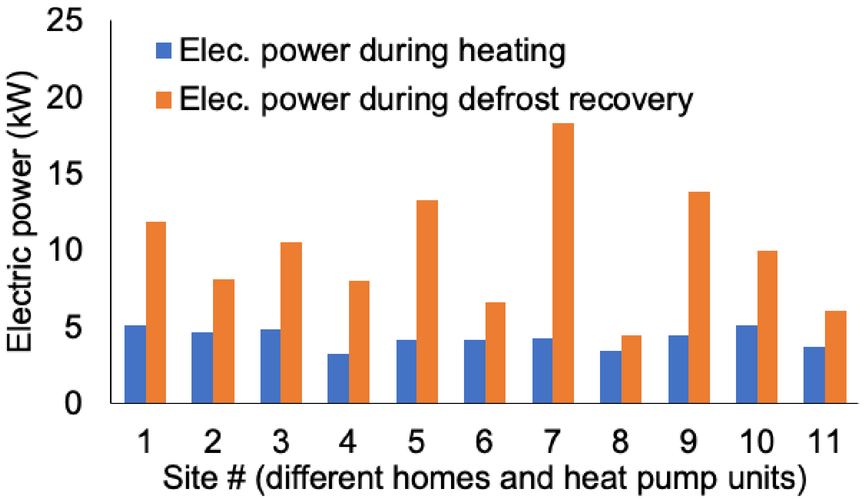
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Quantifying and reducing defrost energy use

Material in this presentation includes unpublished and/or preliminary data and analysis that is subject to change.

Quantifying and reducing defrost energy use



National Renewable Energy Lab
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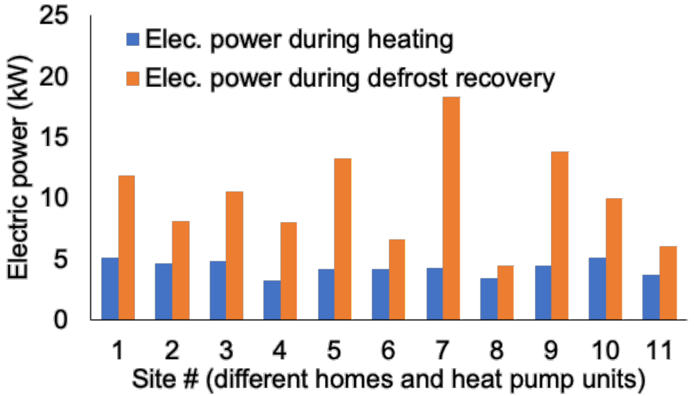
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

This project will evaluate the energy and emission impact of heat pump defrosting and its controls. This supports the DOE Blueprint's goal of electrification by improving defrost performance for heat pumps.

Leveraging NREL's building stock modeling tools, we will provide nationwide energy and emission impact of 1) currently used defrosting methods, and 2) emerging frostless technologies and advanced defrost controls



TEAM & PARTNERS

National Renewable Energy Laboratory

Trane Technologies

STATS

Performance Period: 10/1/2023-09/30/2025

DOE Budget: $675k, Cost Share: $0k

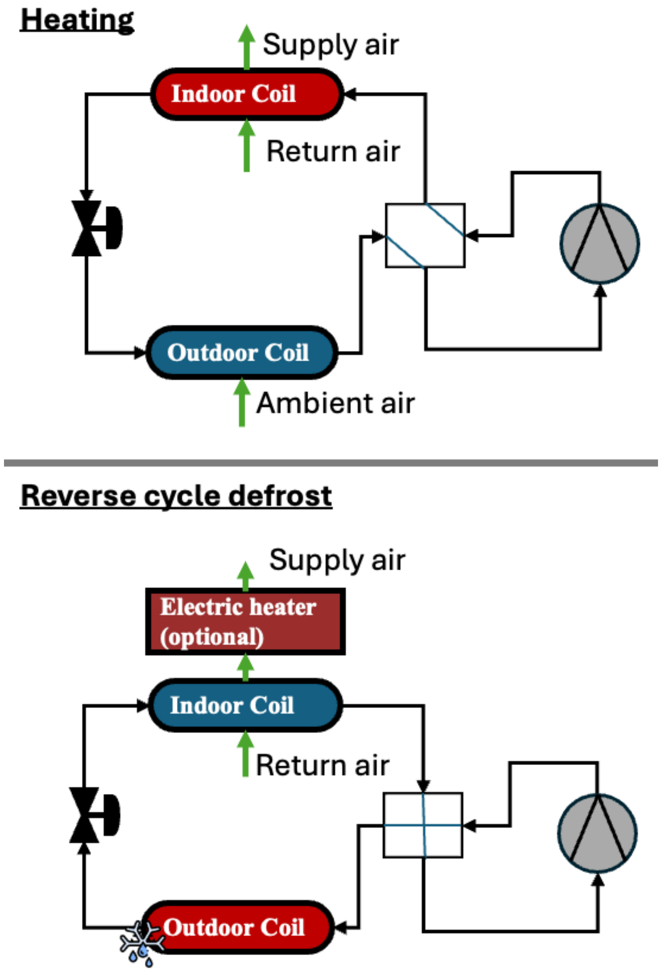
Milestone 1: Finalize HX and system model for impact analysis

Milestone 2: HX test setup for frost/defrost experiments complete

Milestone 3: Impact analysis of HP defrost operation complete

What is defrosting?

