

2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Detailed Air-Source Heat Pump Evaluation for Very Cold Climates

Performance Mapping and the Effect of
Controls on Efficiency



Detailed Air-Source Heat Pump Evaluation for Very Cold Climates



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WBS 3.2.2.64

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

This project evaluated a 1-ton ductless mini-split heat pump in a climate chamber and the outdoor environment in Fairbanks, AK to evaluate performance in extreme conditions. Several opportunities for improved performance through software changes were identified and tested in the field, resulting in ~50% increase in operational efficiency at temperatures below 25°F. A journal article and one-page paper on installation guidance is planned for early FY25.



TEAM & PARTNERS

National Renewable Energy Laboratory (NREL)
Haier/GE Appliances

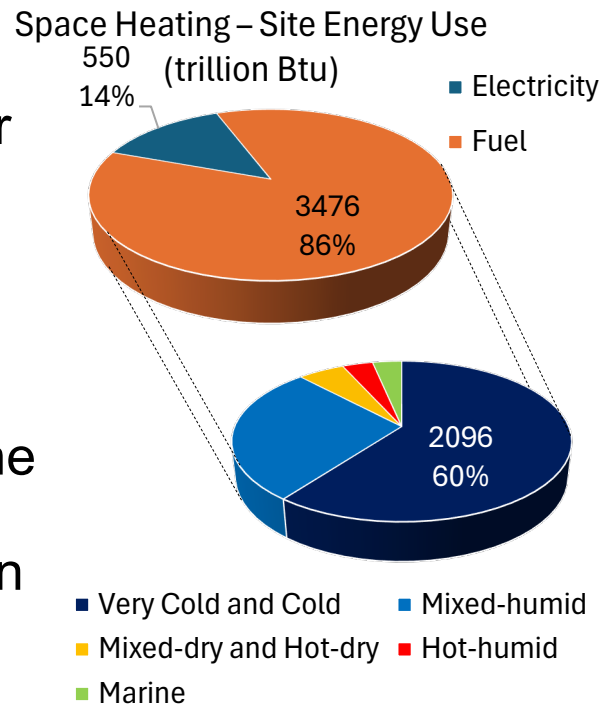
STATS

Performance Period: 1/2023–9/30/2025
DOE Budget: \$400k, Cost Share: \$0k
Milestone 1: Draft experimental plan
Milestone 2: Heat pump installed
Milestone 3: Data collection complete



Problem

- Almost **3.5 quads of on-site fuel** are used for **residential space heating** annually.
- Homes in **very cold and cold climates** account for **60% of fuel use for residential space heating** in the U.S.
- While cold climate heat pumps are entering the market with operating temperatures down to -31°F , they have not been thoroughly tested in the extreme cold.
- To accelerate adoption of heat pumps in cold climates, homeowners and installers need confidence that they will perform as expected.



EIA. 2020 Residential Energy Consumption Survey



Alignment to Blueprint and Outcomes

- To meet the Blueprint goals for heat pump installations:
 - Increase confidence in heat pumps in cold climates.
 - **Avoid dissatisfied heat pump owners.**
- Suboptimal controls can result in wasted energy, decreased comfort, and increased utility bills

Need 10X increase in pace by 2030—many homes will also require envelope upgrades

100M
homes
without heat
pumps



5M
conversions
per year



20
years
for full
conversion

Source: Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector

STRATEGIC OBJECTIVES



Increase building energy efficiency

Reduce on-site energy use intensity in buildings 35% by 2035 and 50% by 2050 vs. 2005



Accelerate on-site emissions reductions

Reduce on-site GHG emissions in buildings 25% by 2035 and 75% by 2050 vs. 2005

Current

Future

Haier/GE has implemented software changes to their current product as a result of this project.

Data indicates a 50% increase in efficiency at temperatures below 25°F is achievable through controls for some climates.

Robust controls that provide optimal operation in all climates.



Current Situation

- There is a lot of momentum behind heat pump deployments in cold climates but not a lot of empirical data on heat pump performance in these conditions.
- Two recent field tests of 13+ units each showed mixed results for ducted and ductless cold climate heat pumps.¹

Uniqueness of this project

- Collaboration with the manufacturer provides valuable insights, the ability to modify software, and direct feedback of potential improvements.
- Controlled testing environments result in cleaner data and removes uncertainty of occupant behavior.
- Long and extreme winters allow for collection of more data in a season.



