

(Hot) Water: The Next Frontier

***Architectural Compactness, Right-Sizing,
and Integrated Air-Source HPWH***

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Do you know anyone who:

- Waits a long time to get hot water after they turn on a tap?
- Thinks a tankless water heater will deliver hot water more quickly than a storage water heater?
- Is concerned that some of the hot water system requirements in Passive House are difficult to implement?
- Wonders why buildings that are efficient to operate are so expensive to construct?
- Would like to know ways to make these buildings less expensive to construct?
- Wants hot water to arrive in less than 15 seconds?

Today we are going to discuss ways to make great buildings (elegant, affordable, environmentally friendly) that are “infrastructurally efficient”

Provisions Related to Hot Water

Single Family National Program Requirements
Version 2 (Rev. 3)

DOE Efficient New Homes

Multifamily National Program Requirements
Version 2 (Rev. 2)

Concerns for Phius:

Minimum room volume for HPWH

Space for future HPWH

Controls for Hot Water Recirculation Systems

Wall thickness of pipe insulation

Limit waste waiting for hot water to arrive:

Why are SF and MF different? Conflicting?

SF Volume in Pipe: 0.5 gallons

Volume until Hot: ≤ 0.6 gallons down drain, $\geq 10^\circ\text{F}$ rise

SF, MF Volume in Pipe: 1.8 gallons

Volume until Hot: ≤ 2.0 gallons down drain, $\geq 10^\circ\text{F}$ rise

Efficient Water Delivery

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

There are many parallels to HVAC and Electrical systems

Integrated Air-Source Heat Pump Water Heaters

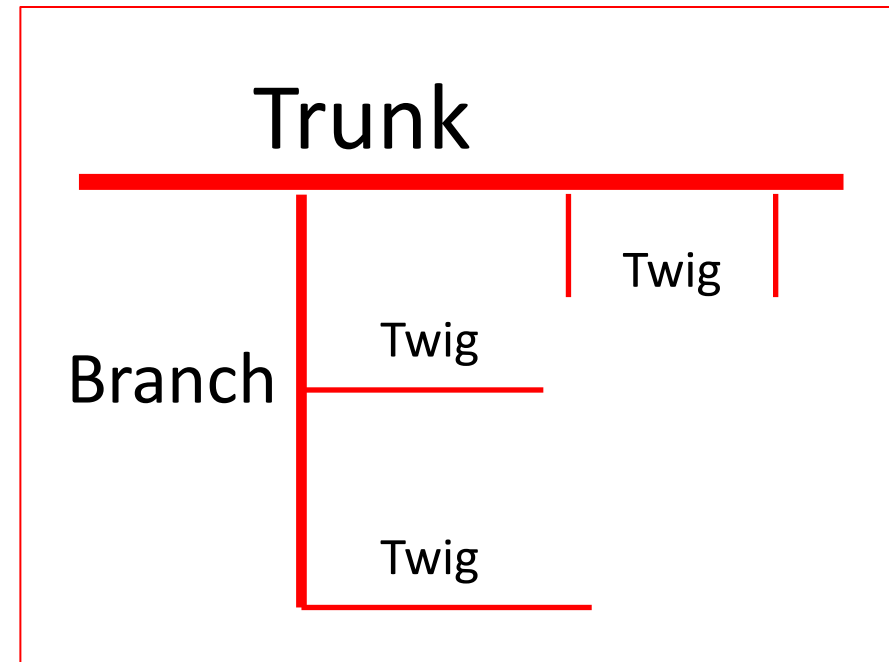
1. Size the heat rate to meet the daily load within 16 hours
2. Match the temperature of the source air to the refrigerant's capabilities
3. Exhaust and intake air should share one pressure zone
4. Exhaust air usually falls below the dew point. Manage it accordingly!

Key Principles

The Ideal Hot Water Distribution System

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

Applies equally to cold water piping!



The Challenge

Deliver (hot) water
to every (hot) water outlet
wasting no more than 1 cup
waiting for the (hot) water to arrive.

And do so using the least amount of energy!

Time-to-Tap and Volume-until-Hot

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

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

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

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

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

How Long Do You Want to Wait for Hot Water?

Volume in the Pipe (ounces)	<u>Minimum</u> Time-to-Tap (seconds) at Selected Flow Rates					
	0.25 gpm	0.5 gpm	1 gpm	1.5 gpm	2 gpm	2.5 gpm
2 1	4	1.9	0.9	0.6	0.5	0.4
4 2	8	4	1.9	1.3	0.9	0.8
8 4	15	8	4	2.5	1.9	1.5
16 8	30	15	8	5	4	3
24 12	45	23	11	8	6	5
32 16	60	30	15	10	8	6
64 32	120	60	30	20	15	12
128 64	240	120	60	40	30	24

Cut the pipe volume in half to get these times

ASPE Time-to-Tap Performance Criteria

	Acceptable Performance	1 – 10 seconds
	Marginal Performance	11 – 30 seconds
	Unacceptable Performance	31+ seconds

Source: Domestic Water Heating Design Manual – 2nd Edition, ASPE, 2003, page 234

Volume Per Foot of Piping

UPC

TABLE L 502.7
WATER VOLUME FOR DISTRIBUTION PIPING MATERIALS*

OUNCES OF WATER PER FOOT LENGTH OF PIPING													
NOMINAL SIZE (inch)	COPPER M	COPPER L	COPPER K	CPVC CTS SDR 11	CPVC SCH 40	PEX-AL- PEX	PE-AL- PE	CPVC SCH 80	PEX CTS SDR 9	PE-RT SDR 9	PP SDR 6	PP SDR 7.3	PP SDR 11
3/8	1.06	0.97	0.84	NA	1.17	0.63	0.63	NA	0.64	0.64	0.91	1.09	1.24
1/2	1.69	1.55	1.45	1.25	1.89	1.31	1.31	1.46	1.18	1.18	1.41	1.68	2.12
3/4	3.43	3.22	2.90	2.67	3.38	3.39	3.39	2.74	2.35	2.35	2.23	2.62	3.37
1	5.81	5.49	5.17	4.43	5.53	5.56	5.56	4.57	3.91	3.91	3.64	4.36	5.56
1 1/4	8.70	8.36	8.09	6.61	9.66	8.49	8.49	8.24	5.81	5.81	5.73	6.81	8.60
1 1/2	12.18	11.83	11.45	9.22	13.20	13.88	13.88	11.38	8.09	8.09	9.03	10.61	13.47
2	21.08	20.58	20.04	15.79	21.88	21.48	21.48	19.11	13.86	13.86	14.28	16.98	21.39

For SI units: 1 ounce = 29.573 mL

* NA: Not Applicable

IPC

TABLE E202.1
INTERNAL VOLUME OF VARIOUS WATER DISTRIBUTION TUBING

OUNCES OF WATER PER FOOT OF TUBE									
Size Nominal, Inch	Copper Type M	Copper Type L	Copper Type K	CPVC CTS SDR 11	CPVC SCH 40	CPVC SCH 80	PE-RT SDR 9	Composite ASTM F 1281	PEX CTS SDR 9
3/8	1.06	0.97	0.84	N/A	1.17	—	0.64	0.63	0.64
1/2	1.69	1.55	1.45	1.25	1.89	1.46	1.18	1.31	1.18
3/4	3.43	3.22	2.90	2.67	3.38	2.74	2.35	3.39	2.35
1	5.81	5.49	5.17	4.43	5.53	4.57	3.91	5.56	3.91
1 1/4	8.70	8.36	8.09	6.61	9.66	8.24	5.81	8.49	5.81
1 1/2	12.18	11.83	11.45	9.22	13.20	11.38	8.09	13.88	8.09
2	21.08	20.58	20.04	15.79	21.88	19.11	13.86	21.48	13.86

For SI: 1 ounce = 0.030 liter.

Reduce the Distance

Reduce the Distance from Source to Use

- The shorter the pipe, the less time it takes.
 - The smaller the pipe diameter, the less time it takes too!
 - ***But***, the lower the flow rate, the longer it takes.
 - How long is too long?
 - We need to decide what is an “acceptable” time-to-tap or volume-until-hot and work backwards to determine the maximum allowable in the pipe between the source and the use.
1. **Water, energy and time efficient hot water systems start with deciding how long we want people to wait.**
 2. *The decision on the location of the wet-room(s) and the mechanical room(s) is made by the architect.*
 3. **Better floor plans can lead to better hot water system performance.**
 4. *Better floor plans decrease the residence time in the premise plumbing system (hot and cold) too!*

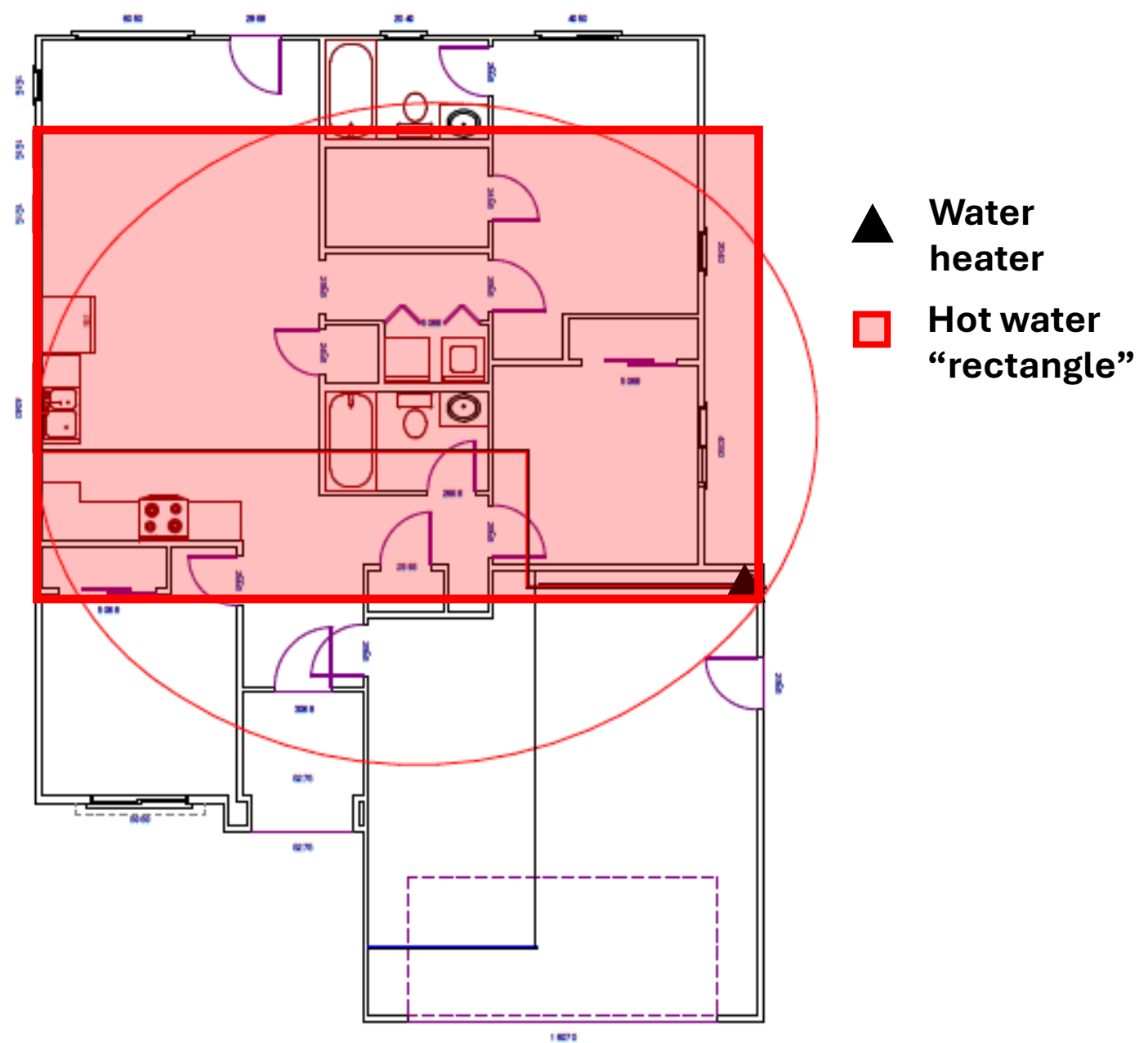
Best 1-Story So Far...

Best 1-Story to Date:

In the beginning:

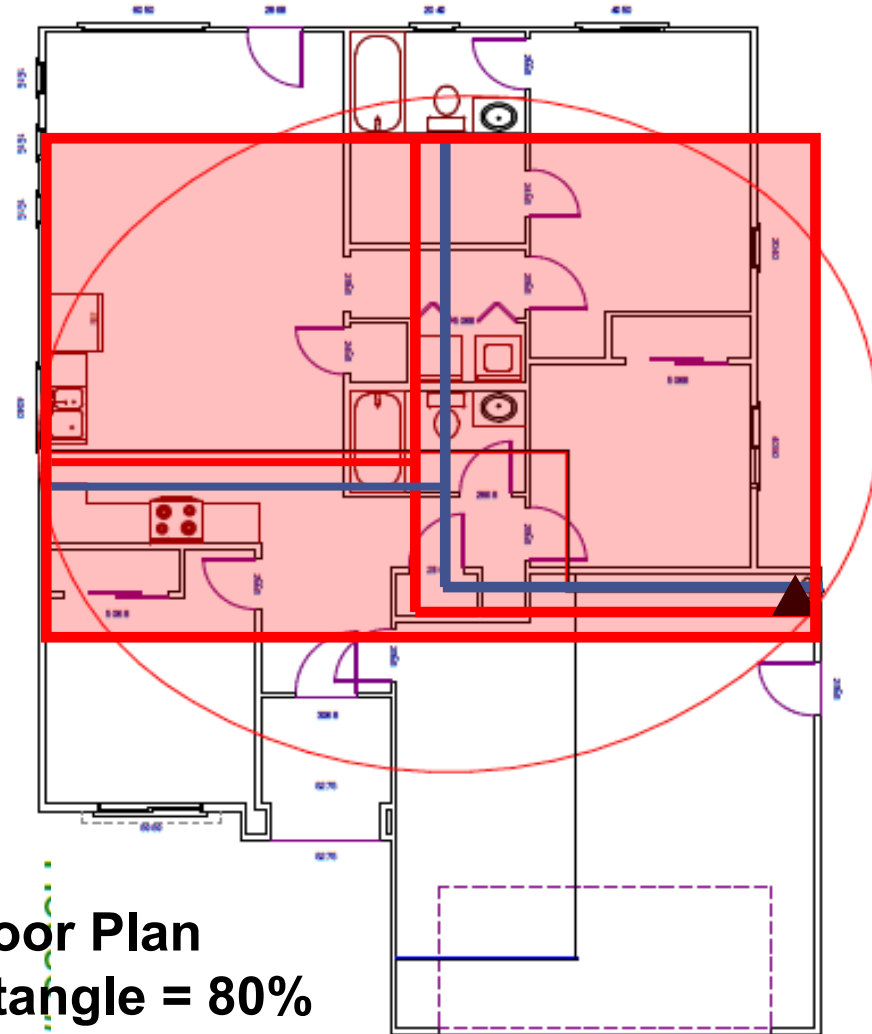
1 Story
3 Br/2 Ba
1,619 sq ft
Stockton, CA

~80%
(1,279 sq ft)



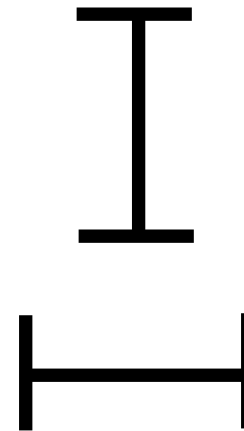
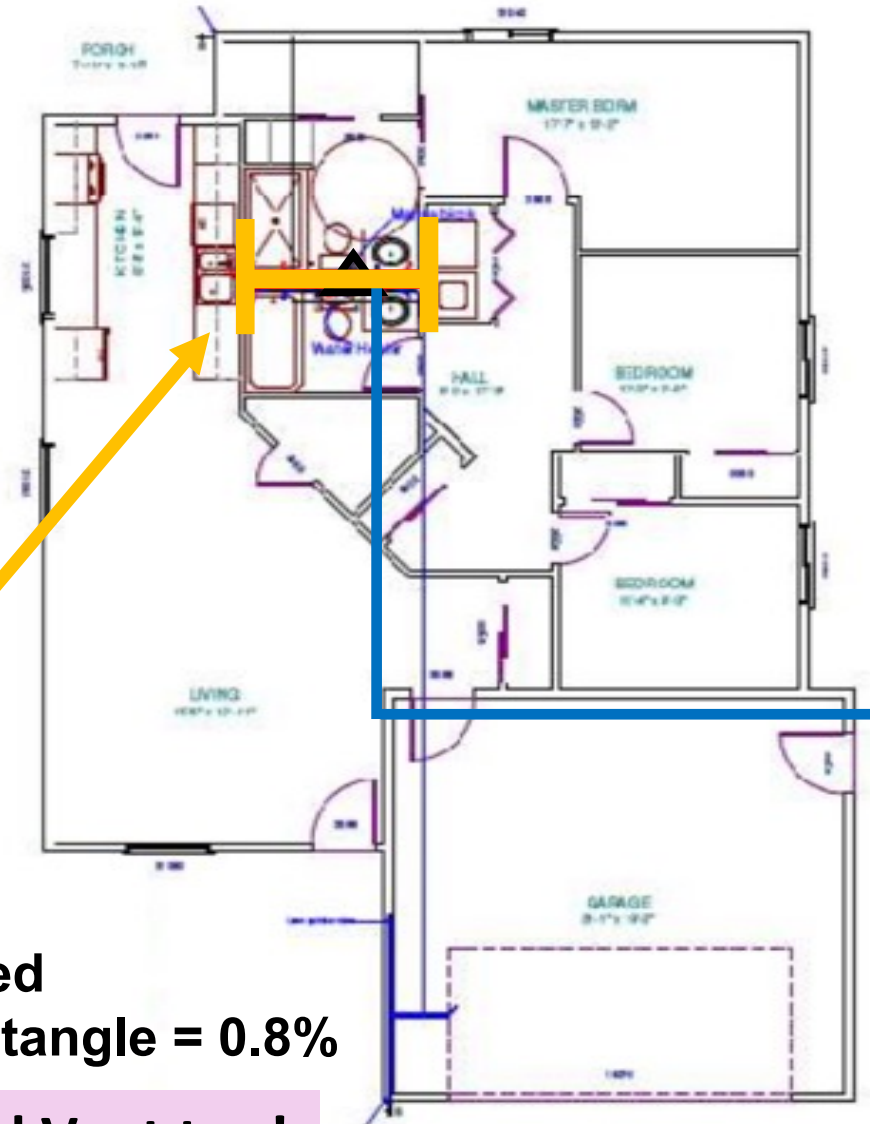
Where are the “wet-rooms? Where are the “wet-walls?