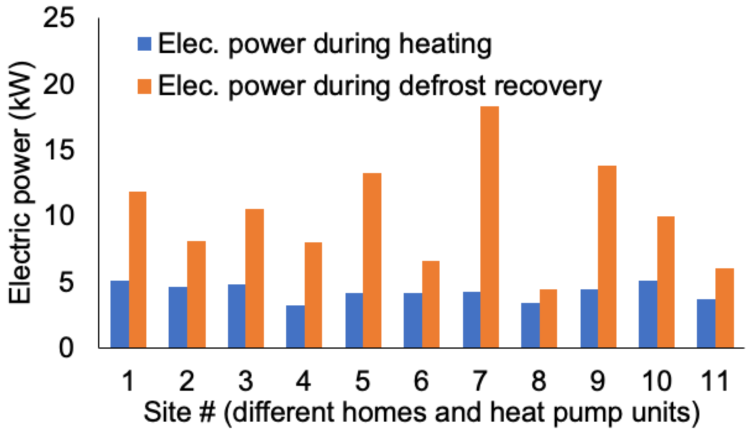
- Frost forms on the outdoor coil during heat pump operation.
- Defrosting is the process that removes this frost, typically by reversing the refrigerant cycle (running the heat pump as an air conditioner)



Why is frosting and defrosting important?

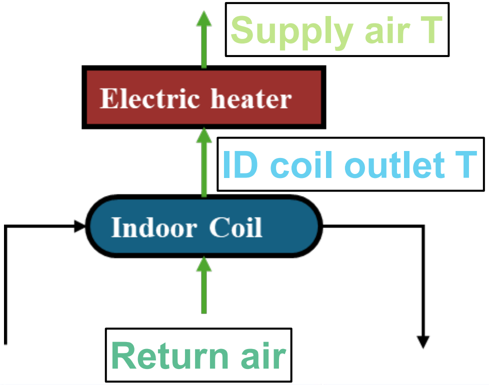
- Degraded equipment performance from frost growth and its removal
  - Example [1]: Seasonal COP reduction: 1.5% - 12.7%

- Higher electric power [2]
  - Increased utility bills
  - Higher required electric capacity
  - Impact on the electric grid

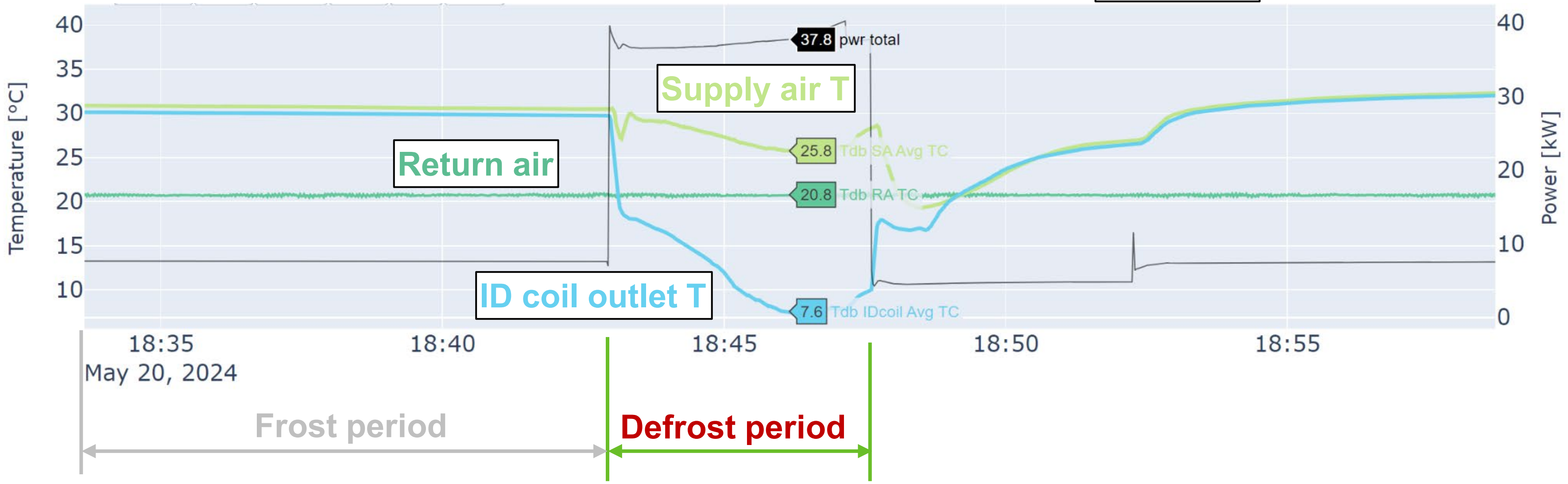


[1] Vocale, et al, Influence of Outdoor Air Conditions on the Air Source Heat Pumps Performance, Energy Procedia. 45 (2014) 653–662.
[2] Winkler, J and S Ramaraj. 2023. Field Validation of Air-Source Heat Pumps for Cold Climates. Golden, CO: NREL/TP-5500-84745.

