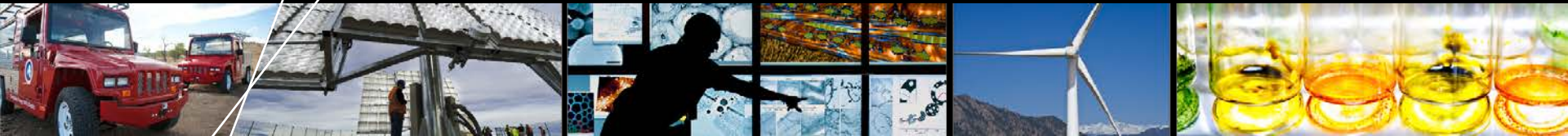


Heat Pump Water Heater Modeling in EnergyPlus



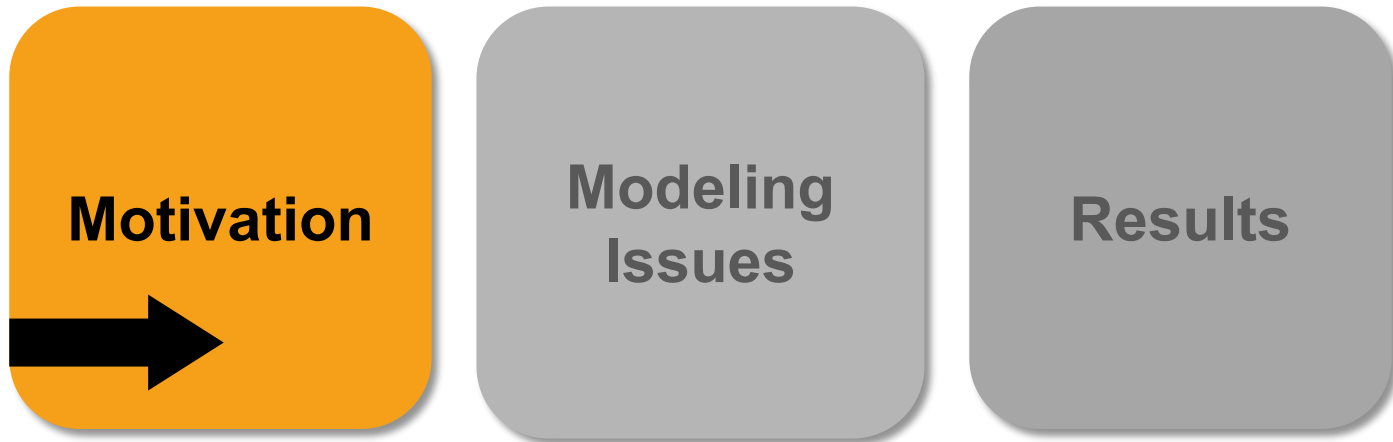
**Building America Residential Energy
Efficiency Stakeholder Meeting**

**Eric Wilson
Craig Christensen**

March 1, 2012

NREL/PR-5500-54318

Heat Pump Water Heater Modeling...





Photos by Kate Hudon, NREL/PIX 18675, NREL/PIX 18671, NREL/PIX 18667, NREL/PIX 18676, and NREL/PIX 18919

Gap: Existing analysis tools cannot accurately model HPWHs with reasonable runtime.



What have we achieved so far?

Field Monitoring

14 x



Photo from Steven Winter Associates, Inc.

Laboratory Evaluations



Photos by Kate Hudon, NREL/PIX 18675, NREL/PIX 18671, NREL/PIX 18667, NREL/PIX 18676, and NREL/PIX 18919

Closing the Gap

Field Monitoring

14 x

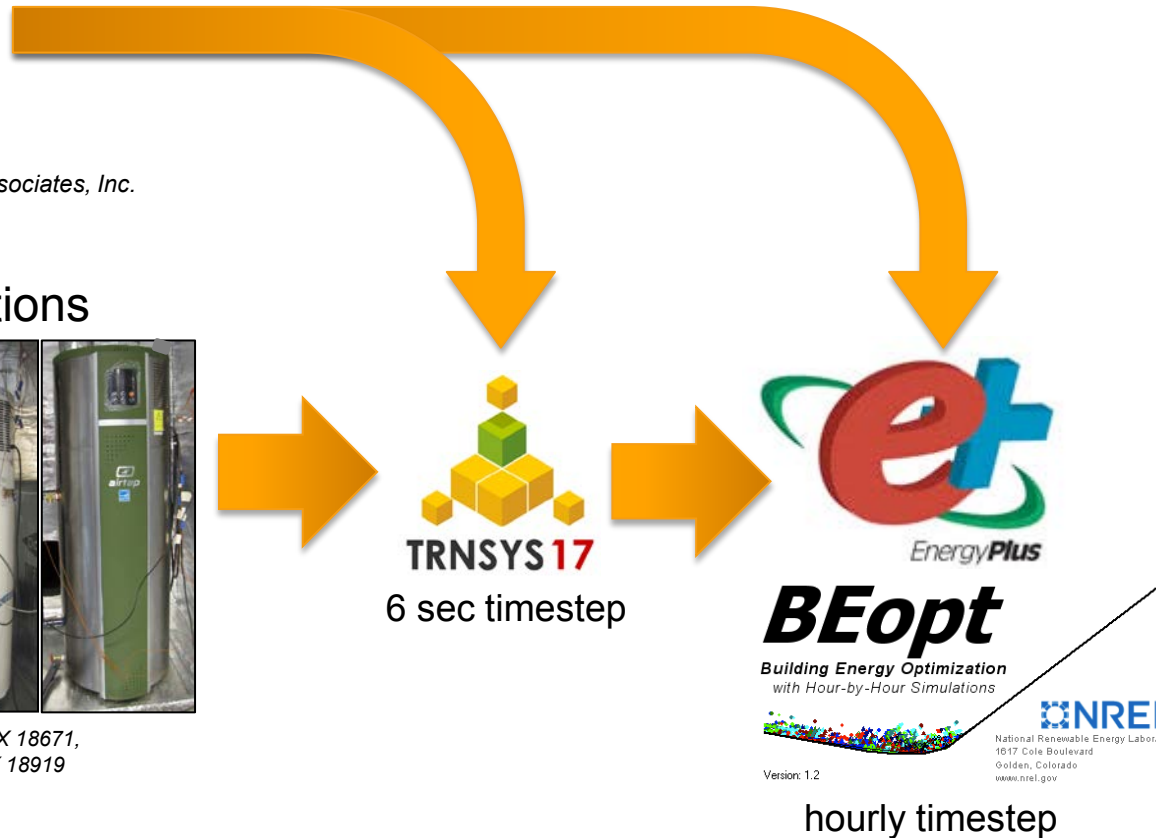


Photo from Steven Winter Associates, Inc.

Laboratory Evaluations

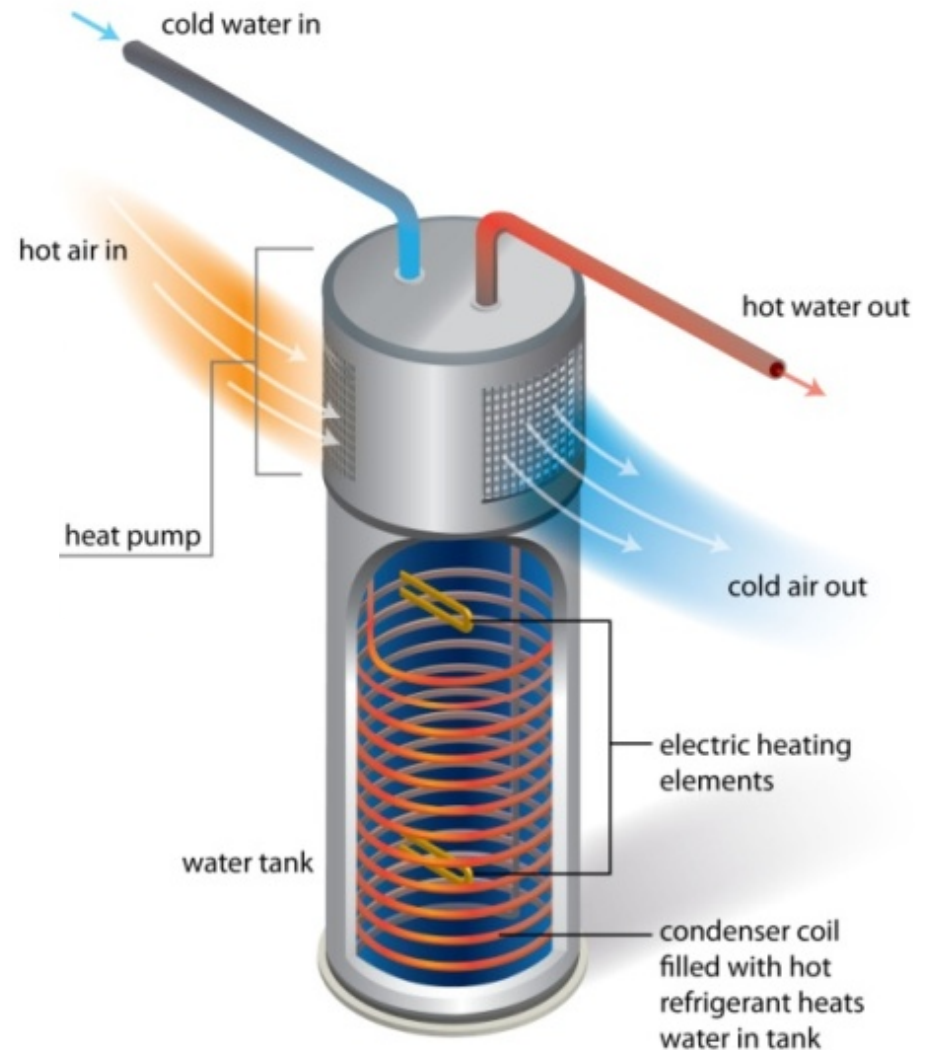


Photos by Kate Hudon, NREL/PIX 18675, NREL/PIX 18671, NREL/PIX 18667, NREL/PIX 18676, and NREL/PIX 18919



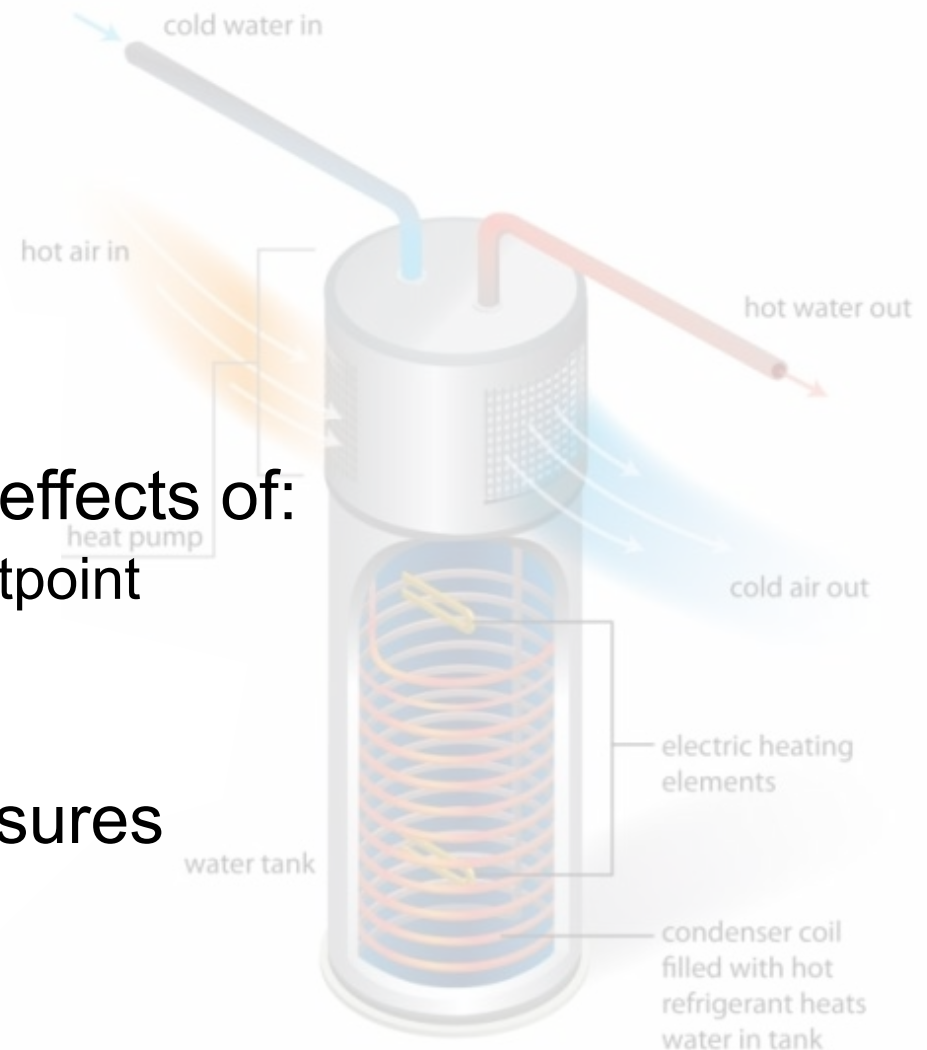
Why is modeling important?

