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

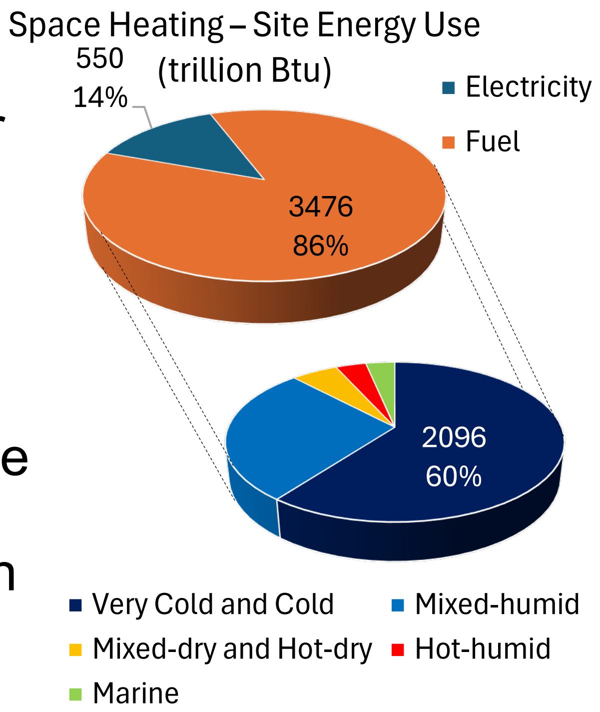
Milestone 1: Draft experimental plan

Milestone 2: Heat pump installed

Milestone 3: Data collection complete

Problem

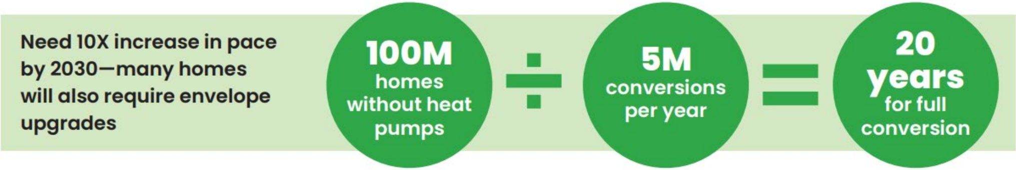
- Almost **3.5 quads of on-site fuel** are used for **residential space heating** annually.
- Homes in **very cold and cold climates** account for **60% of fuel use for residential space heating** in the U.S.
- While cold climate heat pumps are entering the market with operating temperatures down to –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.



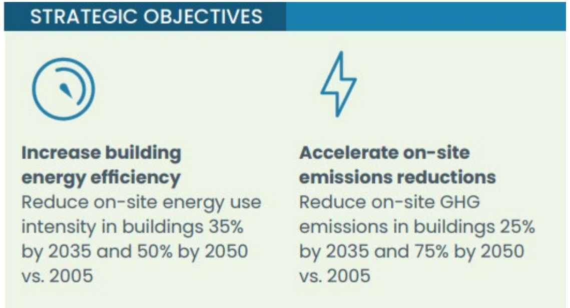
EIA. 2020 Residential Energy Consumption Survey

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



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



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.

[1] https://www.osti.gov/servlets/purl/2000471, https://www.nrel.gov/docs/fy23osti/84745.pdf

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”.

