    

HPWH Modeling Improvements in EnergyPlus and BEopt

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Outline

- Introduction to modeling tools
  - EnergyPlus and BEopt
- EnergyPlus HPWH model
  - Algorithms, capabilities and limitations
- BEopt HPWH modeling
  - Capabilities and an examples
- Future work
  - Improvements to the HPWH model in EnergyPlus and BEopt

What is EnergyPlus (E+)?

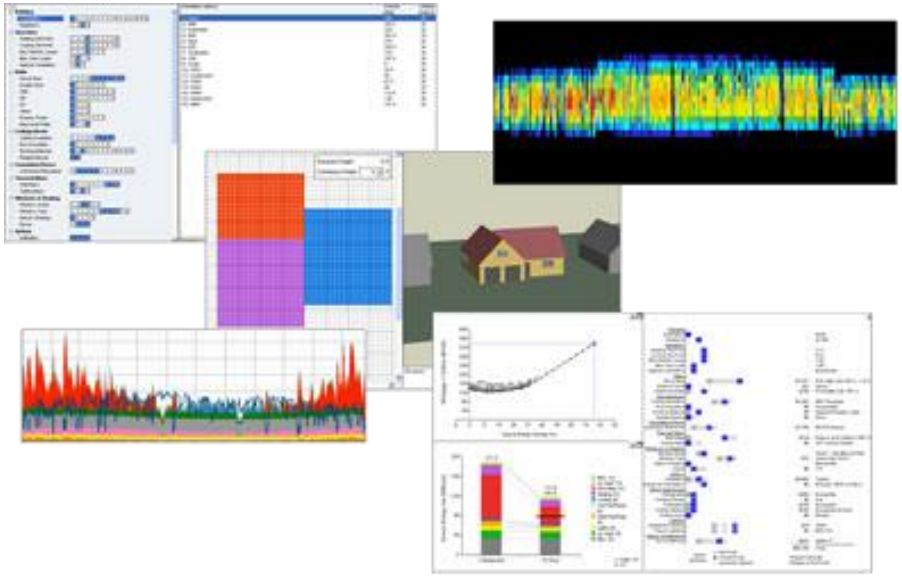
- EnergyPlus is a whole building, open source, energy simulation engine
- Developed and maintained by DOE and other partners
- EnergyPlus in the context of water heating:
    - Good energy consumption and delivered energy results
    - Capture interactions with space temperature/HVAC equipment
    - Not intended for WH design

What is BEopt?

BEopt
Building Energy Optimization
with Hour-by-Hour Simulations

NREL
National Renewable Energy Laboratory

- BEopt is a residential building simulation tool built on EnergyPlus
- Geometry tool and options library
    - Includes HPWH options corresponding to units on the market today
- Allows users without E+ experience to take advantage of it’s capabilities

