

**Best Practices for High Performance Hot Water Systems**  
by Gary Klein on November 11, 2025  
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**Description**

- Do you want higher performance at lower costs? Every decision that increases pipe length decreases efficiency and adds costs. Right-sizing pipes and water heaters is essential. Integrating air source heat pump water heaters into high performance homes can be challenging. This session will do a deep dive into the essentials. Bring the key questions you would like to have answered!



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**Learning Objectives**

- Explain why time-to-tap and volume-until-hot are goals set during the schematic design process can reduce water consumption by incorporating right-sizing into the plumbing design process via the IAPMO Water Demand Calculator
- Discuss the benefits of architectural compactness.
- Appreciate the decisions that need to be made to minimize pressure loss in the building's water distribution system and specify pressure independent flow regulators for faucets and showerheads
- Understand the best ways to potentially lower utility bills by integrating air-source heat pump water heaters into a high-performance home.



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**Best Practices for  
High Performance Hot Water Systems**

Pennsylvania Housing Research Center  
November 11, 2025

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### Water, Energy, and Time Efficient Hot Water Systems

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#### Do You Know:

- *Anyone who waits a long time to get hot water somewhere in their house? At their job? In their favorite restaurant?*
- *Someone who has ever run out of hot water?*
- *Any Communities that have a "you can't build unless you can guarantee a long-term supply of water" ordinance?*
- *Someone who has a "routine" that they do while waiting for hot water to arrive at their shower? At the kitchen sink? For the dishwasher?*
- *Anyone who wants instantaneous hot water?*
- *Someone who thinks that a tankless water heater is instantaneous?*
- *Anyone who would like to learn how to get hot water to every fixture wasting no more than 1 cup waiting for the hot water to arrive?*

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#### What Are We Aiming For?

1. People want:
  - The water flowing from their showers and faucets to "feel" right.
  - Their toilets to flush first time, every time.
  - Clean clothes, dishes and bodies
  - The service of hot water, as efficiently as possible.
    - Hot water now
    - Never run out in my shower
2. It does not make sense to discuss efficiency until the desired service has been provided.

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### How Do We Increase Customer Satisfaction?

#### *a.k.a. Best Practices for Hot Water Distribution*

1. Reduce the Time-to-Tap
  - a) Reduce the Distance from the Source to the Use
  - b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the Pressure Drop
  - a) In the Pipe and Fittings
    - 1) Minimize the length
    - 2) Minimize the number of pressure-consuming fittings
  - b) In the Faucets and Shower Valves
3. Install Pressure-Independent Faucet Aerators and Showerheads

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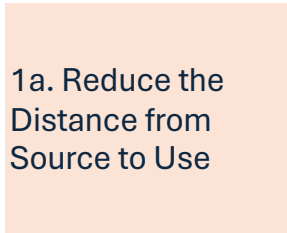
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### 1a. Reduce the Distance from Source to Use

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### 1a. 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?
    - 5 seconds?
    - 10 seconds?
    - Longer? Shorter?
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!*

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**The Ideal  
Hot Water Distribution System**

- Has the smallest volume (length and smallest “possible” diameter) of pipe from the **source of hot water** to the hot water outlet.
- Sometimes the **source of hot water** is the water heater, sometimes a trunk line.
- For a given layout (floor plan) of hot water locations the system will have:
  - The shortest buildable trunk line
  - Few or no branches
  - The shortest buildable twigs
  - The fewest plumbing restrictions
  - Insulation on all hot water pipes, minimum R-4

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**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.**

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**Question:**

If you want to waste no more than 1 cup  
while waiting for hot water to arrive,  
what is the maximum amount of water  
that can be in the pipe that is not usefully hot?

**Answer:**

*1 cup = 8 ounces = 1/16<sup>th</sup> gallon = 0.0625 gallon*

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### How Close Can We Get?

