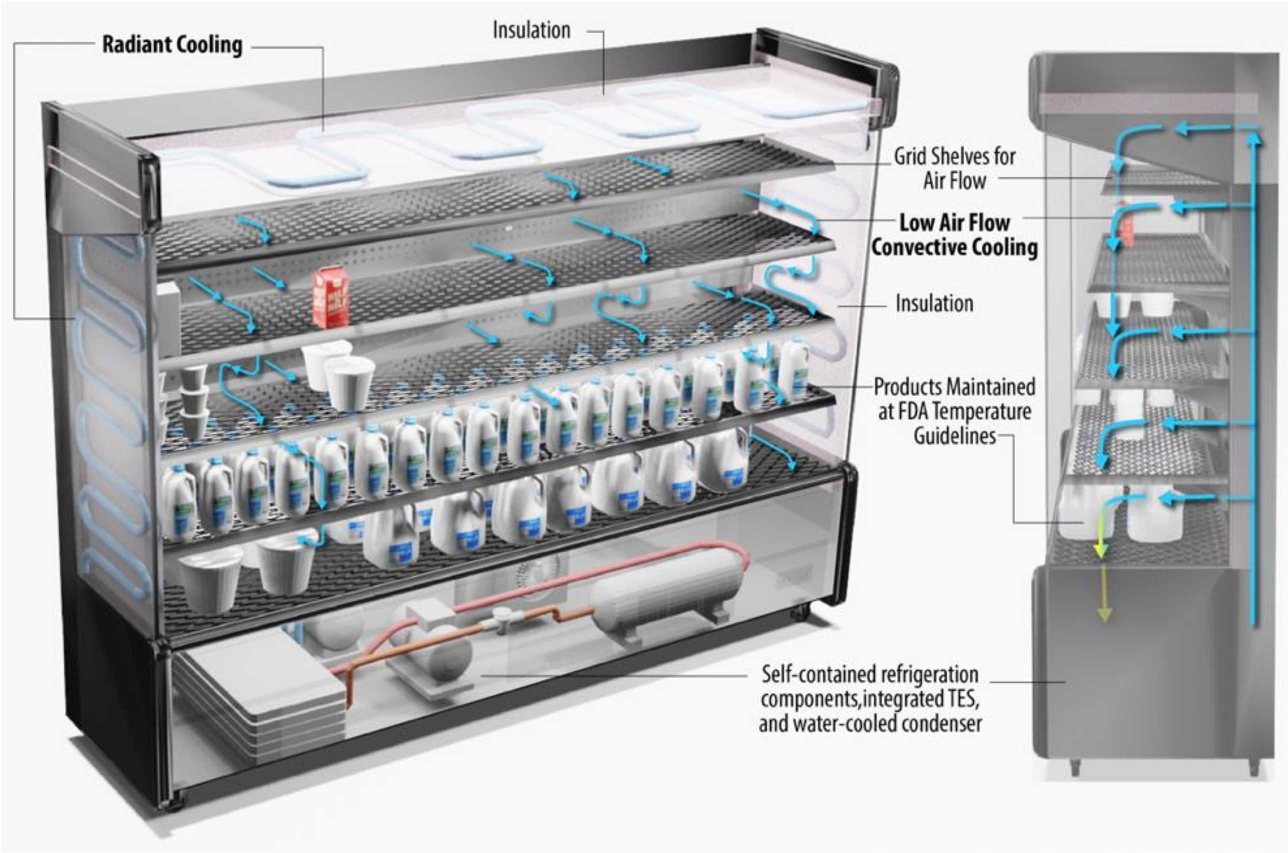
Grid Interactive Micro-Distributed Refrigerated Display Case



Emerson, National Renewable Energy Laboratory (NREL), NETenergy, Albertsons, ComEd

Dr. Juan Catano, Sustainability Innovation Lead

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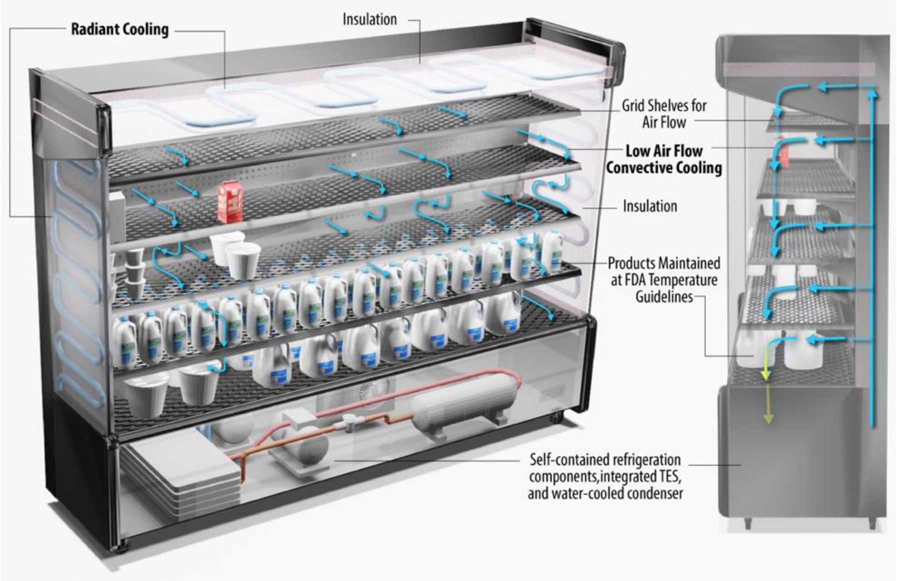
WBS # 3.2.2.127

Project Summary

Objective and Outcome

To design and experimentally test a next-generation self-contained, refrigerated open vertical display case (OVDC) that:

- Improves **energy efficiency**
- Provides **demand flexibility**
- Improves **human comfort**
- Uses **environmentally friendly refrigerants**



Team and Partners

- Emerson
- National Renewable Energy Laboratory (NREL)
- NETenergy
- Albertsons
- ComEd

