A Model of In-Home Hot Water Distribution Systems Energy Losses Using EPANET, Public Domain Software For Pipe Networks

By

Toritseju Omaghomi and Steven Buchberger, PhD

ACEEE Portland OR.

March 22nd, 2018

A Model of In-Home Hot Water Energy Losses

By

Toritseju Omaghomi and Steven Buchberger, PhD

ACEEE Portland OR.

March 22nd, 2018

Acknowledgments

This work is was supported in part by a grant from the Ohio Water Development Authority for project 2016OH506B entitled:

Improved Estimates of Peak Water Demand in Buildings: Implications for Water-Energy Savings

Also matching support in the form of residential water use data was provided by The International Association of Plumbing and Mechanical Officials (IAPMO) and from a Graduate Scholarship provided by the University of Cincinnati.

Outline

- Introduction
  - Motivation
  - Objective
- Method
  - Analyze Variables
    - Variable 1: Fixture Efficiency
    - Variable 2: Pipe Sizing Method
    - Variable 3: Pipe Layout
  - WDC
  - PRP
  - EPANET
- Results
- Conclusion

Introduction

Motivation:

What is the combined effect of low flow fixtures, reduced pipe size and pipes layout on residential energy consumption related to hot water use?

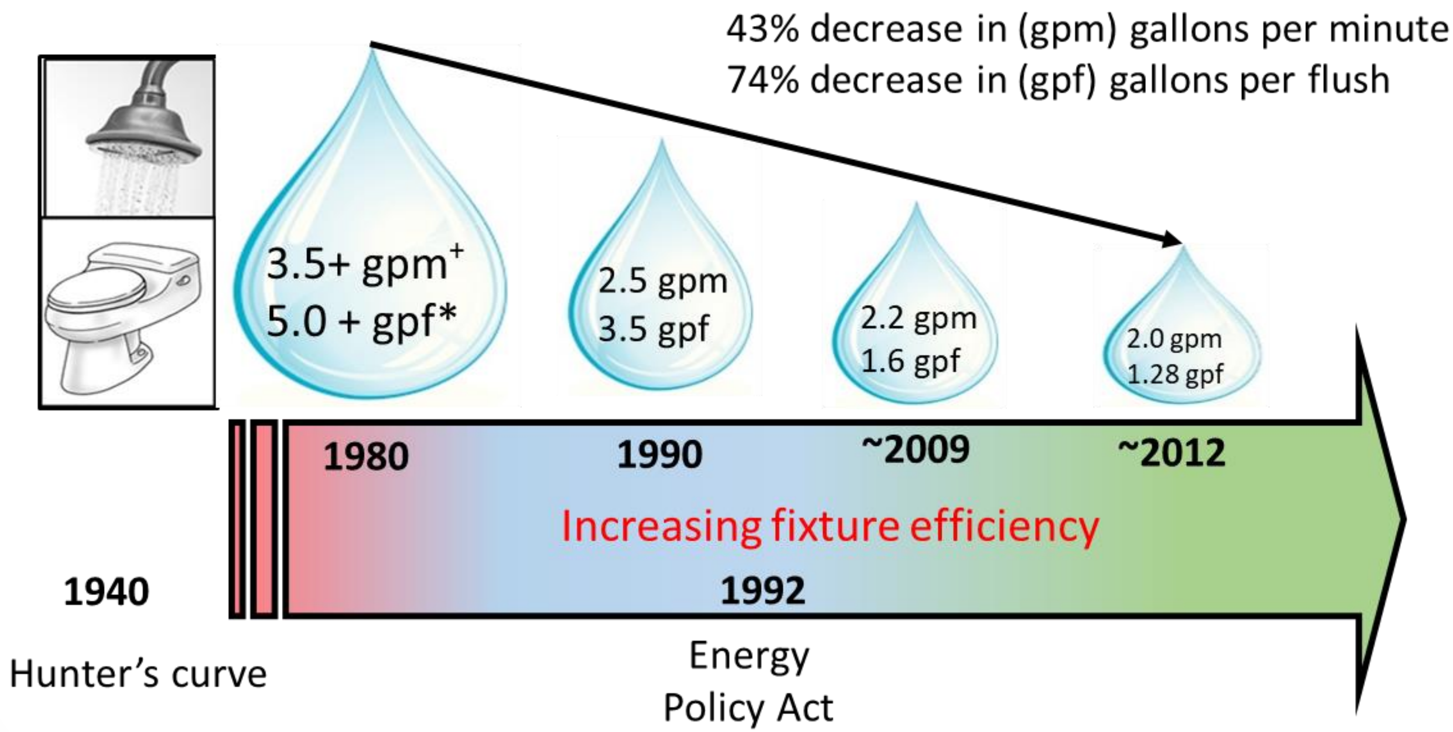
Introduction

Objective:

Quantify water and energy savings in residential buildings resulting from efficient (water-conserving) fixtures.