(Hot) Water System “Rectangle”



Initial Floor Plan
HW Rectangle = 80%

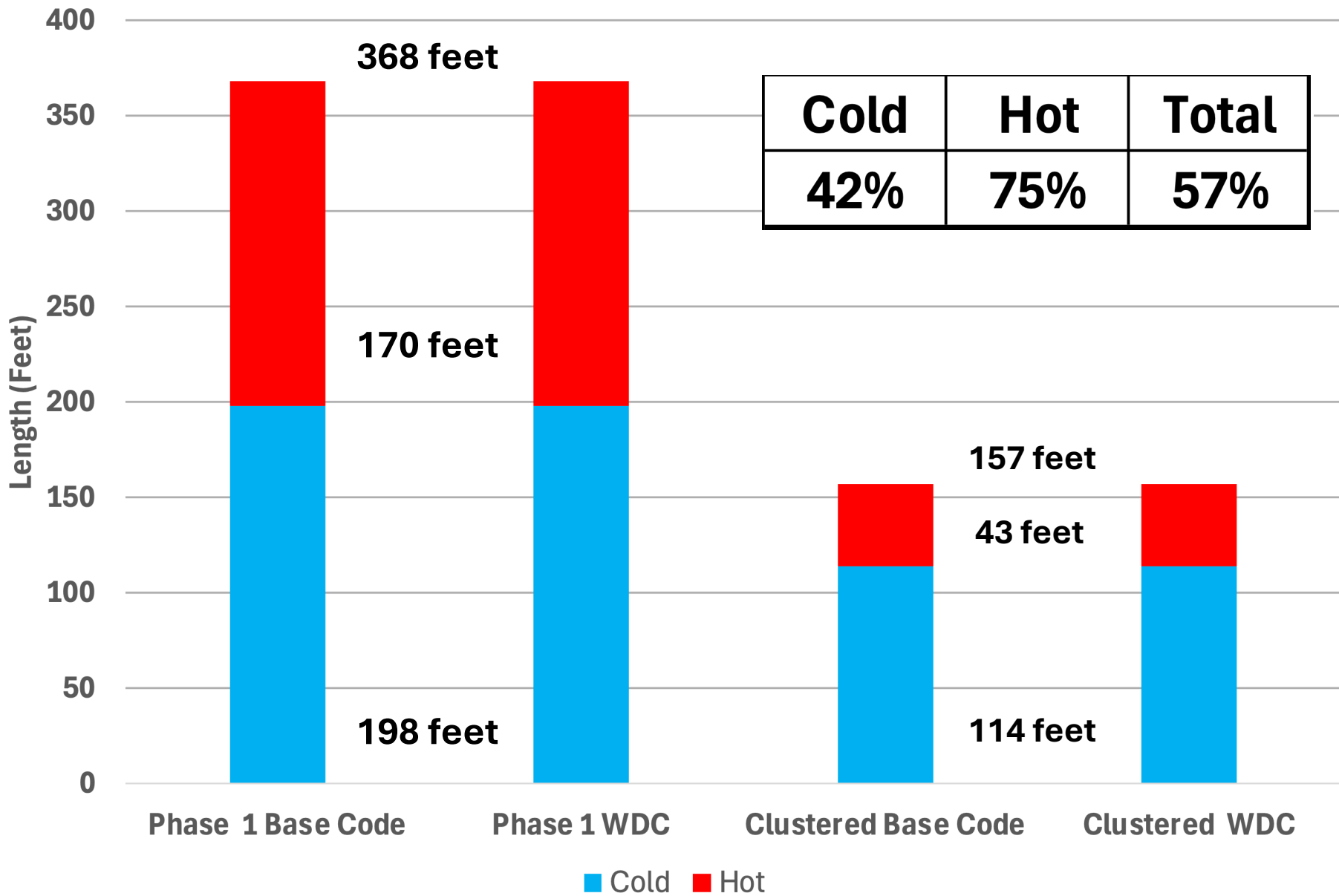
Plumbing Wall
Looks like an
I-beam



Clustered
HW Rectangle = 0.8%

Fewer feet of Drain, Waste, and Vent too!

Stockton House-Pipe Lengths



Right-Size the Piping

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

1. Improve Estimates of Peak Flow Rates

1. Measure flow rates in similar occupancies before designing new ones

2. Utilize Modern Peak Flow Rate Estimation Tools

1. For mains and branches – match to modern flow rates and probabilities of simultaneous use
2. Twigs – match to the flow rates of the fixture/appliance that is attached

3. Select Pipe Sizes that Optimize Velocities and Residual Pressure

1. Velocities

1. Hot: 5 feet per second (continuous)
2. Cold: 8 feet per second (continuous)
3. Twigs: 8 feet per second (intermittent, maybe even higher?)

2. Residual Pressure

1. Minimize Pressure Loss in Piping, Fittings, Fixtures, and Appliances
2. Higher residual pressure increases performance and customer satisfaction

Estimating Peak Flow Rates

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

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

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

Water Demand Calculator (WDC v2.0)

PROJECT NAME:
Click for Drop-down Menu →

Sunday, May 30, 2021
6:42 AM

FIXTURE GROUPS	FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1 Bathtub (no Shower)	0	1.00	5.5	5.5
	2 Bidet	0	1.00	2.0	2.0
	3 Combination Bath/Shower	0	5.50	5.5	5.5
	4 Faucet, Lavatory	0	2.00	1.5	1.5
	5 Shower, per head (no Bathtub)	0	4.50	2.0	2.0
	6 Water Closet, 1.28 GPF Gravity Tank	0	1.00	3.0	3.0
Kitchen Fixtures	7 Dishwasher	0	0.50	1.3	1.3
	8 Faucet, Kitchen Sink	0	2.00	2.2	2.2
Laundry Room Fixtures	9 Clothes Washer	0	5.50	3.5	3.5
	10 Faucet, Laundry	0	2.00	2.0	2.0
Bar/Prep Fixtures	11 Faucet, Bar Sink	0	2.00	1.5	1.5
Other Fixtures	12 Fixture 1	0	0.00	0.0	6.0
	13 Fixture 2	0	0.00	0.0	6.0
	14 Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation

99th Percentile Demand Flow

Hunter Number

Stagnation Probability

DOWNLOAD RESULT

RESET WDC

Select Units for Water Demand ↓

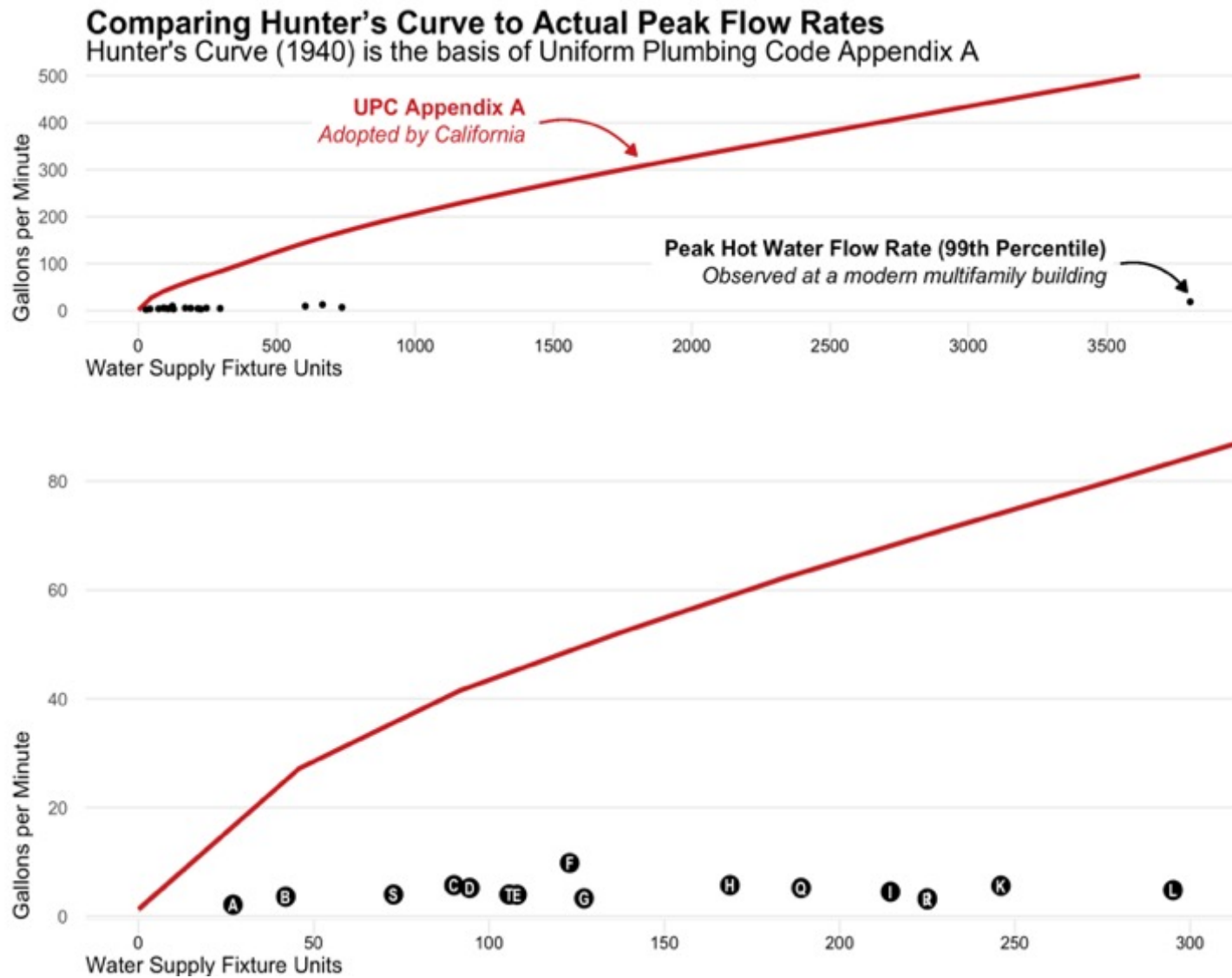
GPM LPM LPS

RUN WDC

CLICK BUTTON

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

What if we could use real data for different occupancies?



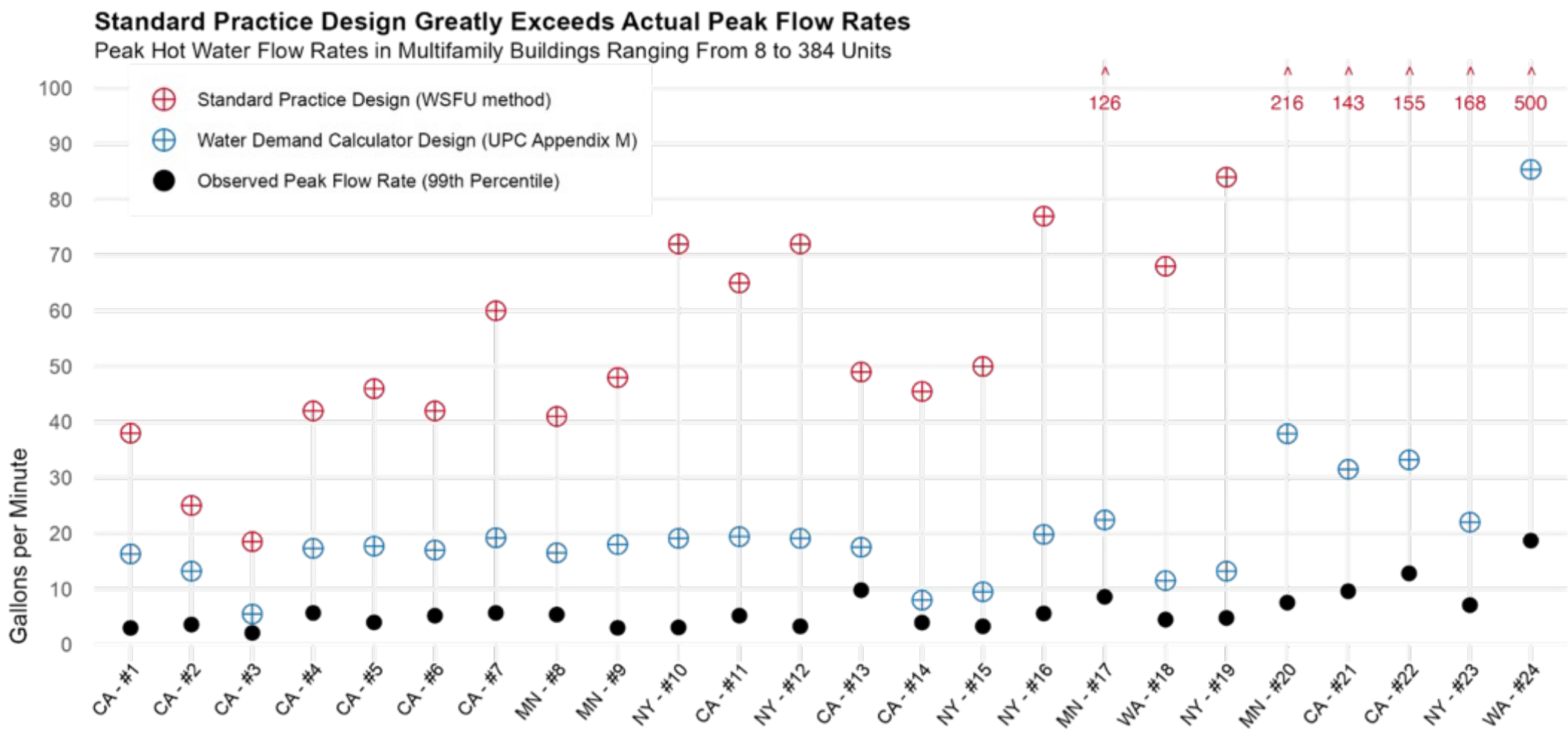
Water Supply Fixture Units = WSFU

California Plumbing Code (CPC)/Uniform Plumbing Code (UPC) Appendix A codifies the standard practice WSFU method.

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

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

The **WDC design flow rates are between 2 and 6 times** the observed peak hot water flow rates in **24 multifamily buildings.**



CPC/UPC Appendix M codifies the Water Demand Calculator.
Data was collected during the period of 2019 to 2025; monitoring period ranged from 9 days to over 2 years, and logging interval ranged from 1 to 60 seconds. Observed peak flow rate is the 99th percentile of non-zero flow rates observed over each study's duration.

Time-to-Tap is the Tip of the Iceberg

Reduce the
Time-to-Tap

Right Size the Piping

Right Size the Rest of the
Plumbing

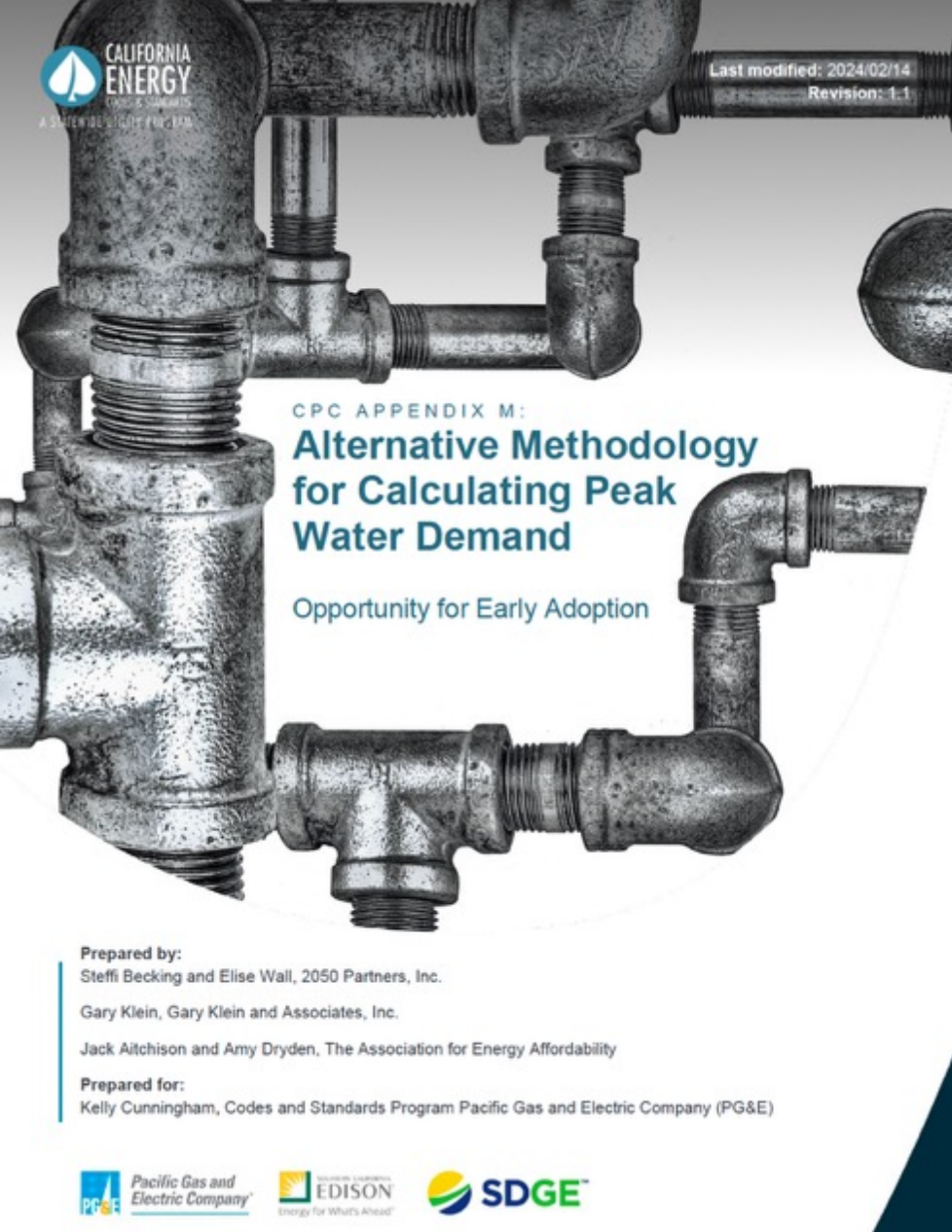
Right Size the
Water Heater

Right Size the
Water Meter

Ongoing Operational
Savings

Benefits of Right-Sizing in Multi-family

92-Unit Apartment Building	Savings
Time-to-Tap	Increased Satisfaction
Right Size Piping	\$5,000
Right Size the Rest of the Plumbing	\$5,000
Right Size the Water Heater	\$30,000
Right Size the Water Meter	\$16,000 – \$68,000
Total First Cost Savings	\$58,000 – \$108,000
First Cost Savings/Apartment	\$600 – \$1,200
Annual Operational Savings (Does not include energy and sewer)	\$1,800 - \$3,600



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



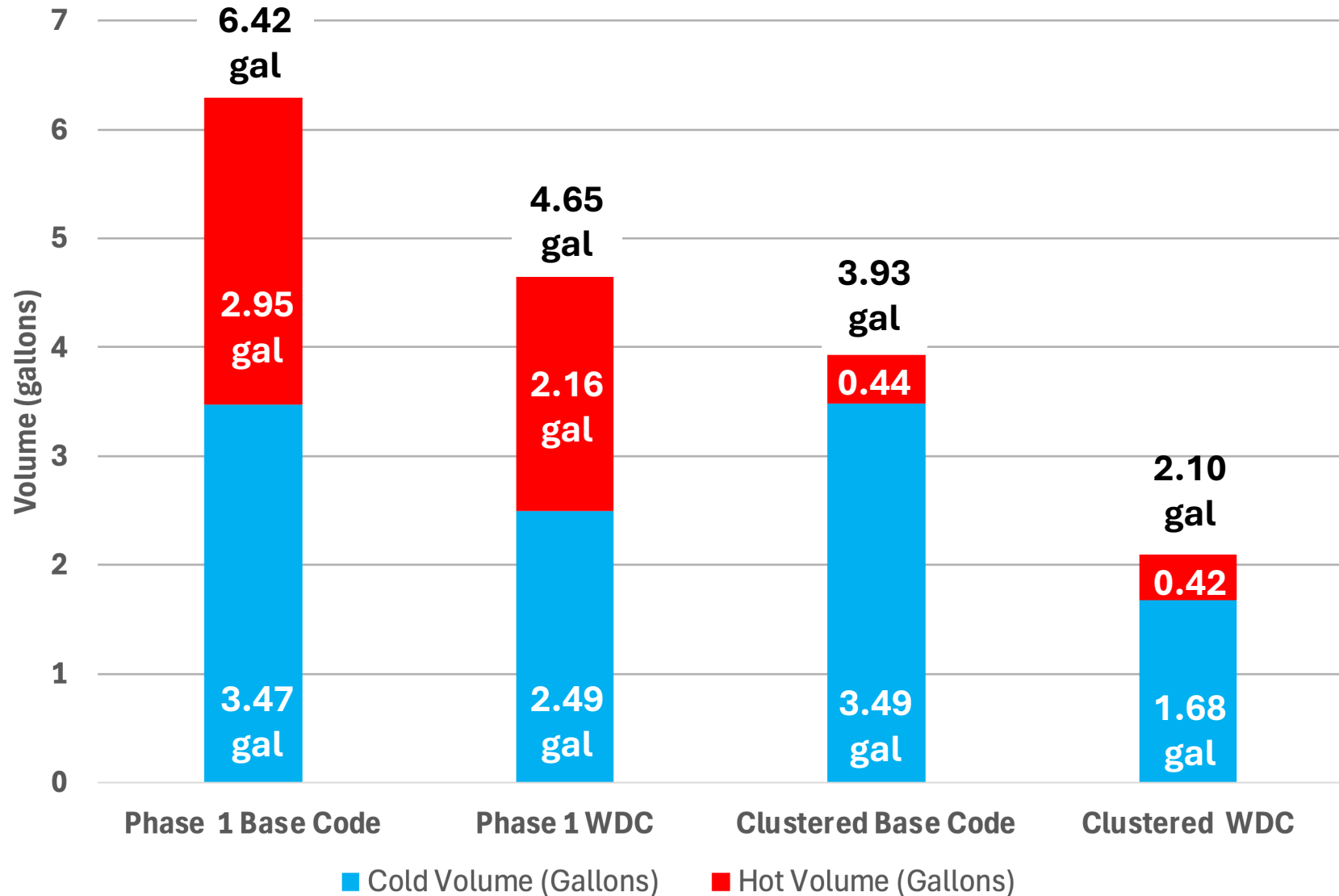
Source:

<https://localenergycodes.com/content/reach-codes/energy-plus-water-1>

(to access the report, click "VIEW AND DOWNLOAD RESOURCES" for the "require alternative method for sizing water pipes in residential buildings" measure)

https://localenergycodes.com/download/1461/file_path/fieldList/2024%20CPC%20Appx%20M-Alternative%20Calc%20Water%20Demand.pdf (direct download link)

Stockton House-Pipe Volume



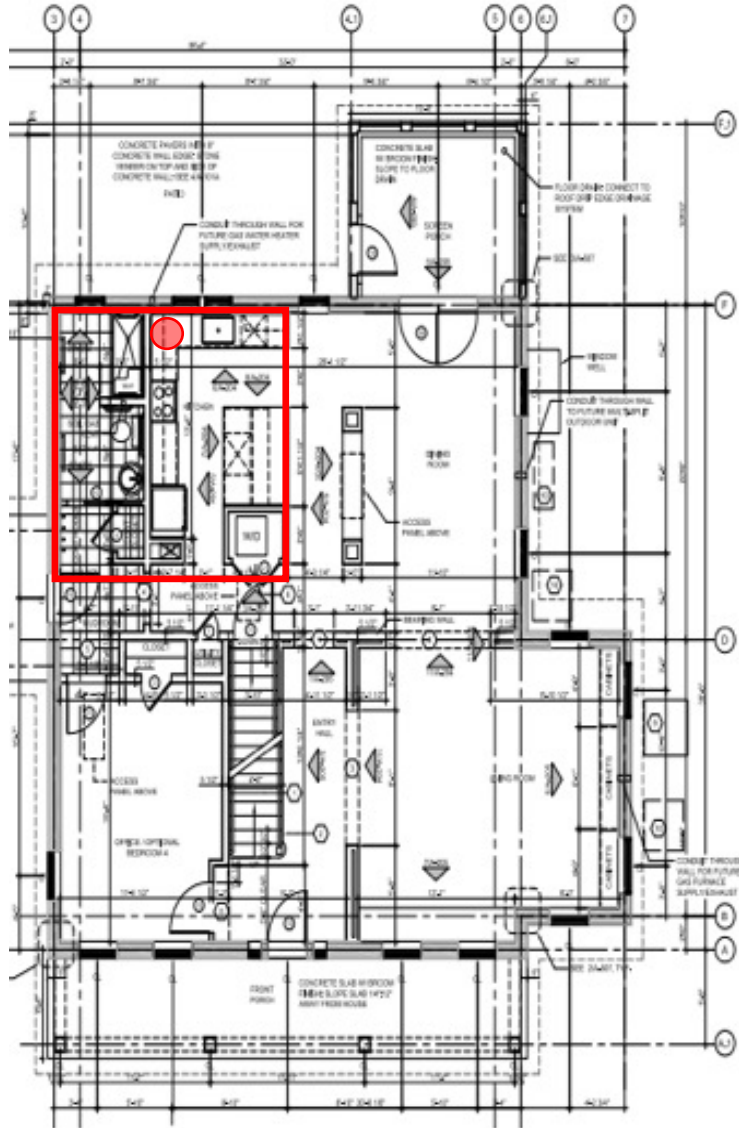
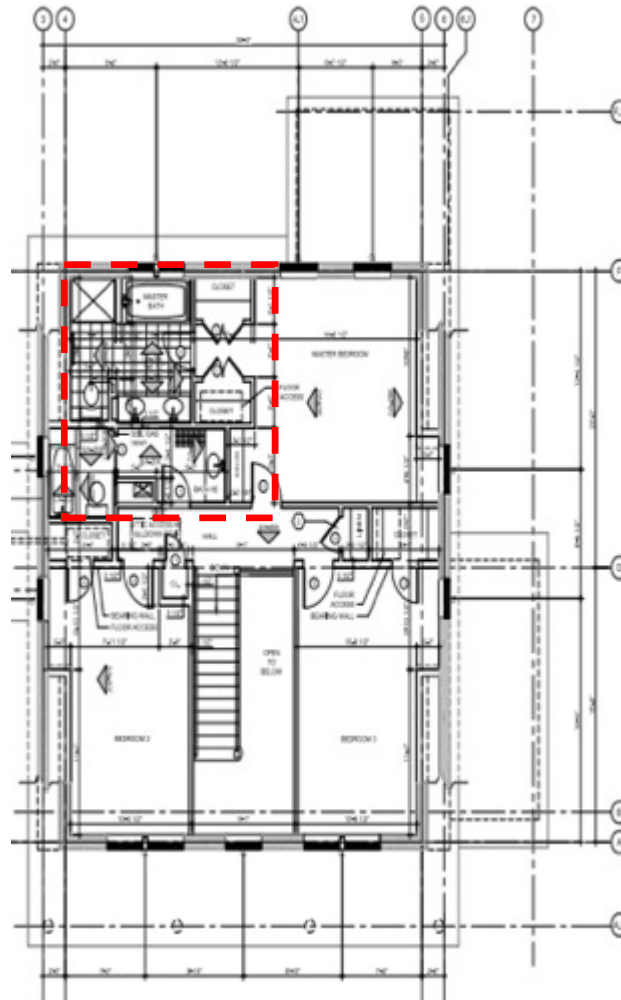
Combining Clustering and Right-Sizing

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

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

Best 2-Story So Far...

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



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

Architects: We Need You!

Courtesy: Betsy Pettit, and NIST

Improve Performance of Fixtures

Stream Patterns for Faucets



Aerated stream

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



Spray stream

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



Laminar stream

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

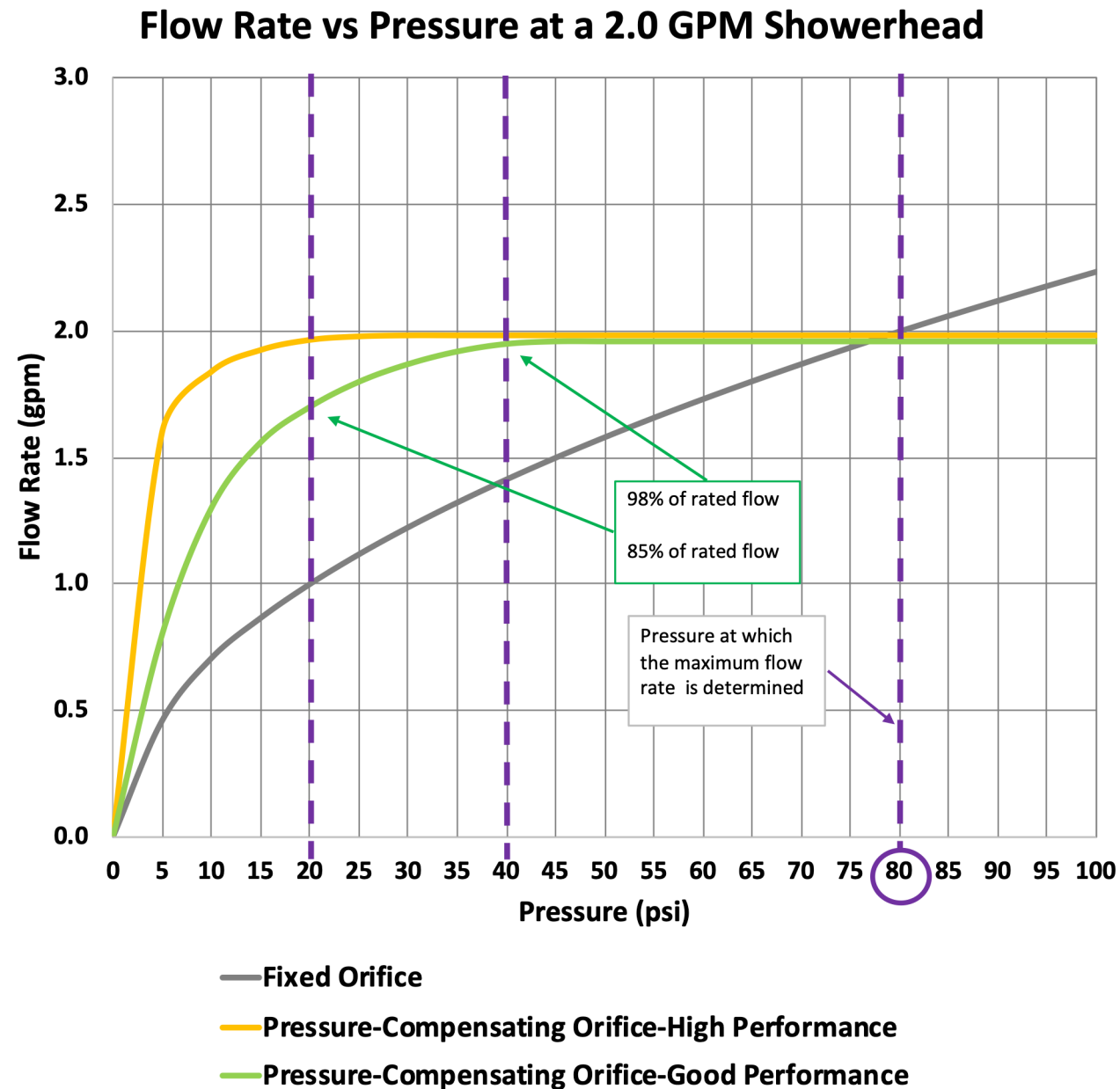
Aerated



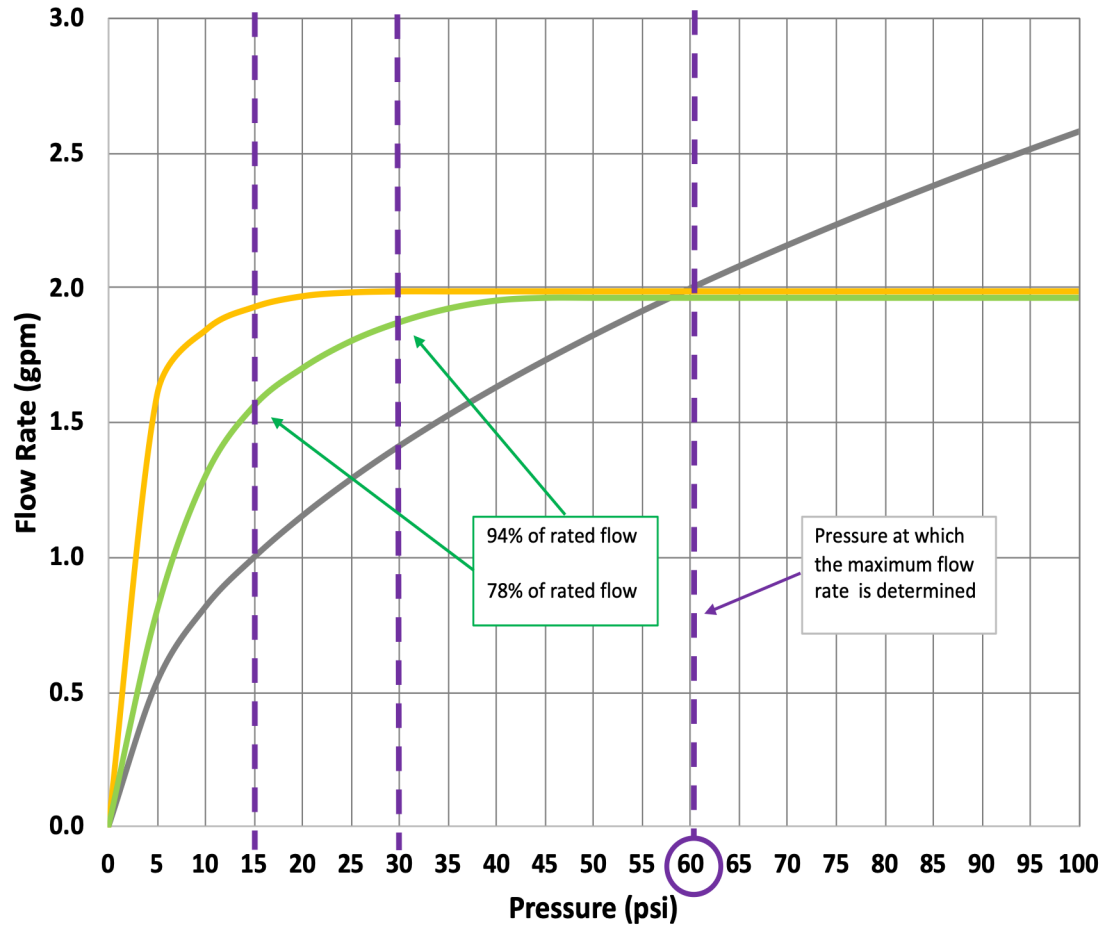
Non-Aerated



Which one do you want?



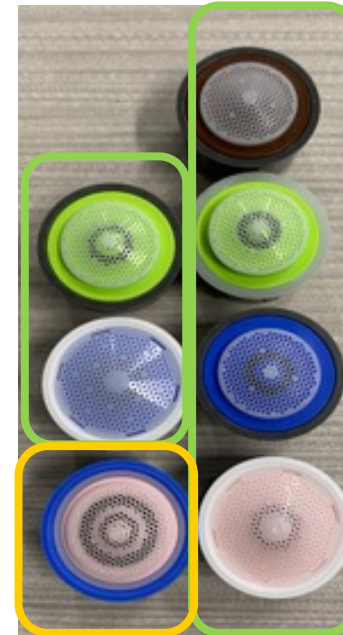
Flow Rate vs Pressure at a 2.0 GPM Faucet



- Fixed Orifice
- Pressure-Compensating Orifice-High Performance
- Pressure-Compensating Orifice-Good Performance

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

Flow Rate (GPM)



0.375

0.5

1.0

1.2

1.5

1.75

2.2

Which one do you want?

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

Integrated Air-Source HPWH

In principle, much more efficient...

The Big Problem:

Poor Installations Have Consequences



Unintended issues from poor HPWH installation

Health and Safety Risks



Cold air impacts surface → condensation, moisture damage & mildew and mold on surface



Cold air trapped → condensation & mold inside building cavities

Lower Operating Efficiency



Limited airflow → reduced efficiency & higher costs



Limited airflow → reduced efficiency & higher costs

Real-World Case Studies...

From 2025: <https://buildingscience.com/documents/building-science-insights/bsi-150-alice-cooper-does-heat-pump-hot-water-heatersc>
<https://heatinghelp.com/systems-help-center/air-source-heat-pump-water-heaters/>

Garage Install Failure

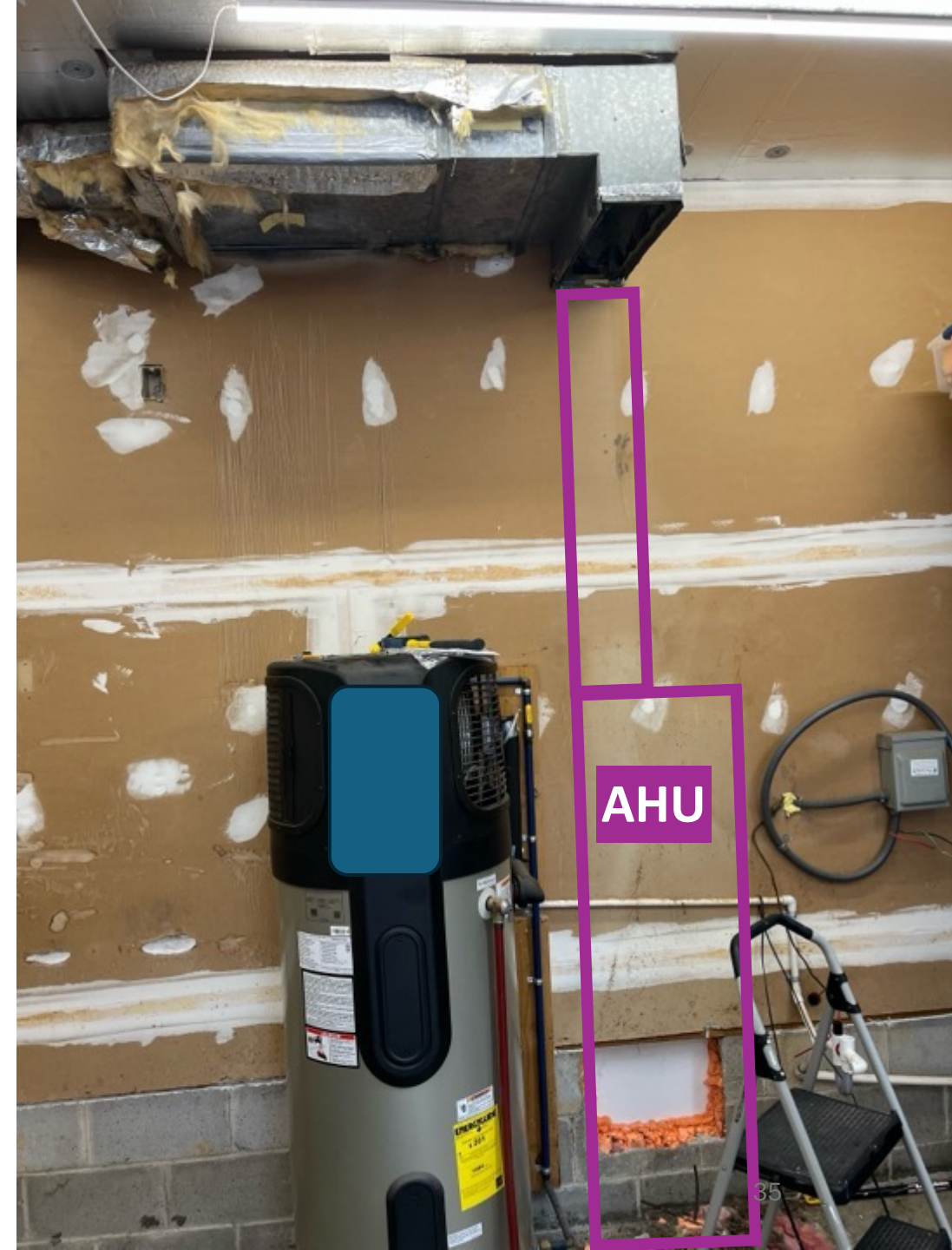
Richmond, VA

Resulted in Mold Growth

- ✓ Plenty of air exchange
- ✗ Cold discharge air impacts air handler and ductwork
- ✗ Humid garage air condensed on air handler and supply ductwork, causing mold
- ✗ Equipment was removed

🚨 **Lesson Learned: Plan exhaust direction & airflow carefully!**

***Issue:** Installation instructions say that the space volume is large enough. However, the instructions do not address where the exhaust air is directed, or the potential to create condensation on exposed surfaces.*



Indoor Closet Install Failure

Richmond, VA

Resulted in Mold Growth

- ✓ Plenty of air exchange through louvered door
- ✗ Cold discharge air impacts back wall
- ✗ Humid air condenses on back wall
- ✗ Dehumidifier was added as part of the mold mitigation effort

🚨 **Lesson Learned: Don't cool surfaces below the dew point!**

***Issue:** Installation instructions say that the full louvered door provides enough airflow and require minimum spacing to the back wall, which appears to have been met. However, the instructions do not address the high humidity/dewpoint of the incoming air.*

