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Space Conditioning Interactions with Heat Pump Water Heaters: A Test in the PNNL Side-by-Side Lab Homes

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March 22, 2018
ACEEE Hot Water Forum
Portland, OR

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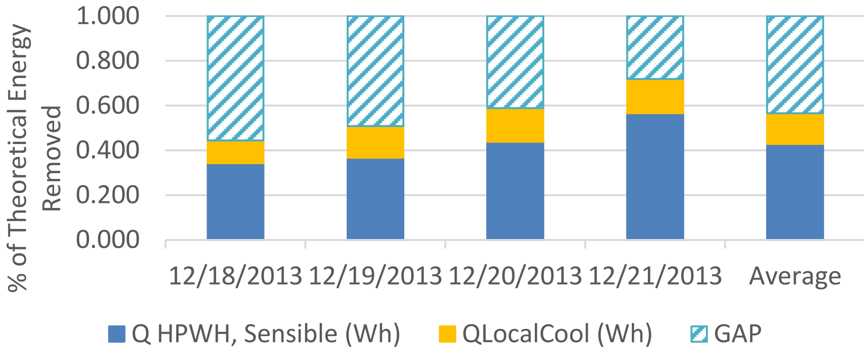
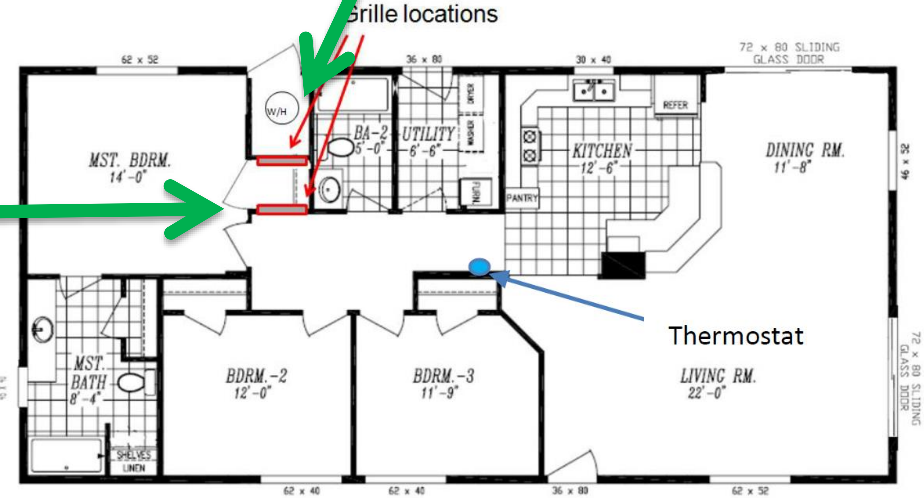
BACKGROUND

Results from Previous Studies

- Previous work in PNNL Lab Homes suggest that the space conditioning system may not necessarily make up 100% of the heat removed from the air
  - 43 ± 12% in heating season and 37 ± 5% in cooling season for water heater closet location



Water heaters in water heater closet. Only access from exterior.



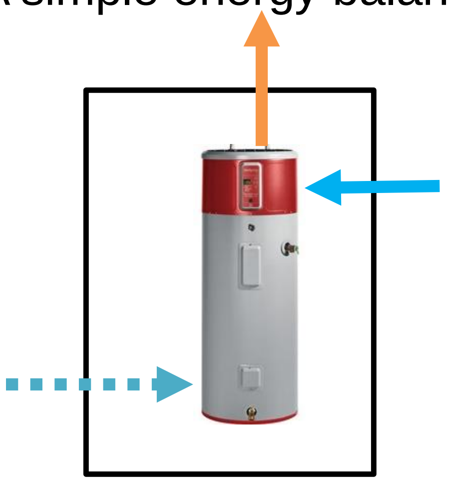
Installed grilles aiming to simulate HPWH in conditioned space.

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, WA.

- No other field studies have successfully measured HPWH interaction factor

Interaction of HPWH and HVAC System

- In general, previous models have assumed the cooling load introduced by the HPWH must be 100% made up by the HVAC system based on an energy balance on the water heater
  - A simple energy balance would suggest:



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

$$Q_{hotwater} = m_{H2O} \times C_{p,H2O} \times (T_{out,H20} - T_{in,H20})$$

E_{HPWH} = measured HPWH electricity use

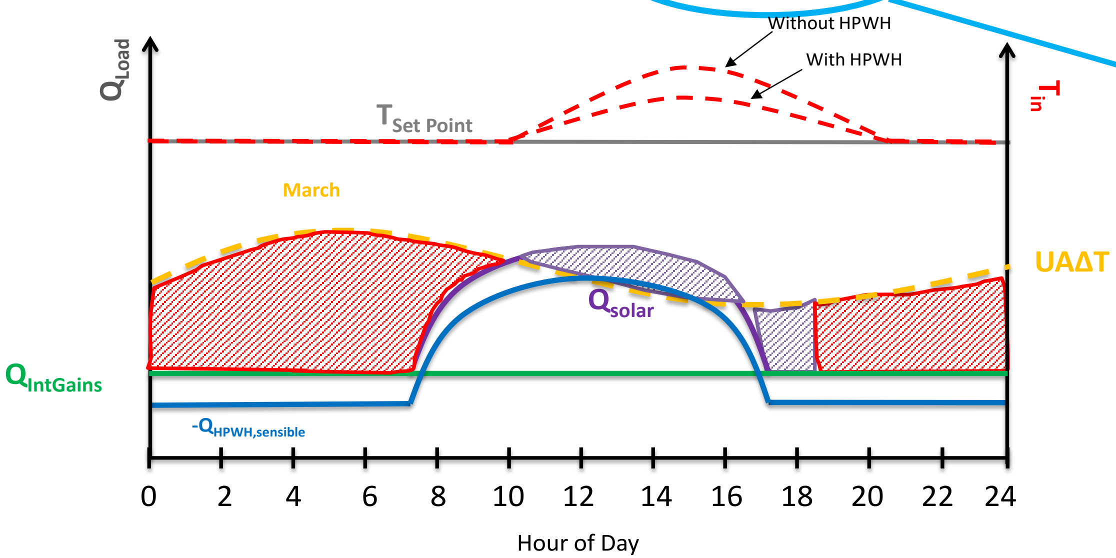
  - Models include BeOpt,[2,3] SEEM,[4] and DOE's Residential Water Heater Energy Use Analysis.[5]
    - SEEM and BeOpt should account for solar impacts
    - BeOpt may account for latent impact

[2] Wilson E and D Christensen. 2012. *Heat Pump Water Heater Modeling in EnergyPlus*. NREL/PR-5500-54318, National Renewable Energy Laboratory, Golden, CO.
[3] Maguire J, J Burch, T Merrigan, and S Ong. 2013. *Energy Savings and Breakeven Cost for Residential Heat Pump Water Heaters in the United States*. NREL/TP-5500-58594, National Renewable Energy Laboratory, Golden, CO.
[4] Larson B, M Logsdon, and D Baylon. 2011. *Residential Heat Pump Water Heater Evaluation: Lab Testing & Energy Use Estimates*.
[5] U.S. Department of Energy. "10 CFR Part 430 Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule." 75 FR 20112. April 16, 2010.

Theoretical Interaction

- HVAC system may not need to make up 100% of energy removed because:
  1. Some of the heat from the space is **latent heat** ($Q_{HPWH,latent}$), which will not affect the ambient dry bulb temperature of the space
  2. **Localized cooling** may decrease the heat transfer from the space as compared to the pre-retrofit case ($UA\Delta T_{HPWH} < UA\Delta T_{no\ HPWH}$)
  3. Some of the heat imparted to the water heater from the space may be **"free heat" from solar gains (Q_{solar})** that would also decrease the total heat transfer from the space if the house drifts above set point

$$Q_{HPWH,theoretical} = Q_{HPWH,sensible} + Q_{HPWH,latent} - Q_{localcool} - Q_{extrasolar}$$



$$Q_{HVAC} = Q_{Load} = UA\Delta T - Q_{IntGains} - Q_{solar}$$

$$Q_{IntGains} = Q_{HeatGains} + Q_{HPWH,sensible}$$

Motivation

- November 2014, RTF accepted a preliminary interaction factor (HC_f)= 65% based on preliminary data from the PNNL Lab Homes.[1]
- The RTF also directed staff to develop a research plan to study the HVAC interaction effect induced by heat pump water heaters (HPWHs), which was accepted in April 2015.
- Research plan consists of two primary components:
  1. Theoretical analysis (Ecotope) to describe basis for F_{HPWH}
  2. Experimental study in the PNNL Lab Homes to determine/validate range of expected field F_{HPWH} values

[1] Widder, et al. 2015. "Impact of Ducting on Heat Pump Water Heater Space Conditioning Energy Use and Comfort." PNNL-23526. Pacific Northwest National Lab. Richland, WA.

TEST PLAN & EXPERIMENTAL SET UP

Research Strategy: PNNL Lab Homes

(from April 2015 RTF meeting)

- **Research Goal**
  - Observe the space conditioning energy interaction that results from the installation of a HPWH in interior spaces
- **Data Collection**
  - PNNL Lab Home Study: Test four install locations throughout home
    - Use a HPWH on a dolly operating on a known "high" load profile compared to a ERWH operating in the baseline home
- **Analysis**
  - Compute change in space heating requirement, change in latent heat across the coil, and any impact on localized cooling to compute HVAC interaction factor for each location
  - Observe range of results
    - depending on range, results may be combined (averaged) if within a narrow band, or results could point to needing additional measure identifiers

What are Lab Homes in General?

