Low-Cost TES for Refrigerated Display Cases

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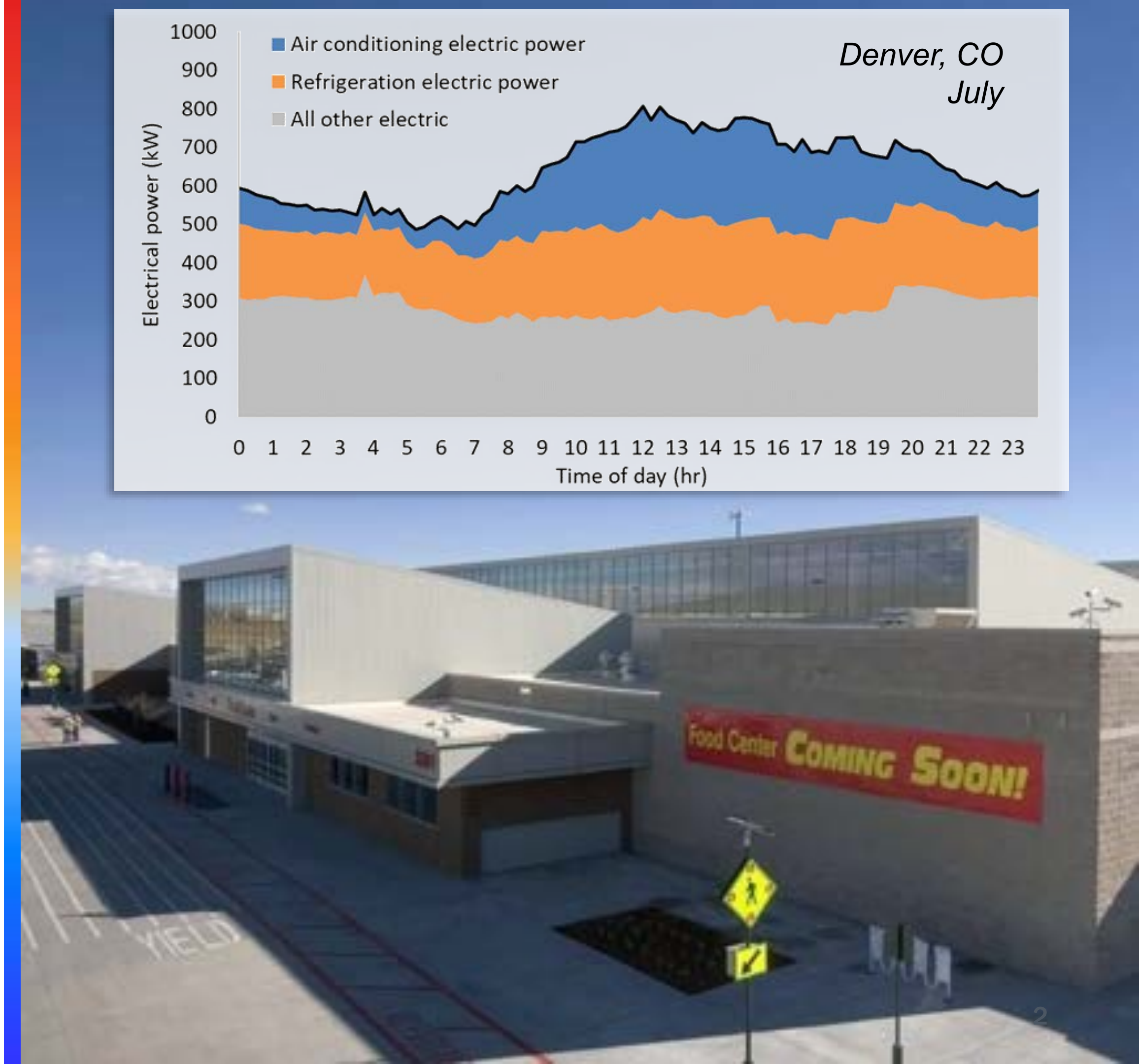
Why use TES in a refrigerated case?

- Refrigeration is the largest load in the highest EUI building (grocery stores)
- The load occurs year round, providing many opportunities to use the TES



Why use TES in a refrigerated case?

