Heat Pump Water Heaters @ Passive Houses

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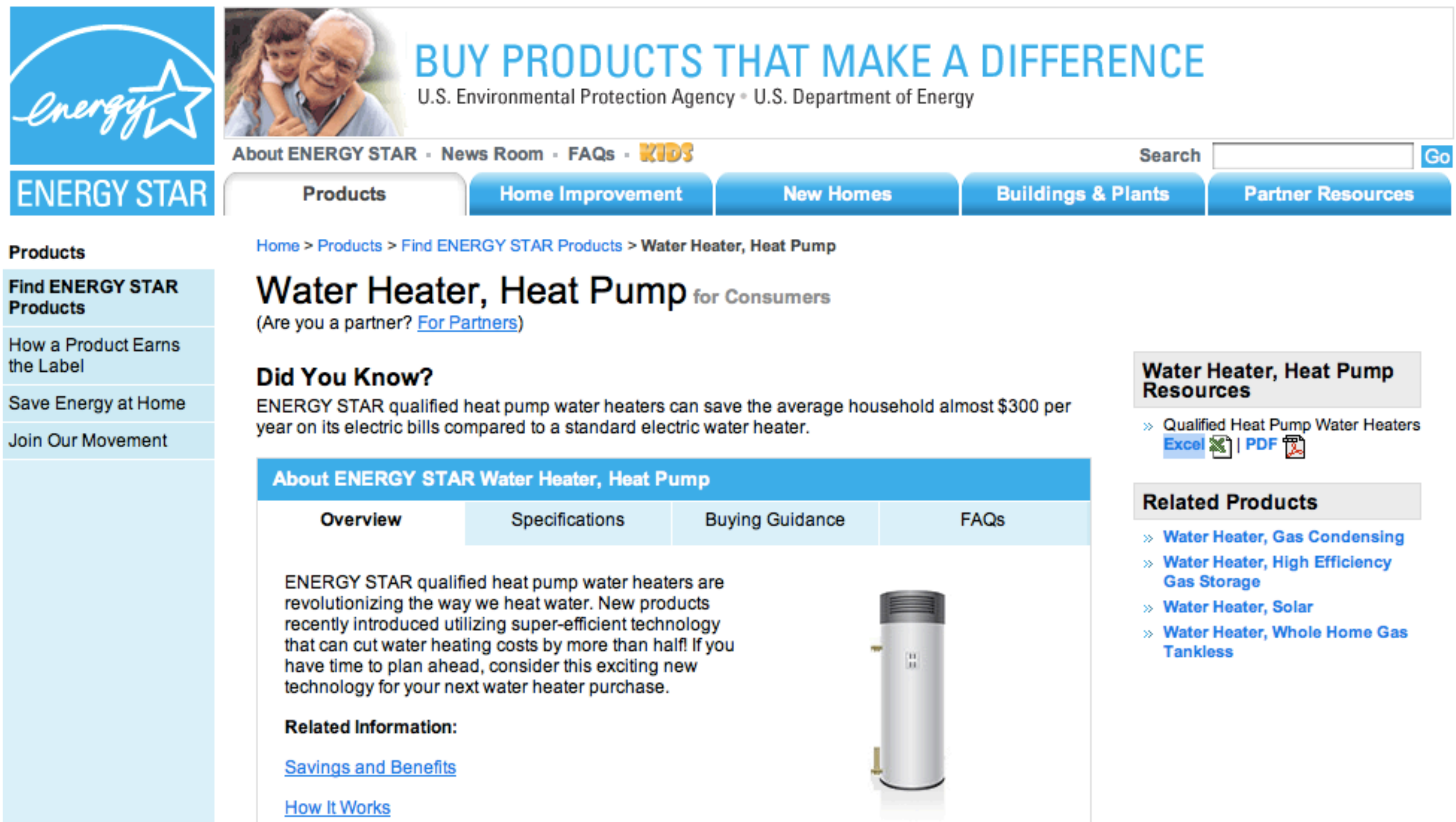
Overview

- The US Dept. of Energy view of water heating
- The Passive House planner's view of water heating
- Heat pump water heater **inside**
- Heat pump water heater **outside**

Energy Star info

www.energystar.gov > Products > Find ENERGY STAR Products > **Water Heater, Heat Pump**



As of Oct 17, 2011

- 35 models listed, 40-80 gallons
- Energy Star criteria
  - First hour rating ≥ 50 gal/hr
  - Energy Factor ≥ 2.0
    - A coefficient of performance measured under specific conditions.
      - Code of Federal Regulations, Title 10 (Energy)
        - » Section 430 (Energy Conservation for Consumer Products)
          - Subpart B (Test Procedures)
            - Appendix E (Uniform test method for measuring the energy consumption of water heaters.)

DOE 24-hour simulated use test

- Conditions
  - Ambient air 67.5±1 F
  - Relative humidity 49-51%
  - Cold water supply 58±2 F
  - Storage tank temp 135±5 F
- Procedure
  - Total of 64.3±1 gallons water removed in six equal draws spaced 1 hour apart, followed by 18 hours of standby operation.
- Calculations
  - Energy Factor = Total $mc_p\Delta T$ heat in the draws / total energy to the unit.
  - Estimated annual = total energy to the unit x 365.

SAME PROTOCOL FOR ALL STORAGE-TYPE WATER HEATERS. IT'S PARTICULARLY FORGIVING FOR HEAT-PUMP WATER HEATERS.

SAME PROCEDURE IN PLACE SINCE ~1998.

DOE <-> PHPP crossover

- Standard personal-use gallons are hotter in the Passive House Planning Package (PHPP), need less of them.

$$Vol_{PH}\rho c_P \Delta T_{PH} = Vol_{Gov}\rho c_P \Delta T_{Gov}$$

$$Vol_{PH} = Vol_{Gov}\frac{135 - 58\text{ F}}{140 - 50\text{ F}}$$

$$Vol_{PH} = 0.856 \cdot Vol_{Gov}$$

DOE <-> PHPP crossover

- DOE test

$$64.3\,\frac{\text{gal}}{\text{htr}\cdot\text{day}}\cdot\frac{8\text{ lb}}{\text{gal}}\cdot\frac{1\text{ Btu}}{\text{lb F}}\cdot(135-58)\text{ F}=39.6\,\frac{\text{kBtu}}{\text{htr}\cdot\text{day}}$$

- PHPP standard personal hot water use (excluding laundry & dishwash)

$$6.6\,\frac{\text{gal}}{\text{person}\cdot\text{day}}\cdot\frac{8\text{ lb}}{\text{gal}}\cdot\frac{1\text{ Btu}}{\text{lb F}}\cdot(140-50)\text{ F}=4.75\,\frac{\text{kBtu}}{\text{person}\cdot\text{day}}$$

PHPP view of water heating

- For residential buildings: personal water use, laundry, dishwash, and individual pipe loss all scale per person, and occupancy scales with treated floor area.

$$6.6 \frac{\text{gal}}{\text{person} \cdot \text{day}} \rightarrow 4.75 \frac{\text{kBtu}}{\text{person} \cdot \text{day}}$$

$$\times \frac{365 \text{ day}}{\text{yr}} \times \frac{1 \text{ person}}{377 \text{ ft}^2} = 4.60 \frac{\text{kBtu}}{\text{ft}^2\text{yr}}$$

$$\text{add laundry \& dish} \rightarrow 5.5 \frac{\text{kBtu}}{\text{ft}^2\text{yr}}$$

$$\text{add indiv. pipe loss} \rightarrow 7.0 \frac{\text{kBtu}}{\text{ft}^2\text{yr}}$$

