SEDTAPP

DESIGN
ENGINEERING
DESIGN

System Performance of Heat Pump Water Heaters

Andy Lau, September 29, 2016

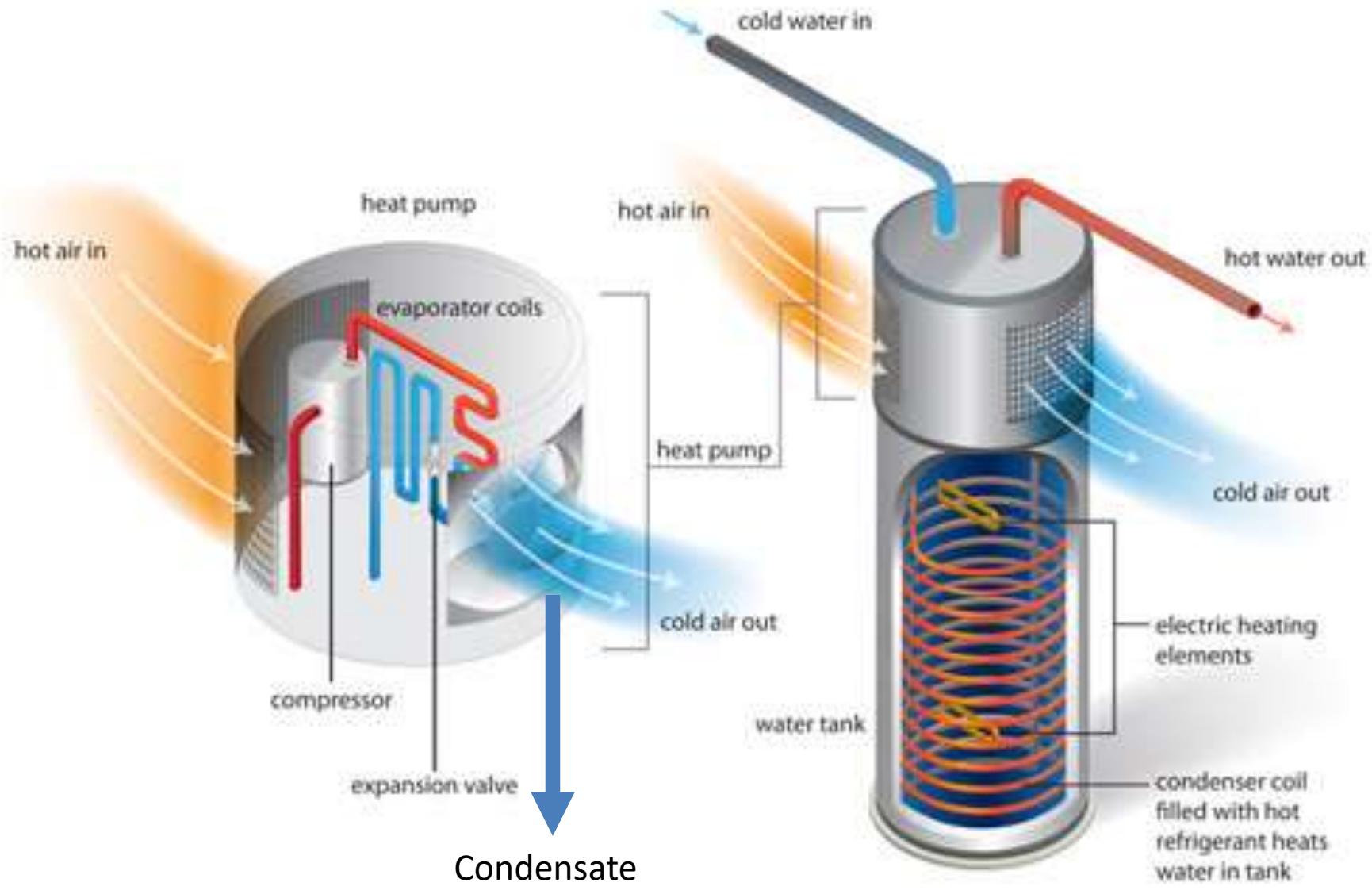
EEBA 2016, Dallas, TX

PennState
College of Engineering

ENGINEERING DESIGN, TECHNOLOGY,
AND PROFESSIONAL PROGRAMS

What's in Store?

- Bit of thermo
- Possible locations
  - Unconditioned
  - Conditioned
- Effective COP
- Climate effects
- Results
- Next?

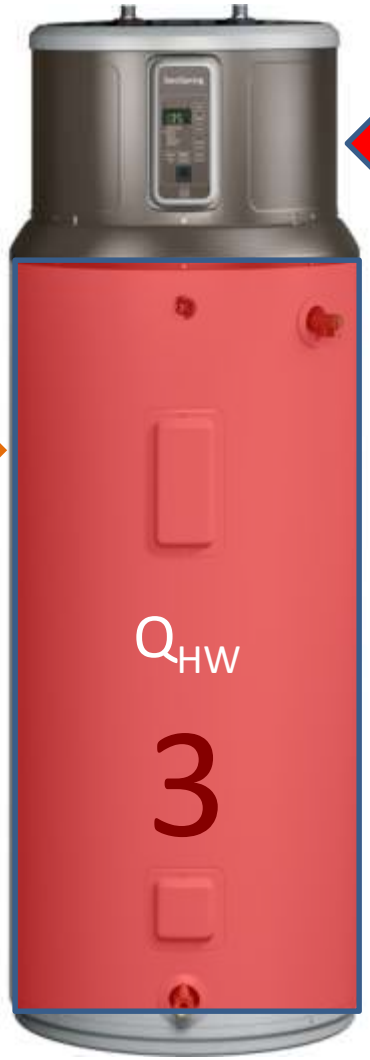


https://www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/how_it_works

If COP = 3;

