Clustering Stuff

The Many Benefits of Architecturally Compact Mechanical Infrastructure

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Do you know anyone who:

- Wonders why buildings that are efficient to operate are so expensive to construct?
- Would like to know ways to make these buildings less expensive to construct?

Today we are going to discuss ways to make great buildings
(elegant, affordable, environmentally friendly)
that are <u>"infrastructurally efficient"</u>

Efficient Water Delivery

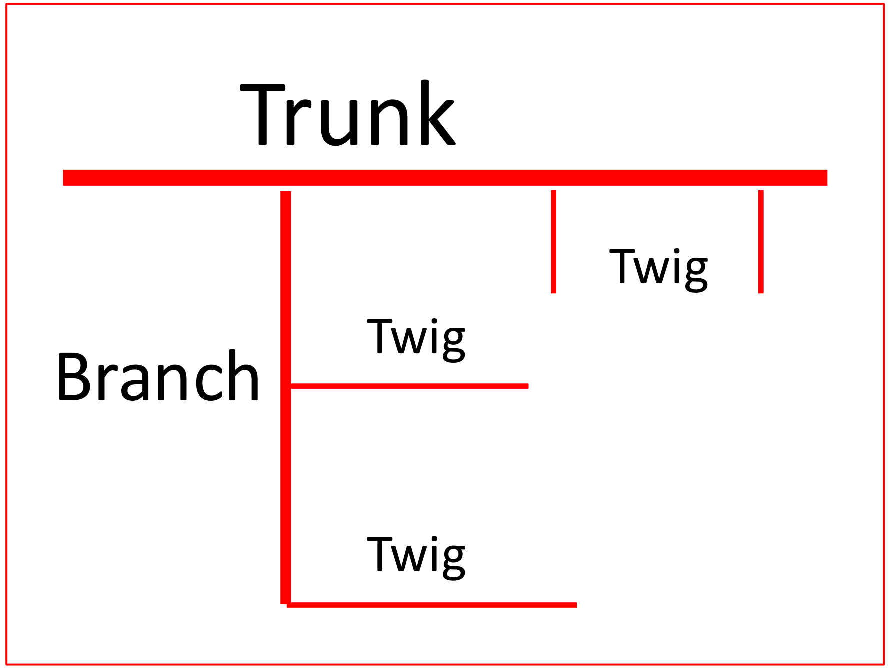
1. Reduce the distance from source to use
2. Improve estimates of peak flow rates to right-size the piping
3. Select pipe sizes that optimize velocities and residual pressure
4. Improve the performance of faucets and showerheads
5. Optimize volume of things that store water

There are many parallels to HVAC and Electrical systems

Key Principles

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 fixture or appliance.
- 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
  - Continuous insulation on all hot water pipes



Applies equally to cold water piping!

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.

Time-to-Tap and Volume-until-Hot

More water than is in a pipe comes out of it before water hot enough to shower or wash dishes in (105-110F) arrives. How much more?

- Carl Hiller measured this in the early 2000s for 3/8 to 3/4-inch copper, CPVC and PEX piping
- Yanda Zhang reviewed the data in 2018 and found that for flow rates of 0.5 to 2 gpm in 3/4-inch pipe, 1.5-2.5 times the pipe volume comes out before hot water (>105F) comes out the other end. Roughly 2:1.

We need to decide what is an “acceptable” time-to-tap or volume-until-hot and work backwards to determine the maximum allowable in the pipe between the source and the use.

Conclusion: if you want hot water to arrive within 10 seconds, make sure there is no more than 5 seconds of volume in the pipe between the source of hot water and the use.

To reach the water heater temperature : 3-5 times the volume is needed!

How Long Do You Want to Wait for Hot Water?

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

	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

Volume Per Foot of Piping

UPC

TABLE L 502.7
WATER VOLUME FOR DISTRIBUTION PIPING MATERIALS*

OUNCES OF WATER PER FOOT LENGTH OF PIPING													
NOMINAL SIZE (inch)	COPPER M	COPPER L	COPPER K	CPVC CTS SDR 11	CPVC SCH 40	PEX-AL- PEX	PE-AL- PE	CPVC SCH 80	PEX CTS SDR 9	PE-RT SDR 9	PP SDR 6	PP SDR 7.3	PP SDR 11
⅜	1.06	0.97	0.84	NA	1.17	0.63	0.63	NA	0.64	0.64	0.91	1.09	1.24
½	1.69	1.55	1.45	1.25	1.89	1.31	1.31	1.46	1.18	1.18	1.41	1.68	2.12
¾	3.43	3.22	2.90	2.67	3.38	3.39	3.39	2.74	2.35	2.35	2.23	2.62	3.37
1	5.81	5.49	5.17	4.43	5.53	5.56	5.56	4.57	3.91	3.91	3.64	4.36	5.56
1¼	8.70	8.36	8.09	6.61	9.66	8.49	8.49	8.24	5.81	5.81	5.73	6.81	8.60
1½	12.18	11.83	11.45	9.22	13.20	13.88	13.88	11.38	8.09	8.09	9.03	10.61	13.47
2	21.08	20.58	20.04	15.79	21.88	21.48	21.48	19.11	13.86	13.86	14.28	16.98	21.39

For SI units: 1 ounce = 29.573 mL
* NA: Not Applicable

IPC

TABLE E202.1
INTERNAL VOLUME OF VARIOUS WATER DISTRIBUTION TUBING

OUNCES OF WATER PER FOOT OF TUBE									
Size Nominal, Inch	Copper Type M	Copper Type L	Copper Type K	CPVC CTS SDR 11	CPVC SCH 40	CPVC SCH 80	PE-RT SDR 9	Composite ASTM F 1281	PEX CTS SDR 9
$^3/_8$	1.06	0.97	0.84	N/A	1.17	—	0.64	0.63	0.64
$^1/_2$	1.69	1.55	1.45	1.25	1.89	1.46	1.18	1.31	1.18
$^3/_4$	3.43	3.22	2.90	2.67	3.38	2.74	2.35	3.39	2.35
1	5.81	5.49	5.17	4.43	5.53	4.57	3.91	5.56	3.91
$1^1/_4$	8.70	8.36	8.09	6.61	9.66	8.24	5.81	8.49	5.81
$1^1/_2$	12.18	11.83	11.45	9.22	13.20	11.38	8.09	13.88	8.09
2	21.08	20.58	20.04	15.79	21.88	19.11	13.86	21.48	13.86

For SI: 1 ounce = 0.030 liter.

Reduce the Distance

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?
  - We need to decide what is an "acceptable" time-to-tap or volume-until-hot and work backwards to determine the maximum allowable in the pipe between the source and the use.

1. **Water, energy and time efficient hot water systems start with deciding how long we want people to wait.**
2. ***The decision on the location of the wet-room(s) and the mechanical room(s) is made by the architect.***
3. **Better floor plans can lead to better hot water system performance.**
4. ***Better floor plans decrease the residence time in the premise plumbing system (hot and cold) too!***

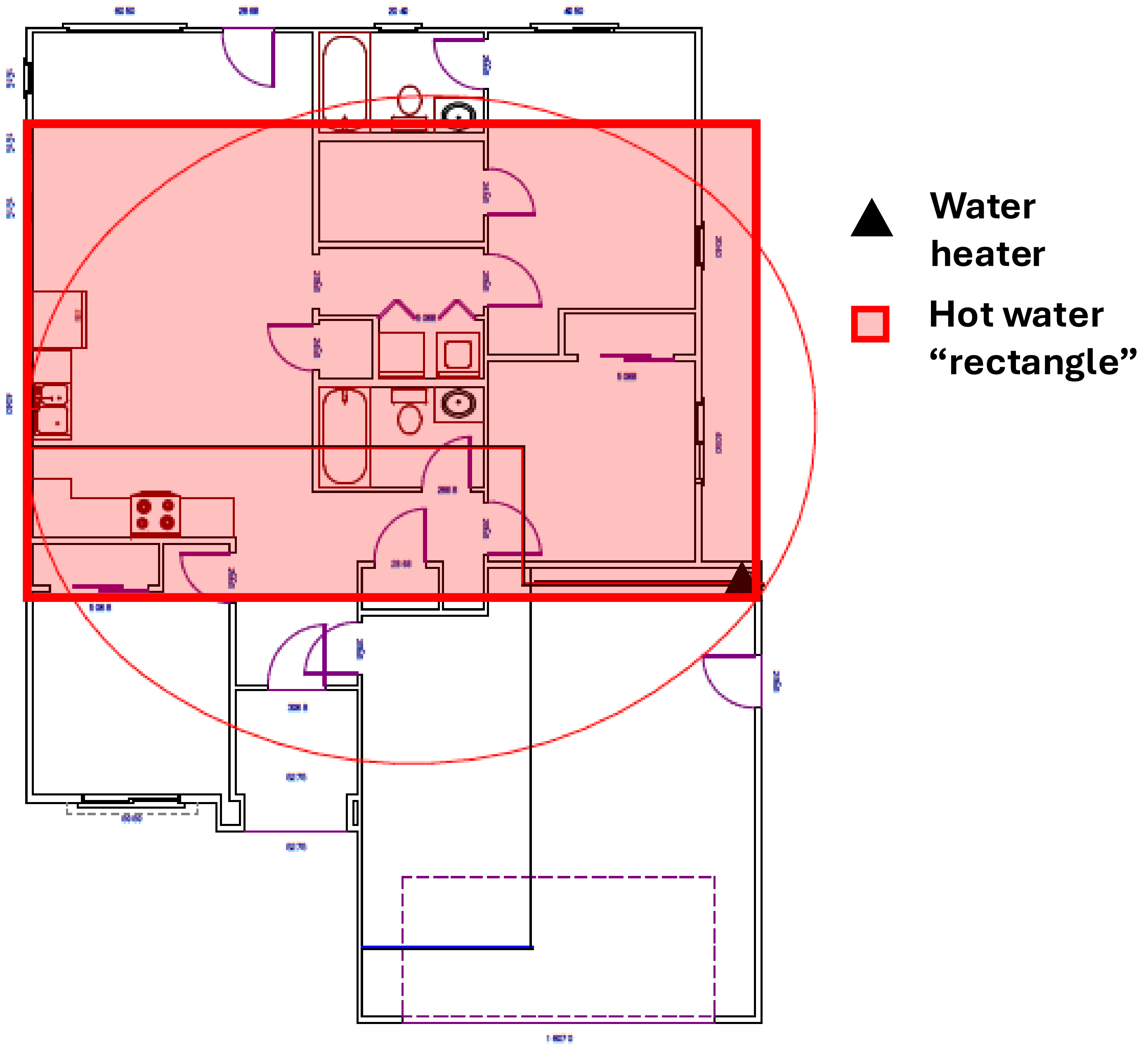
Best 1-Story So Far…

Best 1-Story to Date:

__In the beginning:__

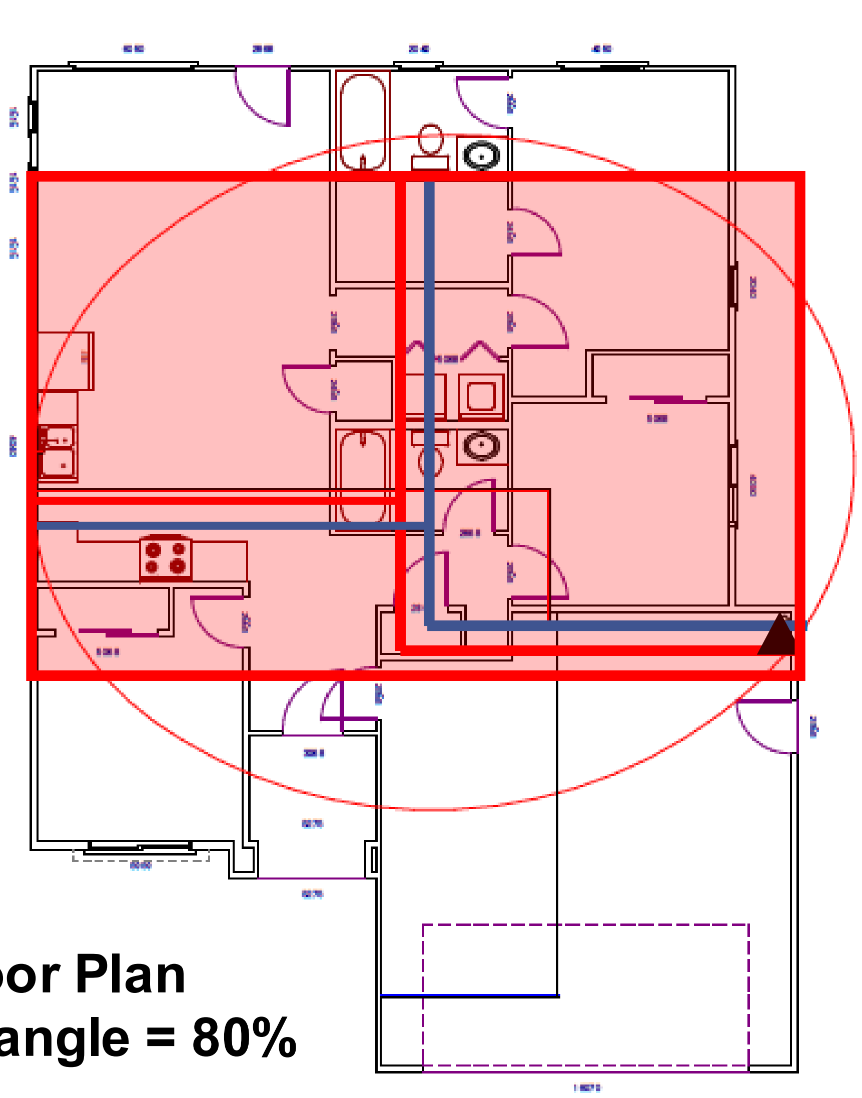
1 Story
3 Br/2 Ba
1,619 sq ft
Stockton, CA

~80%
(1,279 sq ft)

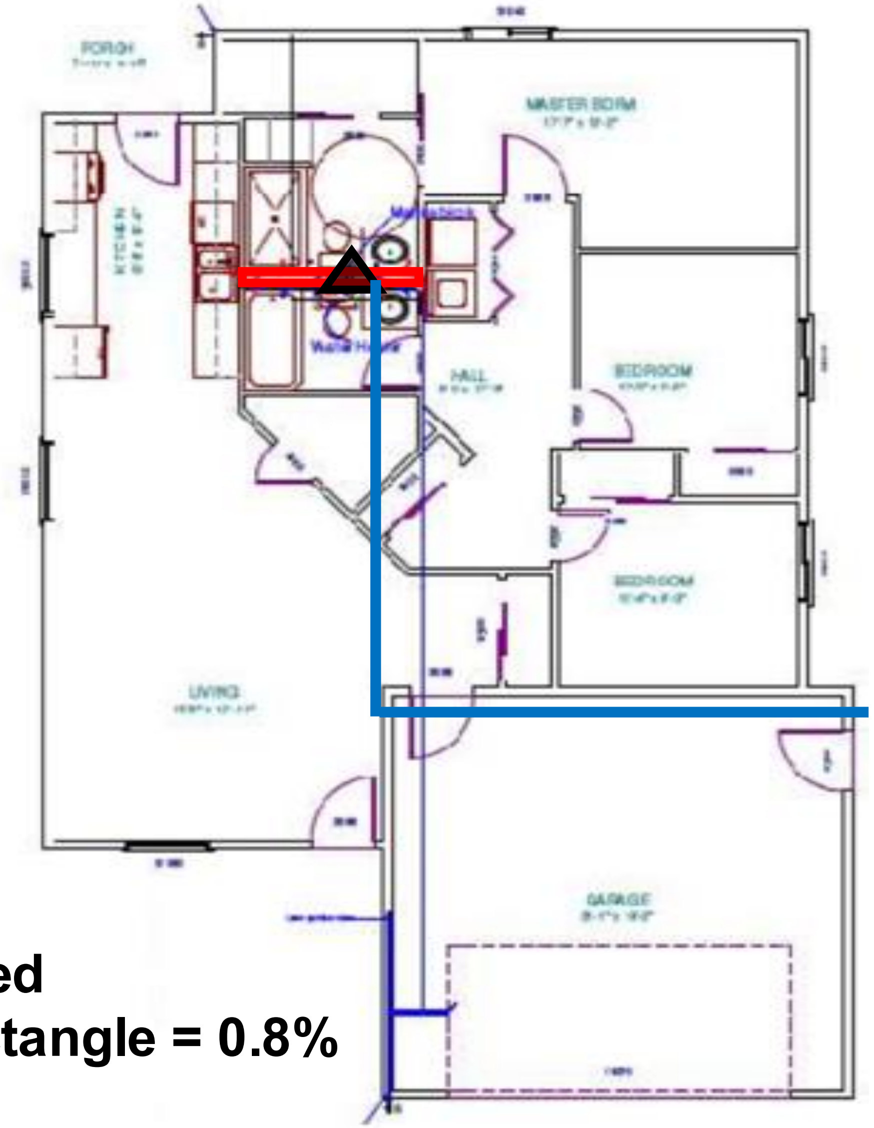


Where are the "wet-rooms? Where are the "wet-walls?

(Hot) Water System "Rectangle"



Initial Floor Plan
HW Rectangle = 80%



Clustered
HW Rectangle = 0.8%

Stockton Initial Design

	Stockton House							
	Phase 1 Base Code				Phase 1 WDC			
	Cold		Hot		Cold		Hot	
	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)
Service Entrance	0.27	6	0.00	0	0.11	6	0.00	0
Branch to Water Heater	0.06	2	0.00	0	0.04	2	0.00	0
Cold Trunk	1.99	65	1.99	65	1.19	65	1.19	65
Branch to Kitchen Sink	0.18	20	0.18	20	0.18	20	0.18	20
Twigs	0.97	105	0.78	85	0.97	105	0.78	85
Total	3.47	198	2.95	170	2.49	198	2.16	170