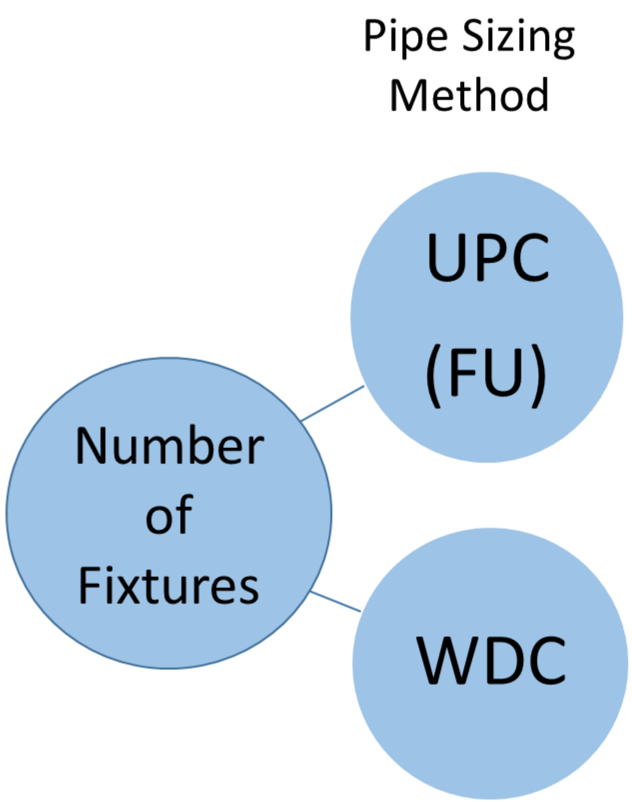
Variable # 1: Fixture Efficiency

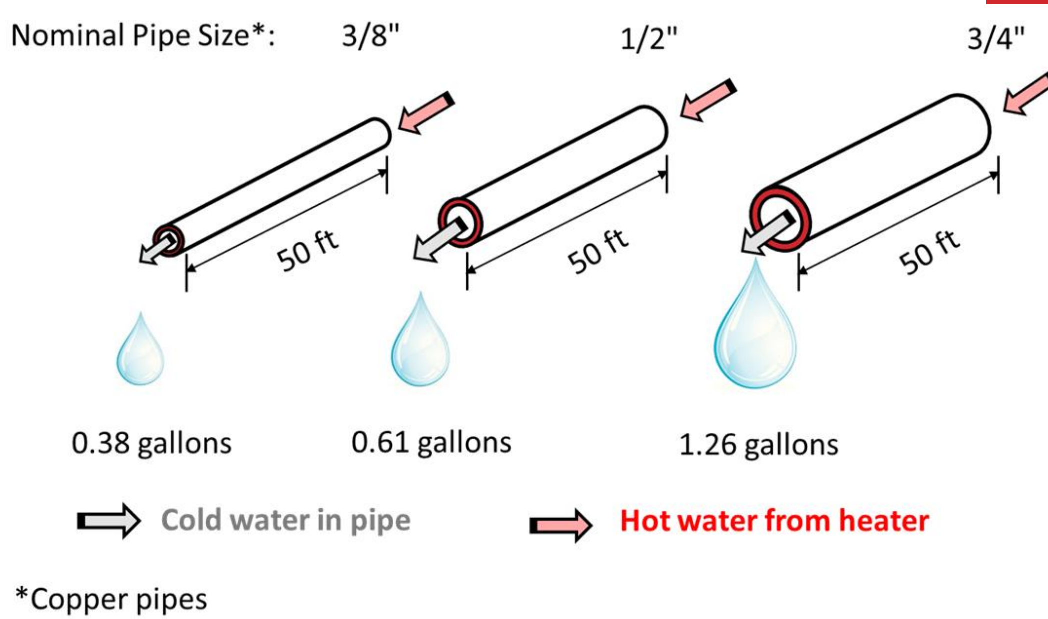
Fixture efficiency is determined by the amount of water consumed per fixture function e.g. gallons per minutes, flush or load



Reduced flow rate increases the waiting time for hot water at a fixture

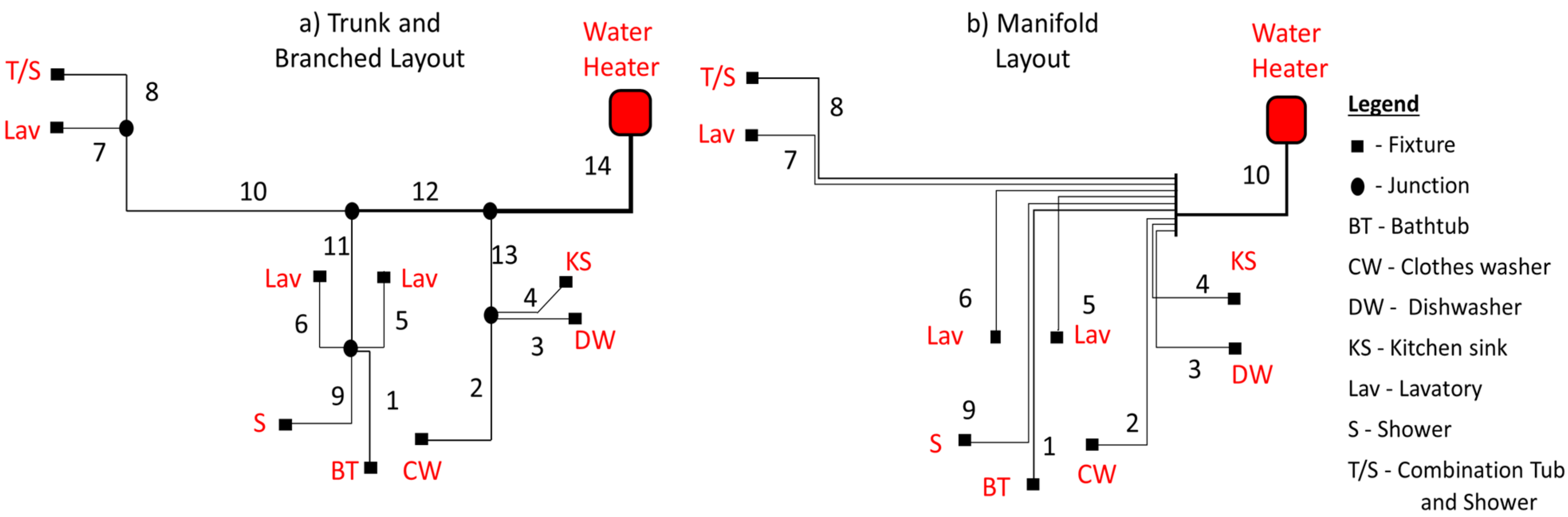
Variable # 2: Pipe Sizing Method





- Reduced flow rate increases the waiting time for hot water at a fixture.
- **Pipe size determines the volume of water in the pipes.**

Variable # 3: Pipe Layout



- Reduced flow rate increases the waiting time for hot water at a fixture.
- Pipe size determines the volume of water in the pipes.
- **Combined pulse characteristics from multiple fixtures and pipe layout.**

WDC: Estimate Peak Demand & Size Pipe

Select Units → GPM | LPM | LPS

	[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
1	Bar Sink	0	2.0	0.00	1.50
2	Bathtub	1	1.0	5.50	5.50
3	Bidet	0	1.0	0.00	2.00
4	Clothes Washer	1	5.5	3.50	3.50
5	Combination Bath/Shower	1	5.5	5.50	5.50
6	Dishwasher	1	0.5	1.30	1.30
7	Kitchen Faucet	1	2.0	2.20	2.20
8	Laundry Faucet	0	2.0	0.00	2.00
9	Lavatory Faucet	3	2.0	1.50	1.50
10	Shower, per head	1	4.5	2.00	2.00
11	Water Closet, 1.28 GPF Gravity Tank	0	1.0	0.00	3.00
12	Other Fixture 1	0	0.0	0.00	6.00
13	Other Fixture 2	0	0.0	0.00	6.00
14	Other Fixture 3	0	0.0	0.00	6.00