TOTAL SPECIFIC DEMAND.
10 gal/p/day
11.6 DOE gal/p/day

My recent cases, Total Specific Demand

Bob	7.0
Carol	6.8
Ted	4.0
Alice	8.2
Dinesh	7.1
Uma	7.9
Boris	5.7
Doris	6.2

Personal reality check

- Measured shower water use, omitting warmup (37 foot pipe to water heater).

$$47 \times 20.5 \times 3 \text{ in deep} = 2890 \text{ in}^3 = 12.5 \text{ gal}$$

- PHPP allowance, mixed down to a comfy 102 F

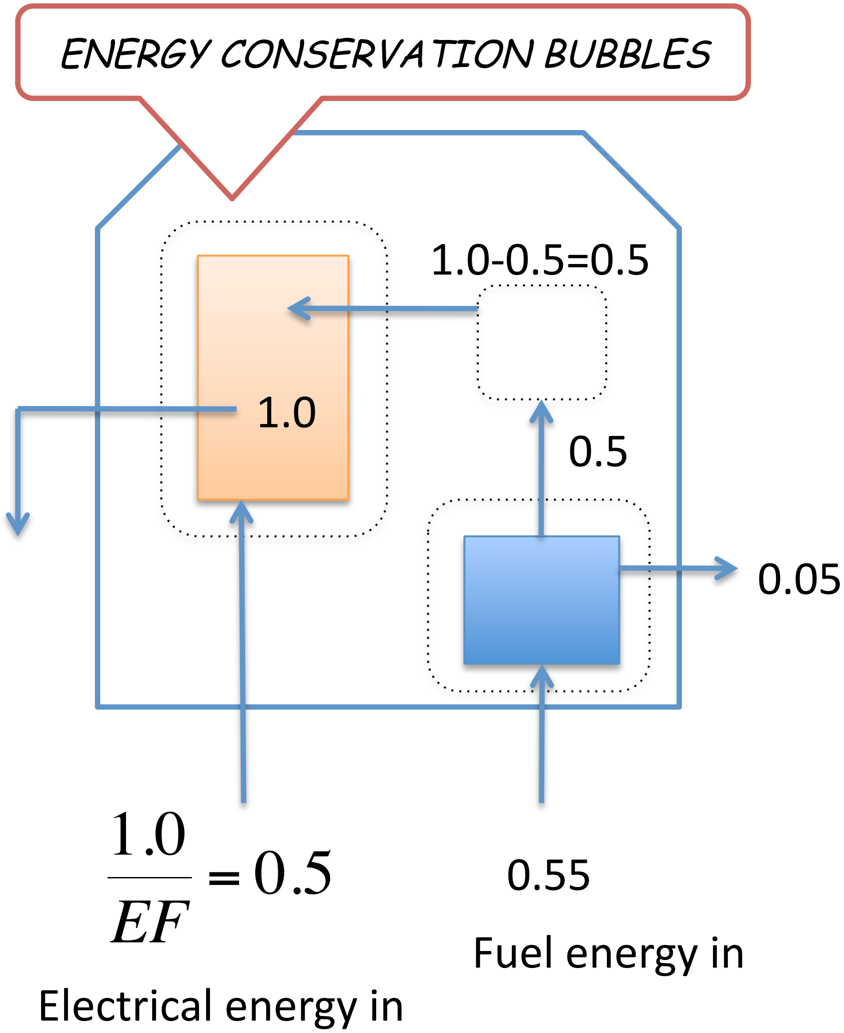
$$\text{Shower gallons} = \text{PHPP gallons} \times \frac{140 - 50\,\text{F}}{102 - 50\,\text{F}}$$

$$= 6.6 \times {}^{90}\!/_{52}$$

$$= 11.4 \text{ gal}$$

I NEED TO SPEED UP 10%.