- Test houses that belong to the research community for a long term
- High precision monitoring devices
- Most experimental research questions relate to:
  - Initial product testing
  - System/integrated performance
  - Weather dependency
- Often have some simulated occupancy

Experimental Plan

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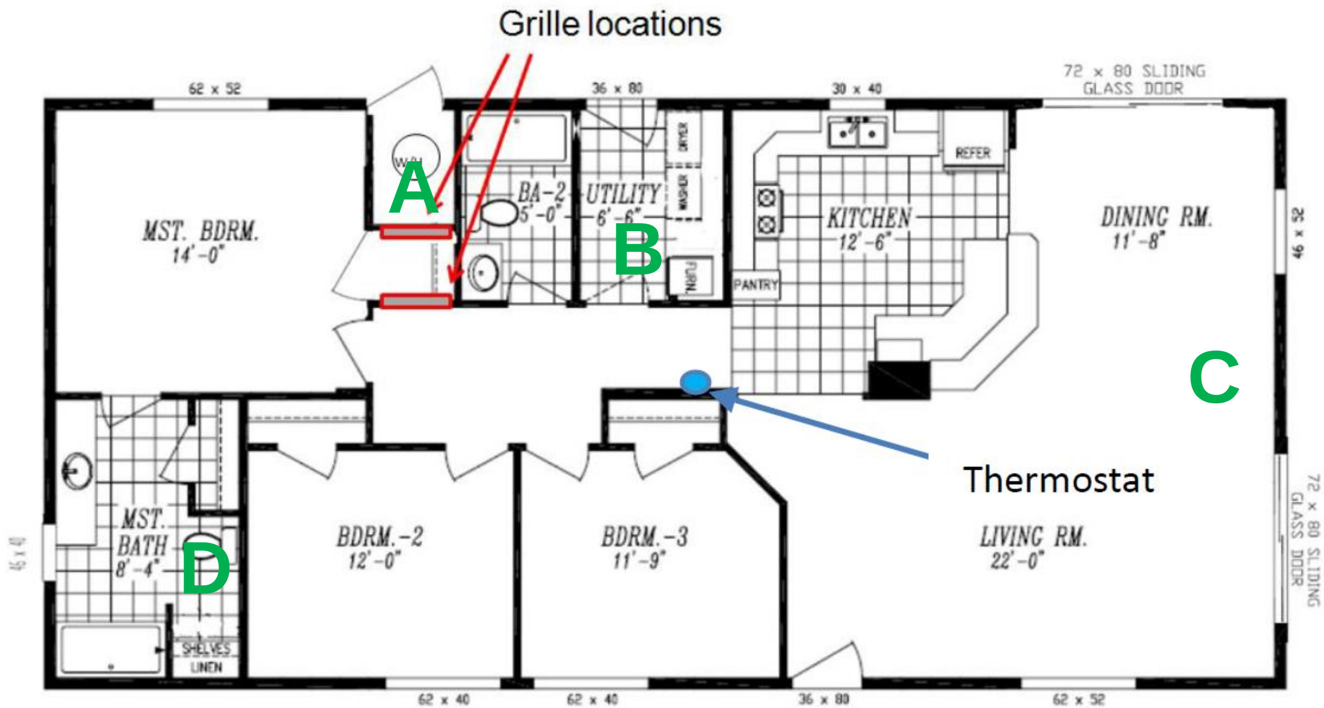
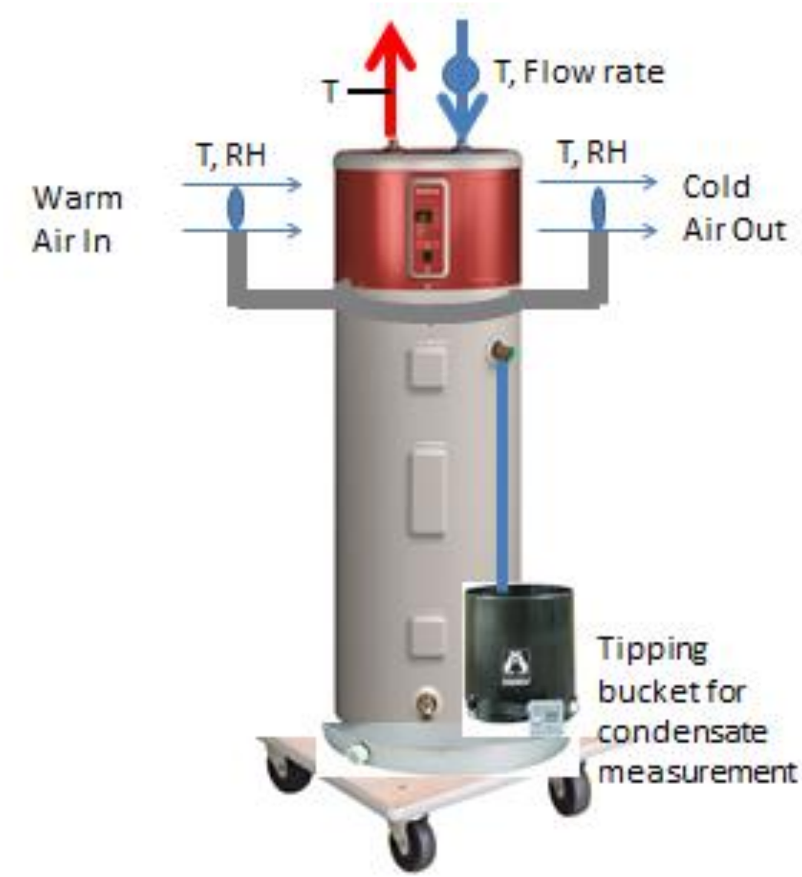


Test Case Description	Test Location	Reason to Include Test Case
Master Bath, Door Closed	A	Most disconnected to thermostat, but still in conditioned space
Utility Closet	B	Most connected to the return duct
Living Room	C	Most connected to the thermostat
Water Heater Closet	D	Represents semi-conditioned space

Monitored Data Around Water Heater



*Note: Picture demonstrates monitored values only. Location of sensors is not necessarily accurate.

Fully Mobile Water Heaters

Air Flow Sensor Bracket

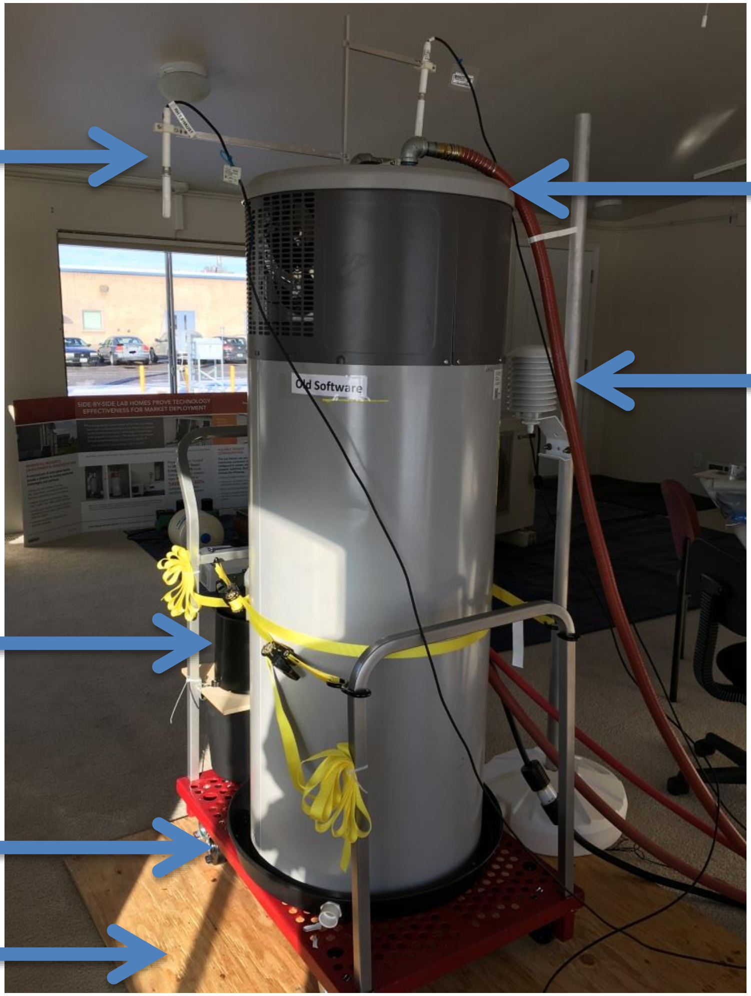
Flexible Hoses for Water Inlet and Outlet

Solar shielded T/RH

Tipping Bucket

Rolling Platform

Plywood False Floor



Josh McIntosh, Joe Petersen, Greg Sullivan

RESULTS

Analysis Approach

Step 1: Calibrate homes based on baseline data

- Two primary calibration approaches:
  1. Direct **thermal adjustment** (Wh/HDD) of HVAC load from baseline period
  2. **Linear regression** of all non-water heating loads (HVAC + simulated internal gains) with respect to HDD

Step 2: Compare change in HVAC energy use between homes and theoretical energy impact from HPWH

- Change in HVAC energy use calculated based on two calibration approaches above
- Theoretical energy impact =
  energy delivered as hot water – HPWH electrical energy consumption (measured)

$$= m \times C_{p,H20}(T_{out} - T_{in})$$

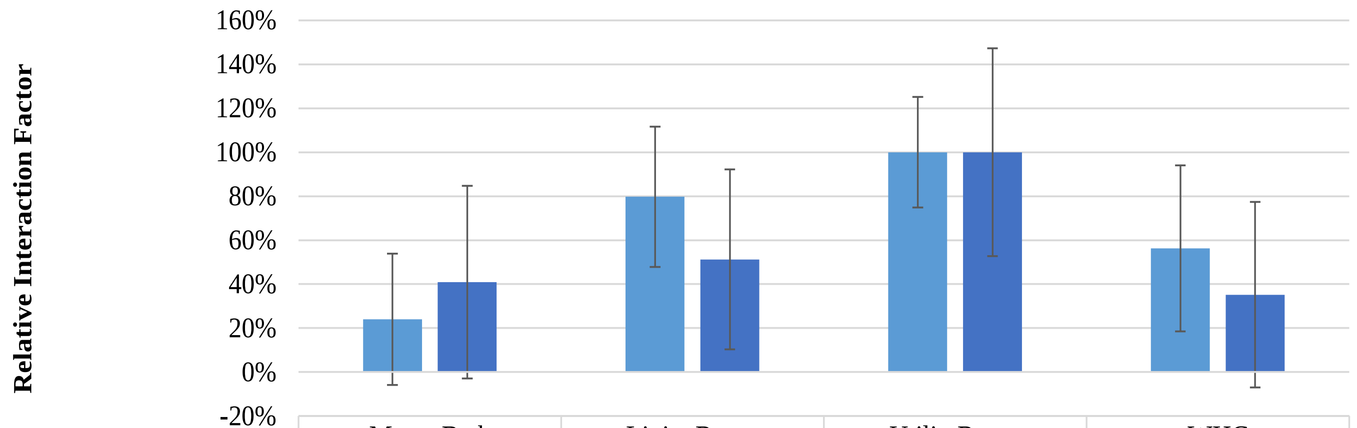
$$Q_{HPWH,theoretical} = Q_{hotwater} - E_{HPWH}$$

- Interaction factor = ratio of change in HVAC energy (measured) over theoretical energy impact

$$F_{HPWH} = \frac{(E_{HVAC\_HPWH} - E_{HVAC\_NoHPWH})}{(Q_{hotwater} - E_{HPWH})}$$

