Architectural Compactness and Hot Water Systems:

Good Design Lowers Cost:

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Do you know anyone who …

- Wants to reduce the first costs of construction by $1,000 to $2,000 – and ±40 hours of labor – per dwelling?
- Would like to improve customer satisfaction with their hot water system?
- Would like to “right-size” water supply systems based on current flow rates and modern piping materials and plumbing fixtures and appliances?
- Wondered why the “well-designed” plumbing system didn’t work as expected?
- Actually measured the performance of a plumbing system? And then compared what they measured to the design?
- Wondered why pipe sizes haven’t gotten smaller even though flow rates have been dropping for the past 50 years?
- Wants to increase their profit by $1,000 to $2,000 per dwelling?

Part of today's session is based on:

CEC Grant PIR-16-020
Code Changes and Implications of
Residential Low Flow Hot Water Fixtures
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John Koeller

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Agreement Goals

- Develop code change recommendations based on comprehensive assessment of technical, economic, and market feasibility improvement strategies that can significantly increase hot water distribution system efficiency in new construction and existing buildings;
- Characterize the impact of low flow fixtures on distribution system performance and determine the theoretical lowest flow possible for hot water fixtures.

Why This Research is Important?

- Plumbing fixture flow rates, flush volumes and appliance fill volumes have been reduced every decade since the 1950s.
- Pipe sizing rules have not been revisited since written down in the 1940s.
- The median square footage of a house is roughly 1.5 times larger than it was in 1970.
- Result:
  - It takes much longer than it used to for hot water to arrive.
  - More energy is lost when the pipes cool down.
  - Dissatisfied occupants
  - Potentially unsafe conditions in the piping network

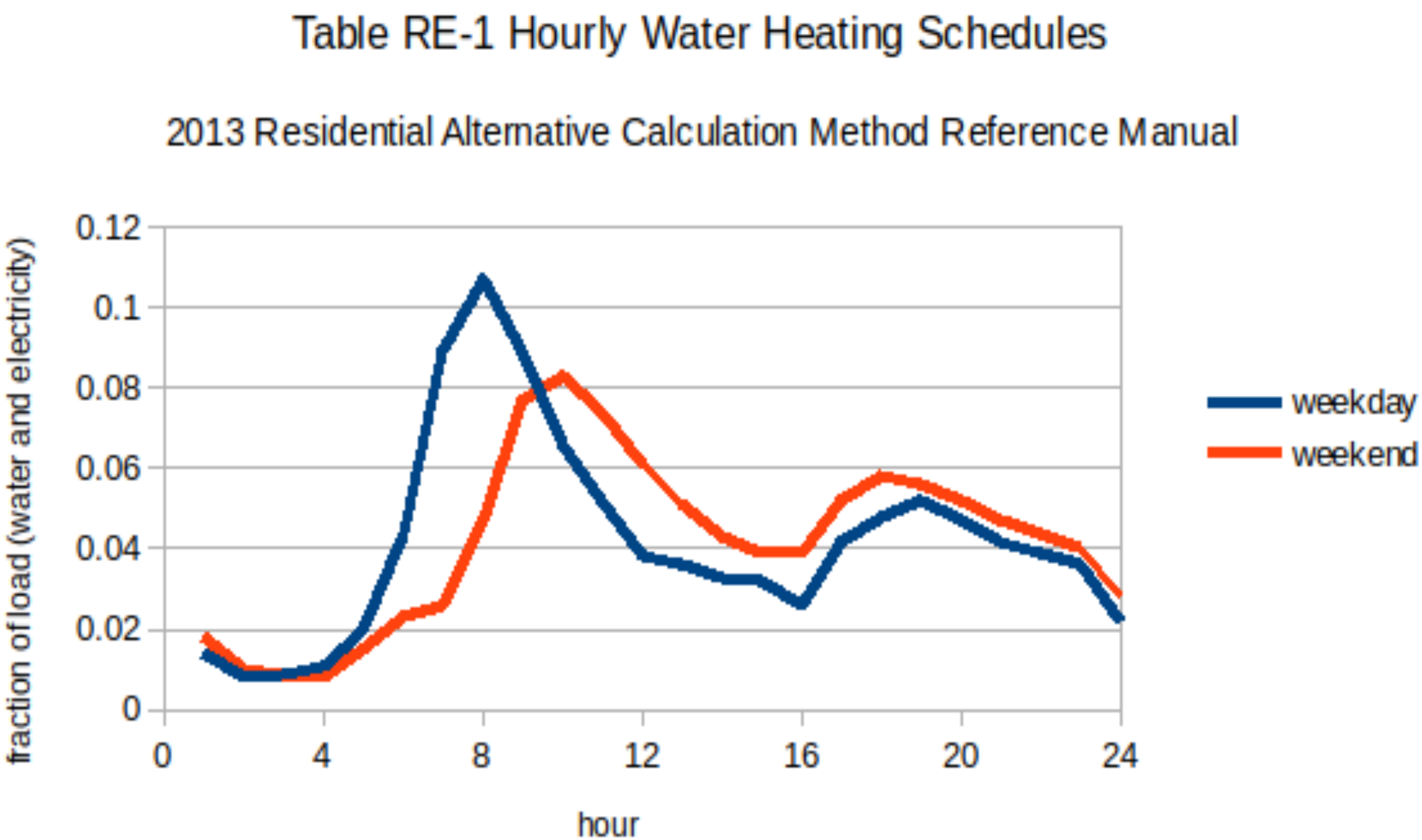
Water Consumption 1980-2017

Water-using Fixture or Appliance	1980s Water Use (typical)	1990 Requirement (maximum)	EPAct 1992 Requirement (maximum)	2009 Baseline Plumbing Code (maximum)	"Green Code" Maximums (2017 CALGreen)	% Reduction in avg water use since 1980s
Residential Bathroom Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.2 gpm	66%
Showerhead	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	1.8 gpm	49%
Residential ("private") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Commercial ("public") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Urinal	1.5 to 3.0+ gpf	1.5 to 3.0+ gpf	1.0 gpf	1.0 gpf	0.125 gpf	96%
Commercial Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
Food Service Pre-Rinse Spray Valve	5.0+ gpm	No requirement	1.6 gpm *(EPAct 2005)*	No requirement	1.3 gpm	74%
Residential Clothes Washing Machine	51 gallons per load	No requirement	26 gallons per load *(2012 std)*	No requirement	12.6 gallons per load *(Energy Star)*	75%
Residential Dishwasher	14 gallons per cycle	No requirement	6.5 gallons per cycle *(2012 std)*	No requirement	3.5 gallons per cycle *(Energy Star)*	75%

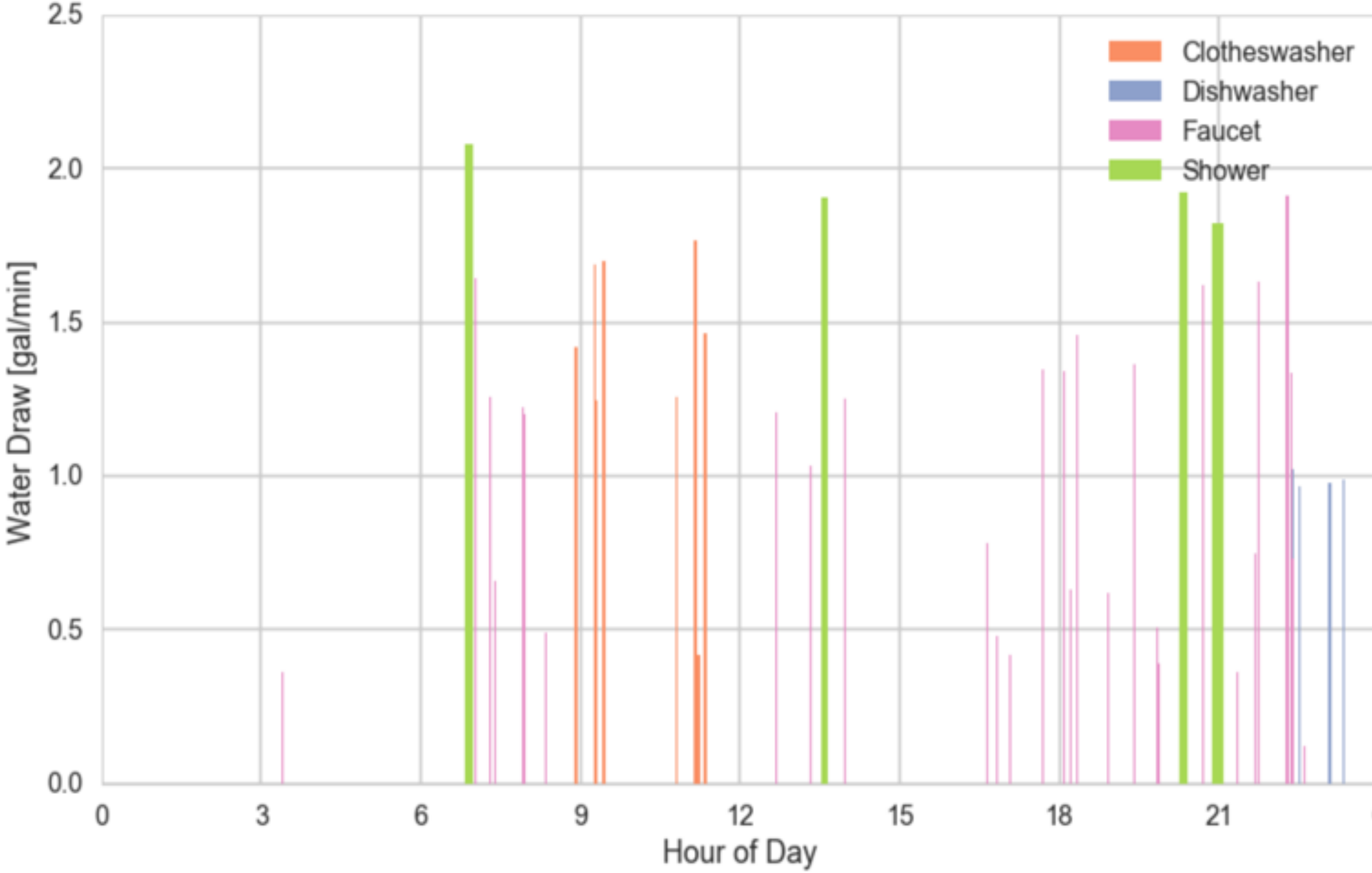
From 1980 to 2017: Reductions range from 49 to 96%

Source: *The Drainline Transport of Solid Waste in Buildings*, PERC 1 Report - J. Koeller, P. DeMarco

Traditional Daily Hot Water Load



Actual Daily Hot Water Load

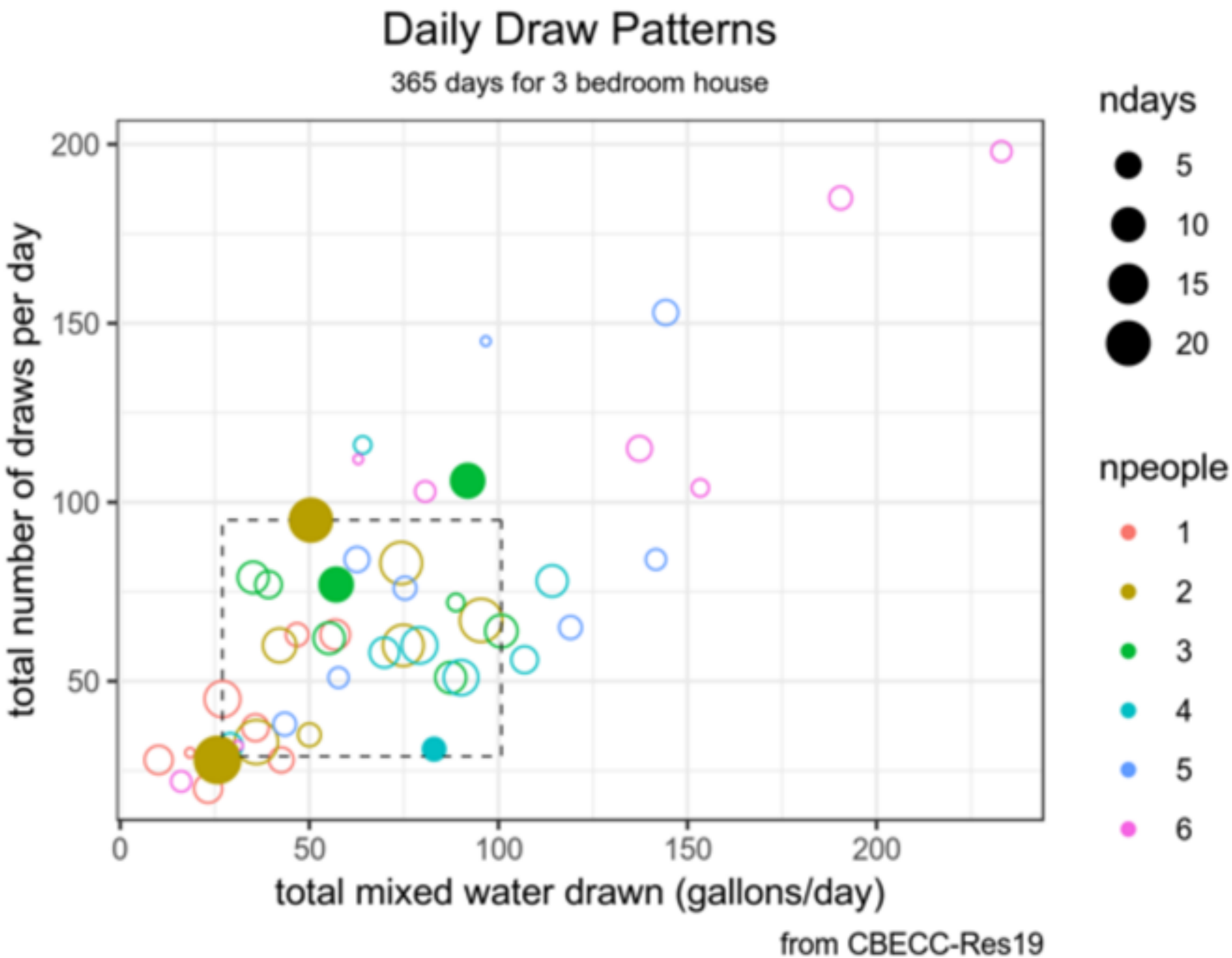


Types of Draws

End Use	Hot/Cold Mix	Miscellaneous
showers (clearing)	100% hot	shower/tub only
showers (use)	105°F mixed	
faucets	all draws 50%	clearing draws on long draws
clothes washers	draws 22% hot	multiple draws per cycle
dishwashers	100%	multiple draws per cycle benefits of plumbing to cold water?
baths	105°F mixed	

These are modeling assumptions built into CBECC-Res. The research team used these assumptions and the CBECC-Res draw patterns for compatibility and ease of explanation.

CBECC-Res Hot Water Draw Patterns



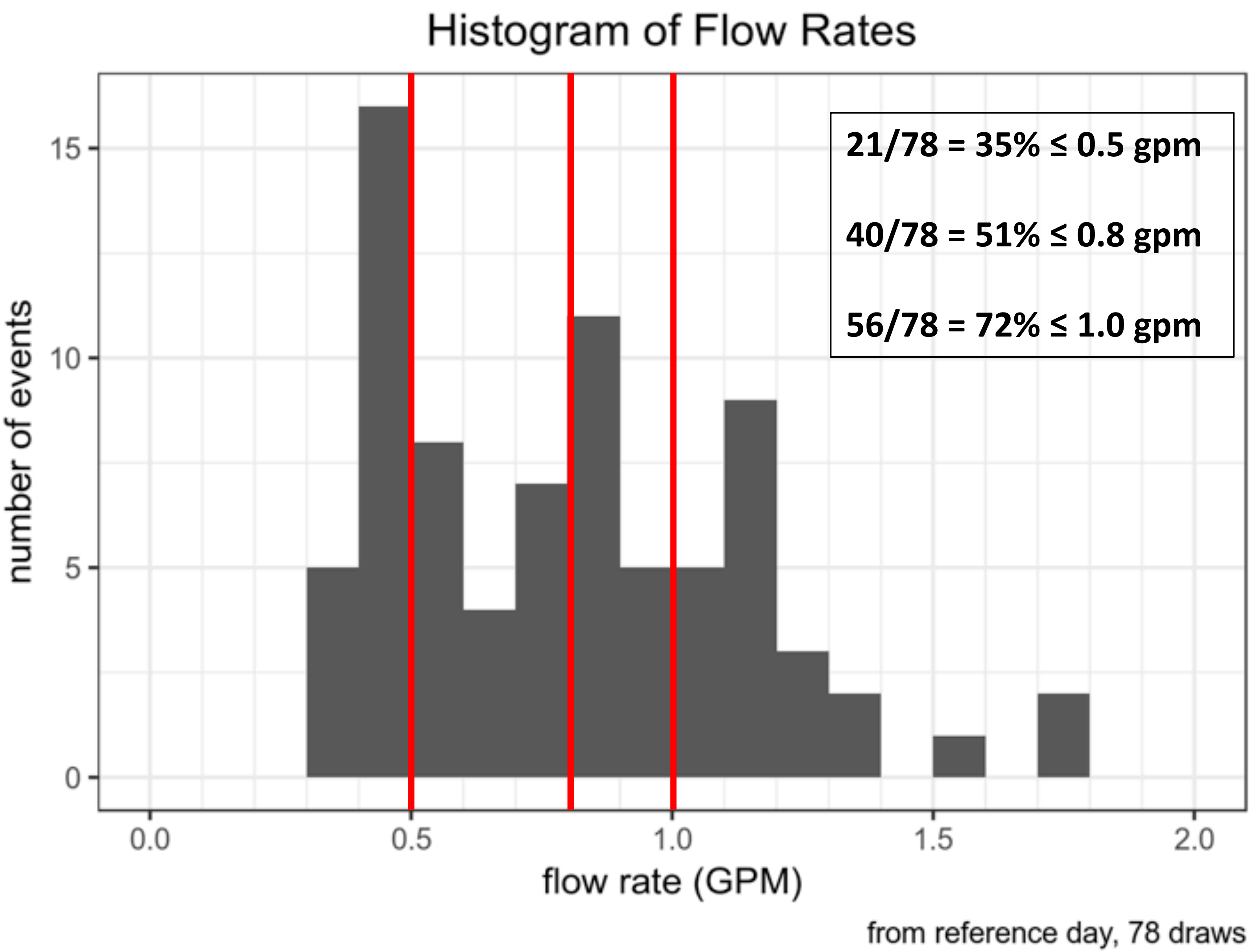
Daily Draw Patterns Considered for Analysis

•

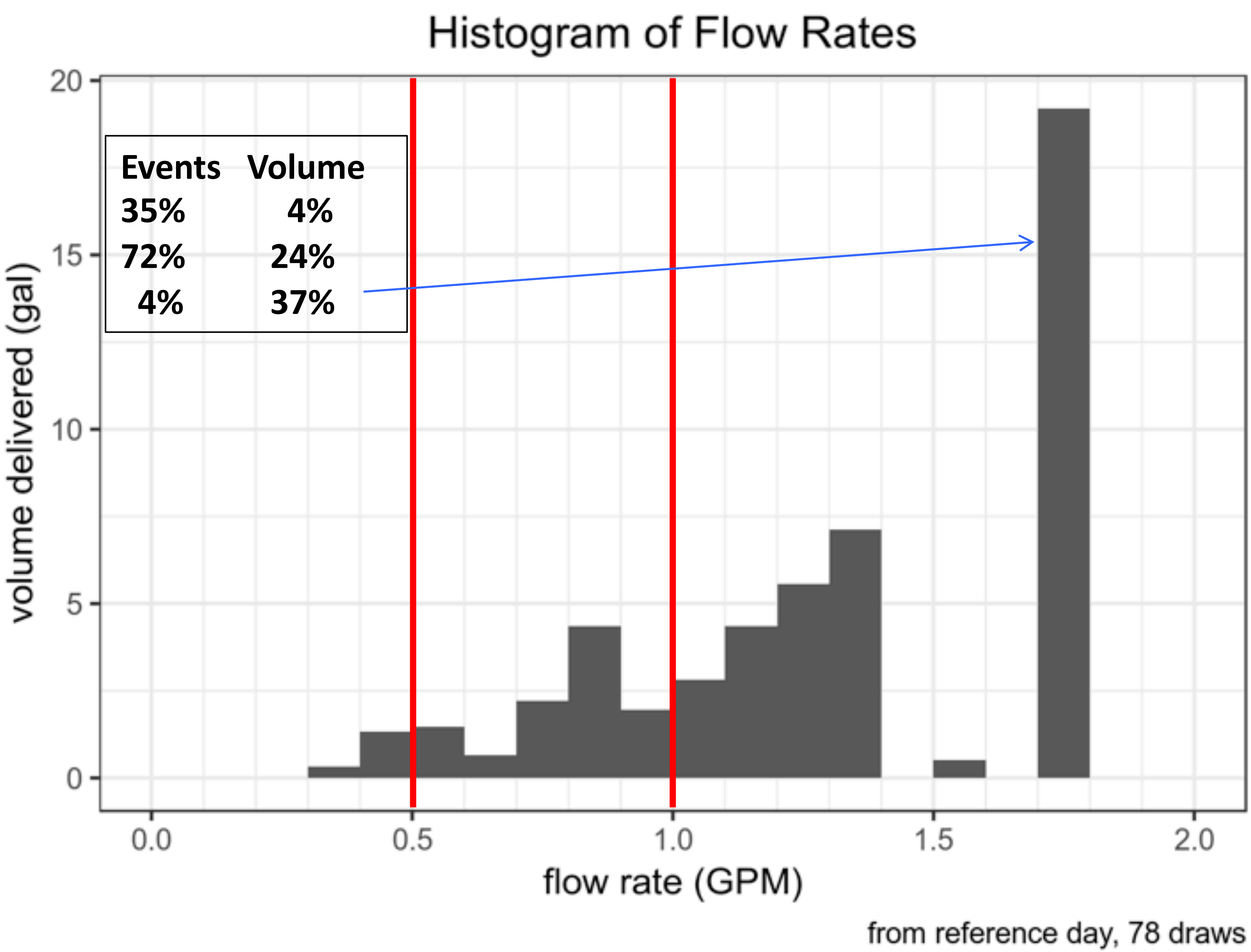
Day	People	Day of Week	Daily Volume of Water (gal)	Number of Daily Draws						Percent Faucets
				Total	Shower	Faucet	CW	DW	Bath	
1	2	Wed	25.53	28	1	23	4	0	0	82%
2	2	Sat	47.57	94	0	81	6	6	1	86%
3	3	Thu	95.91	106	4	87	10	4	1	82%
4	3	Thu	52.29	77	2	70	5	0	0	91%
5	4	Mon	75.05	31	2	17	12	0	0	55%

CW = Clothes Washer, DW = Dishwasher,

Number of Events by Volume



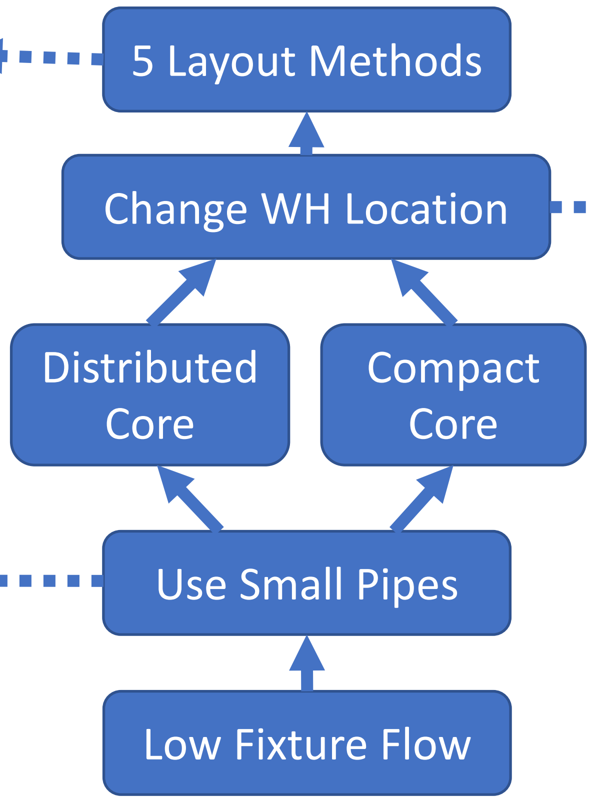
Volume Delivered by Flow Rate



Improvement Strategies

Layout Methods

1. Trunk and branch
2. Hybrid
3. Home run
4. Two water heaters
5. One zone w/o recirc



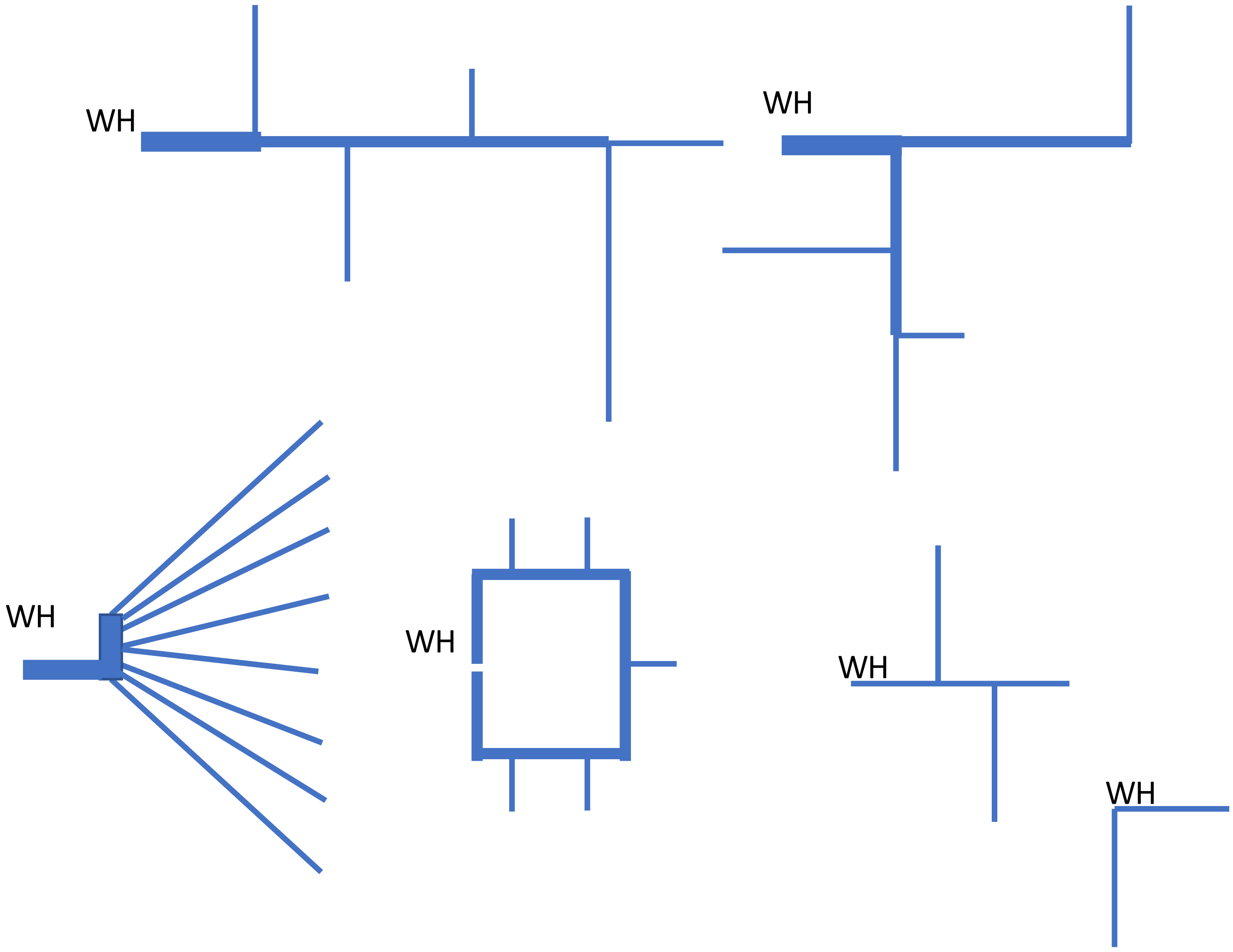
Water Heater Locations

1. **Normal**: WH in garage, away from the wet-room rectangle
2. WH in garage: move to center line of the wet-room rectangle
3. Move WH to the edge of the wet-room rectangle
4. Move WH to the center of the wet-room rectangle
5. WH in garage: located far away from the wet-room rectangle

Use Small Pipes

1. ½ inch → 3/8 inch
2. 1 inch → ¾ inch
3. Both

Layout Methods



Low-Flow and High-Efficiency Fixtures

The current Federally required maximum flow rates are designated as “low-flow”, whereas the lower volumes adopted by California and others are designated separately as “high-efficiency”.

Hot water-using plumbing fixtures and fixture fittings	Maximum water consumption		
	Federal Standard	2016 CalGreen, Part 11 (mandatory)	Title 20, Article 4, Sections 1605.1 & 1605.3
Lavatory faucet-private	2.2 gpm	1.2 gpm	1.2 gpm
Lavatory faucet-public	2.2 gpm	0.5 gpm	0.5 gpm
Metering faucet-residential	0.25 gpc	0.25 gpc	0.25 gpc
Metering faucet-nonresidential		0.20 gpc	
Kitchen faucet	2.2 gpm	1.8 gpm	1.8 gpm
Showerheads	2.5 gpm	2.0 gpm	1.8 gpm

Analysis of Architectural Compactness

New Single-Family Homes Completed in 2017

Median Home Size in Western United States
-2,398 sq ft

Average Home Size in Western United States
-2,548 sq ft

6% under 1,400
15% 1,400 to 1,799
29% 1,800 to 2,399
25% 2,400 to 2,999
17% 3,000 to ,3,999
8% 4,000 or more

(Source: United States Census Bureau)

New Multi-Family Units Completed in 2017

Median Unit Size in Western United States
-1,045 sq ft

Average Unit Size in Western United States
-1,088 sq ft

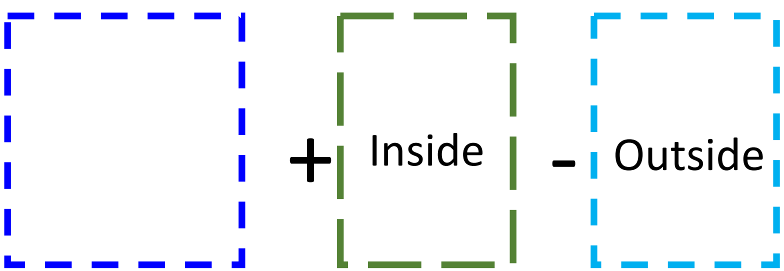
42% under 1,000
31% 1,000 to 1,199
15% 1,200 to 1,399
9% 1,400 to 1,799
4% 1,800 or more

(Source: United States Census Bureau)

= Wet Room Rectangle

Ratio in Percent: Hot Water System Rectangle/Floor Area x 100%

Use the dimensions available on the floor plan when available. Otherwise, determine the areas based on the formula below. The dimensions come from the drawing program.

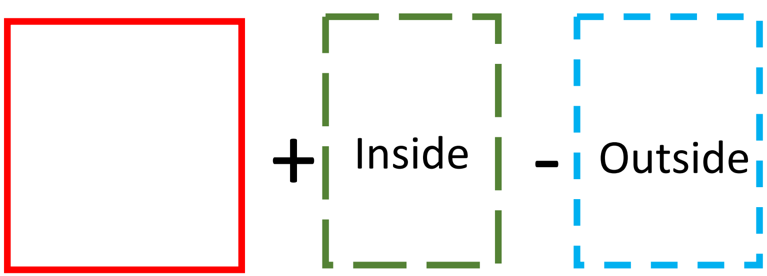


= Home Floor Area

= Hot Water System Rectangle

Ratio in Percent: Hot Water System Rectangle/Floor Area x 100%

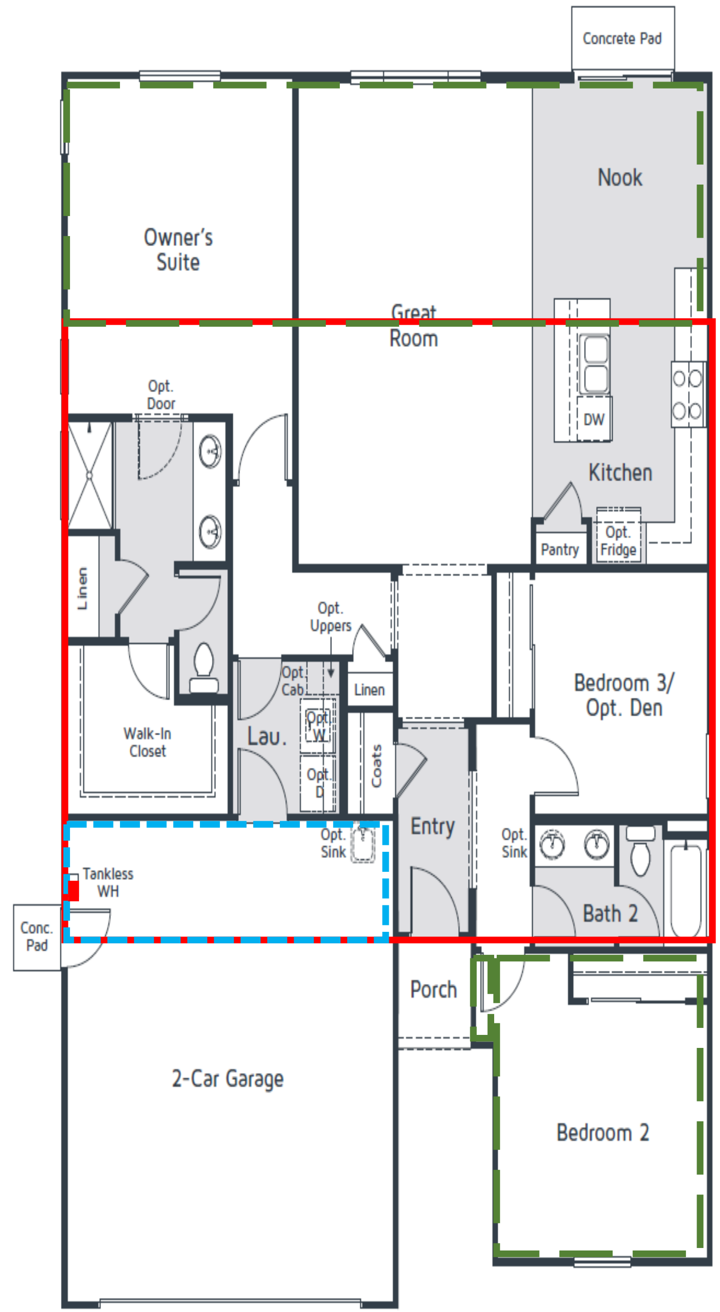
Use the dimensions available on the floor plan when available. Otherwise, determine the areas based on the formula below. The dimensions come from the drawing program.



= Home Floor Area

Example:

1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA
~67% (1137 sq ft)



Relationship between the Hot Water System and the Floor Area – The Logical Worst Case

Number of Stories	Hot Water System/ Floor Area (%)
1-story	100%
2-story	50%
3-story	33.3%
4-story	25%
5-story	20%

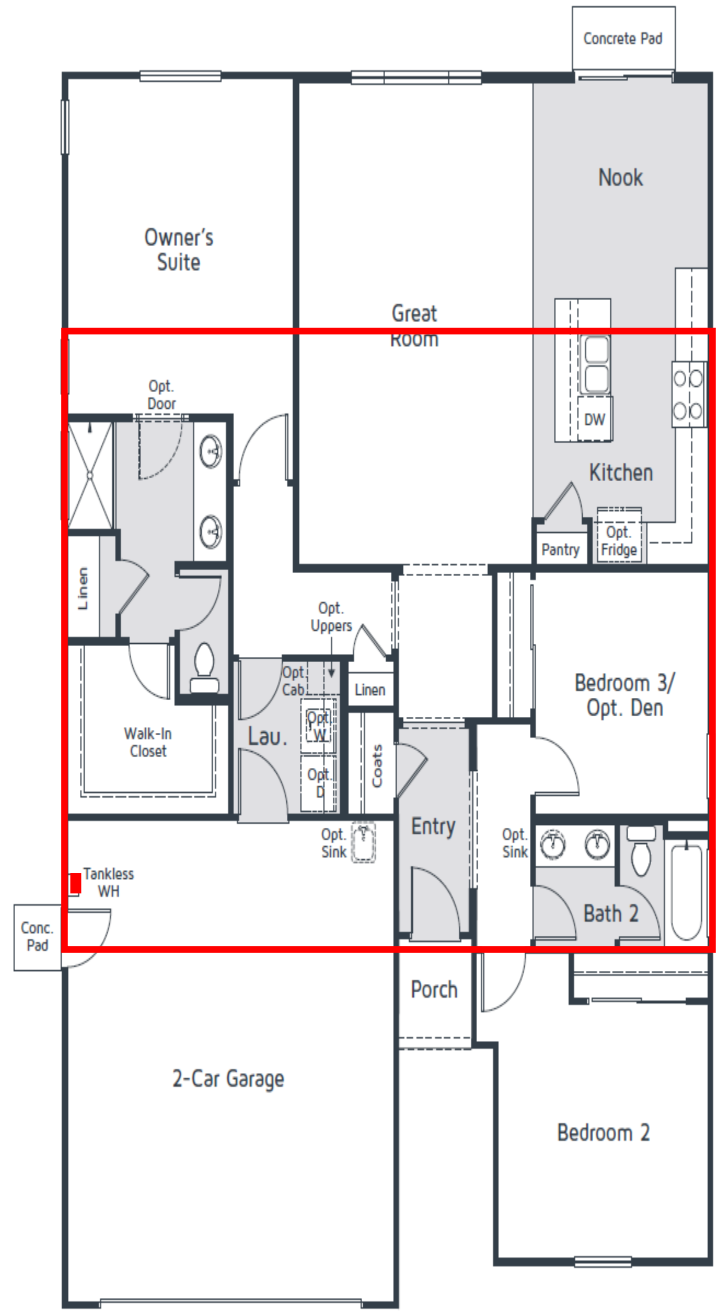
Basements count as stories if they contain wet rooms.

1-Story Floor Plans

- The wet room rectangle has the same area as the hot water system rectangle for all of the 1-story homes in this sample.

