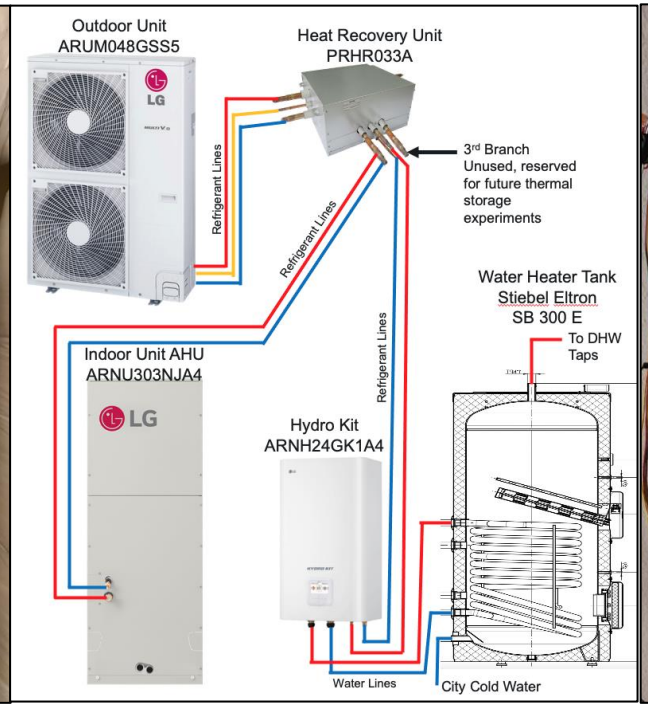
Combination HP and HPWH (New Project)









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1.4.1.19 Task 7

Project Summary

Objective and Outcome

Test and document the water heating and space conditioning performance of a residential cold climate heat pump capable of heat recovery and report on the results. Compare the performance to an identical home with a standard ducted split heat pump and a unitary heat pump water heater.



Team and Partners

PNNL
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LG Electronics
Sangok Kweon, Aushutosh Suri, John Hwang

Stats

Performance Period: FY22–FY24

DOE FY23 Budget: $289k, Official Cost Share: $0k

Milestone 1: Install and commission the system

Milestone 2: Collect winter results

Milestone 3: Collect summer results

Problem

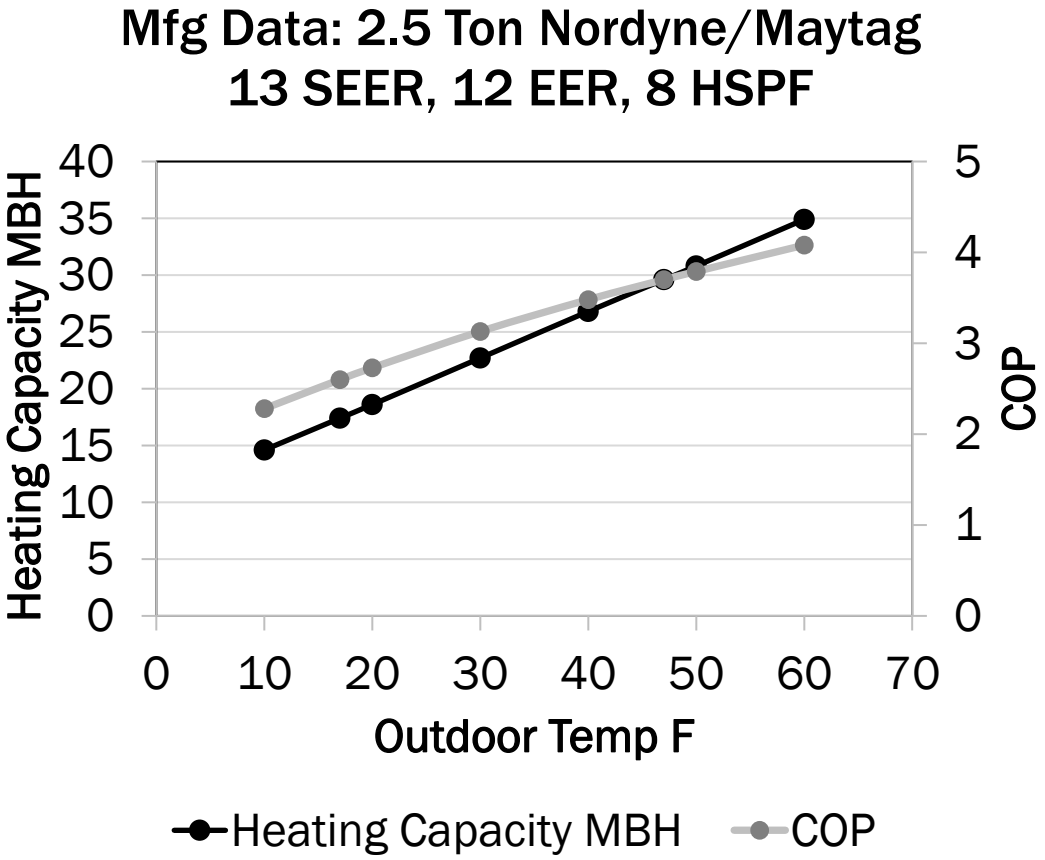
- **Unitary/packaged HPWHs are not a good fit in all homes**, as some have one or more of the following challenges:
  - The water heater is located in a space with insufficient air volume
  - The water heater is located in a space where the noise is unacceptable
  - Cold air generated in conditioned space can result in comfort problems and create additional space heating load
  - Semi-conditioned spaces in cold climates can get cold enough that electric resistance is used often
  - High water heater recovery rates are required due to hot water usage pattern
  - The electrical panel lacks the space to add a two-pole 240v circuit for a unitary HPWH and 120v HPWHs wouldn't meet needs
  - Insufficient height for a HPWH or insufficient height for the upsized HPWH that is needed to satisfy hot water needs
- Heat pump cooling capacity and system coefficient of performance (COP) are diminished during peak outdoor temperatures, creating urban heat island while energy is used for domestic hot water heating
- Heat pump heating capacity is reduced due to cold temp when heating is needed most



Problem

- Most heat pumps on the market have significant heat capacity declines as outdoor temperatures fall below 40 ºF and rely on auxiliary heat to supplement heating capacity. Since auxiliary heat has a maximum COP of just 1, they create a peak demand on the grid, and require high ampacity from the electrical panel.