Key Findings

- Interaction Factors vary among tested locations throughout home

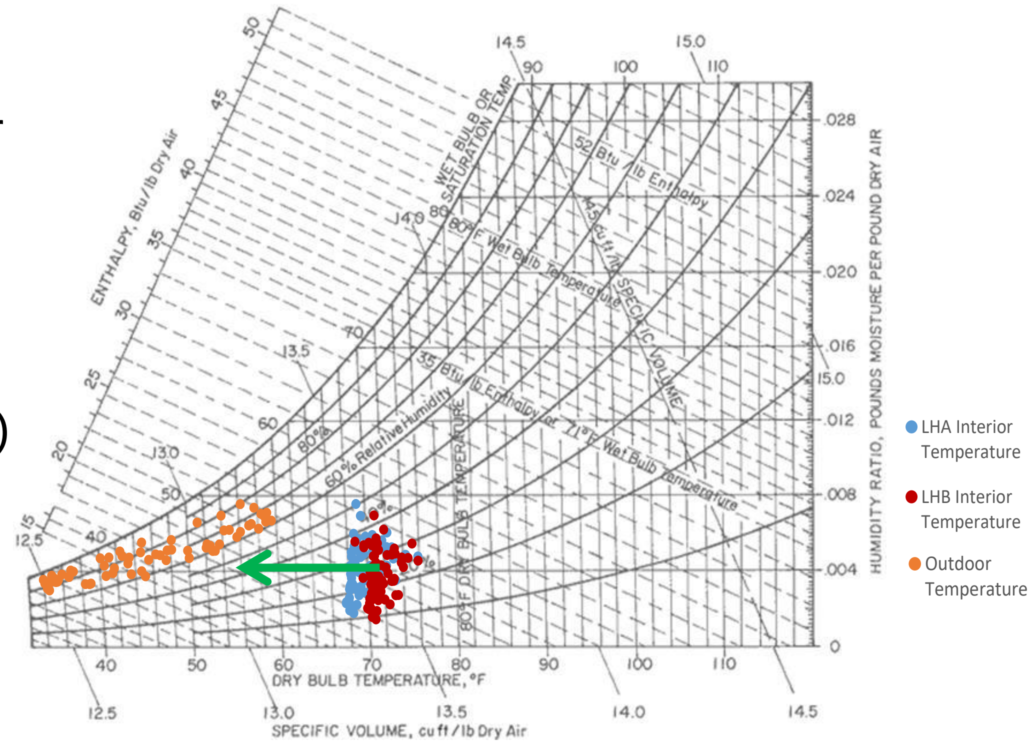


	MasterBath	LivingRoom	UtilityRoom	WHC
Thermal Adjustment Method	0.24	0.80	1.00	0.56
Linear Regression Method	0.41	0.51	1.00	0.35

- Variation is due to relative magnitude of three primary factors influencing the interaction factor:
  1. Latent removal
  2. Localized cooling
  3. Excess solar gains

Latent Removal

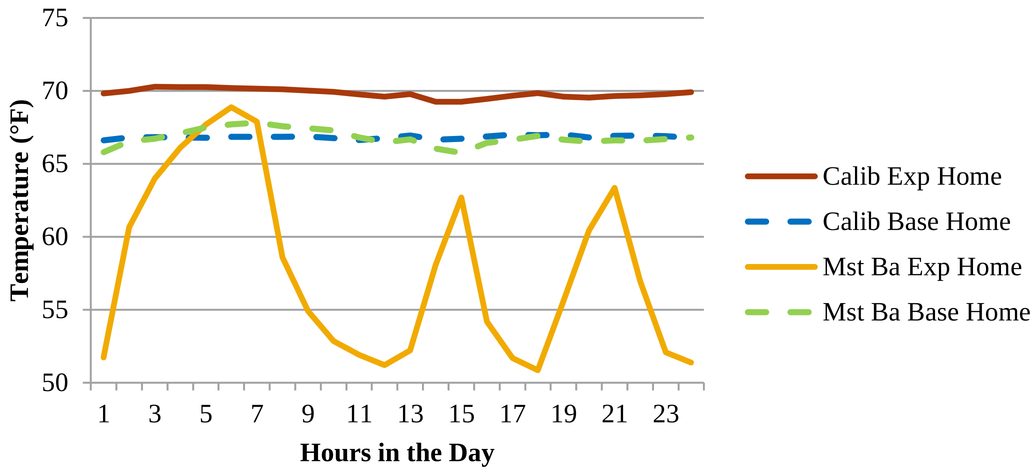
- Latent removal was not apparent in Lab Homes experiment
  - Not uncommon for cold winter temperatures during the heating season (low moisture content in air)
  - Some areas in PNW or specific locations (basements) may experience more latent removal
    - Would further reduce F_{HPWH}
    - Simulations can develop regional/national estimates
      - Existing laboratory data has quantification of latent removal across the coil for model calibration



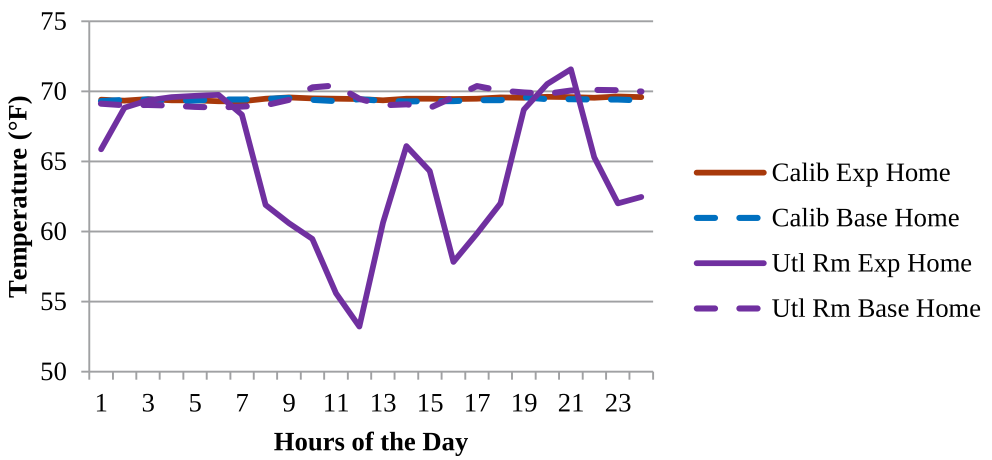
Localized Cooling

- Temporary localized cooling is a function of the size of the room based on the size of the room
- *Sustained* localized cooling is a function of the "thermal distance" of the room from the thermostat

Master bathroom furthest from thermostat



Utility room closest to thermostat



Solar Impacts

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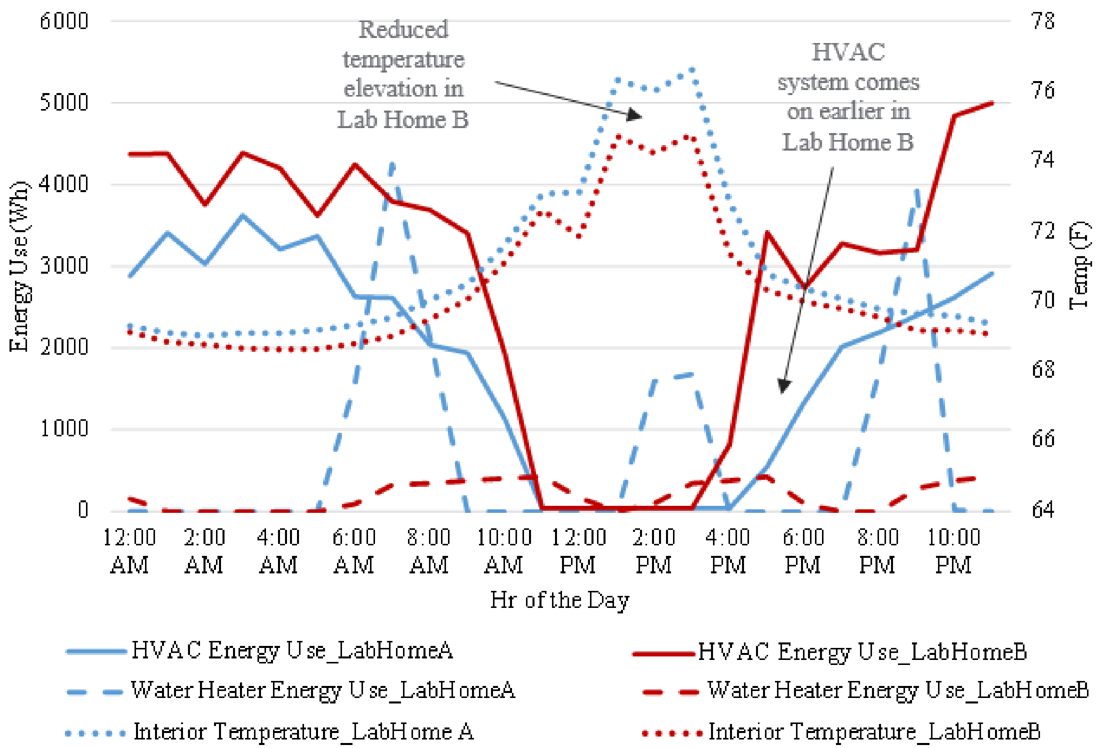
- Utilization of solar energy apparent during most experiments
- Limited data did not allow for looking at variability of solar impact by experiment
  - Aggregate impact = 30-40% reduction in interaction factor on sunny days
  - Data seem to indicate significant impact in all experimental locations, not just those with high direct solar gains



Absolute Interaction Factors

- Interaction factors ranged from 0.47-1.40 (based on thermal adjustment approach)
  - Lower interaction factors = less space heating penalty
- "Thermal distance" dominated interaction factors in most experiments

Thermal Location	Point-Source Load	Furthest From Thermostat	Least Distributed	Closest to Thermostat	Most Distributed
Actual Location		Master Bathroom	Water Heater Closet (no direct supply or return air duct)	Living Room	Utility Room (where air handler is located)
Interaction Factor	Cooling	0.6 ± 0.2	0.5 ± 0.1	0.8 ± 0.2	1.4 ± 0.4
	Heating**	0.6 ±	N/A	0.8 ±	N/A
Localized Cooling	Cooling	13.8 ± 2.1 °F	9.9 ± 2.8 °F	1.7 ± 1.9 °F	2.1 ± 1.9 °F
Notes		Greatest "thermal distance" from thermostat	Representative of semi-conditioned space	Small "thermal distance" (minimal localized cooling)	Greatest interaction (thermostat influenced by localized cooling); F_{HPWH} >1.0 due to overheating of house

* Based on HPWH experimental results.
** Normalized with respect to load; presented for same size load as cooling load.

agrees well with previous PNNL Lab Homes study (0.4 ± 0.1)!