- Power outages are very disruptive to grocery stores—food not kept cold must be thrown away

Refrigerated food removed from the store in Boulder, CO during power outage in April (kept in refrigerated trailers in the parking lot)

Outline

- Design considerations for adding TES into refrigerated cases
- Bench-scale prototype
- Model and experimental results
- Next steps

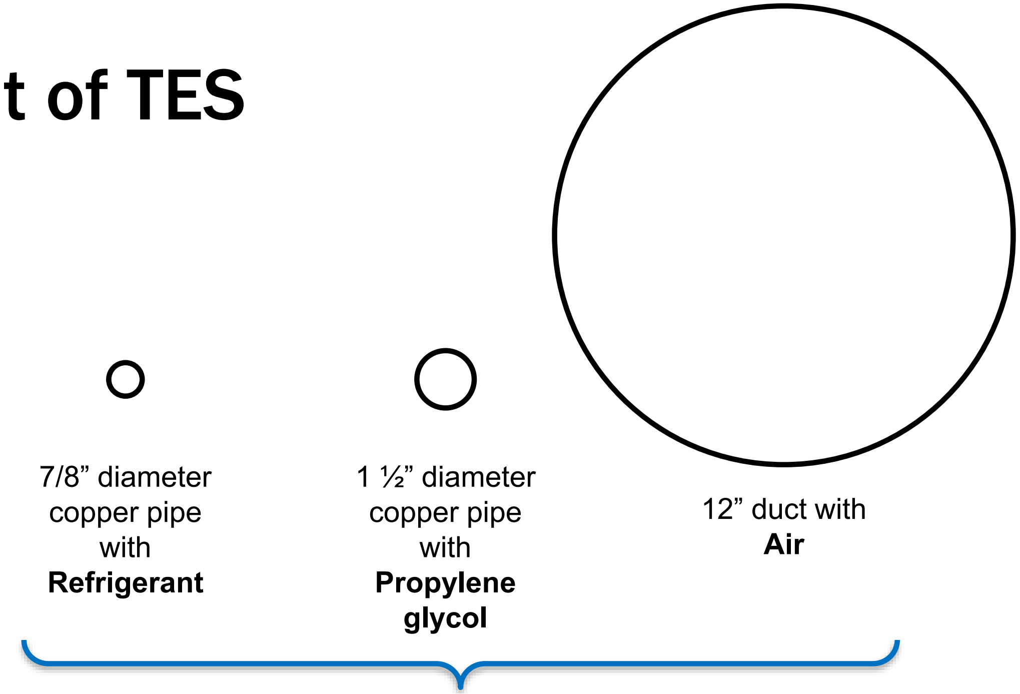
Design considerations for adding TES into refrigerated cases

- Moving heat into / out of TES
- Minimize integration costs
- Minimize parasitic energy
- What TES temperature?

Moving heat into / out of TES

How well do fluids carry heat?

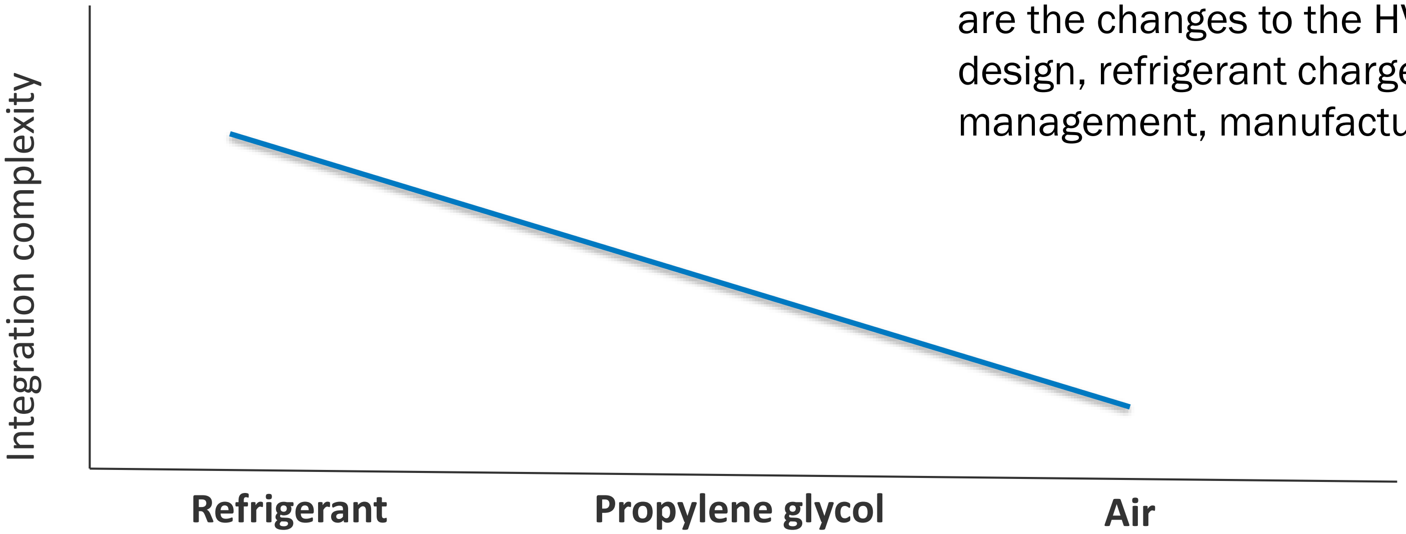
- Great: Refrigerants
- Good: Water/glycol solutions
  - But they require a secondary loop between refrigerant and air
- Poor: Air
  - But air is the fluid that is used by the application



