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# PNNL Lab Home Results for CO2 Combi System Stress Tests

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# BACKGROUND

# Benefits: $CO_2$ as a Refrigerant (R744)

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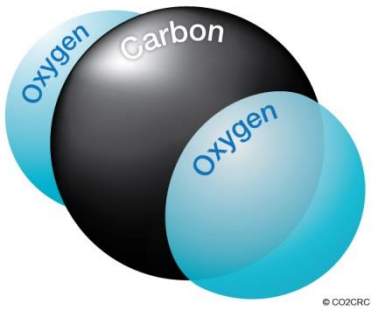
- Thermal lift at cold temperatures exceeds standard refrigerant capacity
- Flexible in different climate zones
- Non-flammable
- Global Warming Potential of 1 (vs 2,088)



# Past Lab Home Demand Response Experiments with Sanden $CO_2$ HPWHs

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| Experiment Metric | Unitary System | Split-System |
|---|---|---|
| Dispatchable Power (kW) | 1.3 | 1.2 |
| Recovery Energy Shift (kWh)* | 2.65 | 2.95 |
| Oversupply duration (hours) | 6 | 6 |
| Maximum off period while delivered temperature is met (hours) | 6 | 12 |

*Energy required to recover tank to set point after DR event

Opportunity!

GP Sullivan and JP Petersen. July 2015. *Demand-Response Performance of Sanden Unitary and Split-System Heat Pump Water Heaters* . PNNL - 24224, Pacific Northwest National Laboratory, Richland, WA.

# Project Participants

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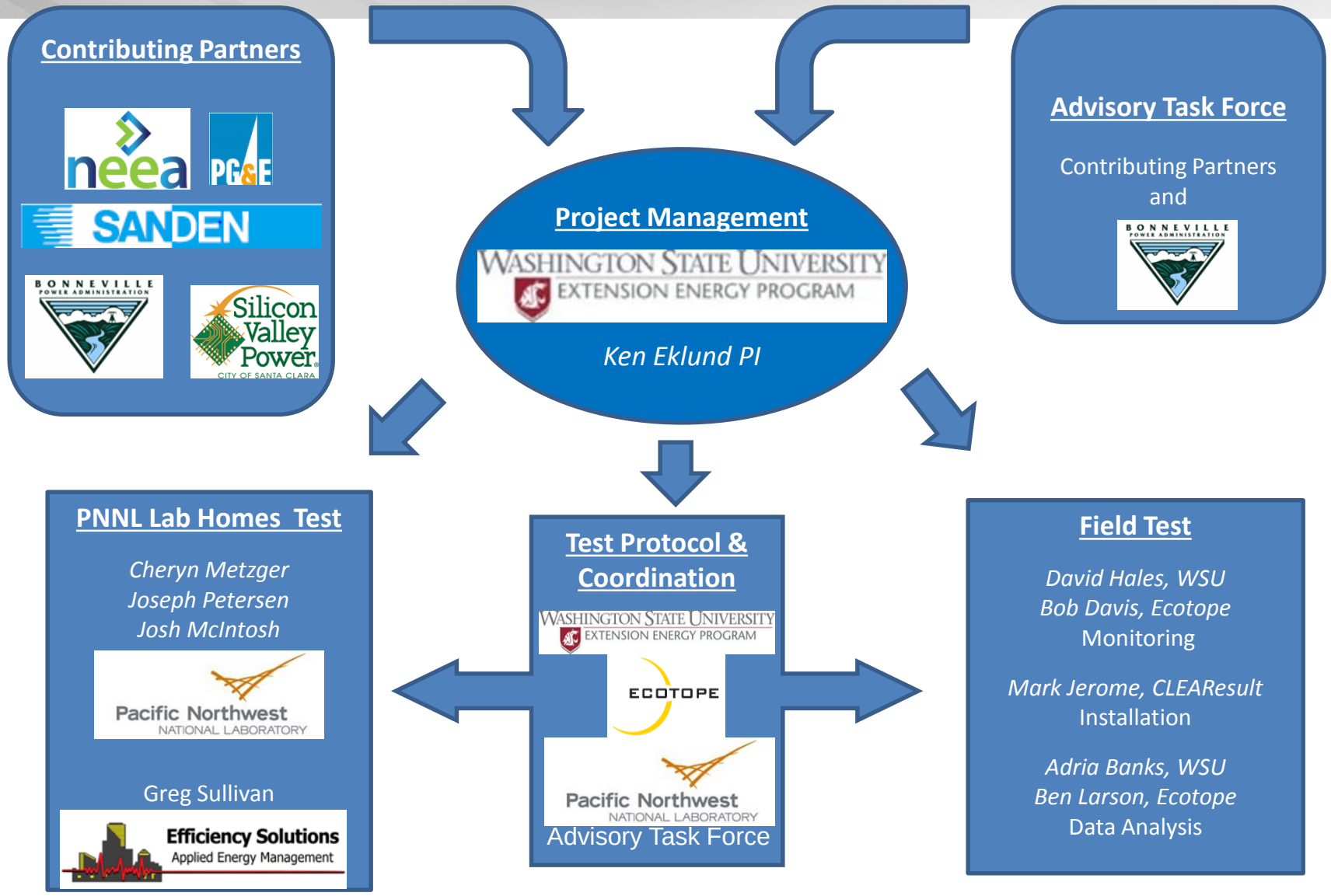


# EXPERIMENTAL PLAN

# Lab Homes Characteristics



- Represent existing homes
  - 3 BR/2BA 1493-ft$^2$ double-wide, factory-built to HUD code
  - All-electric with 13 SEER/7.7 HSPF heat pump central HVAC + alternate Cadet fan wall heaters throughout
  - R-22 floors, R-11 walls & R-22 ceiling with composition roof
  - Incandescent lighting
  - Bath, kitchen, whole-house exhaust fans
  - Carpet + vinyl flooring
  - All electric
- Modifications include end-use metering, sensors, weather station, and three electric vehicle charging stations

# Research Questions



During the heating season:

1. Does the system meet common space and water heating loads in these homes?
2. What is the impact on the system's ability to meet space and water heating needs when occupant-controlled variables such as thermostat settings, hot water draws, and hot water temperature settings are moved beyond average?
3. What is the DR oversupply mitigation capability and its ability to meet space and water heating loads?
    a. When occupant-controlled variables are moved beyond average?