Summary and Next Steps

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- Interaction factors vary based on installation locations based on degree of:

Interaction Factor component:	Which is a function of:
Latent heat extraction	Dew point of ambient air compared to HPWH coil temp
Localized cooling	Size and “thermal distance” of space from thermostat
Excess solar insolation	Home heating load, solar gains

- Typical range = 0.5 ± 0.2 for **far** locations (semi-conditioned space) to 0.8 ± 0.2 for **near** locations (conditioned spaces)

- PNNL Lab Homes experiments dominated by localized cooling impact

- Next steps:
  - Estimate interaction factors for common water heater installation locations
  - Simulate annual impacts in representative housing types and climate zones

Thank you!

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Analysis: Latent heat $Q_{HPWH,latent}$

- Latent heat removed from the space will result in decreased moisture content of air
  - Magnitude of impact (amount of moisture removed) depends on: ambient thermal conditions and temperature of refrigerant

$$Q_{HPWH,latent} = f(T_{ambient}, RH_{ambient}, T_{refrigerant})$$

$$Q_{HPWH,latent} > 0 \text{ IF } (dp_{ambient} < T_{refrigerant})$$

  - Even if amount of water is small, impact may be large because $\Delta H_{vap} >>> C_{p,air}$

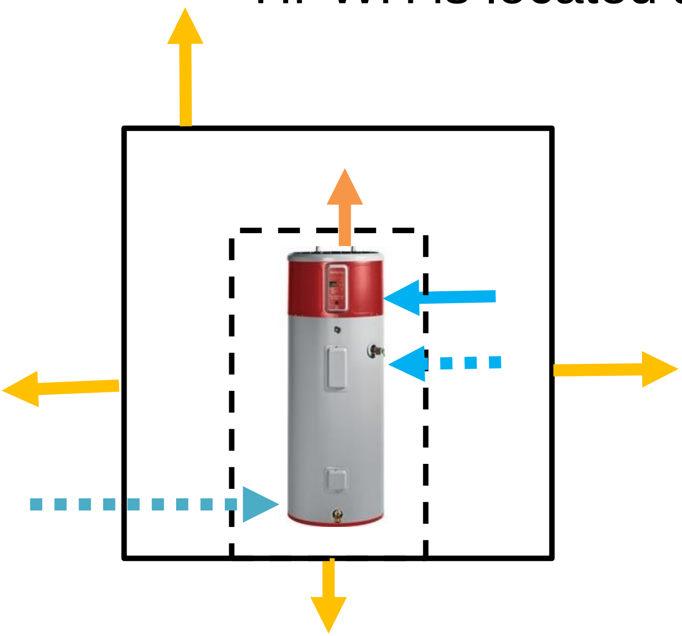
Results Summary: Latent heat removal

- Lab Homes RH measurements not precise enough to quantify (avg RH in hall, not near WH)
- FSEC data shows average latent heat removal (condensate) of 3.2 pints/day across many exterior temperature and humidity conditions[6]
- Can more precisely quantify based on NREL/NIST lab measurements for different ambient conditions and draws?
  - Perhaps simplify this relationship by looking at most common temp/RH/coil conditions that occur in PNW with typical hot water draw profiles

[6] C. Colon, et al. 2013. “Side-by-Side Testing of Water Heating Systems: Results from the 2010-2011 Evaluation.” National Renewable Energy Laboratory. Golden, CO.

Analysis: Localized cooling $Q_{localcool}$

- HPWH will cool surrounding air, which will decrease thermal losses through envelope
  - Magnitude of impact depends on: volume of space in which HPWH is located and surface area of outside wall in that space



$$Q_{localcool} = UA_{localcool}\Delta T_{no\ HPWH} - UA_{localcool}\Delta T_{HPWH}$$

$$= UA_{localcool}(T_{in,noHPWH} - T_{out}) - UA_{localcool}(T_{in,HPWH} - T_{out})$$

$$= UA_{localcool}(T_{in,noHPWH} - T_{in,HPWH})$$

and

$$(T_{in,noHPWH} - T_{in,HPWH}) = f(V_{HPWHspace})$$

Where:

$A_{localcool}$ = surface area of outside wall,

U = thermal resistance of water heater space,

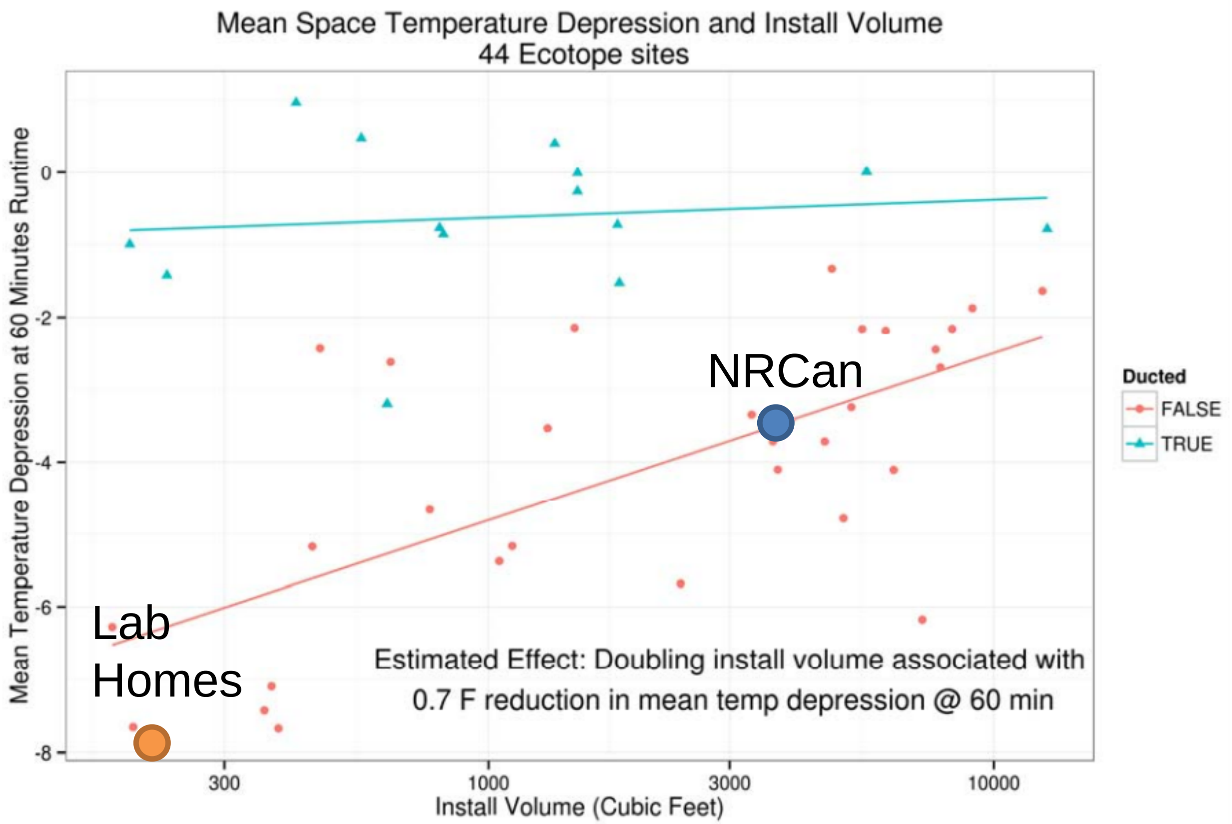
T_{in} = temperature of water heater space (with and without HPWH), and

T_{out} = outside ambient temperature

Past Results Localized Cooling

- Can generalize relationship between amount of localized cooling and $V_{HPWHspace}$ based on Ecotope HPWH field study.[7]
  - Lab Homes and NRCan data generally consistent with Ecotope findings

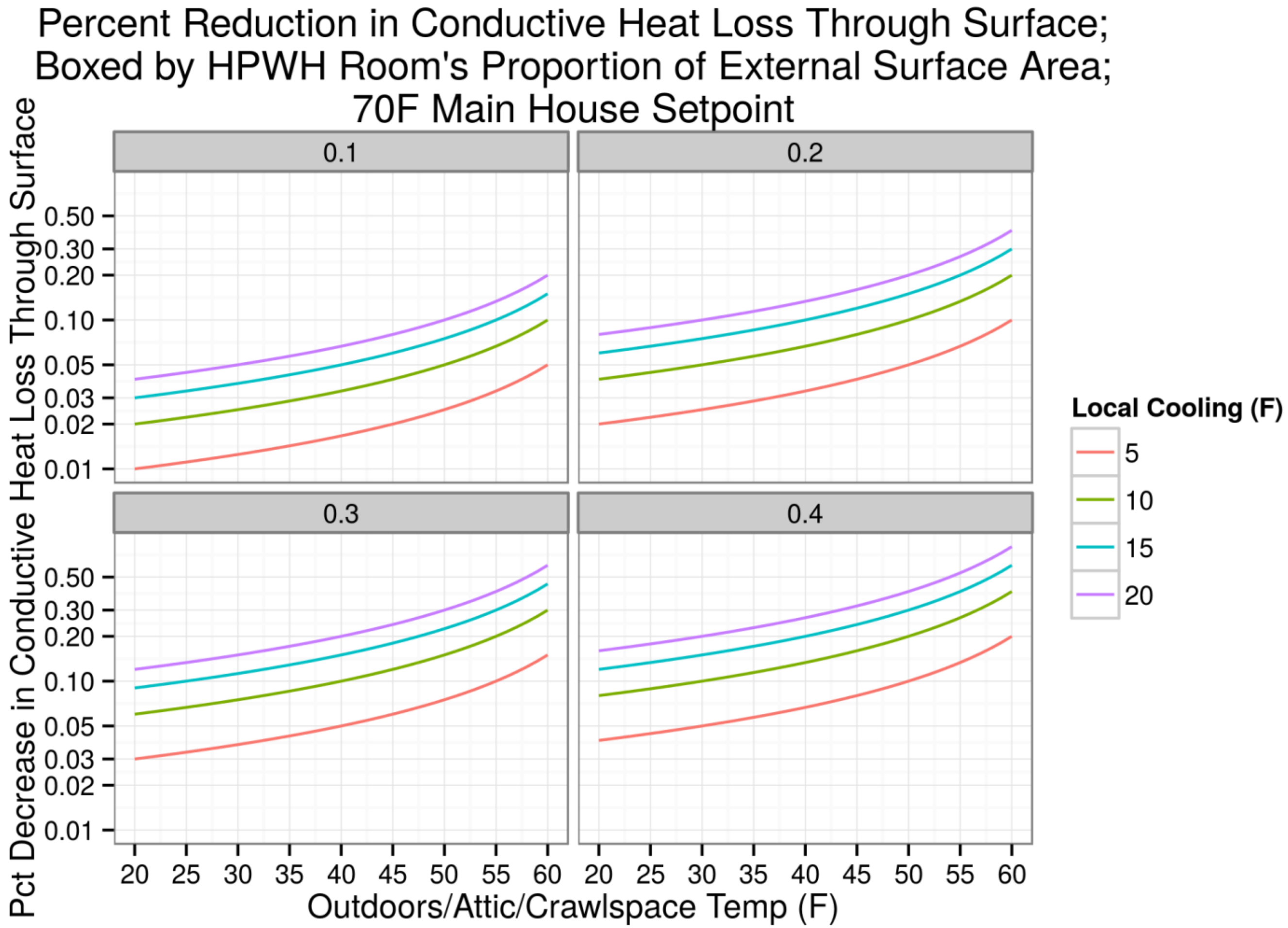
Figure 22. Intake Air Temperature Depression During Water Heater Recoveries



[7] Ecotope. 2015. *Heat Pump Water Heater Model Validation Study*. Report #E15-306, Ecotope, Seattle, WA.

