Towards a Universal Test Pattern:

Lab Studies of Water Heater Control Responses to Various Draws

ACEEE Hot Water Forum 2017

Session 4B

Understanding Electric Heat Pump Water Heater (HPWH) Energy Use across Climates and Draw Patterns

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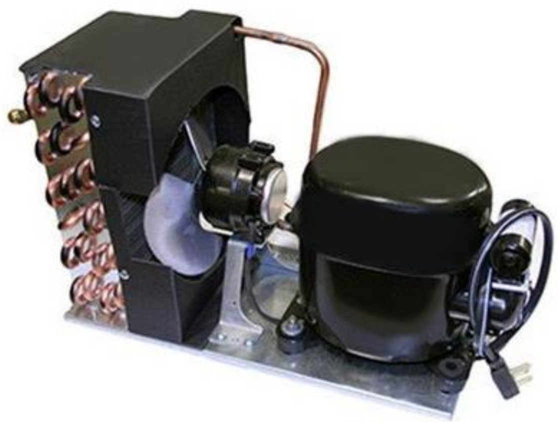
Problem Statement

- For a given electric utility, how do we predict the energy use of a heat pump water heater within their service territory?
- HPWHs are extremely non-linear devices
  - Two heating methods. Two drastically different efficiencies.



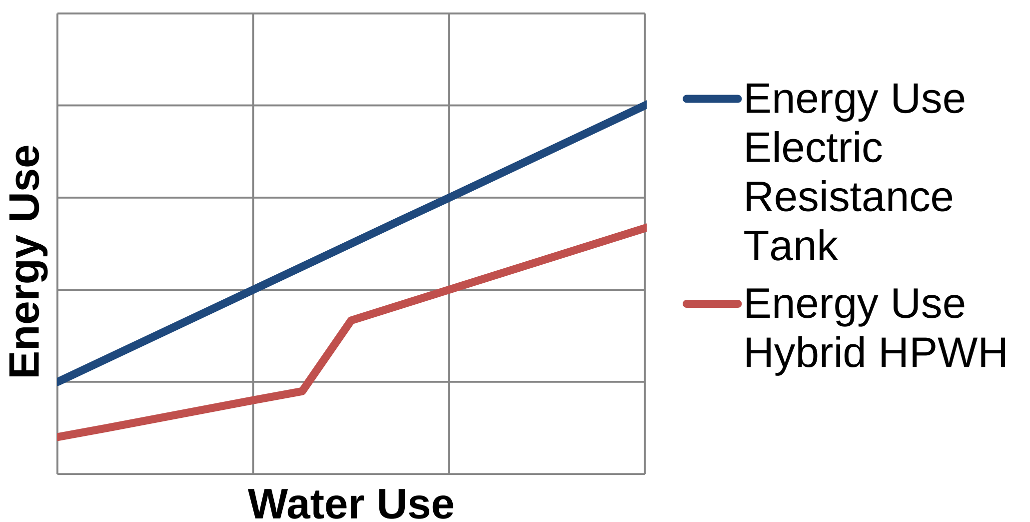
OR

???

  - Small changes to inputs like draw profile or inlet water temperature can have large changes to outputs (energy consumption)

Nonlinear Response

- With a gas water heater, the an extra gallon drawn at the end of a 20 gallon draw will only use 5% more energy.
- With a HPWH, it might use 50% more energy.



Energy Estimation Method Options

- Use the UEF?
  - HPWHs don’t operate in a constant 67.5F degree environment
  - Hot water use can vary, by utility service territory, from the test draw patterns
- Measurement?
  - Directly meter the energy use of every water heater
    - Expensive
    - Time consuming

Energy Estimation via Simulation

- Currently used to underpin Pacfic NW utility programs and for CBECC-Res in California for energy code compliance
  - https://github.com/EcotopeResearch/HPWHsim
  - Go to session 6A to learn more about simulations
- Relatively easy to get COP map and determine when compressor turns on/off
- Much harder to determine when resistance elements turn on and off