Total Number of Fixtures 9

99th PERCENTILE DEMAND FLOW = 9.00 GPM

RESET

RUN WATER DEMAND CALCULATOR

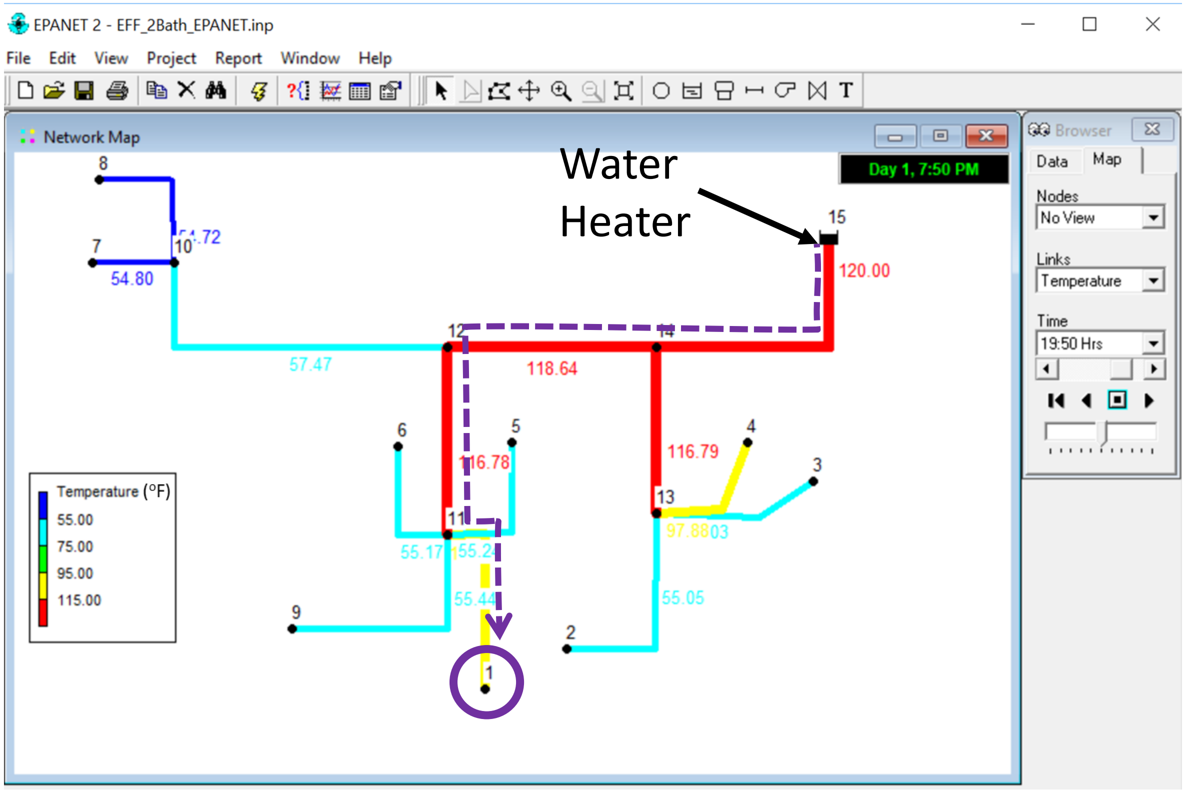
Found at: http://www.iapmo.org/Pages/WaterDemandCalculator.aspx

PRP: Arrival at Fixtures & Demand Pulses

- Poisson Rectangular Process (PRP) method (Buchberger and Wu 1995)
  - Simulates arrival time at fixture as a Poisson process
- Ensure there are no overlapping pulses at individual fixtures
- Fixture flowrate and duration of use are based on fixtures in IAPMO database (Inefficient or efficient)

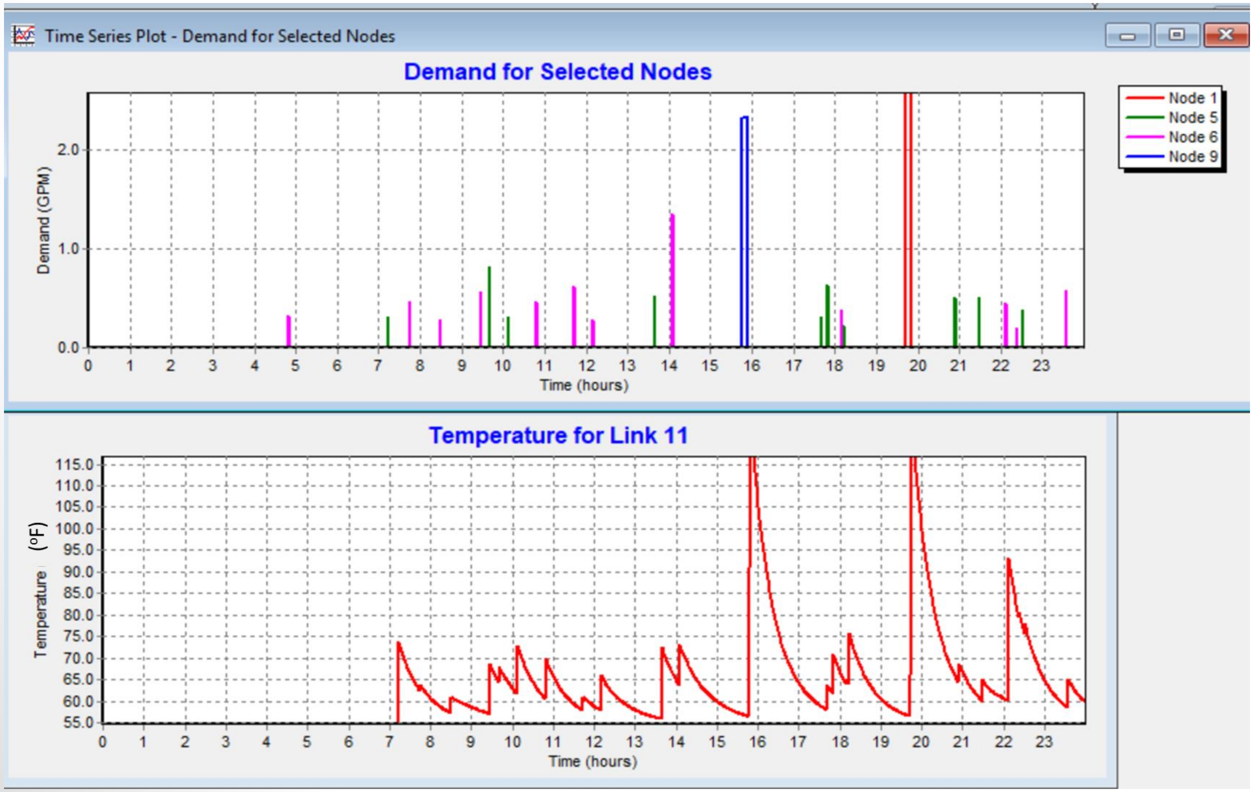
EPANET: Simulate Heat loss

- Input
  - Fixture base flow
  - Fixture multipliers generated from pulses
  - Heat loss rate for Copper L pipe



