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Verifying Simulation Models of Water Heaters

Jeff Maguire
ACEEE Hot Water Forum
3/21/18

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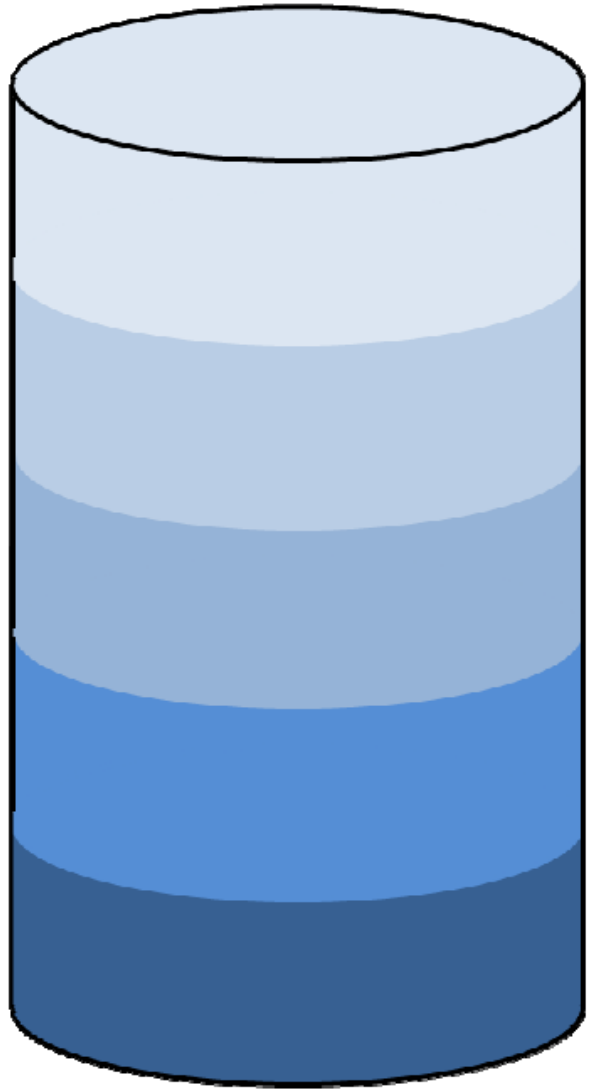
Introduction

- Water heater models are used as part of:
  - Home energy ratings
  - Demonstrating compliance with performance based codes
  - Predicting energy savings (and cost effectiveness) of upgrades
- Need accurate results that reflect real world performance
- Models need to be validated!
  - Tank dynamics are complicated

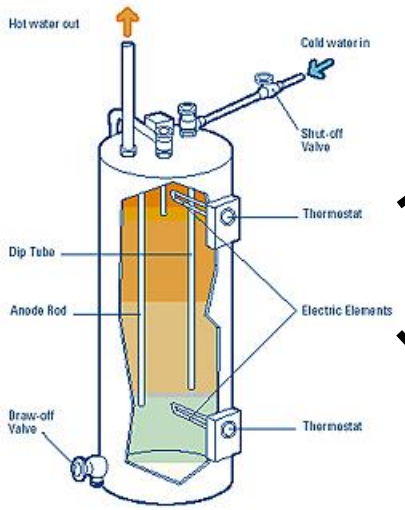


Why Do We Need to Validate?

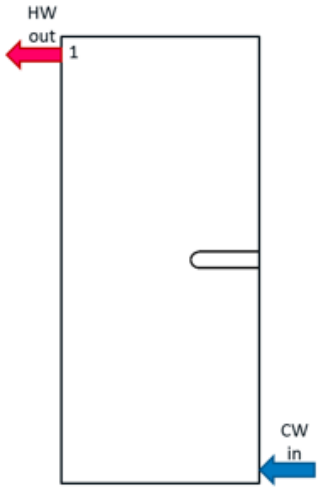
- Tank dynamics are complicated
  - Buoyancy driven flow, conduction, mixing flow in the tank due to draws
- Controls and the amount of delivered energy depends on the temperature at certain locations in the tank
  - Big impact for HPWHs, timing of heating events is important with TOU rates or when trying to provide grid services
- Need to ensure that the model accurately predicts the energy consumed and outlet temperature (delivered energy)
  - You're disappointed if you don't save energy, you're mad if you don't have hot water

