NSF Hot Water System Workshop

5 Nov 2021: Welcome and Hot Water System Bootcamp

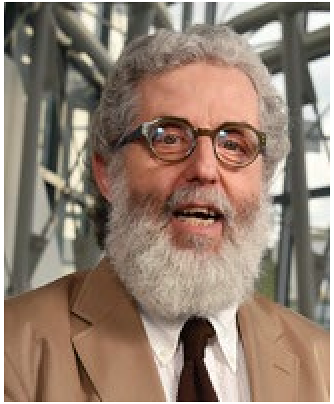
Katherine Alfredo, Assistant Professor, University of South Florida

Tim Bartrand, Executive Director, The Environmental Science, Policy and Research Institute

Charles Haas, LD Betz Professor of Environmental Engineering, Drexel University

NSF Award # 2129570

The Team



Katherine Alfredo
USF
PI

Charles Haas
Drexel University
Co-PI

Tim Bartrand
ESPRI
Co-PI

Katelyn Long
USF
Graduate RA

http://hotwatersystems.eng.usf.edu/

HOT WATER SYSTEMS

We hypothesize that hot water systems can be reengineered as beneficial and distributed treatment applications that significantly control and improve downpipe chemical and microbial water quality while still maintaining thermal efficiency through their design life.

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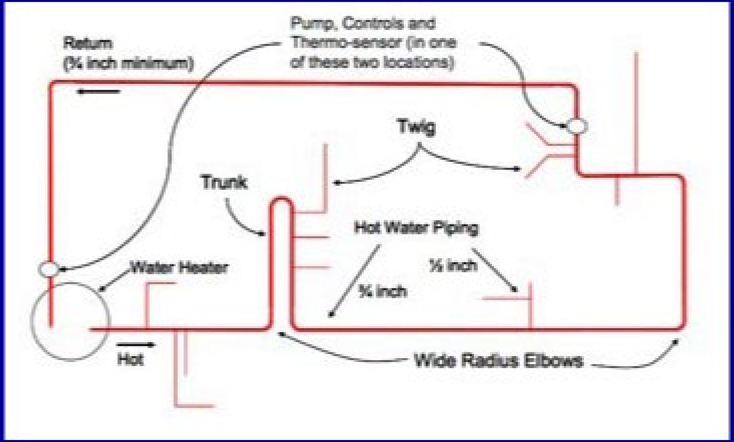
Hot Water System Bootcamp

- Goal: to create a common diagram and lexicon
- Interactive (so please interrupt and ask questions as we go)



https://www.garykleinassociates.com/

Expert

Gary Klein

Team Lead

Tim Bartrand

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Hot Water Systems Bootcamp

NSF Hot Water Systems Research Group Primer

5 November 2021

Gary Klein, Gary Klein and Associates, Inc.
gary@garykleinassociates.com
916-549-7080

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Hot Water Systems: Goals and Objectives

- The goal of hot water systems is to deliver water to plumbing fixtures
  - That is **healthy and safe**
  - At a **desired temperature** and
  - At an **acceptable pressure** (high enough to achieve desired/required flow but lower than the maximum operating pressure for the fixture)
- Beyond these minimum requirements, hot water systems should be designed and operated to
  - Minimize energy consumption
  - Promote water conservation and
  - Maintain or improve water quality

Hot Water System Expectations

Safety and Aesthetics

- Not too hot
- Not too cold
- “Safe” water
  - Pathogens and chemical compounds not present at levels posing excessive risk
- Appealing water
  - No color or turbidity
  - No off odors

Reliability

- Little or no maintenance
- Last forever
- Low cost

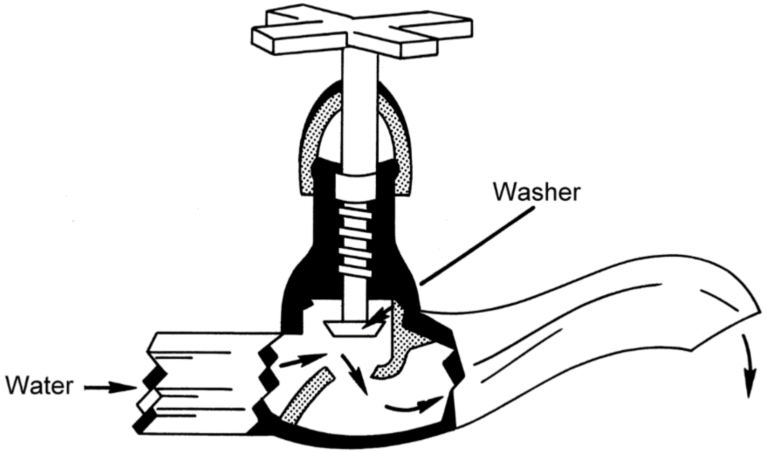
Convenience

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

Hot Water System Opportunities for Improvement

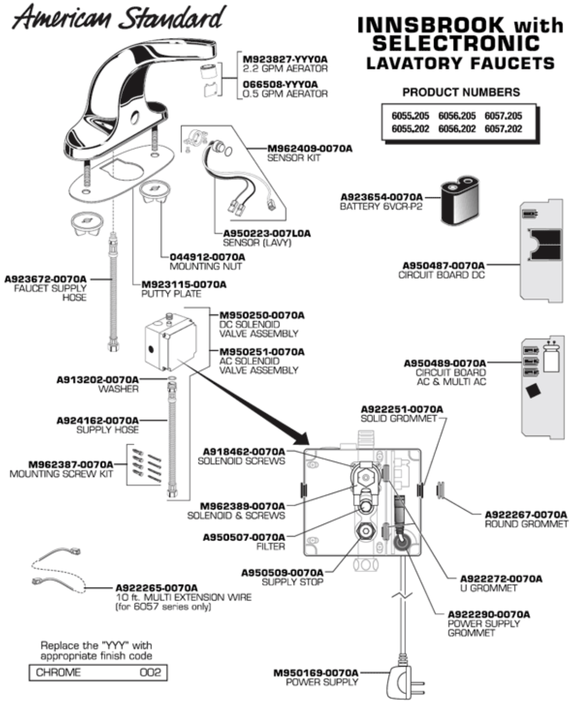
- Components
  - Water heaters
  - Appliances
  - Fittings
  - Plumbing fixtures
  - Treatment within the hot water system
- Layouts
  - Where water is heated
  - How hot water is distributed
  - How architects design buildings
- Materials
  - Pipe materials
  - Fitting materials
  - Plumbing fixture materials
- Usage and operation
  - Designing systems to be consistent with usage
  - Encouraging efficient use of systems
  - Operational and controls strategies (e.g., thermal kill cycles)

Yesterday



Courtesy of Tim Keane

Today



Codes, Standards and Guidances

Codes, Standards and Guidances

- Codes, standards and guidances are important, but should not be held out as a constraint to innovation
- One outcome of the 2018 NIST water systems experts' workshop was a recommendation research designed to inform better code
- Influencing and changing code are more difficult than meets the eye
  - Many interests at the table
  - Lots of $ at stake
- For the hot water system, pertinent codes, standards and guidances for both plumbing and energy; plumbing and energy codes are sometimes at odds.

Some Key Codes and Standards

Code	Type	Description and Applicability
IPC	Code	International Plumbing Code
UPC	Code	Uniform Plumbing Code
State and local	Code	Often adoption of IPC or UPC, sometimes with modifications
ASHRAE 188	Standard	Standard for management of *Legionella* in potable water systems
ASHRAE 514	Standard	In development. Standard for maintaining water quality in potable water systems
ASSE 12080	Standard	ASSE 12080 has been modified to include "Professional Qualifications Standard for *Legionella* Water Safety and Management Personnel." The standard pertains primarily to training and qualifications for developing water management plans
International Energy Conservation Code	Code	Establishes prescriptive minimum energy efficiency requirements for energy efficient buildings; establishes performance requirements for water heaters
ASHRAE 90.1	Standard	Energy code for all buildings other than low-rise residential (alternative to IECC)