Stats

Performance Period: 10/1/2021 – 9/30/2024

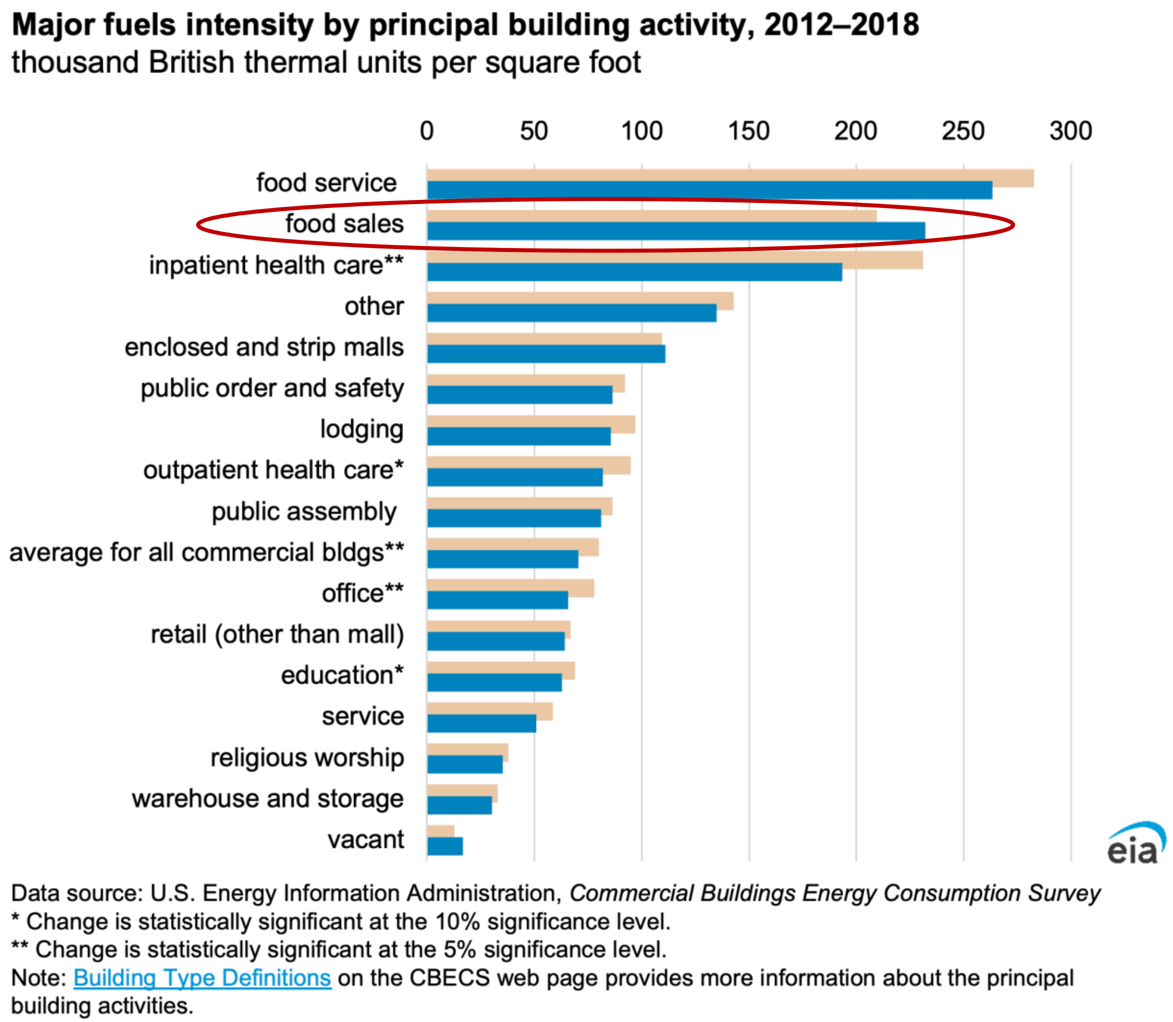
DOE Budget: $2,527k, **Cost Share:** $635k

Milestones:

1. Design
2. Model
3. Bench-scale experimentation
4. Proof-of-concept fabrication
5. Proof-of-concept performance assessment

Problem Statement: Supermarkets

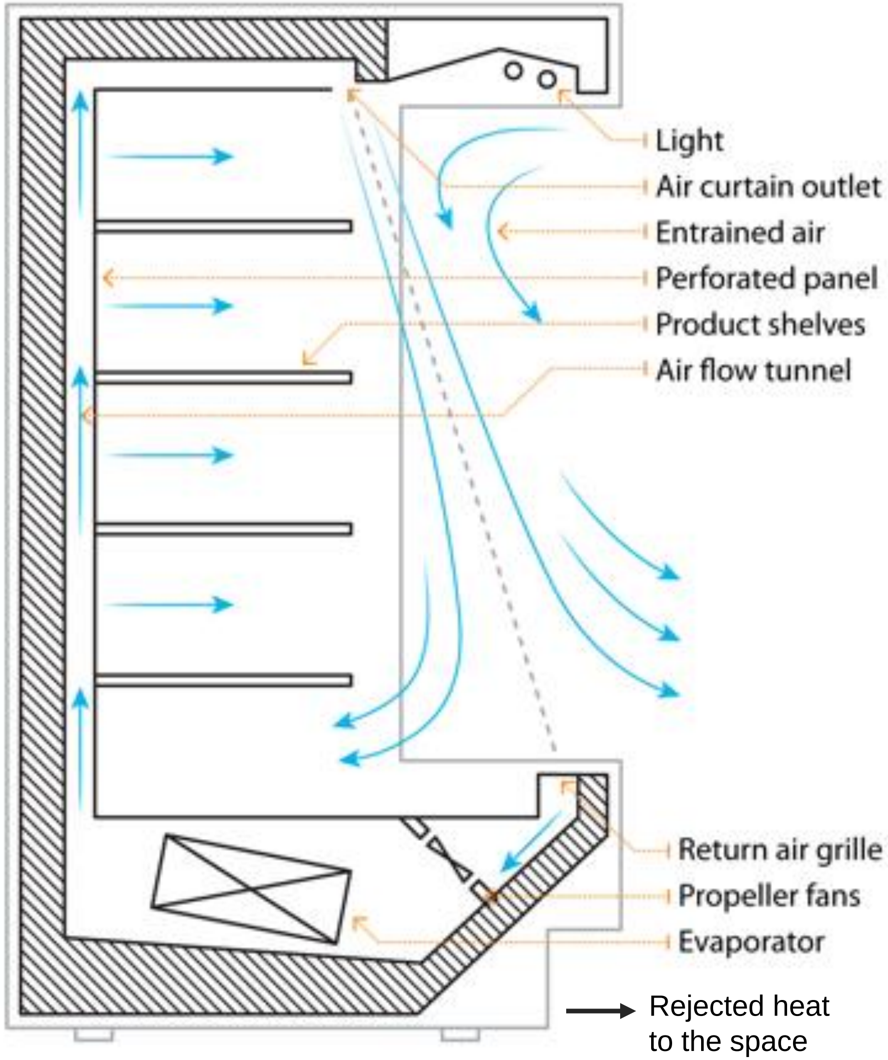
- **Supermarkets** have the **second highest EUIs** in commercial buildings:
  - **Refrigeration** accounts for roughly **50%** of their **electric energy**[1].
  - **OVDCs** comprise nearly **50% of total** case line-ups.