- 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

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### Time-to-Tap and Volume-until-Hot

More water than is in a pipe comes out of it before hot water 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.

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.

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### How Long Should We Wait?

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
1	4	1.9	0.9	0.6	0.5	0.4
2	8	4	1.9	1.3	0.9	0.8
4	15	8	4	2.5	1.9	1.5
8	30	15	8	5	4	3
12	45	23	11	8	6	5
16	60	30	15	10	8	6
32	120	60	30	20	15	12
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 – 2<sup>nd</sup> Edition, ASPE, 2003, page 234

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**Calculating Time-to-Tap and Volume-to-Hot**

**Time-to-tap (seconds)** = Feet \* (Ounces/foot) \* (1 gallon/128 ounces) / gpm \* 1 minute/60 seconds

$$= \frac{\text{Feet} * 1 \text{ oz} * 1 \text{ gallon} * 1 \text{ minute} * 60 \text{ seconds}}{1 \text{ foot} * 128 \text{ oz} * 1 \text{ gallon} * 1 \text{ minute}}$$

= 0.46875 \* Feet \* ounces/foot \* gallons per minute

**Volume-to-Hot (gallons)** =  $\frac{\text{Feet} * 1 \text{ oz} * 1 \text{ gallon}}{128 \text{ oz}}$  1 foot \*

**Adjustment** = Range of extra volume or time until hot is 1.5-2.5  
 ≈ 2 \* time in seconds based on pipe volume  
 ≈ 2 \* gallons in the pipe

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**Length of Pipe that Holds 8 oz of Water**

	3/8" CTS	1/2" CTS	3/4" CTS	1" CTS
	ft/cup	ft/cup	ft/cup	ft/cup
"K" copper	9.48	5.52	2.76	1.55
"L" copper	7.92	5.16	2.49	1.46
"M" copper	7.57	4.73	2.33	1.38
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02
Copper	~8 feet	~5 feet	~2.5 feet	~1.5 feet
CPVC/PEX	~12 feet	~6.5 feet	~3 feet	~2 feet

*Best practice: No more than 2 cups from the source to the use!*

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**Distance Between the Wet Rooms and the Water Heater**

Example:

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



*Hot Water System Rectangle*

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**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.

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**Largest Hot Water System Rectangle So Far**

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

~155%  
(6,924 sq ft)




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**Best 1-Story So Far...**

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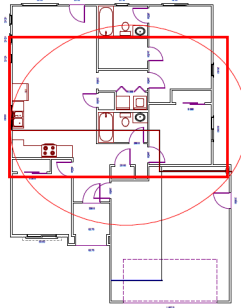
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In the beginning:

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

~79%  
(1,279 sq ft)



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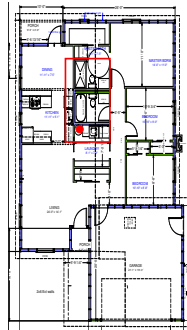
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1<sup>st</sup> iteration v1:

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)



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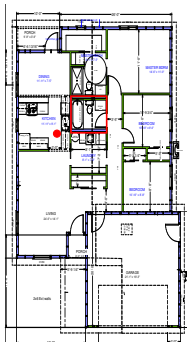
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1<sup>st</sup> iteration v2:

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

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



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**2<sup>nd</sup> iteration:**

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

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



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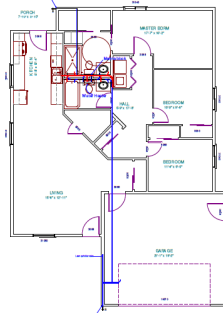
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**3<sup>rd</sup> iteration:**