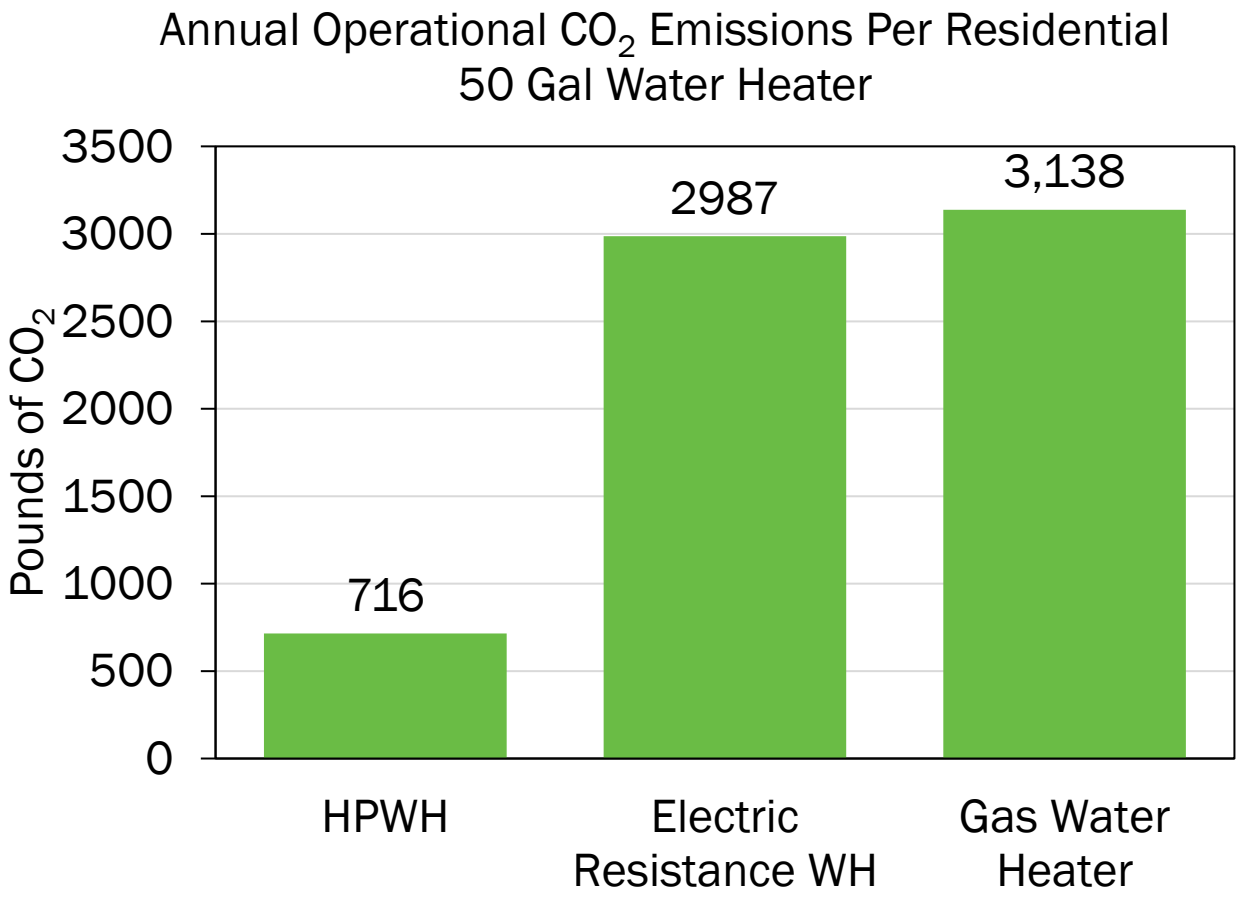
- 240v HPWHs are very efficient, but rely on electric resistance when the intake air falls below ~38-45 ºF and thus create a peak demand on the grid and pull high ampacity from the electrical panel. HPWHs operating in air volume constrained spaces can cool the surrounding air to fall below the low temp cutoff for heat pump operation.



"NOTICE: The heat pump's fan will not turn on if the incoming water temperature is less than 59 ºF/15 ºC and/or the ambient air temperature is above 120 ºF/49 ºC, or below 45 ºF/7.2 ºC."
– HPWH Manual

Alignment and Impact

- BTO's mission is to decarbonize the building stock by 2050.
- HPs and HPWHs are needed to help get there.
- This project can expand HPWHs to roughly 10 million♢ single-family homes that experience the noted constraints to using a unitary HPWHs.
- If these homes currently have electric resistance or gas water heaters, switching them to a heat pump for DHW would result in 11.3–12.1 million tons of CO_2*, respectively.