HPWH inside, fueled space heat

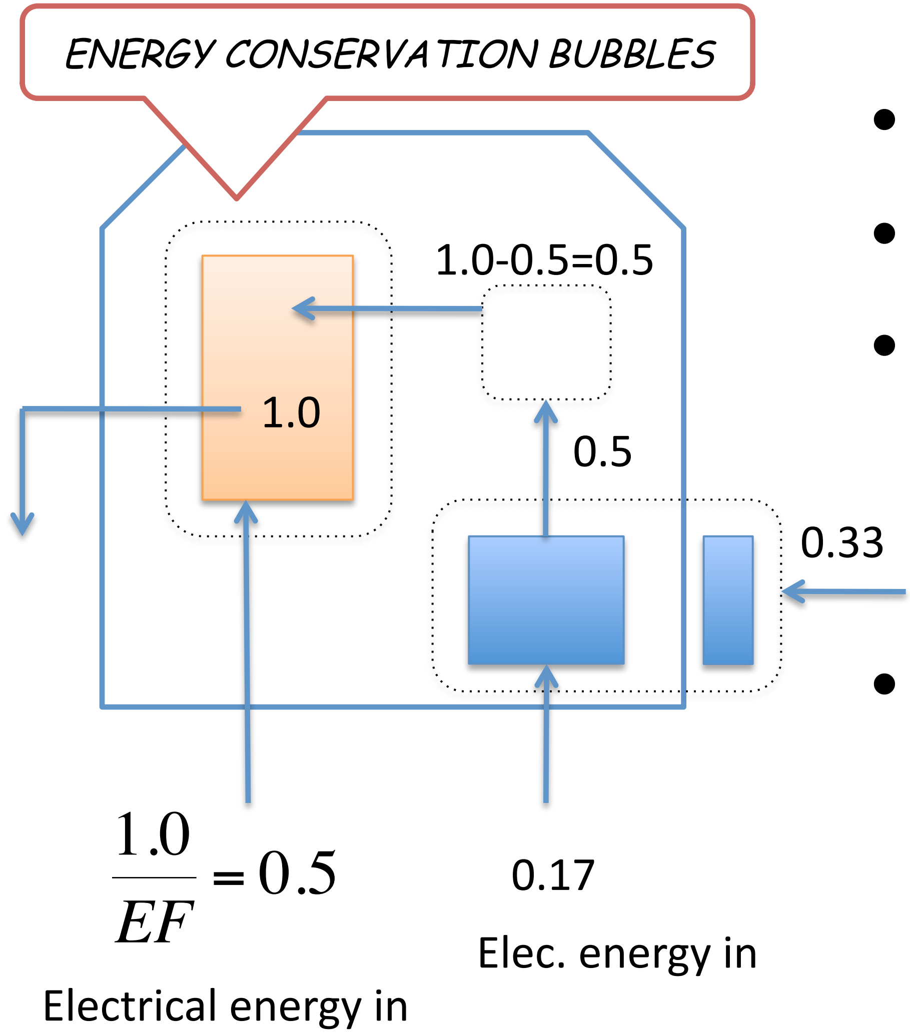


- HPWH with EF=2.0
- 90% efficient furnace
- DHW System COP

$$= \frac{1.0}{0.5 + 0.55} = 0.95$$

- On PE value sheet
  - 50% direct electric
  - 50% fuel

HPWH inside, HP space heat only

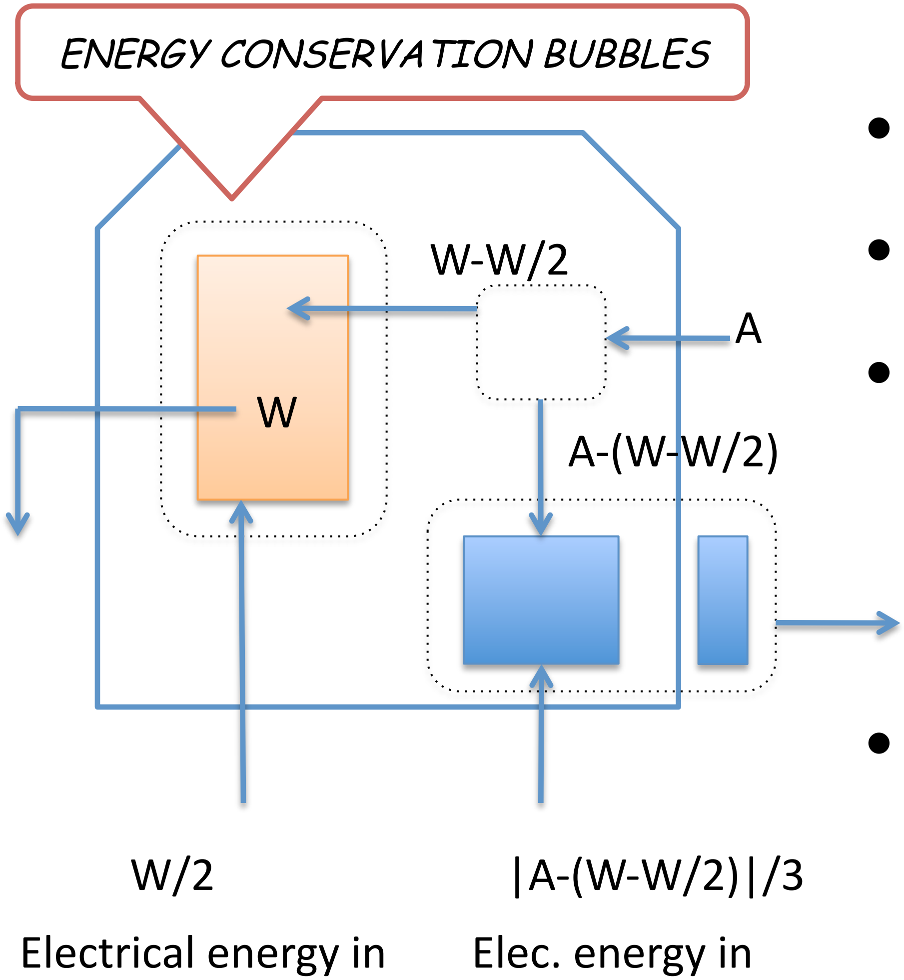


- HPWH with EF=2.0
- Air-to-air HP, COP=3
- DHW System COP

$$= \frac{1.0}{0.5 + 0.17} = 1.5$$

- On PE value sheet
  - COP 3 for space heat
  - COP 1.5 for DHW
    - Put in "Other"

HPWH inside, HP space cool



- HPWH with EF=2.0
- Air-to-air HP, COP=3
- System COP

$$= \frac{A+W}{W/2 + |A-(W-W/2)|/3}$$

- Needs month-by-month calculation.

HPWH inside, effect on Peak Loads

- Daily perspective. Suppose one day is much like another for DHW demand. Typical average hourly rate is then

$$7.0\,\frac{\text{kBtu}}{\text{ft}^2\text{yr}} \times \frac{1\text{ yr}}{8760\text{ h}} = 0.8\,\frac{\text{Btu}}{\text{h ft}^2}$$

- The portion of that drawn from the inside air is

$$0.8\,\frac{\text{Btu}}{\text{h ft}^2} \times \left(1 - \frac{1}{EF}\right) \approx 0.4\,\frac{\text{Btu}}{\text{h ft}^2}$$

- Increases peak heating load, decreases peak cooling load. Compare to PH peak heating load goal of 3.17 Btu/h-ft^2. Compare to standard internal heat gain of 0.67 Btu/h-ft^2.

HPWH inside, affect on Peak Loads

- Hourly perspective. Data for three models from Bonneville Power Administration / Ecotope tests, according to DOE 24 hour protocol.

Model	Power during recovery from draws (W)	X (COP-1) =	Rate of Heat drawn from air (W)	Rate of Heat drawn from air (Btu/h)
AO Smith Voltex PHPT-80	900	X (2.75-1) =	1575	5370
GE Geospring	500	X (2.5-1) =	750	2560
Rheem HP50	1100	X (2.0-1) =	1100	3750

Energy from “your air” -> your “water”

- Your hot shower water: 6.6 gal @ 140 F.
- Your air space: 377 sf * 8.2 ft @ 68 F.
- Mw cpw ΔTw (1-1/EF) = Ma cpa ΔTa
- 6.6 gal * 8 lb/gal * 1 Btu/lb-F * (140-50) F * (1-1/2) = 377 * 8.2 ft3 * 0.018 Btu/ft3-F * (68-Tx)
- 2376 Btu = 55.6452 * (68-Tx)
- 68-Tx=42.7, Tx=25.3 F

IN A FOUR-PERSON HOUSE, RECOVERY FROM ONE SHOWER COULD DROP THE AIR TEMP AS LOW AS 57 F, IF THE SPACE HEATER DID NOTHING.

Figure 2a. DOE 24hr Simulated Use Test.

First 6 hours of test covers all six draws and full tank recovery.