1 ASHRAE Handbook. Atlanta, Ga: American Society of Heating, Refrigerating and Air Conditioning Engineers

Problem Statement: OVDC

- **Forced convection** used to cool refrigerated products results in large mass exchange with the surrounded space:
  - Air infiltration accounts for ***80% of cooling load.***
  - The **spilled cold air** adversely **impacts human comfort.**
  - **Frost formation** on evaporator restricts air flow and **hampers heat transfer** → *degrades energy efficiency.*
  - Highly variable and **non-uniform product temperature** between shelves (up to 10°F).
- **Refrigeration heat** rejected into the sales floor **cannot be reclaimed** by heating systems.
- **Inability** to reliably **participate** in **demand response** (DR) events and load shaving/shifting strategies.



Current State of Technology

Project Goal

- ***Design, fabricate and validate a next-generation self-contained, refrigerated open vertical display case that integrates energy efficiency, demand flexibility, environmentally friendly refrigerant, and improves human comfort.***

  – *The successful completion of this project will:*

    - *Accelerate the deployment of a cost-effective distributed energy resource technology.*
    - *Reduce greenhouse gas emissions.*
    - *Enhance the electric grid integrity.*

Potential Nation-wide Impacts - *(approximate estimates)*

- Annual electric energy and natural gas savings of 9.72 TWh (25% of national refrigeration energy consumption) and 320 million therms.
- Permanent electric peak demand reduction of 1.54 GW.
- DR and load shaving/shifting to enhance grid integrity (3.5 h, 3.4GWh load curtailment).

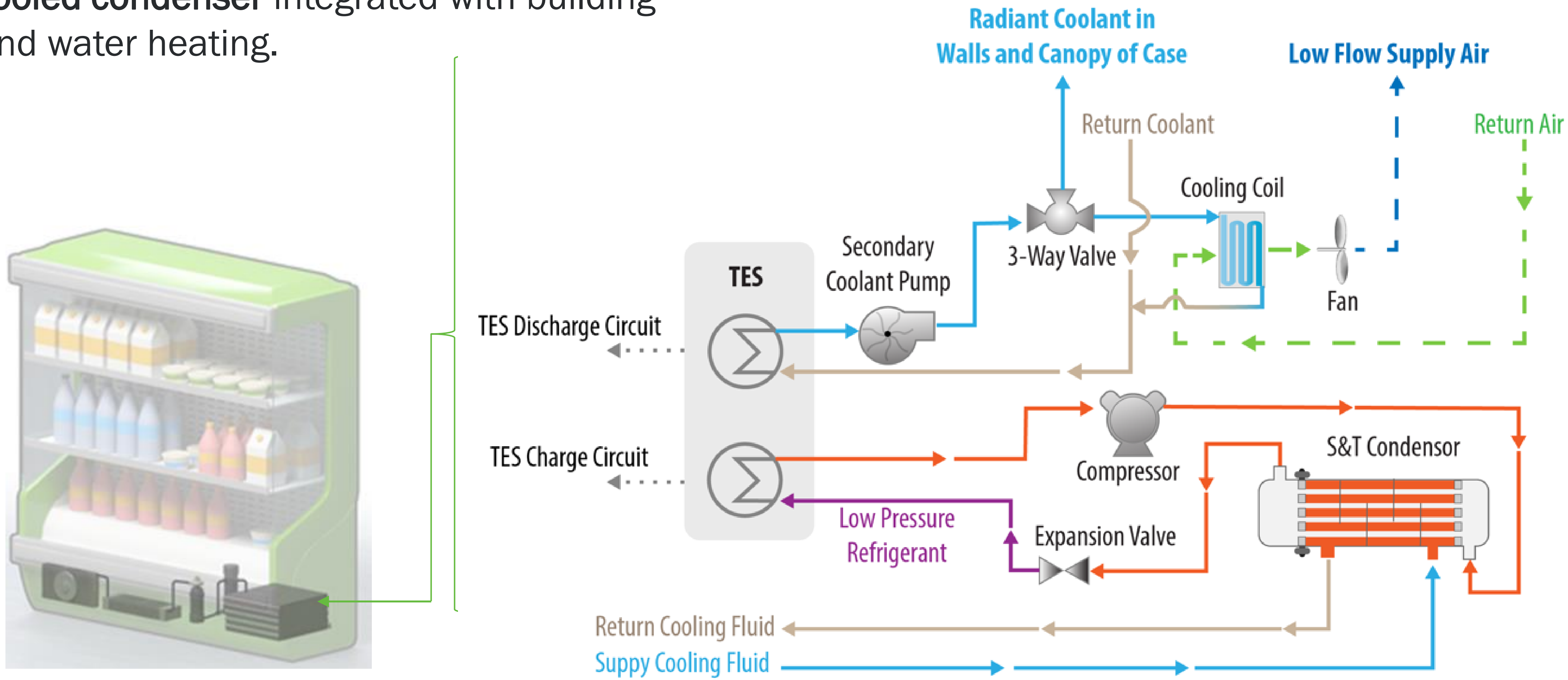
Strategic Partnerships for Technology Deployment Success

- **Through strategic partnerships with key industry actors, this project intends to remove adoption hurdles.**

- **Strategic deployment partners:**
  - ComEd: Through incentive programs, will offset the incremental cost for consumers.
  - Albtersons: field-demonstration of the technology in an actual site will bolster end-user's confidence in benefits of the technology.