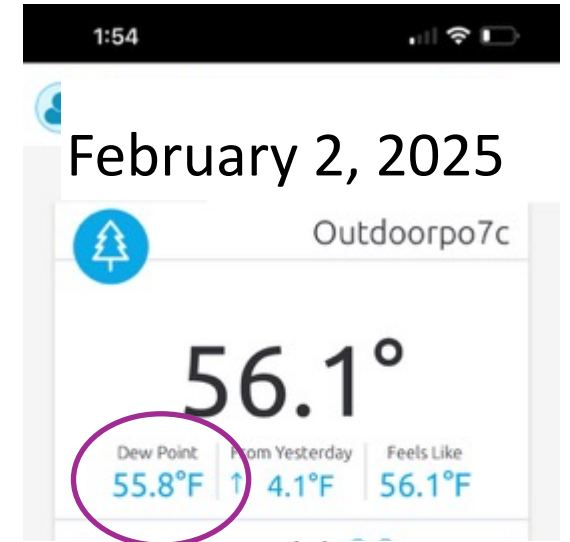
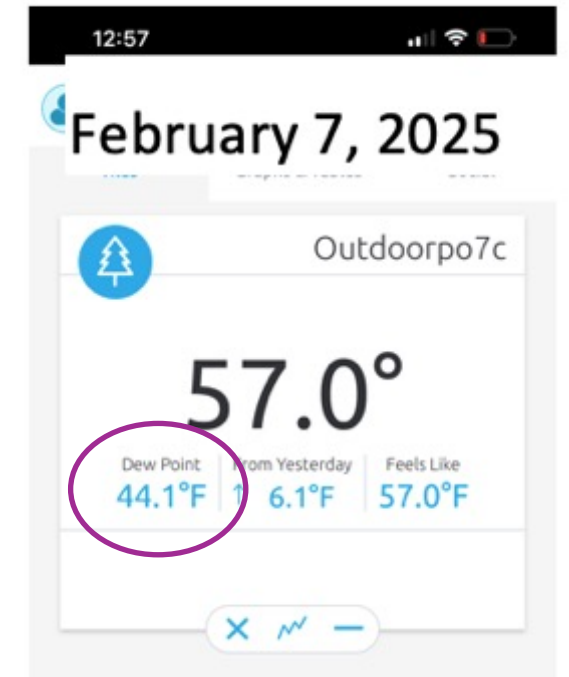


Garage Installation

Sacramento, CA



Condensation on the
outside of the duct



Mechanical Room

Los Angeles, CA

Hotel

- Room temperature in the 40-50°F range
- Condensation on cold air exhaust pipe

Condensation on the
outside of the duct



External Closet

Sacramento, CA

Garden apartment complex
Needs much larger openings



Collar



Intake

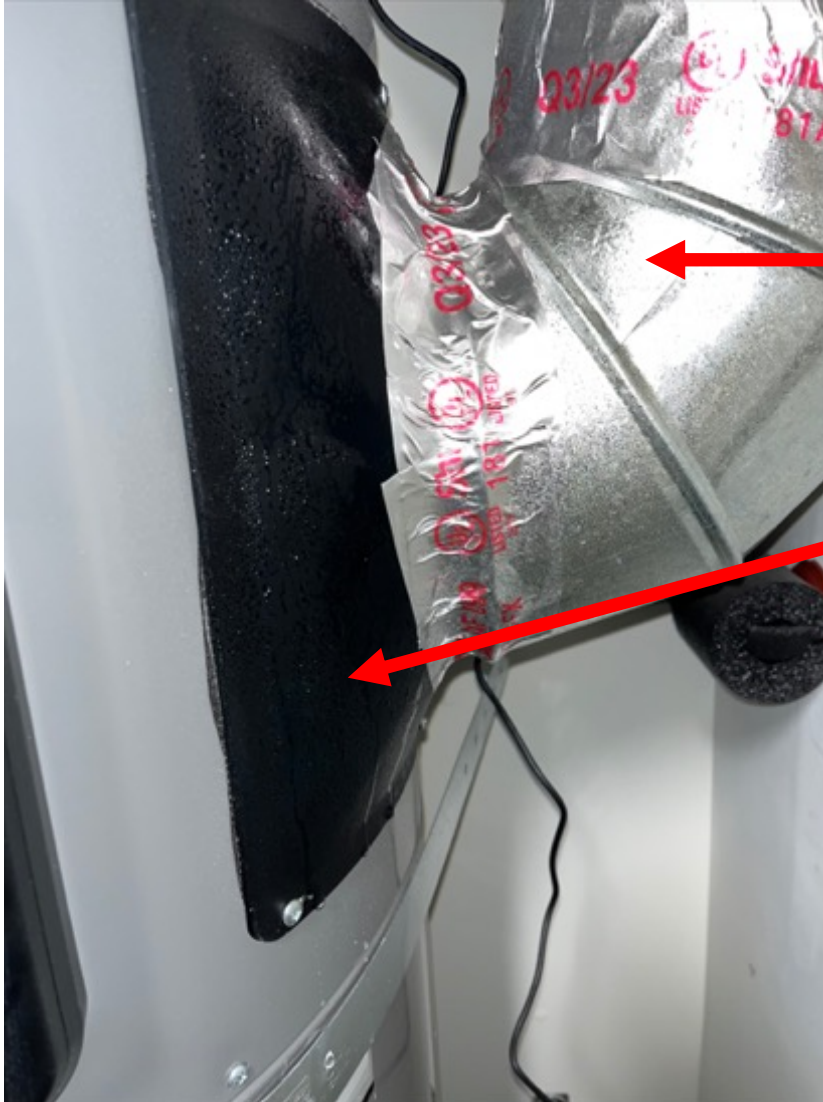


Exhaust

Intake and Exhaust Air Flows:
need to match and be proportional to the number of
water heater and the CFM of the blowers.

Internal Closet

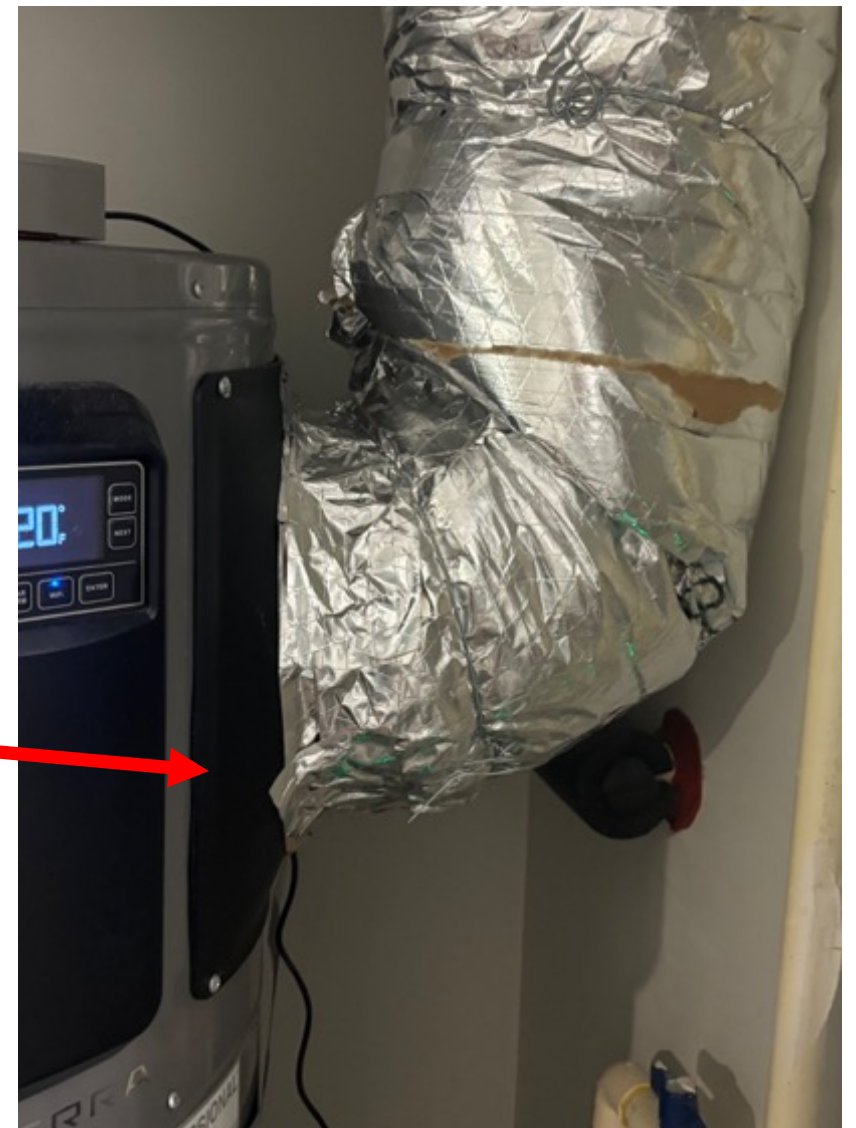
Rancho Cucamonga, CA



**Condensation
on the**

**Duct
and on the**

Take-off boot



“We are continuing to have condensation issues with the exhaust duct kit, which sweats at certain times of the year, creating water that runs downhill, hits the water heater, and goes into drain pan, which then shuts down the water heater.” Apartment Building Owner

Increased Energy Efficiency Cannot Come at the Expense of Protecting Public Health and Safety

		Protect Health and Safety of the Building and Its Occupants	
		High	Low
Energy Efficiency	High	Yes!	Why gamble?
	Low	Why gamble?	Absolutely not!

To protect health and safety,
HPWH installations need to minimize the potential for moisture to condense on surfaces inside the building.

Doing so minimizes the risk of moisture damage, mildew , and mold.

HPWH Installed in Interior Enclosure

Limited access to new thermal resources. No new intake and exhaust stays in the room. New energy can only get into the enclosure via conduction.

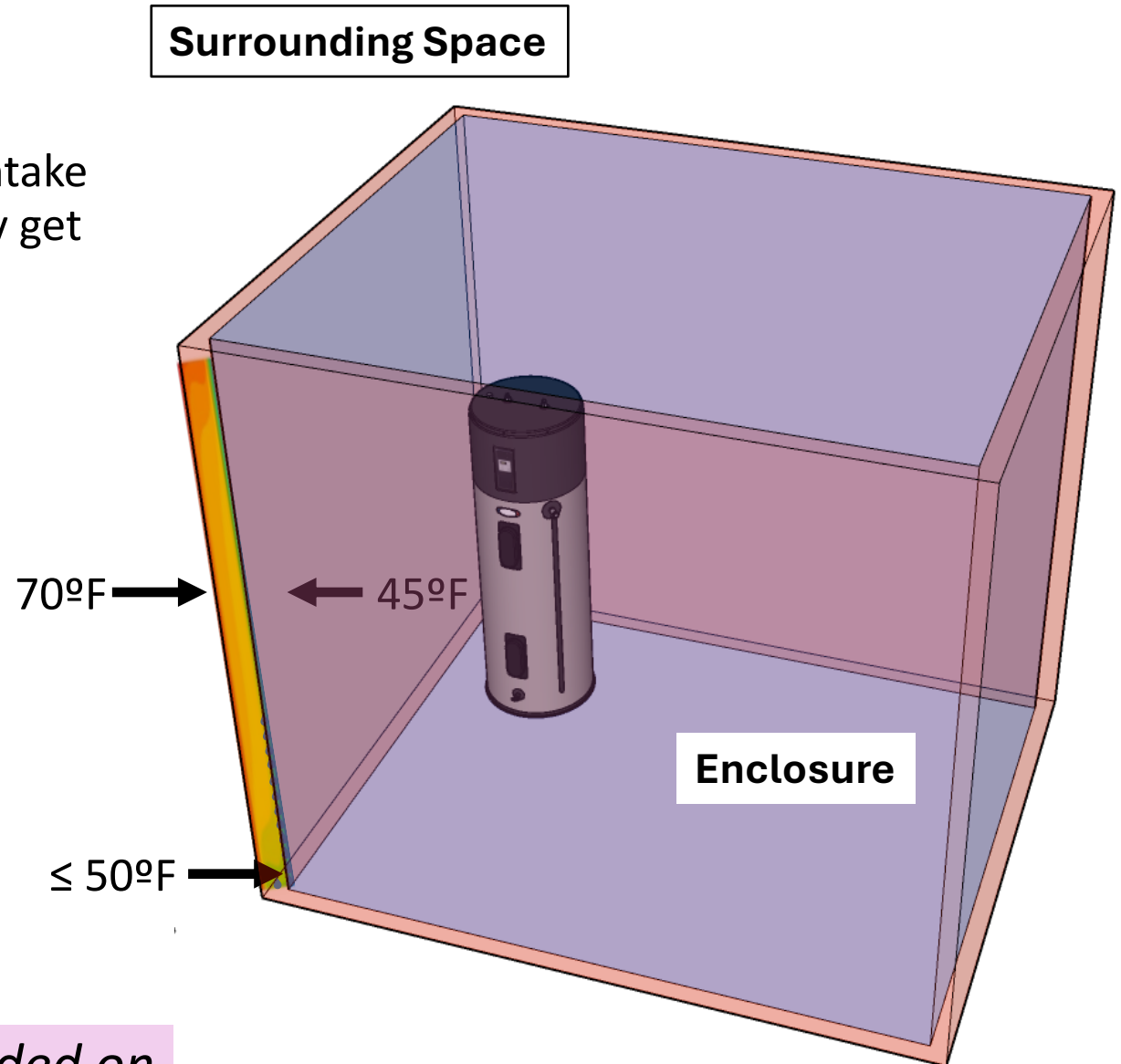
Surrounding Space Air Conditions:

- Dry Bulb Temp: 70°F
- Relative Humidity: 50%
- Dew Point Temp: 50.5°F

Enclosure Air Conditions:

- Dry Bulb Temp: 45°F
- Relative Humidity: Low
 - HPWH removes moisture from the air

Best case is that this enclosure is surrounded on all 6-sides by other rooms at 70°F or higher. This is very rarely the case!

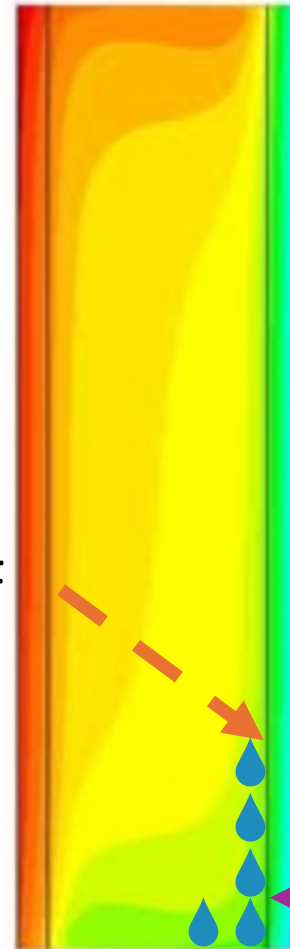


Temperature Gradient

Surrounding Space Air Conditions:

- Dry Bulb Temp: 70°F
- Relative Humidity: 50%
- Dew Point Temp: 50.5°F

Temperature: High 70°F



The **temperature** differential has the Potential to Create Condensation on Surfaces that Results in Moisture Damage and Mold Growth

Enclosure Air Conditions:

- Dry Bulb Temp: 45°F
- HPWH removes moisture from the air

45°F Temperature: Low

≤ 50°F

Issue: Installation instructions do not address the potential for moisture to condense on surfaces inside the walls, floors and ceilings.

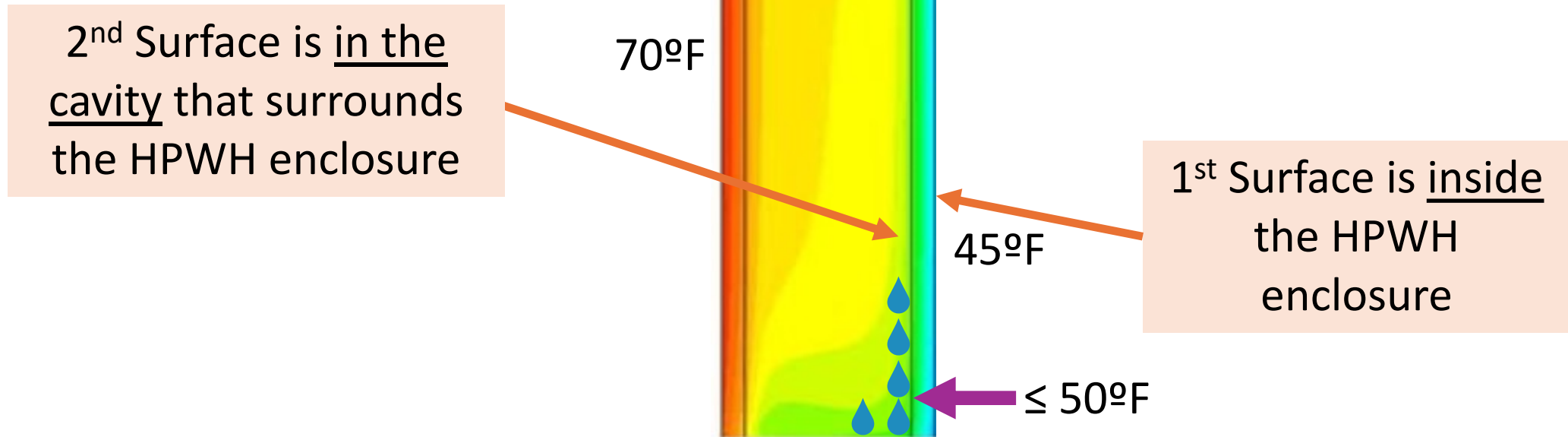
Recommended Reading: The Perfect Wall by Joseph Lstiburek.

<https://buildingscience.com/documents/insights/bsi-001-the-perfect-wall>

Vapor Pressure Gradient

Part 1

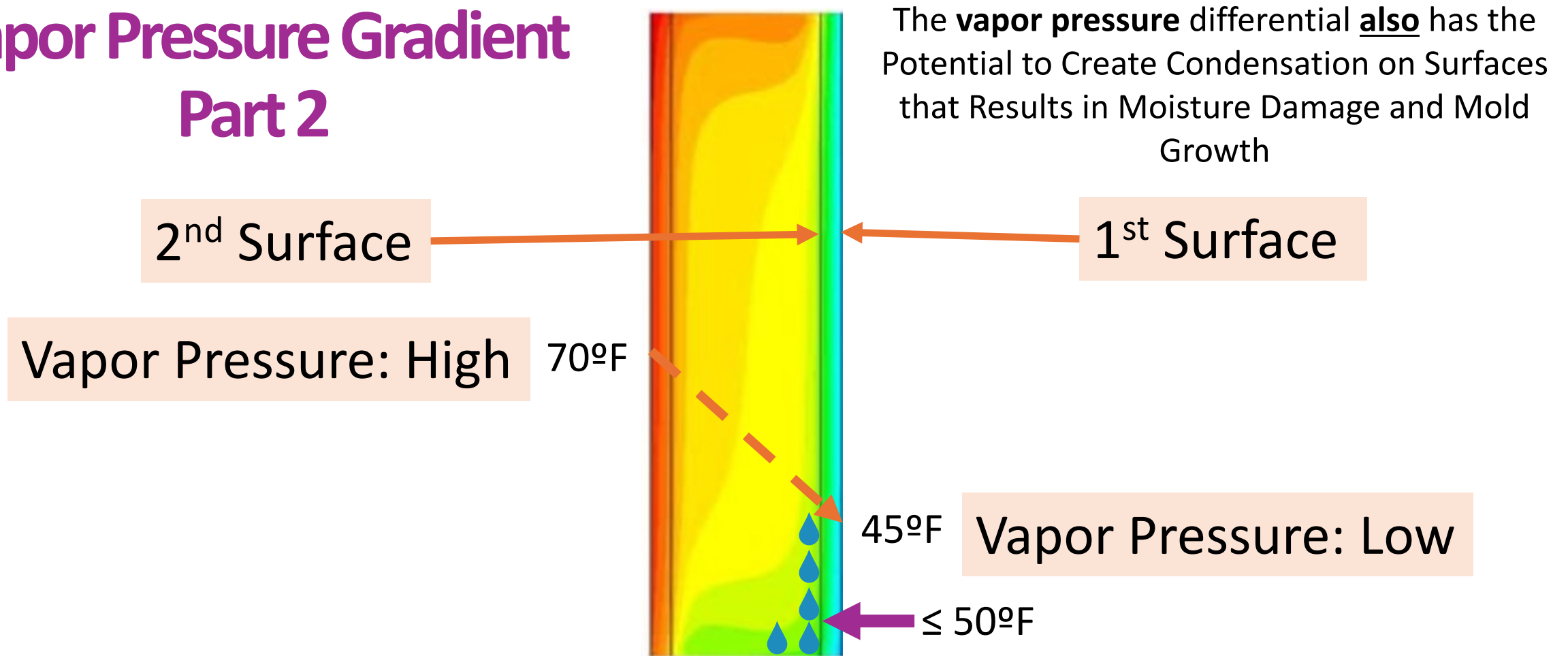
The **vapor pressure** differential also has the Potential to Create Condensation on Surfaces that Results in Moisture Damage and Mold Growth



- When a surface temperature is below the dew point, moisture vapor will:
1. condense on solid surfaces, not on fibrous insulation in the cavity.
 2. condense on the coldest surface it sees.

