2024 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

Residential Cold Climate Heat Pump Technology Challenge

Field Validation and Market Transformation

PNNL

PNNL-SA-204254

Cold Climate Heat Pump Technology Challenge

Field Validation and Market Transformation

Performing Organization: Pacific Northwest National Laboratory
PI Name and Title: Vrushali Mendon, Senior Mechanical Engineer
PI Email and Tel: vrushali.mendon@pnnl.gov | 509-375-2737
WBS #: 3.2.2.52

PNNL

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

- Validate field performance of highly efficient pre-commercial residential heat pumps in cold climates
- Communicate field data to OEMs, utilities and other stakeholders to inform programmatic activities
- Deployment of commercialized units will reduce on-site emissions and provide demand flexibility may avoid winter peaking due to electrification

VP Harris & DOE Sec. Granholm Launch Challenge in 2021

TEAM & PARTNERS

Pacific Northwest NATIONAL LABORATORY

MichaelsEnergy

Guidehouse

ENERGY350

STATS

Performance Period: June 2022 - Present

DOE Budget: $3,087K, Cost Share: CCHP prototypes provided by manufacturing partners

Major Milestones:

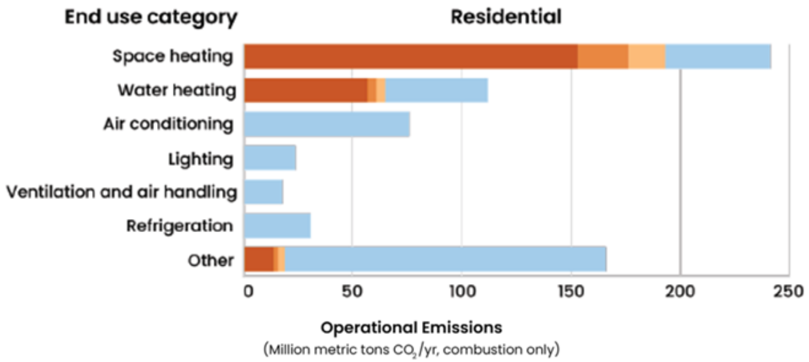
FY22: Data Collection and Analysis Plan

FY23: Winter 2022-2023 Field Performance Testing

FY24: Winter 2023-2024 Field Performance Testing

Problem

- Space conditioning and water heating are a major source of greenhouse gas (GHG) emissions in residential buildings.
- Accelerated use of heat pumps is required for widespread electrification and meeting DOE's Building Decarbonization Blueprint[1] goals.
- However, the performance of conventional heat pumps declines substantially in cold climates.
- Optimizing heat pumps for cold climates (5 °F and below) requires coordinated effort and champions across the sector for widespread adoption.[2]



Residential end-use contributions to operational energy-related emissions. Red/orange colors are fossil fuels and blue is electricity
Image source: DOE Building Decarbonization Blueprint[1]

[1] Source: https://www.energy.gov/eere/decarbonizing-us-economy-2050-national-blueprint-buildings-sector
[2] Source: https://www.energy.gov/eere/buildings/articles/residential-cold-climate-heat-pump-technology-challenge-fact-sheet

Alignment and Impact

Image source: Guidehouse

- The goal of the CCHP Challenge is to de-risk product development and accelerate market acceptance of CCHPs through field validation of pre-commercial products.
- Utilities and state energy programs need highly granular and high-quality field data for emerging products optimized to perform at lower temperatures to accelerate wider adoption of heat pumps in colder climates.
- To enable the overall scaling-up of heat pump installations across the nation, the project also shares lessons learned with BTO workforce development programs.

Alignment and Impact with Blueprint

Equity: Provide access to better space heating solutions, air-quality and health co-benefits and reduce exposure to heating fuel price volatility.

Resilience: Improve energy security for locations that rely on fossil fuel and heating oil. Heat pumps can additionally provide cooling and help homes in colder climates adapt to increasingly hot summers.

Electrification: Deploy high-performance electric heat pumps that are optimized for cold climate performance with low GWP refrigerants.

On-Site Emissions Reductions: Convert fossil-fuel-fired furnaces to efficient heat pumps in residential buildings to support reductions in on-site emissions by 75% by 2050.

Transform the Grid Edge: Remove barriers and scale deployment of high-efficiency DR-enabled space conditioning solutions in residential buildings.