EPANET: Simulate Heat loss

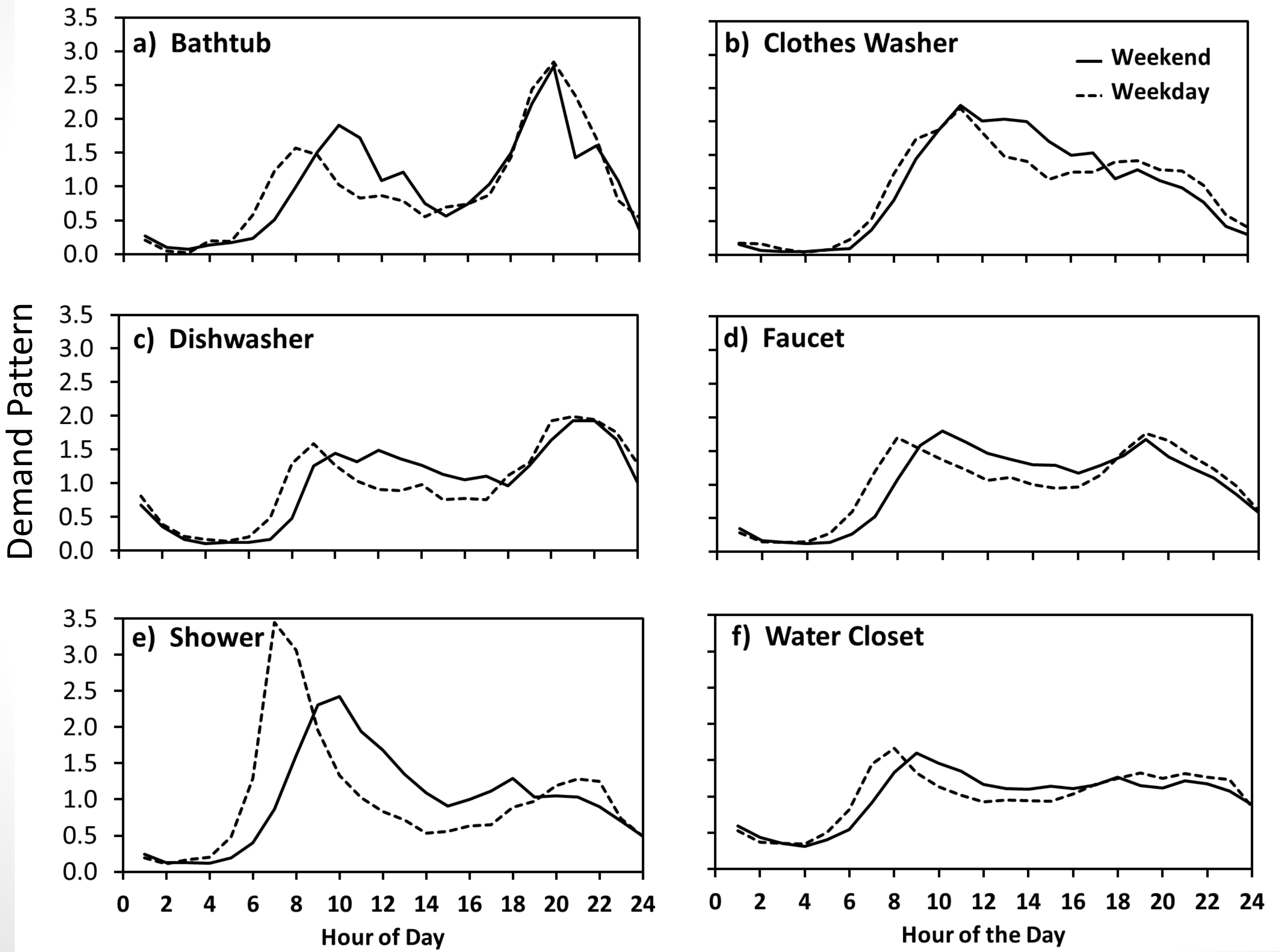
- Input
  - Fixture base flow
  - Fixture multipliers generated from pulses
  - Heat loss rate for Copper L pipe



Output

- Heat loss in pipes with time

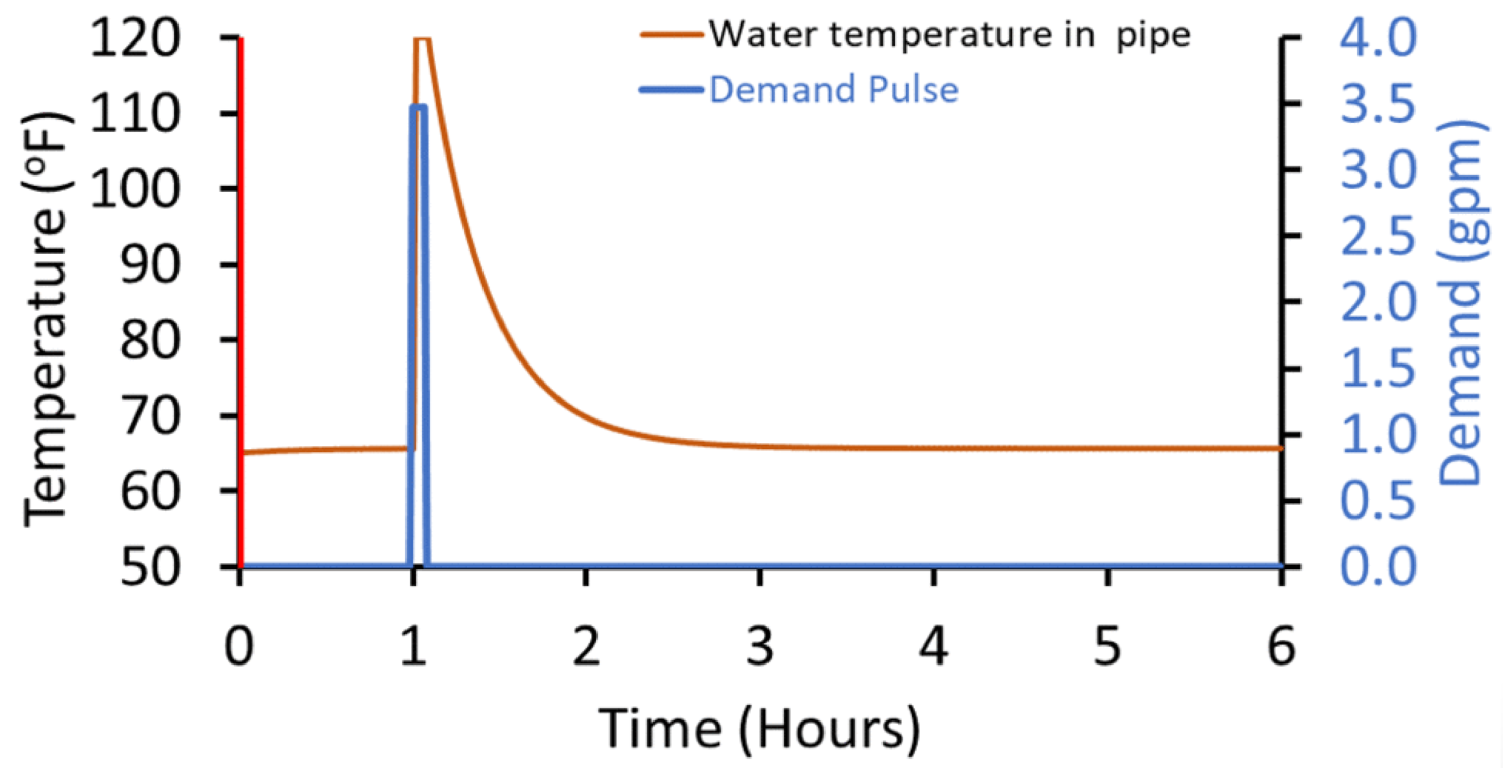
EPANET: Weekday/Weekend "Multiplier"