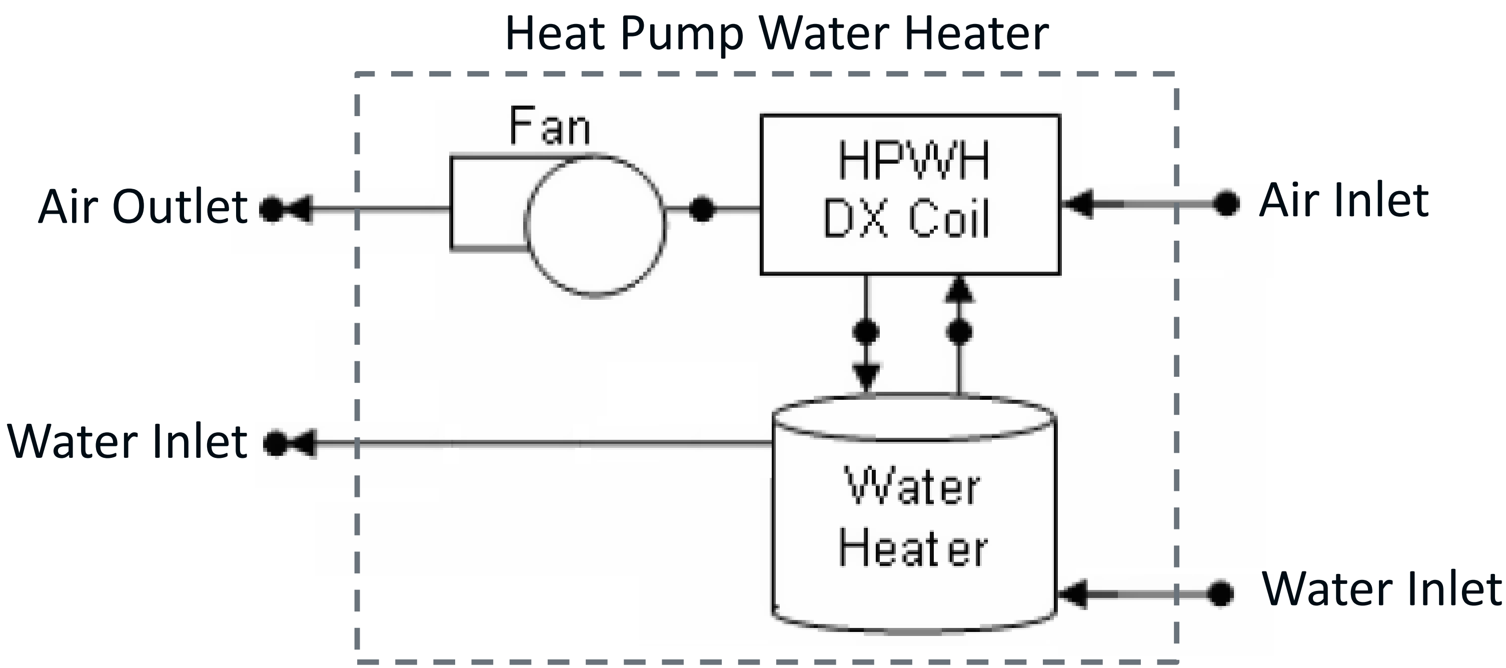


The Old EnergyPlus HPWH Model

- EnergyPlus has had a HPWH model for years, but it had some key limitations that made it difficult to use to model residential HPWHs
  - Mixed tank only (no stratification)
  - Pumped condenser
- New HPWH model allows for a stratified tank, wrapped condenser, and more detailed controls
  - Also fixed several HPWH related bugs

EnergyPlus HPWH Model

- EnergyPlus HPWH model is a compound object that combines a water heater tank, DX coil, and fan
- The HPWH model provides the overall control logic (HP vs. elements), defines how all the components are connected, and how the HPWH interacts with spaces in the building