Partner Engagement

Haier/GE Appliances: Monthly meetings and one in-person meeting to discuss project before, during, and after data collection. Engineers could answer questions from researchers and help interpret results. Data informed software upgrades to increase efficiency.

Deployment programs: Frequent meetings with Alaska deployment programs, Alaska Heat Smart in Southeast Alaska and Northwest Arctic Borough, to share methodology and results.

Project researchers participating in DOE Field Validation Partnership and LG / University of Alaska Consortium for Advanced Heat Pump Research.



Photo by NREL staff



Steady-State Chamber Testing

- A 1-ton, GE-Haier ductless mini-split HP with advertised operating range to -31°F .
- Objectives:
 - Evaluate steady-state performance.
 - Investigate the effect of fan speed on capacity and efficiency.
 - Gain insights into equipment operation.
 - Validate instrumentation and airflow measurement for “field test”.



Photo by NREL staff



Controlled Field Test

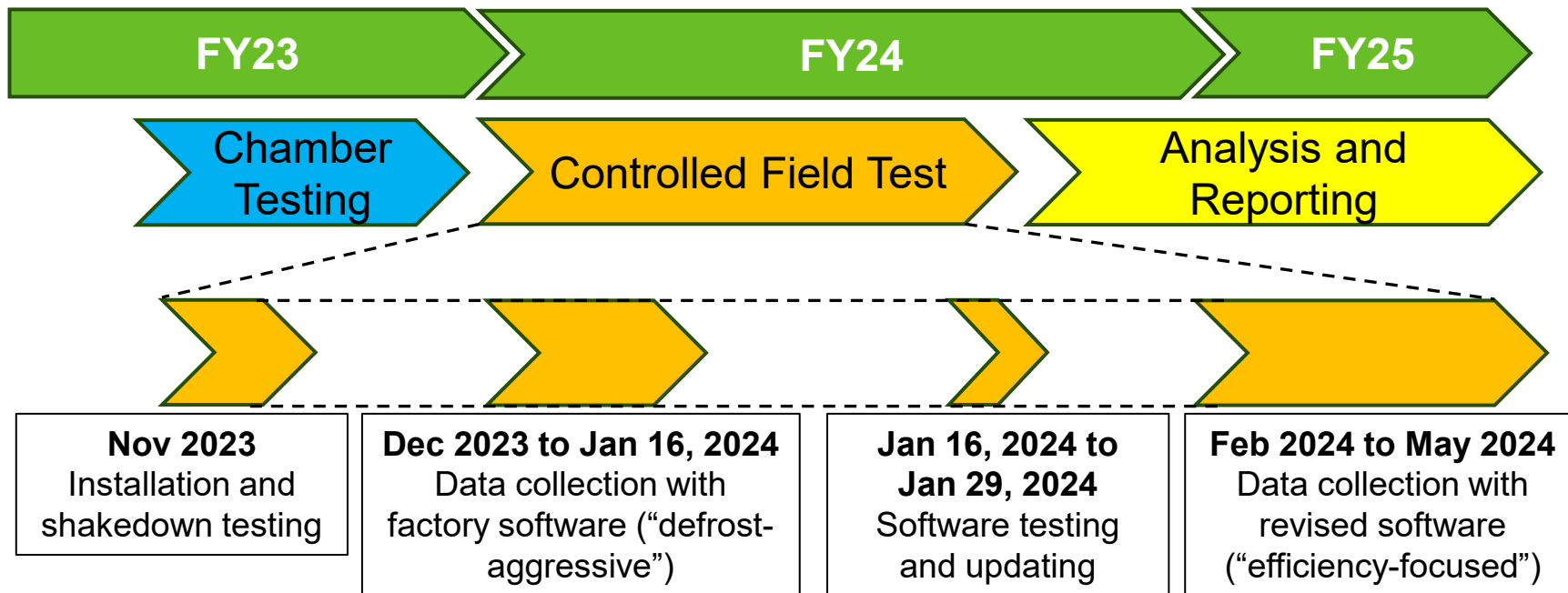
- Heat pump was moved from the chamber to a demonstration space.
 - Heating load was modulated using several space heaters and portable air conditioners.
- Objectives:
 - Evaluate real-world performance (e.g., integrated efficiency).
 - Investigate performance under varying thermal loads.
 - Investigate energy and performance impacts of cold climate-specific challenges for heat pumps (e.g., snow/ice accumulation, base pan heating, frosting and defrosting).