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

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



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**Best 2-Story So Far...**

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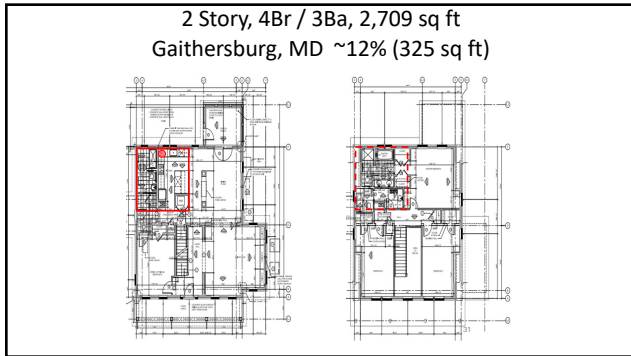
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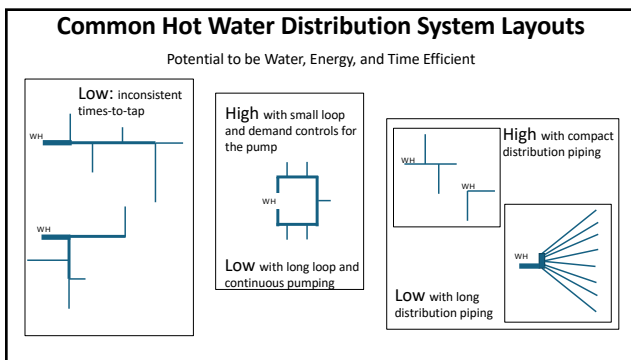
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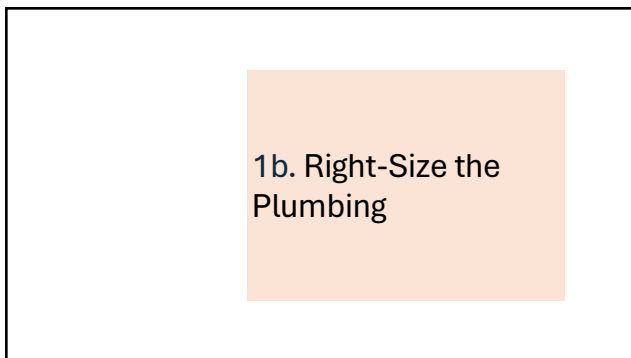
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### 1b. Right-Size the Plumbing

**Which Pipe Sizing Method(s) do you use?**

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

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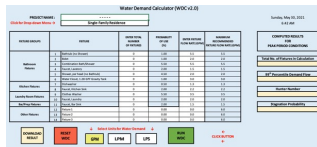
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### Estimating Peak Flow Rates

**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**



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

*What if we could use real data for different occupancies?*

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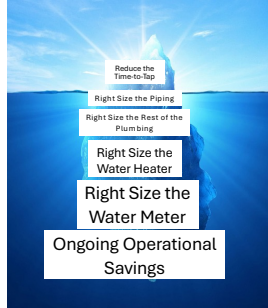
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*Time-to-Tap is the Tip of the Iceberg*



### 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
<b>Total First Cost Savings</b>	<b>\$58,000 – \$108,000</b>
<b>First Cost Savings/Apartment</b>	<b>\$600 – \$1,200</b>
<b>Annual Operational Savings (Does not include energy and sewer)</b>	<b>\$1,800 – \$3,600</b>

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2a. Reduce the Pressure Drop  
- in Pipe and Fittings

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**2a. Reduce the Pressure Drop in Pipe and Fittings**

