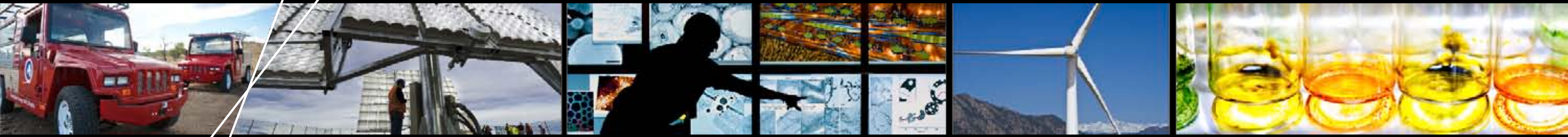
Heat Pump Water Heater Modeling
in EnergyPlus



Building America Residential Energy Efficiency Stakeholder Meeting

Eric Wilson
Craig Christensen

March 1, 2012

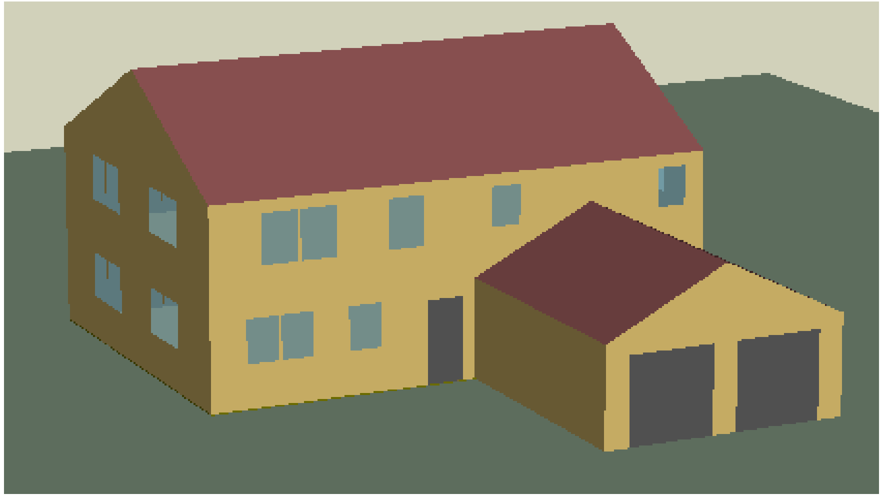
Heat Pump Water Heater Modeling…

Motivation

Modeling Issues

Results

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



What have we achieved so far?

Field Monitoring

14 x

Laboratory Evaluations

Closing the Gap

Field Monitoring

14 x

CARB

Laboratory Evaluations

NREL PIX # 18675, 18671, 18667, 18676, 18919

TRNSYS 17

6 sec timestep

EnergyPlus

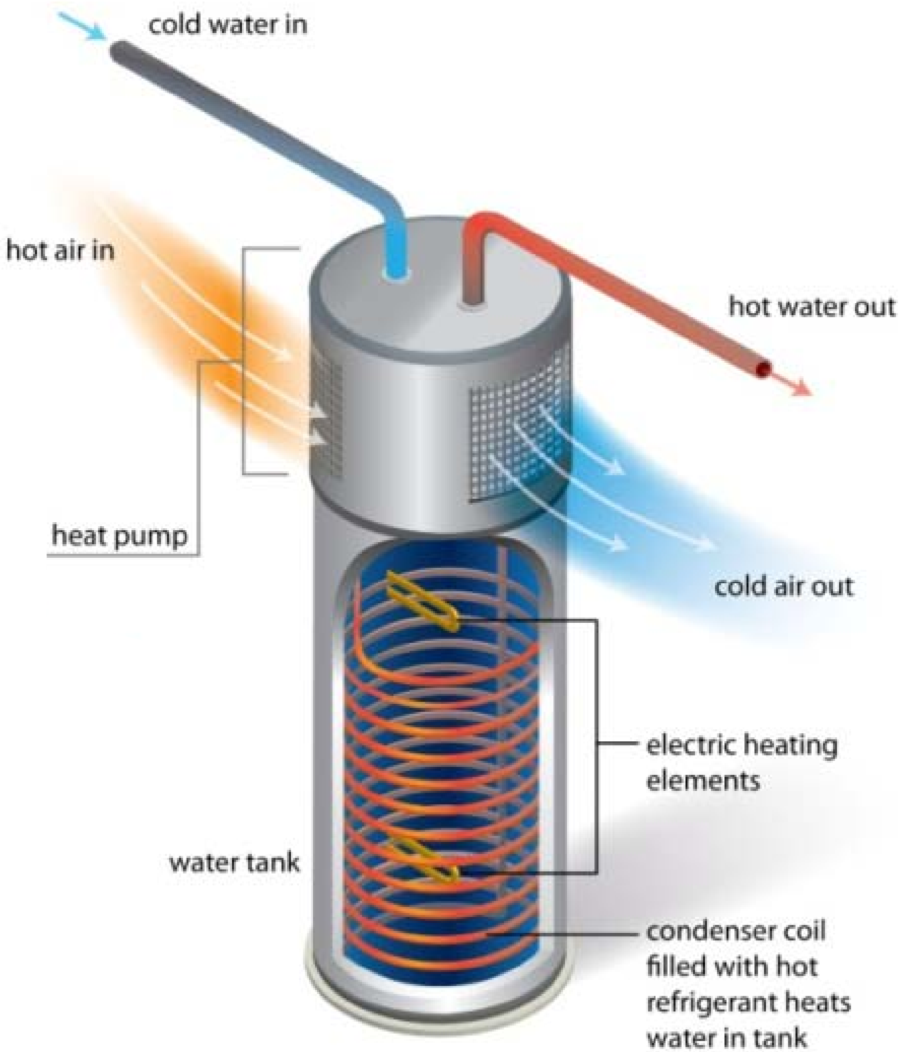
BEopt
Building Energy Optimization
with Hour-by-Hour Simulations
Version: 1.2