1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA

~67%
(1,137 sq ft)



1 Story
3Br/2.5Ba
2,466 sq ft
Roseville, CA

~75%
(1,835 sq ft)

1 Story

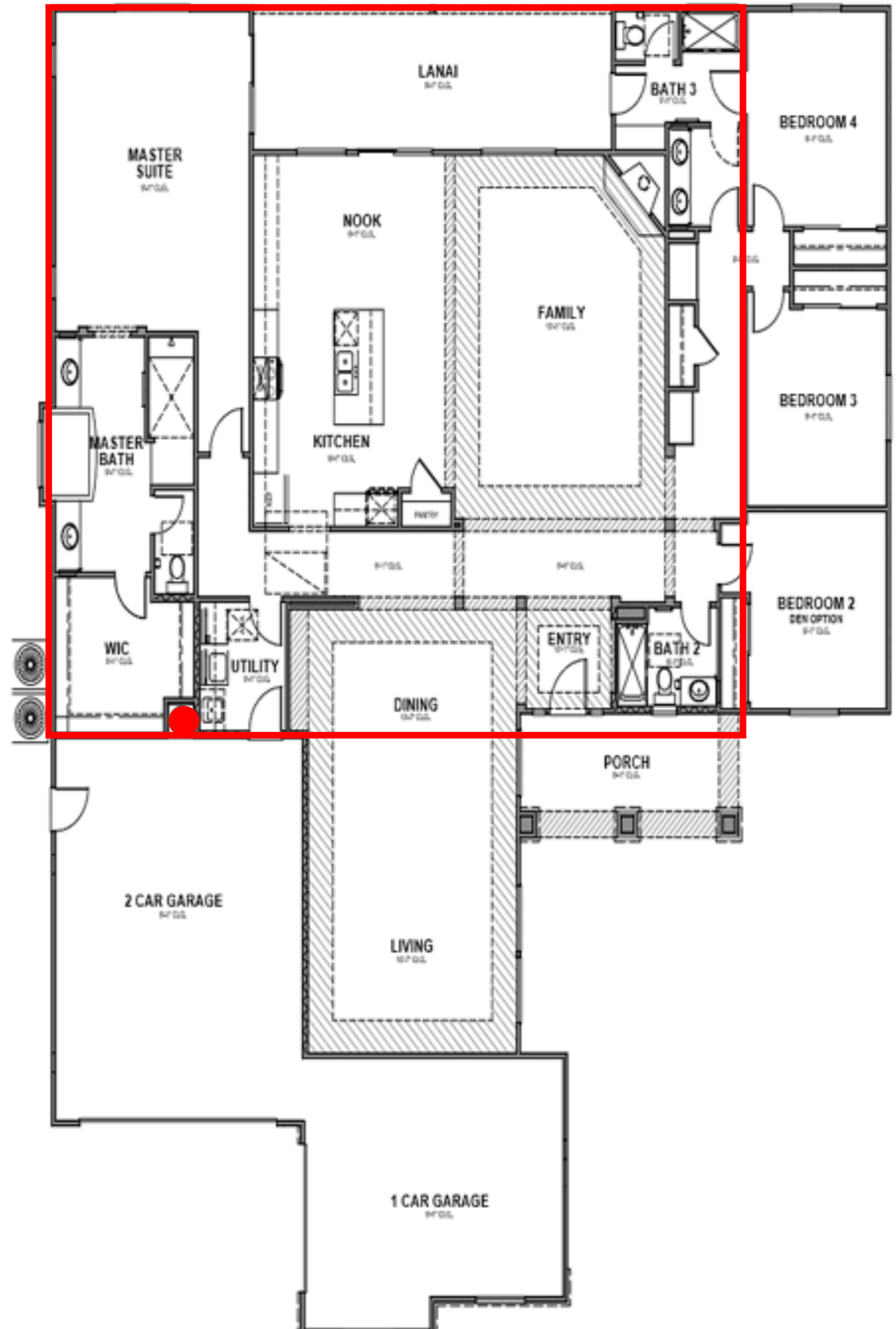
4Br/3Ba

3,073 sq ft

Chico, CA

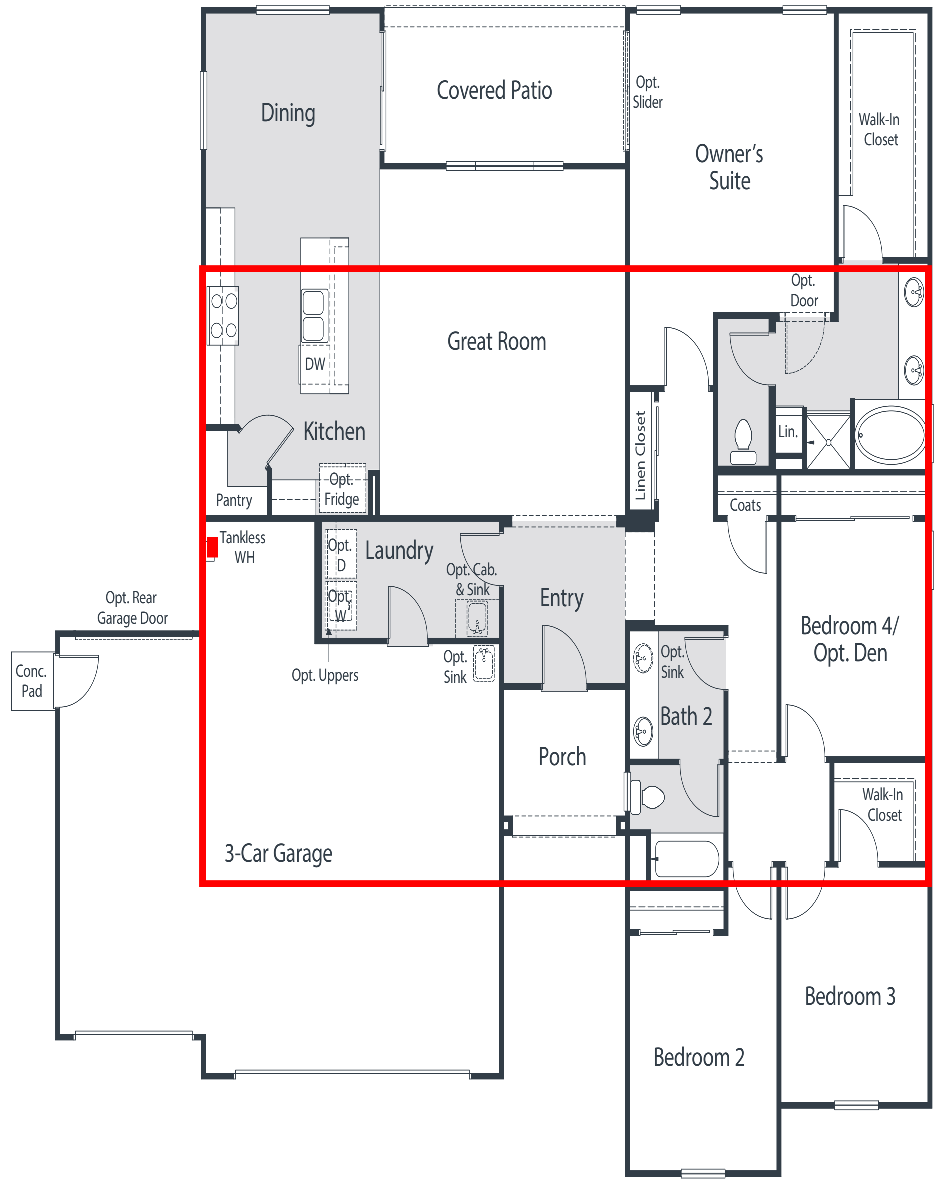
~80%

(2,459 sq ft)



1 Story
4Br/2Ba
2,010 sq ft
Fresno, CA

~81%
(1,628 sq ft)



1 Story

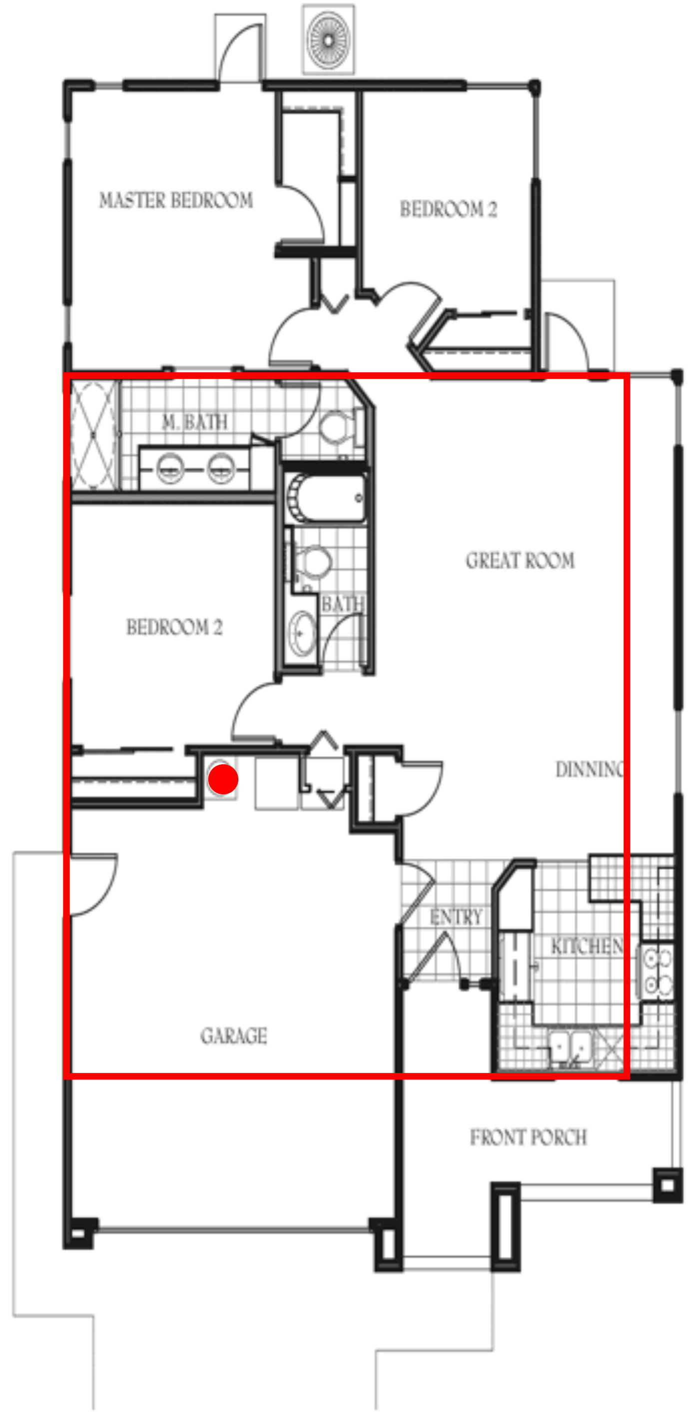
2 Br/2 Ba

1,224 sq ft

Chico, CA

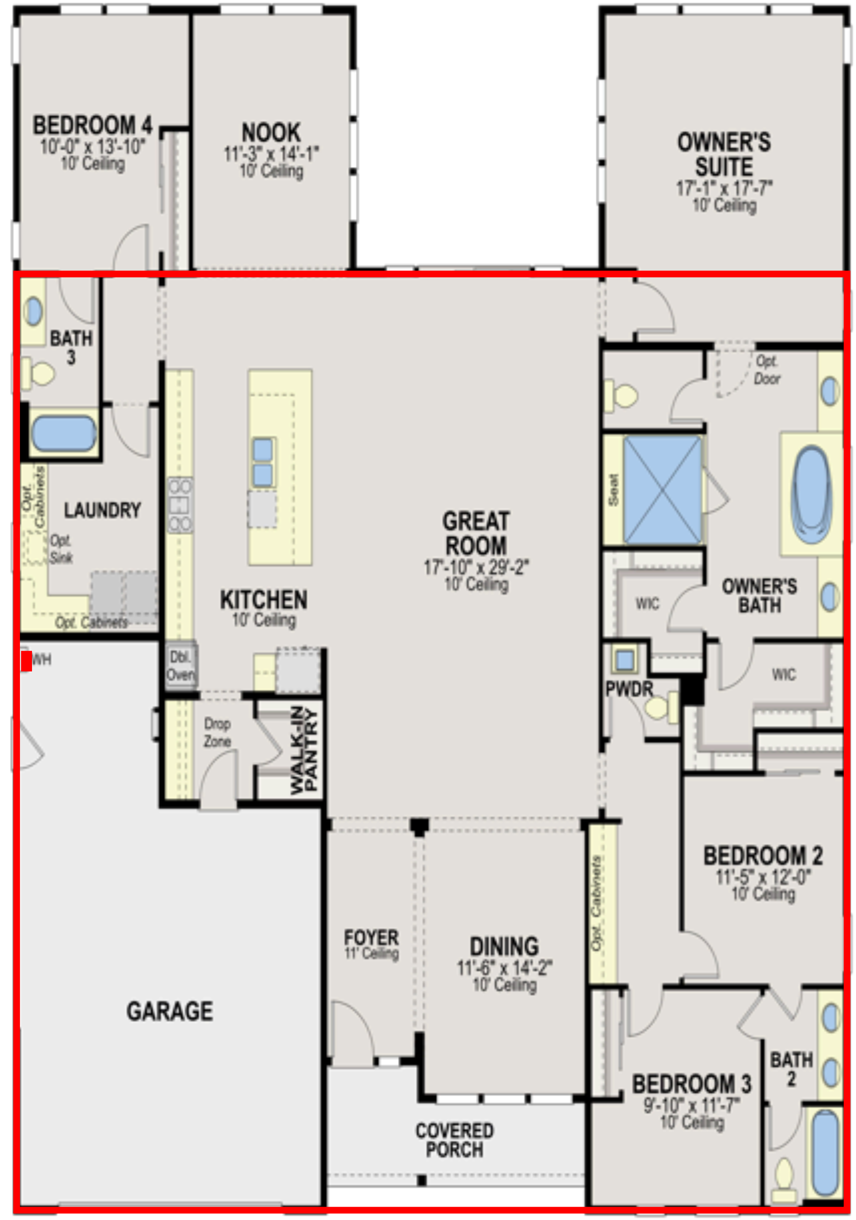
~88%

(1,077 sq ft)



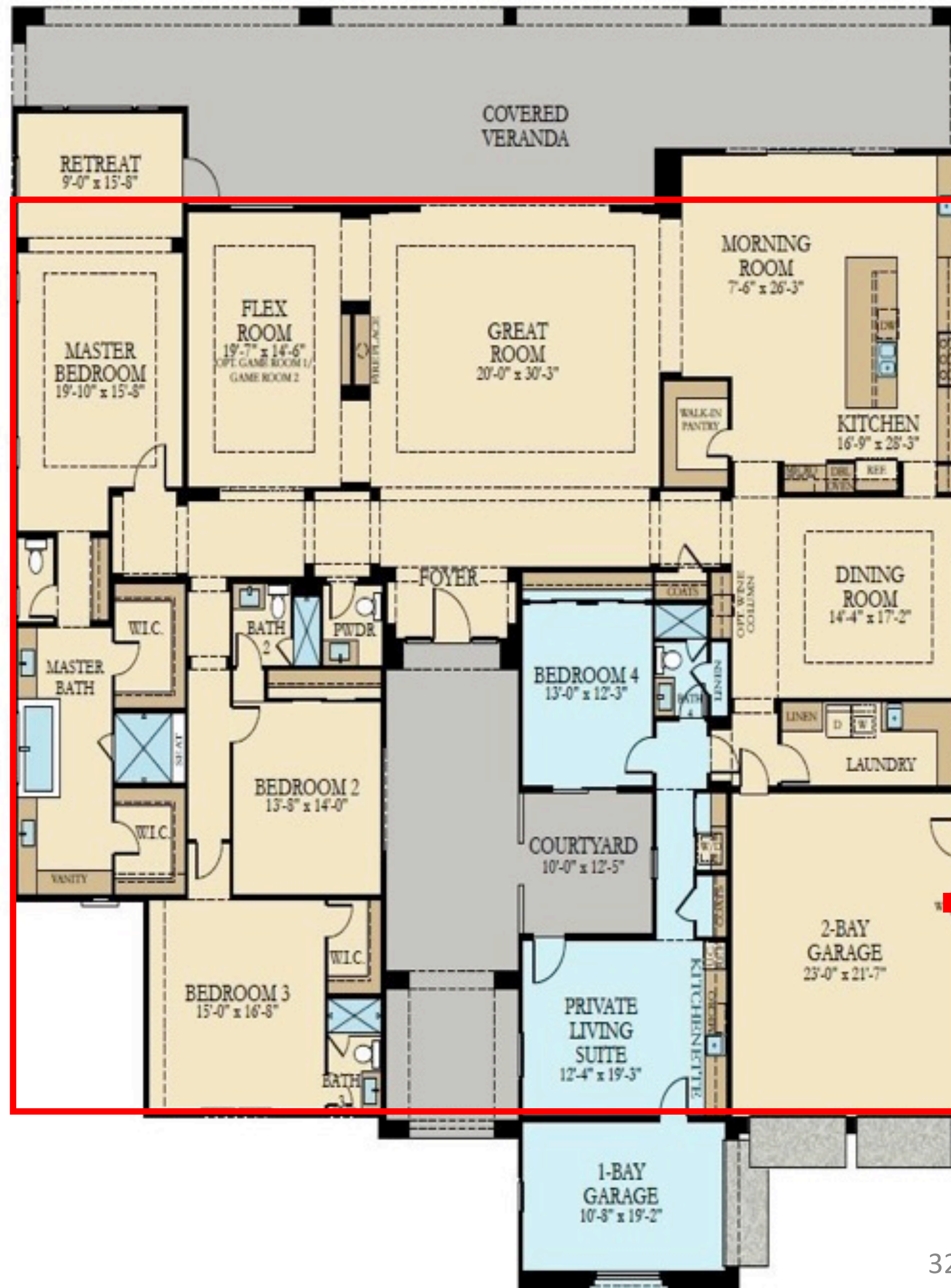
1 Story
4Br/3.5Ba
2,952 sq ft
Morgan Hill, CA

~105%
(3,100 sq ft)



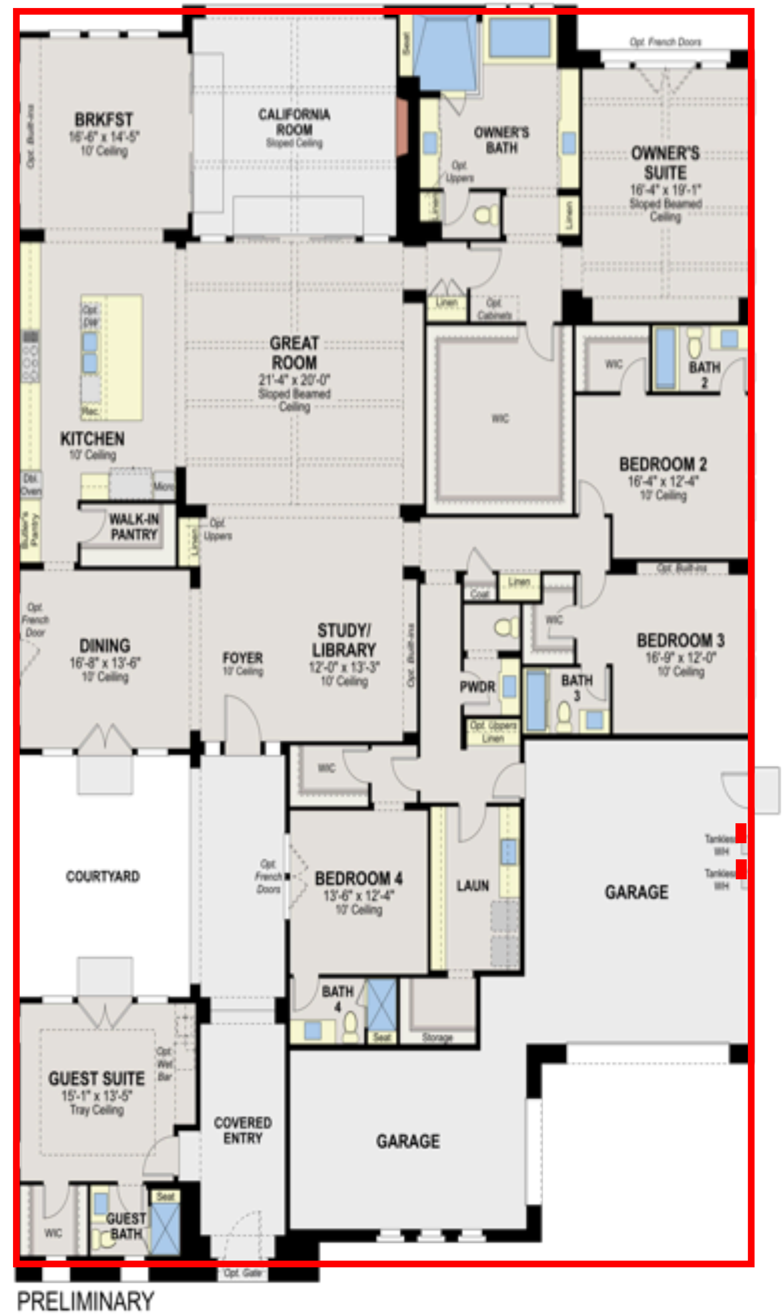
1 Story
4 Br/4.5 Ba
4,820 sq ft
La Quinta, CA

~110%
(5,302 sq ft)



1 Story
5 Br/5.5Ba
4,467 sq ft
San Diego, CA

~155%
(6,924 sq ft)

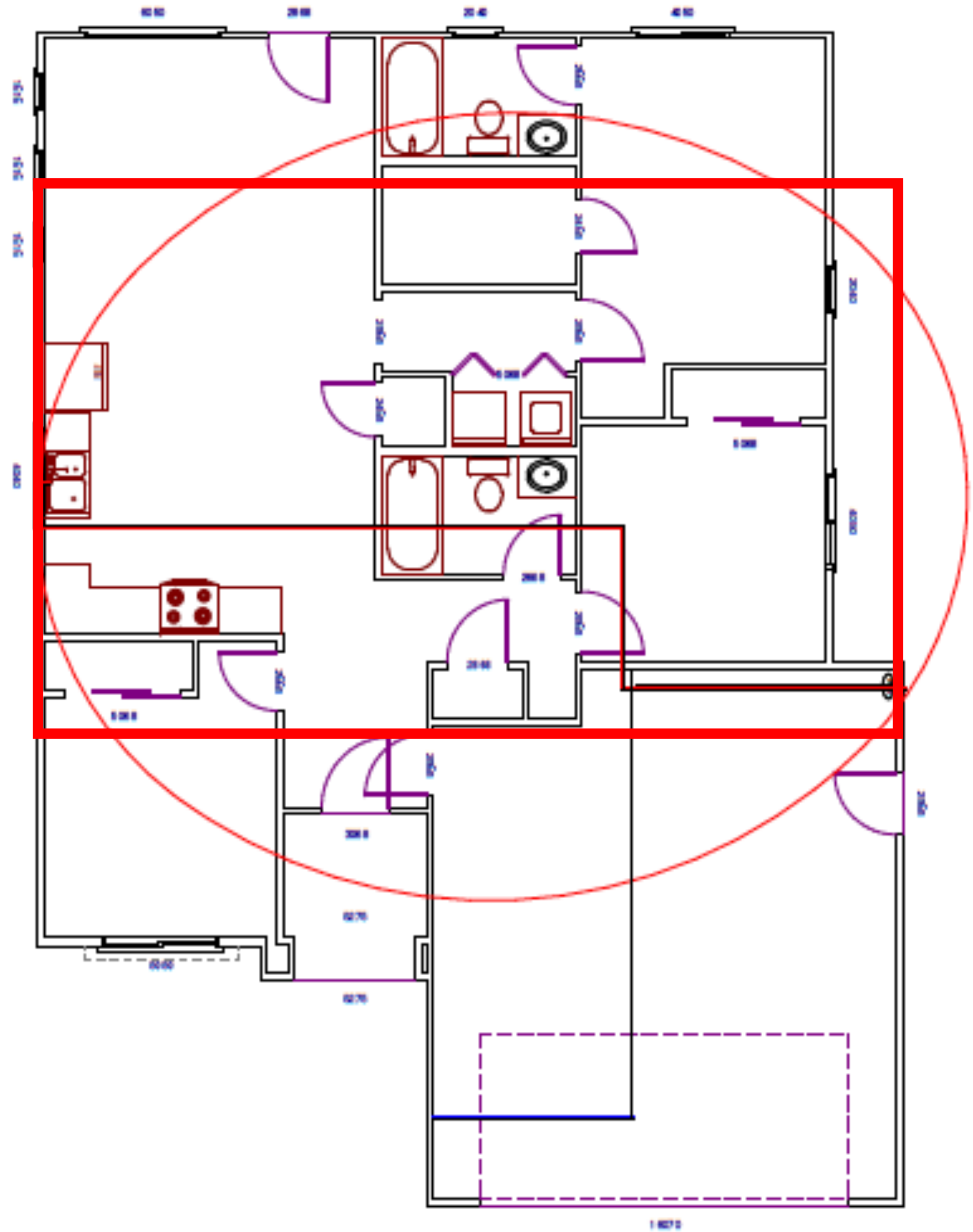


Best 1-Story So Far…

In the beginning:

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

~79%
(1,279 sq ft)



1st iteration v1:

1 Story

3 Br/2 Ba

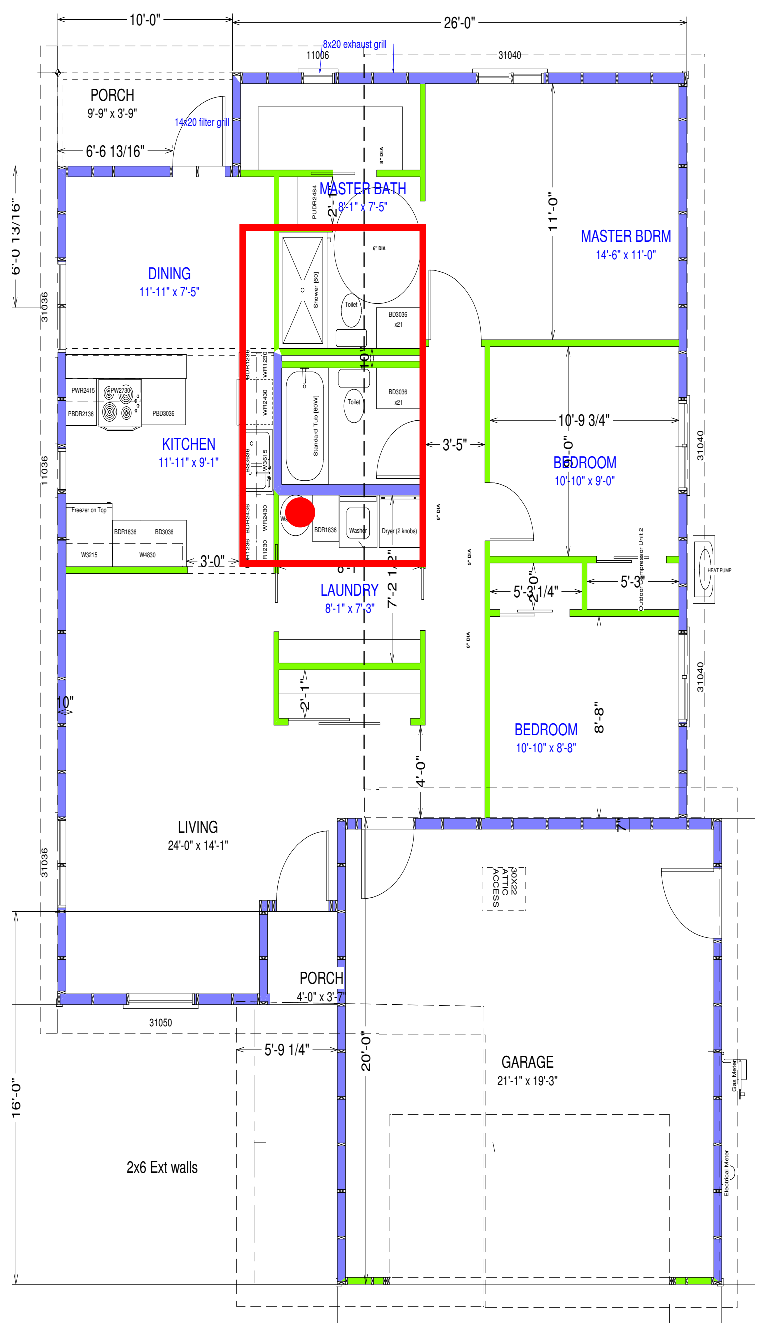
1,223 sq ft

Stockton, CA

~15%

(183 sq ft)

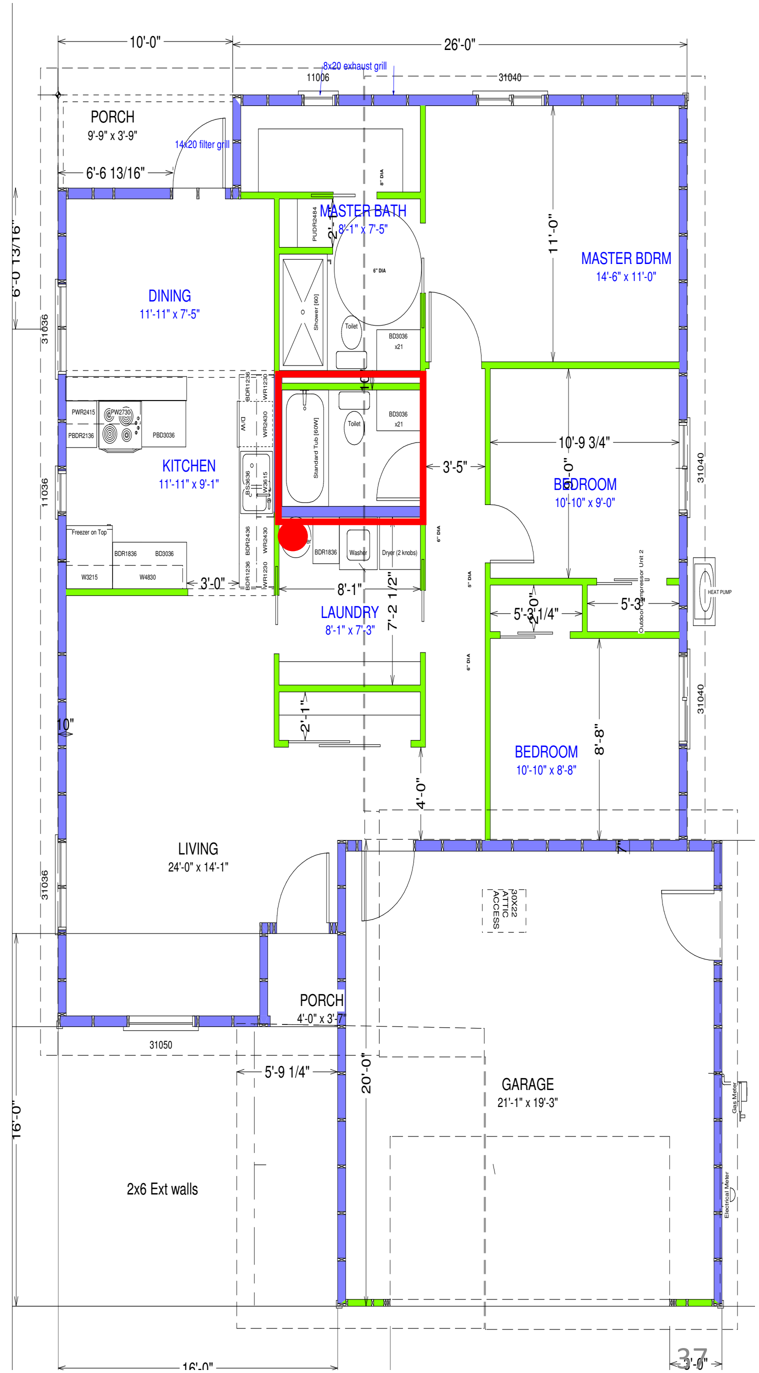
(when bounding the hot water plumbing fixtures and appliances)



1st iteration v2:

1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

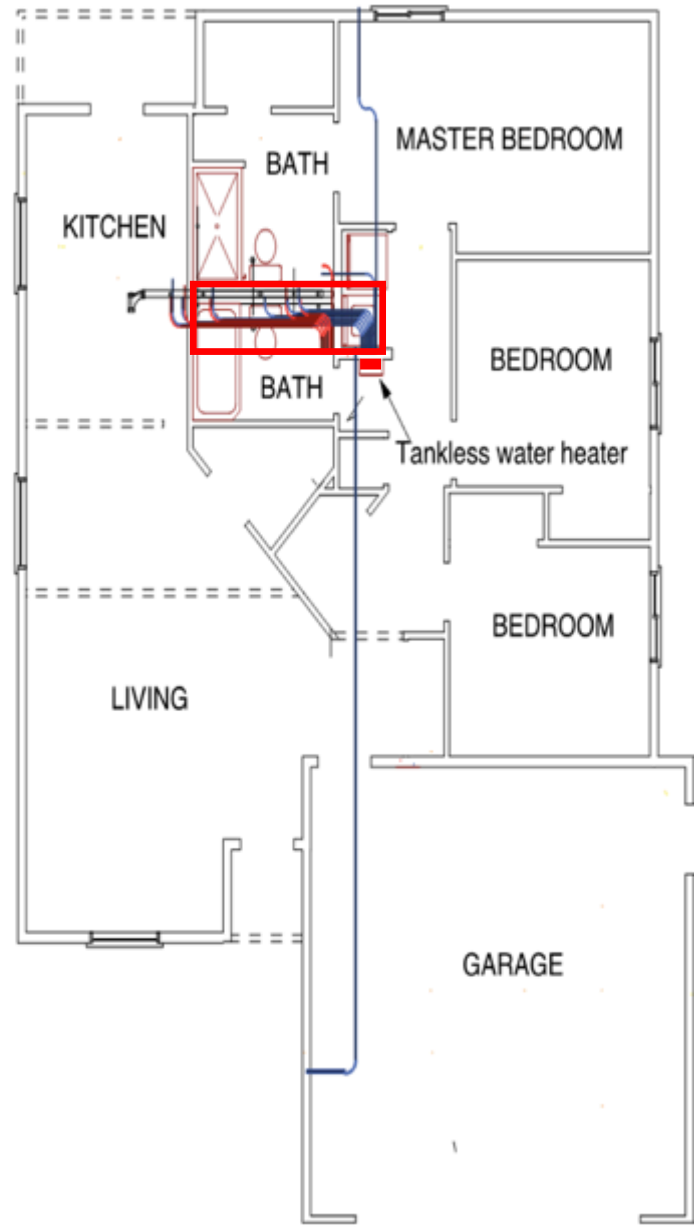
~4%
(49 sq ft)
(when bounding the plumbing walls)



2nd iteration:

1 Story
3 Br/2 Ba
1,223 sq ft
Stockton, CA

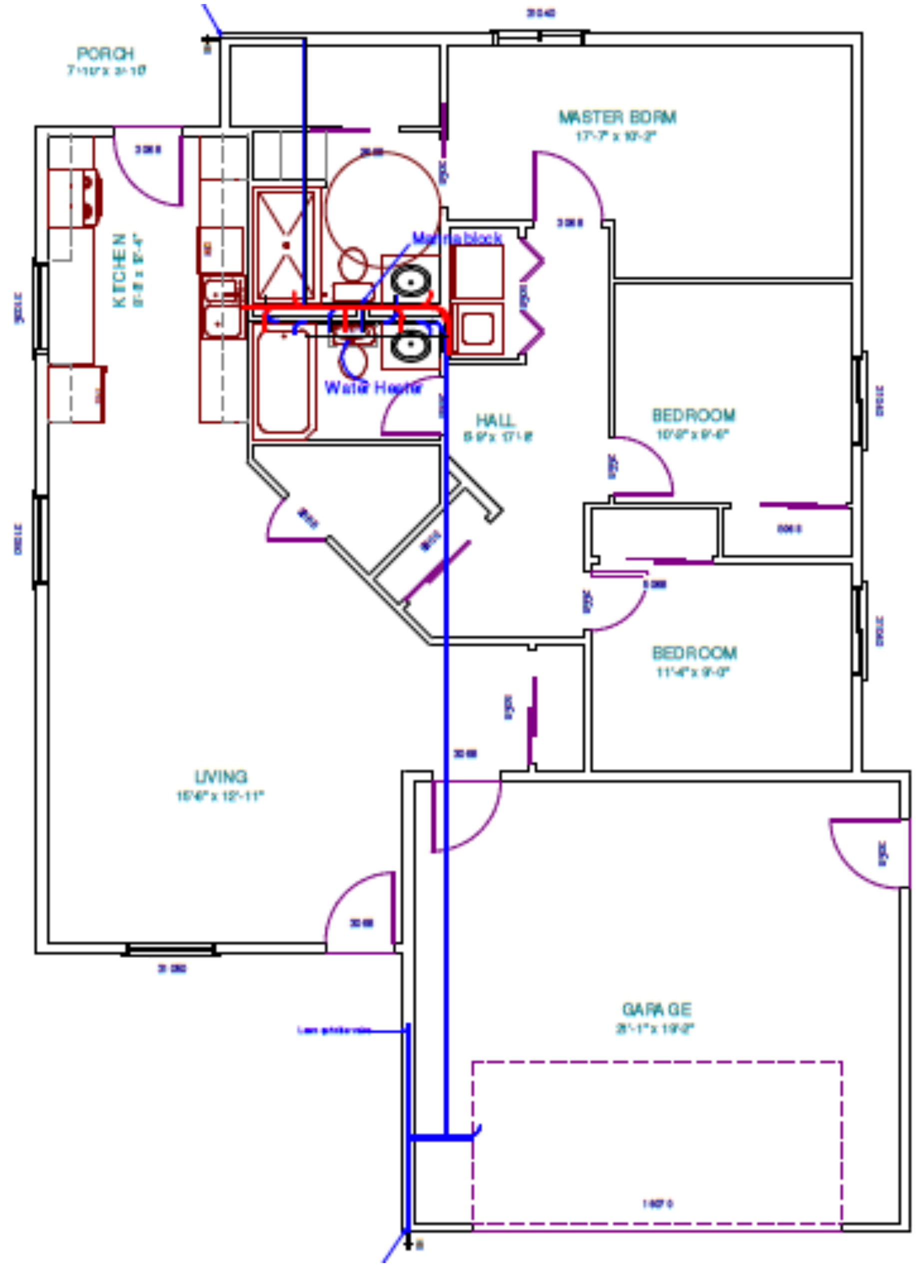
~2.5%
(30 sq ft)
(when bounding the plumbing walls)



3rd iteration:

1 Story
3 Br/2 Ba
1,245 sq ft
Stockton, CA

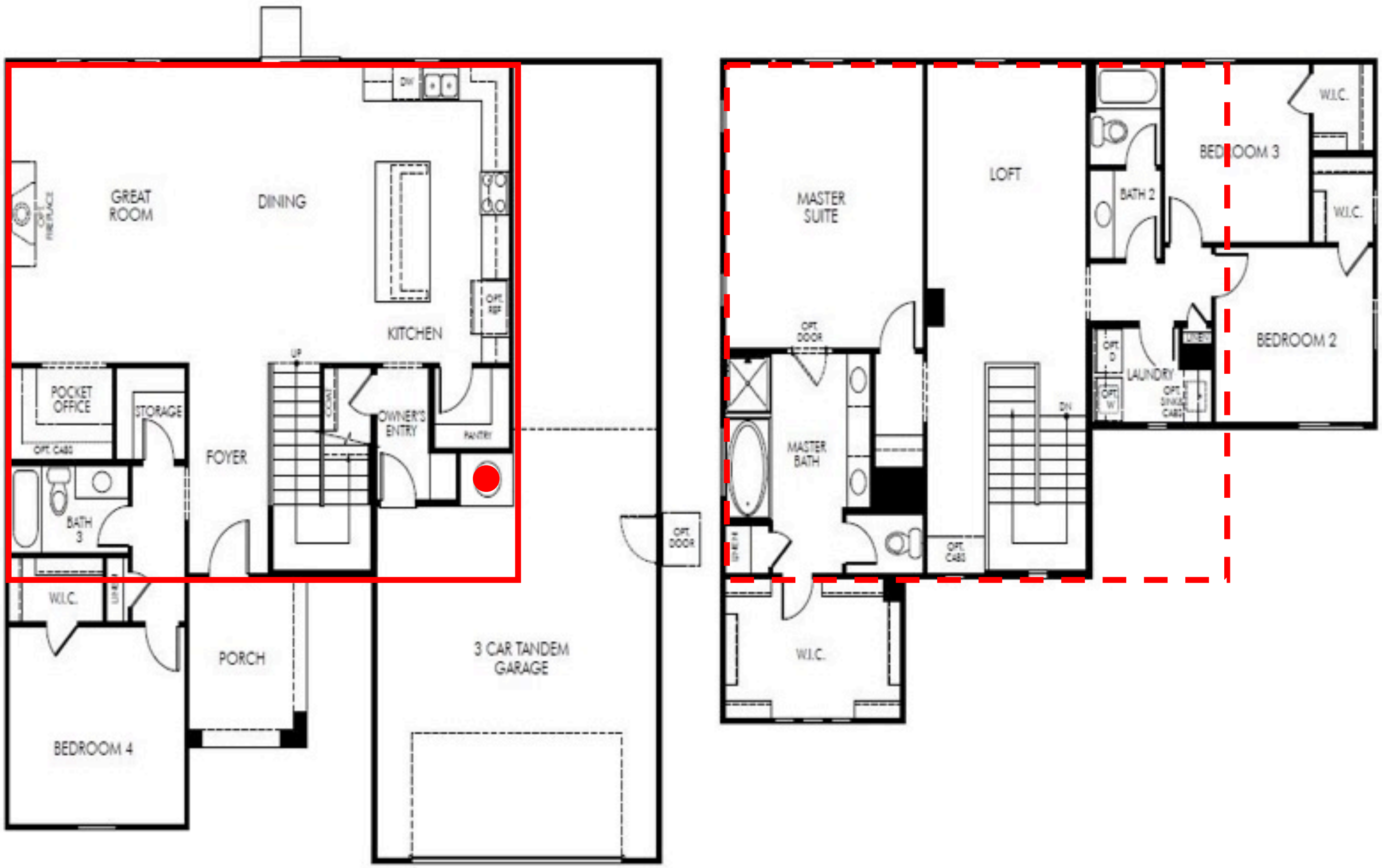
~0.8%
(< 10 sq ft)
(1 short
plumbing wall)



2-Story Floor Plans

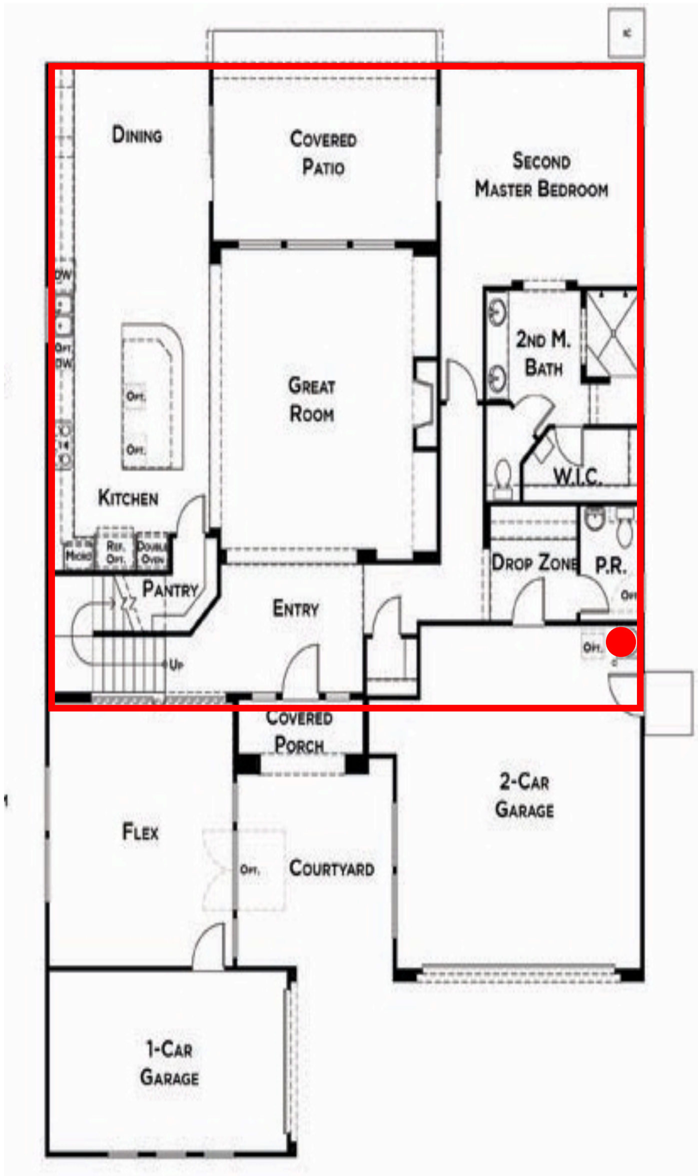
The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