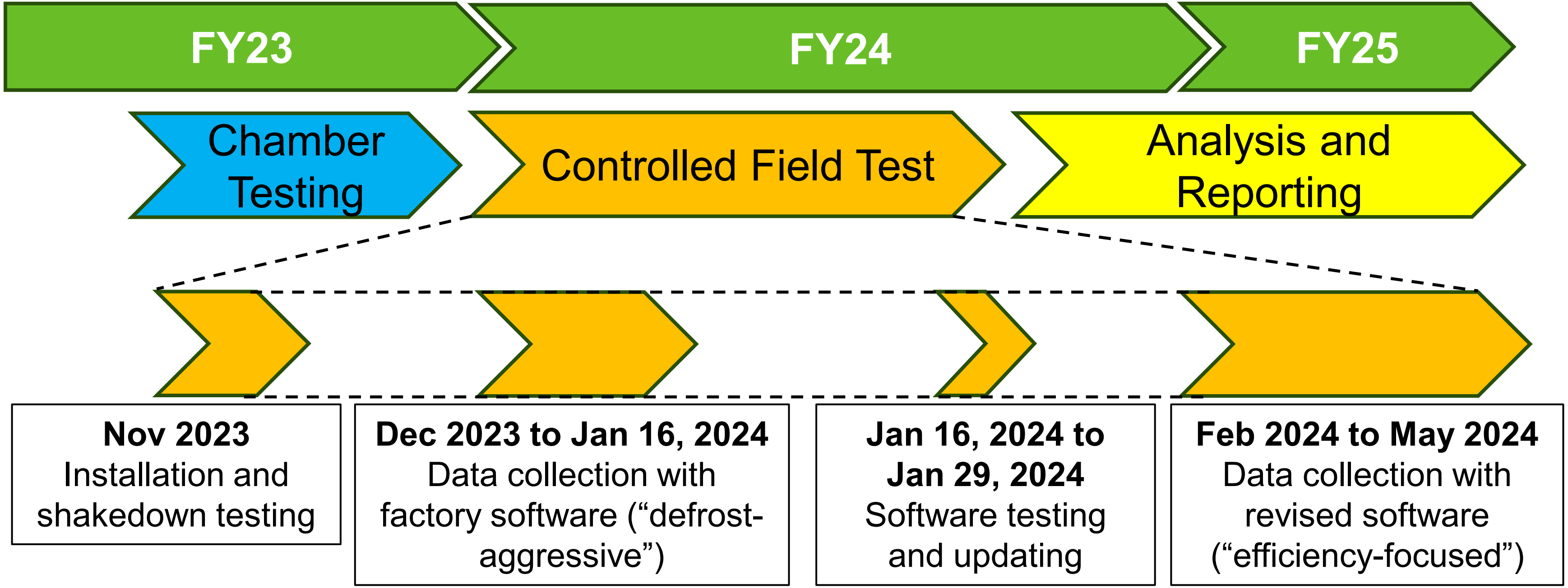
Photo by NREL staff

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).