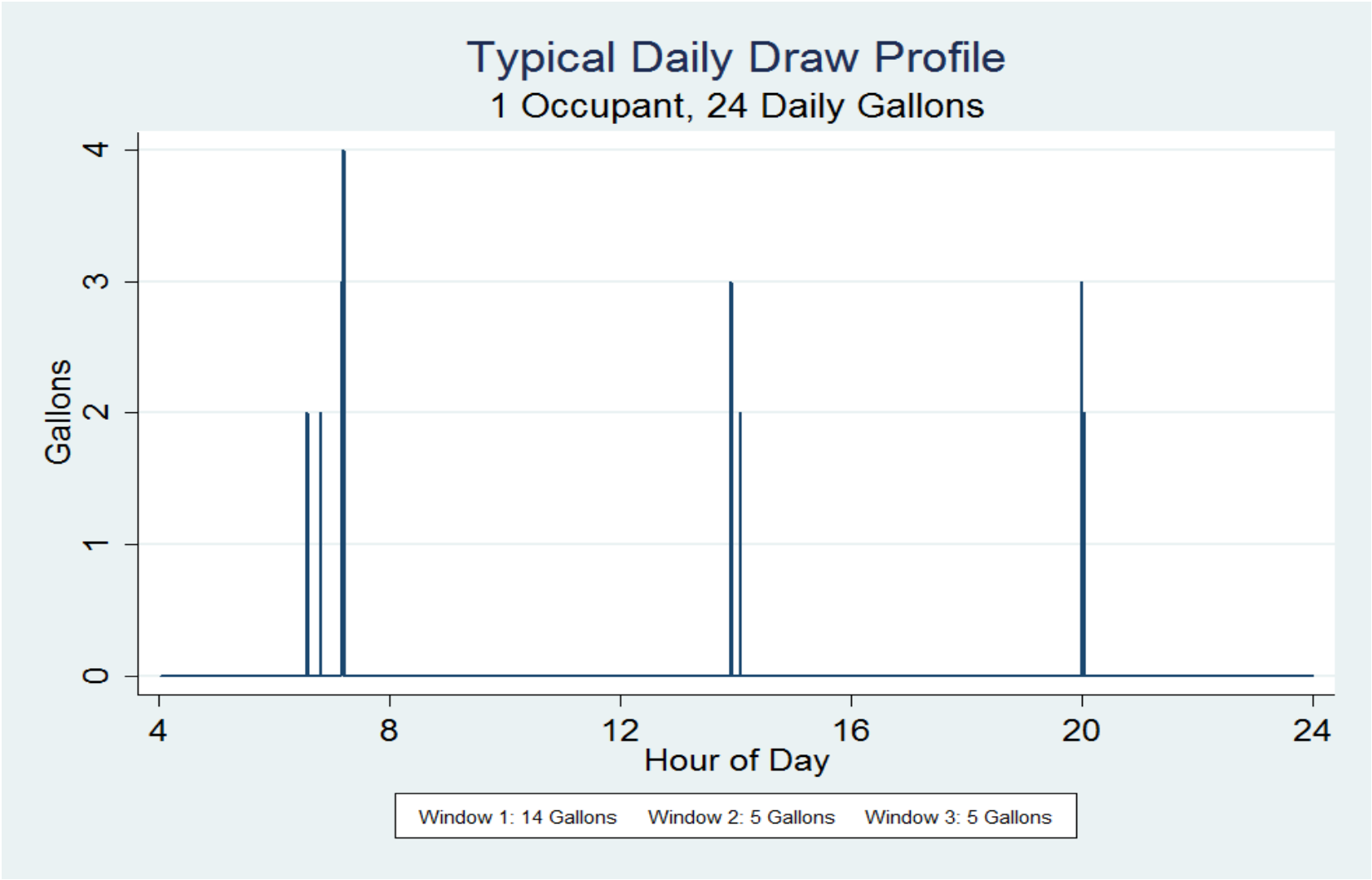
# Load Definitions



- Thermostat settings
  - Low: 65°F
  - Medium: 71°F
  - High: 80°F
- Water Temperature settings:
  - Low: 125°F
  - High: 135°F
- Water Load settings:
  - Low: 24 gpd
  - Medium: 46 gpd
  - High: 85 gpd