Storage Tank Models

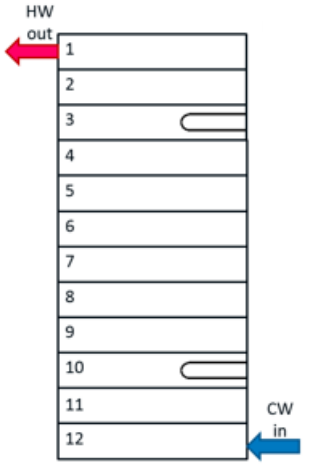
- Simple: 1 node mixed tank
  - Entire tank is assumed isothermal
  - Location of the heating element, inlet and outlet doesn't matter
- Detailed: Stratified tank
  - Stack of isothermal nodes
  - Captures stratification
    - Unheated volume between lower element for electric
    - Better prediction of outlet temperature
    - Needs more complex control logic when multiple heat sources are included
- Model parameters (UA, η_c) are often derived from ratings data (UEF, RE)



Mixed Electric Tank

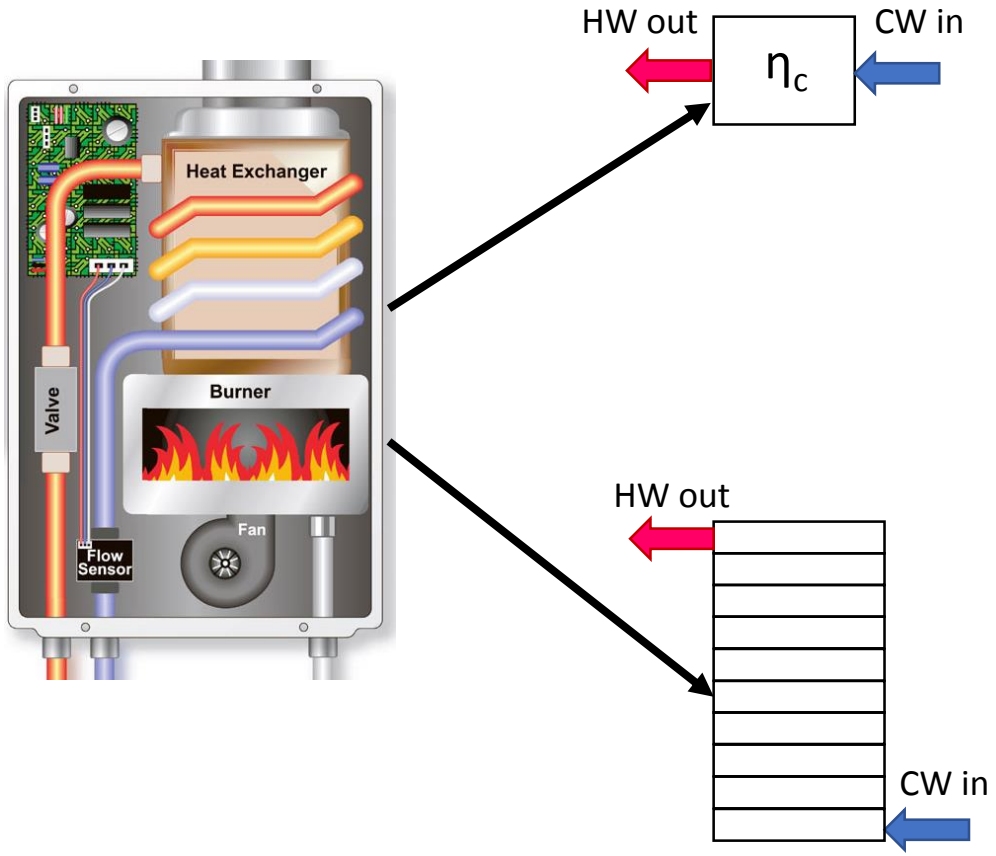


Stratified Electric Tank



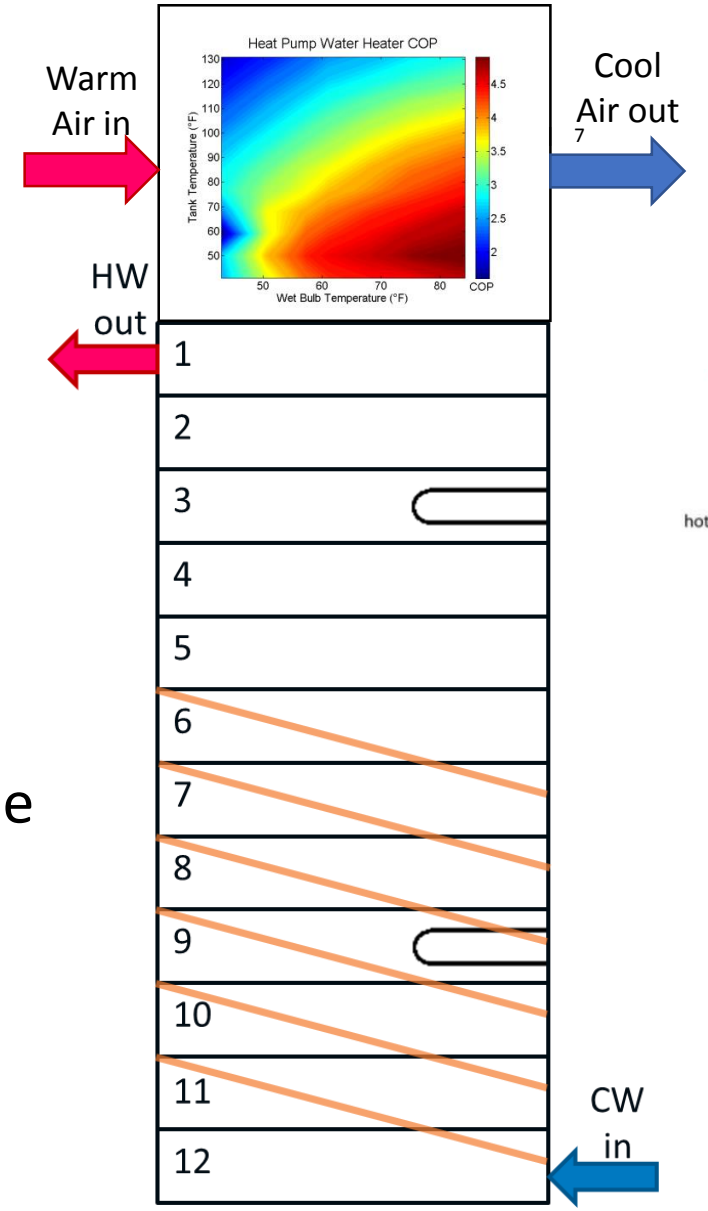
Tankless Models

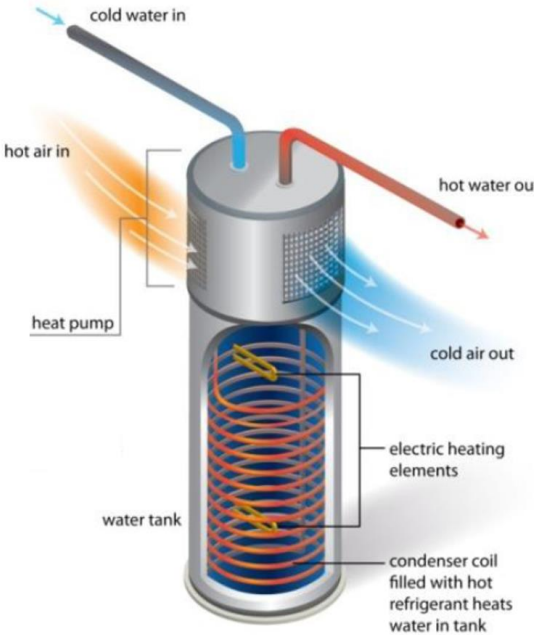
- Simple: Model tankless as fixed efficiency point source of heat
  - A derate is often applied to the rated efficiency of the unit to account for transient behavior
- Detailed: Model the heat exchanger directly
  - Requires lab testing to determine the parameters (mc_p, UA)
  - Modeled using multiple nodes to represent the heat exchanger
  - Needs to be modeled with very short timesteps (seconds) to accurately capture transient behavior



Heat Pump Water Heater Models

- Simple: Doesn't really exist
  - Yet…
- Detailed: Stratified tank combined with a heat pump model
  - Requires a performance map for the heat pump
  - Additional complexity related to whether the heat pump or back up elements are used to recover
  - Lab testing required to determine the control logic of the unit
    - Manufacturer specific