20 kW_{th}

Thermal transport with different heat transfer fluids

Minimizing integration costs



Integration complexity: How significant are the changes to the HVAC system design, refrigerant charge management, manufacturing, controls?

Minimizing parasitic energy

Air side integration (Extra fan power)

dP ~ 75 Pa
Flow ~ 400 cfm/ton
Fan eff. ~ 0.4

→ Additional 47 W

Secondary loop integration (Pump power)

dP ~ 12 psi
Flow ~ 2.5 gpm/ton
Pump eff. ~ 0.7

→ Additional 28 W

What TES temperature?

Medium temperature refrigeration:

- FDA limit: Below 41 ° F (5 °C)
- Typically: 36 to 38 ° F (2.2 to 3.3 °C)

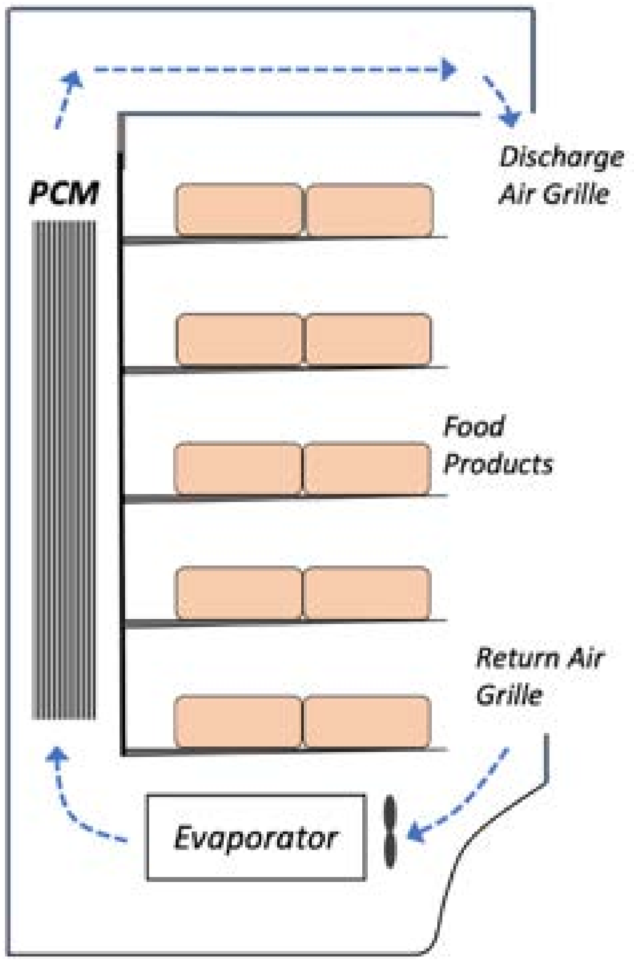
Water/ice @ 0 °C is a viable option

Low temperature refrigeration:

- FDA limit: Below 0 ° F (17.8 °C)