Proposed Solution: Novel Features

1. **Hybrid** radiant and convective **cooling**.
2. **Thermal** energy **storage** (TES).
3. **Water cooled condenser** integrated with building space and water heating.



Technology Improvements Over State of the Art

***Energy Efficiency:** 30% Improvement.*

- by **reducing infiltration** loads and frost formation **with radiant cooling** and minimizing forced convection
- by **integrating water-cooled condenser** with the building's heating systems to reduce temperature lift

***Demand Flexibility:** 80% peak kW reduction over 3 h.*

- by adding **TES**

***Affordability:** 3-year payback period.*

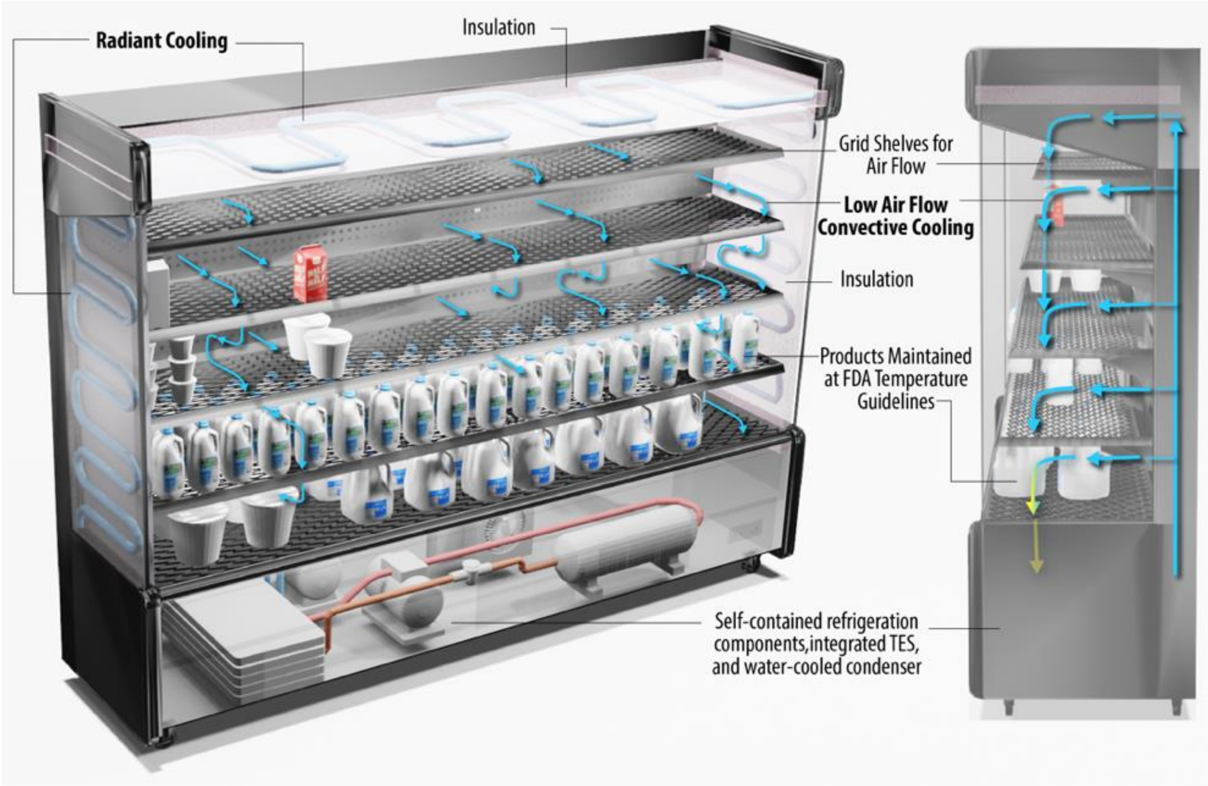
- by **reducing operational costs** w. energy savings and DR

***Environmental Friendliness:** Propane (R-290) refr.*

- by **reducing refrigerant charge**

***Occupant Comfort:** 50% lower infiltration.*

- by **reducing** cold **air spillage** in shopping aisles



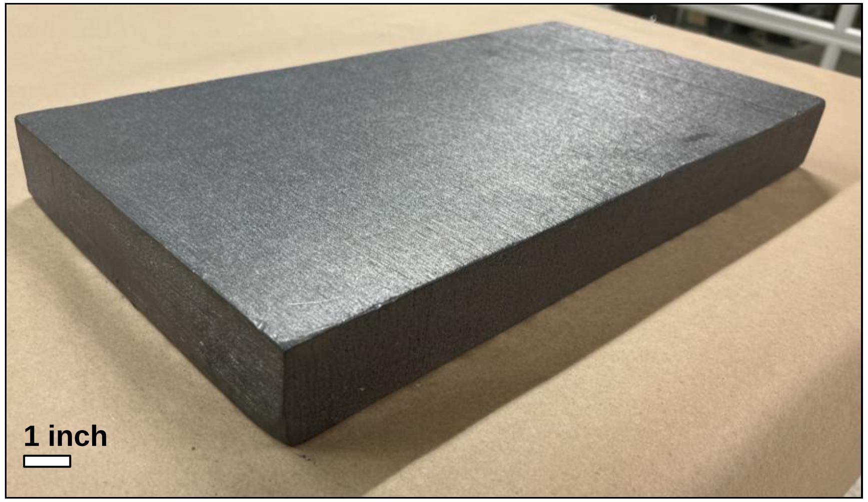
Hybrid Cooled OVDC With an Integrated TES