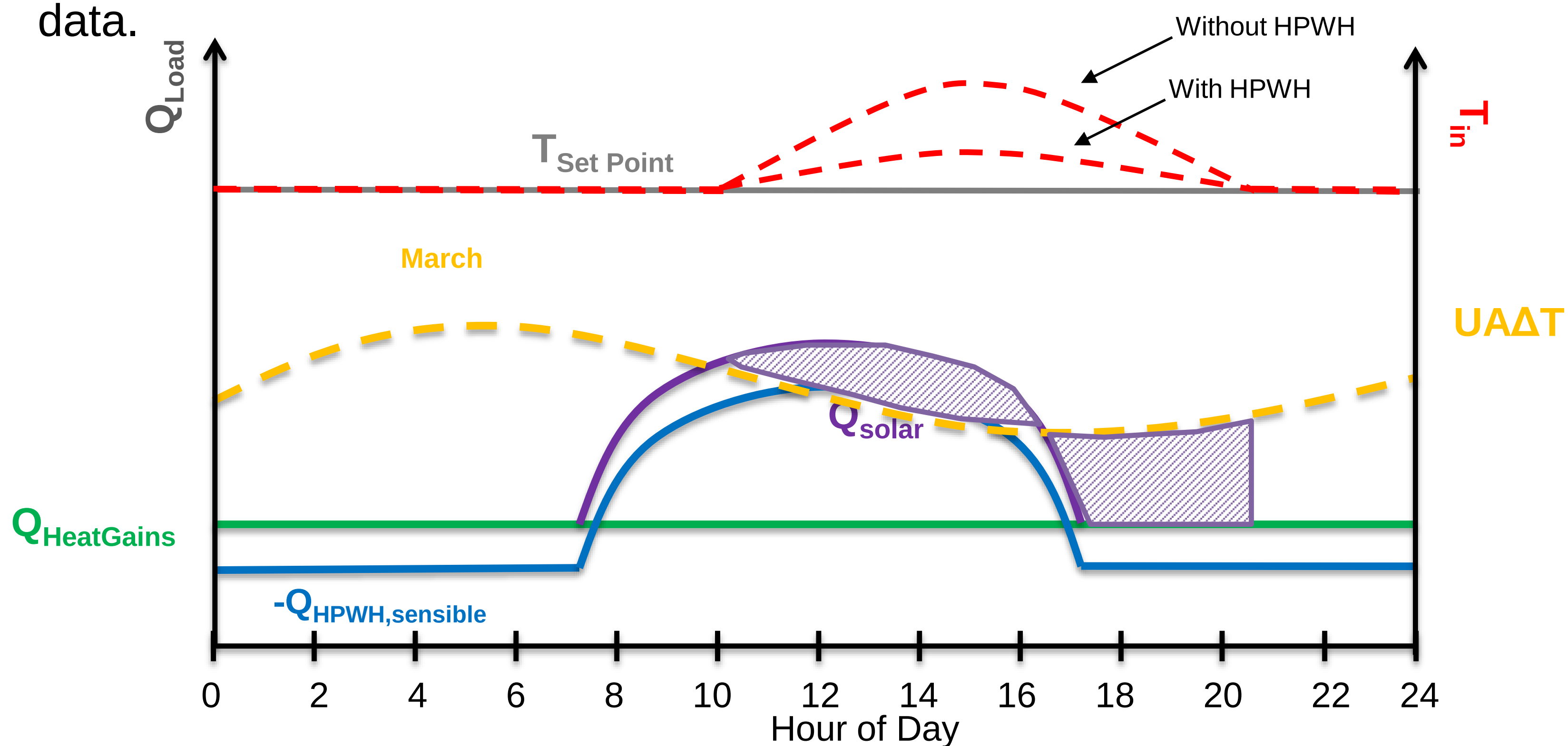
Analysis: Localized cooling (con't)

- Can further generalize based on relative external surface area of HPWH install location for different amounts of localized cooling (=install volume) and outdoor temp differentials



Analysis: Excess solar $Q_{extrasolar}$

- If $Q_{IntGains} + Q_{solar} > Q_{load}$, house floats off set point; load *changes* as heat loss *increases* over that time period. Drywall stores heat. Sun goes away. Some, but not all heat returned to house as it "coasts" back to set point.
- With HPWH, amount of overheating decreases, which decreases amount of *increased* heat loss ($UA\Delta T_{noHPWH} > UA\Delta T_{HPWH}$).
- Impact will be obvious in the data. Data with this phenomenom will be removed from the dataset. This factor will be assumed negligible for all other data.

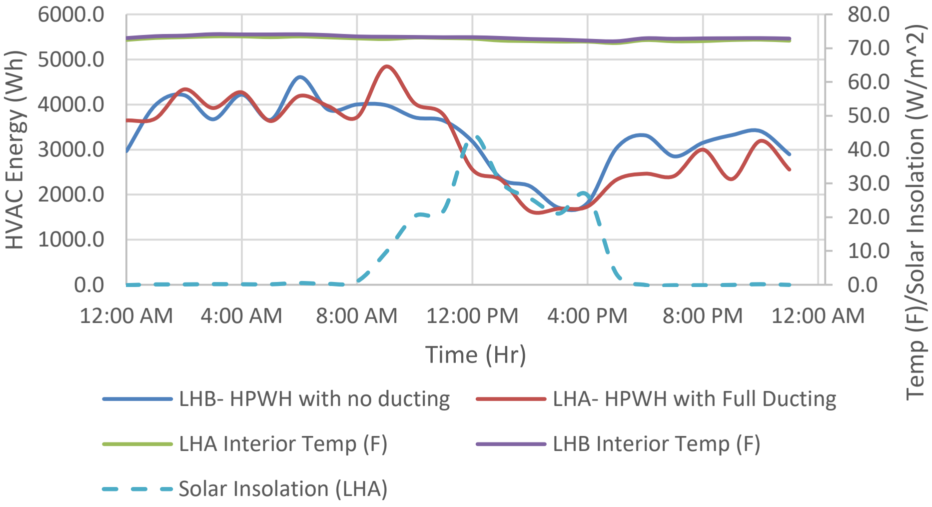


Analysis: Excess solar (con't)

$$Q_{extrasolar} = UA\Delta T_{noHPWH} - UA\Delta T_{HPWH}$$
$$= UA(T_{in,noHPWH} - T_{out}) - UA\,(T_{in,HPWH} - T_{out})$$
$$= UA(T_{in,noHPWH} - T_{in,HPWH})$$

Where:
A = external surface area of house,
U = thermal resistance of external surface area of house,
T_{in} = temperature of interior conditioned space (with and without HPWH), and
T_{out} = outside ambient temperature

- Only a factor for homes operated in heating only mode with significant solar gains in the winter.
  - Is this impact significant for other regions in PNW/nation?
- Lab Homes experimental period did not observe this impact, interior temp did not drift off set point



- If this phenomenon is present during a certain time period in future data collection, that small amount of data will be removed.

Summary of Field/Lab Studies Addressing HPWHs and Space Conditioning Interaction

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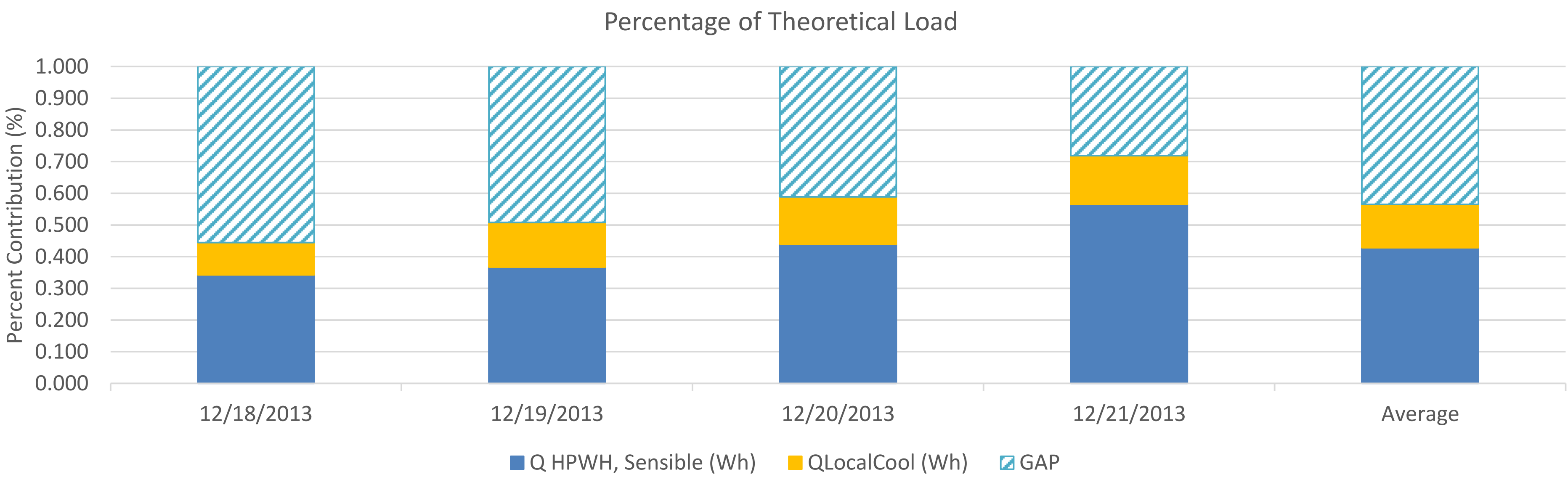
Study	Description	Data	Relevance	HC_f Findings
PNNL (2014)	Side-by-side evaluation of HPWH in unducted, exhaust ducted, and fully ducted configurations	HPWH energy use, HVAC energy use, interior temp and RH, water draw and temp, localized cooling	Can directly evaluate HC_f and impact of different variables (although $Q_{HPWH,latent}$ may be difficult to resolve)	~5.7±1.6 kWh/day increase in heating energy (HC_f =0.43±0.12); ~1.5± kWh/day decrease in cooling energy (HC_f =0.37±0.47).
NRCan (Unpub)	Side-by-side evaluation of HPWH in conditioned basement	HPWH energy use, HVAC energy use, interior temp, water draw and temp, localized cooling	Can directly evaluate HC_f and impact of different variables (except $Q_{HPWH,latent}$)	~5 kWh/day (HC_f =0.65-0.87) in heating energy; ~0.8 kWh/day for cooling.
FSEC (2013)	Evaluation of HPWH compared to other standard and high efficiency water heating technologies	Daily energy use, average condensate latent removal	Potentially quantify Q_{latent} for one/some ambient conditions?	N/A
FSEC (2016)	Field monitoring of 8 homes with HPWH - 3 in conditioned space and 5 in garage ducted to conditioned space	HPWH energy use, HVAC energy use, local and space temps	Evaluate impact on space conditioning loads	Increase in heating energy of -0.76 kWh/day (8.9%). Median cooling energy savings of 1.1 kWh/day (8.2%). Unable to evaluate HC_f.
Ecotope (2015)	Field monitoring of 5 HPWHs in conditioned spaces/basements	HPWH energy use, HVAC energy use, local space temp	Evaluate impact on space conditioning loads and localized cooling	Inconclusive, HC_f likely between 0.5 and 0.9.