1

E_{HPWH}



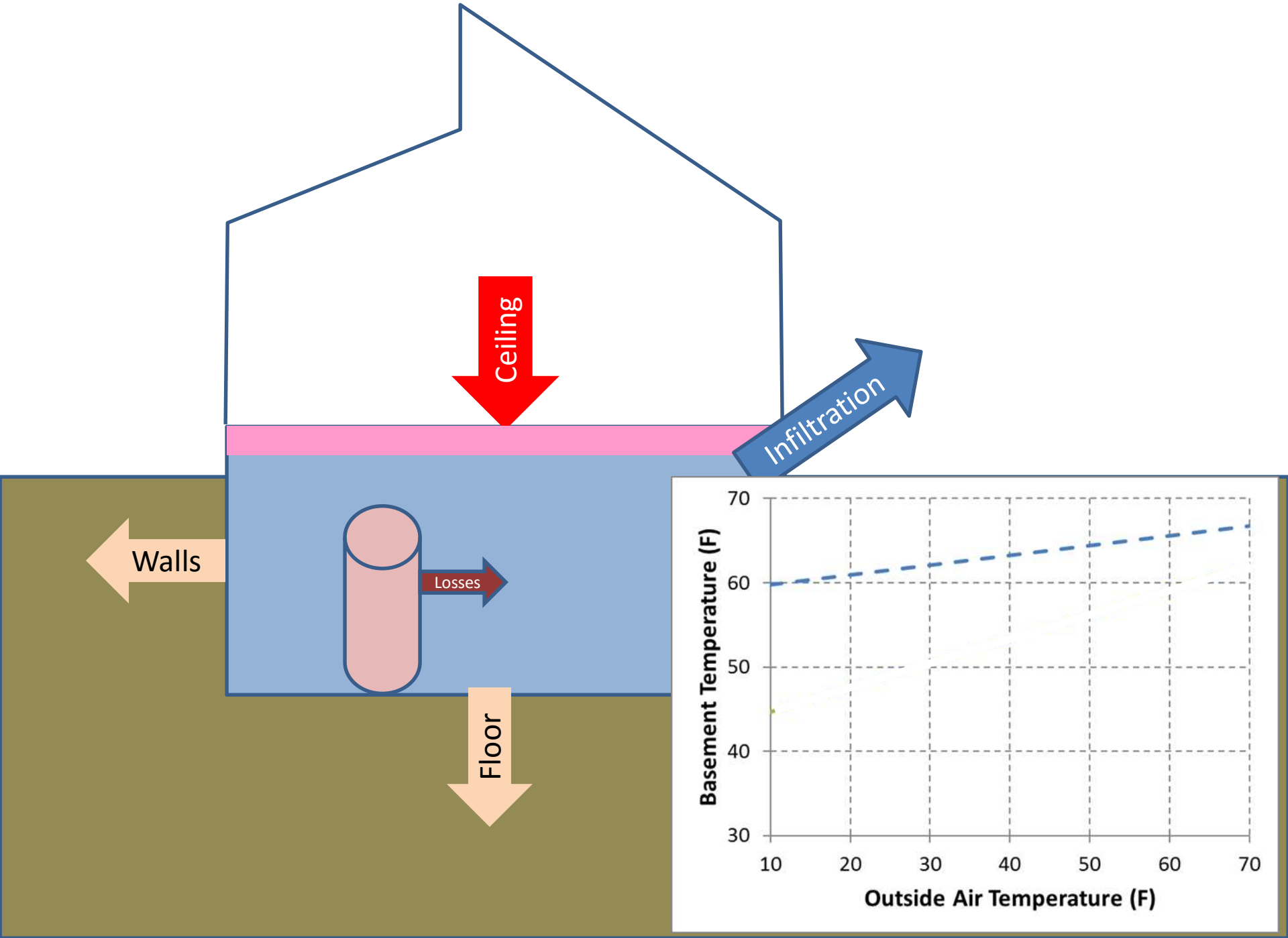
2

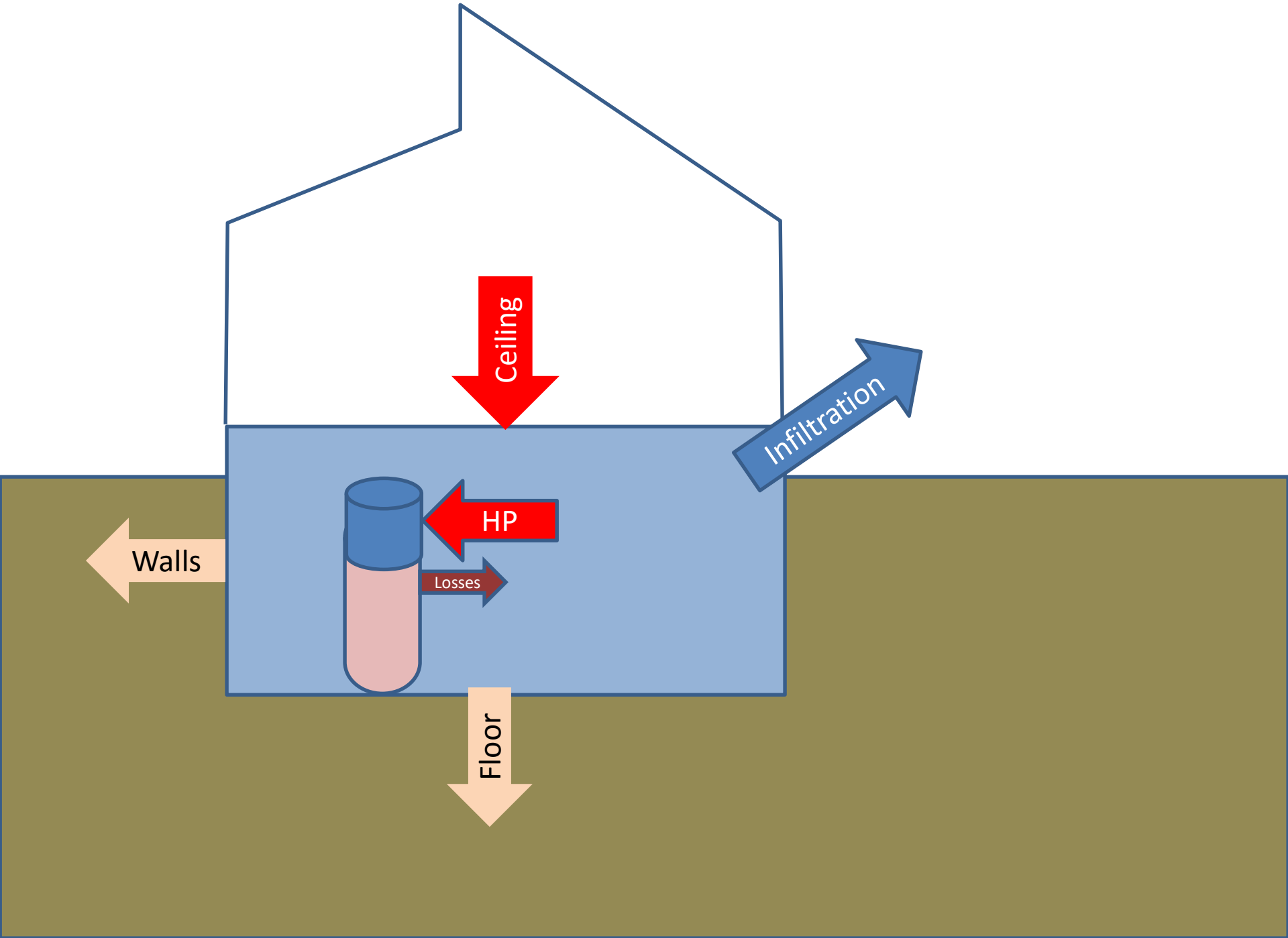
Q_{HPWH}

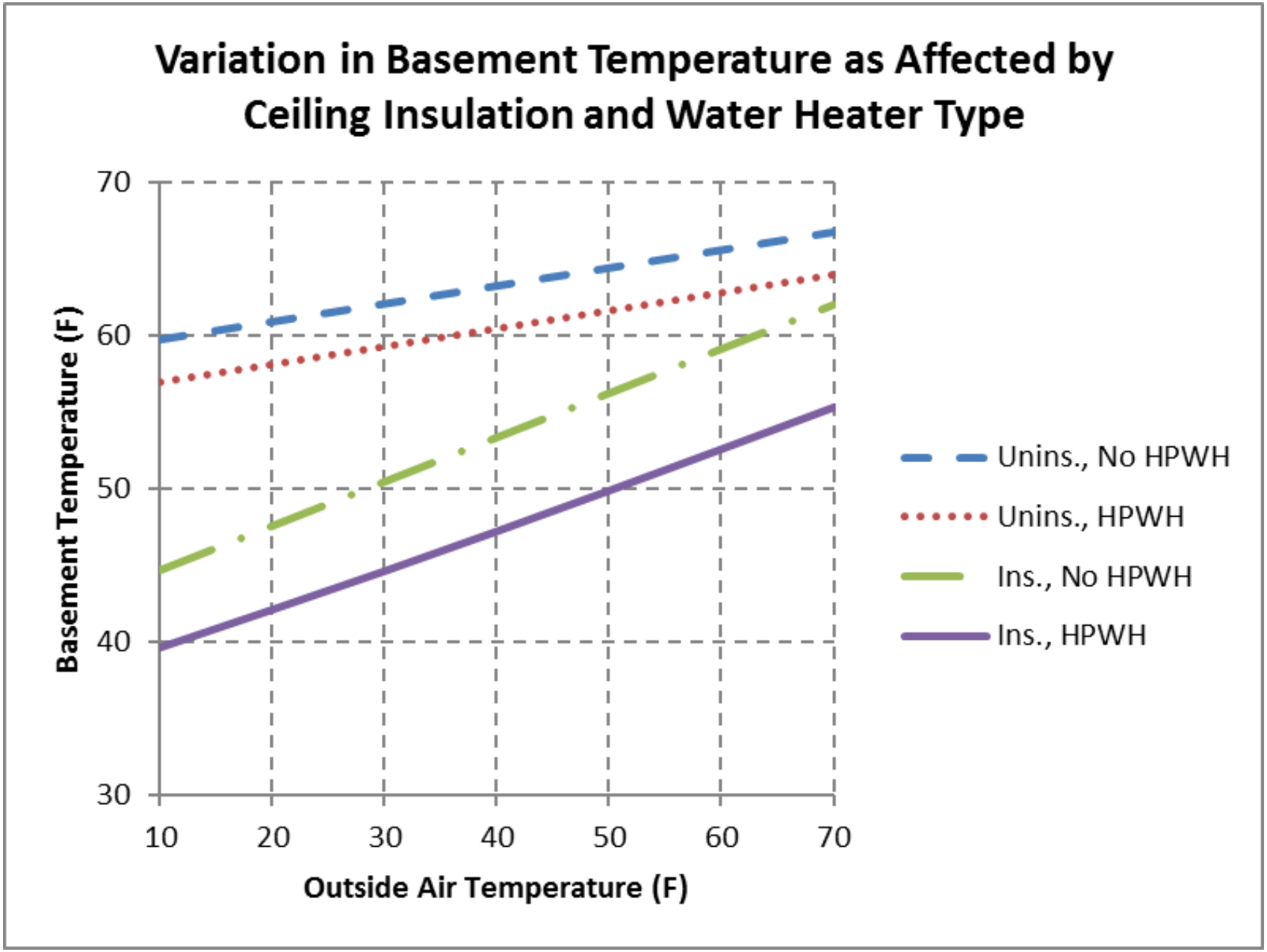
$$Q_{HW} = E_{HPWH} + Q_{HPWH}$$

$$COP_{HPWH} = \frac{Q_{HW}}{E_{HPWH}}$$

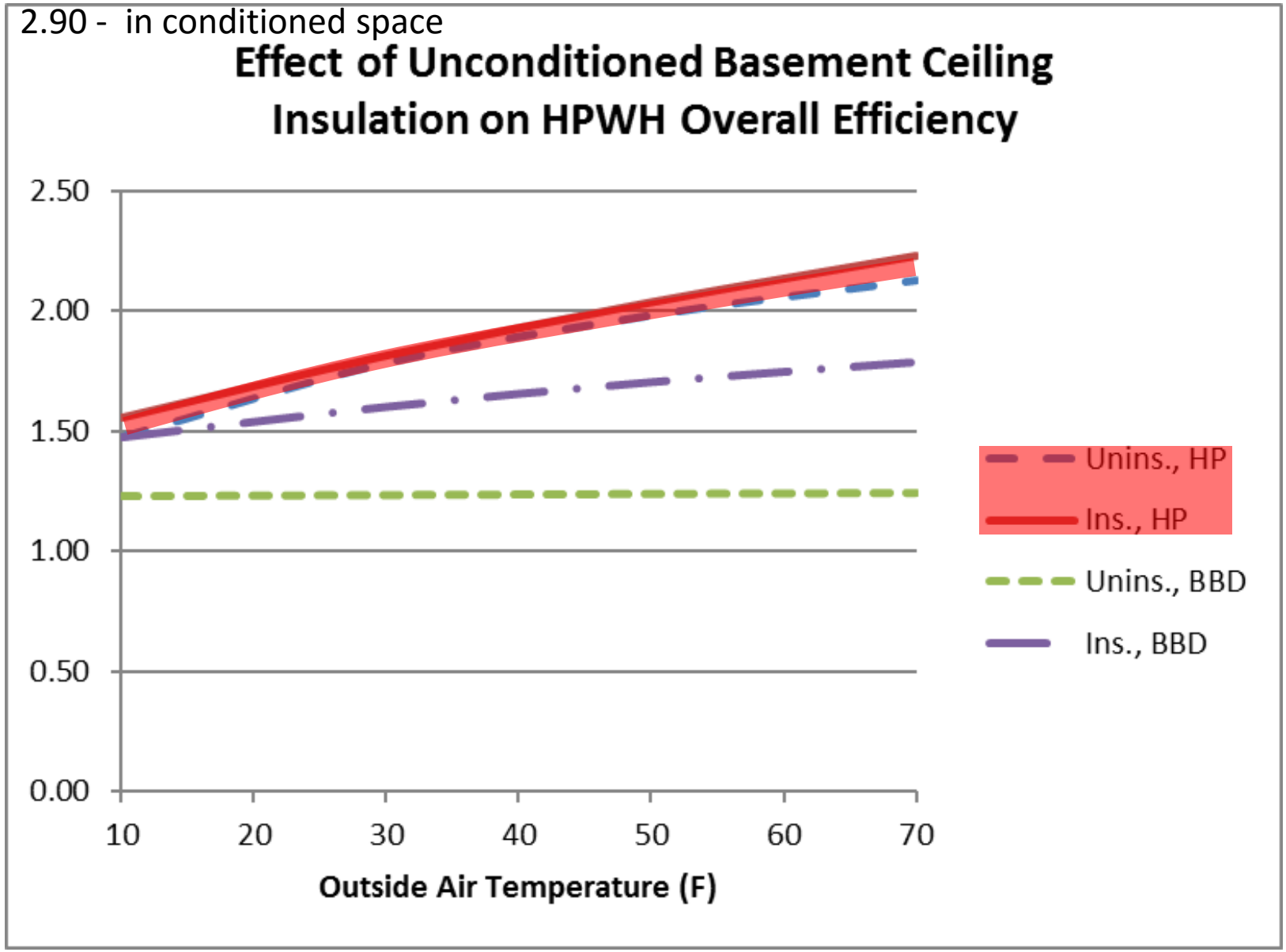
$$Q_{HPWH} = \frac{Q_{HW}\,(COP_{HPWH} - 1)}{COP_{HPWH}}$$