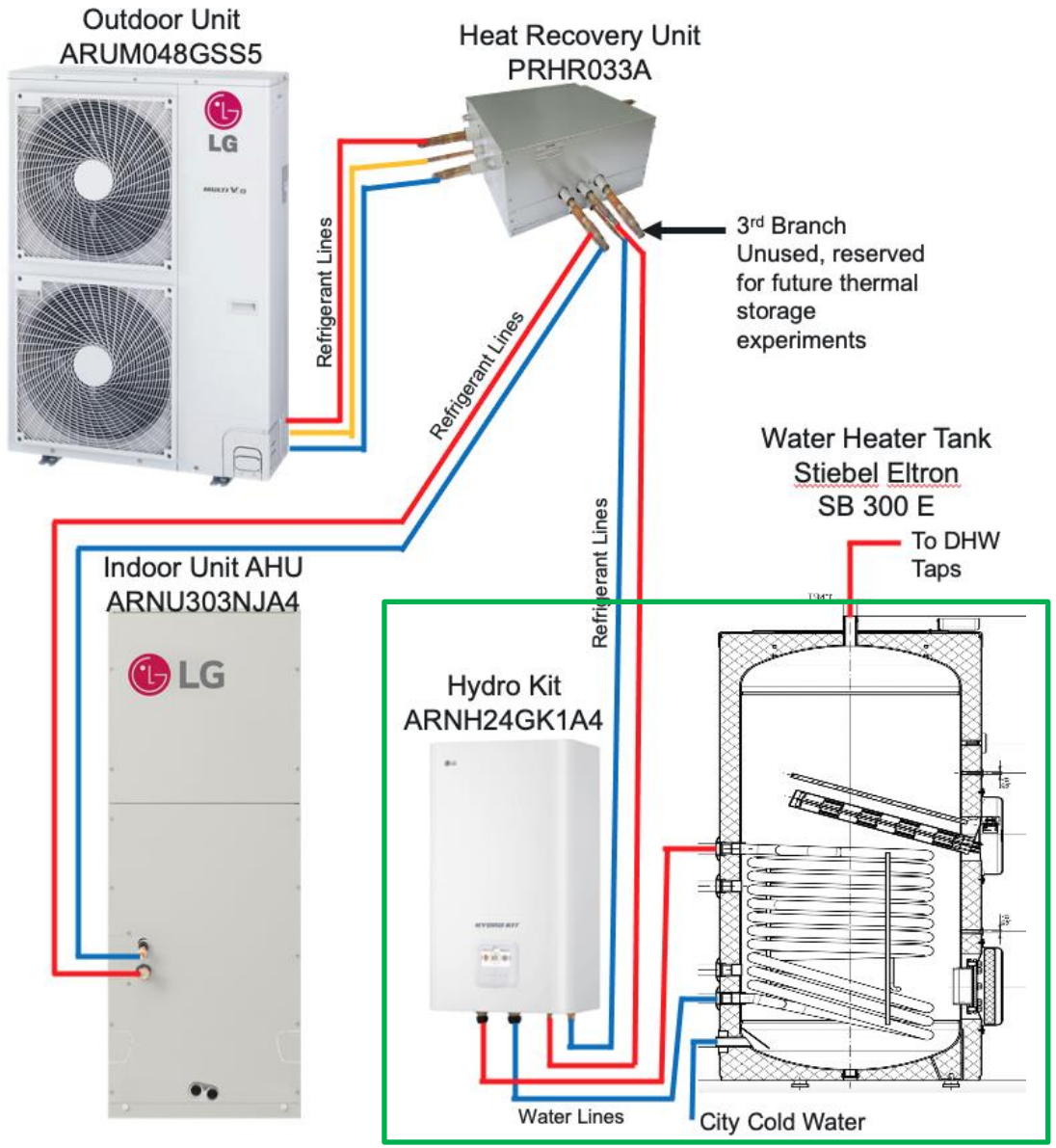


Source: ♢ Estimate from ongoing research by Joshua Butzbaugh (PNNL), * Calculations using EIA average of national electric grid and natural gas

Approach - Technology

Novel System:

- Can do simultaneous heating and cooling during the summer with heat recovery
- Near silent indoor water heating equipment, and no cold air generation, no air volume requirements around the tank