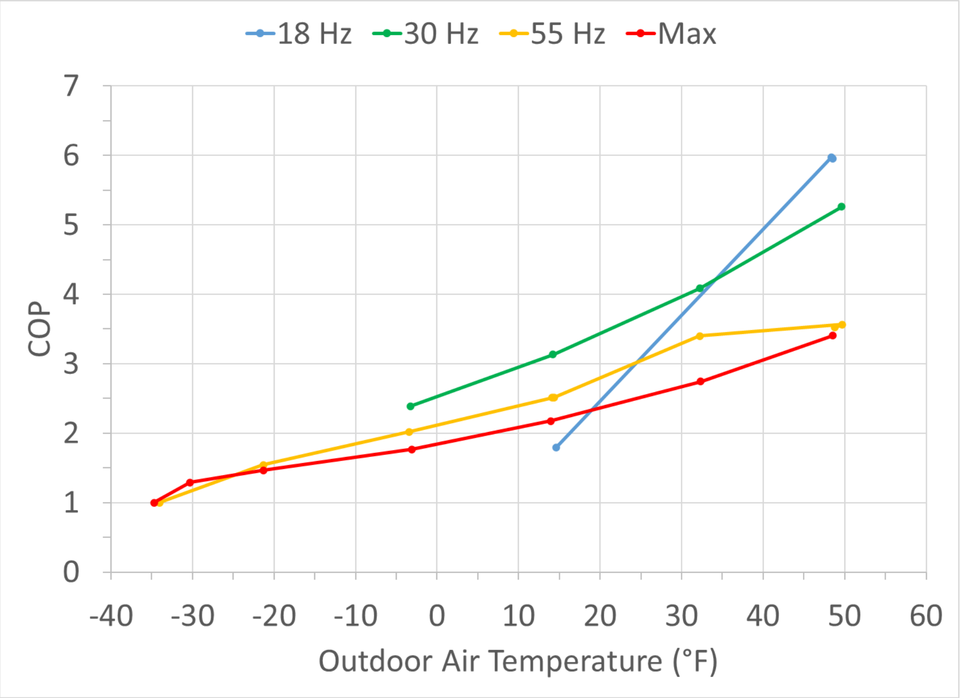
Photos by NREL staff

Timeline


FY23
FY24
FY25
Chamber Testing
Controlled Field Test
Analysis and Reporting
Nov 2023
Installation and shakedown testing
Dec 2023 to Jan 16, 2024
Data collection with factory software ("defrost-aggressive")
Jan 16, 2024 to Jan 29, 2024
Software testing and updating
Feb 2024 to May 2024
Data collection with revised software ("efficiency-focused")

Progress – Chamber Testing Observations

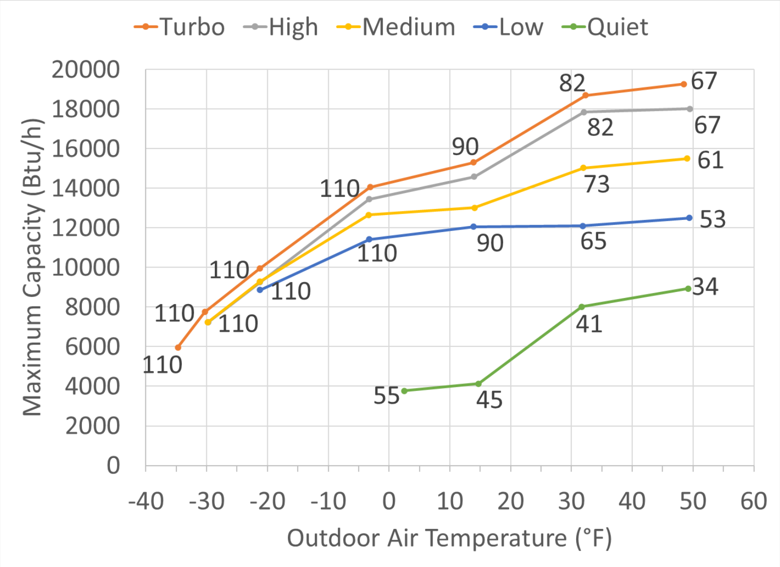
- Generally good COPs and capacity retention.
- COP above 1 down to –35°F.
- 12,000 Btu/h capacity @ –12°F.
- Frequency of defrosts increased at lower temperatures despite dry conditions in chamber.
- 260 W drain pan heater ran 50% of time @ 14°F and 33% of time below –4°F.

