

BTO Peer Review: Load shifting and resiliency for refrigerated display cases

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Load shifting and resiliency for refrigerated display cases

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WBS 3.4.6.94



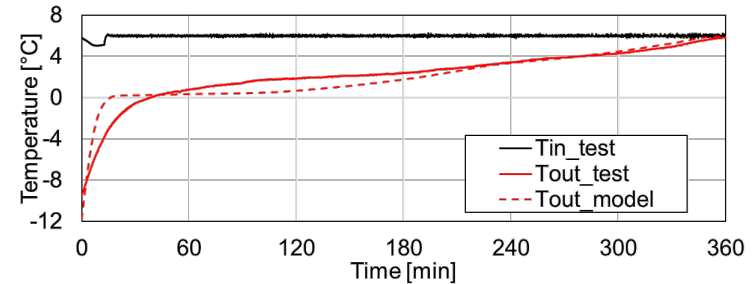
Project Summary

Preliminary results

OBJECTIVE, OUTCOME, & IMPACT

Objective: Integrate ice-based thermal storage on the air side (evaporator outlet) of a refrigerated case to reduce electric use by 90% for 4 hours.

Outcome: Lower utility bills associated with refrigeration, provide load shifting for electric utilities, and maintain product temperatures during a power outage.



Initial prototype maintains $T < 3^{\circ}\text{C}$ for 3 hours

TEAM & PARTNERS

National Renewable Energy Laboratory

PCM partner: Rubitherm

Plan to bring on additional partners in FY25:

- Supermarket
- Refrigerated case manufacturer

Part of **Stor4Build Consortium**



STATS

Performance Period: 10/01/2024-09/30/2026

DOE Budget: \$925k, Cost Share: \$0k

Milestone 1: Bench-scale prototype experiments

Milestone 2: Full-scale prototype experiments

Milestone 3: Testing with prototype connected with refrigerated case



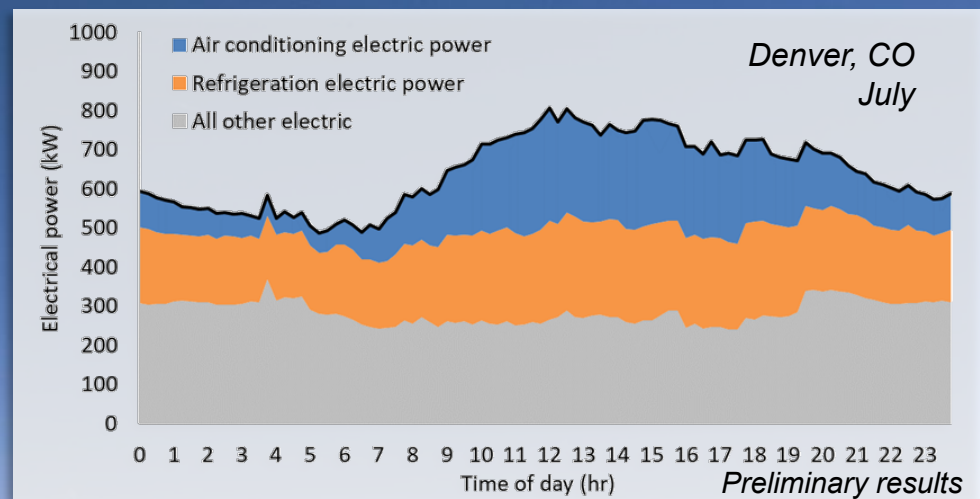
Problem

Context:

- Grocery stores are the second highest EUI building type
- Refrigeration is the largest load in grocery stores

Problem:

- Refrigeration electricity use leads to high demand and utility bills for supermarkets, and these costs are passed on to consumers
- Power outages are very disruptive to supermarkets—FDA mandates that food not kept cold is thrown away





Alignment and Impact: BTO Blueprint ¹

DOE Cross-Cutting Goal #3: Resilience – Increase the ability of communities to withstand and recover from stress

- Adding storage to refrigerated cases can help minimize spoilage of perishable food during power outages

DOE Strategic Objective #3: Transform the grid edge. Reduce electrical infrastructure costs by tripling demand flexibility by 2050 vs. 2020.