NREL
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado
www.nrel.gov

hourly timestep

Why is modeling important**?**

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

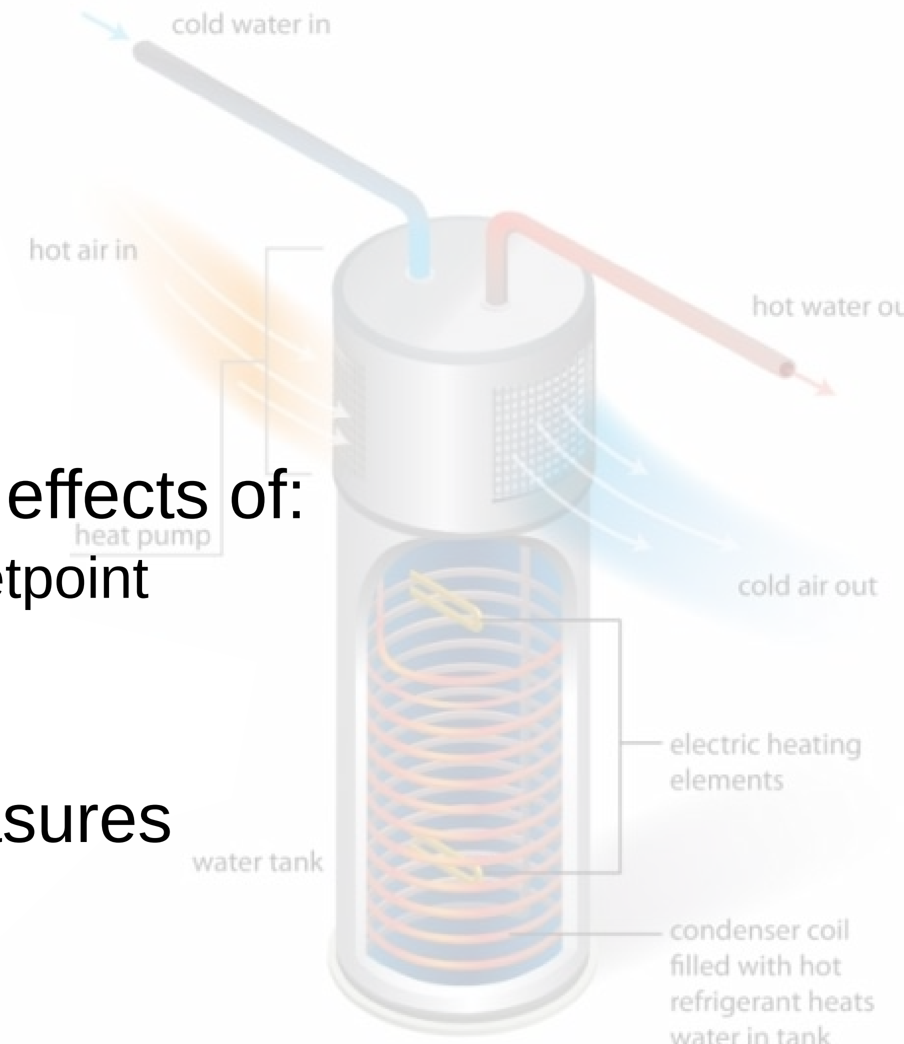


Modeling Goals

- 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…

Motivation

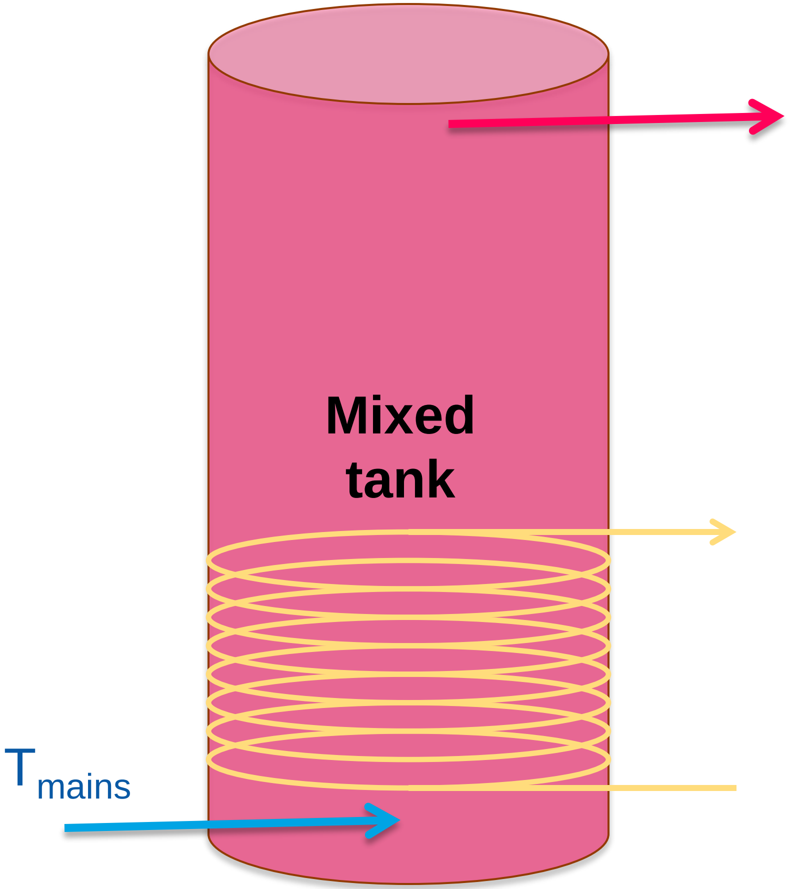
Modeling Issues

Results

1) Tank Stratification
2) Draw Profile
3) Performance Maps
4) Sizing

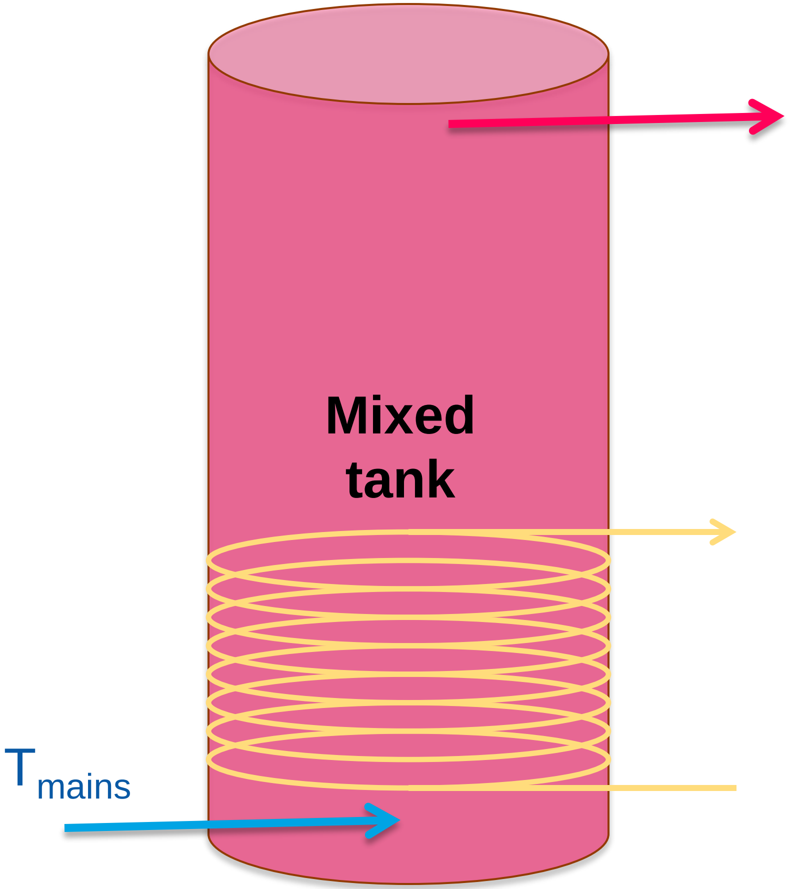
1) Tank Stratification

Existing Model
EnergyPlus HPWH mixed tank

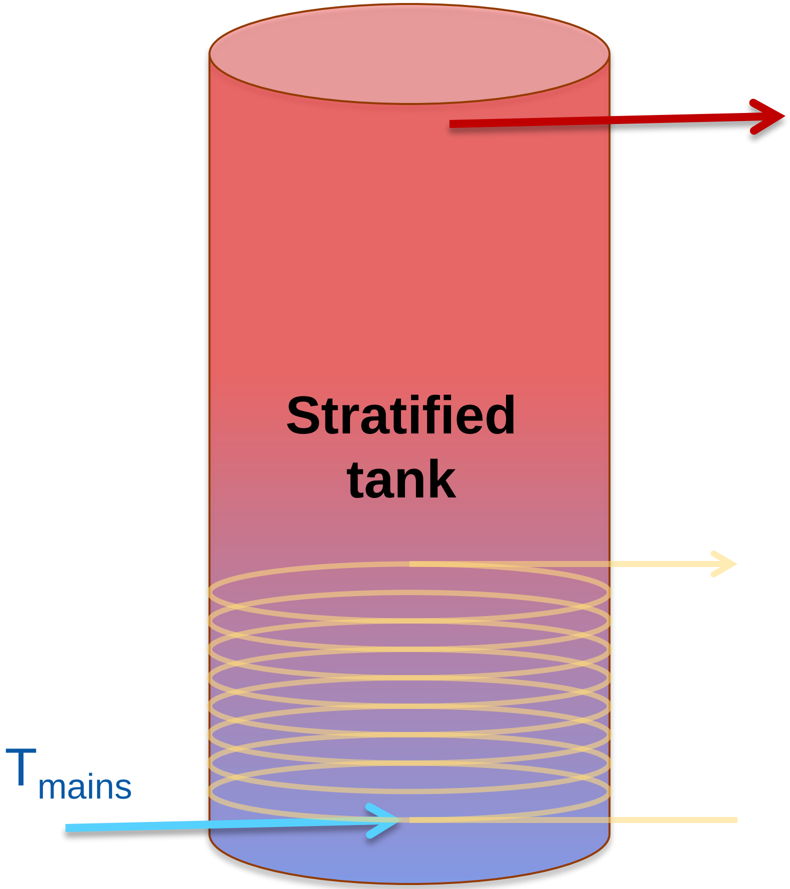


1) Tank Stratification

Existing Model
EnergyPlus HPWH mixed tank



Realistic Performance
Stratified tank



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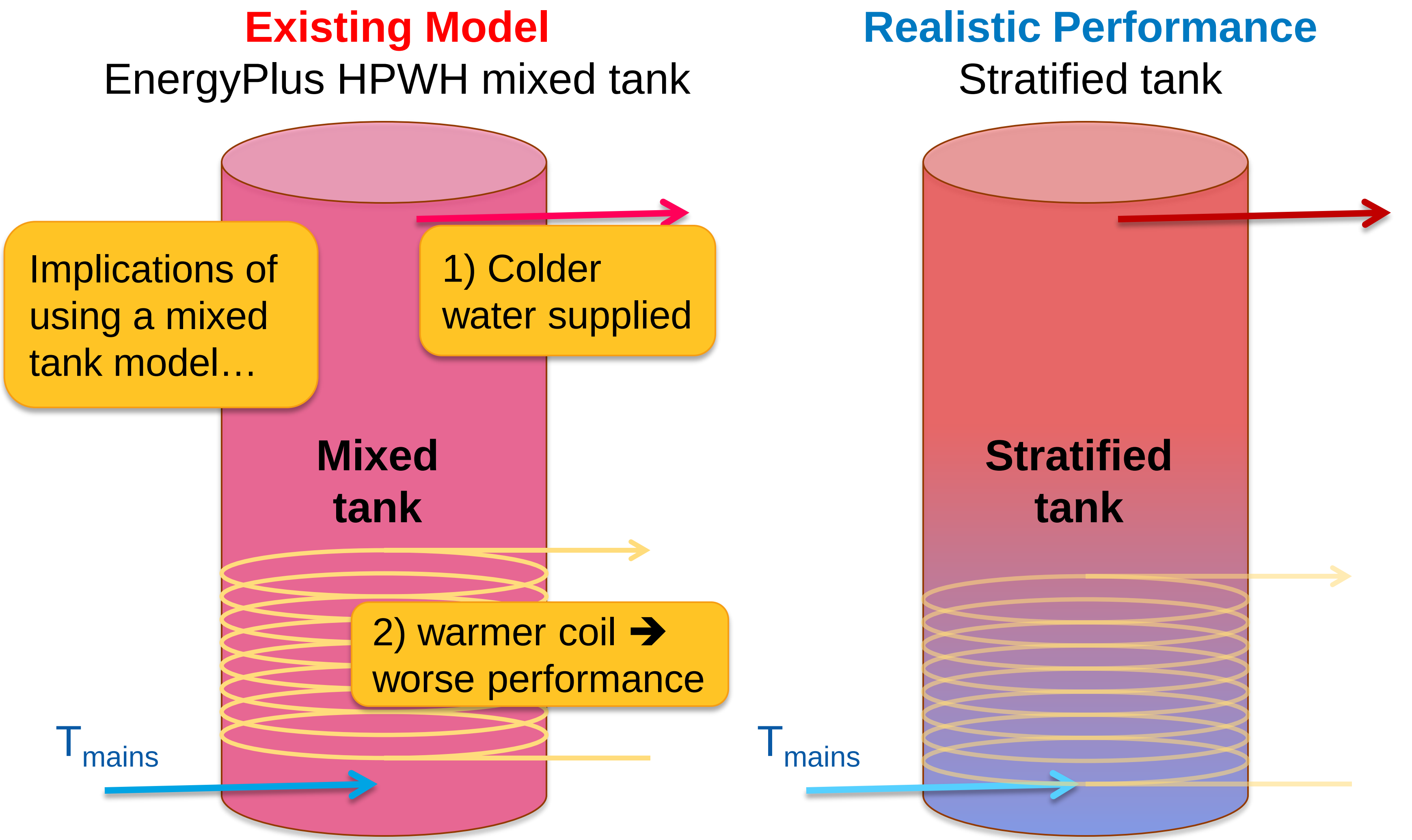
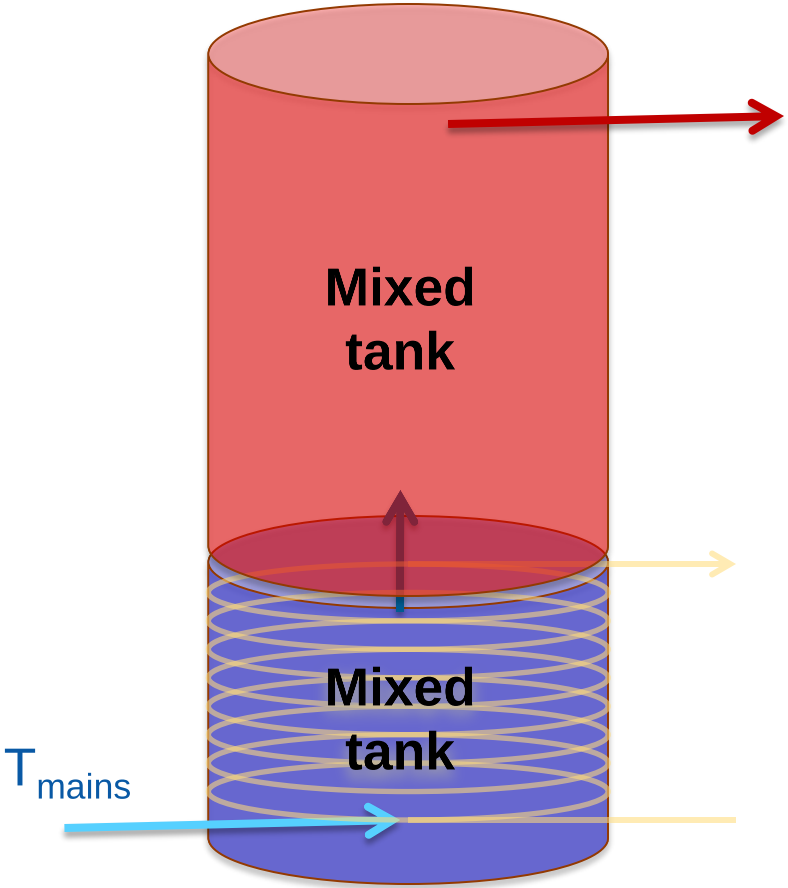
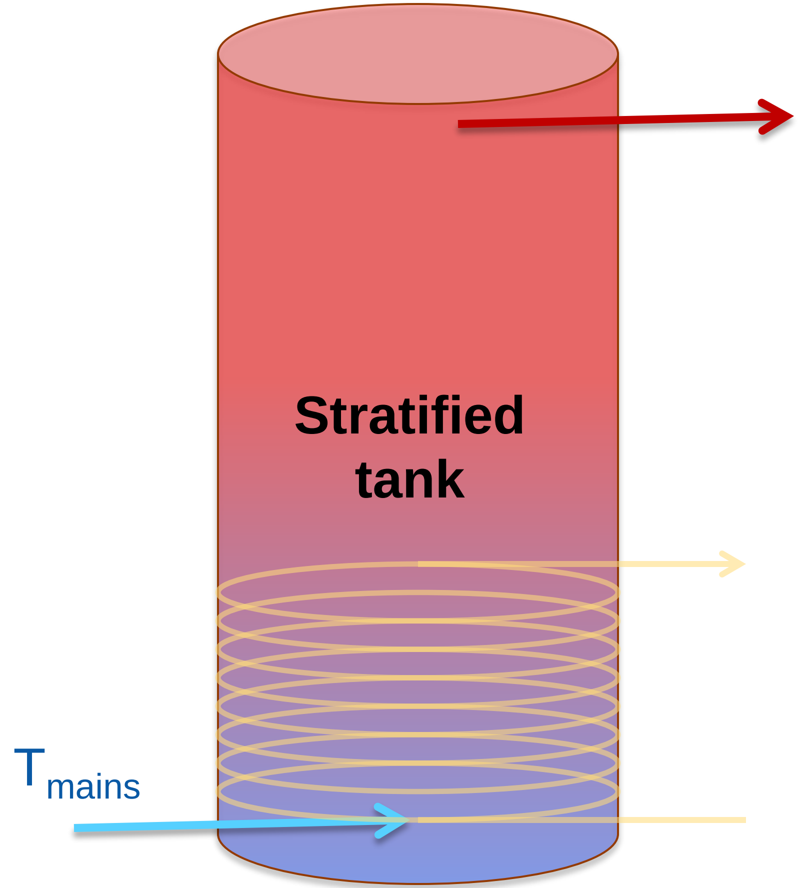


