This presentation premiered at WaterSmart Innovations

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INNOVATIONS

Water Heating, Hot Water Distribution and Water Conservation

…or, how to actually save hot water

Parts 1 and 2

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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 $130 per year for water and sewer (at $0.006 per gallon combined)

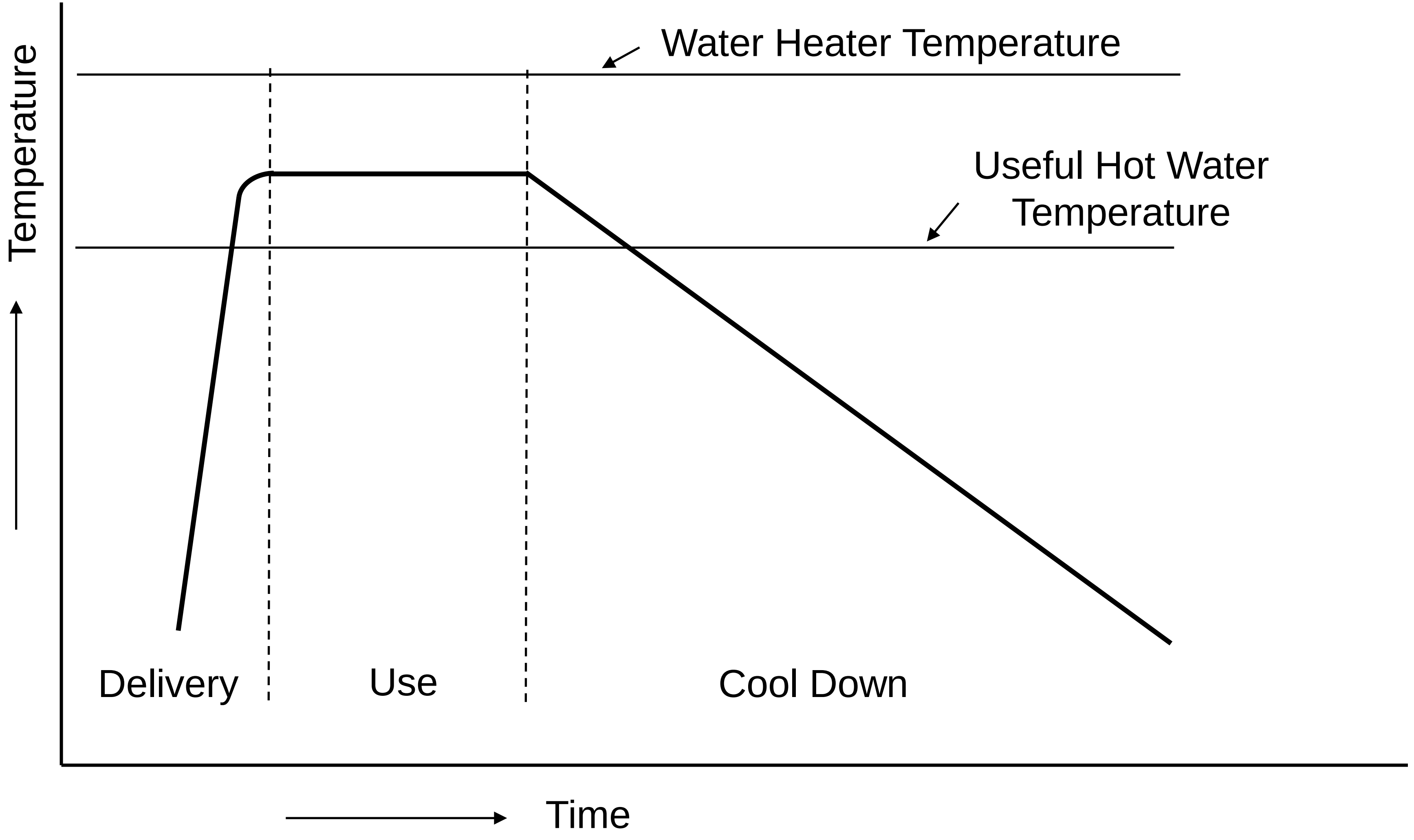
How Big is Hot Water?

- 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?
  - Designer coffee 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?
- *Someone who wants to know “the answer”?*