Design considerations for adding TES into refrigerated cases

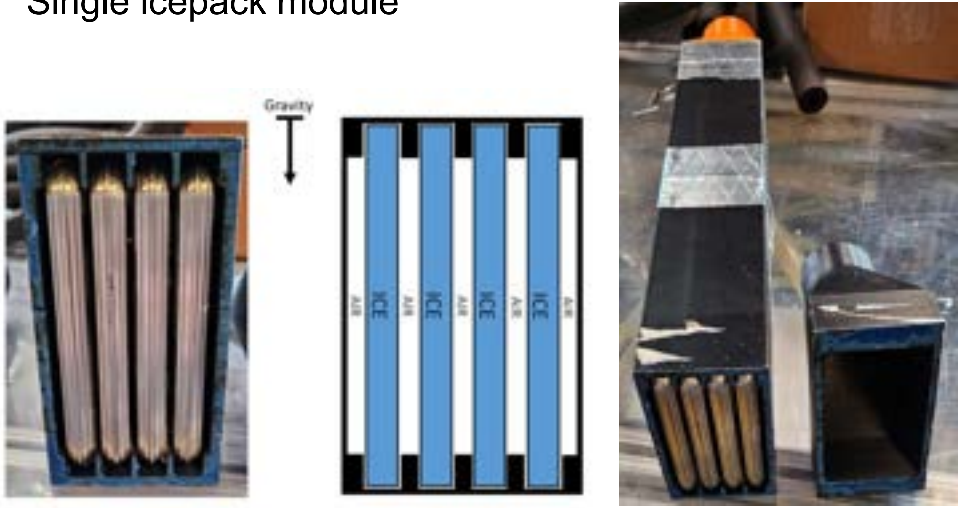
For this study, we selected a design with a PCM integrated directly into the airstream of a refrigerated case, using water (0 °C) as the PCM.



Bench-scale prototype

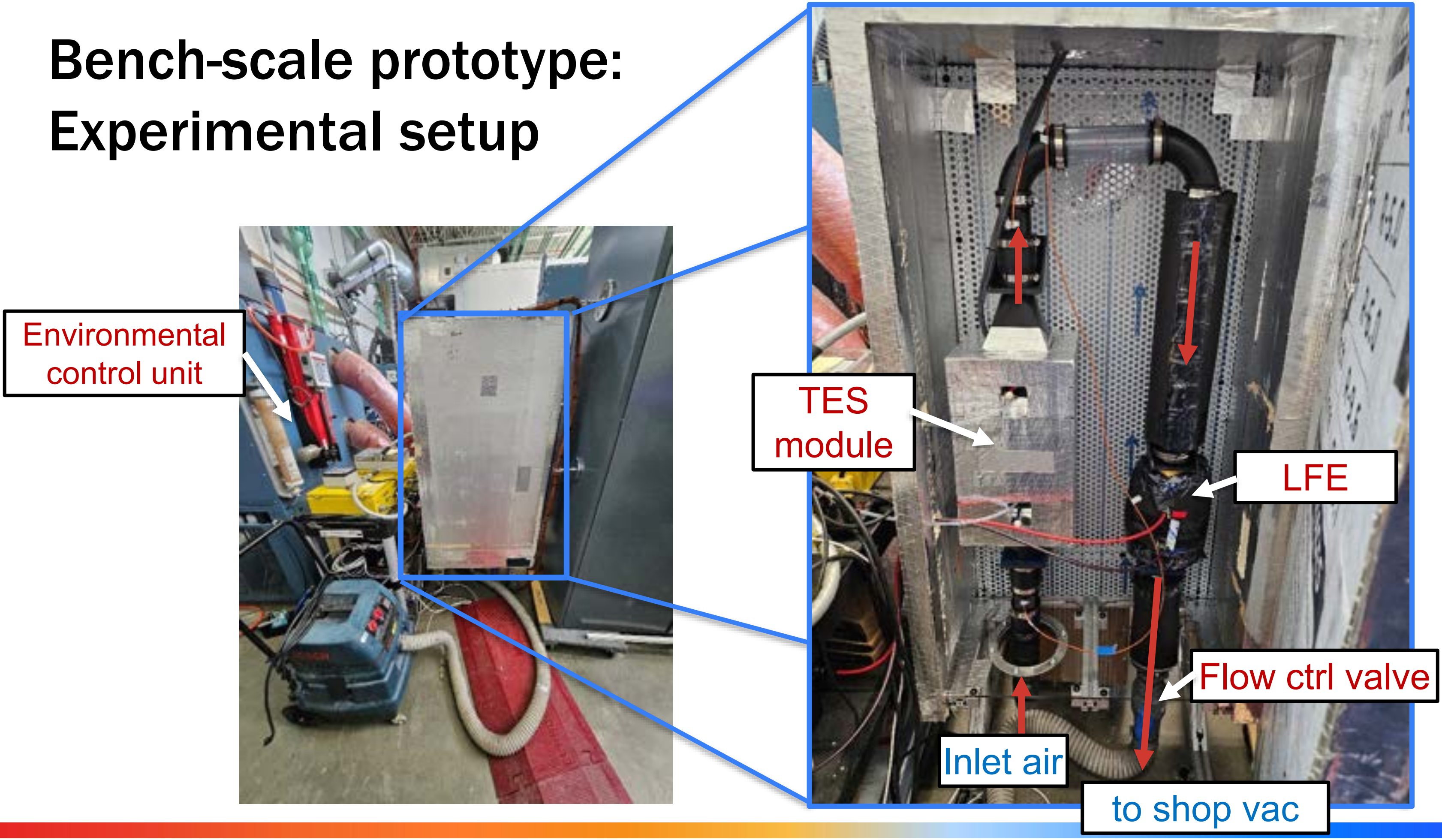
- Eight stainless steel ice packs
- 3-mm air channels
- 96 Wh storage module
- Model discharge process:
    - Initial T = - 15 °C
    - Air inlet T = 6 °C
    - 10 ft^3/min (~1/50^{th} scale)