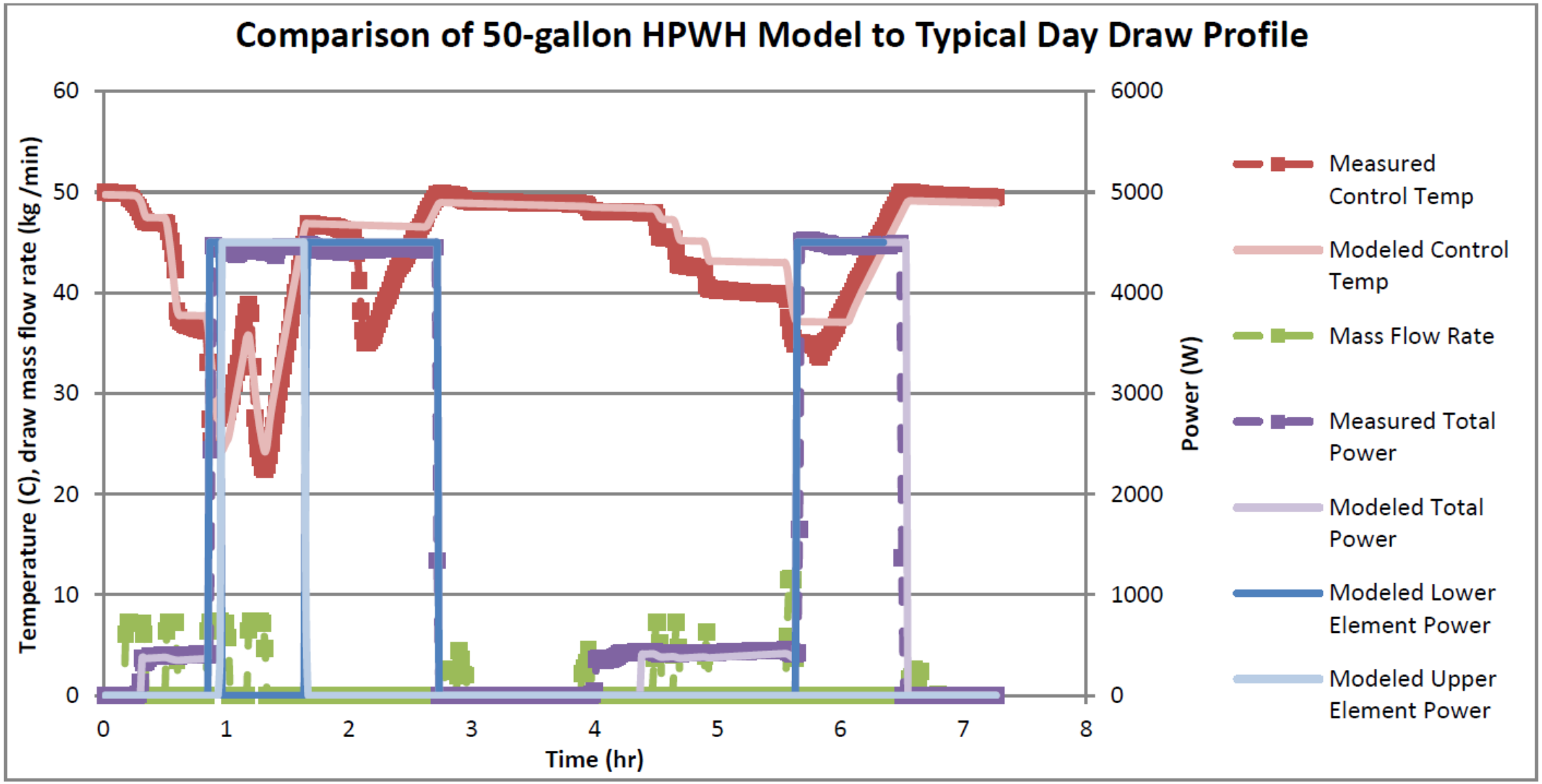




Validation Against Laboratory Data

- Laboratory model validation is most useful for deriving/verifying simulation parameters that can't be obtained from ratings data
  - Tankless HX thermal mass and UA
  - HPWH HP performance map and control logic
  - Condensing water heater burner performance map
- If you're calibrating your model to a specific test, you need to verify it against other tests