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

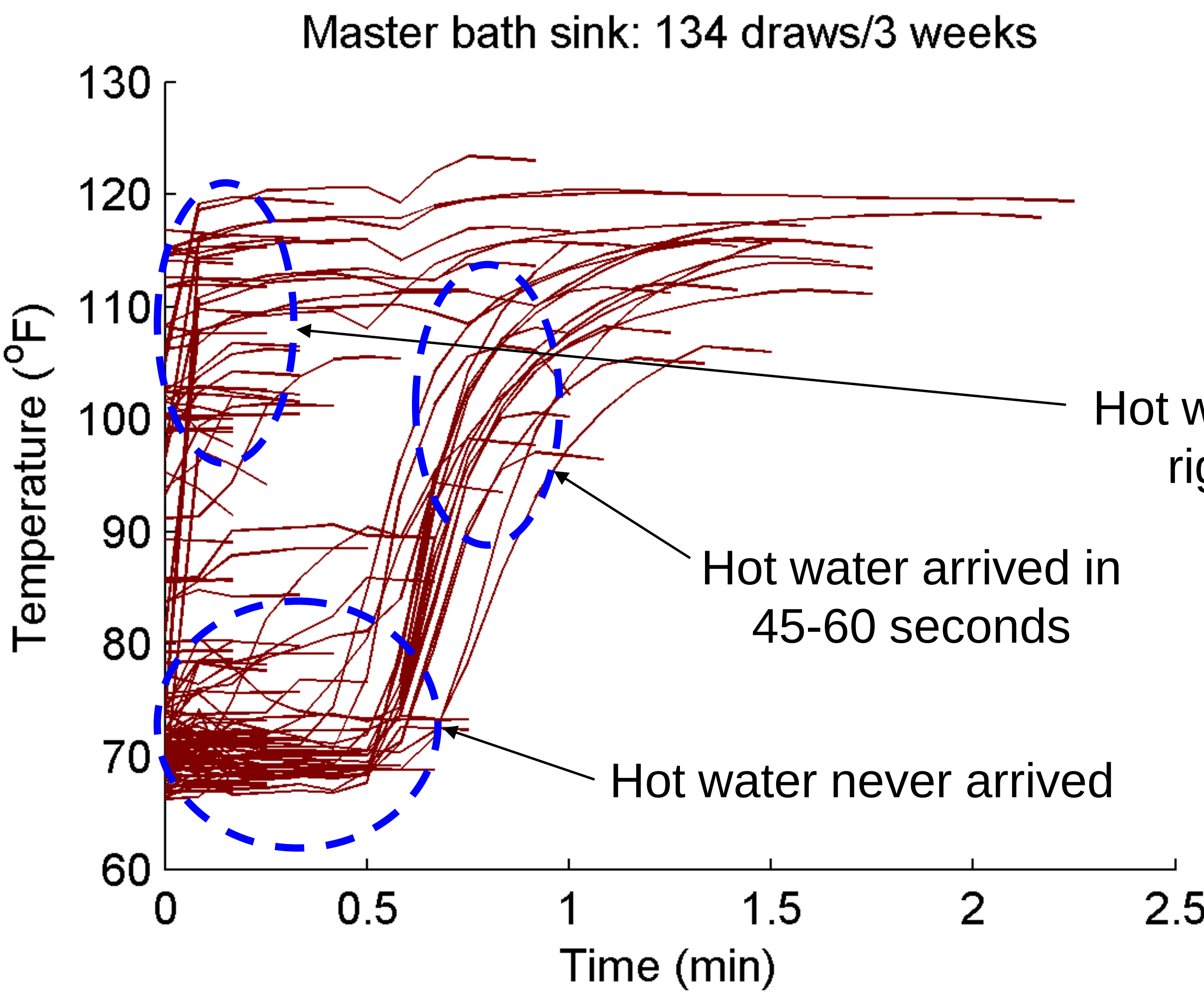
What are Your Hot Water Usage Patterns?

- 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

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

Guiding Principle

Provide people what they want...

The Service of Hot Water

with what they expect…

Safety, Reliability and Convenience

as efficiently as possible

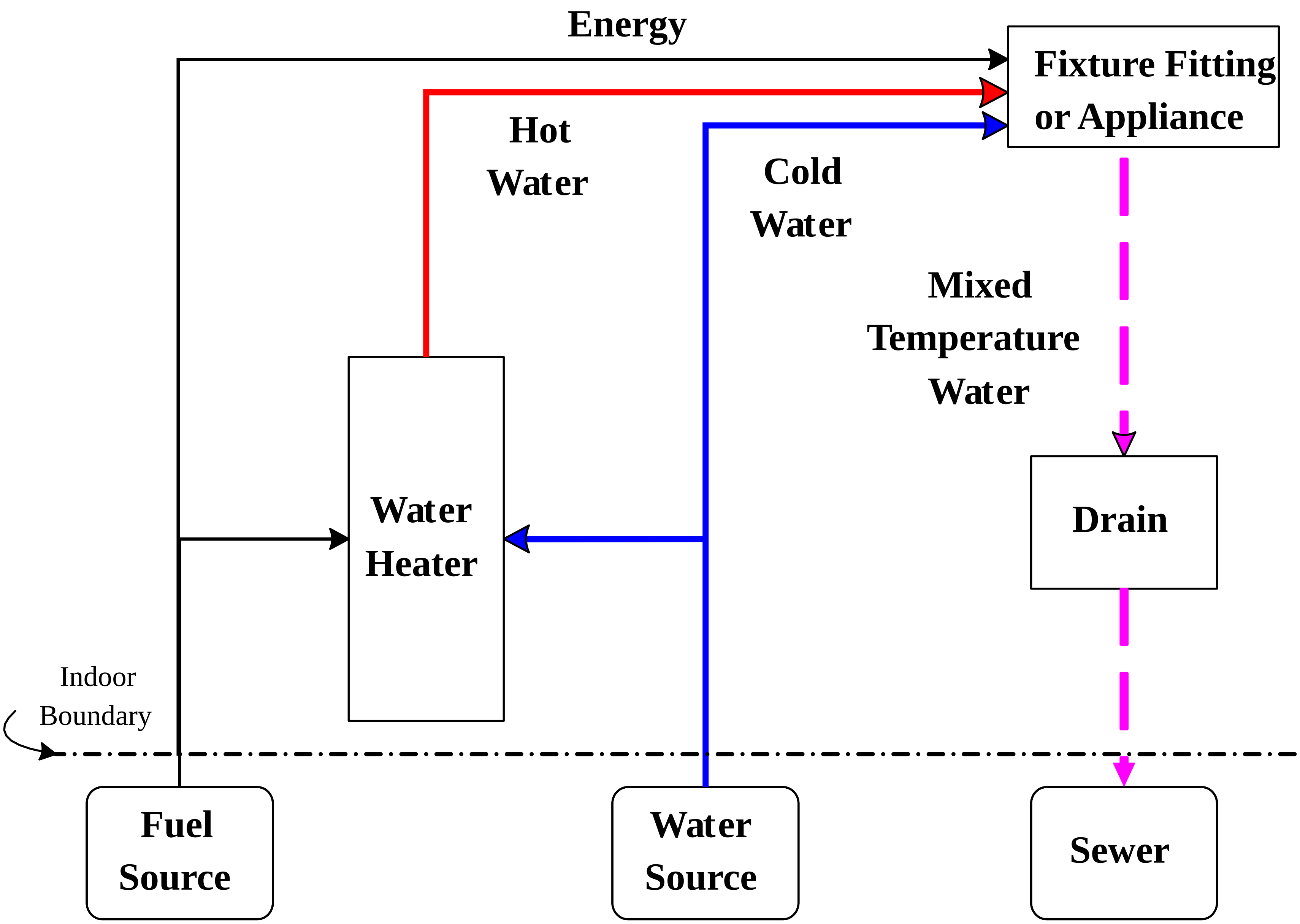
The Hot Water System

- 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 hot water (volume) per event

- Begins with the water heater
- Passes through the hot water distribution system
- Discharges through the hot water outlets
- Mixed temperature water runs down the drain
- 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?