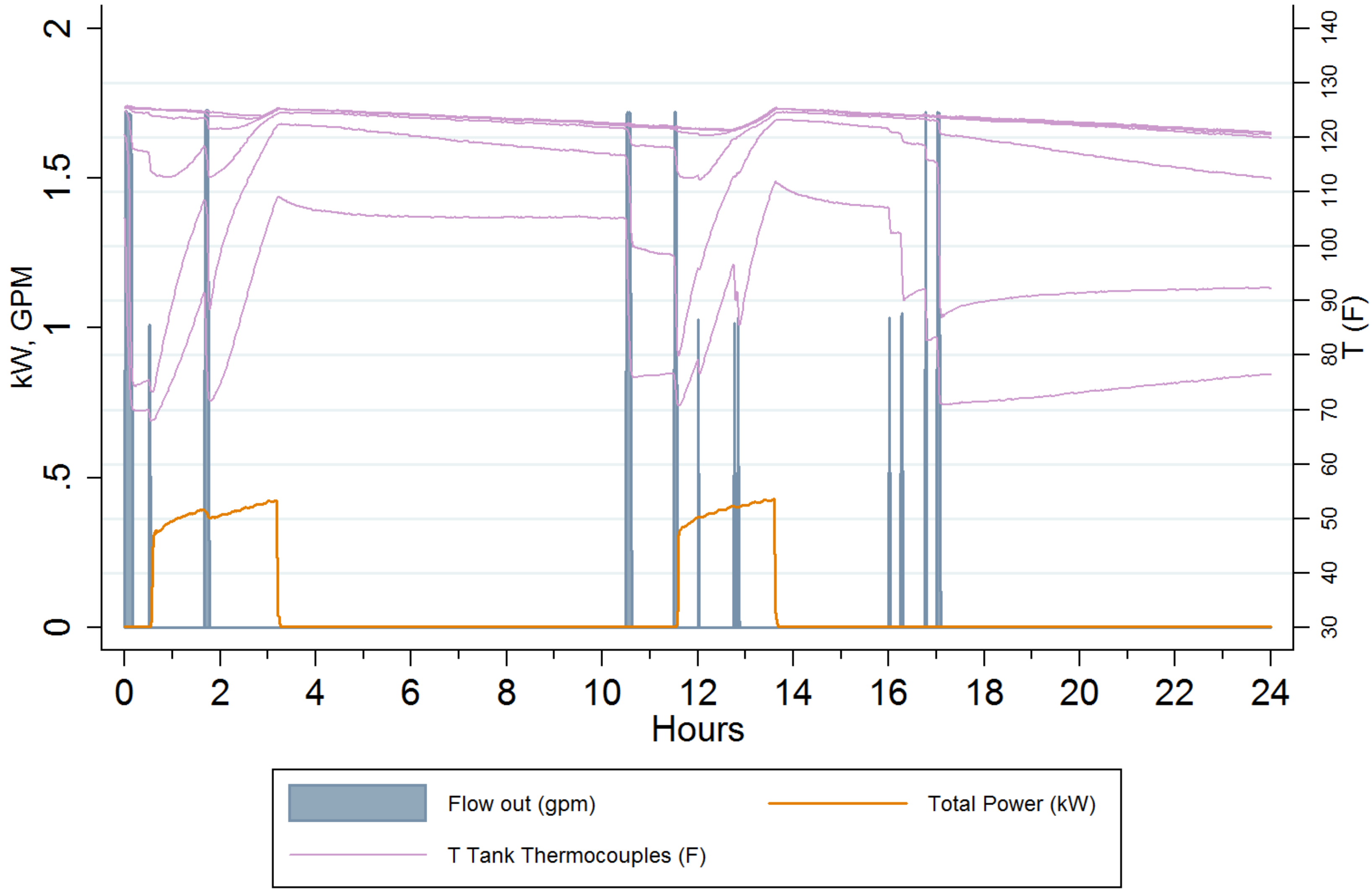
Study Goals

- To devise a lab test to (better) inform when resistance heat elements engage

- Is this even possible?
- How close can we get and to what?
  - Use field measurements as a reference
  - Previous field study in Pacific Northwest with copious field sites on earlier GE and AO Smith equipment