Why is frosting and defrosting important?



Lab data from 7.5-ton HP rooftop unit



Alignment and Impact

DOE Strategic Objective #1: Increase building energy efficiency

- This project can reduce heat pump electricity use. Goal: show efficiency gain of 10%

DOE Strategic Objective #2: Accelerate on-site emissions reductions

- This project supports electrification by mitigating challenges of heat pumps in cold climates
- This project's goal: reduce electrical capacity requirements by 20% for heat pump installations

DOE Cross-Cutting Goal #2: Affordability - Reduce energy burden and technology costs so that all can benefit

- This project can lower utility bill costs associated with both demand and energy. Goal: reduce heat pump related utility bill costs by 20%

Approach – multi-scale modeling

Heat pump control development

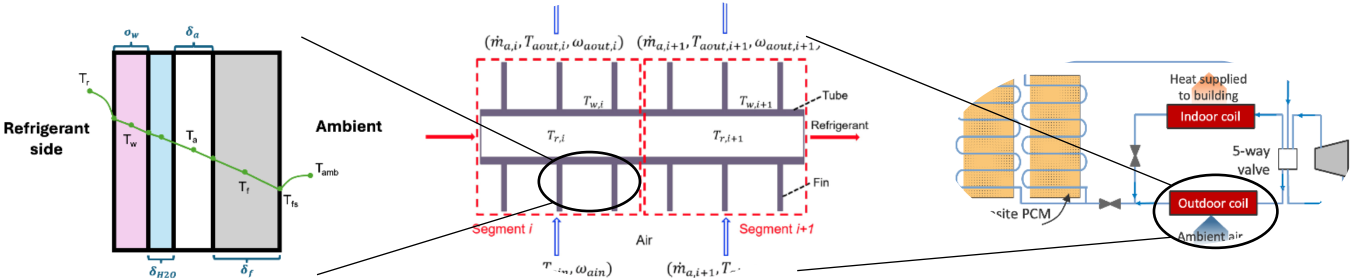
Building model

FY24 scope

Frost/Defrost model

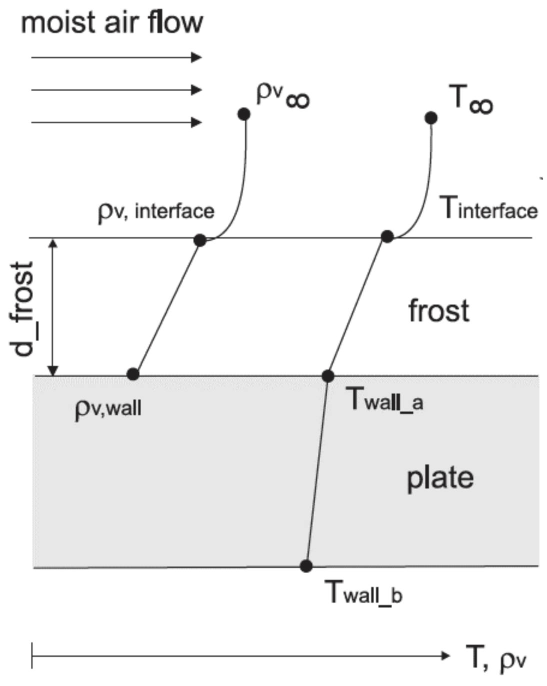
HX model

Heat pump model



EnergyPlus

Approach – frost model

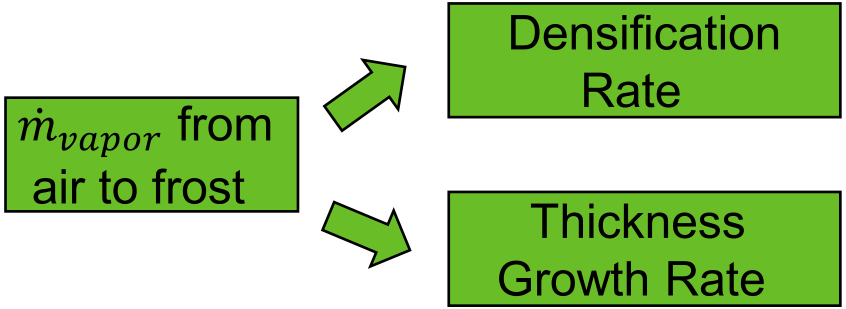


Model inputs

- Air velocity, dry-bulb temperature, RH
- Wall temperature

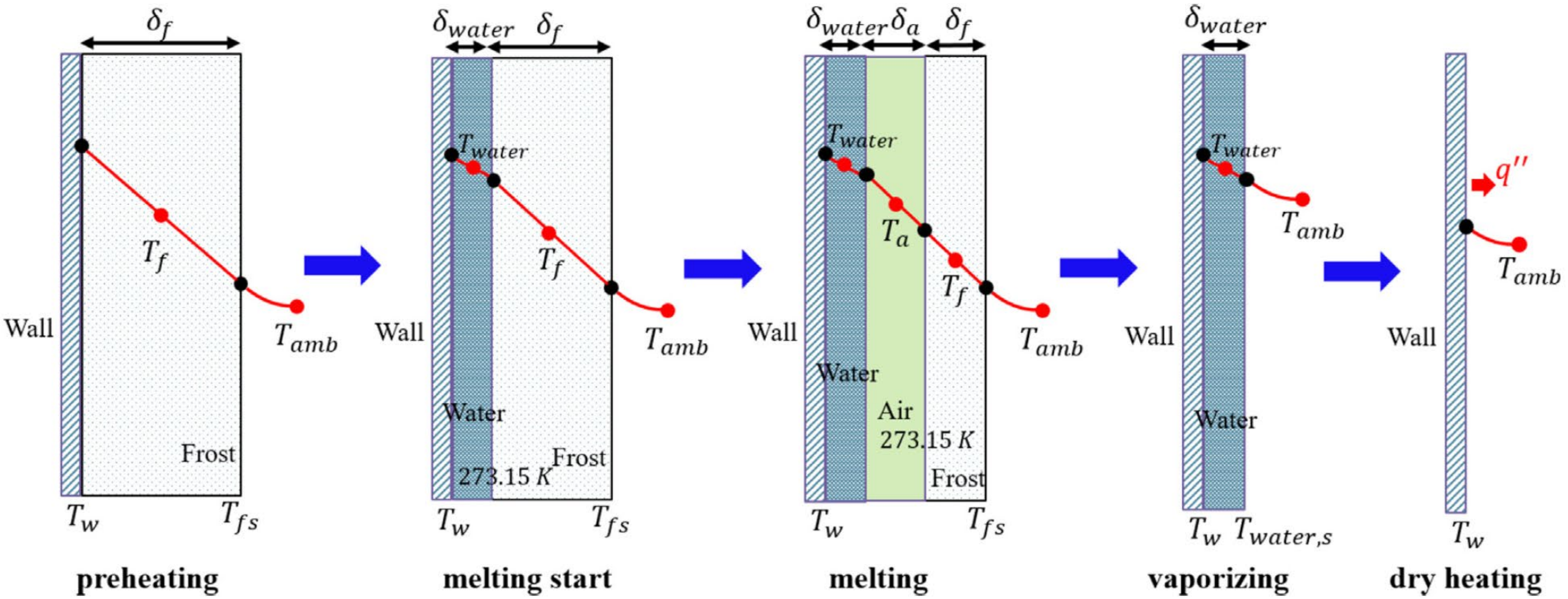
Model outputs

- Frost thickness vs. time
- Frost density vs. time



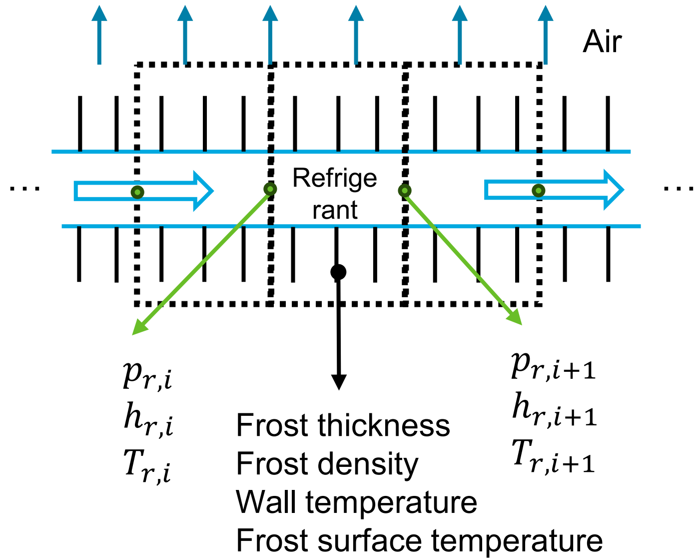
(Figure from Prolss and Schmitz, 2006)

Approach – defrost model



Five-stage frost melting process (Ma et al., 2023)