Single icepack module

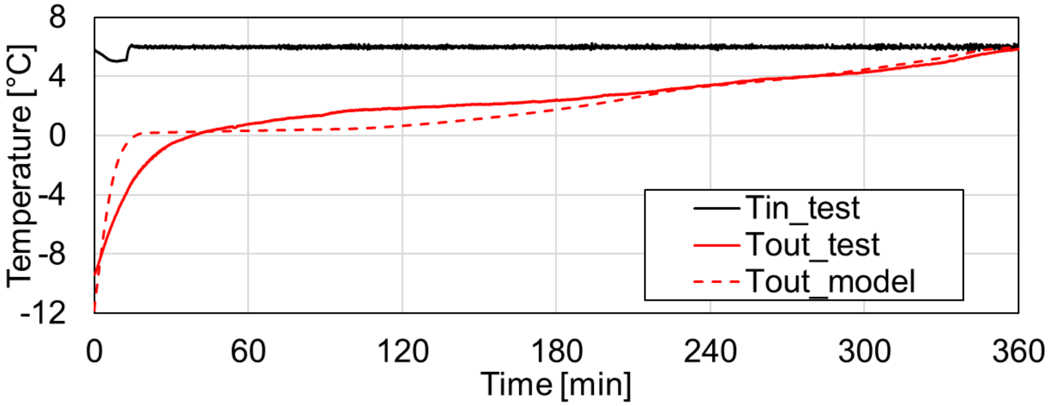


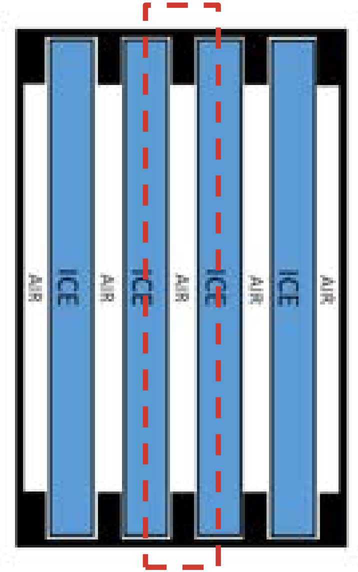
4x2 heat exchanger configuration

Bench-scale prototype: Experimental setup



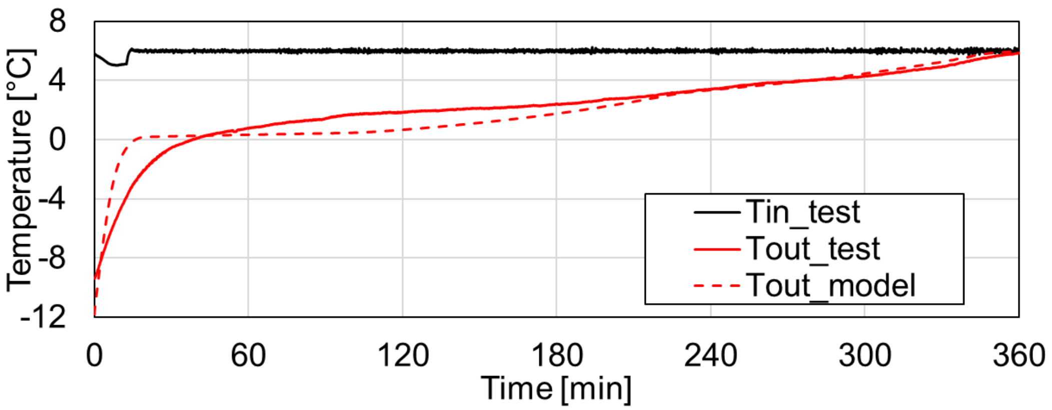
Experiment-model comparison: Discharge