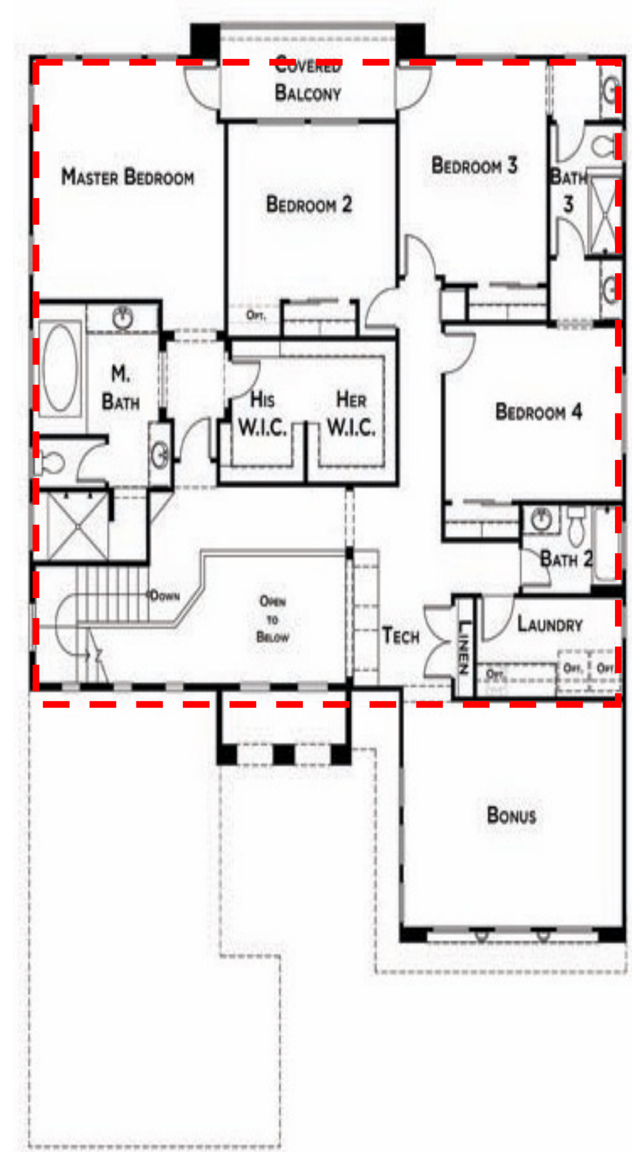
2 Story, 4 Br/3 Ba, 2,625 sq ft
Bakersfield, CA ~37% (962 sq ft)



2 Story, 3 Br/2.5 Ba, 1,837 sq ft
Salinas, CA ~48% (882 sq ft)

2 Story, 5 Br/4.5 Ba, 4,003 sq ft
Rocklin, CA ~51% (2,042 sq ft)

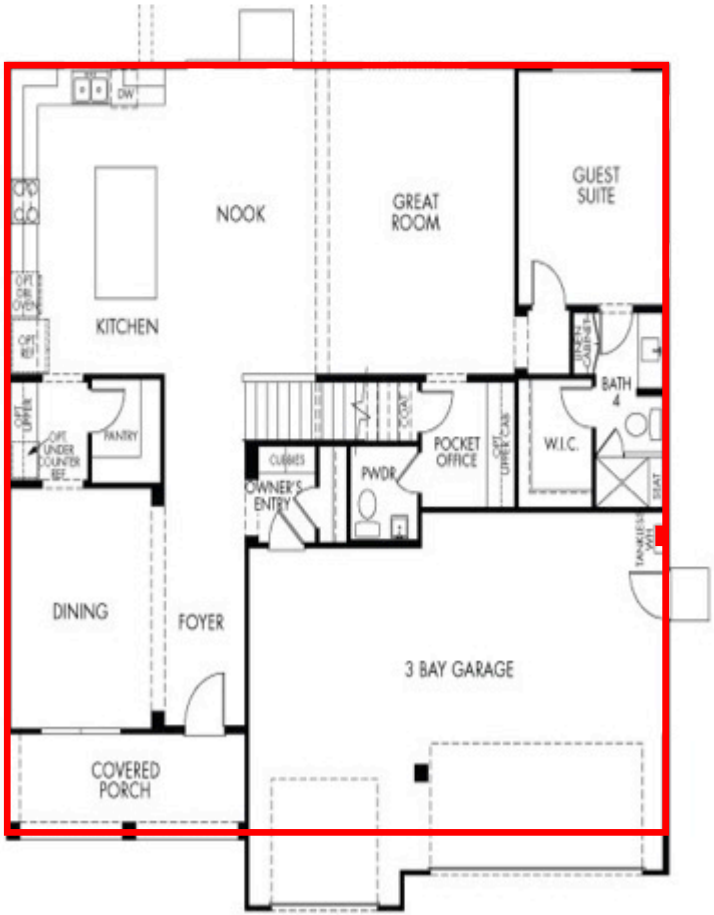


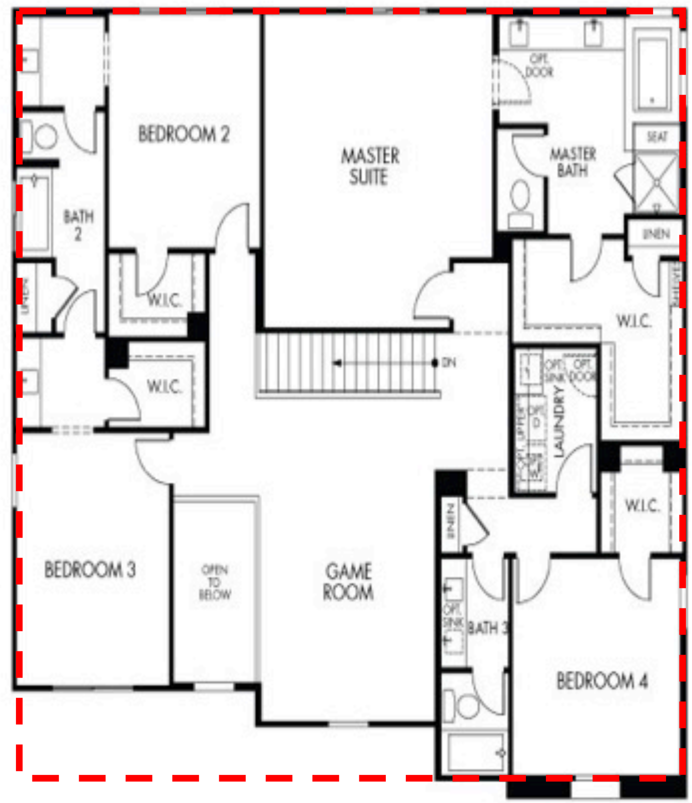


2 Story, 5 Br/5.5 Ba, 3,983 sq ft
Irvine, CA ~58% (2,310 sq ft)

2 Story, 5 Br/ 4.5 Ba, 4,301 sq ft
Rancho Cucamonga, CA ~62% (2,667 sq ft)

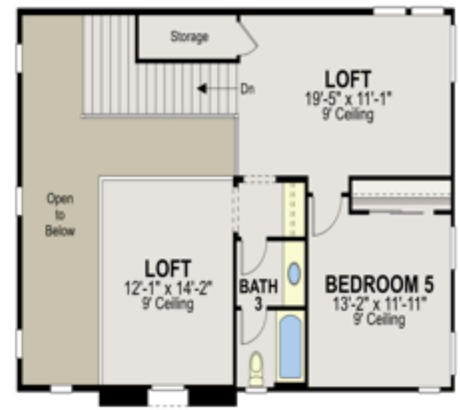
2 Story, 5 BR/4.5 Ba, 3,493 sq ft
Manteca, CA ~63% (3,493 sq ft)





2 Story
4 Br/3.5 Ba
3,853 sq ft
Lincoln, CA

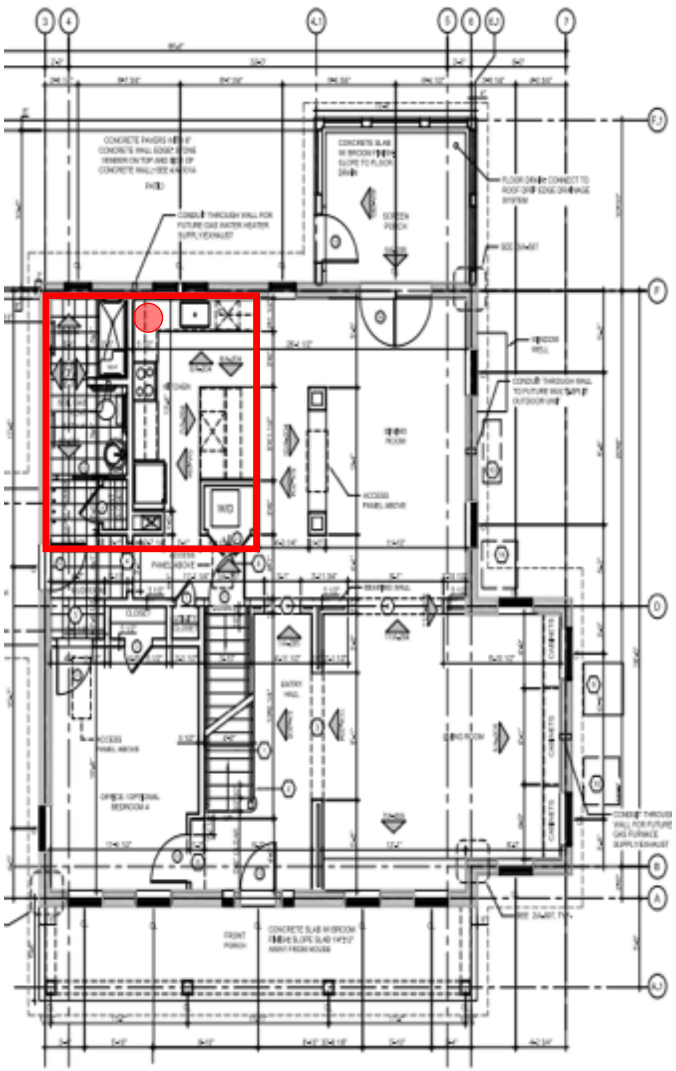
~71 %
(2,026 sq ft)

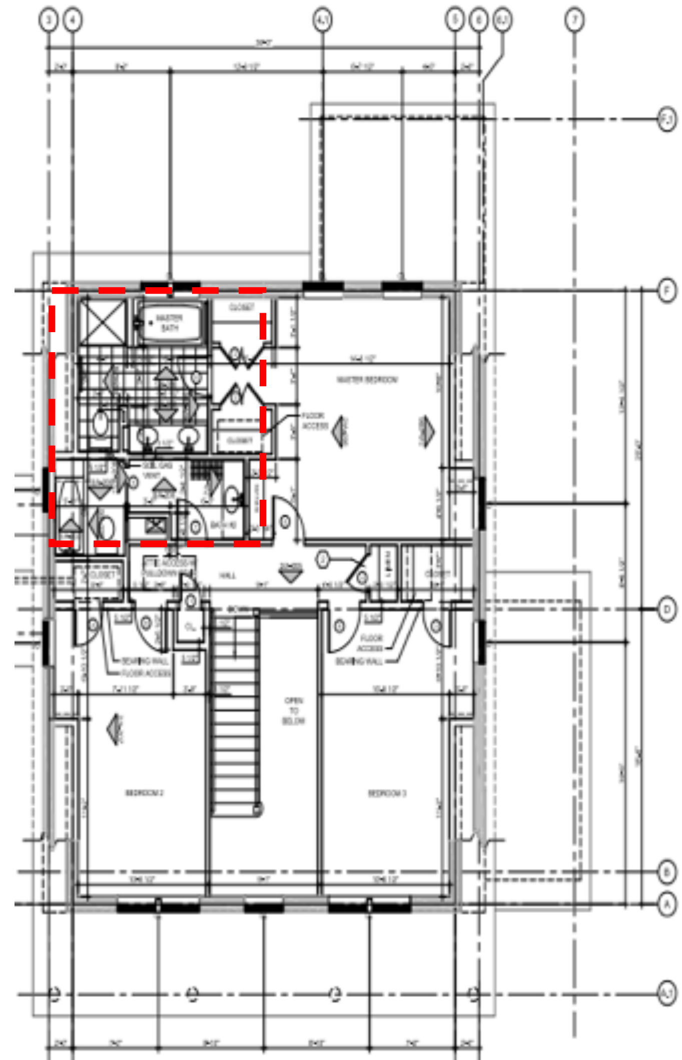


2 Story, 5 Br/5.5 Ba, 4,269 sq ft
La Verne, CA ~72% (3,074 sq ft)

Best 2-Story So Far…

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



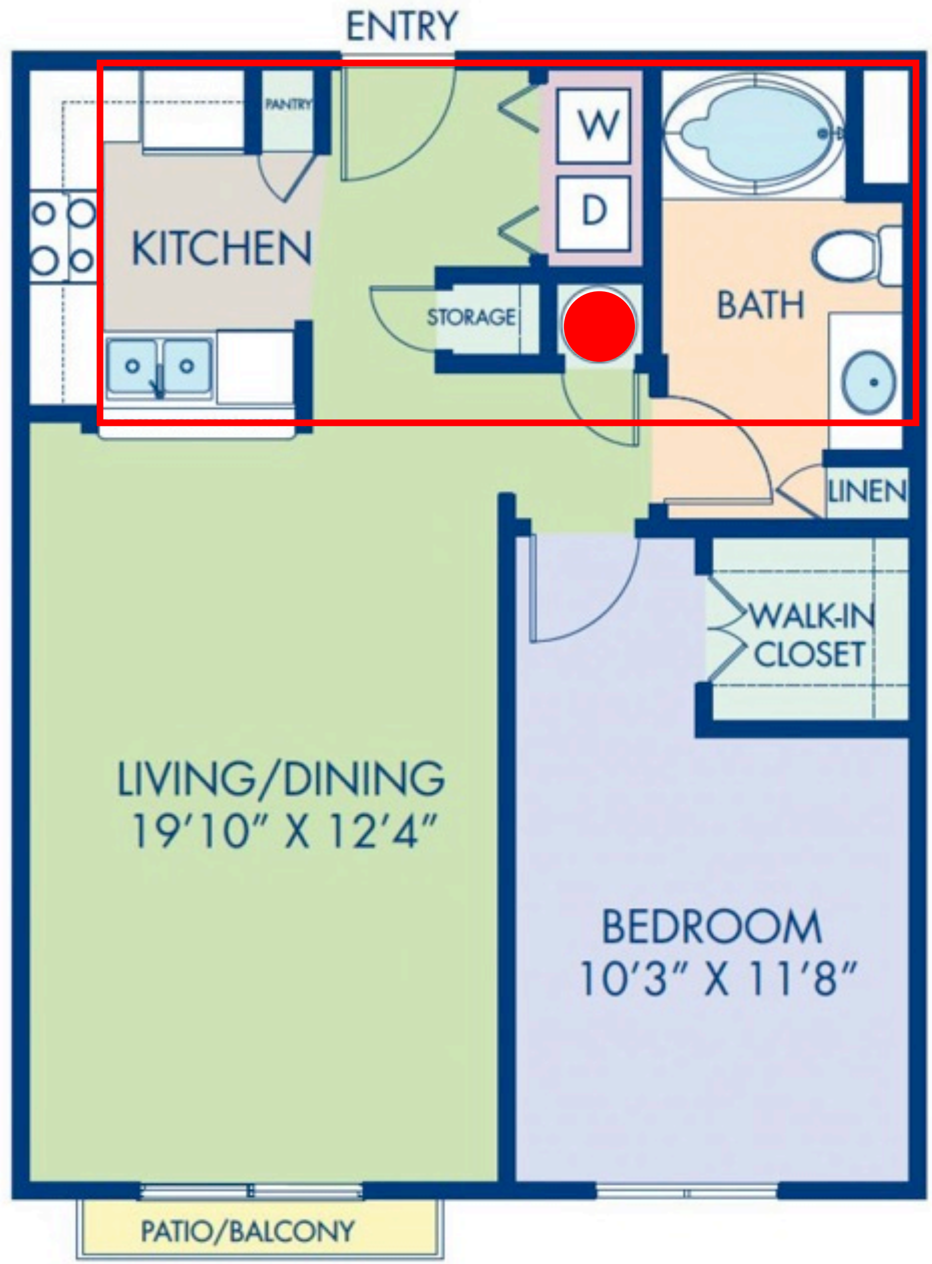


Multi-Family Unit Floor Plans

The wet room rectangle has the same area as the hot water system rectangle for all of the 2-story homes in this sample.

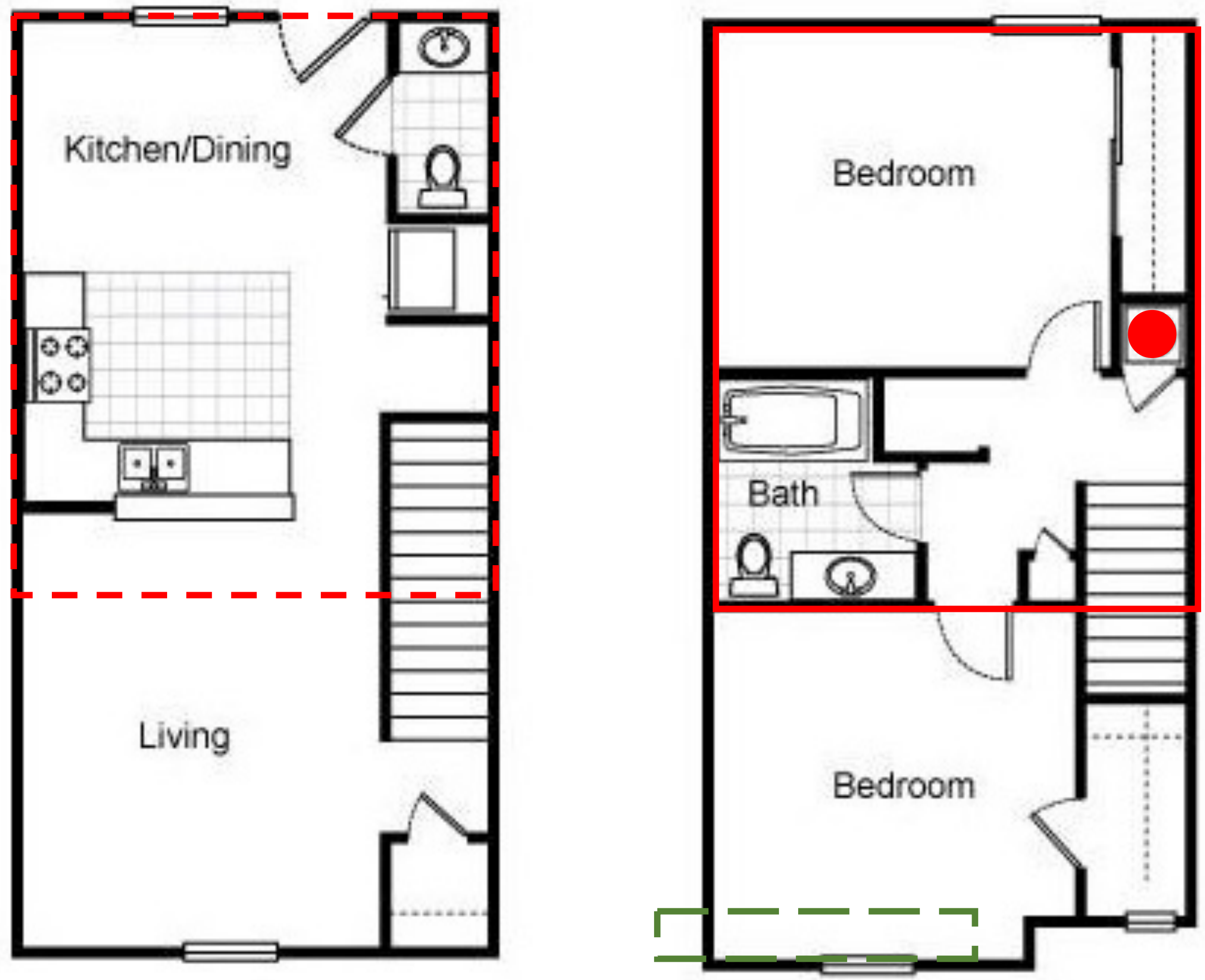
1 Story
1Br/1Ba
720 sq ft
Chula Vista, CA

~29%
(209 sq ft)



2 Story
2Br/2Ba
908 sq ft
Richmond, CA

~33%
(300 sq ft)



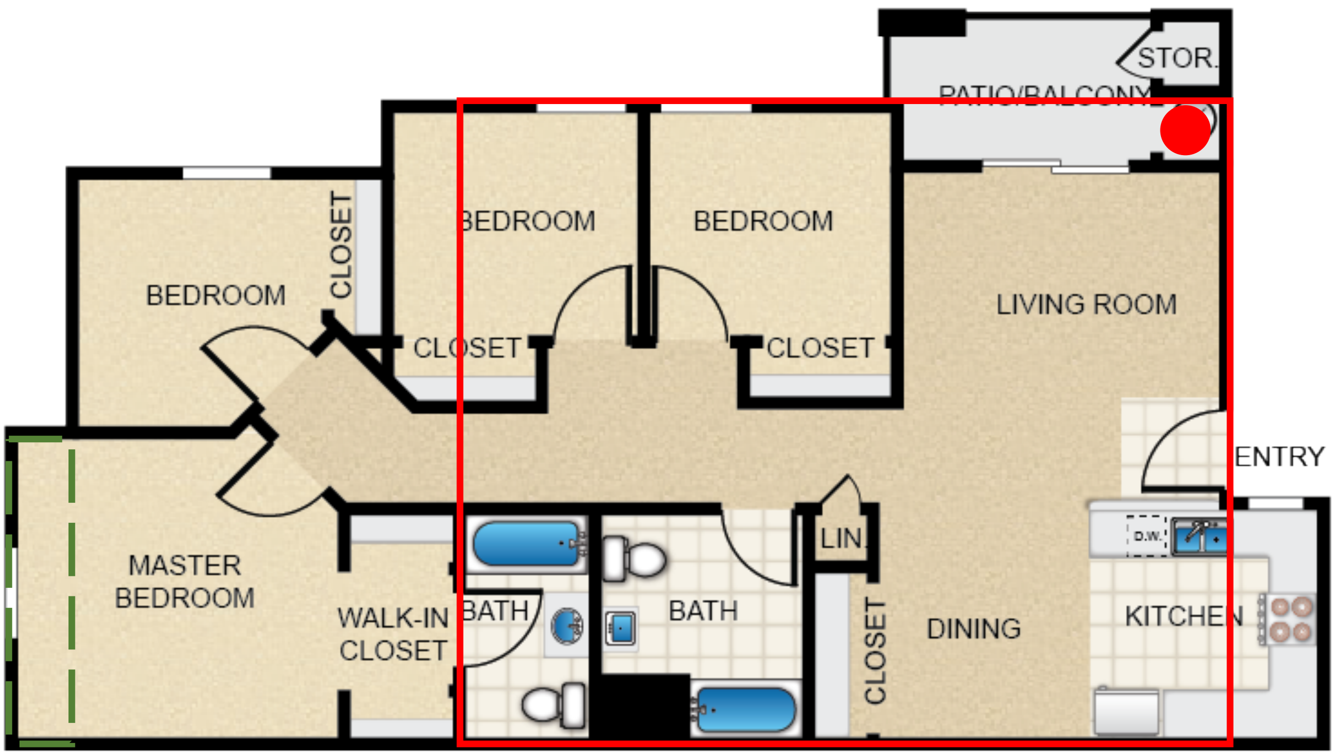
2 Story, 2 Br/2.5 Ba, 1275 sq ft
Ventura, CA ~34% (434 sq ft)

1 Story
1Br/1Ba
665 sq ft
Newark, CA

~50%
(333 sq ft)

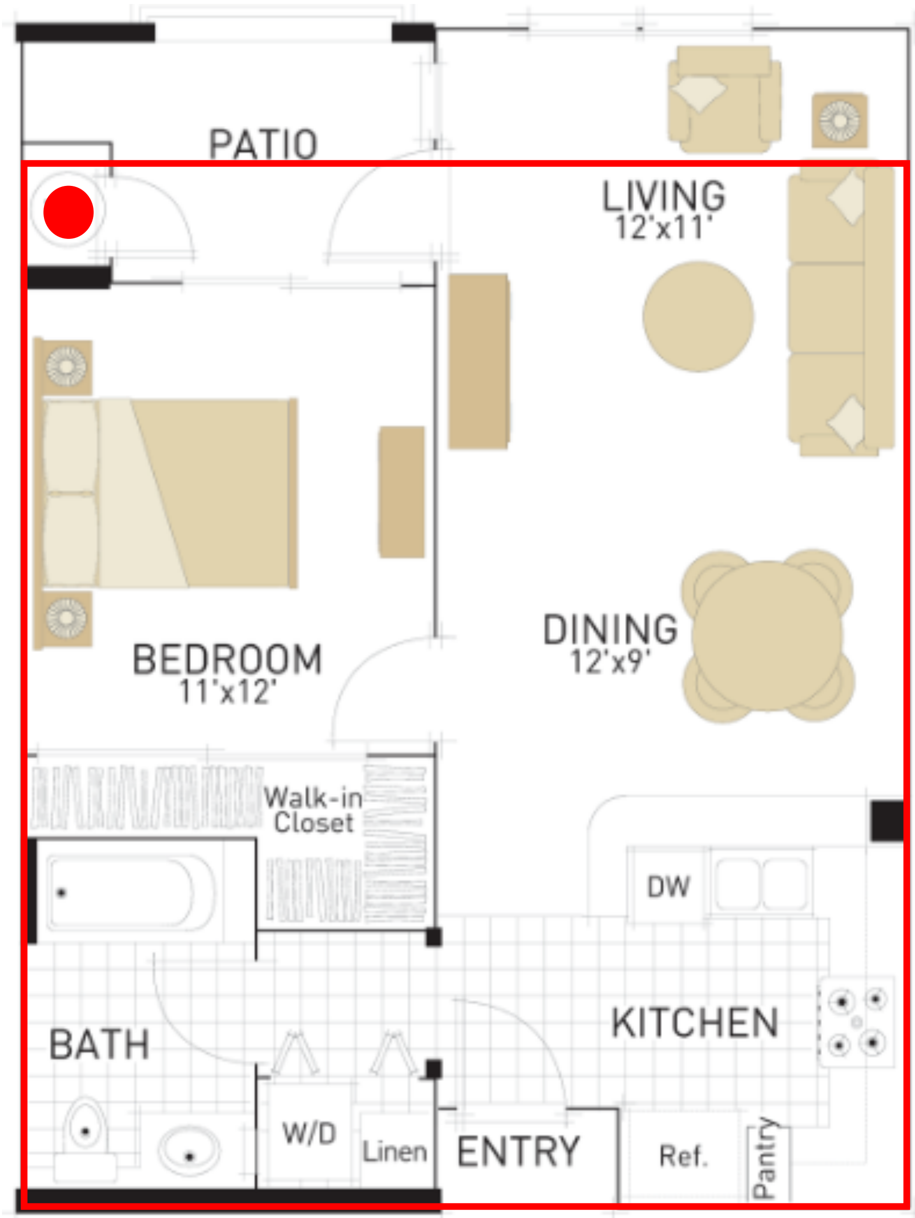
1 Story, 3 Br/2 Ba, 1136 sq ft
Bakersfield, CA ~62% (699 sq ft)

1 Story, 4Br/2Ba, 1217 sq ft
Banning, CA ~67% (815 sq ft)



1 Story
1Br/1Ba
670 sq ft
San Jose, CA

~90%
(603 sq ft)



1 Story

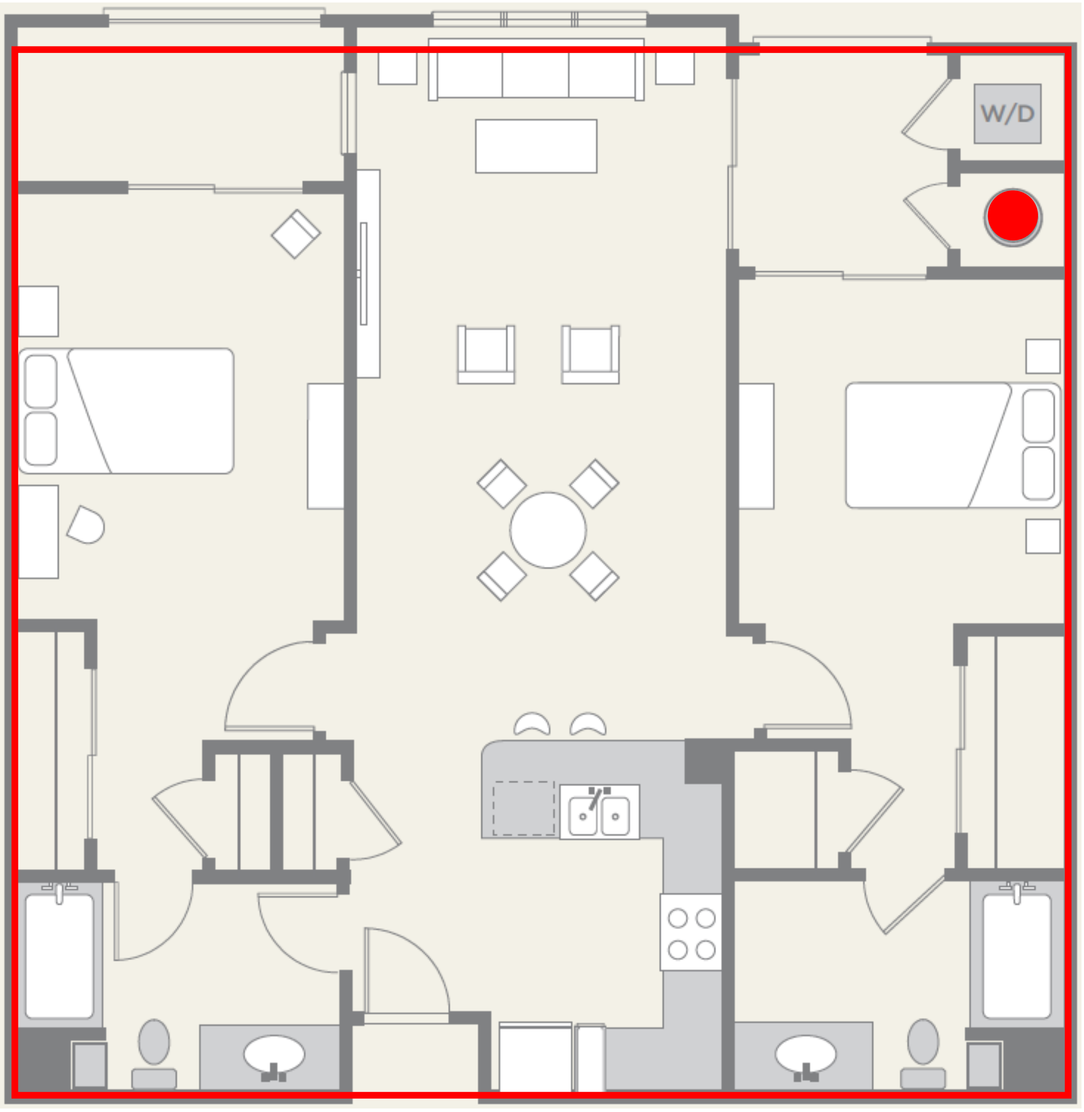
2Br/2Ba

1232 sq ft

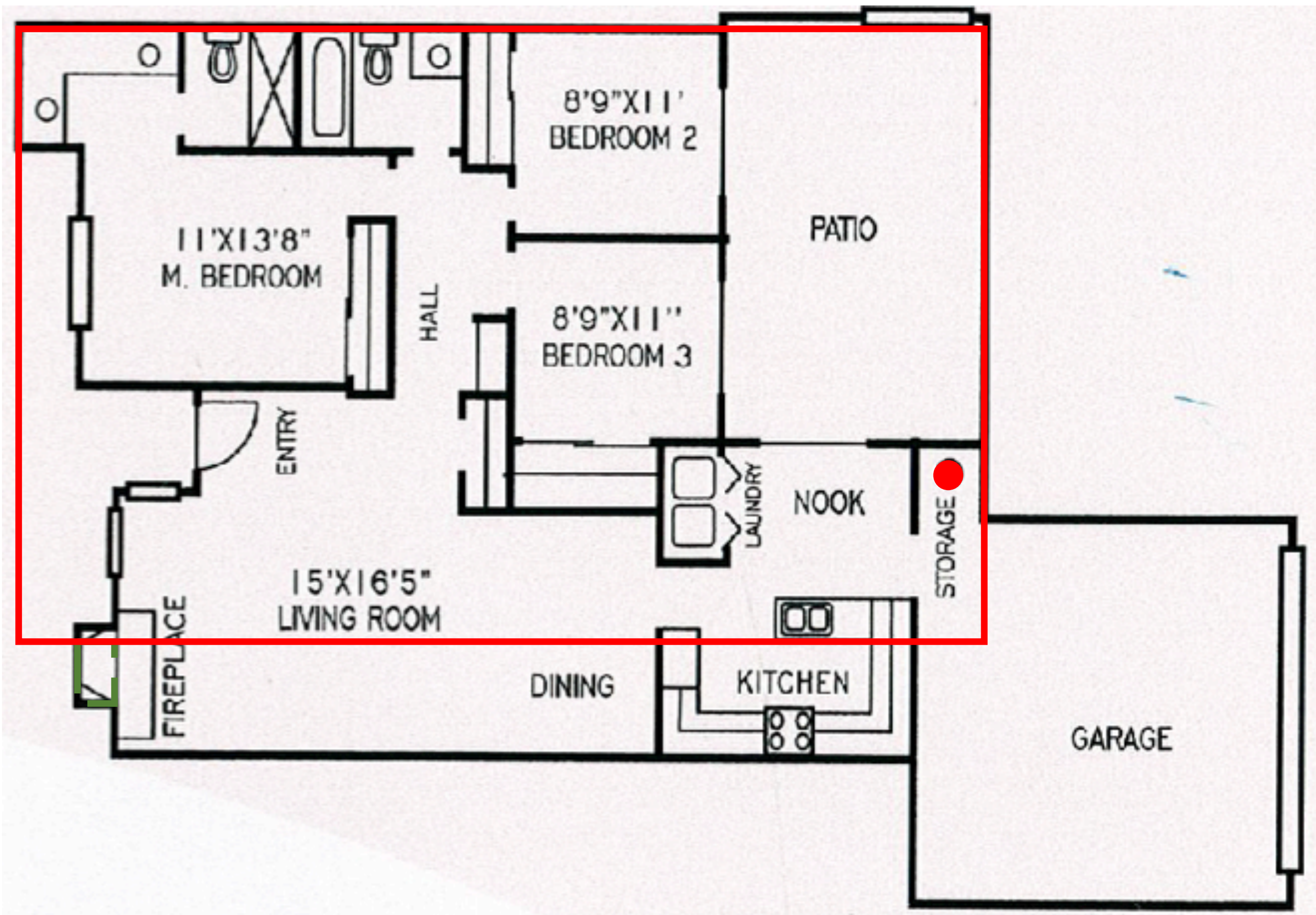
San Diego, CA

~99%

(1220 sq ft)



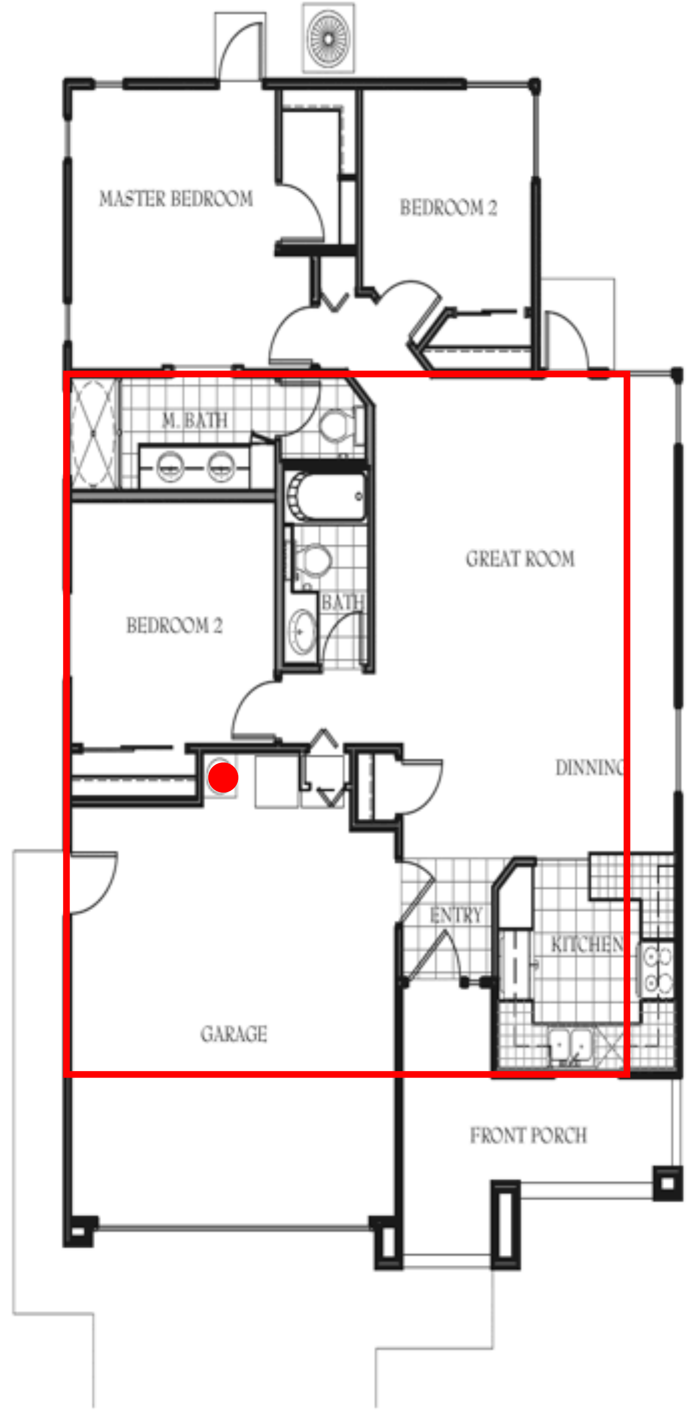
1 Story, 3Br/2Ba, 1360 sq ft
Fresno, CA ~115% (1564 sq ft)



Locating water heaters nearer to the fixtures…

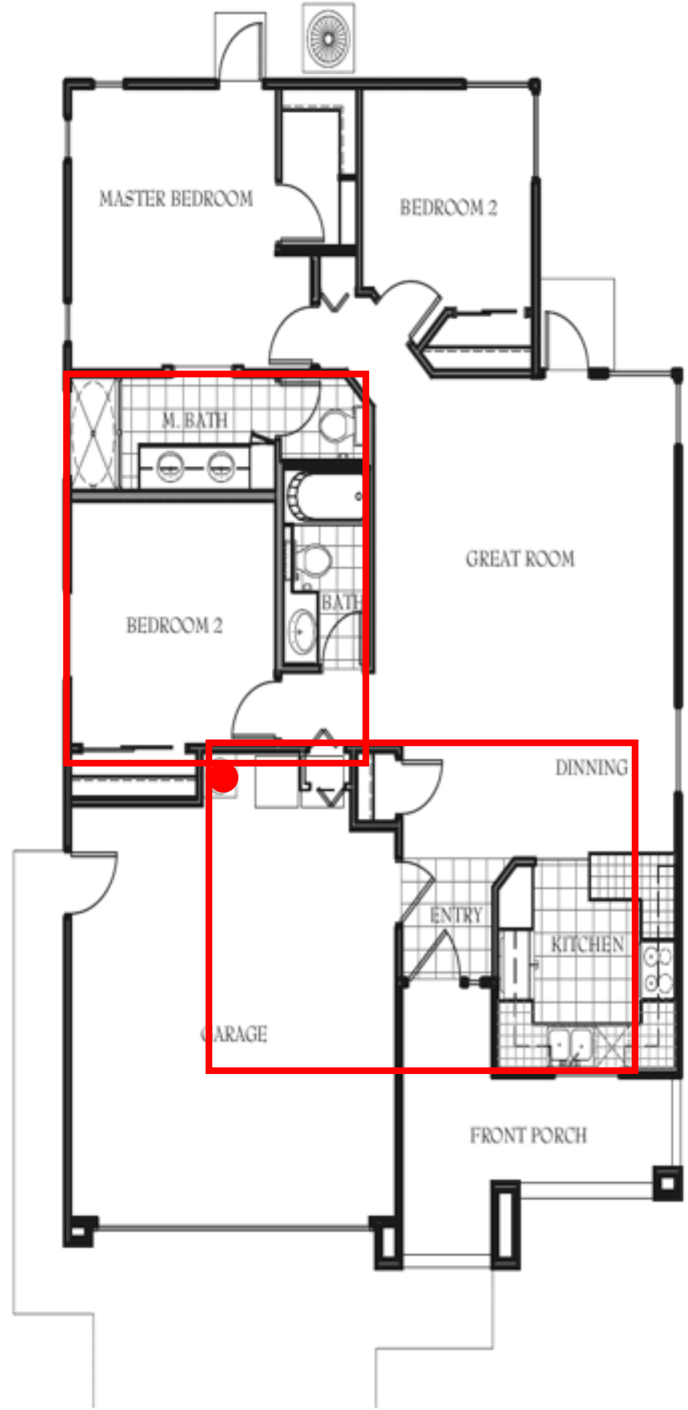
1 Story
2 Br/2 Ba
1,224 sq ft
Chico, CA

~88%
(1,077 sq ft)