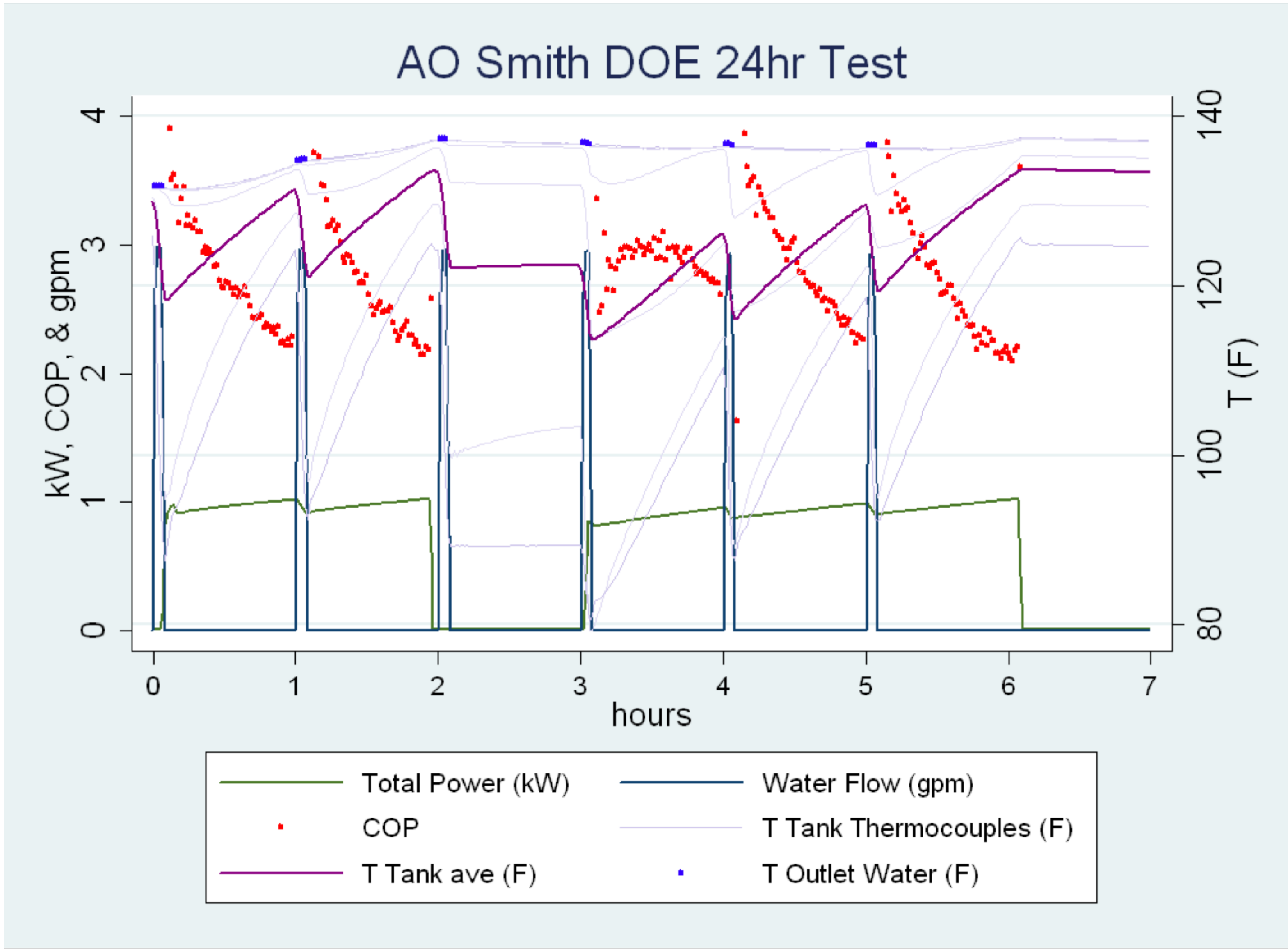
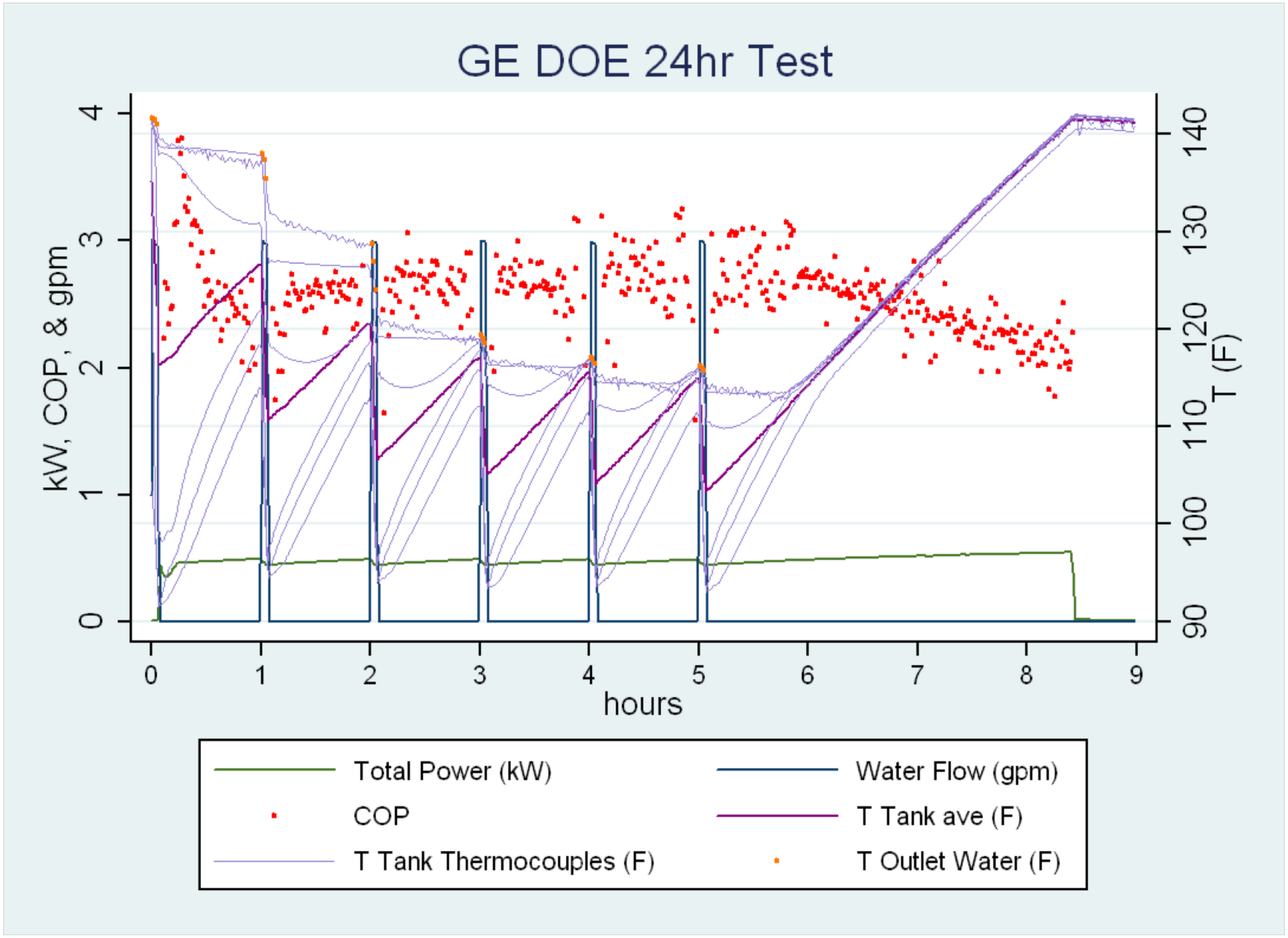


Figure 2a. DOE 24hr Simulated Use Test. First 9 hours of test.



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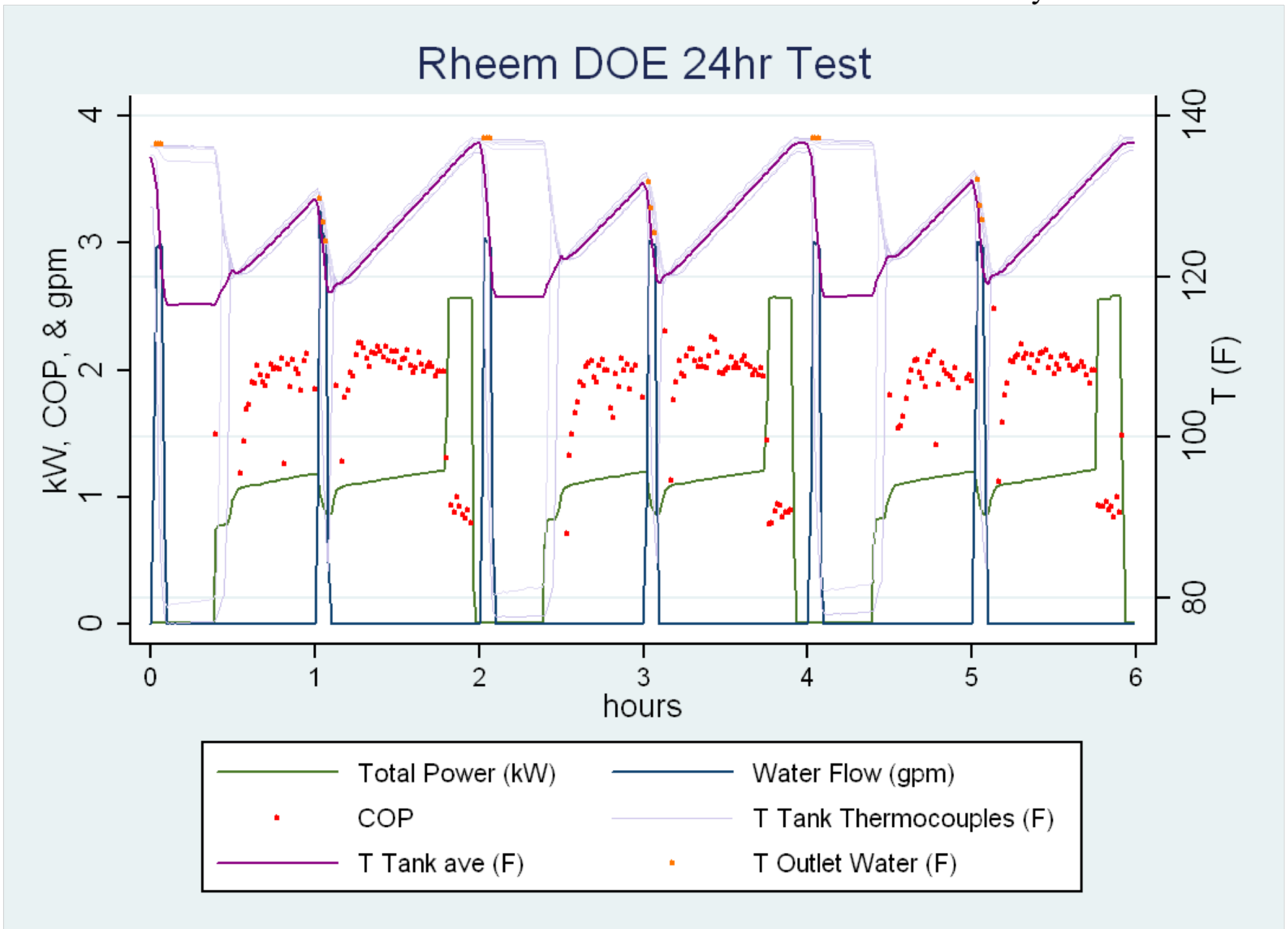