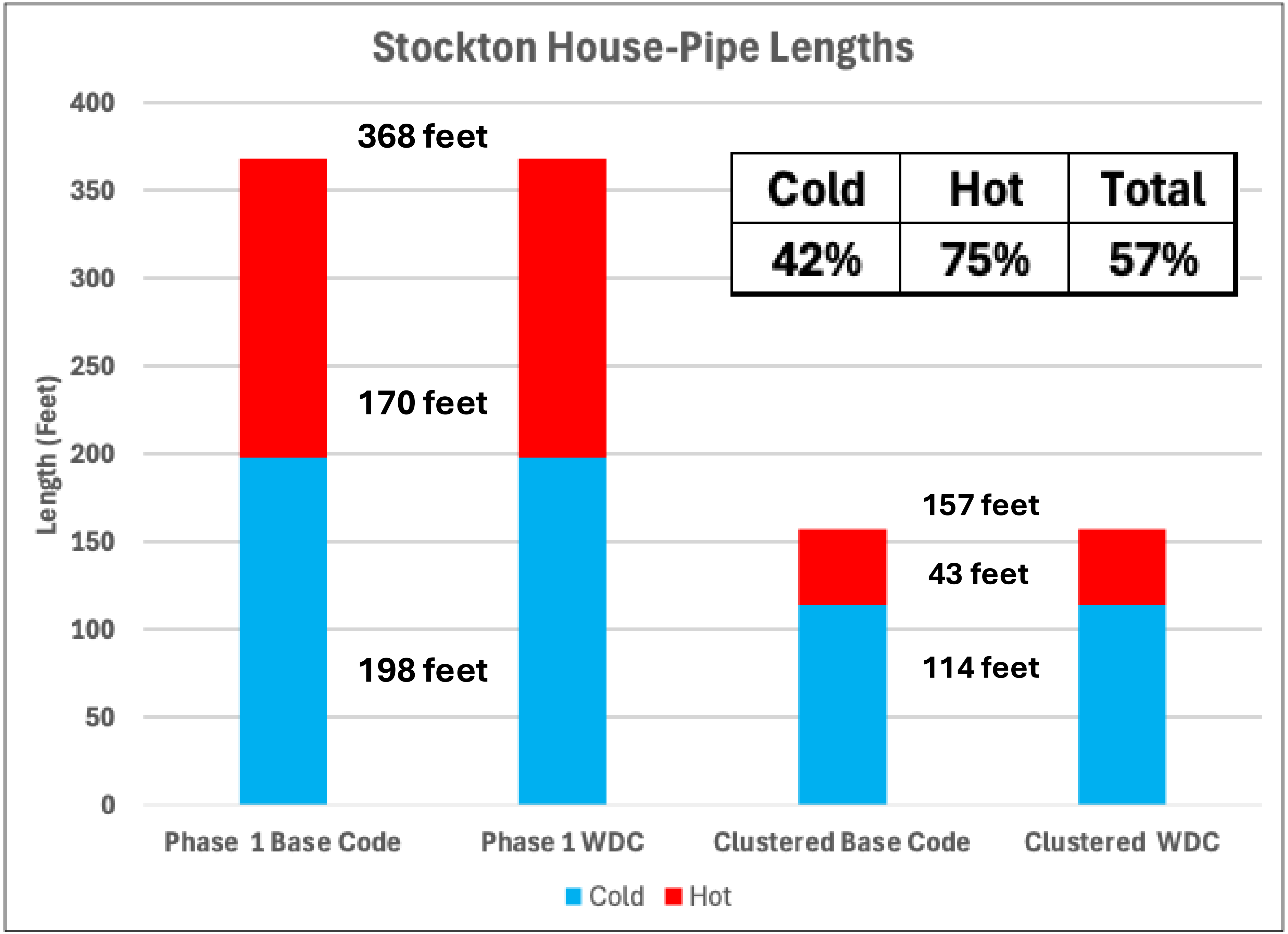
Effect of Right-Sizing:
Same Lengths. Less Volume

Stockton House: Clustered Design

	Stockton House							
	Clustered Base Code				Clustered WDC			
	Cold		Hot		Cold		Hot	
	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)
Service Entrance	2.95	65	0.00	0	1.19	65	0.00	0
Branch to Water Heater	0.06	2	0.00	0	0.04	2	0.00	0
Cold Trunk	0.06	2	0.06	2	0.04	2	0.04	2
Branch to Kitchen Sink	0.00	0	0.00	0	0.00	0	0.00	0
Twigs	0.41	45	0.38	41	0.41	45	0.38	41
Total	3.49	114	0.44	43	1.68	114	0.41	43

Effect of Clustering:
Less Length. Less Volume

Effect of Right-Sizing:
Same Length. Less Volume



Stockton House-Pipe Lengths
400
350
300
250
200
150
100
50
0
Length (Feet)
368 feet
170 feet
198 feet
157 feet
43 feet
114 feet
Cold
Hot
Total
42%
75%
57%
Phase 1 Base Code
Phase 1 WDC
Clustered Base Code
Clustered WDC
Cold
Hot

Right-Size the Piping

Improve estimates of peak flow rates to right-size the piping

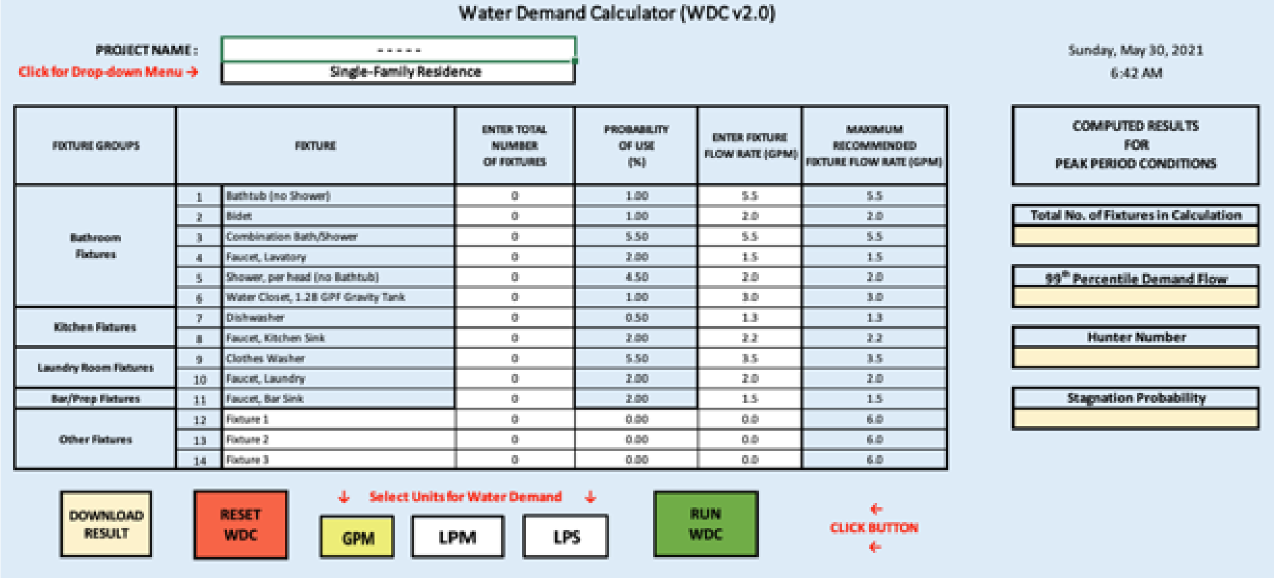
1. Improve Estimates of Peak Flow Rates
    1. Measure flow rates in similar occupancies before designing new ones
2. Utilize Modern Peak Flow Rate Estimation Tools
    1. For mains and branches – match to modern flow rates and probabilities of simultaneous use
    2. Twigs – match to the flow rates of the fixture/appliance that is attached
3. Select Pipe Sizes that Optimize Velocities and Residual Pressure
    1. Velocities
        1. Hot: 5 feet per second
        2. Cold: 8 feet per second
        3. Twigs: 8 feet per second
    2. Residual Pressure
        1. Minimize Pressure Loss in Piping, Fittings, Fixtures and Appliances
        2. Higher residual pressure will increase performance and customer satisfaction

Estimating Peak Flow Rates

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

- Values date from the 1940s
- Not directly tied to actual flow rates
- Assumes most occupancies act like theaters with lines during intermission

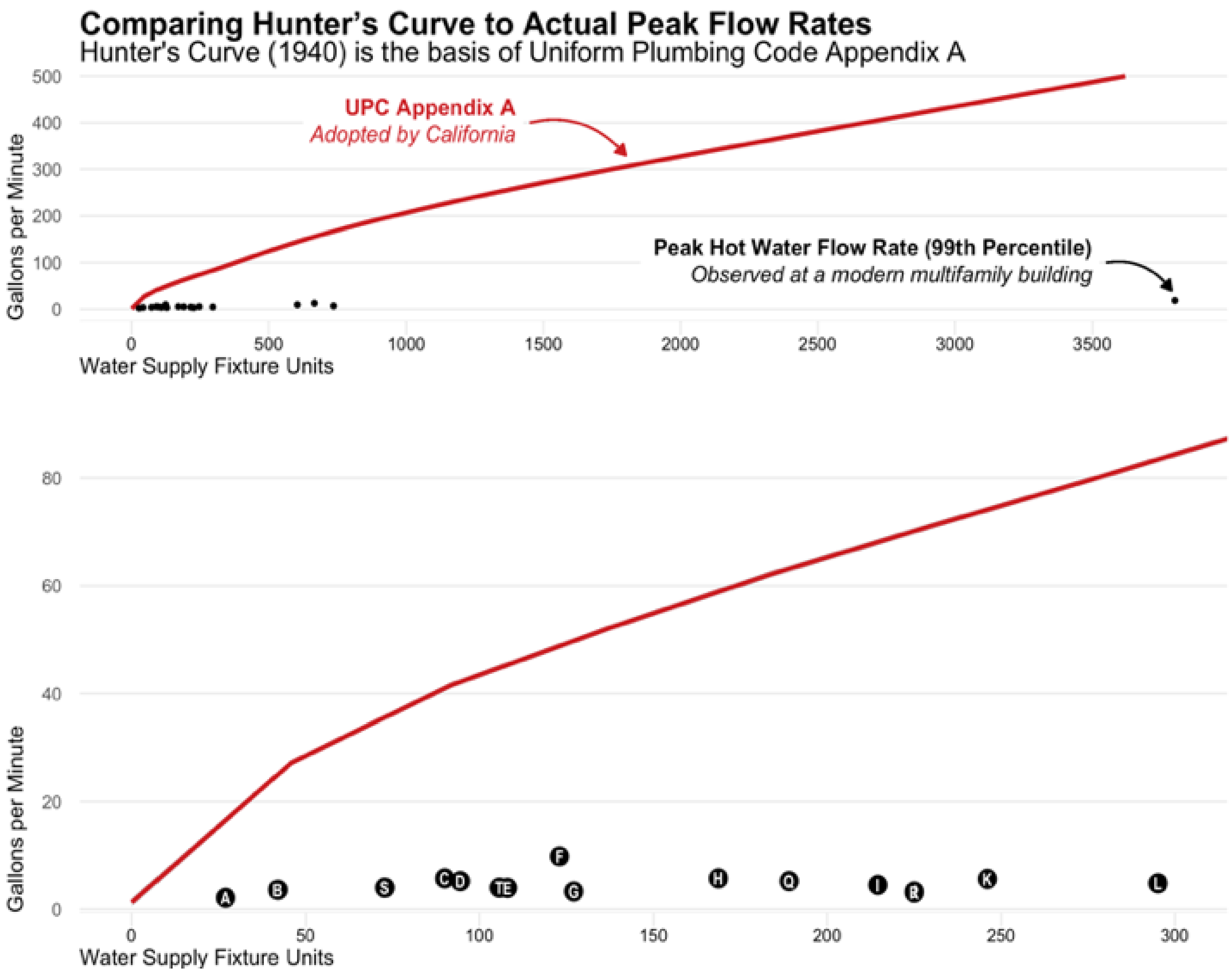
2. Appendix M (2024 IAPMO UPC & CA CPC): Water Demand Calculator



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	1.00	5.5	5.5
	2	Bidet	0	1.00	2.0	2.0
	3	Combination Bath/Shower	0	5.50	5.5	5.5
	4	Faucet, Lavatory	0	2.00	1.5	1.5
	5	Shower, per head (no Bathtub)	0	4.50	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	1.00	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.50	1.3	1.3
	8	Faucet, Kitchen Sink	0	2.00	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	0	5.50	3.5	3.5
	10	Faucet, Laundry	0	2.00	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	2.00	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

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

What if we could use real data for different occupancies?