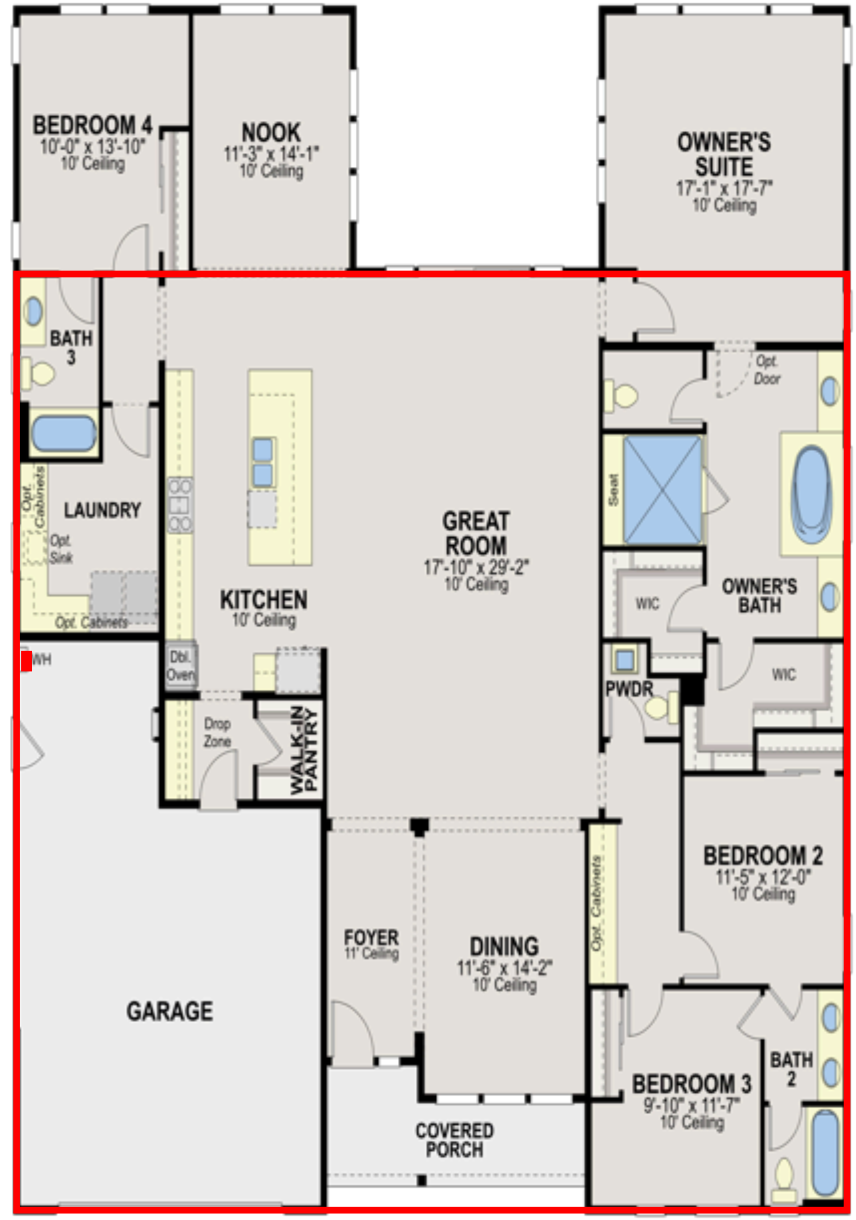
1 Story
2 Br/2 Ba
1,224 sq ft
Chico, CA

~58%
(710 sq ft)



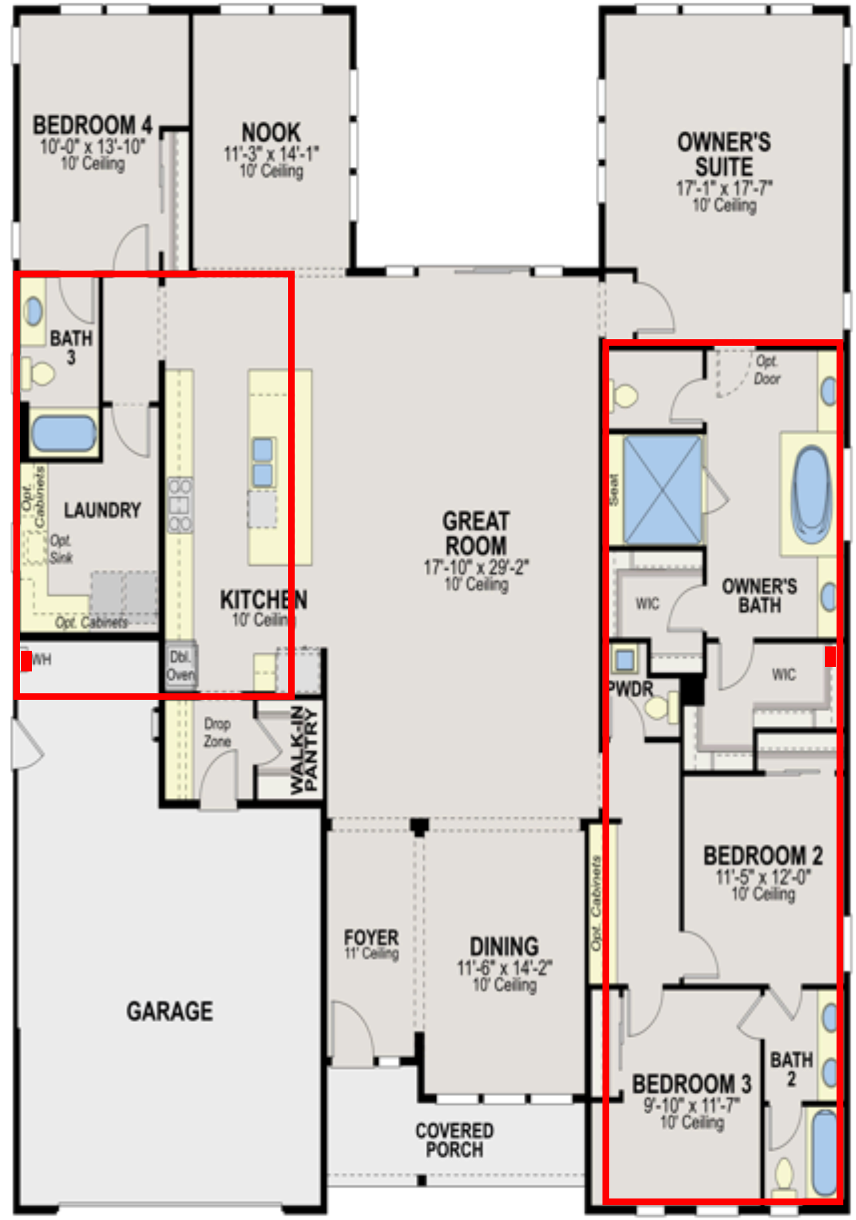
1 Story
4Br/3.5Ba
2,952 sq ft
Morgan Hill, CA

~105%
(3,100 sq ft)



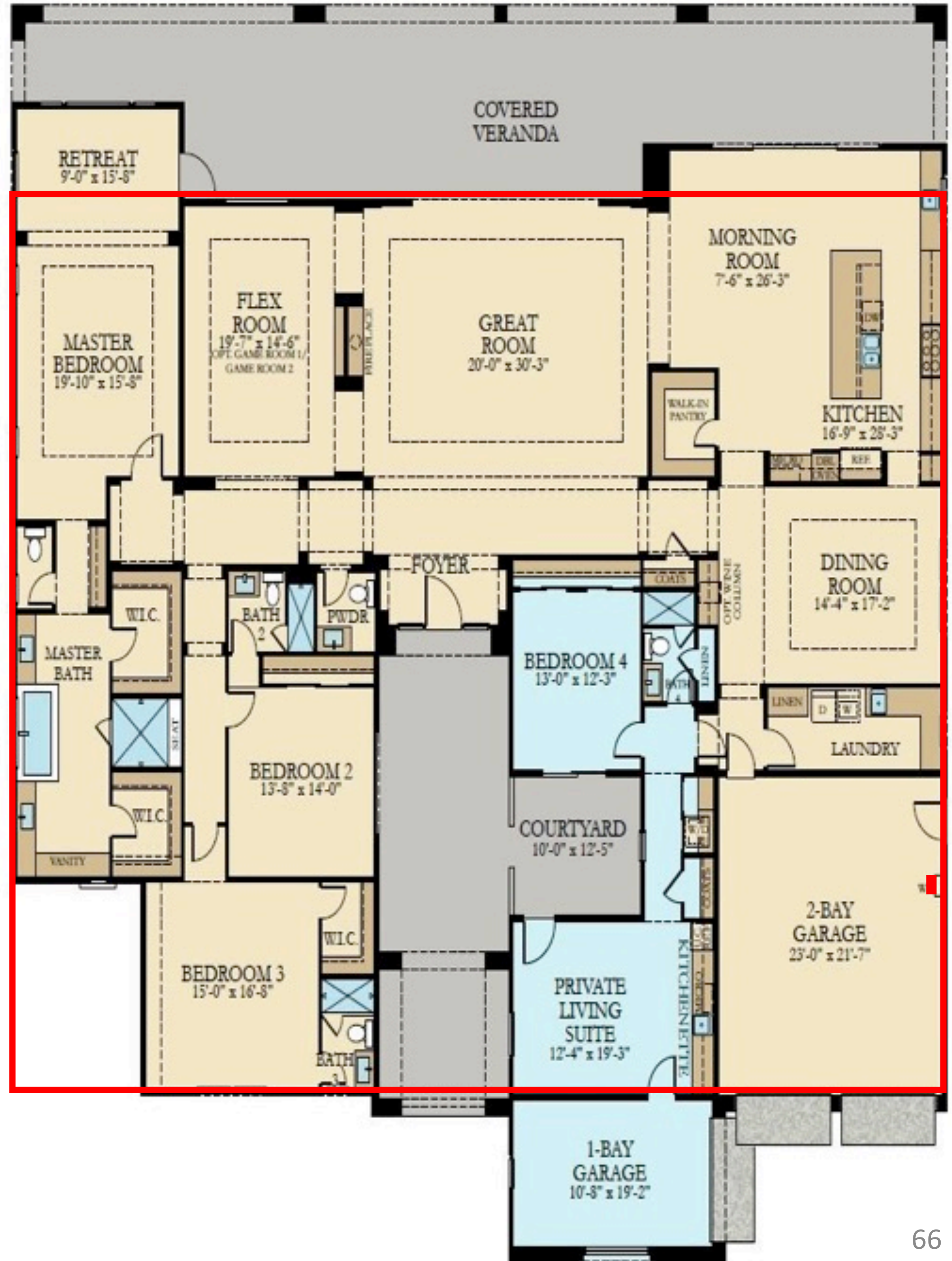
1 Story
4Br/3.5Ba
2,952 sq ft
Morgan Hill, CA

~43%
(1,269 sq ft)



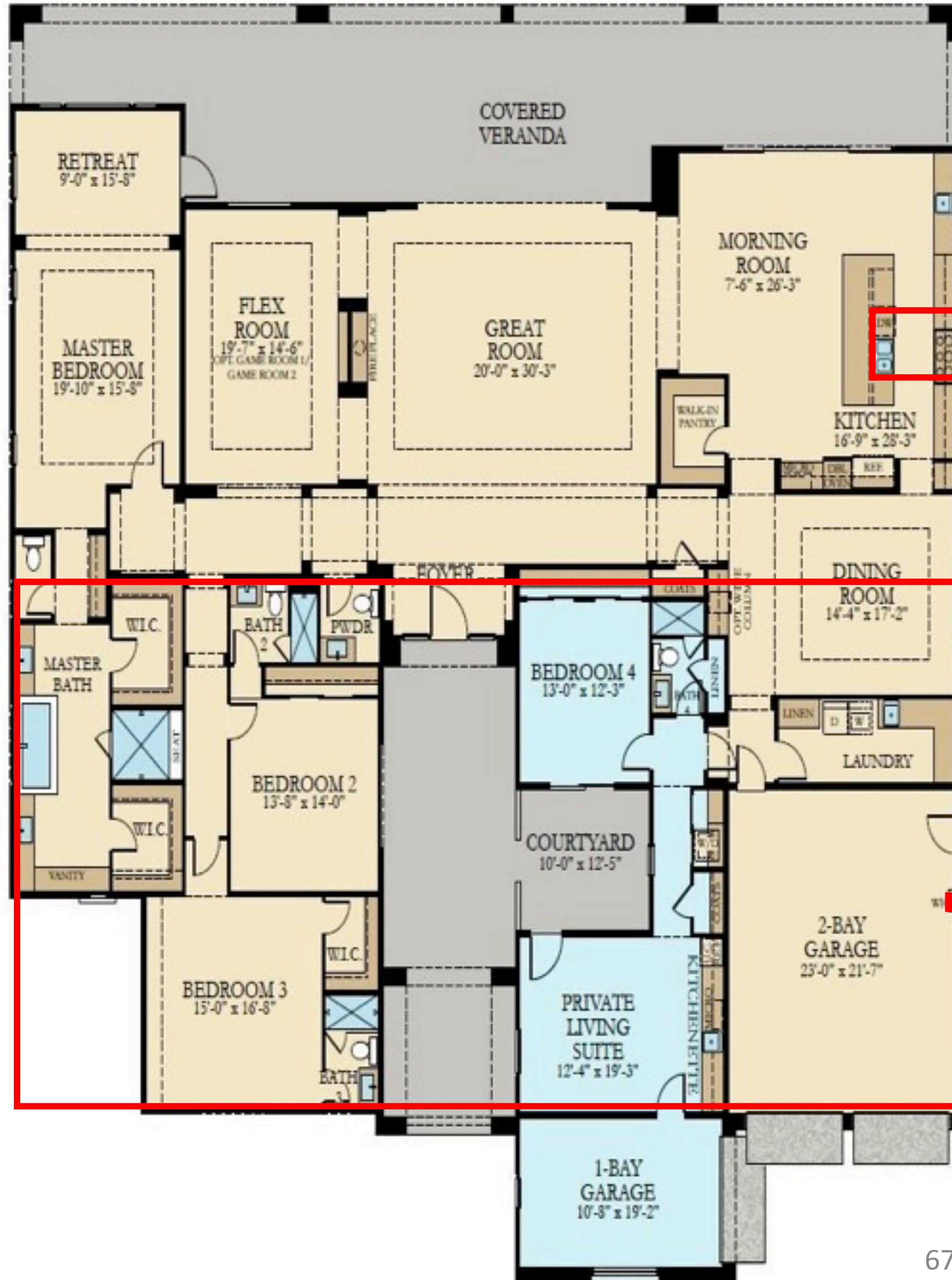
1 Story
4 Br/4.5 Ba
4,820 sq ft
La Quinta, CA

~110%
(5,302 sq ft)



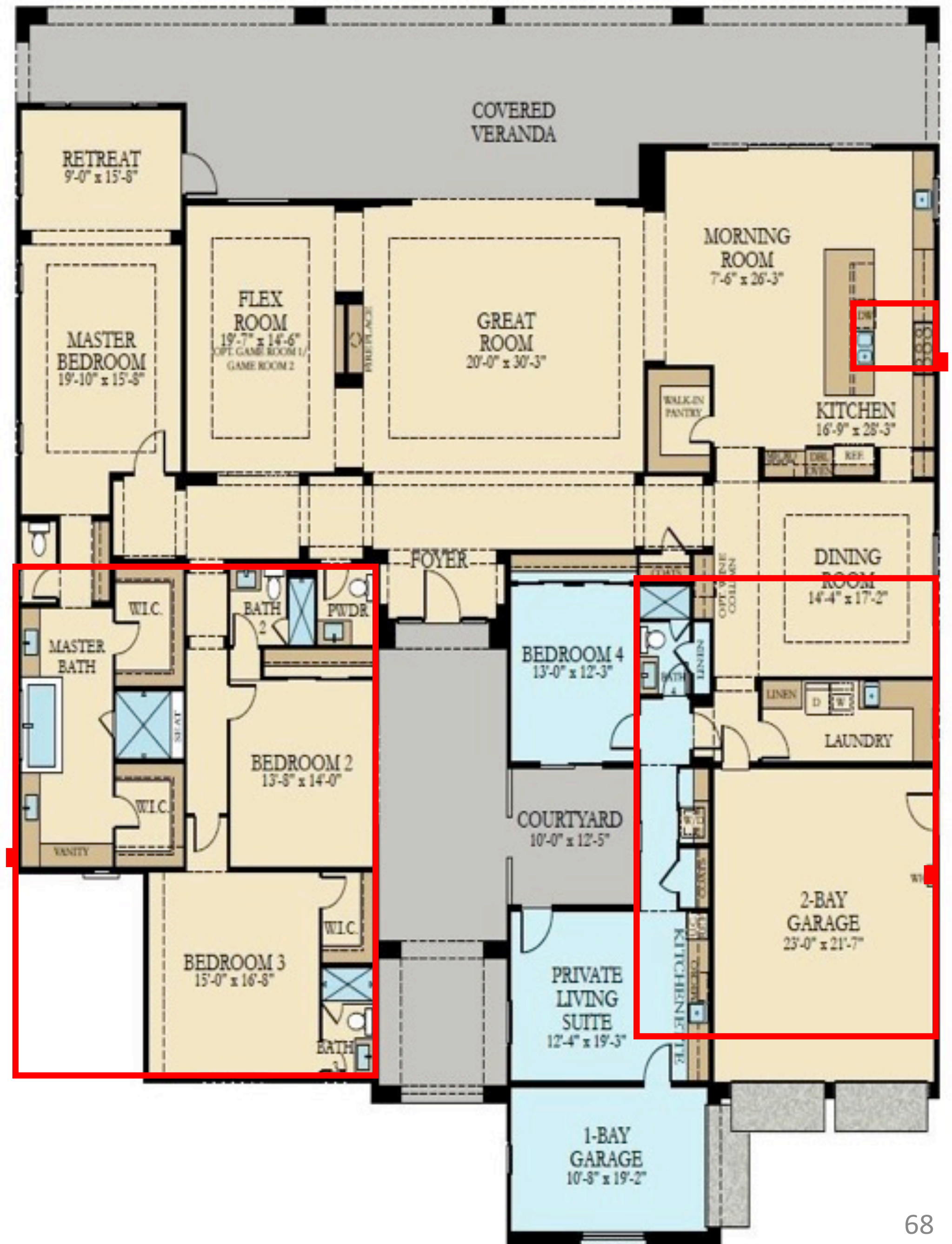
1 Story
4 Br/4.5 Ba
4,820 sq ft
La Quinta, CA

~64%
(3,085 sq ft)



1 Story
4 Br/4.5 Ba
4,820 sq ft
La Quinta, CA

~44%
(2,120 sq ft)



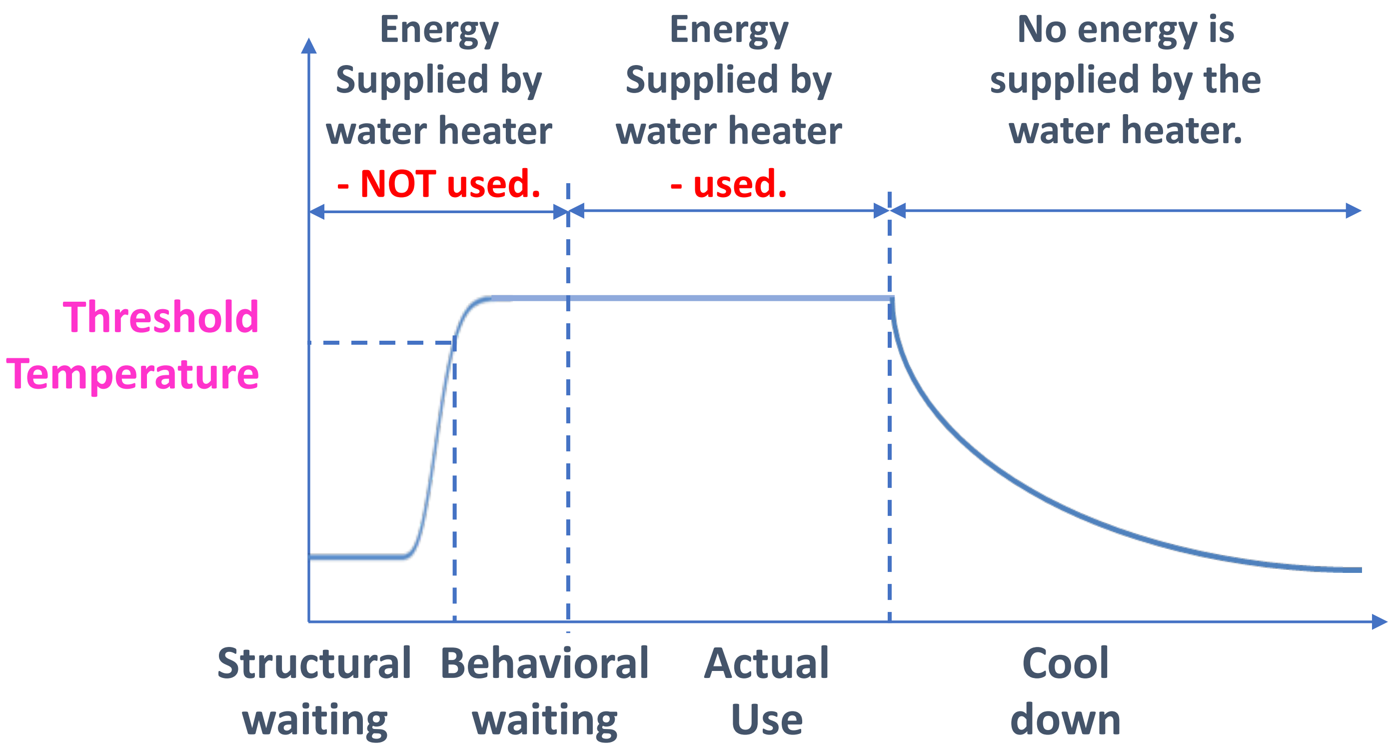
Scatter Plot of the Relationship between the Hot Water System and the Floor Area

Source: http://kiddywampus.blogspot.com

Performance Model Development

- Transient hot water delivery process
- Interaction between hot water draws
- Complicated distribution piping configurations
- In-depth understandings of distribution performance

A Typical Hot Water Use Event



Numerical Solution for Pipe Warm-up Process

Derivation.

Let T_{ij} denote the temperature of the water in pipe section i at time j, and P_{ij} denote the temperature of pipe section i at time j. Let Δx denote the length of one section of pipe, and Δt denote the difference between time j and $j+1$.

Define:

$$\alpha = \frac{h_1 S_1}{vA\rho_w C_w} = \frac{h_1 \cdot 2\pi r_1 \cdot \Delta x}{v \cdot \pi r_1^2 \cdot \rho_w C_w} = \frac{\pi r_1}{\pi r_1} \cdot \frac{2h_1}{\rho_w C_w r_1} \cdot \frac{\Delta x}{v} = \frac{2h_1 \Delta t}{\rho_w C_w r_1}$$

$$\beta = \frac{h_1 S_1 \Delta t}{M_p C_p} = \frac{h_1 \cdot 2\pi r_1 \cdot \Delta x \Delta t}{\rho_p \cdot \pi(r_2^2 - r_1^2) \cdot \Delta x \cdot C_p} = \frac{\pi \Delta x}{\pi \Delta x} \cdot \frac{2h_1 r_1 \Delta t}{\rho_p C_p (r_2^2 - r_1^2)} = \frac{2h_1 r_1 \Delta t}{\rho_p C_p \cdot (r_2^2 - r_1^2)}$$

$$\gamma = \frac{h_2 S_2 \Delta t}{M_p C_p} = \frac{h_2 \cdot 2\pi r_2 \cdot \Delta x \Delta t}{\rho_p \cdot \pi(r_2^2 - r_1^2) \cdot \Delta x \cdot C_p} = \frac{\pi \Delta x}{\pi \Delta x} \cdot \frac{2h_2 r_2 \Delta t}{\rho_p C_p (r_2^2 - r_1^2)} = \frac{2h_2 r_2 \Delta t}{\rho_p C_p \cdot (r_2^2 - r_1^2)}$$

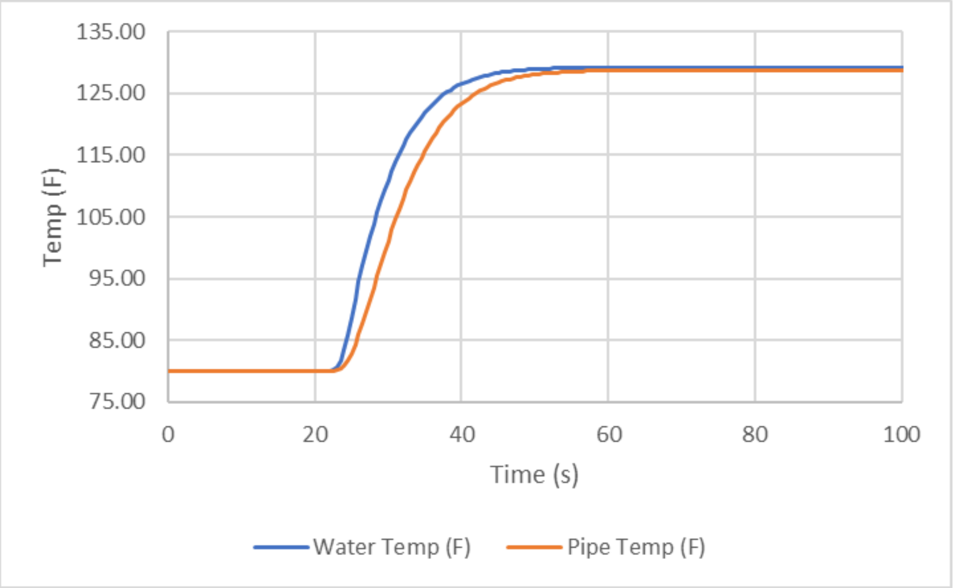
Energy of Water:

$$\frac{\rho_w A C_w \cdot \Delta x \cdot (T_{i,j+1} - T_{ij})}{\Delta t} = \frac{1-k}{2} vA\rho_w C_w T_{i-2,j} + kvA\rho_w C_w T_{i-1,j} - \frac{1+k}{2} vA\rho_w C T_{ij} - h_1 S_1 \left(T_{i-1,j} - \frac{P_{i-1,j} + P_{ij}}{2}\right)$$

We choose Δt such that $\Delta x = v \cdot \Delta t$, which simplifies our equation to

$$vA\rho_w C_w (T_{i,j+1} - T_{ij}) = \frac{1-k}{2} vA\rho_w C_w T_{i-2,j} + kvA\rho_w C_w T_{i-1,j} - \frac{1+k}{2} vA\rho_w C T_{ij} - h_1 S_1 \left(T_{i-1,j} - \frac{P_{i-1,j} + P_{ij}}{2}\right)$$

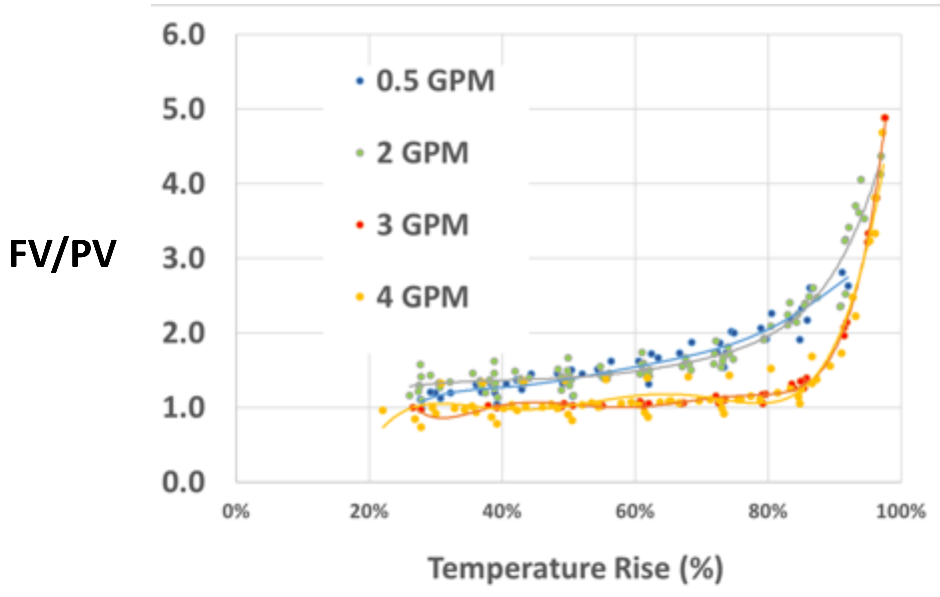
$$T_{i,j+1} = \frac{1-k}{2} T_{i-2,j} + kT_{i-1,j} - \frac{1+k}{2} T_{ij} + T_{ij} - \frac{h_1 S_1}{vA\rho_w C_w} T_{i-1,j} + \frac{h_1 S_1}{2vA\rho_w C_w} P_{i-1,j} + \frac{h_1 S_1}{2vA\rho_w C_w} P$$

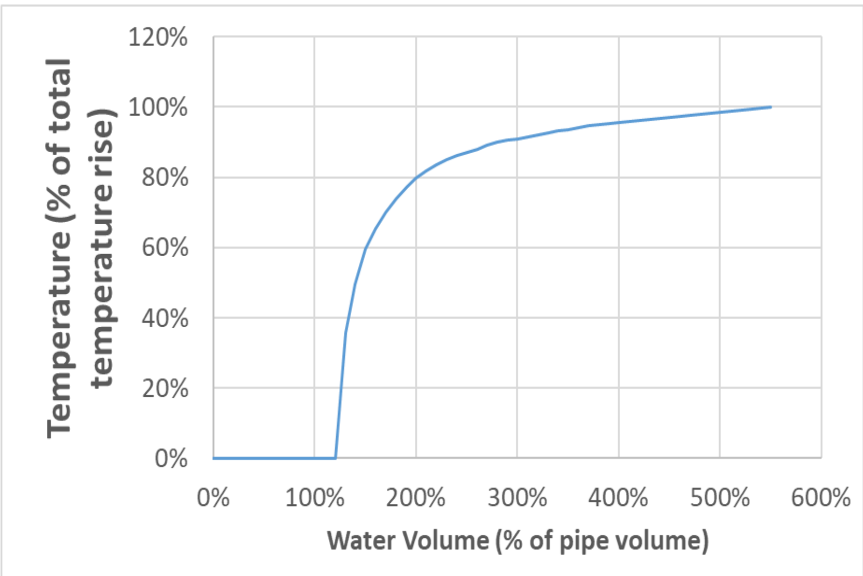


- Too complicated
- Not accurate, not easy to be calibrated
- Not easy to be applied to complicated distribution networks

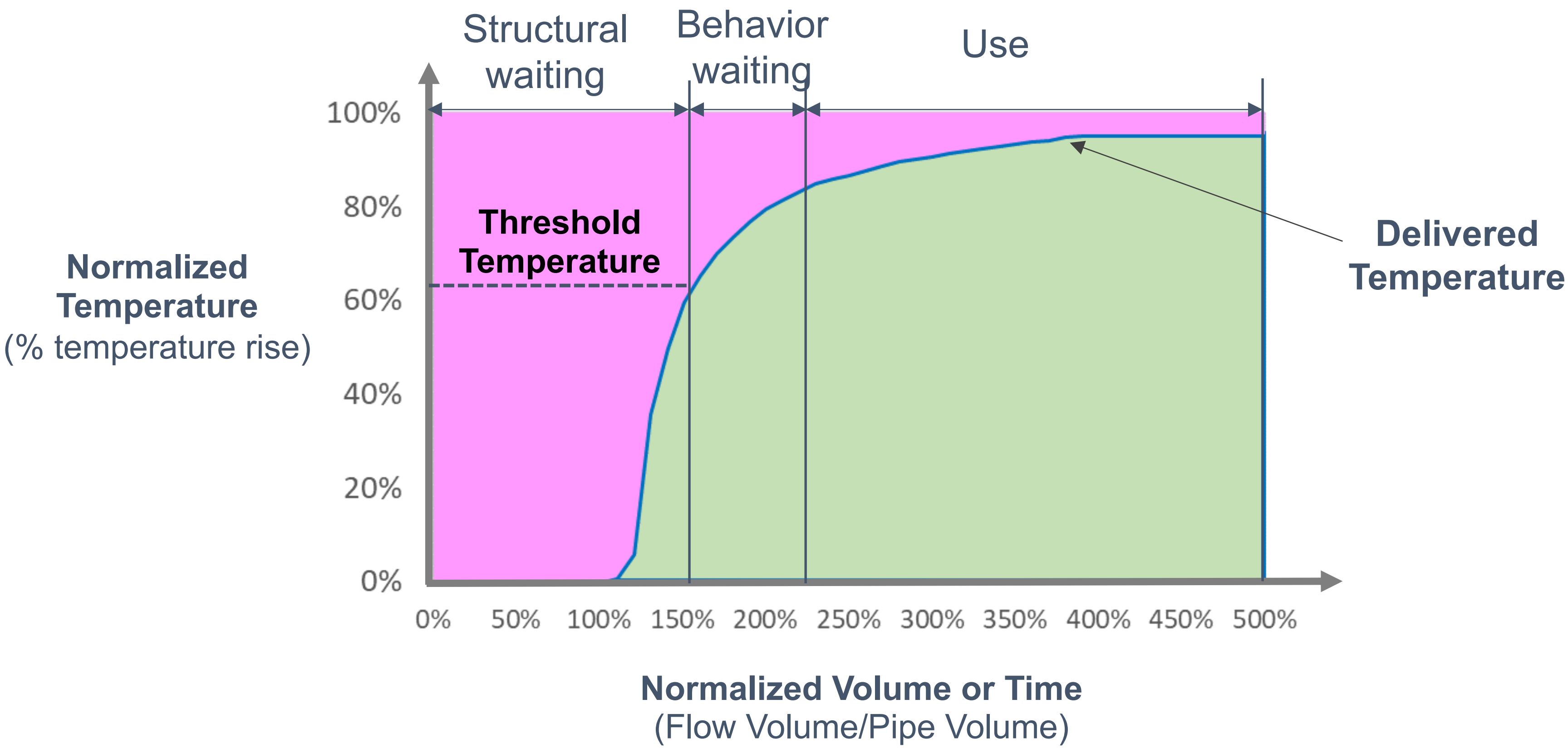
Empirical Approach – Based on Test Data

- Inherently validated
- Normalized temperature profile
  - Normalized temperature:
    <u>% Temp Rise</u> = (Temp–CWT)/(HWT-CWT)
  - Normalized flow/time:
    <u>FV/PV</u> = Flow volume/pipe volume