Thermal Energy Storage

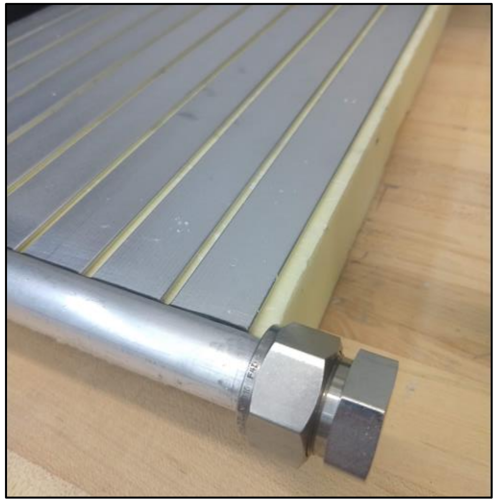
- TES consists of a **PCM composite** of 10% graphite and 90% PCM.
- The PCM composite is integrated with aluminum microchannels to form a **PCM heat exchanger** with both refrigerant and glycol circuits.
- The PCM heat exchanger was designed using a finite difference model to achieve **3-hour load shifting.**

Comparison of PCM to ice

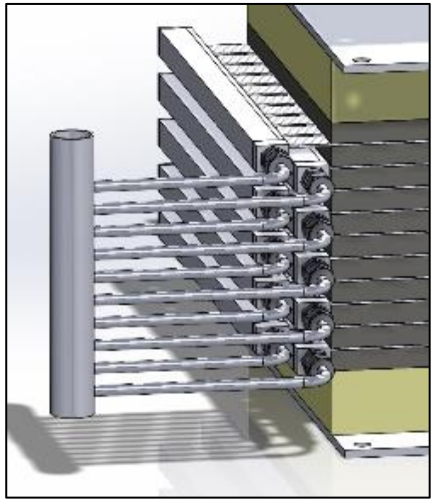
Property	Composite PCM	Ice/water
Transition Temp. [°C]	**-11**	**0**
Energy density [kWh/m^3]	60	85
Thermal Conductivity [W/m-K]	**8**	**0.6**
Form in liquid state	Shape-stable	Flows



Graphite/PCM composite



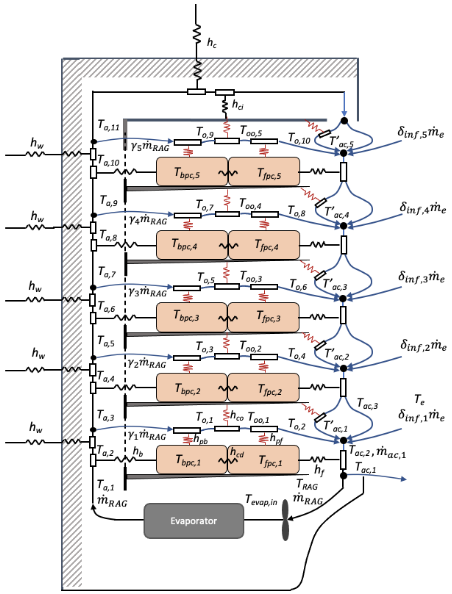
Aluminum microchannels



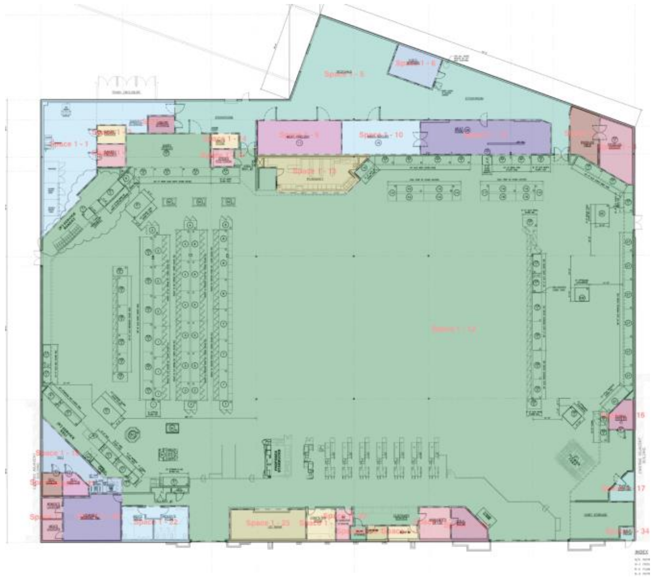
Composite PCM heat exchanger

Modeling Approach based on Experimental Data

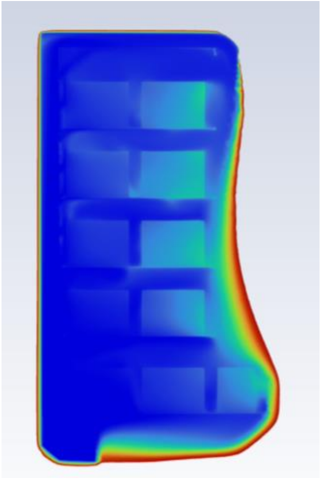
1. Thermo-fluid heat extraction modeling of the OVDC
   - Validation using 3-D CFD modeling
2. Refrigeration system modeling
3. Thermal energy storage system modeling
4. Integrated system model
5. Whole-building EnergyPlus® simulation based on an actual Albertsons store