Indoor water heating equipment is nearly silent

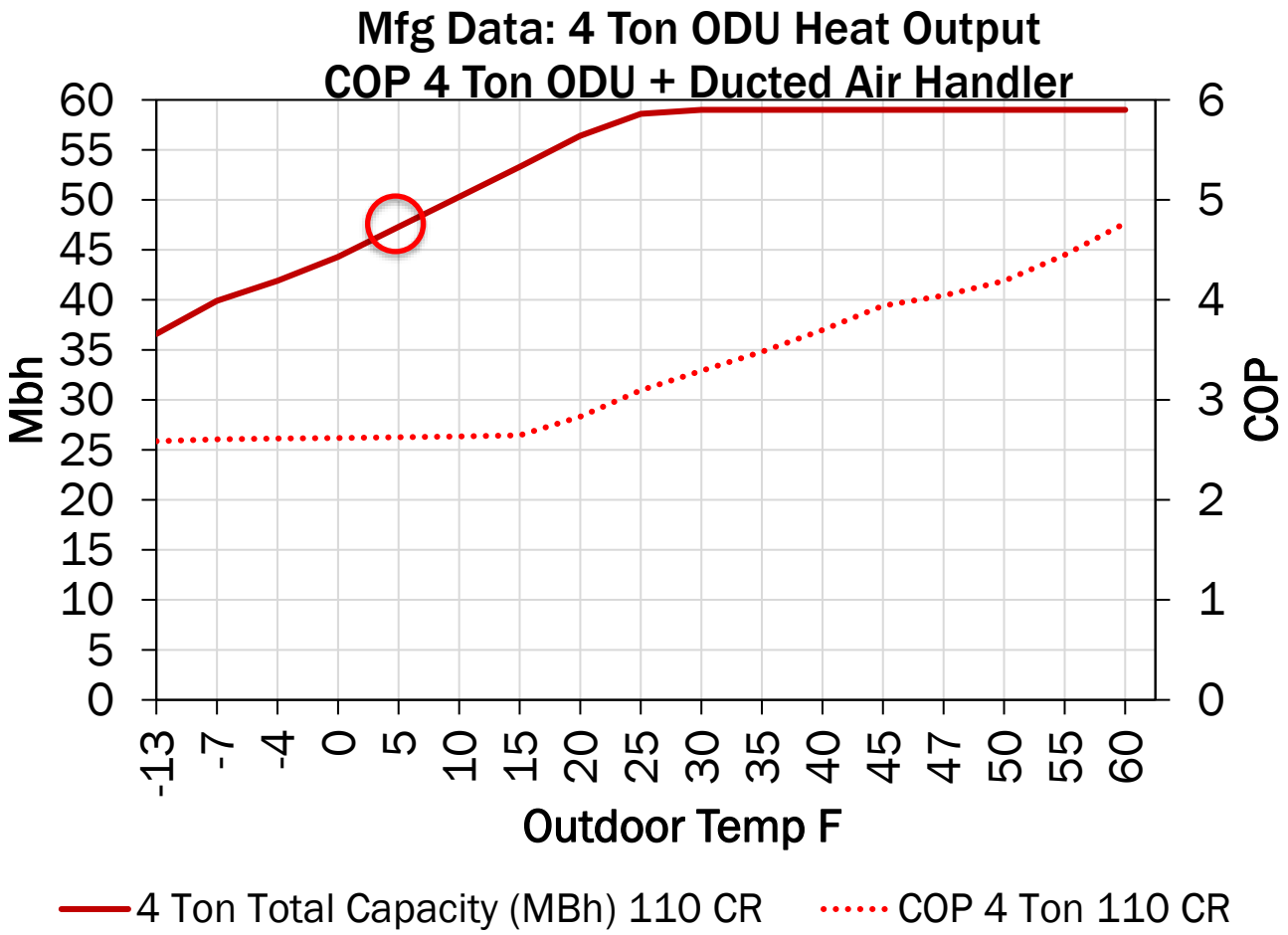
Approach - Technology

- Cold climate heat pump - 100% of the rated output down to 5 °F
- Inverter VRF tech allows capacity to modulate down when only DHW or only space heating is needed

Performance Specs

Mfg data provided to NEEP's Cold Climate Air Source Heat Pump Database

Heating / Cooling	Outdoor Dry Bulb	Indoor Dry Bulb	Unit	Min	Rated	Max
Heating	47°F	70°F	Btu/h	26,900	54,000	54,000
			kW	1.71	3.76	3.75
			COP	4.61	4.21	4.22
Heating	17°F	70°F	Btu/h	26,900	35,400	54,000
			kW	3.17	5.61	5.51
			COP	2.49	1.85	2.87
Heating	5°F	70°F	Btu/h	26,900	-	54,000
			kW	4.02	-	6.51
			COP	1.96	-	2.43



Approach – PNNL Lab Homes

- PNNL's Lab Homes are designed for testing a residential technology against a baseline.
- PNNL's Lab Homes are two identical 1,500 ft^2 double-wide manufactured homes built in 2011. After being delivered, PNNL instrumented the homes with many sensors including circuit level energy monitors and temperature sensors.
- This project is using the Lab Homes to answer these key questions:
  - How does the energy consumption of the combi heat pump compare with a home with a traditional heat pump and a unitary HPWH?
  - How does the water heating capability of the Hydro Kit compare with a unitary HPWH?

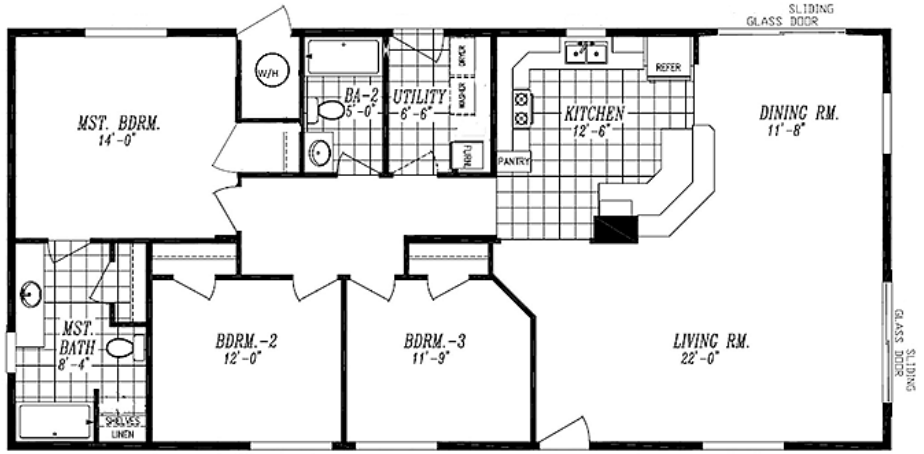


Lab Home A – Combi Heat Pump

- 4 Ton LG Multi V S ODU
- 2.5 Ton AHU
- 2 Ton Hydro Kit (refrigerant to water heat exchanger)
- 80 Gal indirectly fired water heater tank with single wall internal heat

Lab Home B - Traditional

- 2.5 Ton Maytag(Nordyne) ODU 13 SEER, 12 EER, 8 HSPF
- 2.5 Ton AHU w 10 kW + 5 kW Aux Heat
- 50 Gal A.O. Smith HPWH – 3.45 UEF



Approach – Test Procedure

Test procedure:

- Set the thermostat to result in the same 72 °F interior temperature between the Lab Homes
- Run the DOE/ASHRAE Standard 118.2-2022 84 Gallon High Usage Draw Profile
- The Lab Homes can schedule hot water draws at selectable flow rates (GPM) and duration.
  - Do this daily across a range of daily temperature, especially cold days, and record hot water temperatures, energy use—and based on the energy use, how long it takes to recover the water tank after draws—refrigerant temps, and indoor temperature.