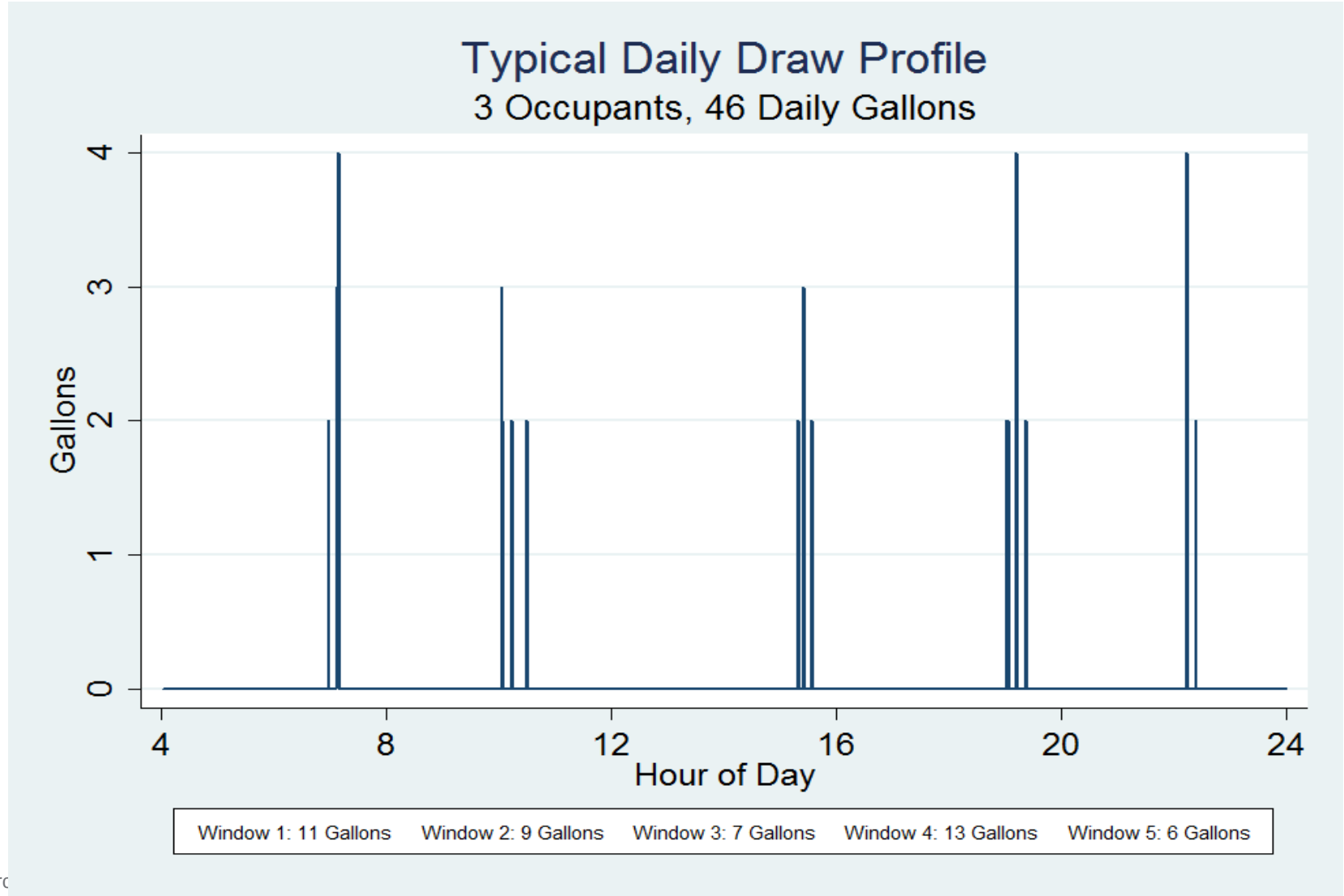
# Low Use – Daily Draw Profile





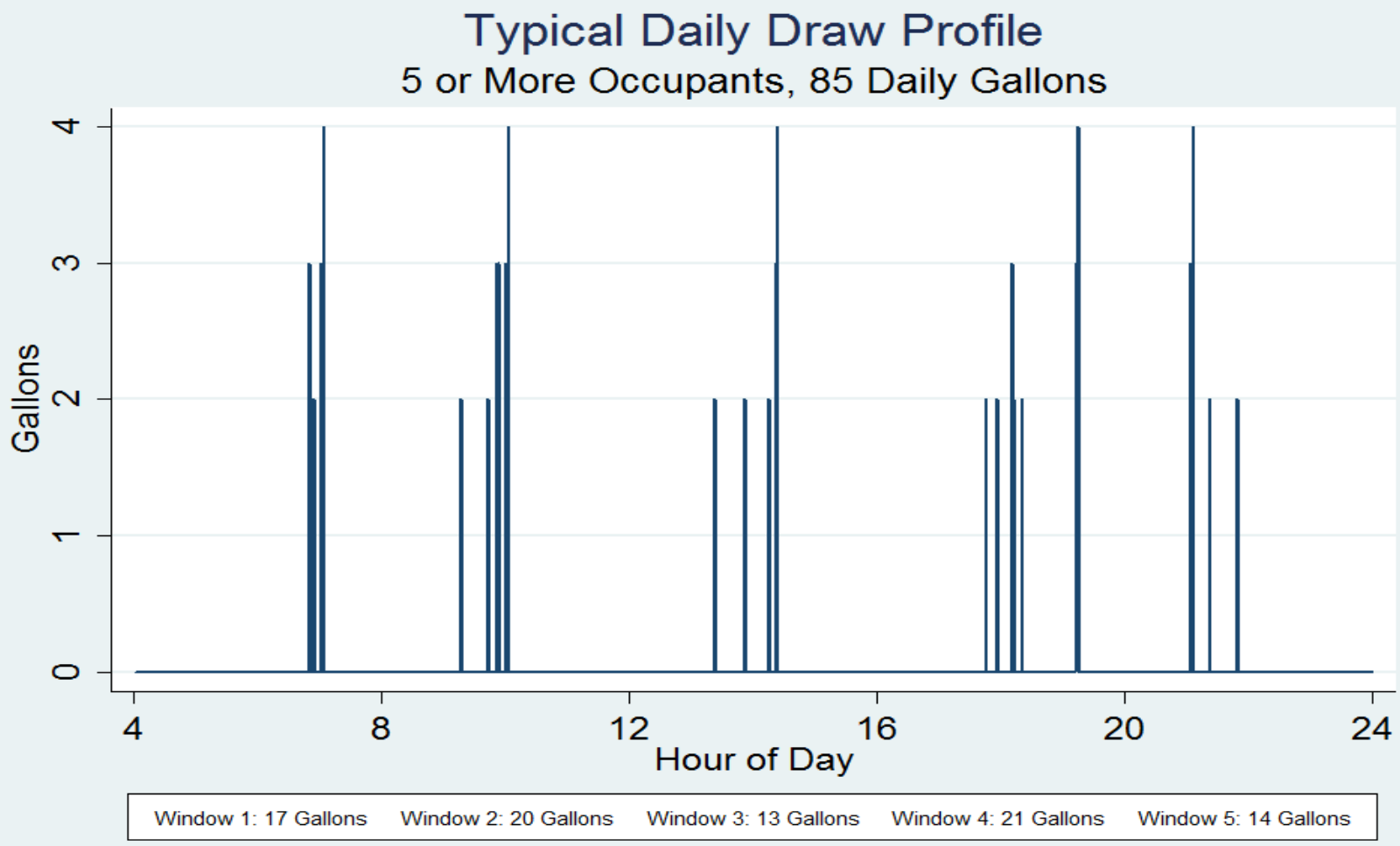
# Average Use – Daily Draw Profile





# High Use – Daily Draw Profile





# Test Conditions

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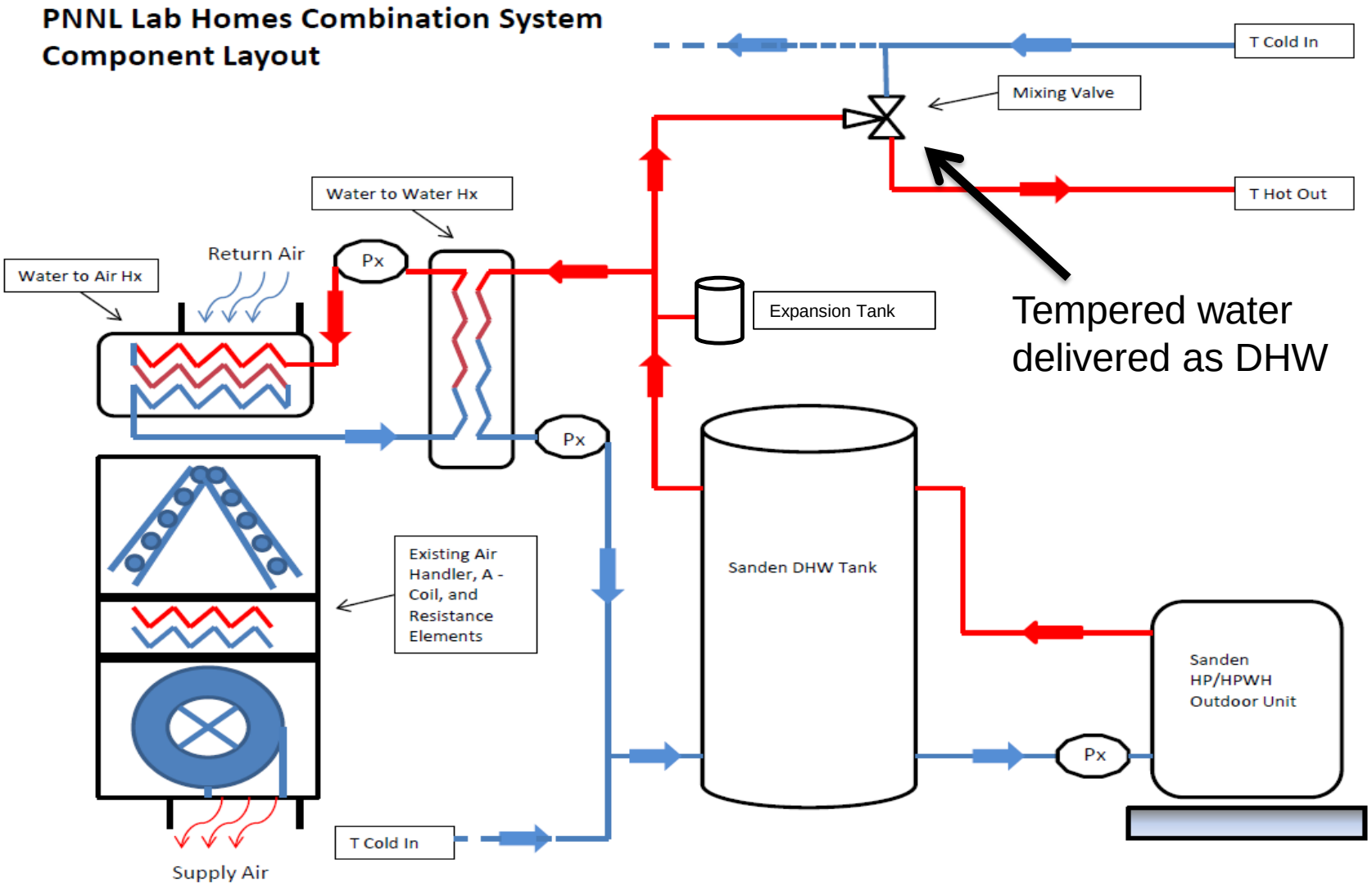
| Test Name | Lab Home A (Control) | | | | Lab Home B (Experiment) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Heating System | Heat Load | Water System | Water Load | Heating System | Heat Load | Water System | Water Load | DR Schedule |
| Stress High Flow | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | High | None |
| Stress Low Flow | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Low | None |
| Stress High Heat | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | High | Sanden HP | High | None |
| Stress Low Heat | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Low | Sanden HP | Low | None |
| Stress High Water T | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | None but water T= 140°F |
| DR 46 GPD | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | 5 hrs off |
| DR 85 GPD | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | Medium | Sanden HP | High | 5 hrs off |