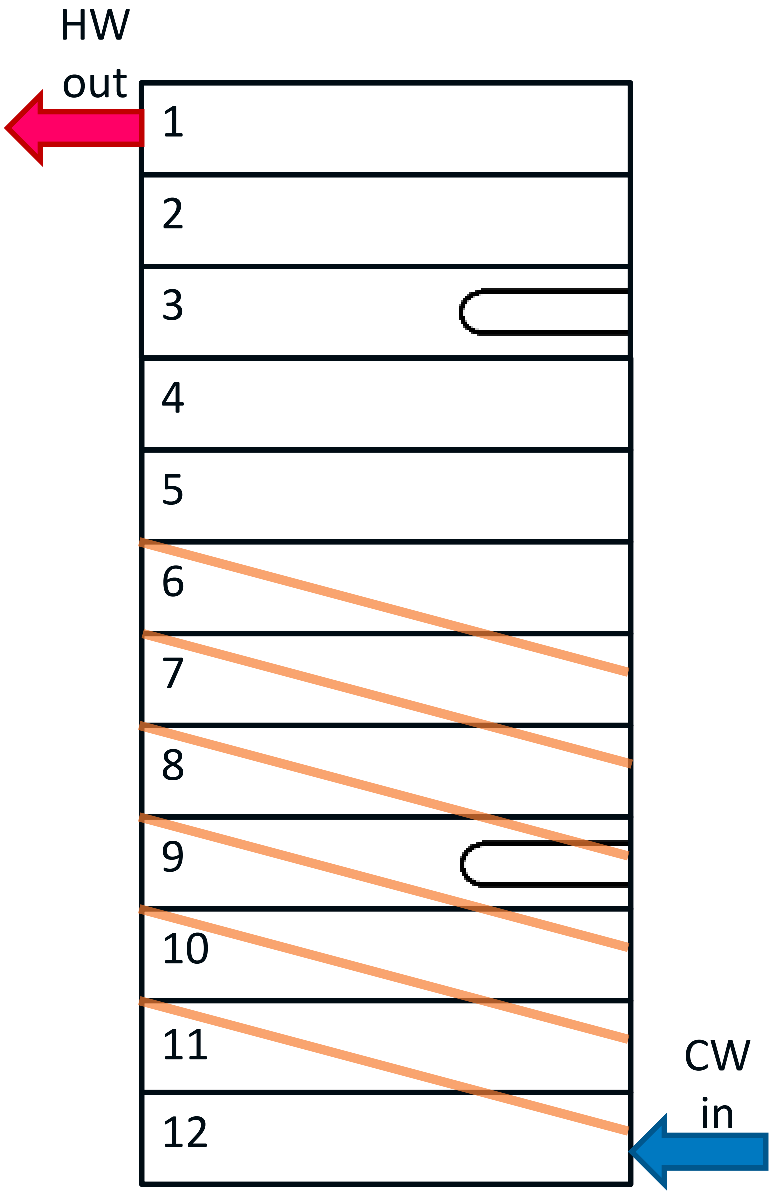


Wrapped Condenser HPWH model

- Allows specification of HPWH controls
  - Setpoints and deadbands for HP
  - Priority between elements and HP
  - Some more advanced controls done via E+ scripting
- Condenser location within the tank
  - Heat from the condenser is evenly distributed to all water heater nodes adjacent to the condenser
- HPWH location
  - Can use temperature schedule or zone temperature

EnergyPlus HPWH Model: Water Heater

- Water heater model consists of stratified storage tank, heating elements, and controls
- Tank is 1D model with 12 nodes to capture stratification
- Up to 2 electric elements
  - Can control independently or master/slave
- Controls based on node temperature



EnergyPlus HPWH Model: Water Heater Thermal Model

- For each node, solve an energy balance to get the node temperature

$$m_n c_p \frac{dT_n}{dt} = q_{net,n}$$

- $q_{net,n}$ takes into account heat transfer due to tank losses, flow through the tank, conduction to adjacent nodes, and mixing

$$q_{net,n} = q_{cond,n} + q_{loss,n} + q_{flow,n} + q_{mix,n}$$

Water Heater Thermal Model: Heat Transfer

- Conduction heat transfer calculated based on temperature difference between nodes

$$q_{cond} = \frac{kA_{n+1}}{L_{n+1}}(T_{n+1} - T_n) + \frac{kA_{n-1}}{L_{n-1}}(T_{n-1} - T_n)$$

- Tank losses based on overall UA of tank and ambient temperature

$$q_{loss,n} = (UA_{tank})(T_{amb} - T_n)$$

- Flow heat transfer based on flow rate and adjacent node temperature
  - Bottom node uses mains water temp

$$q_{flow,n} = \dot{m}_{n+1}c_p(T_{n+1} - T_n) + \dot{m}_{n-1}c_p(T_{n-1} - T_n)$$

Water Heater Thermal Model: Mixing

- Mixing heat transfer calculated based on the mixing flow rate and adjacent node temperatures

$$q_{mix,n} = \dot{m}_{mix,n+1} c_p (T_{n+1} - T_n) + \dot{m}_{mix,n-1} c_p (T_{n-1} - T_n)$$

- Mixing flow is used to resolve any temperature inversions in the tank. The flow rate is the max allowed that provides a stable solution

$$\dot{m}_{invmix} = 0.5 \cdot \frac{m_n}{\Delta t}$$

- Mixing occurs between all nodes

Water Heater Thermal Model: Numerical Solutions

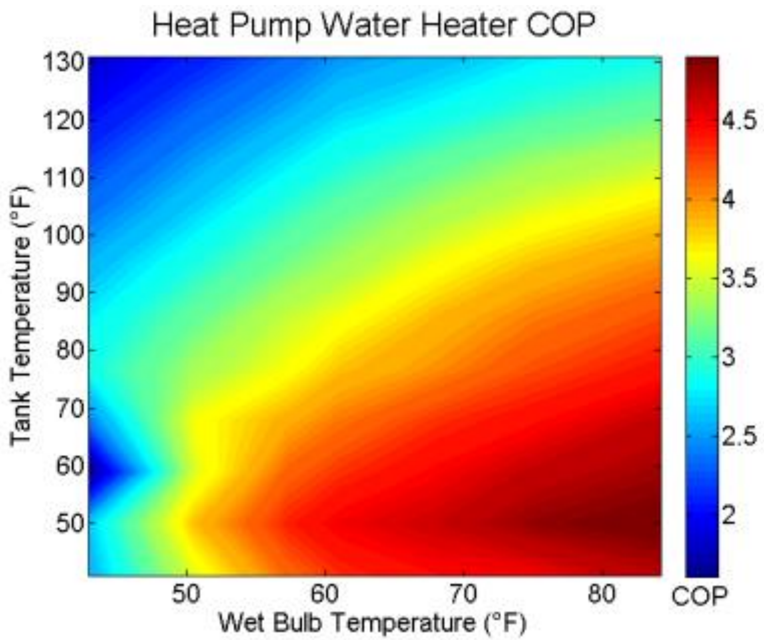
- The tank is broken down into a system of differential equations, solved simultaneously
  - Forward-Euler method
  - Solved for 1 second sub-timesteps