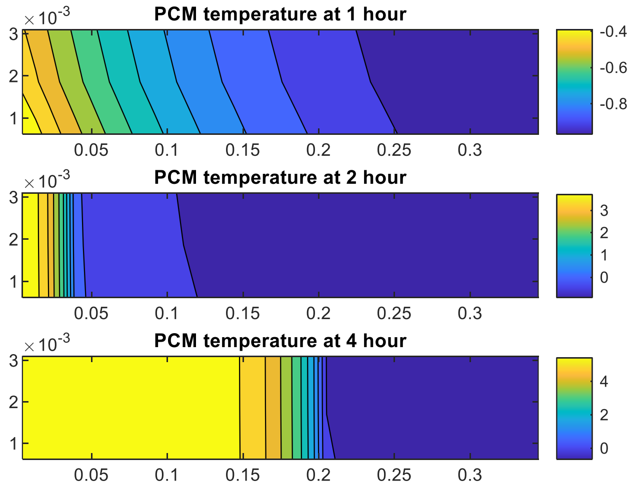




During discharge, TES enables ~3 hours of load shifting (t_{end} @ T_{out} > 3 °C)

Experiment-model comparison: Discharge

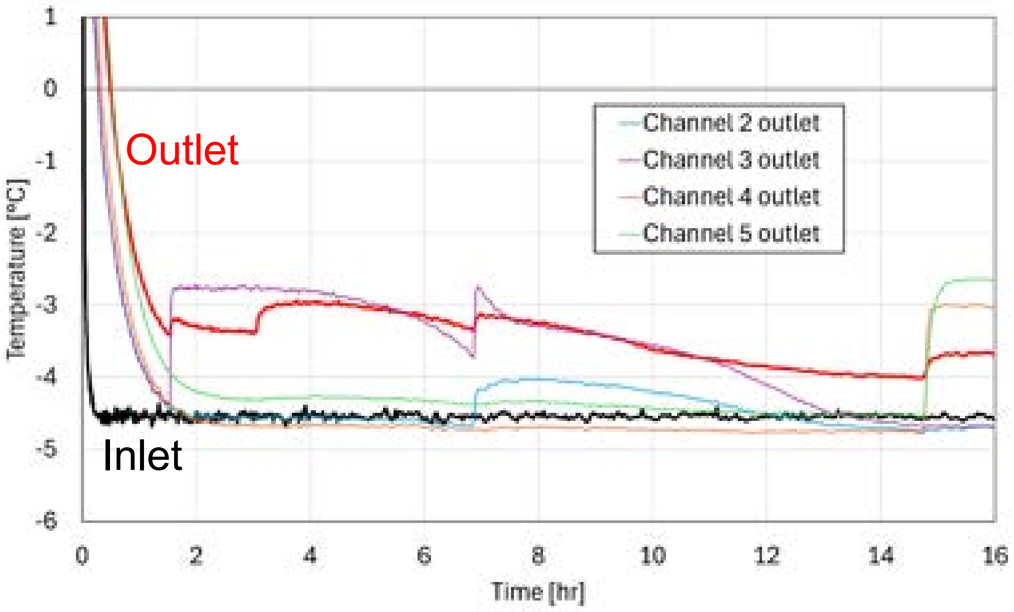




During discharge, TES enables ~3 hours of load shifting (t_{end} @ T_{out} > 3 °C)