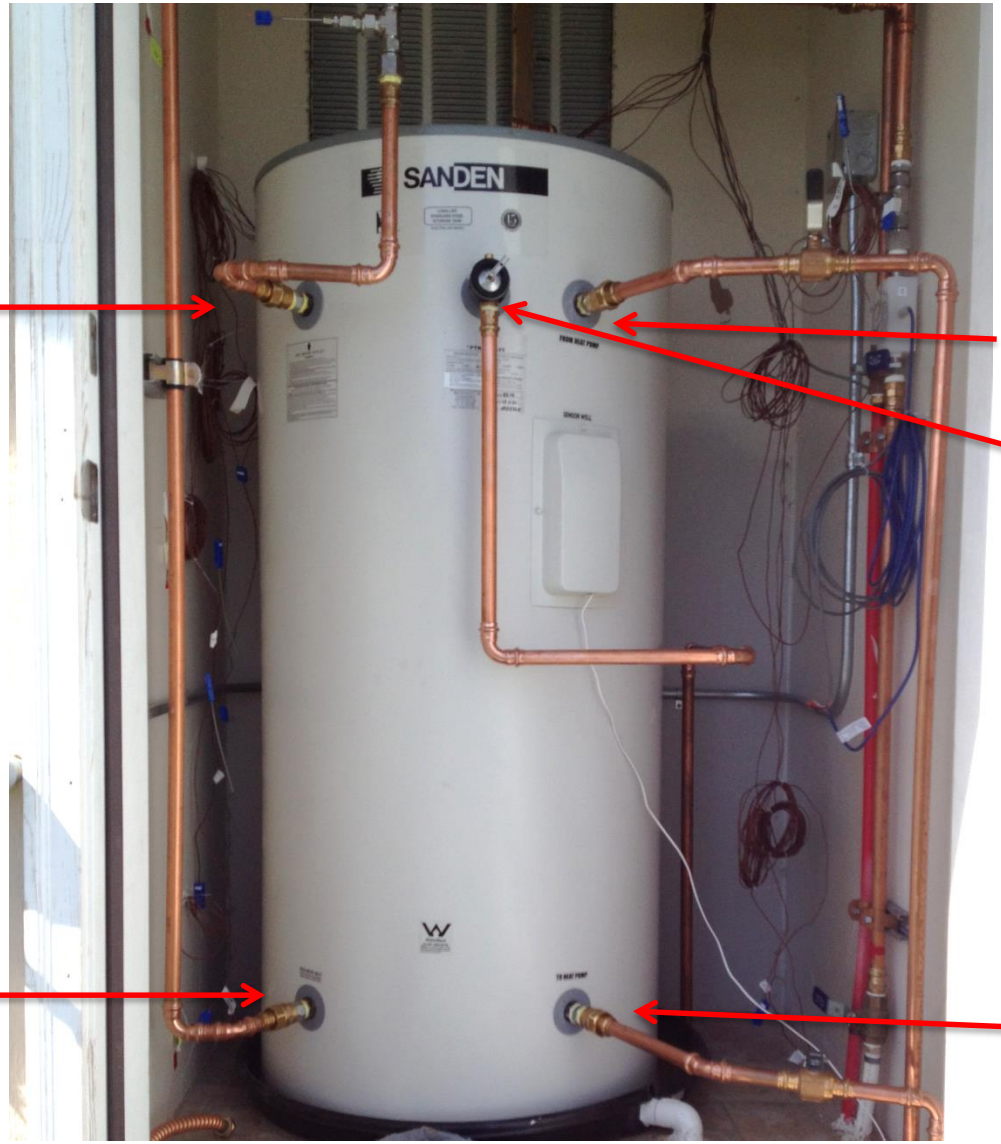
# EXPERIMENTAL SETUP

# Experimental Setup






System design credit to Mark Jerome, CLEAResult




Hot water out

From heat pump

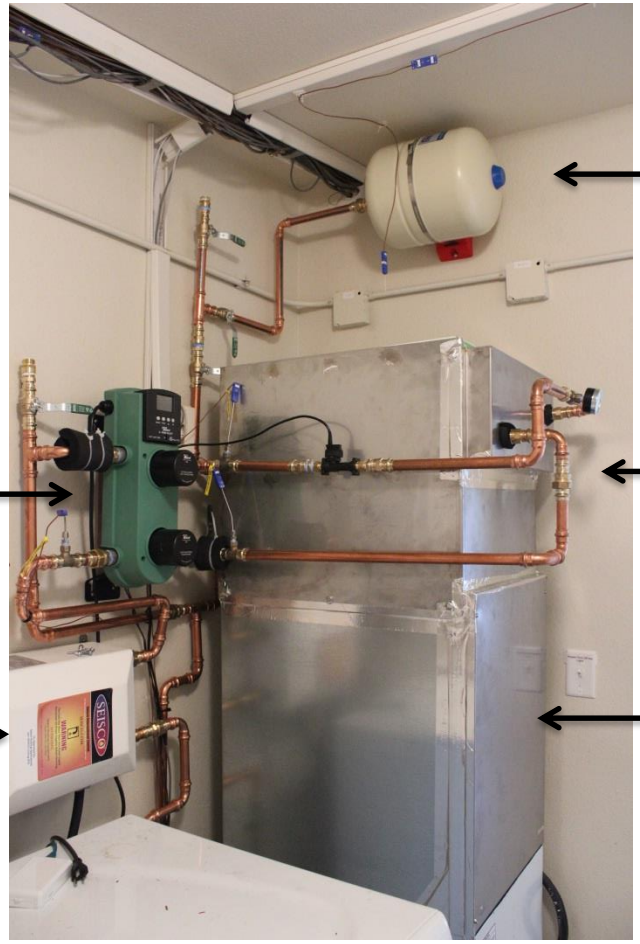
Pressure relief valve

Cold water supply

To heat pump

# Interior Heat Exchange System with Electric Forced Air Furnace





Expansion Tank

Taco water to water heat exchanger

Custom water to air heat exchanger

Back up heater