Vapor Pressure Gradient

Part 2



Moisture vapor always goes from regions of high vapor pressure to regions with low vapor pressure. Transport mechanisms include:

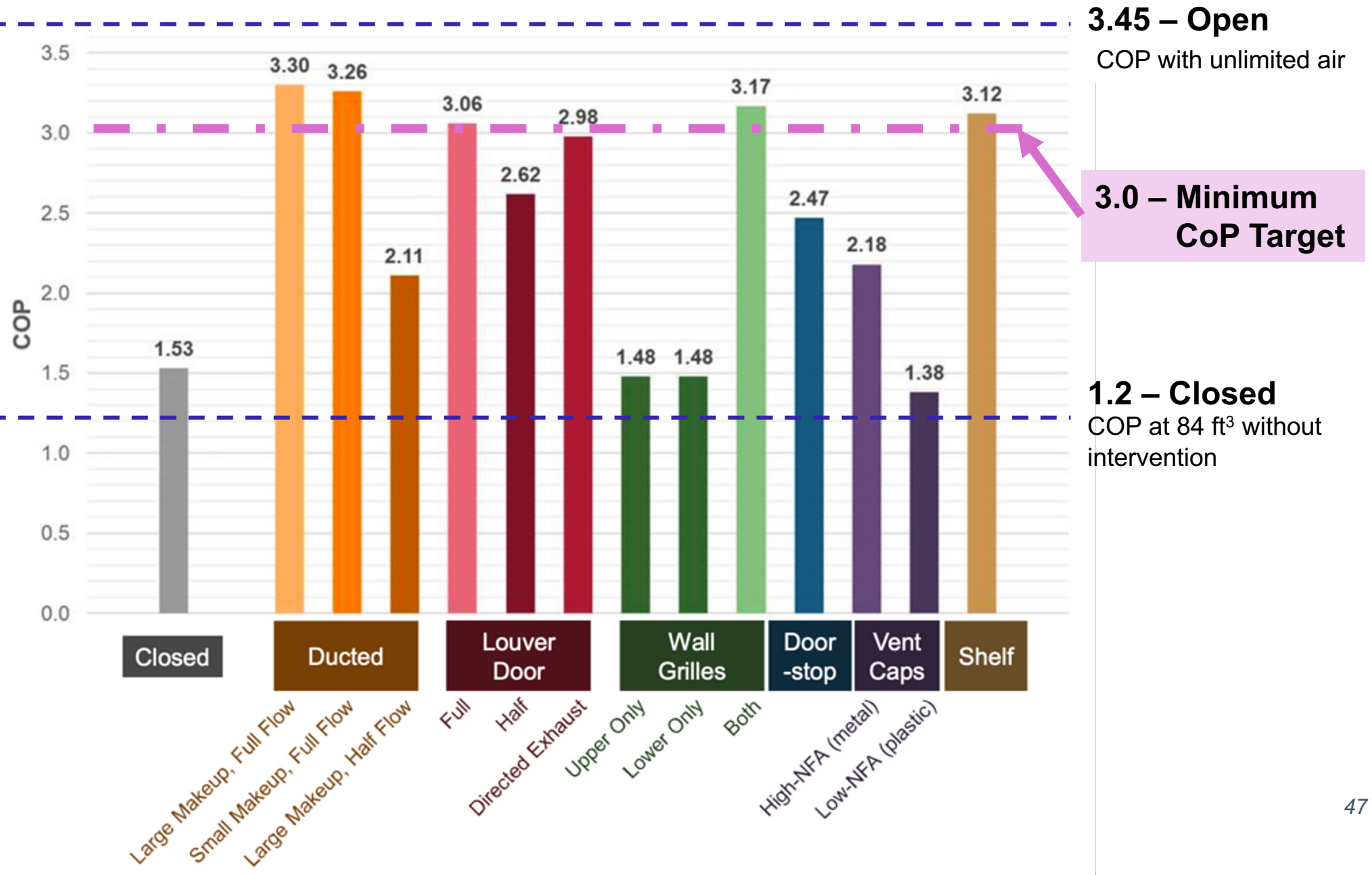
- 1) air that enters the enclosure
- 2) diffusion through the materials of the enclosure's envelope

Summary of COPs

Closed Spaces		
Location	Daily Hot Water Use (GPD)	COP
Large Room (conditioned)	55	3.7
	84	3.5
	135	3.1
1,000 ft ³ Closed	55	3.2
	84	2.6
	135	
700 ft ³ Closed	55	3.2
	84	
	135	2.9
450 ft ³ Closed	55 (50 gal HPWH)	3.3
	84 (50 gal HPWH)	2.7
	84 (80 gal HPWH)	3.3
200 ft ³ Closed	55	2.3
	84	1.9
	135	

Small Closets		
Location	Daily Hot Water Use (GPD)	COP
84 ft ³ Closed	55	1.2
	84	
	135	1.1
84 ft ³ Closed, Down Elbow	55	1.1
	84	
	135	
84 ft ³ Fully Louvered Door	55	3.1
	84	
	135	
84 ft ³ High-Low Grilles	55	3.2
	84	
	135	
84 ft ³ Ducted Exhaust	55	3.3
	84	
	135	

84 ft³ Closets: Effect of Ventilation Strategies

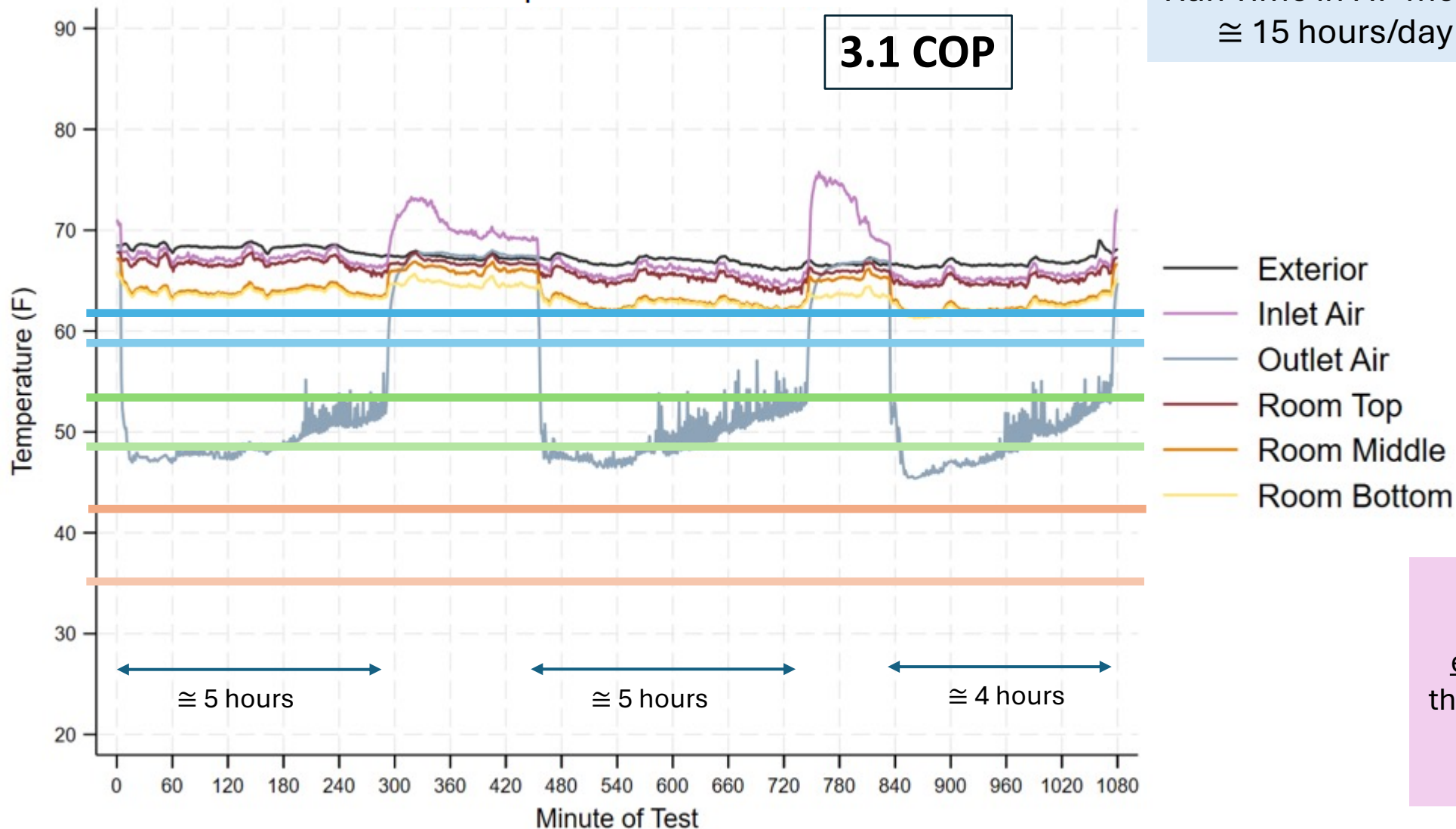


Large Room (Conditioned) – 135 GPD

80 Gallon. Open Room. 135 GPD. 3.1 COP.

3.1 COP

Run Time in HP mode:
 $\cong$ 15 hours/day



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

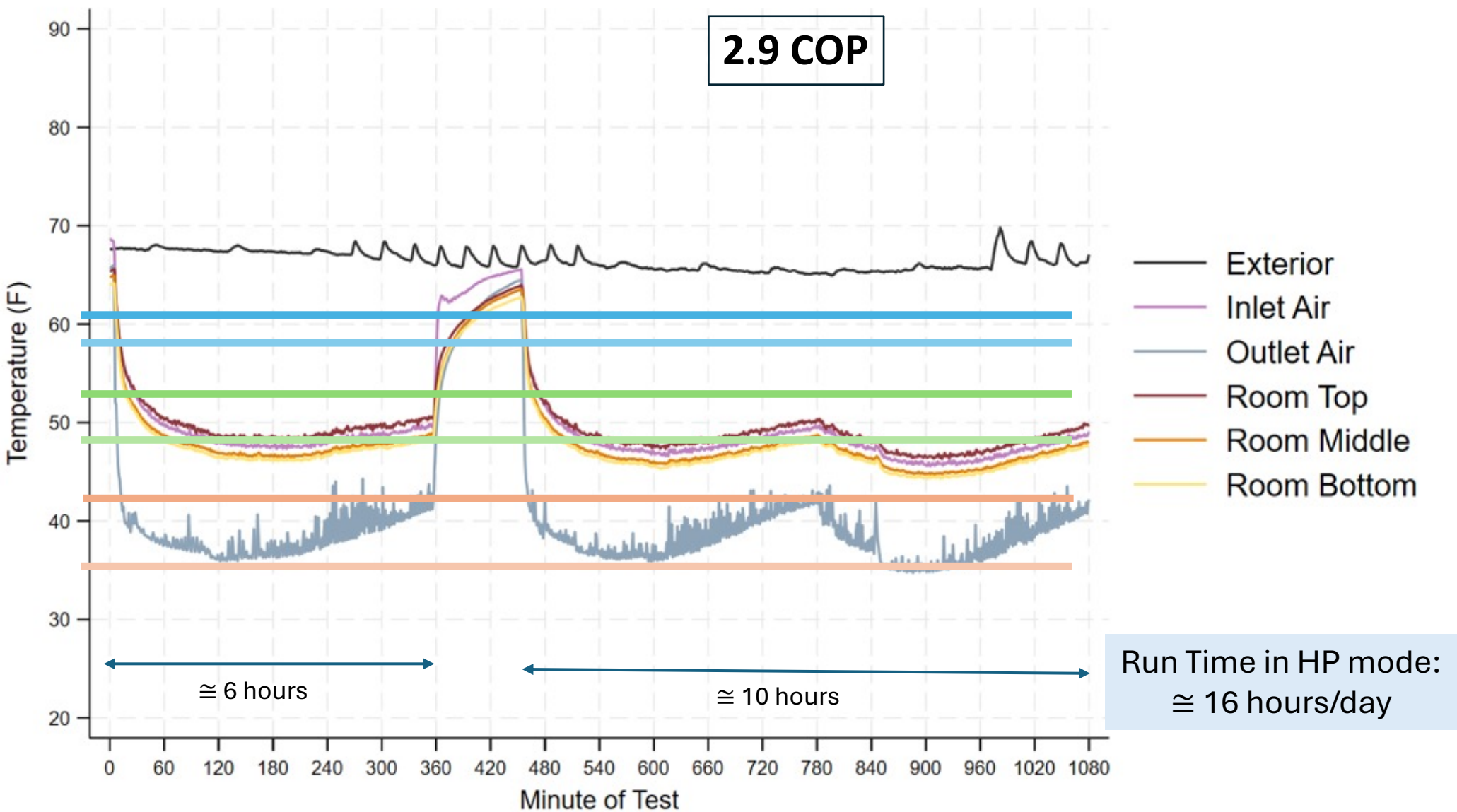
42 (40% RH)

35 (30% RH)

When the room is conditioned, and the exhaust air is well mixed, the surfaces of the room are **not** at risk **unless** RH is greater than 80%

700 ft³ Closet – Closed, 135 GPD

80 Gallon 700 ft³. Closed. 135 GPD. 2.9 COP.



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

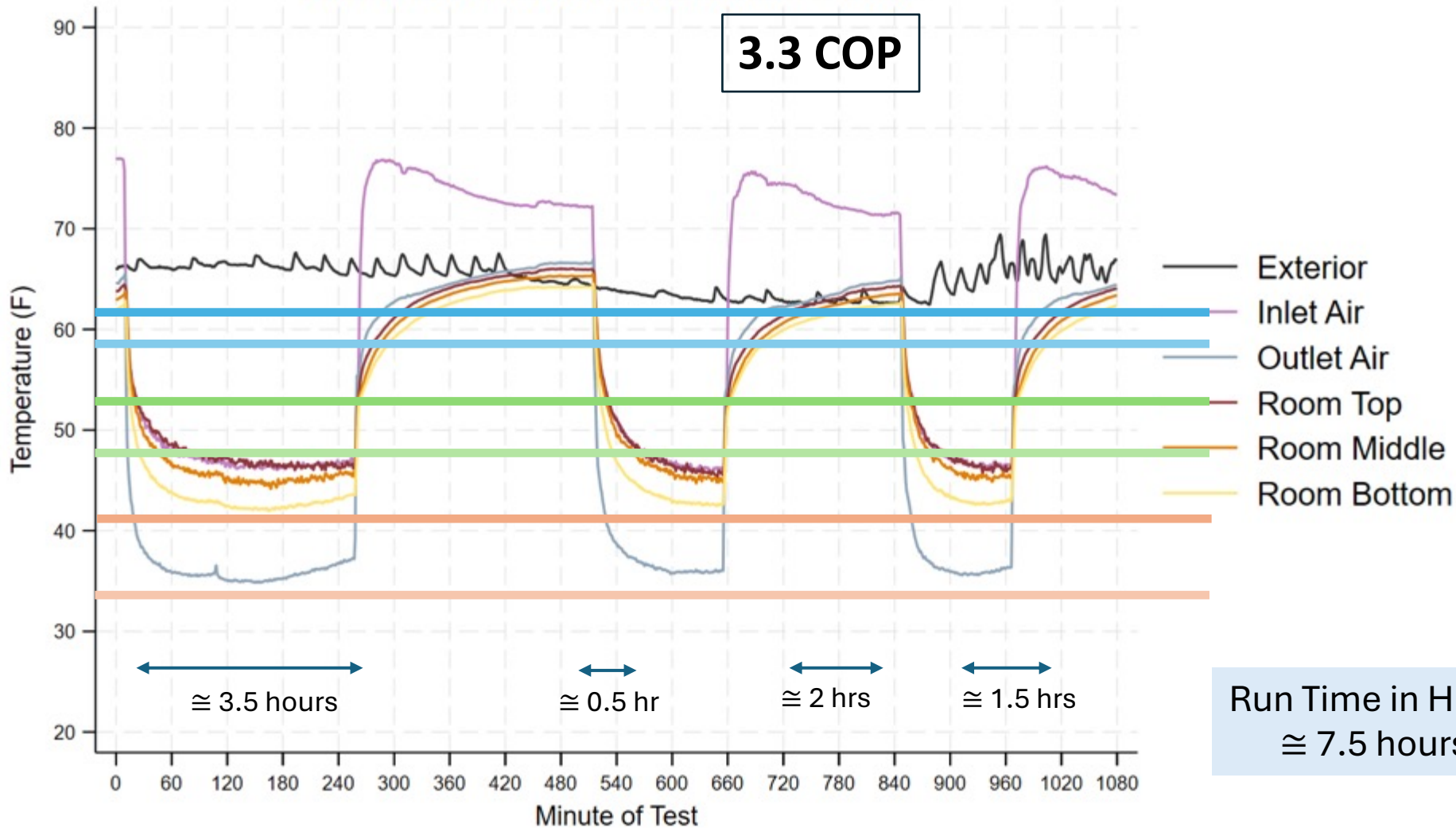
42 (40% RH)

35 (30% RH)

Surfaces at risk
when RH is
above 55%

450 ft³ Closet – 55 GPD

50 Gallon. 450 ft³ Room. Closed. 55 GPD. 3.3 COP.



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

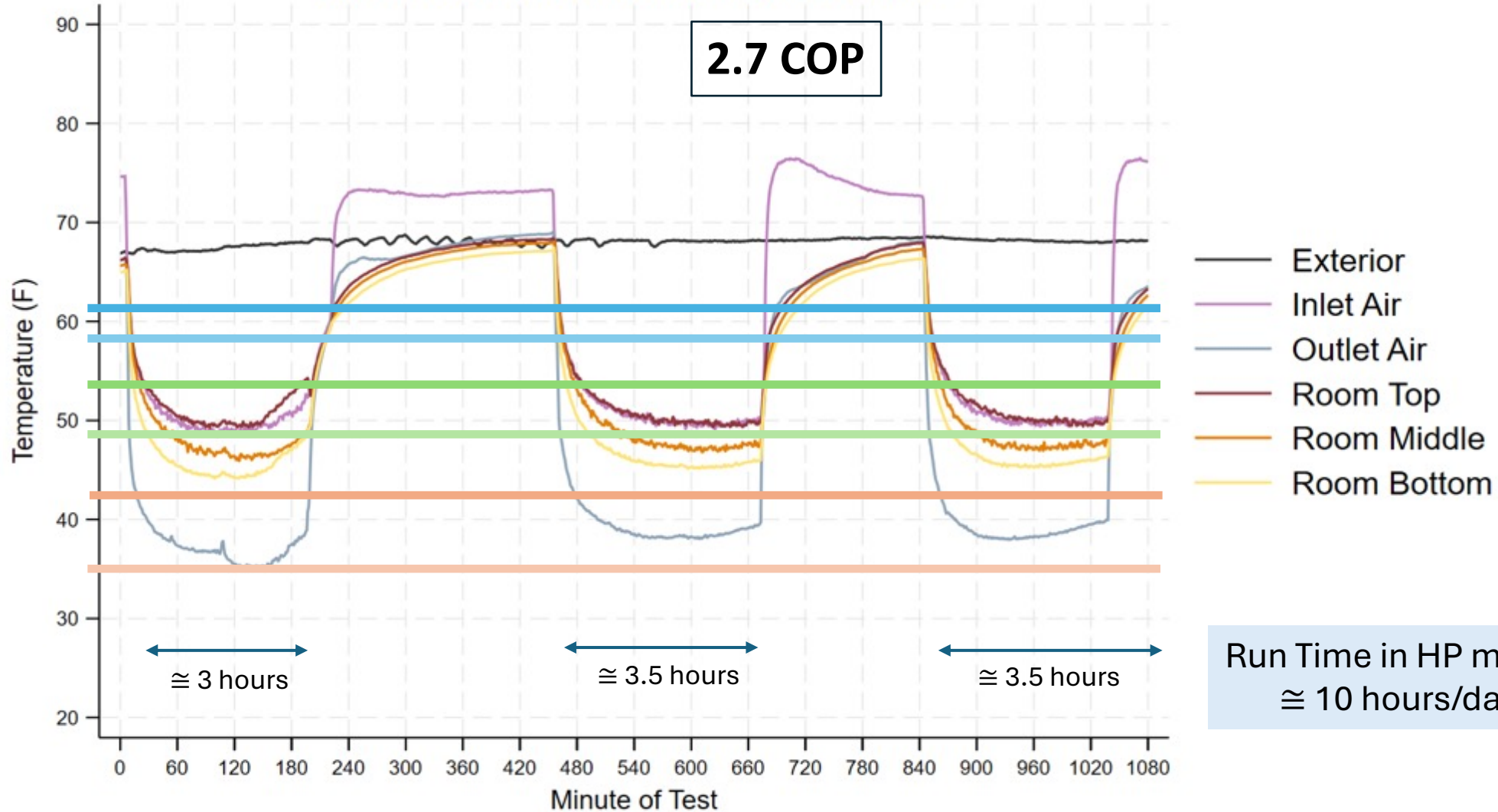
42 (40% RH)