1) Tank Stratification

New Model
Two tanks in Series

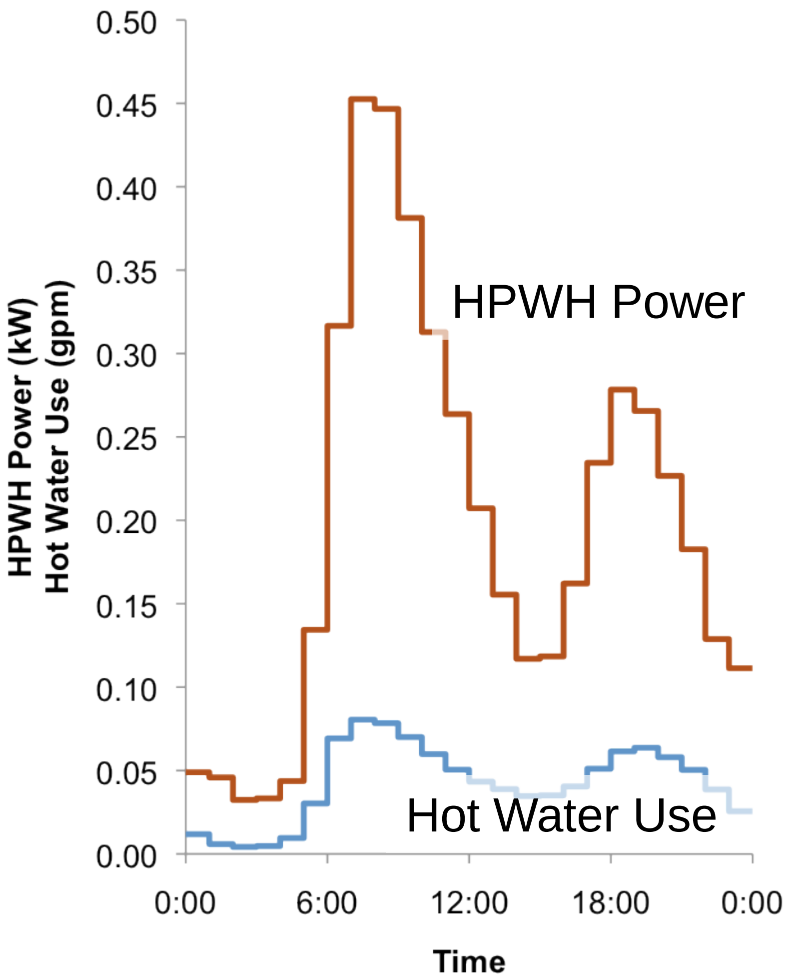


Realistic Performance
Stratified tank



2) Draw Profile

Existing Model
Smooth Draw Profile
Hourly Timestep

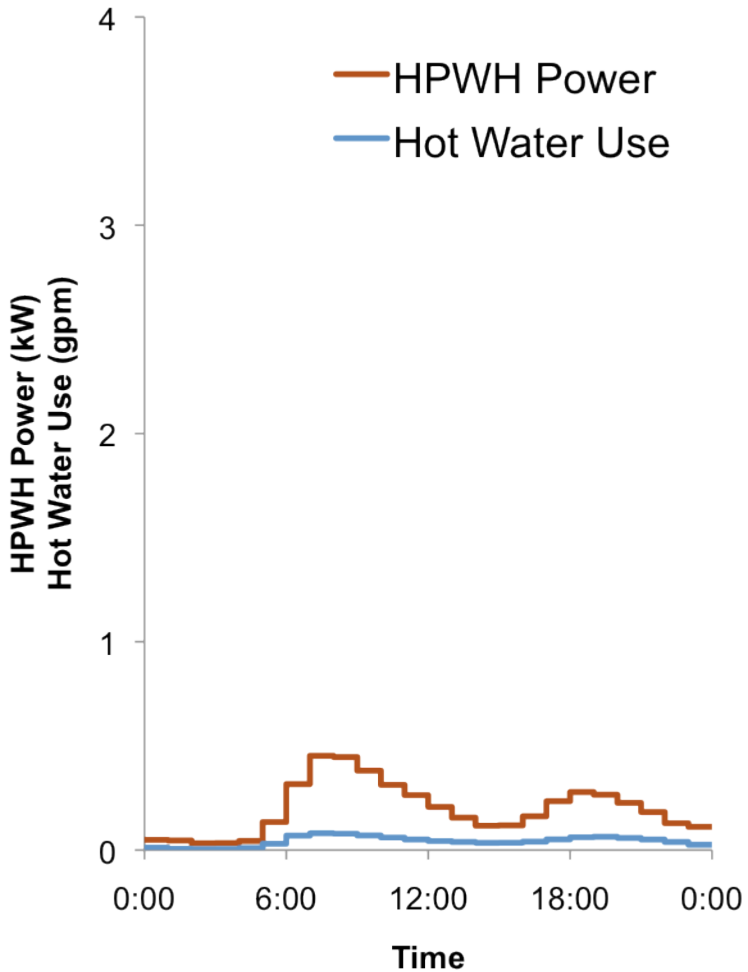


2) Draw Profile

Existing Model

Smooth Draw Profile

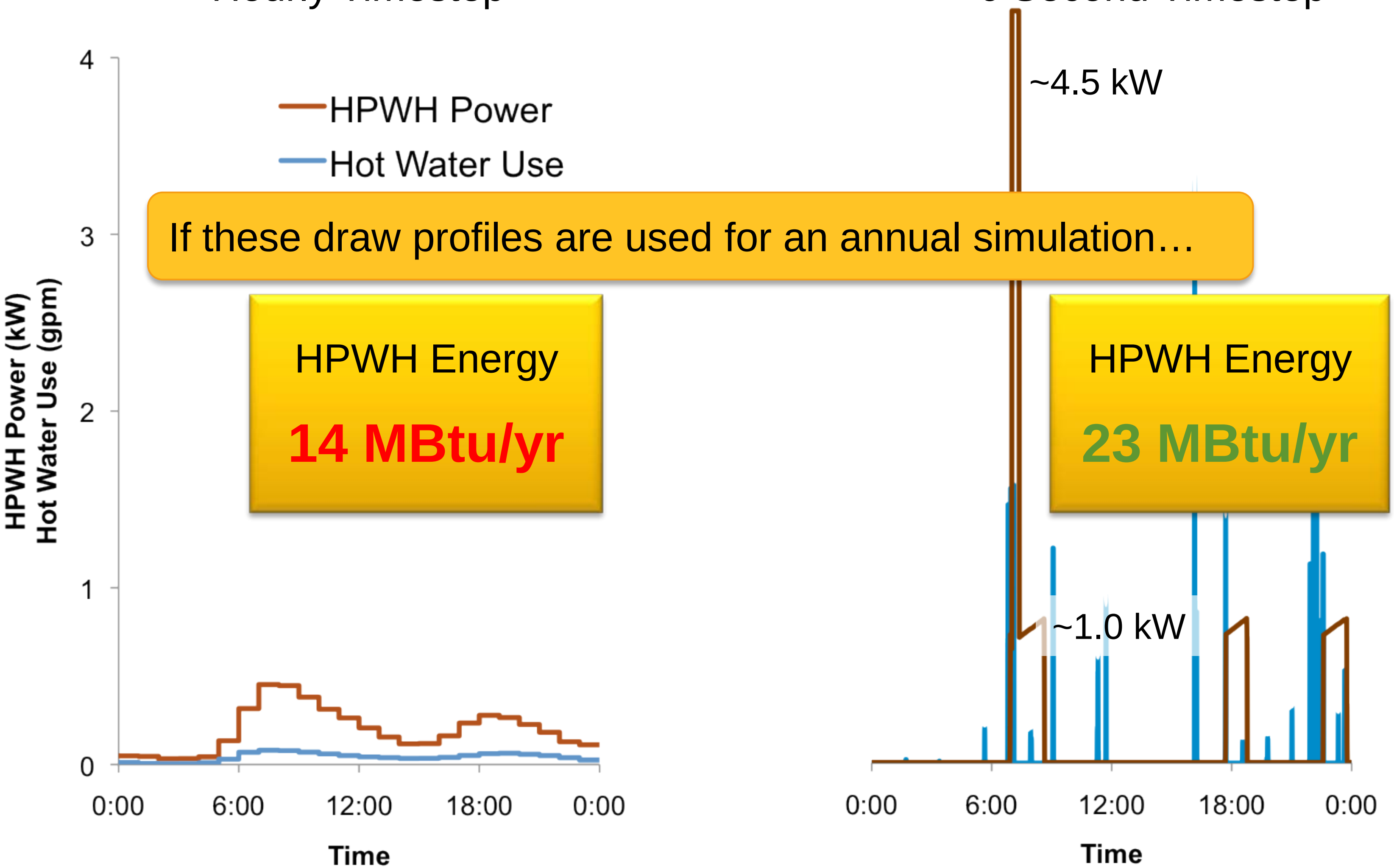
Hourly Timestep



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…

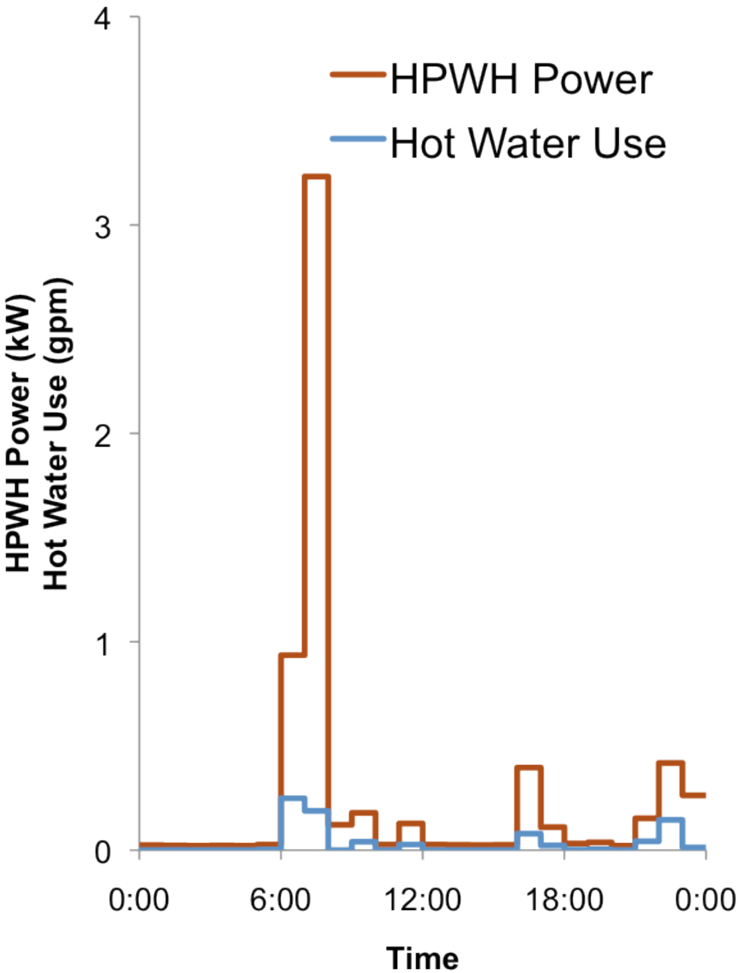
HPWH Energy
14 MBtu/yr

HPWH Energy
23 MBtu/yr

2) Draw Profile

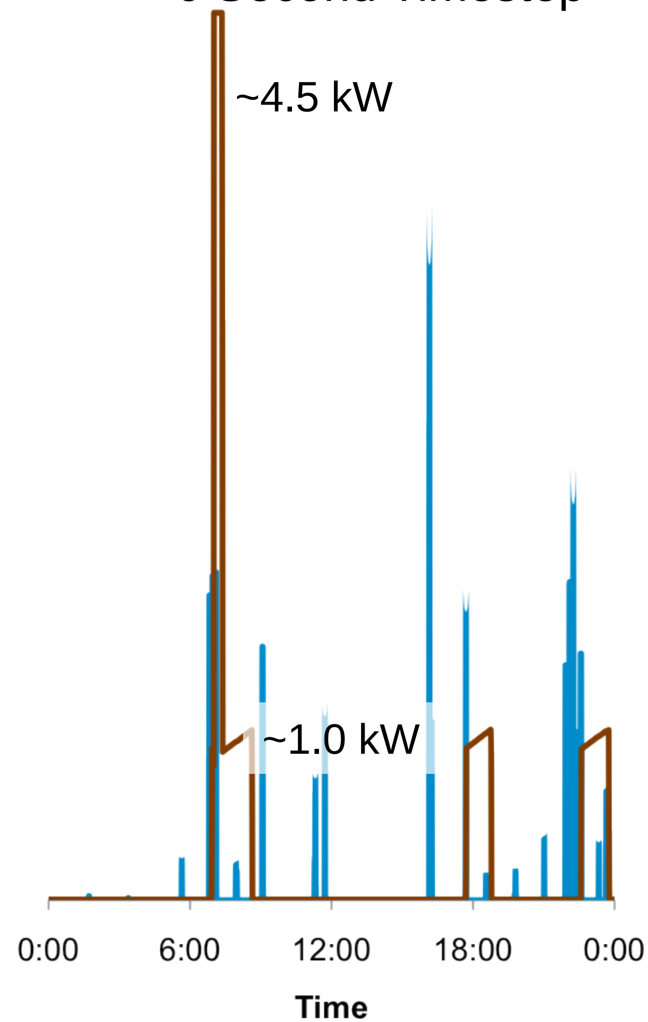
New Model

Hourly Averaged Discrete Draws