**What is it in Modern Pipe and Fittings?**

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

*From the current ASHRAE Fundamentals Pipe Sizing chapter*

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

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**Downey Lab**



**Arcata Lab**



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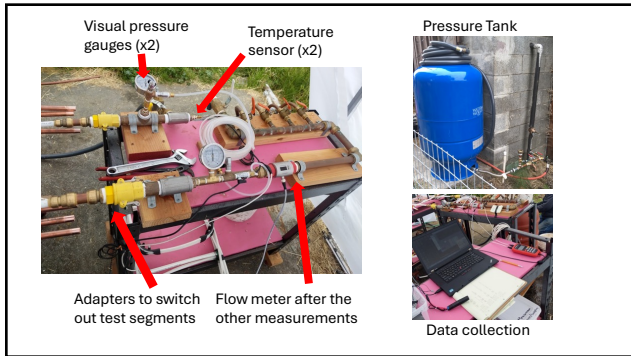
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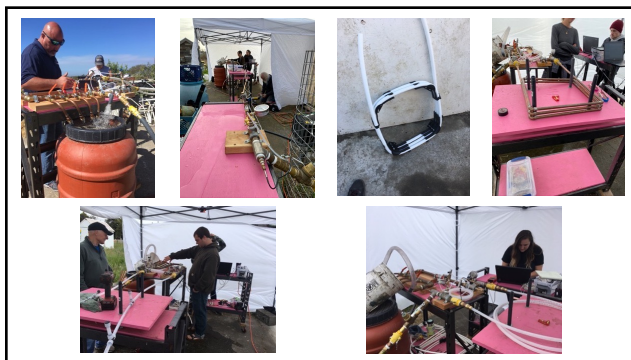
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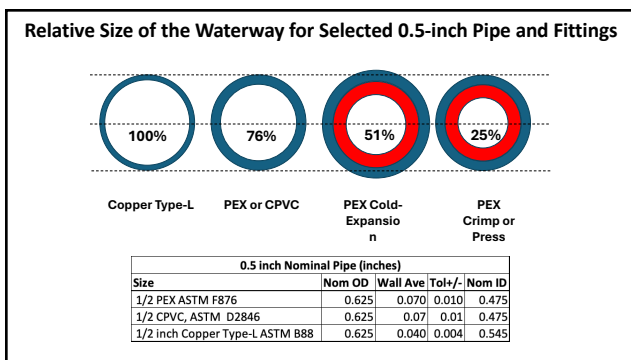
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### Target Flow Rates

