Understanding HPWH Interaction with Space Conditioning Systems in the Field

ACEEE Hot Water Forum 2018

Session 5B

Heat Pump Water Heaters and The Last Mile: Installation, Implementation, and Answers to Lingering Questions

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RESEARCH
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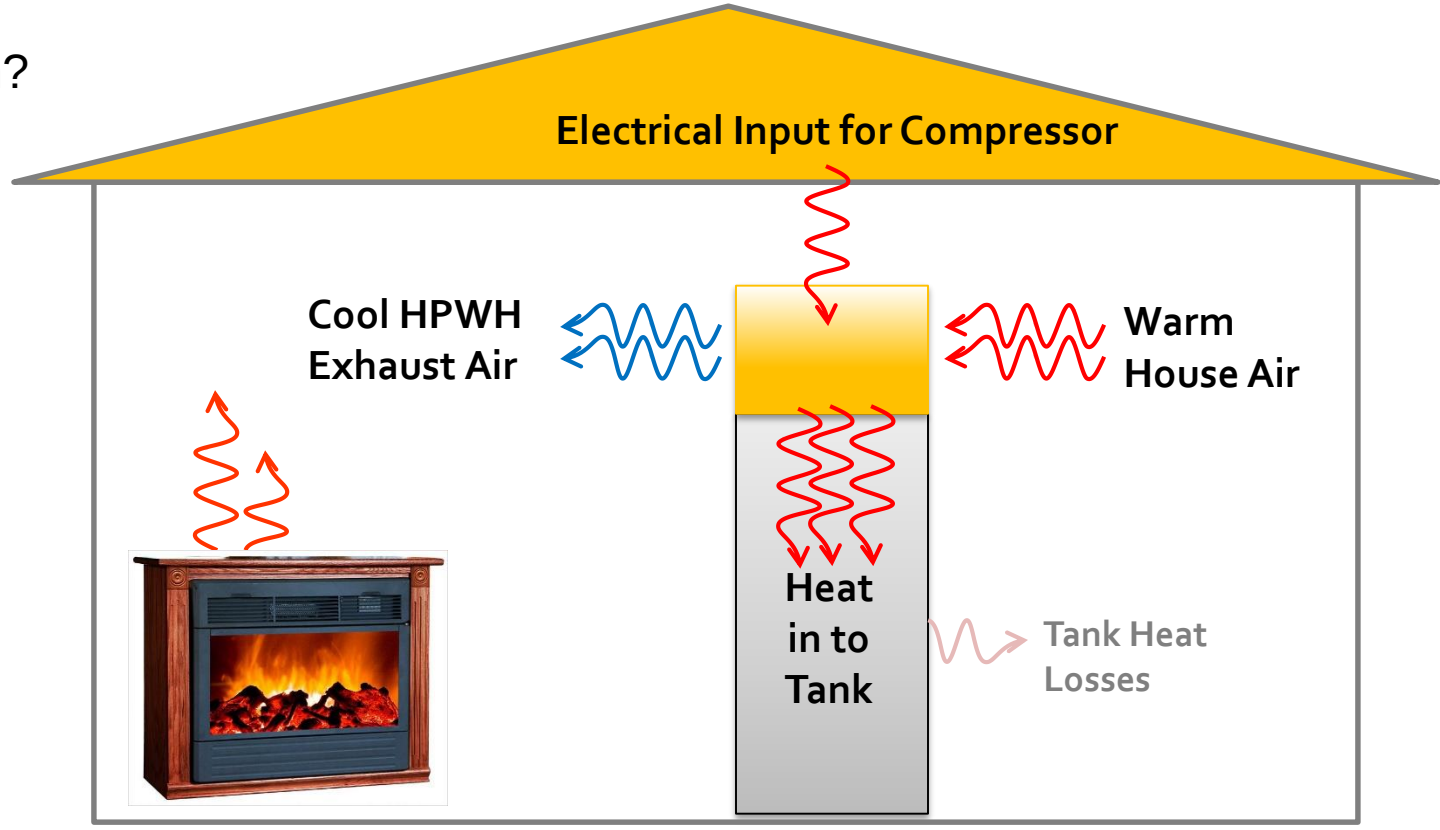
Problem Statement

- For heat pump water heaters installed inside a conditioned space, not every unit of energy removed from the air by the HPWH is replaced by the space conditioning system.
  - Why?
  - How Much?