35 (30% RH)

450 ft³ Closet – 84 GPD

50 Gallon. 450 ft³ Room. Closed. 84 GPD. 2.7 COP.

2.7 COP



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

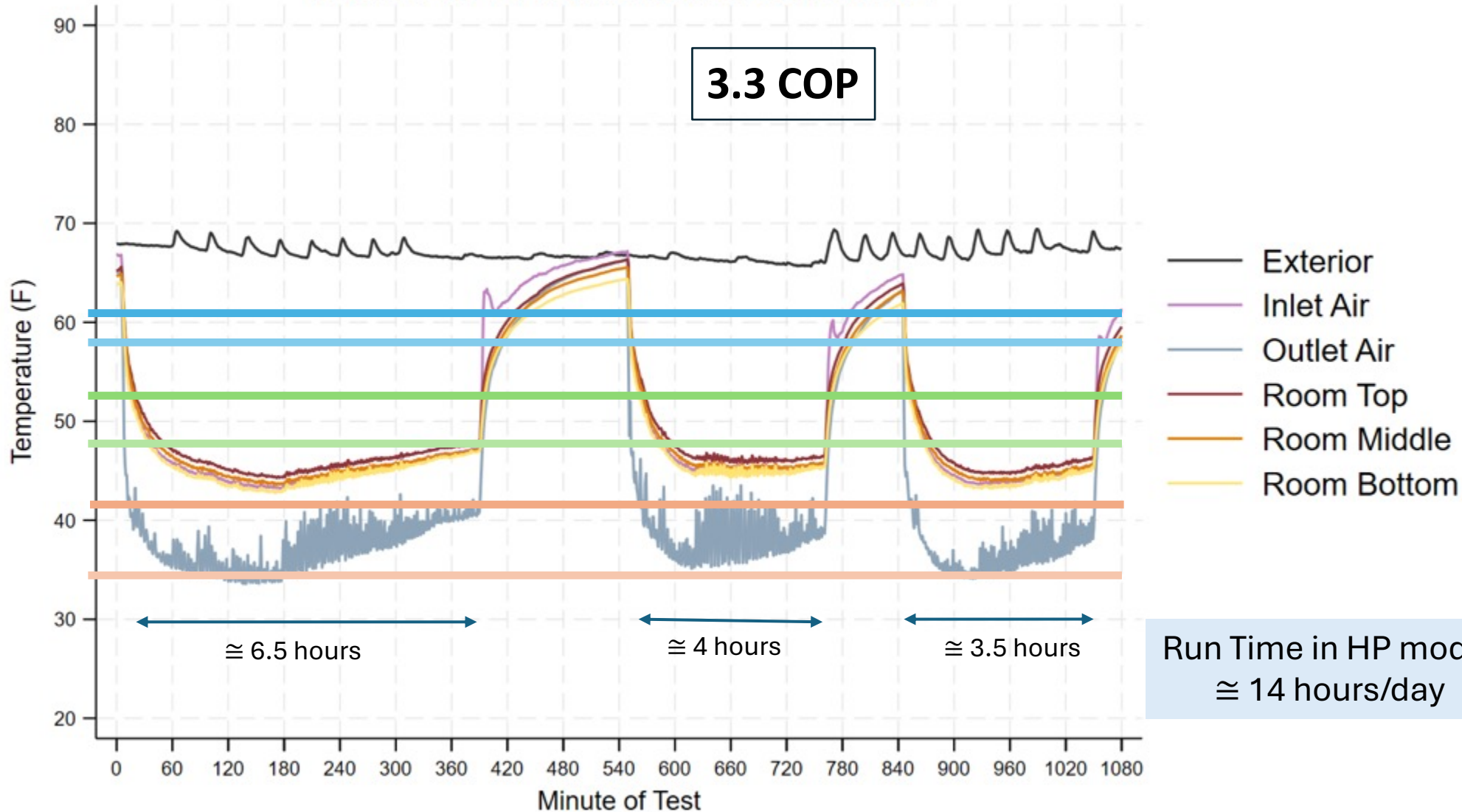
42 (40% RH)

35 (30% RH)

Surfaces at risk
when RH is
above 45%

450 ft³ Closet – 84 GPD

80 Gallon. 450 ft³ Room. Closed. 84 GPD. 3.3 COP.



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

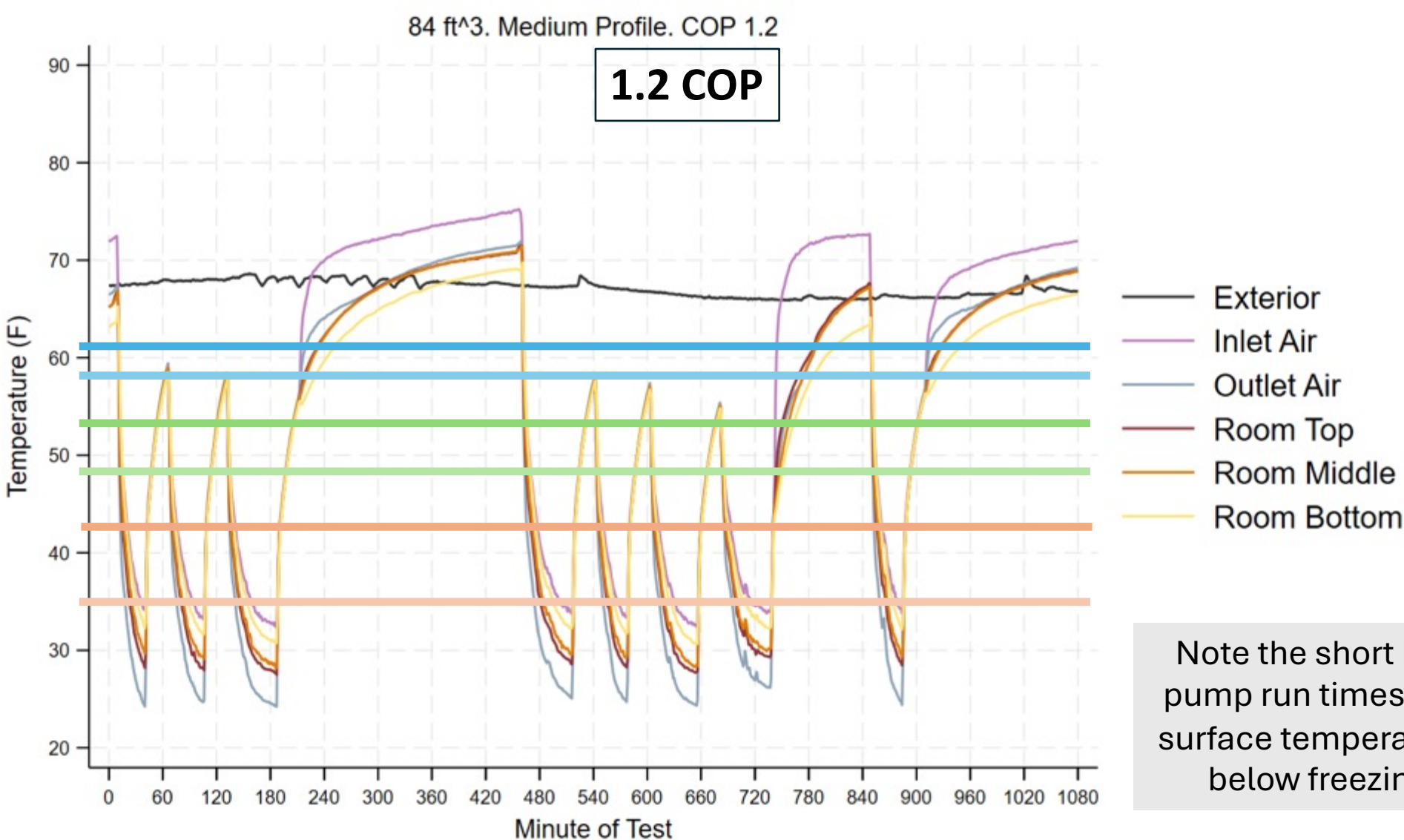
48 (50% RH)

42 (40% RH)

35 (30% RH)

Surfaces at risk
when RH is
above 45%

84 ft³ Closet – Closed, 55 GPD



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

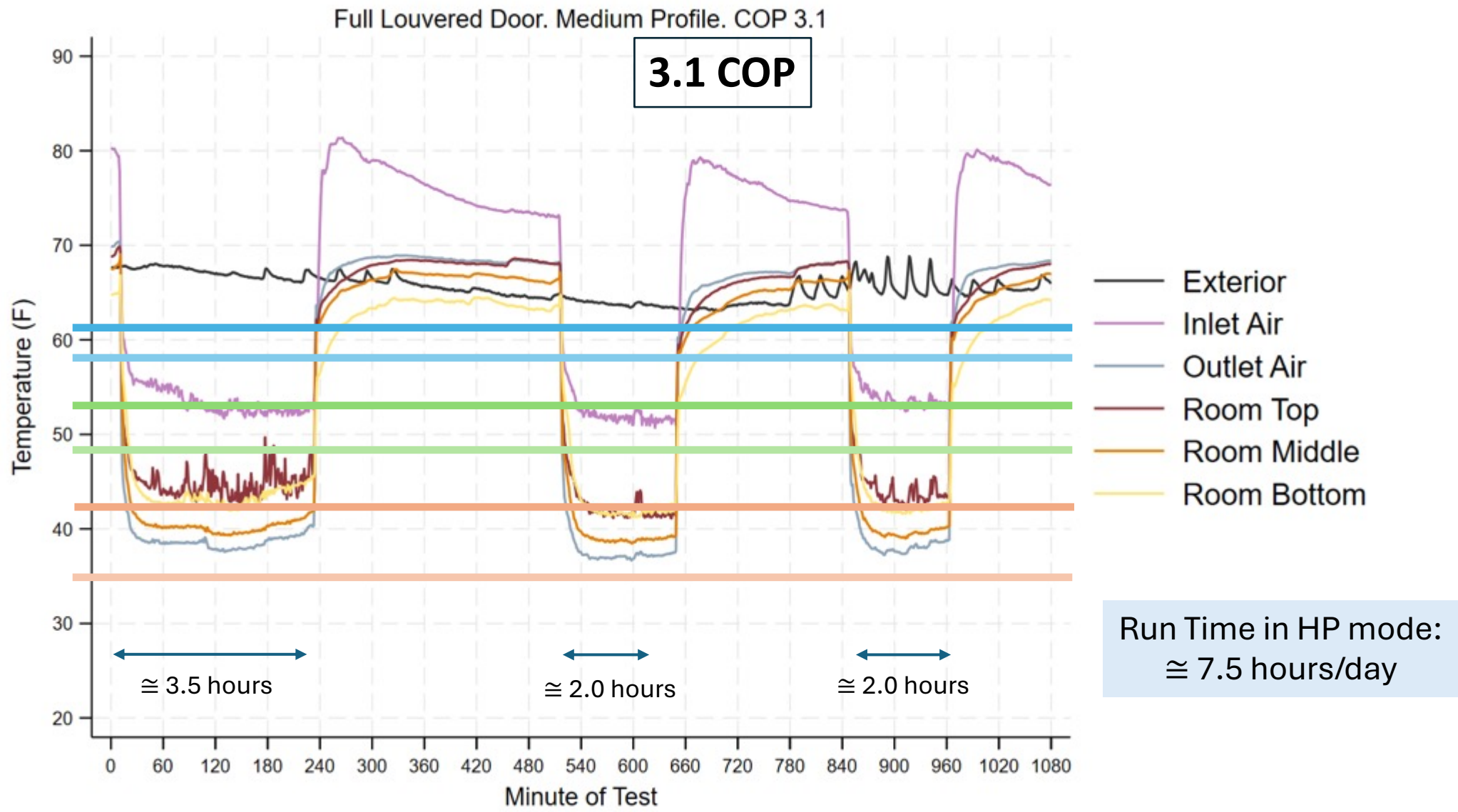
42 (40% RH)

35 (30% RH)

Note the short heat pump run times. And surface temperatures below freezing.

Surfaces at risk when RH is above 30%.

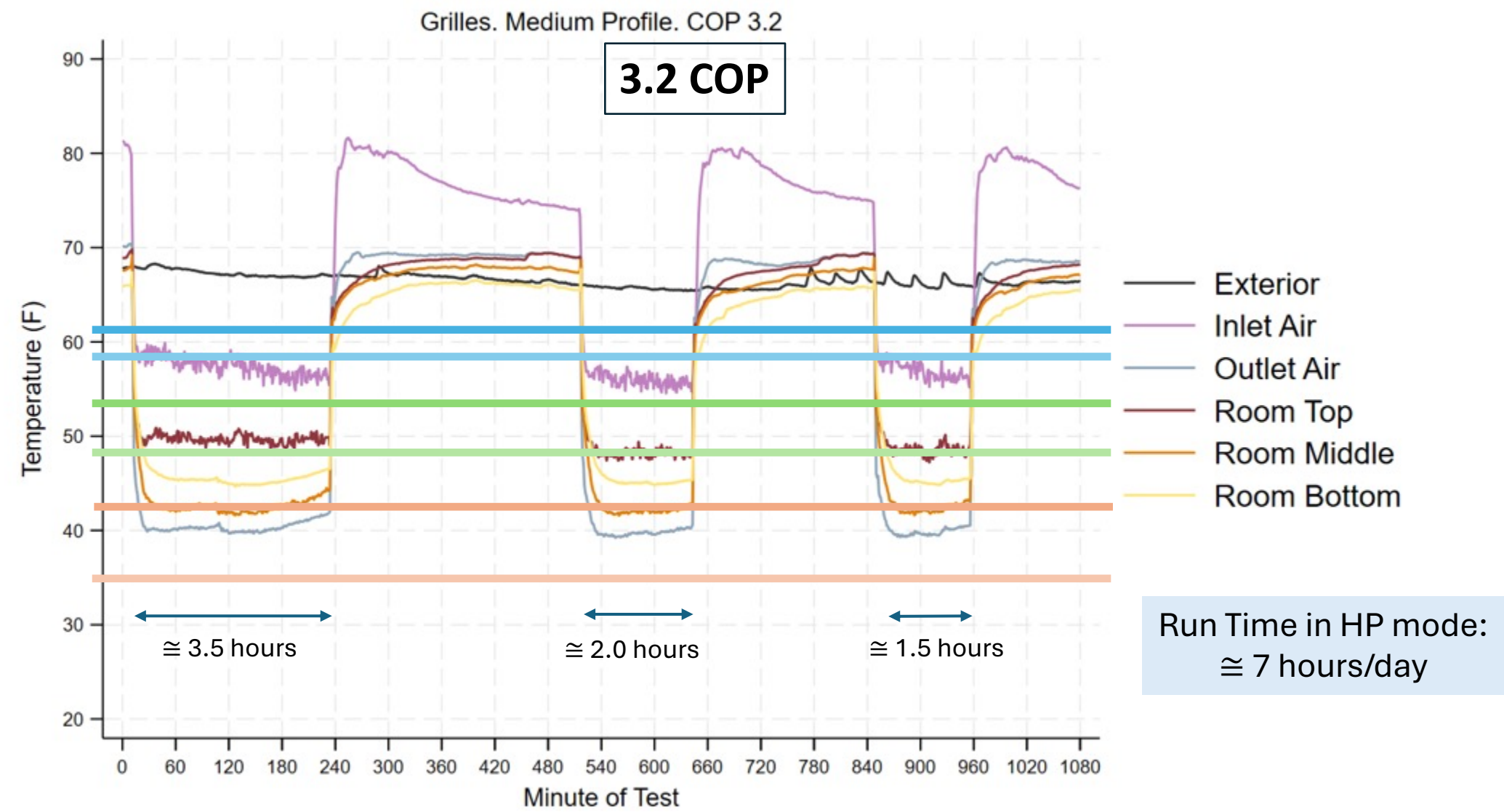
84 ft³ Closet – Fully Louvered Door, 55 GPD



Dew Point (F) @ 67.5F
61 (80% RH)
58 (70% RH)
53 (60% RH)
48 (50% RH)
42 (40% RH)
35 (30% RH)

Surfaces at risk
when RH is
above 45%.

84 ft³ Closet – High and Low Grilles, 55 GPD

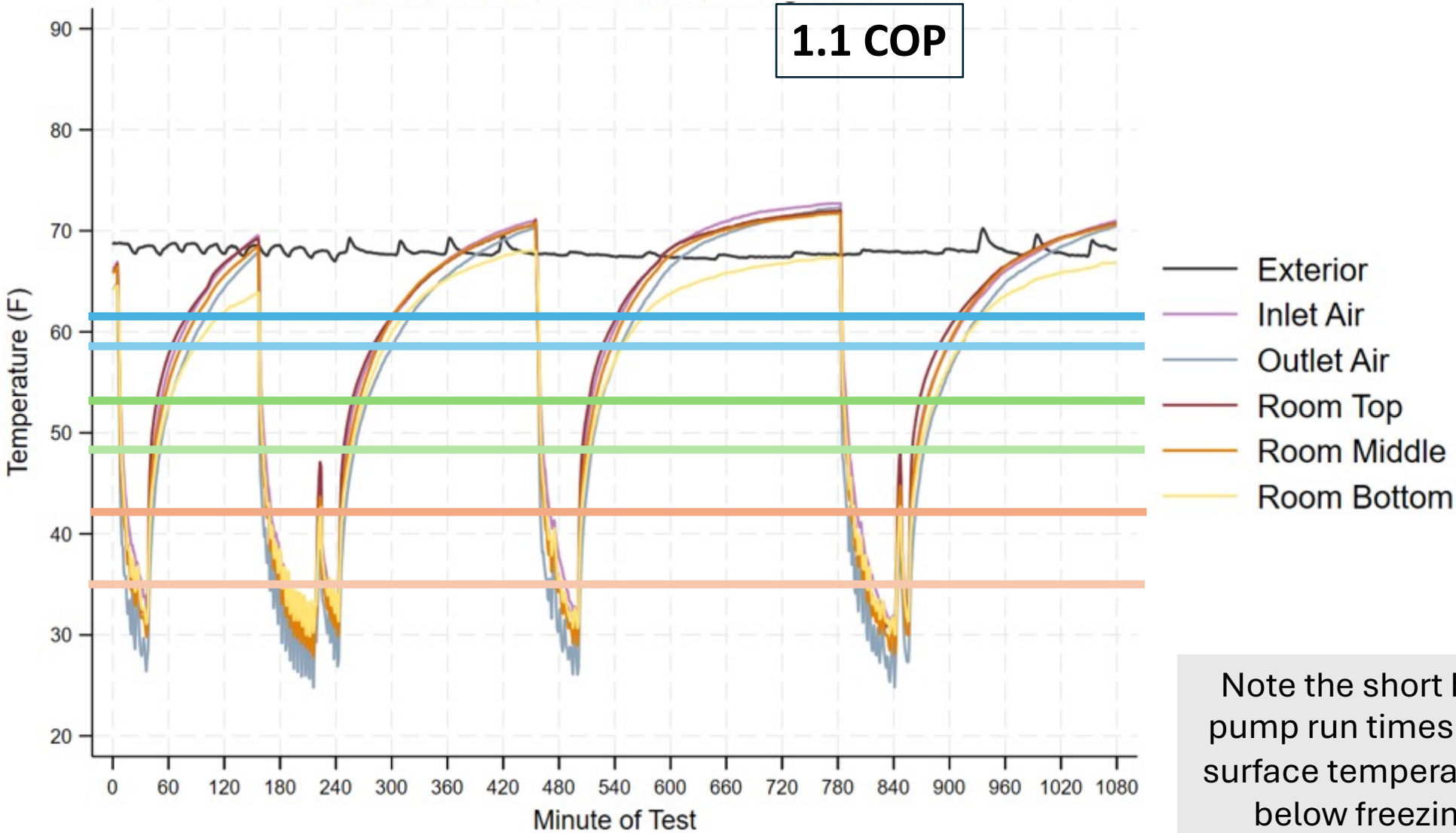


Dew Point (F) @ 67.5F
61 (80% RH)
58 (70% RH)
53 (60% RH)
48 (50% RH)
42 (40% RH)
35 (30% RH)

Surfaces at risk
when RH is
above 50%.

