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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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BACKGROUND

Definition: Interaction Factor

- ▶ (HC_f) = Thermal Coupling as percent of the total theoretical HPWH thermal load that impacts space conditioning load
- ▶ In English: How much energy does the space conditioning system have to make up when a HPWH is in a home?

Motivation

- ▶ [November 2014](#), the Regional Technical Forum (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 HC_f
 2. Experimental study in the PNNL Lab Homes to determine/validate range of expected field HC_f 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.

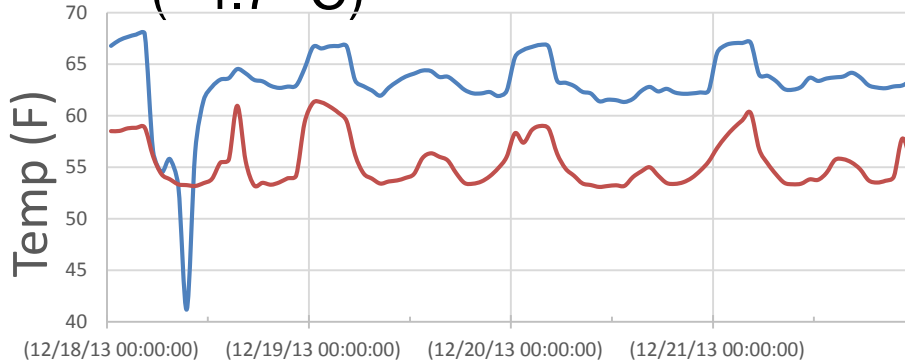
Theoretical Interaction

1. Some of the heat from the space is latent heat ($Q_{\text{HPWH,latent}}$), 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 ($UA\Delta T_{\text{HPWH}} < UA\Delta T_{\text{no HPWH}}$)
3. Some of the heat imparted to the water heater from the space may be “free heat” from solar gains that would also decrease the total heat transfer from the space if the house drifts above set point
4. HPWH near a thermostat may artificially call for more heat than necessary for thermostat to maintain set point

Past Results Localized Cooling

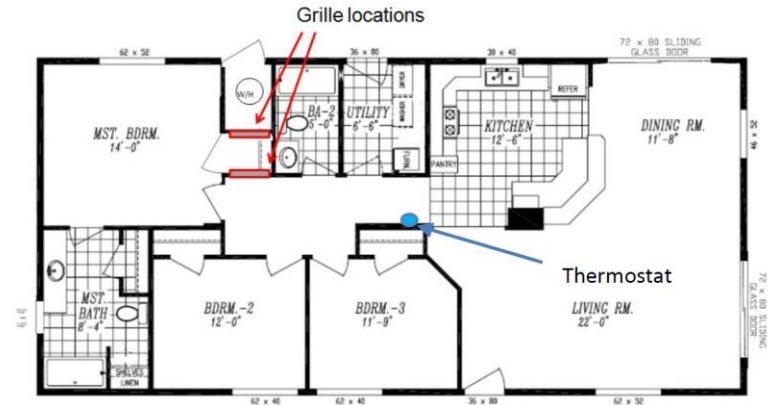
- ▶ Lab Homes show localized cooling in water heater closet of $\sim 8.4^\circ\text{F}$ ($\sim 4.7^\circ\text{C}$)

HPWH Air Inlet

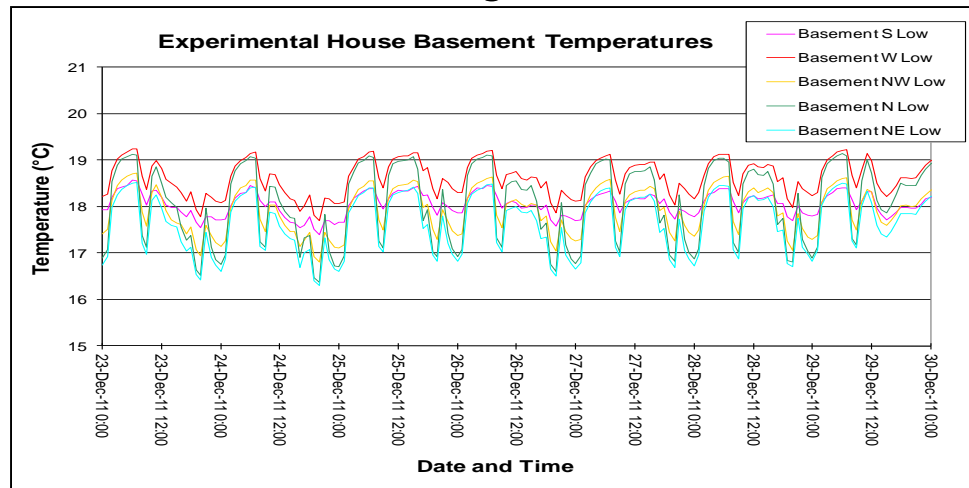


Timestamp

— LHA - Fully Ducted — LHB - Unducted



- ▶ NRCan shows localized cooling in basement of $\sim 3.6^\circ\text{F}$ ($\sim 2^\circ\text{C}$)





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TEST PLAN

Research Strategy: PNNL Lab Homes

▶ Research Goal

- Observe the space conditioning energy interaction that results from the installation of a HPWH in interior spaces