Lab Validation Example: HPWH



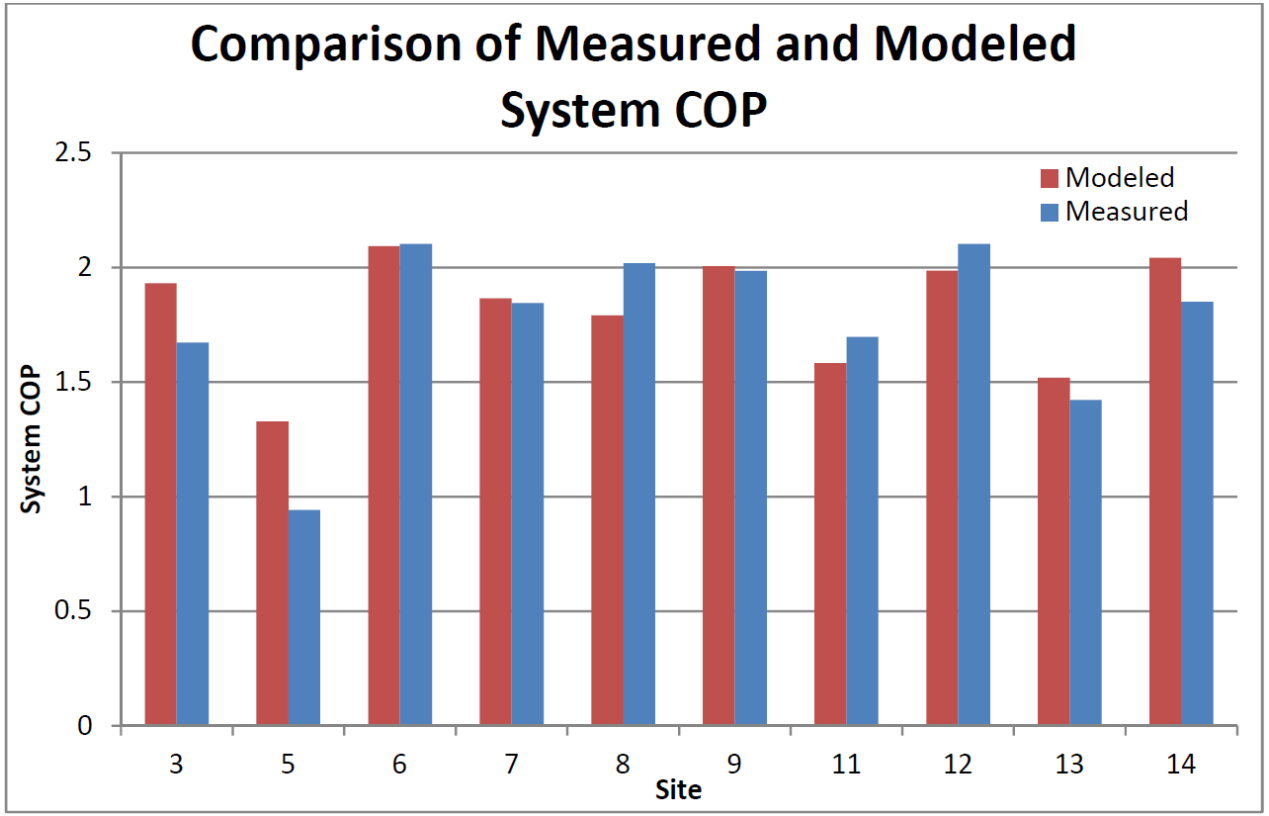
Validation Against Field Data

- Field data is used to ensure the model correctly captures performance in actual use
- Field testing can give insight into effects that weren't tested for in the lab
  - Ex: HPWHs cooling it's own inlet air
- To validate the model, run it with the same conditions seen in the field and compare

***Image Credit: Puttagunta, Srikanth.** Measured Performance of Advanced Water Heating Strategies: Heat Pump Water Heaters. Norwalk, CT : Stephen Winter Associates, 2011.*

Field Validation Example: HPWH

- Comparison of HPWH model to real world measured data for 10 sites in New England*
- Generally good agreement between the model and measured data
- Sites 3 & 5 had significant icing of the evaporator that reduced the efficiency
  - Not captured by the model!



Puttagunta, Srikanth. *Measured Performance of Advanced Water Heating Strategies: Heat Pump Water Heaters. Norwalk, CT : Stephen Winter Associates, 2011.*

Software to Software Comparisons

- Software to software verification allows comparisons at conditions not seen in the lab or field
  - Different draw profiles, temperatures
- Software comparisons lead to additional verification of the code
  - Almost always have to dig into the code for both tools to understand differences
- You always want at least one of the models to have been validated against field/lab data.