Let's Discuss the Interactions

Flow Rates for Hot Water Outlets

Pipe Sizing and Hot Water Distribution

Water Heater Selection and Sizing

Energy Supply Sizing

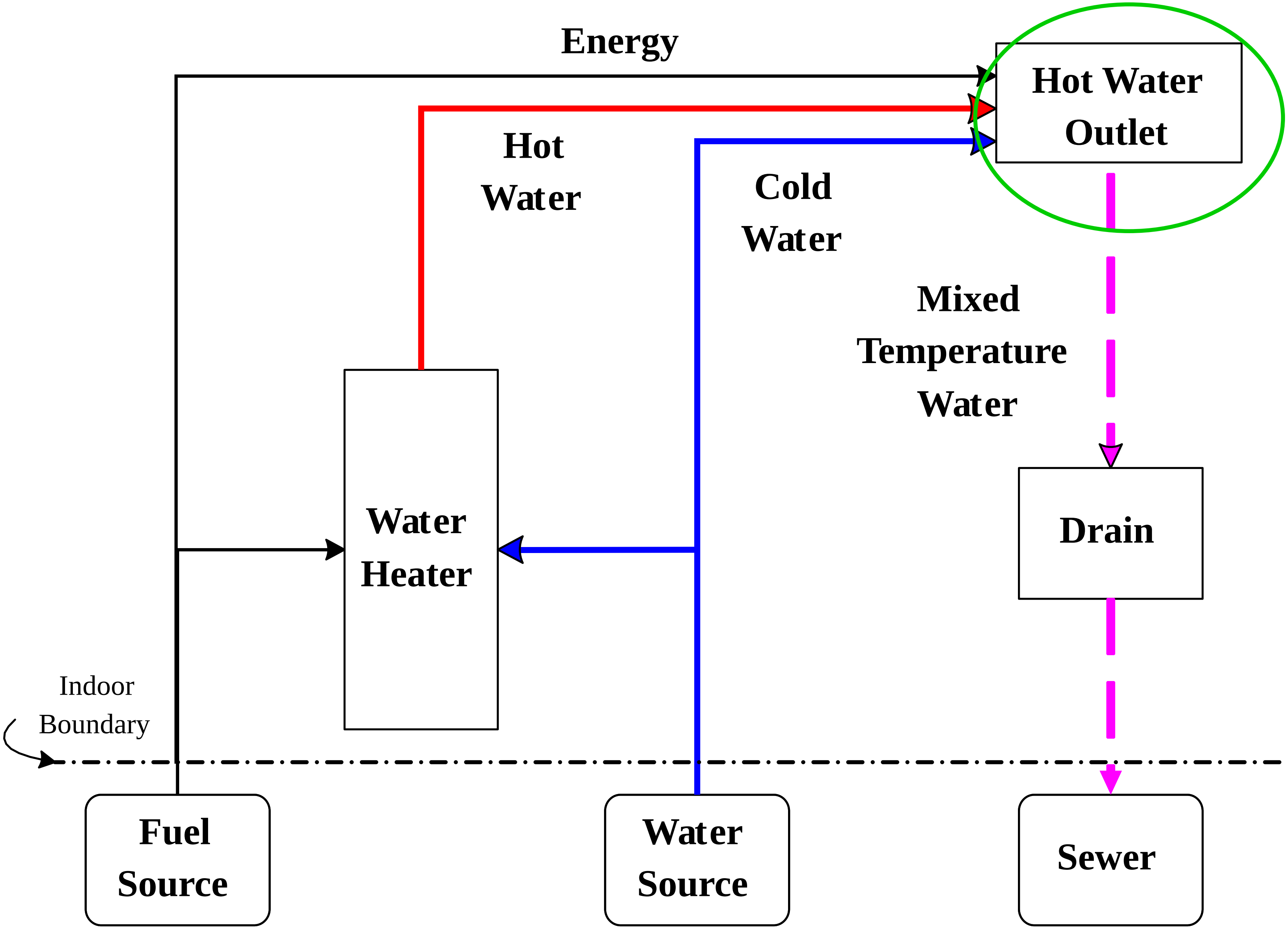
Drain Heat Recovery

Begin with the end in mind…

Remember 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

Typical “Simple” Hot Water System



Hot Water Outlet 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

Concerns:

- Single lever versus dual lever fixture fittings
- Temperature regulation
- Cross-over
- Being held responsible for someone else's problem
- Overbearing and multiple regulations
- Others?