- Project goal: 90% load reduction for at least 4 hours
- US commercial refrigeration electricity use ²:
 - 108,000 GWh -> ~ 18 GW ³
- Additional demand flexibility needed for 2050 Blueprint target:
 - 96 GW
- Theoretical potential for proposed technology:
 - 16 GW (17% of BTO 2050 target)

¹ BTO Blueprint: <https://www.energy.gov/eere/articles/decarbonizing-us-economy-2050>

² CBECS data: <https://www.eia.gov/consumption/commercial/data/2018/ce/pdf/e5.pdf>

³ Assumes case runs 70% of the year



Approach

- Current approach to address high-electric demand problem:
 - Electrochemical storage (expensive)
 - Turn off cases (limited duration and risky).
- Current approach to address resiliency during power outages:
 - Remove food from the store and keep in refrigerated trailers in parking lot





Design considerations for adding TES into a standalone refrigerated case

- What is the best way to move heat into / out of TES
- How do we minimize incremental engineering, manufacturing, and installation costs?

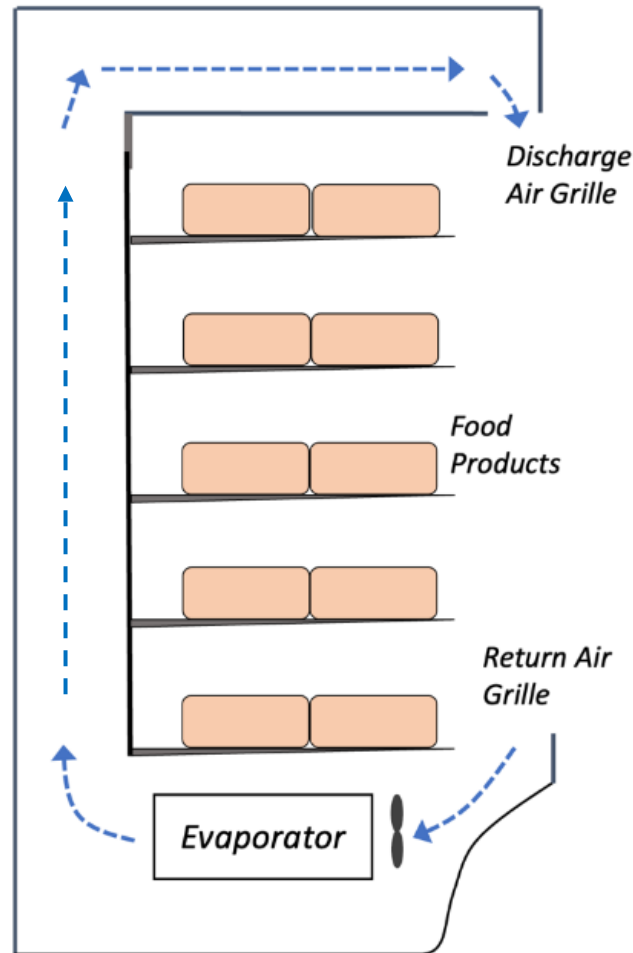




Design considerations for adding TES into a standalone refrigerated case

Which heat transfer fluid should interact with the TES?