Existing air handler for forced air furnace

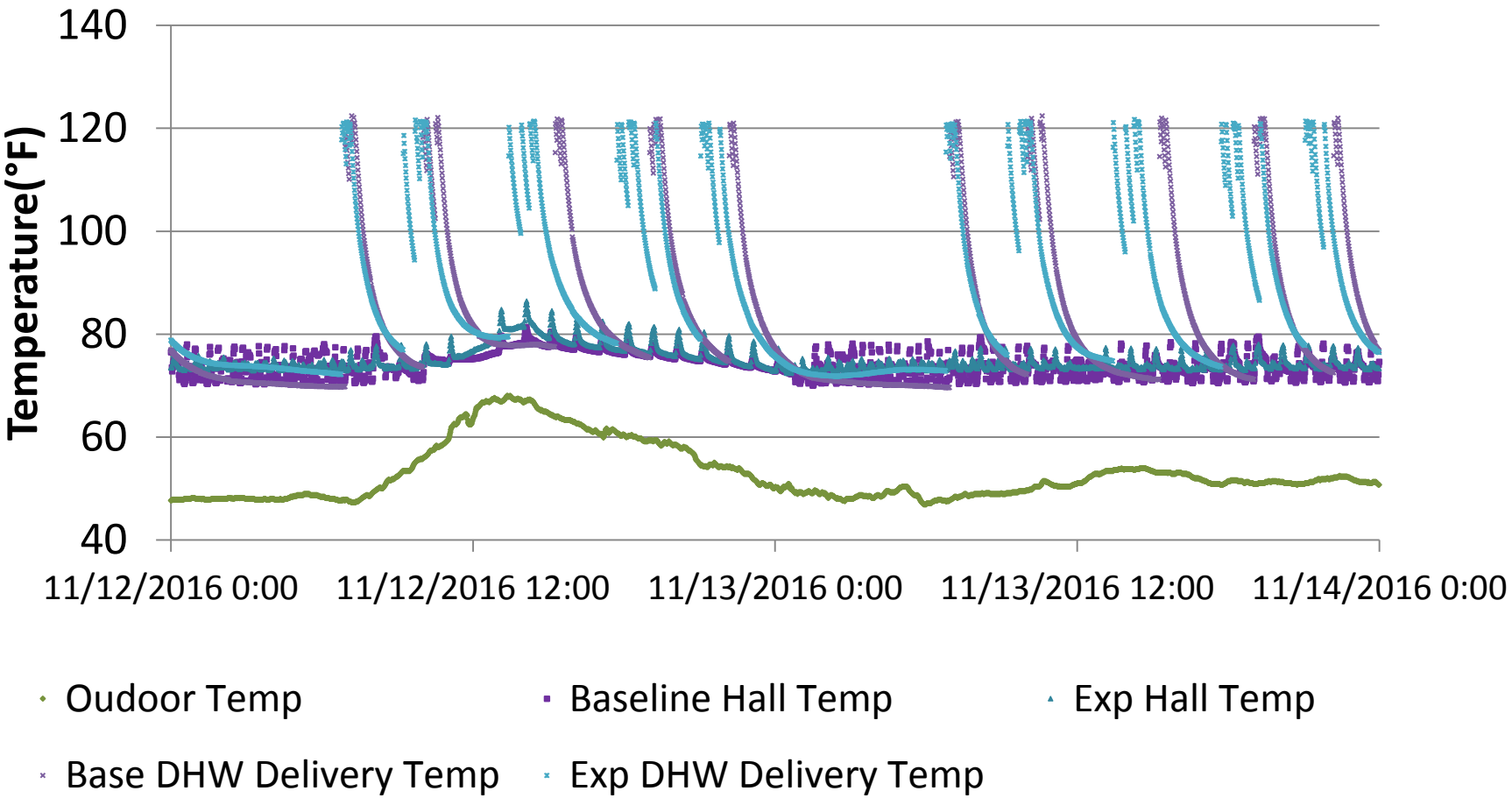
# Installation Issues



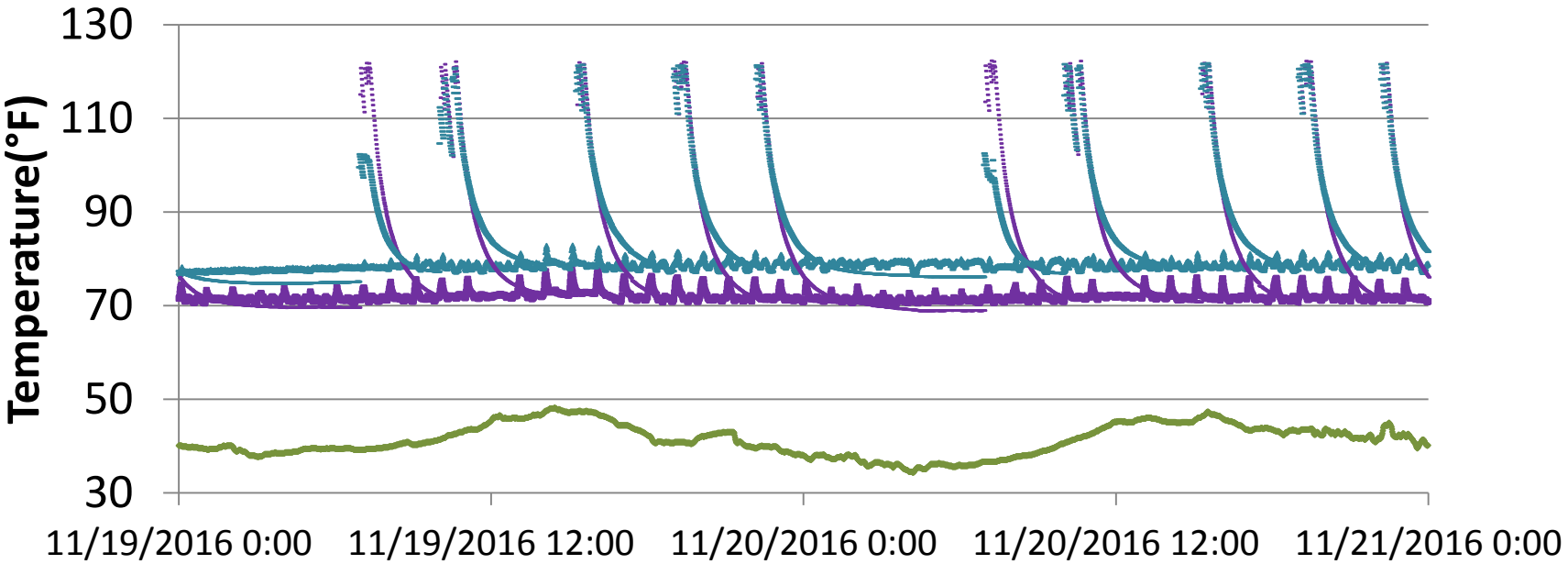
- Equipment procurement
- Limited space of water heater closet and utility room
- Pump leakage on Taco unit due to excess pressure → added expansion tank
- After some initial commissioning, looked closer at control strategy of Taco unit – factory setting was outside air reset control, changed to indoor temperature at thermostat for initial call for heat and on/off state