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)

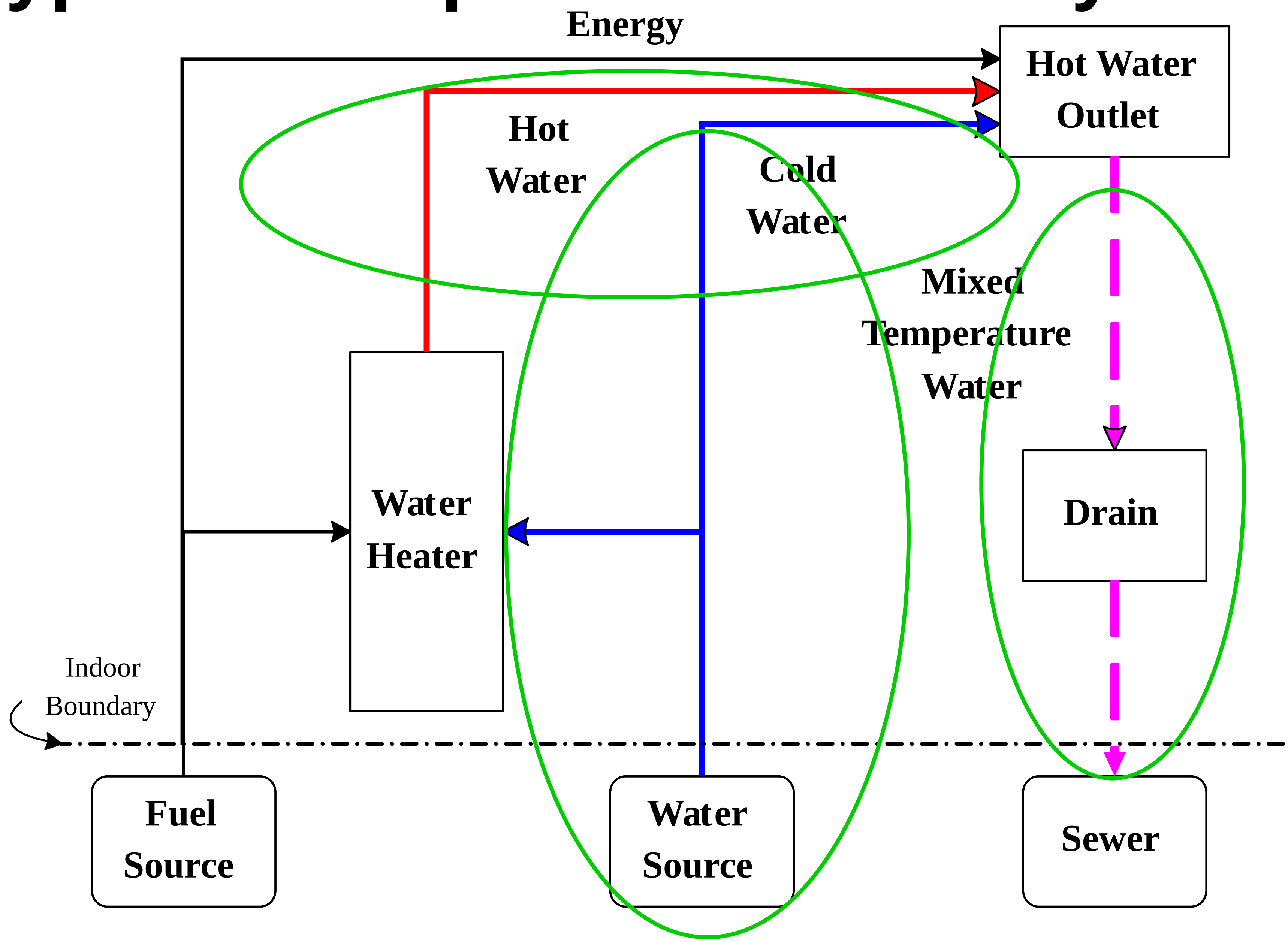
Showers – 1.5 gpm (water down drain)

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?

Typical “Simple” Hot Water System



Hot Water Distribution Systems

Definitions

1. A Twig line serves one hot water outlet. The diameter of the twig should be determined by the flow rate of the outlet.
2. A Branch line serves more than one.
3. A Trunk line serves many.
4. A Main line serves the building.

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 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 hot water outlets 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 outlets 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)

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

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.

To improve the cool-down phase:

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

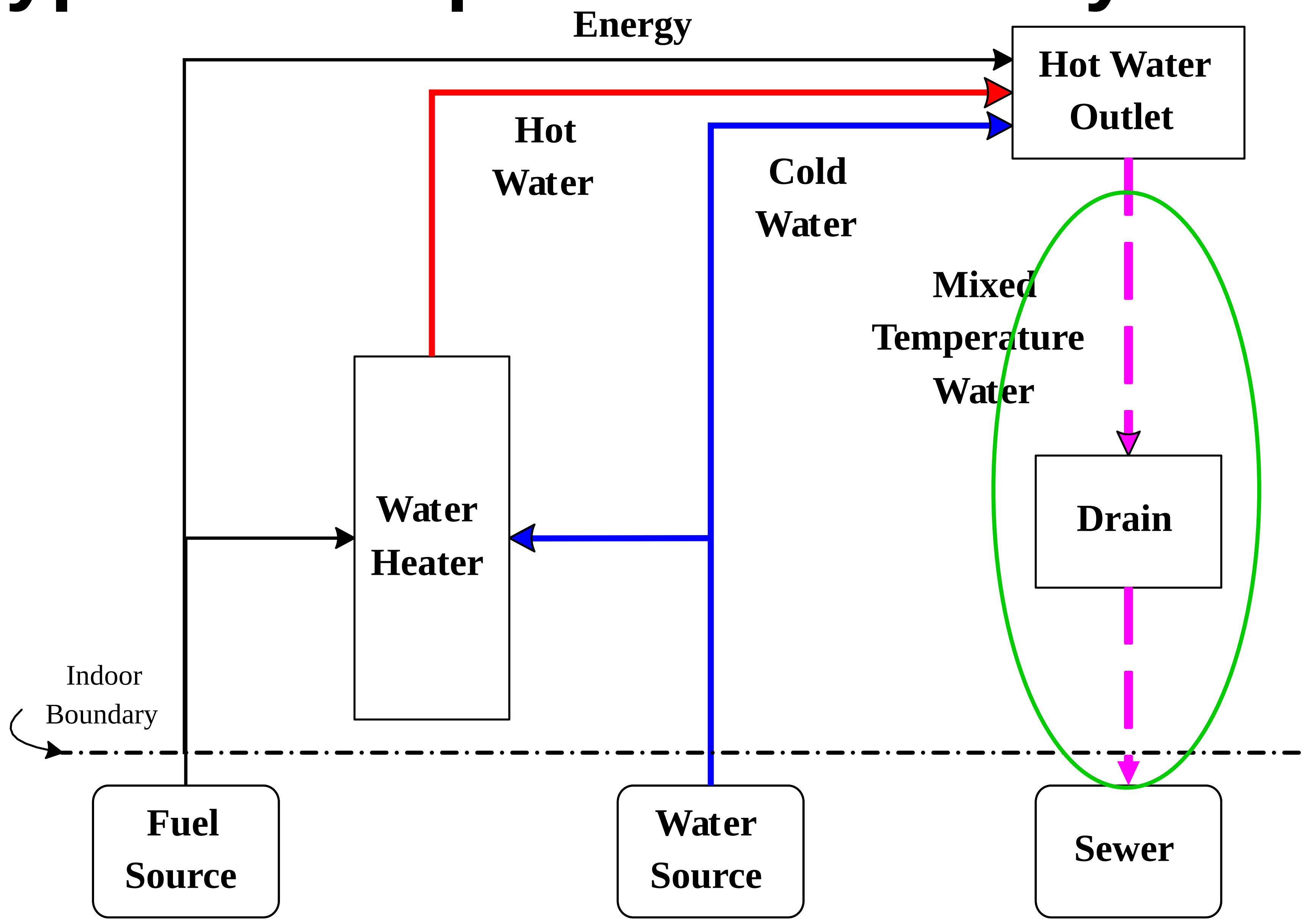
Insulate the pipes

- 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:

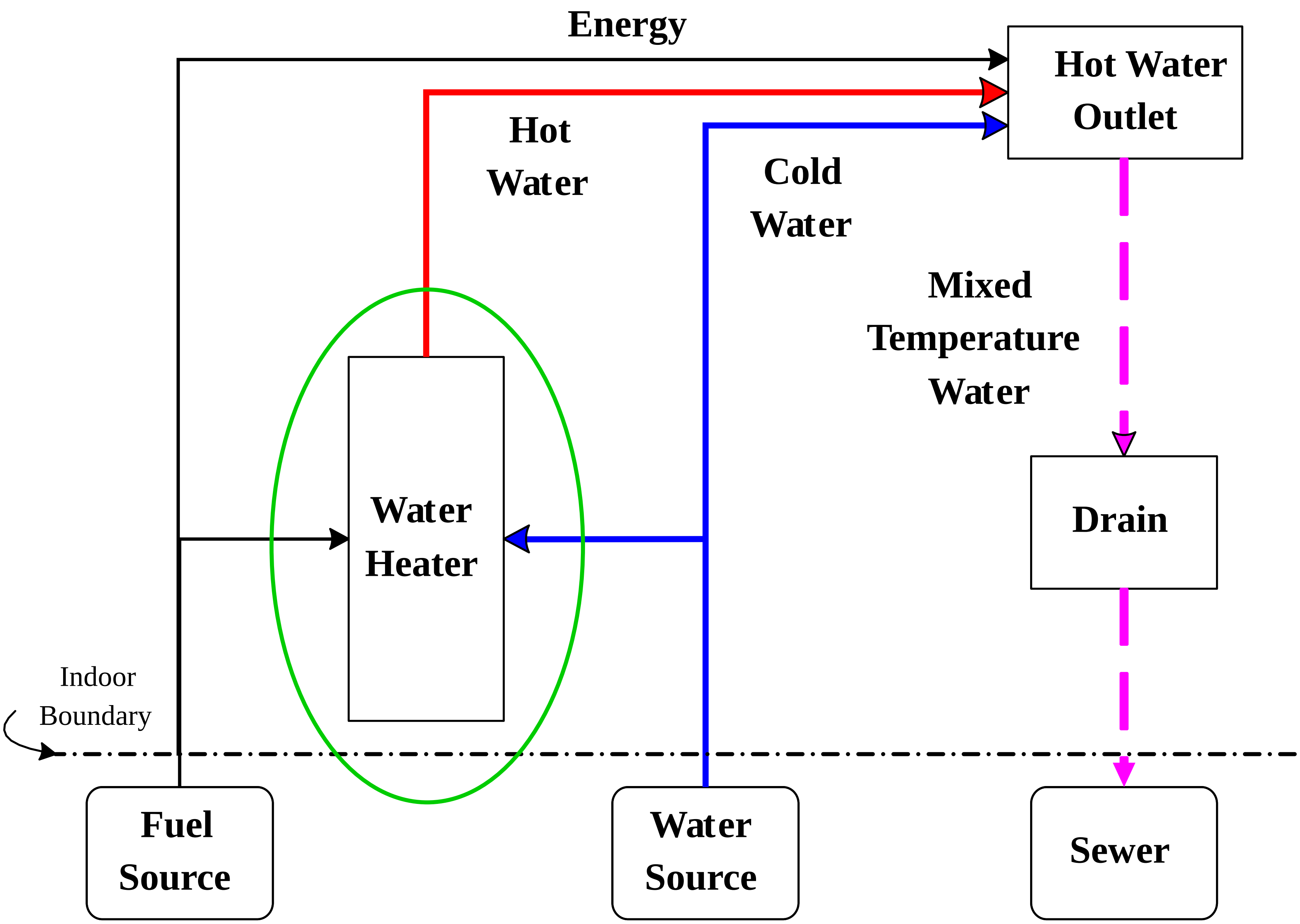
1. Where is the location of the hot water event in relation to the source of hot water?
2. How long is the time until the next hot water event?
3. What is the temperature of the hot water needed for that subsequent event?
4. What is the volume of water in the pipe that eventually cools down?