Layouts and Components

The Hot Water System

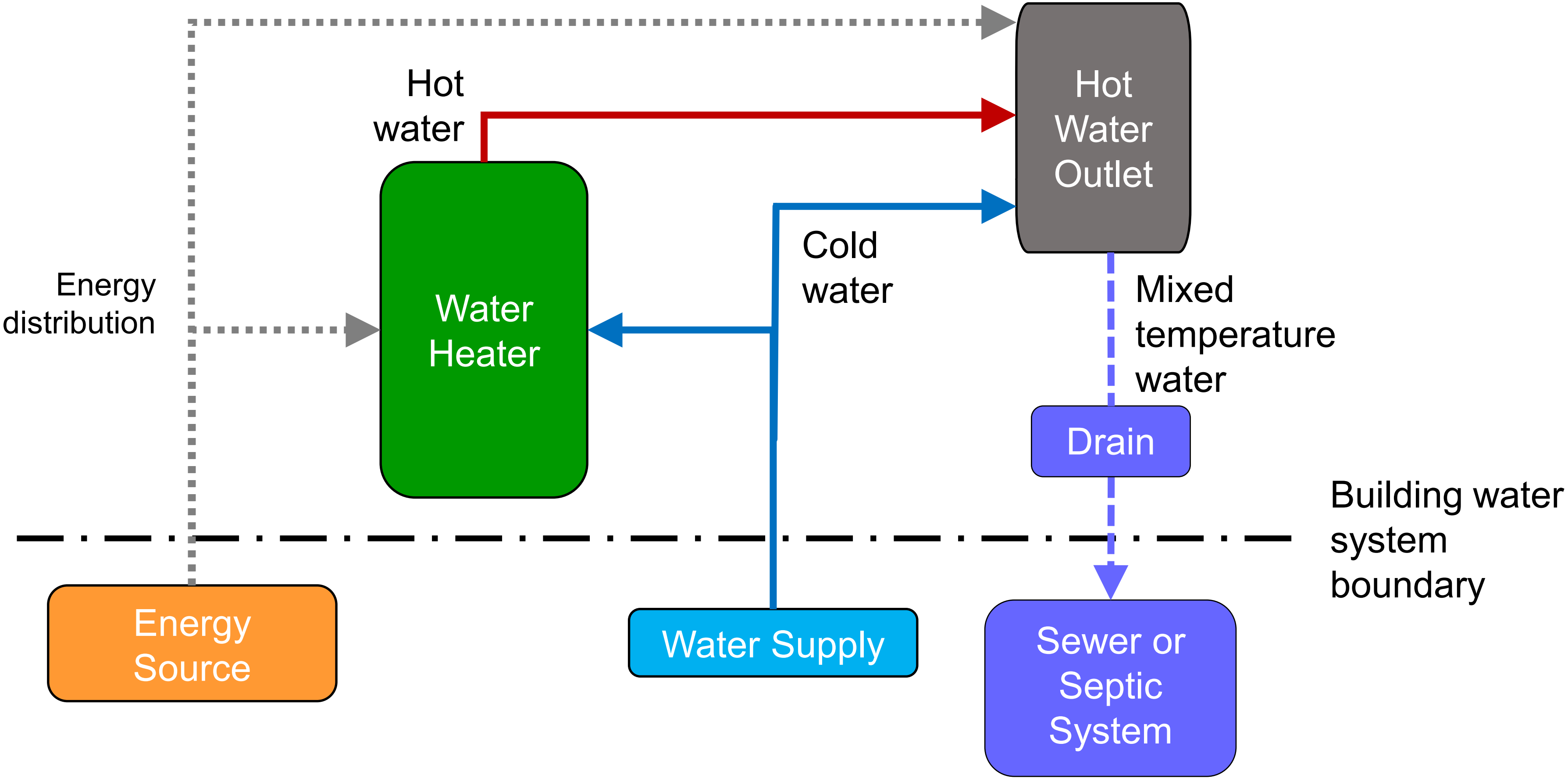
Components

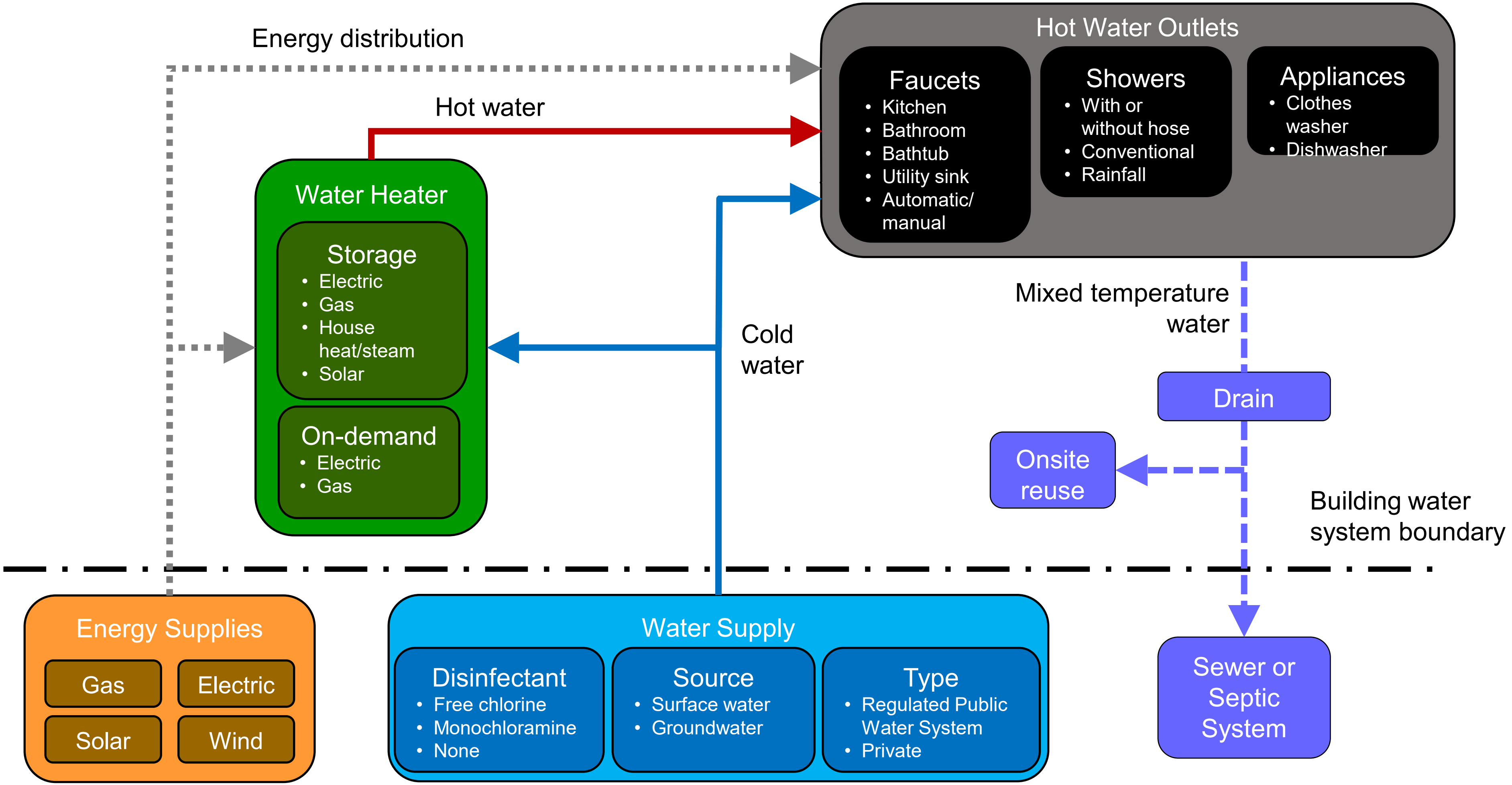
- Delivery to the building
- Treatment in the building
  - Softening
  - Supplemental disinfection
- Use in the Building
  - Water Heater
  - Piping
  - Fixtures, Fittings and Appliances
  - Behavior
  - Water Down the Drain
- Wastewater removal and treatment

Interactions and Performance

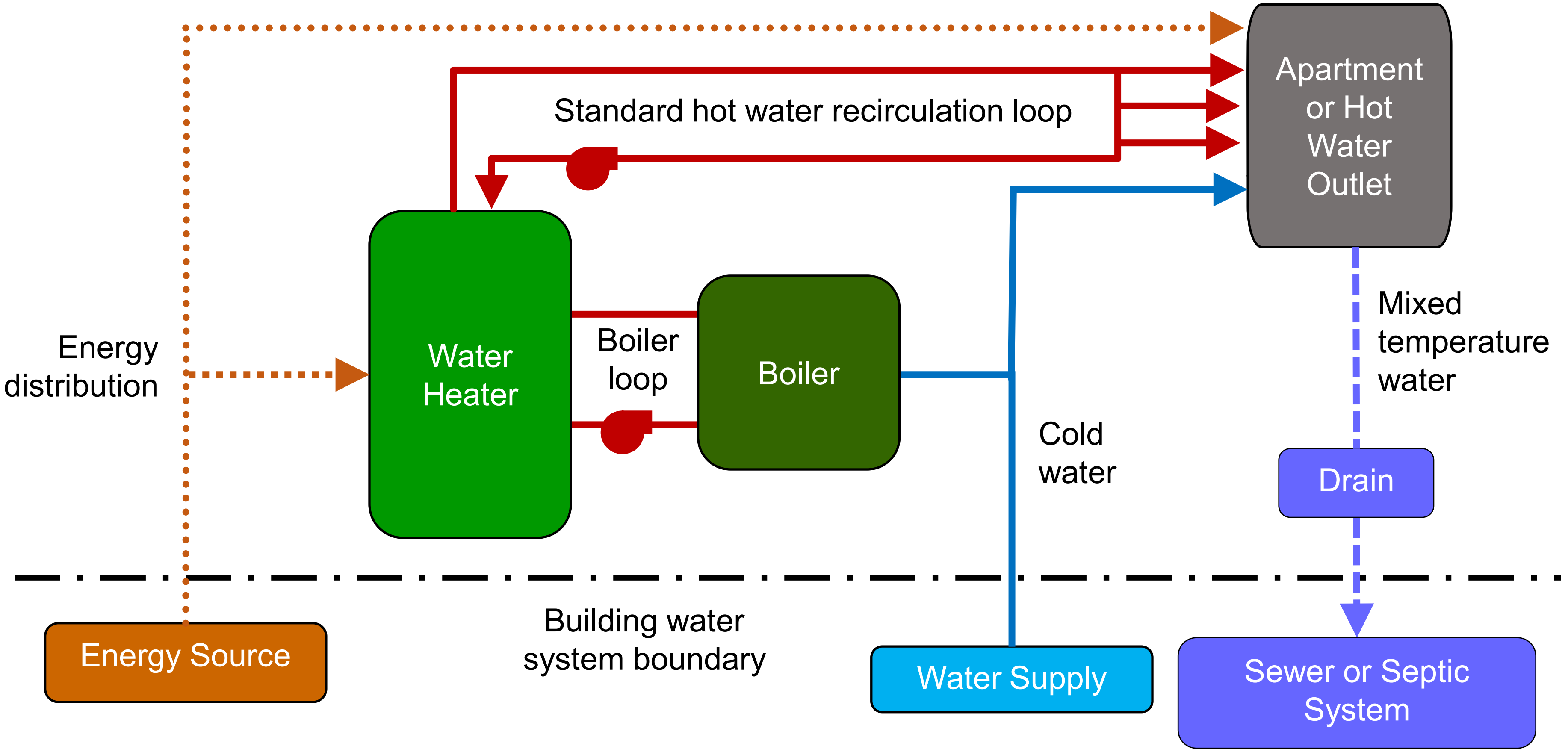
- System performance
  - Energy efficiency (well studied)
  - Water efficiency (somewhat studied)
  - Water quality (less studied)
- Energy use depends on the water heater **and** connected plumbing
  - Water heater is chosen based on characteristics of downstream plumbing
  - Larger diameter pipes store more water and energy than smaller pipes
- Building supply water quality has short- and long-term impacts

Simple Hot Water System




Energy distribution
Hot water
Hot Water Outlets
Faucets
• Kitchen
• Bathroom
• Bathtub
• Utility sink
• Automatic/ manual
Showers
• With or without hose
• Conventional
• Rainfall
Appliances
• Clothes washer
• Dishwasher
Water Heater
Storage
• Electric
• Gas
• House heat/steam
• Solar
On-demand
• Electric
• Gas
Cold water
Mixed temperature water
Drain
Onsite reuse
Building water system boundary
Energy Supplies
Gas
Electric
Solar
Wind
Water Supply
Disinfectant
• Free chlorine
• Monochloramine
• None
Source
• Surface water
• Groundwater
Type
• Regulated Public Water System
• Private
Sewer or Septic System

More Complex System



Layouts

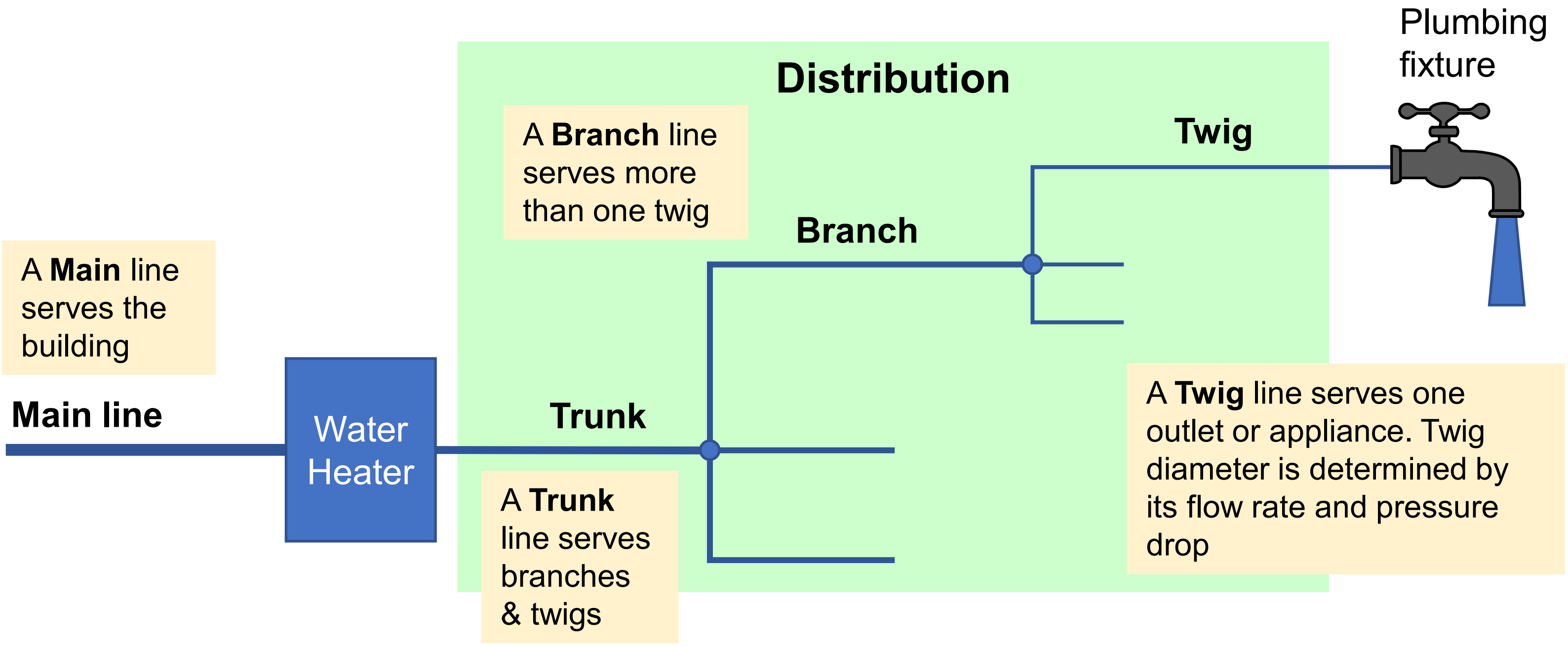
Common Layouts

- Trunk and branch
- Zoned trunk and branch (structured plumbing)
- Manifold/homerun
- Submanifold
- Distributed heating
- Recirculated heating
- Zoned, horizontal layout (large buildings)
- Zoned, vertical layout (large buildings)

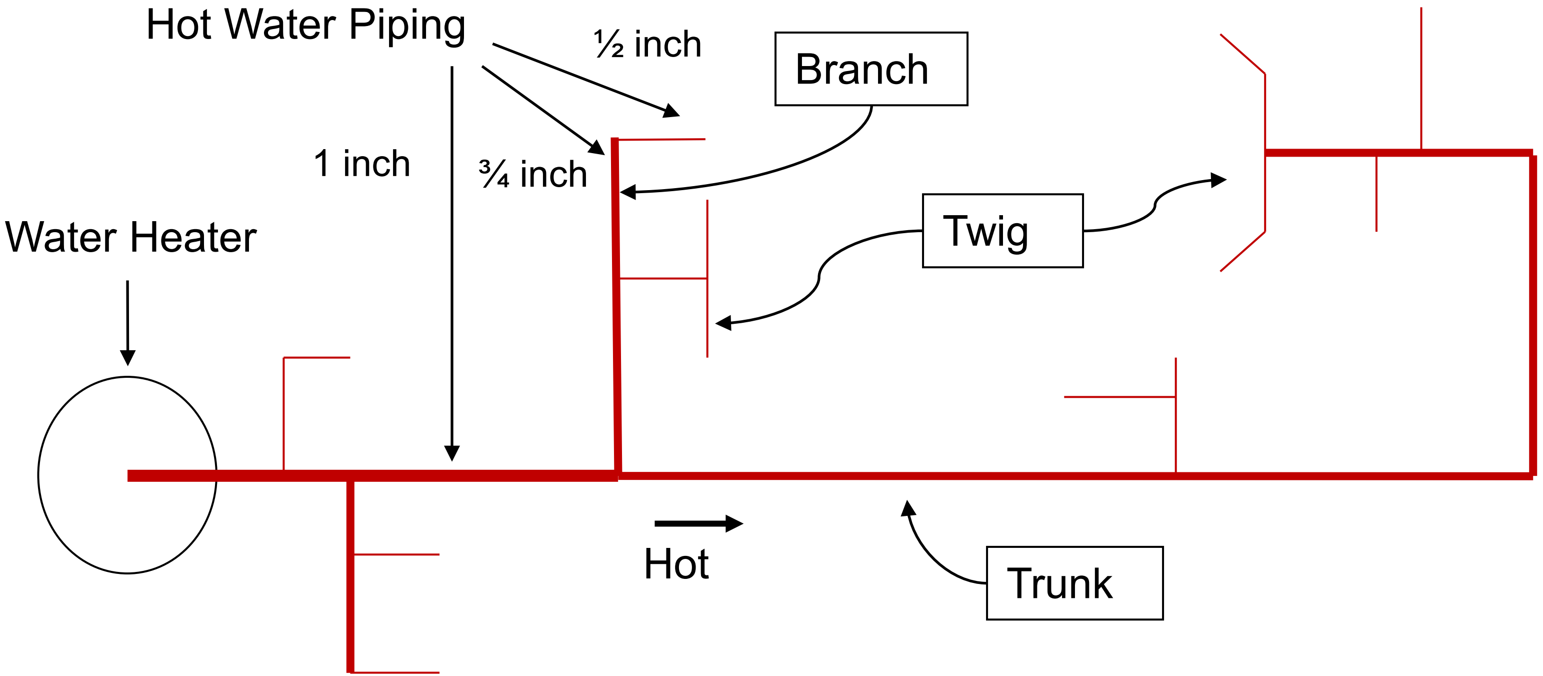
Why Layout is Critically Important

- Layouts influence
  - Materials (capital) costs,
  - Energy consumption,
  - Water consumption, and
  - Water quality at plumbing fixtures
- Other considerations
  - Retrofits are expensive
  - Layout is often based more on architectural needs than water and energy considerations

