NREL
Transforming ENERGY

From Chills to Thrills: Revolutionizing Energy Efficiency and Load Flexibility in Supermarket Refrigeration

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Project Overview

- **Objective and Outcome**
- Develop a next-generation self-contained, refrigerated open vertical display case (OVDC) that leverages radiation and thermal energy storage (TES) to:
  - Improve **energy efficiency**
  - Provide **demand flexibility**
  - Improve **human comfort**
  - Improve **environmentally friendliness of refrigeration system**

Team and Partners

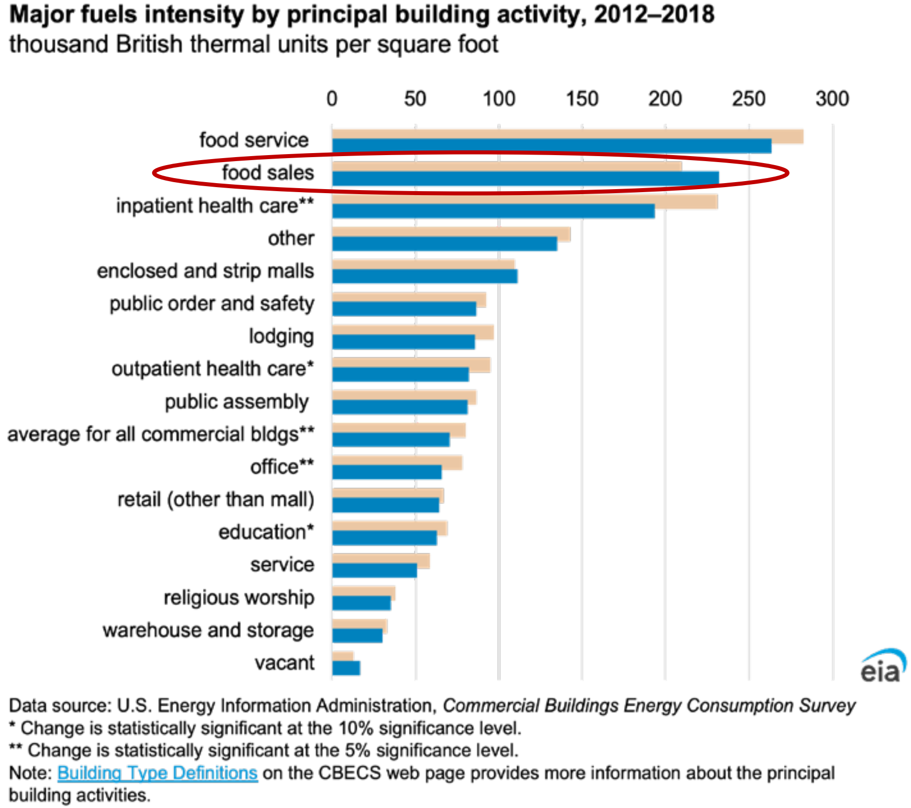
- Emerson/Copeland
- National Renewable Energy Laboratory (NREL)
- NETenergy
- Albertsons
- ComEd

Goal of the Presentation

- Overview of the problem statement
- Discuss the proposed innovation
- Overview of modeling approach and bench-scale experimentation
- Discuss results of the bench scale experiment to validate effectiveness of the proposed cooling system