Ceiling
Infiltration
Walls
Losses
Floor
Basement Temperature (F)
70
60
50
40
30
10
20
30
40
50
60
70
Outside Air Temperature (F)

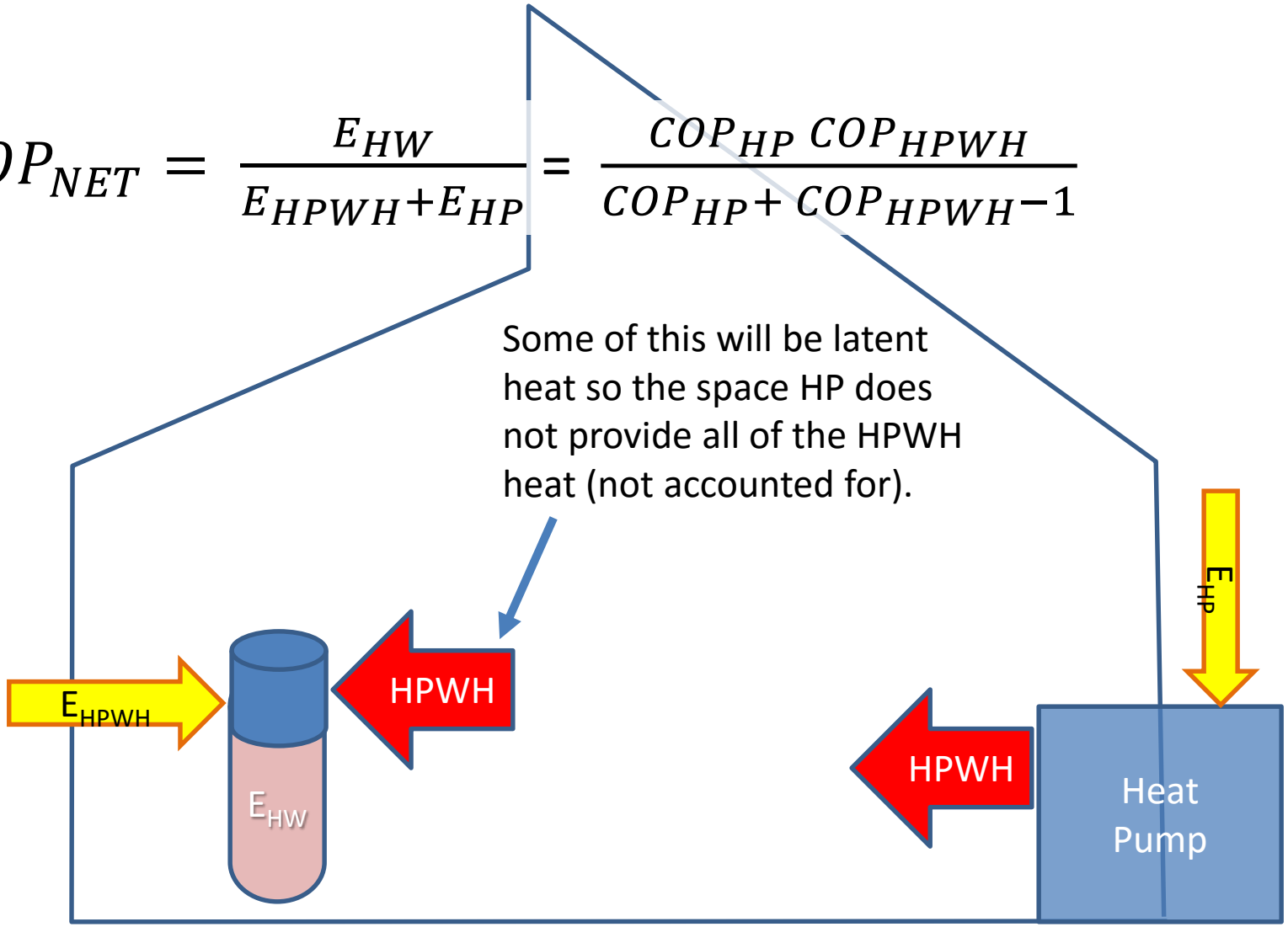

Ceiling
Infiltration
HP
Losses
Walls
Floor


Variation in Basement Temperature as Affected by Ceiling Insulation and Water Heater Type
Basement Temperature (F)
70
60
50
40
30
10
20
30
40
50
60
70
Outside Air Temperature (F)
Unins., No HPWH
Unins., HPWH
Ins., No HPWH
Ins., HPWH

2.90 - in conditioned space



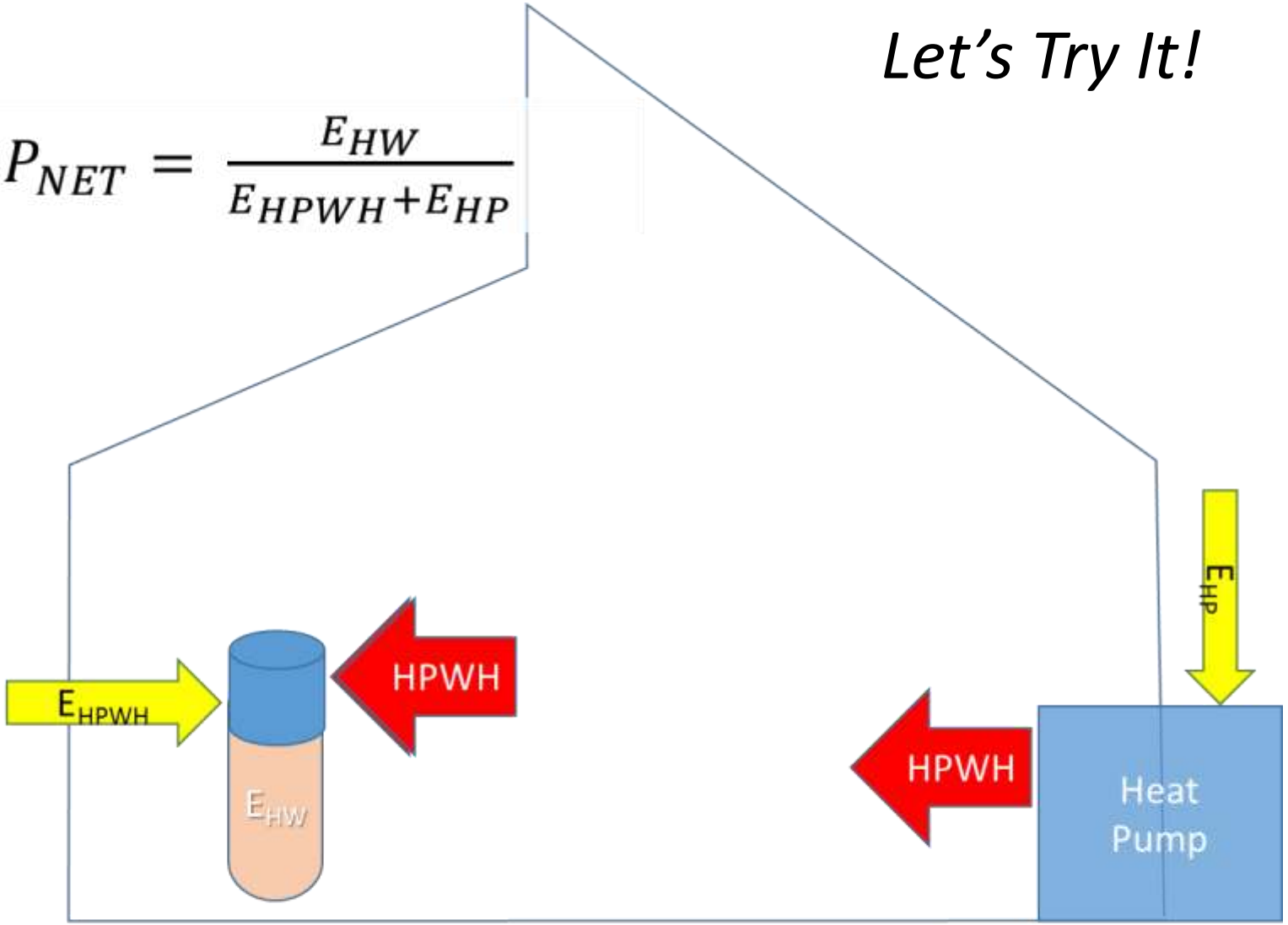
$$COP_{NET} = \frac{E_{HW}}{E_{HPWH}+E_{HP}} = \frac{COP_{HP}\,COP_{HPWH}}{COP_{HP}+COP_{HPWH}-1}$$