Approach: Specification

Specification	DOE CCHP Challenge (link)	ENERGYSTAR v6.1 Cold Climate ASHP (link)	CEE Split Ducted ASHP North and Canada (Link)
COP at 5 °F	≥ 2.4 (24,000-48,000 Btu/hr) ≥ 2.1 (> 48,000 Btu/hr)	≥ 1.75	≥ 1.75
% of Heating Capacity at 5 °F Compared to 47 °F	100%	≥ 70%	≥ 70%
SEER2	Meets or exceeds federal minimums ≥14.3	≥ 15.2	Tier 1 ≥ 15.2 Advanced Tier ≥ 17.0
HSPF2	Meets or exceeds federal minimums ≥ 7.5	≥ 8.1	Tier 1 ≥ 8.1 Advanced Tier ≥ 8.1
Demand Response Criteria under AHRI 1380	Required	Optional	Tier 1 - Optional Advanced Tier - Required
Low-GWP Refrigerant	Required for prototypes developed 2021-2023	No requirement, but products must meet EPA refrigerant requirements in 2025	No requirement, but products must meet EPA refrigerant requirements in 2025

Approach: Field Validation Process

Lab Testing

- Meets Challenge specification in laboratory setting at 5 °F or optional -15 °F test condition
- Demonstrates DR capability in laboratory setting

Field Demo Prep

- Manufacturers identify sites, local HVAC installer, and test unit
- Project team coordinates site visits, works with homeowner on consent forms
- 23 field sites installed (22 completed study)
- Project team provides additional resources for on-site installation

Field Validation

- Installs sensors and data loggers
- Collects and analyzes fine-granularity field data (1-sec power measurements, 1-to-5-minute T/RH measurements)
- Provides briefings with manufacturers, utilities, and others on performance demand response data
- Solicits homeowner feedback

Approach: Data Privacy Protection

Homeowner Data Protection

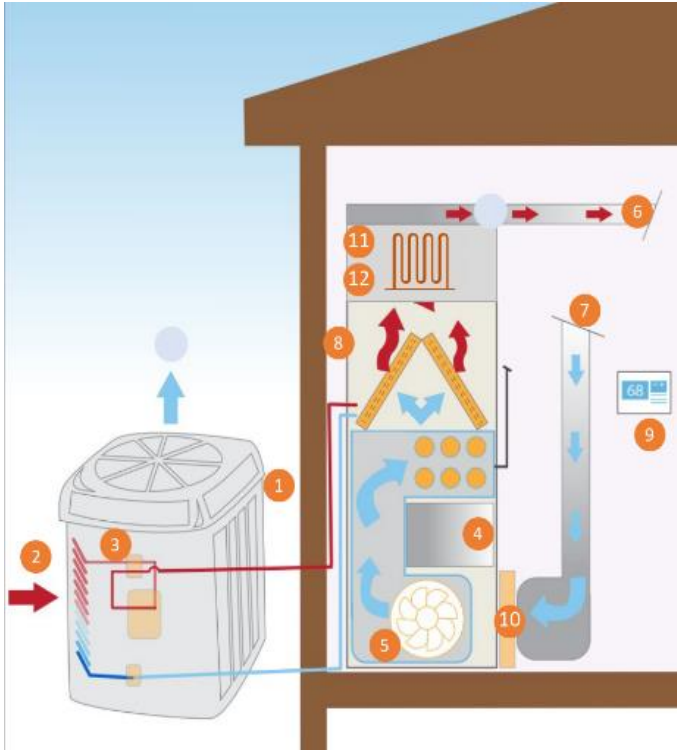
- Study involved human subjects, study design was approved by PNNL Institutional Review Board
  - Required to protect Personal Identifiable Information (PII)
  - Any changes from design are documented and approved prior to implementation
  - Requires annual check-in for compliance
- Part of data privacy protection requires PNNL to collect data cellularly rather than over homeowner Wi-Fi

OEM Data Protection

- Test units are pre-commercial. Need to protect business sensitive data.
- Transmit and store all data on cyber-secured platforms.
- No manufacturer-specific data shared publicly. Manufacturer-specific data only shared with respective manufacturer.

Approach: Data Collection

System	Data Point	Parameter	Measuring equipment	Location	Sampling Interval
Outdoor unit	1	Power	Power meter + current transducer	Outdoor unit circuit	1 second
	2	Temperature/ RH	TC/RH sensor, solar shield	Outdoor unit inlet	5 minutes
	3	Heat / cool / defrost mode	Relay	At reversing valve	1 second
Indoor unit	4, 5	Power	Power meter + current transducer	Indoor unit circuit Indoor fan circuit	1 second
	6, 7, 8, 9, 10	Temperature/ RH	TC/RH sensors	Supply air outlet (4 locations) Return air inlet Unit Ambient Indoor conditioned space (3 locations)	1 minute
	11	Volumetric Air flow	Airflow metering plate	Air handler return / filter housing	Upon installation, airflow rate will be correlated with fan power
Auxiliary Heat	12	Power	Current transducer	Electric strip	1 second



Adapted from MN CEE Field Study (2017 Link)

Approach: Data Analysis

ENERGY.GOV
Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

EERE » Heat Pump Database

Heat Pump & Heat Pump Water Heater Field Database

Residential and commercial heat pump technologies are field tested by programs across the United States. The Heat Pump Field Database is a centralized data repository that provides easy data upload and download for the nation's leading heat pump and heat pump water heater researchers. Users can use the buttons below to get started on any of the actions described.