84 ft³ Closet – Closed, 135 GPD

80 Gallon 84 ft³ Closet. Closed. 135 GPD. 1.1 COP.



Dew Point (F)
@ 67.5F

61 (80% RH)

58 (70% RH)

53 (60% RH)

48 (50% RH)

42 (40% RH)

35 (30% RH)

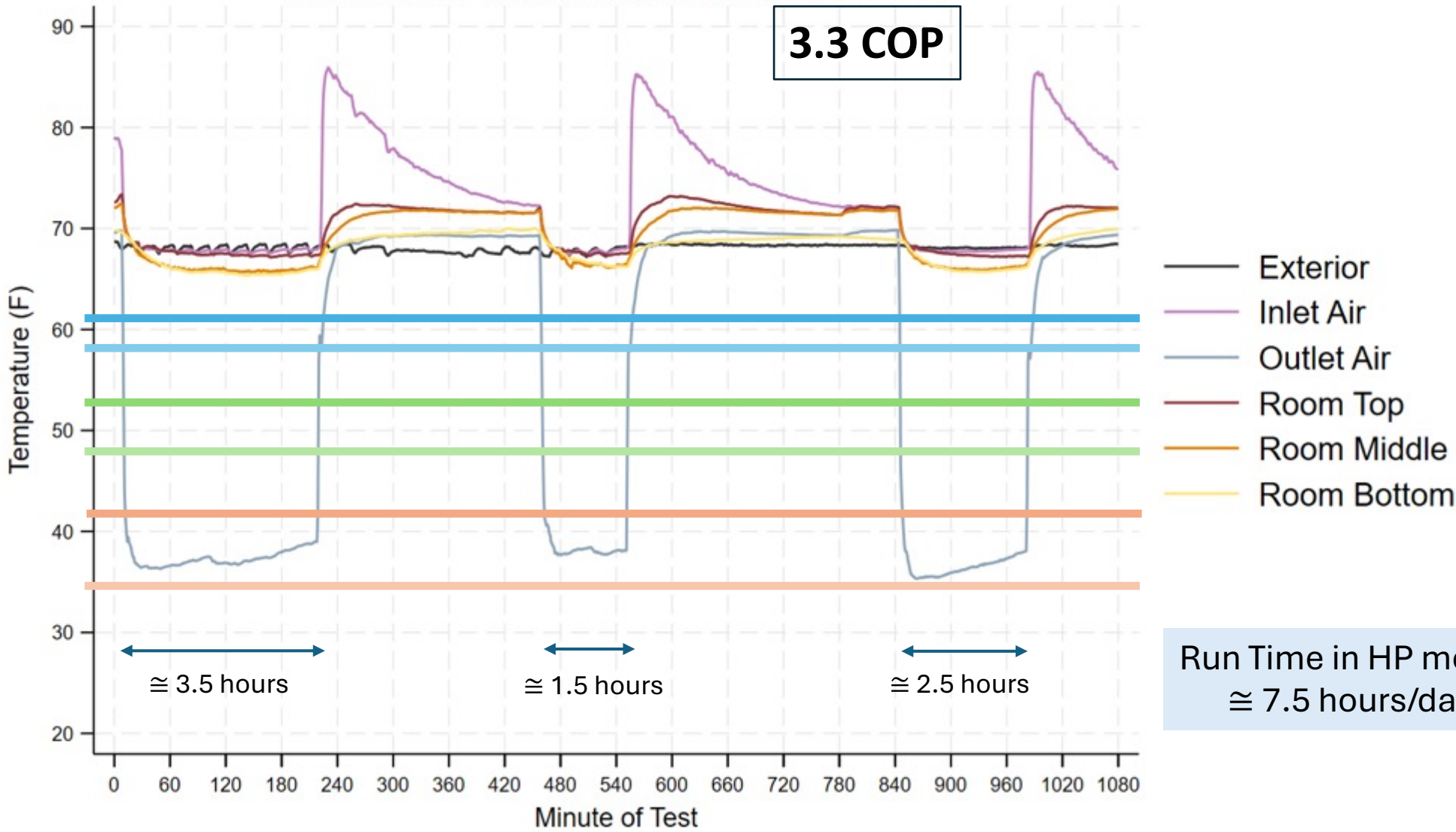
Note the short heat pump run times. And surface temperatures below freezing.

Surfaces at risk when RH is above 35%

84 ft³ Closet – Ducted Exhaust, 55 GPD

Ducted Exhaust - Nominal Flow. Medium Profile. COP 3.3

3.3 COP

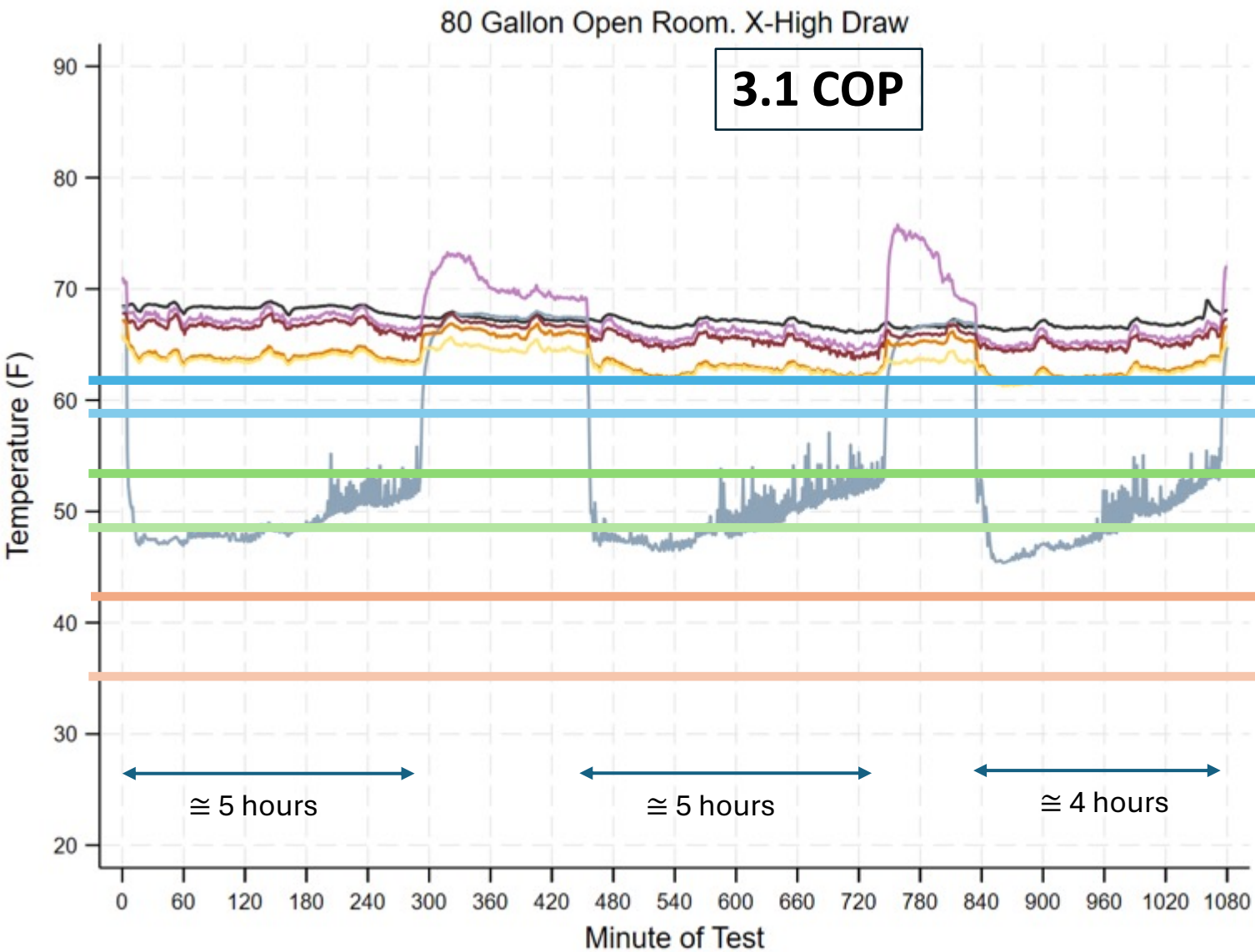


Run Time in HP mode:
 $\cong 7.5$ hours/day

Dew Point (F) @ 67.5F
61 (80% RH)
58 (70% RH)
53 (60% RH)
48 (50% RH)
42 (40% RH)
35 (30% RH)

Surfaces of the HPWH enclosure are **not** at risk.

Large Room (Conditioned) – 135 GPD



Run Time in HP mode:
≈ 15 hours/day

Dew Point (F) @ 67.5F
61 (80% RH)
58 (70% RH)
53 (60% RH)
48 (50% RH)
42 (40% RH)
35 (30% RH)

When the room is conditioned, and the exhaust air is well mixed, the surfaces of the room are **not** at risk **unless** RH is greater than 80%

Two Installation Methods Protect Public Health and Safety, and Increase Efficiency

Closed Spaces

Location	Daily Hot Water Use (GPD)	COP	Run Time (hrs/day)
Large Room (conditioned)	55	3.7	15
	84	3.5	
	135	3.1	
1,000 ft ³ Closed	55	3.2	6
	84	2.6	
	135		
700 ft ³ Closed	55	3.2	16
	84		
	135	2.9	
450 ft ³ Closed	55 (50 gal)	3.3	7.5
	84 (50 gal)	2.7	10
	84 (80 gal)	3.3	14
200 ft ³ Closed	55	2.3	
	84	1.9	
	135		

Small Closets

Location	Daily Hot Water Use (GPD)	COP	Run Time (hrs/day)
84 ft ³ Closed	55	1.2	
	84		
	135	1.1	
84 ft ³ Closed, Down Elbow	55	1.1	
	84		
	135		
84 ft ³ Fully Louvered Door	55	3.1	7.5
	84		
	135		
84 ft ³ High-Low Grilles	55	3.2	7
	84		
	135		
84 ft ³ Ducted Exhaust	55	3.3	7.5
	84		
	135		

When Conditioned:

1. Any room volume and
2. up to 24-hour runtimes in heat pump mode

There is No Conflict: Protecting Public Health and Safety and Increased Energy Efficiency Go Together!

		Protect Health and Safety of the Building and Its Occupants	
		High	Low
Energy Efficiency	High	Yes!	Why gamble?
	Low	Why gamble?	Absolutely not!

To protect health and safety,
HPWH installations need to minimize the potential for moisture to condense on surfaces inside the building.

Doing so minimizes the risk of moisture damage, mildew , and mold.

Public Health and Safety are Protected When:

Option 1. The integrated air-source HPWH:

1. Is installed in a **conditioned space** (65F or warmer), and
2. The exhaust air is not allowed to short circuit into the intake, and
3. The exhaust of the HPWH is well mixed and warmed up above the dew point before it reaches any surface in the room

Option 2. The integrated air-source HPWH:

1. Is installed in an enclosure that is not space conditioned, and
2. The exhaust air is not allowed to short circuit into the intake, and
3. The exhaust of the HPWH is ducted out of that enclosure to a location that is **space conditioned** (65F or warmer), and
4. The exhaust is well mixed and warmed up above the dew point before it reaches any surface in the conditioned space.

Operating Efficiency will be High Too!

How to Get Installations Right, Part 1:

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

Manage the Cold Exhaust Air to Prevent Moisture Issues

- Never trap the HPWH exhaust air in (small) enclosed spaces
- Raise the cold exhaust air above the dewpoint temperature as quickly as possible. Strategies include reheating, mixing or ducting to a safe location
- Keep the air in the room well-mixed; cold air settles, increasing the risk near the floor
- Use R-8 insulated & vapor-sealed ducts

How to Get Installations Right, Part 2:

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



Provide Sufficient Warm Air

1. Never trap the HPWH exhaust air in (small) enclosed spaces
2. Conduction into the space with the HPWH is not sufficient
3. A thermal resource is essential.
 1. It must be in the room or be brought into the room for use by the HPWH.
 2. To enable 24-hour operation, the thermal resource must be greater than or equal to the capacity of the heat pump.
 3. For example, if the CoP is 4, and the capacity of the heat pumps is 4,000 BTU/hour, the air must provide 3,000 BTU/hour. This is approximately 1 kW/hour.
4. Prevent the cold exhaust air from short circuiting into the intake.
5. If the intake air temperature will be below 40F for long periods of time, select a unit that has a defrost cycle

Possible Locations of HPWH Intakes and Exhausts

Intake	Exhaust
Top	Top
Side	Side
Back	Back

Typical Water Heater Locations

Basement

Garage

Attic

Mechanical Room

Closet

Crawl Space

Podium

Others?

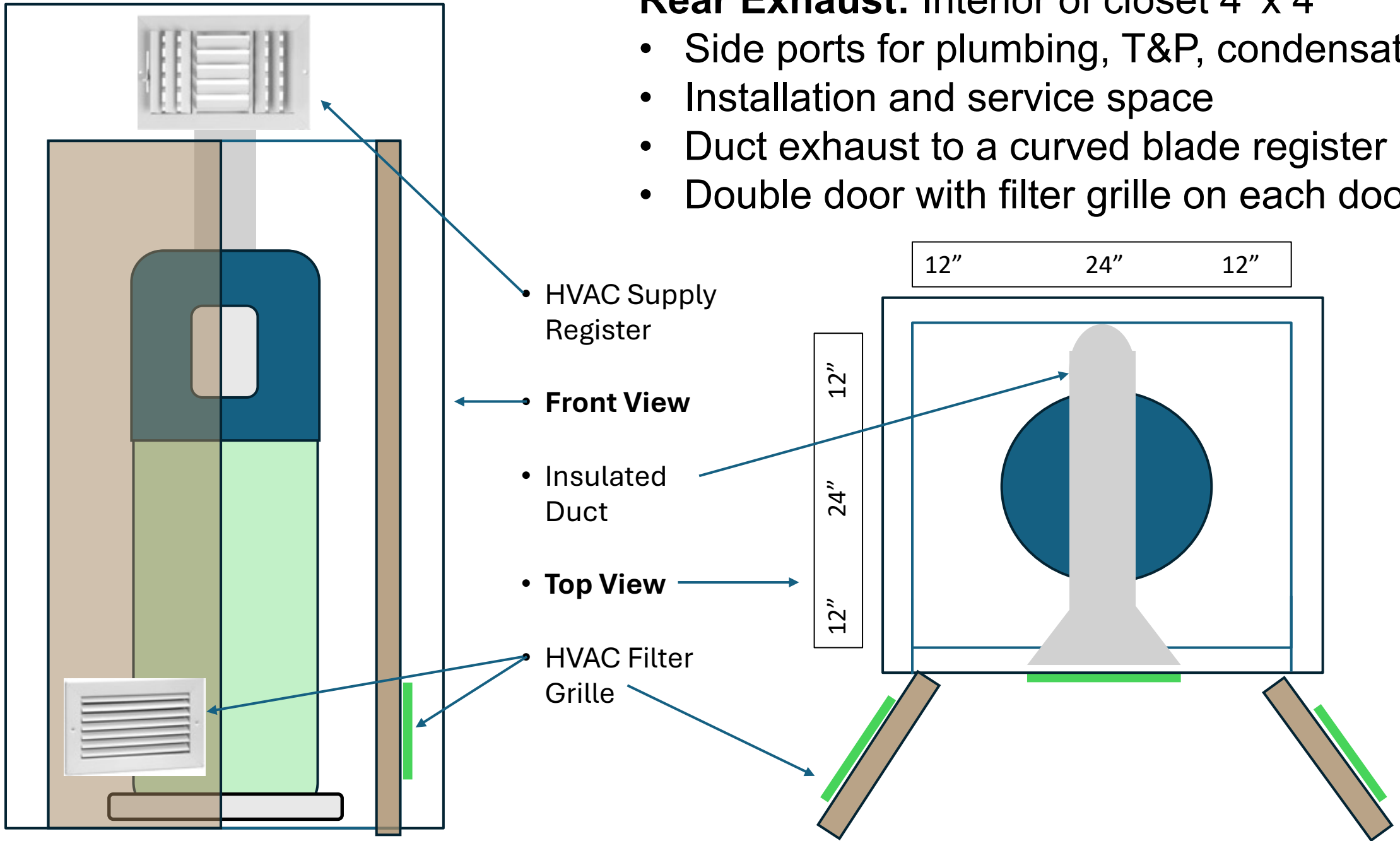
Ensuring the safe discharge of the cold exhaust air in the most confined locations while simultaneously providing warm intake air needs to be our focus.

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

Closets, of any size, are the most confined locations.

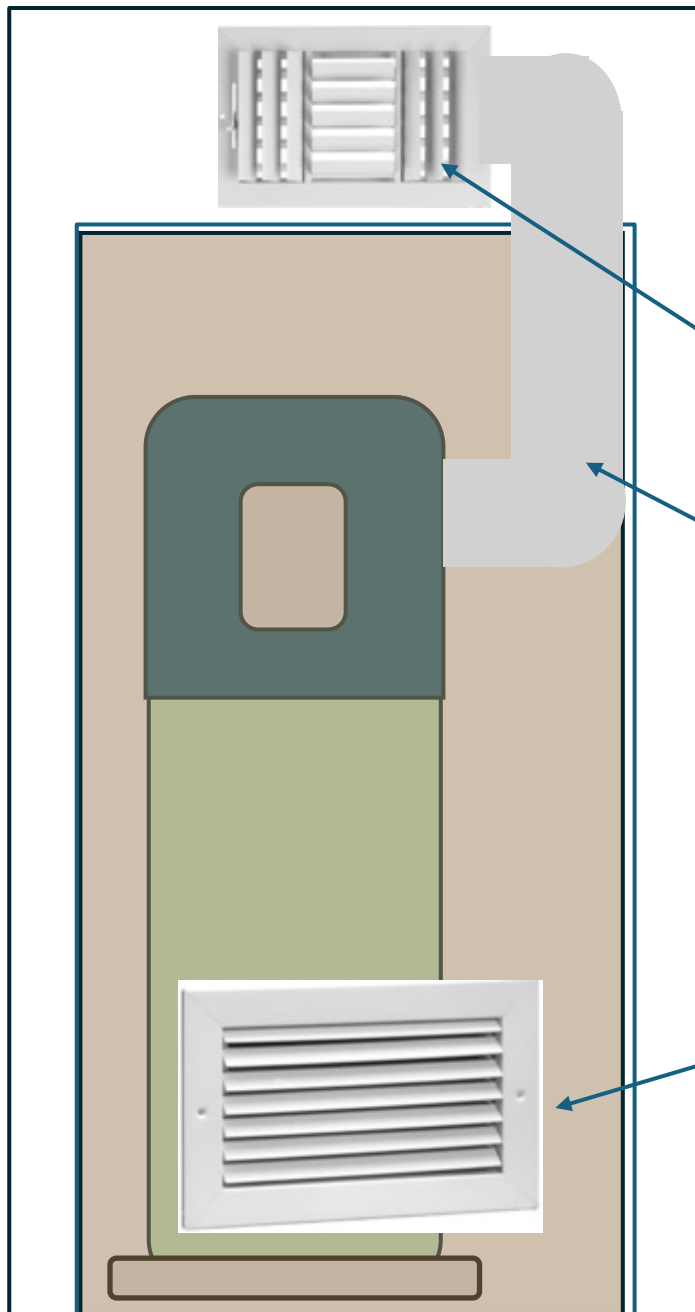
Rear Exhaust: Interior of closet 4' x 4'

- Side ports for plumbing, T&P, condensate
- Installation and service space
- Duct exhaust to a curved blade register
- Double door with filter grille on each door



Side Exhaust: Interior of closet 3' x 3.5'

- Side ports for plumbing, T&P, condensate
- Installation and service space
- Duct exhaust to a curved blade register
- Single door with large filter grille