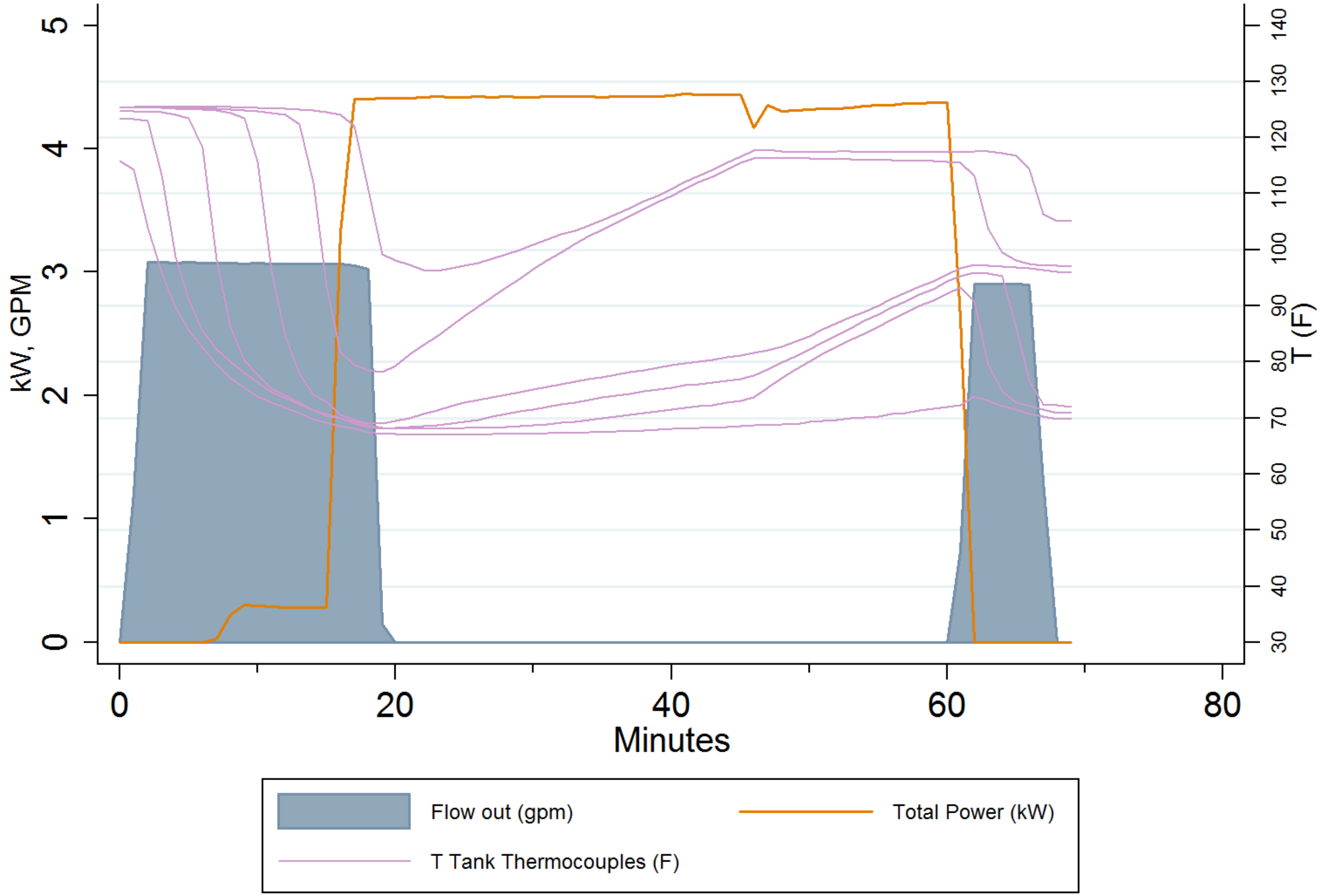
Starting Point 1: UEF Draw Pattern

Large draw pattern on a 66 gallon tank



Starting Point 2: 1st Hour Test

Same 66 gallon tank



Explore More Draw Profiles

- UEF and 1st Hour Draw Patterns tell us something about the controls
- Resistance heat will happen in some draw profiles and not others
- Explore on two water heater products

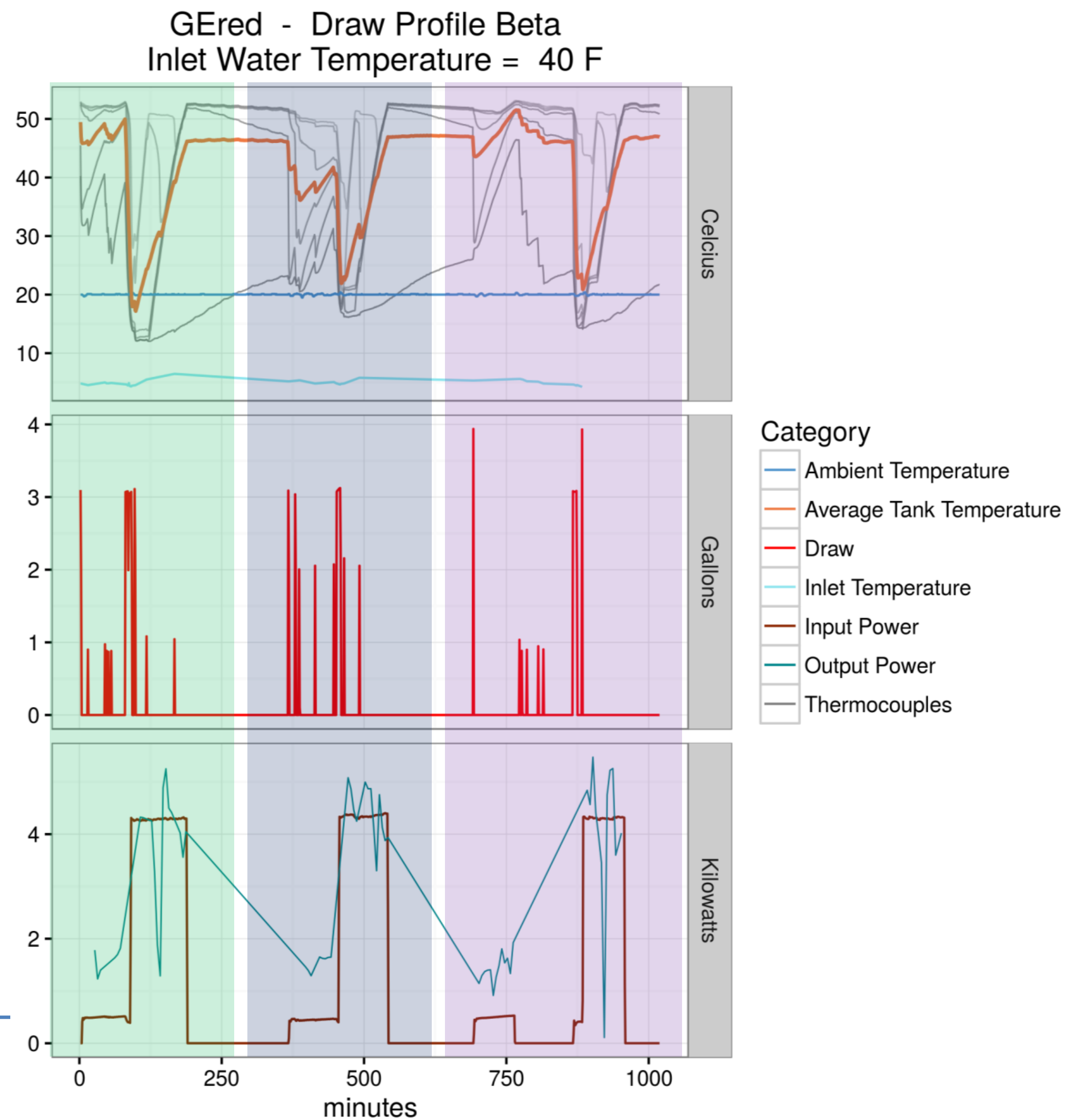
Candidate Draw Profiles

Name	Description	Total Gallons	Inlet Water	Tank Setpoint	Ambient Air
Simulated Use A	3 Draw Clusters with Time to Recover Tank between Each	67, 38, 40	58F	125F	67.5F 50% RH
			40F		
Simulated Use B	3 More Draw Clusters	51, 43, 36	58F		
			40F		
Slow Flow .4	Continuous Draw of 0.4 GPM for 180 minutes	72	58F		
			40F		
Slow Flow .6	Continuous Draw of 0.6 GPM for 180 minutes	108	58F		
			40F		
High Flow	Large, Continuous Draw of 3 GPM for 15 minutes	45	58F		
			40F		