- **Upload Your Complete Datasets:**
  - Publish data to a publicly accessible database that is accessible via the cloud.
- **Download Custom Datasets:**
  - Create queries using project metadata to filter for only the datasets that are relevant to your research.
  - Includes visualizations of data

https://heatpumpdata.energy.gov/about

- Weekly data delivery and analysis
  - Anomalies or operational issues are reported to the manufacturing partner promptly to ensure high quality performance data.
- Share data with manufacturer partners via DOE's Heat Pump Database
  - Secure business sensitive information via role-based access controls.
- Share findings and results with external stakeholders
  - Active participation in conferences and stakeholder presentations.

Progress: Major Accomplishments

Manufacturing Partners

DAIKIN, Johnson Controls, Carrier, Midea, BOSCH Invented for life, LENNOX, Rheem, TRANE TECHNOLOGIES

***8** major HVAC manufacturers representing more than **70%** of the U.S. Unitary AC/HP market completed prototype development, lab testing, and field validation*

*"By working closely with the DOE, and with the invaluable contributions from the National Labs, we have pushed the boundaries of our heat pump technology, achieving performance that not only meets but exceeds DOE standards." **Derek Brasuell**, Senior Director of Engineering, **Rheem***

*"Throughout the field-testing period, Lennox has valued DOE's ongoing communication of validated field information to key utility and state partners, raising awareness of program incentives and arming dealers with the information they need…" **Gary Bedard**, Executive Vice President & President, **Lennox** Home Comfort Solutions*

*The "Challenge is revolutionizing the future of heating, setting new standards not just for the Northern U.S. and Canada, but for heat pump technology worldwide...The new cold climate heat pumps entering the market promise not only to enhance quality of life and drive down carbon emissions but also to create lasting benefits for both people and the planet for generations to come." **Brooke Greenwood**, Director of Residential Product Management at **Carrier** HVAC*

More partner feedback: https://www.energy.gov/eere/buildings/partners

Progress: Major Accomplishments

Challenge CCHPs are coming to the market!

- Carrier starting production on the Challenge units in September 2024[1].
- Bosch to have units available later this fall[2].
- Trane to begin production early next year[3].

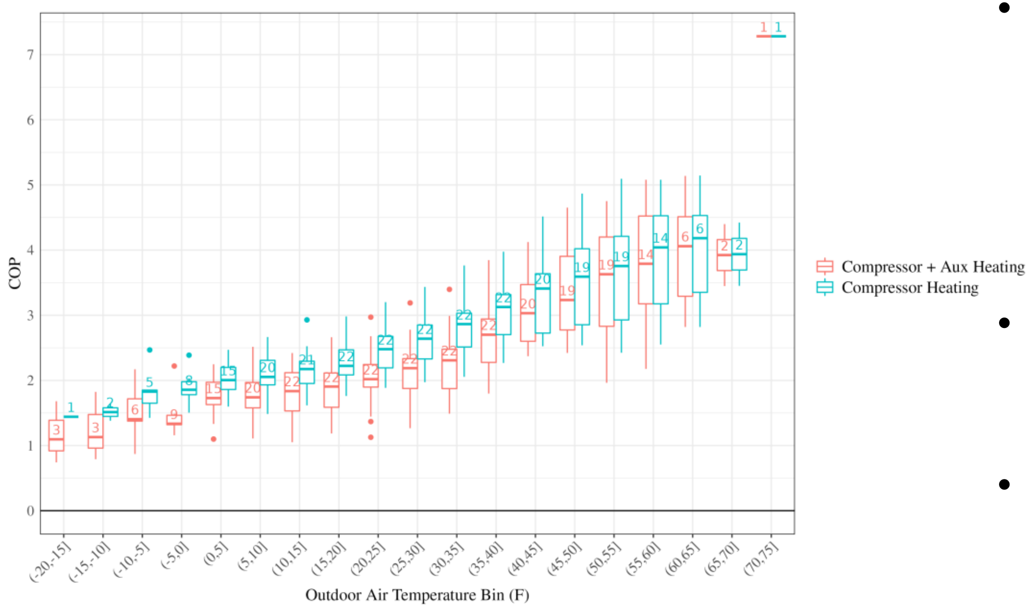
Others plan to announce later this year.