Energy Removed from Air

- Q_{HPWH} is energy moved from air to water tank
- E_{HPWH} is work done on the system by the compressor

$$Q_{HPWH} = Q_{hotwater} - E_{HPWH}$$

$$Q_{hotwater} = m_{water} \times C_{p,water} \times (T_{water\_out} - T_{water\_in})$$

E_{HPWH} = measured HPWH electricity input

Evidence for $I_f < 1$

- Controlled Experiments (found If < 1)
  - PNNL Lab Homes 1:
    - Widder SH, JM Petersen, GB Parker, and MC Baechler. 2014. *Impact of Ducting on Heat Pump Water Heater Space Conditioning Energy Use and Comfort*. PNNL-23526, Pacific Northwest National Laboratory, Richland, Washington.
  - PNNL Lab Homes 2:
    - Widder, S, C. Metzger, J. Petersen, and J. McIntosh. 2017 *Interaction between Heat Pump Water Heaters or Other Internal Point Source Loads and a Central Heating System.* PNNL-26447 Pacific Northwest National Laboratory, Richland, Washington.
  - Florida Solar Energy Center:
    - Colon, C, Martin, E, and Parker, D. 2016a. *Effect of Ducted HPWH on Space-Conditioning and Water Heating Energy Use--Central Florida Lab Home.* FSEC-CR-2050-16. Florida Solar Energy Center; Building America Partnership for Improved Residential Construction, Cocoa, Florida.
    - Colon, C, Martin, E, Parker, D, and Sutherland, K. 2016b. *Measured Performance of Ducted and Space-Coupled Heat Pump Water Heaters in a Cooling Dominated Climate.* FSEC-RR-644-16, Florida Solar Energy Center, Cocoa, Florida.
  - Natural Resources Canada (unpublished)
- Field Work (generally inconclusive yet suggestive)
  - Ecotope. 2015. *Heat Pump Water Heater Validation Study*. Report #E15-306, Seattle, Washington.
  - Shapiro, C and S Puttaguntha. 2016. *Field Performance of Heat Pump Water Heaters in the Northeast.* Consortium for Advanced Residential Buildings, Norwalk, Connecticut.

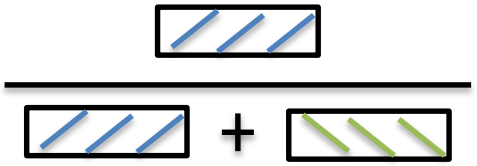
Definitions

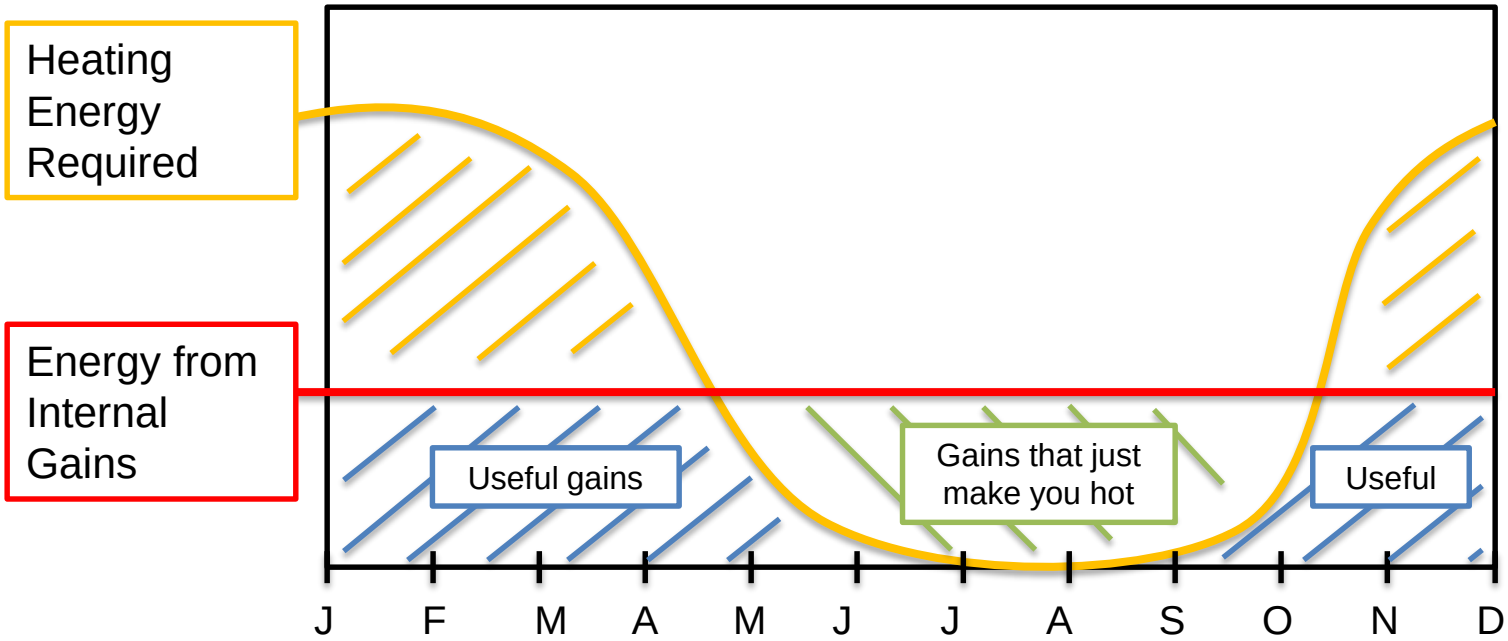
- Thermal Utility
  - Ratio of heating energy offset to non-heating energy (internal gains) input. Typically calculated annually.
- Annual Interaction
  - Increased space heating requirement across the year expressed as a percentage of the total possible additional space heating load from the HPWH.
- Simulation Interaction Factor
  - Amount of energy removed from the space over a given time step within a building energy simulation, expressed as a percentage of the full complement of energy theoretically removed by the HPWH.
- Thermal Distance
  - Or “Coupling” – a qualitative measure of how closely the temperatures in one room of the house track the main house temperature.