Photos by NREL staff



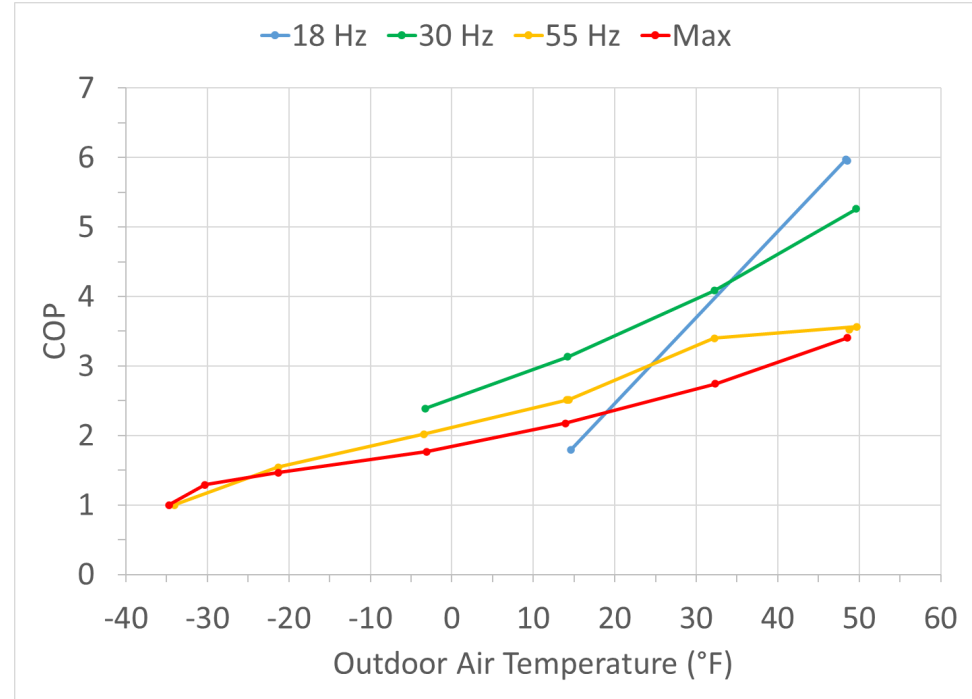
Timeline





Progress – Chamber Testing Observations

- Generally good COPs and capacity retention.
- COP above 1 down to -35°F .
- 12,000 Btu/h capacity @ -12°F .
- Frequency of defrosts increased at lower temperatures despite dry conditions in chamber.
- 260 W drain pan heater ran 50% of time @ 14°F and 33% of time below -4°F .