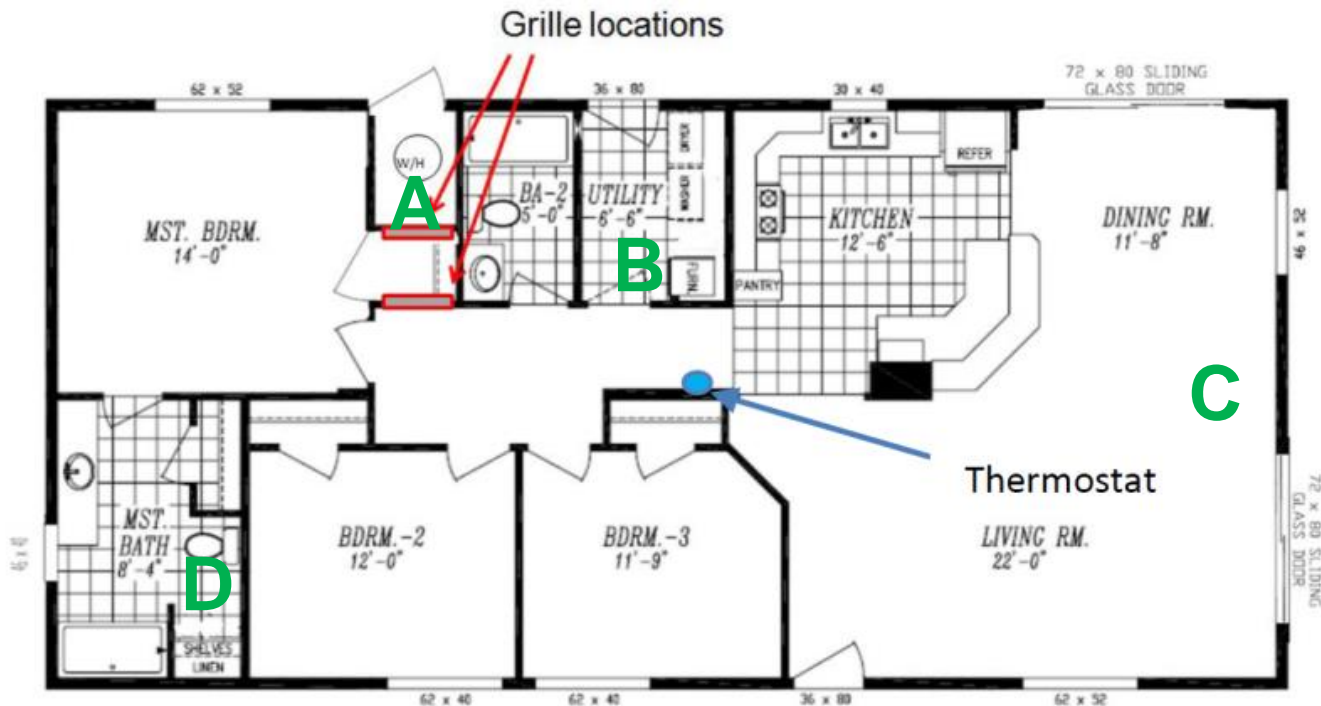
▶ Data Collection

- 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

Experimental Plan



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



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EXPERIMENTAL SETUP

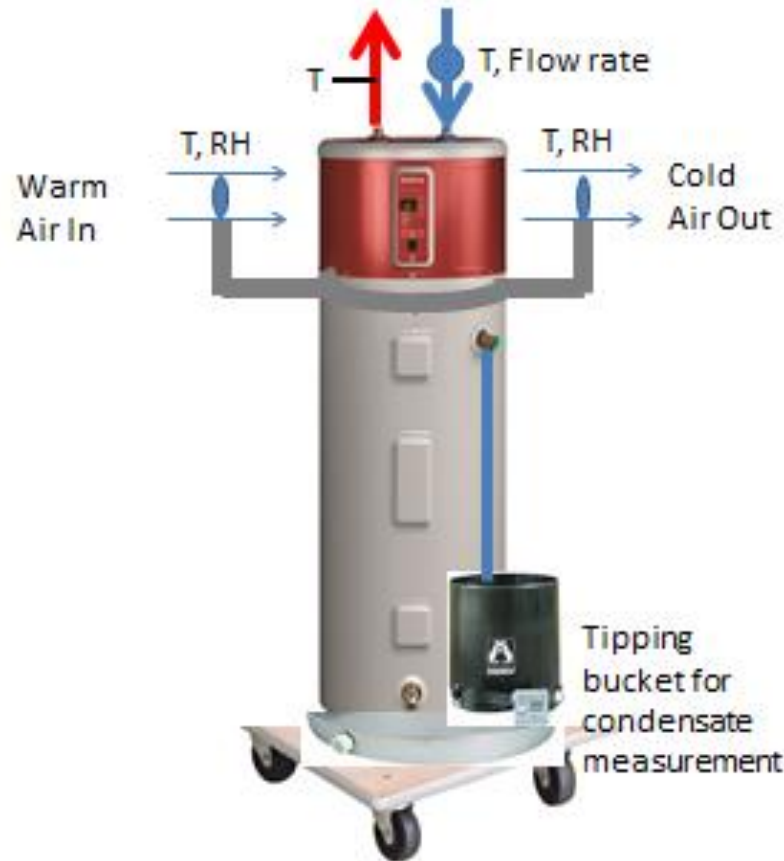
Side-By-Side Homes Are Fully Equipped

- ▶ Energy metering
 - 42 individually monitored breakers with ½ controllable
- ▶ Temperature and relative humidity
 - 15 interior room temperature thermocouples
- ▶ Water and environment
 - Controllable water flows at fixtures
 - On-site weather station
- ▶ Data collection via 2 Campbell Scientific data loggers/home
 - 1 minute data, sometimes averaged over longer periods

Per Home!