Definition: Thermal Utility

- Tells you if “waste heat” is useful or not
- The ratio of useful internal heat gains to total gains that offset a heating requirement
- Example:
  - Heating is required in a house for 6 months of the year
  - Internal gains are 2,000 kWh/yr

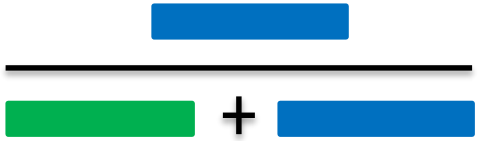
    → Useful gains are 1,000 kWh/yr. Thermal utility is 0.5.

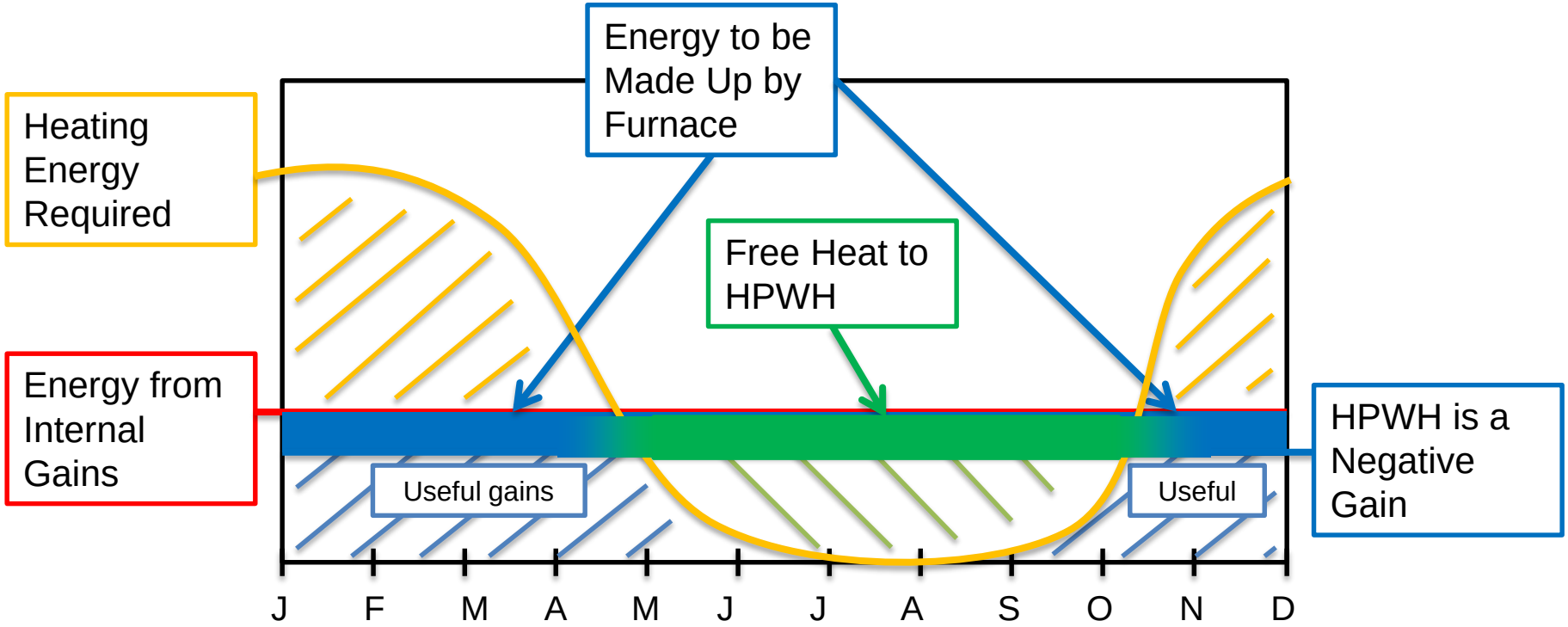




Definition: Annual Interaction

- Ratio of energy made up by furnace to total energy removed from air
- Example:
  - Annual water heating energy need: 3,000 kWh
  - HPWH COP = 3 means 2,000 kWh of heat removed