• HVAC Supply Register

• Insulated Duct

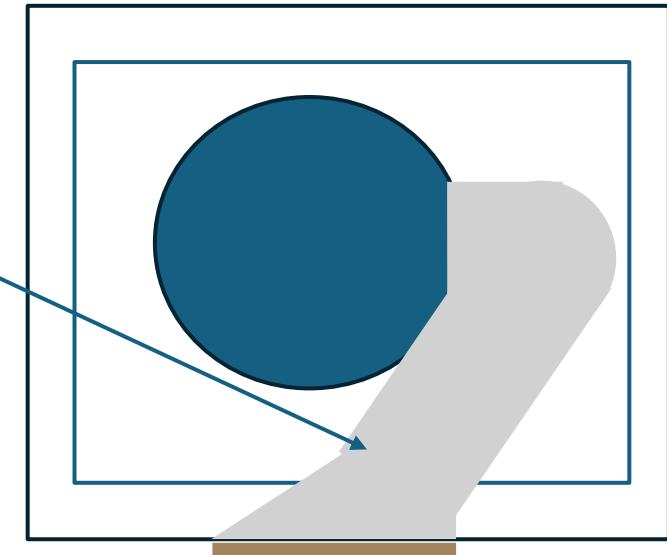
• **Front View**

• **Top View**

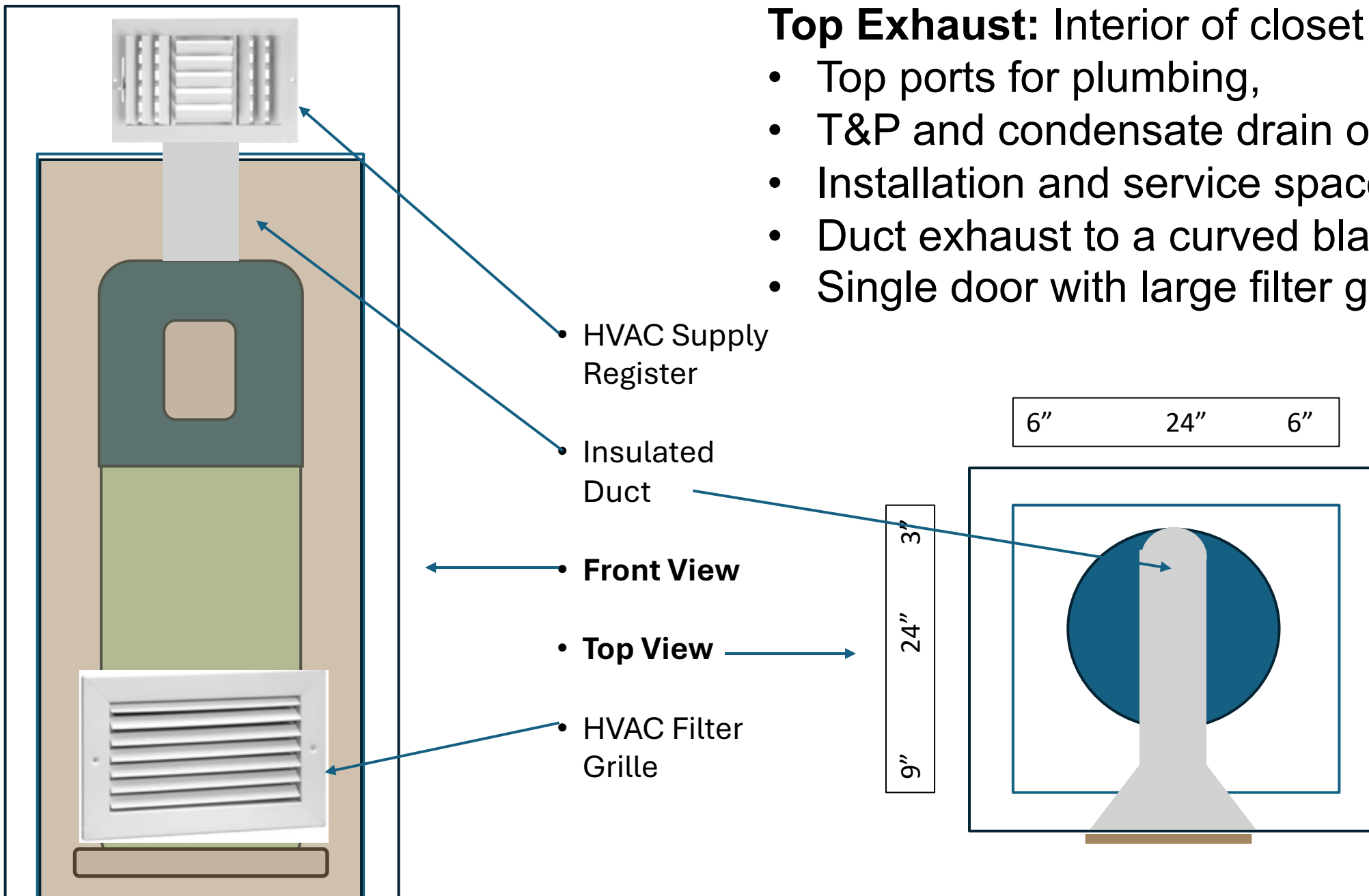
• HVAC Filter Grille

6" 24" 12"

3"
24"
9"



- Top Exhaust:** Interior of closet 3' x 3'
- Top ports for plumbing,
 - T&P and condensate drain on side
 - Installation and service space
 - Duct exhaust to a curved blade register
 - Single door with large filter grille



Insulated and Vapor Tight Ducting



ComfoPipe Compact Pipe



ComfoPipe Compact Bend



ComfoPipe Compact
Directional Coupler



ComfoPipe Compact Coupler

Currently available in 125-200 mm diameters

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

Managing the Air Flow: Part 1

Large areas with full access to warm air

- Do not allow the exhaust air to short circuit into the intake
- Raise the cold exhaust air above the dewpoint temperature as quickly as possible.
- Discharge cold air away from surfaces.
- Ensure that the exhaust air is thoroughly mixed with surrounding air before it becomes intake air

Small areas with limited access to warm air

- Duct cold discharge air out of the enclosure into larger area to mix thoroughly before it becomes intake air
- Bring intake air back through a large filter grille. The surface area of the return grille needs to be 2-4 times the cross-section area of the inside diameter of the exhaust duct
- The lower the intake air temperature, the lower the CoP

Install oversized MERV 13 filters for the intake air

- As part of a filter grille in the door or wall to the small enclosure; or
- In a filter box that is ducted to the intake of the HPWH
- Provides better protection for the coils and less frequent filter maintenance

Managing the Air Flow: Part 2

Integrate the HPWH with the HVAC system

- Install an HVAC return to pull air through the HPWH.
 - Consider ducting the HPWH exhaust into the return plenum.
 - If needed, install a transfer grille into the space where the HPWH is located.
- Use the HVAC system to distribute and mix all air
- Run the HVAC fan at low watts and 150-200 cfm continuously or link the fan to come on whenever the HPWH is running

Conclusions

1. There are many benefits to reducing the volume!!!
 1. Costs less to build.
 2. Improves health and safety
 3. Hot water will arrive much more quickly
 4. Increases energy efficiency
 5. Decreases embodied and operational carbon
 6. Anything else?
2. These two decisions last the life of the building!
 1. Distance is an architectural decision.
 2. Volume is a plumbing decision.
3. Integrated Air-Source HPWH
 1. Don't allow the cold exhaust air to bring surfaces below the dew point

Questions?

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gary@garykleinassociates.com

916-549-7080



Thank you!

Appendix

DOE Efficient New Homes
Single Family National Program Requirements
Version 2 (Rev. 3)

Provisions Related to Hot Water

5. Water Heating Efficiency (comply with 5.1, 5.2, **or** 5.3)

- 5.1 Hot water delivery systems meet efficient design requirements.²⁰
5.2 Water heater and fixtures meet efficiency criteria.^{21, 22}
5.3 Home is certified under WaterSense Labeled Homes Version 2.0.

Water Heater		
DHW equipment modeled at the applicable efficiency levels based on Uniform Energy Factor (UEF)	Electric Systems	Gas / Propane Systems
	2.57	0.95

Hot Water Distribution Part 1: Footnote 20

²⁰ Hot **water** delivery systems meet the following efficiency requirements:

To minimize **water** wasted while waiting for hot **water**, the hot **water** distribution system shall store no more than 0.5 gallons (1.9 liters) of **water** in any piping/manifold between the hot **water** source and any hot **water** fixture, except for fixtures in bathrooms without a shower or bathtub. System options include manifold-fed systems, structured plumbing systems, core plumbing layouts, and on-demand recirculation systems. The following requirements apply to recirculation systems:

- a. Recirculation systems must be based on an occupant-controlled switch or an occupancy sensor. A sensor or switch must be installed for each fixture or set of fixtures within a room (e.g., a bathroom with multiple fixtures) located beyond a 0.5 gallon stored-volume range from the **water** heater.
- b. Recirculation systems which operate based on “adaptive” scheduling, meaning that they “learn” the hot **water** demand profile in the home and adapt their operation to anticipate this profile, are permitted at this time, and do not require the use of occupant-controlled switches or occupancy sensors.
- c. Recirculation systems that are activated based **solely** on a timer and/or temperature sensor are not eligible.

To verify that the system stores no more than 0.5 gallons (1.9 liters), Raters shall either use the Calculation method or the Field Verification method. In the Calculation method, the Rater shall calculate the stored volume between the hot **water** source and the furthest fixture using the piping or tubing inside diameter and the length of the piping/tubing. In the case of on-demand recirculation systems, the 0.5-gallon (1.9 liter) storage limit shall be measured from the point where the branch feeding the furthest fixture branches off the recirculation loop, to the fixture itself. An Excel-based tool is available on the DOE Efficient New Homes website for this calculation.

Using the Field Verification method, no more than 0.6 gallons (2.3 liters) of **water** shall be collected from the hot **water** fixture before hot **water** is delivered. Only the fixture with the greatest stored volume between the fixture and the hot **water** source (or recirculation loop) needs to be tested. To field-verify that the system meets the 0.6-gallon (2.3 liter) limit, Raters shall first initiate operation of on-demand recirculation systems, if present, and let such systems run for at least 40 seconds. Next, a bucket or flow measuring bag (pre-marked for 0.6 gallons) shall be placed under the hot **water** fixture. The hot **water** shall be turned on completely and a digital temperature sensor used to record the initial temperature of the **water** flow. Once the **water** reaches the pre-marked line at 0.6 gallons (approximately 24 seconds for a lavatory faucet), the **water** shall be turned off and the ending temperature of the **water** flow (not the collection bucket) shall be recorded. The temperature of the **water** flow must increase by ≥ 10 °F in comparing the final to the initial temperature reading. Under the DOE Efficient New Homes Single

Hot Water Distribution Part 1: Footnote 20, cont.

- e. The hot water distribution system shall store no more than 1.8 gallons between the hot water source and the furthest fixture. In the case of on-demand recirculation systems, the hot water source is considered as the point at which the branch feeding the fixture branches off the recirculation loop. Recirculation systems must be based on an occupant-controlled switch or an occupancy sensor. A sensor or switch must be installed for each fixture or set of fixtures within a room (e.g., a bathroom with multiple fixtures) located beyond a 1.8-gallon stored volume range from the water heater. This storage limit shall be verified by either (1) a calculation using the piping or tubing interior diameter and the system length based on plans, or (2) by a field verification test, using the protocol described in the prior endnote, which demonstrates a minimum temperature rise of 10 °F by the time 2.0 gallons of water is delivered to the furthest hot water fixture. Fixtures in bathrooms without a shower or bathtub are exempt from the system storage limit requirement.

Projects using this compliance option are not permitted to use hot water recirculation systems which operate continuously or operate based solely on a timer or temperature sensor.

Issue: Conflicting Provisions

Volume in Pipe: 0.5 gallons

Volume until Hot: ≤ 0.6 gallons down drain, ≥ 10 F rise

Volume in Pipe: 1.8 gallons

Volume until Hot: ≤ 2.0 gallons down drain, ≥ 10 F rise

Hot Water Distribution Part 2: Footnote 21

²¹ **Water** heaters and fixtures meet the following efficiency criteria:

- a. Gas **water** heaters, if present, shall have a Uniform Energy Factor ≥ 0.87
- b. Electric **water** heaters, if present, shall have a Uniform Energy Factor ≥ 2.2
- c. Solar **water** heating systems, if present, shall have a minimum solar fraction, as follows:

2021 IECC Climate Zone	1, 2	3, 4A, 4B	4C, 5, 6	7, 8
Minimum Solar Fraction (SF)	0.80	0.64	0.47	0.28

DOE Efficient New Homes
Multifamily National Program Requirements
Version 2 (Rev. 2)

Provisions Related to Hot Water

5. Hot Water Efficiency	<p>5.1 WaterSense labeled fixtures for dwelling unit showerheads, bathroom sink faucets, and/or bathroom sink faucet accessories.²⁵</p> <p>5.2 Hot water delivery systems meet stored volume criteria.²⁶</p> <p>5.3 In-unit recirculation systems use on-demand controls.²⁷</p> <p>5.4 Recirculating central hot water distribution systems meet pipe insulation thickness criteria.²⁸</p>	Dwelling units
10. Heat Pump Water Heater Ready	<p>10.1 Dwelling units with in-unit water heaters meet minimum electric and space requirements.³⁸</p> <p>10.2 Dwelling units with in-unit water heaters have a condensate drain installed within three feet of existing water heater.³⁹</p>	Dwelling units

Water Heater Serving Dwelling Units								
In-Unit Gas Water Heater: UEF = 0.95	In-Unit Electric Water Heater: UEF = 1.95							
Central System Gas Water Heater: E _t = 95%	Central System Electric Water Heater: COP = 1.6							
In-Unit Solar Water Heating System SF ⁴⁷	1	2	3	4A, 4B	4C, 5	6	7	8
	0.80	0.80	0.64	0.64	0.47	0.47	0.28	0.28

<p>12. HPWH Installation Quality Advisory Only</p>	<p>Where heat pump water heaters are installed in dwelling units, partners are encouraged, but not required, to adhere to these installation practices to achieve optimal performance:</p> <p>12.1 HPWH has direct access to manufacturer-specified volume of ambient air (typical specs range from 450 to 1200 ft³), free of major dust sources, in the space surrounding the water heater through the mechanical room volume or the use of a louvered door, wall vents, ducting, or other strategy.</p> <p>12.2 HPWH installation complies with the manufacturer's minimum clearance requirements to make the unit accessible for maintenance and filter cleaning/replacement.</p> <p>12.3 HPWH has a sound rating of ≤ 55 dBA and a louvered door is not used to separate the unit from living space, or the HPWH has a sound rating of ≤ 35 dBA when a louvered door is used. Alternately, the HPWH is separated from living spaces by sound-attenuating assemblies with STC 35 or greater (i.e., by adding batt insulation to the surrounding wall assembly).</p> <p><i>DOE will consider making these installation practices requirements in a future program update.</i></p>
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Issue: Room volume for HPWH

Hot Water Distribution Part 1: Footnote 25

- ²⁵ WaterSense labelling of products may be verified in one of two ways:
- a. A cut sheet for the installed product indicates that it is WaterSense labeled and field verification shows that the installed product is the one described on the cut sheet.
 - b. The installed product can be found in the most recent WaterSense Product Search tool (<https://lookforwatersense.epa.gov/products/>) and field verification shows that the installed product matches the product described in the search tool.

WaterSense: Same as SF

Hot Water Distribution Part 2: Footnote 26:

²⁶ To minimize **water** wasted while waiting for hot **water** and **water** heating energy, the hot **water** distribution system shall store no more than 1.8 gallons (6.8 liters) of **water** in any piping/manifold between the hot **water** source (e.g., central or in-unit hot **water** tank, central or in-unit recirculation loop) and any in-unit hot **water** fixture. This provision applies to in-unit plumbing systems and central hot **water** distribution systems. In-unit system options include manifold-fed systems; structured plumbing systems; core plumbing layouts, and recirculation systems. This provision does not apply to fixtures in dwelling unit bathrooms without a shower or bathtub.

To verify that the distribution system stores no more than 1.8 gallons (6.8 liters), raters shall either use the Calculation method **or** the Field Verification method. In the Calculation method, the rater shall calculate the stored volume between the hot **water** source and the furthest fixture from the source using the piping or tubing inside diameter and the length of the piping/tubing. In the case of recirculation systems (either within the dwelling or central systems), the 1.8 gallon (6.8 liter) storage limit shall be measured from the point where the branch feeding the furthest fixture branches off the recirculation loop, to the fixture itself. An Excel-based tool is available on the DOE Efficient New Homes website for this calculation.

Using the Field Verification method, no more than 2 gallons (7.6 liters) of **water** shall be collected from the hot **water** fixture before hot **water** is delivered. This accounts for any **water** stored in the fixture in addition to the 1.8-gallon limit on pipe storage. Only the fixture with the greatest stored volume between the fixture and the hot **water** source (or recirculation loop) needs to be tested. To field-verify that the system meets the 2-gallon (7.6 liter) limit, raters shall first initiate operation of recirculation systems, if present, and let such systems run for at least 40 seconds. Next, a bucket or flow measuring bag (pre-marked for 2 gallons) shall be placed under the hot **water** fixture. The hot **water** shall be turned on completely and a digital temperature sensor used to record the initial temperature of the **water** flow. Once the **water** reaches the pre-marked line at 2 gallons, the **water** shall be turned off and the ending temperature of the **water flow** (not the collection bucket) shall be recorded. The temperature of the **water** flow must increase by ≥ 10 °F in comparison to the final to the initial temperature reading.

Issue: 1.8 gallons Stored, ≤ 2.0 gallons down drain, ≥ 10 F rise

Hot Water Distribution Part 3: Footnotes 27,28

²⁷ In-unit hot **water** recirculation systems meet the following requirements:

- a. Must be based on an occupant-controlled switch or an occupancy sensor. A sensor or switch must be installed for each fixture or set of fixtures within a room (e.g., a bathroom with multiple fixtures) in the dwelling unit located beyond a 1.8 gallon stored-volume range from the **water** heater or central recirculation loop.
- b. In-unit recirculation systems which operate based on “adaptive” scheduling, meaning that they “learn” the hot **water** demand profile in the dwelling unit and adapt their operation to anticipate this profile, are permitted at this time, and do not require the use of occupant-controlled switches or occupancy sensors.
- c. In-unit recirculation systems that are activated based **solely** on a timer and/or temperature sensor are not eligible.

These provisions do not apply to recirculating central hot **water** distribution systems.

²⁸ For recirculating central hot **water** distribution systems, the following pipe insulation thickness levels or R-values must be met or exceeded. Additionally, pipe insulation shall cover the entire length of the recirculation loop to the extent possible. If piping is routed in building cavities that prevent the noted thickness or R-value from being used due to space constraints, then the maximum thickness of insulation possible within the space shall be used.

Nominal Pipe or Tube Size (inches)	Insulation Thickness (inches)
< 1.5	1.5 (or R10 minimum)
≥ 1.5	2.0 (or R12 minimum)

Issues: Pump controls, On-demand, adaptive, no timer or temp
insulation wall thickness

Hot Water Distribution Part 4: Footnotes 38, 39

- ³⁸ Each dwelling unit with an in-unit fossil fuel **water** heater must have:
- a. An individual branch circuit outlet that is installed and energized and terminates within 3 feet of each installed fossil fuel **water** heater. The individual branch circuit shall have a rating not less than 240V/30A or 120V/20A.
 - b. A volume of open space located within the dwelling unit that is at least 3' x 3' wide and 7' high available surrounding or within 3 feet of the installed fossil fuel **water** heater, to facilitate future heat pump **water** heater installation. The 3' x 3' x 7' volume may contain the existing **water** heater. The 3' x 3' x 7' space does not need to be provided if the installed **water** heater is a tankless **water** heater system.

Dwelling units utilizing an electric **water** heater are exempt from these requirements.

- ³⁹ Drain is no more than two inches higher than the base of the installed **water** heater and allows draining without pump assistance. Drain is not required to be reserved exclusively for use with a future heat pump **water** heater. Drain does not need to be provided if the installed **water** heater is a tankless **water** heater or an electric system with a nominal tank volume less than 50 gallons.

Issues: Space for future HPWH, Drain for water heater

Hot Water Distribution Part 3: Footnote 22

- ²² **WaterSense** label may be verified in one of two ways:
- a. A cut sheet for the installed product indicates that it is **WaterSense** labeled and field verification shows that the installed product is the one described on the cut sheet.
 - b. The installed product can be found in the most recent **WaterSense** Product Search tool (<https://lookforwatersense.epa.gov/products/>) and field verification shows that the installed product matches the product described in the search tool.

WaterSense: Same as MF