- Performance varies:
Can't just use EF
- System interaction
 - HPWH affects building heating and cooling
 - Space conditions affect HPWH performance

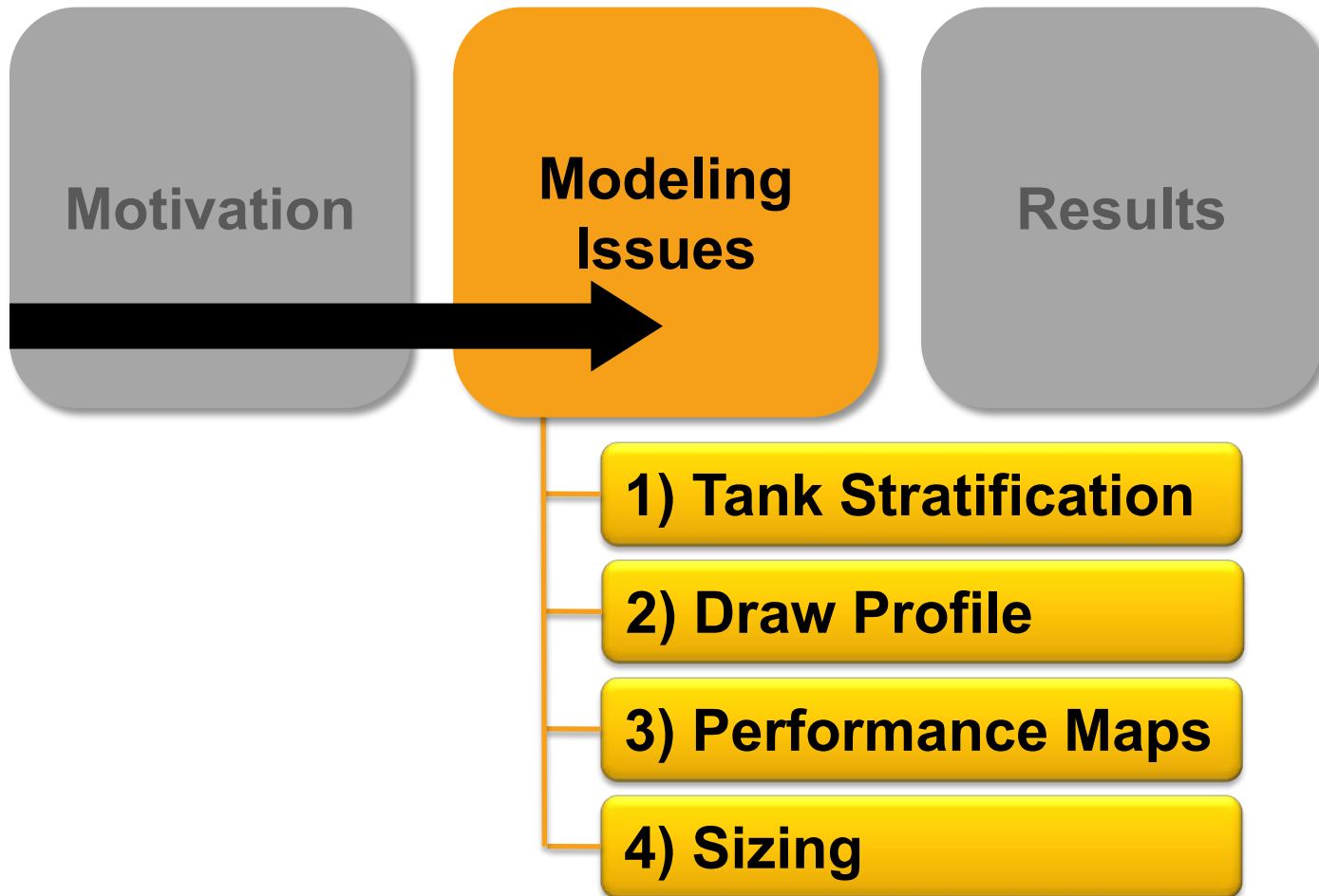


Modeling Goals

- Manage Risks
 - Accuracy
 - Run time
 - Occupant satisfaction
- Flexibility to explore the effects of:
 - Tank location, volume, setpoint
 - Hot water use patterns
- HPWH vs. all other measures (optimization)



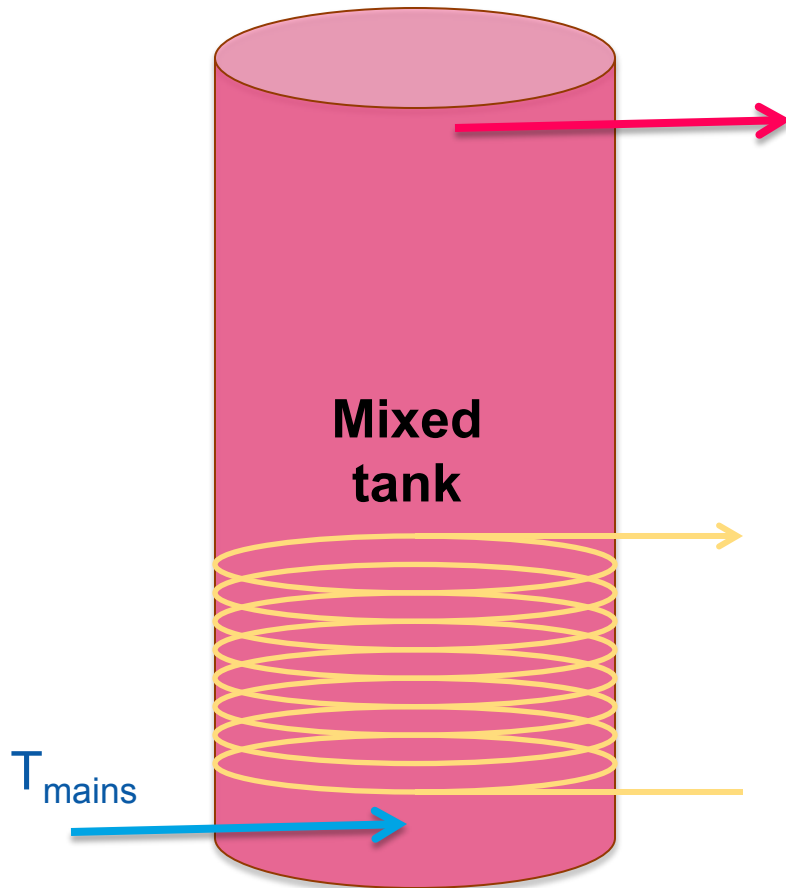
Heat Pump Water Heater Modeling...



