Pacific Northwest NATIONAL LABORATORY

Evaluating the Impacts of Defrost Mode in Cold Climate Residential Heat Pumps

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DOE Cold Climate Heat Pump Challenge

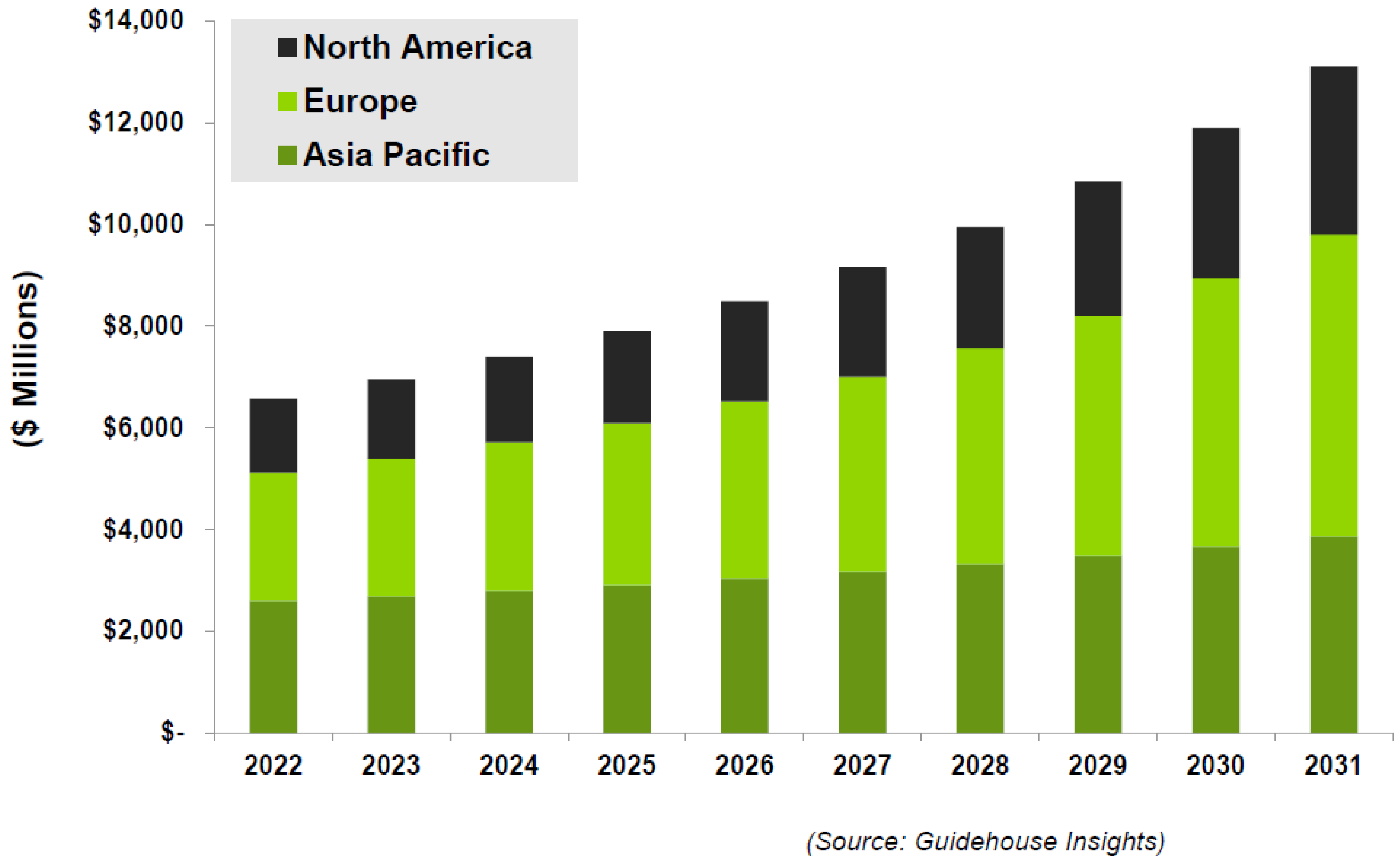
In recent years, specialized cold-climate heat pumps (CCHPs) can operate with greater capacity and efficiency at low outdoor temperatures (below 32 °F).