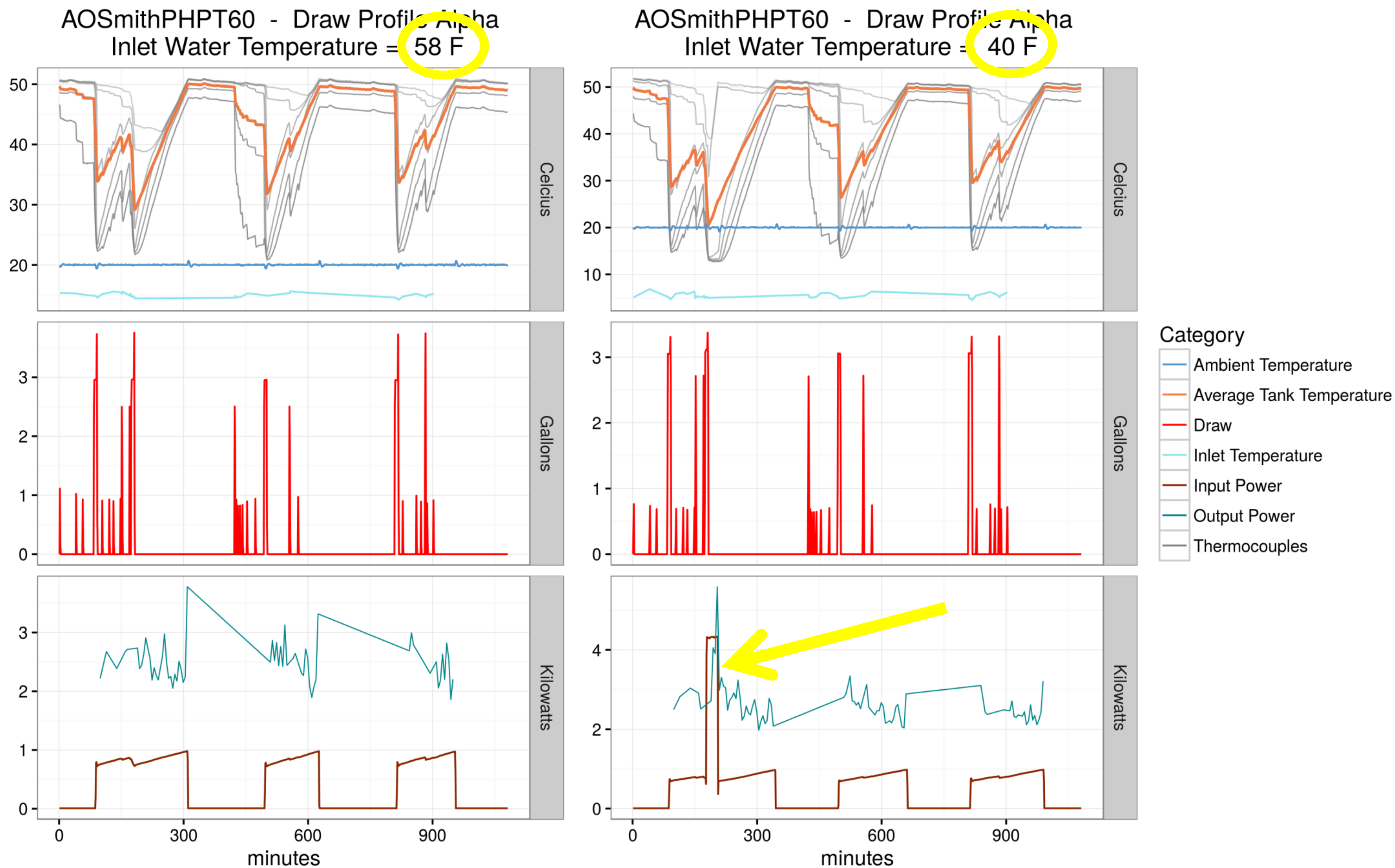
- 6 unique clusters; x 2 inlet temperatures
- 2 slow flow + 1 high flow tests; x 2 inlet temperatures

Test Output

- 3 clusters
- 3 recovery cycles
- 4 compressor events
- 3 resistance element events