1) Tank Stratification

Existing Model

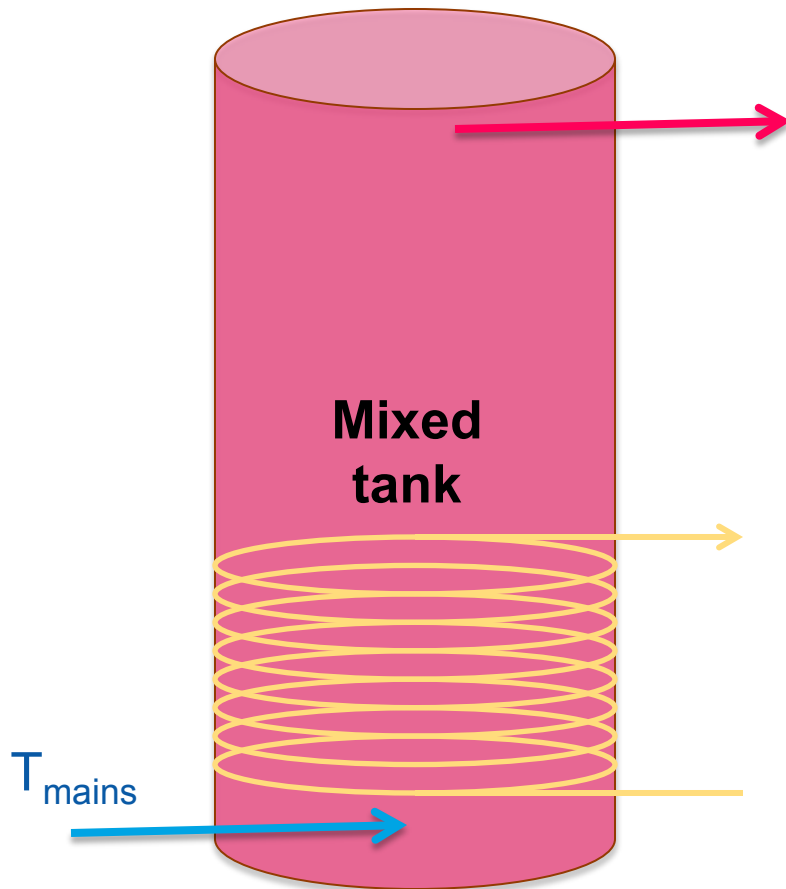
EnergyPlus HPWH mixed tank



1) Tank Stratification

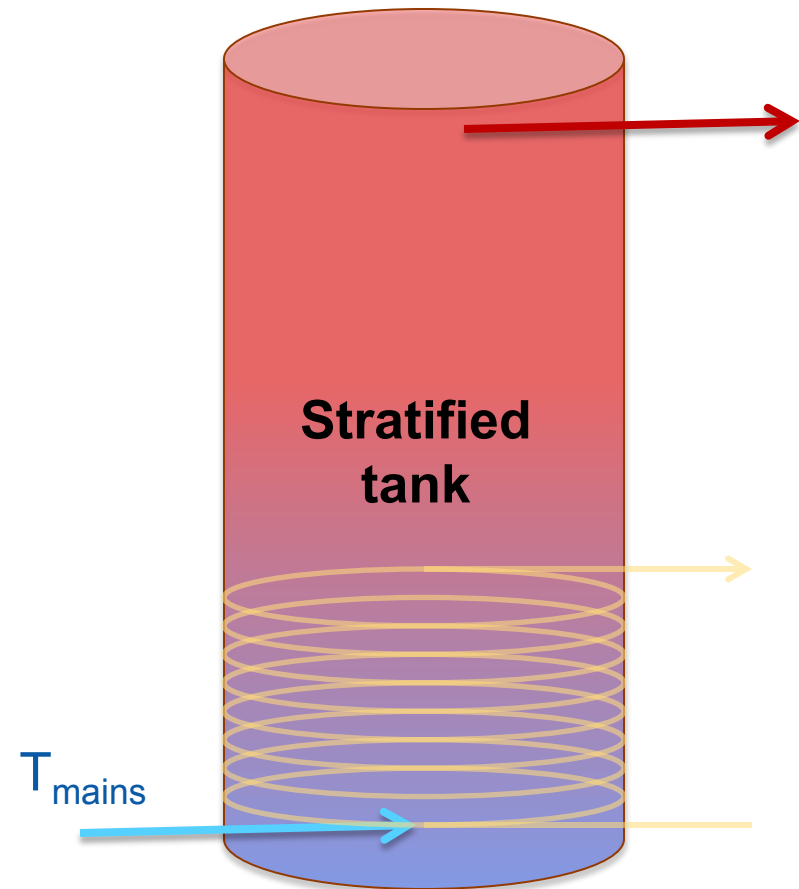
Existing Model

EnergyPlus HPWH mixed tank



Realistic Performance

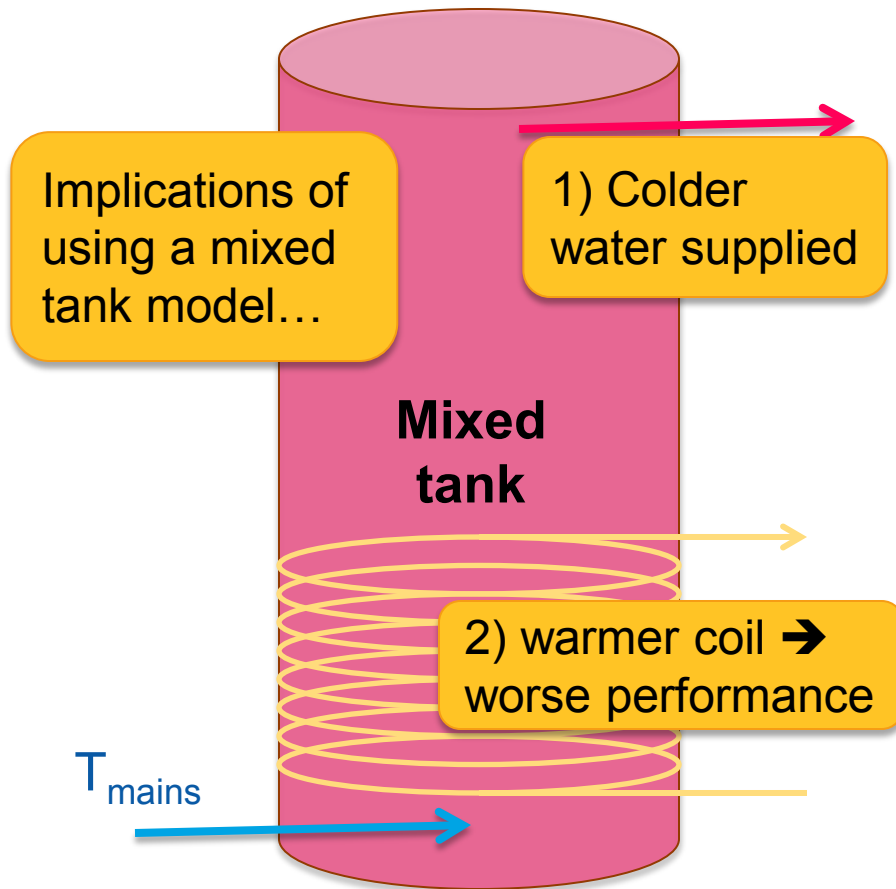
Stratified tank



1) Tank Stratification

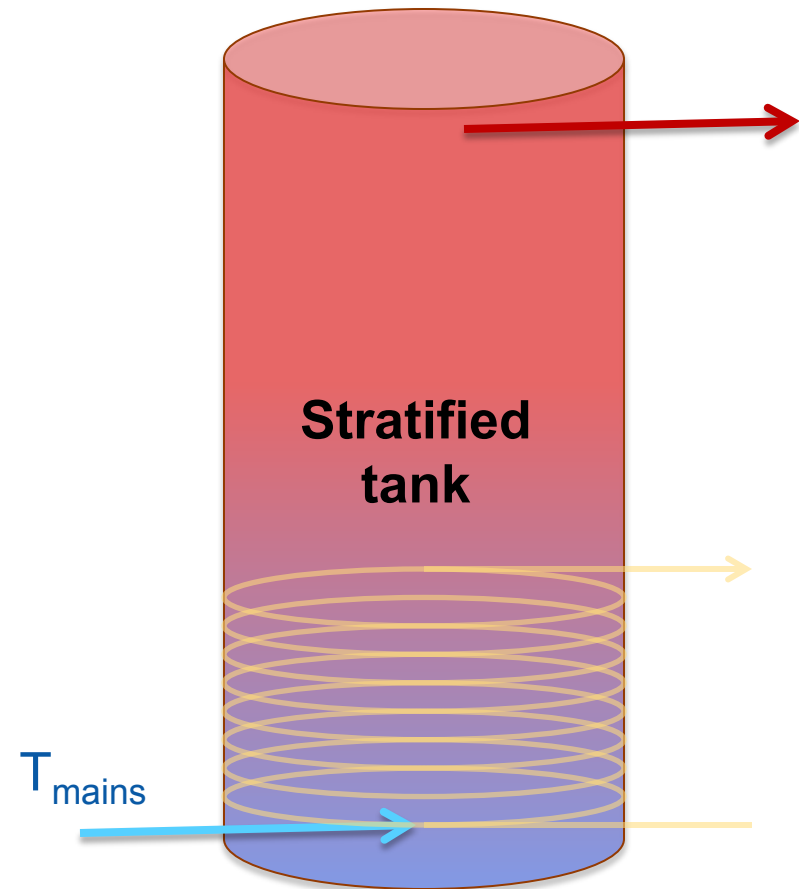
Existing Model

EnergyPlus HPWH mixed tank



Realistic Performance

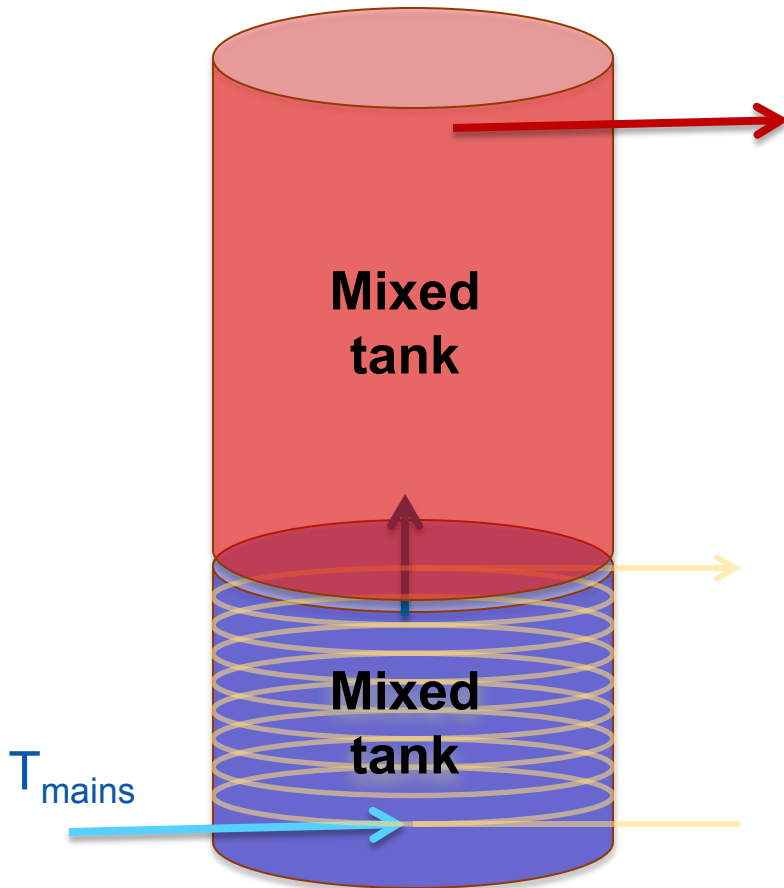
Stratified tank



1) Tank Stratification

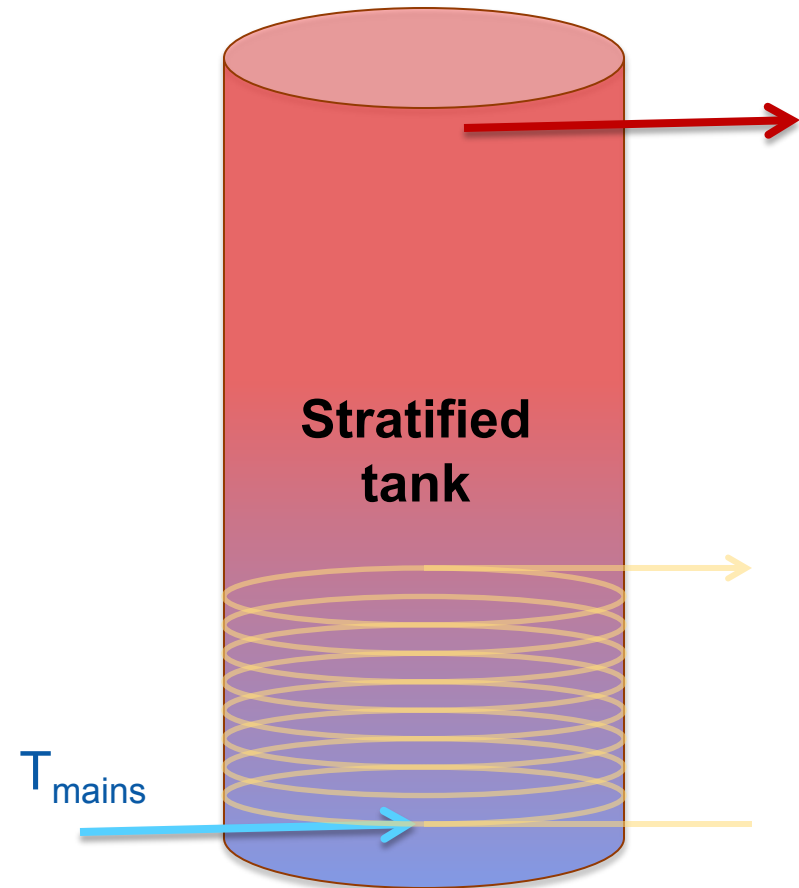
New Model

Two tanks in Series