Problem Statement: Supermarkets

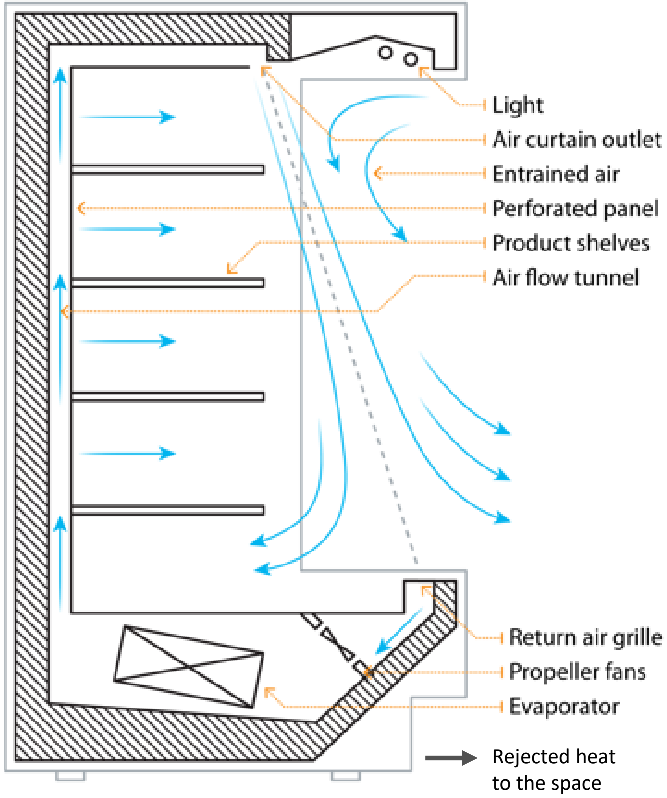
- **Supermarkets** have the **second highest EUIs** in the commercial buildings sector:
  - **Refrigeration** accounts for roughly **50%** of their **electric energy.**[1]
  - **OVDCs** comprise nearly **50% of total** case line-ups.



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.