- Added extra pressure gauges in both homes to help diagnose problems
- Missing a pressure relief valve for one system
- Broke parts upon installation, needed to order new ones
- One Taco system ran continuously, even when HPWH was off and no call for heat → Dipswitch reconfigured
- Faulty mixing valve

# INITIAL RESULTS

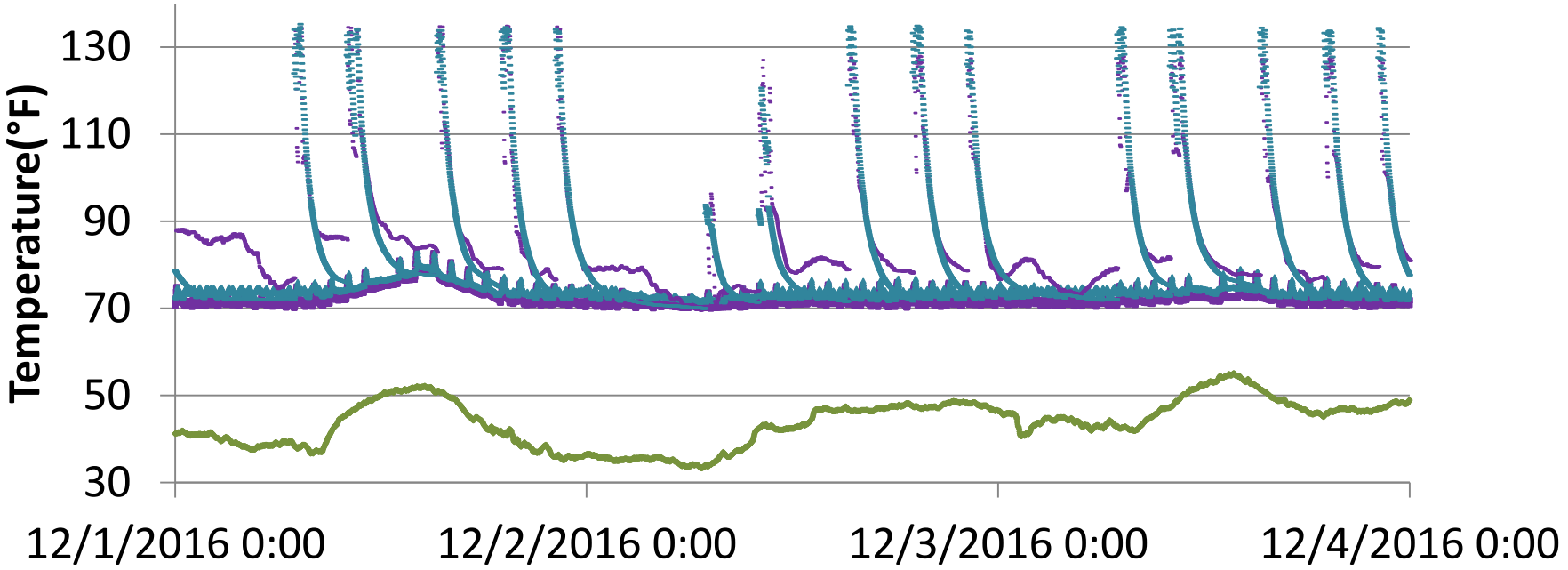
## High Water Heater Load: 46 GPD vs. 85 GPD