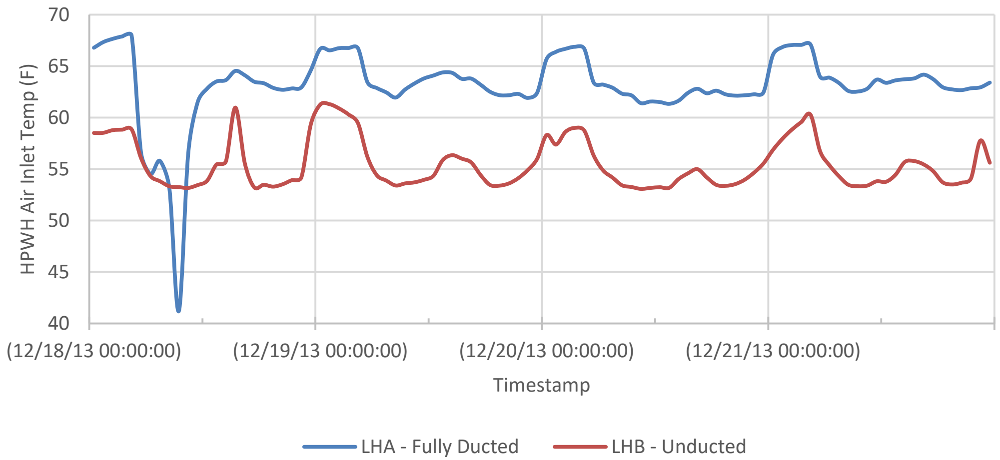
Lab Homes Findings Summary

- HC_f ($Q_{HPWH,sensible}$) ranged from 0.34 to 0.57 during analysis period
- $Q_{localcool}$ accounted for an additional 10.1-15.4 of theoretical load
  - Cooling of ~8.4 °F for 115 ft^3 space
- Unable to quantify latent impact
  - Potentially estimate with NREL data for known ambient conditions?
- No solar impact

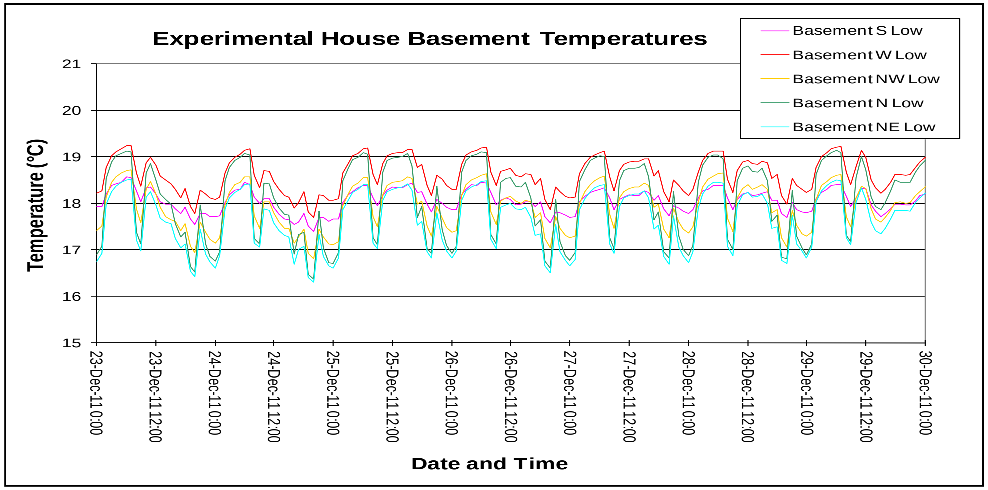


Past Results Localized Cooling

- Lab Homes show localized cooling in water heater closet of ~8.4 °F (~4.7 °C)

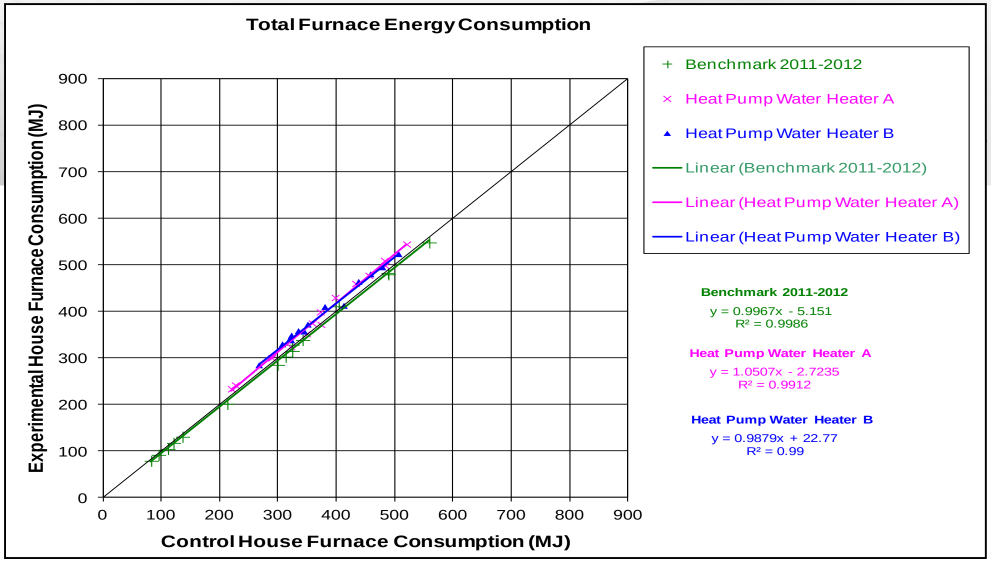


- NRCan shows localized cooling in basement of ~3.6 °F (~2 °C)

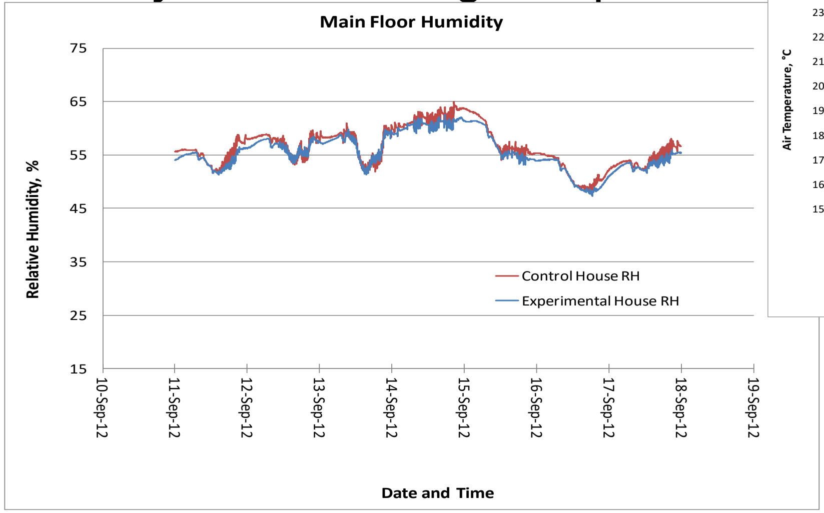


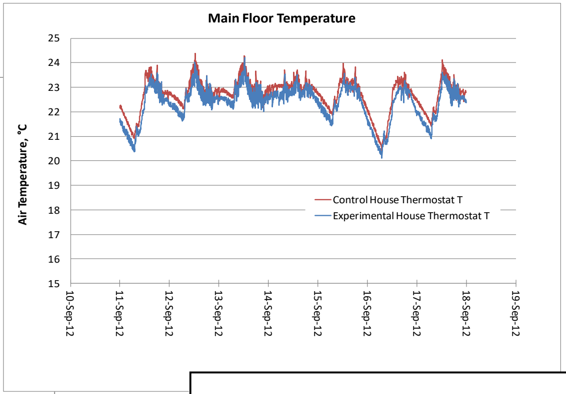
NRCan Study Findings Summary

- NRCan shows space conditioning impact of ~5 kWh/day (4.8-6.6%) in heating season
  - Associated with HC_f of 0.65-0.87
  - HC_f variable day to day



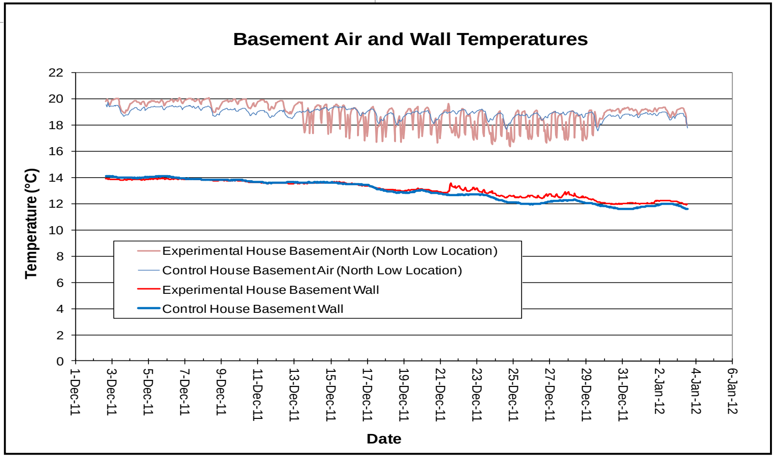
- RH data not available, but results summary indicates slight impact