Approach – heat exchanger model



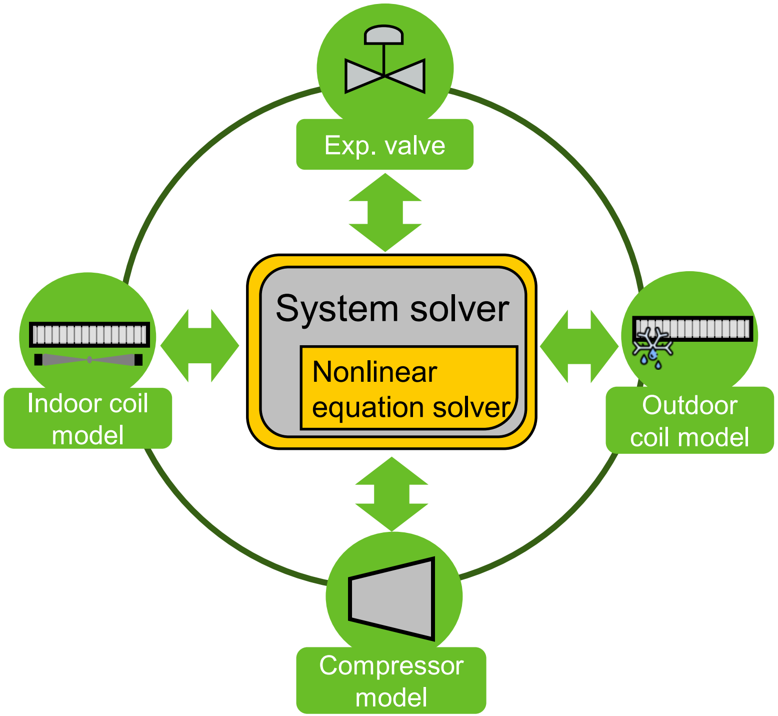
Segment-by-segment HX model

<u>Finite-difference model for tube-fin heat exchangers</u>

- Adds frost and defrost models from prior two slides to a finite-difference refrigerant to air HX
- Tracks frost mass vs. time at each node, as well as changes in flow-passage area and airside pressure drop

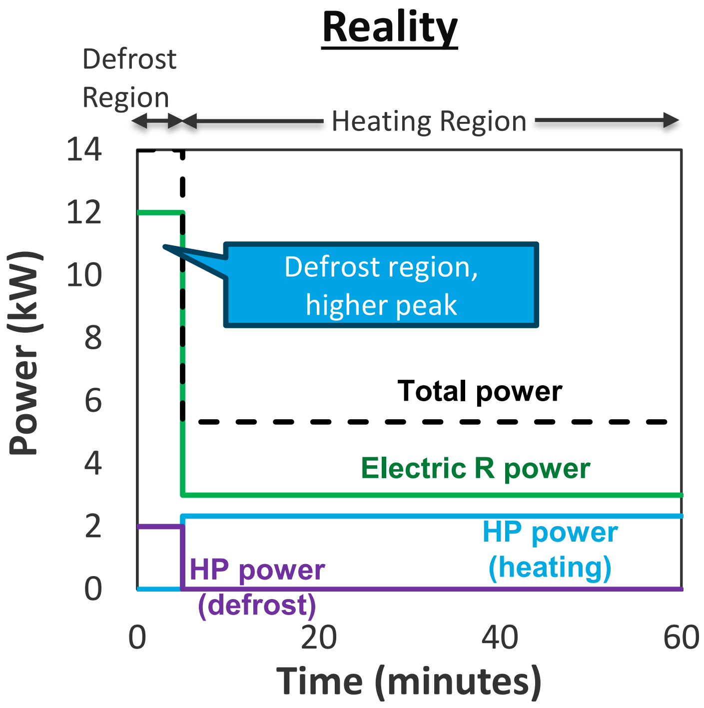
Approach – heat pump model

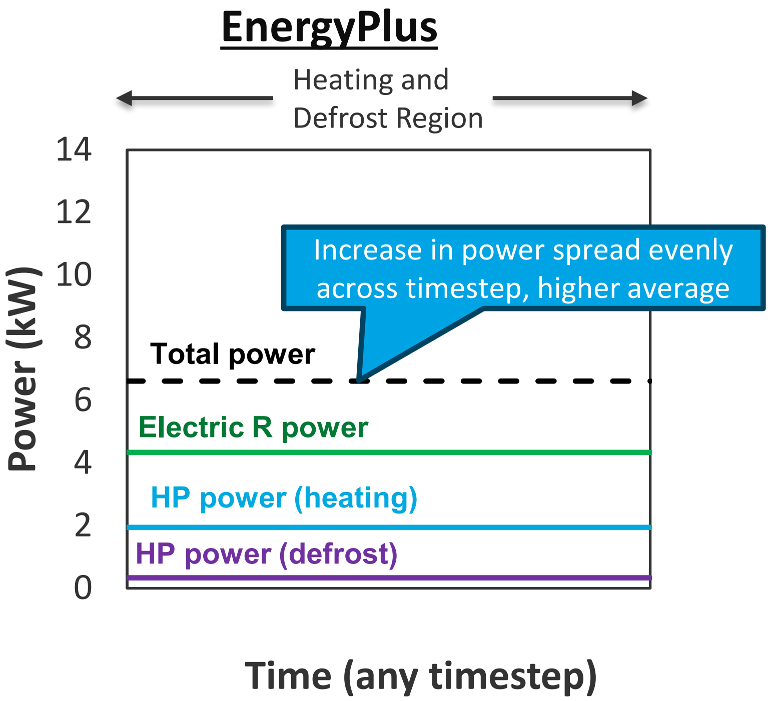
- Component-based architecture
  - Compressor
  - Expansion valve
  - Coil models (one w/ frost and defrost)
- Quasi-steady state framework
  - Tearing based system solver (Huang et al., 2021)
  - Nonlinear solver



Huang, et al. "A tripartite graph based methodology for steady-state solution of generalized multi-mode vapor compression systems." *Applied Thermal Engineering* 185 (2021): 116385.