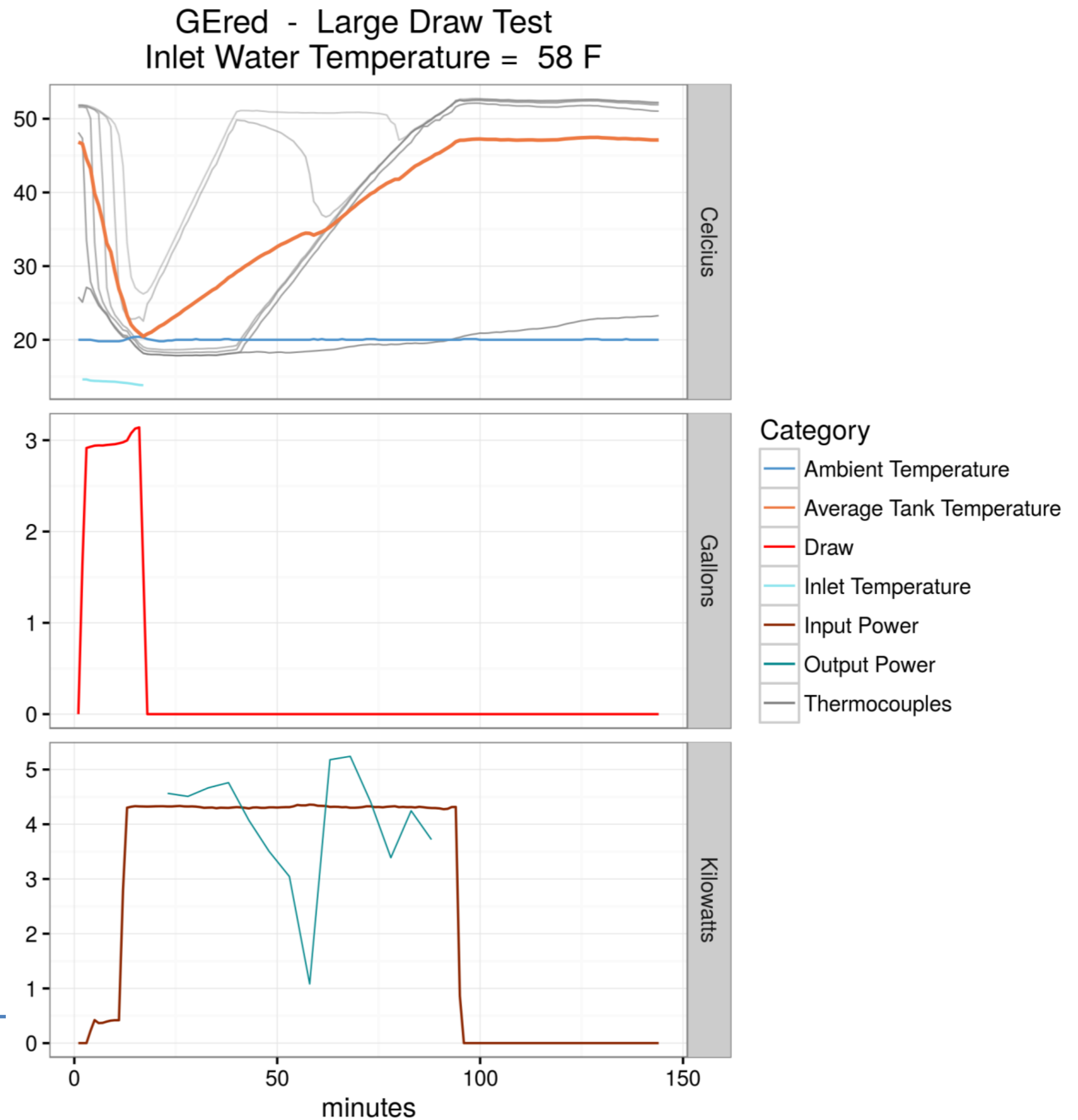


Test Output: Nonlinear Response



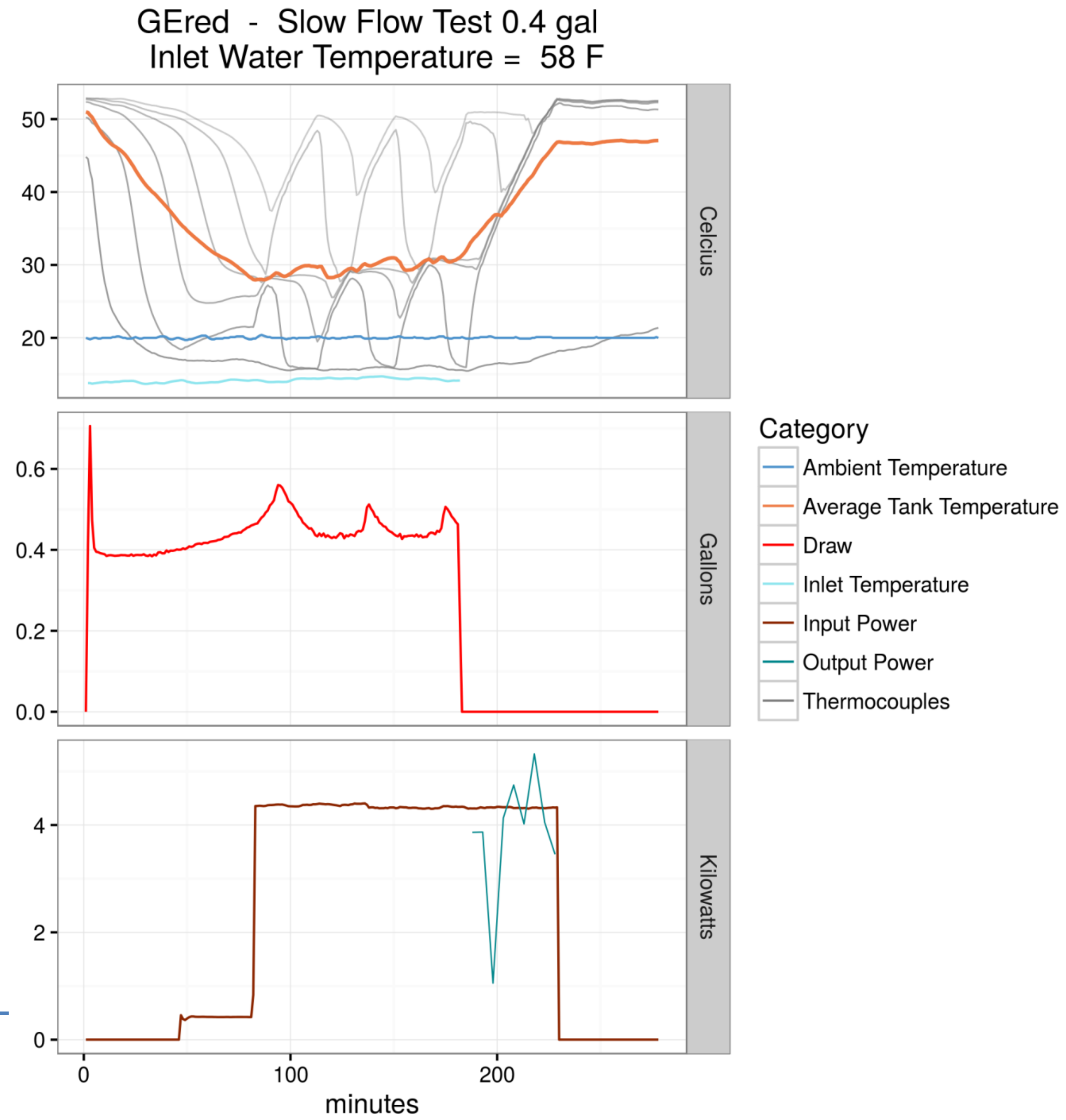
Test Output

- Rapid change in tank temperatures
- 1 compressor event
- 2 resistance element events (upper & lower)