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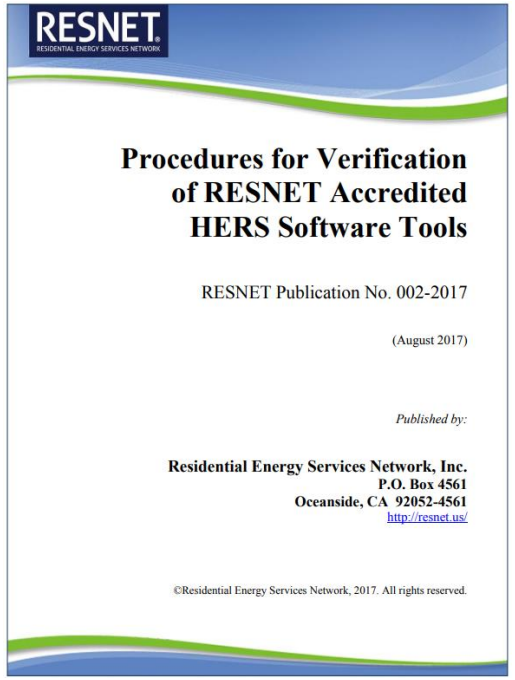
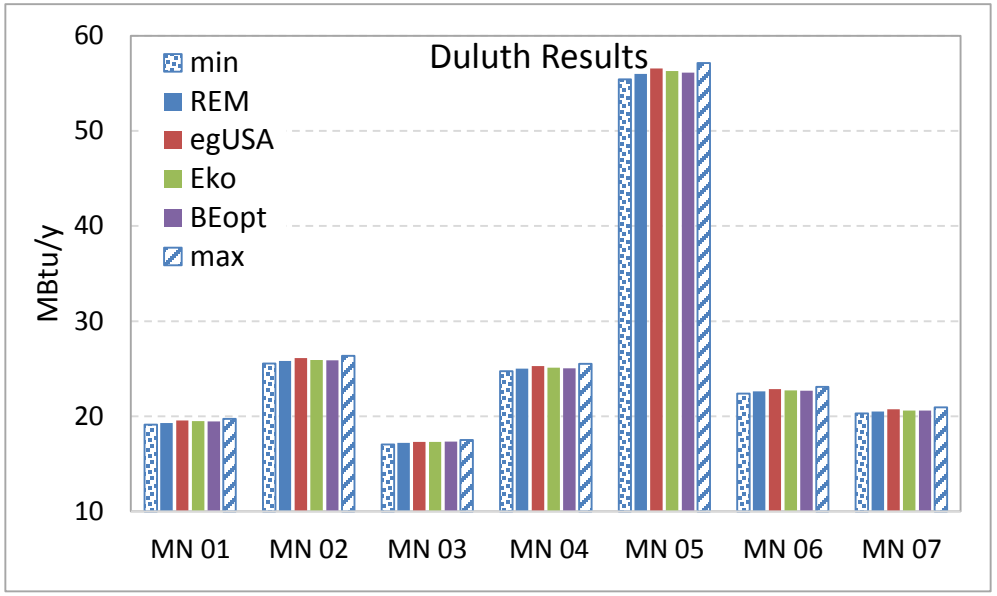
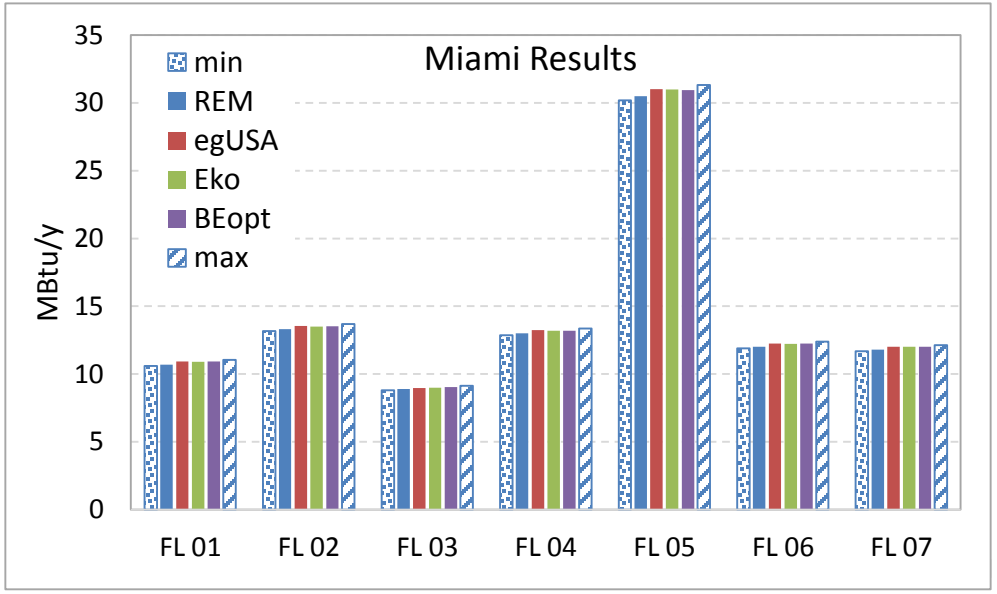
Software Verification Example: HERS Rating Tools