Hourly Timestep



Realistic Performance

Discrete Draw Events
6 Second Timestep



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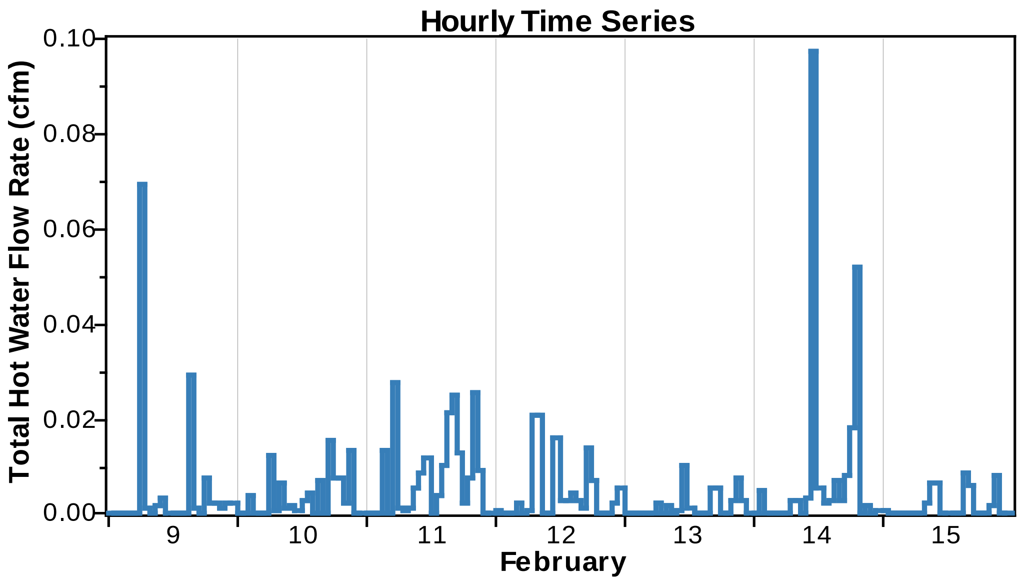
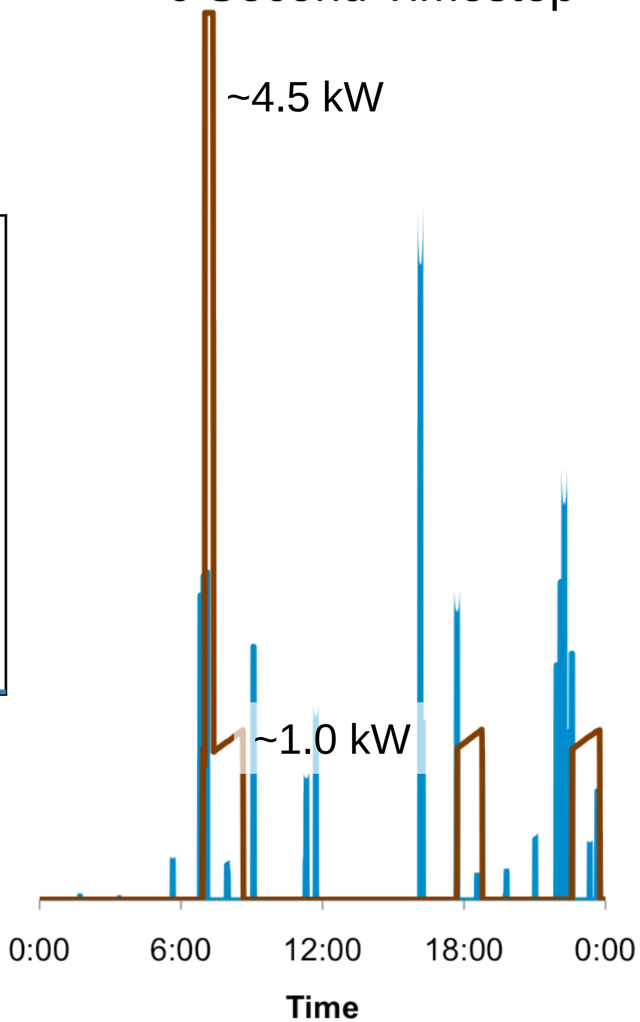
Hourly Timestep



Realistic Performance

Discrete Draw Events
6 Second Timestep

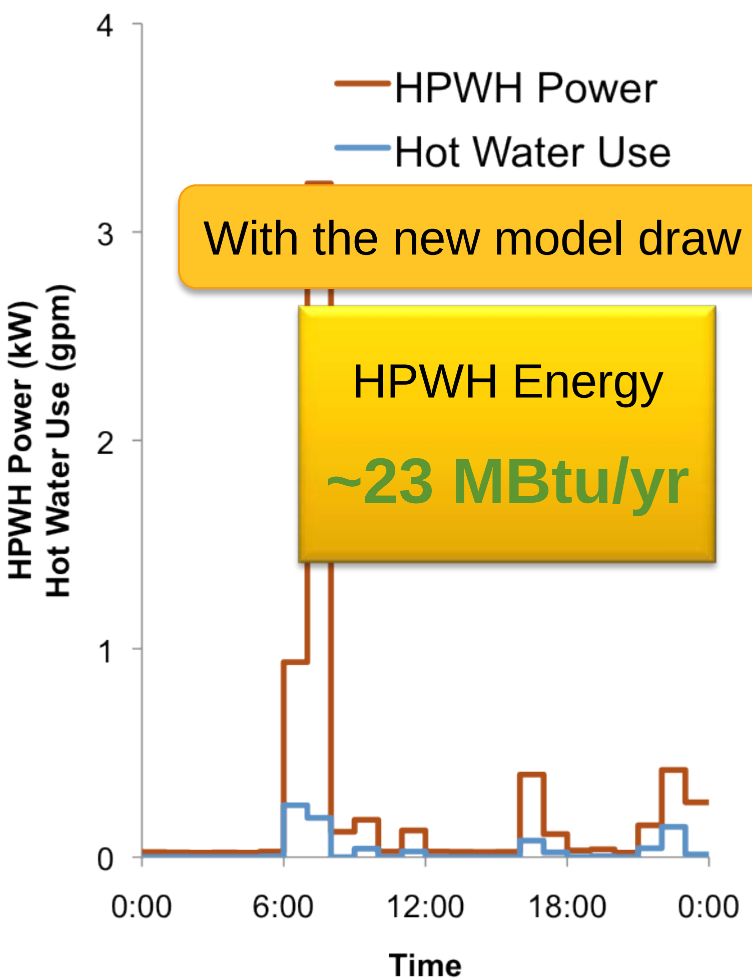


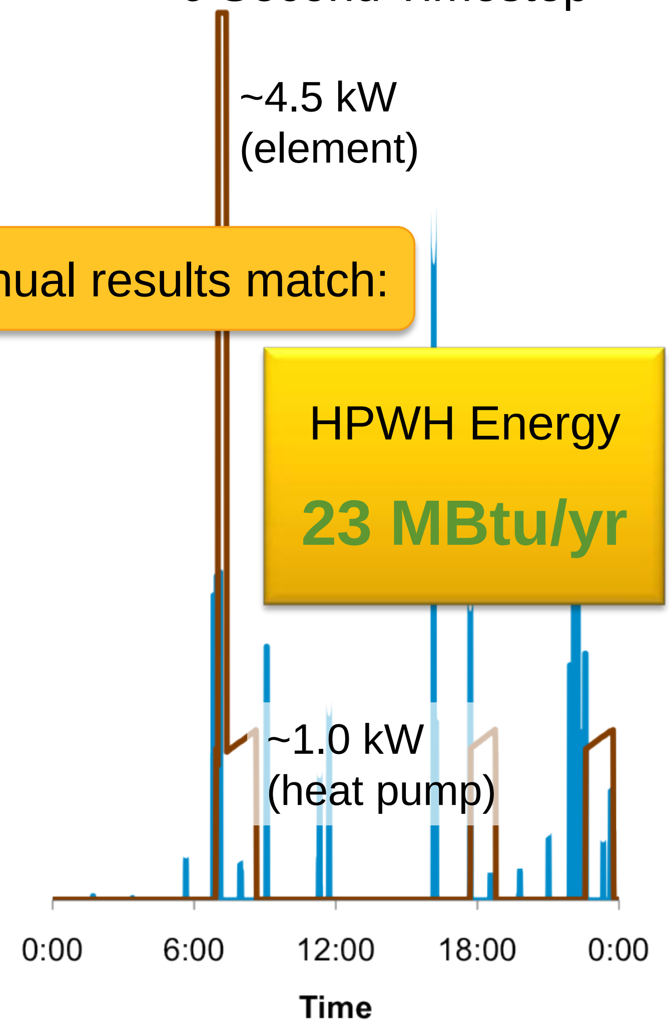
2) Draw Profile

New Model
Hourly Averaged Discrete Draws
Hourly Timestep

Realistic Performance
Discrete Draw Events
6 Second Timestep

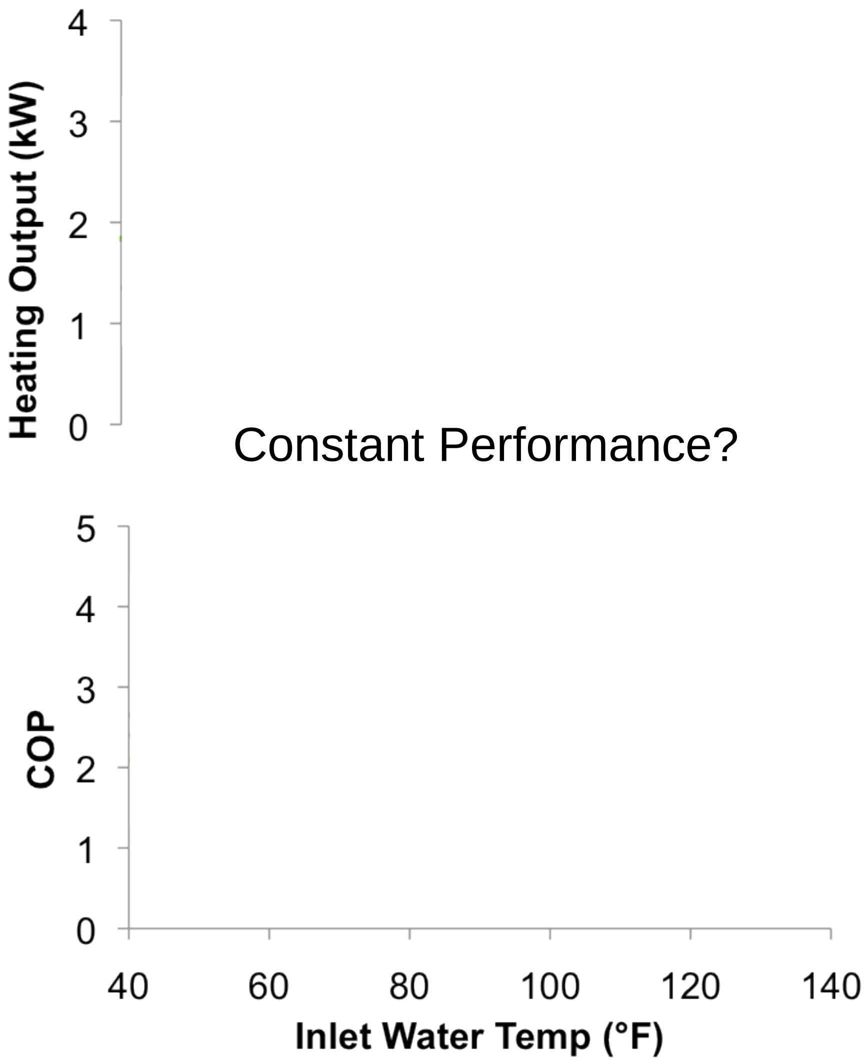
With the new model draw profile, annual results match:





3) Performance Maps

Existing Model



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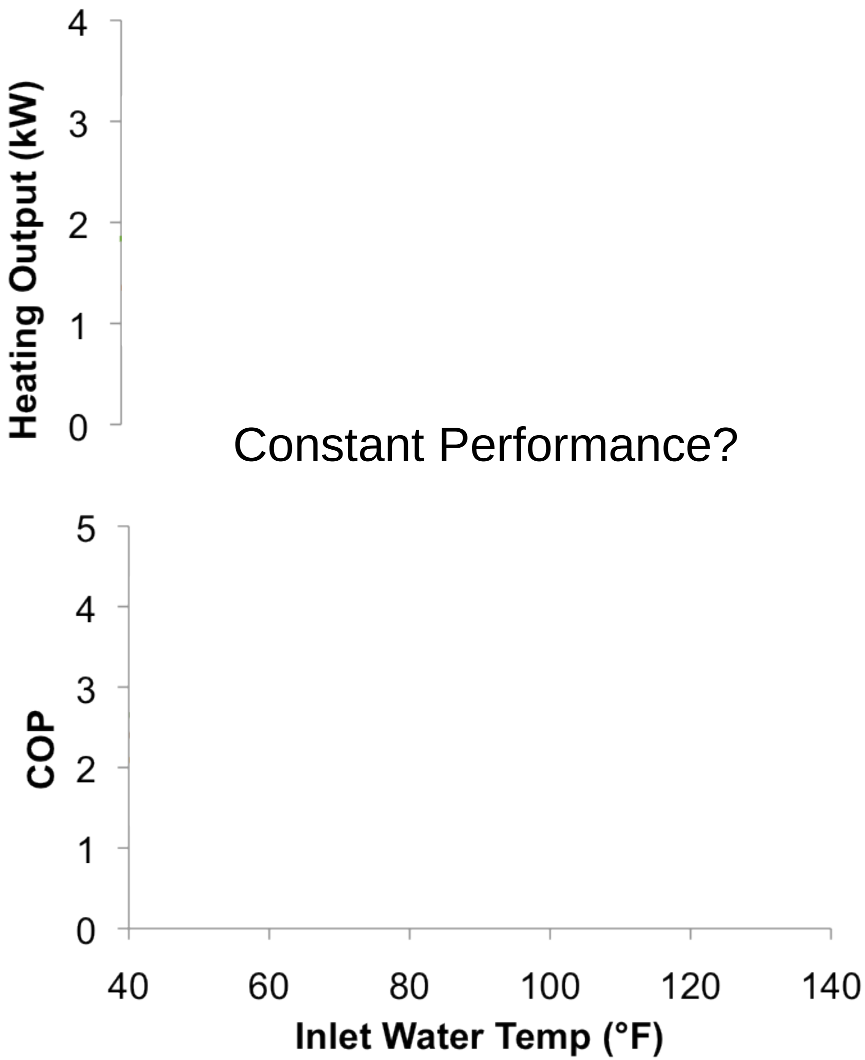
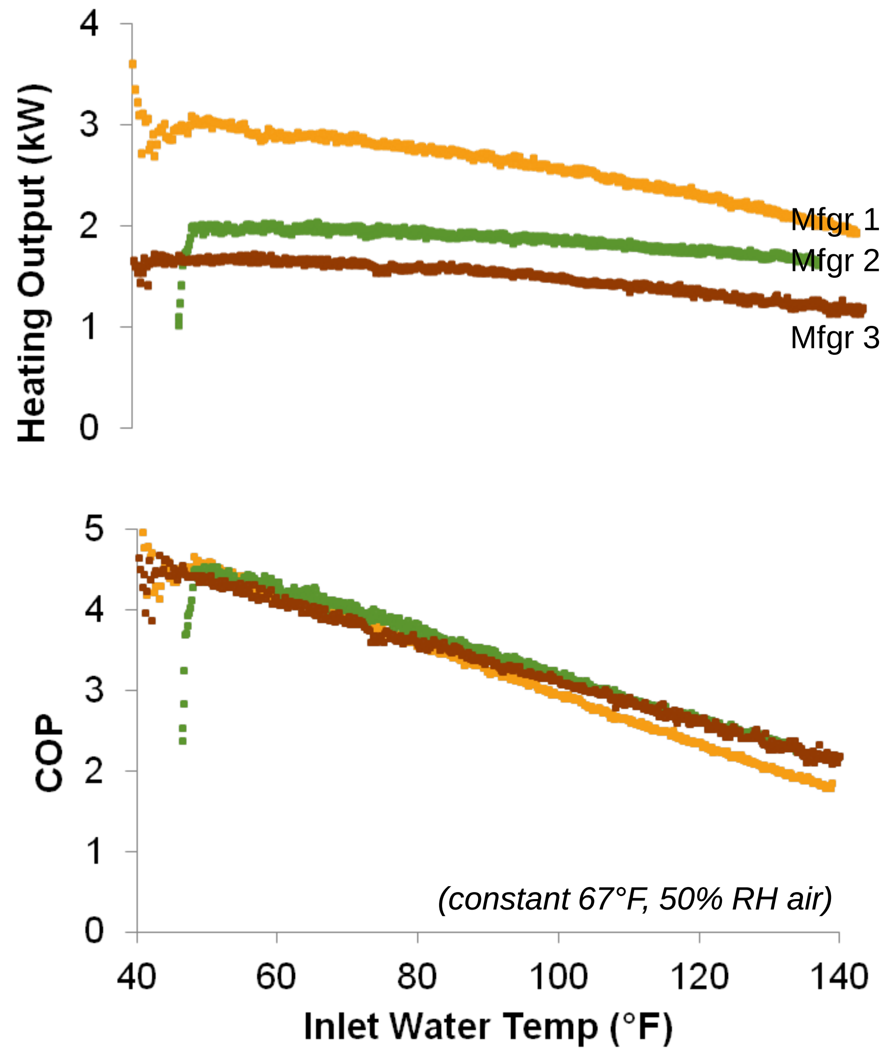


Realistic Performance

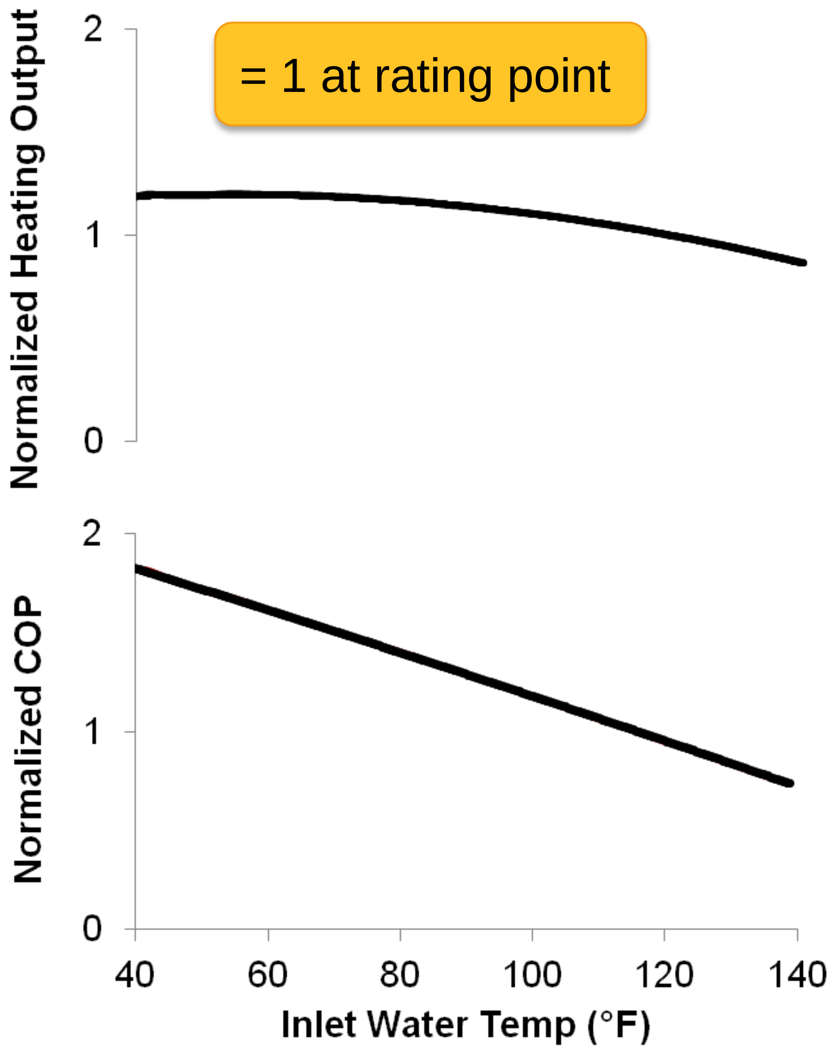
Manufacturer Specific



3) Performance Maps

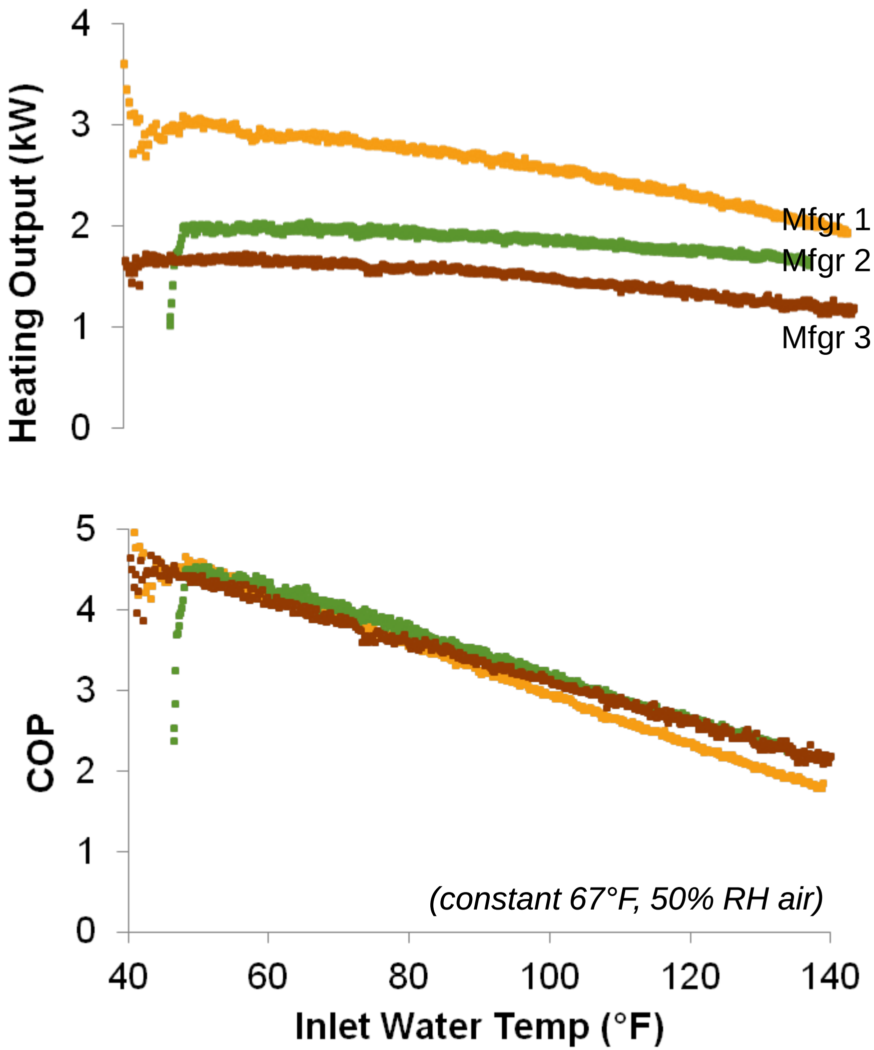
New Model

Generic Normalized Performance Map



Realistic Performance

Manufacturer Specific



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Realistic Performance

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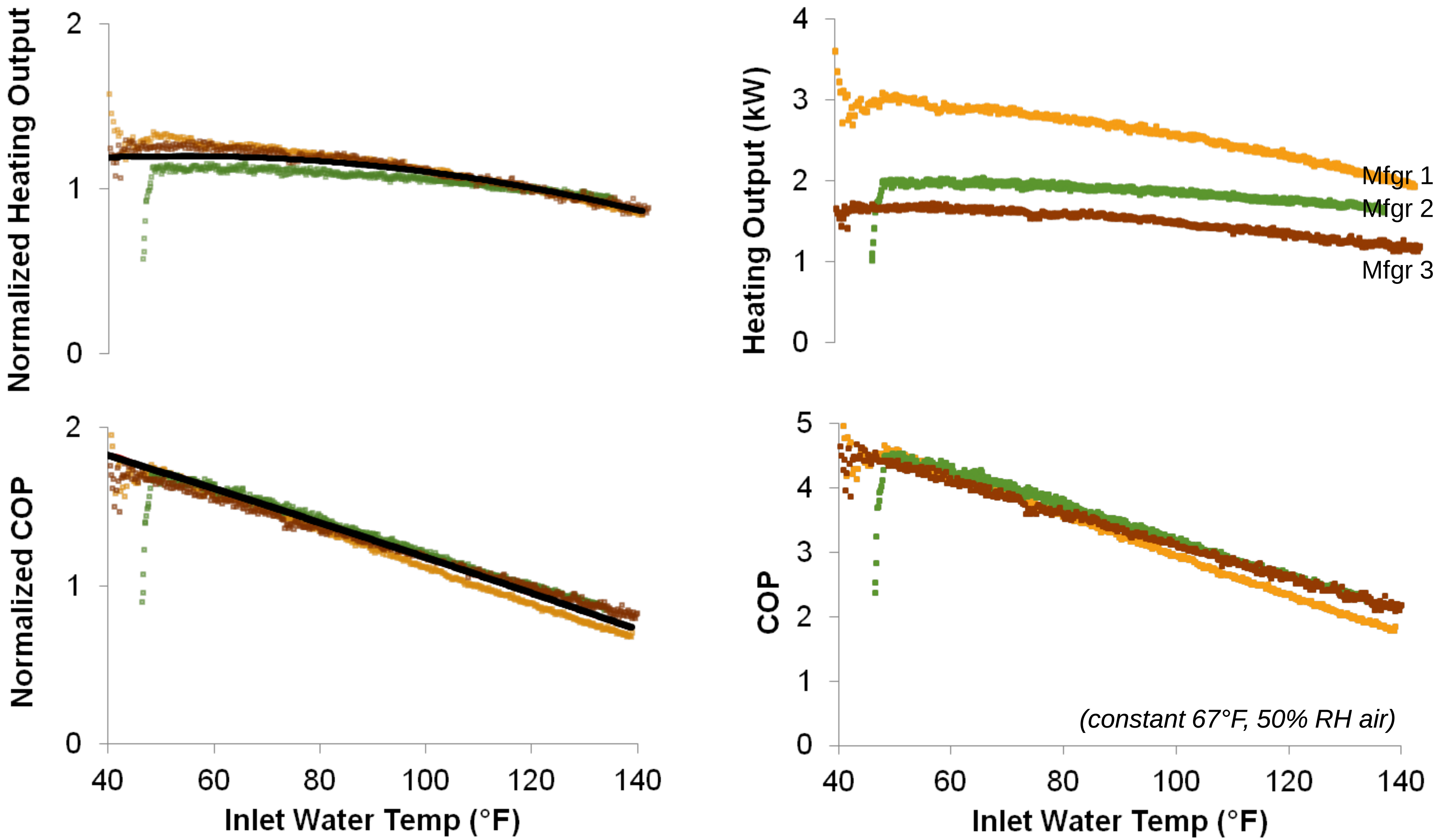