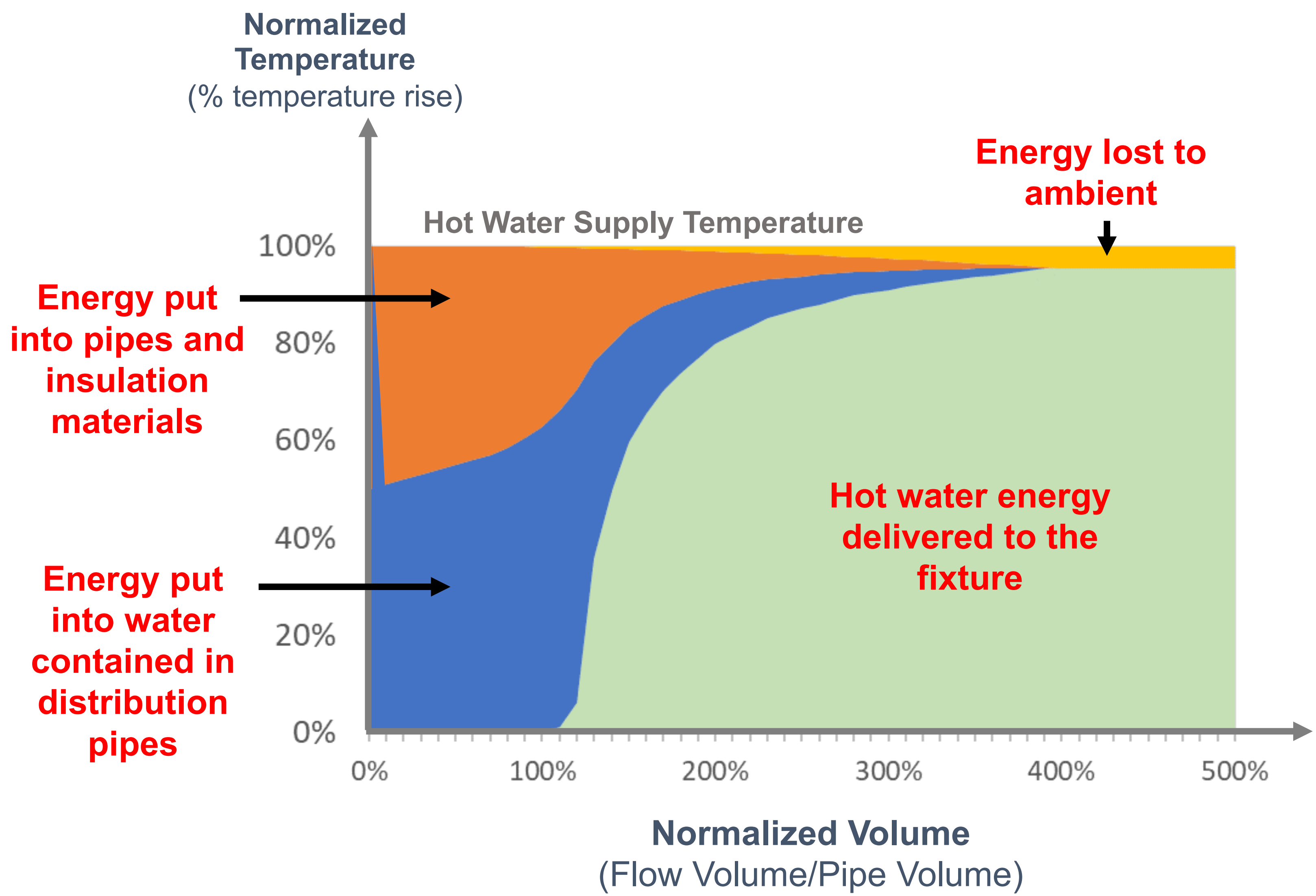




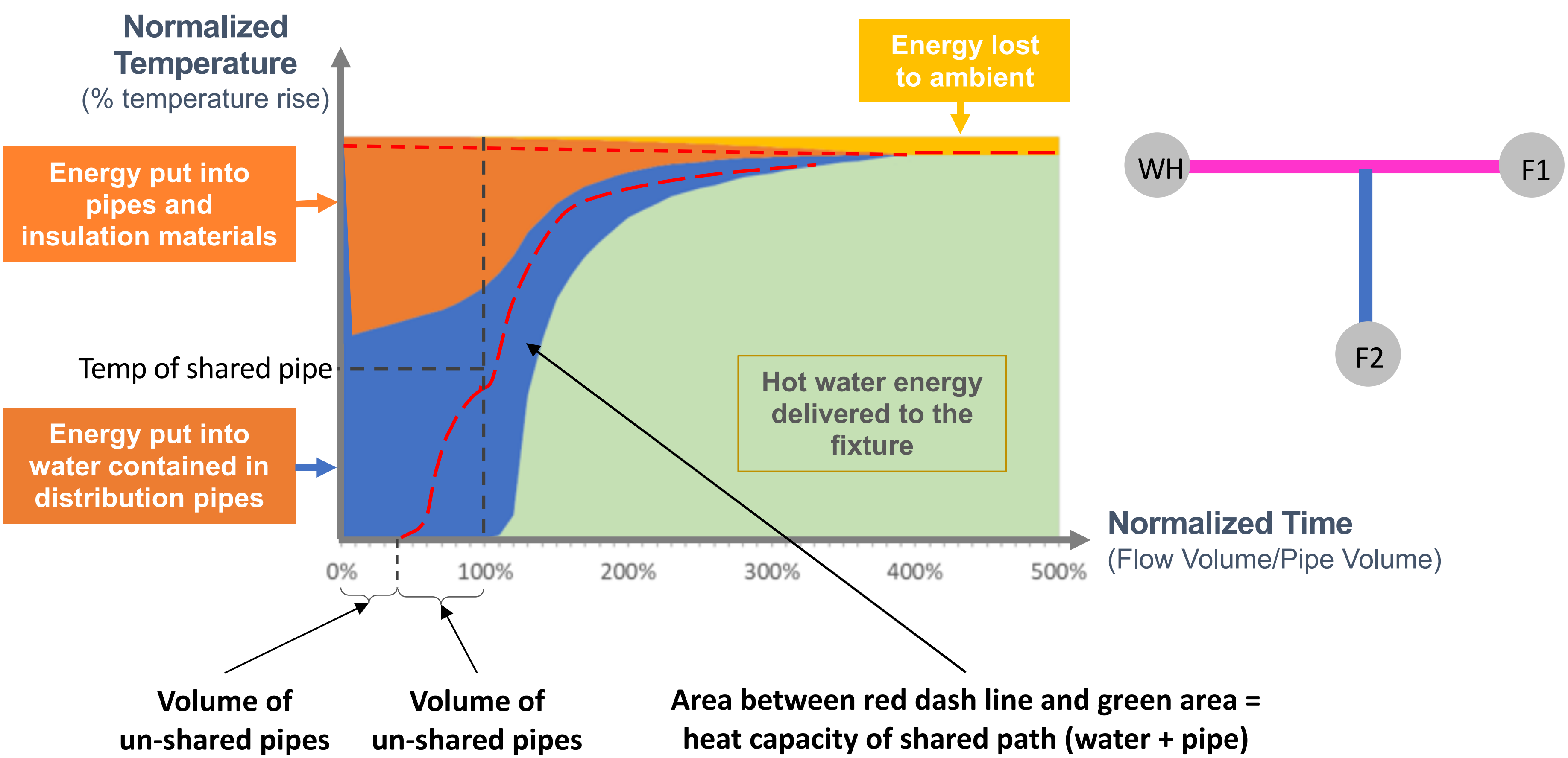
Normalized Pipe Warm-up Curve



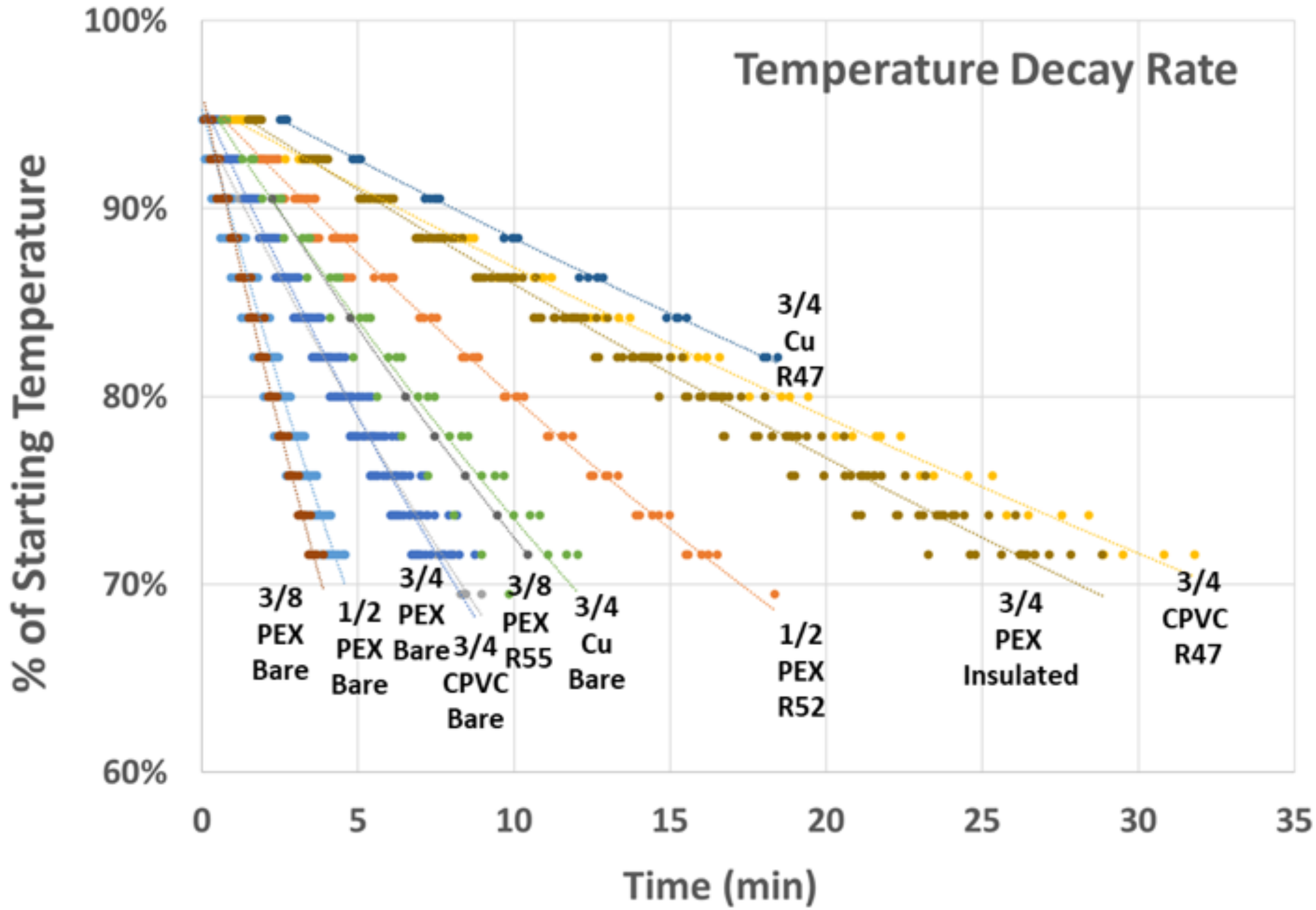
Enhanced Warm-up Curve - Energy Balance



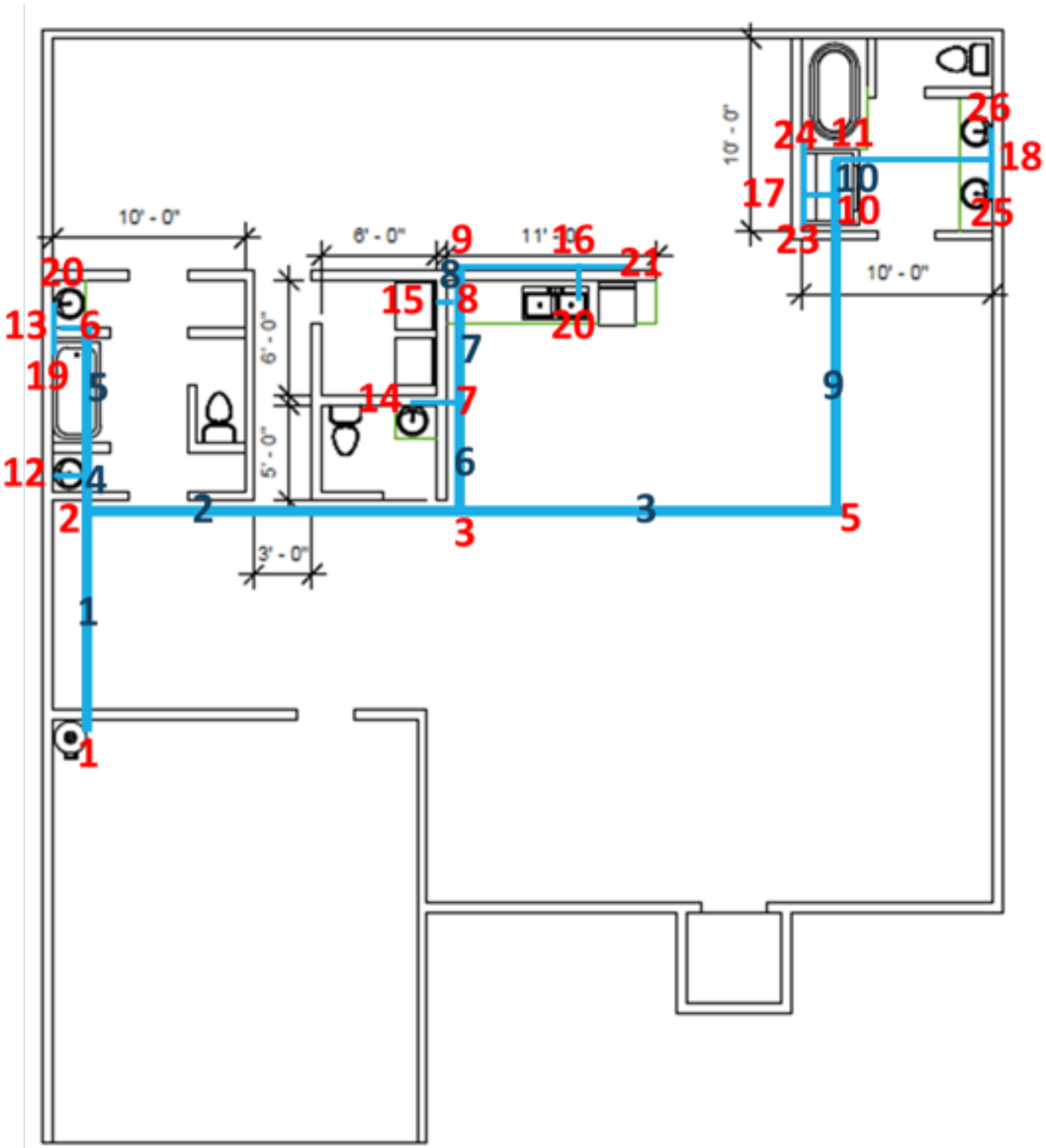
Warm-up Curve for Multiple Pipe & Initial Temperature



Cool-down Process Model



Modeling Method for Distribution System Designs



Trunk and Branch

(reference design)

CEC T24
Prototype
#1
(2.5 bath)

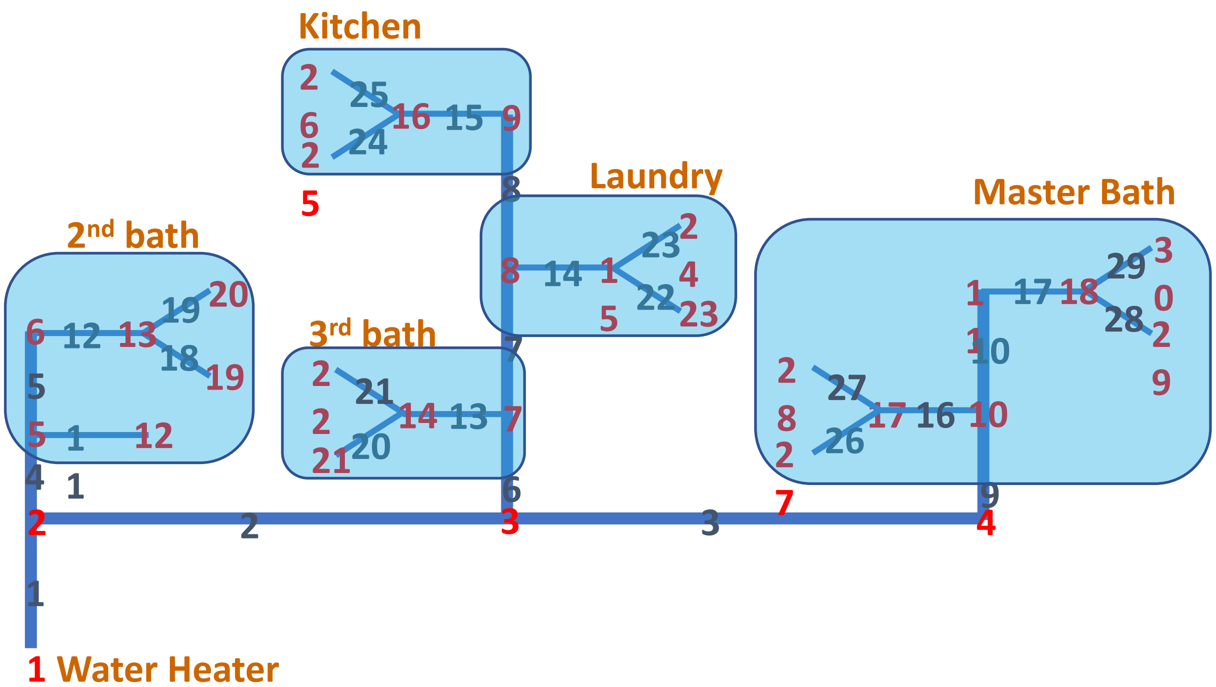
Model for Trunk and Branch (3 branches)

Pipe sections

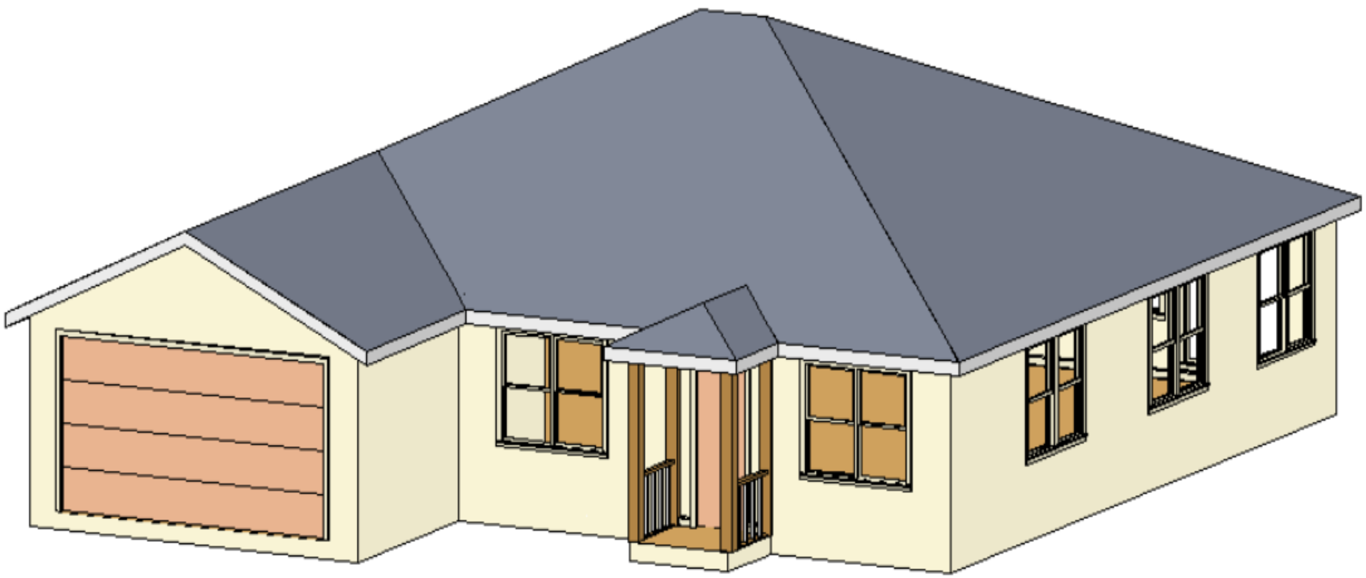
- Length
- Diameter
- Insulation

Connection nodes

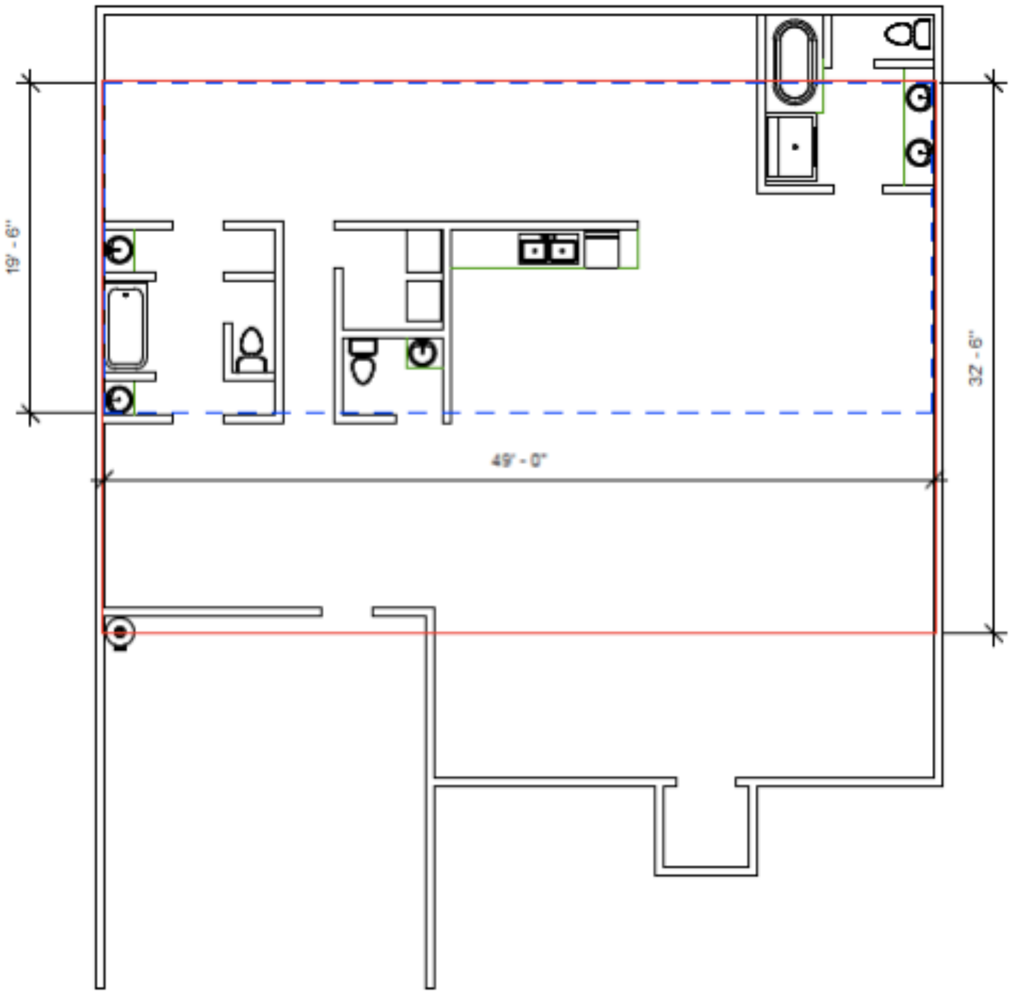
- Fixture



Title 24 Prototype Floor Plan



Distributed Core Case (Reference)



Wet Room Rectangle:

19.5 feet X 49 feet

956 square feet

45.5% of floor area

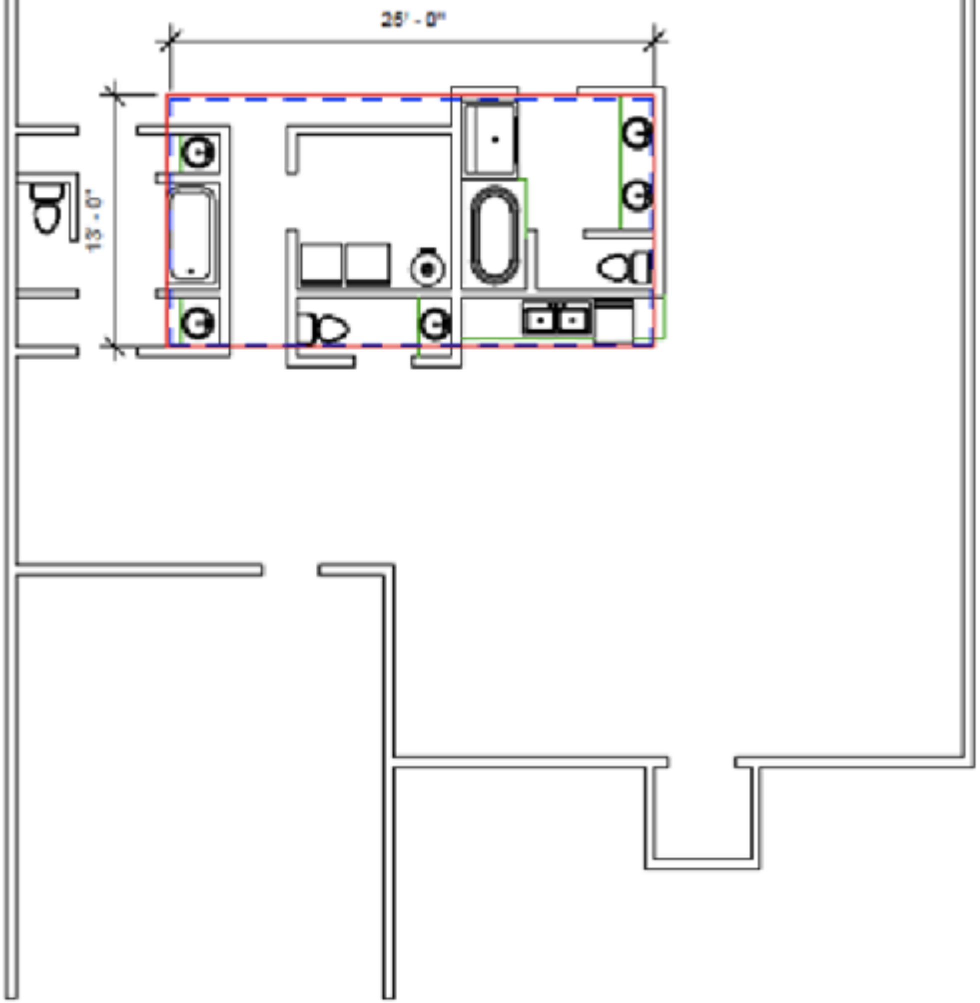
Hot Water System Rectangle

32.5 feet X 49 feet

1592 square feet

76% of floor area

Compact Core Case



Wet Room Rectangle:

13 feet X 25 feet

325 square feet

15.5% of floor area

Hot Water System Rectangle

13 feet X 25 feet

325 square feet

15.5% of floor area

Rating Performance
(it's not just the energy)

- **Which metrics to use?**
  - Energy
    - Energy used
    - Energy delivered but wasted
    - Energy not delivered
  - loads not met
    - compared to water heater set-point temperature
  - temperature delivered
    - wait time?
    - what temperature?
  - water wasted

Distributed Wet Rooms – One Day

Daily Performance, Base Case - Energy

Fixture ID	HW Supply Energy (Btu)	To fixture - used	To fixture - wasted	Lost to Ambient - during use	Stored in Pipe and Insulation	Energy Efficiency %
MB_SH	3,551	3,280	24	69	179	92%
MB_SK1	3,036	430	442	77	2,088	14%
MB_SK2	202	56	-	12	134	28%
MB_TB	-	-	-	-	-	
K_SK	2,736	1,484	244	70	938	54%
K_DW	-	-	-	-	-	
LN_WA	1,272	920	-	52	300	72%
B2_SH	2,383	2,094	24	23	241	88%
B2_SK1	937	515	24	25	373	55%
B2_SK2	817	217	128	6	466	27%
B2_TB	-	-	-	-	-	
B3_SK	165	93	-	2	71	56%
Total	**15,100**	**9,089**	**886**	**337**	**4,789**	**60%**

Daily Performance, Base Case - Water

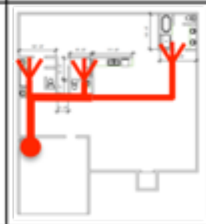
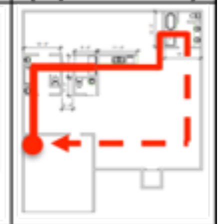
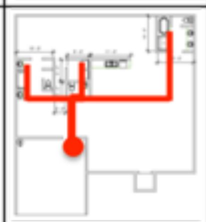
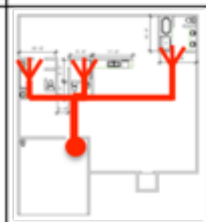
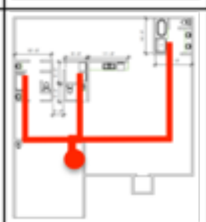
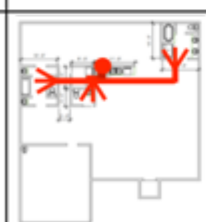
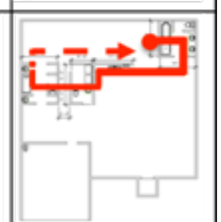
Fixture ID	Water Volume Supplied (Gallon)	Water Volume Used (Gallon)	Water Volume Wasted (Gallon)	Water Efficiency %
MB_SH	7.8	7.6	0.2	98%
MB_SK1	6.6	2.1	4.5	32%
MB_SK2	0.4	0.4	-	100%
MB_TB	-	-	-	
K_SK	6.0	4.5	1.5	75%
K_DW	-	-	-	
LN_WA	2.8	2.8	-	100%
B2_SH	5.2	4.8	0.4	92%
B2_SK1	2.1	1.8	0.2	90%
B2_SK2	1.8	0.7	1.1	39%
B2_TB	-	-	-	
B3_SK	0.4	0.4	-	100%
Total	**33.0**	**25.2**	**7.8**	**76%**

Daily Performance, Base Case - Time

Fixture ID	Structural Waiting (Sec)	Behavior Waiting (Sec)	Total Waiting (Sec)	Use Duration (Sec)	Time Efficiency %
MB_SH	7.8	-	7.8	390.0	98%
MB_SK1	224.8	-	224.8	310.1	58%
MB_SK2	-	-	-	100.0	100%
MB_TB	-	-	-	-	
K_SK	49.0	-	49.0	600.1	92%
K_DW	-	-	-	-	
LN_WA	-	-	-	600.0	100%
B2_SH	8.4	-	8.4	250.0	97%
B2_SK1	10.1	-	10.1	310.1	97%
B2_SK2	54.4	-	54.4	100.1	65%
B2_TB	-	-	-	-	
B3_SK	-	-	-	40.0	100%
Total	**354.6**	**-**	**354.6**	**2,700.4**	**88%**

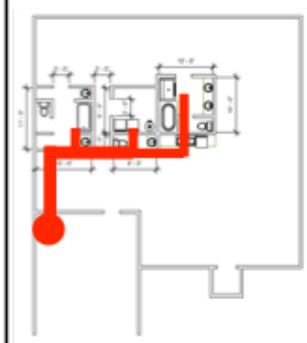
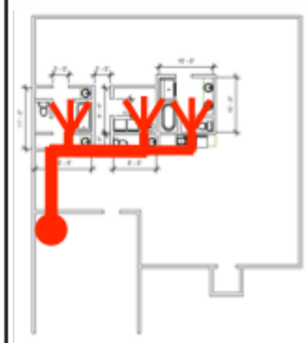
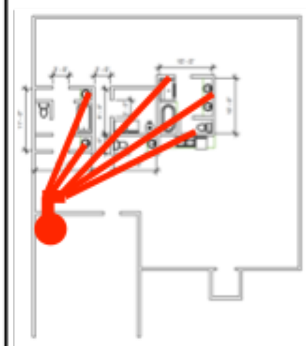
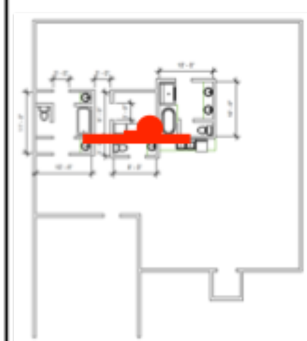
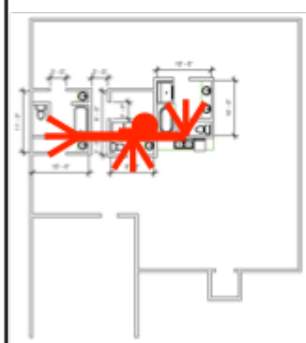
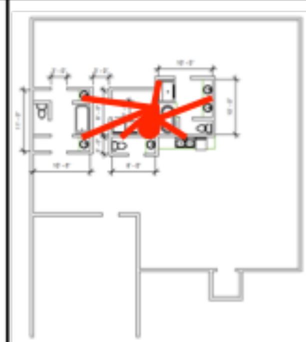
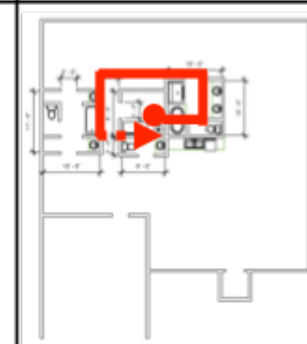
Daily Performance, Base Case - Service

Fixture ID	Theoretical HW demand (Btu)	HW Energy To fixture - used	Load not met (Btu)	Load not met (%)
MB_SH	3,476	3,280	196	6%
MB_SK1	981	430	551	56%
MB_SK2	202	56	146	72%
MB_TB	-	-	-	
K_SK	2,065	1,484	580	28%
K_DW	-	-	-	
LN_WA	1,272	920	352	28%
B2_SH	2,203	2,094	109	5%
B2_SK1	845	515	330	39%
B2_SK2	319	217	103	32%
B2_TB	-	-	-	
B3_SK	165	93	73	44%
Total	**11,529**	**9,089**	**2,440**	**21%**

WH Location	Trunk and Branch	Mini-Manifold	Central Manifold	One-Zone (Opt. ReCirc)
NW Garage				
NW Garage				
NE Garage				
NE Garage or SW Garage				
Kitchen or Master				
2 WH				

Distributed Wet-room Cases

Compact Wet-room Cases

WH Location	Trunk and Branch	Mini-Manifold	Central Manifold	One-Zone (Opt. ReCirc)
NW Garage				
SE Laundry				

Cost Summary-Baseline Case

Item	Materials		Labor		
	Quantity	Cost	Rate	Hours	Total
Supply Piping-PEX	297	$180.91	$43.45	15.0	$653.49
Supply Fittings-PEX	28	$162.45	$43.45	15.5	$672.17
Supply Joints-PEX	60	$25.00	$43.45	0.0	$0.00
Supply Hangers-PEX	137	$16.14	$43.45	35.6	$1,547.69
Drain Piping-ABS	182	$201.34	$43.45	19.5	$849.01
Drain Fittings-ABS	40	$120.05	$43.45	17.4	$756.46
Drain Excavation	60	$0.00	$43.45	0.0	$0.00
Steel Pipe	132	$146.08	$43.45	7.9	$341.95
Steel Fittings	14	$31.16	$43.45	8.9	$385.84
Miscellaneous Joints	122	$27.08	$43.45	0.0	$0.00
Pipe Insulation	111	$135.70	$43.45	3.2	$139.00
Subtotal		$1,046		123	$5,346
					$6,392
Sales Tax					$55
Subtotal					$6,447
Overhead			10%		$644.65
Profit			10%		$709
Total					$7,800

Cost Summary-Compact Core

Item	Materials		Labor		
	Quantity	Cost	Rate	Hours	Total
Supply Piping-PEX	170	$118.04	$43.45	8.8	$381.93
Supply Fittings-PEX	27	$171.55	$43.45	15.0	$652.18
Supply Joints-PEX	57	$25.00	$43.45	0.0	$0.00
Supply Hangers-PEX	46	$5.36	$43.45	12.0	$519.66
Drain Piping-ABS	150	$147.11	$43.45	15.1	$656.10
Drain Fittings-ABS	40	$119.42	$43.45	17.4	$756.46
Drain Excavation	60	$0.00	$43.45	0.0	$0.00
Steel Pipe	118	$152.15	$43.45	7.4	$321.53
Steel Fittings	16	$34.56	$43.45	8.9	$385.84
Miscellaneous Joints	128	$28.13	$43.45	0.0	$0.00
Pipe Insulation	56	$64.30	$43.45	1.6	$70.50
Subtotal		$866		86	$3,744
					$4,610
Sales Tax					$55
Subtotal					$4,665
Overhead			10%		$466
Profit			10%		$513
Total					$5,644

Estimated Benefits to California

	Natural Gas (Therms)	**Water** (Gallons)	**GHG** (Tons CO_2e)	**NOx** (Lbs)	**First cost for Compact Architectural Design** ($)
First-year Savings from One Home					
Distribution Improvement Only	11	1,750	0.056	0.026	1,500
Distribution Improvement and Low-flow Fixtures	19	3,180	0.103	0.046	
	Natural Gas (Million Therms)	**Water** (Billion Gallons)	**GHG** (Thousand Tons CO_2e)	**NOx** (Ton)	**First cost for Compact Architectural Design** ($Billion)
First-year Savings from Annual New Construction of 100,000 Homes					
Distribution Improvement Only	1.1	0.18	5.6	1.3	0.15
Distribution Improvement and Low-flow Fixtures	1.9	0.32	10.3	2.3	
Cumulative Savings in 10 years					
Distribution Improvement Only	59	9.6	310	71	8.3
Distribution Improvement and Low-flow Fixtures	107	17.5	565	129	

Distributed Wet-Rooms
Normal Flow Rates
Normal Pipe

Pipe Layout Method	Water Heater Location	Pipe Size	Distribution Energy Loss (% of Fixture Demand)	Load not Met (% of Fixture Demand)	Distribution Energy Loss Reduction (Compare to Baseline)
Trunk & Branch	Garage, top left corner	Normal	31%	21%	**Baseline**
Trunk & Branch	Garage, top right corner	Normal	28%	21%	11%
Trunk & Branch	Near master bathroom	Normal	29%	18%	5%
Trunk & Branch	Near kitchen	Normal	27%	16%	12%
Trunk & Branch	Garage, bottom left (far) corner	Normal	33%	22%	-6%
Hybrid (Mini-Manifold)	Garage, top left corner	Normal	32%	22%	-4%
Hybrid (Mini-Manifold)	Garage, top right corner	Normal	29%	21%	7%
Hybrid (Mini-Manifold)	Near master bathroom	Normal	32%	20%	-4%
Hybrid (Mini-Manifold)	Near kitchen	Normal	36%	17%	-16%
Hybrid (Mini-Manifold)	Garage, bottom left (far) corner	Normal	34%	23%	-10%
Central Manifold	Garage, top left corner	Normal	32%	24%	-3%
Central Manifold	Garage, top right corner	Normal	39%	22%	-26%
Central Manifold	Near master bathroom	Normal	34%	22%	-10%
Central Manifold	Near kitchen	Normal	21%	19%	33%
Central Manifold	Garage, bottom left (far) corner	Normal	47%	25%	-51%
Two Heaters	Garage, top left corner / near master bathroom	Normal	14%	20%	54%
Two Heaters	Near 2nd bathroom / near master bathroom	Normal	12%	18%	60%
One Zone	Garage, top left corner	Normal	35%	20%	-14%
One Zone	Near master bathroom	Normal	41%	18%	-33%
One Zone	Garage, bottom left (far) corner	Normal	40%	22%	-30%

Distributed Wet-Rooms
Normal Flow Rates
Small Pipe

Pipe Layout Method	Water Heater Location	Pipe Size	**Distribution Energy Loss** (% of Fixture Demand)	**Load not Met** (% of Fixture Demand)	**Distribution Energy Loss Reduction** (Compare to Baseline)
Trunk & Branch	Garage, top left corner	Use 3/8" pipe	30%	20%	2%
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe	29%	20%	7%
Central Manifold	Garage, top left corner	Use 3/8" pipe	20%	22%	35%
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe	13%	20%	58%
One Zone	Garage, top left corner	Use 3/8" pipe	34%	19%	-11%
Trunk & Branch	Garage, top left corner	No 1" pipe	26%	20%	16%
Hybrid (Mini-Manifold)	Garage, top left corner	No 1" pipe	27%	21%	12%
Central Manifold	Garage, top left corner	No 1" pipe	30%	23%	2%
Two Heaters	Garage, top left corner / near master bathroom	No 1" pipe	N/A	N/A	N/A
One Zone	Garage, top left corner	No 1" pipe	27%	19%	12%
Trunk & Branch	Garage, top left corner	Use 3/8" pipe & no 1" pipe	25%	20%	18%
Hybrid (Mini-Manifold)	Garage, top left corner	Use 3/8" pipe & no 1" pipe	24%	20%	23%
Central Manifold	Garage, top left corner	Use 3/8" pipe & no 1" pipe	19%	21%	39%
Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe & no 1" pipe	N/A	N/A	N/A
One Zone	Garage, top left corner	Use 3/8" pipe & no 1" pipe	27%	18%	14%

Compact Wet-Rooms
Normal Flow Rates
Normal Pipe

Pipe Layout Method	Water Heater Location	Pipe Size	Distribution Energy Loss (% of Fixture Demand)	Load not Met (% of Fixture Demand)	Distribution Energy Loss Reduction (Compare to Baseline)
Trunk & Branch	Away from fixtures (Garage, top left corner)	Normal	30%	19%	2%
Trunk & Branch	Near fixtures (Near laundry room)	Normal	17%	15%	45%
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Normal	36%	21%	-15%
Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Normal	19%	17%	39%
Central Manifold	Away from fixtures (Garage, top left corner)	Normal	29%	23%	8%
Central Manifold	Near fixtures (Near laundry room)	Normal	17%	18%	46%
One Zone	Away from fixtures (Garage, top left corner)	Normal	33%	22%	-8%
One Zone	Near fixtures (Near laundry room)	Normal	30%	13%	4%

Compact Wet-Rooms Normal Flow Rates Small Pipe

Pipe Layout Method	Water Heater Location	Pipe Size	Distribution Energy Loss (% of Fixture Demand)	Load not Met (% of Fixture Demand)	Distribution Energy Loss Reduction (Compare to Baseline)
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	30%	18%	5%
Trunk & Branch	Near fixtures (Near laundry room)	Use 3/8" pipe	12%	15%	60%
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	34%	20%	-9%
Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Use 3/8" pipe	13%	16%	57%
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	19%	22%	40%
Central Manifold	Near fixtures (Near laundry room)	Use 3/8" pipe	8%	17%	74%
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe	33%	21%	-5%
One Zone	Near fixtures (Near laundry room)	Use 3/8" pipe	29%	12%	6%
Trunk & Branch	Away from fixtures (Garage, top left corner)	No 1" pipe	26%	18%	16%
Trunk & Branch	Near fixtures (Near laundry room)	No 1" pipe	15%	14%	52%
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	No 1" pipe	30%	20%	2%
Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	No 1" pipe	18%	17%	43%
Central Manifold	Away from fixtures (Garage, top left corner)	No 1" pipe	27%	22%	12%
Central Manifold	Near fixtures (Near laundry room)	No 1" pipe	16%	18%	48%
One Zone	Away from fixtures (Garage, top left corner)	No 1" pipe	23%	21%	25%
One Zone	Near fixtures (Near laundry room)	No 1" pipe	28%	13%	9%
Trunk & Branch	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	25%	17%	19%
Trunk & Branch	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	10%	14%	66%
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	29%	19%	8%
Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	13%	16%	59%
Central Manifold	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	17%	21%	44%
Central Manifold	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	7%	16%	77%
One Zone	Away from fixtures (Garage, top left corner)	Use 3/8" pipe & no 1" pipe	22%	20%	28%
One Zone	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	27%	12%	11%

Distributed Wet-Rooms
Low Flow Rates
Normal Pipe

			Distribution Energy Loss (% of Baseline Fixture Demand)		Energy Demand from the Water Heater (% of Baseline)	
Pipe Layout Method	Water Heater Location	Pipe Size	Low Flow	Normal Flow	Low Flow	Normal Flow
Trunk & Branch	Garage, top left corner	Normal	31.3%	31.0%	88%	100%
Trunk & Branch	Garage, top right corner	Normal	27.60%	27.58%	85%	97%
Trunk & Branch	Near master bathroom	Normal	30.0%	29.5%	87%	99%
Trunk & Branch	Near kitchen	Normal	27.6%	27.3%	85%	97%
Trunk & Branch	Garage, bottom left (far) corner	Normal	33.3%	32.8%	89%	101%
Hybrid (Mini-Manifold)	Garage, top left corner	Normal	32.5%	32.3%	89%	101%
Hybrid (Mini-Manifold)	Garage, top right corner	Normal	28.97%	28.96%	86%	98%
Hybrid (Mini-Manifold)	Near master bathroom	Normal	33.0%	32.3%	89%	101%
Hybrid (Mini-Manifold)	Near kitchen	Normal	36.2%	36.0%	92%	104%
Hybrid (Mini-Manifold)	Garage, bottom left (far) corner	Normal	34.4%	34.0%	90%	102%
Central Manifold	Garage, top left corner	Normal	32.1%	31.9%	88%	101%
Central Manifold	Garage, top right corner	Normal	39.5%	39.2%	94%	106%
Central Manifold	Near master bathroom	Normal	34.6%	33.9%	90%	102%
Central Manifold	Near kitchen	Normal	21.5%	20.8%	80%	92%
Central Manifold	Garage, bottom left (far) corner	Normal	46.95%	46.93%	100%	112%
Two Heaters	Garage, top left corner / near master bathroom	Normal	15.0%	14.3%	75%	87%
Two Heaters	Near 2nd bathroom / near master bathroom	Normal	12.8%	12.3%	74%	86%
One Zone	Garage, top left corner	Normal	36.4%	35.3%	92%	103%
One Zone	Near master bathroom	Normal	41.8%	41.2%	96%	108%
One Zone	Garage, bottom left (far) corner	Normal	40.4%	40.3%	95%	107%

Compact Wet-Rooms
Low Flow Rates
Normal Pipe

Pipe Layout Method	Water Heater Location	Pipe Size	Distribution Energy Loss (% of Baseline Fixture Demand)		Energy Demand from the Water Heater (% of Baseline)	
			Low Flow	Normal Flow	Low Flow	Normal Flow
Trunk & Branch	Away from fixtures (Garage, top left corner)	Normal	30.9%	30.4%	87%	100%
Trunk & Branch	Near fixtures (Near laundry room)	Normal	17.7%	17.1%	77%	89%
Hybrid (Mini-Manifold)	Away from fixtures (Garage, top left corner)	Normal	36.2%	35.7%	92%	104%
Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Normal	19.4%	18.9%	79%	91%
Central Manifold	Away from fixtures (Garage, top left corner)	Normal	29.1%	28.7%	86%	98%
Central Manifold	Near fixtures (Near laundry room)	Normal	17.4%	16.7%	77%	89%
One Zone	Away from fixtures (Garage, top left corner)	Normal	33.5%	33.3%	89%	102%
One Zone	Near fixtures (Near laundry room)	Normal	30.4%	29.7%	87%	99%

The Best Systems We Evaluated

Architectural Design	Pipe Layout Method	Water Heater Location	Pipe Size	Energy/Water Use Reduction from Baseline		Annual Energy Savings (Therm/Year)		Annual Water Savings (Gallon/Year)	
				Normal Flow	Low Flow	Normal Flow	Low Flow	Normal Flow	Low Flow
Compact	Trunk & Branch	Near fixtures (Near laundry room)	Use 3/8" pipe	14%	26%	10.4	19.2	1,700	3,150
Compact	Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Use 3/8" pipe	13%	26%	9.9	18.8	1,630	3,080
Compact	Central Manifold	Near fixtures (Near laundry room)	Use 3/8" pipe	18%	30%	12.9	21.8	2,110	3,580
Compact	Trunk & Branch	Near fixtures (Near laundry room)	No 1" pipe	12%	24%	9.1	17.8	1,500	2,920
Compact	Central Manifold	Near fixtures (Near laundry room)	No 1" pipe	11%	24%	8.4	17.3	1,380	2,840
Compact	Trunk & Branch	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	16%	27%	11.5	19.9	1,890	3,260
Compact	Hybrid (Mini-Manifold)	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	14%	26%	10.2	19.1	1,670	3,130
Compact	Central Manifold	Near fixtures (Near laundry room)	Use 3/8" pipe & no 1" pipe	18%	30%	13.3	22.2	2,190	3,650
Distributed	Two Heaters	Garage, top left corner / near master bathroom	Use 3/8" pipe	14%	25%	10.0	18.6	1,650	3,050
			Average	**14%**	**26%**	**11**	**19**	**1,750**	**3,180**

What Did We Learn?

What Do We Recommend?

Is There a Limit to How Low We Can Go?