Monitored Data Around Water Heater



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

Fully Mobile Water Heaters

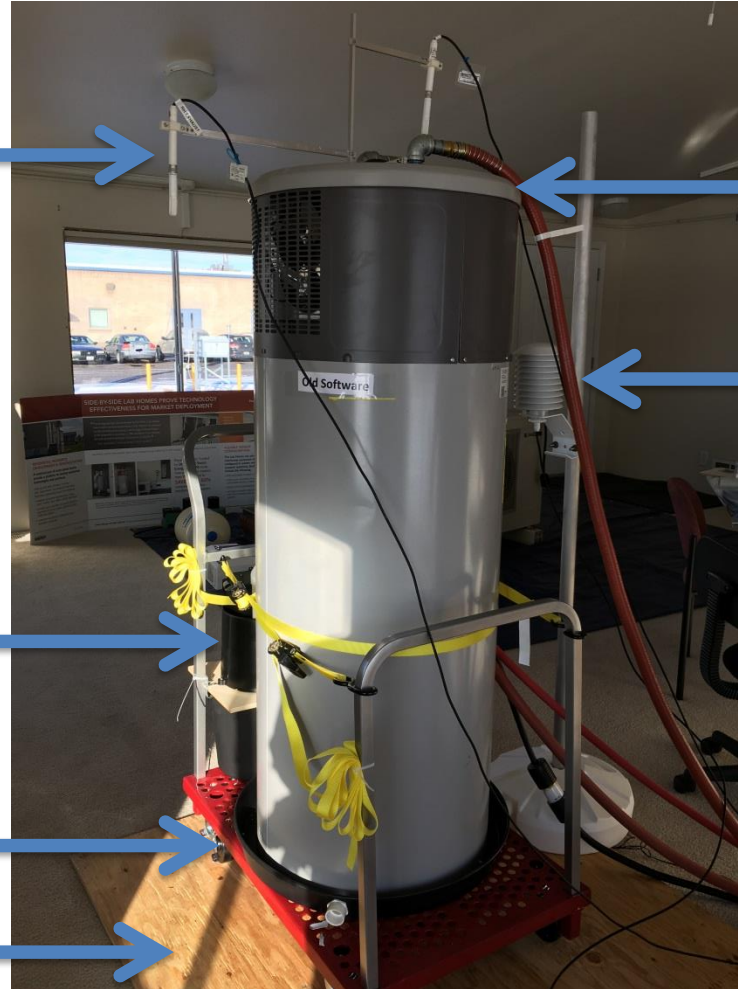
Air Flow Sensor
Bracket

Flexible Hoses
for Water Inlet
and Outlet

Solar shielded
“ambient”
T/RH sensor

Tipping
Bucket

Rolling
Platform
Plywood False Floor

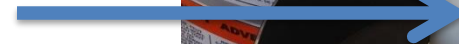


Close Up of Measurements



Two T/RH Sensors (Campbell Scientific HC2S3, 75ft cable, $\pm 0.1^{\circ}0.8\%$ RH). Top arrow points to supply T/RH measurement, bottom arrow points to exhaust T/RH measurement.

Condensate Drain



Tipping Bucket (Rainwise Inc., Rainew 111 Single Counter. 0.01 inches per tip. 2% accuracy at 1.5 inches per hour)