Table A-6 High-Usage Draw Pattern

Draw Number	Time During Test, hh:mm	Volume, gal (L)	Flow Rate, gpm (L/min)
1*	0:00	27.0 (102)	3.0 (11.4)
2*	0:30	2.0 (7.6)	1.0 (3.8)
3*	0:40	1.0 (3.8)	1.0 (3.8)
4*	1:40	9.0 (34.1)	1.7 (6.4)
5	10:30	15.0 (56.8)	3.0 (11.4)
6	11:30	5.0 (18.9)	1.7 (6.4)
7	12:00	1.0 (3.8)	1.0 (3.8)
8	12:45	1.0 (3.8)	1.0 (3.8)
9	12:50	1.0 (3.8)	1.0 (3.8)
10	16:00	2.0 (7.6)	1.0 (3.8)
11	16:15	2.0 (7.6)	1.0 (3.8)
12	16:30	2.0 (7.6)	1.7 (6.4)
13	16:45	2.0 (7.6)	1.7 (6.4)
14	17:00	14.0 (53.0)	3.0 (11.4)
Total Volume Drawn Per Day: 84 gal (318 L)			

* Denotes draws in first draw cluster.

Progress – Commercialization Plan, Risk and Technical Challenges

Commercialization Plan:

- Close relationship with manufacturer – strong willingness to take feedback to improve the product
- Document and publish benefits and barriers to overcome for heat pumps with heat recovery and ability to do both space conditioning and DHW heating to provide a bundle of goods worthy of broad commercialization
- Work with the manufacturer to develop and test additional control logic features, improvements, and ability to control thermal storage.





Risks and Technical Challenges:

- Only two manufactures currently make single phase heat pumps sized for residential applications with heat recovery capabilities. Neither company has deeply explored the application of these heat pumps to provide space conditioning and DHW heating. Both systems are just sized-down versions of commercial equipment. Thus:
  - The hardware or control logic software may not work as intended or as well as it could if optimized
  - It could be complex to install, which could introduce problems during installation

Progress – Accomplishments, Milestones, and Findings

Major accomplishments and milestones:

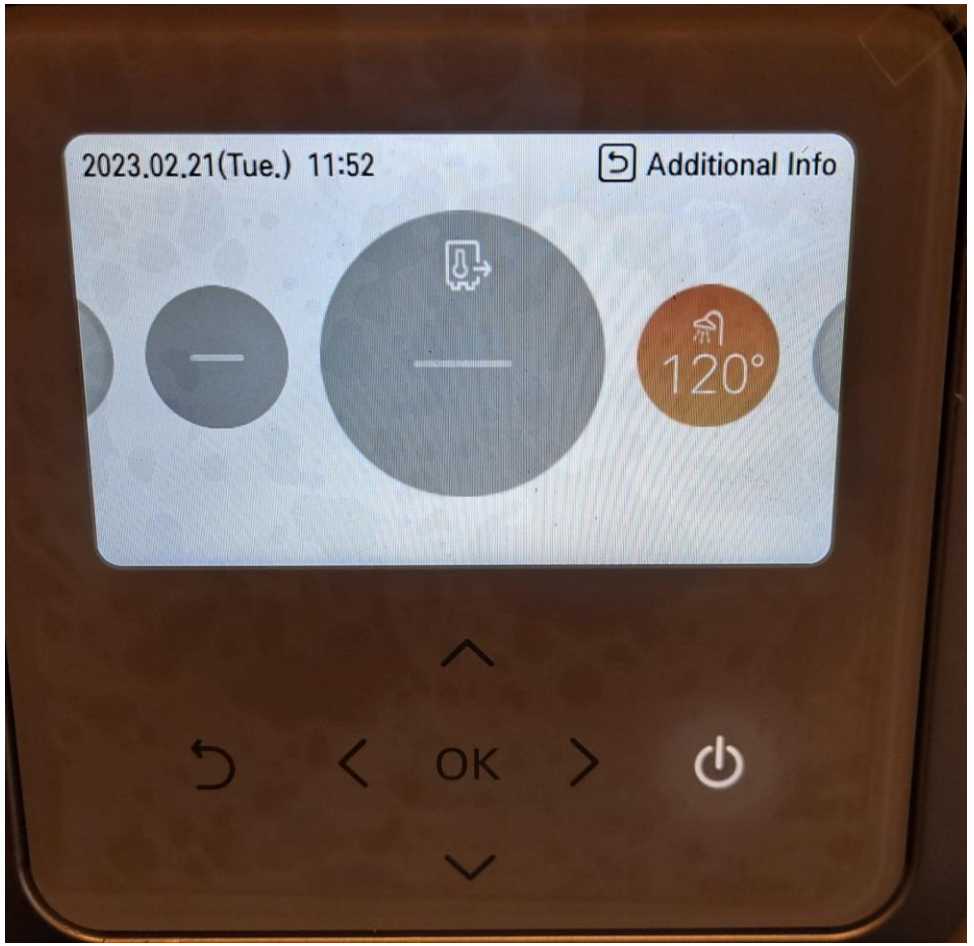
- Successful installation and commissioning
- Winter data – presented at ACEEE Hot Water Forum & Hot Air Forum

Major findings:

- Combi system can produce a lot more hot water than traditional units
- The circulation pump in the Hydro Kit for circulating water (heat transfer fluid) to the water tank is nearly silent

Unexpected findings:

- Combi heat pump system is not as energy efficient as expected, and at times uses more energy than the equipment in the baseline home



Hydro Kit user interface screen for DHW heating only mode.