Residential, centrally ducted, electric-only HPs that perform better than today’s products:

- Nominal cooling capacity 24,000 – 65,000 Btu/hr.
- Perform efficiently at 5 °F (-15 °C)
- Employ low-GWP refrigerants (< 750 GWP, AR4 100 year)
- Incorporate advanced controls and grid-interactive capabilities

Cold Climate Heat Pump Opportunities

Chart 1-1. Residential Heat Pump Revenue by Region, Cold-Climate World Markets: 2022-2031



Guidehouse Insights. Market Analysis and Forecasts for Residential Heat Pumps in Cold Climates, Q2 2022

CCHP Field Testing Overview

Objective: Provide partners with the knowledge and experience to commercialize, deploy, and incentivize CCHP products in future years, including:

1. **Gather data** in real homes for different systems, home designs, and regions.
2. **Evaluate the performance** of the CCHP prototypes around efficiency, customer comfort, lifecycle costs, reliability, and local electricity grid impacts.
3. **Understand best practices and potential issues** related to product sizing, selection, and controls.

Objectives

1. Establishing relationships of defrost mode characteristics (e.g., frequency, cycle duration, and system power) to outdoor air temperature and/or humidity
2. Categorization of the strategies used in the Challenge to defrost units and impact to comfort
3. Quantification of the impacts of defrost mode on CCHP prototype performance based on field measurements

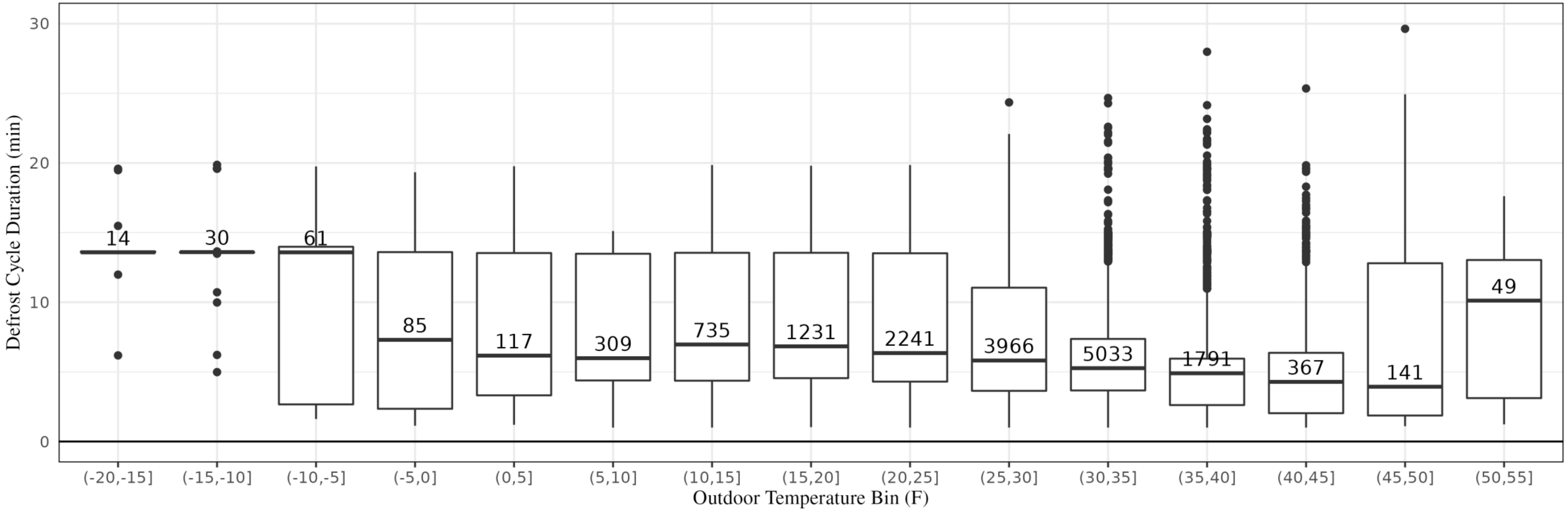
Analysis Overview

- Defrost Characterization
  - Cycle duration
  - Prevalence (total hours defrost / total hours ODU operation)
  - Frequency (cycle count / total hours ODU operation)
  - Power (ODU, auxiliary, supply fan) during defrost
- Defrost Categorization
  - Based on auxiliary power (none, med, high) and supply fan power (none, med, high)
- Comfort Impact
  - Impact of each strategy on supply air and indoor temperature

We have some more content on defrost as well as night setback in our conference paper to check out!

Defrost Duration

***Figure**: Range of defrost cycle durations by outdoor air temperature bin. The sample size (number of defrost cycles) is plotted on top of each boxplot to show which outdoor air temperature bins have few data.*



Defrost duration ranges from less than one minute to twenty minutes for most temperature bins with a median between 5 and 7 minutes for most data. The median duration value decreases at outdoor temperatures above 20 °F.