Realistic Performance

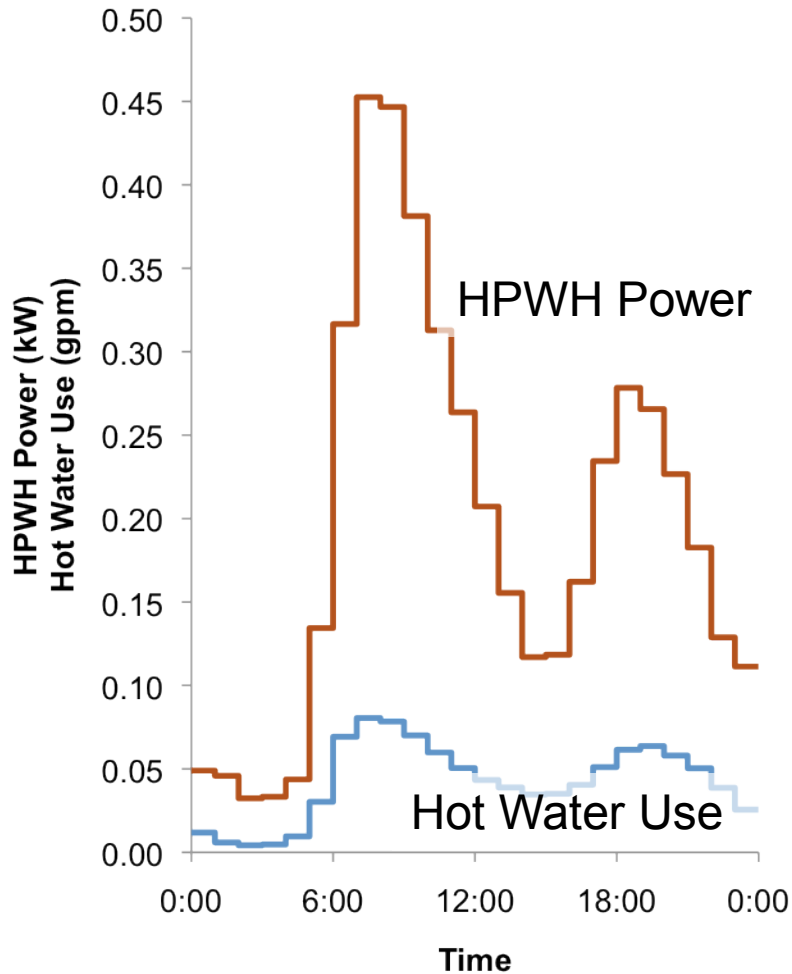
Stratified tank



2) Draw Profile

Existing Model

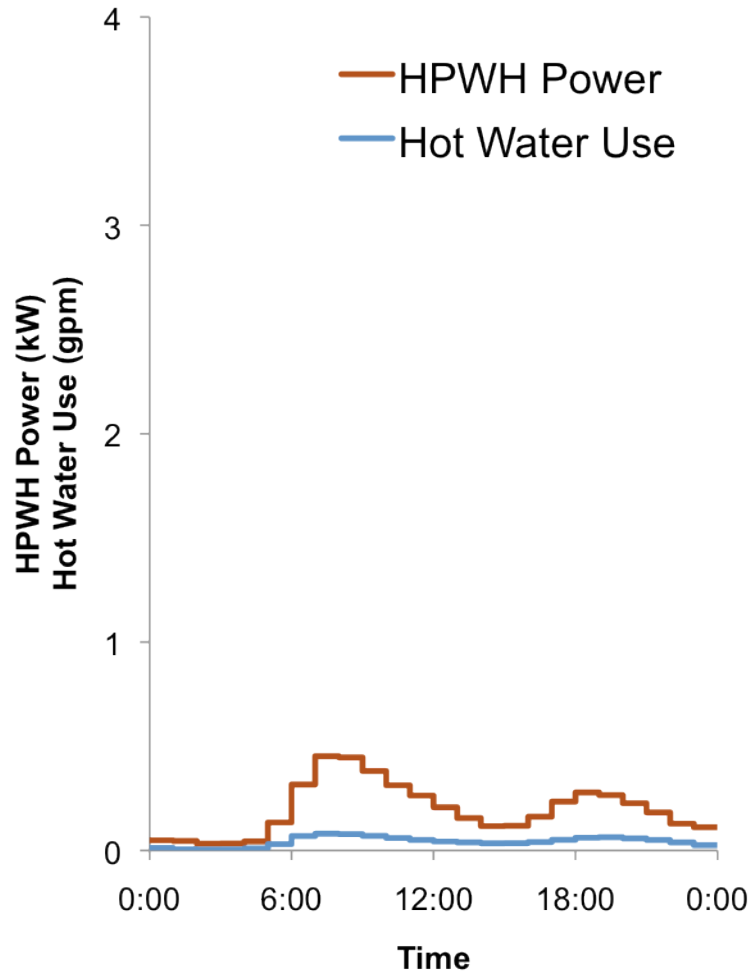
Smooth Draw Profile
Hourly Timestep



2) Draw Profile

Existing Model

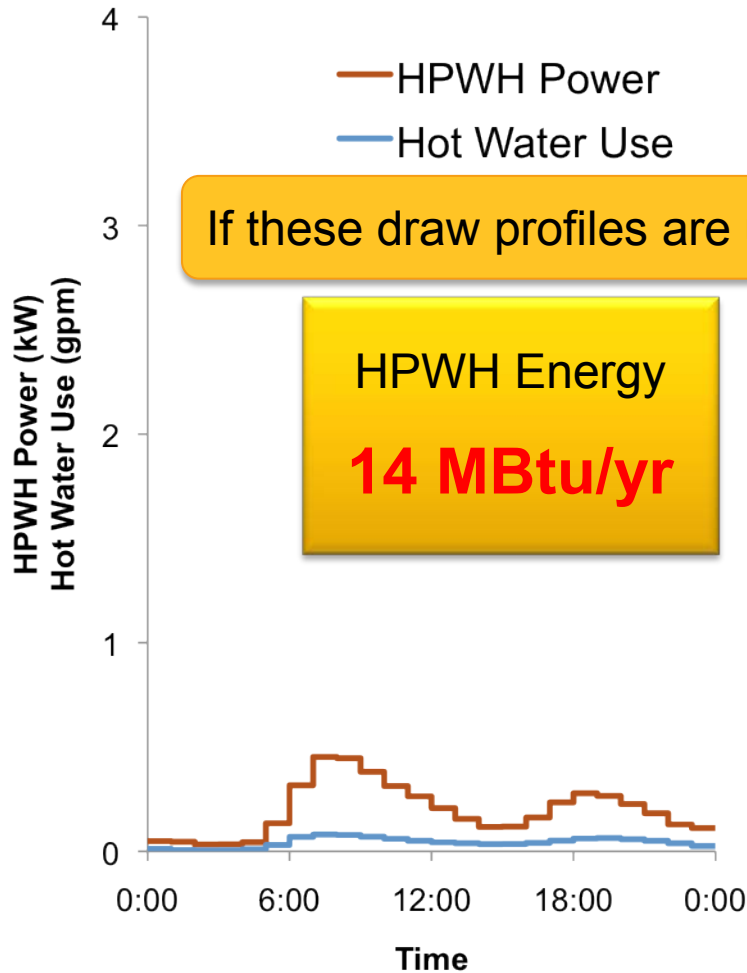
Smooth Draw Profile
Hourly Timestep



2) Draw Profile

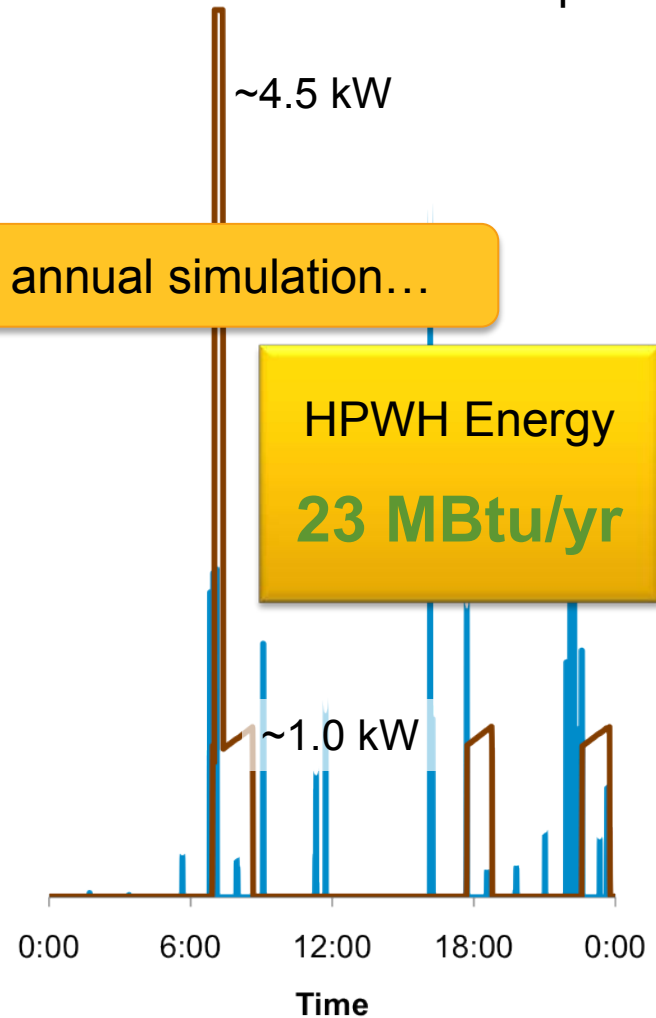
Existing Model

Smooth Draw Profile
Hourly Timestep



Realistic Performance

Discrete Draw Events
6 Second Timestep

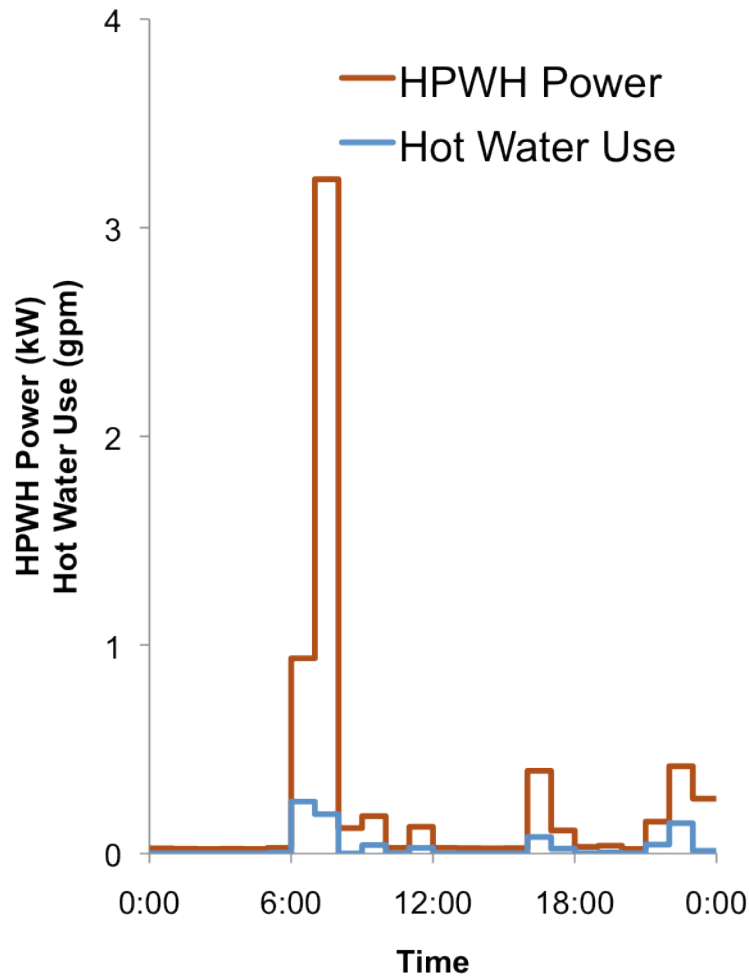


If these draw profiles are used for an annual simulation...