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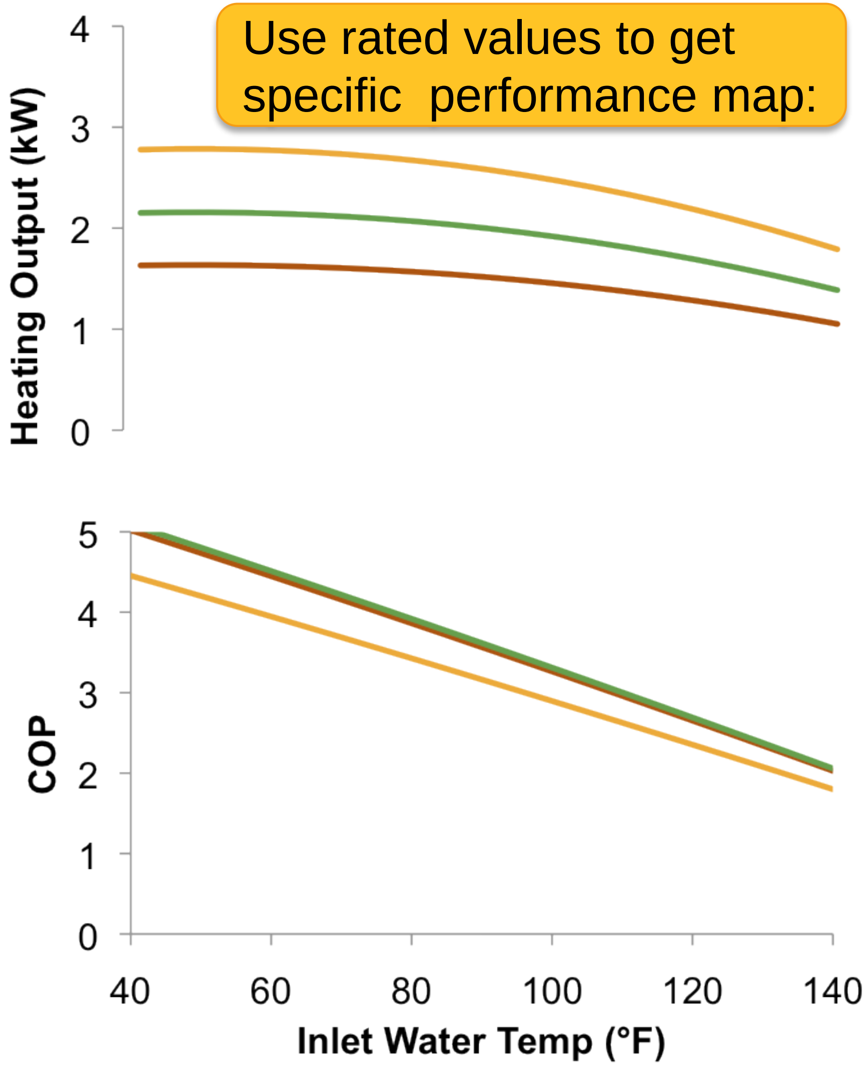

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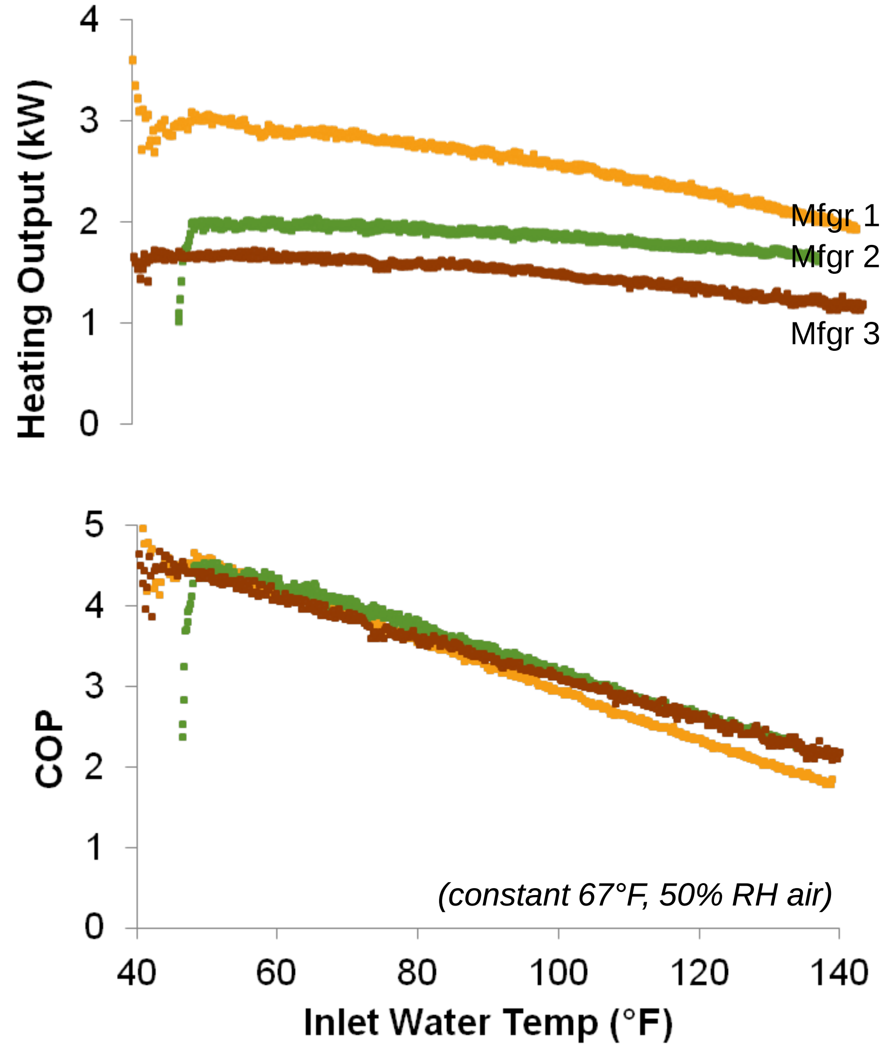
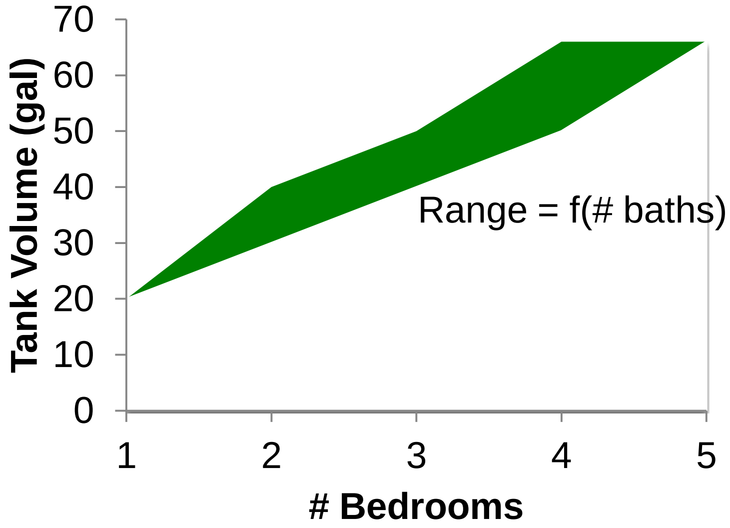


4) HPWH Sizing

Existing Model

- No existing method for HPWH sizing

Conventional Electric WH Sizing:



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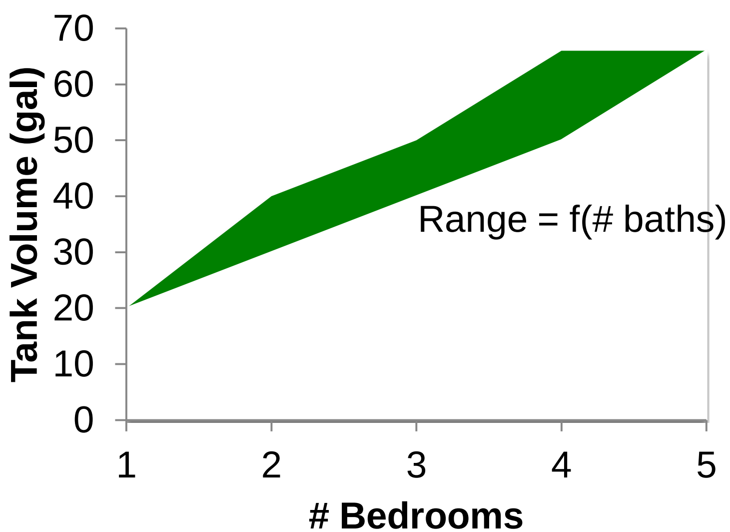
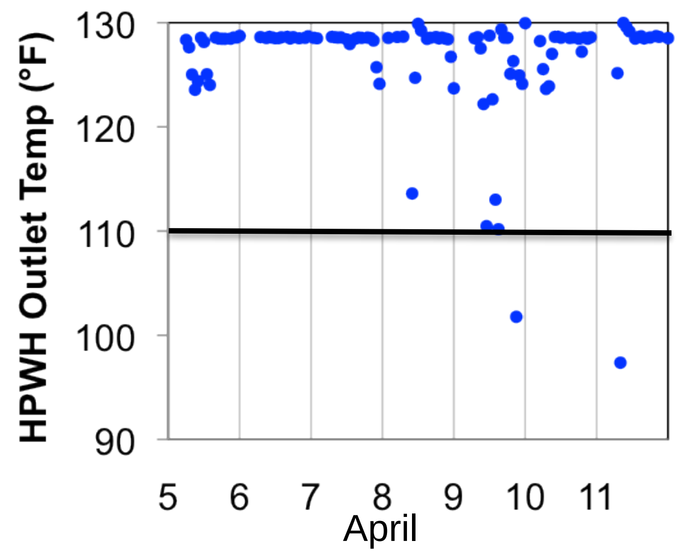


Realistic Performance



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"