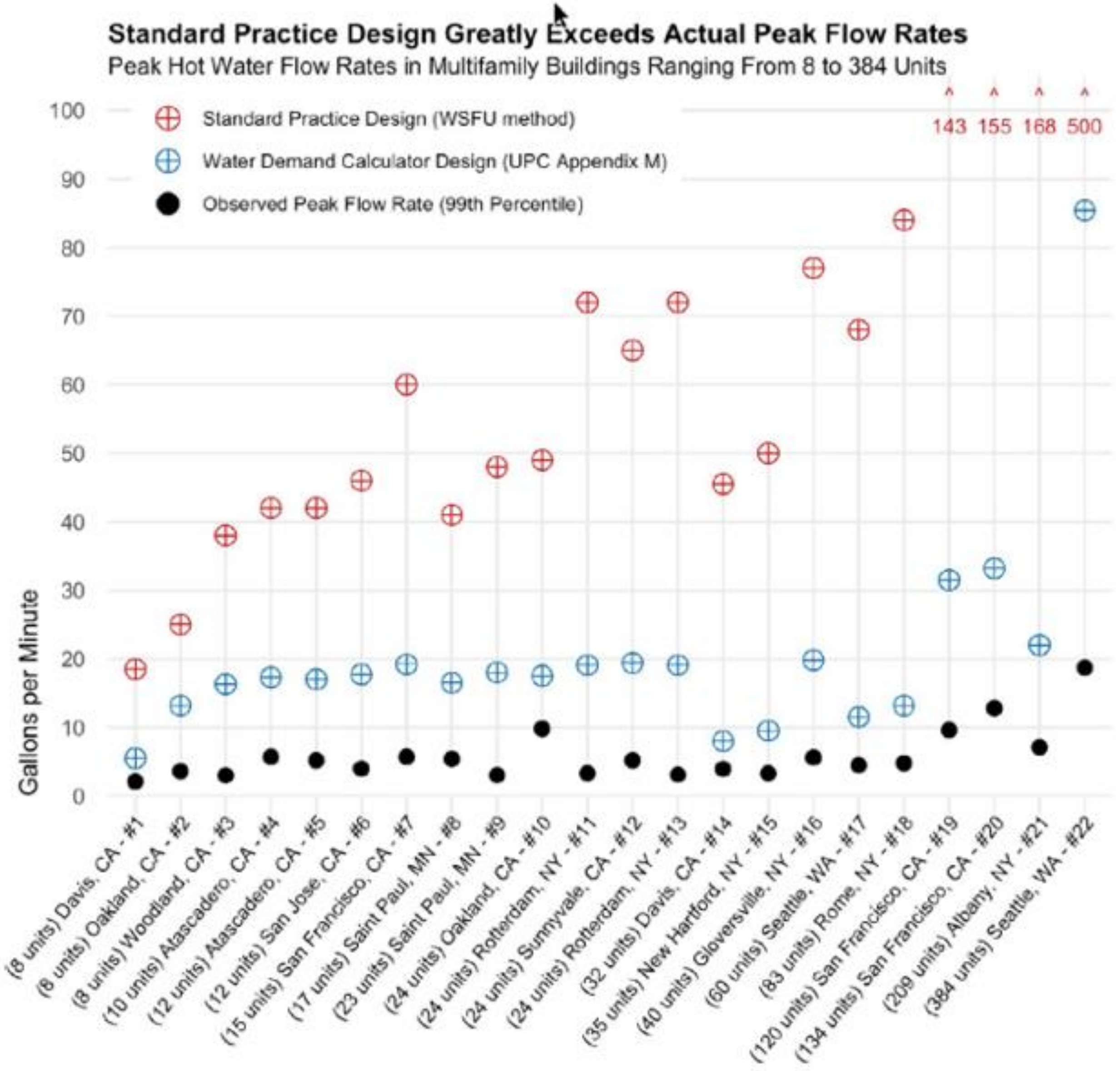


Water Supply Fixture Units = WSFU
California Plumbing Code (CPC)/Uniform Plumbing Code (UPC) Appendix A codifies the standard practice WSFU method.

Based on the analyzed actual hot flow rates from **multifamily buildings** ranging from 8 to 384 apartments,

Standard Practice WSFU design flow rates are 5 to 27 times larger than the observed peak hot water flow rates.

Credits: Observed peak flow rate data was collected and provided by the Association for Energy Affordability, Ecotope, Frontier Energy, E2G Solar, and the University of California Davis Western Cooling Efficiency Center.

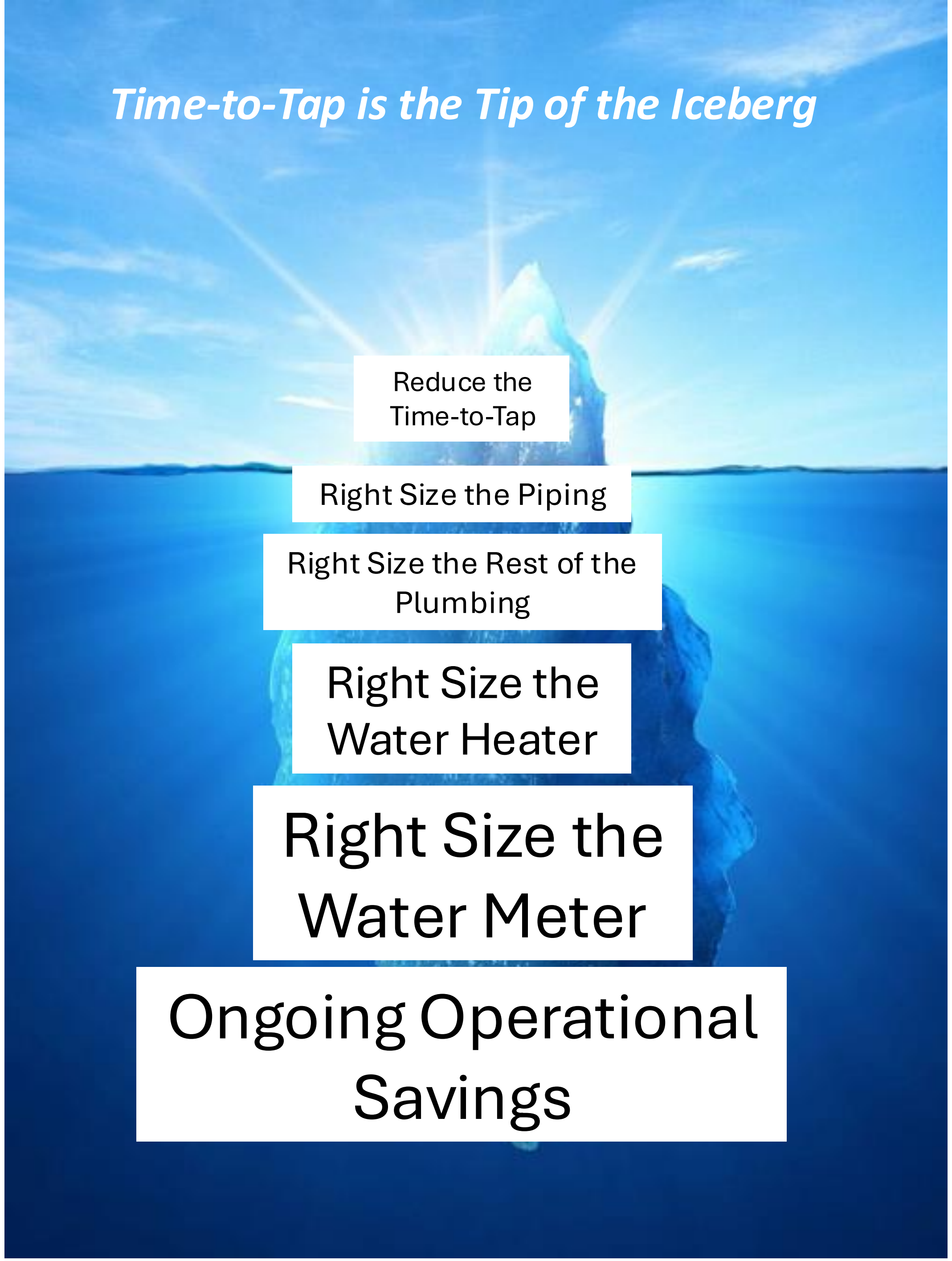


The **WDC design flow rates are between 2 and 6 times** the observed peak hot water flow rates in **22 multifamily buildings**.

CPC/UPC Appendix M codifies the Water Demand Calculator.