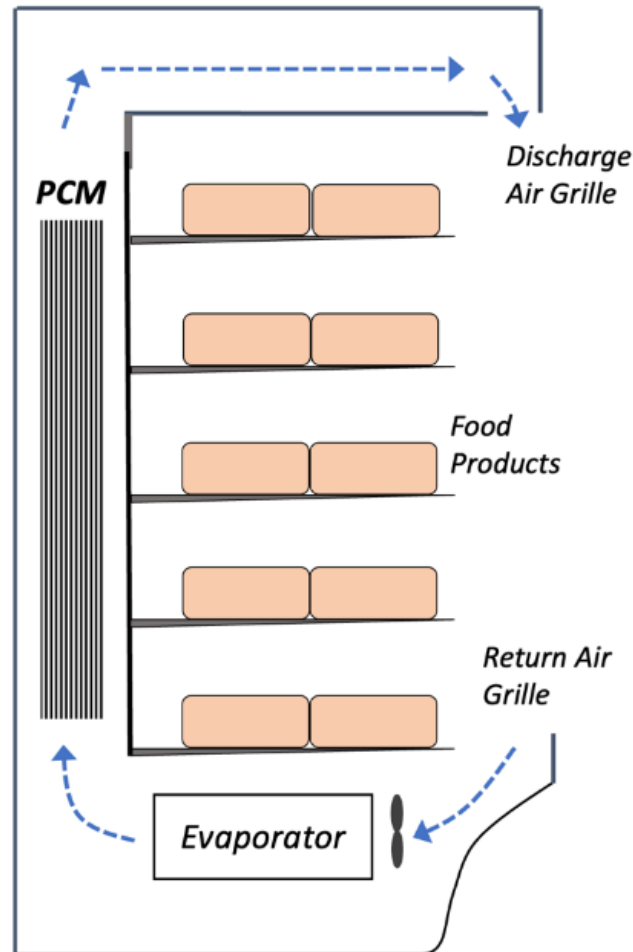
- **Refrigerants**
 - Great heat transfer fluid
 - Increased refrigerant charge / added refrigeration components
- **Secondary loop (glycol)**
 - Good heat transfer fluid
 - Added cost of pump, glycol, changes to other components
- **Air**
 - Poor heat transfer fluid
 - However, air is the fluid that is used by the application, and would require limited changes to the case design





Selected Approach

- PCM integrated directly into the airstream of a refrigerated case, using water (0 °C) as the PCM.
- Modes of operation:
 - Charging (evaporator $T < T_{t,PCM}$)
 - Discharging (evaporator OFF)
 - Cooling only (evaporator ON; bypass TES)
 - Defrost (evaporator OFF; TES provides cooling)



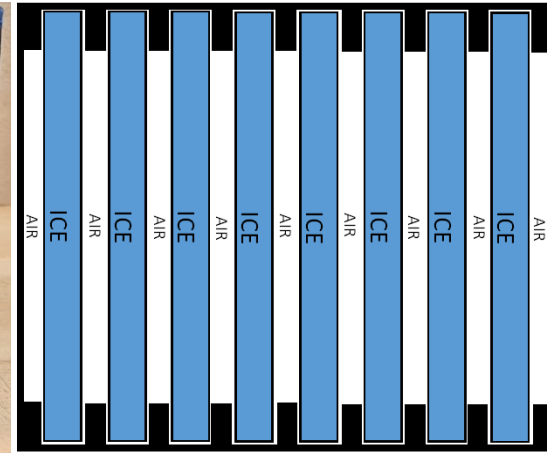


Progress: Bench-scale prototype

- Eight stainless steel ice packs
- 3-mm air channels
- 96 Wh storage module
- Operation:
 - 10 ft³/min (~1/50th scale)
 - Discharge air inlet T = 6 °C
 - Charge air inlet T = -5 °C