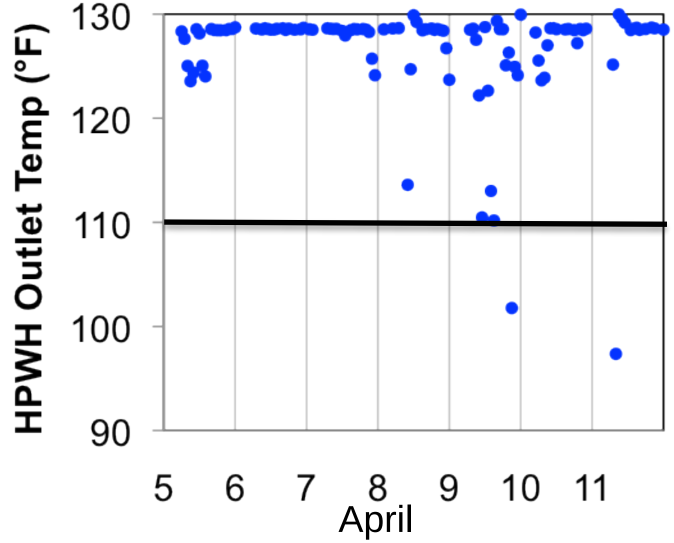
Option | Display Variable

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



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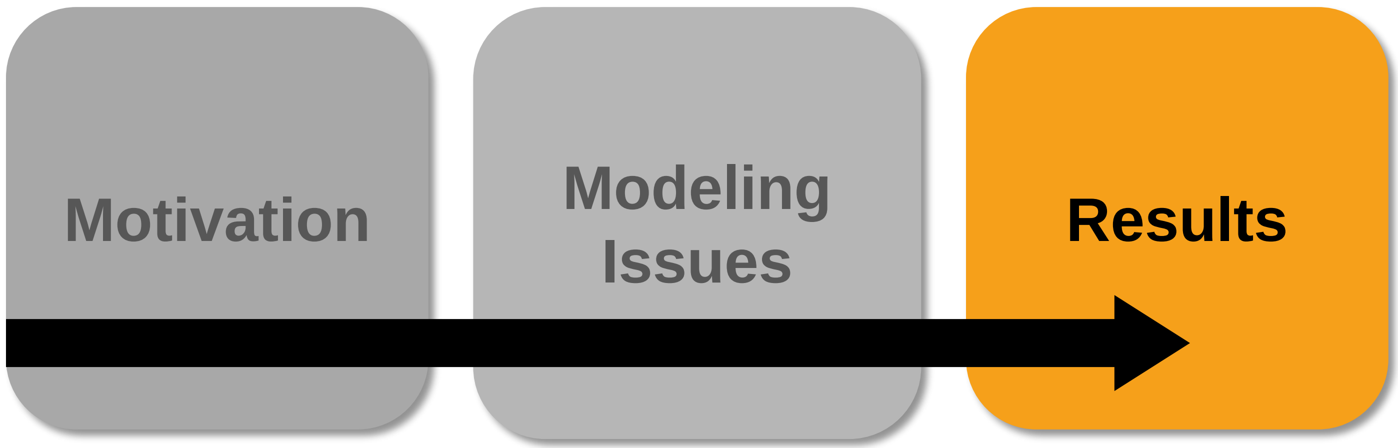
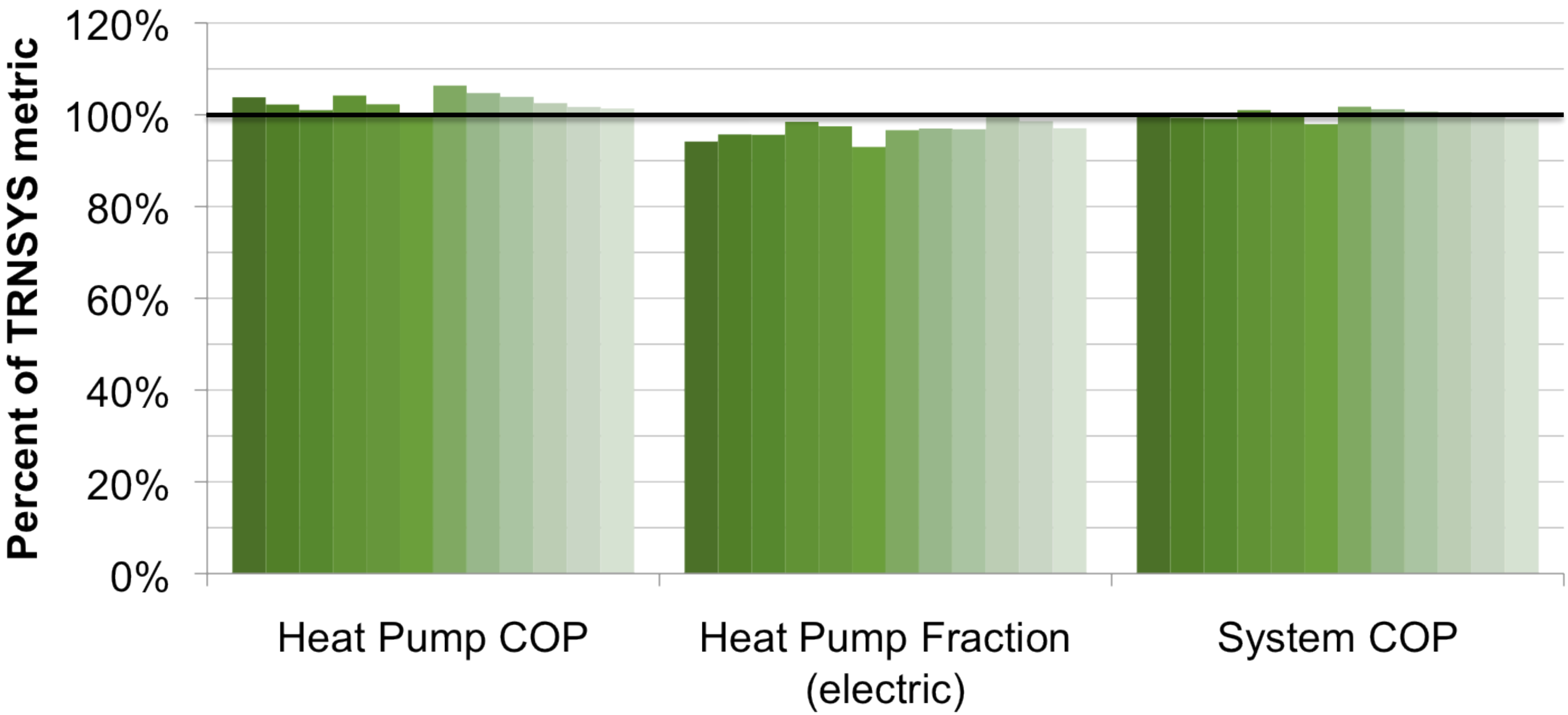
Heat Pump Water Heater Modeling…