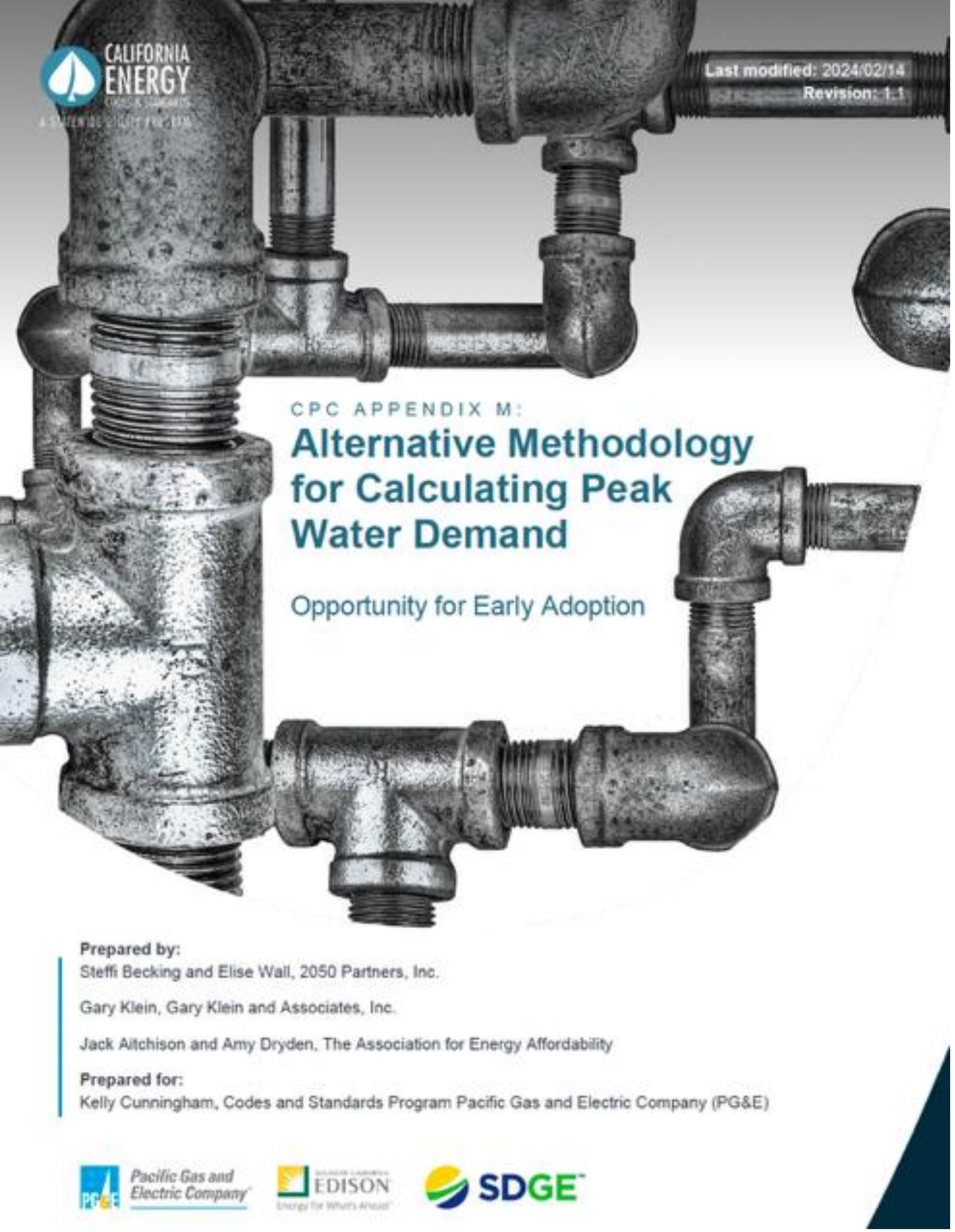
Data was collected during the period of 2019 to 2022; monitoring period ranged from 9 days to over 2 years, and logging interval ranged from 1 to 60 seconds. Observed peak flow rate is the 99th percentile of non-zero flow rates observed over each study's duration.

Credits: Observed peak flow rate data was collected and provided by the Association for Energy Affordability, Center for Energy and Environment, E2G Solar, Ecotope, Frontier Energy, and the University of California Davis Western Cooling Efficiency Center.



Benefits of Right-Sizing in Multi-family

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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Revision: 1.1

CPC APPENDIX M:

Alternative Methodology for Calculating Peak Water Demand

Opportunity for Early Adoption

Prepared by:
Steffi Becking and Elise Wall, 2050 Partners, Inc.
Gary Klein, Gary Klein and Associates, Inc.
Jack Aitchison and Amy Dryden, The Association for Energy Affordability

Prepared for:
Kelly Cunningham, Codes and Standards Program Pacific Gas and Electric Company (PG&E)

For more information, access the **report summarizing the analysis** that compared design flow rates to actual data for hot water flow rates in 20 multifamily buildings.

Source:
https://localenergycodes.com/content/reach-codes/energy-plus-water-1
(to access the report, click “VIEW AND DOWNLOAD RESOURCES” for the “require alternative method for sizing water pipes in residential buildings” measure)
https://localenergycodes.com/download/1461/file_path/fieldList/2024%20CPC%20Appx%20M-Alternative%20Calc%20Water%20Demand.pdf (direct download link)

Stockton House:
Estimating Peak Demand – Benefits of Right-Sizing

	Total	Cold	Hot
WSFU	23.0	17.4	13.9
Equivalent GPM	16	12.4	10.5
UPC Pipe Size-PEX	1.25	1	1

	Total	Cold	Hot
WDC Peak Demand GPM	8	8	8
UPC Pipe Size-PEX	0.75	0.75	0.75

Effect of Right-Sizing:
Smaller Pipe Diameters

Using the UPC Nomographs

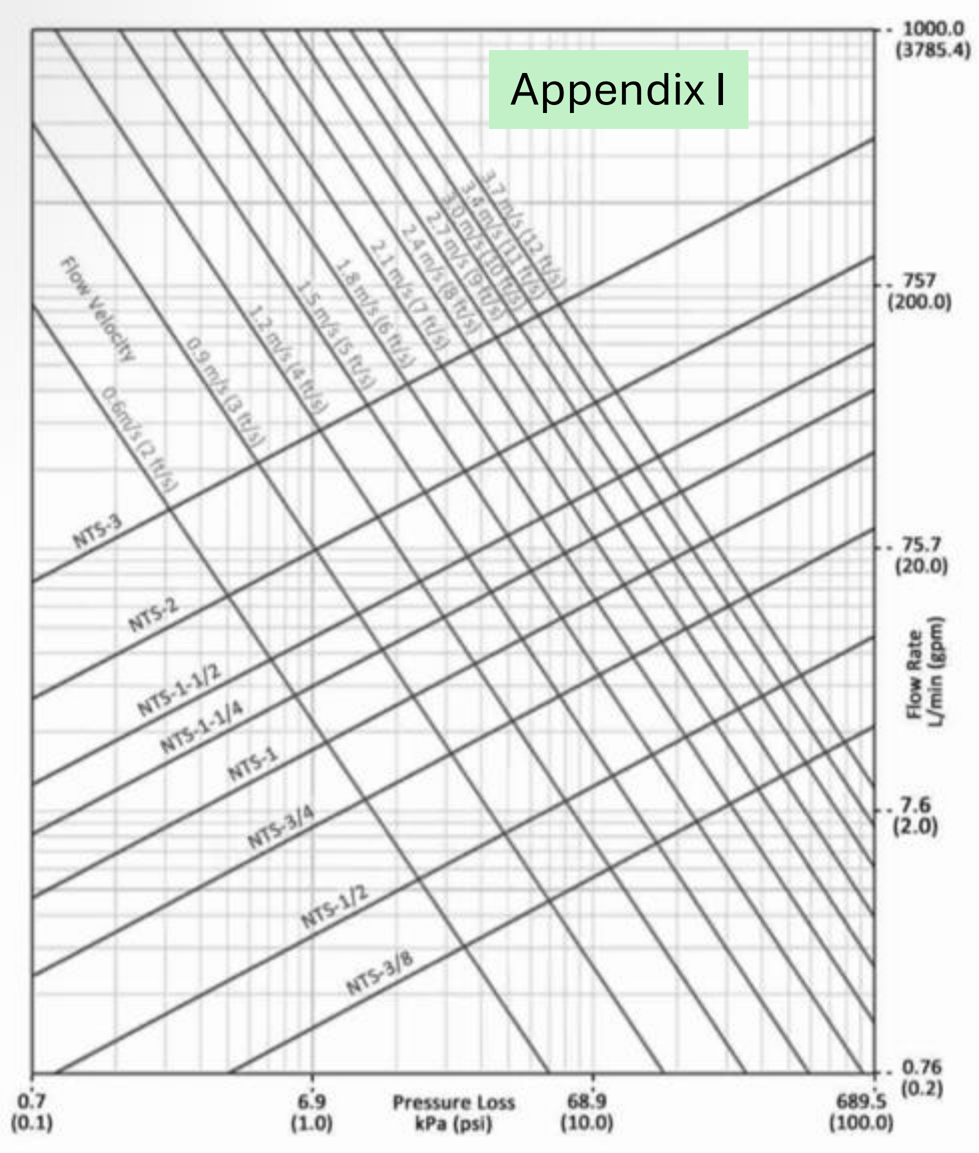


FIGURE 3
PRESSURE LOSS OF PEX TUBING AT 16 °C (60°F)
(See Section 10.6.2)