Single icepack module



8x1 heat exchanger configuration



Experimental setup for bench-scale prototype

Environmental control unit



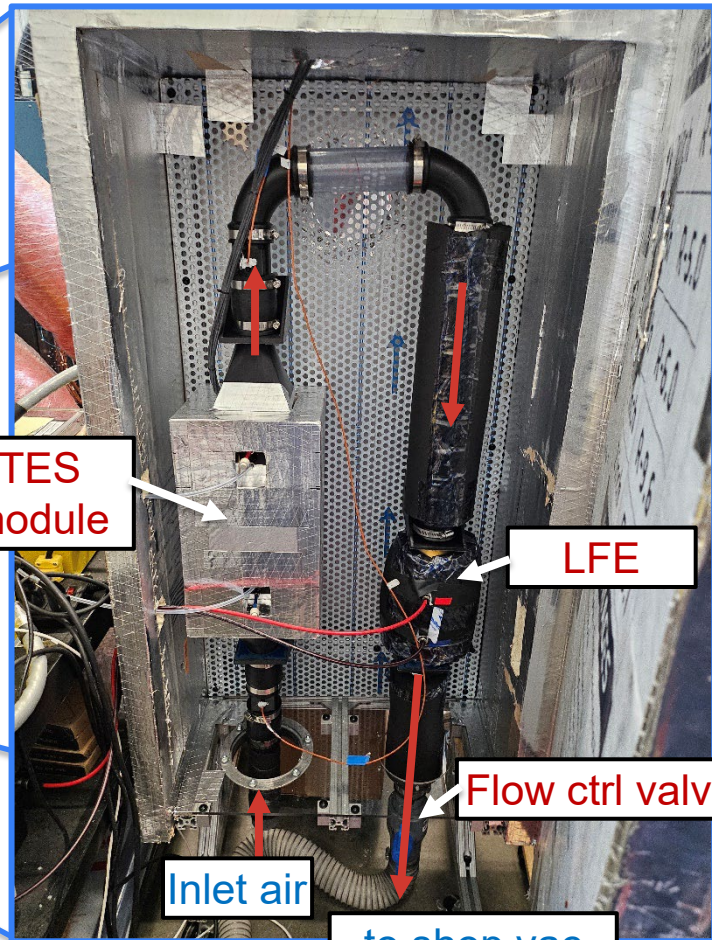
TES module

LFE

Flow ctrl valve

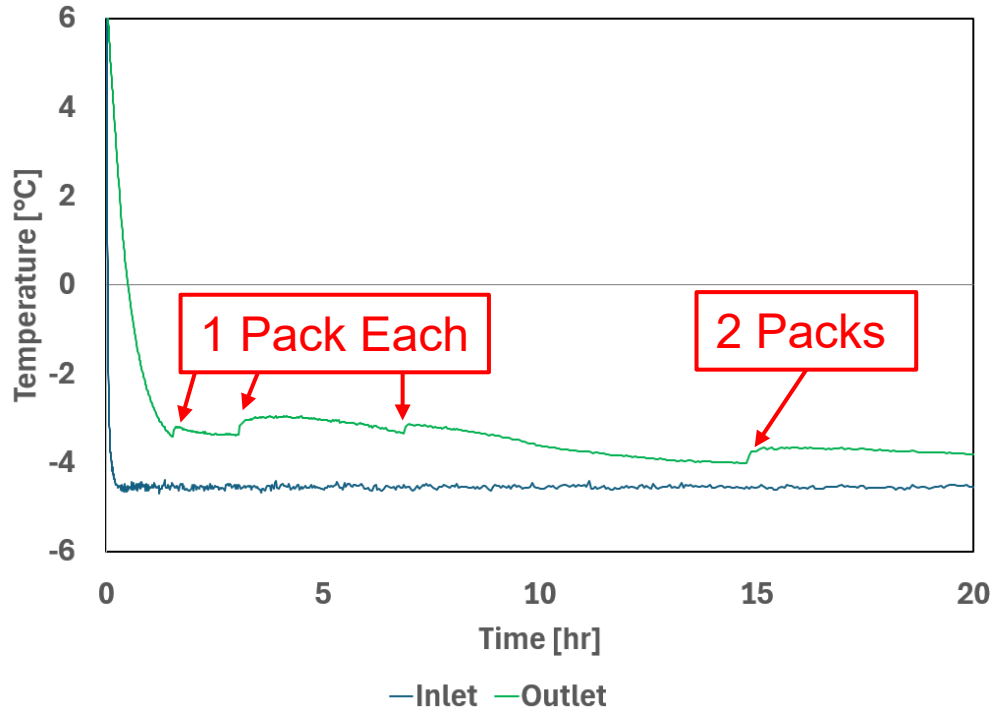
Inlet air

to shop vac





Experimental results: Charging

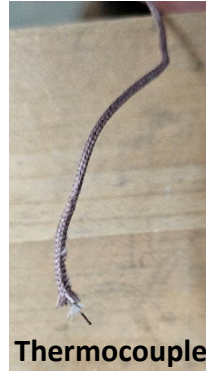
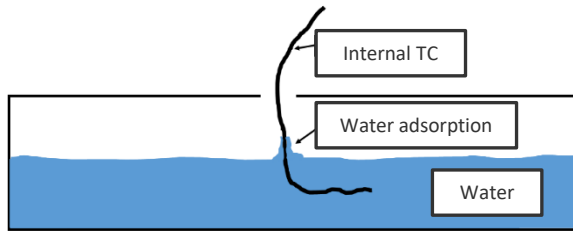
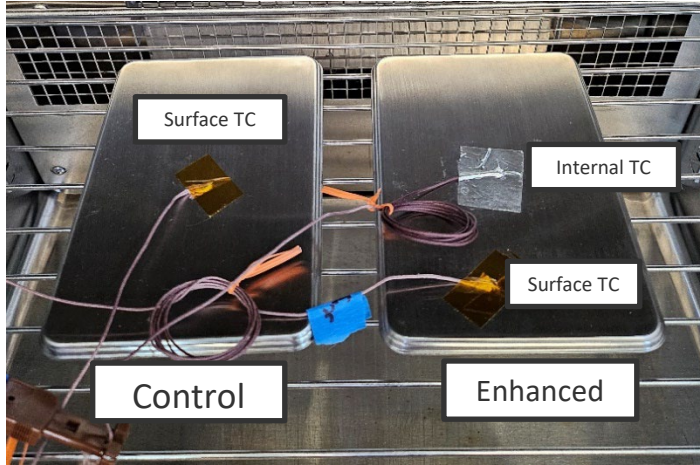