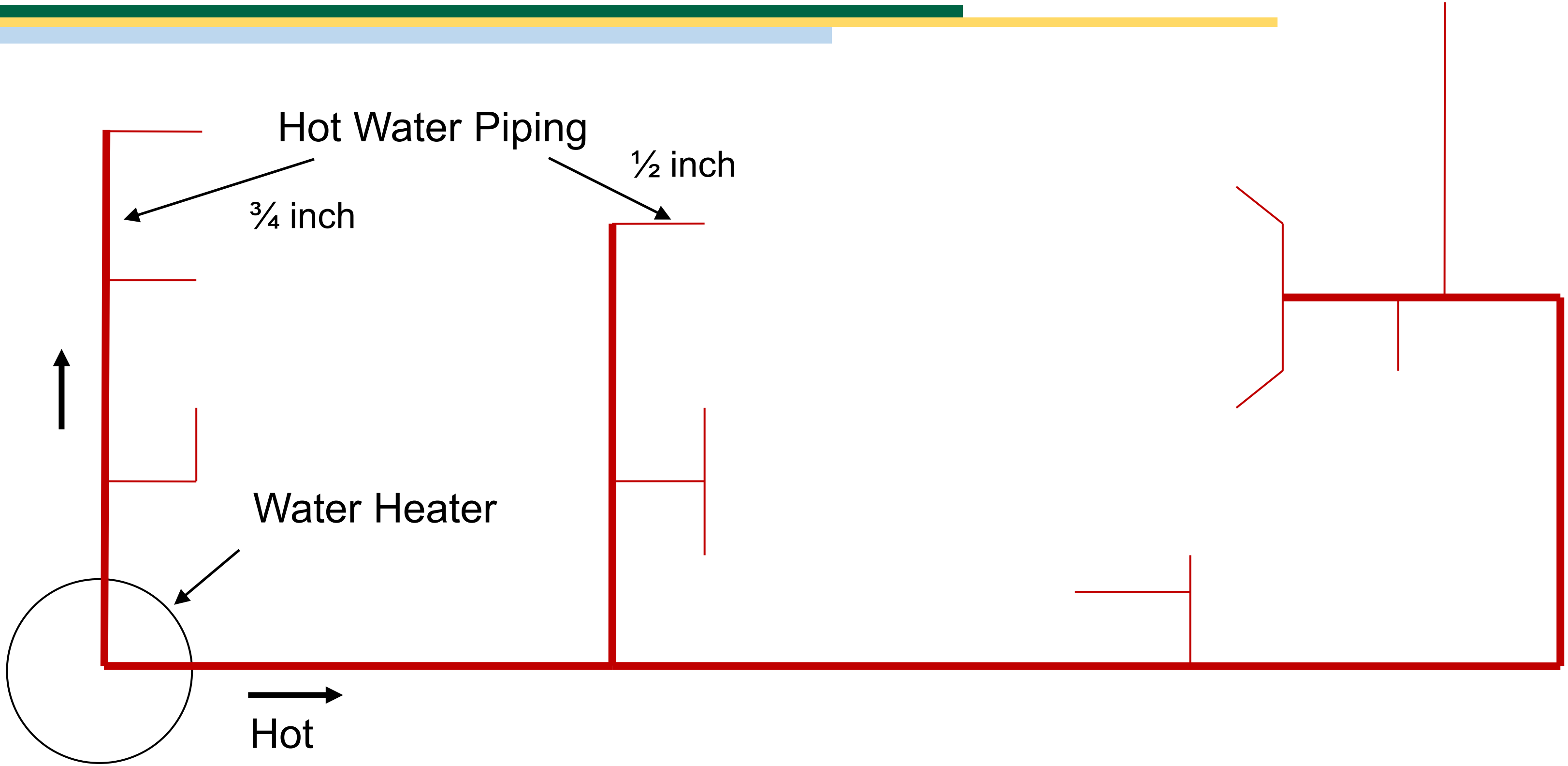
Nomenclature, Simple Branched System



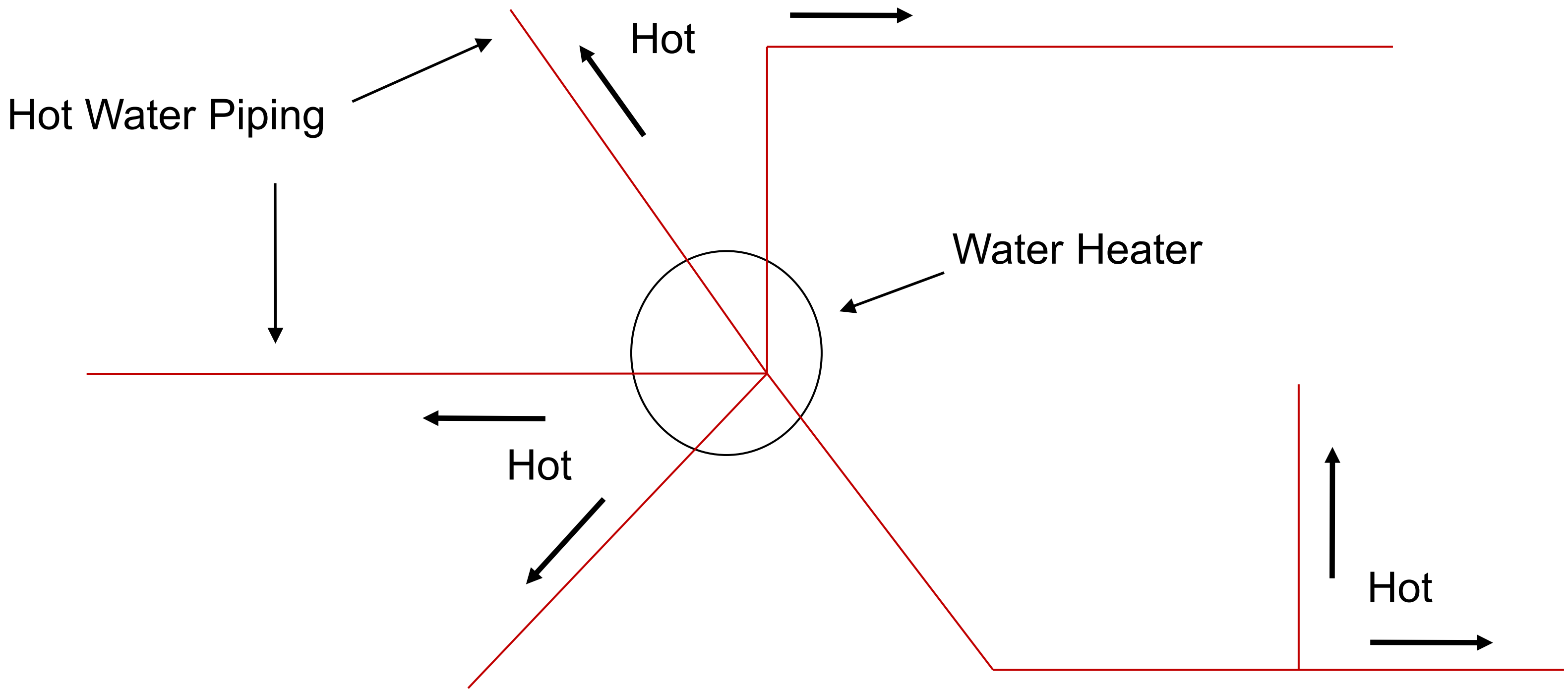
Single Trunk, Branch and Twig



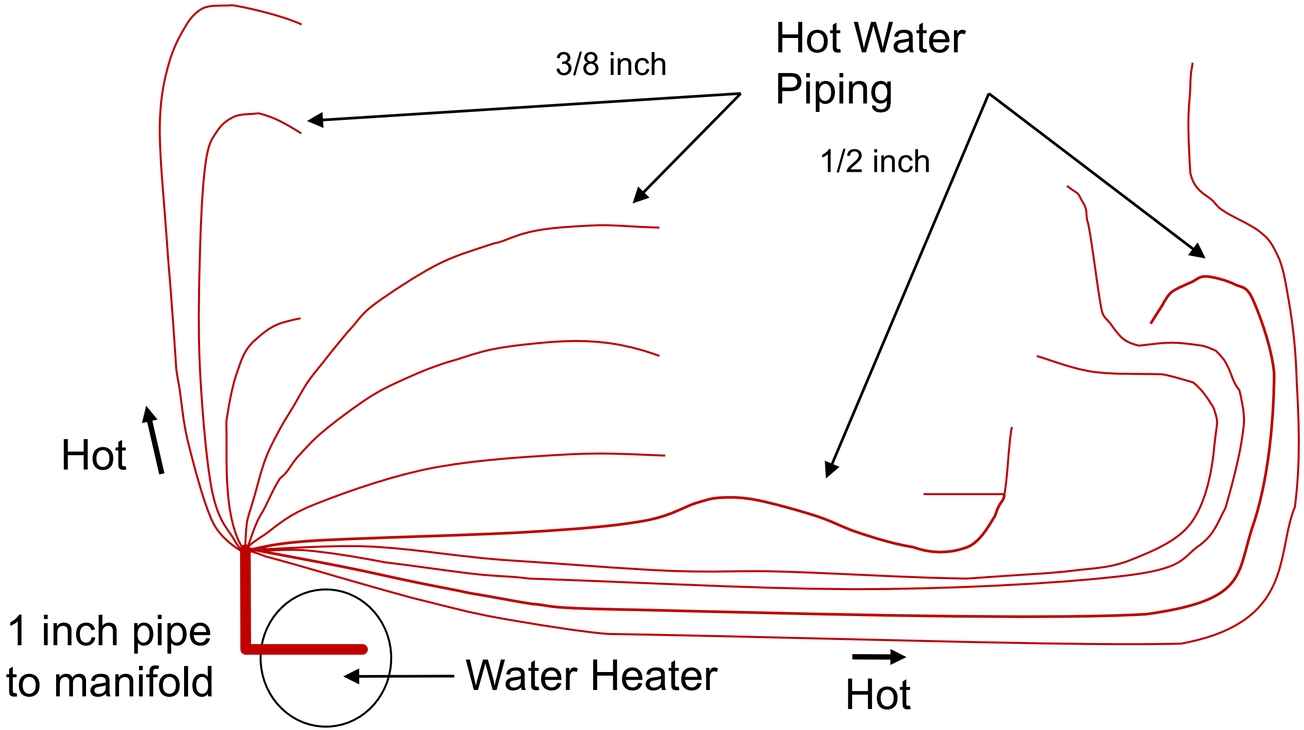
Multiple Trunk, Branch & Twig



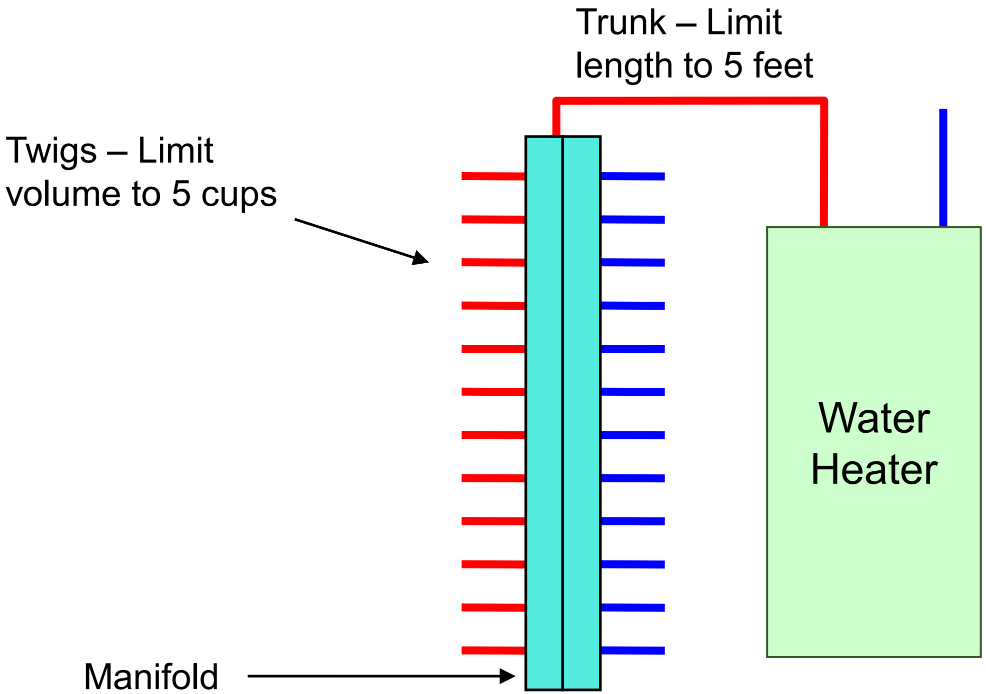
Radial, Manifold, Parallel Pipe - Central Core