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

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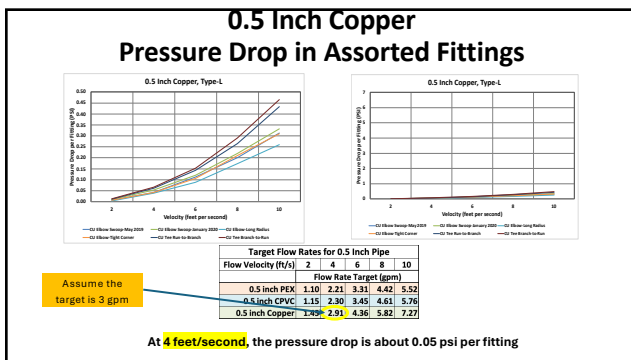
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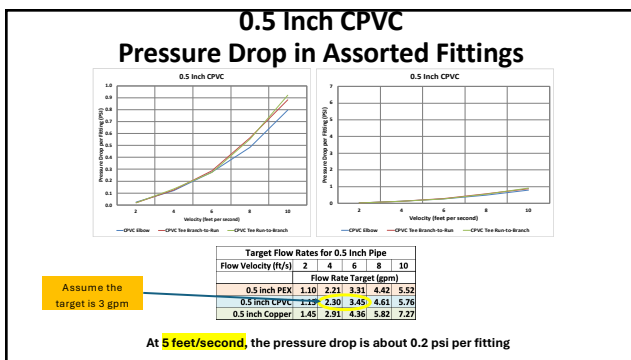
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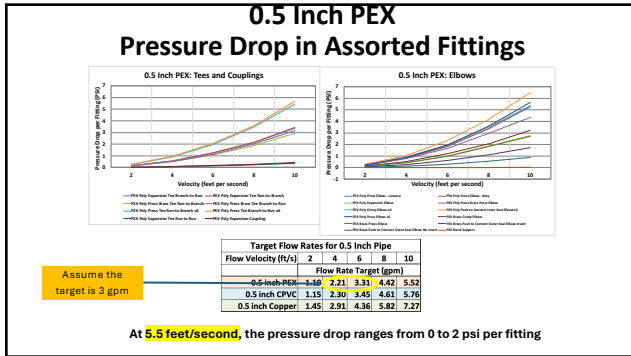
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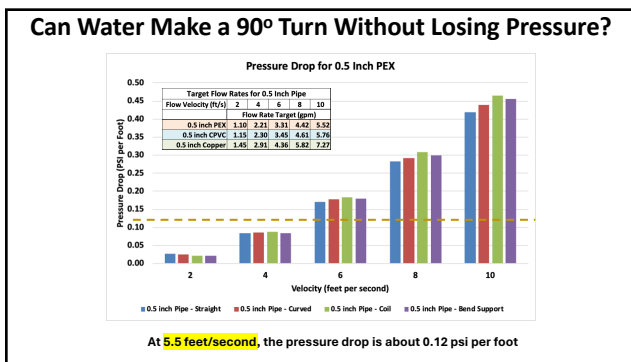
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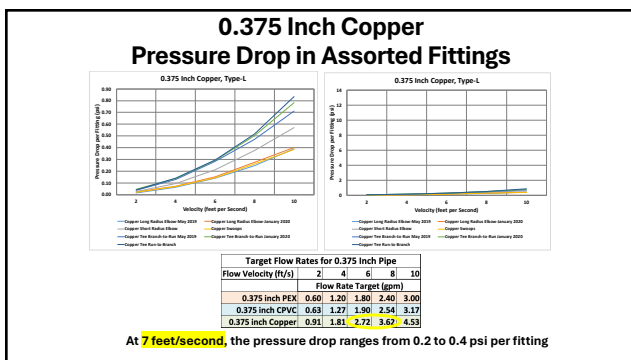
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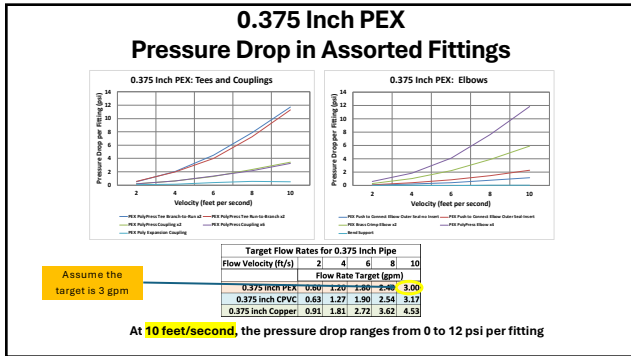


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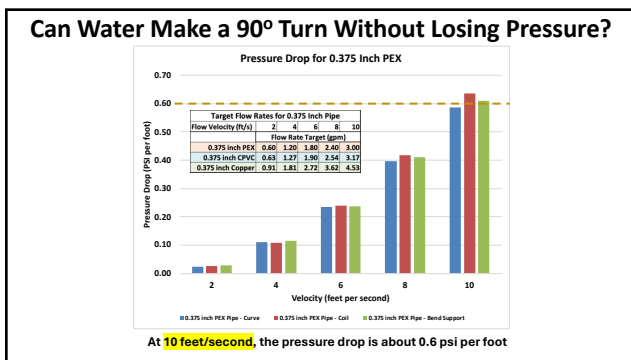
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**Comparing Pressure Loss Per Fitting at 3 gpm**

	Pressure Loss Per Fitting		
1/2 Inch Nominal	Copper	CPVC	PEX
PSI per Fitting	0.05	0.2	0-2
		4 times copper	Up to 40 times copper
3/8 Inch Nominal	Copper	CPVC	PEX
PSI per Fitting	0.2-0.4	NA	0-12
			Up to 30-60 times copper

*Minimize the number of fittings, particularly sharp 90-degree elbows.*

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**2b. Reduce the Pressure Drop - In the Faucets and Shower Valves**