Progress - Installation Experience

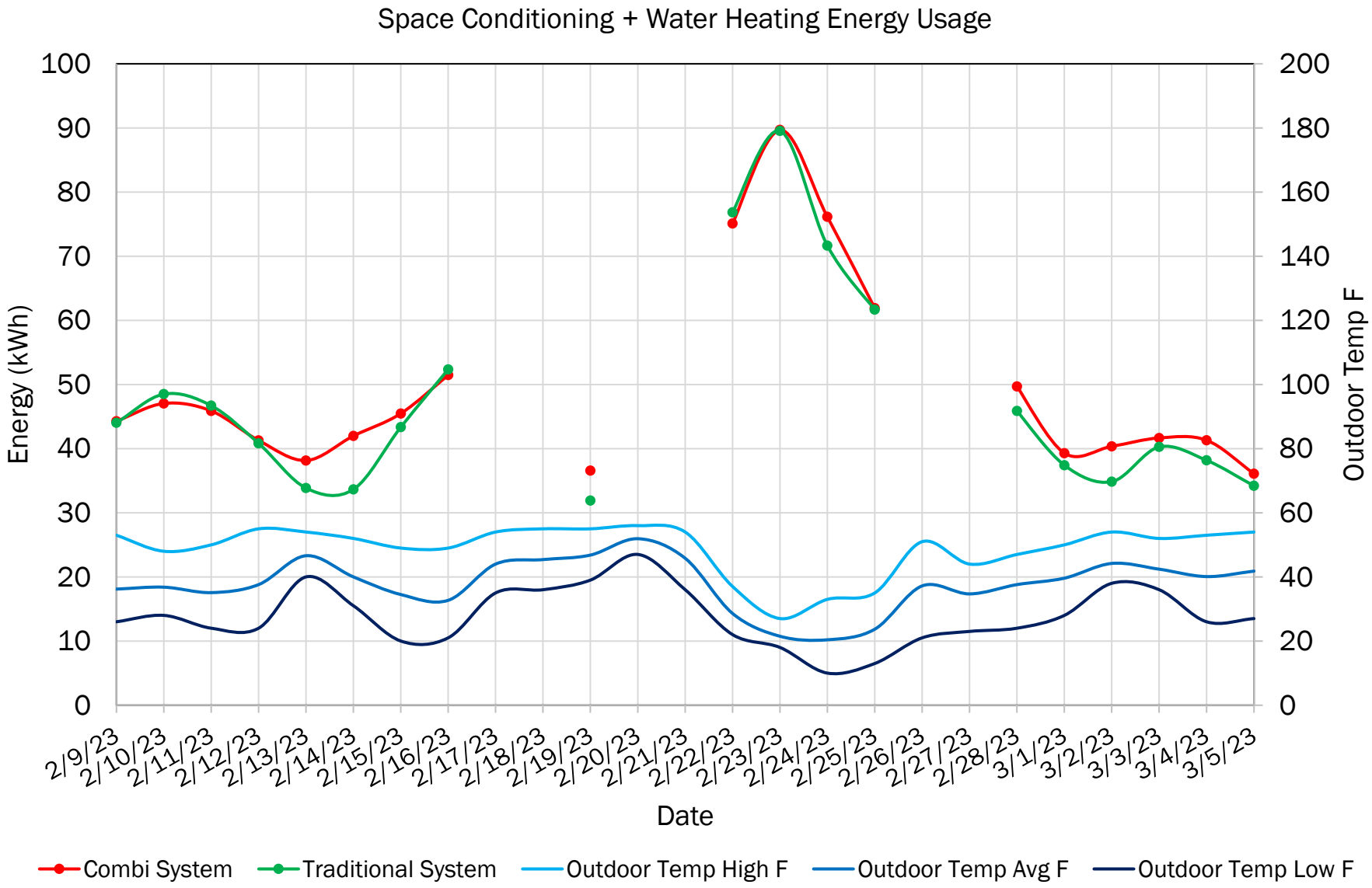
- Variable refrigerant flow (VRF) systems with heat recovery require a great deal of planning to meet the straight pipe length requirements
- Many HVAC techs have never worked on heat recovery systems
- The separate heat recovery box adds to install complexity
- brazed connections are challenging even for experienced techs; press-fit connections were easier and greatly appreciated. There were small size differences between metric versus standard pipe dimensions that required brazing.
- Recommend factory startup by a trained commissioner. VRF with heat recovery is complex; commissioning requires many precise steps.



Combi system during installation

Progress – Initial Winter Energy Results: Space + Water Heating Energy Usage

Combi system's out-of-the-box control logic did not save more energy than a traditional heat pump for space heating and unitary HPWH for water heating