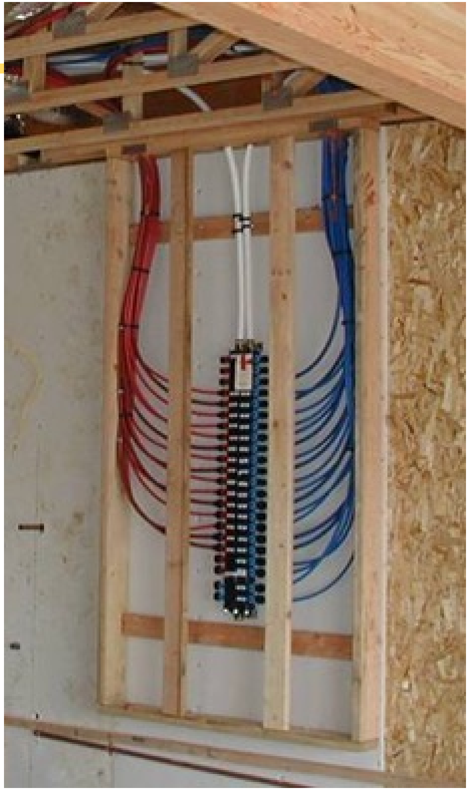


Radial, Manifold, Parallel Pipe – Distributed

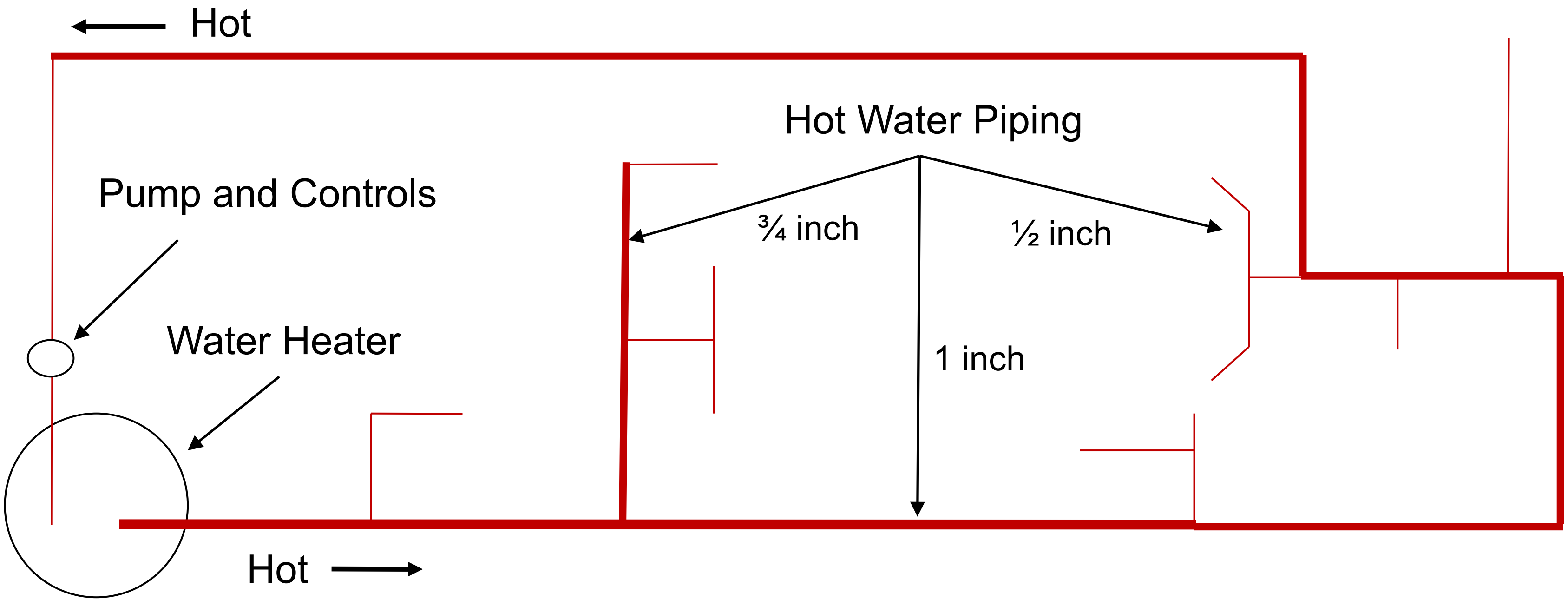


Whole Building Manifold Layout

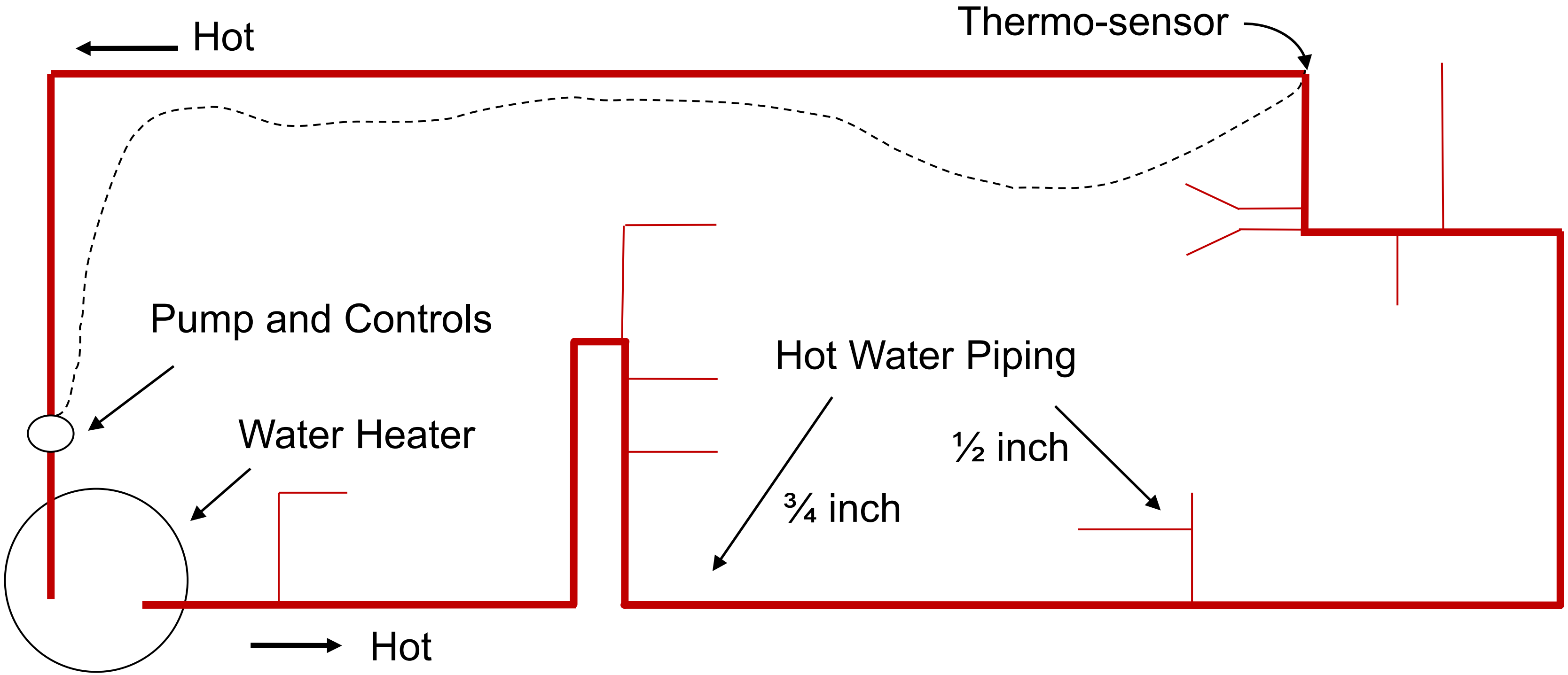




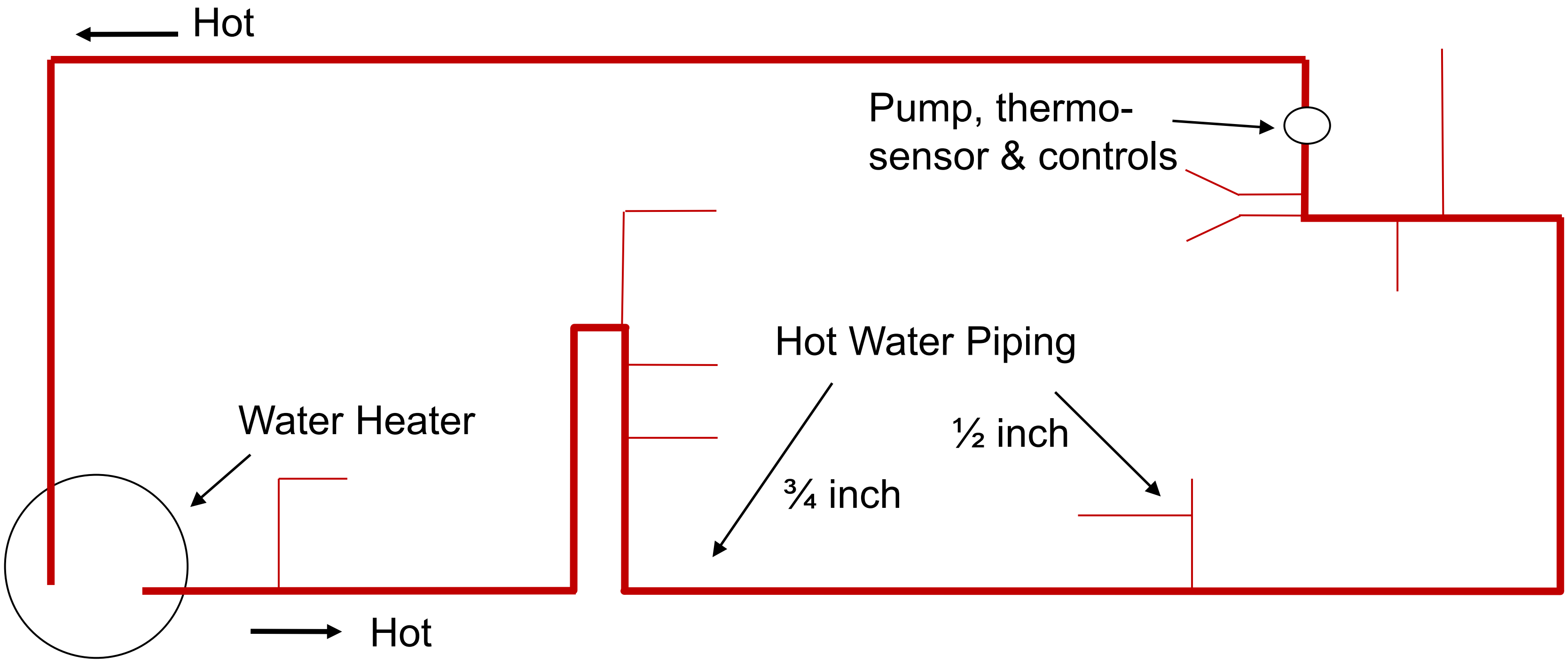
Standard Recirculation – Fully Heated Loop



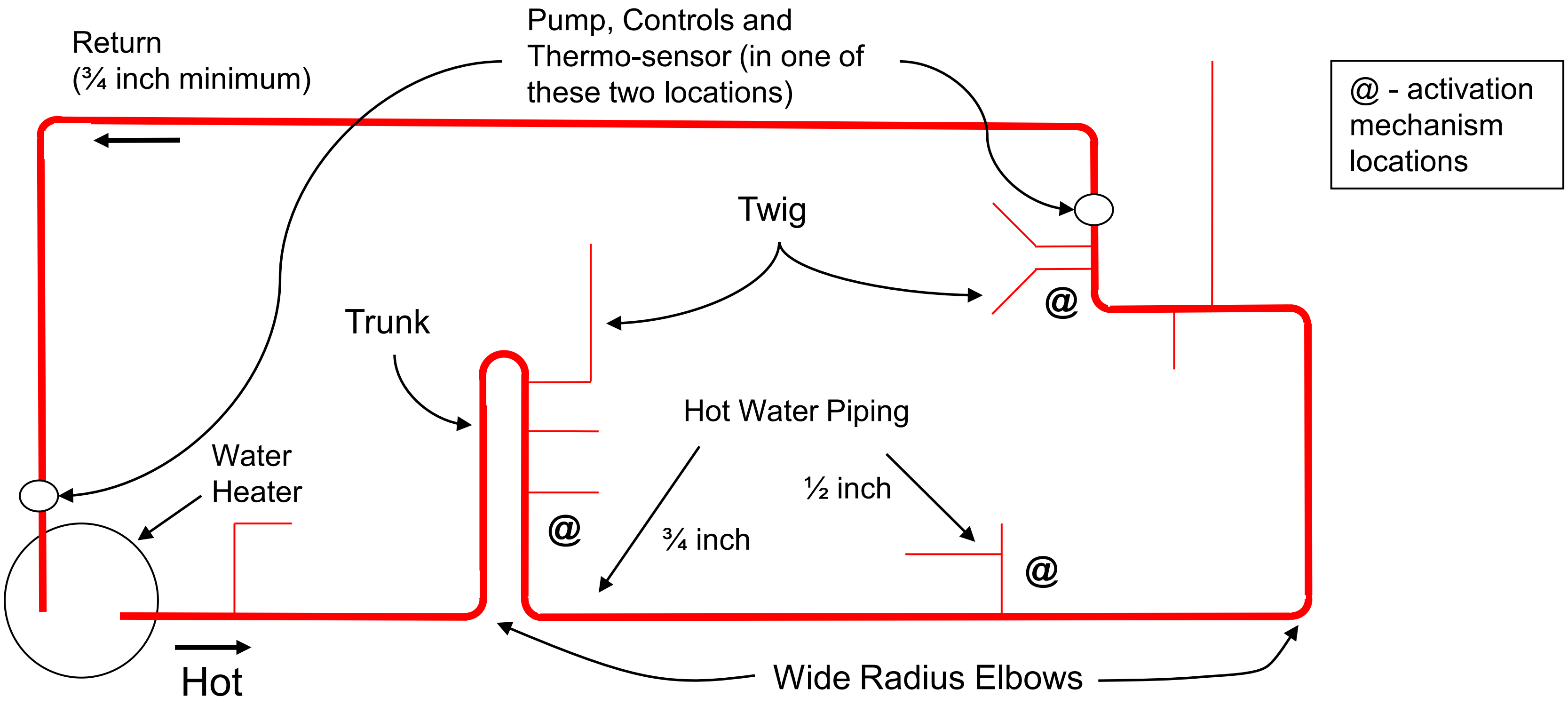
Standard Recirculation, Half Heated Loop, Separated Pump & Thermo-sensor