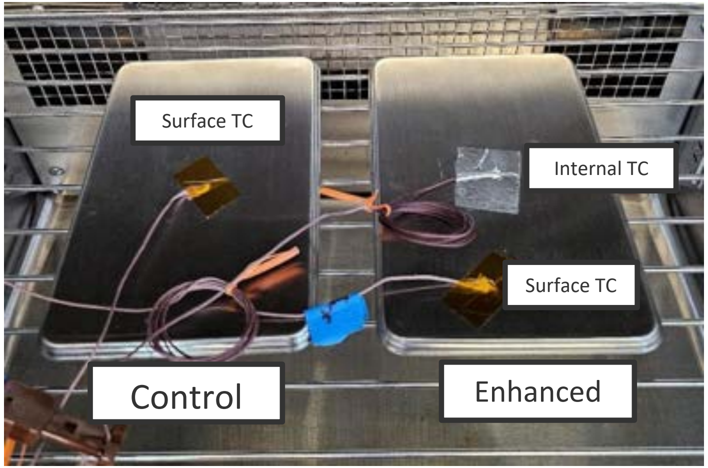
Model showed PCM mainly melts in the airflow direction

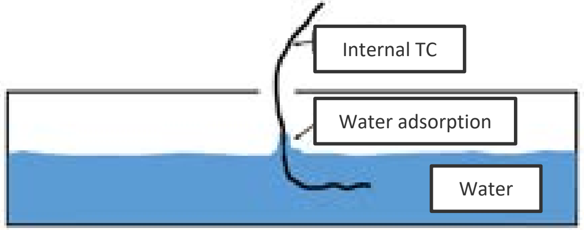
Experiment-model comparison: Charge

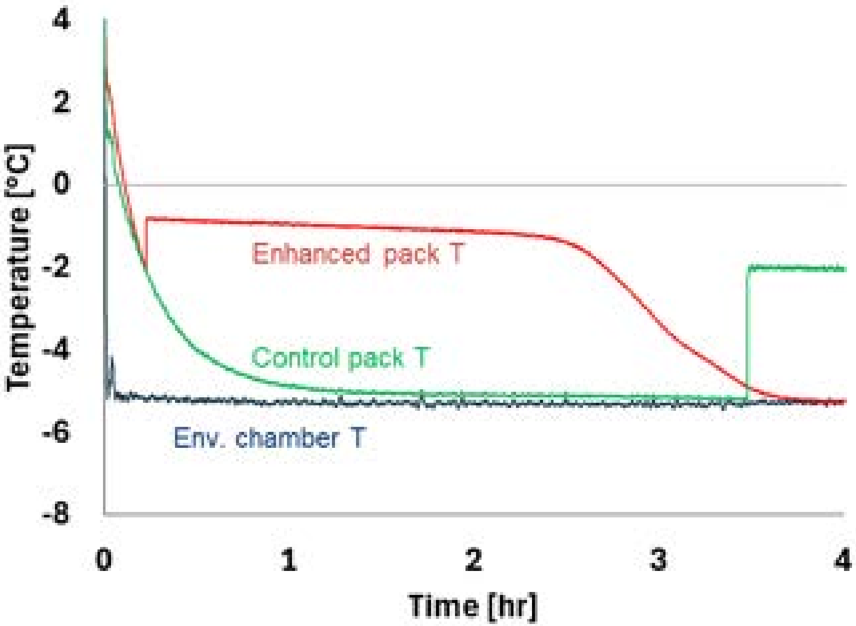


Charging at -5 °C is very slow due to water supercooling.

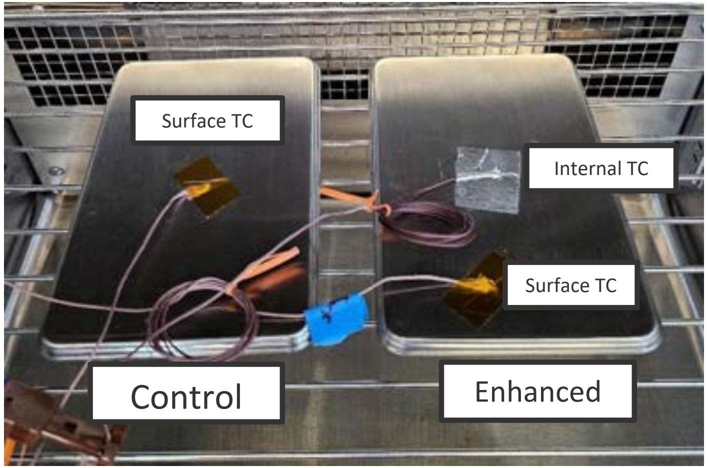
What should we do about water supercooling?