Approach – EnergyPlus simulations





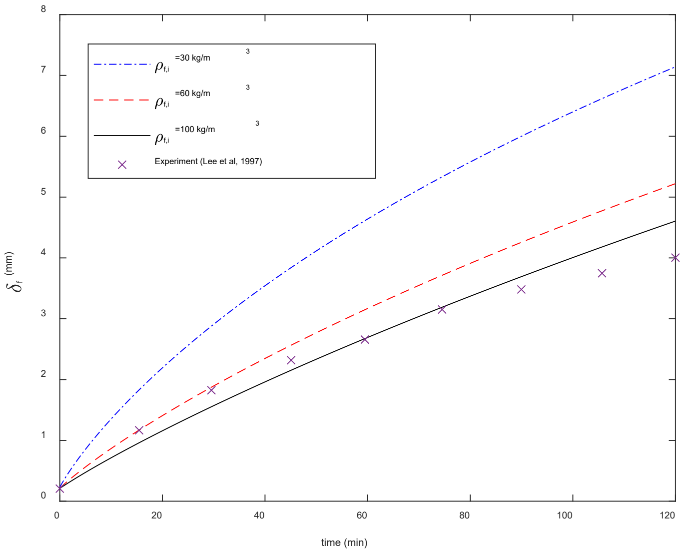
Approach – EnergyPlus simulations

- EnergyPlus limitations:
  - Assumes heating/frosting and defrosting occur simultaneously
  - Doesn’t capture the discrete peak from the supplemental heater during defrost, and in part-load conditions, neglects some of this supplemental heater energy use entirely.

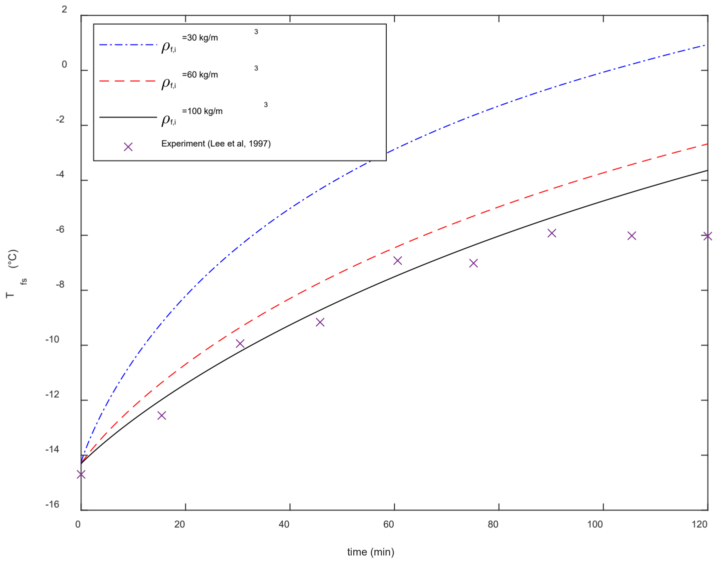
- In this project, we will fix these issues to realistically capture the impact of frost and defrost cycles on heat pump performance.
  - This will leverage NREL’s Comstock and ResStock modeling tools, which include statistical representations of the building stock across all diverse US climates.