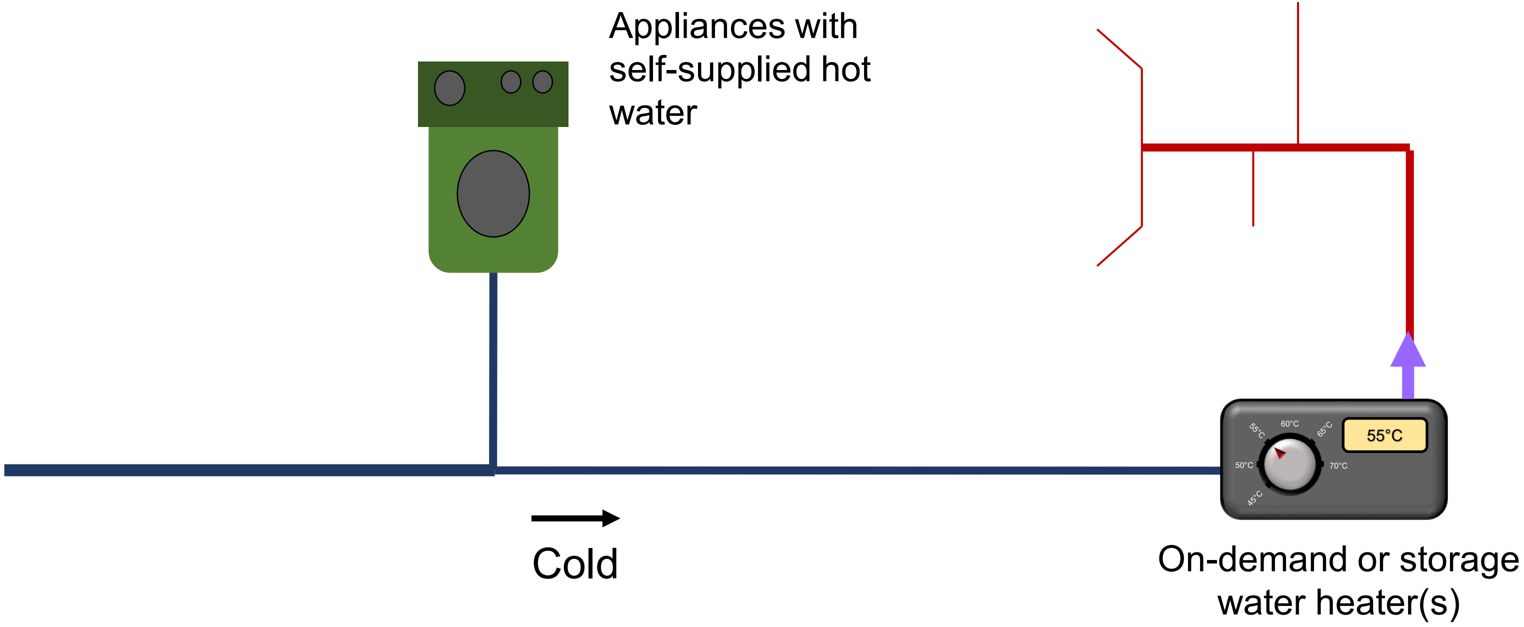
Std Recirculation, Half Heated Loop, Pump Located w/ Thermo-sensor



Structured Plumbing Layout



Distributed Heating



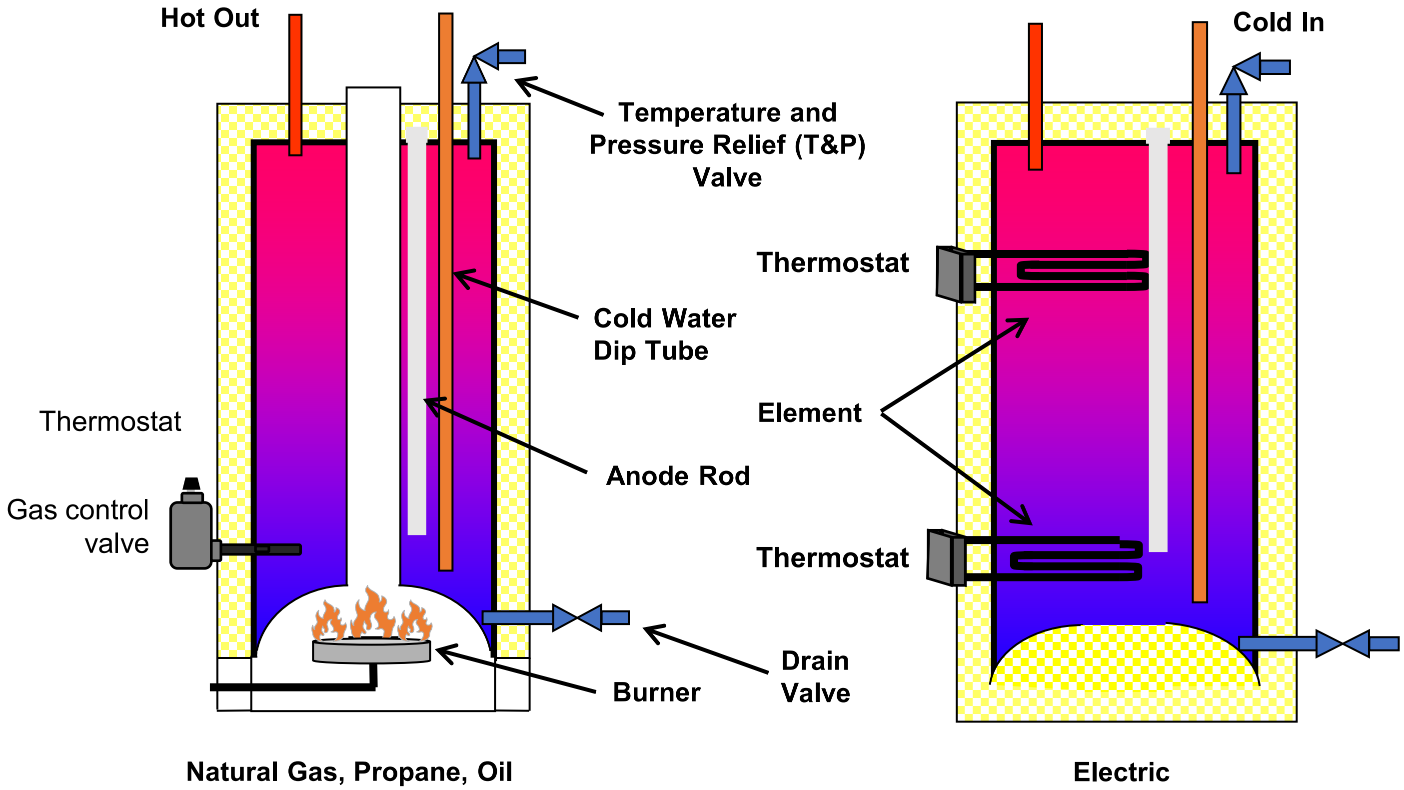
Recirculation

1. There are six types of recirculation systems:
   - Thermosyphon (gravity convection with no pump),
   - Continuously pumped systems,
   - Timer controlled,
   - Temperature controlled,
   - Time and temperature controlled, and
   - Demand controlled.

2. Given the same plumbing layout, all of these systems waste the same amount of water at the beginning of a hot water event.
3. The difference in these systems is in the energy it takes to keep the trunk line primed with hot water.

Water Heaters

Inside a Storage Water Heater

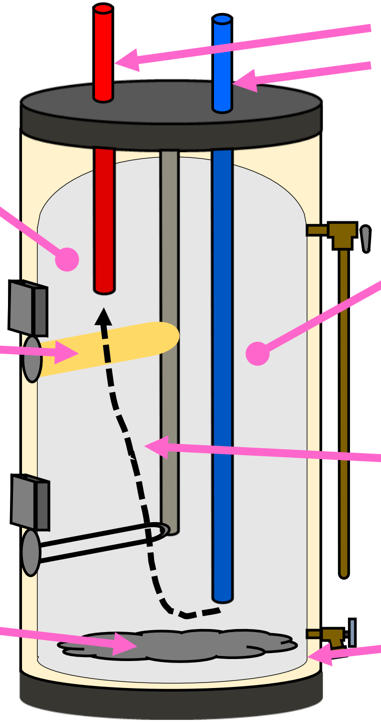


Known Performance and Water Quality Challenges

Thermal stratification during stagnation/ standby
- Electric water heaters

Heat exchanger fouling
- Thermal performance degradation
- Frequent cycling (on/off) and reduced life of heating elements

Sludge accumulation
- Ecological niche?
- Can overtop lower heating element



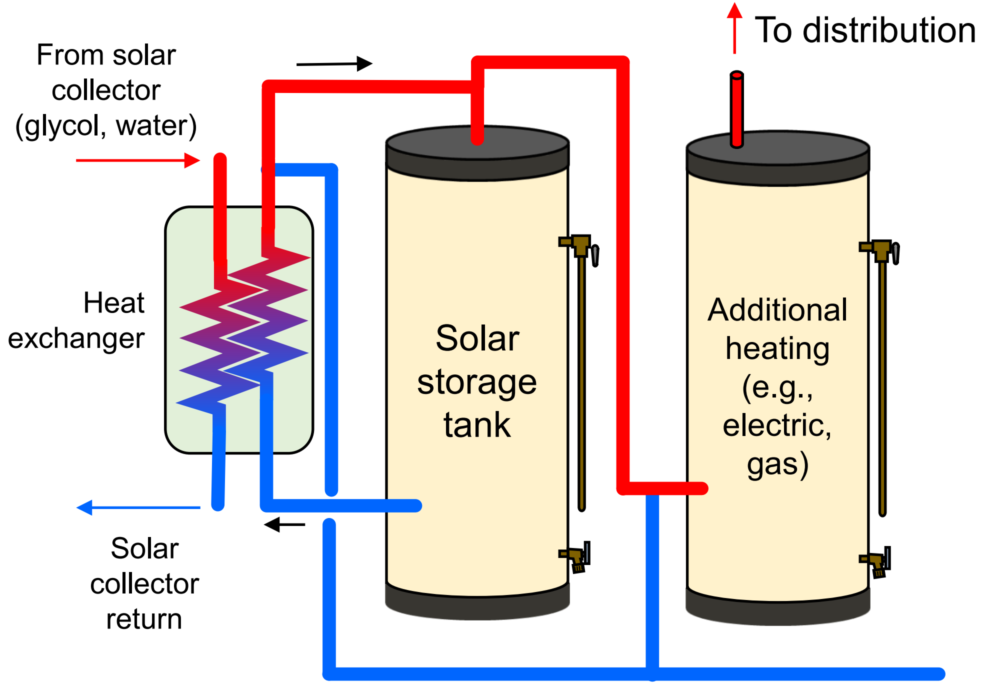
Collateral heating
- Energy loss
- Pathogen growth

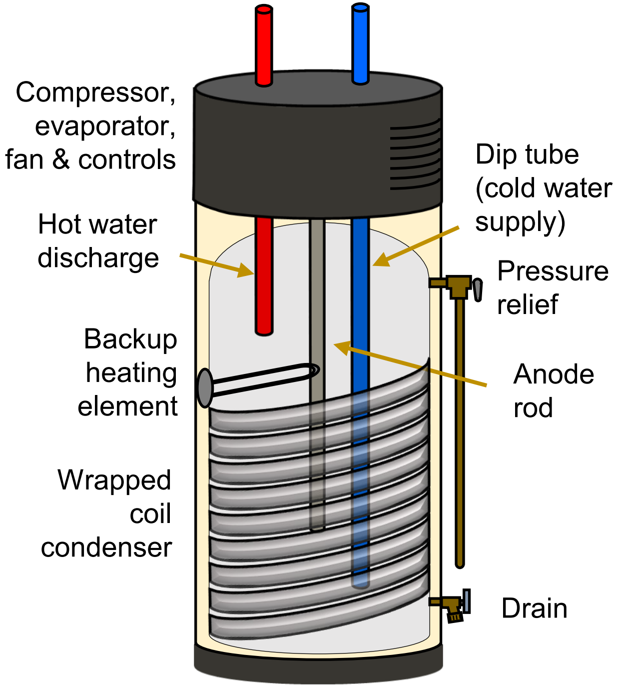
Degraded water quality during stagnation/stand-by
- Disinfection byproducts
- Precipitation