HPWH inside, effect on Annual Heat Demand

- If piping and storage losses are assumed to contribute to internal heat gain, a HPWH of EF=2 inside a typical Passive house would withdraw from the air about

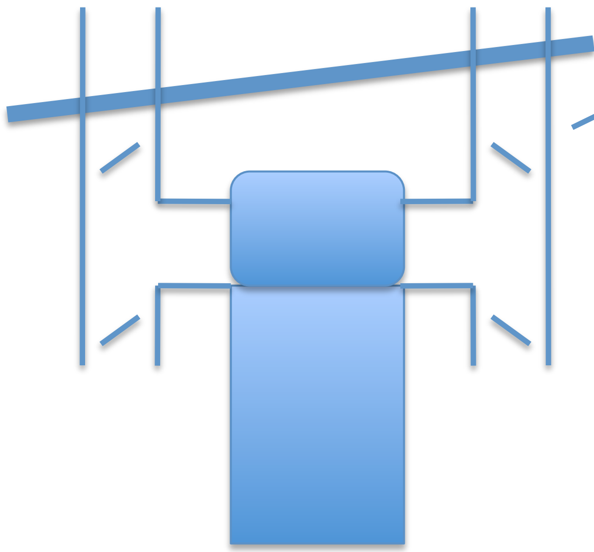
$$5.5\,\frac{\text{kBtu}}{\text{ft}^2\text{yr}} \times \left(1 - \frac{1}{EF}\right) \approx 2.25\,\frac{\text{kBtu}}{\text{ft}^2\text{yr}}$$

- If counted, it would increase Annual Heat Demand and decrease Annual Cooling Demand by up to 2.25, depending on length of heating/ cooling season. A big deal relative to 4.75 criterion.

Point/Counterpoint

- Don't count it: AHD/ACD is an envelope thing, side effects of mechanical systems shouldn't influence the envelope design.
- Count it: Drying closet (interior clothesline) does affect internal heat gain and thus AHD if "PHPP calc residential" mode is used. So there is precedent for an appliance affecting the envelope design.

HPWH inside, ducted w/bypass?



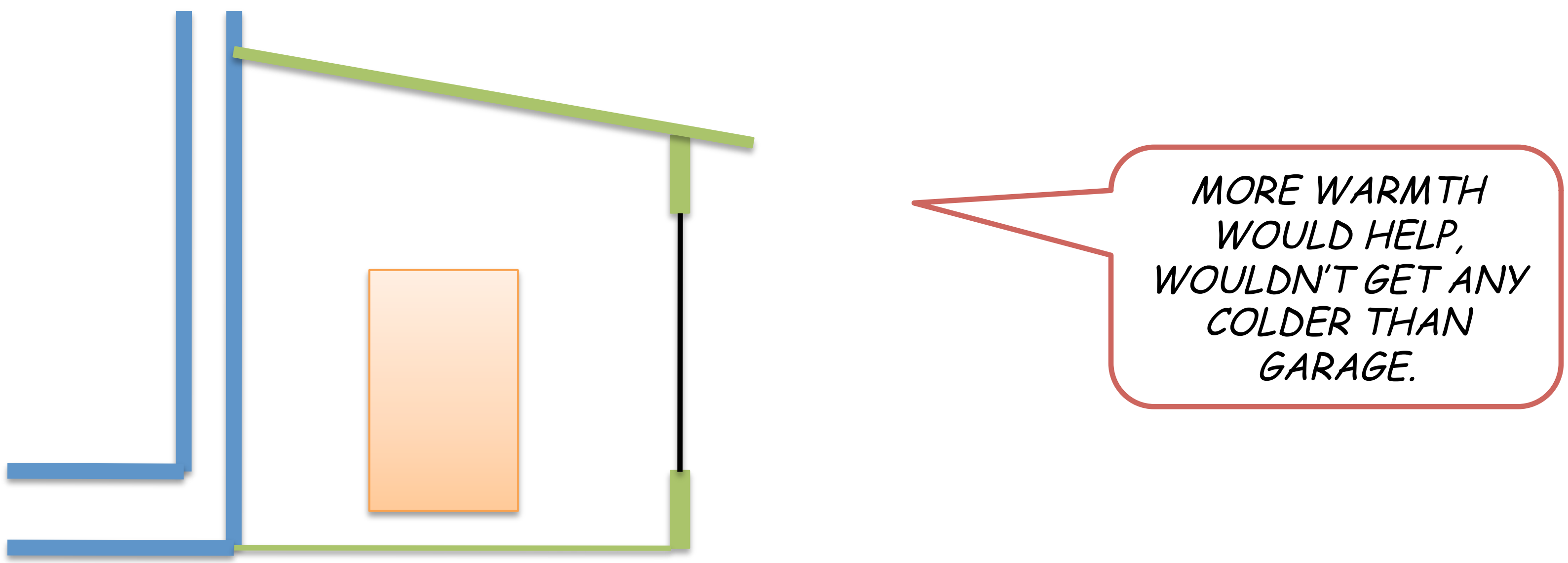
Cooling demand signal controls two 3-way or four 2-way dampers

NEEA GUIDELINES RECOMMEND DUCTING THE EXHAUST OF AN INSIDE HPWH TO THE OUTSIDE, SO IT CAN REDUCE EXFILTRATION AND THUS SERVE AS A HEAT RECOVERY DEVICE! (MAKES NO SENSE IN PASSIVE HOUSE.)

- Pro: Helps with space cooling, doesn't hurt space heating.
- Con: Complicated.

HPWH in attached sunspace?

- Outside the thermal envelope. Cheap high solar heat gain glass (not overhead), no insulation.