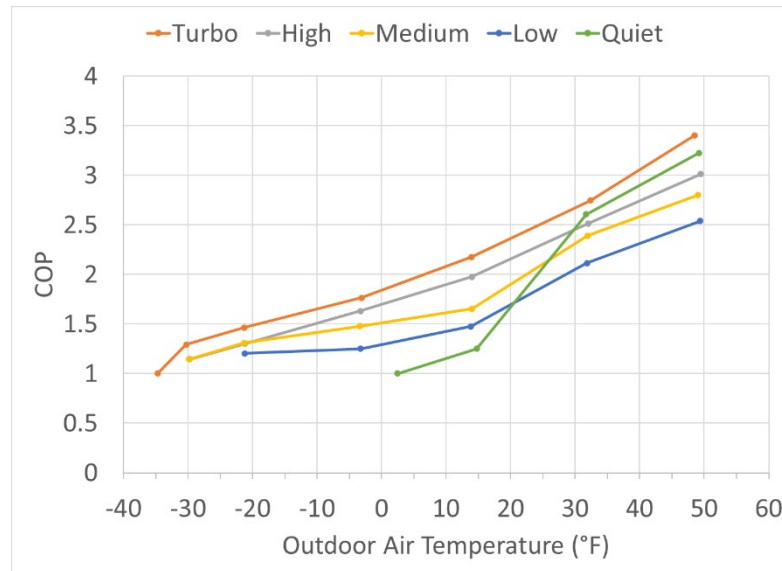
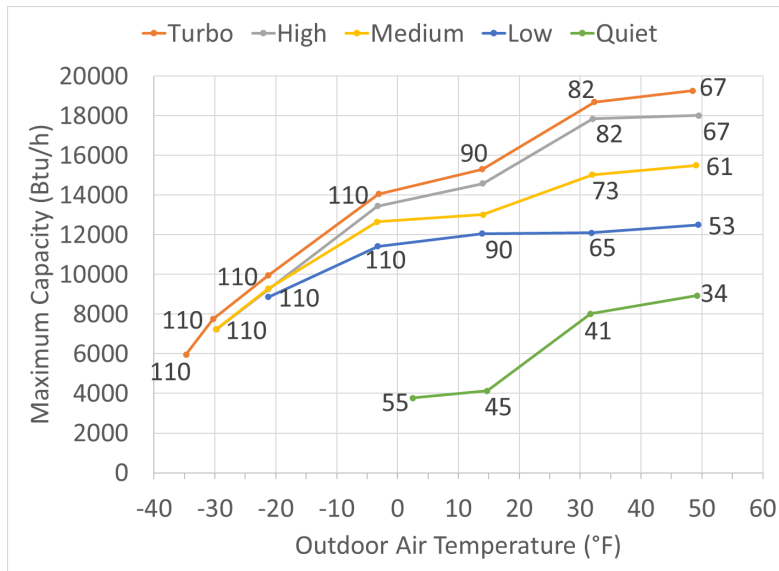


Preliminary Results



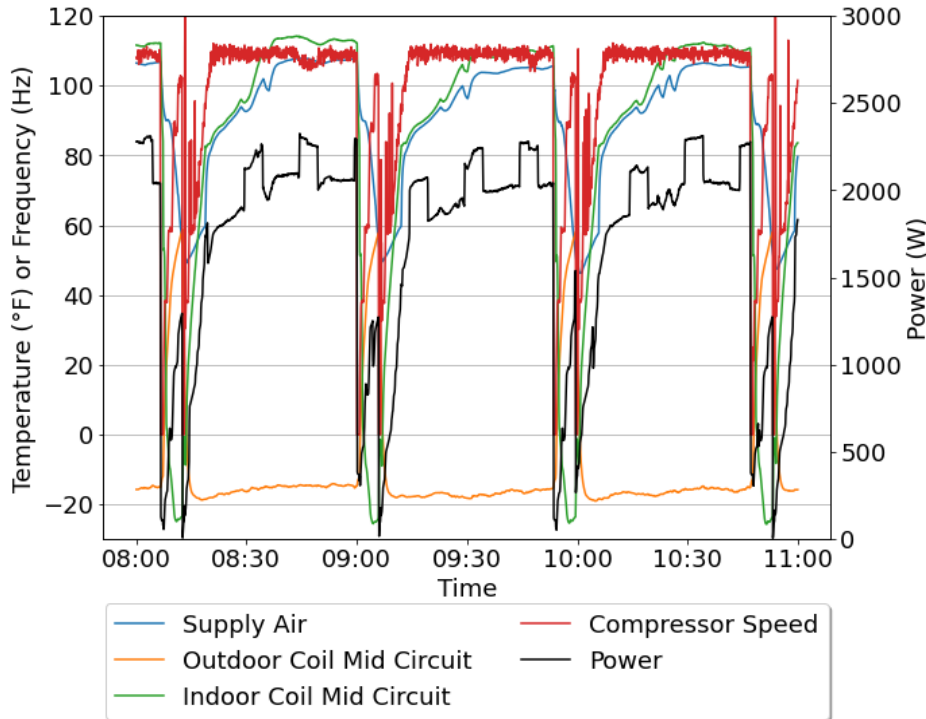
Impact of Fan Speed Setting on Maximum Capacity and Efficiency

- Fan speed setting can limit the maximum compressor speed (labels in Hz).
- At the same compressor speed:
 - 5%–20% decrease in capacity and 8%–32% decrease in COP.