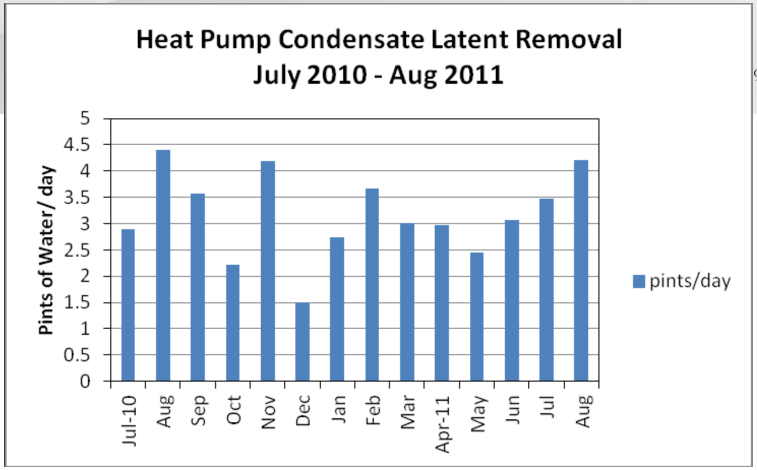


(Note: this is with a slightly cooler interior temp)

- Localized cooling of basement observed near water heater (~2 °C)



Findings from FSEC Studies



- Hybrid Mode Hot Water Lab Tests (2013)
  - Latent Heat Removed from 50 gal GE HPWH in "Garage-Like" installation (not sure of ambient temp or RH)
- Phased Retrofits Phase II Stuc (2016)
  - Median cooling savings of 1.1 kWh/day
  - Median heating savings of -0.76 kWh/day (with heat pump)
- Another FSEC field study was not able to resolve space conditioning impact
  - Field Performance of HPWHs in the NE (2016)

Table 8. Cooling Analysis Results for Conditioned Space-Coupled Heat Pump Water Heater Retrofits

Site #	# of Occupants	Coupling	HPWH Energy Post (kWh/day)	Cooling Energy Pre (kWh/day)	Cooling Energy Post (kWh/day)	Cooling Savings (kWh/day)	Cooling Savings (%)
1	4	Interior	2.07	16.26	14.50	1.76	10.8
5	2	Ducted	2.69	44.68	42.99	1.69	3.8
9	2	Ducted	3.20	11.54	10.01	1.53	13.2
13	2	Interior	2.64	6.81	6.08	0.73	10.7
26	5	Ducted	3.53	11.48	10.07	1.41	12.3
50	4	Ducted	2.65	18.50	17.78	0.72	3.9
51	2	Ducted	1.25	14.99	14.16	0.83	5.6
56	3	Interior	3.09	18.86	18.71	0.15	2.7
Average	**3**	**N/A**	**2.64**	**17.89**	**16.79**	**1.10**	**7.9**
Median	**2.5**	**N/A**	**2.67**	**15.63**	**14.33**	**1.12**	**8.2**

Table 9. Heating Analysis Results for Conditioned Space-Coupled Heat Pump Water Heater Retrofits

Site #	# of Occupants	Coupling	HPWH Energy Post (kWh/day)	Heating Energy Pre (kWh/day)	Heating Energy Post (kWh/day)	Heating Savings (kWh/day)	Heating Savings (%)
1	Insufficient Data						
5	2	Ducted	2.69	6.06	16.56	-10.51	-173.4
9	2	Ducted	3.20	4.85	9.16	-4.31	-88.8
13	Insufficient Data						
26	5	Ducted	3.53	3.71	4.03	-0.33	-8.9
50	4	Ducted	2.65	14.83	12.85	1.98	13.4
51	Insufficient Data						
56	3	Interior	3.09	14.42	15.18	-0.76	-5.3
Average	**3.2**	**N/A**	**2.64**	**8.77**	**11.56**	**-2.89**	**-24.1**
Median	**3**	**N/A**	**3.09**	**6.06**	**12.85**	**-0.76**	**-8.9**

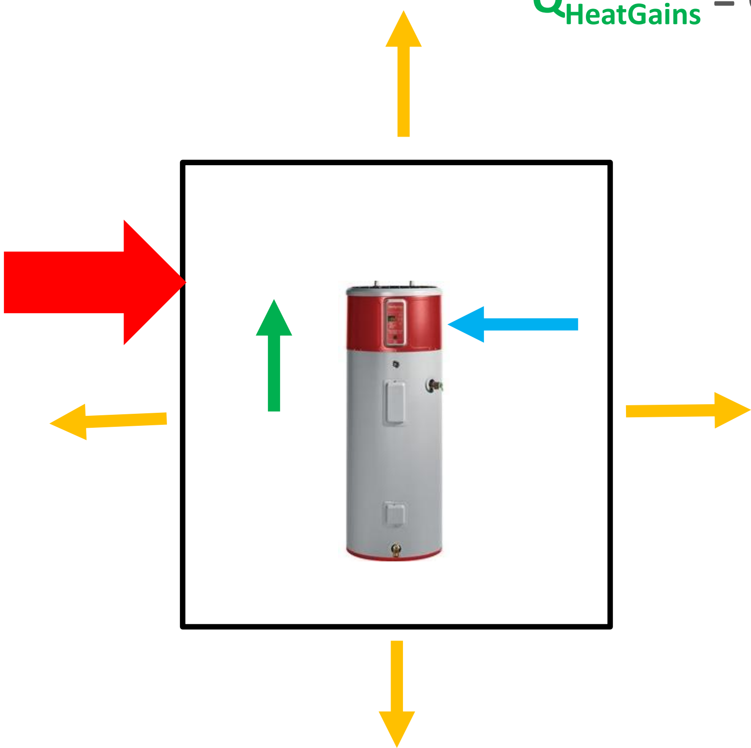
Interaction between HPWH and Space Conditioning Loads

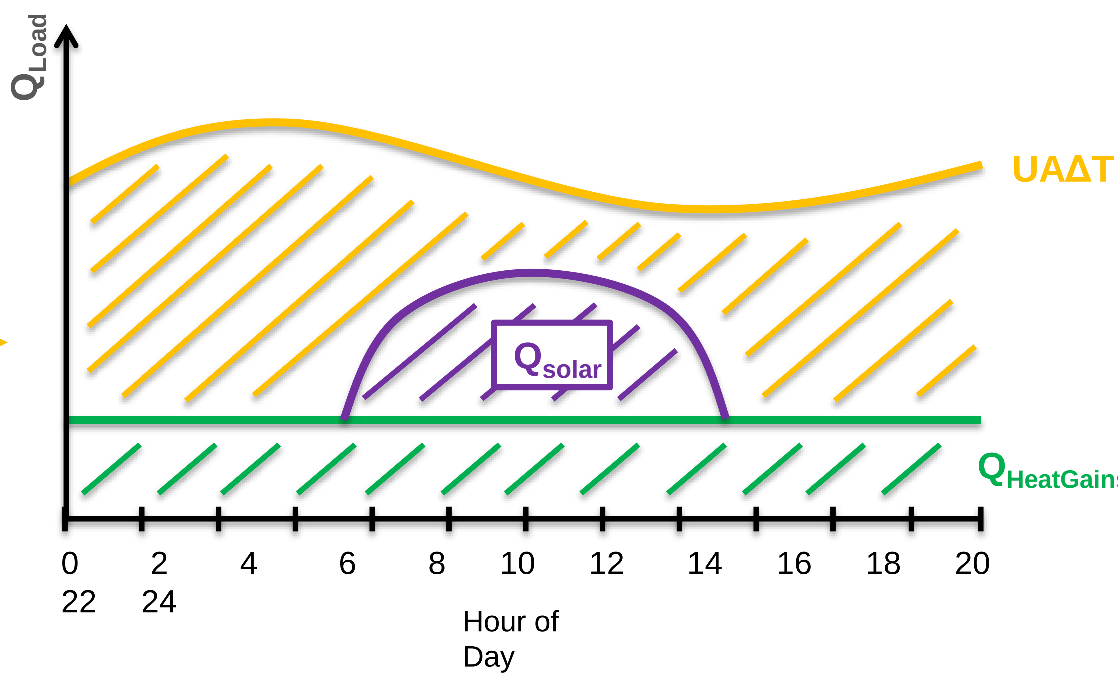
- HPWH's, when installed in the conditioned space, introduce a cooling load (i.e., negative gain), some of which must be made up by the HVAC system

$$Q_{HVAC} = Q_{Load} = UA\Delta T - Q_{IntGains} - Q_{solar}$$

$$Q_{IntGains} = Q_{HeatGains} + (-Q_{HPWH})$$

$$Q_{HeatGains} = Q_{Refrig} + Q_{TV} + Q_{Wii} + Q_{Lights} + \ldots$$





Definition: Interaction Factor

- Can define Interaction Factor (F_{HPWH}) as percent of the total theoretical HPWH thermal load that impacts space conditioning load

$$F_{HPWH} = \frac{Q_{HPWH,sensible}}{Q_{HPWH,\ theoretical}} = \frac{Q_{HPWH,sensible}}{(Q_{hotwater} - E_{HPWH})}$$

$$Q_{HPWH,theoretical} = Q_{hotwater} - E_{HPWH} = Q_{HPWH,sensible} + Q_{HPWH,latent} - Q_{localcool} - Q_{extrasolar}$$

PNNL Lab Homes Characteristics

- Two identical “existing” homes placed side-by-side
  - 3 BR/2BA 1493-ft^2 double-wide, factory-built to HUD code
  - Forced air furnace OR 13 SEER/7.7 HSPF heat pump
  - R-22 floors, R-11 walls & R-22 ceiling with composition roof
  - 195.7-ft^2 (13% of floor) window area

- Metering
  - 42 individually monitored breakers
  - 15 interior room temperature thermocouples

- Water and environment
  - Controllable water flows at fixtures
  - Controllable breakers
  - On-site weather station
- Data collection via 2 Campbell Scientific data loggers/home
  - 1 minute data, sometimes averaged over longer periods

Close Up of Measurements

Two T/RH Sensors (Campbell Scientific HC2S3, 75ft cable, ±0.8% RH)

Condensate Drain

Tipping Bucket (Rainwise Inc., 2% accuracy at 1.5 inches per hour)

Utility Room Setup

Baseline Temperature Distribution (1/15/17)