Heating Season Operation

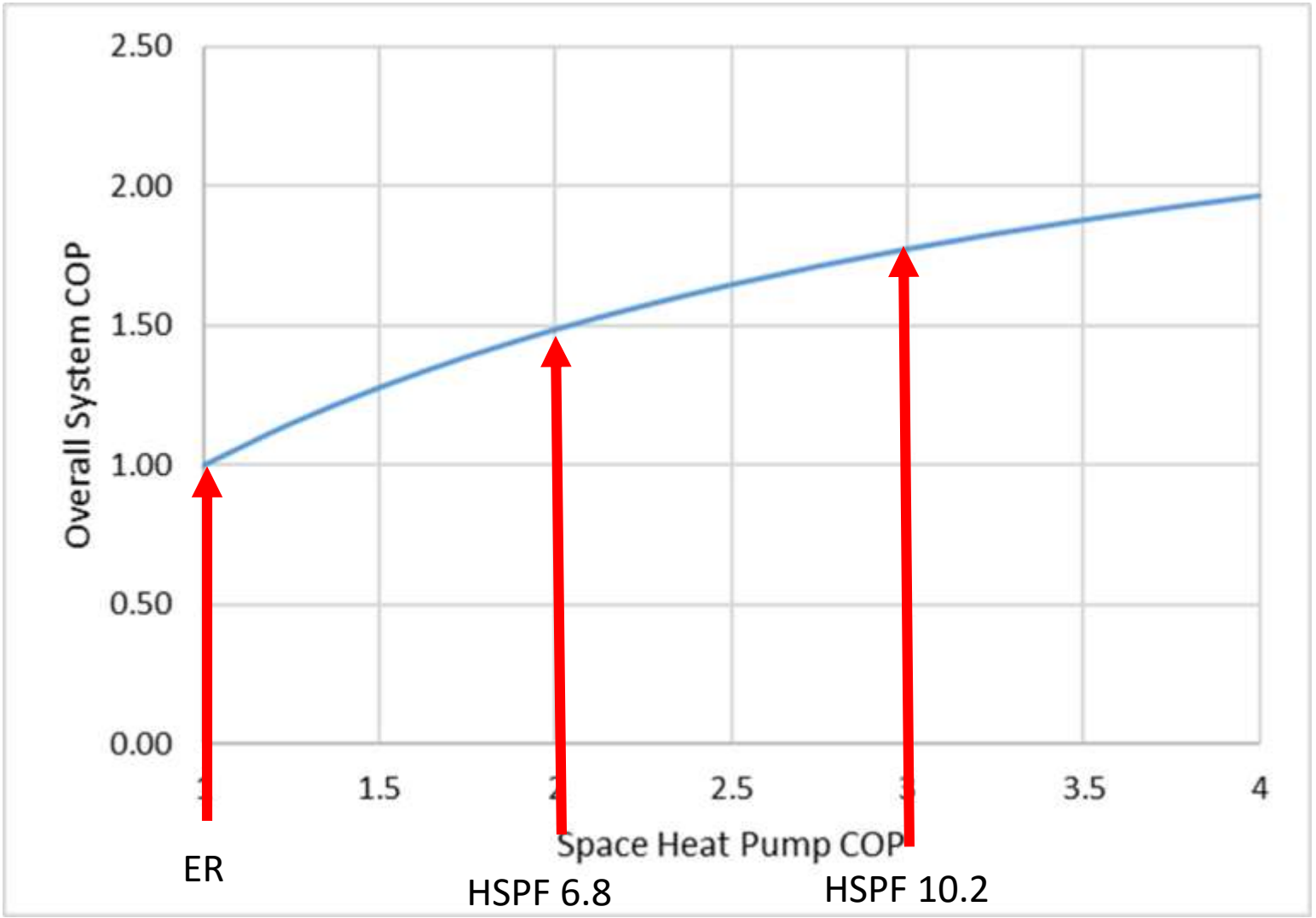
Let's Try It!

$$COP_{NET} = \frac{E_{HW}}{E_{HPWH} + E_{HP}}$$

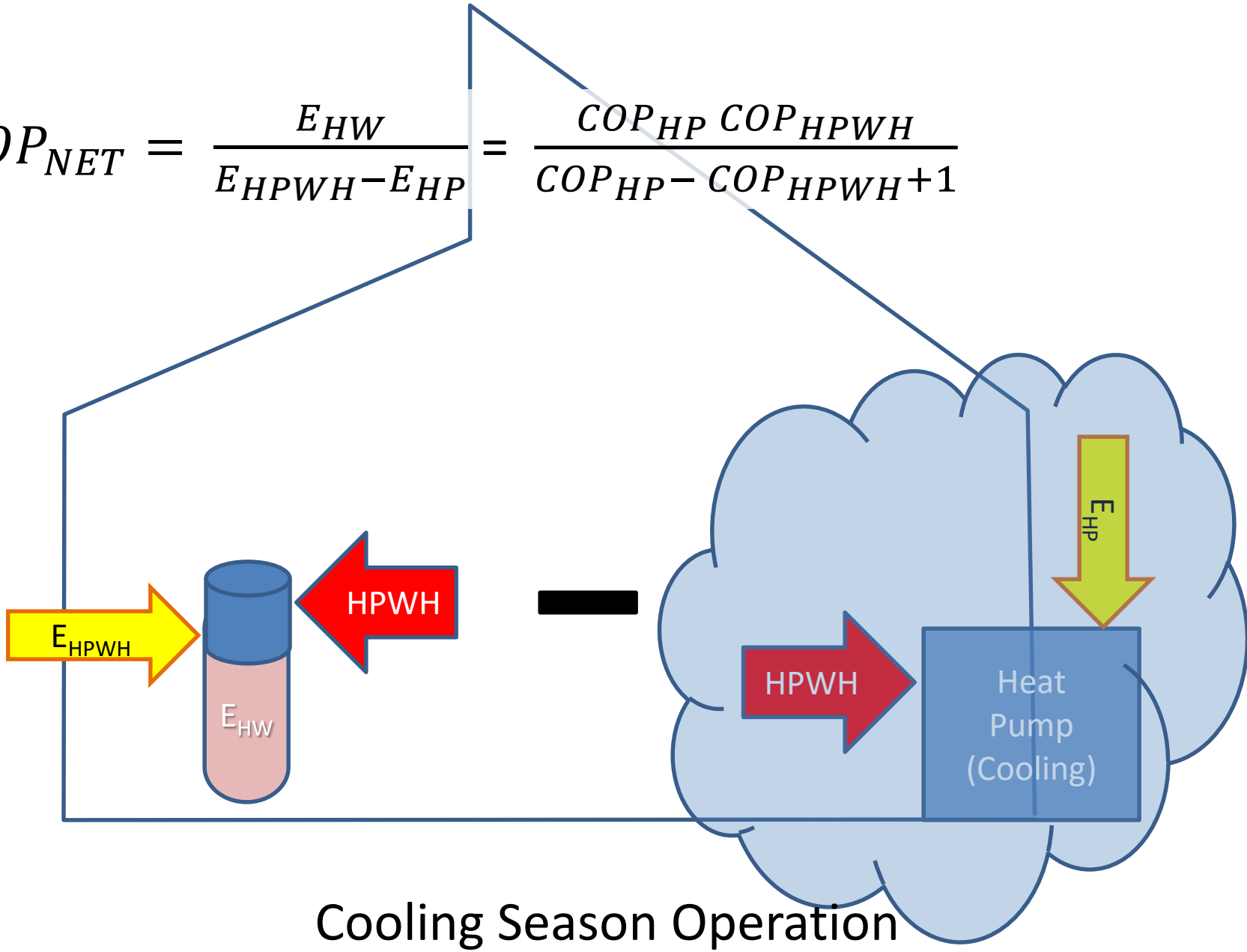


Heating Season Operation

Effective HPWH COP is dependent on the space heat COP



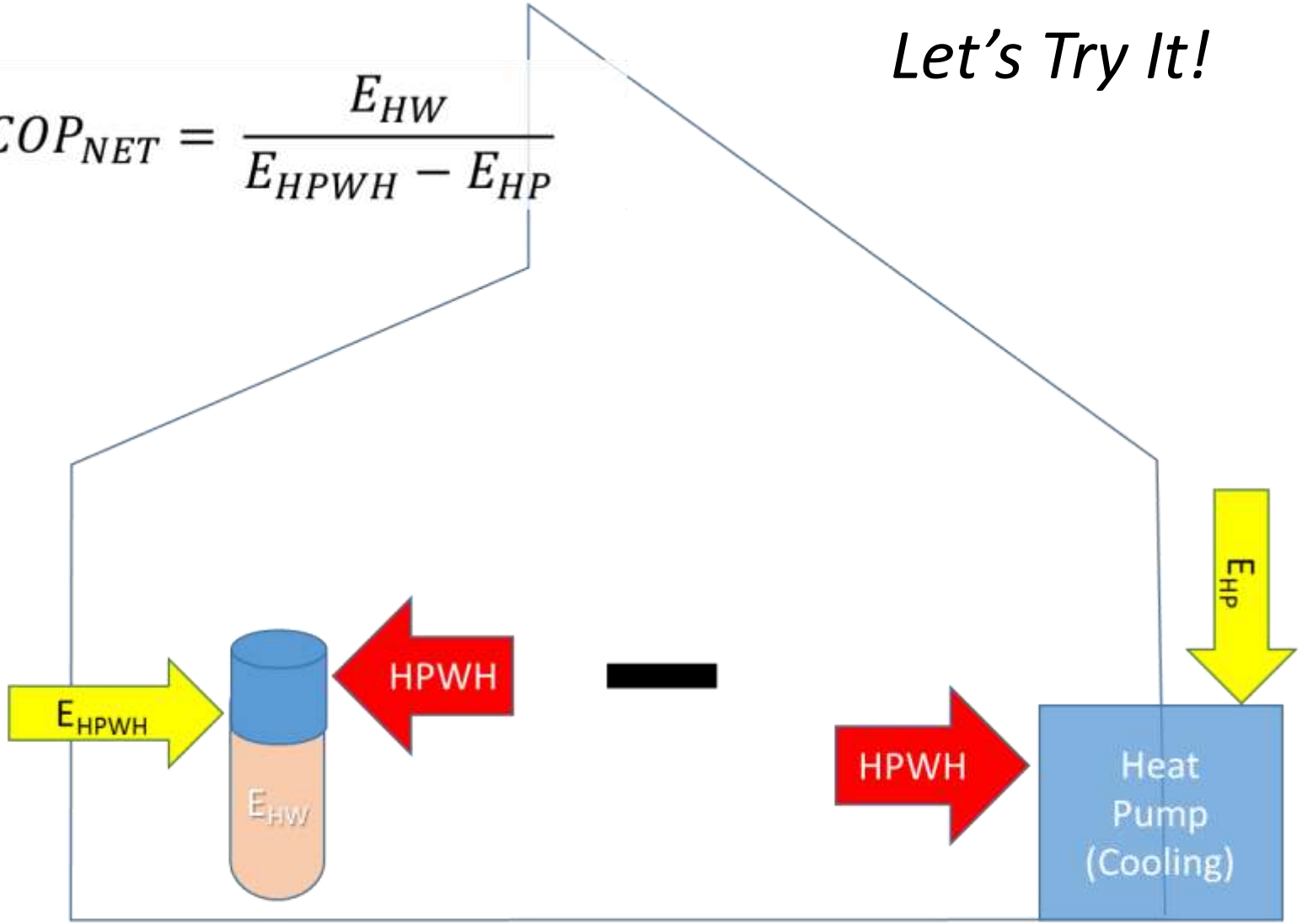
$$COP_{NET} = \frac{E_{HW}}{E_{HPWH} - E_{HP}} = \frac{COP_{HP}\, COP_{HPWH}}{COP_{HP} - COP_{HPWH} + 1}$$