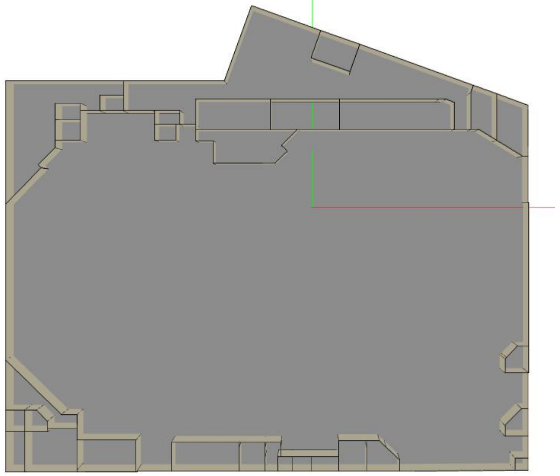
Resistive Network



Actual Albertsons Store

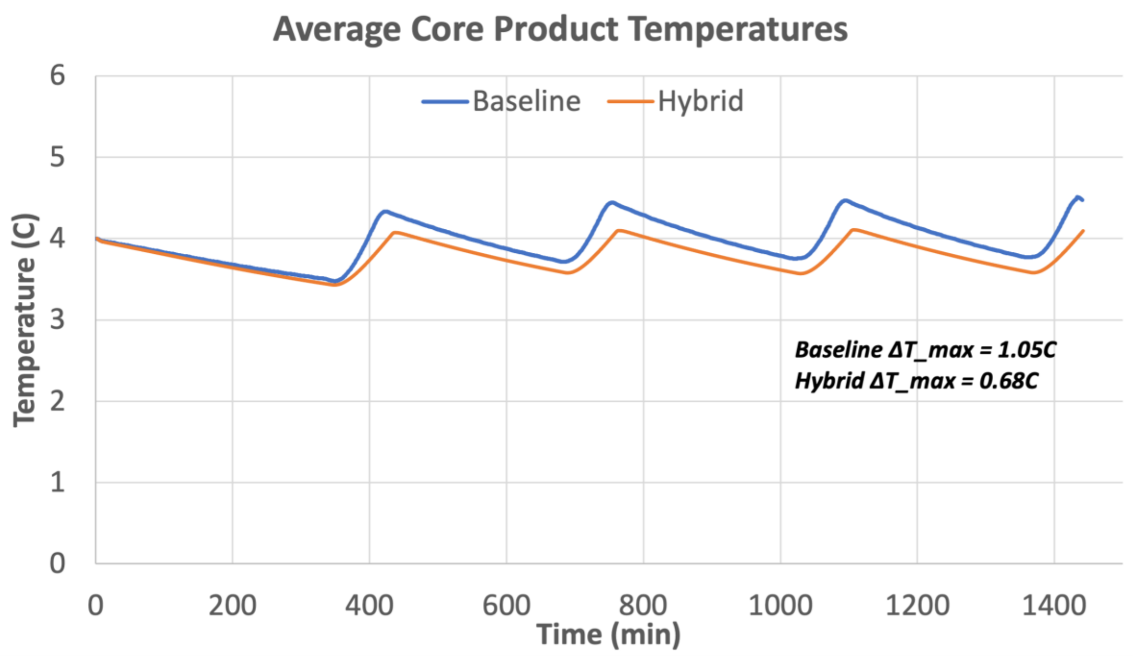


CFD

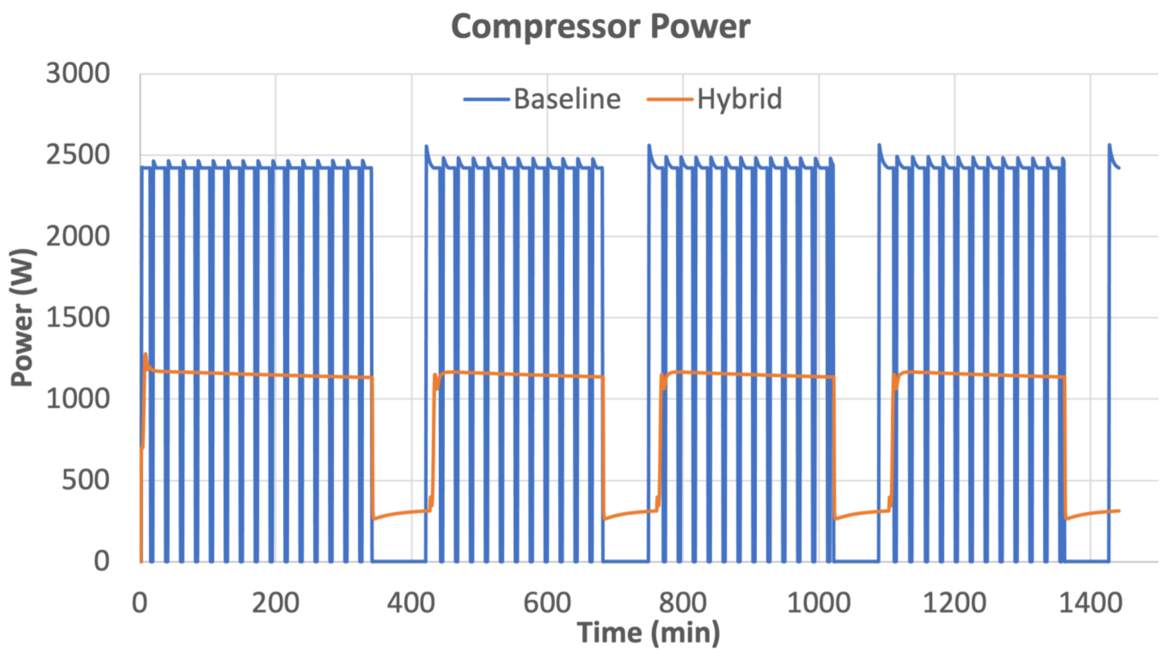


EnergyPlus Building Model

Modeling Results



Product temperature variability improved over baseline.



System Component	Baseline	Hybrid
Compressor	38.88 kWh	22.76 kWh
Evaporator Fan	1.2 kWh (49W)	0.3 kWh
Total Consumption	**41.18 kWh**	**24.16 kWh**

41% Total Energy Reduction over 24 h.

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Project Status and Next Steps

- **Major Completed Milestones**
  - Integrated **system modeling** demonstrates **+30%** permanent **energy savings** over the current state-of-art technology.
  - **Validated** performance of a **bench-scale PCM HX** prototype.
  - **Identified** a suitable **hydrophobic coating** material to mitigate condensation.