Example Timeseries Data from Field Test – Defrost-Aggressive Software



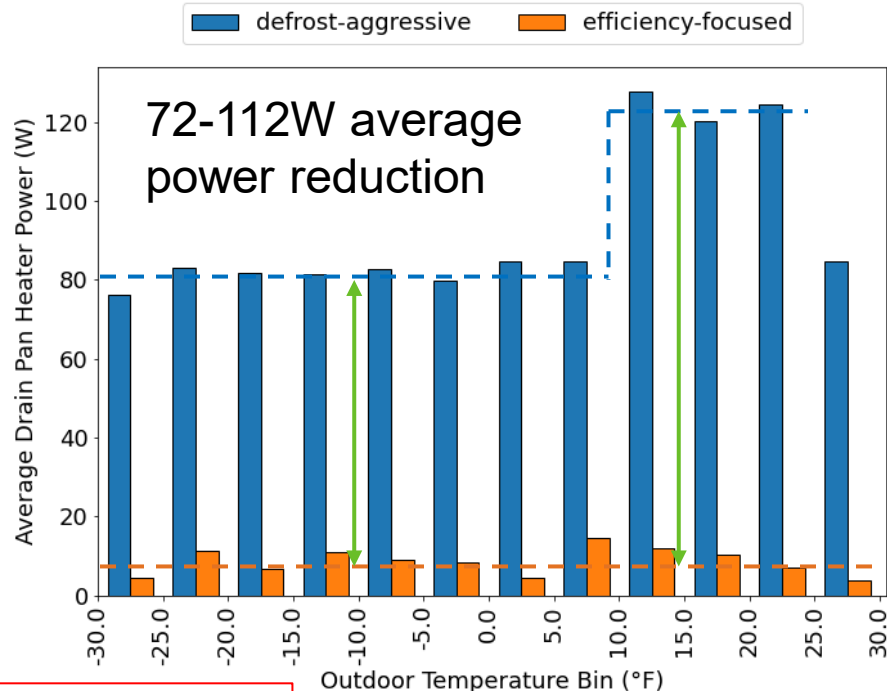
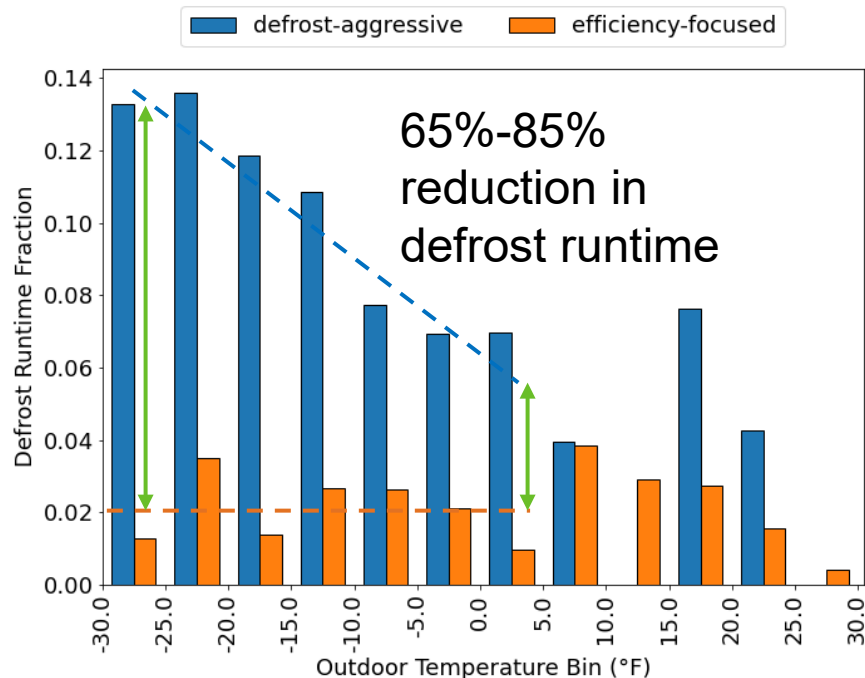
- Frequent defrosts (every 55 min).
- Defrost cycle lasts about 8 min.
- About 25 min. for indoor coil temperature to reach steady-state after defrost.
- ~60% of time in defrost or recovering from defrost.
- No significant frosting observed.
- Drain pan heater operating 33% of time.