Progress: Frost model experiment comparison

<u>Frost on a flat plate:</u> V=1 m/s, T_a=25°C, RH_a=70%, T_p=-15°C



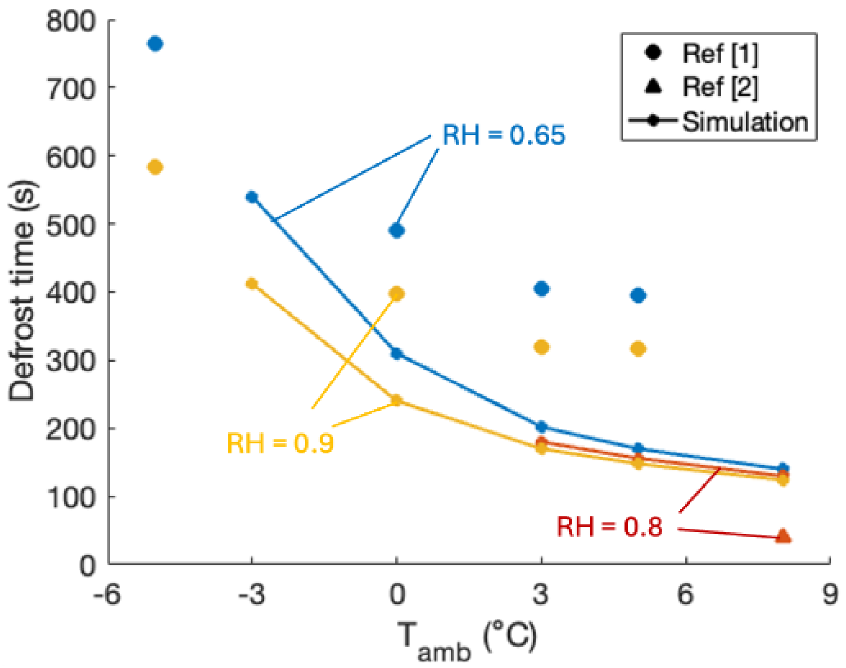
Frost thickness



Frost surface temperature

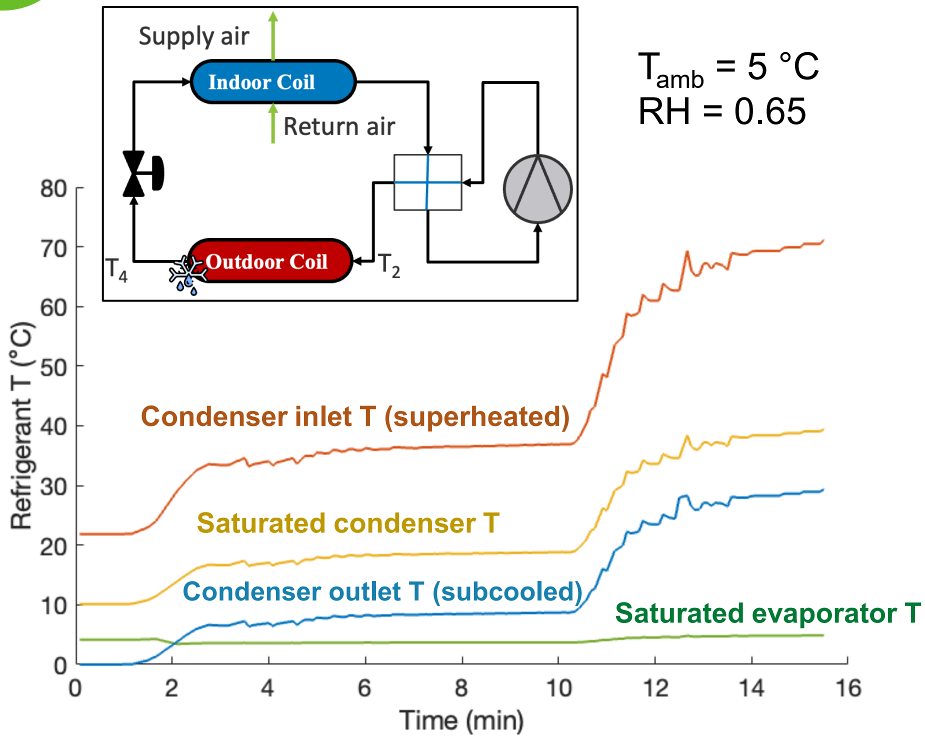
Density is not measured in the experiments. Modeled results depend strongly on assumed initial density.

Progress: Defrost model experiment comparison

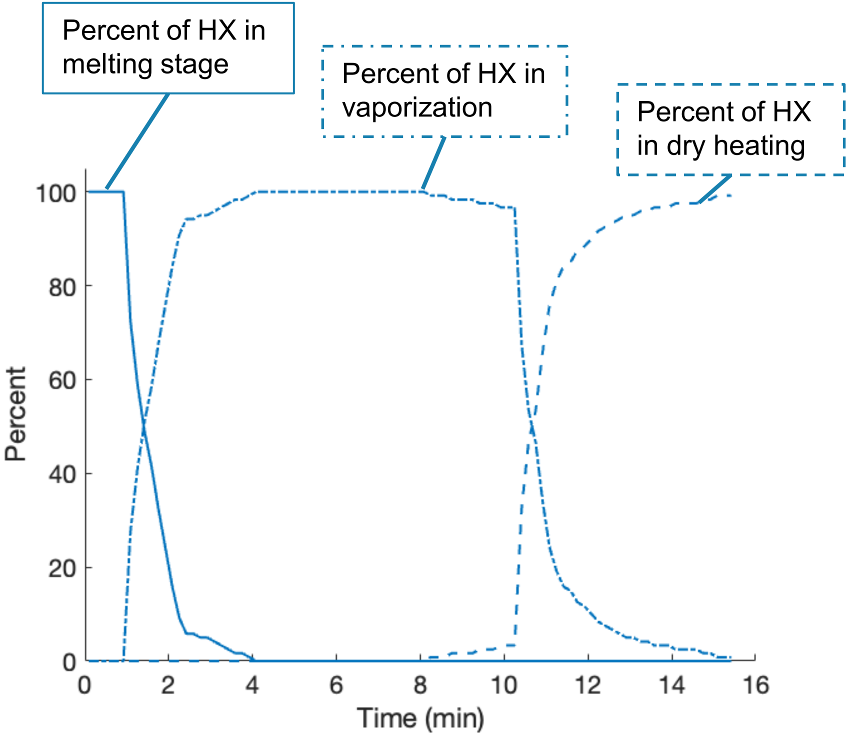


Predicted and measured defrost time at different ambient conditions. [1]: Chen & Guo. 2009. [2]: Dhaddar et al. 2024