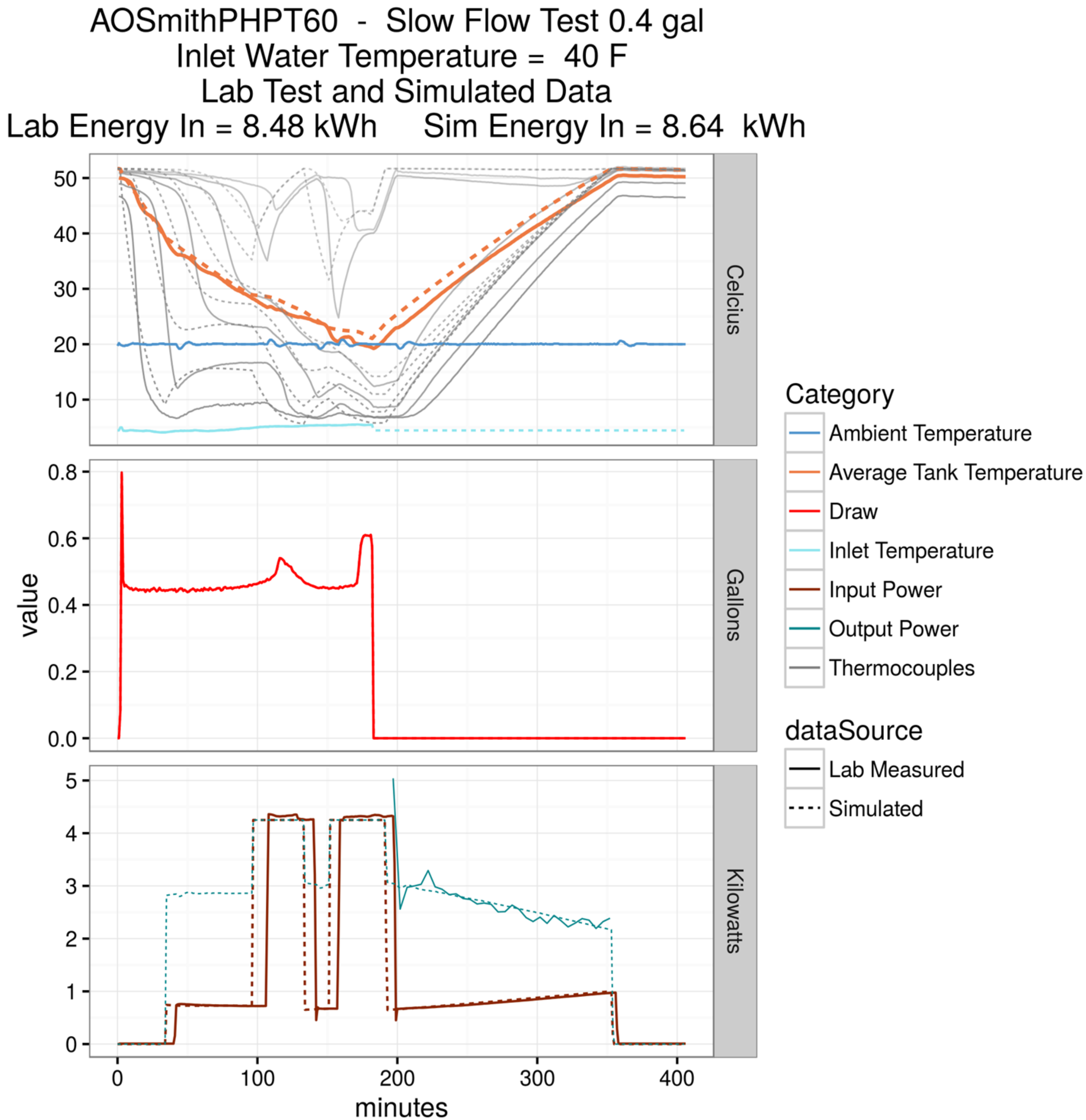
Test Output

- Slower tank temperature change leads to better quantification of control points
- 1 compressor event
- Multiple resistance element events