Defrost Prevalence and Frequency

***Figure**. Prevalence of defrost cycles (hours defrost / hours ODU operation)*

Outdoor Air Temperature Bin	Outdoor Relative Humidity Bin			
	0% to 30%	30% to 60%	60% to 80%	80% to 100%
-20 °F to -15 °F	ND	ND	ND	ND
-15 °F to -10 °F	ND	ND	ND	0.15
-10 °F to -5 °F	ND	ND	0.07	0.07
-5 °F to 0 °F	ND	ND	0.04	0.04
0 °F to 5 °F	ND	ND	0.03	0.04
5 °F to 10 °F	ND	0.01	0.03	0.07
10 °F to 15 °F	ND	0.02	0.05	0.10
15 °F to 20 °F	ND	0.02	0.06	0.11
20 °F to 25 °F	ND	0.02	0.05	0.10
25 °F to 30 °F	ND	0.03	0.04	0.08
35 °F to 40 °F	0.04	0.03	0.03	0.06
45 °F to 50 °F	0.01	0.02	0.02	0.02
50 °F to 55 °F	0.00	0.01	0.01	0.00

Figure. Frequency of defrost (cycle count / hours ODU operation)

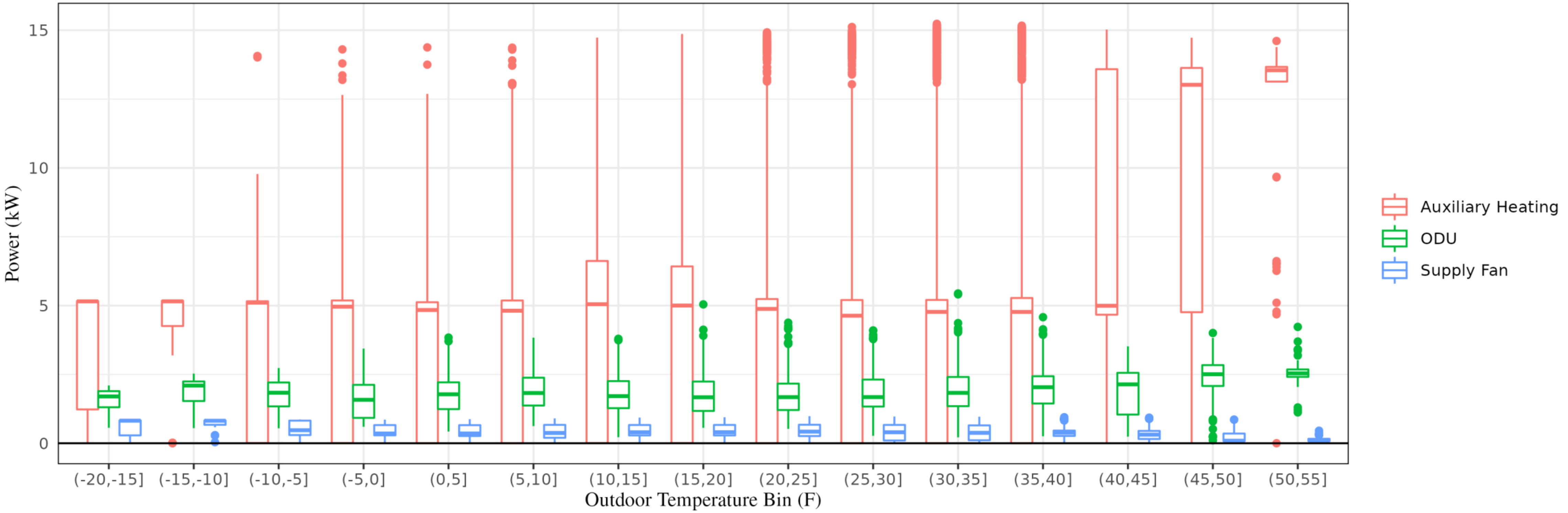
Outdoor Air Temperature Bin	Outdoor Relative Humidity Bin			
	0% to 30%	30% to 60%	60% to 80%	80% to 100%
-20 °F to -15 °F	ND	ND	ND	ND
-15 °F to -10 °F	ND	ND	ND	0.67
-10 °F to -5 °F	ND	ND	0.27	0.31
-5 °F to 0 °F	ND	ND	0.30	0.30
0 °F to 5 °F	ND	ND	0.21	0.29
5 °F to 10 °F	ND	0.09	0.29	0.50
10 °F to 15 °F	ND	0.40	0.42	0.67
15 °F to 20 °F	ND	0.29	0.43	0.70
20 °F to 25 °F	ND	0.31	0.41	0.70
25 °F to 30 °F	ND	0.40	0.40	0.61
35 °F to 40 °F	ND	0.35	0.31	0.55
45 °F to 50 °F	0.26	0.26	0.20	0.23
50 °F to 55 °F	0.03	0.11	0.09	0.05

ND = No data or insufficient data (< 25 hours total ODU operation) available in this bin

Defrost mode becomes both more prevalent and has a greater cycle frequency at higher humidities. There are higher prevalence and frequency at moderate temperatures 10 – 30 °F.