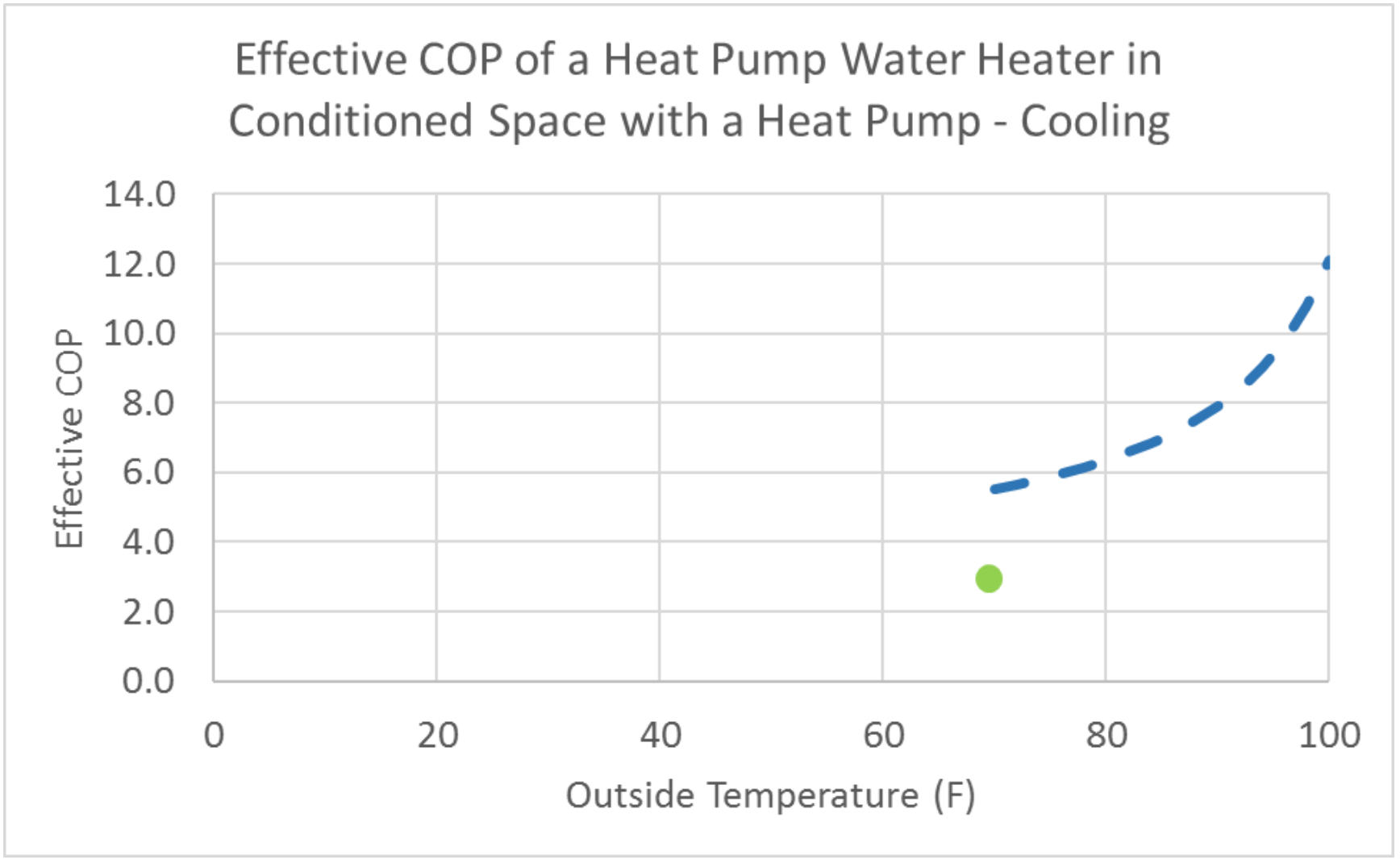
Cooling Season Operation

Let's Try It!

$$COP_{NET} = \frac{E_{HW}}{E_{HPWH} - E_{HP}}$$



Cooling Season Operation


Effective COP of a Heat Pump Water Heater in Conditioned Space with a Heat Pump - Cooling
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Effective COP
0
20
40
60
80
100
Outside Temperature (F)

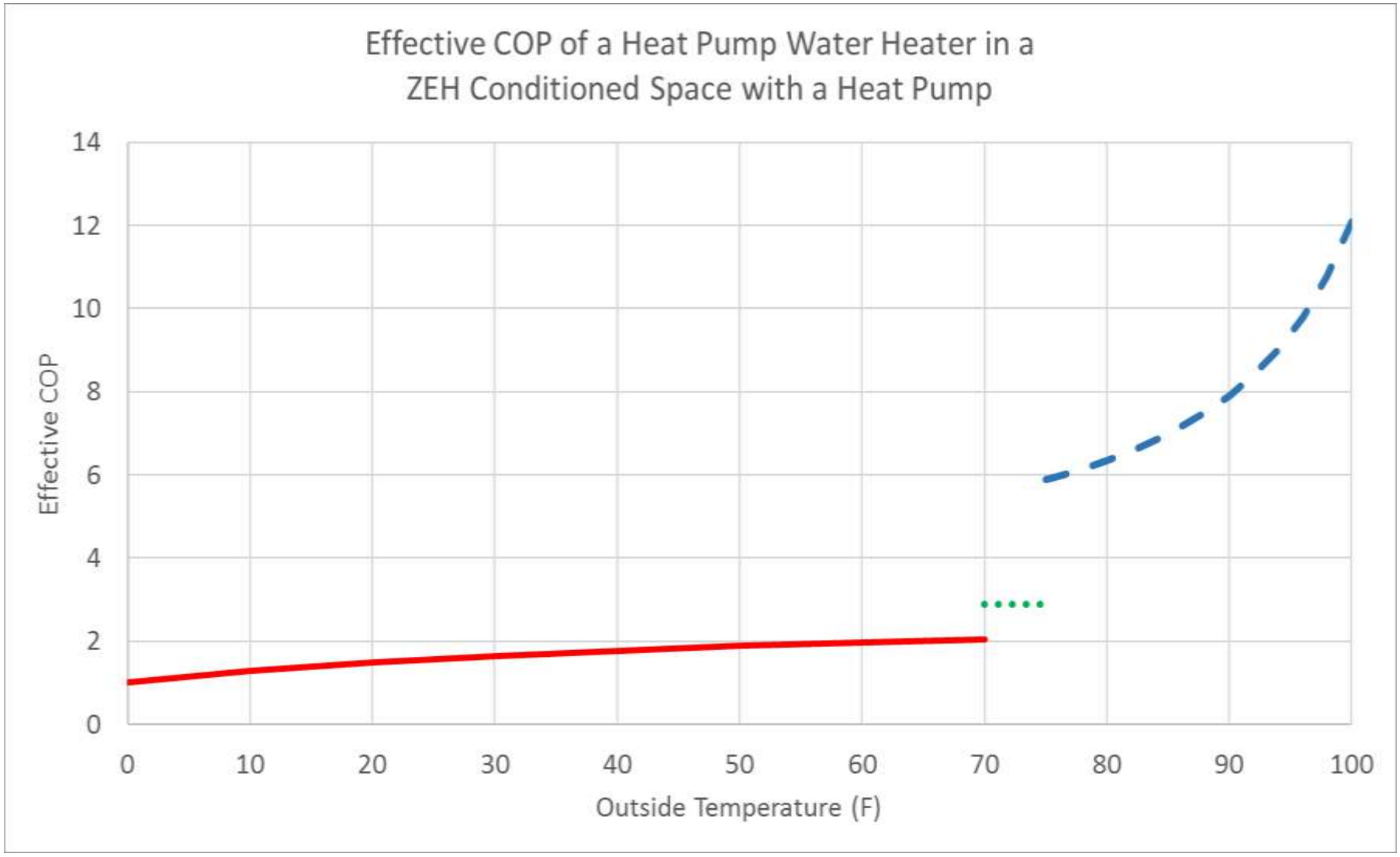
Cooling Equivalence on Average

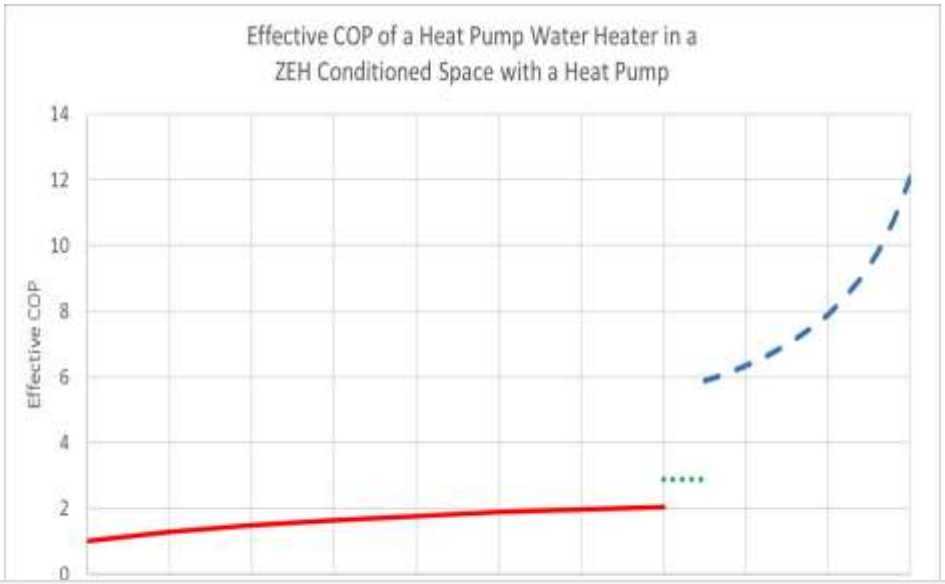
=

~ 1,000 Btuh

(60 gpd)