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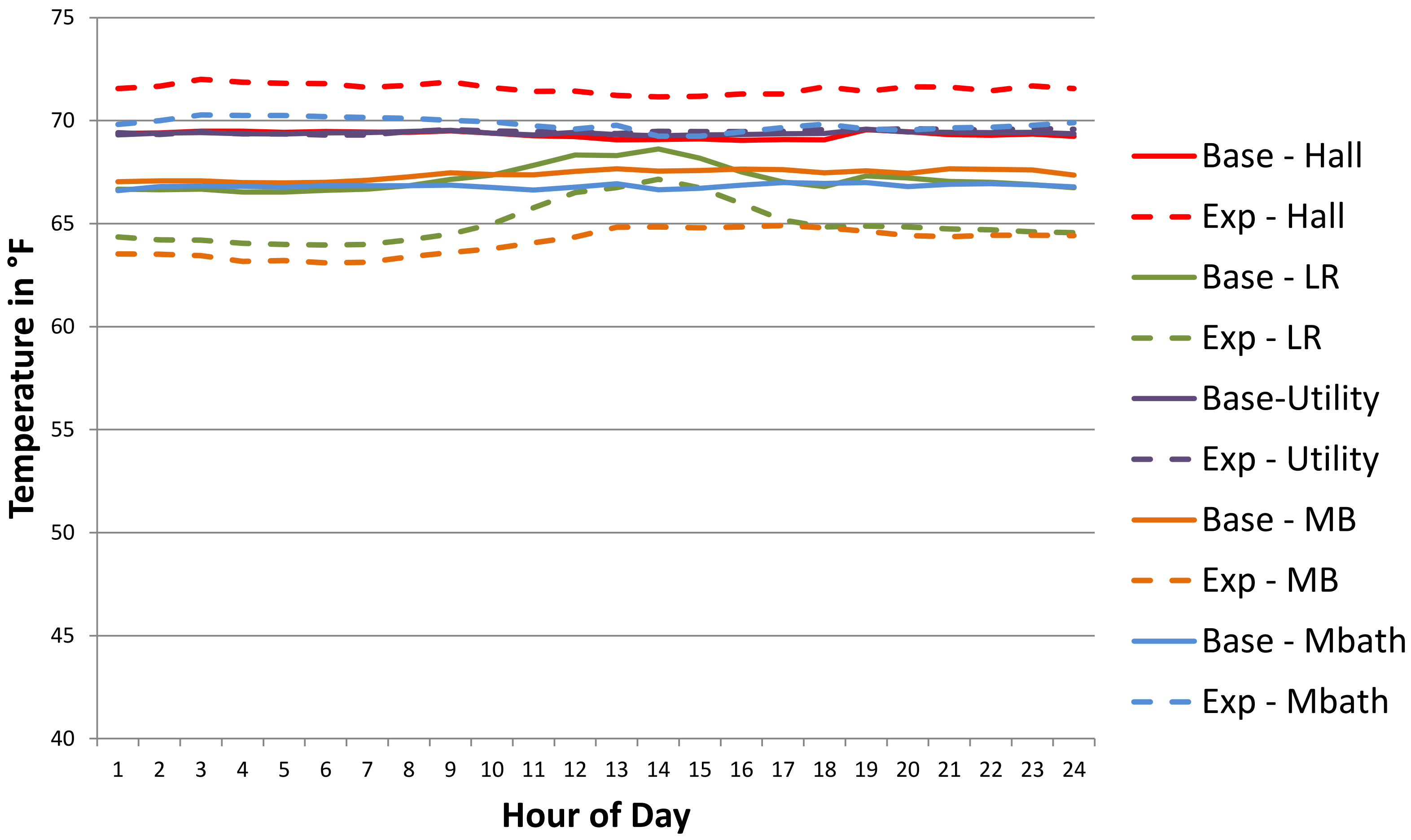
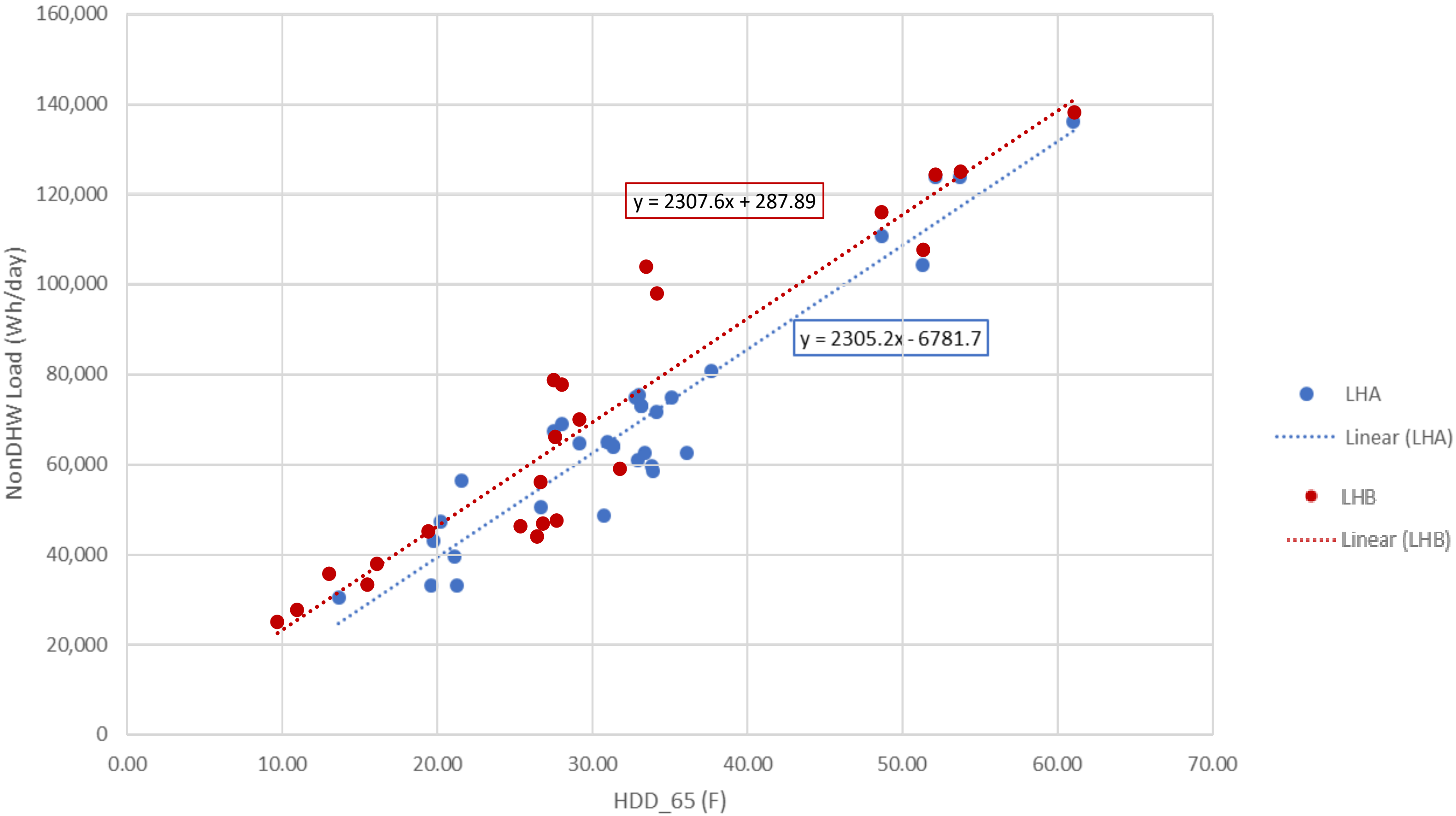


Linear Regression Adjustment Method



Lab Home	Number of days for regression (N)	UA (Wh/F/day)	B (Wh/day)
A	32	2305.2	-6781.7
B	23	2307.6	287.89
Difference	N/A	-2.4	-7069.59

Localized Cooling Details

- Temperature depression varies by location

Location	"Thermal Distance"	Volume (ft^3)	Average Temperature Depression per 24 hr Period (°F)	Maximum Hourly Temperature Depression per 24 hr Period (°F)
Master Bathroom	Farthest from thermostat	952	13.8 ± 2.1	21.8 ± 3.0
Living Room	Large space, well connected to thermostat	3197	1.7 ± 1.9	3.2 ± 2.3
Utility Room	Closest to thermostat and air handler return	464	2.1 ± 1.9	3.2 ± 1.8
Water Heater Closet	Semi-conditioned (no supply or return grills)	31*	9.9 ± 2.8	18.0 ± 5.1
***Transfer grill added to ensure adequate air from master bedroom**				

Comparison of Analytical Approaches

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Method	Linear Regression	Thermal Adjustment
Details	Determine UA and B offset for homes based on linear regression of measured total heating loads (all non-DHW loads) during all baseline (non-experimental) days for each home. Based on baseline UA, determine fixed thermal load in each home based on measured OAT. Take difference in	Assign fixed Wh/HDD_{65} difference based on measured HVAC difference between homes during Baseline 2 period
Number of days	Lab Home A = 32 Lab Home B = 23	N=4 (Baseline 1 disregarded due to extreme temperatures/not representative of experimental periods)
Value	UA = -2.4 (0.1%) B = -7070 (100%)	145.6 Wh/HDD_{65} (8%)
Pros	Accounts for temperature-dependent and fixed thermal (i.e. HPWH) loads separately; Larger sample for analysis because don't need pair analysis for each day	Simpler
Cons	More complex	Assumes 100% of baseline difference is thermally-dependent; Limited sample size

Applications and Future Work

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- Next step is to evaluate impact of measured interaction factors for HPWHs on real-world savings (e.g. RTF UES estimates)
  - Could also look at heating loads
- Can be best and most efficiently done through simulation, calibrated/validated based on empirical results:
  - Simulations can address solar gains and latent removal
  - PNNL Lab Home study results will inform estimation of "thermal distance" impact on HVAC energy use

Season	Load	Factor	Data Source
Heating	Cooling	Latent Removal	NREL/NEEA Experimental Evaluations/Simulation
		Thermal Distance	**PNNL Lab Homes Study (HPWH)**
		Excess Solar Gains	Simulation (validated based on **PNNL Lab Homes Study**)
	Heating	Latent Removal	N/A
		Thermal Distance	**PNNL Lab Homes Study (Space Heater)**
		Excess Solar Gains	N/A
Cooling	Cooling	Latent Removal	NREL/NEEA Experimental Evaluations/Simulation
		Thermal Distance	***PNNL Lab Homes Study (Space Heater)****
		Excess Solar Gains	Simulation
	Heating	Latent Removal	N/A
		Thermal Distance	***PNNL Lab Homes Study (HPWH)****
		Excess Solar Gains	N/A

* While not evaluated directly, a cooling load during the cooling season would be expected to act similarly to a heating load in the heating season with respect to the thermal distance and resultant temperature change in the space. Future experimental work could verify this result.

Lessons Learned

- Using standard HPWH equipment installed on rolling dolly carts worked well to enable collection of data that was both (a) representative of market-available equipment and (b) consistent home-to-home and in different locations throughout the home.

- Hot water temperature measurement should have been taken close to the exit of the water heater.

- High precision manufacturing needle valve worked well to accurately maintain water flows at 1.5 gpm, but is prone to clog if there is any type of blockage within the water lines (e.g. copper shavings); requires cleaning of the lines.

- Important to verify interior temperature profiles as well as HVAC energy consumption during the baseline period.

- Important to locate the supply air thermocouple far enough away/shielded from the exhaust air stream, such that it is not influenced by the cool exhaust air.