[1]https://www.prnewswire.com/news-releases/carrier-completes-department-of-energys-cold-climate-heat-pump-challenge-transformative-innovation-set-for-2024-commercial-rollout-302245339.html
[2]https://www.bosch-homecomfort.com/us/en/ocs/residential/ids-ultra-inverter-ducted-split-cold-climate-heat-pump-20831889-p/
[3]https://www.trane.com/residential/en/resources/blog/cold-climate-heat-pump-challenge

Progress: Key Findings

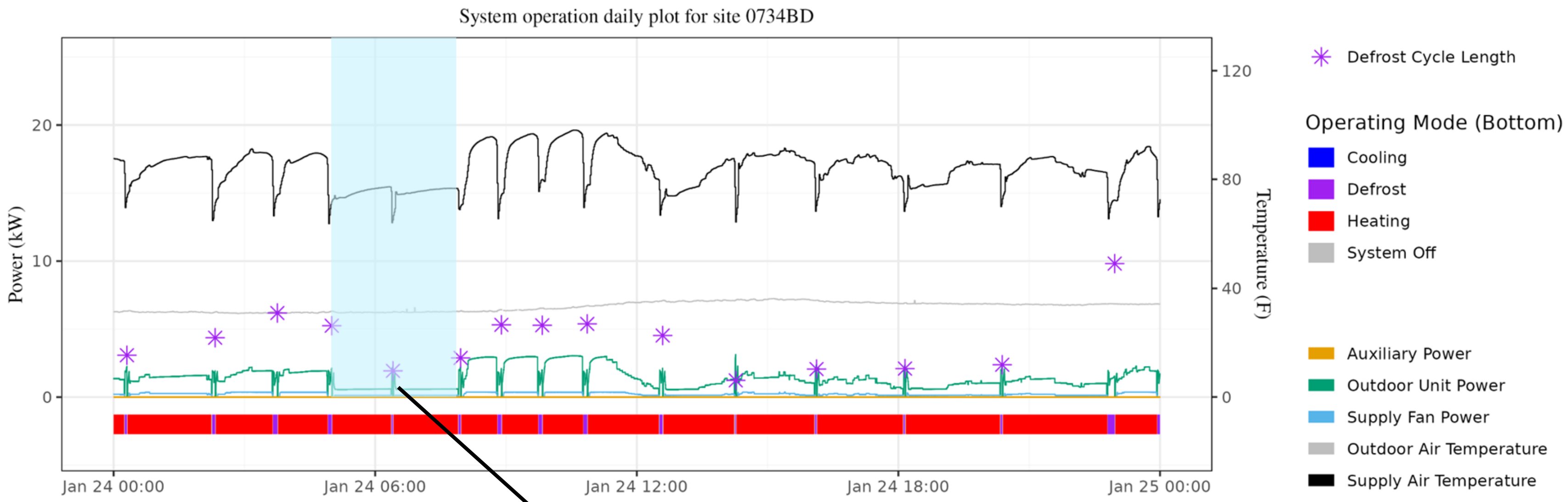
- Installers were able to install CCHPs efficiently and in various configurations and spaces successfully as replacements for old furnaces, indicating strong retrofit potential for residential decarbonization.
- CCHPs were observed to be reliable and were able to provide heat with little assistance from auxiliary elements, even during the coldest winter periods.
- The trends observed during the winter monitoring periods were observed to continue through the shoulder and cooling periods, with high COPs across all seasons.
- DR was verified in the field during summer and winter, at both, general and critical curtailment levels.

Progress: Key Findings - Overall Performance



- Overall HP COPs were observed to be between **1.5 to 4.5** over the entire range of outdoor air temperatures observed over the winter monitoring period (-15 °F to 65 °F).
- When auxiliary heat was included, the system COPs dropped to **1.0 to 4.5** over the same range.
- Even at colder temperatures below 0 °F, the CCHPs were able to provide heat efficiently.

Progress: Key Findings - DR Validation in the Field



Event runs from 5-8 AM: Outdoor unit curtails power draw and modulates to low speed during the event. Aux. heat remains off.

Progress: Key Findings - Homeowner Surveys

- CCHP prototypes performed well in both heating and cooling seasons. No widespread issues with noise, temperature control, comfort, or needing support from an HVAC technician.
- 70% of homeowners would recommend the CCHPs to a friend or neighbor.
    - Respondents who would not recommend primarily noted higher utility bills during the heating season relative to their previous natural gas furnaces.
    - Conversely, several homes in regions with delivered fuels or electric heating showed high satisfaction and would recommend the products, suggesting that utility bills likely decreased or remained even.