Determining Pipe Diameters

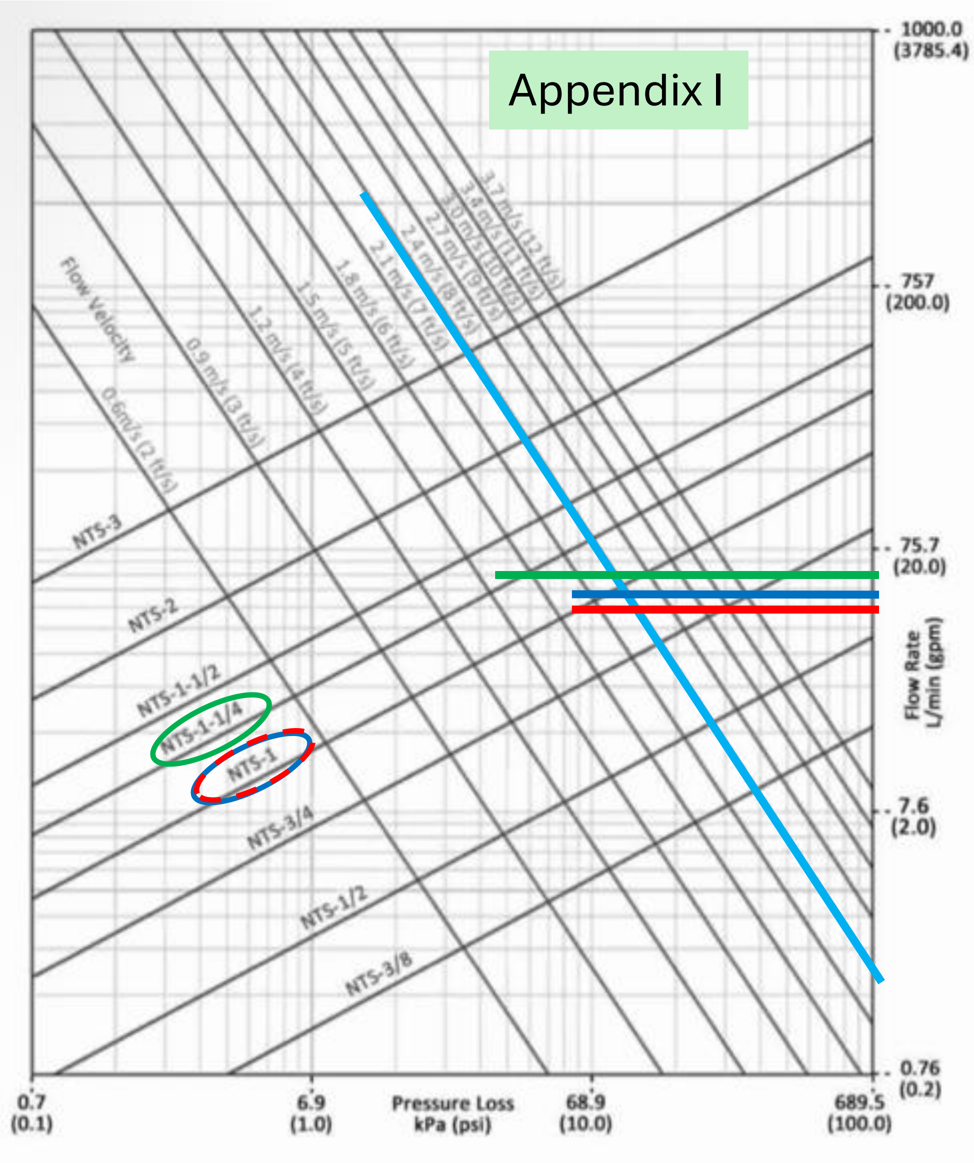


FIGURE 3
PRESSURE LOSS OF PEX TUBING AT 16 °C (60°F)
(See Section 10.6.2)

WSFU

Total

Cold

Hot

WDC

Total
Cold
Hot

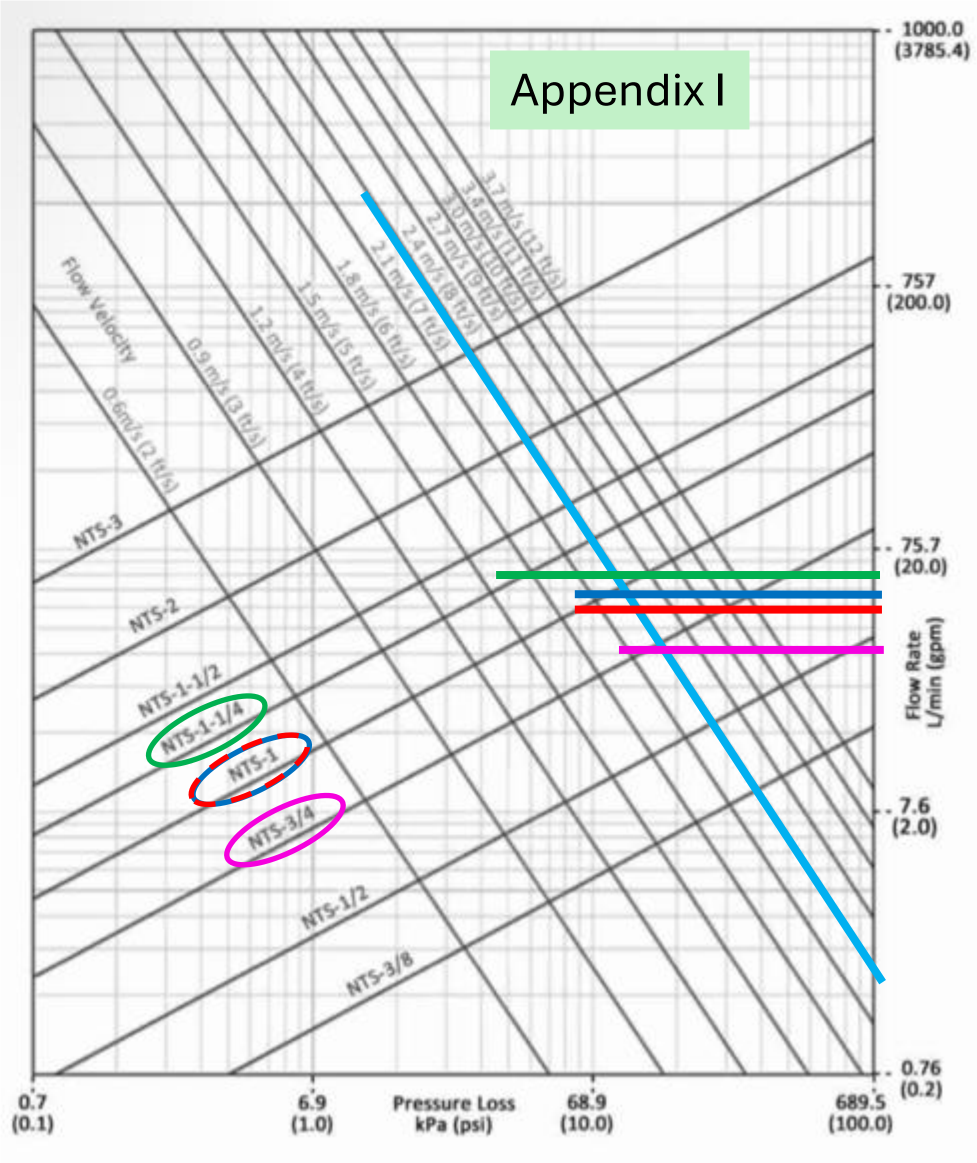
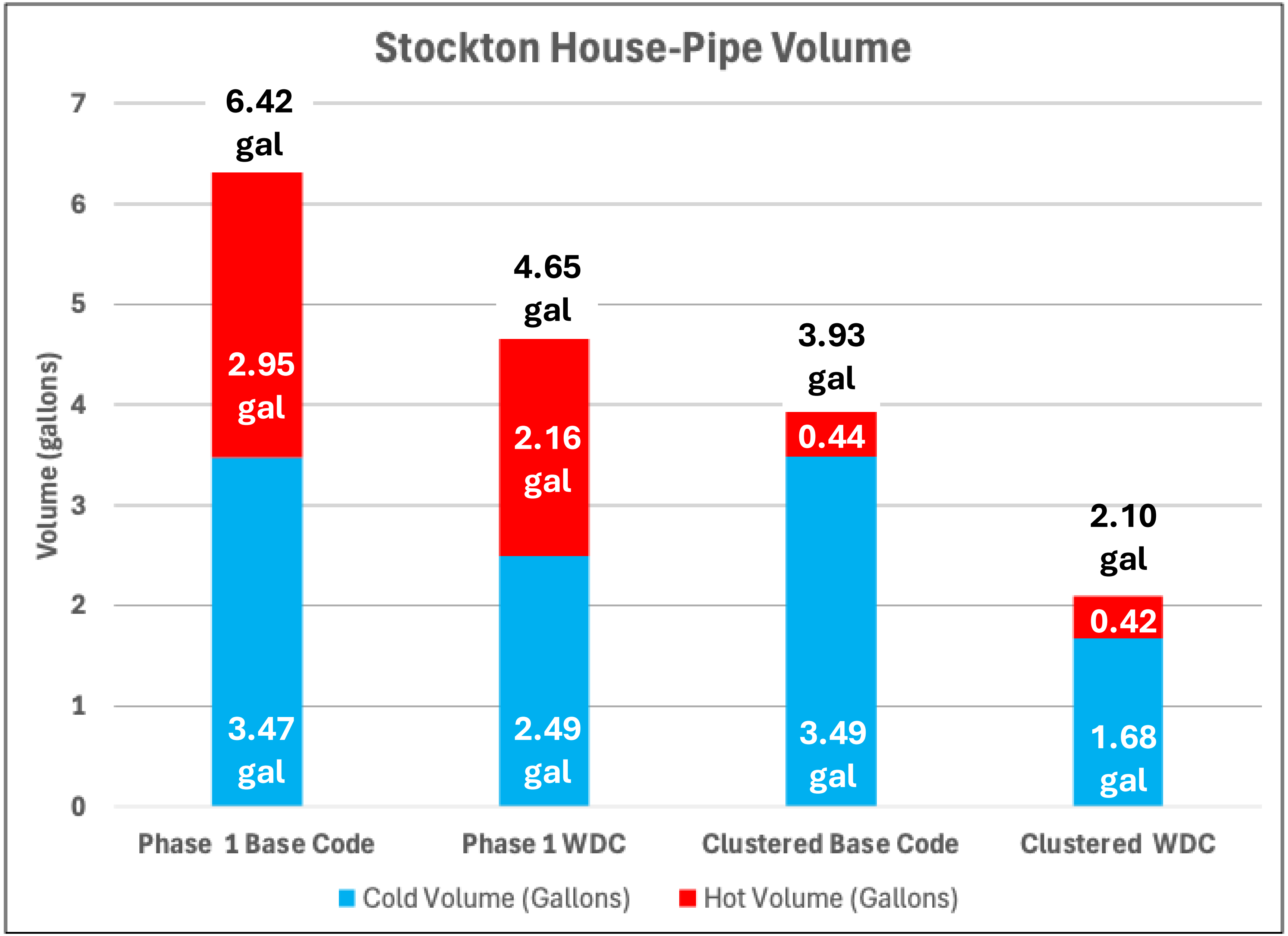