2) Draw Profile

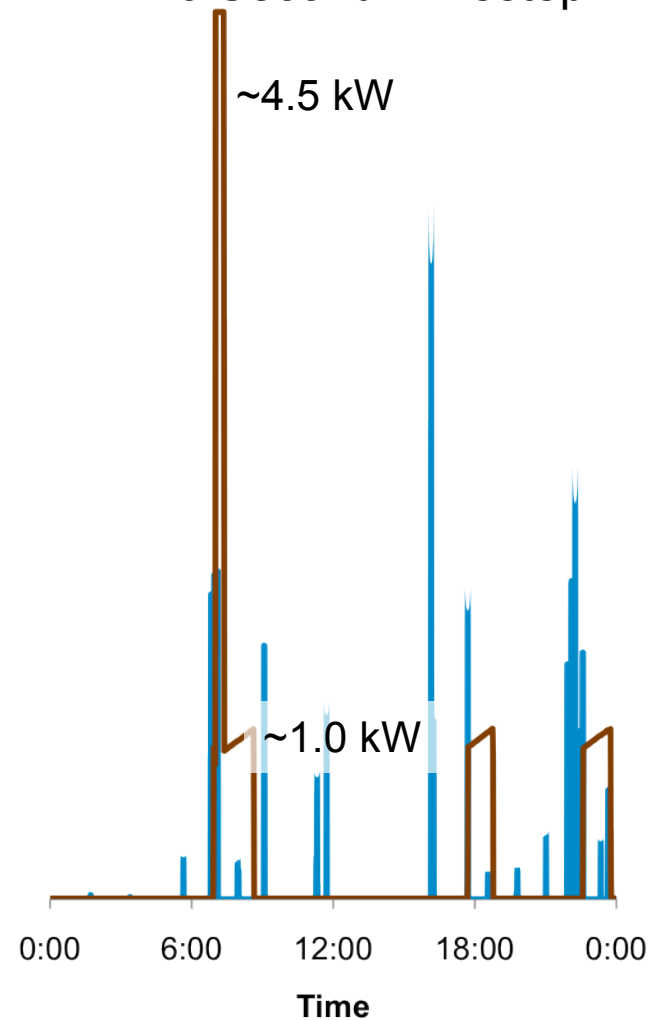
New Model

Hourly Averaged Discrete Draws
Hourly Timestep



Realistic Performance

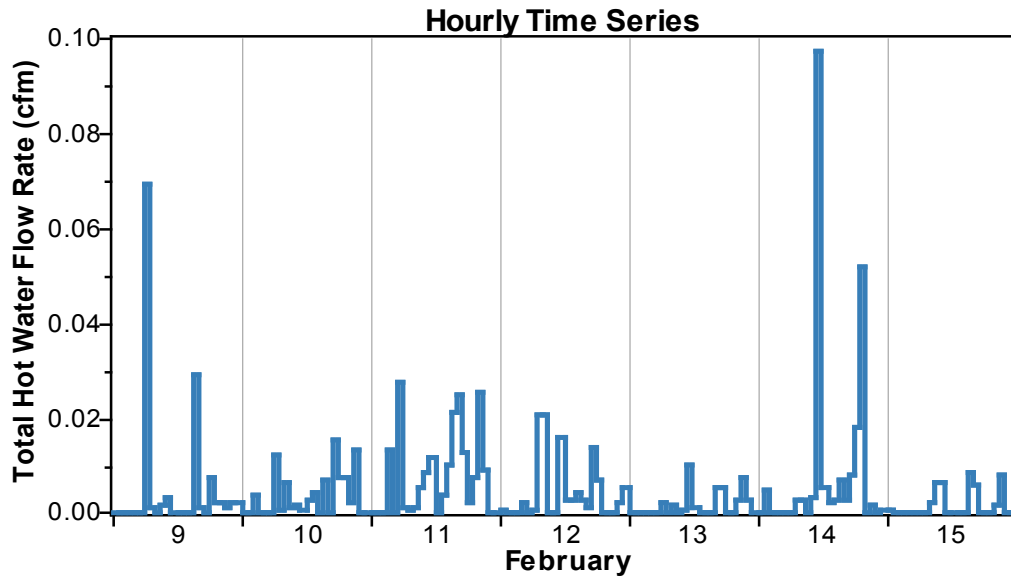
Discrete Draw Events
6 Second Timestep



2) Draw Profile

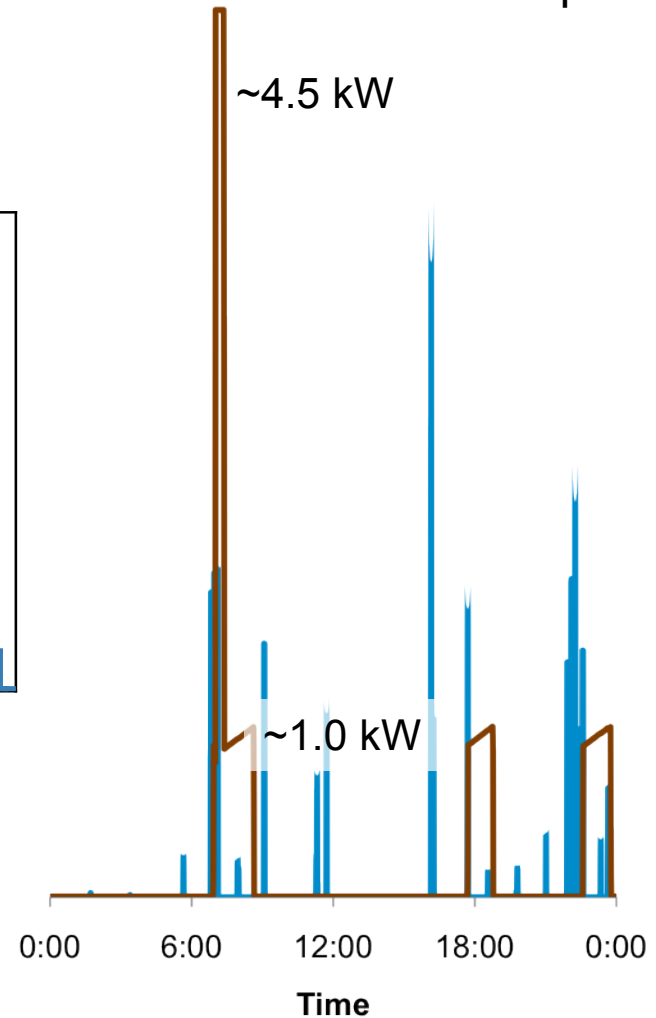
New Model

Hourly Averaged Discrete Draws
Hourly Timestep



Realistic Performance

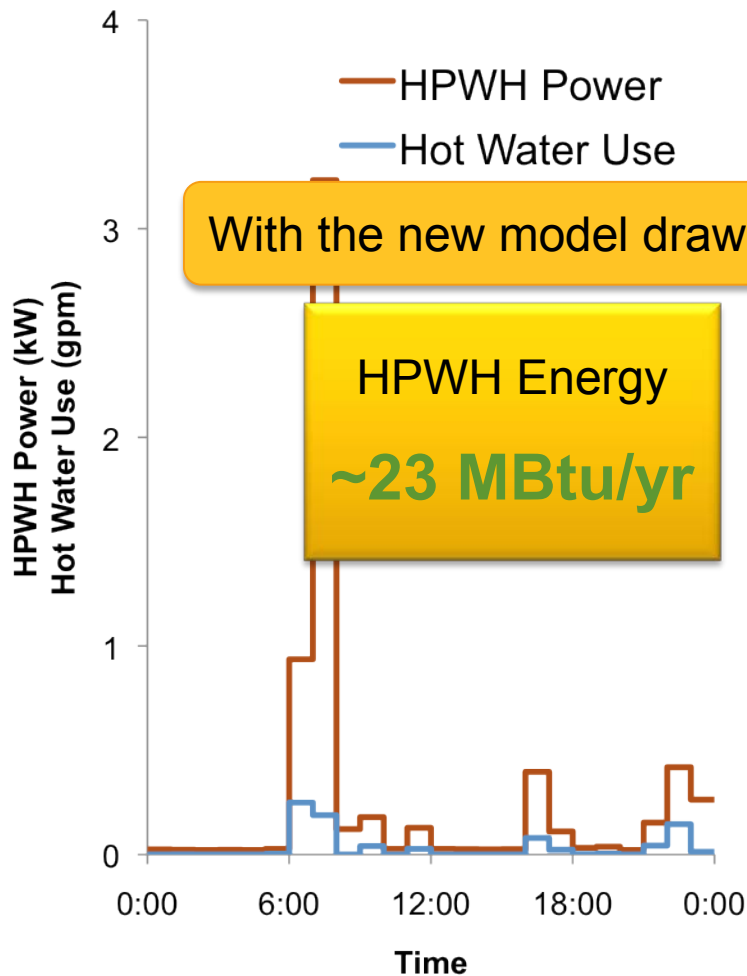
Discrete Draw Events
6 Second Timestep



2) Draw Profile

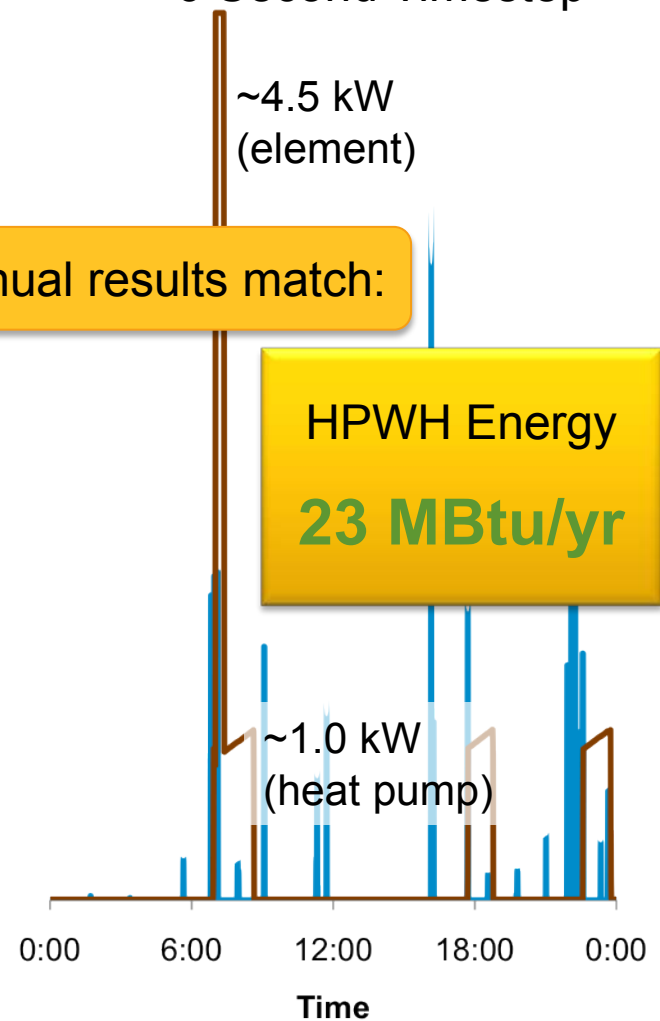
New Model

Hourly Averaged Discrete Draws
Hourly Timestep



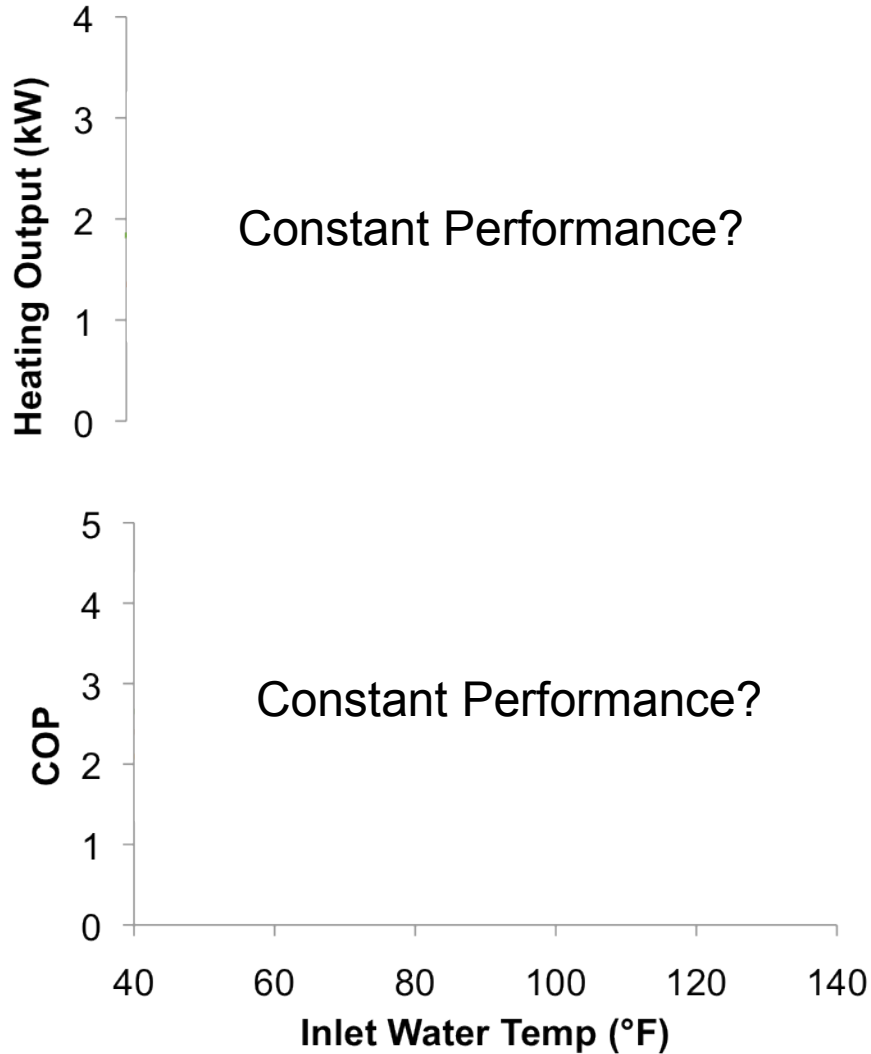
Realistic Performance

Discrete Draw Events
6 Second Timestep



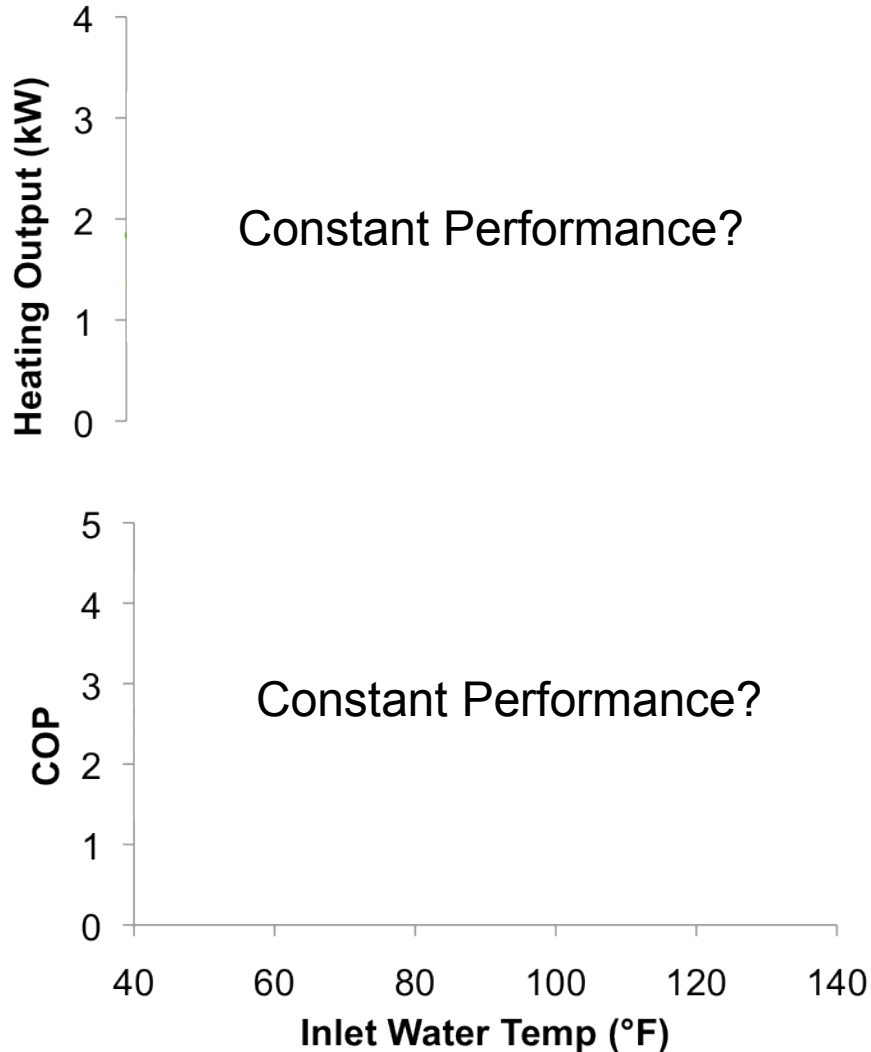
3) Performance Maps

Existing Model

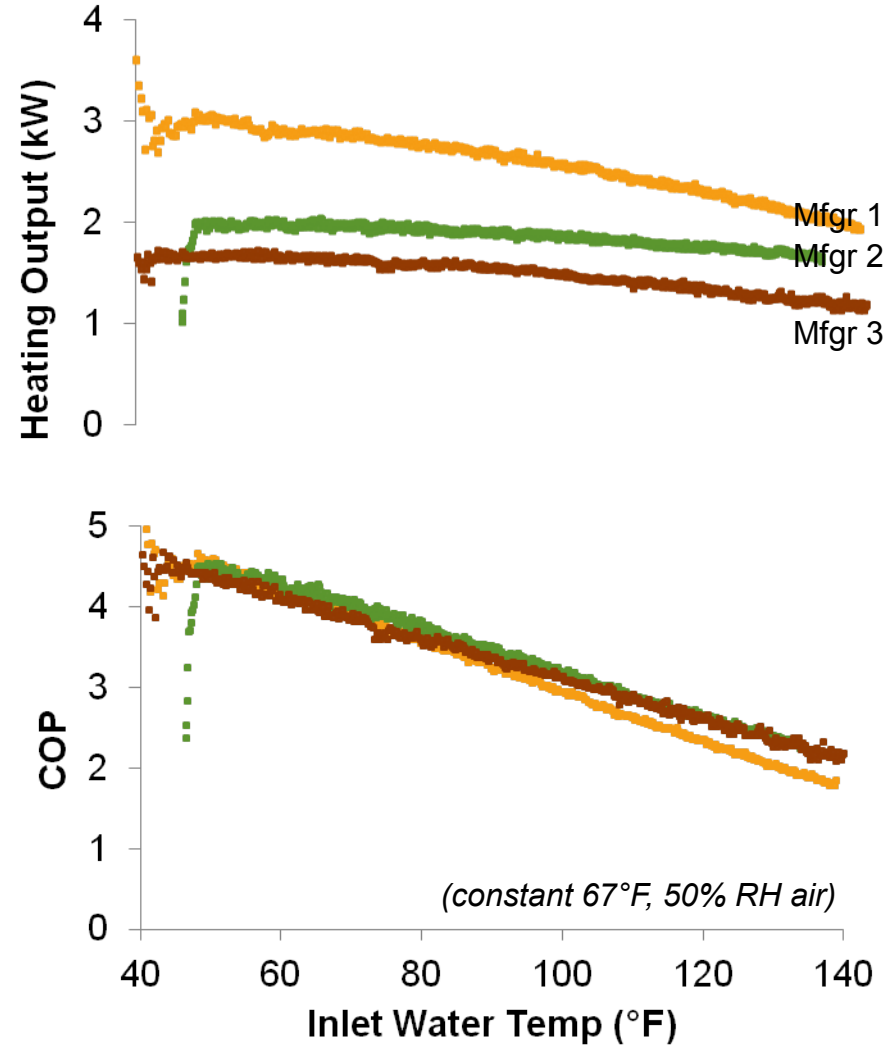


3) Performance Maps

Existing Model



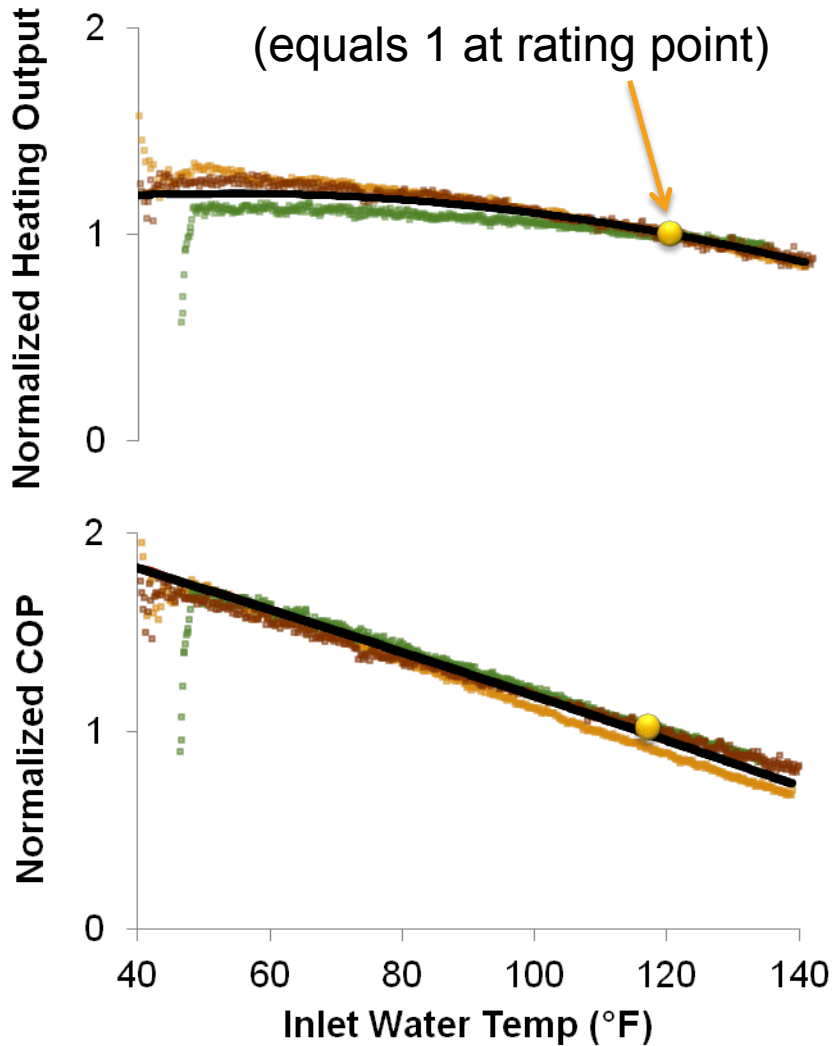
Realistic Performance Manufacturer Specific