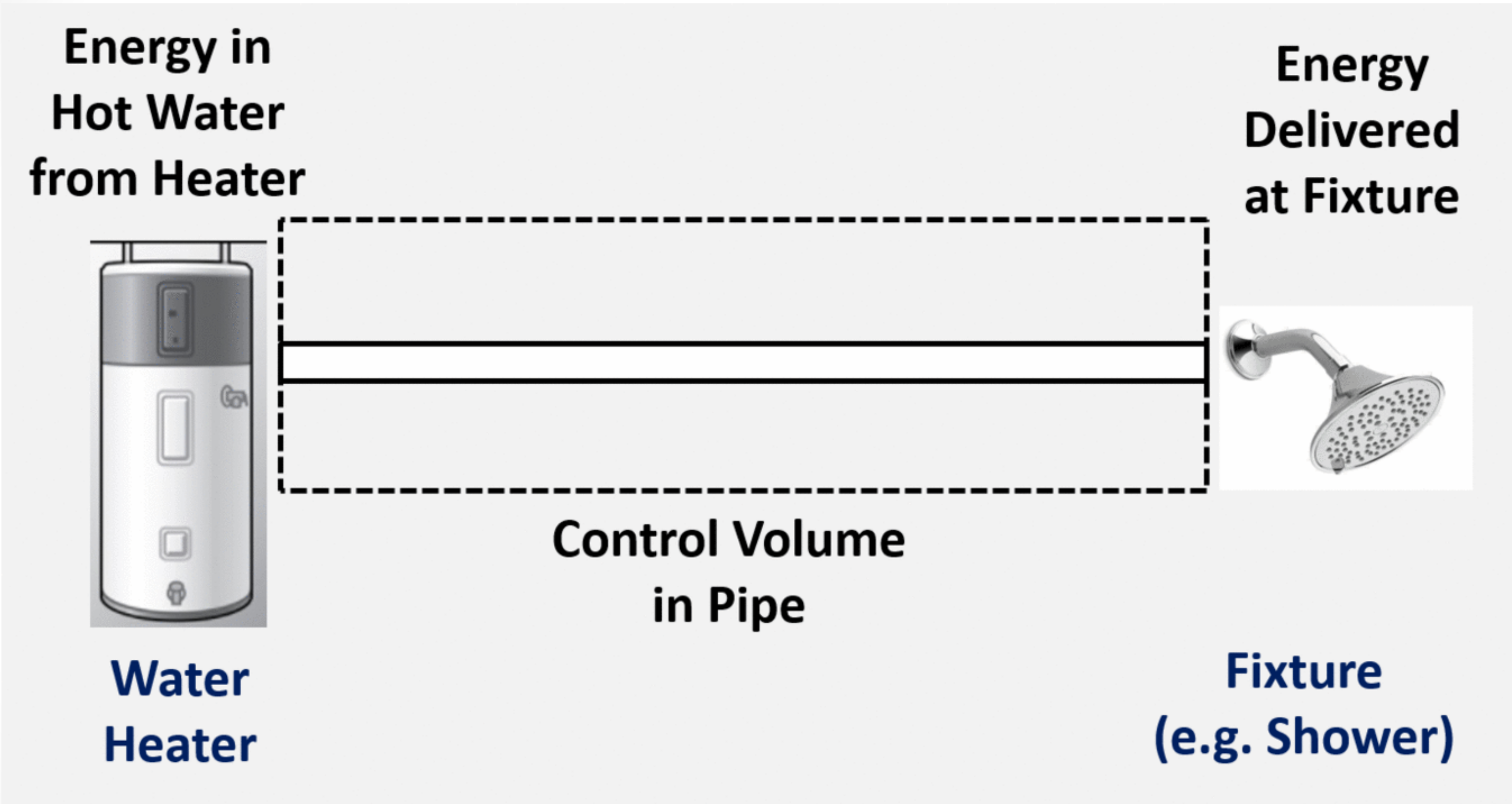
EPANET: Heat loss in Copper L pipes

Heat loss rate for copper L pipe size for different size by combining Heat capacity formula and Heat transfer formula