Power

Figure. *Distribution of mean power (auxiliary heating, outdoor unit (ODU), and supply fan) for each defrost event grouped by outdoor air temperature bin.*



There are not any noticeable trends to outdoor temperature with auxiliary power and ODU power across all data. The supply fan shows a very slight decrease in the median power as outdoor air temperature increases.

Defrost - Categorization

Figure. *Count of observed defrost cycles in each combination of mean auxiliary heating power and fan power category.*

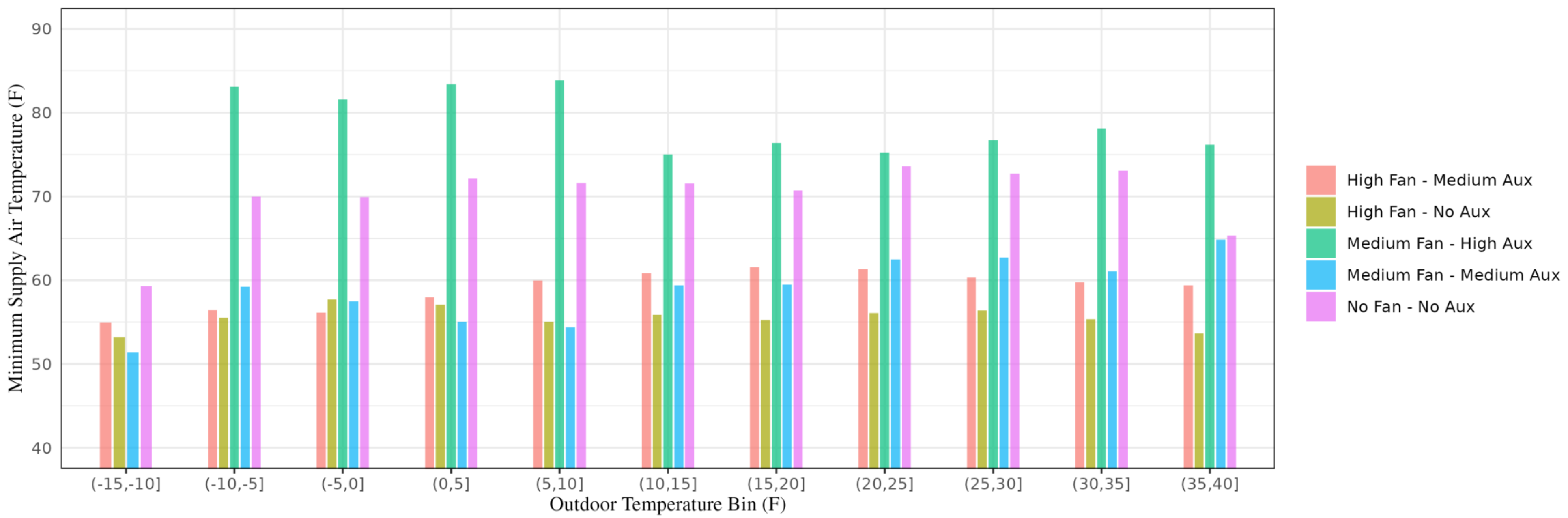
	No Fan (< 0.05 kW)	Medium Fan (0.05 – 0.4 kW)	High Fan (> 0.4 kW)
No Aux (< 0.1 kW)	2,053	544	3,314
Medium Aux (0.1 – 9 kW)	29	3,121	3,727
High Aux (> 9 kW)	0	1,661	329

The table shows that the most common combinations of fan and auxiliary control strategies (highlighted above) are:

Strategy	Observations
No Fan - No Aux	No auxiliary heat needed if there is no supply air; Likely low defrost efficiency because less heat transfer. System must overcome ambient cooling following defrost cycle.
Medium Fan - Medium Aux	Fan power varies throughout defrost cycle; One stage of auxiliary heat.
Medium Fan - High Aux	Two or three stages of auxiliary heat to optimize indoor comfort but will require more energy.
High Fan - No Aux	Blows cold air into home but saves auxiliary energy; Likely better defrost efficiency compared to the “No Fan” version because more air is passing over the indoor coil (more heat transfer).
High Fan - Medium Aux	High fan should increase defrost efficiency (more heat transfer). One stage of auxiliary heat.