Non-ideal flow
- Pathogens in supply evade contact with hot water (low Ct)
- Cold water short-circuits to effluent (energy waste)

Corrosion

Solar and Condenser Water Heaters



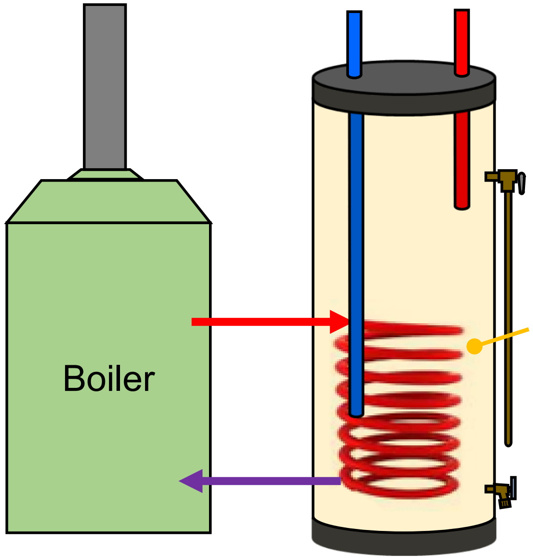


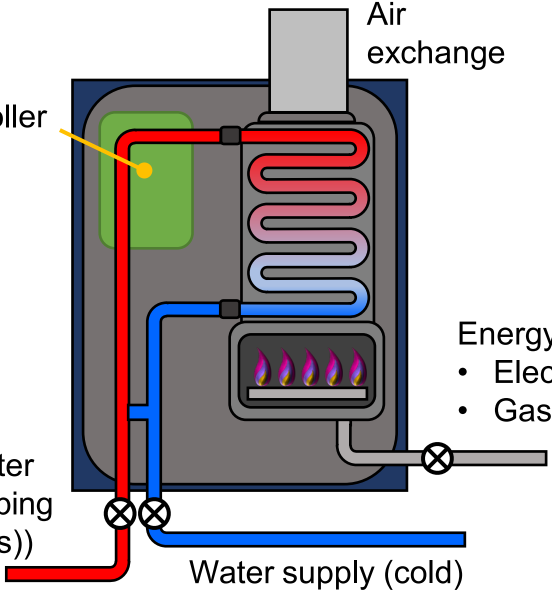
Look at the bottom of the tanks

76,000 Btu

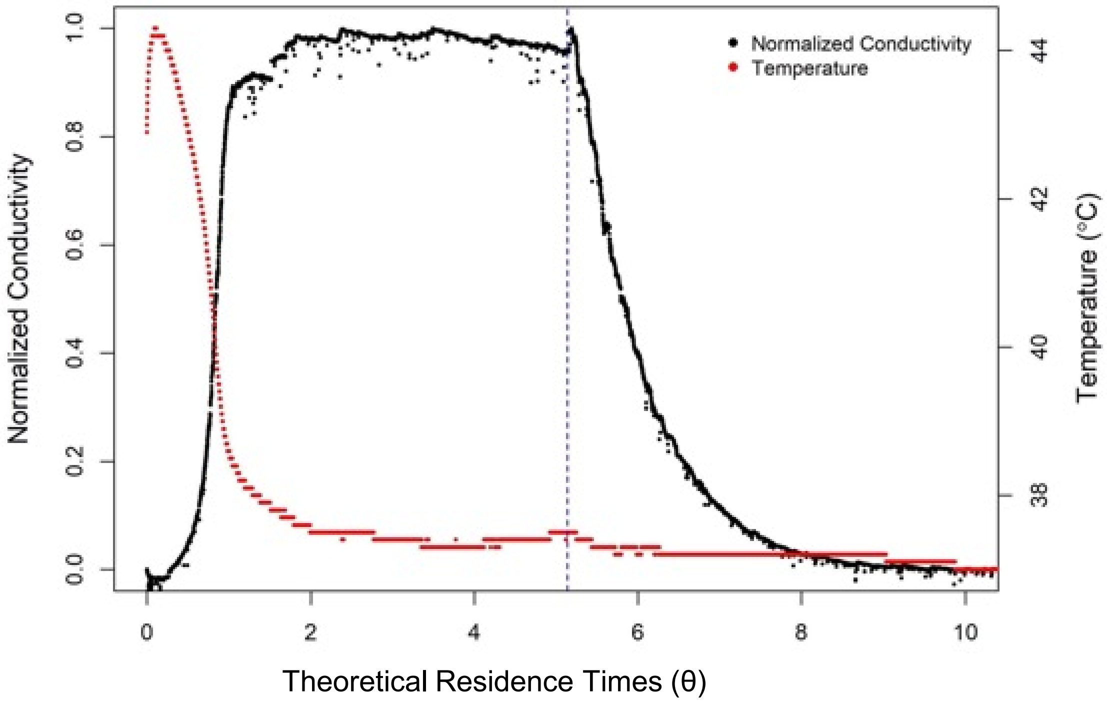
100,000 Btu

Indirect and Tankless Water Heaters





Water Heater Hydraulics

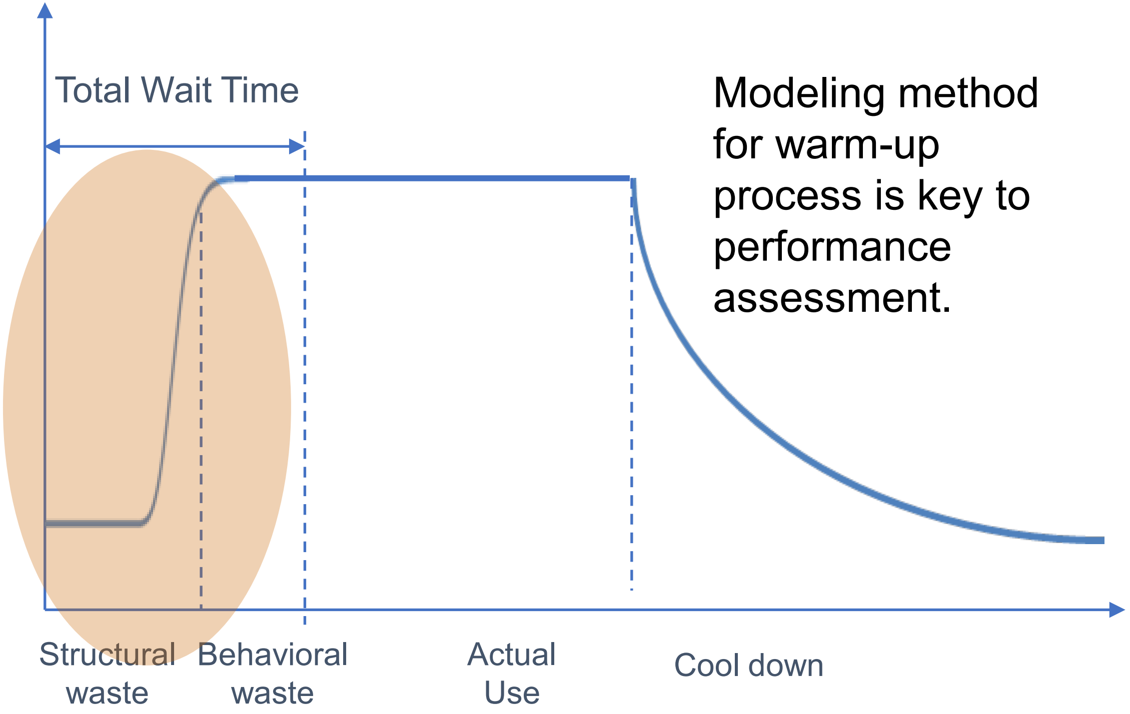


- 50-gallon electric storage type water heater
- Nearly plug flow during early use
  - Cold influent water sinks
- Approaches completely mixed reactor after a long draw
  - Lower ΔT between influent & tank

Hot Water System Energy

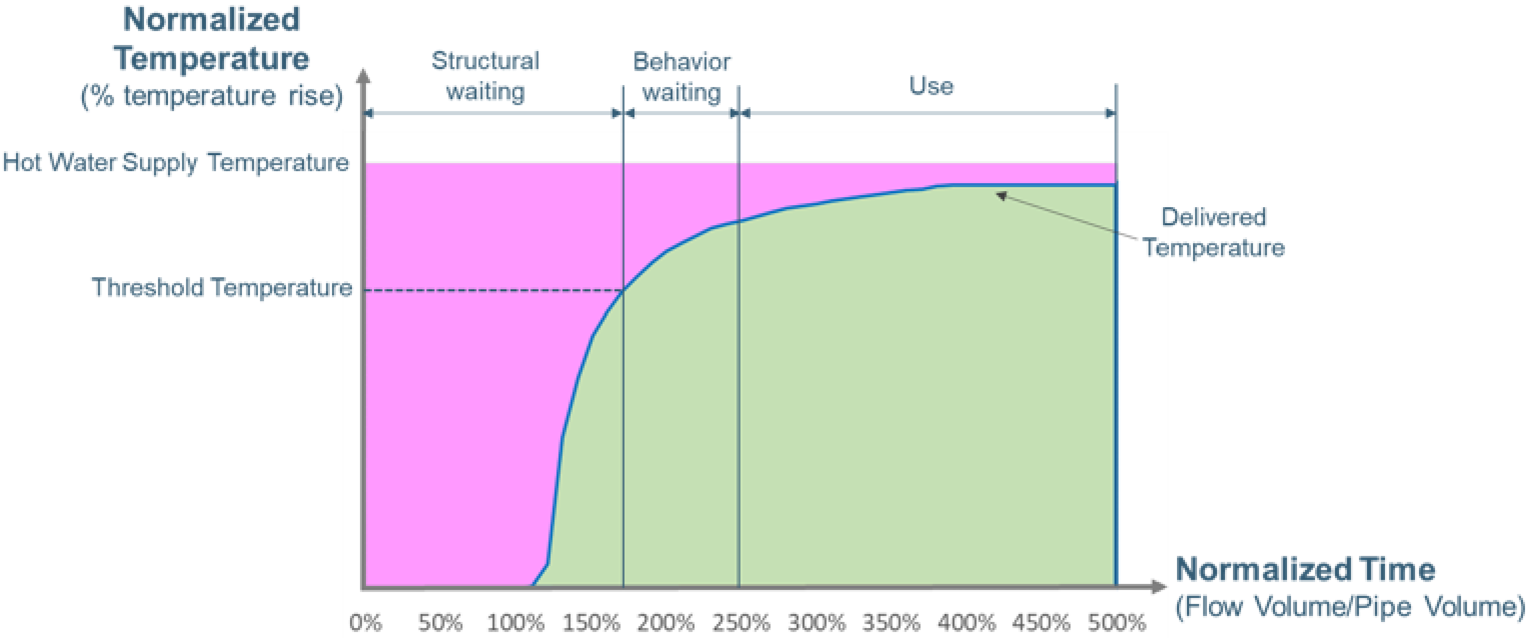
A Typical Hot Water Use Event

- Analytical solution – too difficult, not sure possible
- Numerical solution based on heat transfer models – can be generalized
- Empirical formula based on test data - inherently validated

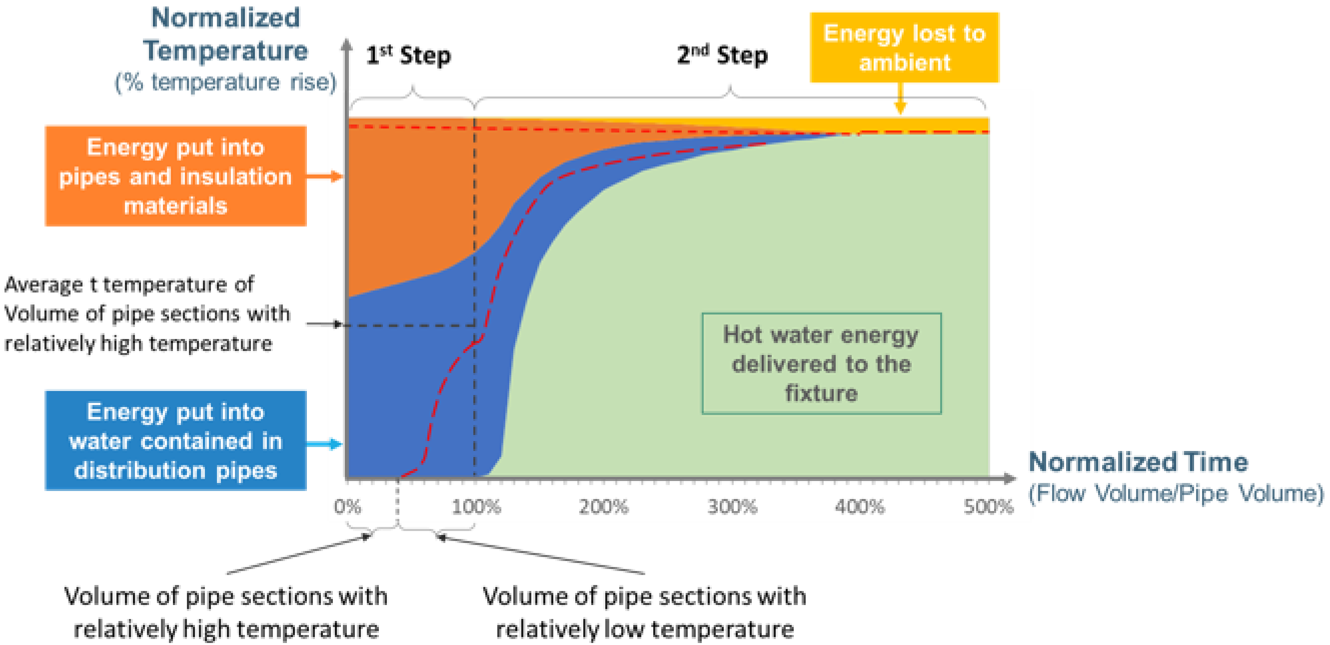


Modeling method for warm-up process is key to performance assessment.