3) Performance Maps

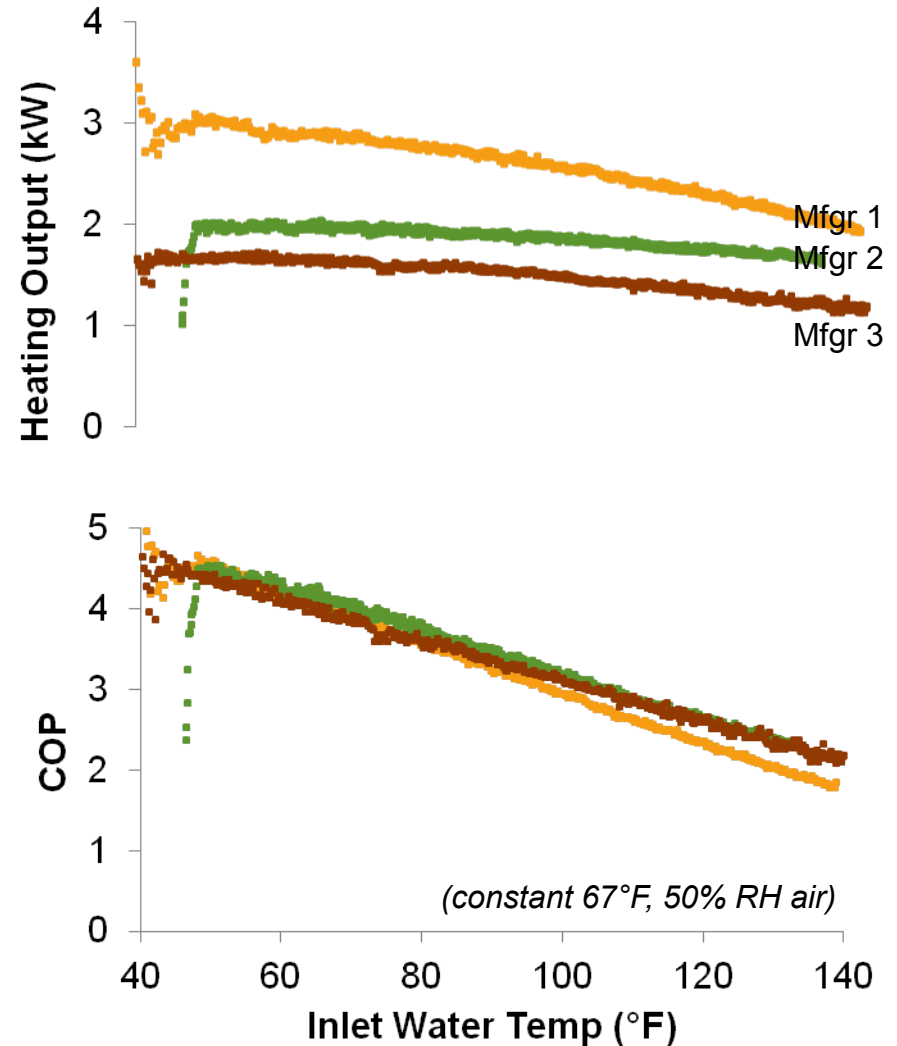
New Model

Generic Normalized Performance Map



Realistic Performance

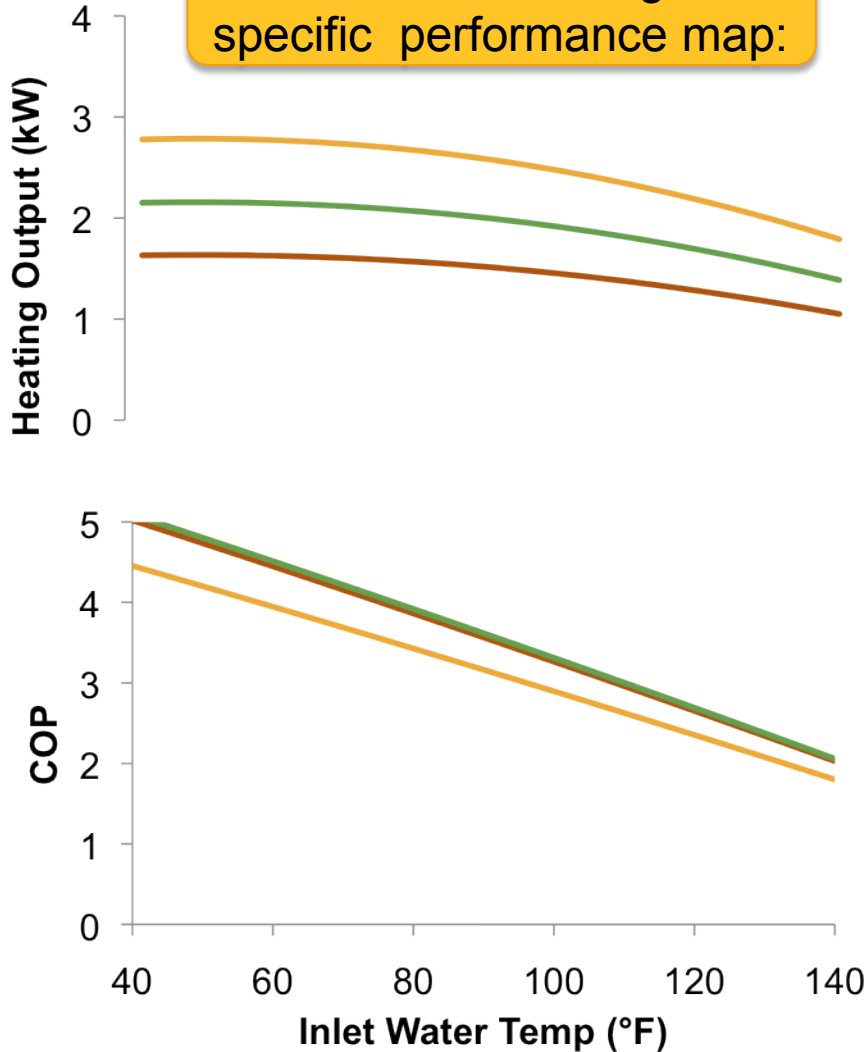
Manufacturer Specific



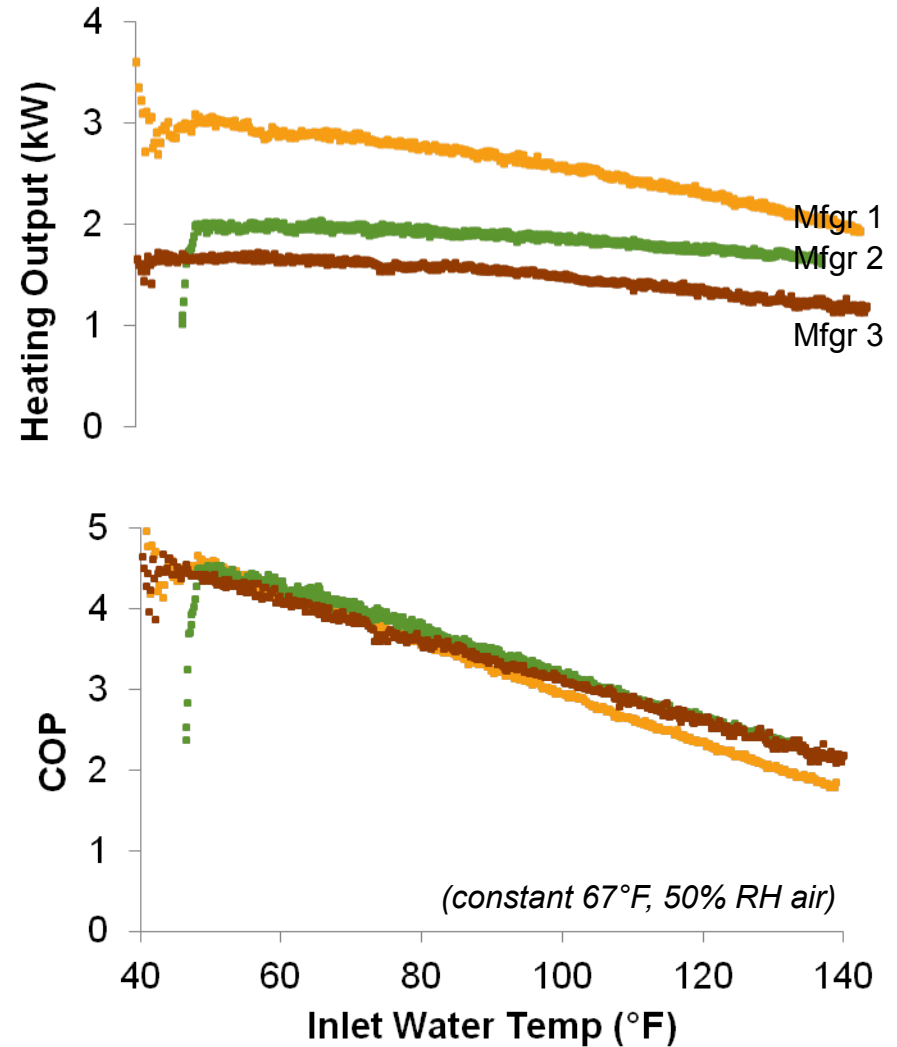
3) Performance Maps

New Model

Use rated values to get specific performance map:



Realistic Performance Manufacturer Specific

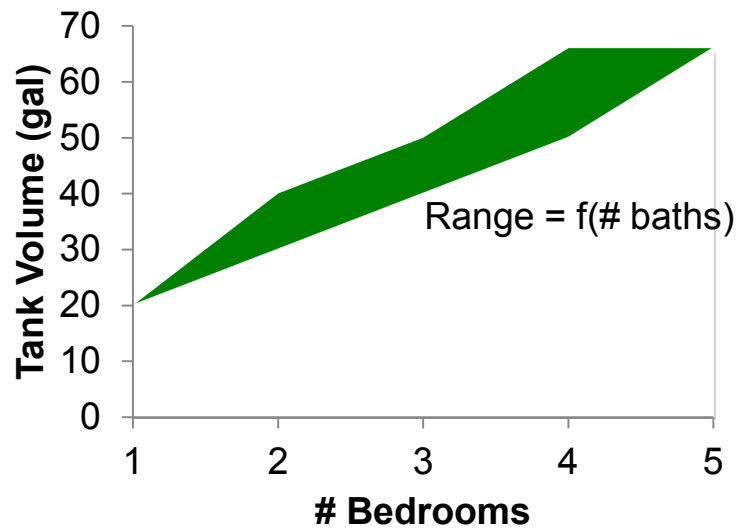


4) HPWH Sizing

Existing Model

- No existing method for HPWH sizing

Conventional Electric WH Sizing:

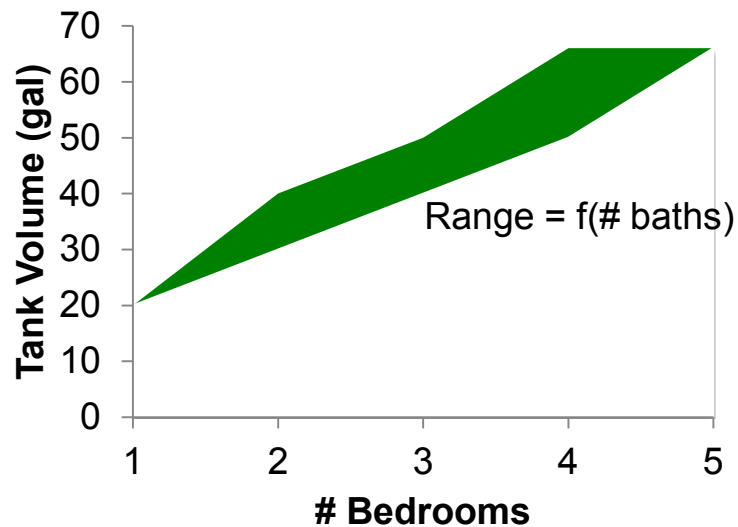


4) HPWH Sizing

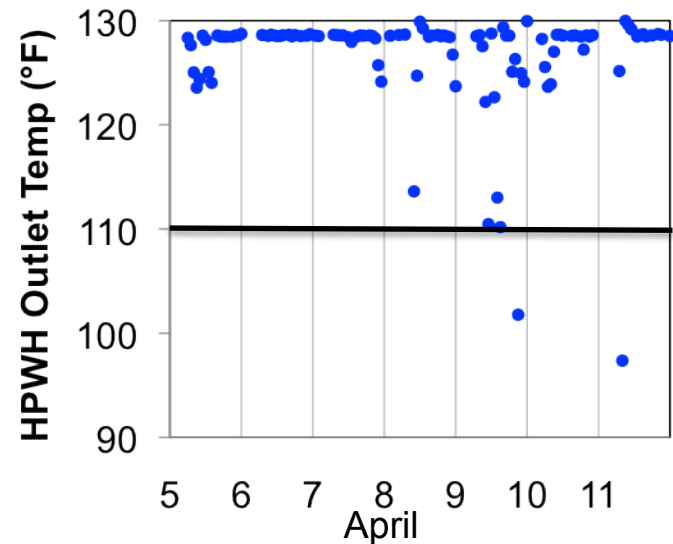
Existing Model

- No existing method for HPWH sizing

Conventional Electric WH Sizing:



Realistic Performance



Reduced capacity to meet DHW demand (vs. conventional WHs)

Function of:

- Climate
- # bedrooms
- Tank Volume
- Setpoint Temperature

4) HPWH Sizing

New Model

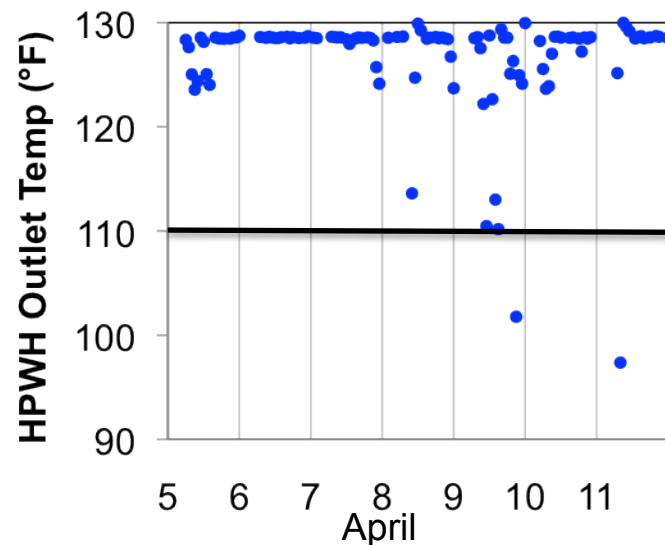
“Percent Unmet Showers”

| Option | Display Variable |
|-------------------------|----------------------------------|
| Water Heater options | % Unmet Shwrs [std, low-flow] |
| 15) HPWH, 50 gal, 130 F | 4.8%, 0.2% |
| 16) HPWH, 50 gal, 140 F | 0.0%, 0.0% |
| 17) HPWH, 80 gal, 130 F | 0.0%, 0.0% |
| 18) HPWH, 80 gal, 140 F | 0.0%, 0.0% |

Percent Unmet Showers

- Function of climate, # bedrooms, tank volume, setpoint
- Estimate of shower time < 110°F
- Helps users select acceptable options
- Sensitive to hot water use patterns so will vary from one set of occupants to the next