Typical “Simple” Hot Water System



Drain Water Heat Recovery

Typical "Simple" Hot Water System



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

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 85% thermal efficiency

Electric – nominal 98% thermal efficiency

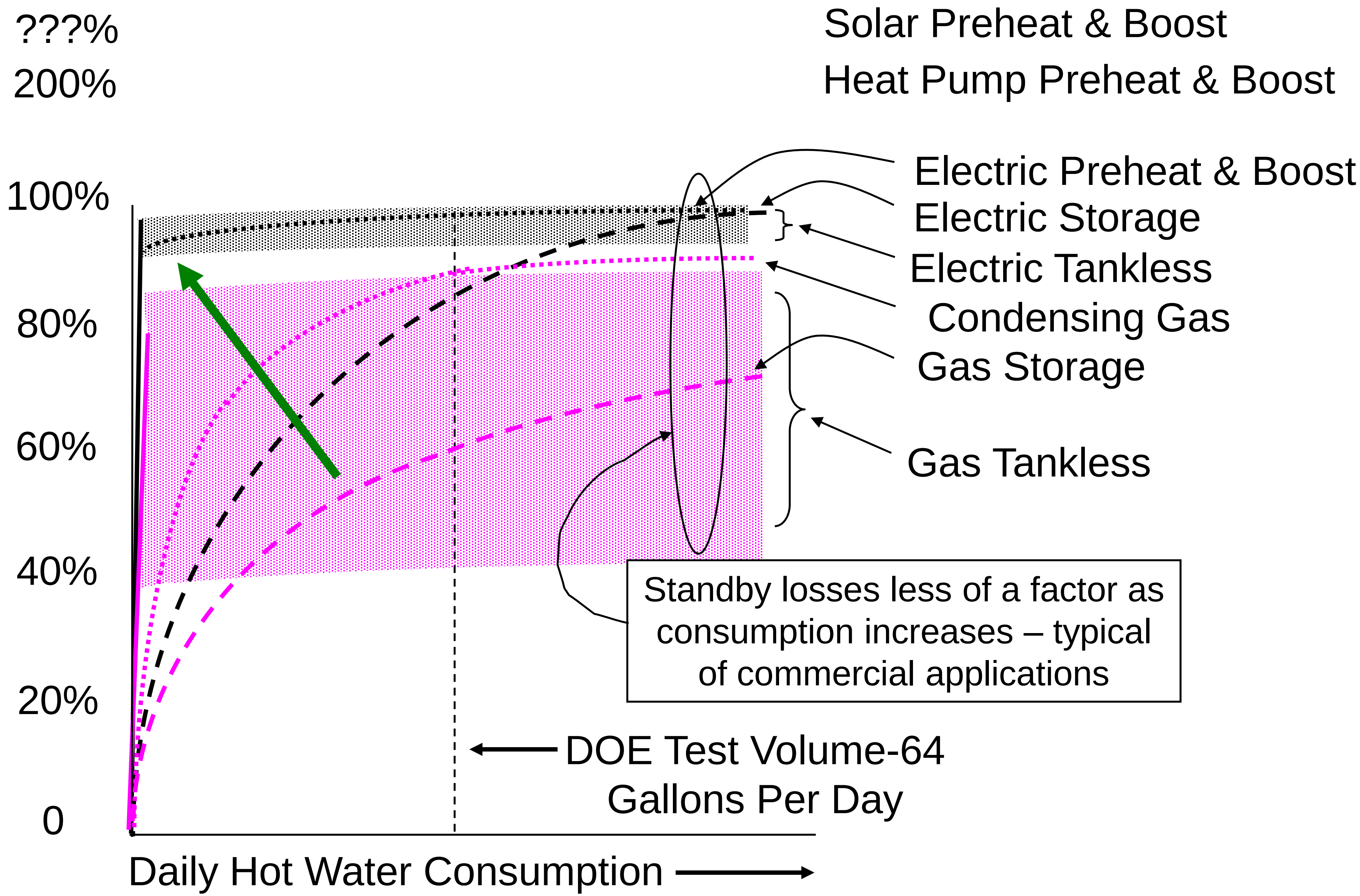
Neither Tank or Tankless is Necessarily the Answer

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**
  - Hot water available at the beginning of every draw
  - Some volume for peak conditions
  - Enables a simpler burner control strategy
- **Possible in both gas and electric**

How does the water heater interact with the fixtures?