FIGURE 3
PRESSURE LOSS OF PEX TUBING AT 16 °C (60°F)
(See Section 10.6.2)



Stockton House-Pipe Volume
Volume (gallons)
0
1
2
3
4
5
6
7
6.42 gal
2.95 gal
3.47 gal
4.65 gal
2.16 gal
2.49 gal
3.93 gal
0.44
3.49 gal
2.10 gal
0.42
1.68 gal
Phase 1 Base Code
Phase 1 WDC
Clustered Base Code
Clustered WDC
Cold Volume (Gallons)
Hot Volume (Gallons)

Combining Clustering and Right-Sizing

	Stockton House					
	Cold		Hot		Total	
	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)	Volume (Gallons)	Length (Feet)
Phase 1 Base Code	3.47	198	2.95	170	6.42	368
Clustered WDC	1.68	114	0.41	43	2.10	157
Difference	1.79	84.0	2.54	127	4.33	211
Reduction (%)	52%	42%	86%	75%	67%	57%

If we optimized the diameter of the twigs, the percent reductions in volume would be increased to 59% cold, 95% hot and 75% total.

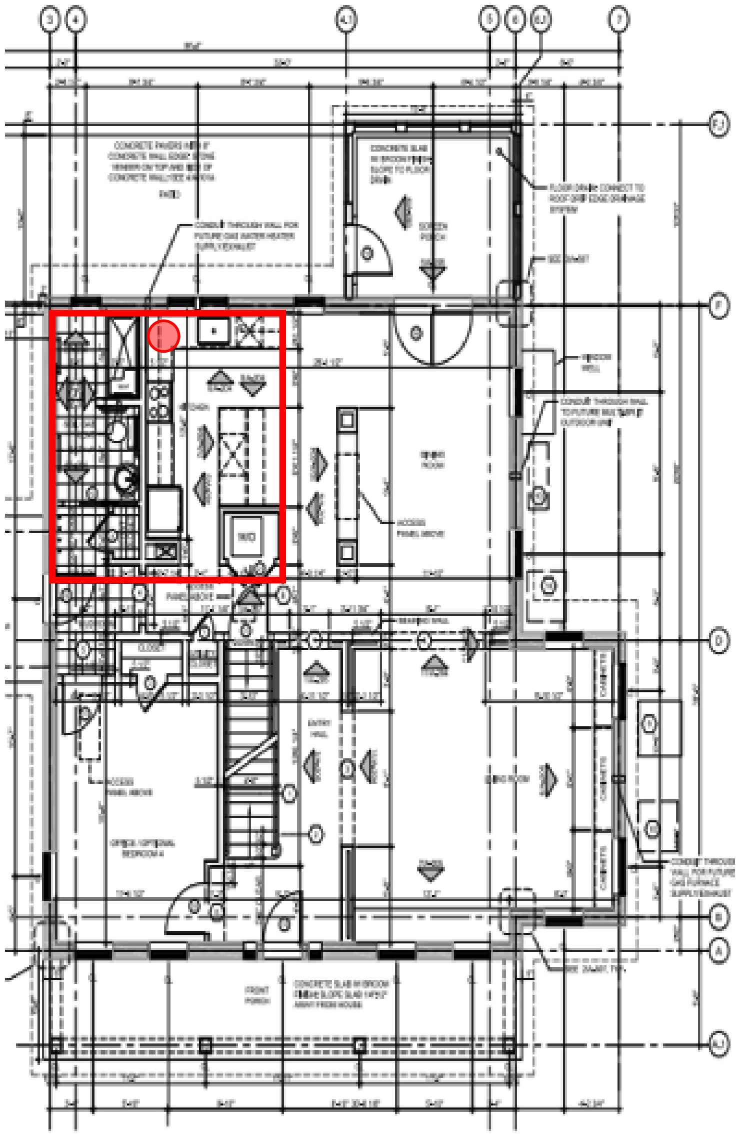
Summary Data

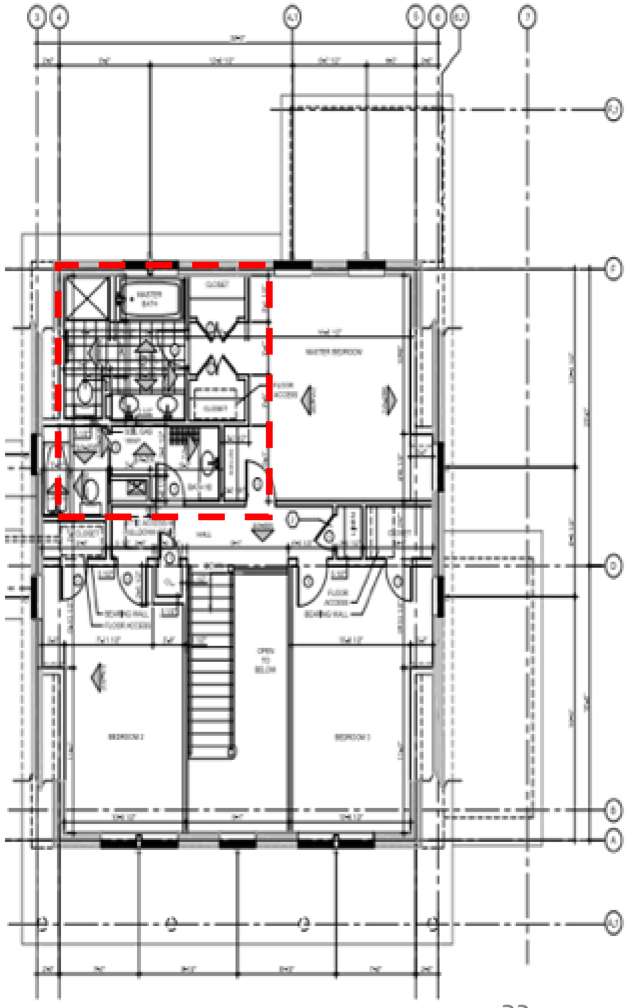
	Stockton House					
	Cold Volume (Gallons)	Cold Length (Feet)	Hot Volume (Gallons)	Hot Length (Feet)	Total Volume (Gallons)	Total Length (Feet)
Phase 1 Base Code	3.47	198	2.95	170	6.42	368
Phase 1 WDC	2.49	198	2.16	170	4.65	368
Clustered Base Code	3.49	114	0.44	43	3.93	157
Clustered WDC	1.68	114	0.41	43	2.10	157

You can use these numbers to get percent reductions for any combination of these options

Best 2-Story So Far…

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





Enjoyable houses to live in are possible with compact plumbing (and mechanical) cores.

Architects: We Need You!

Courtesy: Betsy Pettit, and NIST

Improve Performance of Fixtures

Stream Patterns for Faucets

Aerated stream

The aerator adds air to the water flowing through the faucet. This creates a soft, aerated stream that feels pleasant and plentiful.

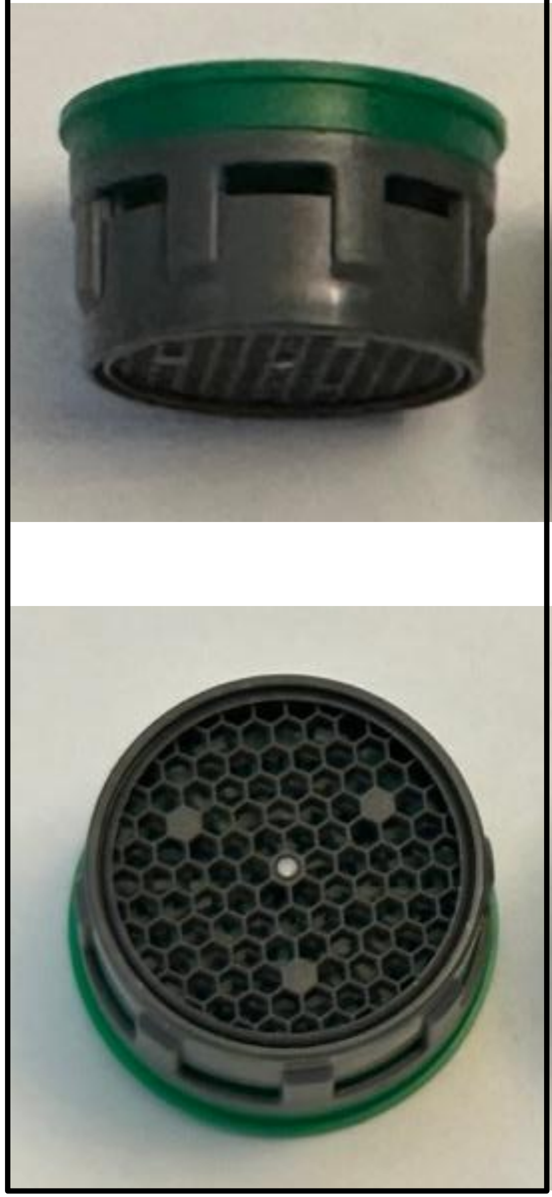
Spray stream

The spray stream provides full coverage of the hands with a low flow. Sprays are recommended for use in public lavatories.