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**2b. Pressure Drop Through Tub/Shower and Shower Valves**




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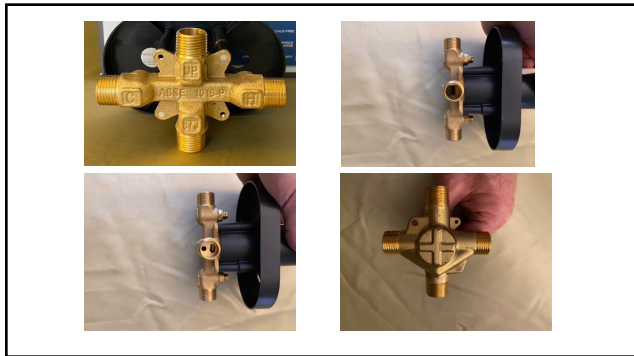
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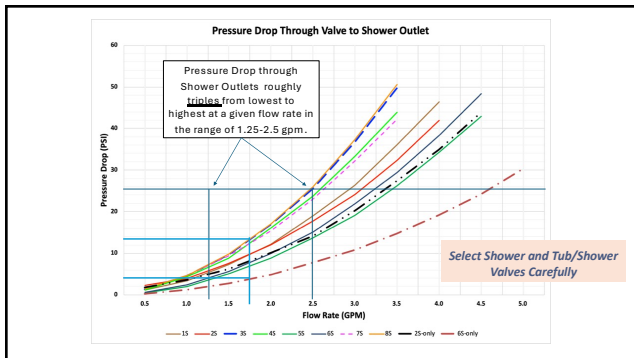
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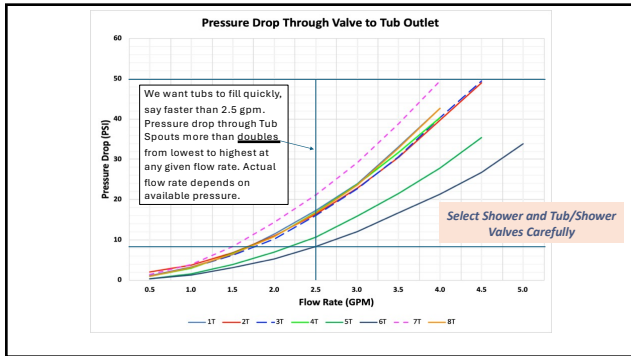
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### 3. Install Pressure-Independent Faucet Aerators and Showerheads

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

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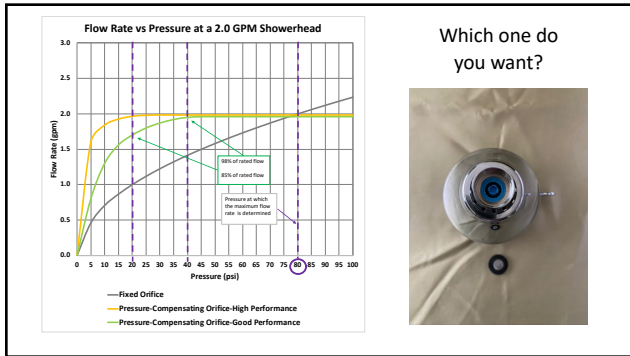
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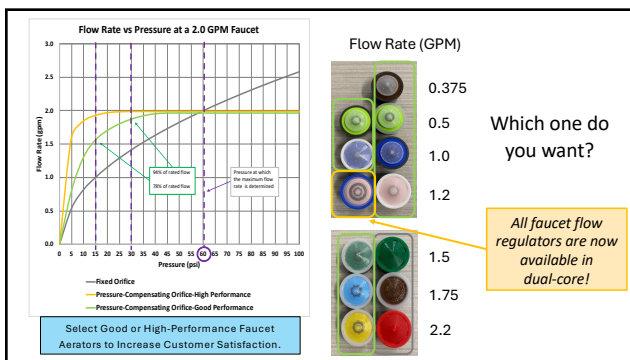
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**Install Pressure Compensating Flow Regulators for Faucets and Showerheads**

Doing so will get you closer to the flow rate on the label regardless of the available pressure

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# Air-Source Heat Pump Water Heaters

Installation Practices that Protect Health and Safety and Increase Efficiency

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## What's Different about HPWH?