  - Suppose space heating load increases 500 kWh
  - Then annual interaction is 500 / 2,000 = 1/4





Example HPWH Annual Interactions

- Example assumes *every* unit of energy removed from the air by the HPWH is made up by the furnace

City	Heating Degree Days Base 65	Energy Extracted from Air by HPWH (kWh/yr)	Heating System Energy Change (kWh/yr)	Annual Interaction
Seattle	4,641	2031	1477	0.73
Portland	4,187	2001	1358	0.68
Spokane	6,716	1864	1312	0.70
Boise	5,396	1882	1198	0.64
Kalispell	7,928	1999	1470	0.74

- Results will vary with: house insulation levels, internal gains, & climate

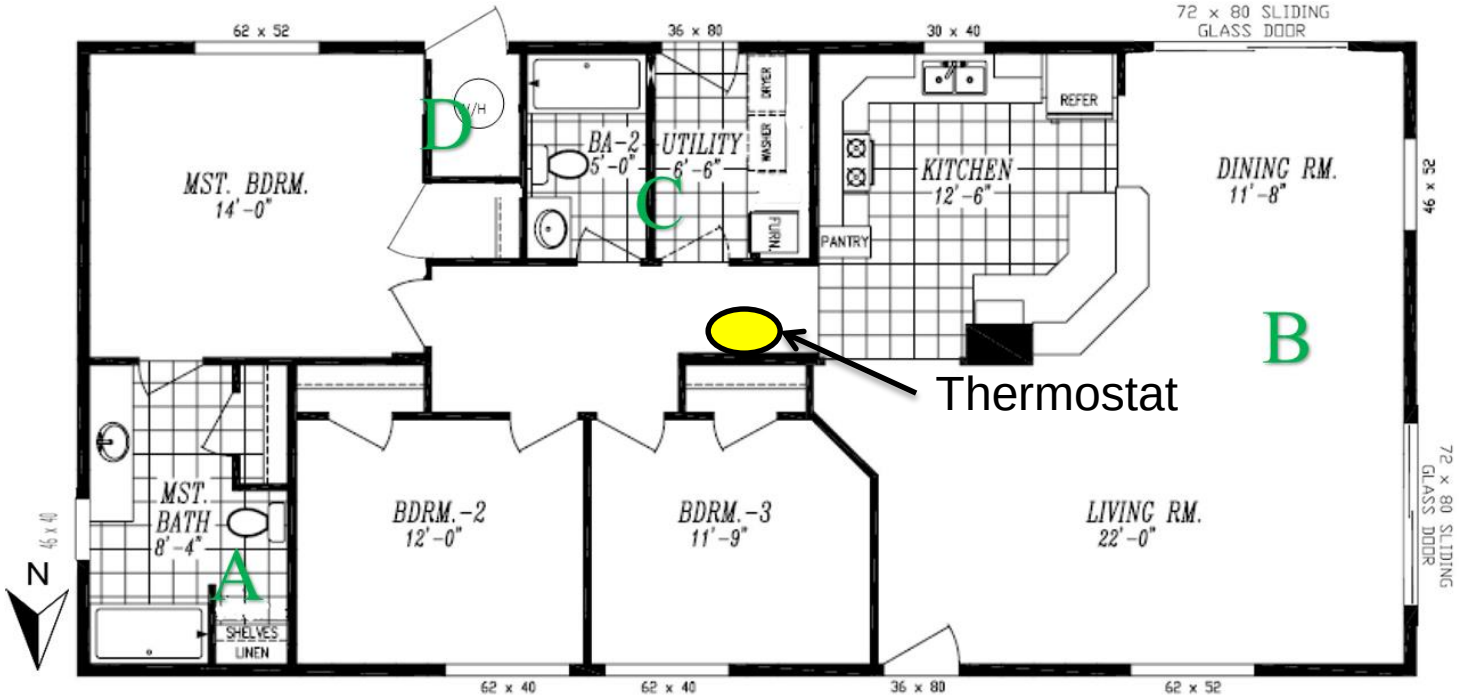
Definition: Simulation Interaction Factor