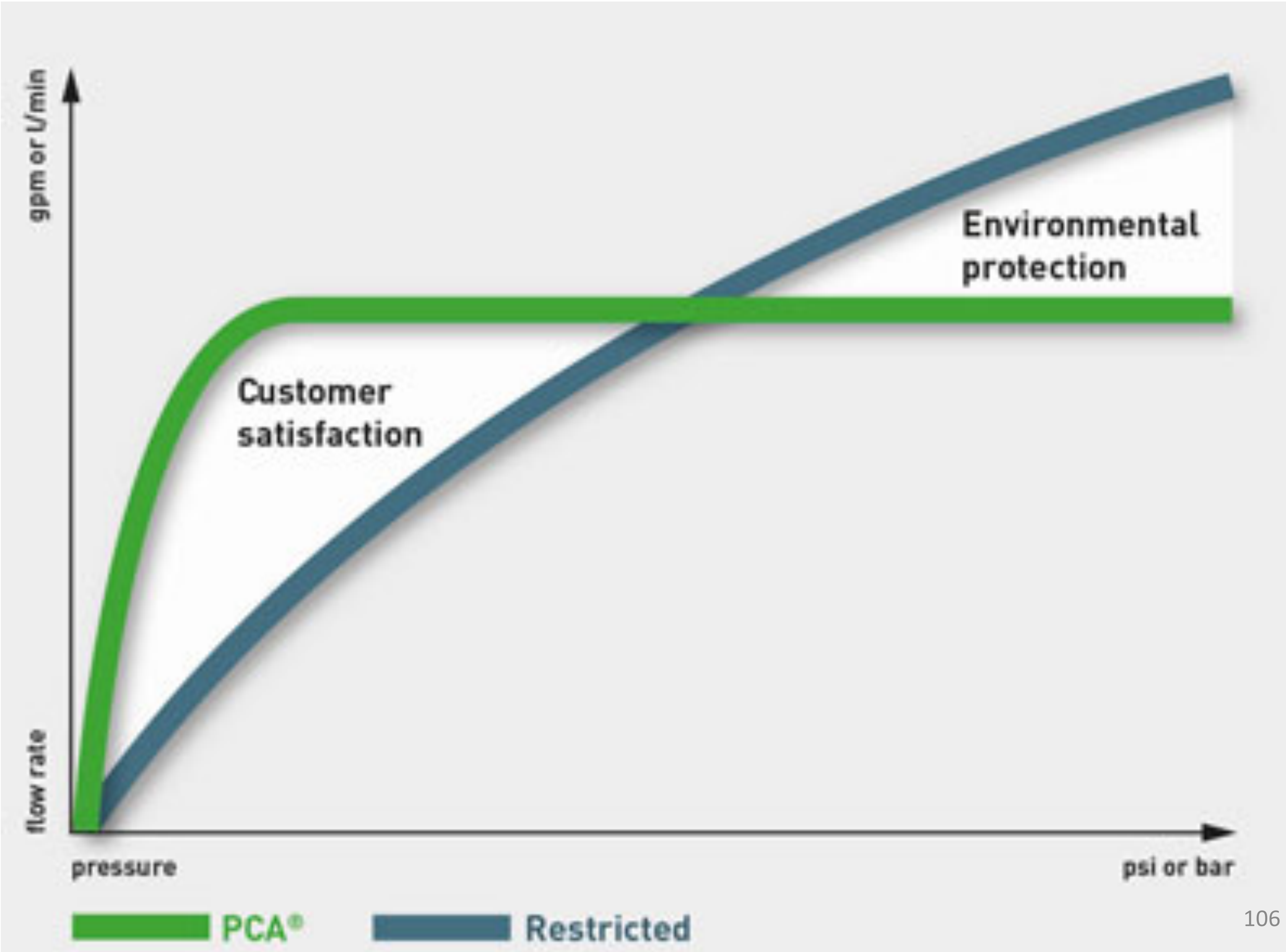
Flow Rates for Faucets, Tubs and Showers

Fixture	Flow Rate-Rated (gpm)	Flow Rate- All Hot (gpm)
Shower- stand alone	2.0 [1.0-2.5]	1.4 [60%-80%]
Tub/shower combination	5.0 [4.0-6.0	3.5 [60%-80%]
Lavatory faucet	1.5 [0.5-2.2]	1.5 [100%]
Kitchen faucet	2.0 [1.5-2.2]	2.0 [100%]

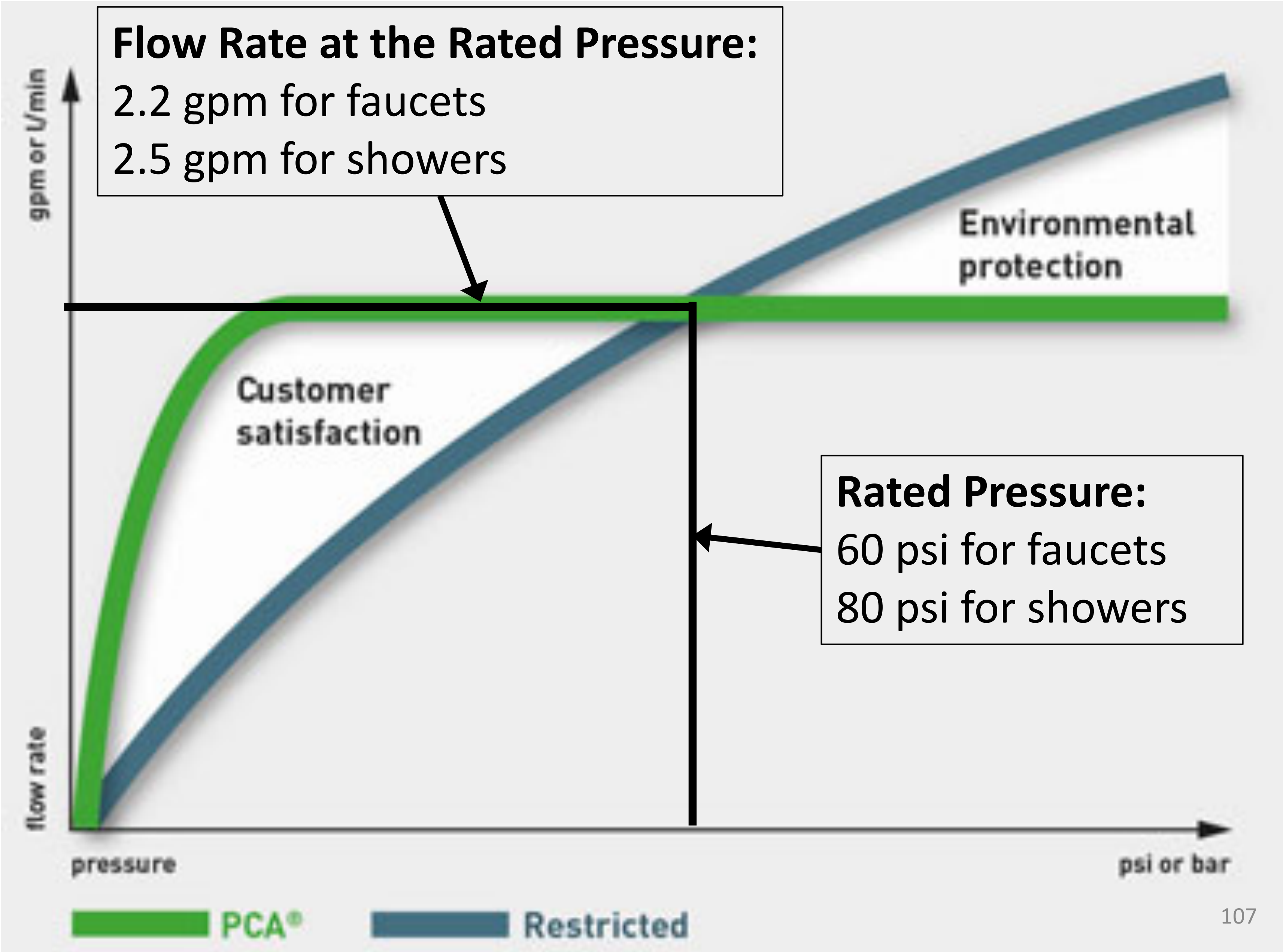
Fixed vs. Variable Orifices

- **Fixed Orifice:**
  - High pressure: High flow rate
  - Low pressure: Low flow rate
  - Before 2000, practically all fixture fittings and appliances
- **Pressure Compensating Aerators**
  - 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

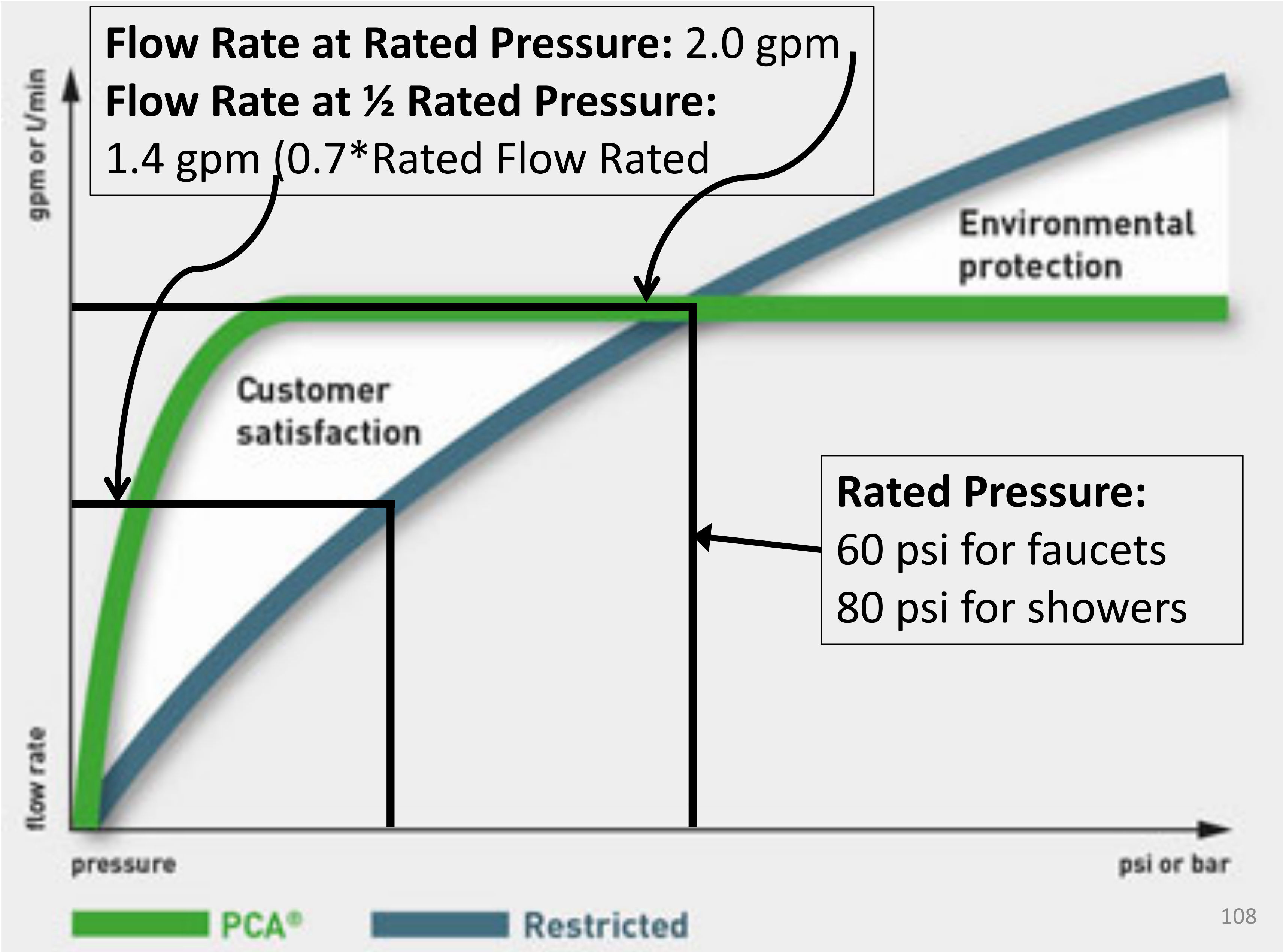
Pressure Compensating Aerators - 1



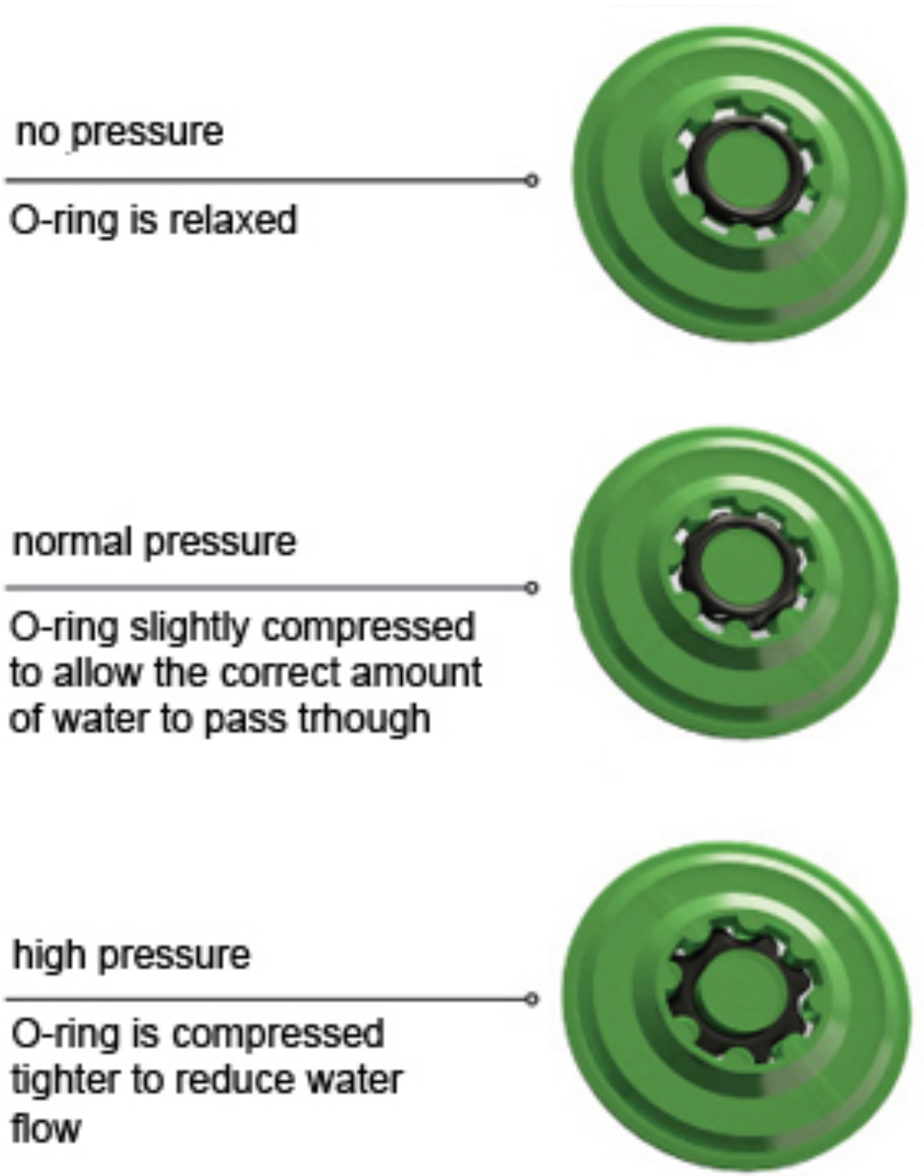
Pressure Compensating Aerators - 2



Pressure Compensating Aerators - 3



Pressure Compensating Aerators - 4

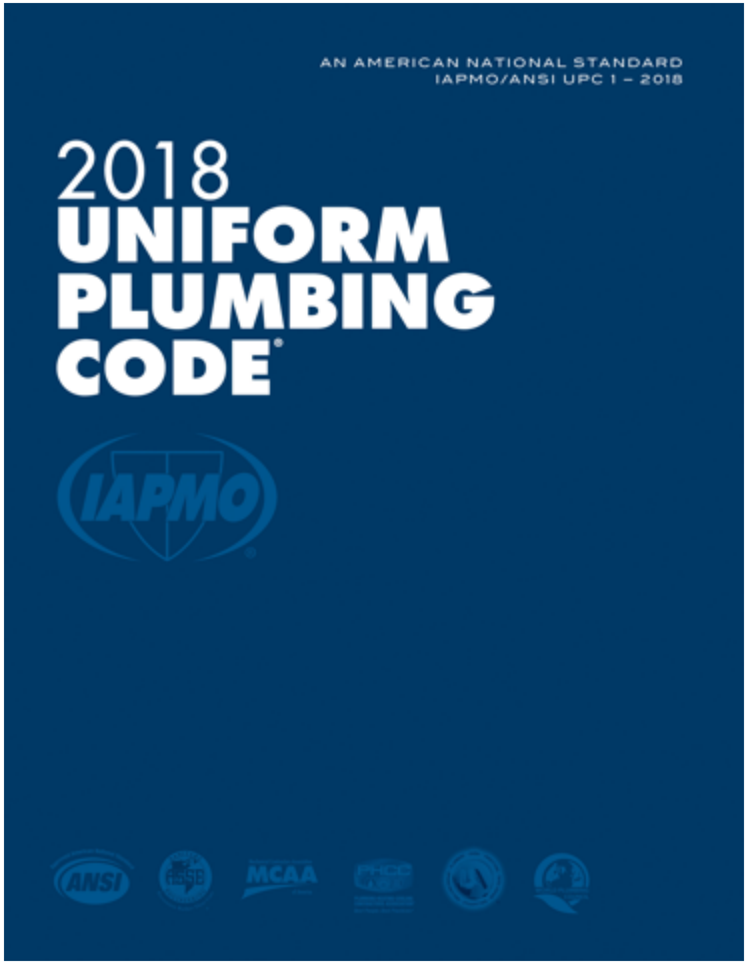


A pressure compensating flow regulator maintains a constant flow regardless of variations in line pressure thereby optimizing system performance and comfort of use at all pressures.

Source: Neoperl's website for this and the pressure-flow diagrams

Pipe Sizing for Peak Flows

Standard Method



Appendix M: Water Demand Calculator

↓ Select Units ↓

Tuesday, July 24, 2018 11:04 PM

PROJECT NAME : XXX-XXX   GPM   LPM   LPS

FIXTURE GROUPS		[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	1.0	5.5	5.5
	2	Bidet	0	1.0	2.0	2.0
	3	Combination Bath/Shower	0	5.5	5.5	5.5
	4	Faucet, Lavatory	0	2.0	1.5	1.5
	5	Shower, per head (no Bathtub)	0	4.5	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	1.0	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.5	1.3	1.3
	8	Faucet, Kitchen Sink	0	2.0	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	0	5.5	3.5	3.5
	10	Faucet, Laundry	0	2.0	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	2.0	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.0	0.0	6.0
	13	Fixture 2	0	0.0	0.0	6.0
	14	Fixture 3	0	0.0	0.0	6.0

Total Number of Fixtures 0

99th PERCENTILE DEMAND FLOW = GPM   RESET   RUN WATER DEMAND CALCULATOR

↑ CLICK BUTTON ↑

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

Appendix M

1. Provides a method to estimate the demand load for the building water supply and principal branches
   - For single and multi-family dwellings
   - With water conserving plumbing fixtures, fixture fittings and appliances
2. The method used in the Peak Water Demand Calculator is based on probabilities of simultaneous use from residential water use surveys and actual fixture flow rates
3. A useful tool for “right-sizing” pipe.

There is a Limit to How Low We Can Go.

- Unless the heater is in the fixture or appliance, there will always be some volume in the pipe between the source and the use.
- It takes roughly twice the volume in the pipe for hot water to come out the other end.
- 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.
  - Plumbing up from below needs about 5 feet of pipe.
  - Plumbing down from above needs about 10 feet of pipe

Time-to-Tap, Volume-until-Hot – 5 ft. of Pipe

Pipe Material	Pipe Diameter (nominal, inches)				
	0.25	**0.375**	**0.5**	**0.75**	**1**
Gallons to Hot: 5 Feet of Pipe					
Copper-Type L	0.04	0.08	0.12	0.25	0.43
CPVC	NA	NA	0.10	0.21	0.35
PEX	0.03	0.05	0.09	0.18	0.31
Time to Hot @ 0.5.gpm: 5 Feet of Pipe (seconds)					
Copper-Type L	5	9	15	30	51
CPVC	NA	NA	12	25	42
PEX	3	6	11	22	37
Time to Hot @ 1.0 gpm: 5 Feet of Pipe (seconds)					
Copper-Type L	2	5	7	15	26
CPVC	NA	NA	6	13	21
PEX	2	3	6	11	18

Time-to-Tap, Volume-until-Hot – 10 ft. of Pipe

Pipe Material	Pipe Diameter (nominal, inches)				
	0.25	0.375	0.5	0.75	1
Gallons to Hot: 10 Feet of Pipe					
Copper-Type L	0.08	0.15	0.24	0.50	0.86
CPVC	NA	NA	0.20	0.42	0.69
PEX	0.05	0.10	0.18	0.37	0.61
Time to Hot @ 0.5.gpm: 10 Feet of Pipe (seconds)					
Copper-Type L	10	18	29	60	103
CPVC	NA	NA	23	50	83
PEX	6	12	22	44	73
Time to Hot @ 1.0 gpm: 10 Feet of Pipe (seconds)					
Copper-Type L	5	9	15	30	51
CPVC	NA	NA	12	25	42
PEX	3	6	11	22	37

How Low Can We Go? How Close Can We Get?

- The shorter the pipe, the less time it takes.
- The lower the flow rate, the longer it takes.
- How long is too long?
  - 5 seconds?
  - 10 seconds?
  - Longer?

Water, energy and time efficient hot water systems start with deciding how long we want people to wait.

Proposal RE 162

- **2021 International Energy Conservation Code (IECC)**
- Proposal RE 162
- Gives credit for architectural compactness in the performance compliance path
  - Locate the wet rooms close to each other and to the water heater that serves them.
  - Obtain a 5-15% reduction in daily hot water volume and the energy needed to heat it
- ICC Code Hearings and Expo, October 20-30, 2019 in Las Vegas, NV

Changes to IECC Table R405.5.2(1)

<table>
<tr><th>Building Component</th><th>Standard Reference Design</th><th colspan="3">As Proposed</th></tr>
<tr><td rowspan="8">Service Water Heating [d,e,f,g]</td><td rowspan="8">As proposed. ~~Use: same as proposed design.~~

Use, in units of
gal/day = 30 + (10 x N_{br})
where:
N_{br} = number of bedrooms.</td><td colspan="3">As proposed
Use, in units of
gal/day = (30 + (10 x N_{br})) x (1 - HWDS)
where:
N_{br} = number of bedrooms.
HWDS = factor for the compactness of the hot water distribution system</td></tr>
<tr><td colspan="2">Compactness Ratio</td><td>HWDS Factor[i]</td></tr>
<tr><td>1 Story</td><td>2 or More Stories</td><td></td></tr>
<tr><td>> 60%</td><td>>30%</td><td>0</td></tr>
<tr><td>>30% - ≤ 60%</td><td>>15% - ≤ 30%</td><td>0.05</td></tr>
<tr><td>>15% - ≤ 30%</td><td>>7.5% - ≤ 15%</td><td>0.10</td></tr>
<tr><td>< 15%</td><td>< 7.5%</td><td>0.15</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Supporting Footnote

- The factor for the compactness of the hot water distribution system is the ratio of the rectangle that bounds the water heater and the fixtures that it serves divided by the area of the dwelling.
  - The hot water distribution system rectangle shall include the source of hot water and the termination of the fixture supplies on the hot water piping that are furthest from that water heater. Sources of hot water include water heaters, or in multi-family with central water heating systems, circulation loops or electric heat traced pipes.
  - The hot water distribution rectangle shall be shown on the floor plans and the area shall be computed to the nearest square foot.
  - Where there is more than one water heater and each water heater serves different plumbing fixtures and appliances, it is permissible to determine the area of each hot water distribution system and add these together to determine the Compactness Ratio.
  - The basement or attic shall be counted as a story when it contains the water heater.

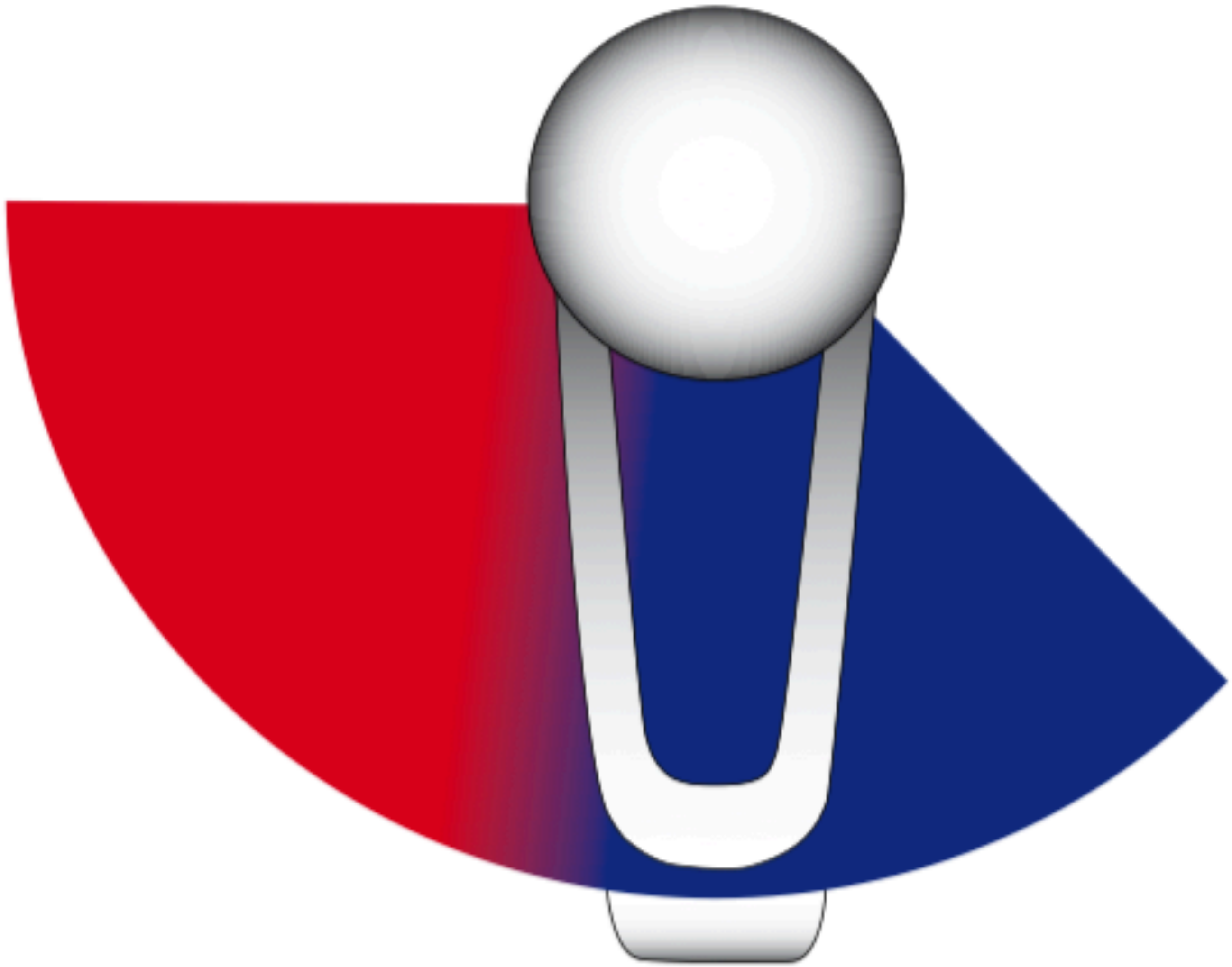
Cold-Start Function Faucets

Do you know…

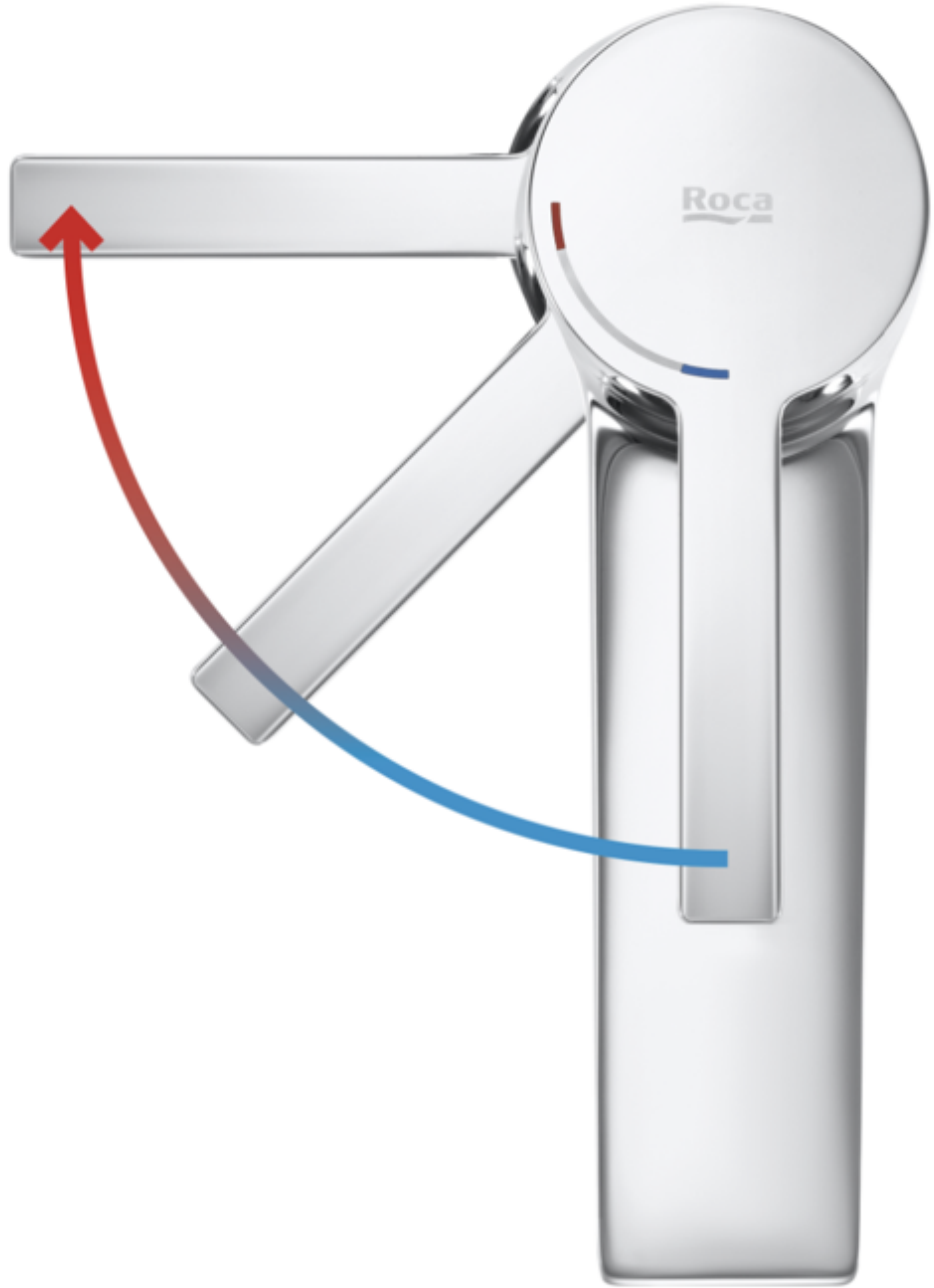
- Anyone who lifts a single lever faucet straight up just to rinse something?
  - Sort of half-hot, half-cold and half-flow?
  - Typically for a very short time?
- This means you get whatever temperature is in the pipes, but you drew hot water from the water heater, the heat content of which most often dissipates into the building?
- What if there was a single lever faucet that provided only cold water in the neutral position and which you needed to move intentionally “left-of-center” to get hot water at all?

Here’s how it works

- The cold-start function avoids hot water waste, saving up to 30% in energy. When you lift the lever straight up, only cold water is released. The function restricts opening the lever fully to the right.
- Hot water is released by turning the lever to the left. It is only then that hot water is consumed.





Next Steps?

- Any ideas to improve the functionality?
- Any ideas to improve energy efficiency?
- Standards?
- Incentive programs?
- Codes?

Pressure Drop in Modern Pipe and Pipe Fittings

The Search for Up-to-Date Information Continues…

Do you know someone who has ever…

- Compared the inside diameter of different pipe materials of the same nominal dimension; and noticed they were very different?
- Looked up data on pressure drop in pipe fittings and wondered why different sources had different numbers for the same materials?
- Wondered why the "well-designed" plumbing system didn't work as expected?
- Actually measured the performance of a plumbing system? And then compared what they measured to the design?
- Wondered why pipe sizes haven't gotten smaller even though flow rates have been dropping for the past 50 years?
- Thought it would be useful to have an up-to-date manual to use for the design and installation of modern plumbing systems?

Background

- Pipe fitting types and materials have changed since the development of plumbing design charts (Hunter Curves, Moody Diagram)
- Theoretical / calculation-based methods vs. measured data
  - Based on steel pipe and threaded and flanged fittings.
  - No copper, no plastic.
  - Now we have a large variety of fitting types and materials
- 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 1895.

The work of Giesecke (1926) and Giesecke and Badgett (1931, 1932a, 1932b may not be representative of current materials.

EXPERIMENTS UPON THE FLOW OF WATER IN PIPES AND PIPE FITTINGS

Made at Nashua, New Hampshire,
June 28 to October 22, 1892

By
JOHN R. FREEMAN, C. E.

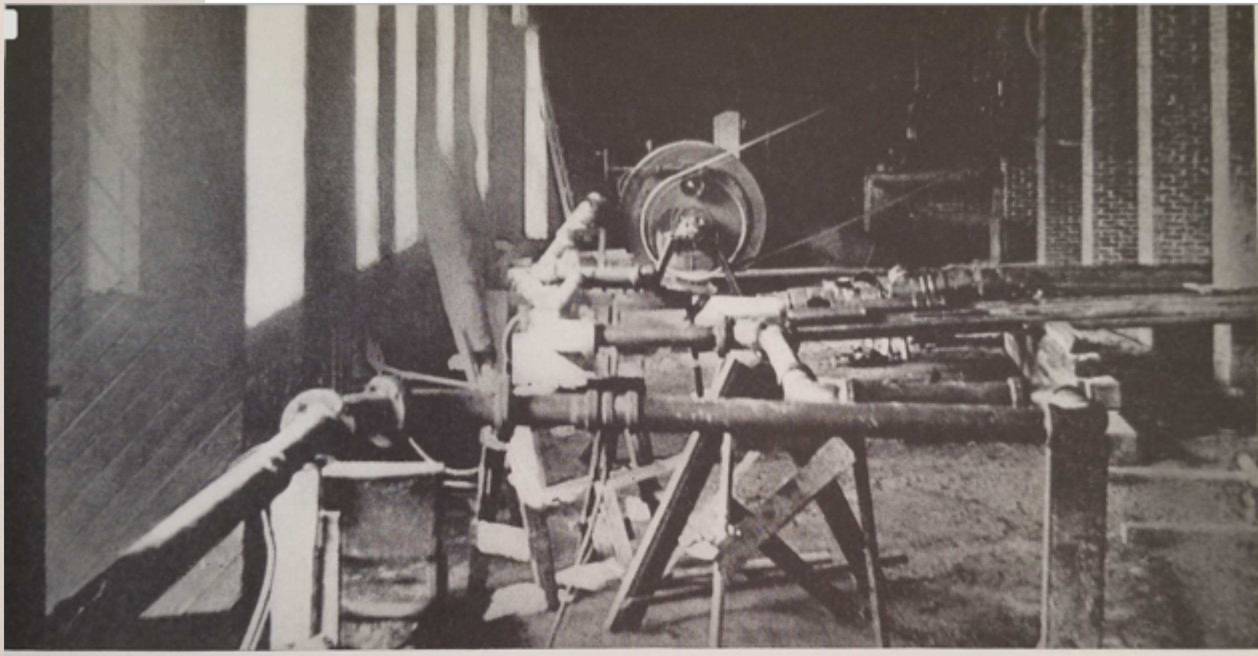


PLATE 6

View from measuring tank looking toward the forebay. The 4-inch flange-type and 4-inch drainage-type elbows, shown in Fig. 152, page 312, were under test. Note that two piezometers are visible in the foreground. This photograph shows clearly the inclination of the pipe to prevent the formation of air pockets. See pages 20–21.

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29 West Thirty-ninth Street, New York, N.Y.
1941

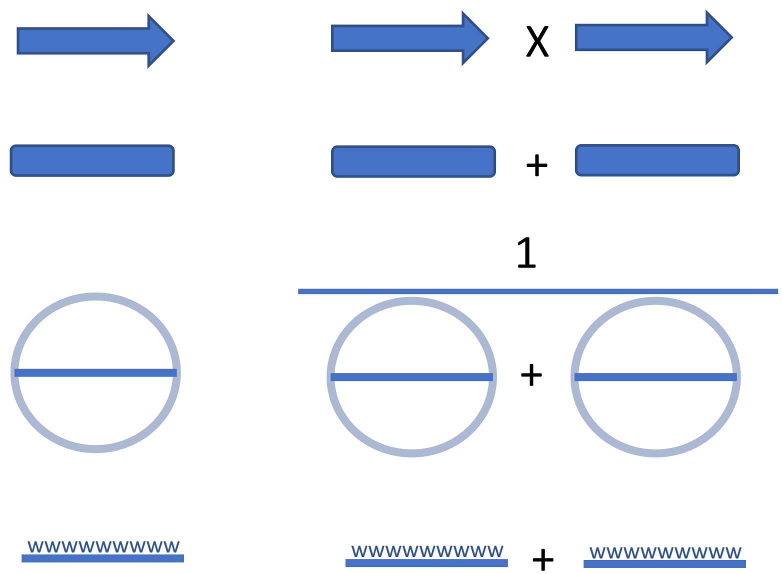
Before going too far…

Please share your understanding of pressure drop through pipe and fittings

Theory – Pressure Loss in a Circular Pipe

What happens to pressure drop when we double the:

- **Velocity (V)**
- **Length (L)**
- **Diameter (D)**
- **Friction Factor (f_D)**



Darcy Weisbach Equation

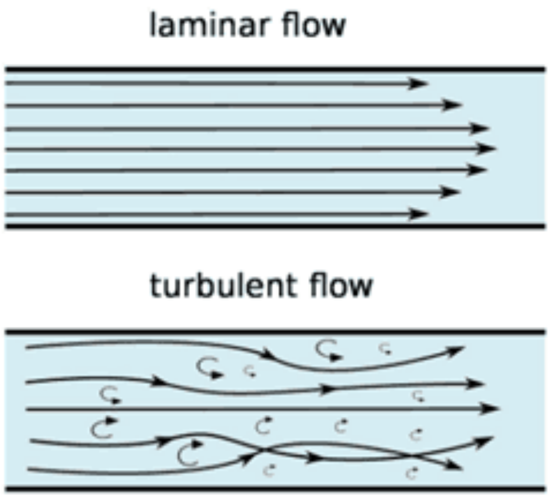
$$\Delta p = f_D \frac{L}{D} \frac{\rho V^2}{2}$$

Δp – pressure loss in N/m^2
f_D – darcy friction factor
L – pipe length in m
D – hydraulic diameter in m
V – fluid flow avg velocity in m/s
ρ – fluid density kg/m^3

Equation Image: https://ncalculators.com/mechanical/darcy-weisbach-equation-pressure-loss-calculator.htm?rel=site-search

Theory – Flow Types

- **Friction Factor**
  - Based on the Reynolds Number and Relative Roughness of the pipe.
- **Relative Roughness**
  - the characteristics of the type of pipe and diameter
- **Reynolds Number**
  - based on velocity, fluid density, fluid viscosity, and diameter, determines the type of flow



$$Re = \frac{\rho V D}{\mu}$$

μ – *fluid dynamic viscosity in* $kg/(m.s)$
ρ – *fluid density in* kg/m^3
V – *fluid velocity in* m/s
D – *pipe diameter in* m

Image: https://ncalculators.com/mechanical/darcy-weisbach-equation-pressure-loss-calculator.htm?rel=site-search

Currently Available Pressure Drop Data for Fittings

Copper Type-L: Fittings and Equivalent Length

Size (in)	Equivalent Length (feet)			
	90^o Elbow	45^o Elbow	Line Tee	Branch Tee
1/2	0.9	0.4	0.6	2.0
5/8	1.0	0.5	0.8	2.5
7/8	1.5	0.7	1.0	3.5
1 1/8	1.8	0.9	1.5	4.5
1 3/8	2.4	1.2	1.8	6.0
1 5/8	2.8	1.4	2.0	7.0
2 1/8	3.9	1.8	3.0	10.0
2 5/8	4.6	2.2	3.5	12.0

http://www.engineeringtoolbox.com/equivalent-length-copper-pipe-fittings-d_1670.html

Source of the data? Size= ID or OD? What velocity?

Copper Type-L: Fittings and Equivalent Length

Nominal or standard size, inches	Fittings					Valves			
	Standard ell		90° tee		Coupling	Ball	Gate	Btfly	Check
	90°	45°	Side branch	Straight run					
⅜	.5	-	1.5	-	-	-	-	-	1.5
½	1	.5	2	-	-	-	-	-	2
⅝	1.5	.5	2	-	-	-	-	-	2.5
¾	2	.5	3	-	-	-	-	-	3
1	2.5	1	4.5	-	-	.5	-	-	4.5
1¼	3	1	5.5	.5	.5	.5	-	-	5.5
1½	4	1.5	7	.5	.5	.5	-	-	6.5
2	5.5	2	9	.5	.5	.5	.5	7.5	9
2½	7	2.5	12	.5	.5	-	1	10	11.5
3	9	3.5	15	1	1	-	1.5	15.5	14.5
3½	9	3.5	14	1	1	-	2	-	12.5
4	12.5	5	21	1	1	-	2	16	18.5
5	16	6	27	1.5	1.5	-	3	11.5	23.5
6	19	7	34	2	2	-	3.5	13.5	26.5
8	29	11	50	3	3	-	5	12.5	39

CDA Publication A4015-14/16: Copper Tube Handbook, Table 14-7, Page 78

Source of the data? Size= ID or OD? What velocity?