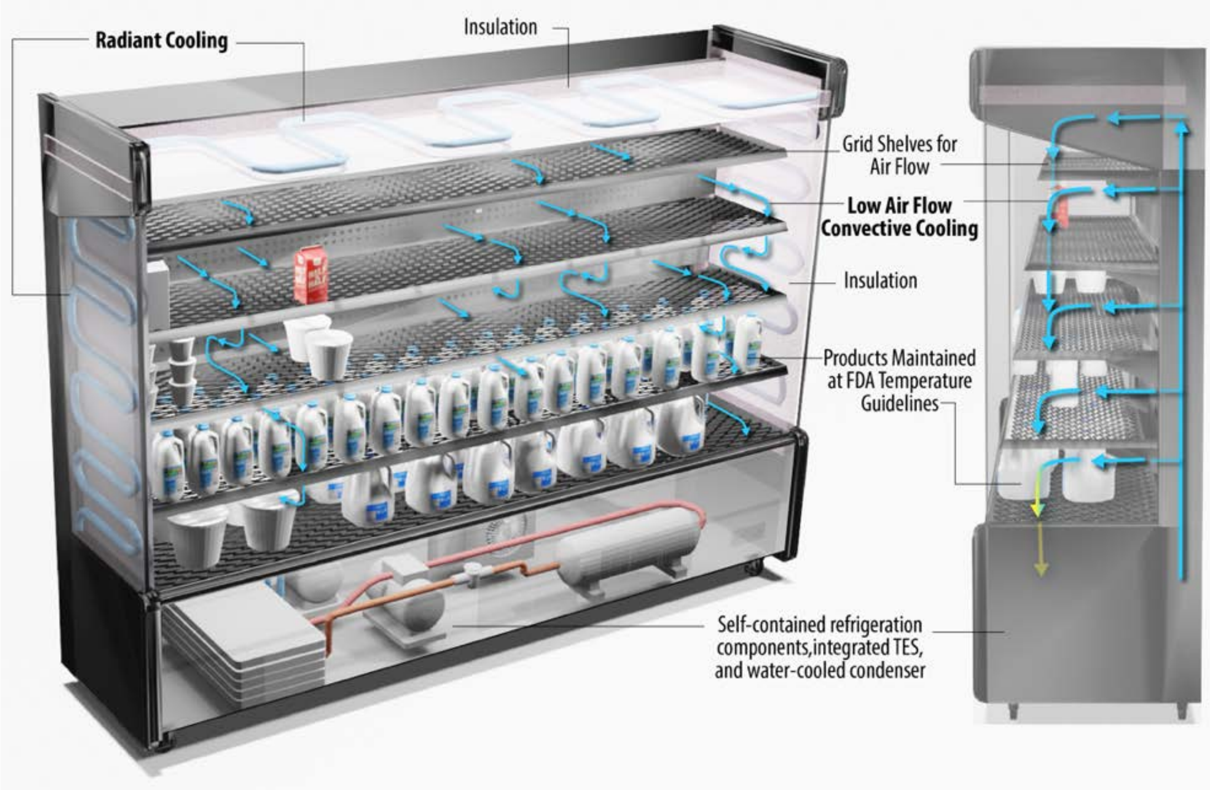
Current State of Technology

Proposed Technology

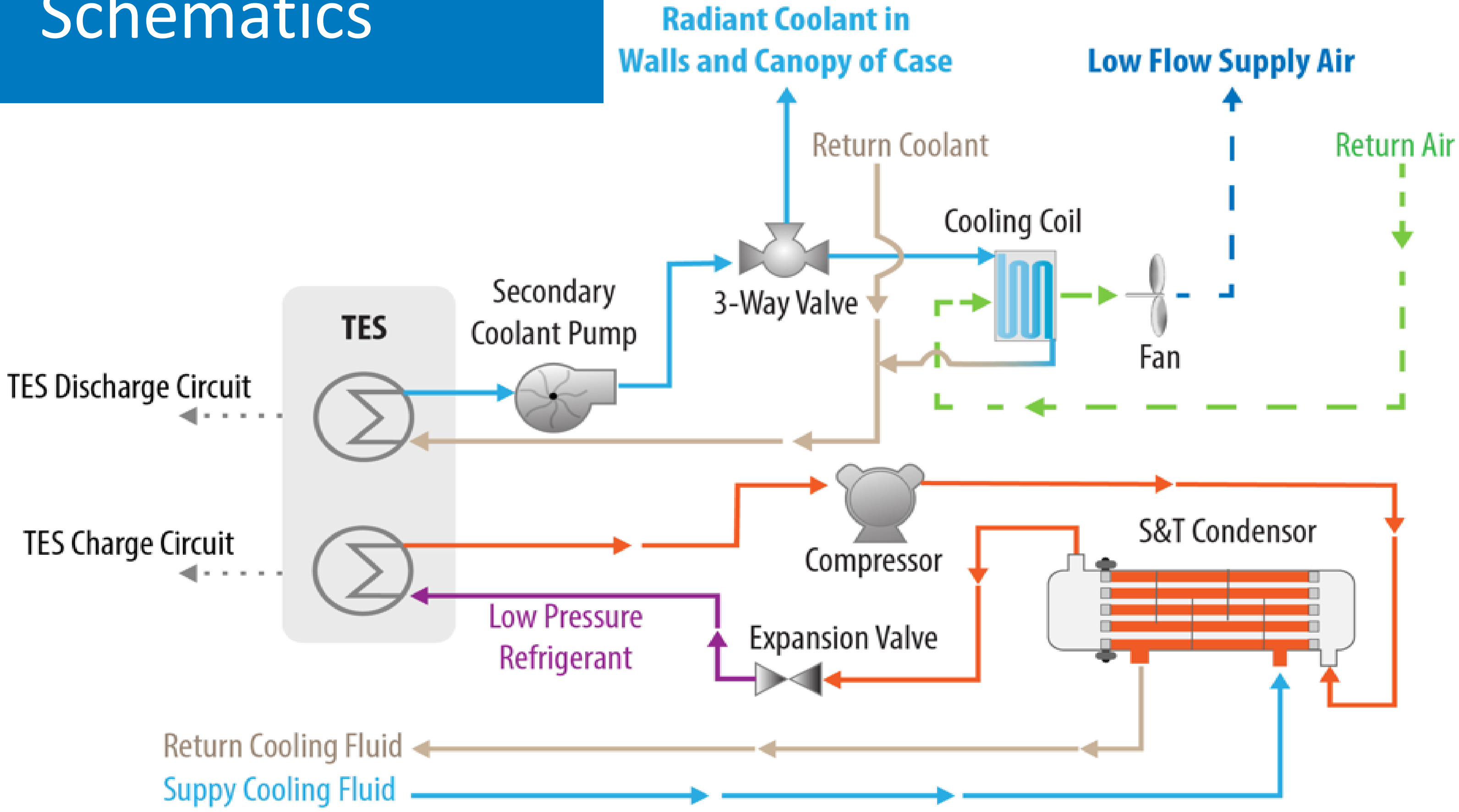
Novel Features:

1. Complete removal of air curtain system
2. Hybrid radiant and convective cooling using R290.
3. Thermal energy storage (TES).
4. Water cooled integrated with building space and water heating.