Utility Room Setup





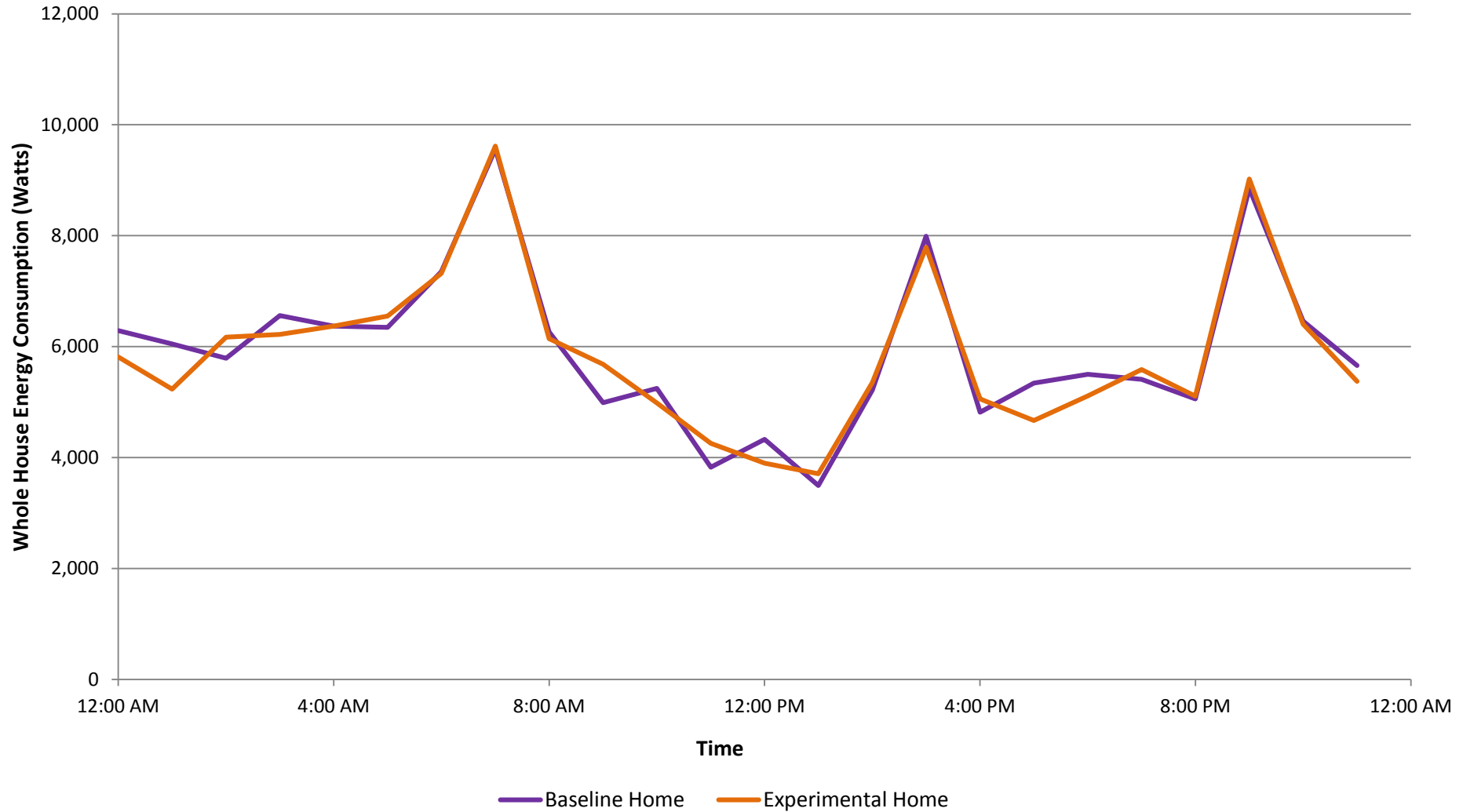
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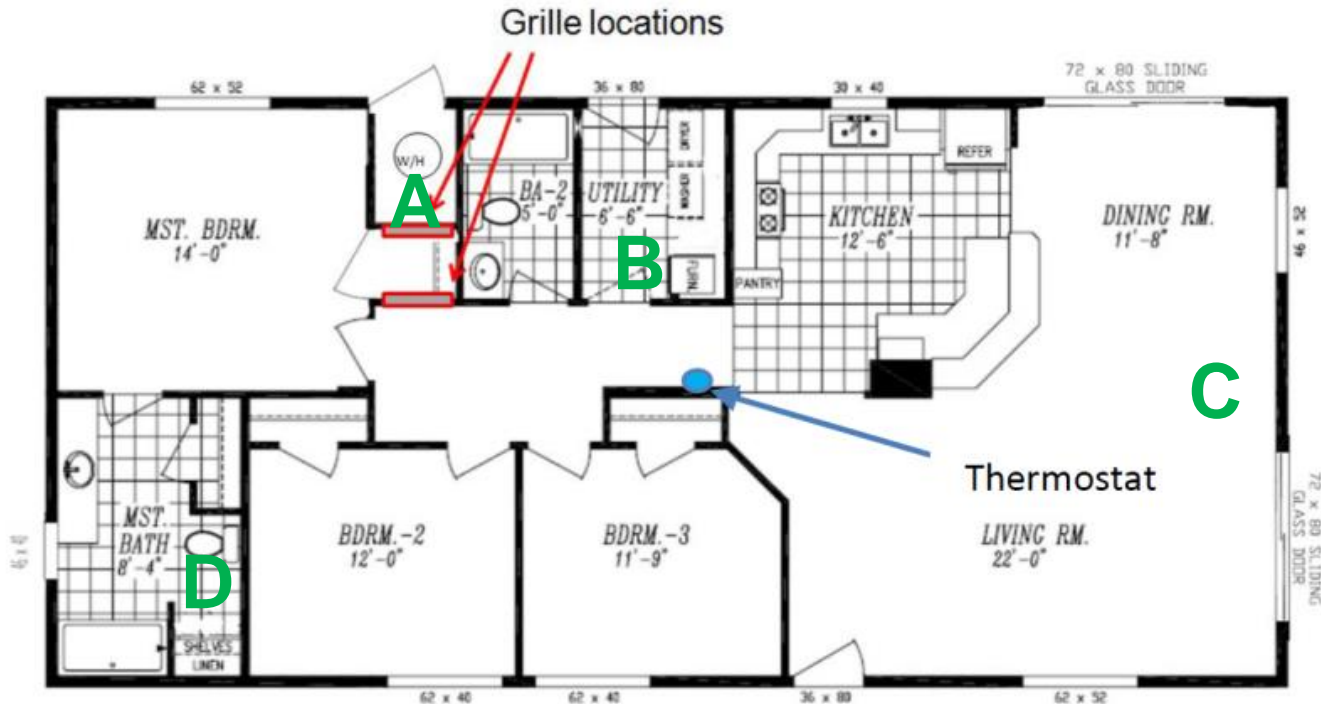
INITIAL RESULTS