Using the Empirical Temperature Curve to Determine Hot Water Delivery Phases

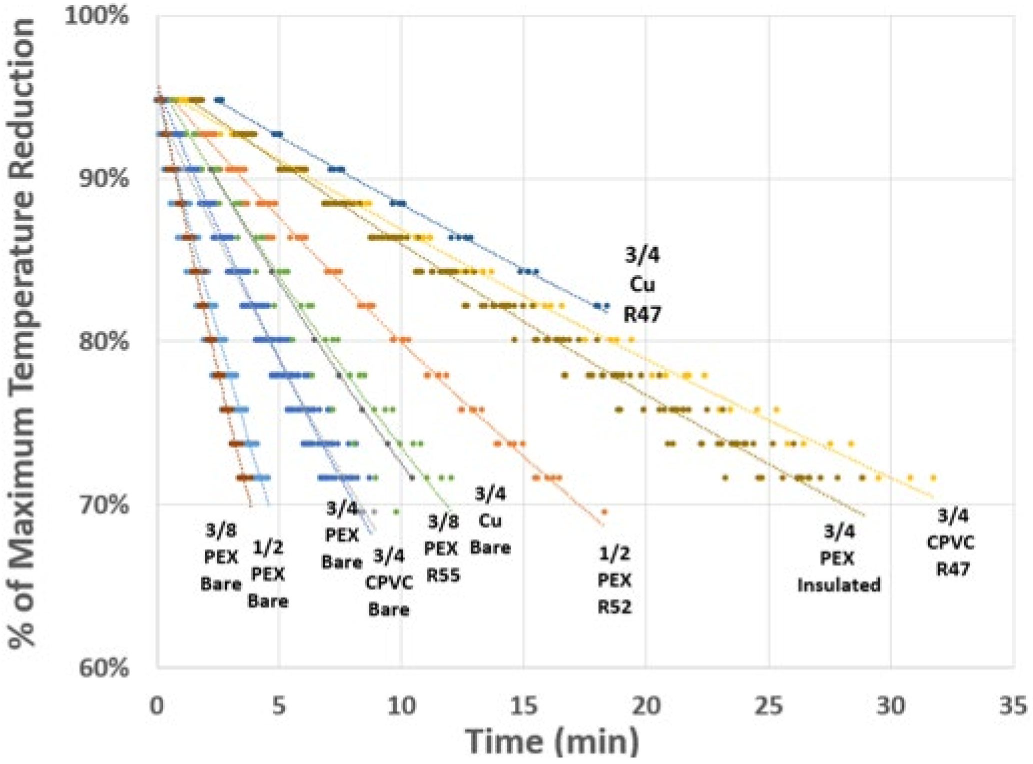


Overlay of the Empirical Temperature Curve on the Heat Balance



Pipe Cool Down Rates

- Features that have a significant impact on cooldown time
  - Pipe material
  - Insulation
- Feature that has a minor impact
  - Pipe diameter
- What does a longer cooldown time mean in system efficiency or in meeting expectations?
- Why does code in the Netherlands preclude hot water pipe insulation?



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Water and Energy Waste

Wasted Water

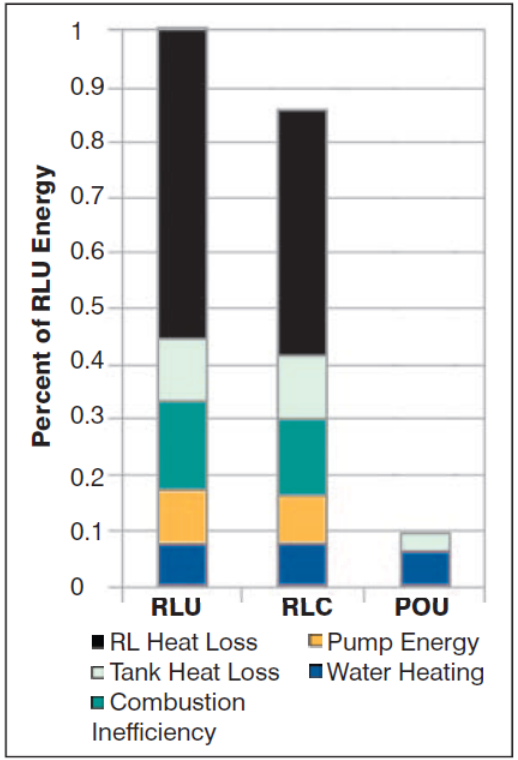
Wasted Energy

- System flushing for water quality control
- Flush to drain
- Water to drain while awaiting hot water at fixture
- Waste to drain
- Cool down heat loss between draws
- Natural convection from tanks, recirc loops & connected plumbing during periods of no use
- Heat transfer from pipe and fittings during draws

Stand-by Energy Losses

Connecting Layout and Energy Use

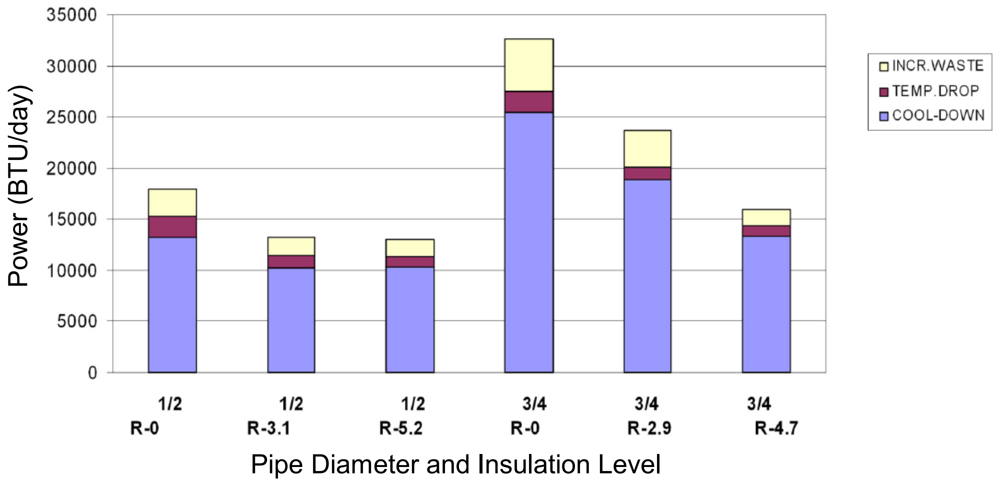
- Hiller compared three hot water layouts for three high schools in TN
  - School plumbing tends to have long pipes (horizontal layout)
- Abbreviations
  - RLU – Recirculating loop, uncontrolled system
  - RLC – Recirculating loop, controlled system
  - POU – Point of Use (in attic near bathrooms)
- Layout had a far greater impact than adding controls



Hiller, CC, 2005. ASHRAE Journal, 47(5):48-56

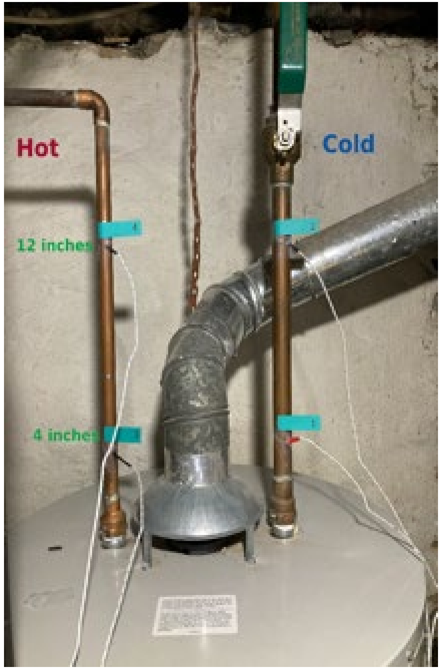
Estimated Heat Loss in 100 ft (30 m) Pipe Section

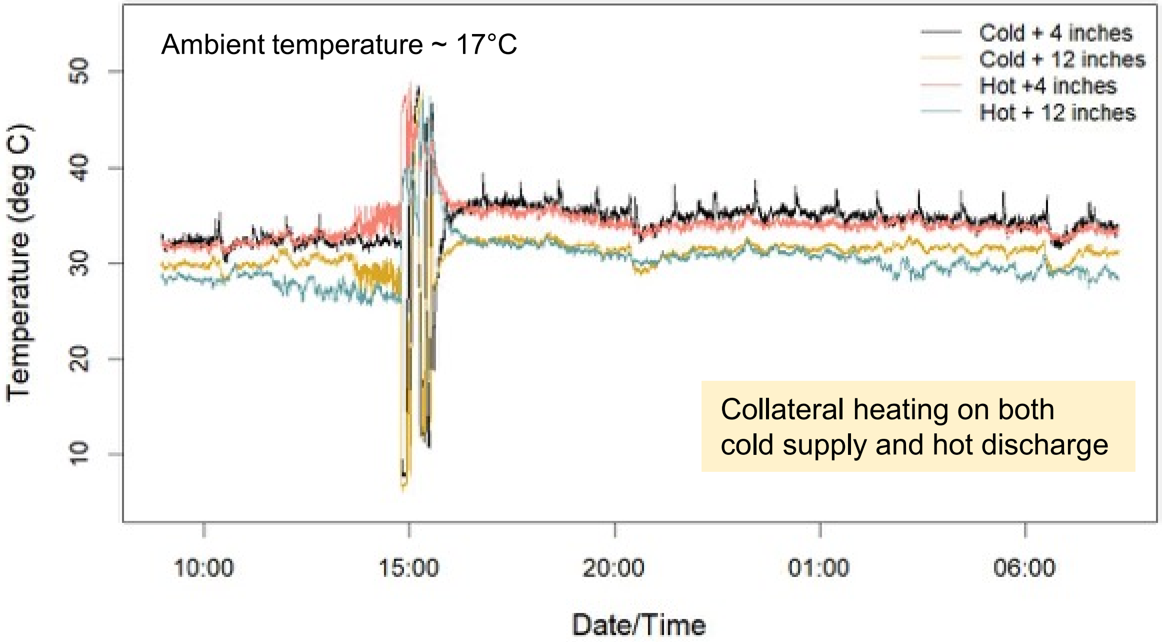
- Heat loss components
  - Water pumping and treatment energy for the wasted water,
  - RL pump energy (if present),
  - natural convection heat loss from tank into piping,
  - pipe cool-down energy loss,
  - Steady state temperature drop/delivery energy loss, and
  - Incremental wasted water (amount above pipe volume) – thermal energy loss due to mixing & heat transfer during delivery
- Beware of cool-down losses!
  - For some short uses hot water never reaches the plumbing fixture, but cooldown still occurs



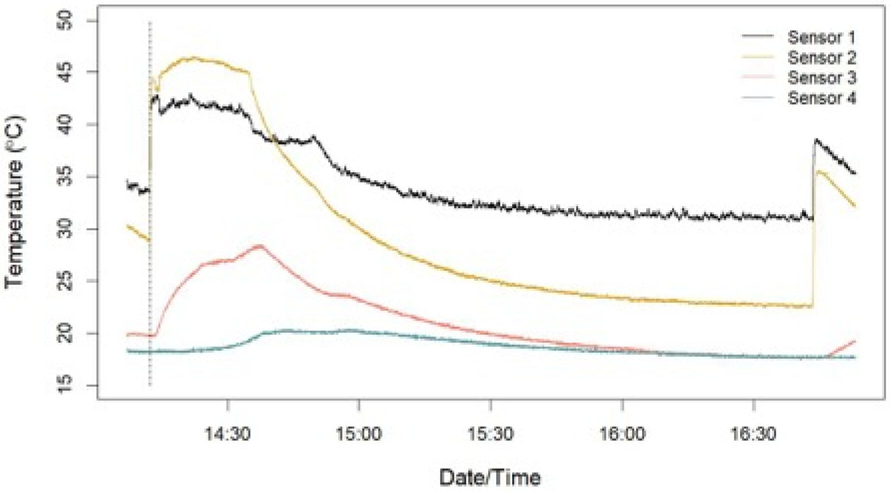
Hiller, CC, 2005. ASHRAE Transactions, 111(2):407-417

Collateral Heating, Water Heaters during Stand-by

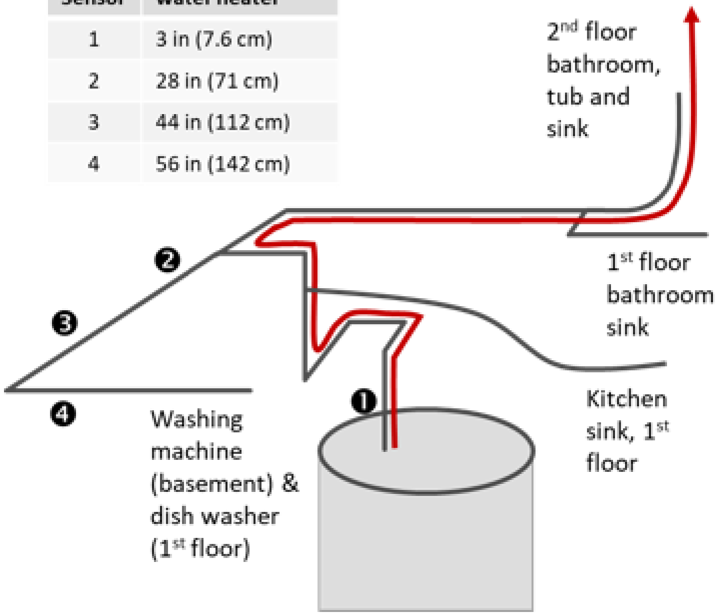




Collateral Heating, Non-Flowing Branch



Sensor	Pipe length from water heater
1	3 in (7.6 cm)
2	28 in (71 cm)
3	44 in (112 cm)
4	56 in (142 cm)



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The Rest of the System

What Else is part of the Hot Water System?