Model Calibration

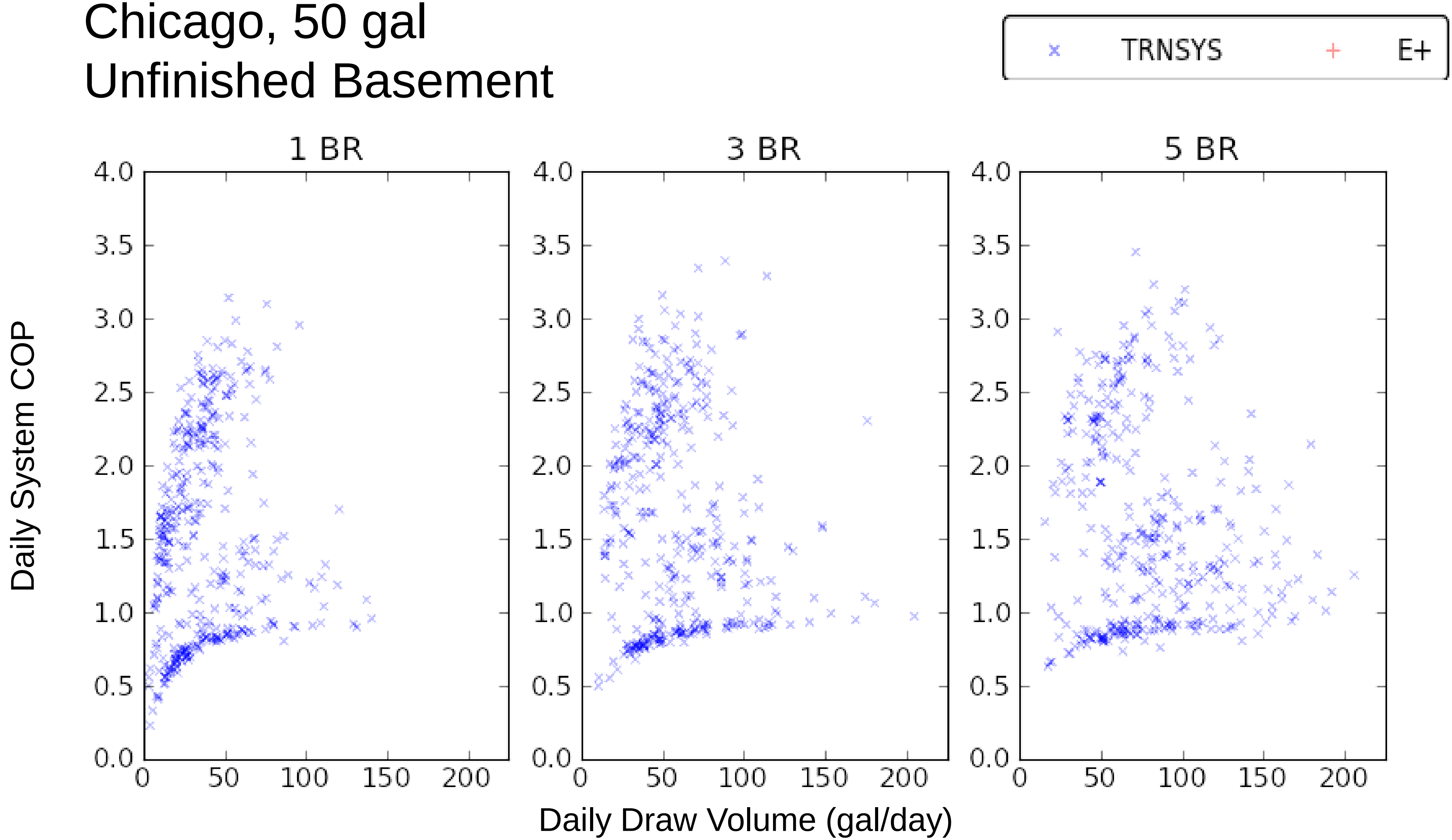
Calibrated to TRNSYS results ±5%

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



Model Calibration

Chicago, 50 gal
Unfinished Basement



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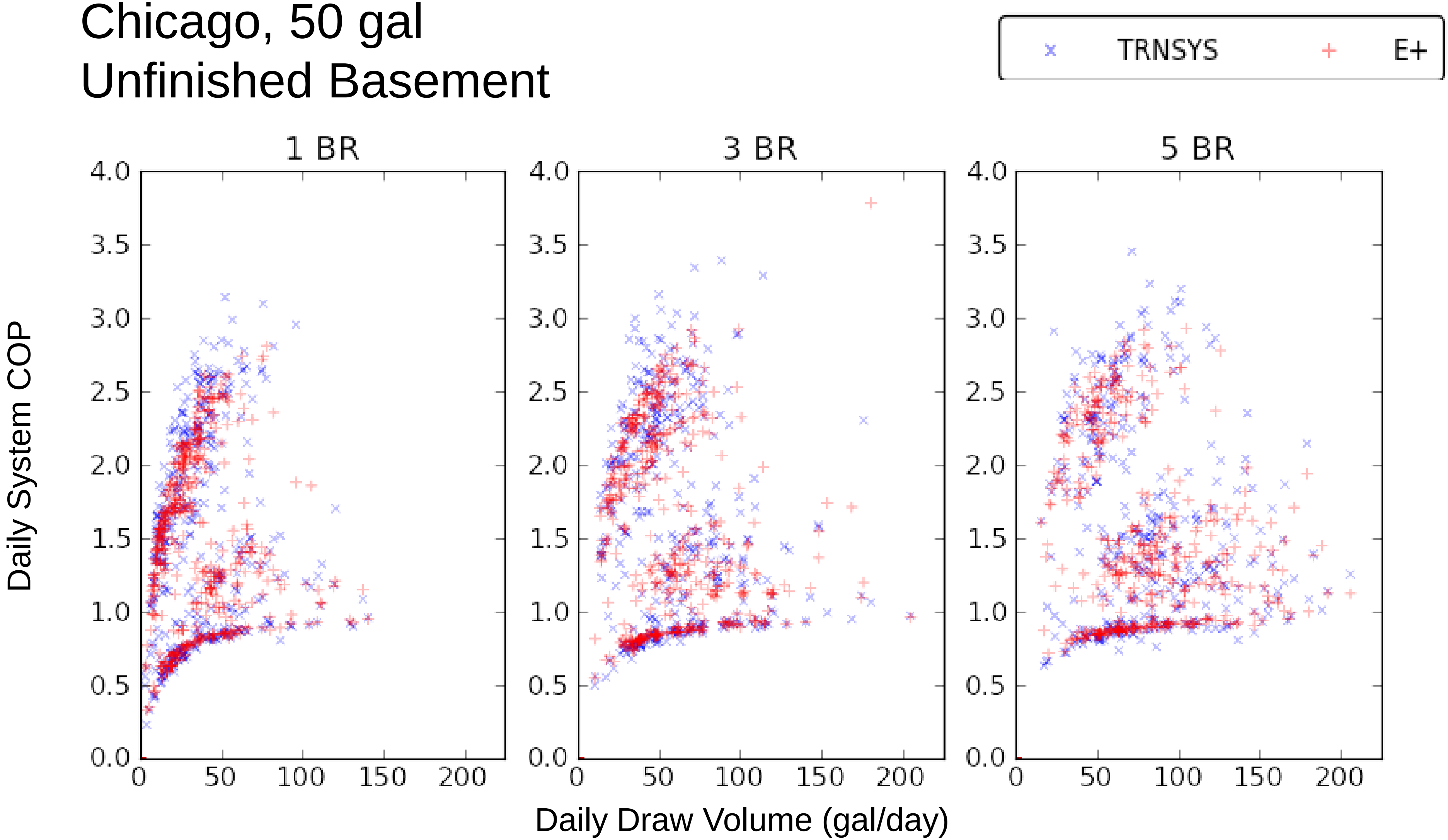
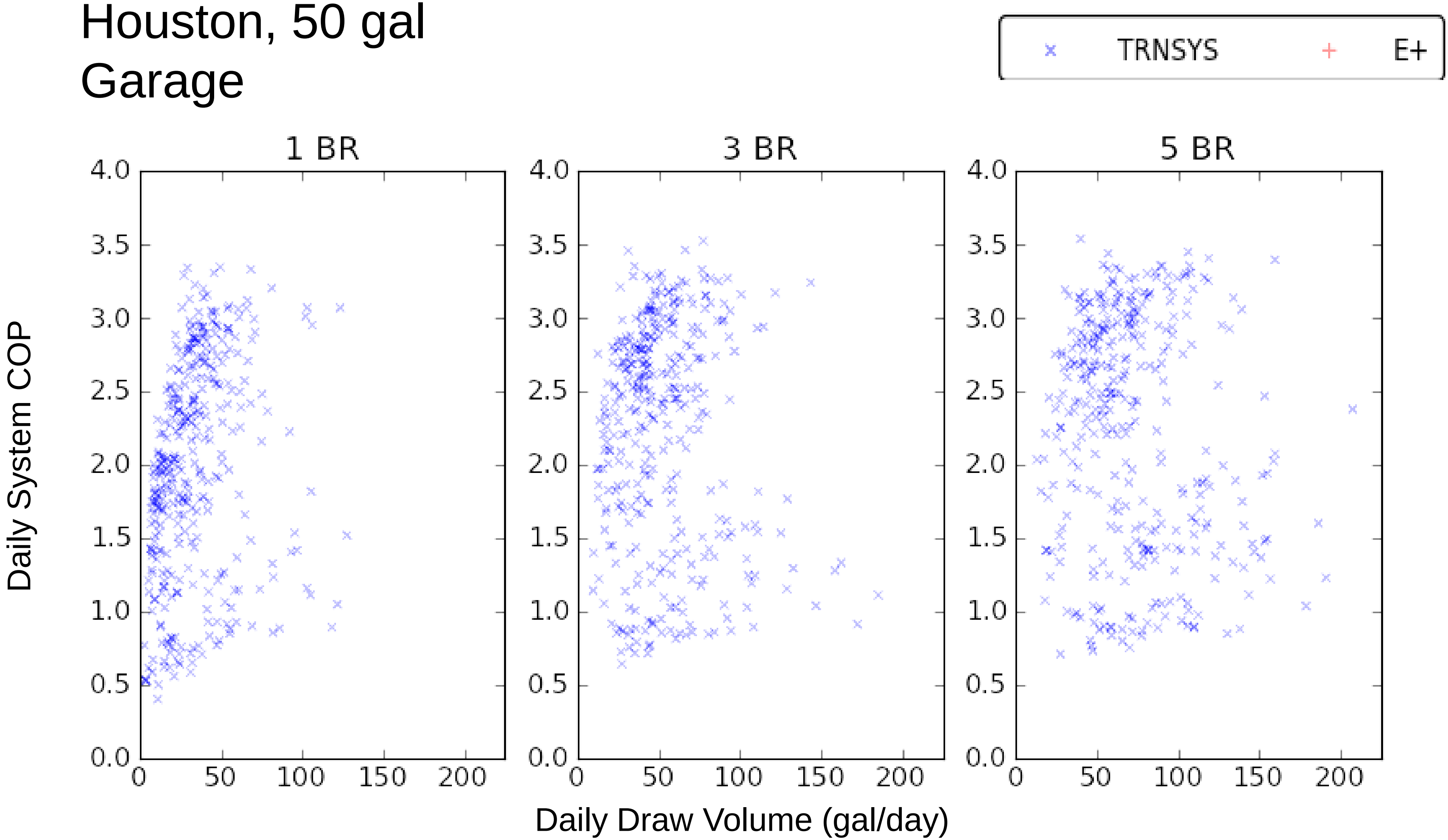


Model Calibration

Houston, 50 gal
Garage



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Houston, 50 gal
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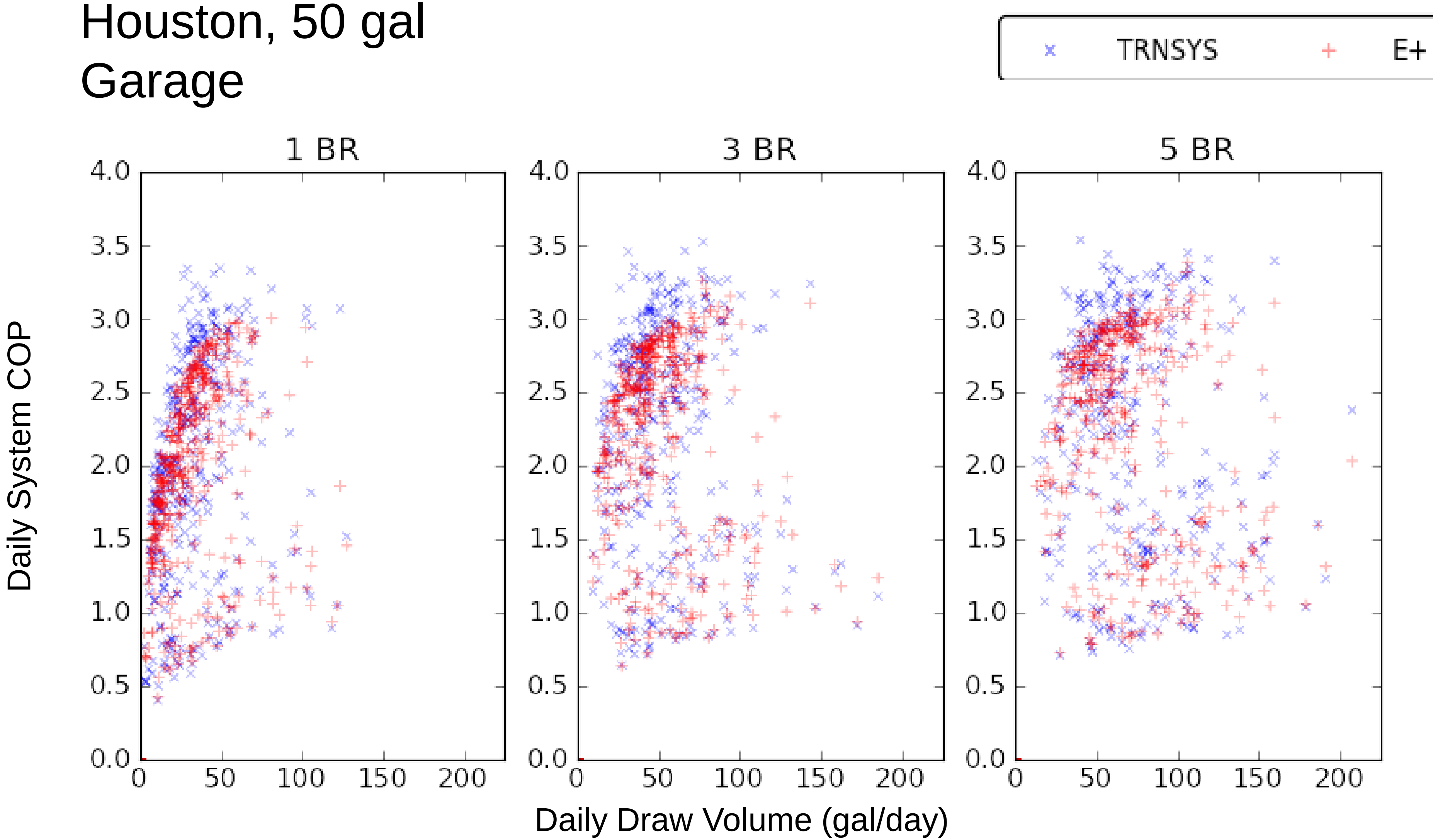
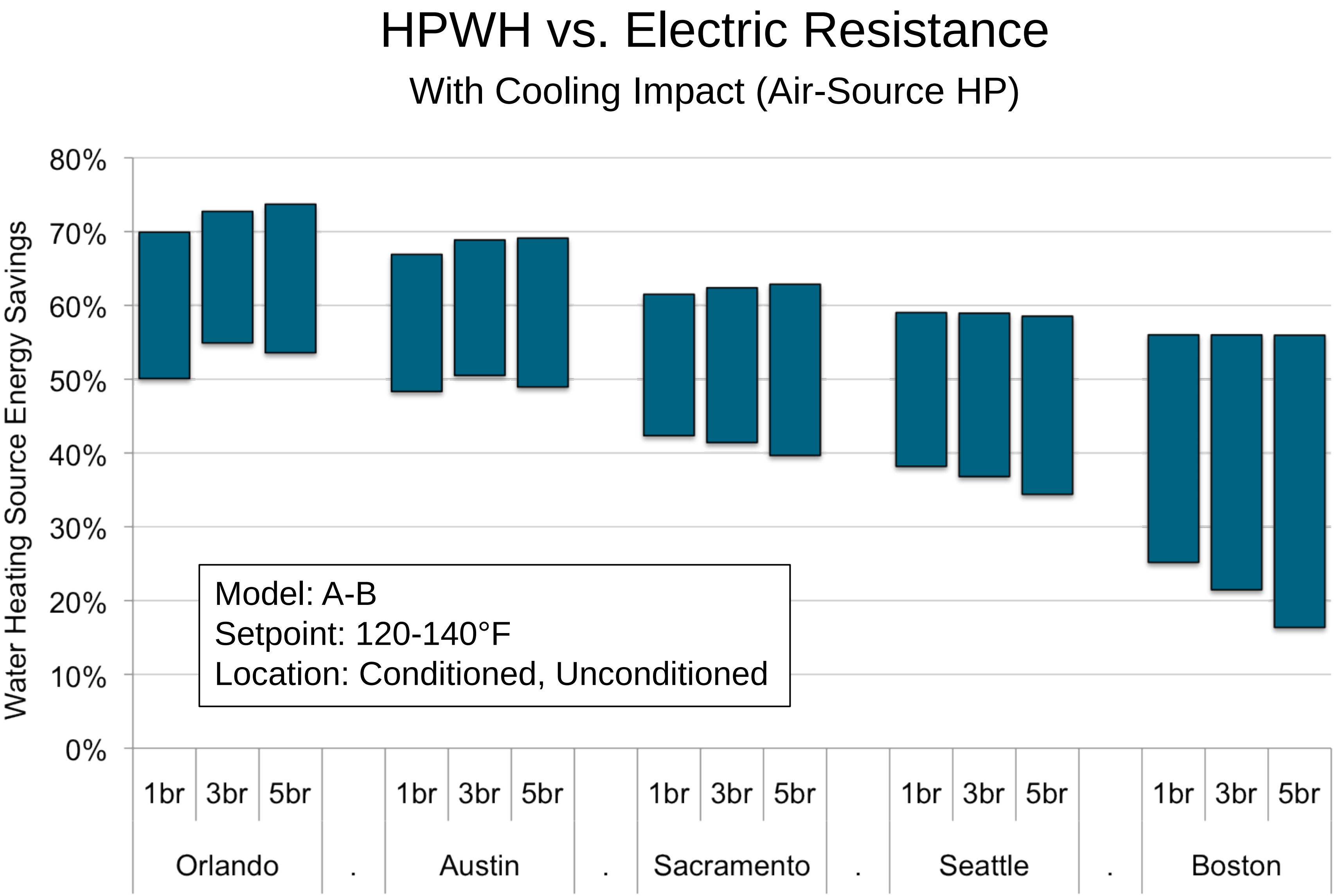


BEoptE+ Modeling Results



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

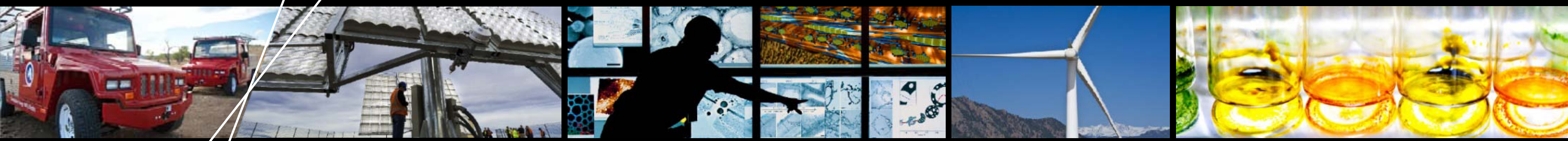
Conclusions

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:

<u>Laboratory Testing Report:</u>

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.

<u>TRNSYS Modeling Results:</u>

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