Hybrid Cooled OVDC With an Integrated TES



Proposed Technology Schematics



Proposed Technology: R&D Targets

Energy Efficiency: *30% Improvement.*

- by **reducing infiltration** load, frost formation, defrost cycles, and post-defrost pull-down loads **with radiant cooling** and minimizing forced convection by air curtain removal.
- by **integrating water-cooled condenser** with the building's heating systems to reduce temperature lift and recover waste heat.

Demand Flexibility: *80% peak kW reduction of display case over 2 hours.*

- by adding **TES**

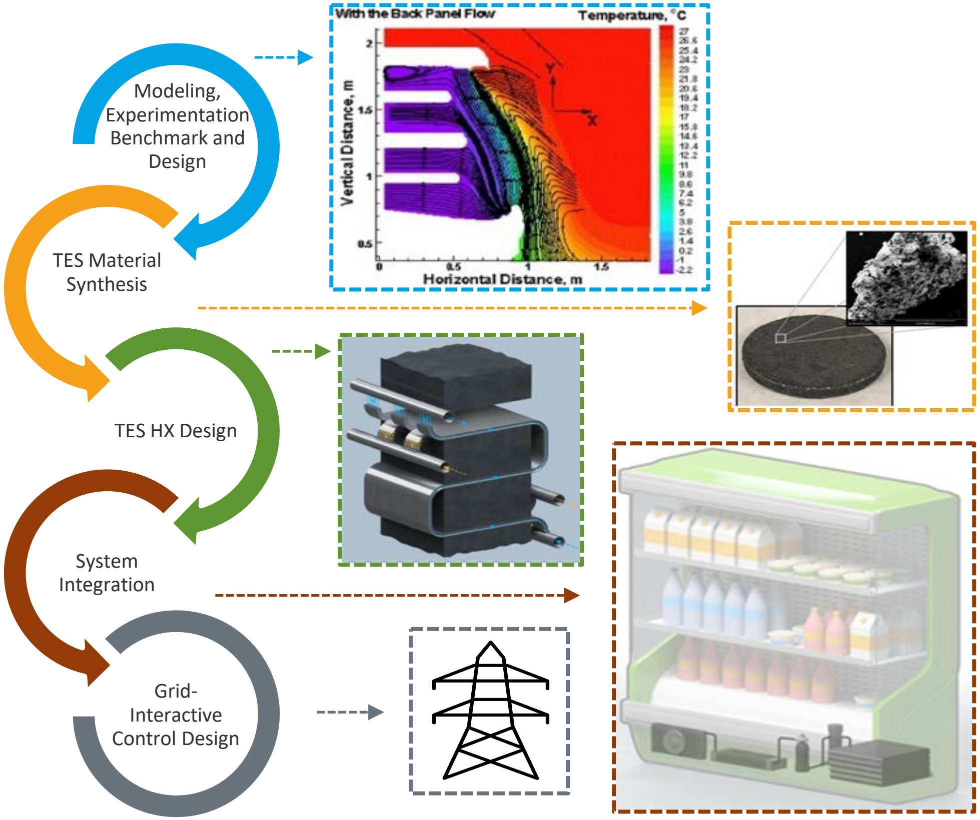
Affordability: *3-year payback period.*

- by **reducing operational costs** with energy savings and DR programs.

Occupant Comfort: *50% lower infiltration.*

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

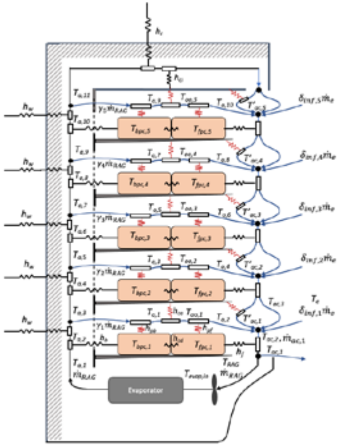
Integrated Research Approach



Modeling Methodology

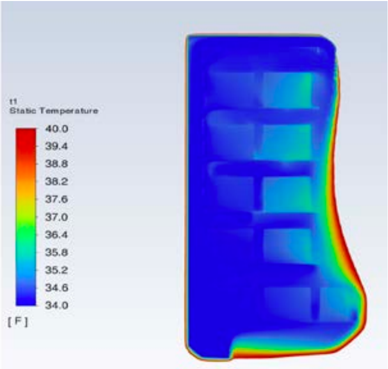
Modeling Approach based on **Experimental Data**