$$Q = mc\Delta T \qquad Q = \frac{kA\Delta T}{d}$$



Energy Balance

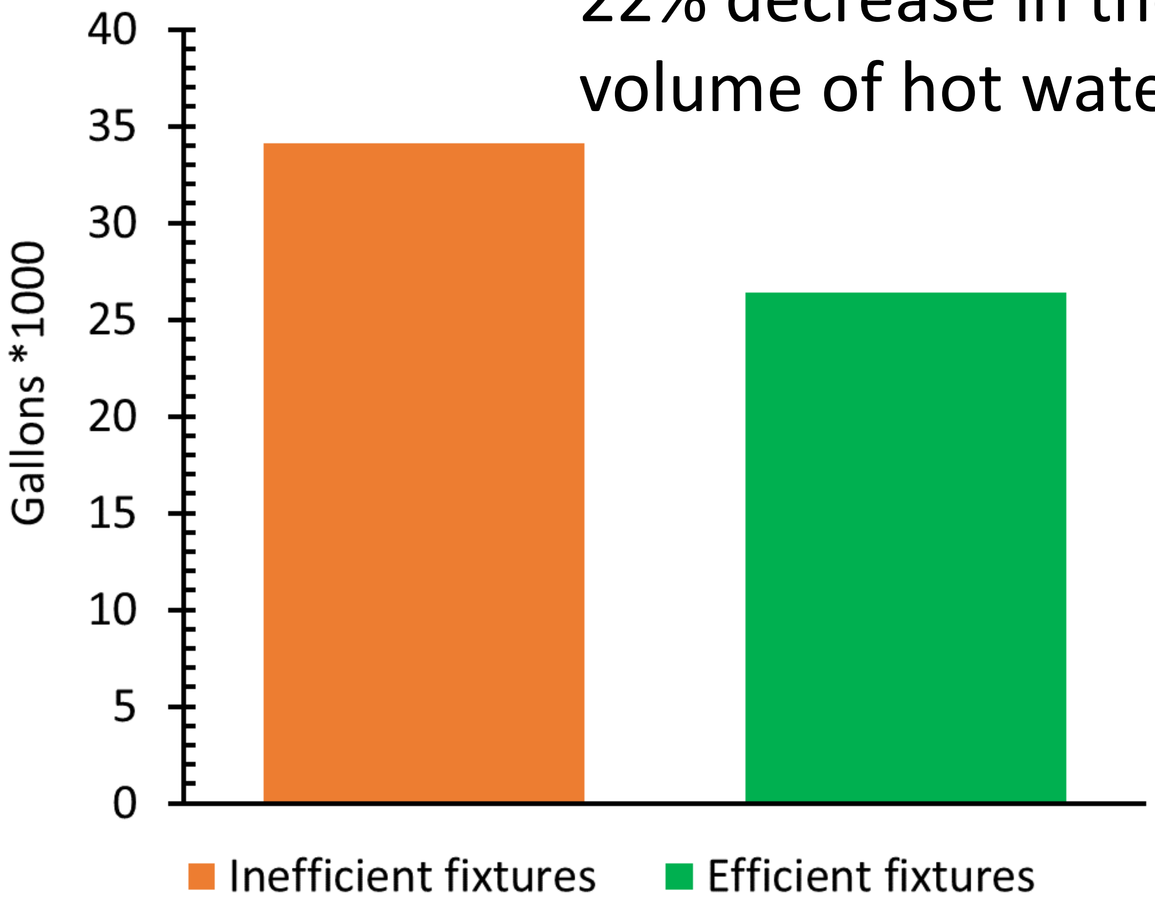


Assumptions

- Hot water temperature: 120 °F
- Copper L pipes are not insulated

Results: Variable #1 – Fixture Efficiency

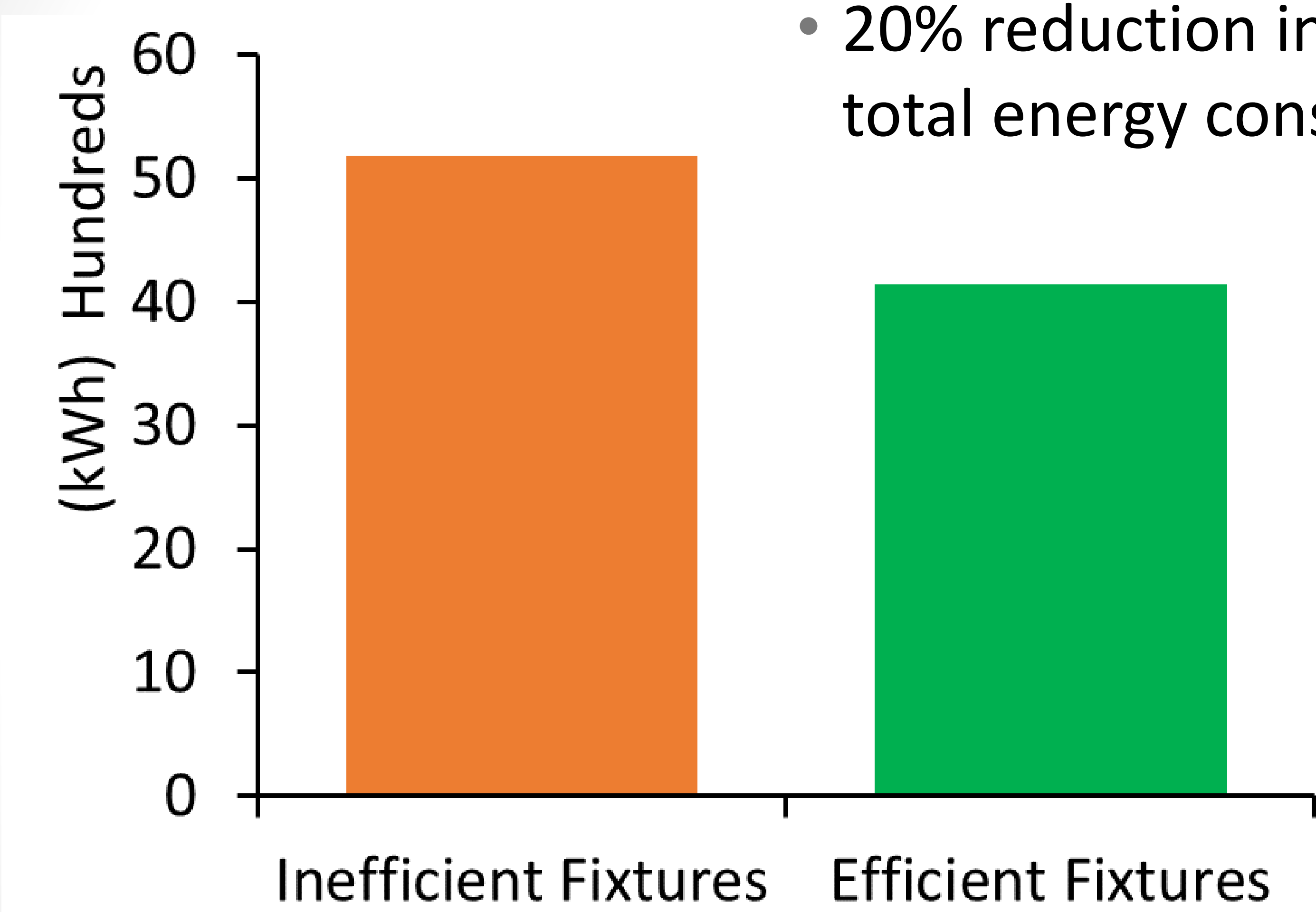
22% decrease in the annual volume of hot water consumed



For example, **Pre-retrofitted** 2 bath single family home with **inefficient fixtures** vs **Post-retrofitted** 2 bath single family home with **efficient fixtures**, both having a trunk and branched layout

Results: Variable #1 – Fixture Efficiency

- 20% reduction in annual total energy consumed



For example, **Pre-retrofitted** 2 bath single family home with inefficient fixtures vs **Post-retrofitted** 2 bath single family home with efficient fixtures, both having a trunk and branched layout

Results: Variable #2-Pipe Sizing Method

#	Feature	UPC (FU) vs (WDC)	
1	Peak demand estimate	↓	
2	Pipe sizes (Single fixture)	↓↑	Rightly sized
3	Pipe sizes (Multiple fixtures)	↓	
4	Annual thermal energy delivered	=	No Significant difference
5	Annual thermal energy dissipated in pipes	↓	- 13 %

For example, **Retrofitted** vs **Newly constructed** 2-bath single family home, both having efficient fixtures and a trunk and branched layout