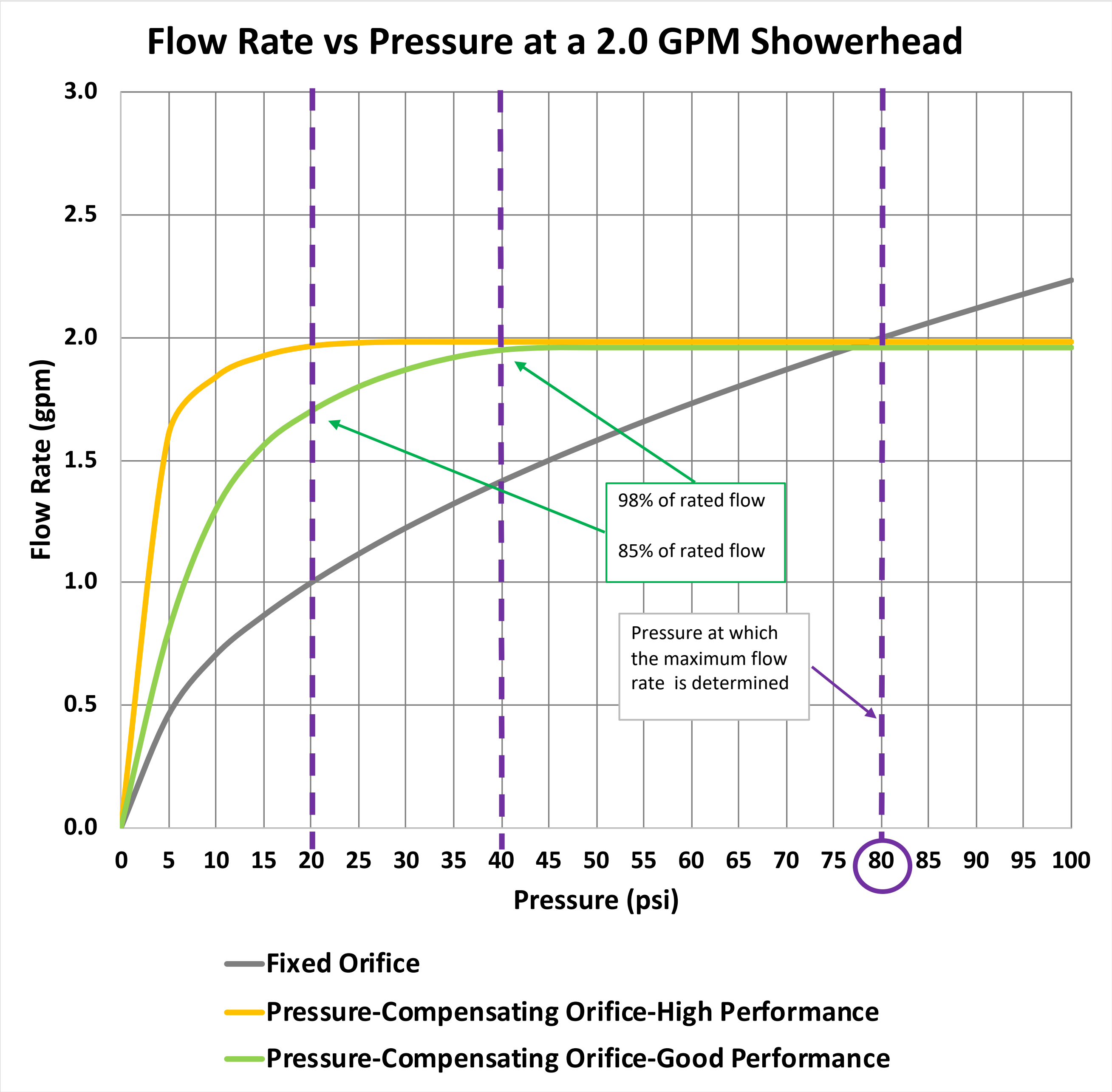
Laminar stream

A vortex-free flow makes the laminar stream appear crystal clear and natural – for a feeling of extra cleanliness. This is a real trend in Japan and a hygiene factor in hospitals.

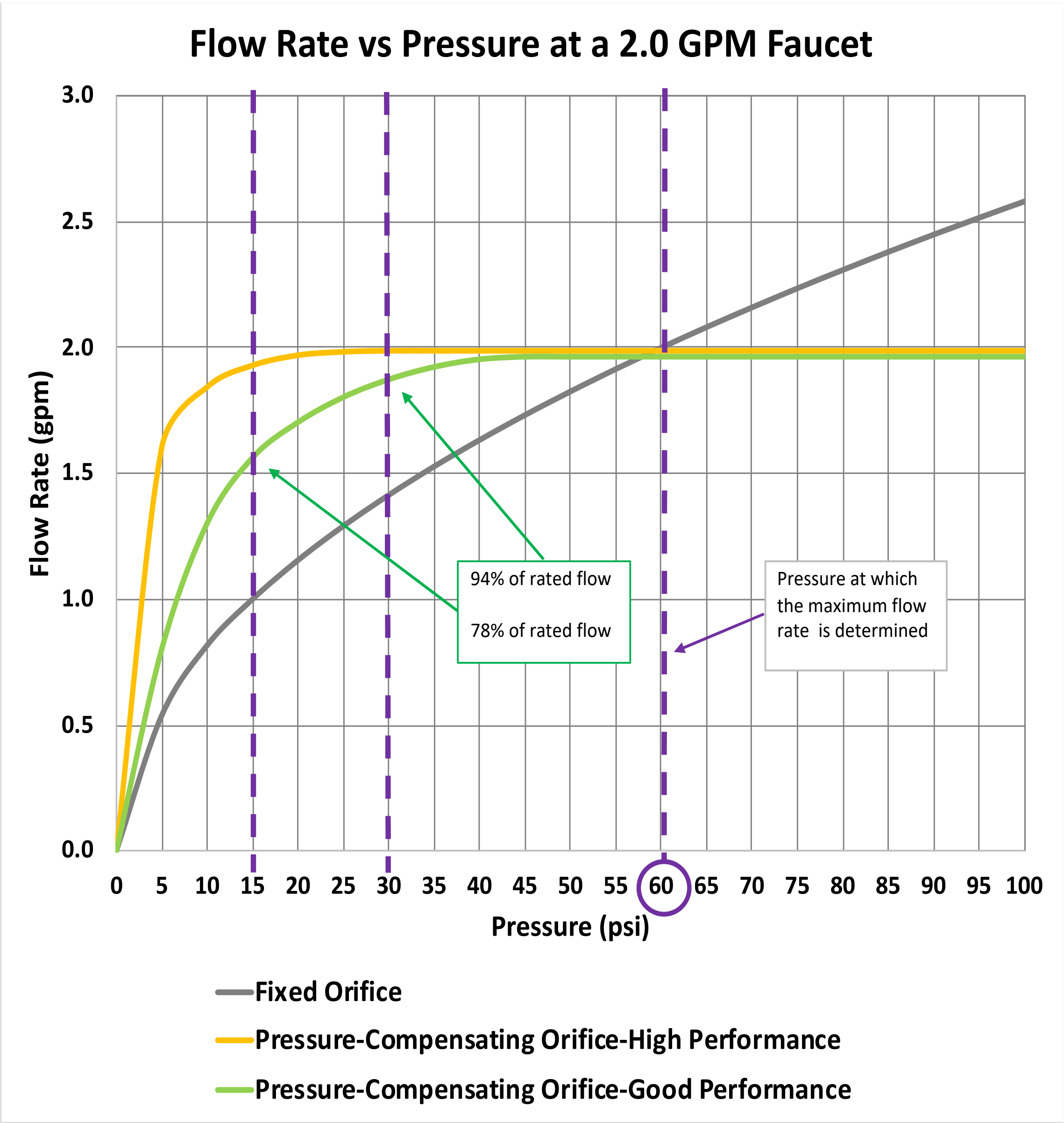
Aerated



Non-Aerated

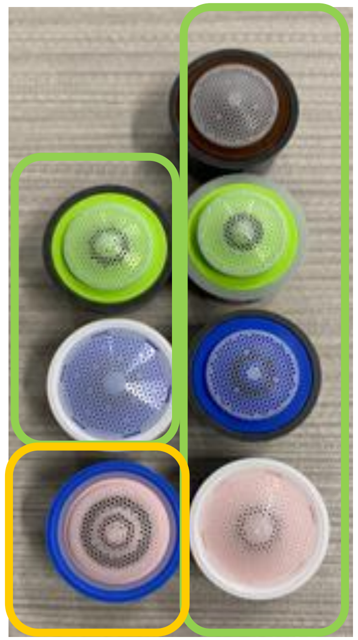


Which one do you want?



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

Flow Rate (GPM)



0.375

0.5

1.0

1.2

1.5

1.75

2.2

Which one do you want?

All faucet flow regulators are now available in dual-core!

Minimizing Backsplash

Compact laminar stream, splash-free

In addition: aim the faucet away from the drain, and from the user.

Conclusions

1. There are many benefits to reducing the volume!!!
    1. Costs less to build.
    2. Improves health and safety
    3. Hot water will arrive much more quickly
    4. Increases energy efficiency
    5. Decreases embodied and operational carbon
    6. Anything else?

2. These two decisions last the life of the building!
    1. Distance is an architectural decision.
    2. Volume is a plumbing decision.

There are analogs for the other mechanical systems

Questions?

Thank you!