PEX: Fittings and Equivalent Length

Type of Fitting	Equivalent Length of Tubing (ft.)			
	3/8" Size	1/2" Size	3/4" Size	1" Size
Coupling	2.9	2.0	0.6	1.3
Elbow 90°	9.2	9.4	9.4	10.0
Tee-branch	9.4	10.4	8.9	11.0
Tee-run	2.9	2.4	1.9	2.3

https://www.huduser.gov/portal/publications/pex_design_guide.pdf Page 79

Source of the data? Size= ID or OD? What velocity?

PVC and CPVC: Fittings and Equivalent Length

Approximate Friction Loss For PVC and CPVC Fittings In Equivalent Feet Of Straight Pipe

Fitting	½″	¾″	1″	1¼″	1½″	2″	2½″	3″	4″	6″	8″
Tee (Run)	1.0	1.4	1.7	2.3	2.7	4.3	5.1	6.2	8.3	12.5	16.5
Tee (Branch)	4.0	5.0	6.0	7.3	8.4	12.0	15.0	16.4	22.0	32.7	49.0
90° Elbow	1.5	2.0	2.5	3.8	4.0	5.7	6.9	7.9	12.0	18.0	22.0
45° Elbow	.80	1.1	1.4	1.8	2.1	2.6	3.1	4.0	5.1	8.0	10.6
Male/Female Adapter	1.0	1.5	2.0	2.75	3.5	4.5	5.5	6.5	9.0	14.0	—

http://www.charlottepipe.com/Documents/PL_Tech_Man/Charlotte_Plastics_Tech_Manual.pdf Page 48

Source of the data? Size= ID or OD? What velocity?

How Does One Measure Pressure Drop?

- Look for an official *Method of Test*. Still looking!
- Ask knowledgeable colleagues. We have and still do!
- Develop a reasonable test procedure.
    - We need to know the water temperature, delta-p and velocity.
    - Establish a range of velocities. Determine target flow rates for each velocity for each pipe material. Measure water temperature before and after the test segments. Same for pressure. Measure flow rate.
    - Hold each target flow rate constant for a specified amount of time.
    - Record data. Analyze. Share results.

What are we missing?

- What water temperature(s) should be used? How constant does it need to be?
- What happens if available water pressure varies during a test?
- Where do you put the pressure taps? How far from the fitting? Orientation on the pipe? Any issues with really small diameters?
- What is the measurement accuracy of each device? The system? How accurate do we think we can be?
- What if we measure the pressure drop of more than one fitting at a time?
- Does water hardness matter?
- Anything else?

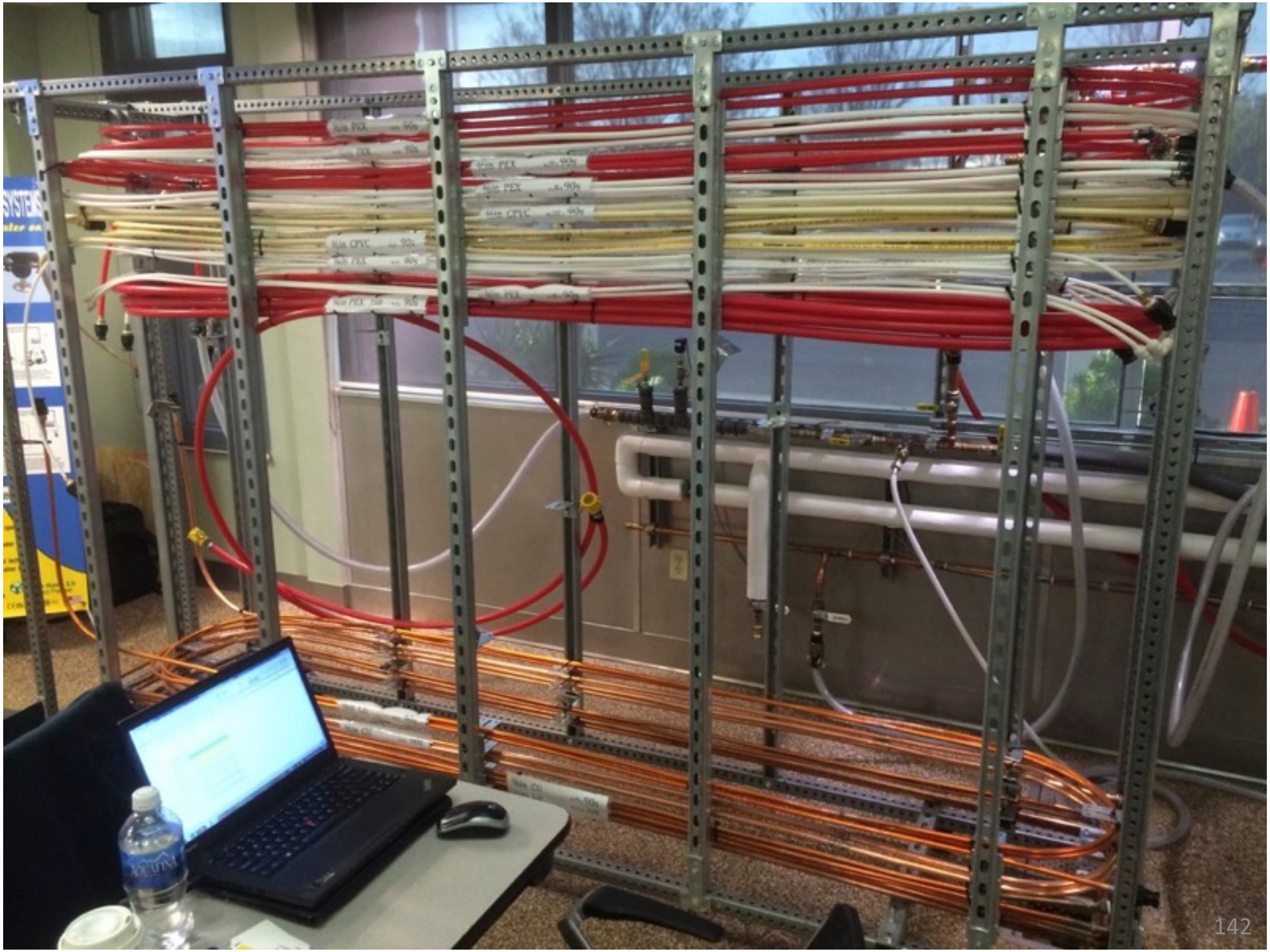
We Decided to:

Measure the pressure drop for a pipe segment with and without multiple fittings then calculate:

- **Pressure drop per fitting**
  - Subtract the pressure drop due to the straight pipe from total for the test segment to get the pressure drop due to the fittings. Divide by the number of fittings to get pressure drop per fitting.
- **Equivalent length per fitting**
  - Convert the pressure drop from PSI to equivalent length. Divide the pressure drop per fitting by the PSI per foot of the straight pipe. Answer will be in feet.

Test Site #1
Southern California Gas Company
Hot Water Demonstration Lab
Downey, CA

50 feet of pipe, with and without elbows



Pipe from ¼ inch to ¾ inch Nominal

Matrix of Tests

Nominal Diameter

3/4"
5/8"
1/2"
3/8"
1/4"
1/8"

Fitting material, type and technology

Real-time data

Pressure Drop Due to Elbows

	Equivalent Feet of 1/2" Tubing			
	Water Velocity in Tubing Feet per Second			
90° Elbow Type	**2 FPS**	**4 FPS**	**5 FPS**	**8 FPS**
PEX Crimp Insert	8.6	10.1	9.8	11.9
PEX Poly SS Press	7.9	8.9	8.9	9.6
PEX Cold Expansion	6.6	7.3	8.0	9.1
CPVC (Std Elb)	1.7	0.8	0.9	1.3
Copper (Std Tight Elb)	0.0	0.4	0.3	0.6

Pressure Drop Due to Elbows

	Equivalent Feet of 3/4" Tubing			
	Water Velocity in Tubing Feet per Second			
90° Elbow Type	2 FPS	4 FPS	5 FPS	8 FPS
PEX Poly SS Press	7.0	6.3	6.7	7.1
PEX Cold Expansion	4.8	4.5	4.9	5.2
PEX Push to Connect	2.3	2.0	2.6	2.6
CPVC (Std Elb)	N/A	N/A	N/A	N/A
Copper (Std Tight Elb)	N/A	N/A	N/A	N/A

Lessons Learned

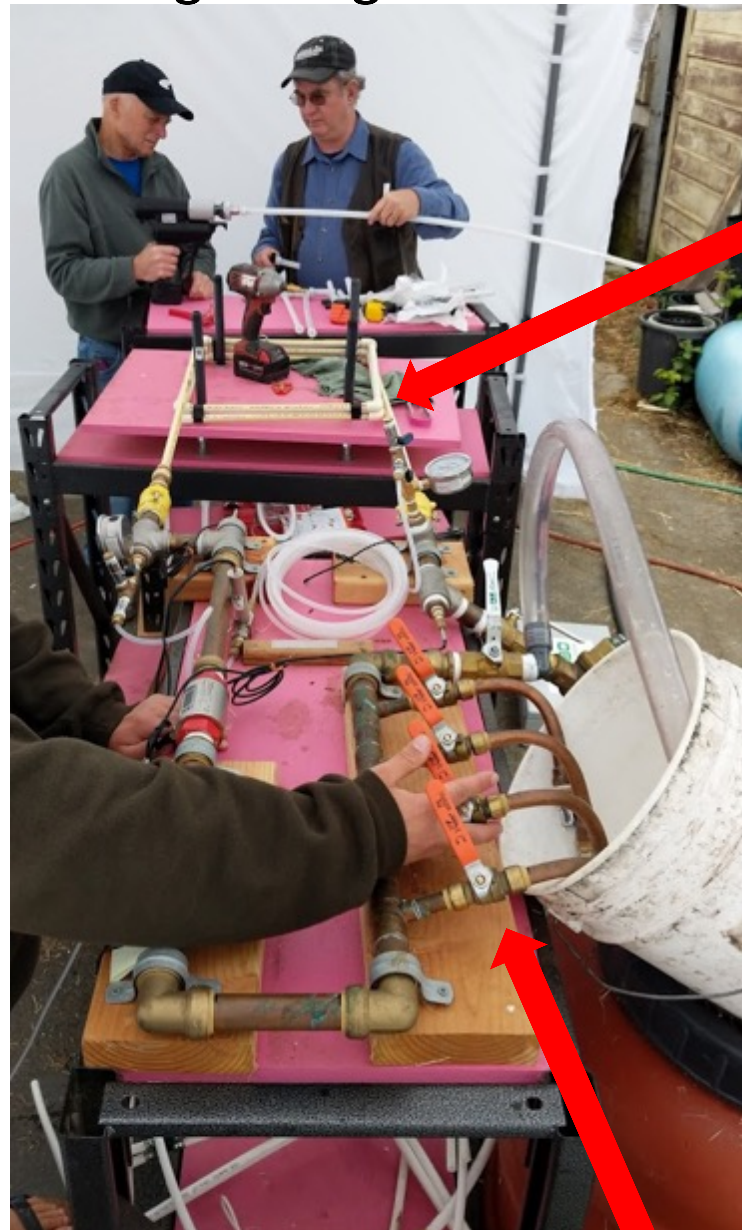
- Need steady pressure and consistent temperature
- Use a differential pressure gauge for more accurate data collection

Test Site #2
Arcata, CA

Start from Scratch…

- Shorten pipe length
- Increase signal (fittings) to noise (pipe)
- Portable
- Up to 1 inch nominal diameter pipe
- Site has relatively consistent temperature
- Add pressure tank to stabilize already relatively steady water pressure

Added a pressure regulating tank



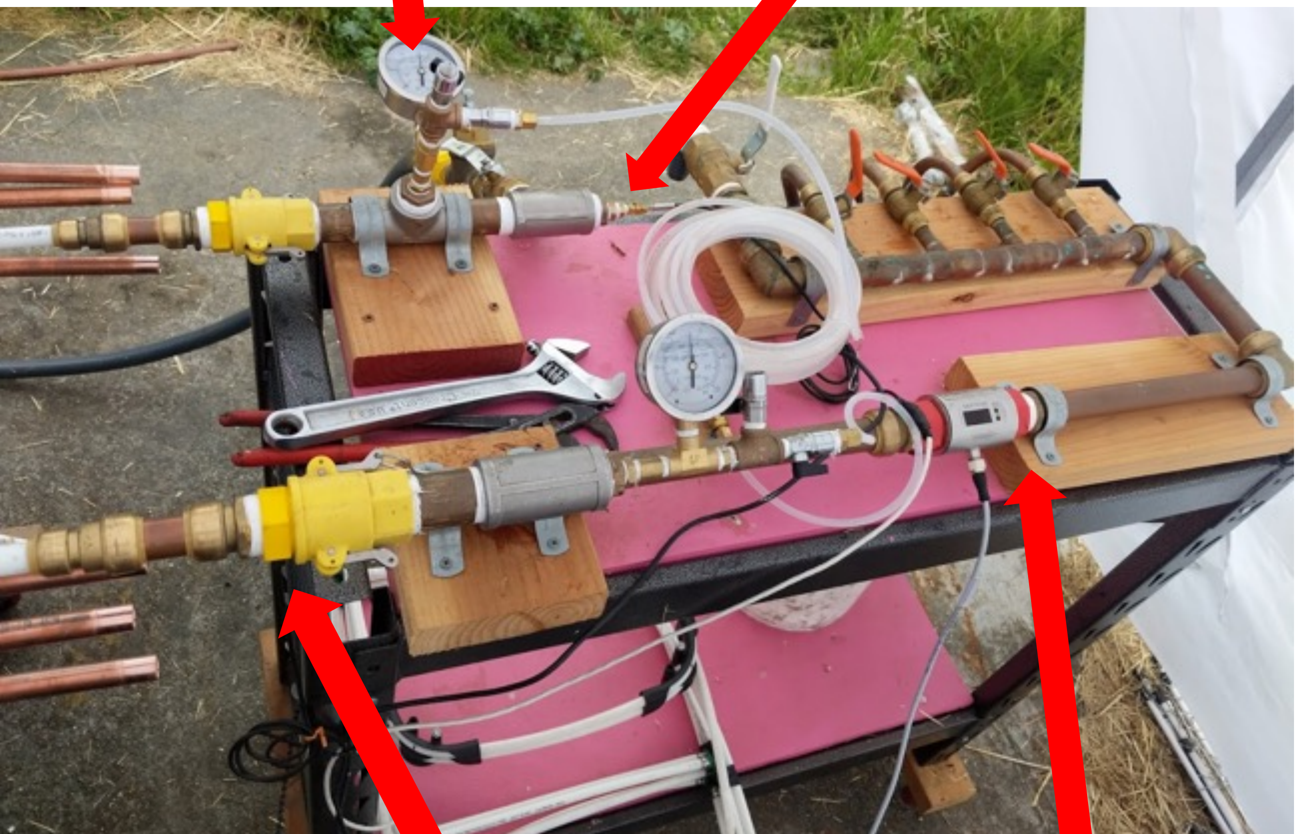
Test segment

Added a differential pressure gauge

Flow control

Visual pressure gauges (x2)

Temperature sensor (x2)



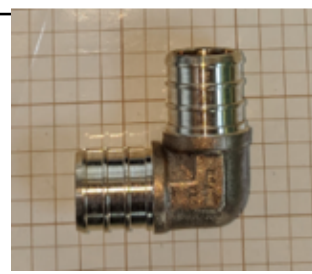
Adapters to switch out test segments

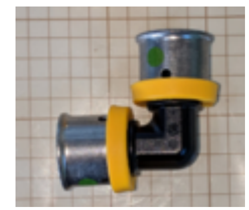
Flow meter after the other measurements

Pressure Tank

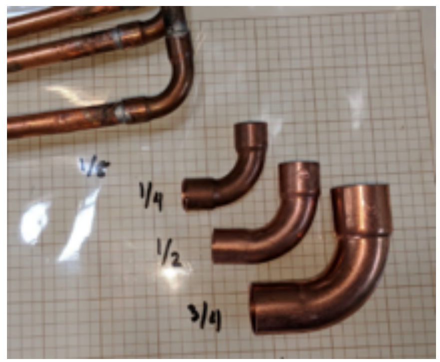
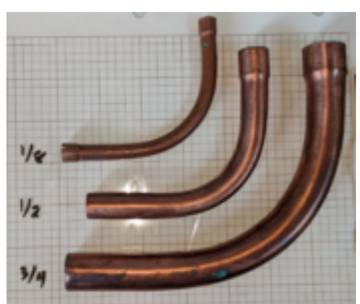
Data collection

Elbows - PEX

Technology (PEX)	Image
Poly Push to Connect Inner Seal ¾ in	 
Brass Push to Connect Outer Seal ¾ in	 
Brass Crimp ¾ in	
Poly Crimp ¾ in	

Technology (PEX)	Image
Brass Press ½ in	
Poly Press ½ in	
Bend Support	
Poly Expansion ¾ in	

Elbows – Copper Type-L

Technology (Copper)	Image
Elbow (tight inside corner)	
Long Radius Sweep	
Swoop	

More Copper Elbows – Type L

Long radius   Short radius

Nominal Diameter

1”

3/4”

5/8”

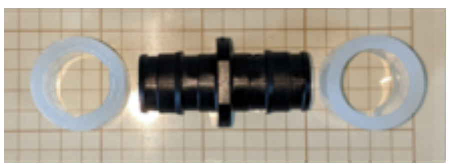
1/2”

3/8”

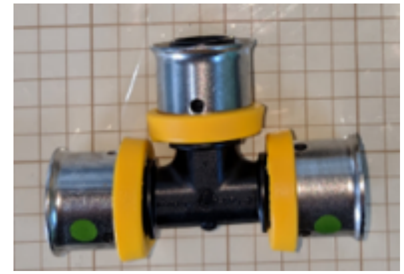
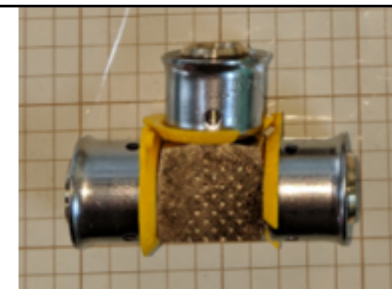
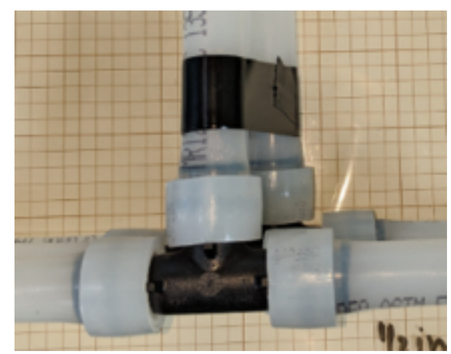
1/4”

1/8”

Couplings

Technology (PEX)	Image
Poly Press ¾ in	
Brass Press ¾ in	
Poly Expansion ½ in	

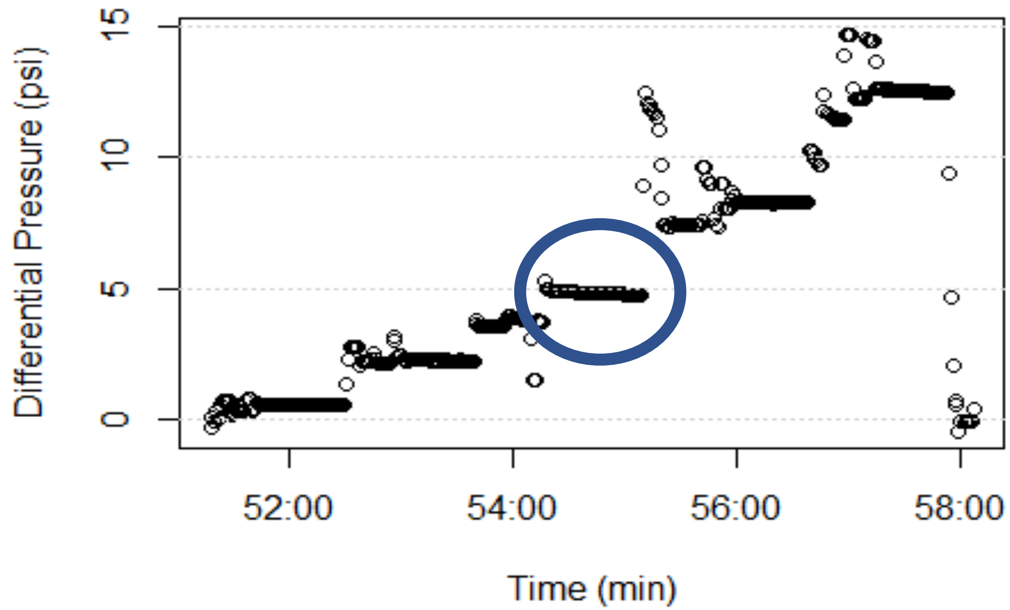
Tees

Technology (PEX)	Image
Poly Press ½ in	
Brass Press ½ in	
Poly Expansion ½ in	

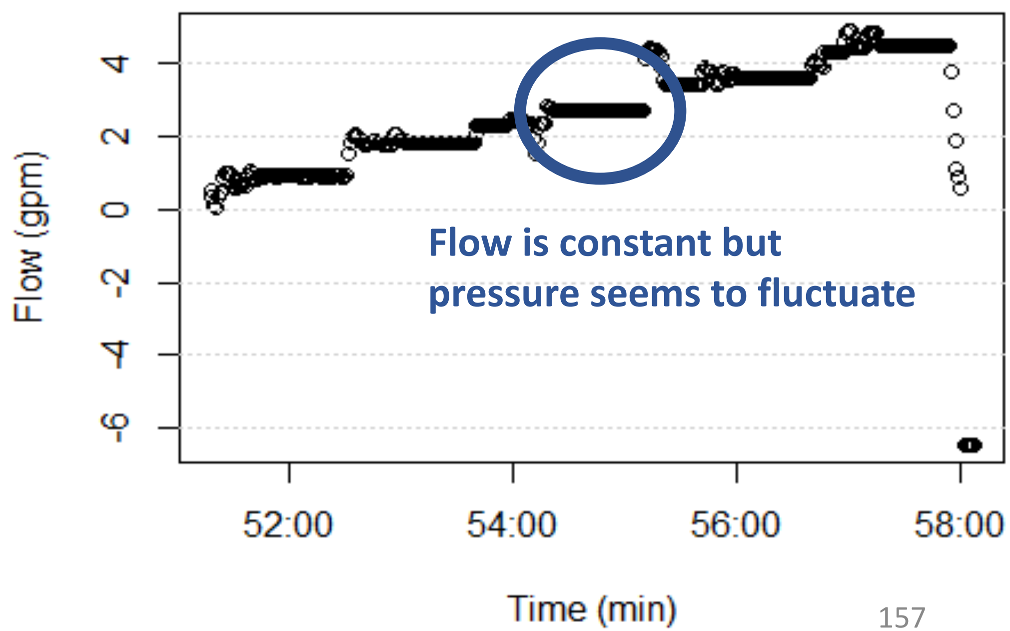
Data Collection

- Start test by running at maximum velocity. If it fails, reduce the number of fittings
- Observe raw data between runs to see if pressure was steady during test
- When flow switches regimes causes pressure to fluctuate more?

3/8 in Copper Elbow Pressure (psi)



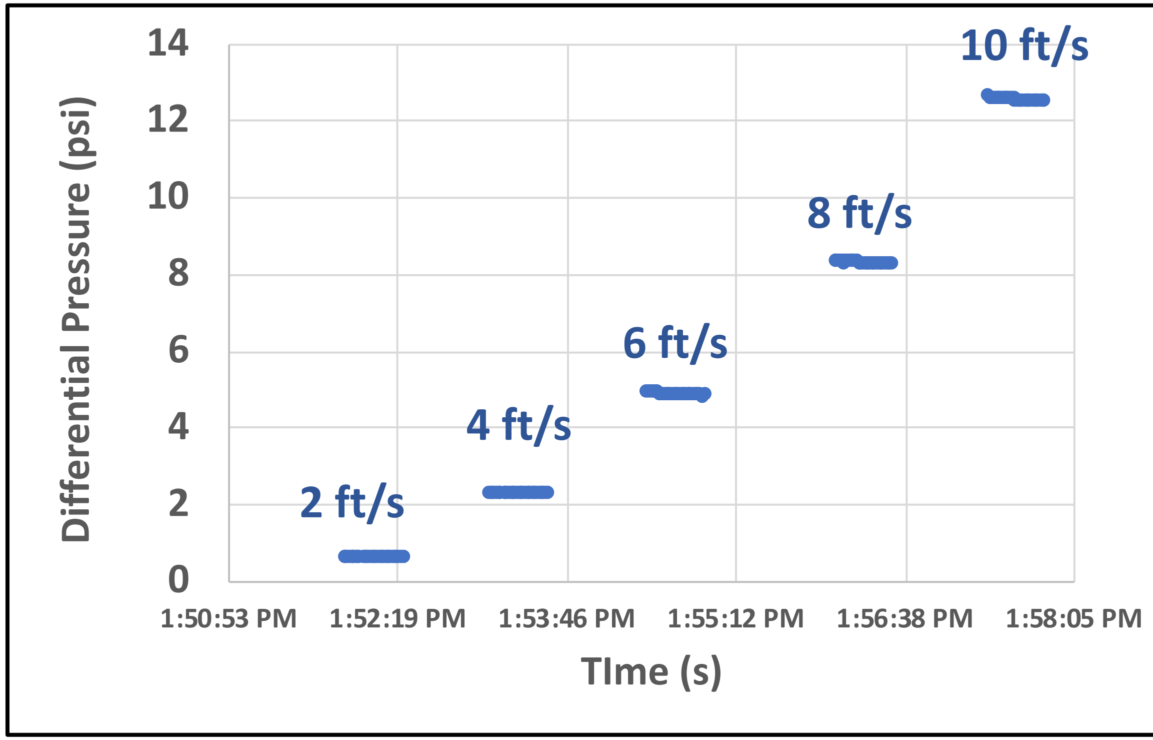
3/8 in Copper Elbow Flow (gpm)



Data Collection

- If pressure and flow look steady then data is cleaned to get a clear 30 seconds at each target flow rate (really velocity @ 2,4,6,8,10 ft/s)

3/8 in Copper Elbow Pressure (psi)



Target Flow Rates

Target Flow Rates for 0.375 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.375 inch PEX	0.60	1.20	1.80	2.40	3.00
0.375 inch CPVC	0.63	1.27	1.90	2.54	3.17
0.375 inch Copper	0.91	1.81	2.72	3.62	4.53

Target Flow Rates for 0.5 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.5 inch PEX	1.10	2.21	3.31	4.42	5.52
0.5 inch CPVC	1.15	2.30	3.45	4.61	5.76
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

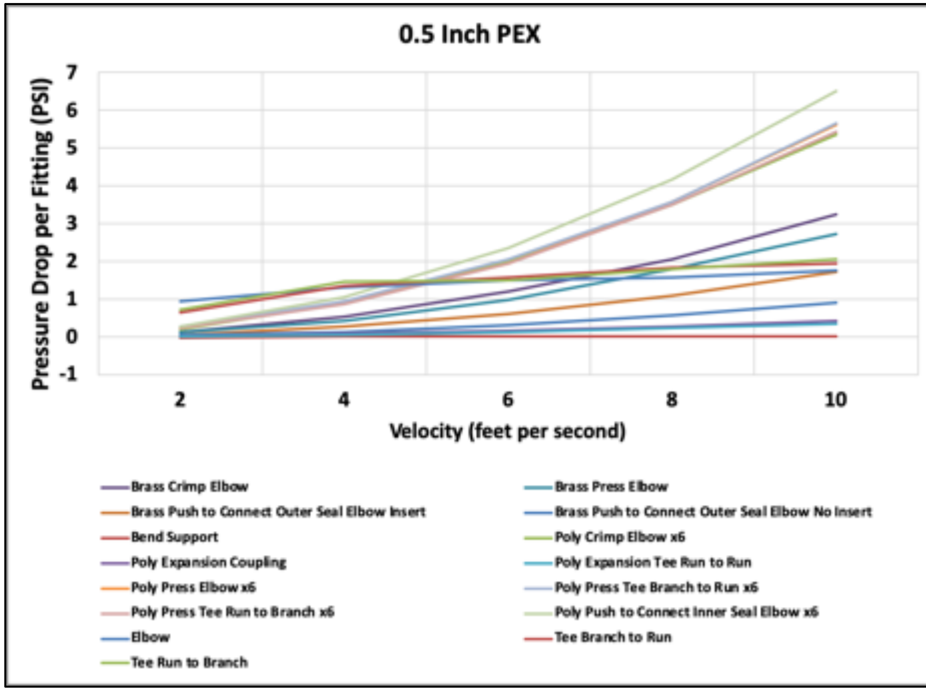
Comparing Pressure Drop – 0.5 inch Nominal

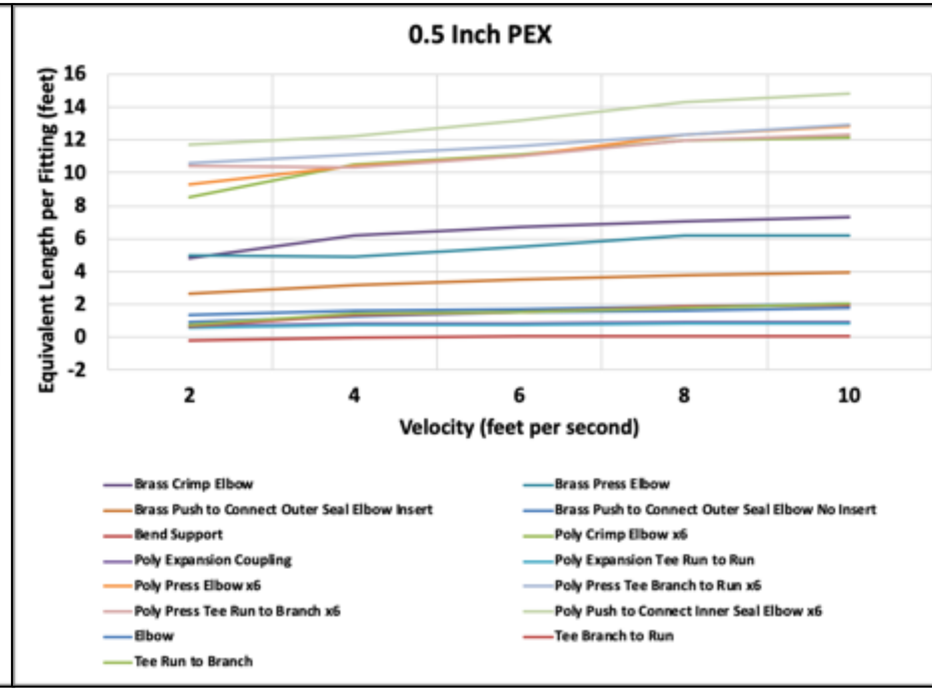
Pressure per Fitting (psi/fitting)					
Flow Velocity (ft/s)	**2**	**4**	**6**	**8**	**10**
	Flow Rate Target (gpm)				
0.5 inch PEX	**1.10**	**2.21**	**3.31**	**4.42**	**5.52**
0.5 inch CPVC	**1.15**	**2.30**	**3.45**	**4.61**	**5.76**
0.5 inch Copper	**1.45**	**2.91**	**4.36**	**5.82**	**7.27**
PEX Bend Support	0.00	0.00	0.01	0.01	0.03
Copper Elbow-Swoop	0.01	0.04	0.11	0.20	0.31
PEX Poly Expansion Tee Run to Run	0.01	0.06	0.13	0.24	0.36
PEX Poly Expansion Coupling	0.02	0.07	0.16	0.28	0.43
CPVC Tee Branch to Run	0.02	0.13	0.29	0.56	0.88
CPVC Tee Run to Branch	0.02	0.13	0.27	0.55	0.92
CPVC Elbow	0.03	0.12	0.28	0.48	0.80
PEX Brass Push to Connect Outer Seal Elbow No Insert	0.03	0.14	0.31	0.56	0.89
PEX Brass Push to Connect Outer Seal Elbow Insert	0.1	0.3	0.6	1.1	1.7
PEX Brass Crimp Elbow	0.1	0.5	1.2	2.1	3.2
PEX Brass Press Elbow	0.1	0.4	1.0	1.8	2.7
PEX Poly Crimp Elbow x6	0.2	0.9	2.0	3.5	5.4
PEX Poly Press Elbow x6	0.2	0.9	2.0	3.6	5.6
PEX Poly Press Tee Run to Branch x6	0.3	0.9	2.0	3.5	5.4
PEX Poly Press Tee Branch to Run x6	0.3	1.0	2.1	3.6	5.7
PEX Poly Push to Connect Inner Seal Elbow x6	0.3	1.0	2.3	4.2	6.5

Comparing Pressure Drop – 0.5 inch Nominal

Equivalent Length per Fitting (ft/fitting)					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.5 inch PEX	1.10	2.21	3.31	4.42	5.52
0.5 inch CPVC	1.15	2.30	3.45	4.61	5.76
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27
PEX Bend Support	-0.17	-0.03	0.03	0.04	0.06
Copper Elbow-Swoop	0.35	0.65	0.87	0.94	0.99
PEX Poly Expansion Tee Run to Run	0.55	0.72	0.75	0.81	0.82
CPVC Tee Branch to Run	0.65	1.36	1.57	1.84	1.96
PEX Poly Expansion Coupling	0.70	0.84	0.88	0.95	0.97
CPVC Tee Run to Branch	0.74	1.45	1.50	1.81	2.05
CPVC Elbow	0.94	1.32	1.51	1.59	1.77
PEX Brass Push to Connect Outer Seal Elbow No	1.4	1.6	1.7	1.9	2.0
PEX Brass Push to Connect Outer Seal Elbow Insert	2.7	3.2	3.5	3.7	3.9
PEX Brass Crimp Elbow	4.8	6.2	6.7	7.0	7.3
PEX Brass Press Elbow	5.0	4.9	5.5	6.2	6.2
PEX Poly Crimp Elbow x6	8.5	10.5	11.1	12.0	12.2
PEX Poly Press Elbow x6	9.3	10.4	11.0	12.3	12.8
PEX Poly Press Tee Run to Branch x6	10.4	10.3	11.1	11.9	12.3
PEX Poly Press Tee Branch to Run x6	10.6	11.1	11.6	12.3	12.9
PEX Poly Push to Connect Inner Seal Elbow x6	11.7	12.3	13.2	14.3	14.8

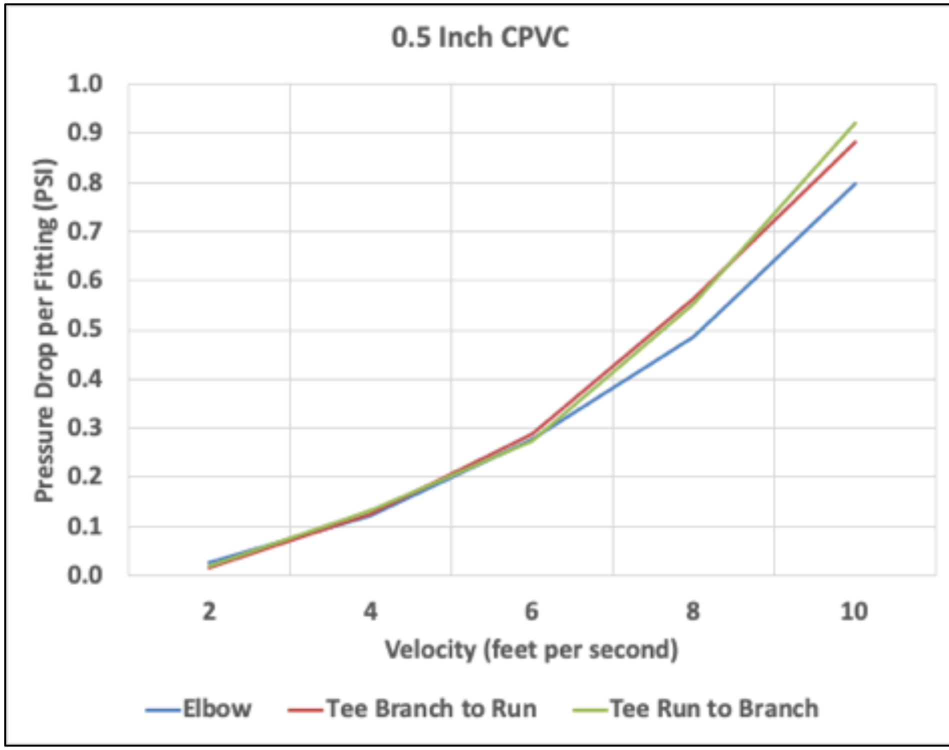
PEX-Pressure Drop in Assorted Fittings

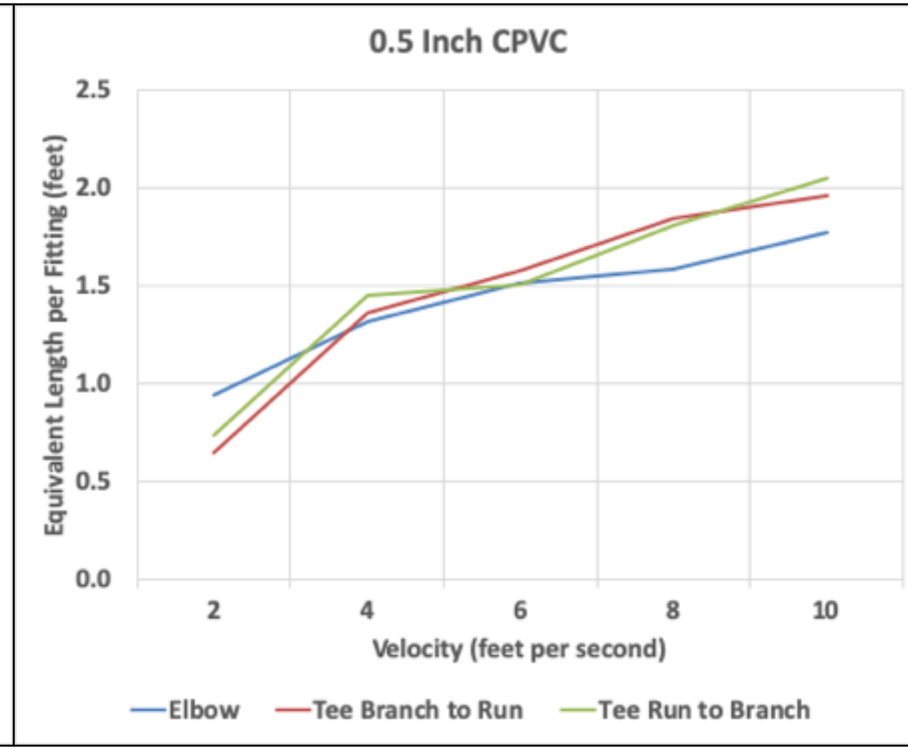




Target Flow Rates for 0.5 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.5 inch PEX	1.10	2.21	3.31	4.42	5.52
0.5 inch CPVC	1.15	2.30	3.45	4.61	5.76
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