- ▶ Previously mentioned studies could be considered semi-conditioned space (garage, basement, water heater closet). In current experiment, water heaters are truly interacting with the thermostat in conditioned space.
- ▶ Water draw profile is high (84 gallons per day) compared to national or regional averages in order to capture the high end of a realistic signal.
- ▶ Heat pump only mode so no input energy coming from resistance elements. All input energy from either the air or the compressor motor.
- ▶ Thermostat set at 71°F, water heater set at 125°F

Whole House Energy Use During Calibration (1/15/17)

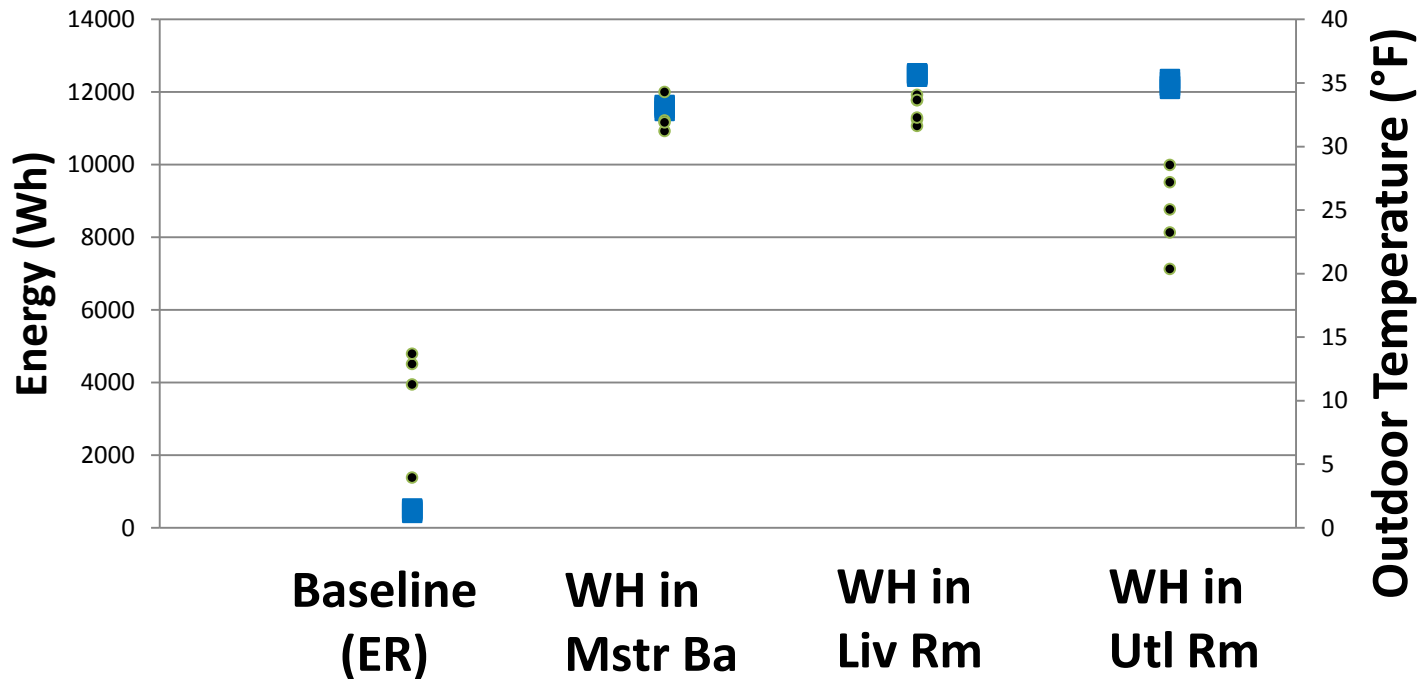


Experimental Plan



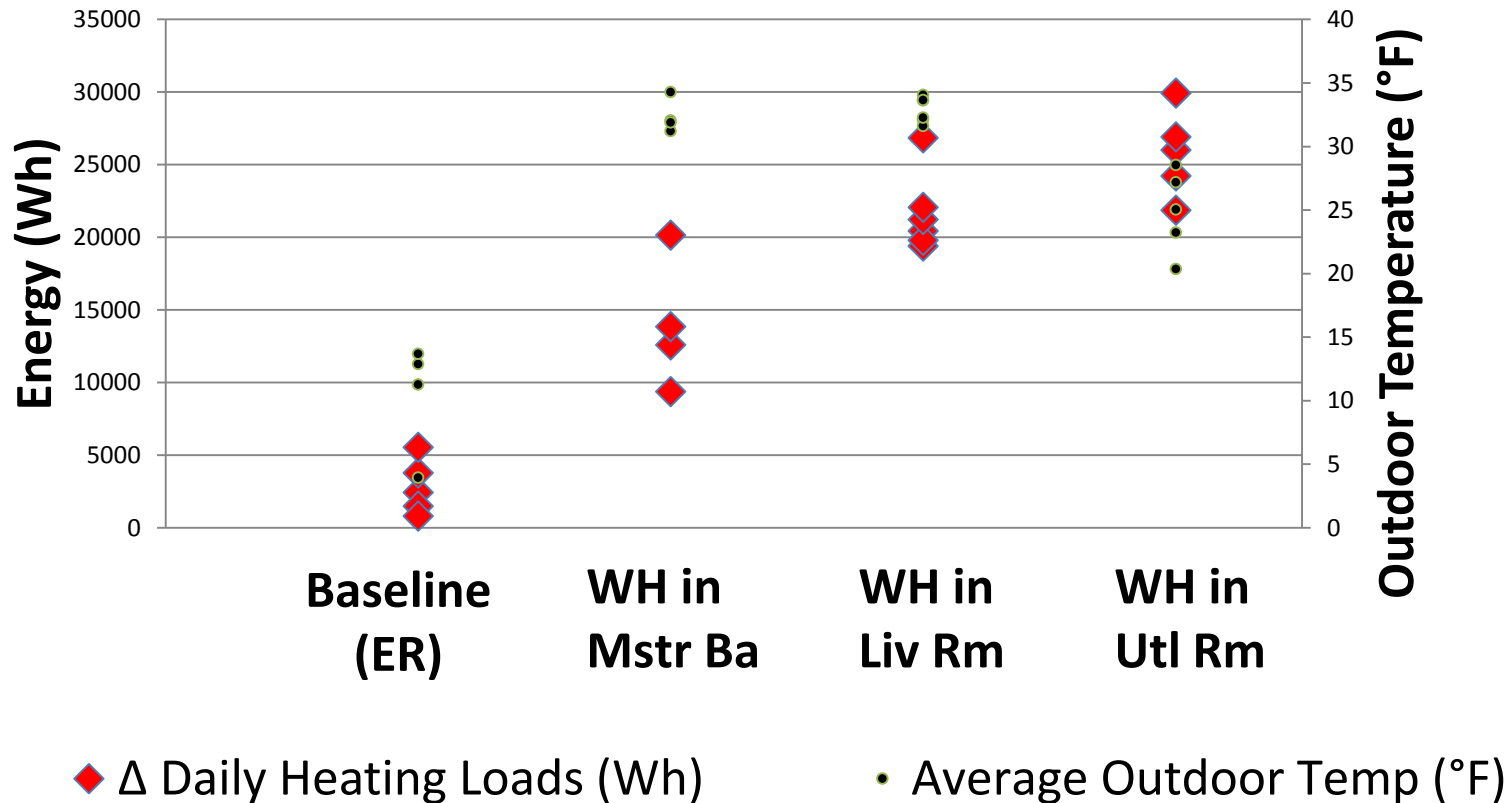
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Difference in Daily Water Heater Energy: (Baseline minus Experimental Home)