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



Resistive Network


Actual Albertsons Store



CFD


EnergyPlus Building Model

Experimentation Methodology

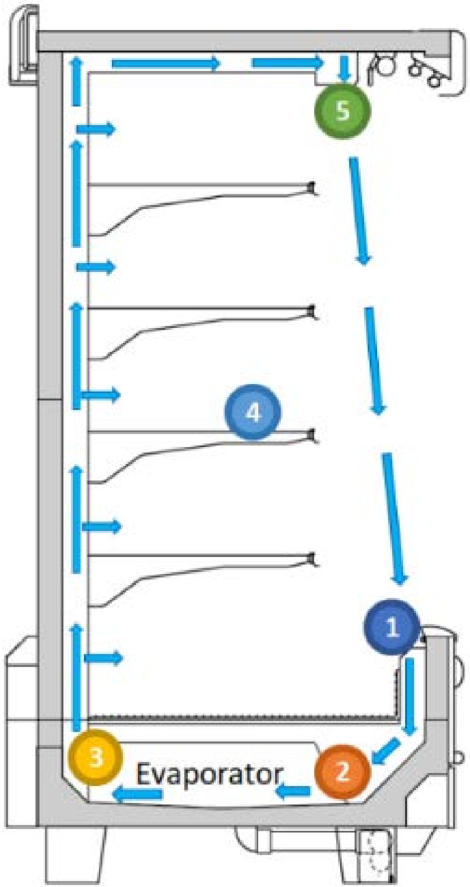
Baseline Fixture

Bench Scale Fixture (Modified Baseline unit)

Baseline Experimentation

- Laboratory characterization of a typical 8-ft long, 5-deck, self-contained OVDC with a water-cooled condenser to calibrate the thermo-fluid model
  - ASHRAE 72 / AHRI 1200

- **117** channels of data collected every 1s over 24 hrs monitoring:
  - Temperatures: Air, refrigerant, water, product
  - Pressure: Refrigerant Suction & Discharge, Condenser water
  - Power: Total case and components
  - Mass Flow: Condenser water
  - Condensate Mass measured to calculate latent load



Baseline System

Baseline Display Case Cabinet:
8ft, 5-deck 13 ft3 gross volume

Electronic Expansion Valve

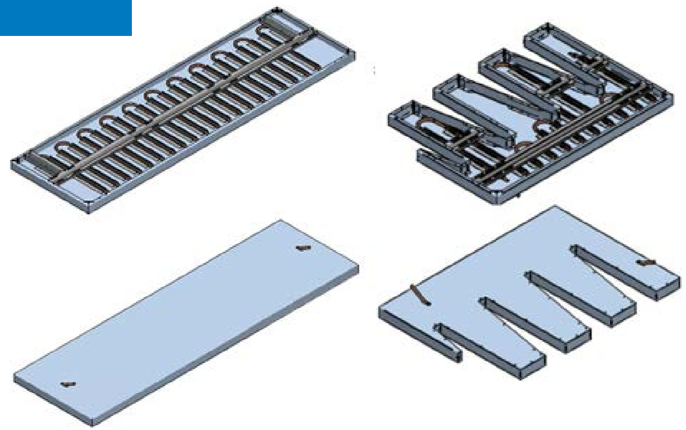
Advanced Controls

Liquid-cooled Condensing Unit with Variable Speed Compressor

The Baseline refrigerated case is equipped with:

- water-cooled condensing unit
- advanced controls
- variable speed compressor
- electronic expansion valve

Bench Scale Hybrid Refrigerated Case

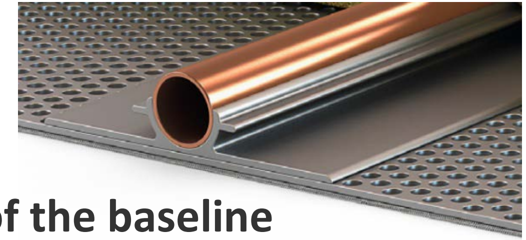


Baseline case was modified with:

1. **Complete elimination of the air curtain**
2. **Custom-fit radiant panels,**
3. **Variable-speed evaporator fan motors/controller**
4. **Back panel with modified perforations**

Four Custom-Design Panels:

- bottom deck of the case (over the evaporator),
- two on the left and right wall around the shelves, and
- one on the canopy of the case.