Progress: Simulated system defrost performance



Simulated refrigerant temperatures during reverse cycle defrost



Percent of HX in different defrost stages

Future Work

- Key limitations uncovered that still need to be investigated:
  - Does uniform air gap persist through entire melting stage?
  - How much frost/ice falls off the coil prior to melting?
  - How important is melting/de-sublimation from the frost to the ambient air, particularly for warm ambient conditions (often ignored)?
- FY25 plans
  - Collect HX and system data for better model validation
  - Investigate impact of control choices on performance
  - Develop surrogate model appropriate for building simulations
  - Quantify impact of standard and advanced defrost controls on utility bills, peak demand, and CO_2 emissions across US climates

Thank you

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Reference Slides

Project Execution

	FY2024				FY2025				FY2026			
Planned budget	$150k				$450k				$75k			
Spent budget	$150k				$0k				$0k			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1: Review – Complied list of defrost technologies												
Q2: Review – Frost/defrost modeling methods and correlations												
Q3: Initial HX model developed with frost/defrost process												
Q4: Vapor compression system model with heat exchangers that include frost/defrost process, with initial example results												
Current/Future Work												
Q1: Finalize HX and system model for impact analysis												
Q2: Impact analysis methodology determined												
Q3: HX test setup for frost/defrost experiments complete												
Q4: Impact analysis of HP defrost operation complete												
Q4: Evaluate alternative defrost strategy in the lab (planned)												

Team

Jason Woods

Sr. Research Engineer

Co-PI

Ransisi Huang

Research Engineer

Co-PI; Lead VC system and frost/defrost modeling

Zechao Lu

Post-doctoral Researcher

Model development and execution

Eric Bonnema

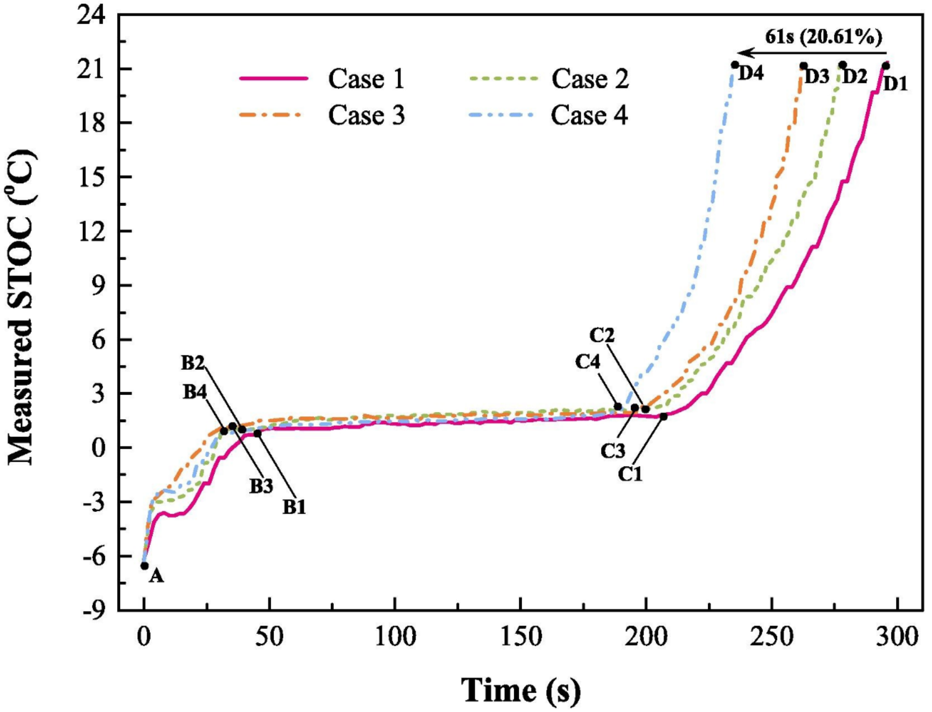
Sr. Research Engineer

Lead EnergyPlus building modeling

Team, continued

- Rohit Dhumame, Trane Technologies
  - Providing detailed frost model for cross-verification
- Matt Cambio, Trane Technologies
  - Providing data for frost and defrost model validation

Measured wall surface temperature from literature



Ref: Wei, Wenzhe, et al. "Experimental investigation on improving defrosting performance of air source heat pump through vapor injection." *Energy and Buildings* 256 (2022): 111696