- Amount of energy removed from the space over a given time step within a building energy simulation, expressed as a percentage of the full complement of energy theoretically removed by the HPWH.
- Necessity arises due to oversimplifications in simulations
  - Houses are not single, well-mixed zones
  - HPWHs remove moisture from the air (latent heat removal)
- Also used to *calibrate* a building energy simulation

$$Q_{Load} = UA\Delta T - Q_{IntGains} - Q_{solar} + Q_{HPWH}*SIF$$

Lab Home Test Scenario Attributes

Water Heater Install Location	Connection Regime to House	Heat System Connection	Volume (ft^3)
Master Bath	Door Closed	Supply Register	952
Living Room	Open	Supply Register	3197
Utility Room	Door Open	Return	464
Water Heater Closet	Enclosed – Transfer grills	None	31



Manufacturers specify installations in spaces with at least 800ft^3 of space or transfer grills.

Lab Homes Findings

Location	Physical Interaction Factor	Average Daily Localized Cooling (°F)	Max Hourly Localized Cooling (°F)	Thermal Distance
	Mean			
Master Bath	.57	13.8 ± 2.1	21.8 ± 3.0	**Far**
Living Room	.82	1.7 ± 1.9	3.2 ± 2.3	**Near**
Utility Room	1.4	2.1 ± 1.9	3.2 ± 1.8	**Near**
Water Heater Closet	.47	9.9 ± 2.8	18.0 ± 5.1	**Far**

- Range of interaction factors observed. Noticeable difference between installation locations – in other words, this is a real effect
- Localized cooling is the average daily temperature depression experienced in the space where the water heater is installed