Realistic Performance

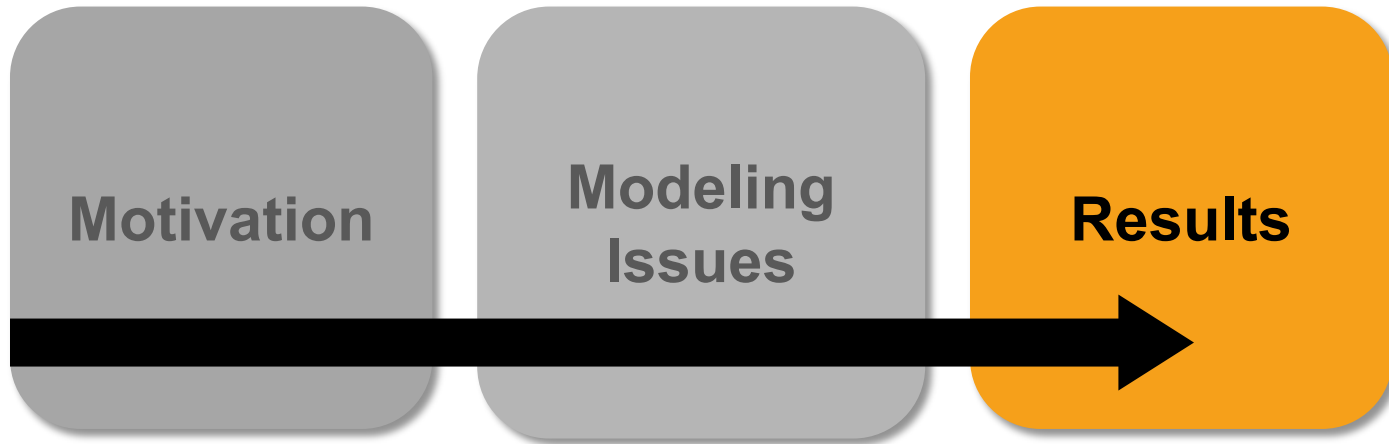


Reduced capacity to meet DHW demand (vs. conventional WHs)

Function of:

- Climate
- # bedrooms
- Tank Volume
- Setpoint Temperature

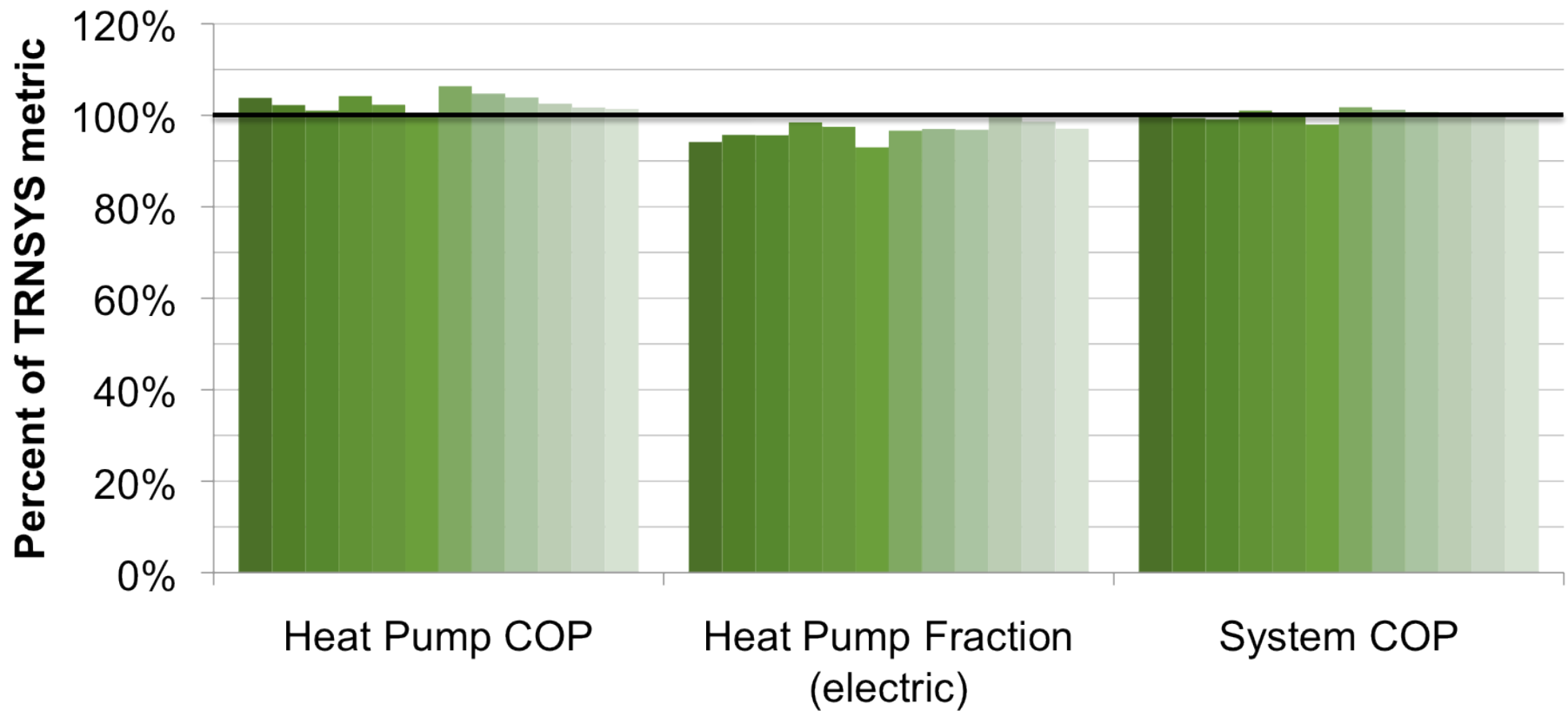
Heat Pump Water Heater Modeling...