Nucleating ice in these water packs is a challenge

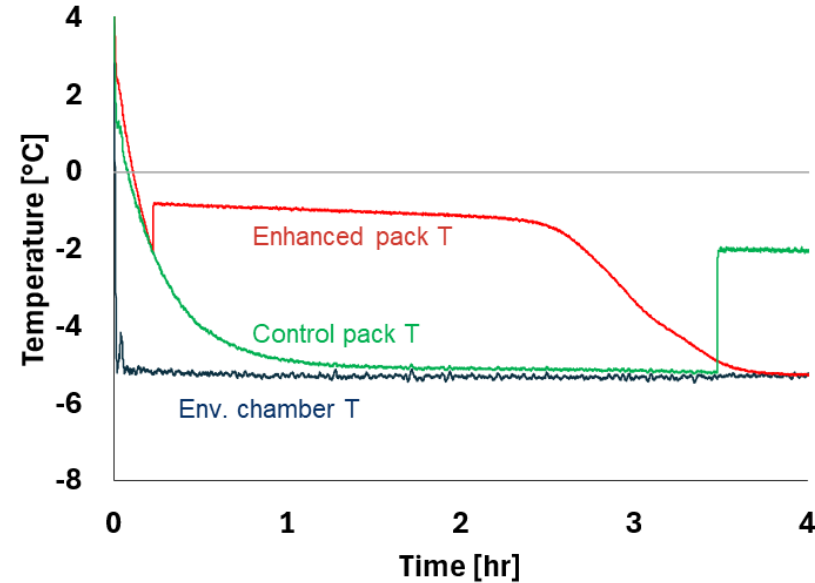
5/8 Packs nucleated over 20 hours



Experimental results: Charging



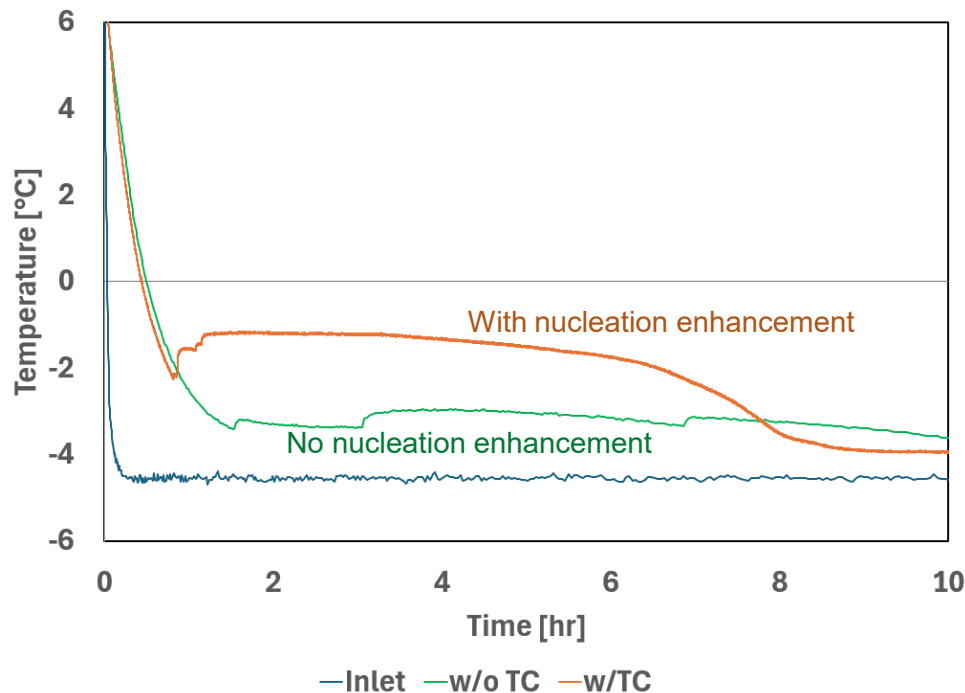
Thermocouple



Adding thermocouple with braided insulation shows improved nucleation