$$T_n = T_{n,old} + \frac{q_{net,n}\Delta t}{m_n c_p}$$

- Before solving, determine the flow rate through the tank, if the heating elements/HP should be on, if temperature inversions exist, and if top of tank has overheated

EnergyPlus HPWH Model: DX coil

- Heat pump is modeled using a single speed DX coil object
- Performance map based approach to modeling heat pump capacity, COP
  - Biquadratic equations for each as a function of average tank temperature adjacent to condenser and ambient wet bulb
- SHR calculated with ADP/BF method
  - Analogous to effectiveness/NTU approach



BEopt HPWH model

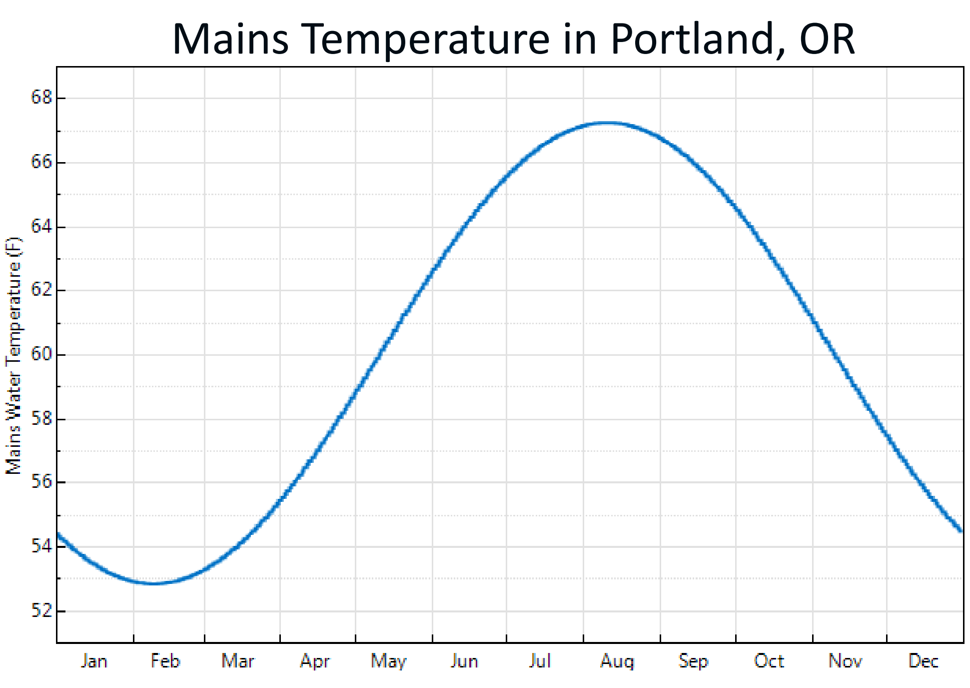
- When users select a HPWH object in BEopt, that option gets translated into an E+ input file
- BEopt includes code for HPWH performance maps, tank properties, control logic, and interaction with the ambient zone
- BEopt also includes annual draw profiles and mains water temperature