Model Calibration

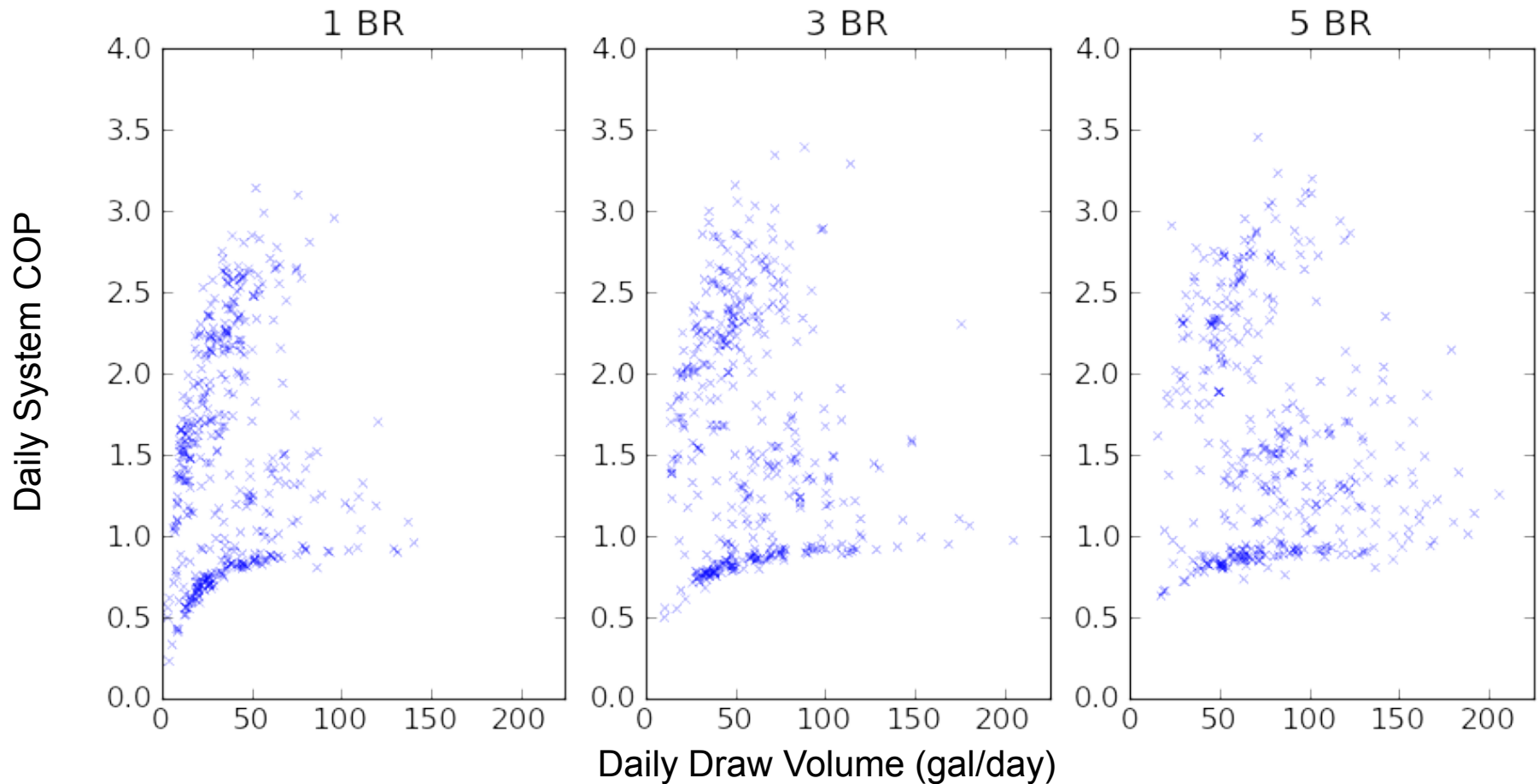
Calibrated to TRNSYS results $\pm 5\%$

12 cases: Chicago, Houston;
1, 3, 5 BR;
50, 80 gal



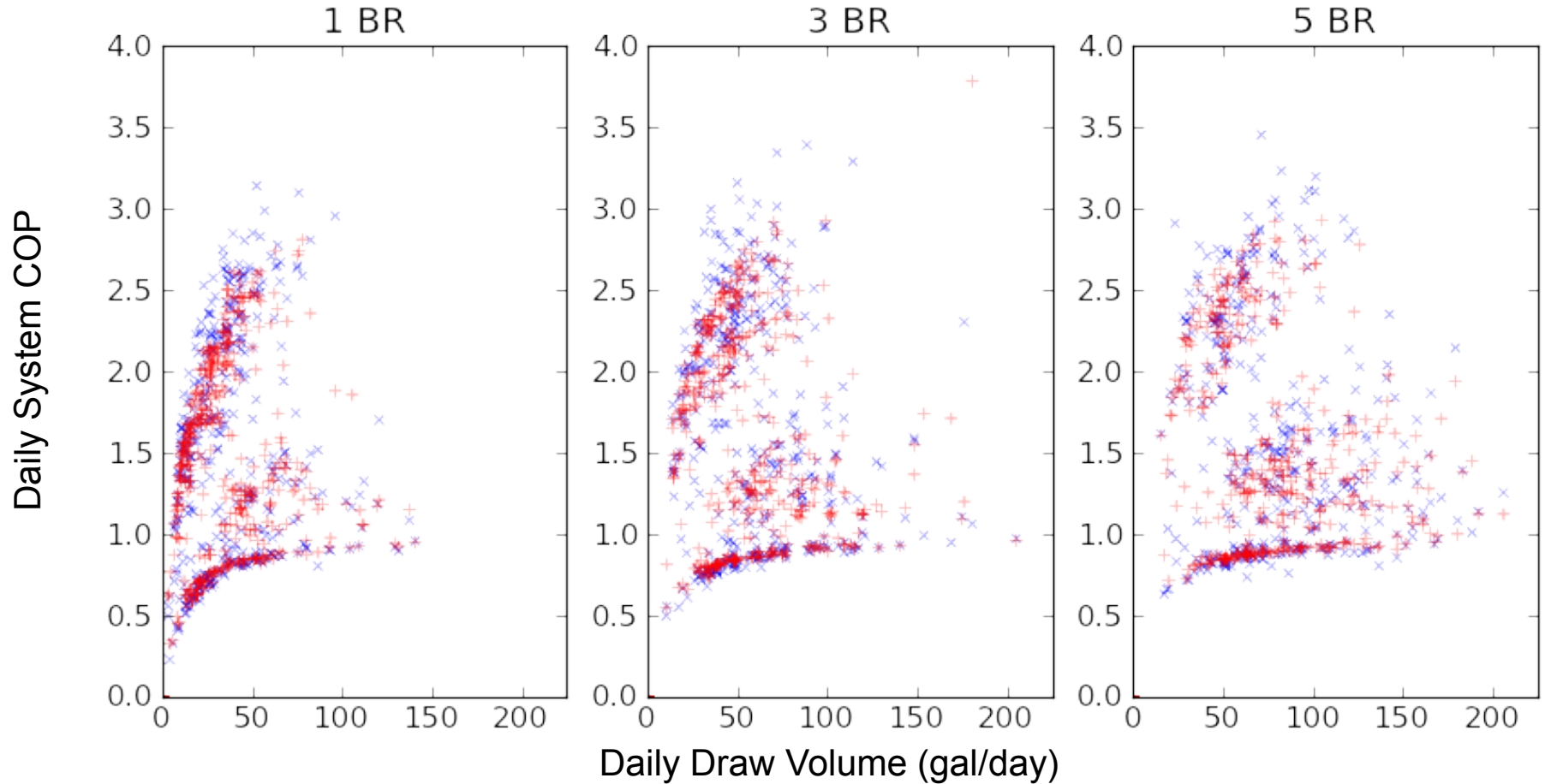
Model Calibration

Chicago, 50 gal
Unfinished Basement



Model Calibration

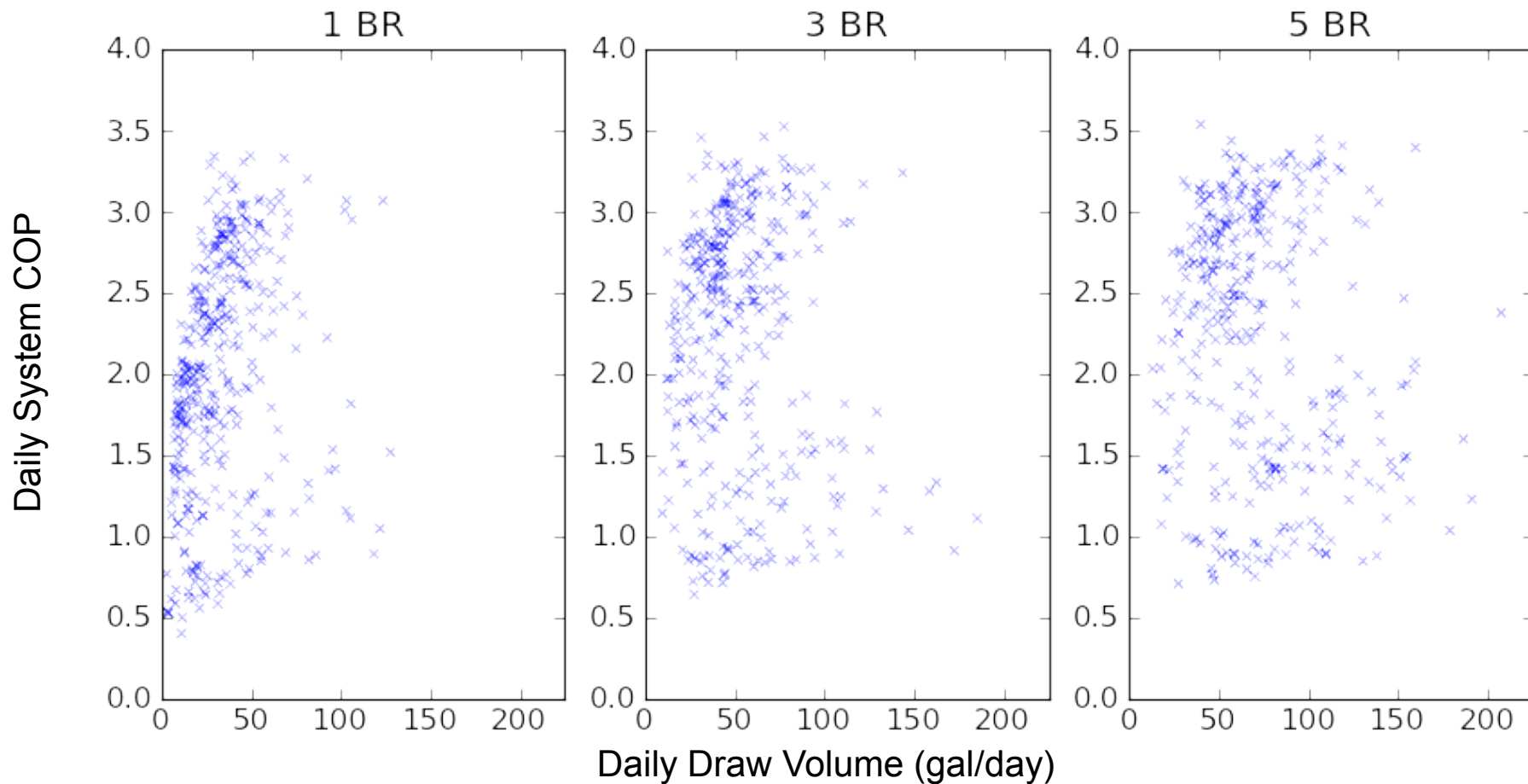
Chicago, 50 gal
Unfinished Basement



Model Calibration

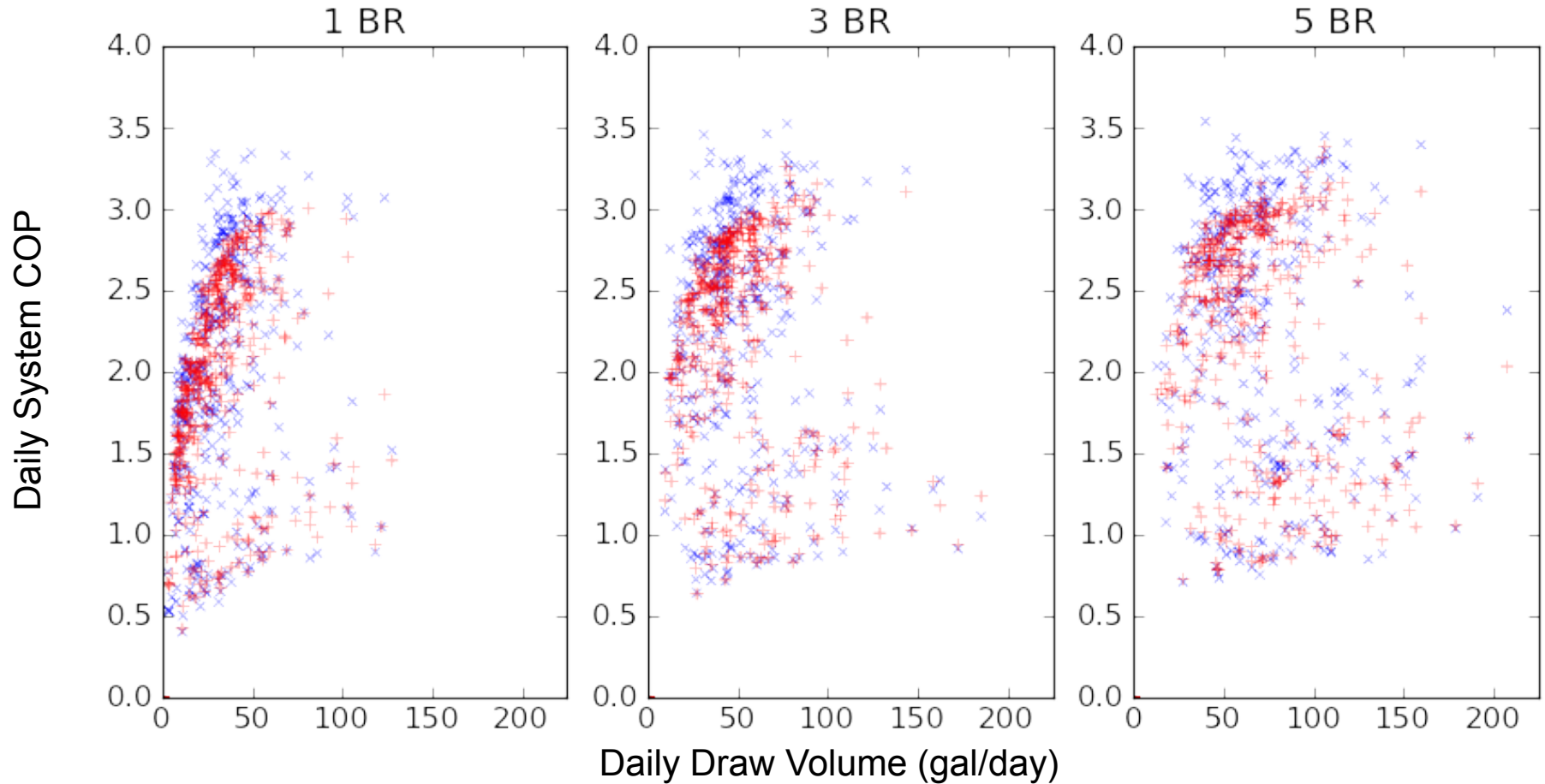
Houston, 50 gal
Garage

× TRNSYS



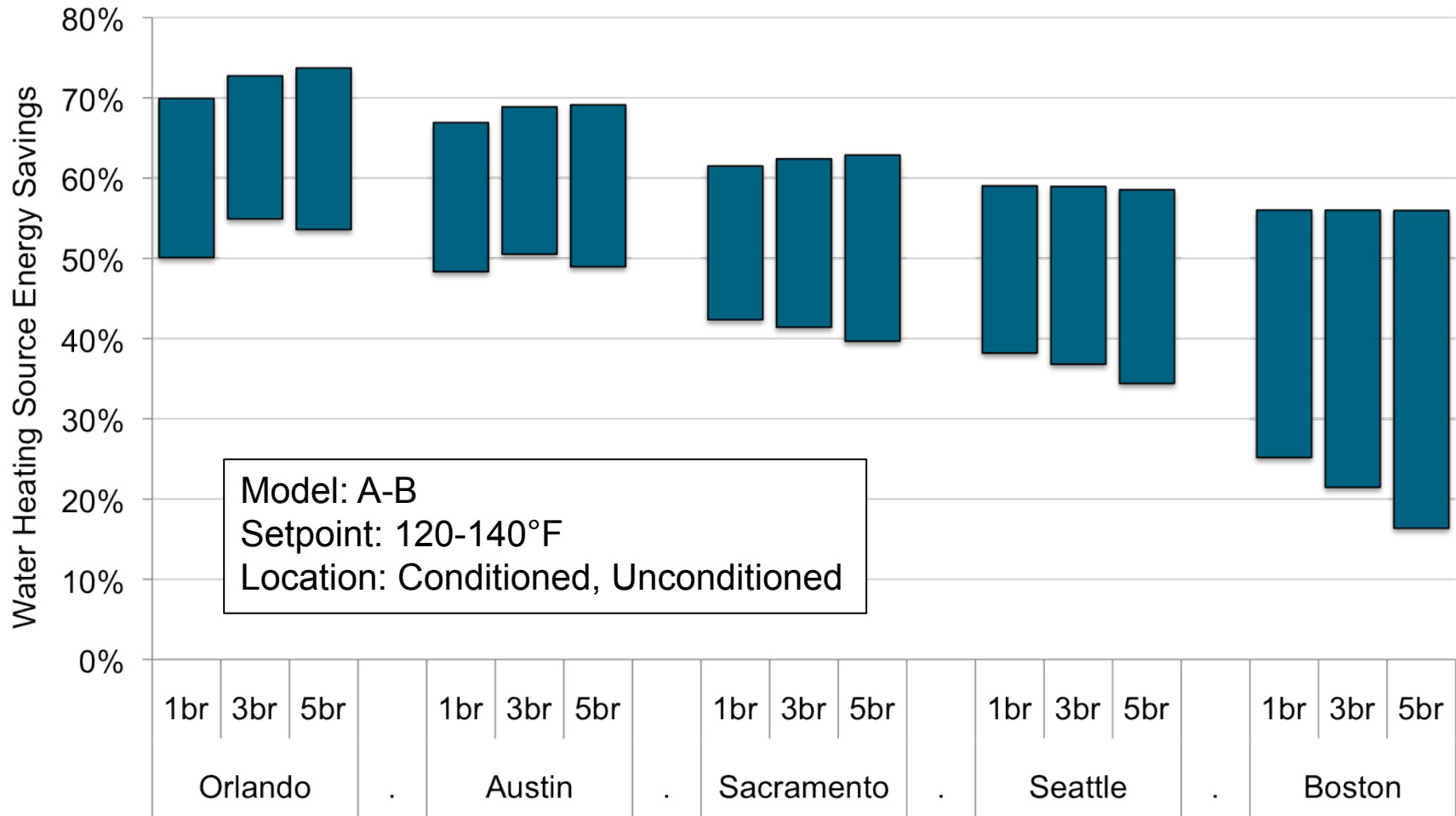
Model Calibration

Houston, 50 gal
Garage



BEoptE+ Modeling Results

HPWH vs. Electric Resistance With Cooling Impact (Air-Source HP)



BEoptE+ Optimization Results

Space Conditioning = Air-Source Heat Pump

(state average utility rates,
Nat'l avg Source/Site ratio)

| | Maximum Energy Savings | | | Lowest Life-Cycle Cost | | |
|------------|------------------------|------|------|------------------------|---------|---------|
| | 1 BR | 3 BR | 5 BR | 1 BR | 3 BR | 5 BR |
| Orlando | HP | HP | HP | Elec | Elec/HP | Elec/HP |
| Austin | HP | HP | HP | Elec/HP | Elec/HP | Elec/HP |
| Sacramento | HP | HP | HP | Elec/HP | Elec/HP | Elec/HP |
| Seattle | HP | HP | HP | Elec | Elec | Elec |
| Boston | HP | HP | HP | Elec/HP | Elec/HP | Elec/HP |

(“HPWH” includes various models/volumes, locations, and setpoints)

Space Conditioning = Gas Furnace

| | Maximum Energy Savings | | | Lowest Life-Cycle Cost | | |
|------------|------------------------|--------|--------|------------------------|------|------|
| | 1 BR | 3 BR | 5 BR | 1 BR | 3 BR | 5 BR |
| Orlando | Gas/HP | Gas/HP | Gas/HP | Gas | Gas | Gas |
| Austin | Gas/HP | Gas/HP | Gas/HP | Gas | Gas | Gas |
| Sacramento | Gas | Gas | Gas | Gas | Gas | Gas |
| Seattle | Gas | Gas | Gas | Gas | Gas | Gas |
| Boston | Gas | Gas | Gas | Gas | Gas | Gas |

(“Gas” includes: standard, premium, tankless, or tankless condensing.)

Conclusions

HPWH model for EnergyPlus/BEopt

- Market Benefits:
 - Integrated with existing tool
 - Fast
 - Flexible
 - Accurate

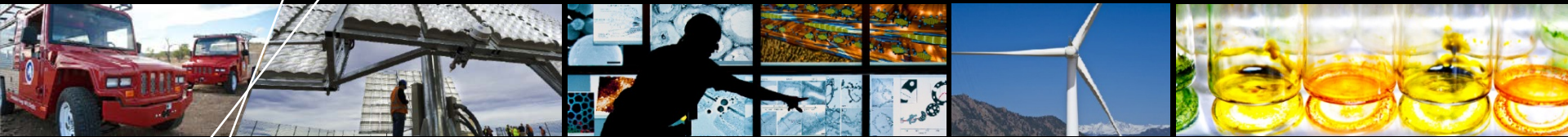
Conclusions

Lessons Learned

- Rated EF for HPWHs not good indicator of performance
- Don't use "smooth" BA HSP draw profile for HPWH testing
- Control logic matters
- Sizing HPWHs for adequate HW delivery: many factors

Remaining Issues

- Better draw profiles for HPWH modeling/testing
- Performance in enclosed spaces



For more information:

Laboratory Testing Report:

Sparn, B.; Hudon, K.; Christensen, D. (2011). *Laboratory Performance Evaluation of Residential Integrated Heat Pump Water Heaters*. 77 pp.; NREL Report No. TP-5500-52635.

TRNSYS Modeling Results:

Maguire, J. (2011). *A Parametric Analysis of Residential Water Heaters*. Master's Thesis. Boulder, CO: University of Colorado.