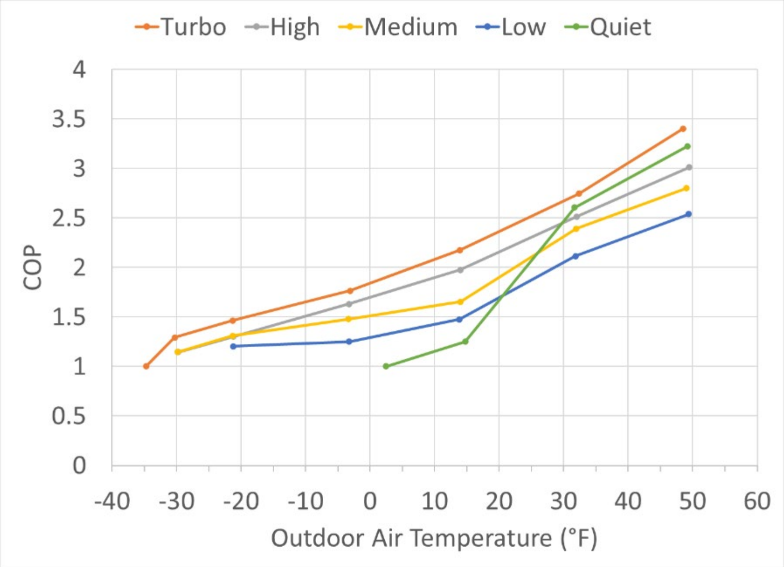


Preliminary Results

Impact of Fan Speed Setting on Maximum Capacity and Efficiency

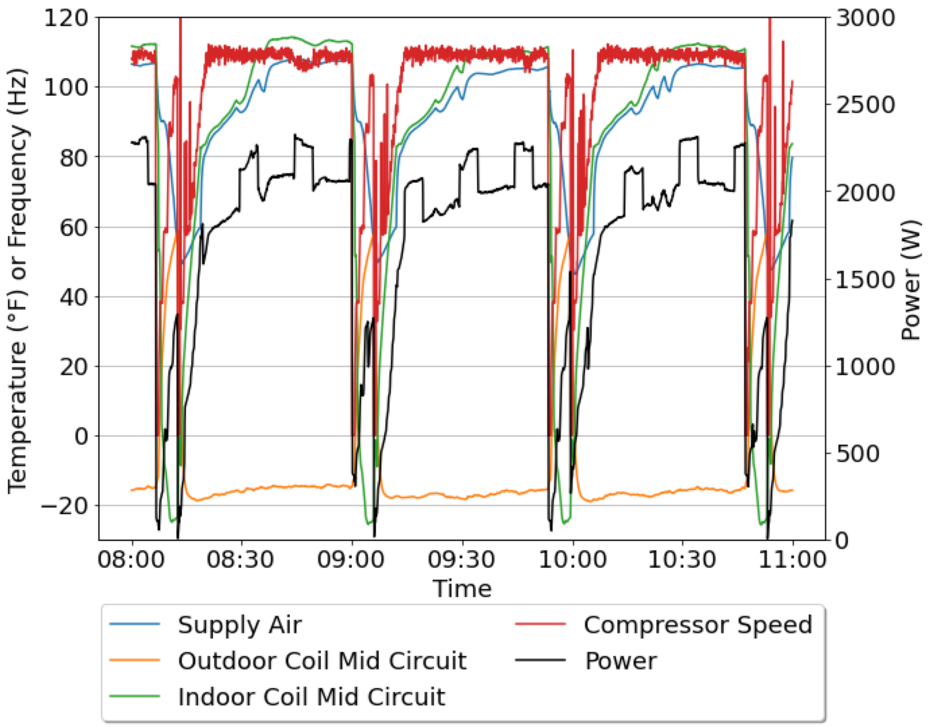
- Fan speed setting can limit the maximum compressor speed (labels in Hz).
- At the same compressor speed:
  - 5%–20% decrease in capacity and 8%–32% decrease in COP.





Preliminary Results

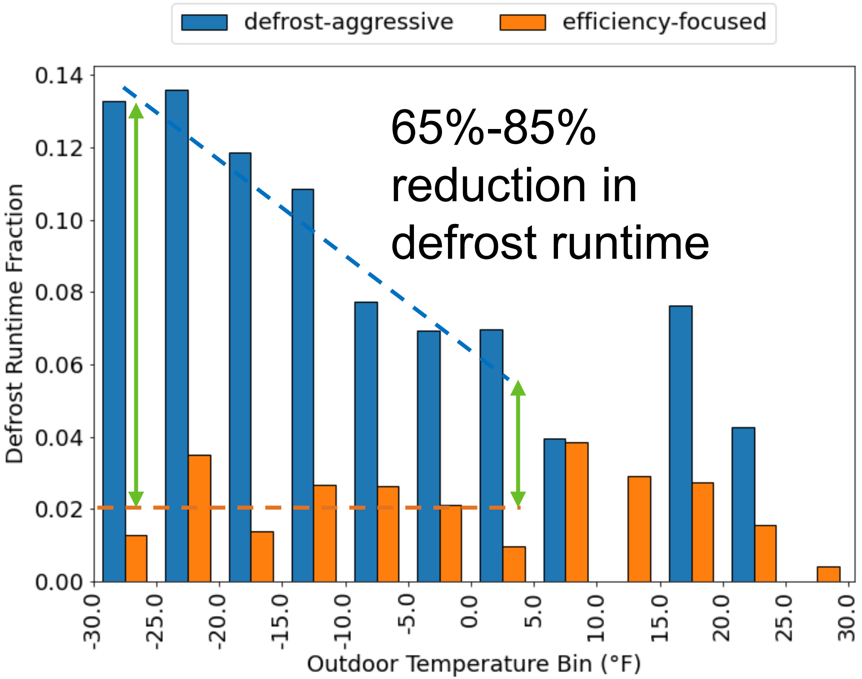
Example Timeseries Data from Field Test – Defrost-Aggressive Software