Software Impacts on Defrost and Drain Pan Heater Operation

4-hour minimum runtime between defrosts

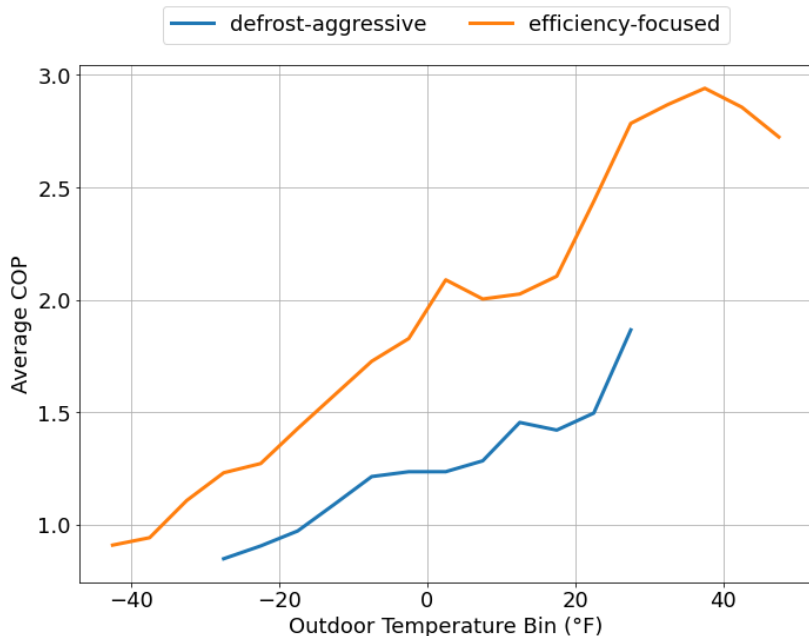
Drain pan heater runs only during defrost and the 5 minutes following



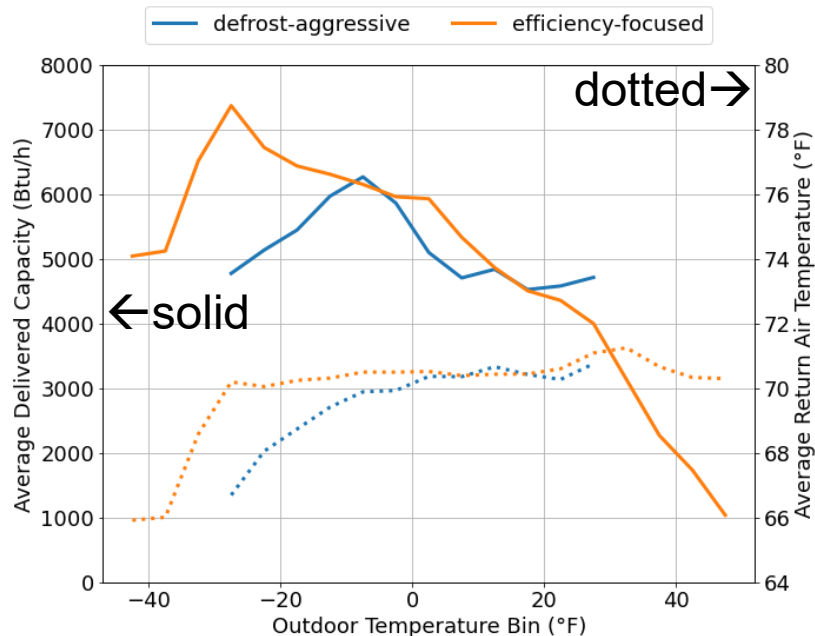


Software Impacts on Efficiency and Comfort

~50% increase in average COP.



Met load at 20°F colder temperatures. Able to provide 50% more capacity @ -25°F.