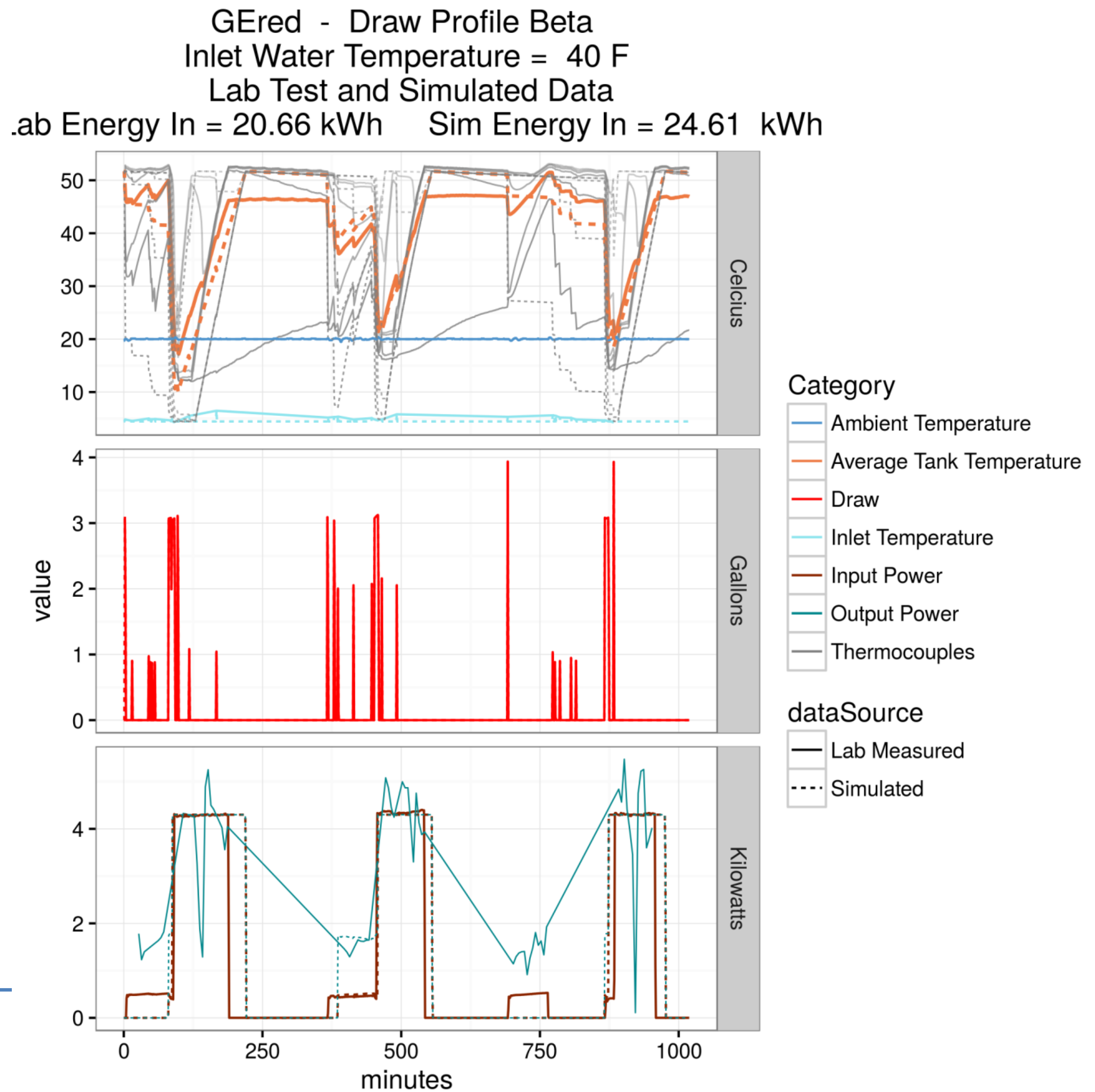


Lab Tests & Simulation Comparisons

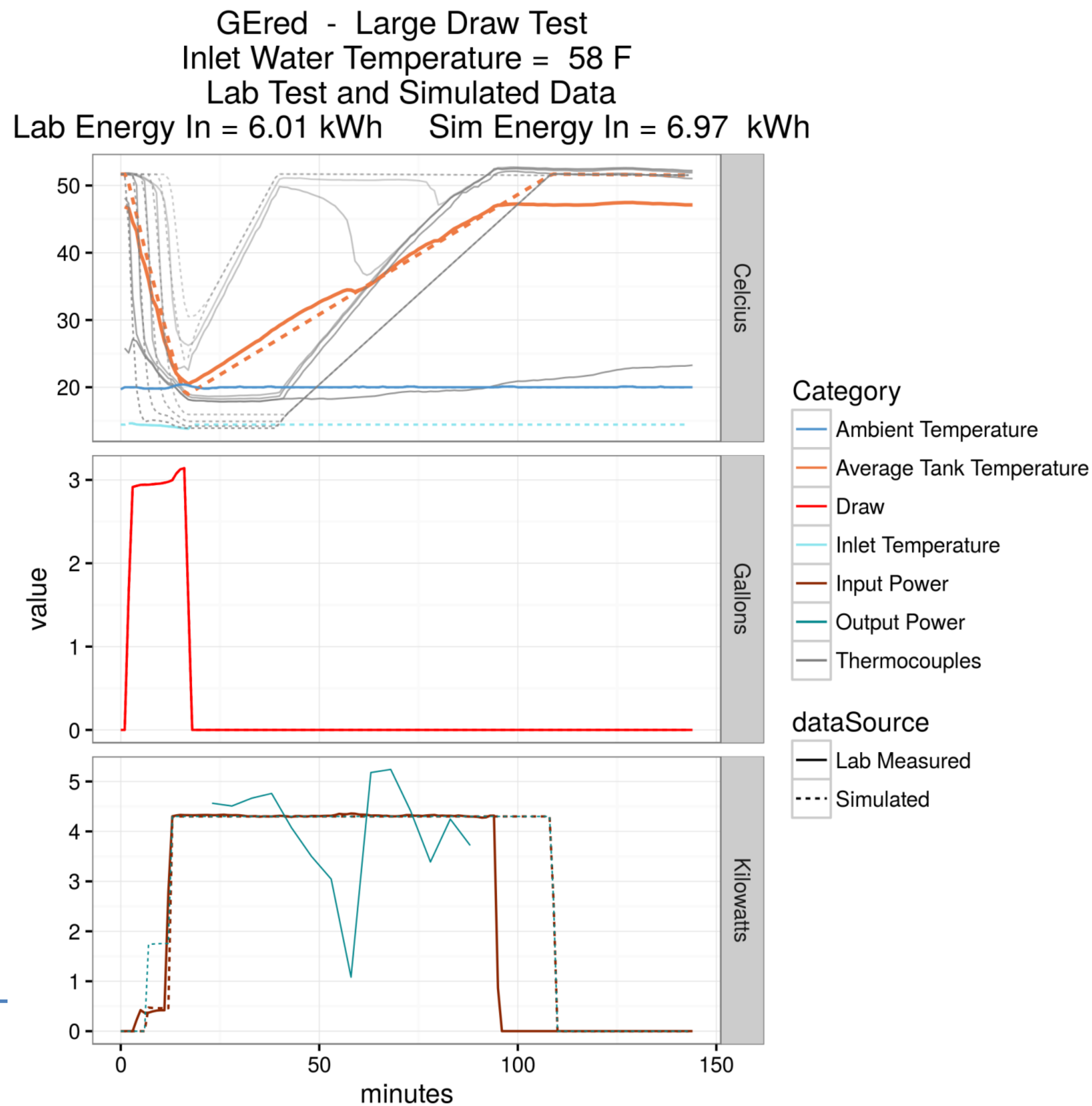
- Slow Flow Test
- Good Agreement



- Simulated Use B
- Moderate agreement



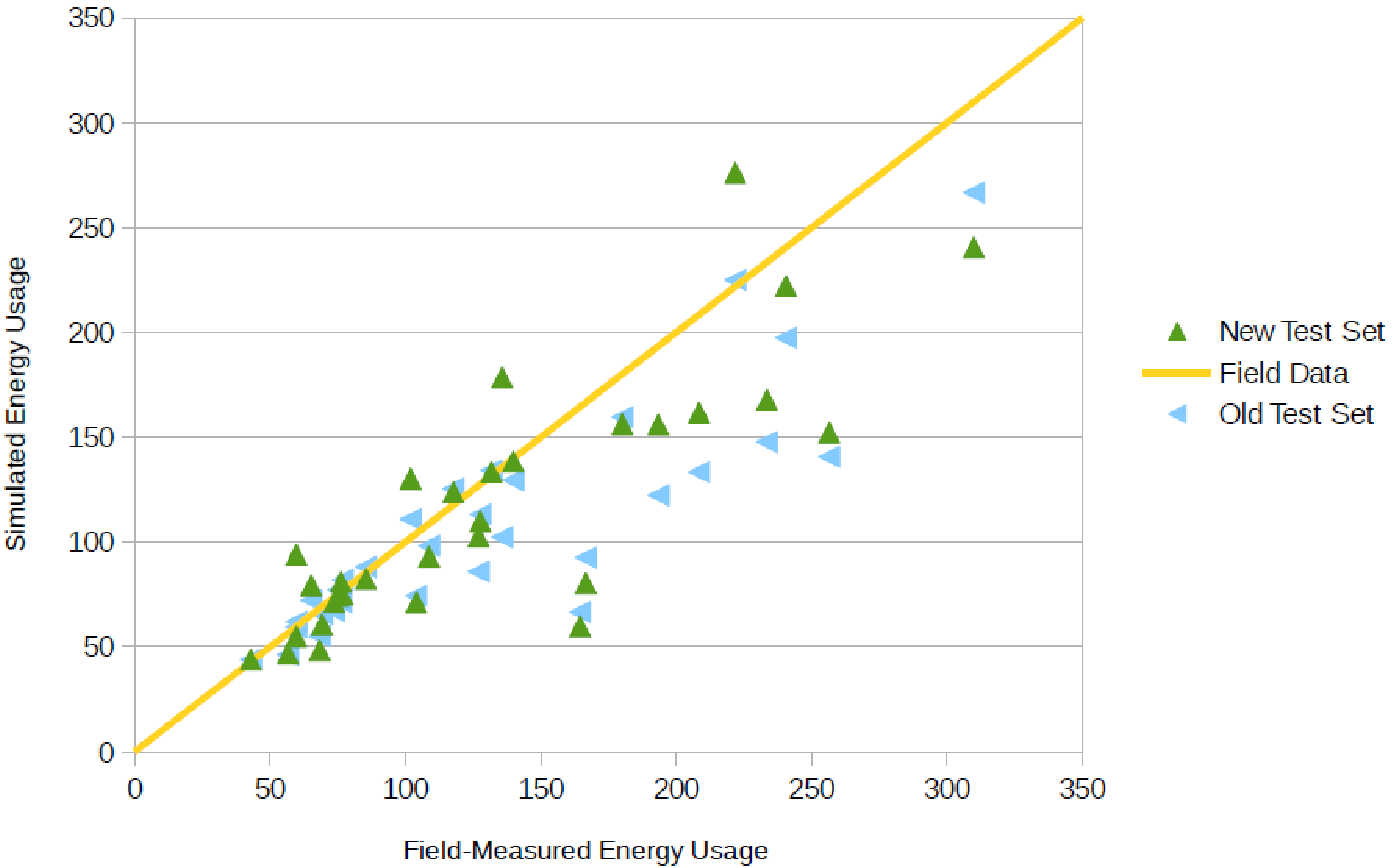
- Large draw
- Good agreement for compressor and resistance element turn on conditions



Comparison to Field Measurements

- Simulation run with old control parameters
  - Based mostly on UEF and 1st Hr Draw Patterns
- Simulation run with new control parameters
  - Includes additional calibration to slow flow
- Compare old and new simulation output to one month of field data from ~40 houses

Measured vs Modeled Energy:
New & Old Test Set Calibrations



Conclusions

- Observations of more test patterns lead to better predictive capability
- Slow flow draws provide more accurate understanding of temperature control points for all heating components
- At least 3 distinct tests can be conducted in an 18 hour period

What's Next

- Tightly quantify model prediction improvement vs field data
- Assess lab testing burden
- Recommend best test patterns to aid in simulation prediction

Q & A

- Thanks!