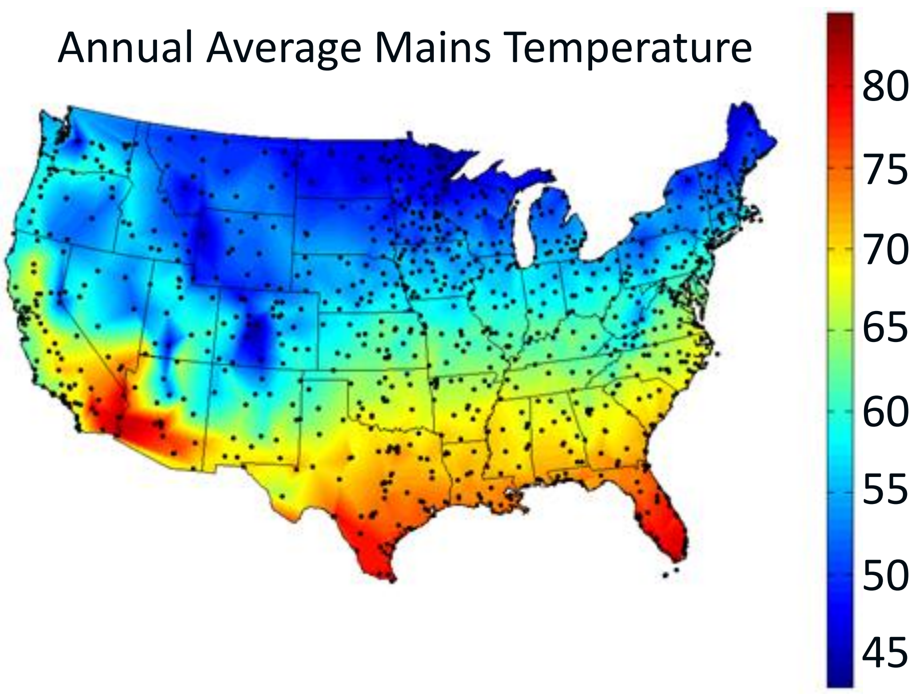
BEopt HPWH Model: Control Logic

- Control logic for each BEopt model is unit specific
  - Derived directly from lab testing results
- Since each manufacturer has rather unique control logic, implemented in EMS scripts
  - EnergyPlus allows users to specify if element and heat pump can run simultaneously and use a weighted average temperature to control the heat pump
- Controls take into account priority between top element, bottom element and HP

BEopt HPWH model: Mains Water Temperature

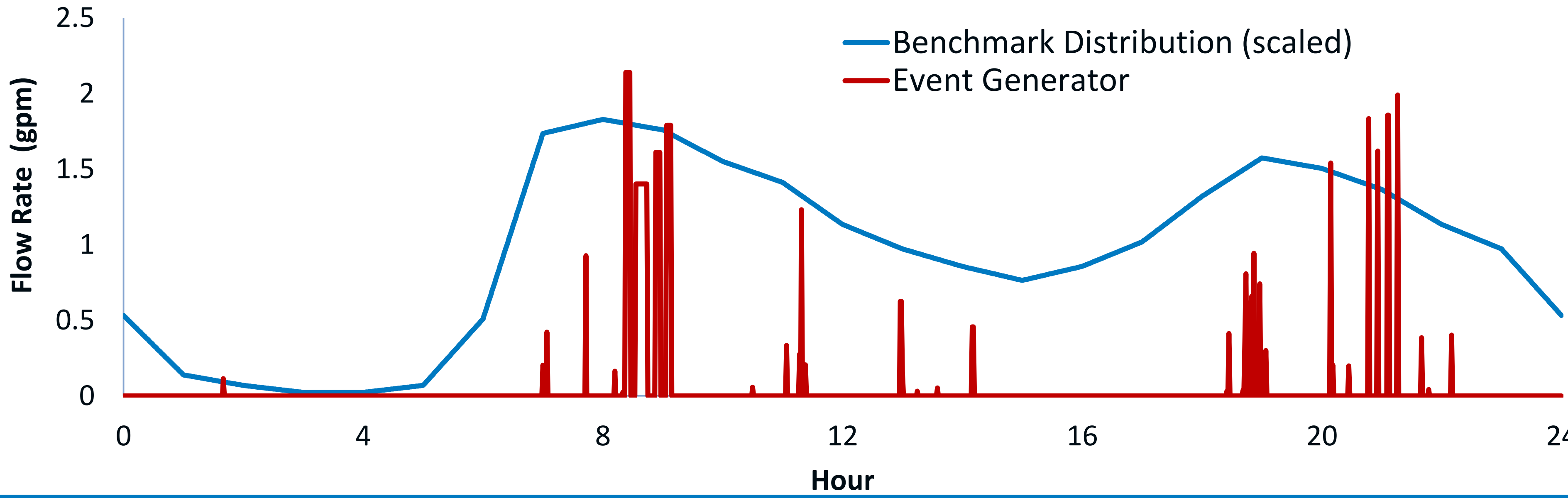
- Based on algorithm developed at NREL
  - Sinusoidal annually, with values that depend on min/max ambient air temperature
- Incorporated directly into EnergyPlus