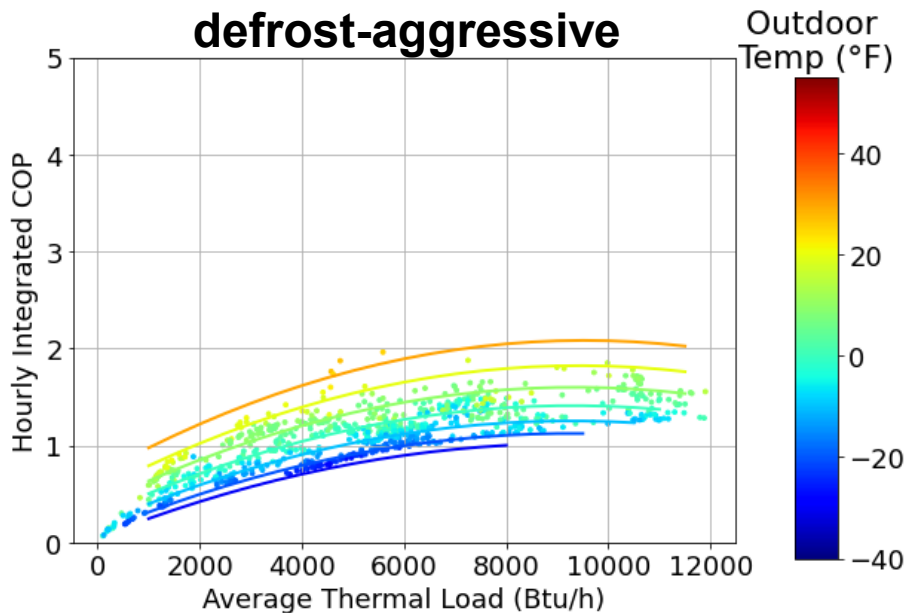




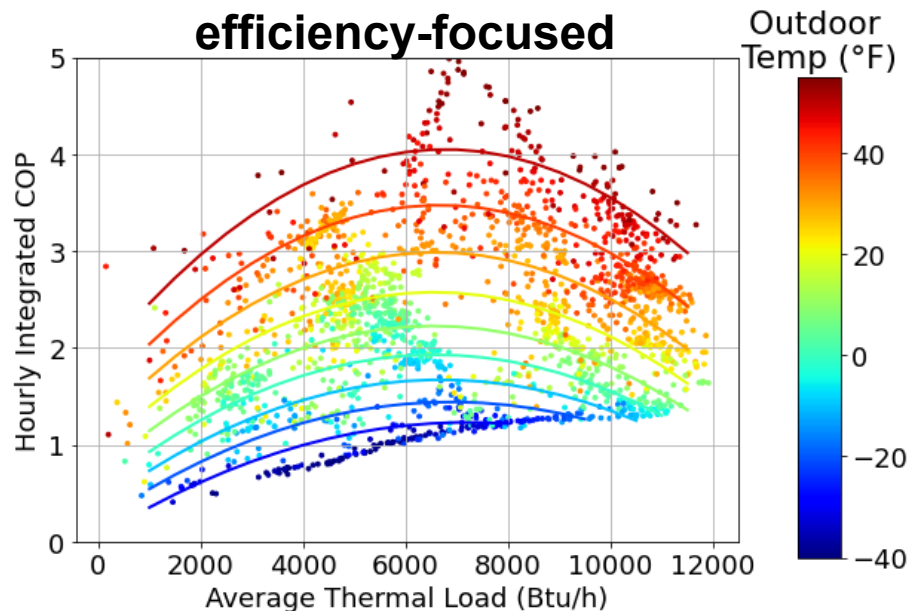
Simplified Efficiency Model Based on Thermal Load and Outdoor Temperature

Bivariate polynomial fitted to data. Can be used to estimate heat pump performance using average outdoor temperatures and building heat load.

