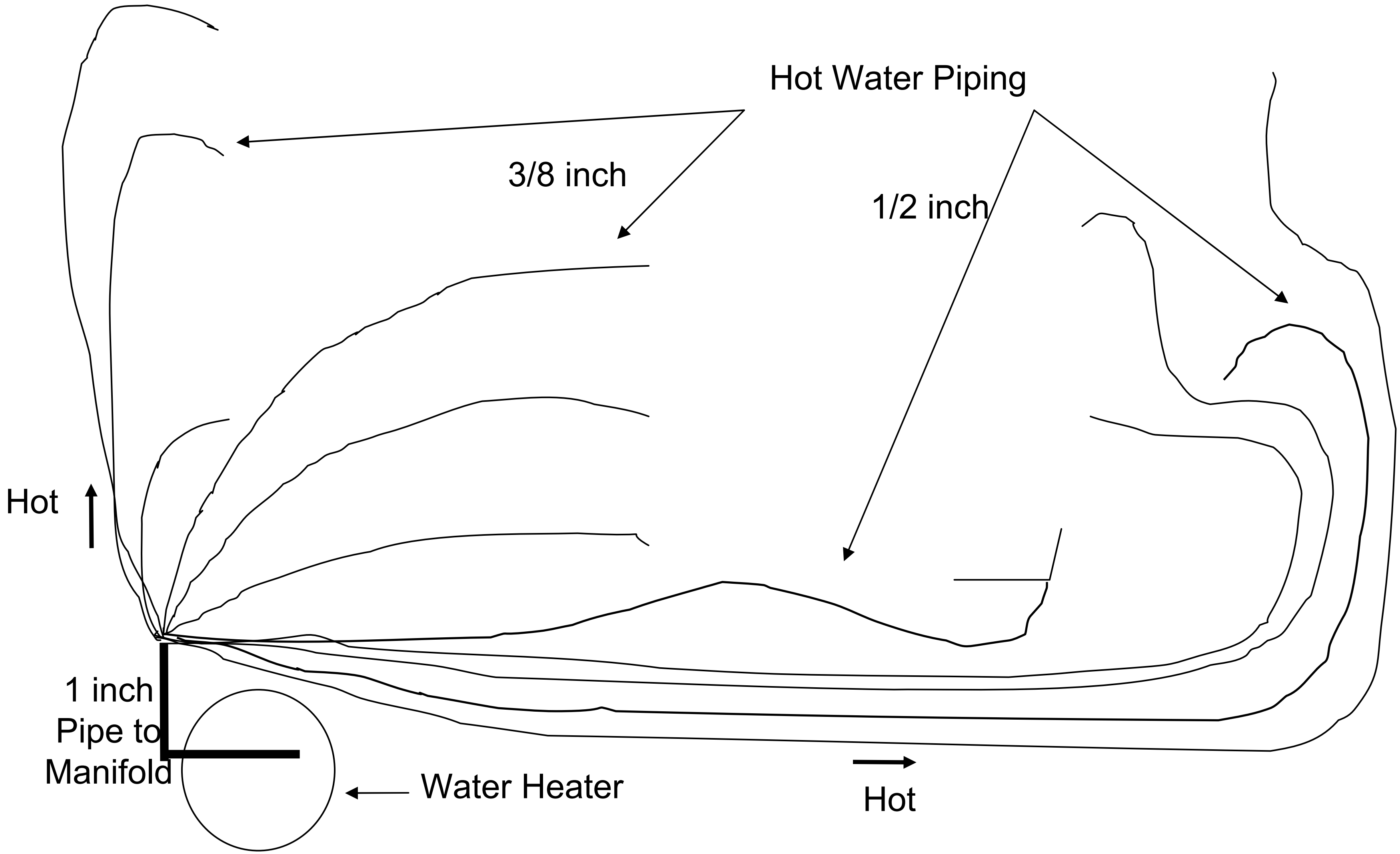


Central Plumbing Core

Radial, Manifold, Parallel Pipe

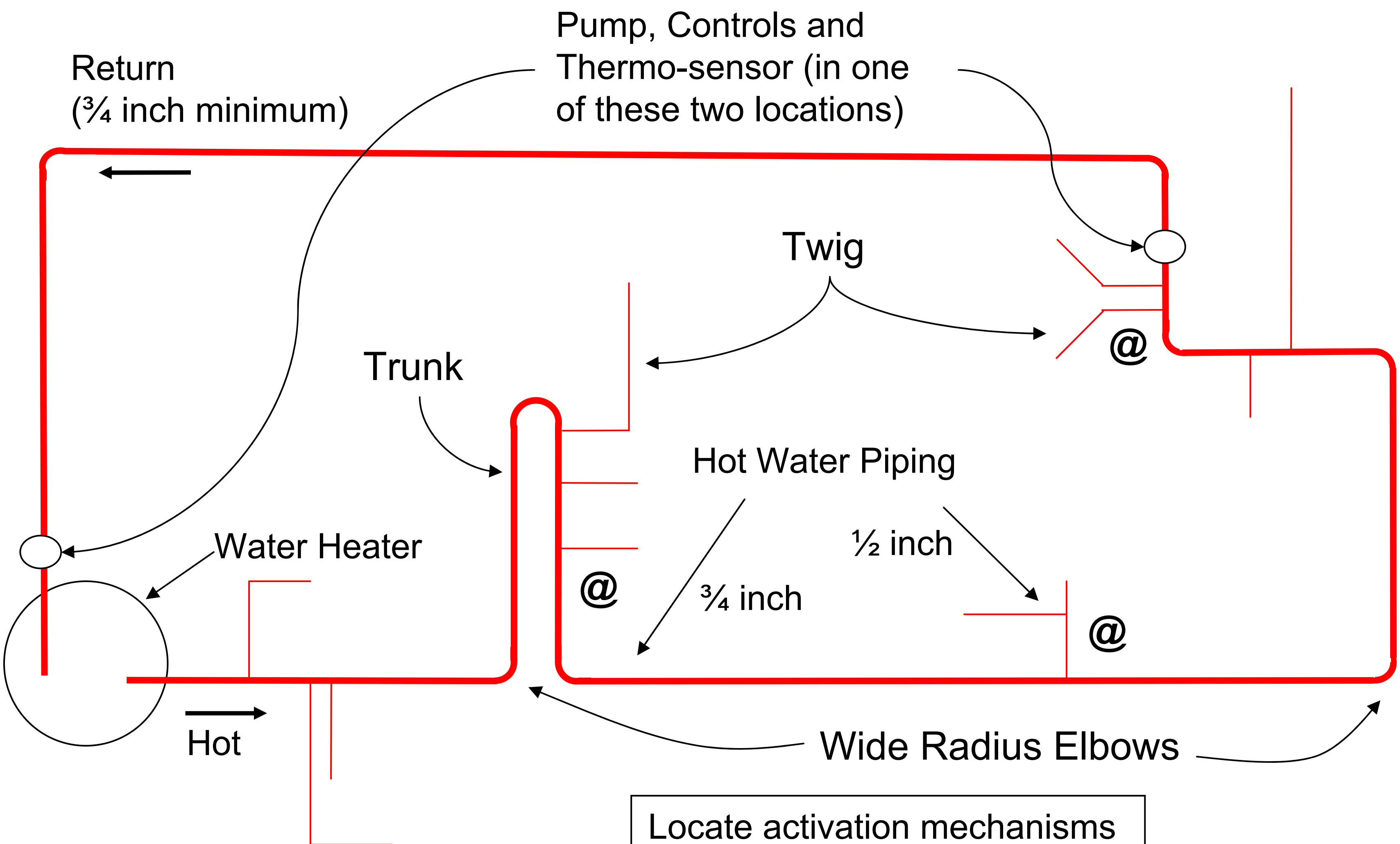


Radial, Manifold, Parallel Pipe- Distributed



Structured Plumbing Layout

Using a Dedicated Return Line



Locate activation mechanisms in hot water locations - @

Structured Plumbing

Circulation loop located close to the fittings and appliances

- Fully-heated or half-heated loop, with dedicated or cold-water return line, depending on floor plan

Small volume twig lines

- No larger than ½ inch diameter
  - May need larger diameter for high flow rate fittings and appliances
- No more than 10 plumbing feet long - 2 cups volume
  - Some exceptions: garden tubs, washing machines, island & peninsula sinks

Demand-controlled pumping system.

- Wired or wireless buttons or motion sensors
- Activate the pump to “prime (or preheat) the insulated line”
- Pump shuts off automatically, usually in much less than a minute

Minimum R-4 insulation on all hot water pipes.

- Water in pipes stays hot 30-60 minutes after last hot water event

Benefits:

- Minimizes the waste of water, energy and time
- The most flexible and cost effective solution for today’s floor plans – high customer satisfaction

Pipe Sizing

For House Pressure ≥ 50 psi:

Maximum allowable velocity dictates pipe sizing.

For House Pressure ≤ 35 psi:

Friction loss in the pipe dominates pipe sizing.

↑Flow rate → ↑Pipe Size → ↑Volume in Pipe → ↑Energy waste during the use and cool down phases of a hot water event.

If the pipes are sized for increased flow and a lower flow rate fitting is used → ↑Energy waste during the delivery phase too.

To improve the use phase:

Minimize the thermal losses the water heater needs to overcome in the piping during a hot water event.