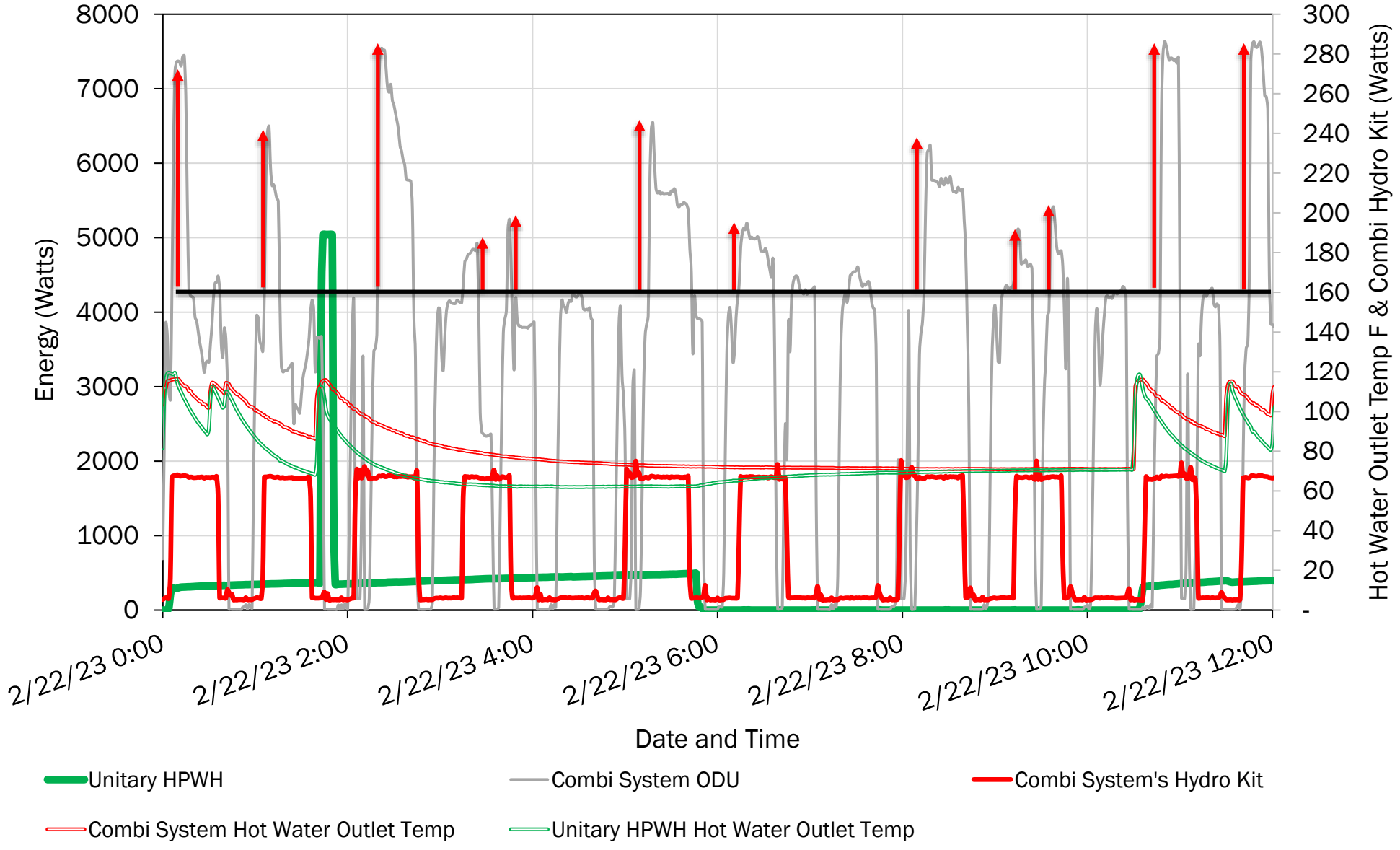
Progress – Initial Results Showing More Hot Water and Faster Reheat than Traditional Units

- **82% more hot water** (60 vs 33 gal) during a 90 gal water draw
- **33% faster reheat** (5 vs 7 hours) even though combi system is reheating 80 gal of water versus 50 gal of water



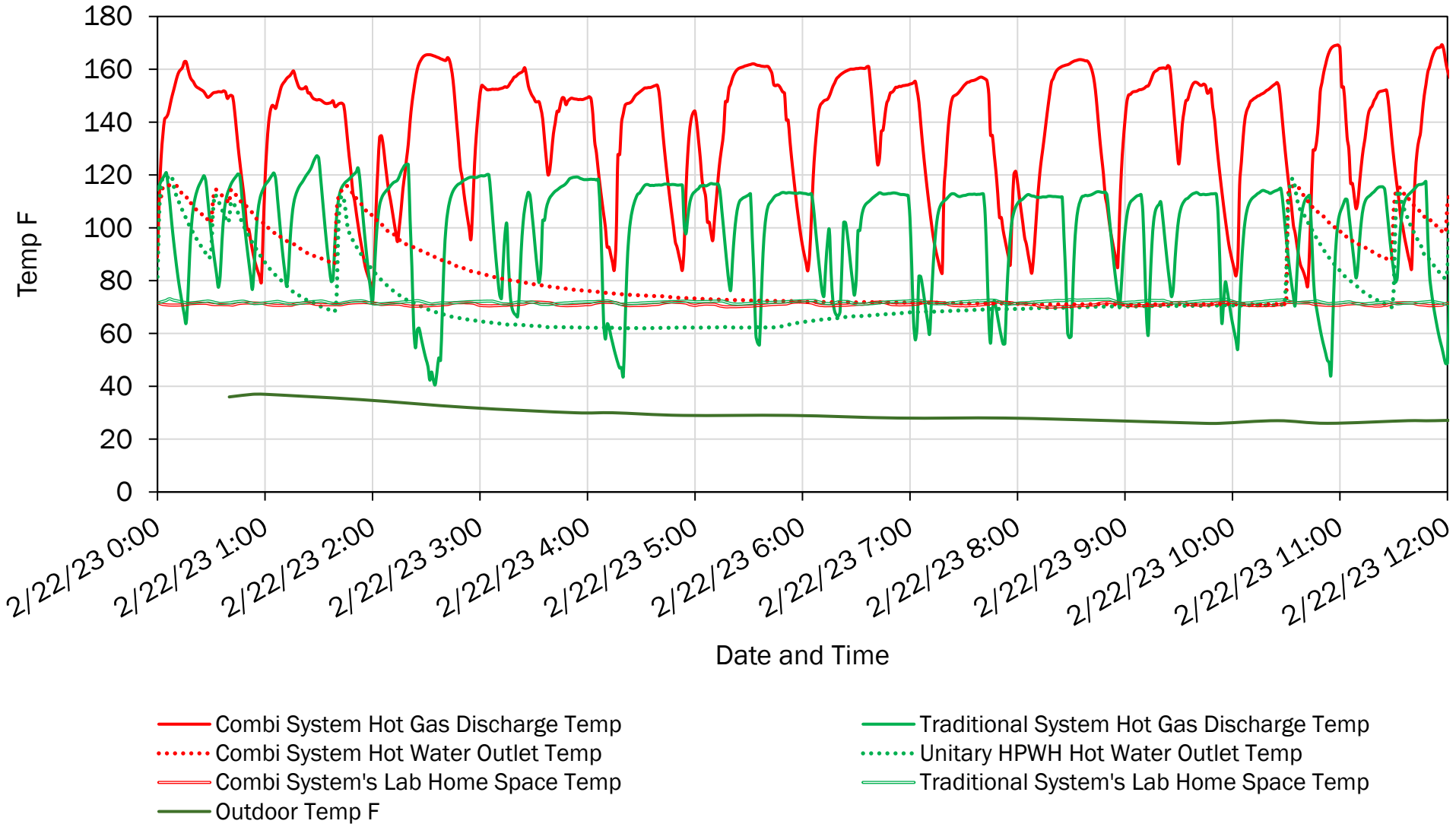
Progress – Initial Result: Consolidated vs Scattered Water Heating