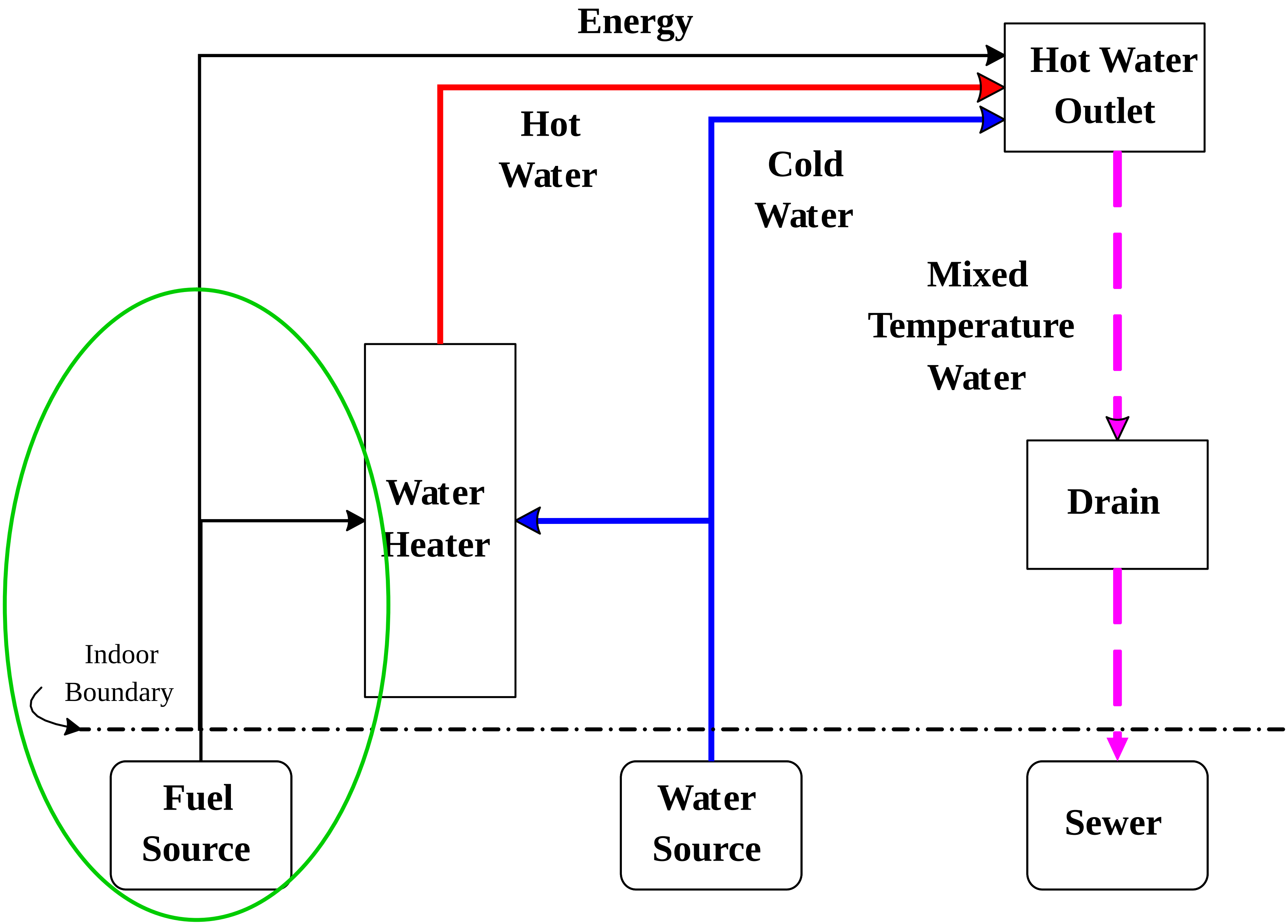
Relative Efficiency of Water Heaters



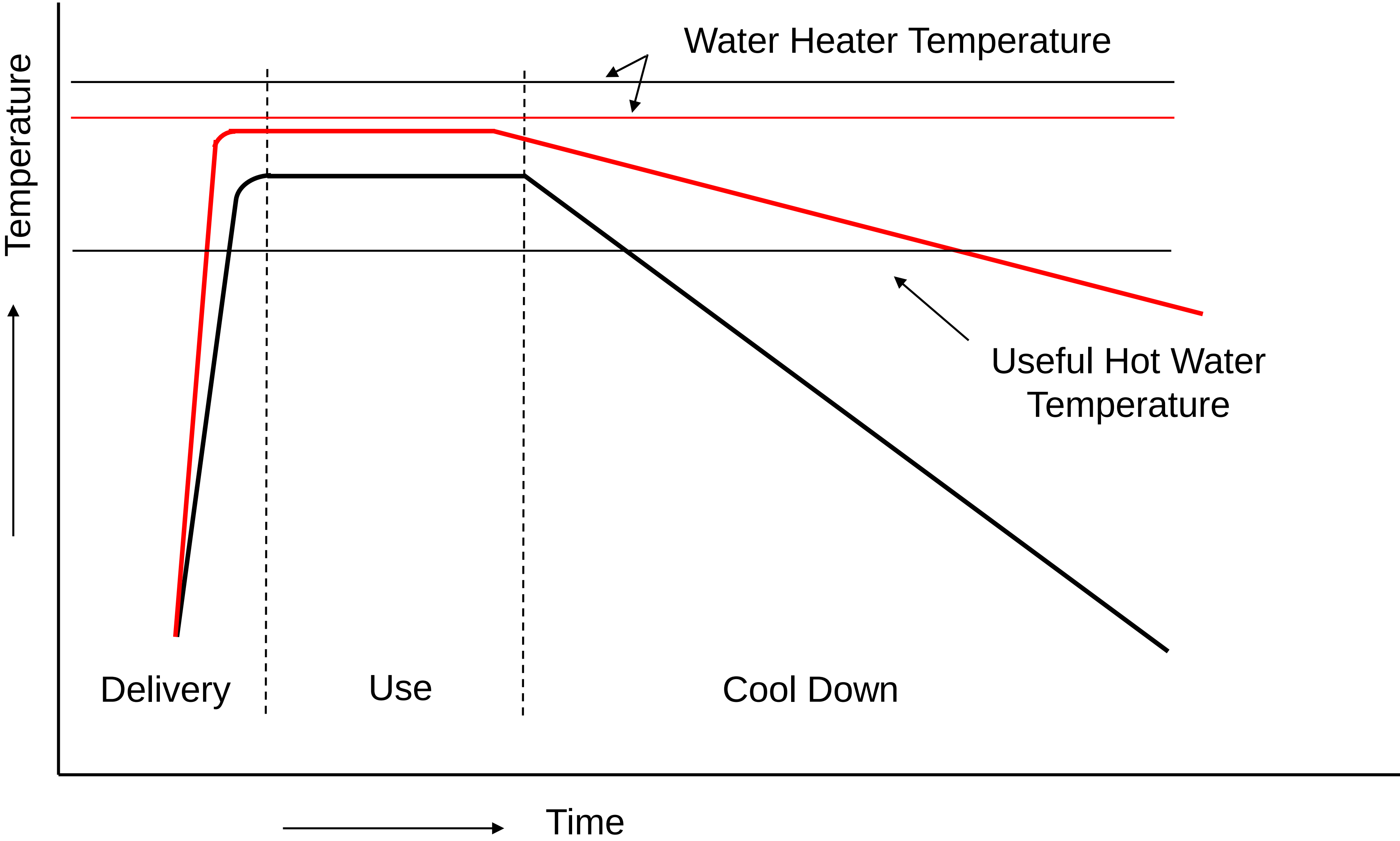
What About Solar Water Heating?