Air-source HPWH get the energy to heat water from the air



HPWH have slower recovery rates than gas water heaters



HPWHs use electric resistance at very low temperatures

Best Practice: Combine HPWH with excellent hot water distribution systems

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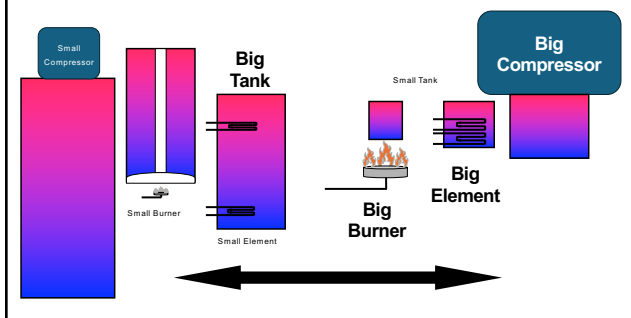
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## How to Ensure Enough Hot Water



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**Best Practice Air-Source HPWH Installations:**

Manage the Cold Exhaust Air to Protect Health and Safety and Increase Efficiency

✓ **Manage Cold Exhaust Air to Prevent Moisture Issues**

- Never trap exhaust in small enclosed spaces
- Raise the cold exhaust air above the dewpoint temperature as quickly as possible, either by mixing or ducting to a safe location
- Use R-8 insulated & vapor-sealed ducts

✓ **Provide Sufficient Warm Air**

- Conduction into the space with the HPWH is not sufficient
- A thermal resource is essential. It must be in the room or be brought into the room for use by the HPWH
- Minimum airflow of 40 CFM per 100 W of compressor power

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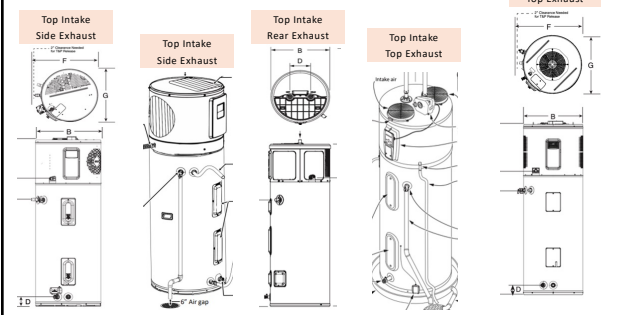
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**Unitary HPWH Intake and Exhaust Locations**




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**Typical Water Heater Locations**

- Basement
- Garage
- Attic
- Mechanical Room
- Closet
- Others?

Ensuring the safe discharge of the cold exhaust air in the most confined locations while simultaneously providing warm intake air needs to be our focus.

***Protecting health and safety will lead to increased efficiency.***

Closets are the most confined locations.