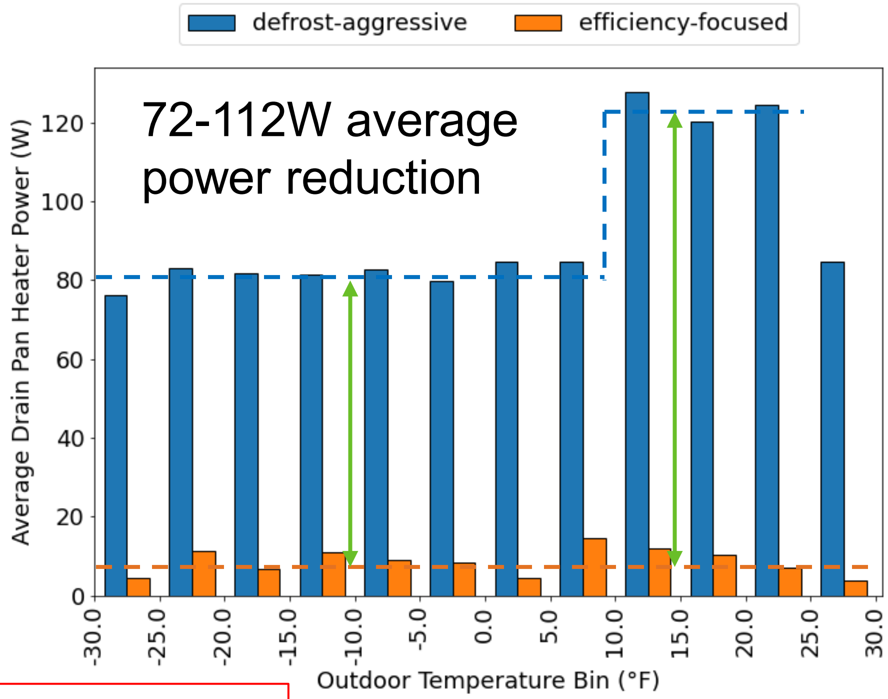
- Frequent defrosts (every 55 min).
- Defrost cycle lasts about 8 min.
- About 25 min. for indoor coil temperature to reach steady-state after defrost.
- ~60% of time in defrost or recovering from defrost.
- No significant frosting observed.
- Drain pan heater operating 33% of time.

Software Impacts on Defrost and Drain Pan Heater Operation

4-hour minimum runtime between defrosts



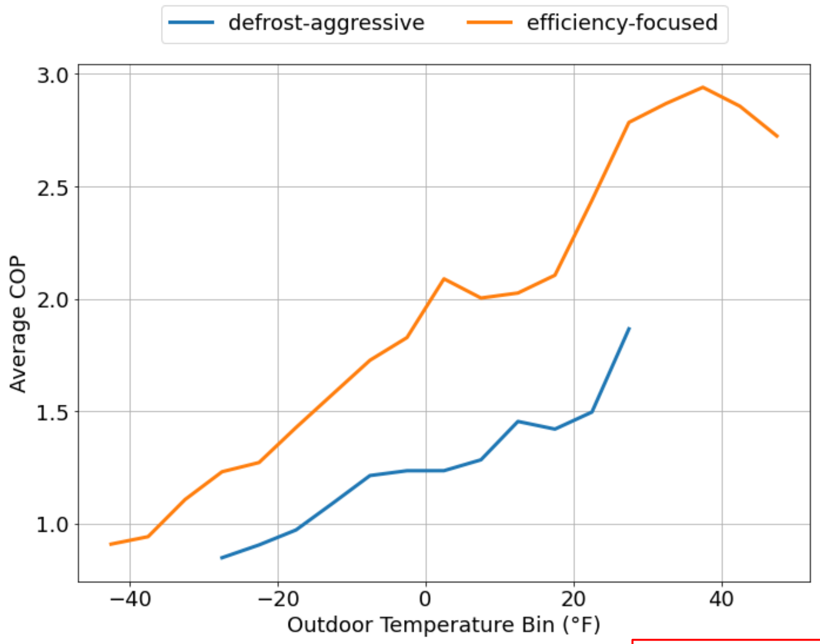
Drain pan heater runs only during defrost and the 5 minutes following