- Back-up
  - Will you have a back-up?
  - What is your expectations for cloudy days?
  - How does the back-up handle almost-hot-enough pre-heated water?
- Solar Fraction
  - Combined Water and Space Heating
- Cost
- Maintenance
- Simple Solar

Typical "Simple" Hot Water System



Improved Hot Water Event



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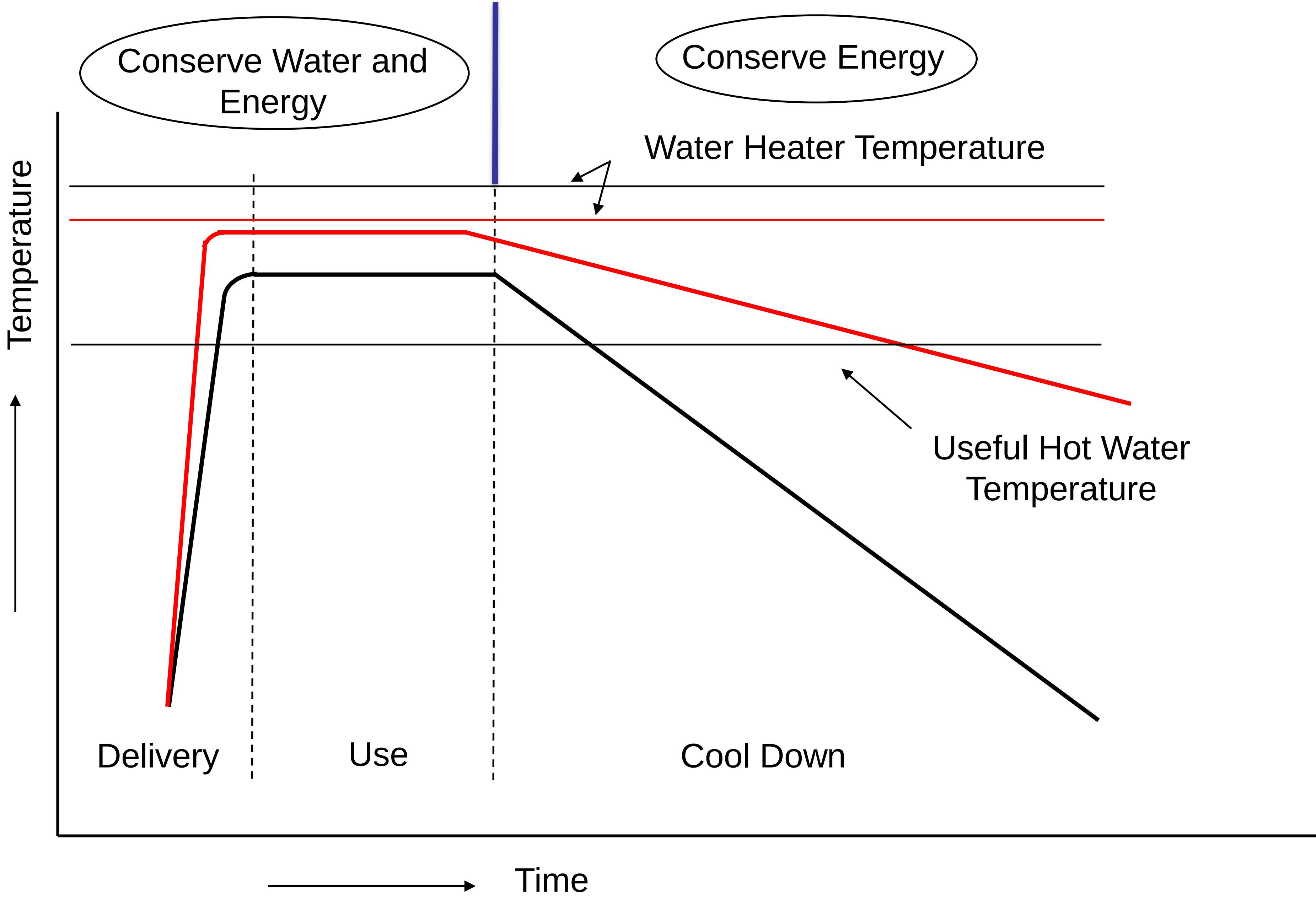

Potentially Conflicting Trends

On one hand:

- Larger houses
- More hot water outlets
- 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

The Answer – Part 1

- Reduce the waste.
  - Decrease the volume between source of hot water and the use – instantaneousness
    - This is a benefit in delivery, use and cool down phases of a hot water event.
  - Utilize the waste heat running down the drain
- Improve the use.
  - Reduce hot water outlet flow rates
  - Reduce the volume of hot water needed for each task
- Increase the efficiency.
  - Preheat – solar, heat pump, off-peak electric
  - Select a very efficient booster that works with preheated water to reach the desired temperature and for continuousness
  - Combine water and space heating

The Answer – Part 2

SHORT, skinny pipe