- All tools used to generate HERS ratings have to pass a series of tests, including water heating specific tests
- Includes cases with different draw volumes, distribution systems, and DWHR
- Designed to ensure consistency between different tools

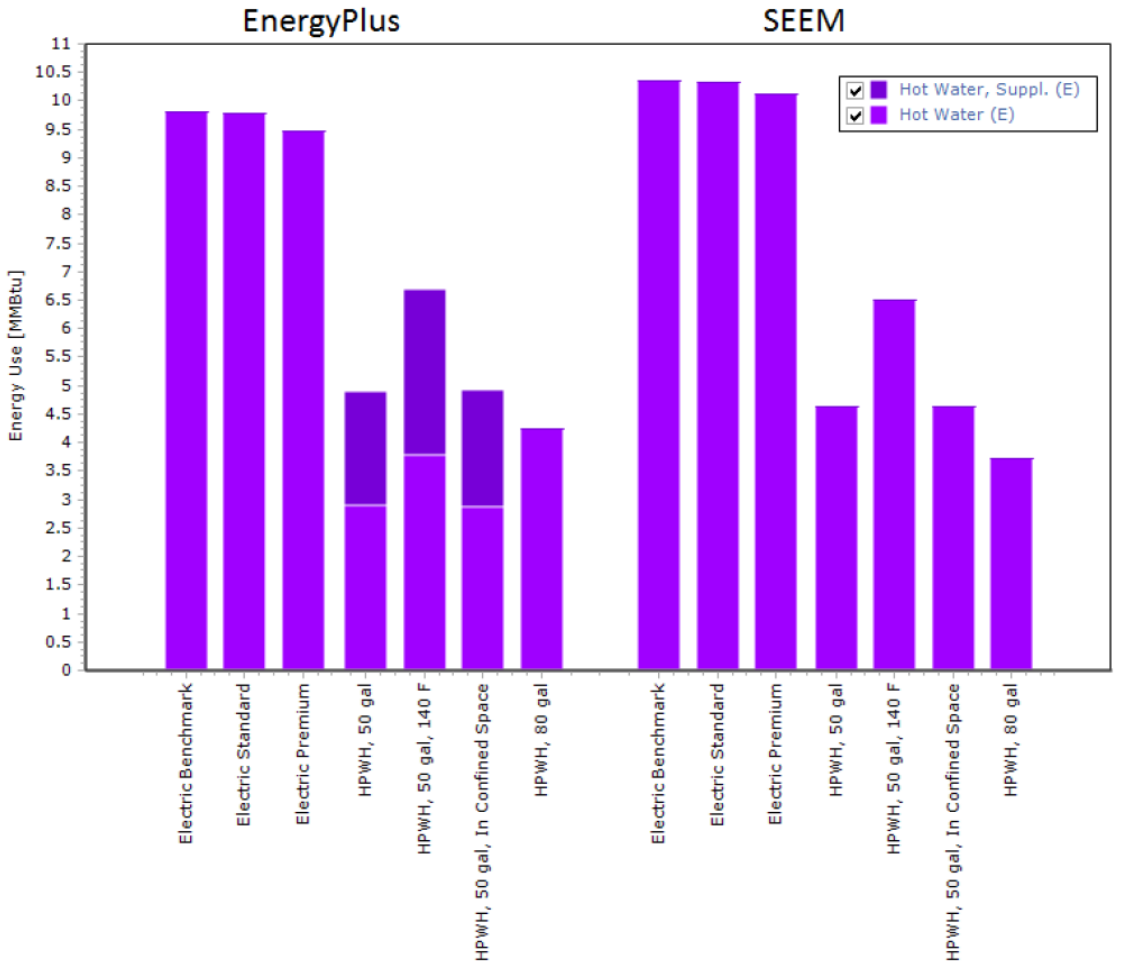






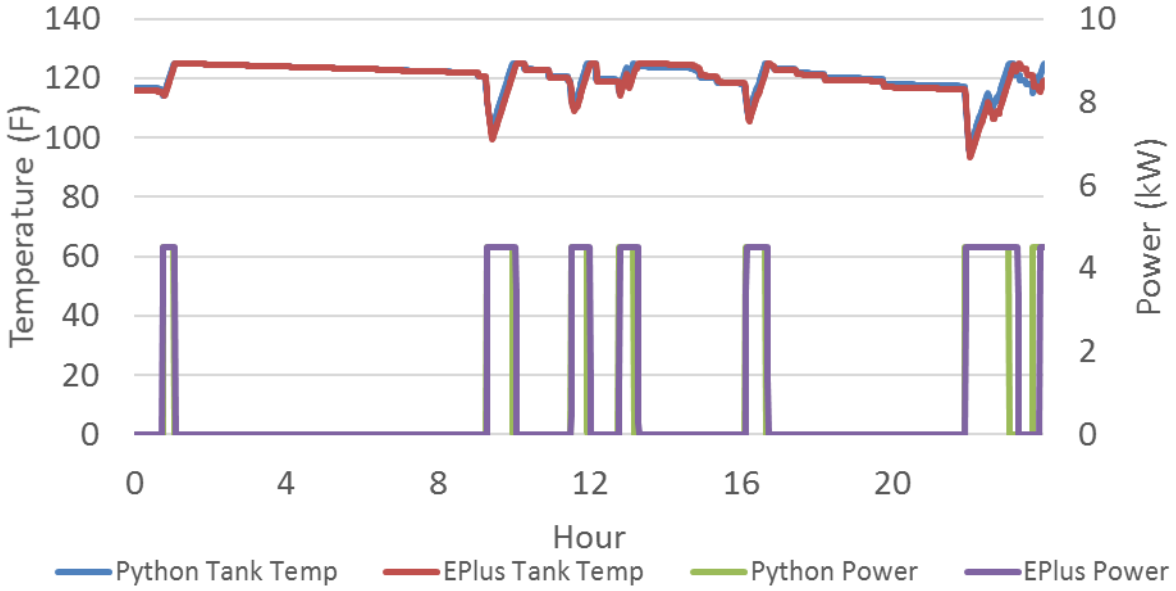
Software Verification Example: HPWH

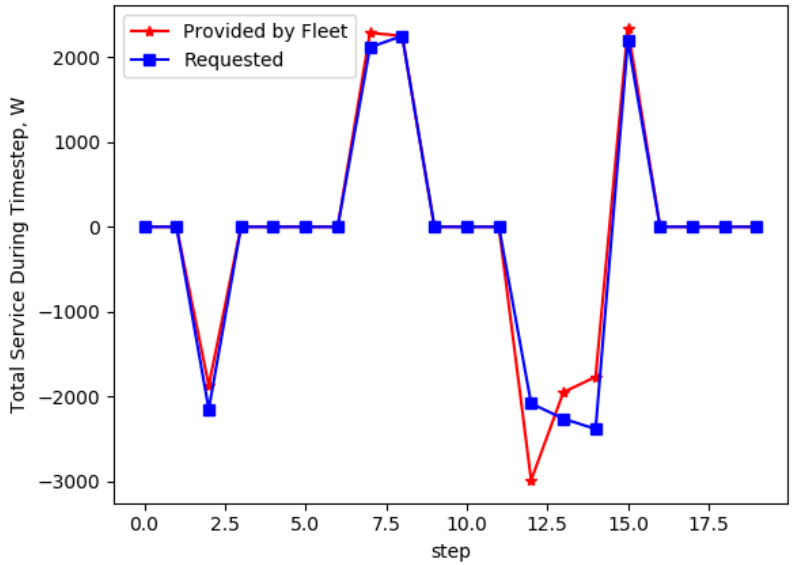
- Detailed comparisons of HPWH models in SEEM to BEopt-EnergyPlus
- Required work on the BEopt-EnergyPlus side to include all the functionality of SEEM
  - Software verification can encourage developers to add in new features
- Comparison revealed bugs that may otherwise have not been noticed



Software Verification Example: Grid Service Potential

- As part of a DOE GMLC project, modeling electric water heaters to try to evaluate the grid service potential of a fleet of water heaters
- Need to run a lot of water heaters quickly at small timesteps
  - Trying to use simpler models to minimize runtime
- Still a work in progress





Conclusions

The ideal way to fully validate a model would be:

- Use laboratory data to derive any necessary model parameters
  - Compare against other tests to ensure your calibration applies more generally
- Use field test data to ensure that your accurately represents the unit when installed in homes
  - Tweak if necessary
- Perform software to software validation to check performance at conditions not seen in the field or lab
  - Ideally, at least one tool has been compared to lab/field data