- **Next Steps**
  - Bench-scale thermal performance experiment.
  - Fabricate and experimentally characterize performance of full-scale proof-of-concept.

Potential Technical Challenge and Mitigation Strategy

- **Challenge:**
  - Radiant cooling could potentially cause condensation on the interior display case walls.

- **Mitigation Strategy:**
  - Explore the use of hydrophobic coatings to prevent condensation build up and management.

Major Accomplishments

USPTO patent application was published on September 22, 2022. Publication No. US 2022/0299242 A1

US 20220299242A1

(19) **United States**

(12) **Patent Application Publication**

FARAMARZI et al.

(10) **Pub. No.: US 2022/0299242 A1**

(43) **Pub. Date: Sep. 22, 2022**

(54) **GRID INTERACTIVE MICRO-DISTRIBUTED REFRIGERATED DISPLAY CASE**

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(21) Appl. No.: **17/697,126**

(22) Filed: **Mar. 17, 2022**

Related U.S. Application Data

(60) Provisional application No. 63/162,074, filed on Mar. 17, 2021.

Publication Classification

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A47F 3/04 (2006.01)
F25B 1/00 (2006.01)

(52) **U.S. Cl.**

CPC ***F25B 23/003*** (2013.01); ***A47F 3/0443*** (2013.01); ***F25B 1/00*** (2013.01); *F25B 2400/24* (2013.01)

(57) **ABSTRACT**

The present disclosure relates to an improved open vertical display case (OVDC) which utilizes radiant cooling to cool and/or maintain food products at a target temperature. The radiant cooling is performed using a plurality of piping routed through the walls and containing a first refrigerant stream. The plurality of piping may be cooled using a refrigeration circuit. In some embodiments, a phase change material may be used for thermal energy storage and positioned between the plurality of piping and the refrigeration circuit. In some embodiments, the refrigeration circuit may be connected to heating ventilation and air conditioning (HVAC) systems and water heating systems within the building.

Future Work

- Field demo at Albertsons site.
- Identify and partner with a display case OEM.
- Work with ComEd to include the technology in their incentive portfolio.

Thank You

Emerson, National Renewable Energy Laboratory (NREL), NETenergy, Albersons, ComEd

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REFERENCE SLIDES

Project Execution

Required to complete, but does not count towards total slide count and doesn't need to be focused on during presentation

	FY2022				FY2023				FY2024			
Planned budget	$994k				$1,307k				862k			
Spent budget	$972k											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Task 2 Collect data on commercial refrigeration		▲										
Task 3.1c Hybrid radiative and convective cooling			▲									
Task 3.1f Total case performance over 24 hrs						▲						
Task 4.1a Model and design PCM HXs			▲									
Task 4.2.b Characterize PCM material					▲							
Task 4.3.b Characterize PCM HX prototype (bench-scale)						▲						
Current/Future Work												
Task 5.1.b Optimize case design and TES controls for efficiency							▲					
Task 5.1.c Develop cost estimate based on optimized design							▲					
Task 4.3.d Characterize PCM HX prototype (full-scale)								▲				
Task 6.4 Characterize hybrid system heat extraction (bench-scale)								▲				
Task 6.8 Characterize hybrid system heat extraction (full-scale)									▲			
Task 7 Display Case System Integration										▲		
Task 8.1 Characterize hybrid refrigerated case											▲	
Task 9 Information Dissemination												▲

- Go/no-go decision points
- Explanation for slipped milestones and slips in schedule

EERE/BTO goals

(Not a template slide – for informational purposes only)

The nation's ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

EERE/BTO's vision for a net-zero U.S. building sector by 2050

Modeling Approach

24hr Period Experiment of Baseline Display Case

***Experimental performance evaluation** of baseline technology in NREL's environment-controlled thermal testing chambers*

→ To validate baseline and hybrid** system-level and component-level **models

Baseline and Hybrid System Model Development

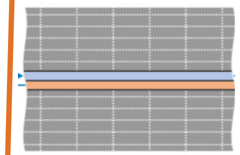
Separate Models of Major Components

Refrigeration Cycle

TES

Display Case Heat Extraction

Detailed TES & Refrigeration Cycle Model



***Independent modeling approaches** to build confidence in predictions*

Component-Based Framework

Finite Difference Model

3D, Steady State, CFD

2D, Transient, Resistive Network

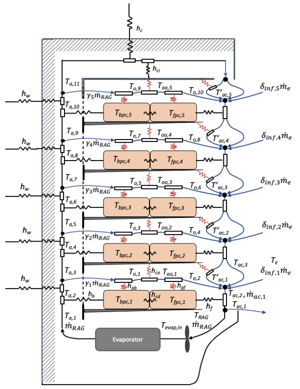
Surrogate model for ease of integration

Validated Neural-Network Surrogate Models

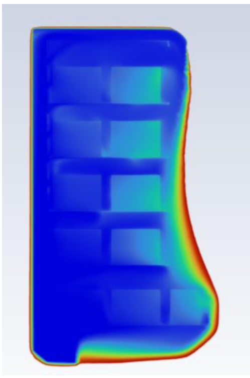
Validated Transient Resistive Network Model