HPWH outside

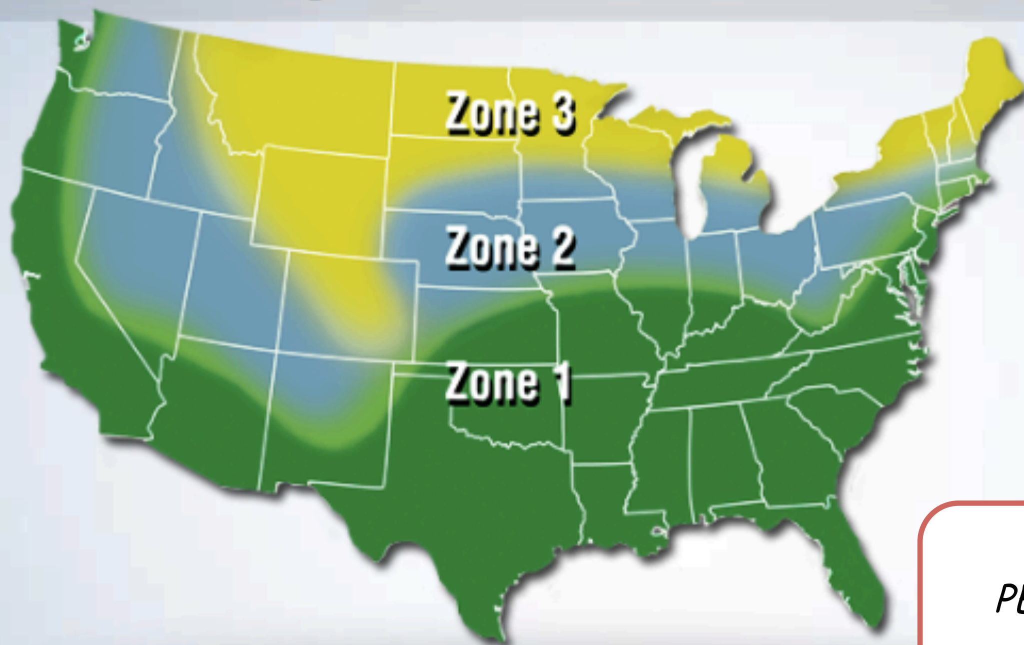
- Current Heat pump water heaters switch to electric resistance in ambient temperatures below low-40s to low-50s F.
- We need annual average COP for energy calculations.

IT'S RUMORED THE AIRTAP INTEGRATED UNIT FROM AIRGENERATE IS GOOD TO THE LOW 30S...

HPWH outside

- Compressor COP varies strongly with air temperature and water tank temperature, weakly with humidity.

Efficiency Zones



Rollover each Zone for efficiency

THOSE PERCENTAGES MAY NEED ADJUSTMENT. ;)

The map above indicates, on average, the most favorable locations for he[...]mp water heaters.

Annual weather patterns and other factors will determine your overall ene[...]y efficiency.

Zone 1: Heat pump will be used most of the year (90-100%)

Zone 2: Combination heat pump (60%) and electric heating elements (40%)

Zone 3: Combination heat pump (50%) and electric heating elements (50%)

HPWH outside

- Bonneville Power Administration (BPA) measured compressor performance maps for 3 models.
- 40-house field test underway through March 2012, some results reported already.