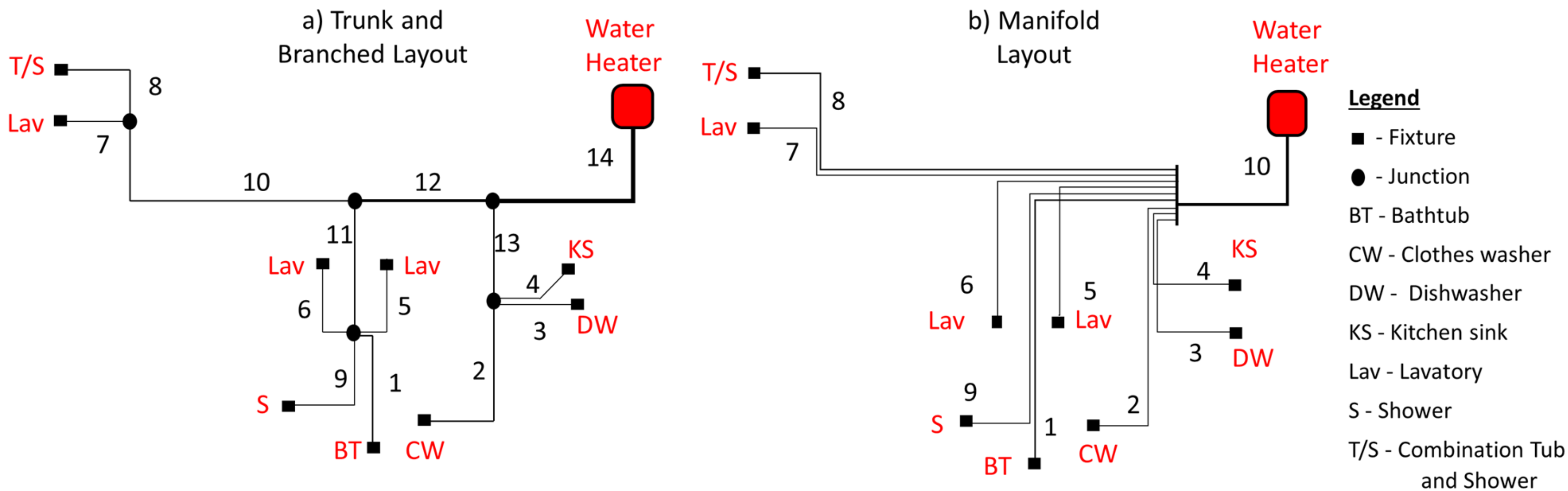
Results: Variable #2-Pipe Sizing Method

	Building Size: Number of Units	Number of fixtures	UPC (FU)		WDC		Decrease in Expected Flow
			Peak Demand (gpm)	Pipe Size (in)	Peak Demand (gpm)	Pipe Size (in)	
	1	9	14.0	1-1/4	9.0	1	36 %
	10	90	65.0	2-1/2	21.3	1-1/2	67 %
	50	450	208.0	5	67.1	2-1/2	68 %

Note:

- Pipe sizes are for hot water flowing at 5ft/sec
- Each is a 2-bath unit has 1 bathtub, 1 clothes washer, 1 tub/shower combined, 1 kitchen sink, 1 dishwasher, 3 bathroom sinks, and 1 shower. (**<u>Efficient</u>** fixtures only)

Results: Variable #3 - Pipe Layout



#	Characteristics	Trunk and Branched vs. Manifold	
1	Distribution system size (total pipe run)	↑	
2	Volume of water between heater and <u>a</u> fixture	↓	
3	Annual thermal energy delivered to fixtures	↑	+ 15 %
4	Annual thermal energy dissipated in pipes	↓	- 6 %

For example, Newly Constructed building & efficient fixtures with **different layout**

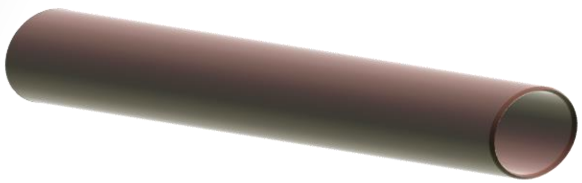
Conclusion (1 of 4)

- Lutz *et al.* (2014) – Less than half of the hot water drawn arrives at a fixture. TRUE
  - Hot water pulse duration: about 80% < 1 minute
  - Hot water pulse intensity: about 77% < 1 gpm

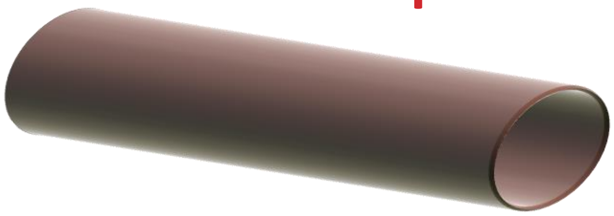
- Sizing pipes with the new WDC method would not only reduce the amount of water between the heater and a fixture, it will also reduce the energy consumed by hot water use in residential buildings

Conclusion (2 of 4)