- Other Equipment
  - Pressure Expansion Tanks
  - Water Softeners
- How Do We Increase Customer Satisfaction
- Pipe diameters and the opportunity to "right-size"
- Fixtures and Appliances
  - Shower valves, Showerheads, Shower hoses and flow regulators
  - Faucets and flow regulators (aka aerators)
  - Washing machines, dishwashers

Inside a Single-Port Expansion Tank

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

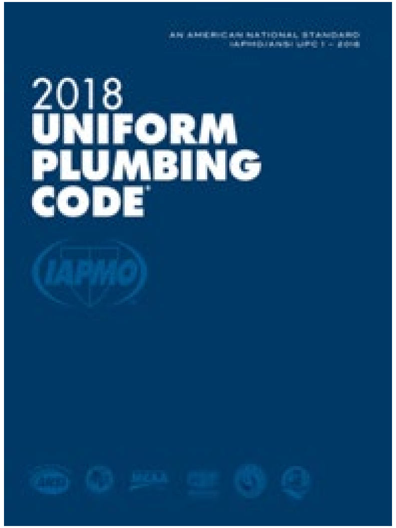
Right-Size the Plumbing

Which Pipe Sizing Method(s) do you use?

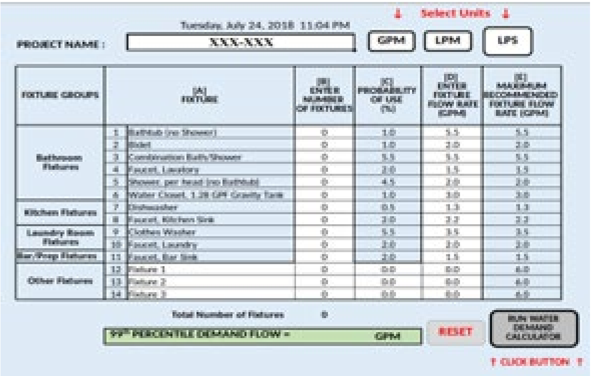
1. International Code Council (ICC)
   1. International Residential Code (IRC)
   2. International Plumbing Code (IPC)
   3. Local adoption as amended?
2. International Association of Plumbing and Mechanical Officials (IAPMO)
   1. Uniform Plumbing Code (UPC)
   2. Appendix M (UPC), Water Demand Calculator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

Estimating Peak Flow Rates

1. IPC/IRC and UPC Standard Method: Water Supply Fixture Units (WSFU)



2. Appendix M (IAPMO UPC): Water Demand Calculator



https://www.iapmo.org/water-demand-calculator/

Reduce the Pressure Drop

What is it in Modern Pipe and Fittings?

- Many materials and types of fittings
- Calculations vs. measured data
- Are the data we use representative of present-day materials and fittings?

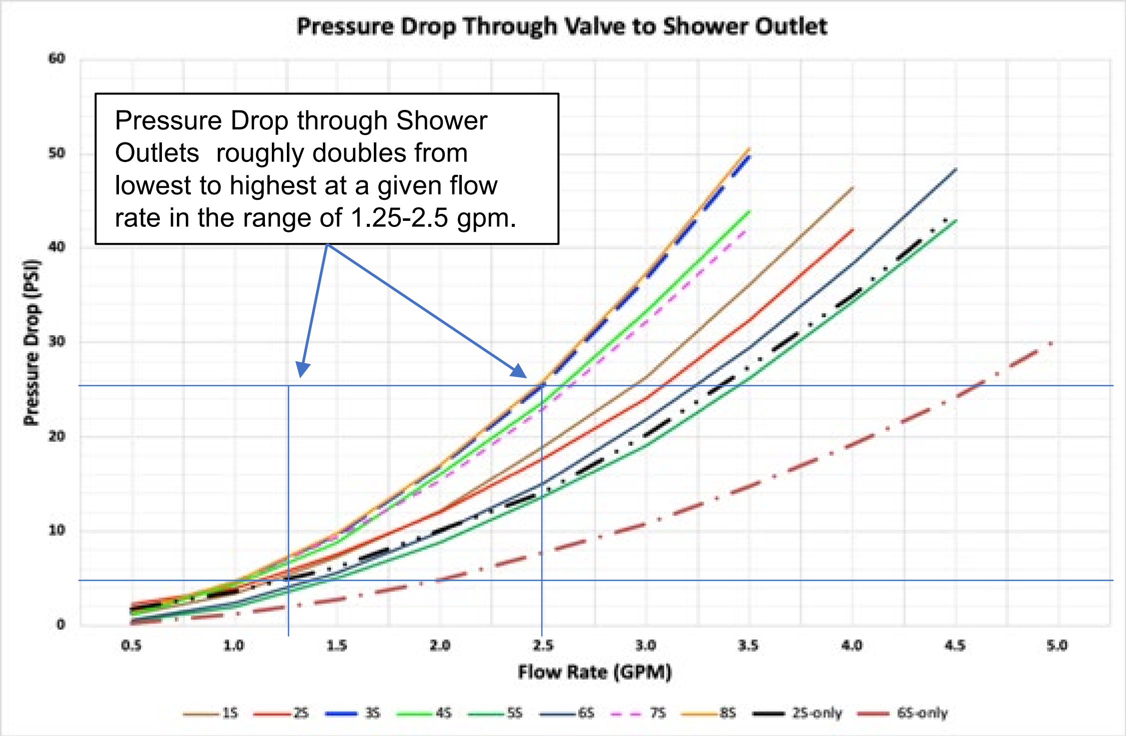
From the current ASHRAE Fundamentals Pipe Sizing chapter

- *Hegberg (1995) and Rahmeyer (1999a, 1999b) discuss the origins of some of the data shown in Tables 4 and Table 5.*
- *The Hydraulic Institute (1990) data appear to have come from Freeman (1941), work that was actually performed in 1892.*
- *The work of Giesecke (1926) and Giesecke and Badgett (1931, 1932a, 1932b may not be representative of current materials.*

Downey Lab

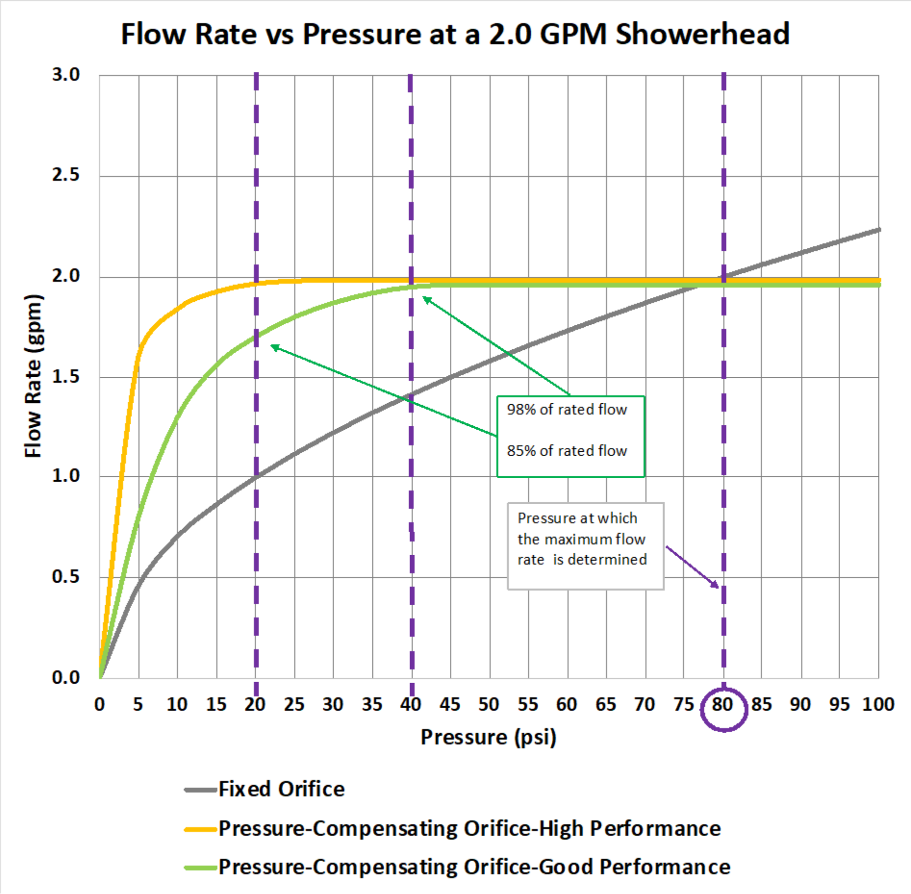
Arcata Lab

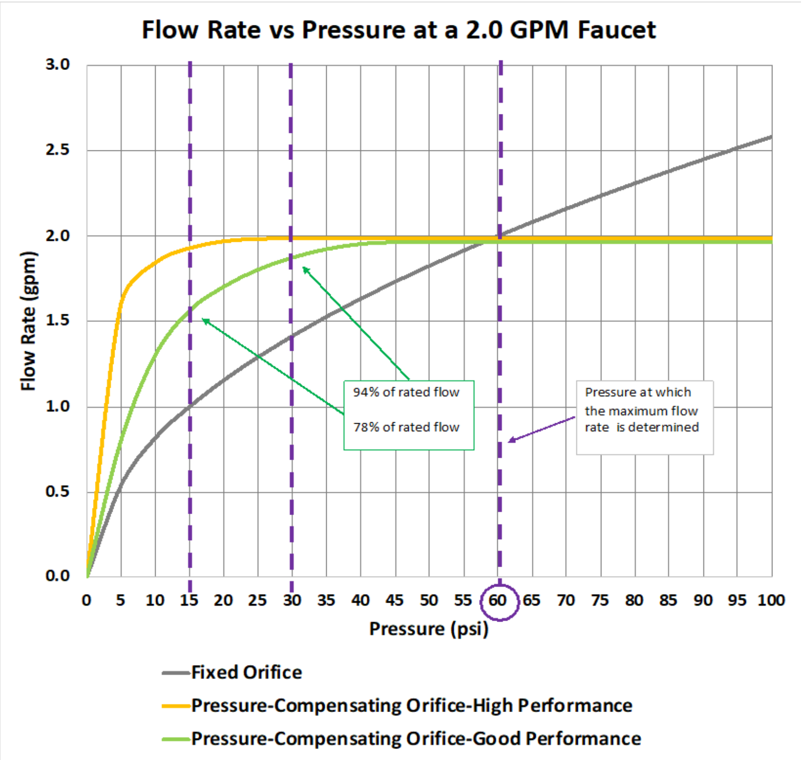
Pressure Drop Through Tub/Shower and Shower Valves

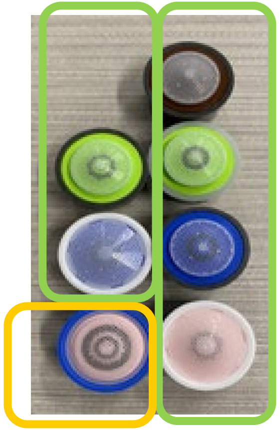

Pressure Drop Through Valve to Shower Outlet
Pressure Drop through Shower Outlets roughly doubles from lowest to highest at a given flow rate in the range of 1.25-2.5 gpm.
Pressure Drop (PSI)
60
50
40
30
20
10
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Flow Rate (GPM)
1S
2S
3S
4S
5S
6S
7S
8S
2S-only
6S-only

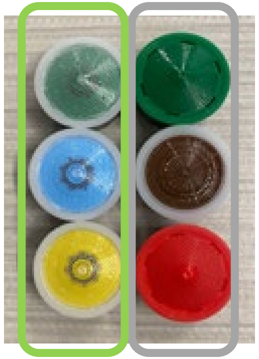
Install Pressure – Independent Faucets and Showerheads

- **Fixed Orifice:**
  - High pressure: High flow rate
  - Low pressure: Low flow rate
  - Before 2000, practically all fixture fittings and appliances
- **Pressure-Independent (Compensating) Orifice:**
  - Adjusts flow rate to compensate for available pressure
  - Almost the same flow rate for all pressures above 20-25 psi
  - Ramped up from 2000-2012 for showerheads
  - Today more than 90% and many faucet aerators


Flow Rate vs Pressure at a 2.0 GPM Showerhead
Flow Rate (gpm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Pressure (psi)
98% of rated flow
85% of rated flow
Pressure at which the maximum flow rate is determined
Fixed Orifice
Pressure-Compensating Orifice-High Performance
Pressure-Compensating Orifice-Good Performance







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

UNIVERSITY of SOUTH FLORIDA

DREXEL UNIVERSITY College of Engineering

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

Discussion