***perforated and replaced the DAG and enclosed canopy vent of the baseline**

Each radiant panel contains a copper coil seated in a conductive trough to transfer heat from the low-emissivity panel surface

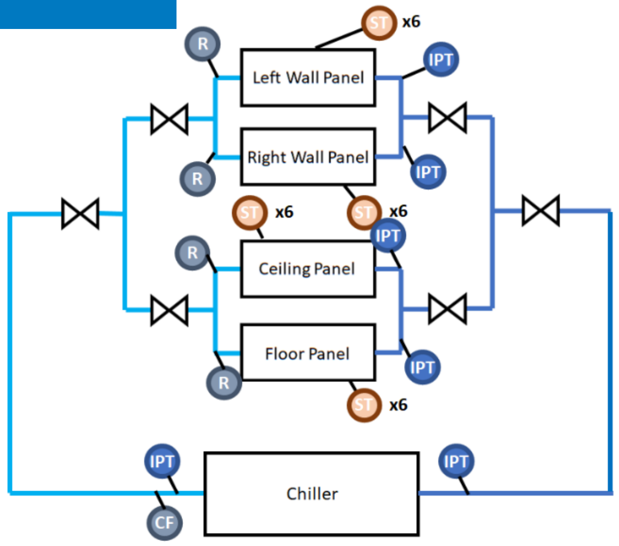
Bench Scale Refrigerated Case with Installed Radiant Panels

Experimentation Approach

- ASHRAE 72 and AHRI 1200 Standards were used to maintain consistent conditions between tests

  *except used water bottles for filler material

- For the bench-scale validation, a chiller supplied the panels' coils with silicone coolant at controlled temperature and flow rate.