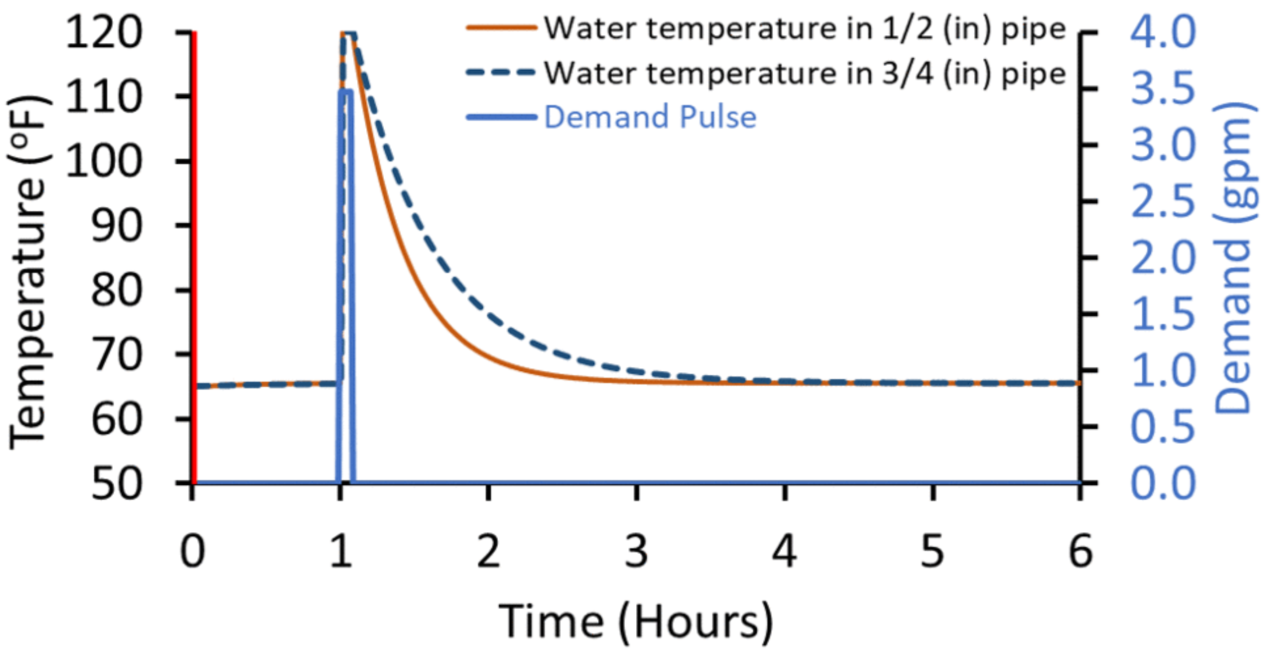
½" Pipe



¾ " Pipe



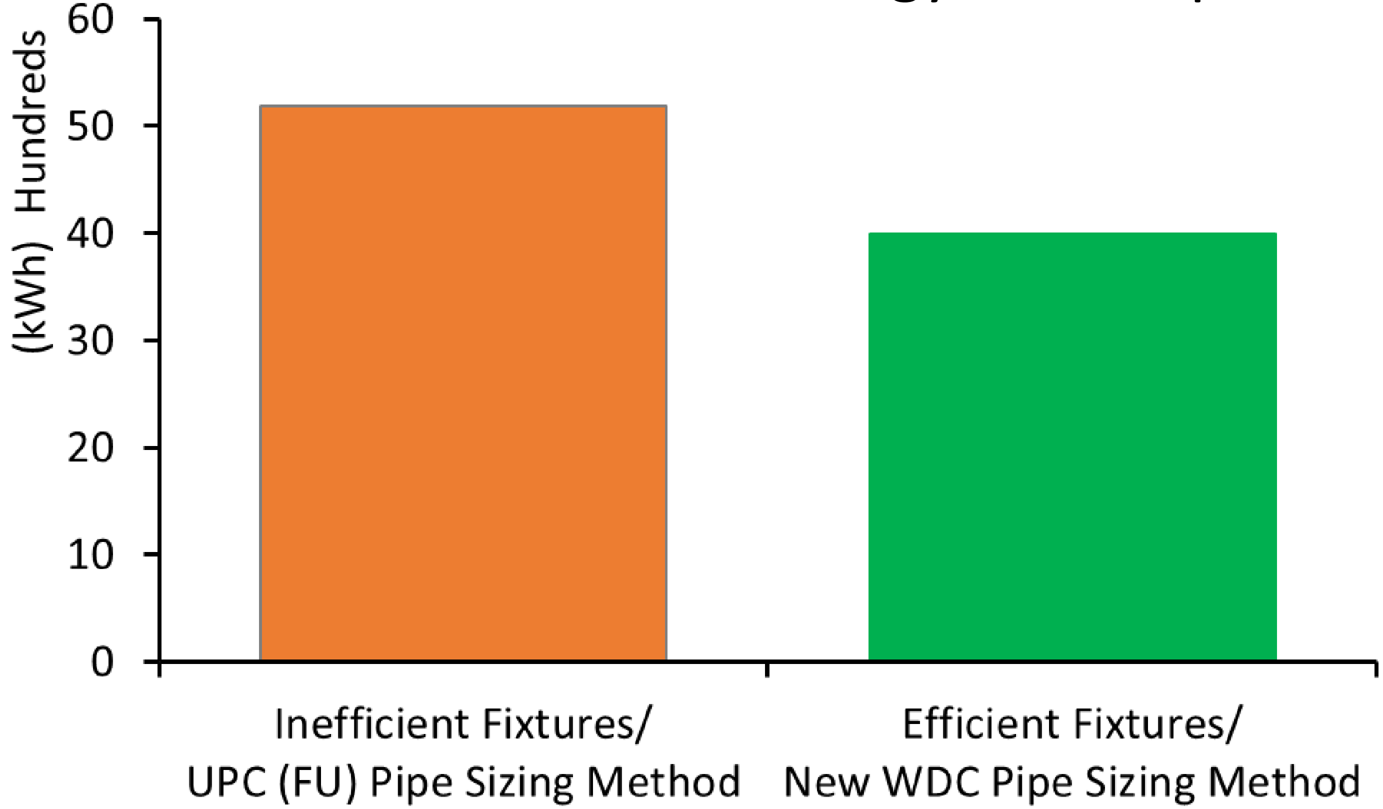
Heat loss in different sizes of Copper L pipes



- Water in smaller pipes lose heat at a faster rate compared to water in large pipes

Conclusion (3 of 4)

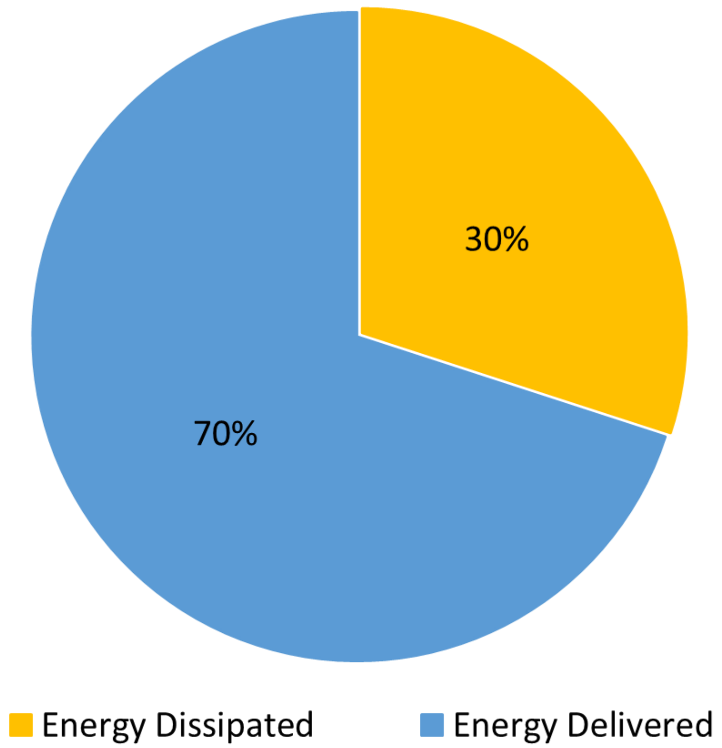
- Efficient fixtures and right sized pipes resulted in a 23% reduction in annual hot water energy consumption



For example, **Old** 2-bath single family home with **inefficient fixtures** vs **Newly Constructed** 2-bath single family home **with efficient fixtures**, both having a trunk and branched layout

Conclusion (4 of 4)

- About 30% of the total annual energy consumed in a hot water distribution system of a 2 bath single family residential building is related to pipes - Pipe size, pipe length and pipe layout.



Questions?

Omaghotu@mail.uc.edu