BEopt HPWH Model: Draw Profile

- Annual, discrete draw profile for each end use in the home
- Mixed and hot events
- Based on the BA DHWESG
- Each day has a different draw profile, but the annual average for each end use represents typical profiles

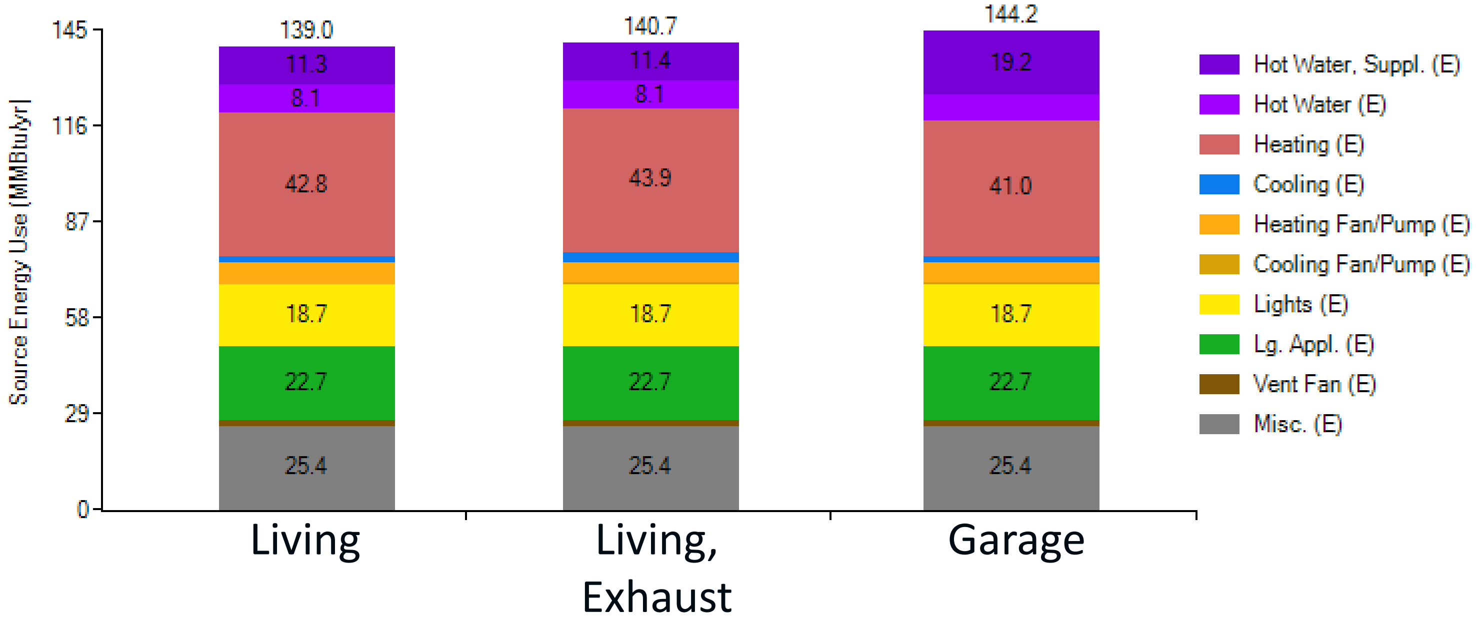


BEopt HPWH model: Interaction with building model

- Sensible and latent cooling from the heat pump impacts the loads of the space it's installed in
- BEopt includes "interaction factor" and self cooling
- Supply, exhaust, or balanced ducting to the outside

HPWH Example: Where should I install my HPWH?

- 50 gal HPWH, 55 gal/day, ASHP, in Portland, OR
- Living space installation is assumed in a utility closet, not co-located with anything that would provide waste heat



What’s next?

- Migrating BEopt to OpenStudio
  - Maintain existing HPWH modeling capabilities in new platform
- EnergyPlus: Speeding up HPWH model runtime
  - Better solvers for iterating tank temperature in stratified tank.
- BEopt: Updating HPWH models with newer performance data
- BEopt: “Generic” models that use EF to determine efficiency
- Always open to feature requests!

Questions?