Definition: Thermal Distance

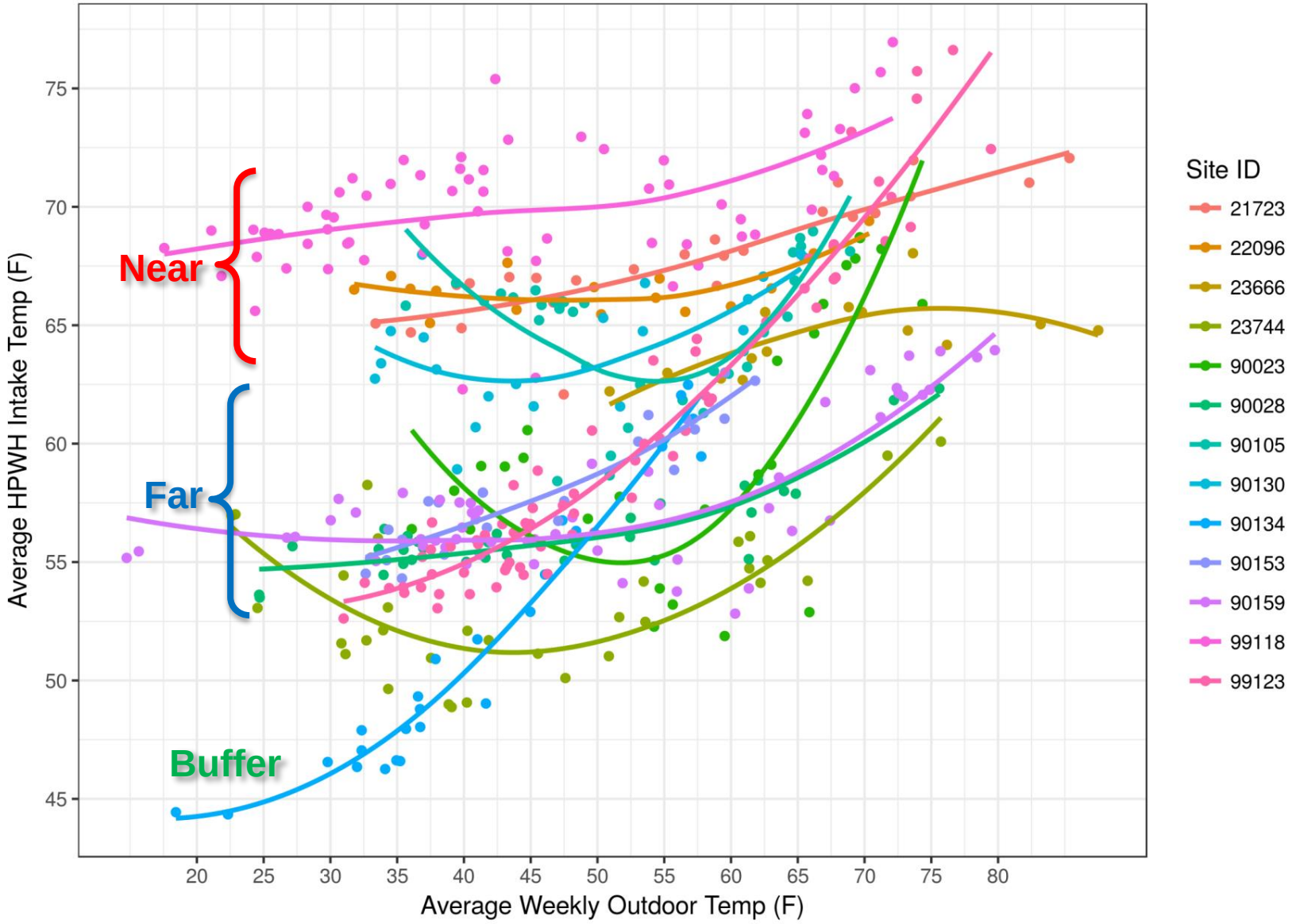
- Or “Thermal Coupling” – a qualitative measure of how closely the temperatures in one room of the house track the main house temperature.

Thermal Distance	Temperature Below Main Conditioned Zone	Notes
Near	< 5F	The space temperature is maintained.
Far	5 – 15F	The space temperature drops.
Buffer	> 15F	The space temperature is below any conceivable “conditioned” space temperature. These behave like buffer spaces.