- Insulate the pipes
  - Increases pipe temperature and reduces heat loss during a hot water event. This is particularly important for low flow fittings and appliances.
- Take advantage of the energy savings:
  - Keep the water heater temperature the same and change the mix point
  - Reduce the water heater temperature setting.
  - Combine both strategies.

Fixture Flow Rates

Maximum allowable flow rates allowed by Federal and California regulation:

- Shower heads: 2.5 gpm @ 80 psi
- Lavatory and kitchen faucets: 2.2 gpm @ 60 psi
- Replacement aerators: 2.2 gpm @ 60 psi
- Commercial Pre-rinse Spray Valves
  - 1.6 gpm @ 60 psi
  - Capable of cleaning 60 plates at not more than 30 seconds per plate

- What is the future of fixture 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)

To improve the cool-down phase:

Increase the availability of hot water and minimize the waste of water, energy and time

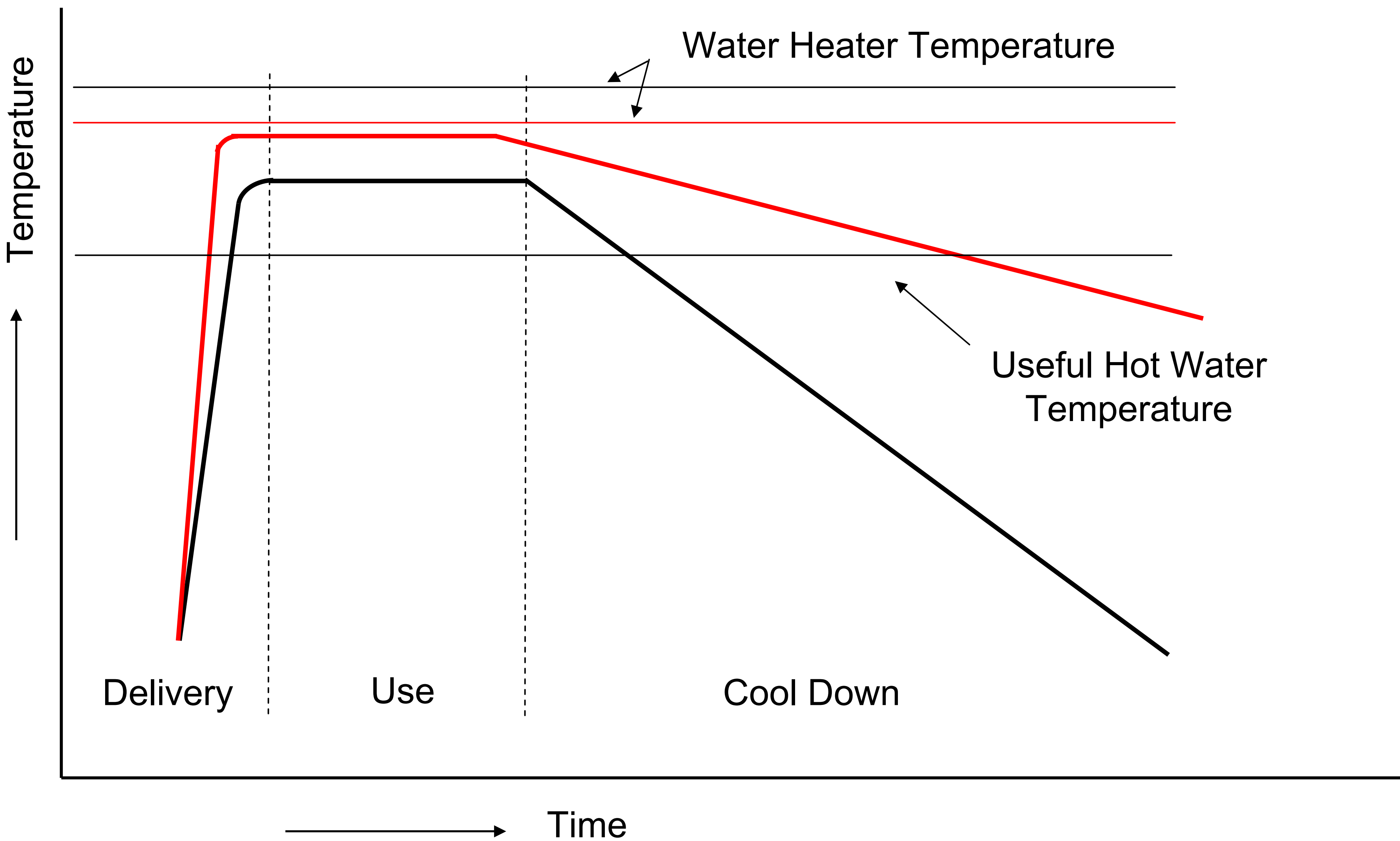
Insulate the pipes

- Increases the time pipes stay hot between events.
- R-4 insulation doubles cool down time with ½ inch pipe, triples it with ¾ inch pipe.