__**Instrumentation Used to Calculate Thermal Load of Panels**__:

ST = surface thermocouples

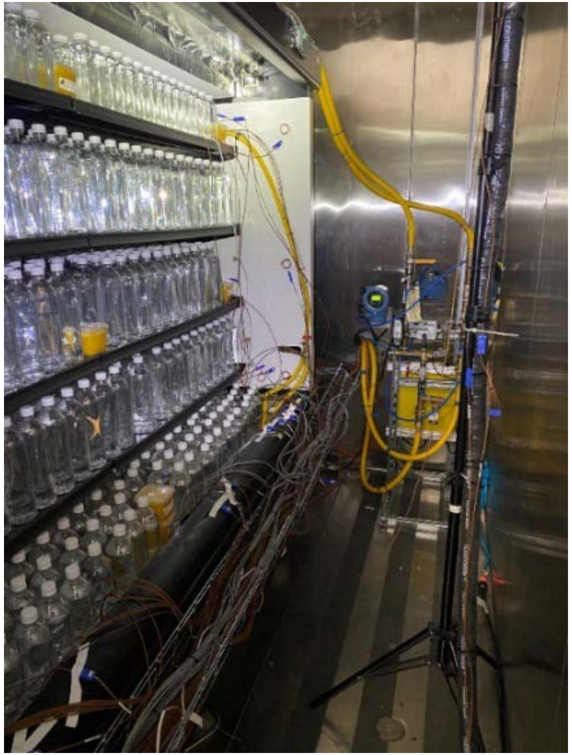
IPT = insertion probe thermocouple

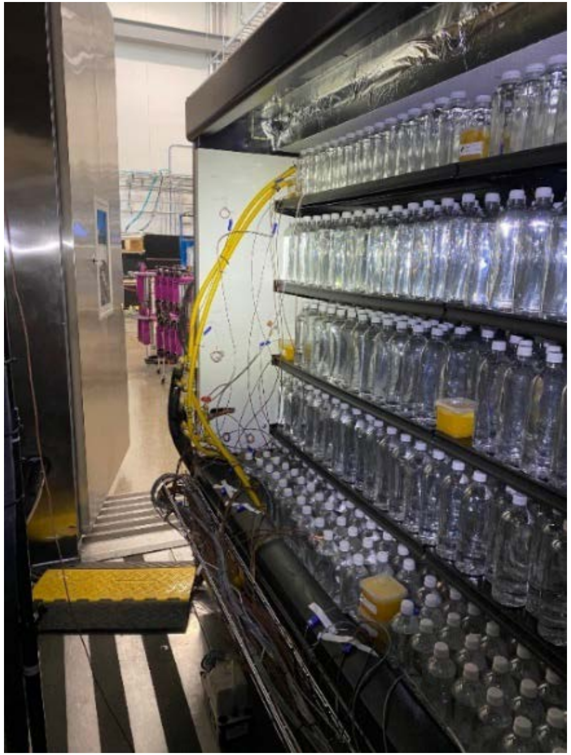
R = rheometer flowmeter

CF = high-accuracy Coriolis flowmeter

Experimental Setup – Bench Scale

Case Inside Environmental Chamber





Radiant Cooling Loop

A: port into/out of chamber

B: condensate drum and scale

C: flowmeters, pressure gauges, and thermocouples

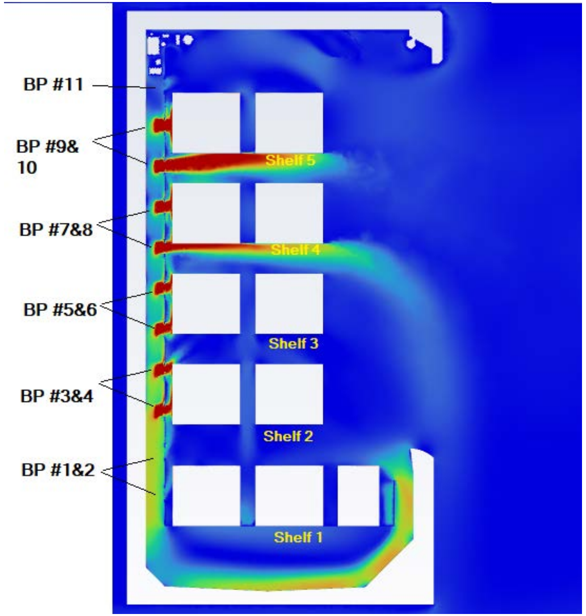
D: chiller – serving radiant panels

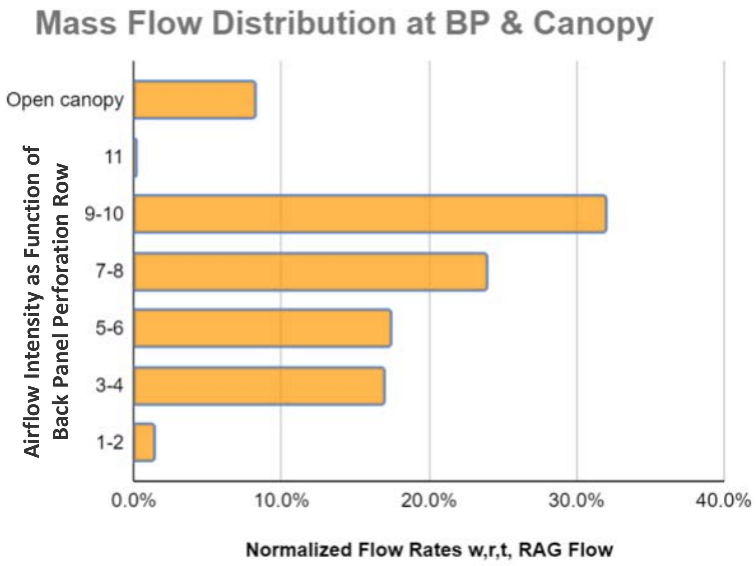
E: control box for the chiller, valves, and flood switches to detect leaks.

Results

Modeling Results Informing Hybrid Case Design

- Both CFD and EES models closely aligned with measured data:
  - Informed back panel air flow at 900 RPM and custom perforation for optimally-distributed air flow
  - Informed mean panel surface temperature of 32°F