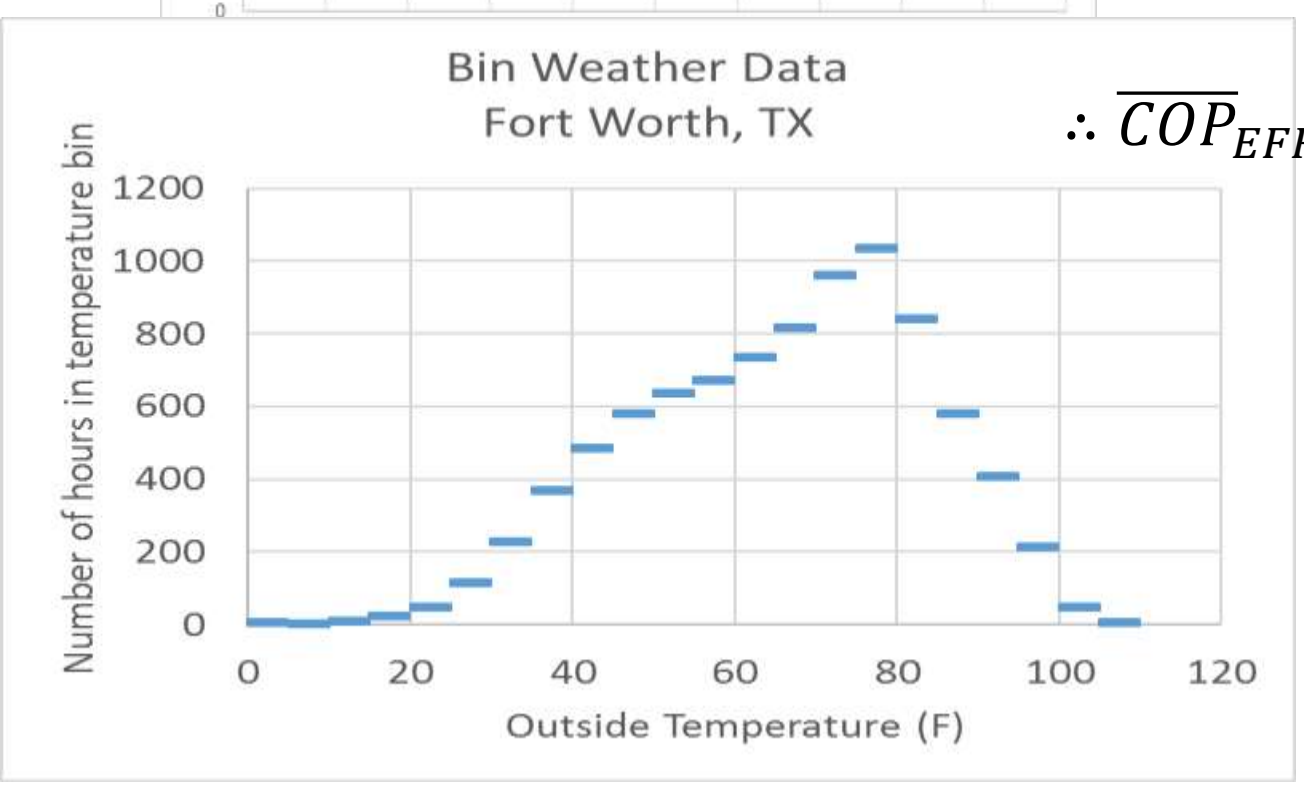
Putting it all together





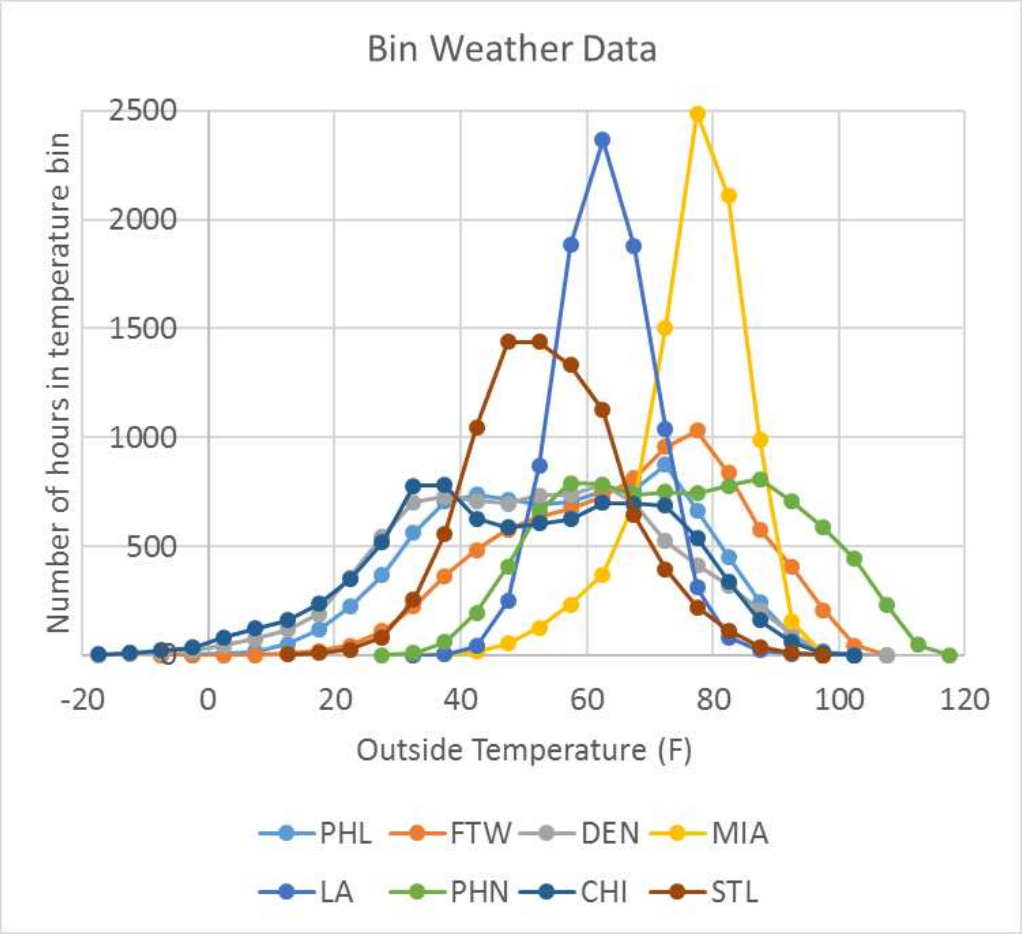
$$E_{NET} = \frac{\dot{Q}_{HW}\, t}{\overline{COP}_{EFF}}$$

$$= \sum_{BINS} \frac{\dot{Q}_{HW}\, t_{BIN}}{COP_{EFF@tBIN}}$$

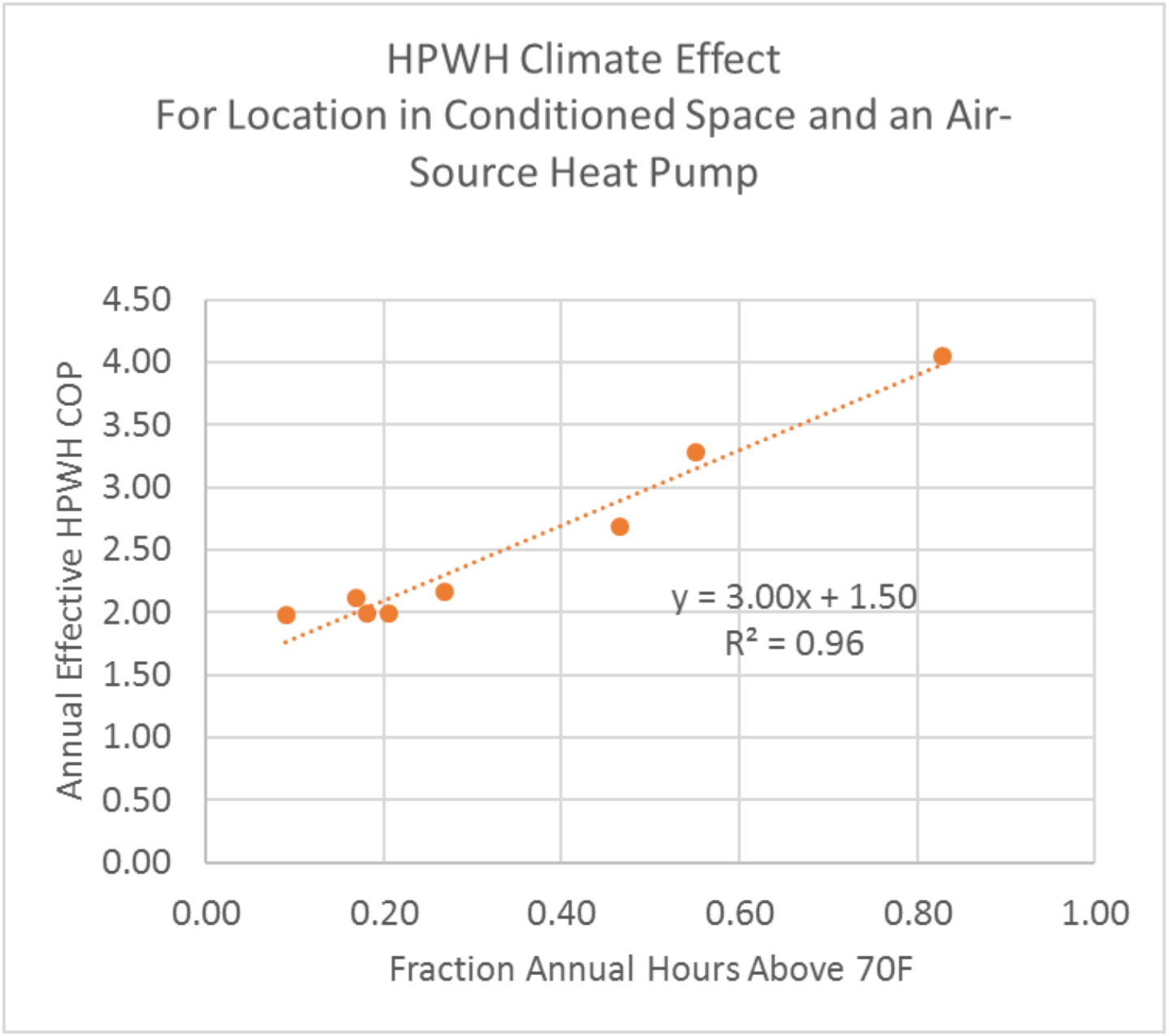


$$\therefore \overline{COP}_{EFF} = \frac{8760\ h}{\sum \frac{t_{BIN}}{COP_{EFF@tBIN}}}$$