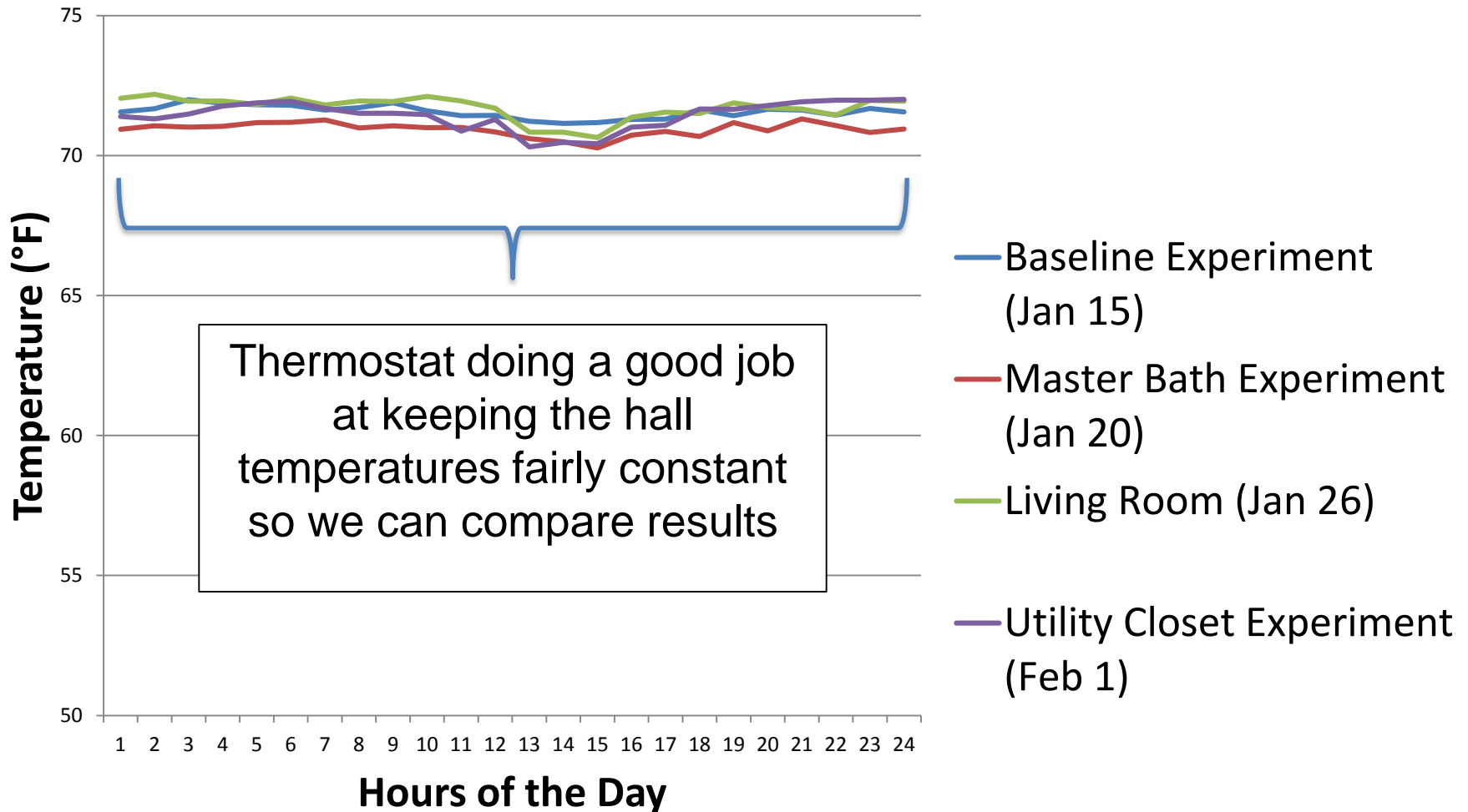


■ Δ Daily Water Heater Energy (Wh) • Average Outdoor Temp (°F)

Difference in Daily HVAC Energy: (Experimental minus Baseline Home)