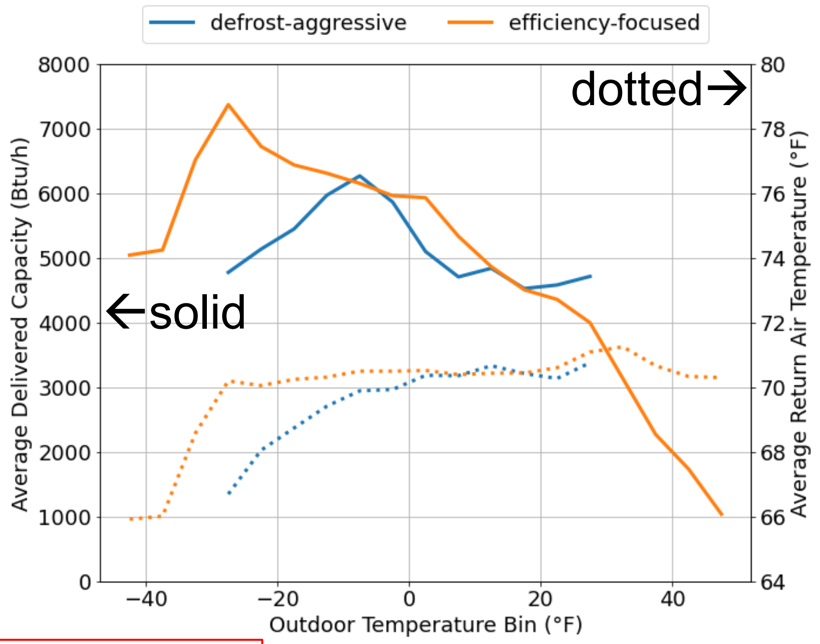
Preliminary Results

Software Impacts on Efficiency and Comfort

~50% increase in average COP.