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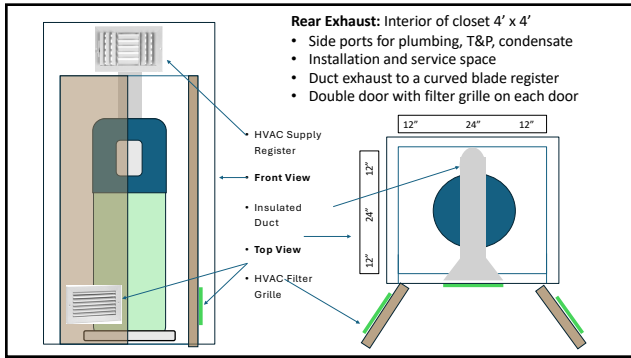
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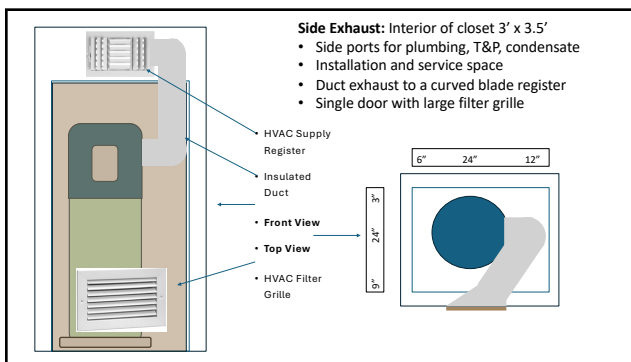
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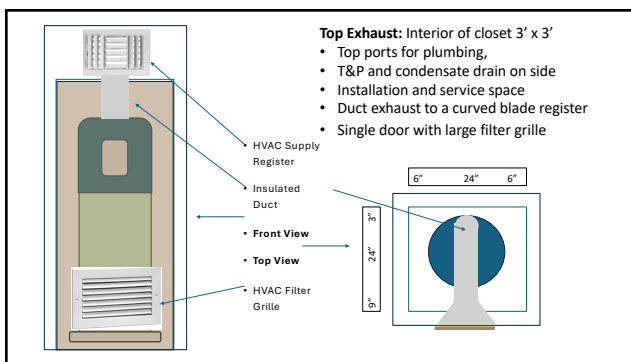
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### Low-Risk Strategies

#### Large areas with full access to warm air

- Discharge cold air away from surfaces to mix thoroughly with surrounding air before it becomes intake air

#### Small areas with limited access to warm air

- Duct cold discharge air out into larger area to mix thoroughly before it becomes intake air.
- Bring intake air back through a filter grille.

#### Install oversized MERV 13 filters

- As part of a filter grille in the door or wall to small areas
- In a filter box that is ducted to the intake
- Better protection for the coils and less frequent filter maintenance

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### Insulated and Vapor Tight Ducting



Currently available in 125-200 mm diameters

<https://zehnderamerica.com/products/ducting/comfopipe/>

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### Best Practices for Hot Water Systems

#### That Deliver Increased Customer Satisfaction

1. Reduce the Time-to-Tap
  - a) Reduce the Distance from the Source to the Use
  - b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the Pressure Drop
  - a) In the Pipe and Fittings
    - 1) Minimize the length
    - 2) Minimize the number of pressure-consuming fittings
  - b) In the Faucets and Shower Valves
3. Install Pressure-Independent Faucet Aerators and Showerheads
4. Install HPWH that:
  - a) Are right-sized
  - b) Get enough "warm" air
  - c) Manage the cold exhaust air to protect health and safety and increase efficiency

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

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## Questions?

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916-549-7080

77 [phro.psu.edu](http://phro.psu.edu)



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## PHRC YouTube Channel

- Link and QR Code to the PHRC YouTube Channel
- <https://www.youtube.com/@PHRCPennState>



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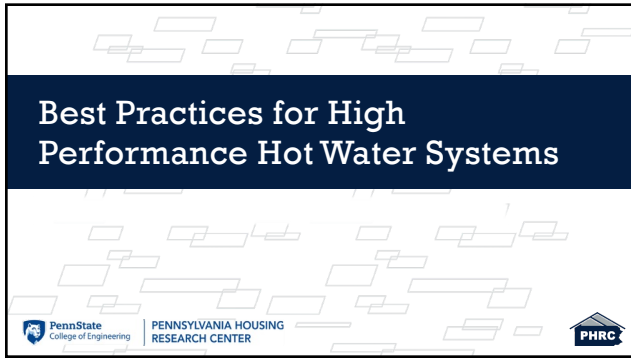
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