defrost-aggressive



efficiency-focused

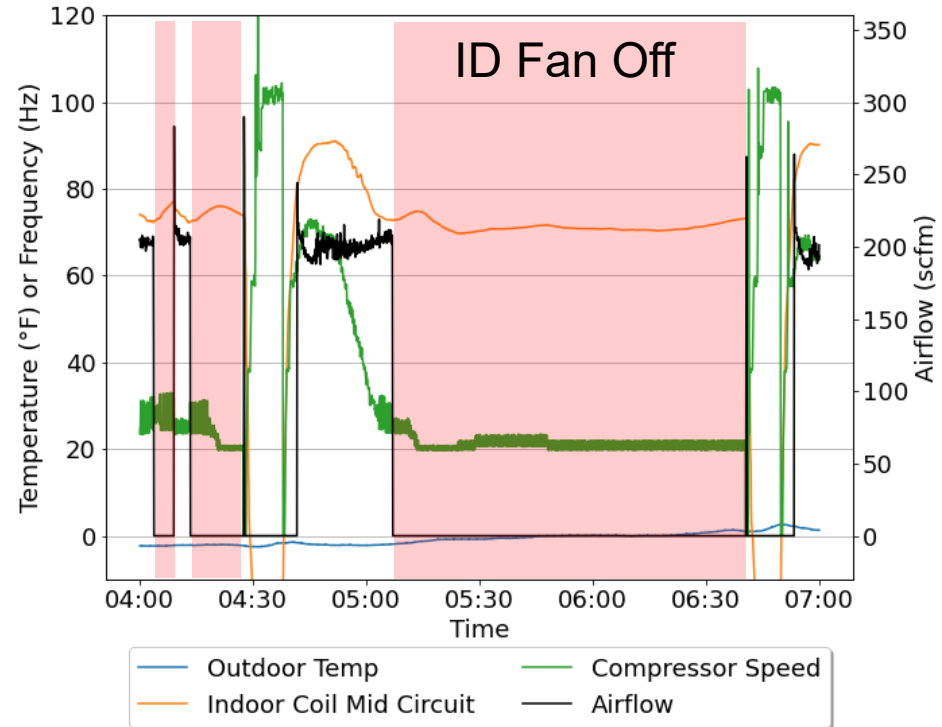


Preliminary Results



Inefficient Operation at Low Temperatures and Low Loads

- At low temperatures and low loads, the indoor fan would sometimes shut off while the compressor stayed running.
- This scenario could occur in homes with mini-splits and a backup heating system running concurrently.
- Without integrated controls, the load that each system meets could vary significantly.





Future Work — Disseminating Results

- Share results with manufacturers:
 - Haier/GE Appliances (continuing meetings to share finalized results).
 - LG (Consortium for Advanced Heat Pump Research).
- One-pager summarizing best practices learned during field and lab testing – planned for Q2 FY25 – Plans to share with:
 - Energy Manager of the Northwest Arctic Borough (Ingemar Mathiasson) leading deployment of 850 heat pumps in rural Alaska.
 - Alaska Heat Smart, a nonprofit leading heat pump deployment efforts including two rebate programs, a carbon offset fund to install HPs in low-income homes, and homeowner education.
 - Alaska utilities and state entities that have or are considering heat pump rebate programs.
- Journal article highlighting the effect of controls on integrated performance – planned for Q1 FY25.

Thank you

National Renewable Energy
Laboratory

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Reference Slides





Project Execution

	FY2023				FY2024				FY2025			
Planned budget	200k				200k				0			
Spent budget	126k				199k				75k			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
FY23 Milestone 1: Draft Experimental Plan		◆										
FY23 Go/No-Go: Annual review on project progress				◆								
FY23 Milestone: Heat pump installed				◆								
FY24 Milestone: Heating season update					◆							
FY24 Milestone: Data collection and preliminary analysis							◆					
FY24 Milestone: Data analysis complete								◆				
FY24 Milestone: Draft journal paper									◆			
Current/Future Work												
FY25 Milestone: Journal paper and one-pager published												◆



Team



Jeff Munk

Principle Investigator
Senior Researcher, NREL



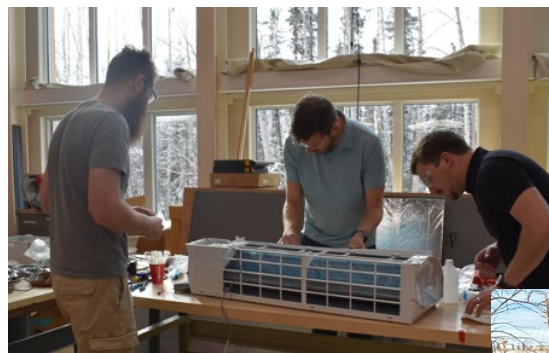
**Haier / GE
Appliances**

Collaboration on research
plan and software upgrades



Tom Marsik, PhD

Senior Researcher, NREL
Faculty, University of Alaska
Fairbanks



NREL Staff

**Ness Stevens, Conor Dennehy, Jon Winkler PhD,
Dana Truffer-Moudra PhD, Robby Strunk, Q Mackey**

Project management, instrumentation, data collection, and analysis