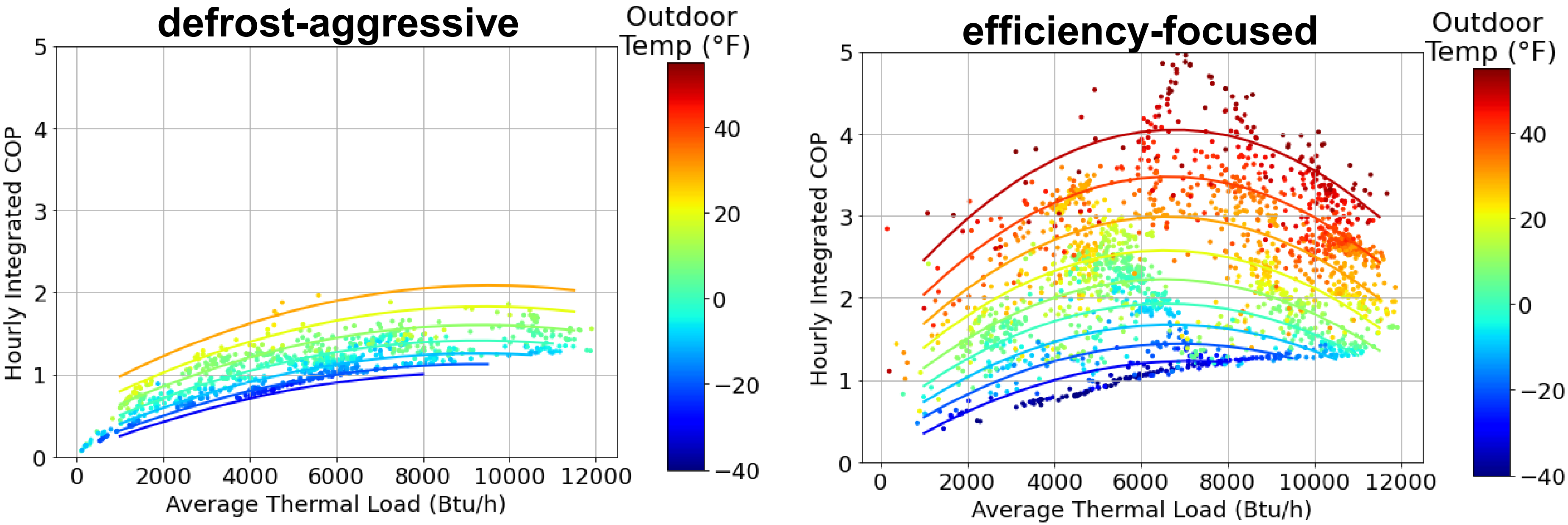
Met load at 20°F colder temperatures. Able to provide 50% more capacity @ –25°F.



Preliminary Results

Simplified Efficiency Model Based on Thermal Load and Outdoor Temperature

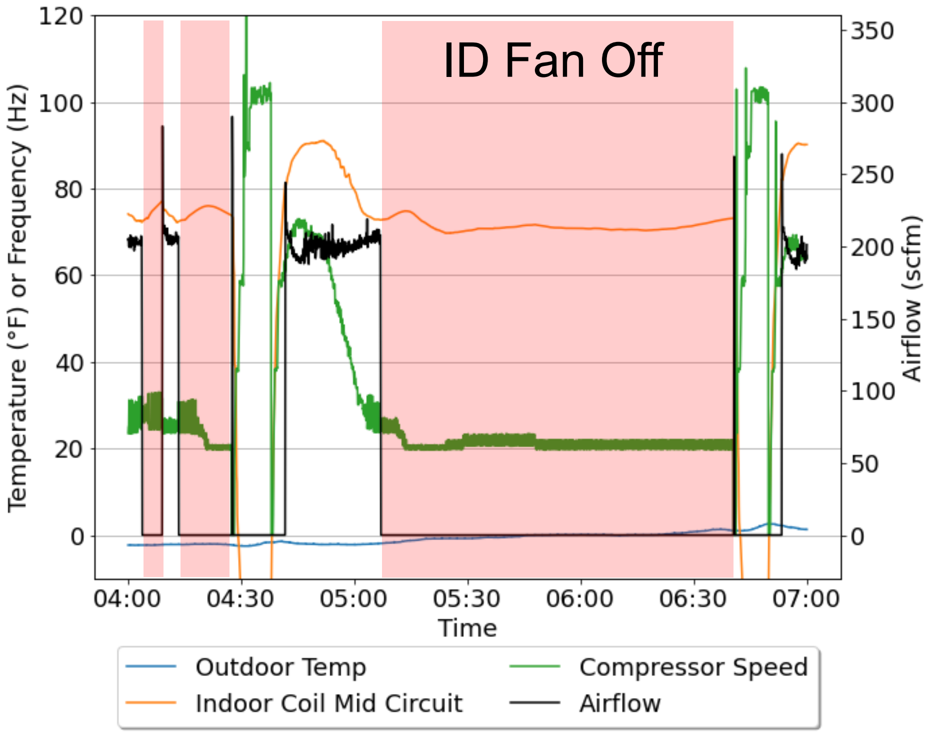
Bivariate polynomial fitted to data. Can be used to estimate heat pump performance using average outdoor temperatures and building heat load.



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

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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
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Haier / GE Appliances
Collaboration on research plan and software upgrades

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