Validated models to predict performance

Integrated, Transient, and Validated Baseline and Hybrid System Model



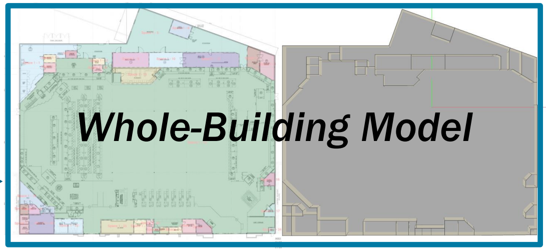
Resistive Network



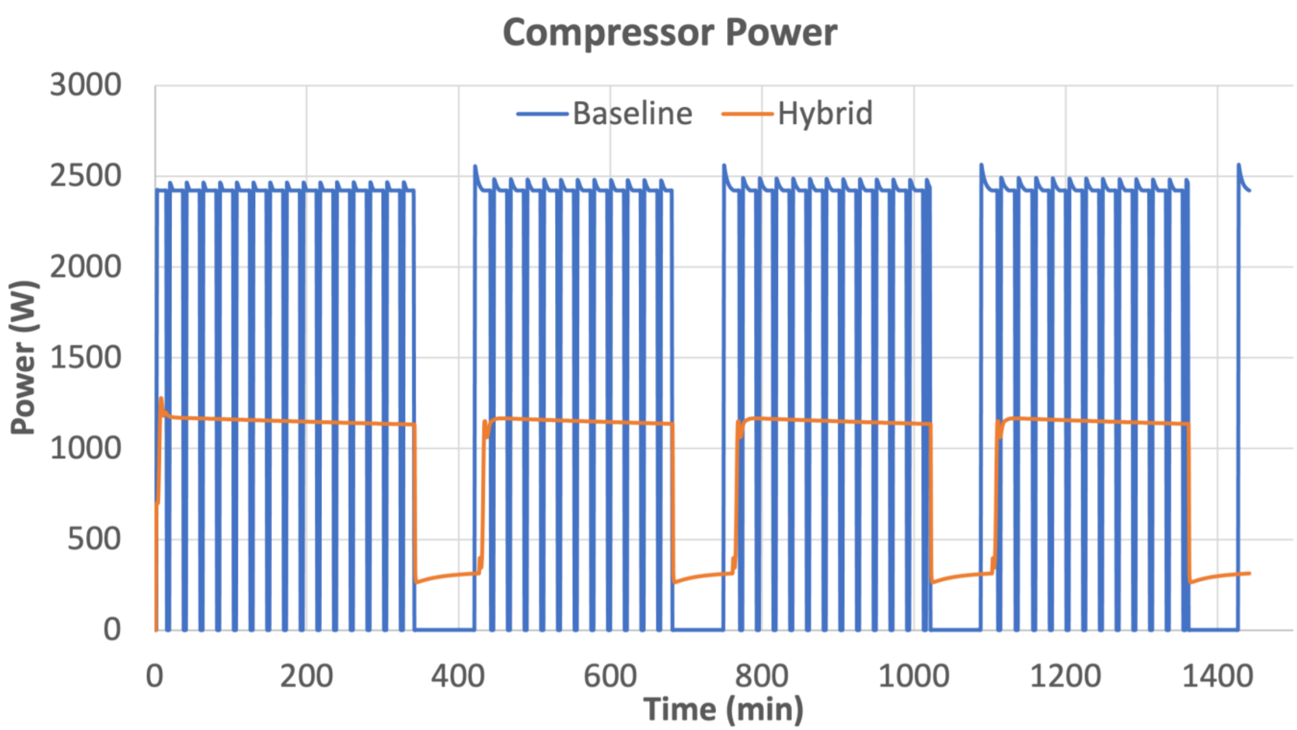
CFD

*Modified E+ DOE prototype to reflect **typical Albertsons store** specifications*

→ Assess** 8,760 hr **whole-building performance



Modeled Load, Power, and Energy Consumption over 24 h



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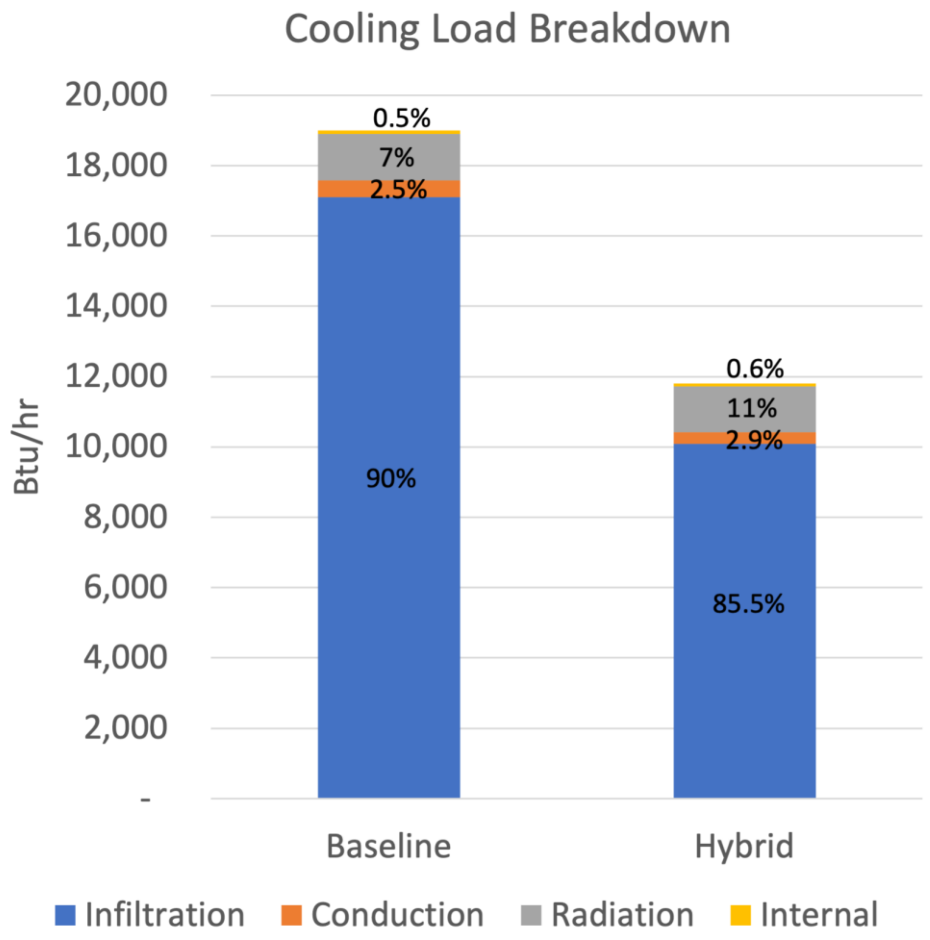

41% Total Energy Reduction over 24hrs