Comfort Impact – Supply Air Temperature

***Figure**. Minimum supply air temperature from defrost cycles to home for each defrost category.*

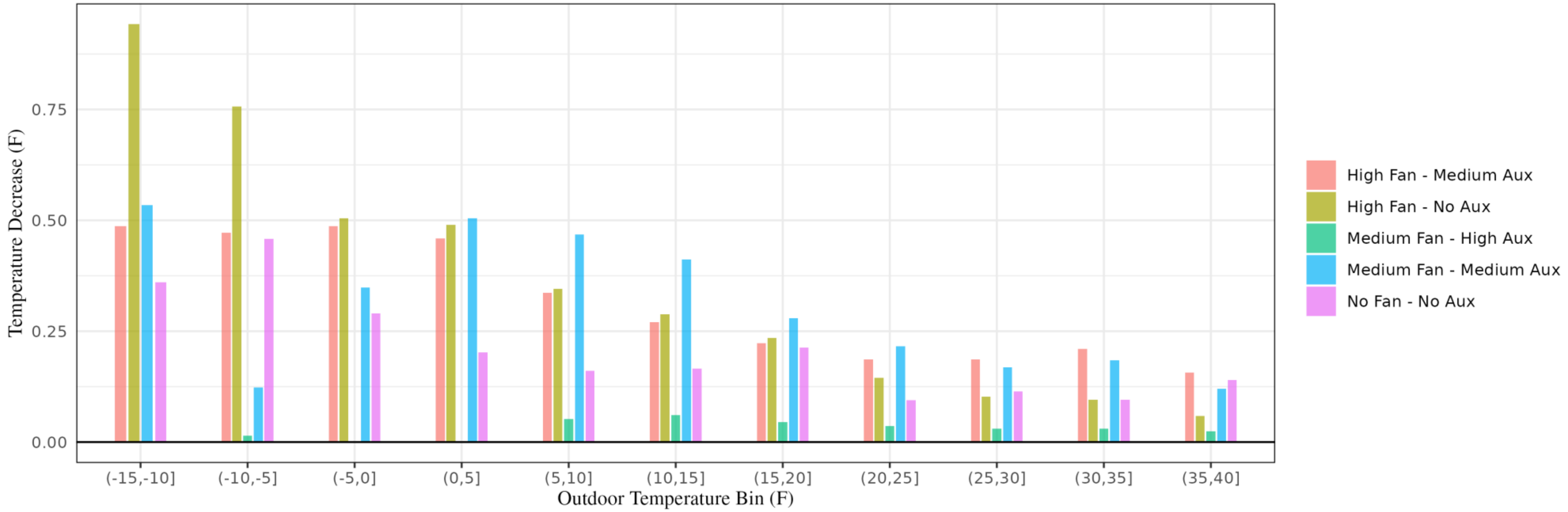


- **Best for comfort**: "Medium Fan – High Aux" followed by "No Fan - No Aux".
- **Worst for comfort**: "High Fan – No Aux" with the other two categories close behind, all three with supply temperatures mostly below 60 °F (15.6 °C).

Categories with higher auxiliary power (controlling for fan power) have higher supply temperatures, but it takes more energy to provide that comfort.

Comfort Impact – Room Temperature

Figure. *Decrease in indoor temperature resulting from defrost cycle for each defrost category.*



Overall, there is a greater temperature decrement at lower outdoor temperatures.

- **Best for comfort**: "Medium Fan – High Aux" at all outdoor air temperature bins.
- **Worst for comfort**: "High Fan – No Aux" at lowest outdoor air temperatures (-15 to 0 °F) and "Medium Fan – Medium Aux" at 0 to 25 °F.

Limitations and Conclusions

- Main limitation from a field study is no control to standardize operation and home features.
  - Confounding factors for evaluating defrost impacts to comfort could include home size, unit size, home envelope efficiency, and air supply locations.
- None of the strategies had significant impacts to average room temperature throughout the homes (median impact all less than 1 °F), but three strategies not listed all had regular supply temperatures less than 60 °F, which could have comfort impacts during winter to occupants near supply vents.
- Of the control strategies observed, “Medium Fan – High Aux” had the best comfort results based on supply air temperature and room temperature, followed by the “No Fan - No Aux” strategy.
- Future work could include identifying a strategy to evaluate the energy impact of the defrost categories.

Thank you