- Combi system's Hydro Kit scatters water heating while unitary HPWH's water heating is consolidated
- **Inefficiencies from cycling and scattered heating**



Progress – Initial Results Show Unnecessarily High Refrigerant Temps

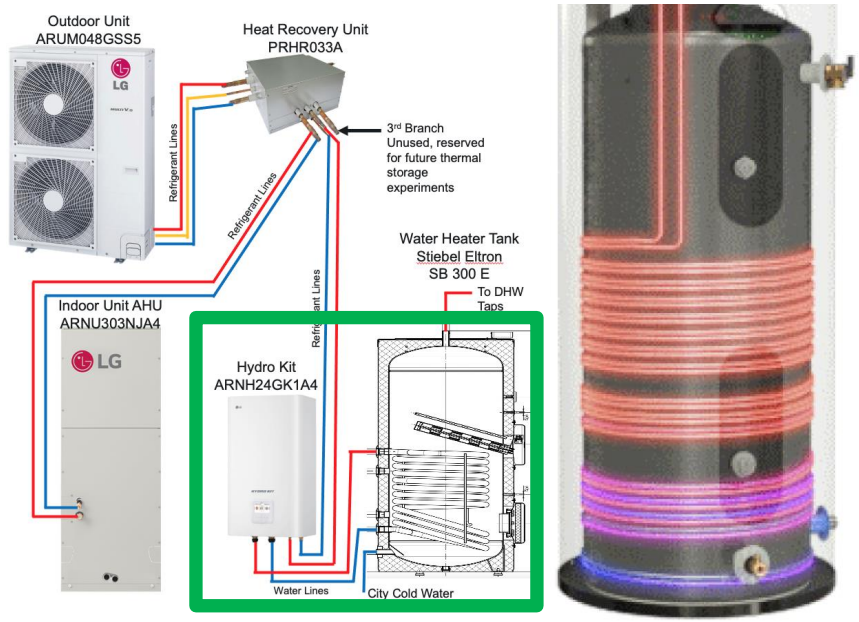
- Combi system produces very hot refrigerant even when the system is only providing heat for space heating.
- This hotter than necessary refrigerant results in inefficiency.



Feedback already given to manufacturer; controls improvement already underway

Future Work

- Collect swing season results
- Collect summertime results
- Report swing and summertime results in Aug/Sept 2023
- Continue to work with manufacturer on:
  - Control optimization
  - Hardware cost optimization
  - Equipment sizing guidance optimization for this application
  - Expanding into control and integration of dedicated **thermal energy storage**



Ex: What will it take to develop a tank that could replace green box items



- A cold climate heat pump that effectively ties DHW and space conditioning with heat recovery capabilities is a <u>first step</u> that can <u>open the door</u> to:
  - Low-cost, short-term (4–8hr) thermal energy storage → reduced heating capacity loss in extreme cold temperatures → increased viability of heat pumps as the sole heat source even in climate zones that experience extreme cold events without causing stress to service entrance ampacity or the grid from auxiliary heat
  - Long term (seasonal) thermal energy storage → reduced peak winter electric bill → heat pump viability for income-sensitive customers

Thank You

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1.4.1.19 Task 7

REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	$182,505				$289,246							
Spent budget	$153,225				$250,023							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Compile lessons learned from installation of HP and HPWH in lab homes				◆								
Current/Future Work												
Initial findings from data collection in PNNL lab homes						◆						

Another project in FY24 will continue to use this heat pump system to explore thermal energy storage and controls

Team

Pacific Northwest National Laboratory



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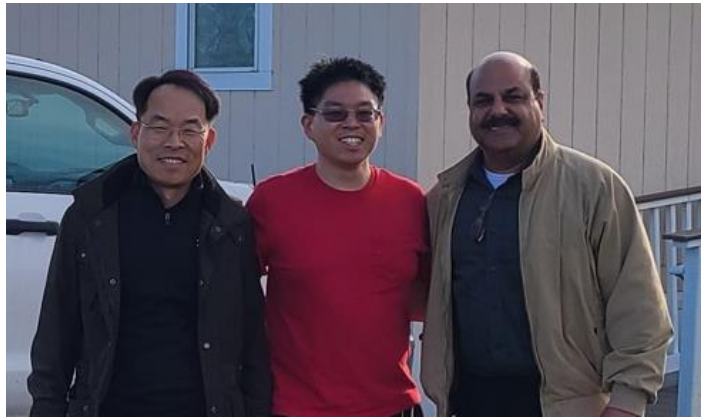


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LG HVAC



Sangok Kweon, Director of R&D

Aushutosh Suri, Senior Engineer

Not Pictured: John Hwang, R&D Lab Lead