Future Work

- Conclusion of M&V data collection at remaining sites.
- Final technical report for DOE and a publicly available version with overall trends and observations.
- Key stakeholder engagement to help address:
  - Where can the Challenge specification be incorporated in other programmatic efforts (e.g., EnergyStar, CEE)?
  - How can the data from this project be used to inform Technical Reference Manual (TRM) development and state energy program efforts?
  - How can lessons learned from the DR testing be used to inform AHRI 1380 efforts?
  - How can lessons learned from installation and performance inform BTO-RBI workforce development efforts?
- Potential value of a similar Challenge for additional heat pump technologies
  - Exploration regarding air-to-water heat pumps underway.

Future Work

- Additional data analysis with collected field data.
  - Counterfactuals through energy modeling.
  - Extrapolation to different locations.
- Value proposition for weatherization and CCHPs
  - Current study design did not include weatherization prior to installation.
  - Increasing envelope efficiency prior to CCHP installation will provide additional homeowner benefits and differentiate unit performance from current, non-cold climate optimized HP models.
- Homeowner education and best practices for heat pumps
  - Current study design did not include any homeowner education or interventions for optimal heat pump operation. Observed data indicates that homeowner education may help to improve performance in some homes.
    - For e.g., some homeowners used large thermostat setbacks in the morning resulting in excessive auxiliary heat use.

Thank you

Performing Organization: Pacific Northwest National Laboratory

PI Name and Title: Vrushali Mendon, Senior Mechanical Engineer

PI Email and Tel: Vrushali.Mendon@pnnl.gov | 509-375-2737

WBS #: 3.2.2.52

Reference Slides

Project Execution

- As of Oct. 2, still waiting on FY25 funding and scope direction
- Due to timing of sub-contracts, equipment procurement, needed to plan up to 40 sites across Year 1 and Year 2, but ultimately fewer participated which resulted in lower spend

	FY2022	FY2023	FY2024	FY2025
Planned budget	$ 356,385	$ 2,181,730	$ 1,790,639	
Spent budget	$ 103,598	$ 1,398,546	$ 1,393,893	
	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
Past Work				
Q3 Milestone: Review and finalize test plan and M&V strategy for stakeholder review				
Q3 Milestone: Draft stakeholder engagement plan, including identifying field partner recruitment material needs				
Q4 Milestone: Draft data collection and analysis plan including the identification of methodologies and data security, to address overall project goals				
Q1 Milestone: Status update for BTO on HVAC equipment installation and M&V installation at all sites				
Q2 Milestone: Status update on M&V data acquisition from field validation sites				
Q2 Milestone: Draft lessons learned from Winter 2022 data collection period				
Q2 Milestone: Status report on customer satisfaction data collection effort and progress on M&V data collection and cleaning of data received to date				
Q3 Milestone: Draft reports for Winter 2023- 2024 performance data				
Q4 Milestone: Update all stakeholder				
Q4 Milestone: Draft reports for Shoulder Season 2023				
Q1 Milestone: Status update for BTO on HVAC equipment installation and M&V installation at all sites				
Q2 Milestone: Status update on M&V data acquisition from field validation sites				
Q3 Milestone: Draft summary findings on air-to-water heat pump challenge for residential buildings feasibility				
Q3 Milestone: Draft report for Winter 2023- 2024 performance data				
Q4 Milestone: Update all stakeholders				
Q4 Milestone: Draft reports for Shoulder Season 2024				
Current/Future Work				
Q1 Milestone: Briefing to DOE on utility engagement strategy				
Anticipated Q1 Milestone: Final DOE report				

Team

PNNL

Guidehouse

Vrushali Mendon
Principal Investigator

Julia Rotondo
Project Manager

Bill Goetzler
Research Advisor

Kevin Keene
Data Analysis

Sam Rosenberg
Data Analysis

Jim Young
Partner Coordination Lead

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Natural Resources Canada / Ressources naturelles Canada — Canada

ENERGY350

MichaelsEnergy

Lab Partners

(separate AOPs)

NREL — NATIONAL RENEWABLE ENERGY LABORATORY
DR Testing

OAK RIDGE National Laboratory
Lab Testing

Manufacturing Partners

DAIKIN

Johnson Controls

Carrier

Midea

BOSCH Invented for life

LENNOX

Rheem

TRANE TECHNOLOGIES

9 State & 19 Utility Partners