Equipment Examined

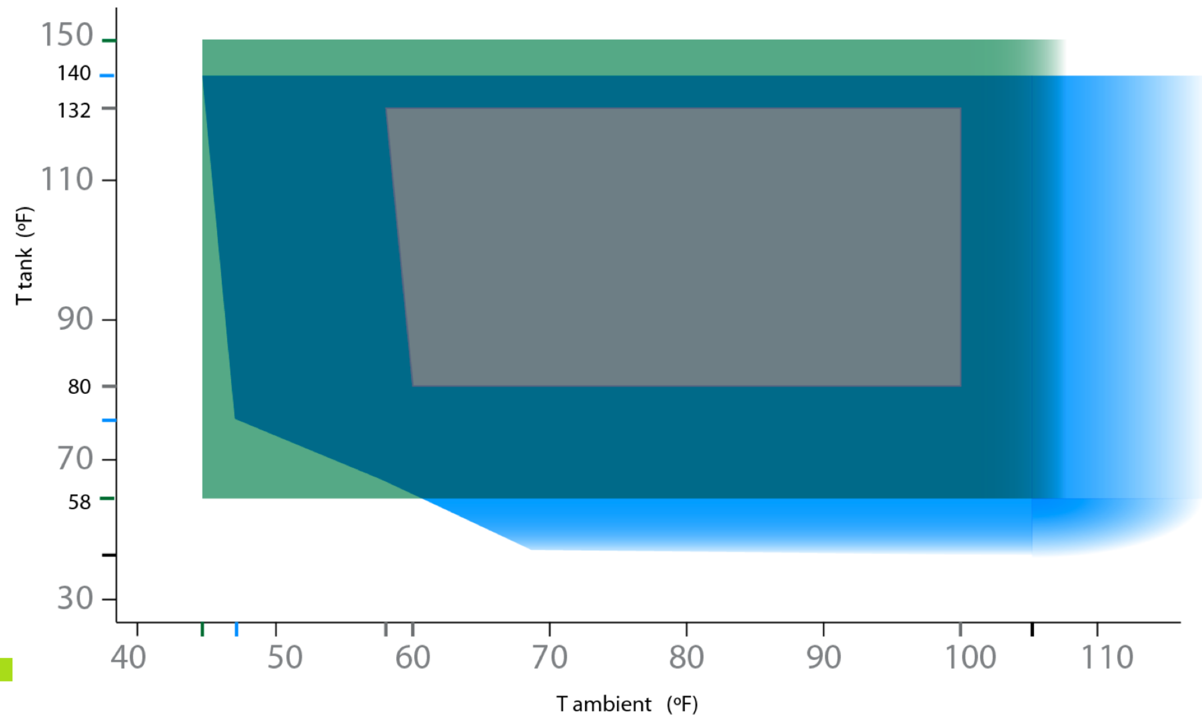
GE
50-gallon

AO Smith
80-gallon

Rheem
50-gallon

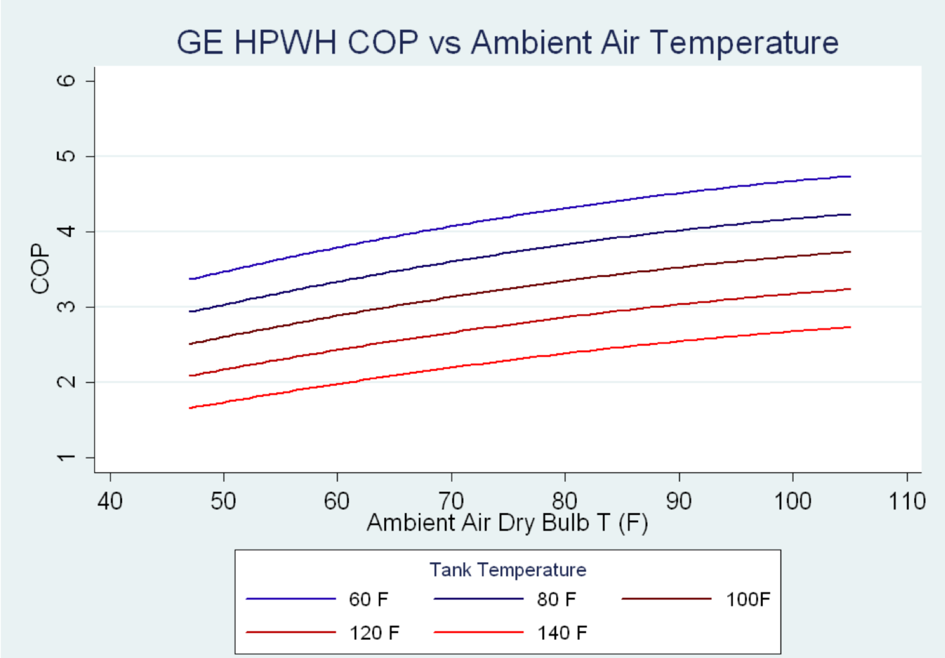
Compressor Operating Ranges

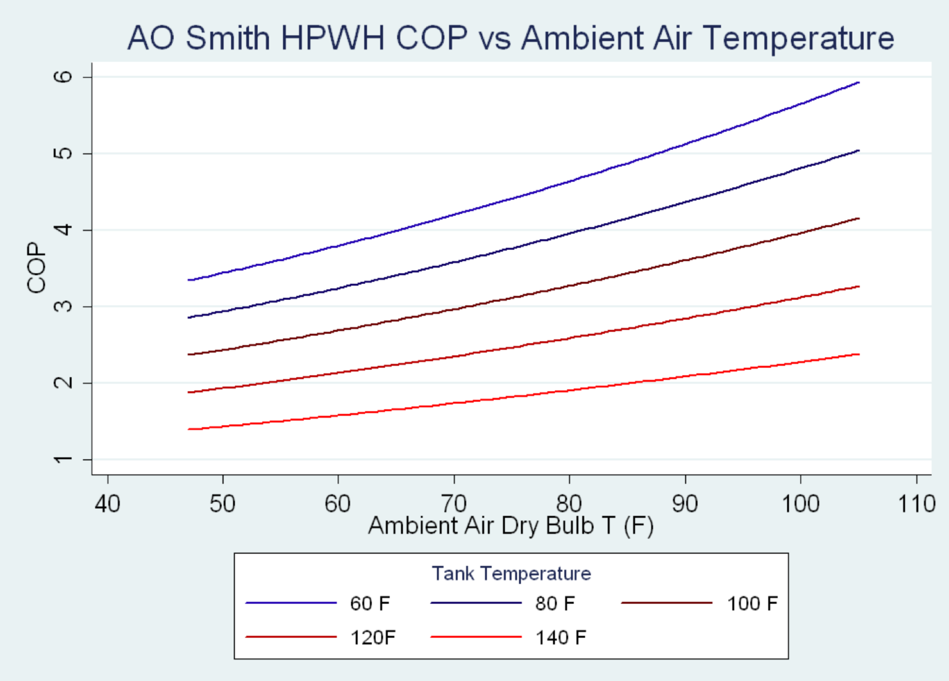
- Colored areas show ambient air T and ave tank T in which the compressor operates. Compressor cycles off at low T_{amb} & T_{Tank}
  - T_{amb} operation verified up to 105F – spec sheets indicate higher values (shown by fade).
  - Likewise, T_{Tank} verified up to 140F – spec sheet data indicates higher operation for some models.
- Green – AO Smith, Blue – GE, Gray -Rheem

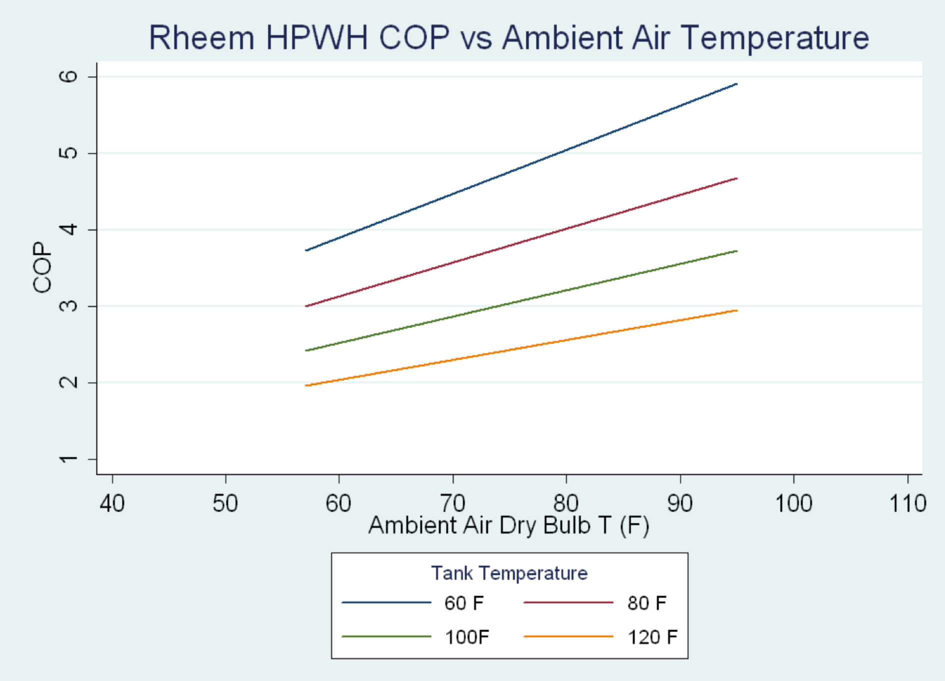


COP Mapping Results

- Compressor curves for 3 units.
  - COP depends strongly on T_{db} & T_{Tank} and less so on T_{wb}
- Empirical fits to measured data – not a unified model across units. Leads to different shaped curves which reflects different physical configurations.







Summary Findings

- Lab measured basic characteristics of equipment and performed DOE rating tests achieving results comparable to published data.
- Collected data to:
  - completely map compressor performance over all operating ranges
  - determine under what draw conditions units switch to resistance element
- Draw profiles show link between storage capacity and overall efficiency
- Key equipment findings:
  - Circulation pumps can destratify the tank potentially leading to compromised user experience
  - Rheem has limited low temperature compressor range leading to more element use
  - Both Rheem and GE storage capacity of 45 gallons tends to result in more element use especially around peak draw periods
  - AO Smith larger storage capacity of 75 gallons reduces element use

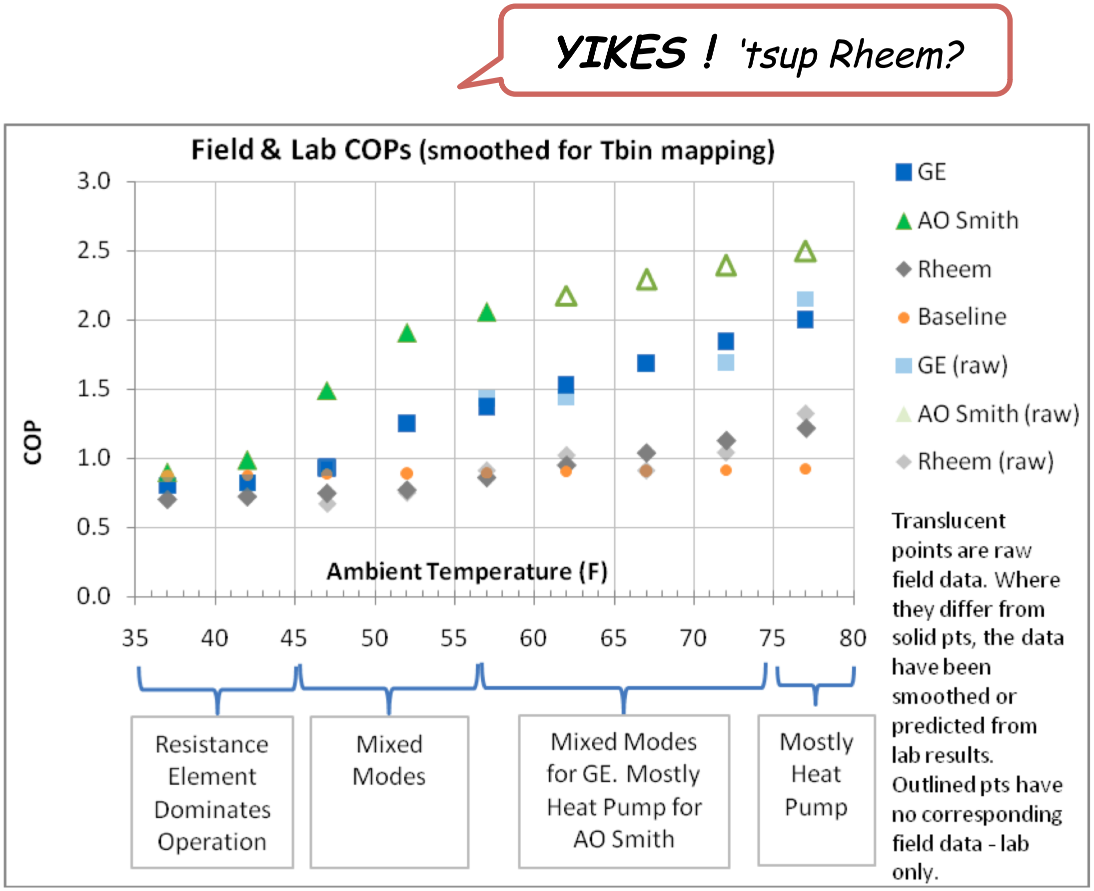
IT ALSO HAD A BIG BLOWER.