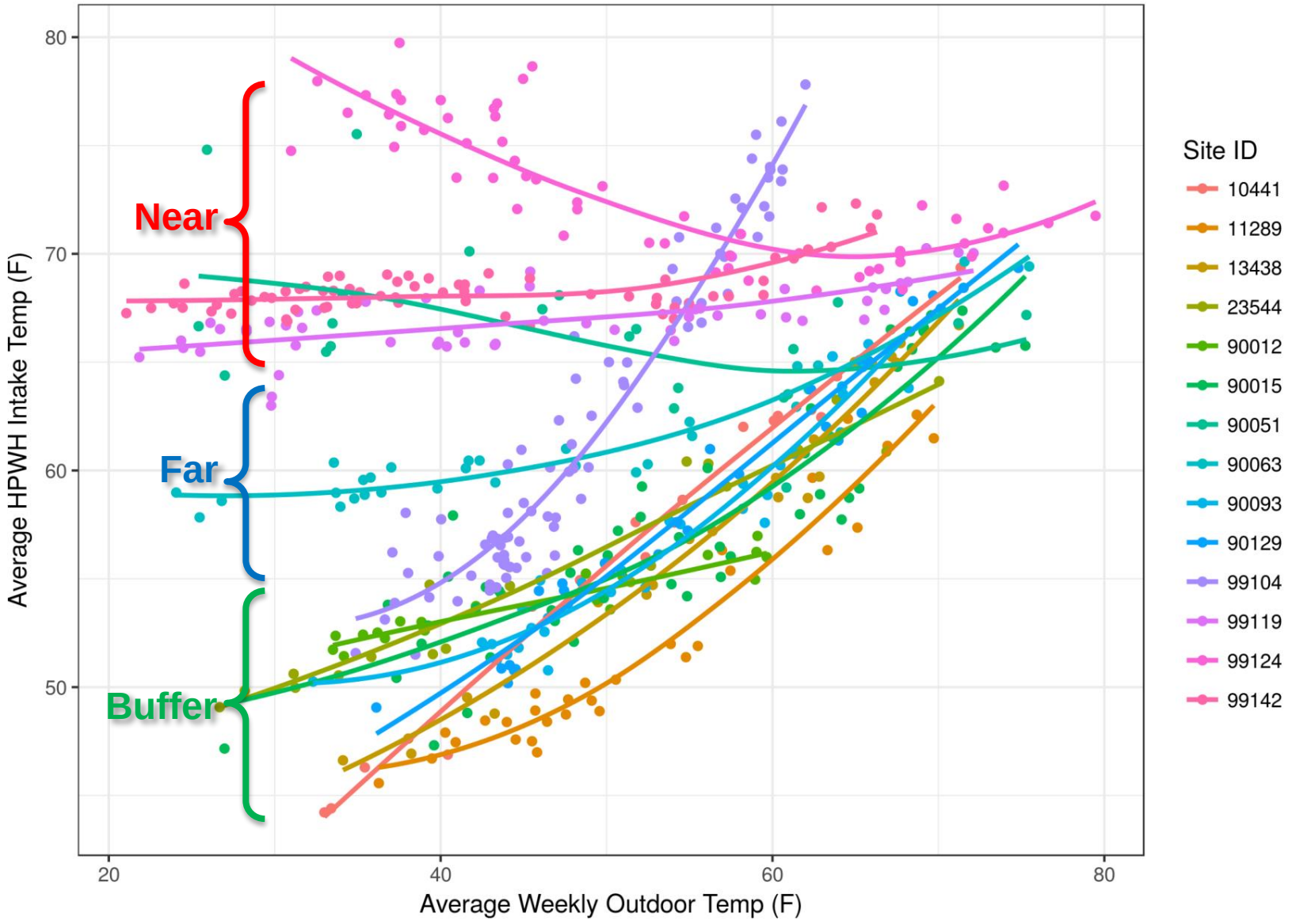
Field Measured HPWH Source Air T

- Following two graphs from Ecotope field study conducted for NEEA
- All water heaters installed inside a space identified as conditioned

Conditioned Main Floor Locations

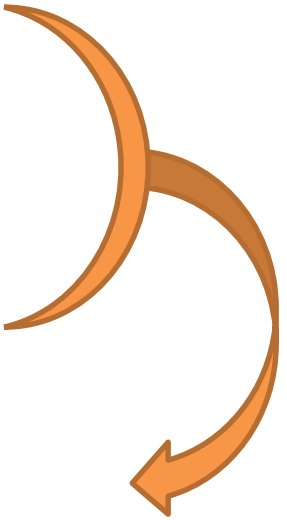


Conditioned Basement Locations



Generalizing Findings

- Thermal distance provides the link between lab homes and field sites
- Building Stock Assessments identify type & location of installation
- Combined data gives method to weight lab homes findings



Simulation Interaction Factor: 0.68

Annual Interactions with SIF

		Simulation Interaction Factor			
		1.0		0.68	
City	Energy Extracted from Air by HPWH (kWh/yr)	Heating System Energy Change (kWh/yr)	Annual Interaction	Heating Energy Change (kWh/yr)	Annual Interaction
Seattle	2031	1477	0.73	988	0.49
Portland	2001	1358	0.68	911	0.46
Spokane	1864	1312	0.70	863	0.48
Boise	1882	1198	0.64	782	0.43
Kalispell	1999	1470	0.74	877	0.50

- Results will vary with: house insulation levels, internal gains, & climate

Conclusions I

- Persistent, localized cooling and latent cooling reduce effective load on heating system in winter by 1/3 (simulation interaction)
- In heating dominated climates:
  - HPWHs interact with space heating system 60-75% of year (annual interaction)
  - Over the course of the year, 1/2 of all heat removed from air by HPWH is replaced by the heating system
- Methods and results also applicable to cooling system interaction

Conclusions II

- Energy Implications for Installation
  - In new construction, optimum location of garage, buffer space, or conditioned space depends on climate
  - In existing construction, installs inside conditioned space work just fine