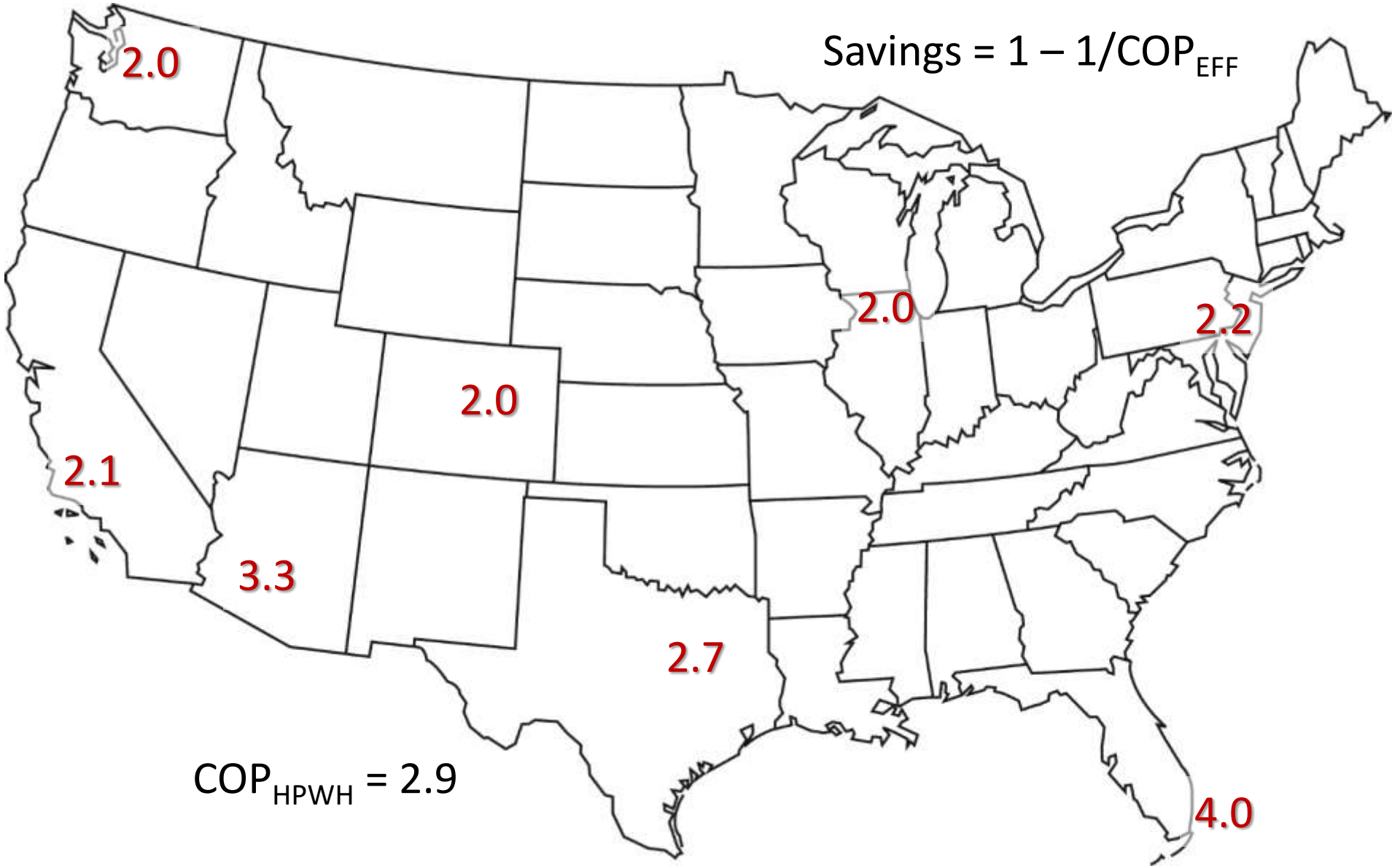
Effect of Climate?



	PHL	FTW	DEN	MIA	LA	PHN	CHI	STL
$\overline{COP_{EFF}}$	2.2	2.7	2.0	4.1	2.1	3.3	2.0	2.0


HPWH Climate Effect
For Location in Conditioned Space and an Air-Source Heat Pump
Annual Effective HPWH COP
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
0.20
0.40
0.60
0.80
1.00
Fraction Annual Hours Above 70F
y = 3.00x + 1.50
R² = 0.96

Effective COP for HPWH in HP conditioned space



Comparison with Other Investigators

Table 11. Water Heater Annual Source Energy Consumption in Conditioned Space						
Location	HPWH compared to a gas WH in kWh (MMBtu)	HPWH compared to an electric WH in kWh (MMBtu)	Gas Water Heater in kWh (MMBtu)	Electric Water Heater in kWh (MMBtu)	HPWH Savings vs. Gas	HPWH Savings vs. Electric
Atlanta, GA*	4895 (16.70)	4526 (15.44)	4700 (16.04)	9428 (32.17)	-4.15%	51.99%
Chicago, IL*	7396 (25.24)	7105 (24.24)	5702 (19.46)	11885 (40.55)	-29.71%	40.21%
Houston, TX	2787 (9.150)	2923 (9.975)	4134 (14.11)	8054 (27.48)	32.59%	63.70%
Los Angeles, CA	4836 (16.50)	4709 (16.07)	4681 (15.97)	9428 (32.17)	-3.30%	50.06%
Phoenix, AZ	2491 (8.499)	2672 (9.118)	3639 (12.42)	6840 (23.34)	31.55%	60.93%
Seattle, WA*	7253 (24.75)	6960 (23.75)	5527 (18.86)	11407 (38.92)	-31.23%	38.99%

50%

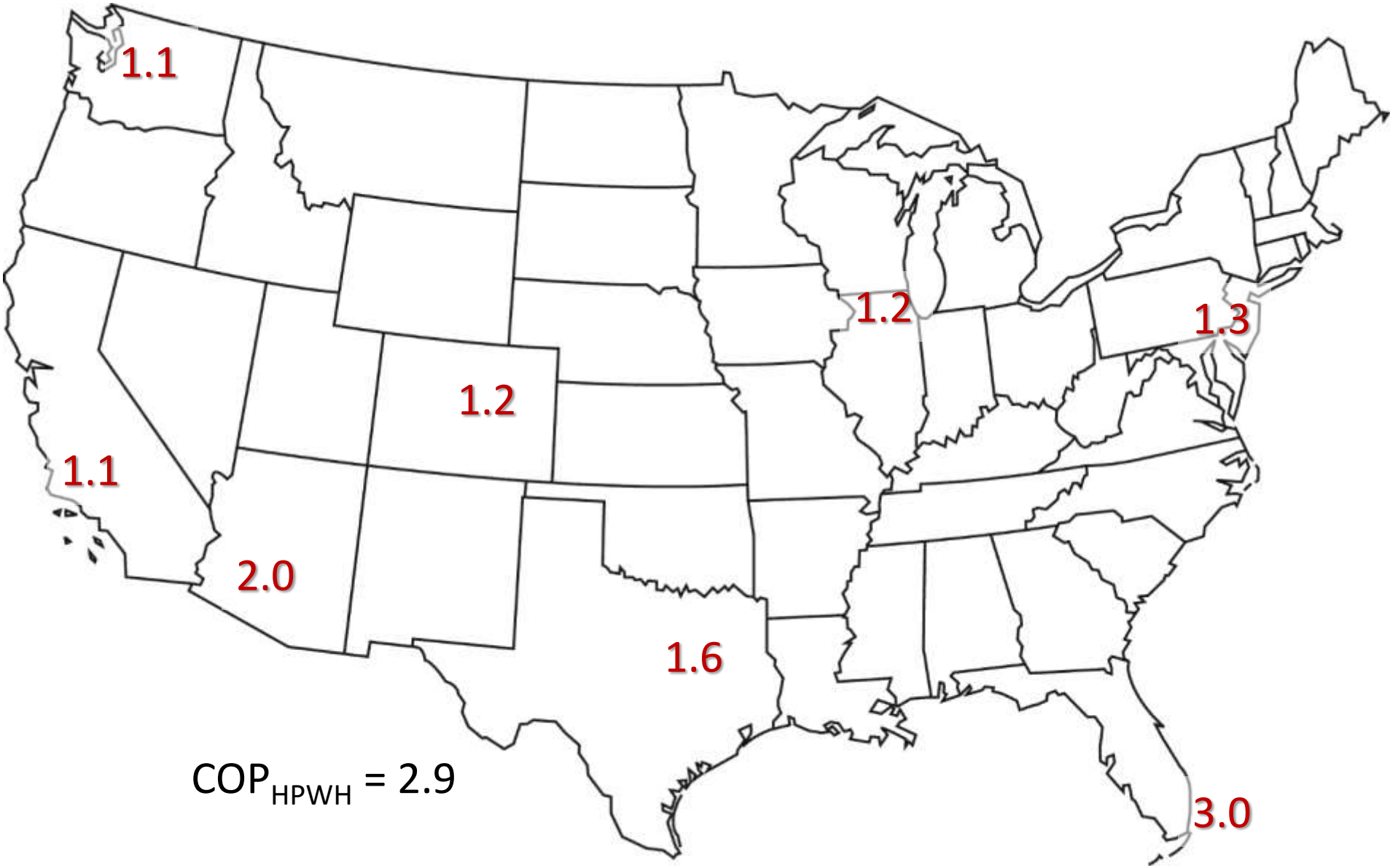
53%

68%

50%

Heat Pump Water Heater Technology Assessment Based on Laboratory Research and Energy Simulation Models, NREL/CP-5500-51433, February 2012