Field Data from BPA Study

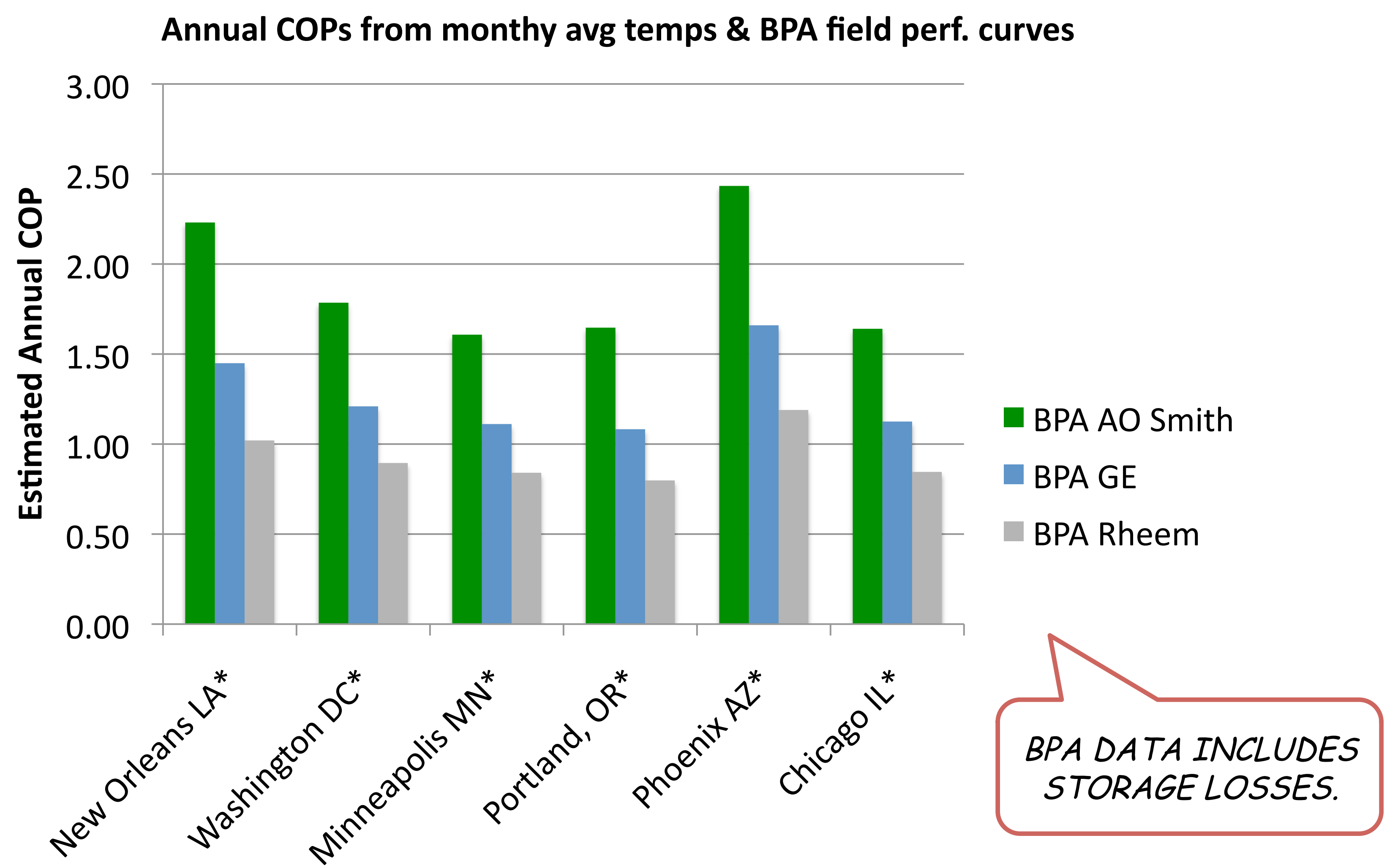
- Study conducted by EPRI is currently underway
  - Sites selected are not a random or an engineered sample
- Examined four months of available data which has the following characteristics:
  - Jan-Apr 2011
  - 32 sites. GE: 21, AO Smith: 3, Rheem: 8
  - Climate categories:
    - PDX: 16, SEA: 8, SPO: 3, BOI: 1, KAL: 4
  - Install locations:
    - Garage: 21, Unhtd Basement: 5, Unhtd Utility Rm: 1: Conditioned Space (any): 5
  - Average daily hot water use: 47.5 gallons
  - Average Outlet – Inlet Water ΔT=70.3 F

COP Map

- Using lab and field results, created a COP map vs ambient T
  - Field data smoothed to create stable, less noisy trend that matched lab results.
- Electric resistance element use has substantial influence on COP especially at the mid and low T_{amb}
- Baseline use also impacted by ambient temperature: lower temperature leads to increased standby losses.
- In all resistance heat mode, $COP_{HPWH} < COP_{baseline}$ because HPWH tank standby losses are greater



HPWH outside in different climates



HPWH outside in different climates

- Similar calculations using the BPA compressor maps suggest that if low ambient temperature was the only condition that caused resort to electric resistance, COPs would be much better (possibly at the expense of 1st-hour rating.)
- The "Econ" mode of the AirTap ATI's shuts off electric resistance entirely. Also, exhaust can be ducted.

Conclusions

- PHPP personal water use allowance is reasonable.
- Real world performance of a HPWH, in conditioned space, held up to government ratings in one out of three cases tested for BPA. Ratings may be more reliable for the larger tanks. Operation modes vary as to how much the resistance elements are used.

Mfg	DOE EF	Lab, per DOE	Field
AO Smith Voltex PHPT-80	2.33	2.29	2.3
GE Geospring	2.35	2.41	1.7
Rheem HP50	2.0	1.69	1.0

Conclusions

- On a daily average basis, the effect of a HPWH inside is about 0.4 Btu/h-ft^2. Large relative to standard PH internal heat gain, small relative to typical peak load.
- However, on an hourly basis, a HPWH inside, recovering from a shower draw, could cool a residential Passive House by up to 10 F. (Space heater would need to be upsized by 2500-5000 Btu/h.)
- System efficiency is low if space heater has to make up heat drawn from air.

Conclusions

- A HPWH inside could offset up to about 2.25 kBtu/ft^2-yr of annual cooling demand.
- Presently it looks like they only work well outside, in places where you'd want them inside.
- They make the most sense in hot climates. Possibly helpful to small, over-glazed PH with summer overheating.
- For cool/mixed climates installation in attached sunspace outside the Passive House envelope might be advantageous (future work.)