Experimental results: Charging

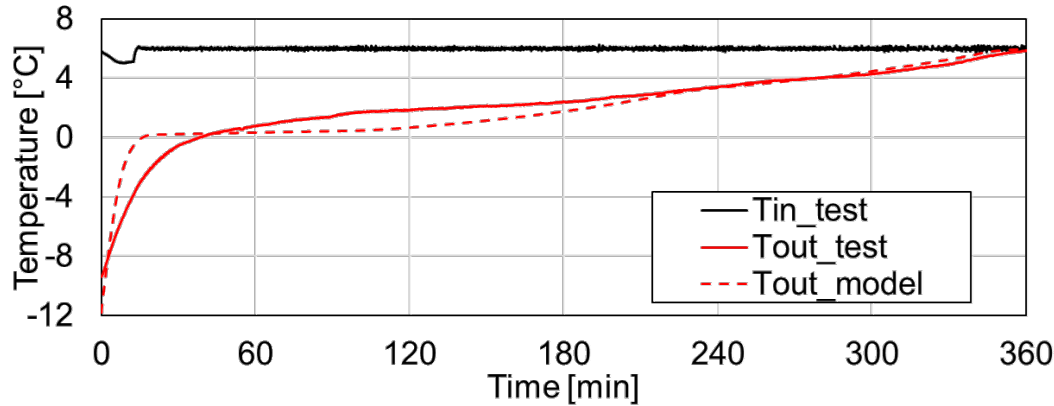


Nucleation strategy works in our bench-scale prototype

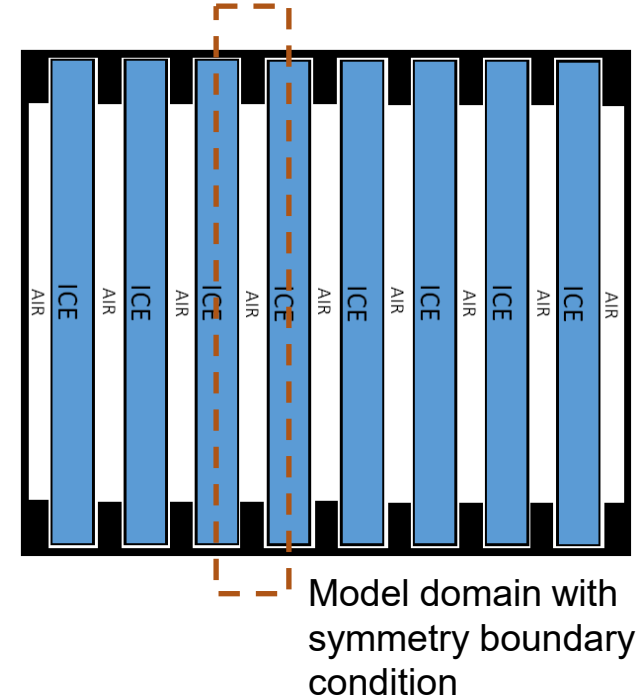
w/TC, all 8 Packs nucleated in less than 1.5 hours