Effective COP for HPWH in ER conditioned space



$COP_{HPWH} = 2.9$

Comparison with Other Investigators

Table 12. Water Heater Annual Source Energy Consumption in Unconditioned Space

Location	HPWH compared to a gas WH in kWh (MMBtu)	HPWH compared to an electric WH in kWh (MMBtu)	Gas Water Heater in kWh (MMBtu)	Electric Water Heater in kWh (MMBtu)	HPWH Savings vs. Gas	HPWH Savings vs. Electric
Atlanta, GA*	4964 (16.93)	4965 (16.94)	4983 (17.00)	9649 (32.91)	0.37%	48.54%
Chicago, IL*	8691 (29.64)	8601 (29.34)	6221 (20.32)	12432 (42.41)	-39.70%	30.82%
Houston, TX	3741 (12.76)	3753 (12.80)	4188 (14.29)	8109 (27.66)	10.68%	53.72%
Los Angeles, CA	4721 (16.10)	4710 (16.07)	4882 (16.65)	9513 (32.45)	3.30%	50.48%
Phoenix, AZ	3351 (11.43)	3354 (11.44)	3520 (12.01)	6745 (23.01)	4.80%	50.27%
Seattle, WA*	6938 (23.67)	6870 (23.43)	5957 (20.32)	11865 (40.47)	-16.47%	42.10%

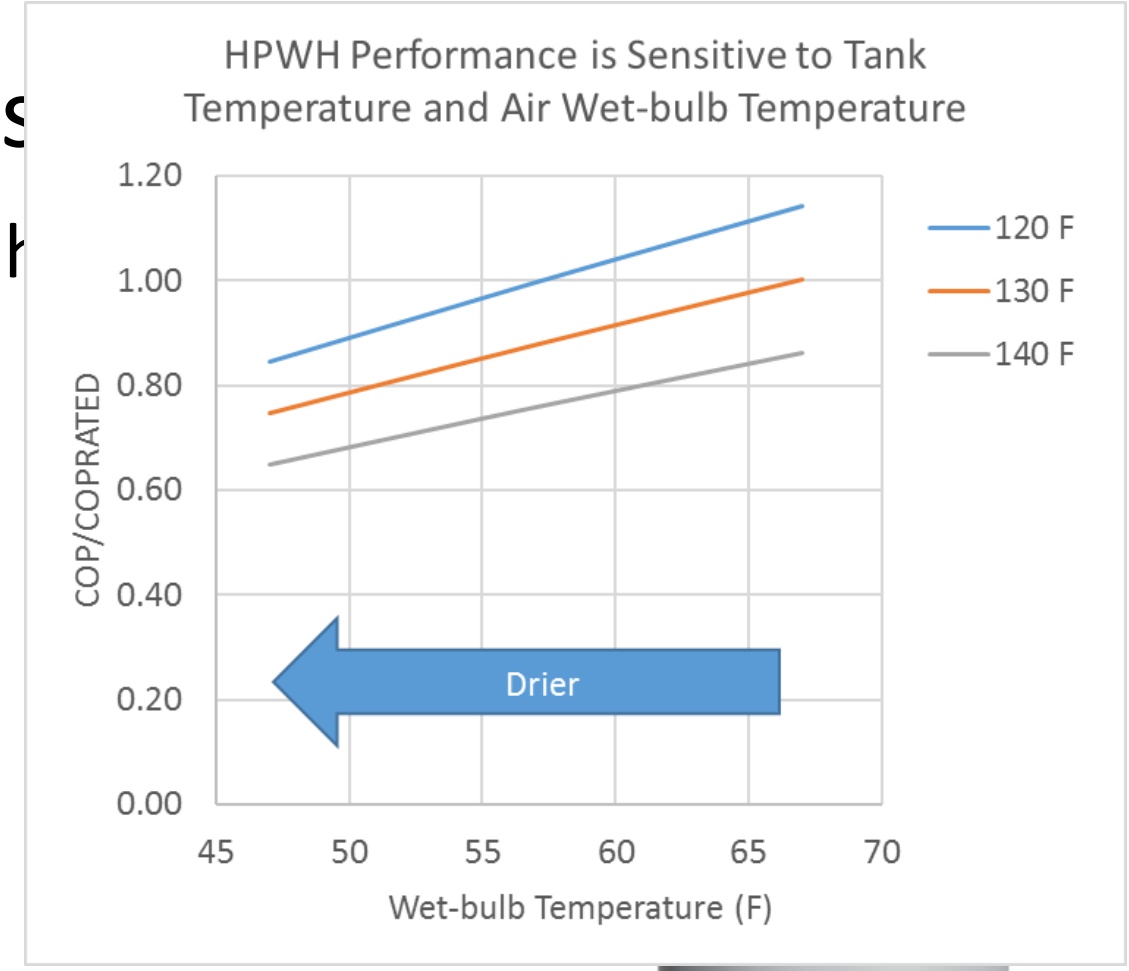
*These homes have the HPWH located in the basement. In all other homes, the HPWH is in the garage.

	Ins, BB:	Unins, BB:
50%	40%	20%

"It should be noted that for homes without air source heat pumps, the energy savings presented in Tables 11 and 12 are invalid and must be reevaluated based on the source energy consumption of the space conditioning equipment in that home."

Take Away Mess

- House uses more h cooling
- Savings vary with
  - HPWH model
  - Climate
  - HVAC type
  - Location of unit
  - Settings
  - Usage
- Located in conditioned space:
  - In cooler climates with HP, saves 50%.
  - In warm climates with HP, saves 60-80%

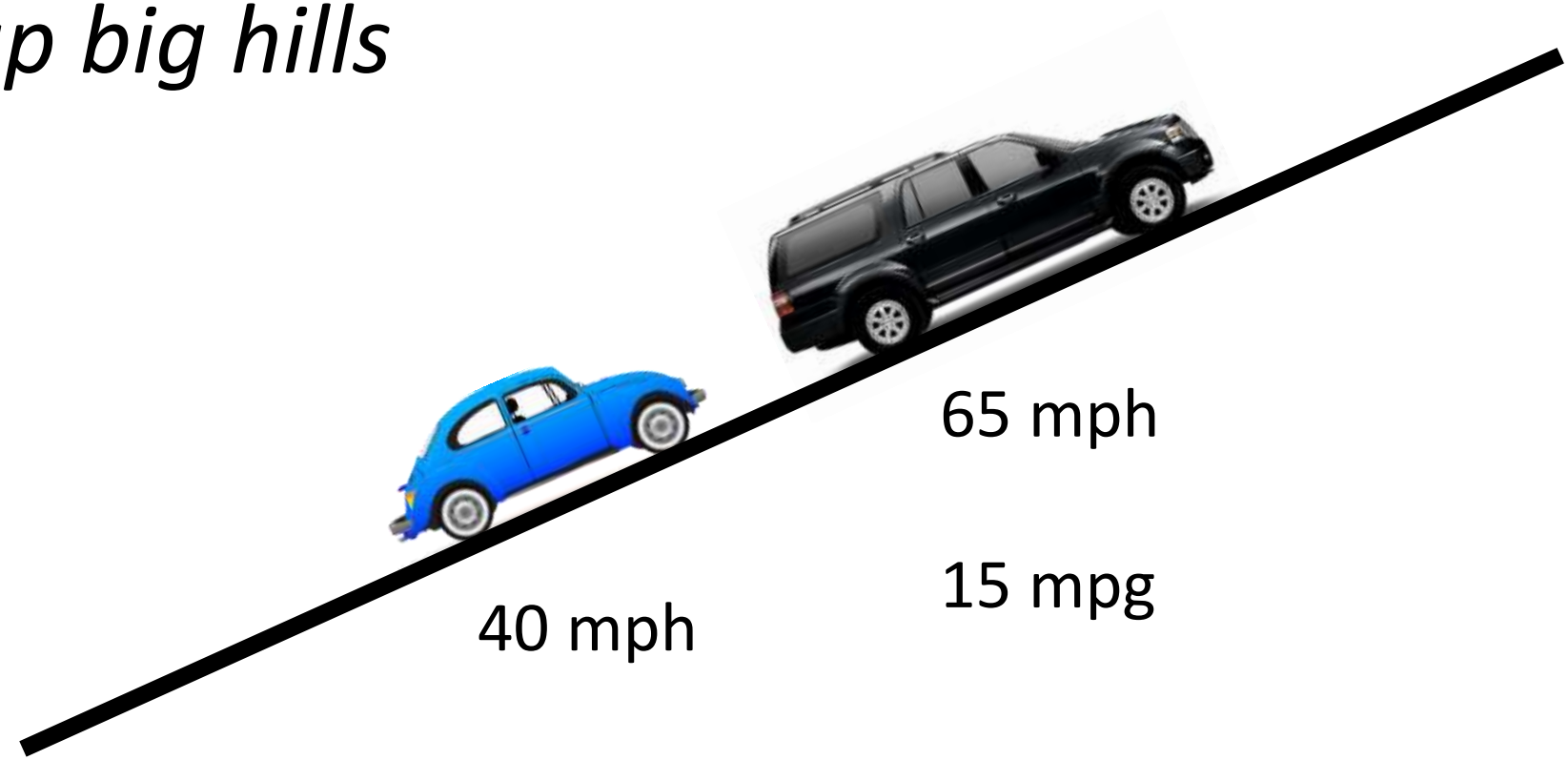


Take Away Messages

- Placement in unconditioned basement:
  - With HP, annual savings is about 50%,
  - With ER, ~20% savings for uninsulated ceiling, ~40% insulated ceiling

The Beetle Analogy

Most of the time you're not going fast up big hills



For Further Study:

1. All heating analysis assumes no dehumidification.
   - Some of the HPWH cooling effect is latent? What would that do to the effective COP?
2. What about other non-electric heating?
   - Compare on BTU basis or $ or ?
3. How does HPWH performance vary with humidity, climate, setpoint, usage, etc.?
   - COP ↑ as RH ↑

For Further Study:

4. Can reduce Dehumidifier energy use in unconditioned basements: COP ↑
5. For small ZEHs, HVAC space heat is not needed until Tout is ~50 F.

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The End - Thanks