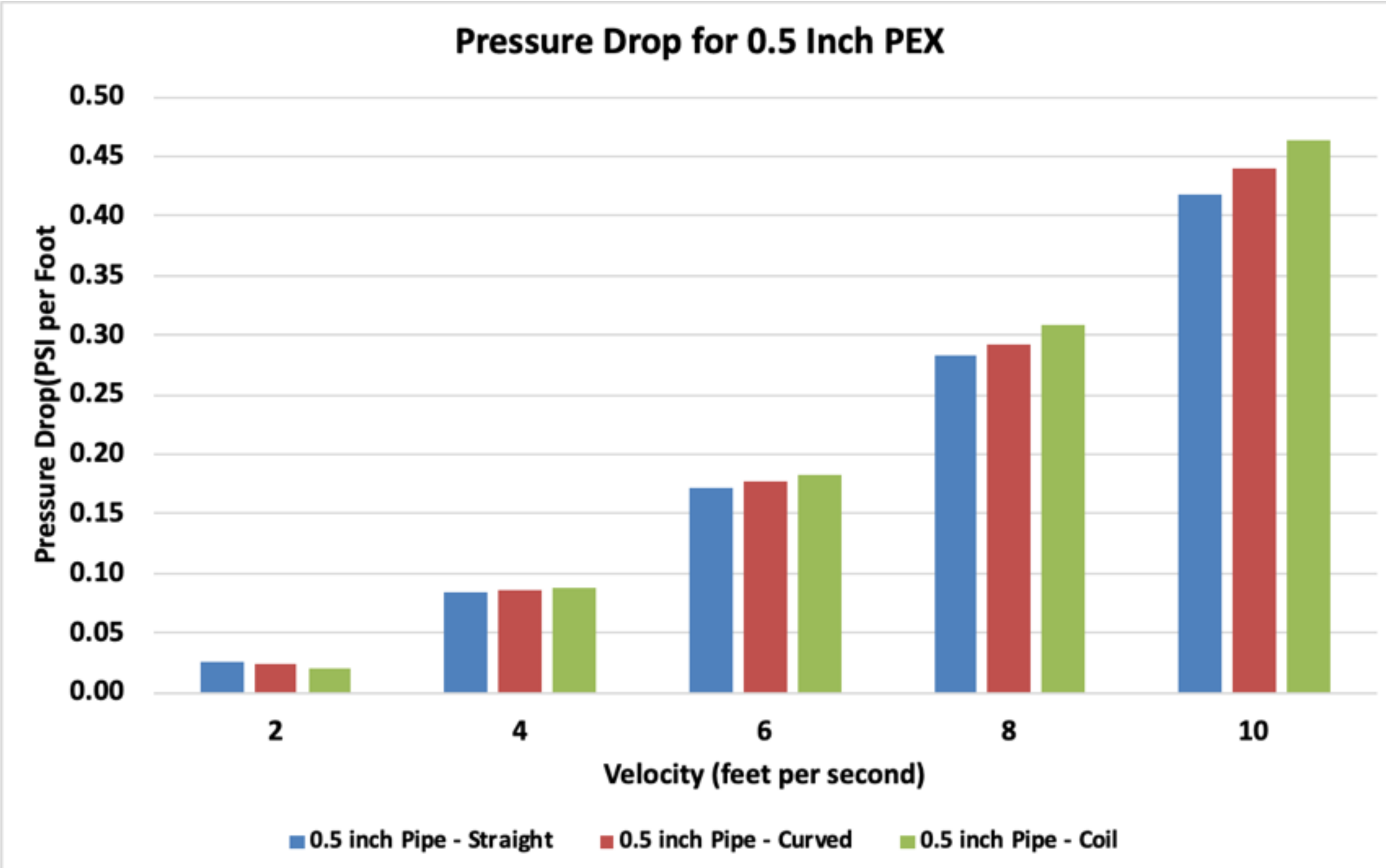
CPVC-Pressure Drop in Assorted Fittings



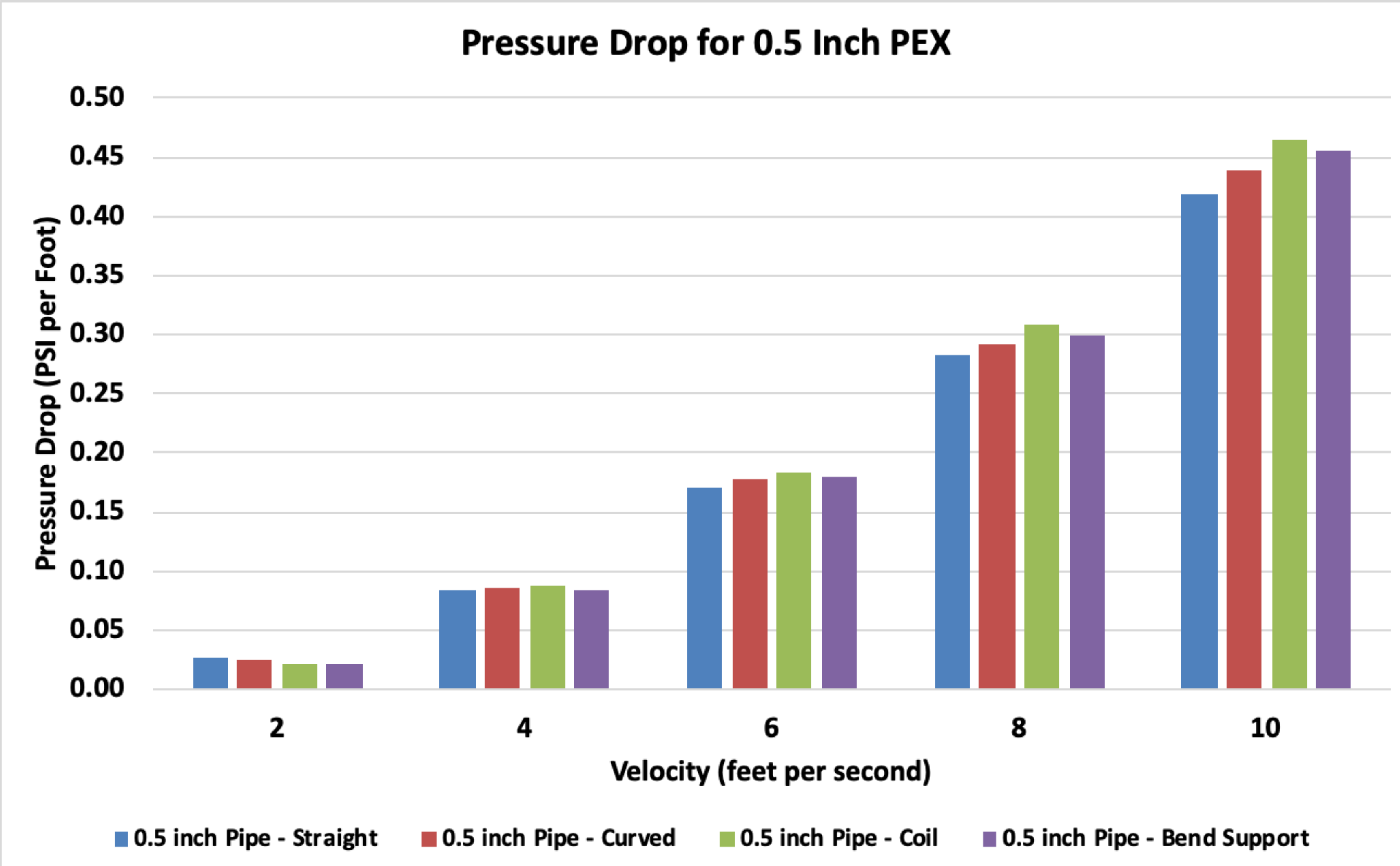


Target Flow Rates for 0.5 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.5 inch PEX	1.10	2.21	3.31	4.42	5.52
0.5 inch CPVC	1.15	2.30	3.45	4.61	5.76
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

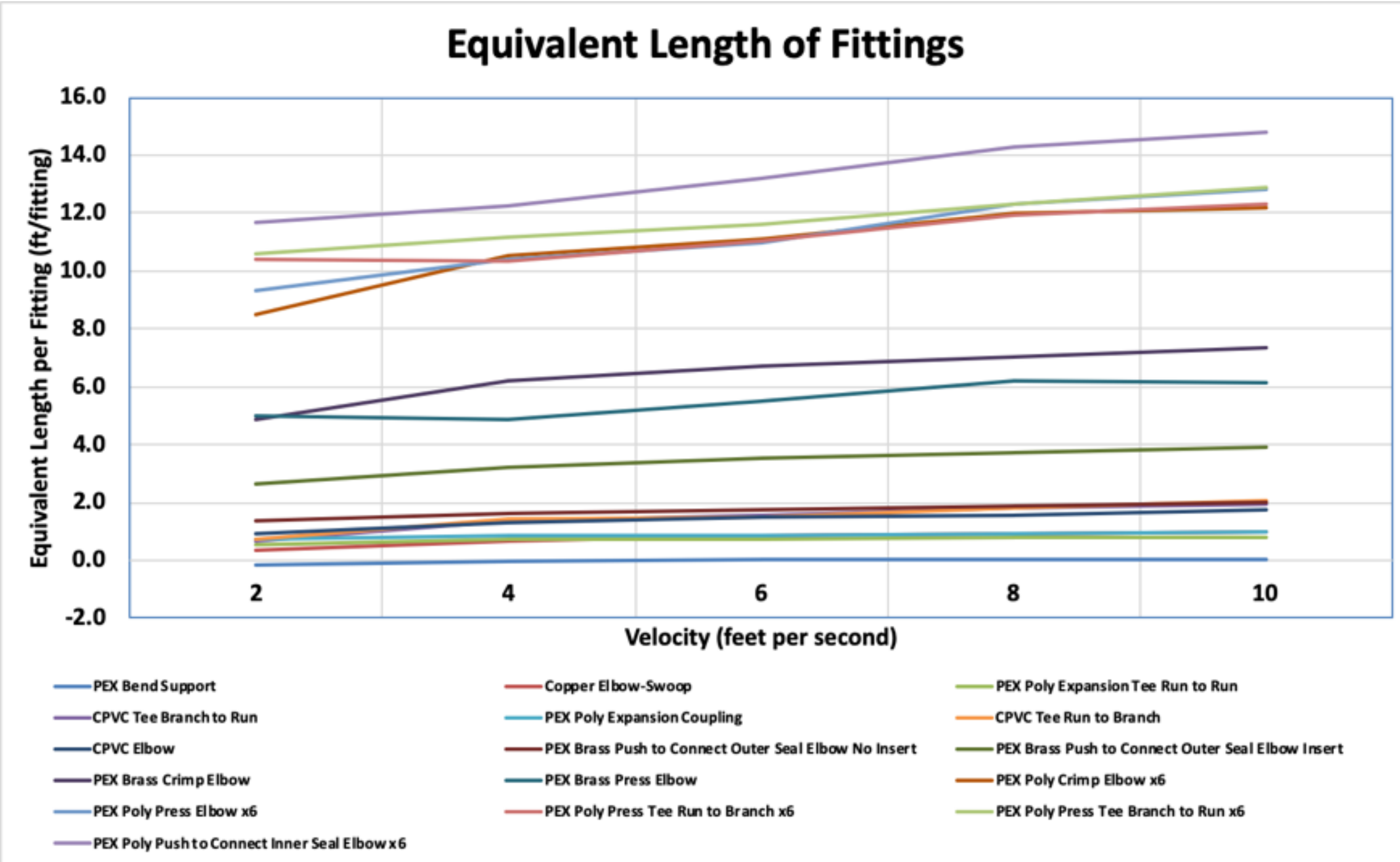
Comparing Configurations of PEX Pipe



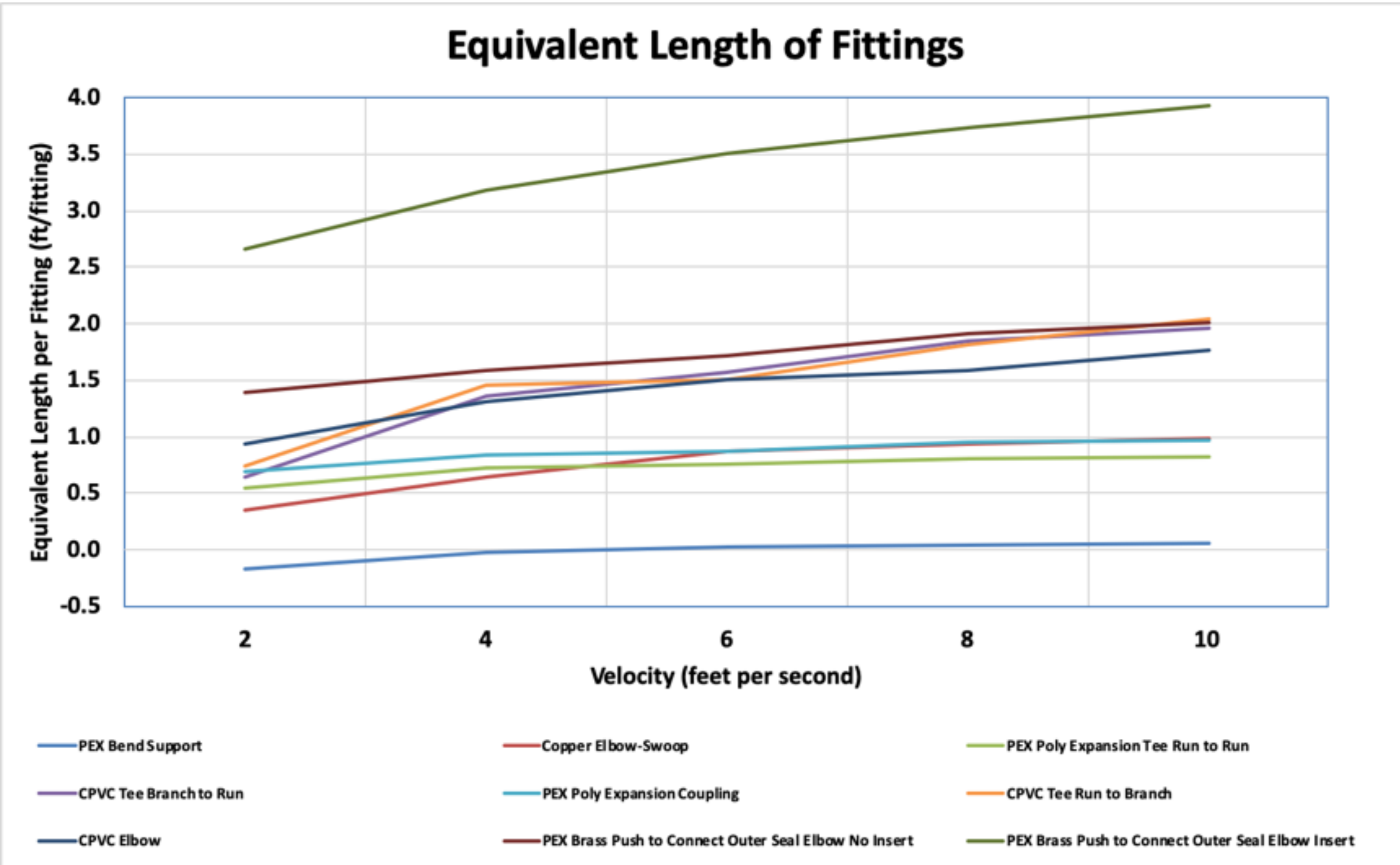
Comparing Configurations of PEX Pipe



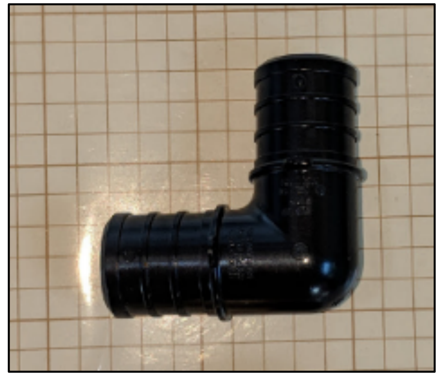
Equivalent Length of Assorted Fittings

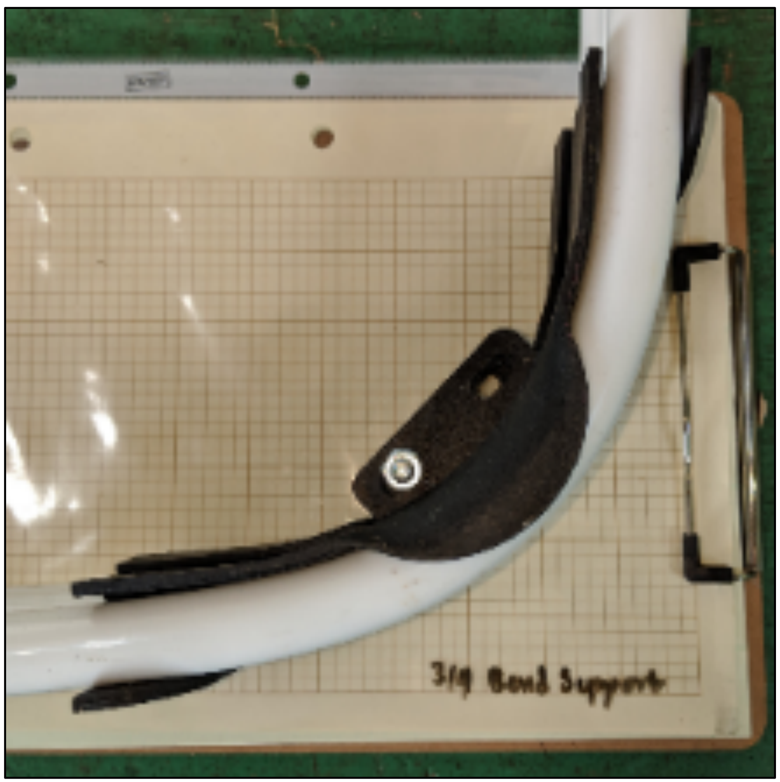


Equivalent Length of Assorted Fittings



Comparing a Range of Elbows for PEX Pipe

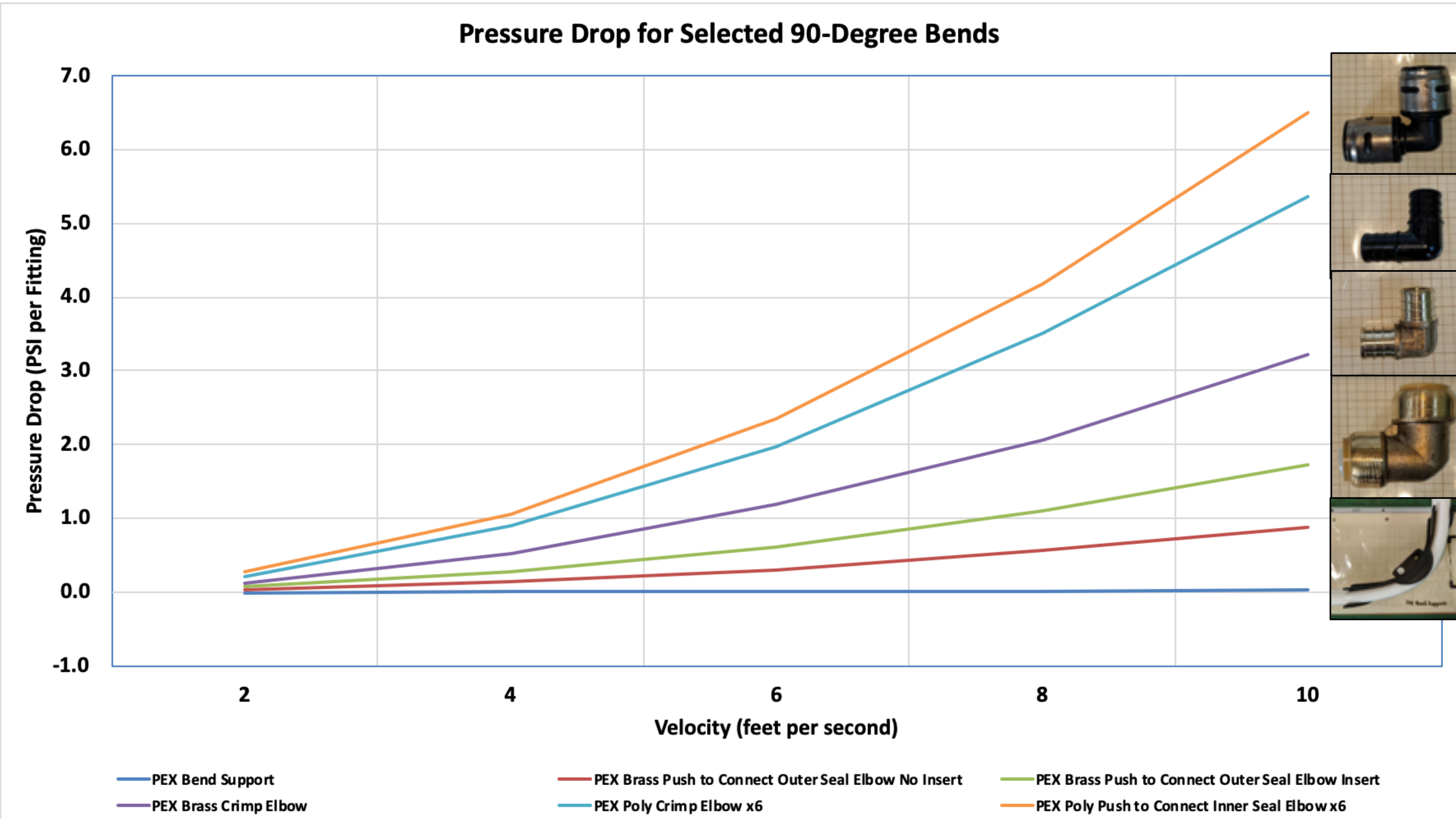




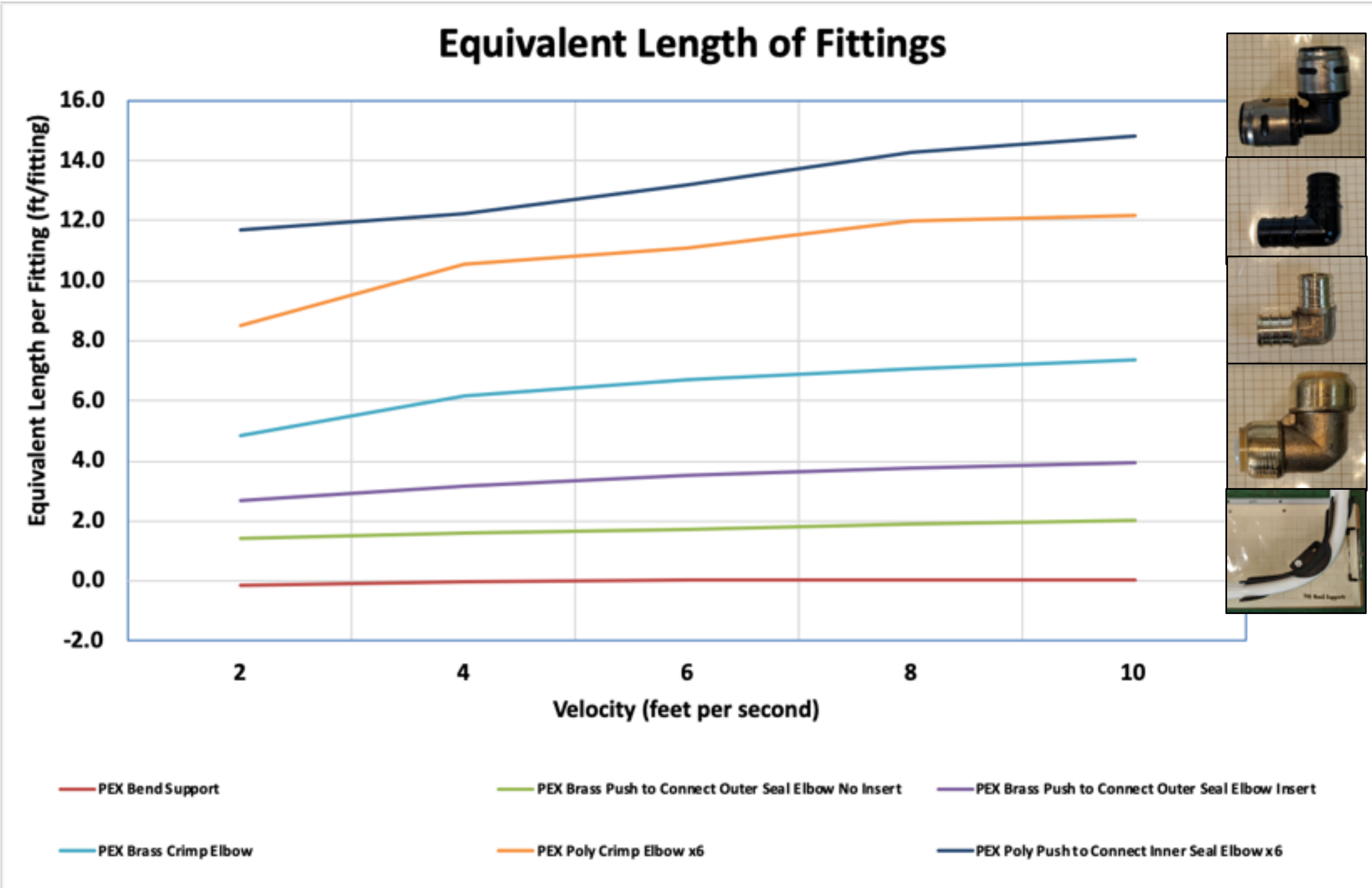
½ Inch PEX

With and without insert

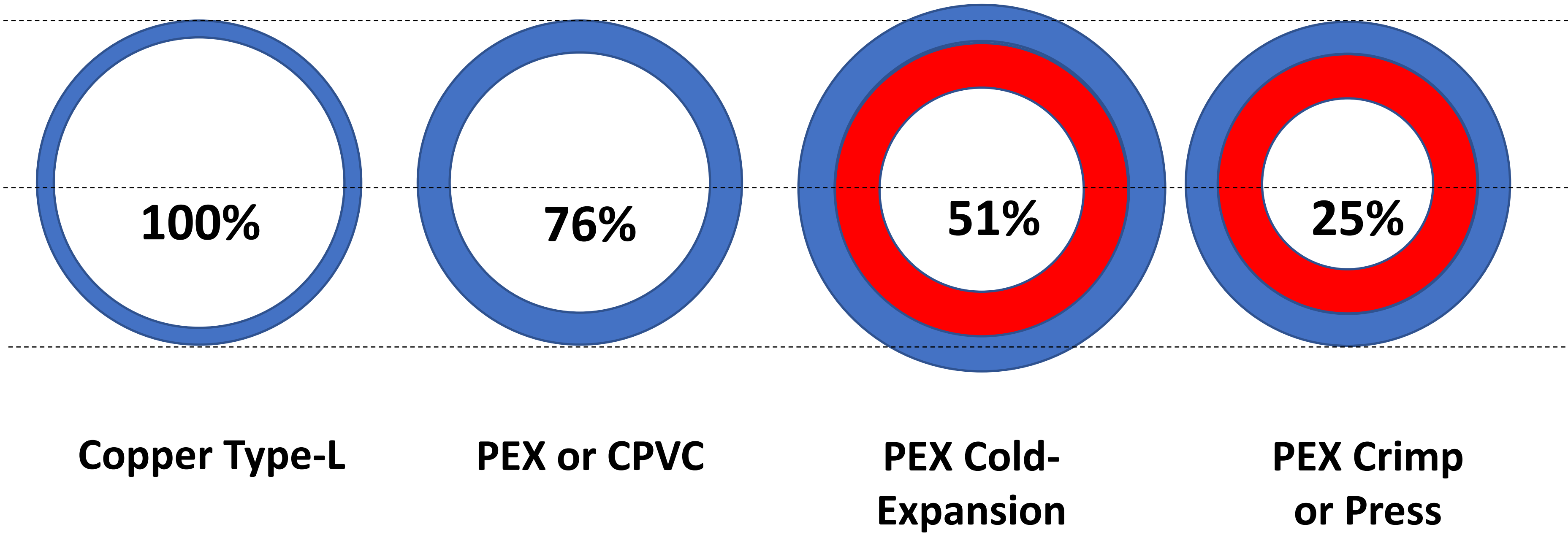
Pressure Drop of Assorted Elbows



Equivalent Length of Assorted Elbows

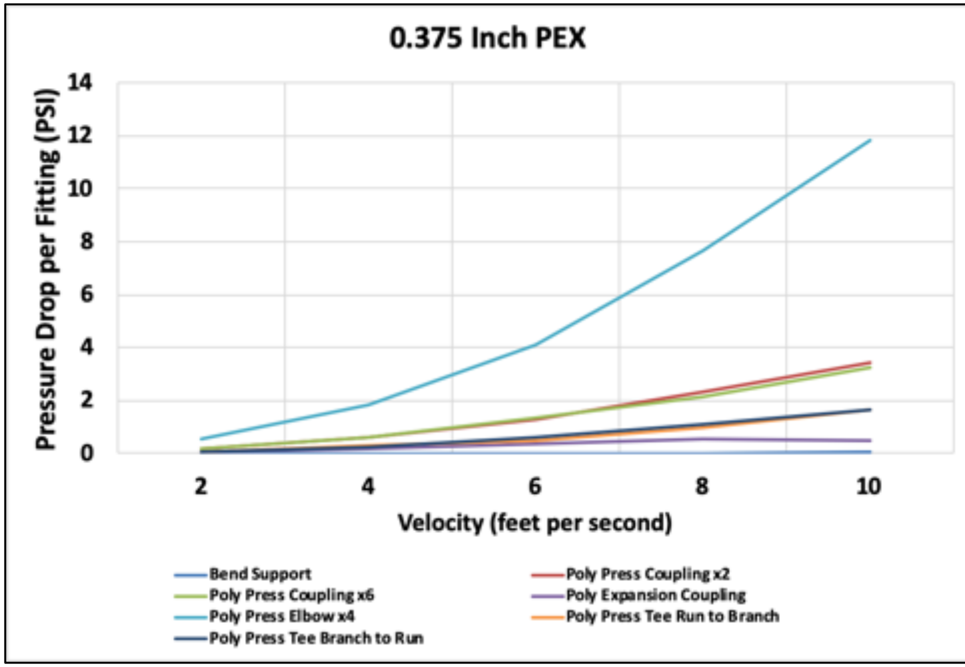


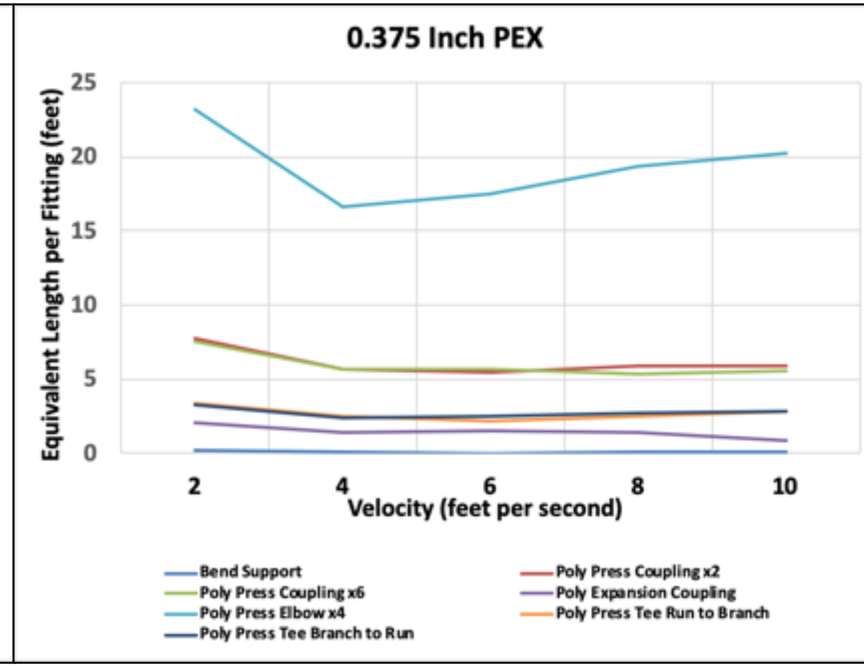
Relative Size of the Waterway for Selected 0.5 inch Pipe and Fittings



0.5 inch Nominal Pipe (inches)				
Size	**Nom OD**	**Wall Ave**	**Tol+/-**	**Nom ID**
1/2 PEX ASTM F876	0.625	0.070	0.010	0.475
1/2 CPVC, ASTM D2846	0.625	0.07	0.01	0.475
1/2 inch Copper Type-L ASTM B88	0.625	0.040	0.004	0.545

PEX-Pressure Drop in Assorted Fittings





Target Flow Rates for 0.375 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.375 inch PEX	0.60	1.20	1.80	2.40	3.00
0.375 inch CPVC	0.63	1.27	1.90	2.54	3.17
0.375 inch Copper	0.91	1.81	2.72	3.62	4.53

What is the Flow Regime?

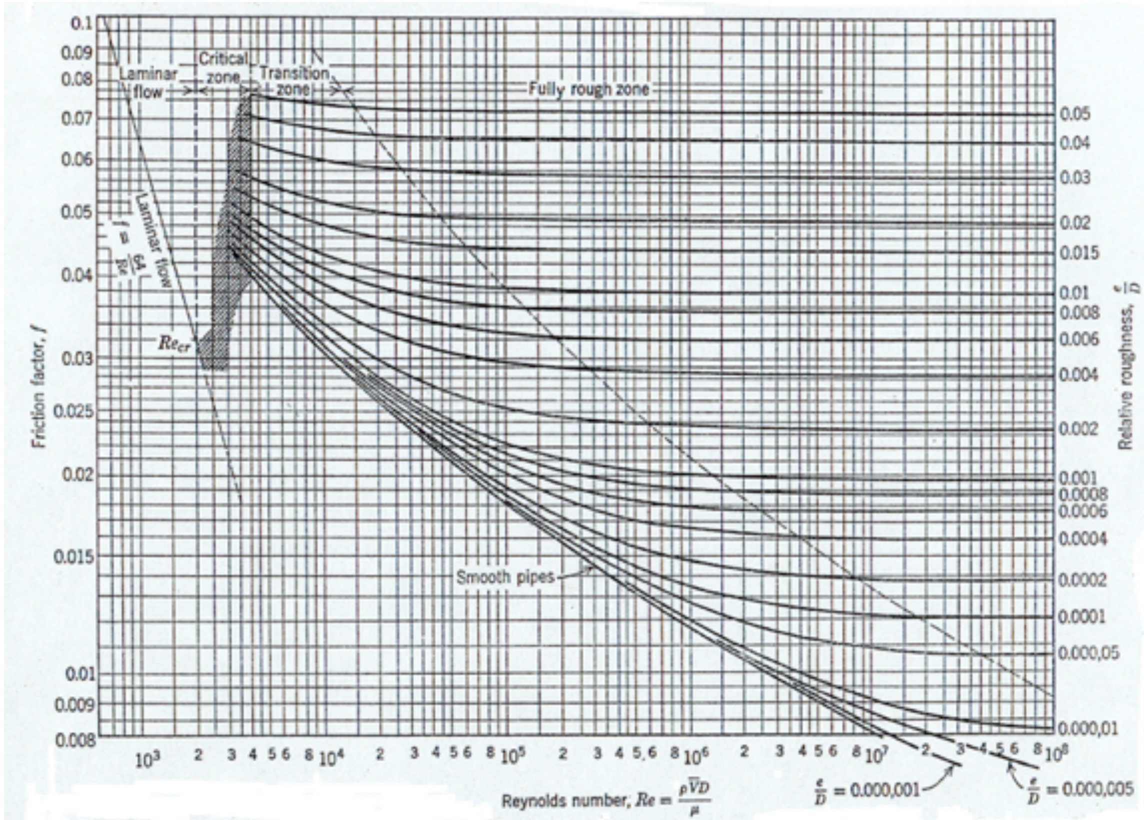


Fig. 8.14 Friction factor for fully developed flow in circular pipes. (Data from [6], used by permission.)

Legend	Regime	Re Range	1-D Dispersive Transport
	turbulent	20,000<**Re**	low (probably not important)
	transition	4,000<**Re**<20,000	low to moderate (might be important)
	critical	2,000<**Re**<4,000	moderate to high (likely to be important)
	laminar	0<**Re**<2,000	high (important)

Variation of Viscosity Due to Temperature

How large is the difference in viscosity between water at 70F and water at 140F?

Temp (F)	Viscosity (ft^2/s)
50	0.000014063
60	0.000012075
70	0.000010503
80	0.00000925
90	0.000008234
100	0.000007392
110	0.000006682
120	0.000006075
130	0.000005551
140	0.000005102

Ratio of the Viscosity at
70F and 140F

0.000010503/0.000005102 = 2.01

Copper Type-L

Temp = 50 F / 10 C		Flow Rate (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.315	1921	3842	7684	11526	15368	19211	23053	26895	30737	34579	38421
0.375	0.430	1407	2815	5629	8444	11258	14073	16887	19702	22517	25331	28146
0.500	0.545	1110	2221	4441	6662	8883	11103	13324	15545	17765	19986	22207
0.750	0.785	771	1542	3083	4625	6167	7709	9250	10792	12334	13876	15417
1.000	1.025	590	1181	2361	3542	4723	5904	7084	8265	9446	10627	11807
1.250	1.265	478	957	1913	2870	3827	4784	5740	6697	7654	8611	9567
Temp = 70 F / 21 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.315	2572	5144	10289	15433	20578	25722	30866	36011	41155	46300	51444
0.375	0.430	1884	3769	7537	11306	15074	18843	22611	26380	30149	33917	37686
0.500	0.545	1487	2973	5947	8920	11894	14867	17840	20814	23787	26760	29734
0.750	0.785	1032	2064	4129	6193	8257	10322	12386	14450	16515	18579	20643
1.000	1.025	790	1581	3162	4743	6324	7905	9486	11067	12648	14229	15810
1.250	1.265	641	1281	2562	3843	5124	6405	7686	8967	10248	11529	12810
Temp = 120 F / 49 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.315	4447	8894	17788	26682	35576	44471	53365	62259	71153	80047	88941
0.375	0.430	3258	6515	13031	19546	26062	32577	39093	45608	52124	58639	65155
0.500	0.545	2570	5141	10281	15422	20563	25703	30844	35984	41125	46266	51406
0.750	0.785	1784	3569	7138	10707	14276	17845	21414	24983	28552	32121	35690
1.000	1.025	1367	2733	5467	8200	10933	13667	16400	19133	21867	24600	27333
1.250	1.265	1107	2215	4429	6644	8859	11074	13288	15503	17718	19933	22147
Temp = 140 F / 60 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.315	5295	10590	21181	31771	42361	52952	63542	74132	84722	95313	105903
0.375	0.430	3879	7758	15516	23274	31032	38790	46548	54306	62064	69822	77580
0.500	0.545	3061	6121	12242	18363	24484	30605	36726	42847	48968	55089	61210
0.750	0.785	2125	4250	8499	12749	16998	21248	25498	29747	33997	38247	42496
1.000	1.025	1627	3255	6509	9764	13018	16273	19527	22782	26037	29291	32546
1.250	1.265	1319	2637	5274	7911	10548	13186	15823	18460	21097	23734	26371

Reynolds Number and Flow Regime for Circular Pipes (water temperatures from 50 F to 140 F)

PEX

Temp = 50 F / 10 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.25	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.241	2421	4841	9682	14523	19364	24205	29046	33888	38729	43570	48411
0.375	0.350	1614	3227	6455	9682	12910	16137	19364	22592	25819	29046	32274
0.500	0.475	1210	2421	4841	7262	9682	12103	14523	16944	19364	21785	24205
0.750	0.671	807	1614	3227	4841	6455	8068	9682	11296	12910	14523	16137
1.000	0.862	605	1210	2421	3631	4841	6051	7262	8472	9682	10892	12103
1.250	1.054	484	968	1936	2905	3873	4841	5809	6778	7746	8714	9682

Temp = 70 F / 21 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.241	3241	6482	12964	19446	25928	32410	38892	45374	51856	58338	64820
0.375	0.350	2161	4321	8643	12964	17285	21607	25928	30249	34570	38892	43213
0.500	0.475	1620	3241	6482	9723	12964	16205	19446	22687	25928	29169	32410
0.750	0.671	1080	2161	4321	6482	8643	10803	12964	15125	17285	19446	21607
1.000	0.862	810	1620	3241	4861	6482	8102	9723	11343	12964	14584	16205
1.250	1.054	648	1296	2593	3889	5186	6482	7778	9075	10371	11668	12964

Temp = 120 F / 49 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.250	0.241	5603	11207	22413	33620	44826	56033	67240	78446	89653	100859	112066
0.375	0.350	3736	7471	14942	22413	29884	37355	44826	52297	59768	67240	74711
0.500	0.475	2802	5603	11207	16810	22413	28016	33620	39223	44826	50430	56033
0.750	0.671	1868	3736	7471	11207	14942	18678	22413	26149	29884	33620	37355
1.000	0.862	1401	2802	5603	8405	11207	14008	16810	19612	22413	25215	28016
1.250	1.054	1121	2241	4483	6724	8965	11207	13448	15689	17931	20172	22413

Temp = 140 F / 60 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
0.250	0.241	6672	13344	26688	40031	53375	66719	80063	93407	106750	120094	133438
0.375	0.350	4448	8896	17792	26688	35583	44479	53375	62271	71167	80063	88959
0.500	0.475	3336	6672	13344	20016	26688	33359	40031	46703	53375	60047	66719
0.750	0.671	2224	4448	8896	13344	17792	22240	26688	31136	35583	40031	44479
1.000	0.862	1668	3336	6672	10008	13344	16680	20016	23352	26688	30024	33359
1.250	1.054	1334	2669	5338	8006	10675	13344	16013	18681	21350	24019	26688

Reynolds Number and Flow Regime for Circular Pipes (water temperatures from 50 F to 140 F)

CPVC

Temp = 50 F / 10 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
0.250	0.245	2421	4841	9682	14523	19364	24205	29046	33888	38729	43570	48411
0.375	0.360	1614	3227	6455	9682	12910	16137	19364	22592	25819	29046	32274
0.500	0.485	1210	2421	4841	7262	9682	12103	14523	16944	19364	21785	24205
0.750	0.695	807	1614	3227	4841	6455	8068	9682	11296	12910	14523	16137
1.000	0.901	605	1210	2421	3631	4841	6051	7262	8472	9682	10892	12103
1.250	1.105	484	968	1936	2905	3873	4841	5809	6778	7746	8714	9682

Temp = 70 F / 21 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
0.250	0.245	3241	6482	12964	19446	25928	32410	38892	45374	51856	58338	64820
0.375	0.360	2161	4321	8643	12964	17285	21607	25928	30249	34570	38892	43213
0.500	0.485	1620	3241	6482	9723	12964	16205	19446	22687	25928	29169	32410
0.750	0.695	1080	2161	4321	6482	8643	10803	12964	15125	17285	19446	21607
1.000	0.901	810	1620	3241	4861	6482	8102	9723	11343	12964	14584	16205
1.250	1.105	648	1296	2593	3889	5186	6482	7778	9075	10371	11668	12964

Temp = 120 F / 49 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
0.250	0.245	5603	11207	22413	33620	44826	56033	67240	78446	89653	100859	112066
0.375	0.360	3736	7471	14942	22413	29884	37355	44826	52297	59768	67240	74711
0.500	0.485	2802	5603	11207	16810	22413	28016	33620	39223	44826	50430	56033
0.750	0.695	1868	3736	7471	11207	14942	18678	22413	26149	29884	33620	37355
1.000	0.901	1401	2802	5603	8405	11207	14008	16810	19612	22413	25215	28016
1.250	1.105	1121	2241	4483	6724	8965	11207	13448	15689	17931	20172	22413

Temp = 140 F / 60 C		Flow (gpm)										
Nominal Diameter (in)	Actual Diameter (in)	0.250	0.500	1.000	1.500	2.000	2.500	3.000	3.500	4.000	4.500	5.000
0.250	0.245	6672	13344	26688	40031	53375	66719	80063	93407	106750	120094	133438
0.375	0.360	4448	8896	17792	26688	35583	44479	53375	62271	71167	80063	88959
0.500	0.485	3336	6672	13344	20016	26688	33359	40031	46703	53375	60047	66719
0.750	0.695	2224	4448	8896	13344	17792	22240	26688	31136	35583	40031	44479
1.000	0.901	1668	3336	6672	10008	13344	16680	20016	23352	26688	30024	33359
1.250	1.105	1334	2669	5338	8006	10675	13344	16013	18681	21350	24019	26688

Reynolds Number and Flow Regime for Circular Pipes (water temperatures from 50 F to 140 F)

Questions?

Thank you!