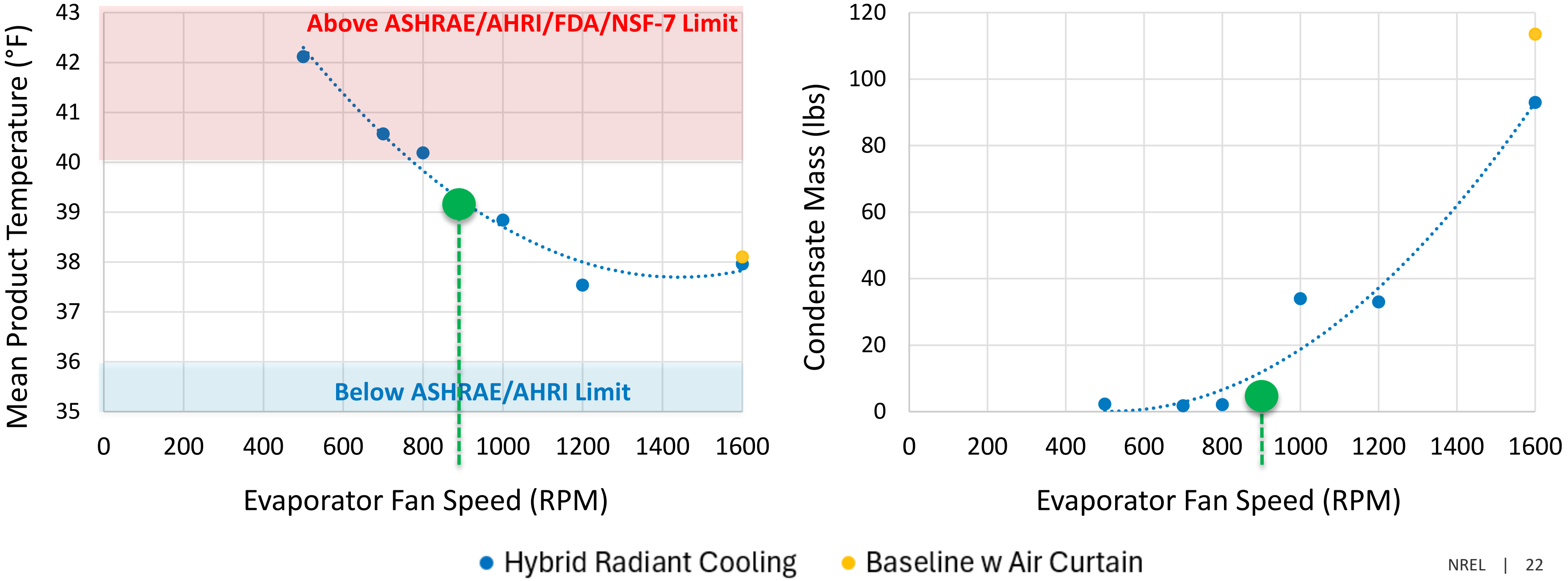
Convergence of Resistive Model with CFD and Experimentation Data

Average product temperatures from EES, CFD, and experimental measurements:

	EES (model approach 1)	CFD (model approach 2)	Experimental Measures
Baseline system	38.4°F	38.2°F	38.45°F
Hybrid system (bench-scale)	39.2°F	39.1°F	39.01°F

Hybrid Radiant + Convective Cooling Experimental Results

- *Varied fan speeds from 500 RPM (fan motor minimum) to 1600 RPM (baseline airflow)*
- *900 RPM provided optimum BP airflow while maintaining mean product temp & minimizing Infiltration*



Conclusions

Conclusions

- Convergence of resistive model with CFD and experimentation data increased confidence in modeling platform, which will be leveraged to design the POC

- The hybrid cooling system:
    - Complied with FDA product temp targets. *(39.0°F mean product temp at 900 RPM evaporator fan speed)*
    - Reduced infiltration load by 96% *(at 900 RPM evaporator fan speed) based on mass of condensate data)*

Next Steps

- Use validated thermo-fluid model to identify further strategies for minimizing the cooling load of the case & developing specs
- Fabricate a hybrid proof-of-concept prototype fixture (including TES and advanced controls integration)
- Ascertain the energy efficiency benefits of the hybrid proof-of-concept in a laboratory setting
- Assess the impacts of load flexibility strategies by leveraging the TES system in a laboratory setting

Thank you!

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Appendix

Thermo-Fluid Modeling

- **1st approach (thermal resistive network model) used Engineering Equation Solver (EES): considers conduction, convection, and radiation heat transfer modes and predicts temperatures**
- **2nd independent approach leveraged 3D CFD modeling.**

*models reflect the geometry of an actual OVDC.