Q & A

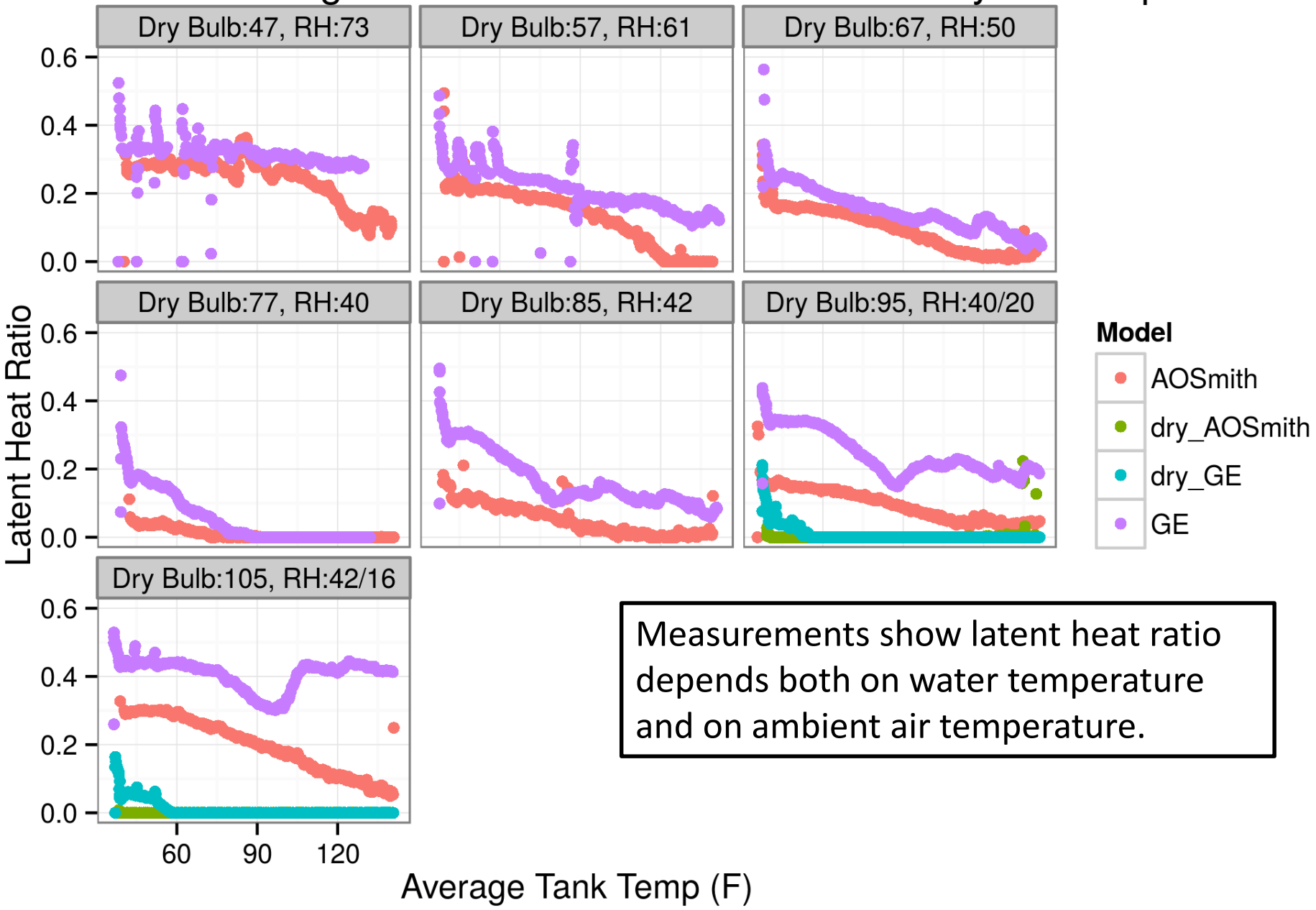
- Thanks!

Backup Slides

Factors and Weights

Thermal Distance	Lab Homes Scenario	Observed Factor	Proposed Factor	Rationale	Weight
Near	Living Room	0.82	0.82	Use Living Room scenario only. Water heaters not installed next to thermostats.	33%
	Utility Room	1.4			
Far	Water Heater Closet	0.47	0.52	Average both scenarios to create a factor for "far" thermal distances	30%
	Master Bath	0.57			
Buffer	na	--	0.0	Any change to buffer space temperature interacts only weakly, if at all, with the conditioned house.	37%

BPA HPWH Testing - Latent Heat Ratio in COP Tests by Air Temp



Measurements show latent heat ratio depends both on water temperature and on ambient air temperature.