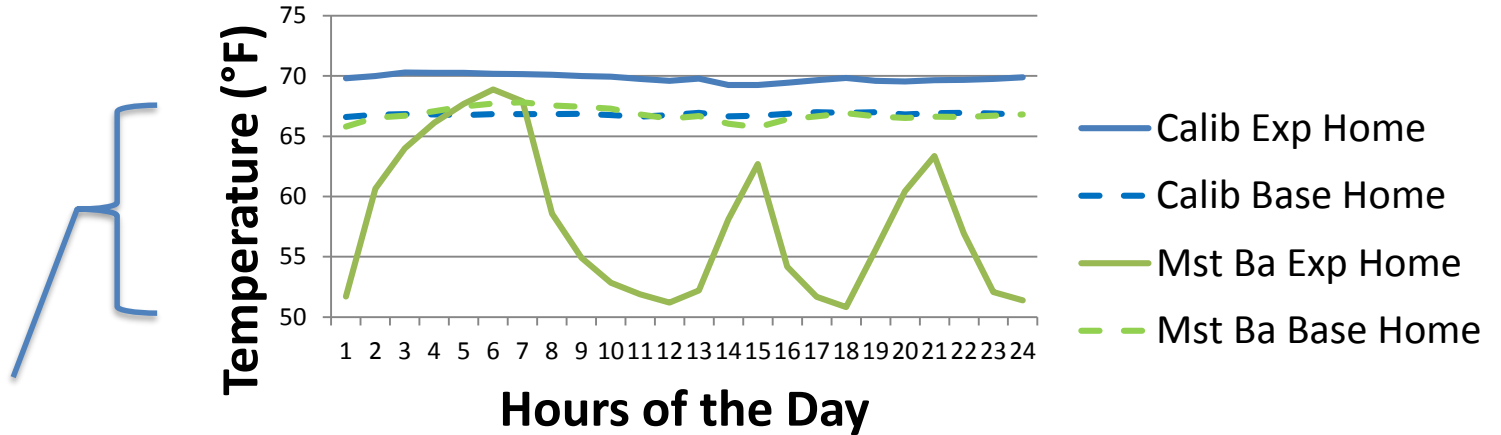


Experimental Home - Hall Temperatures in the Experimental Home

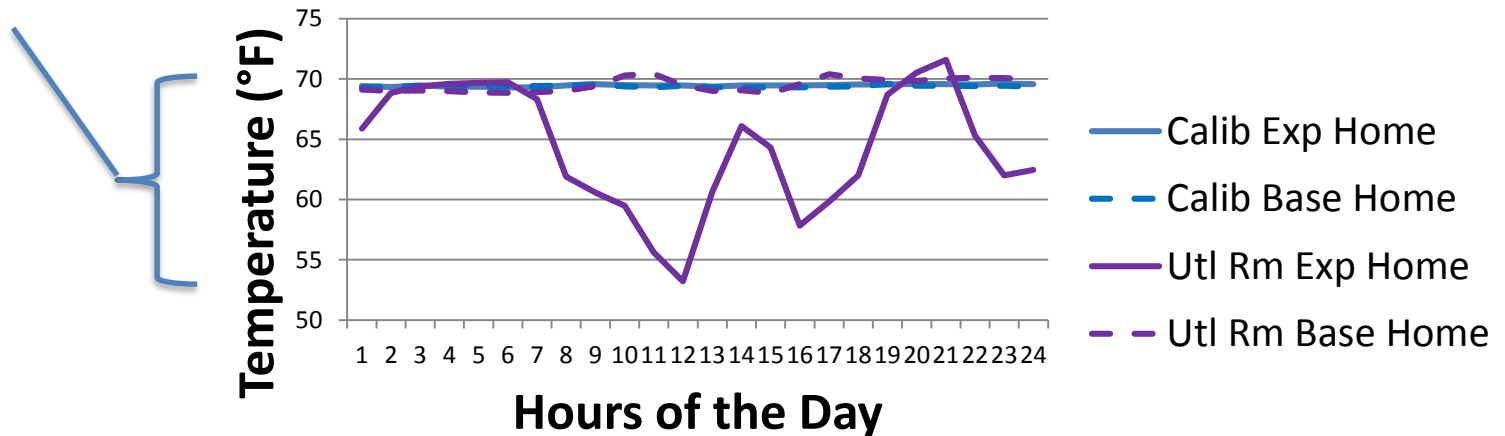


Local Cooling Effect in Small Spaces

Master Bathroom Temperatures

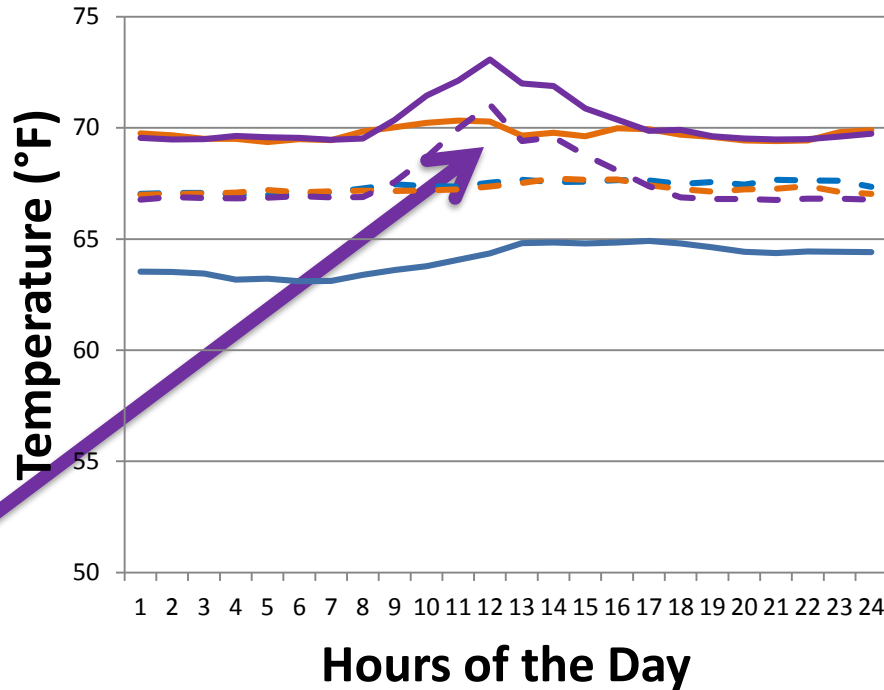


Local cooling is about
17-20°F in small spaces



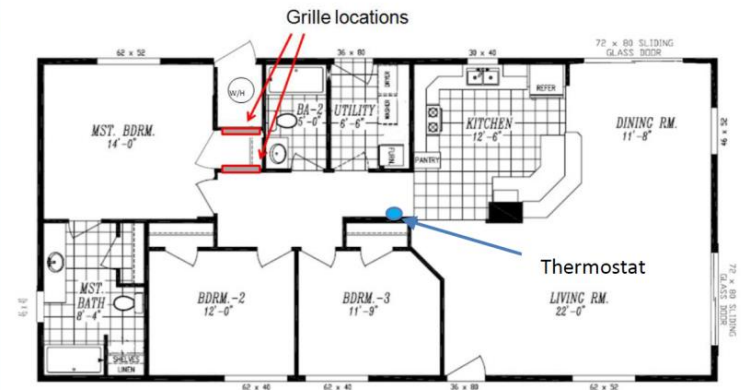
Master Bedroom Temperatures

Increased space temperatures in master bedroom - potentially due to local cooling around thermostat



- ERWH Calib Exp Home
- - ERWH Calib Base Home
- HPWH in LR
- - ERWH in LR
- HPWH in Util Rm
- - ERWH in Util Rm

Solar gains because master bedroom on south side



- ▶ Theoretical interaction factors assume a single, well-mixed zone miss most of the relevant processes.
- ▶ Energy use in home with HPWH increases as HPWH is closer to the thermostat and/or return grille
- ▶ Local cooling effect is more than double of previous experiments in small spaces. Conditioned space, not ducted to the outside.
- ▶ As expected, indoor winter conditions are dry so no condensate measured
 - HVAC load due to HPWH interaction is exaggerated in this instance

- ▶ Flip flop homes. Put water heater in HPWH mode in “baseline” home and in ER mode in “experimental” home. Compare results to previous experiments.
- ▶ Additional experiment still needs to take place in the water heater closet. Results can be compared with previous experiments in the water heater closet.
- ▶ Determine if stratification is occurring in each room, and contributing to elevated temperatures
- ▶ RTF contract analysts have requested a space heating experiment using similar approach, but with space heaters instead of HPWHs. This may shed light on sensible heating interaction vs. sensible cooling interaction
- ▶ Report all results in HCF