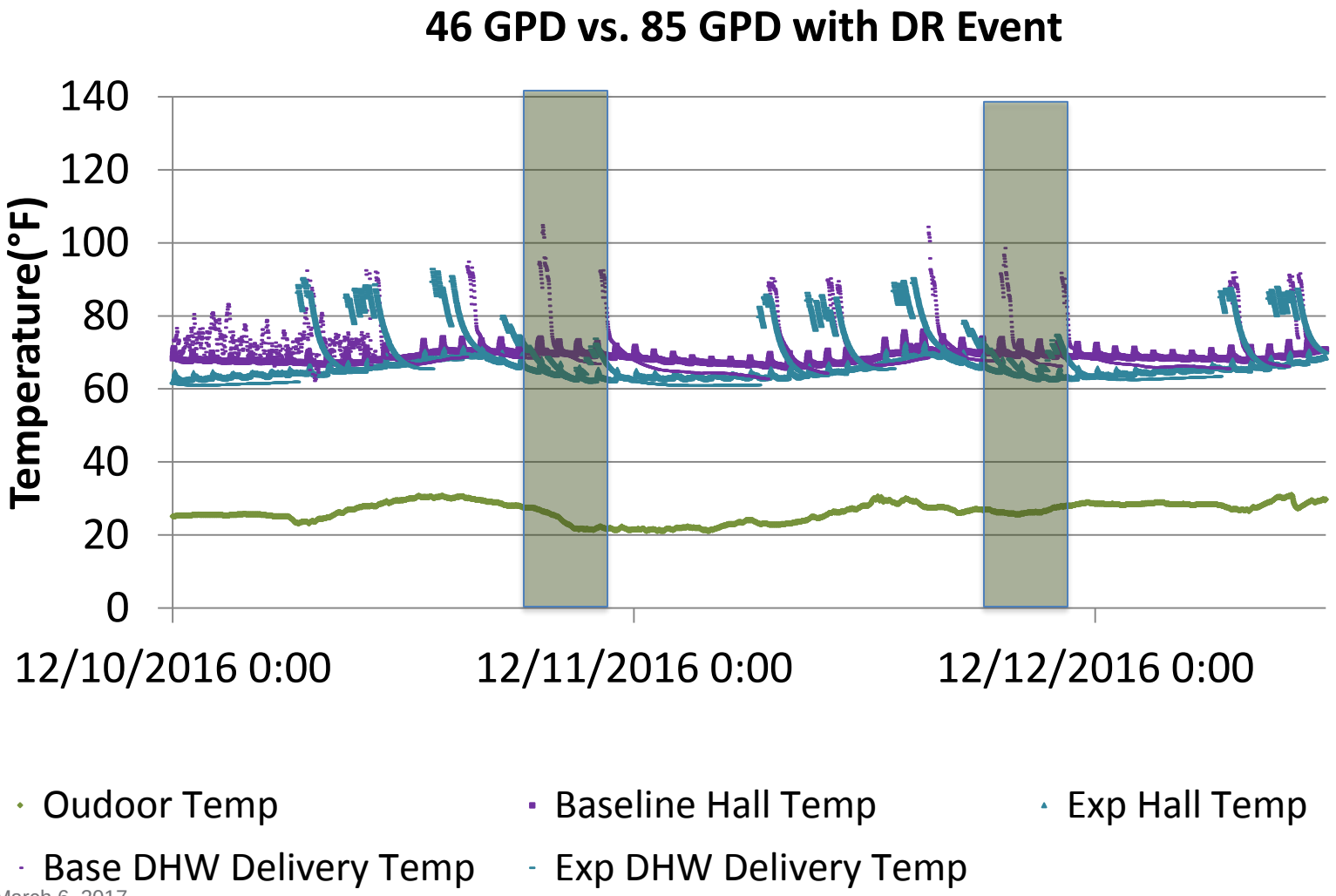


# Thermostat Set Point Increase: 71°F vs. 80°F



# DHW Set Point: 125°F vs. 135°F




46 GPD vs. 85 GPD with DR Event
Temperature(°F)
140
120
100
80
60
40
20
0
12/10/2016 0:00
12/11/2016 0:00
12/12/2016 0:00
Oudoor Temp
Baseline Hall Temp
Exp Hall Temp
Base DHW Delivery Temp
Exp DHW Delivery Temp

# Possible Loads



- When outdoor temp is above 40°F, system can meet loads:
  - 85 GPD
  - 80°F thermostat set point
  - 135°F water heater set point
- System cannot meet loads consistently:
  - When outdoor temperature is below 40°F
- Inconclusive if system can meet loads consistently following a DR event if temperatures are above 40°F
- System favors space conditioning temperature over water heating temperature

# Future Work



- Technical report
- 1 page fact sheet
- Installation guidance
- Web content
- Power point presentation for funders to share with other utilities

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# THANK YOU!

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Let me know if you would like to be added to the new Lab Homes Newsletter!