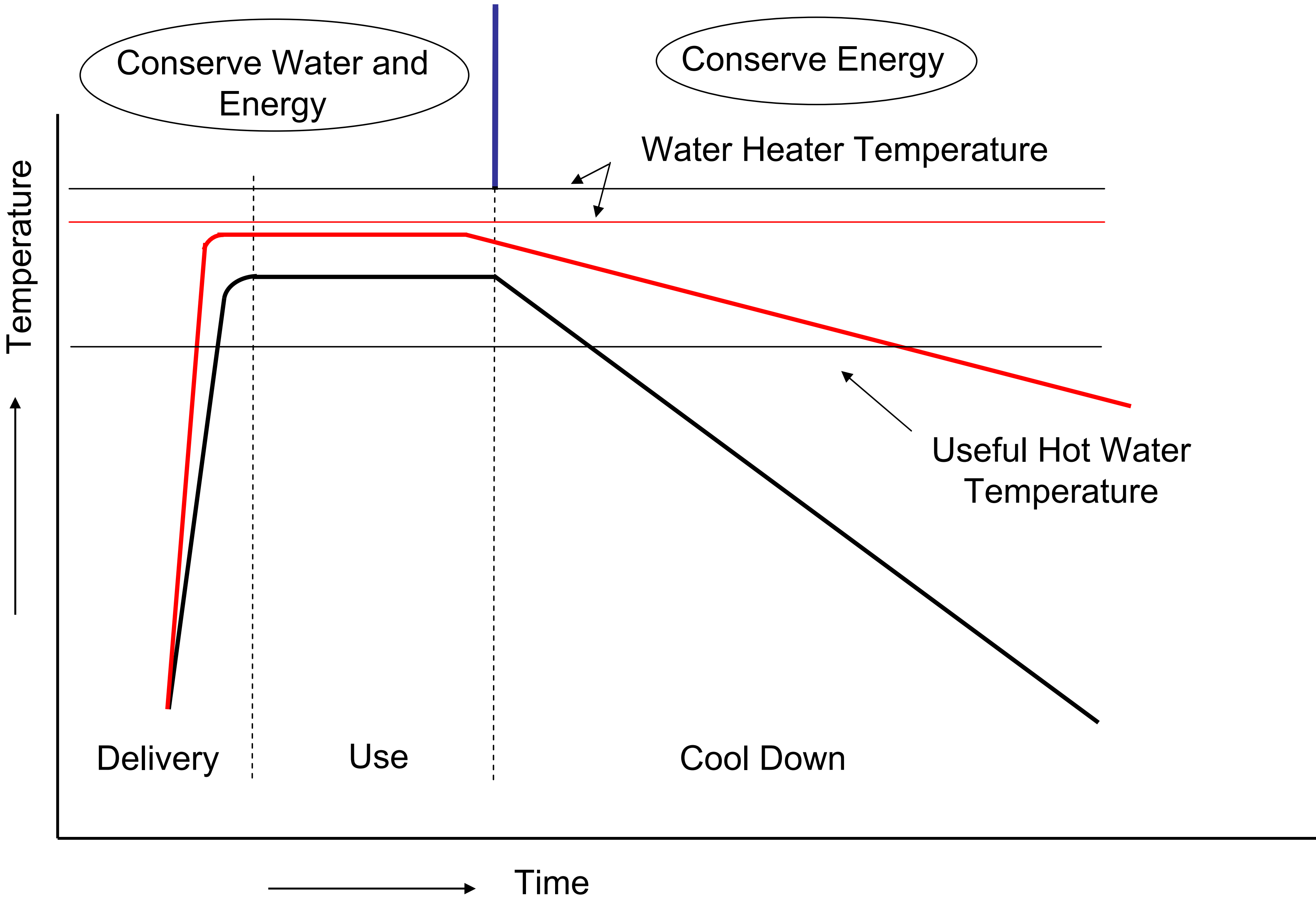
Four Questions:

1. Where is the location of the hot water event in relation to the source of hot water?
2. How long is the time until the next hot water event?
3. What is the temperature of the hot water needed for that subsequent event?
4. What is the volume of water in the pipe that eventually cools down?

Improved Hot Water Event



Improved Hot Water Event



Potentially Conflicting Trends

On one hand:

- Larger houses
- More plumbing fittings
- Increased desire for hot water
- Higher expectations of performance
- Desire to be Green

On the other:

- Lower city water pressures
- Lower fitting flow rates
- Greater pressure drop in piping
- Tightening of codes and standards
- New policies to reduce GHG emissions

Result:

Longer wait, less pressure, lower performance, less satisfied customers, increased complaints