Experimental results: Discharge

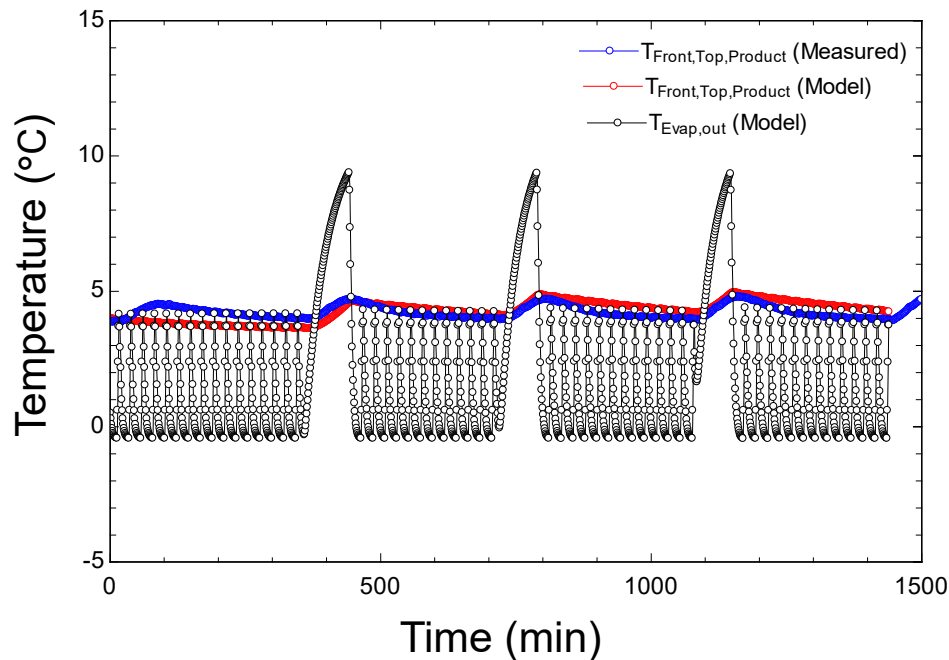


During discharge, TES enables ~3 hours of load shifting ($t_{end} @ T_{out} > 3^{\circ}\text{C}$)





Initial system-level estimates: Baseline



System Component	Modeled daily energy (kWh)	Measured daily energy use
Compressor	38.88 kWh	40.26 kWh
Evaporator Fan	1.2 kWh (63W)	1.2 kWh (49W)
Lighting	1.1 kWh (56W)	1.1 kWh (45.5W)
Total	41.18 kWh	42.56 kWh

This validated model of an open vertical display case will be updated to:

- Match specs of selected display case
- Add airside PCM heat exchanger



Future work

- Combine TES model with refrigerated case model
- Test full-scale prototype integrated with a refrigerated case

Preliminary specs for full-scale TES prototype:

Parameter	Units	Refr case	TES	% of refr case
Cooling capacity	btu/hr	3,000	3,000	100%
Storage duration	hours	-	8	-
Weight, filled	lb	1,172	170	15%
Volume	ft ³	173	4	3%

*Preliminary
results*



Thank you

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**2024 PROJECT
PEER REVIEW**

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

Reference Slides





Project Execution

	FY2024				FY2025				FY20ZZ			
Planned budget	\$325k				\$500k				\$100k			
Spent budget	\$400k				\$0k				\$0k			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1: Initial model for air-to-PCM HX	◆											
Q2: Investigate applications for air-to-PCM HXs; select two		◆										
Q3: PCM HX model complete; results for selected use case			◆									
Q4: Bench-scale experiments of selected use case				◆								
Current/Future Work												
Q1: Select refrigerated display case for design/experiments					◆							
Q2: 1.5 kWh prototype experiments						◆						
Q3: Scaled-up design and display case integration plan							◆					
Q4: Full-scale prototype testing; system model results								◆				
Q3: Field test in supermarket (planned)									◆			



Team



**Jason
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Sr. Research Engineer
PI



**Thomas
Freeman**

Post-doctoral Researcher
Lead: Thermal storage
experiments



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Sr. Research Engineer
Lead: Thermal storage
modeling