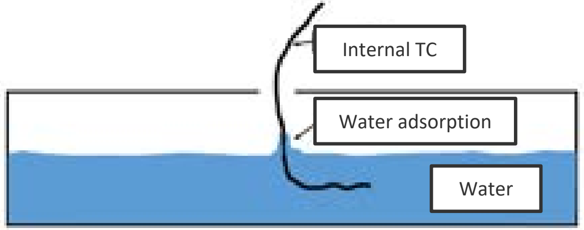


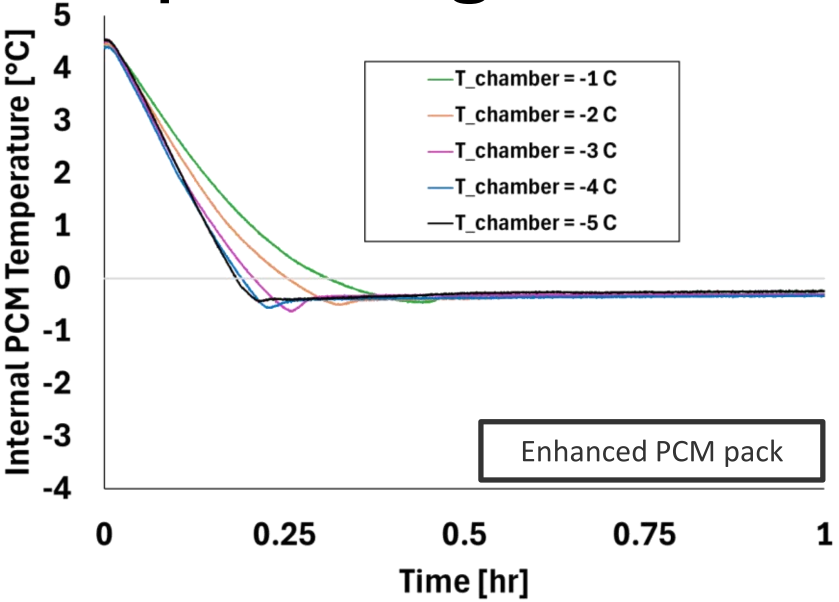




What should we do about water supercooling?







Initial tests indicate an inserted thermocouple reduces supercooling to < 0.5 °C, even when the air temperature is only -1 °C.

Next steps

- Combine TES model with a 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%

Summary and next steps

- TES for refrigerated cases can provide traditional load shifting, or resiliency for perishable products.

- For medium-temperature refrigeration, initial modeling and experiments show promise for using low-cost water as the PCM.

- We will perform TES + refrigerated case modeling and testing in 2025 to confirm the value proposition.

Acknowledgements

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Standalone Thermochemical Reactor for Seamless HVAC Integration

Session 4:Innovative Integration Strategies for Thermal Energy Storage with HVAC&R Systems

Moderator: Dr. Zhenning, ORNL & Dr. Yiyuan, ORNL

Presenter: Dr. Sumanjeet Kaur, LBNL

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TCM Team

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Outline

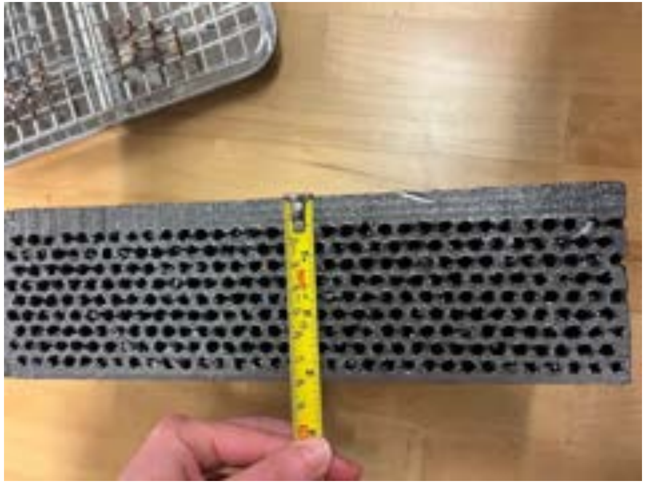
- At NetEnergy- Scaled up reactor to understand performance
- TCM Reactors to test and optimize performance

  At LBNL (Test Rig)

  - system optimization

  - precise control and measurement for Ragone plots and cascade system

NetEnergy- Using $CaCl_2.6H_20$



Salt Hydrate:

$CaCl_2.6H_20$

Host:

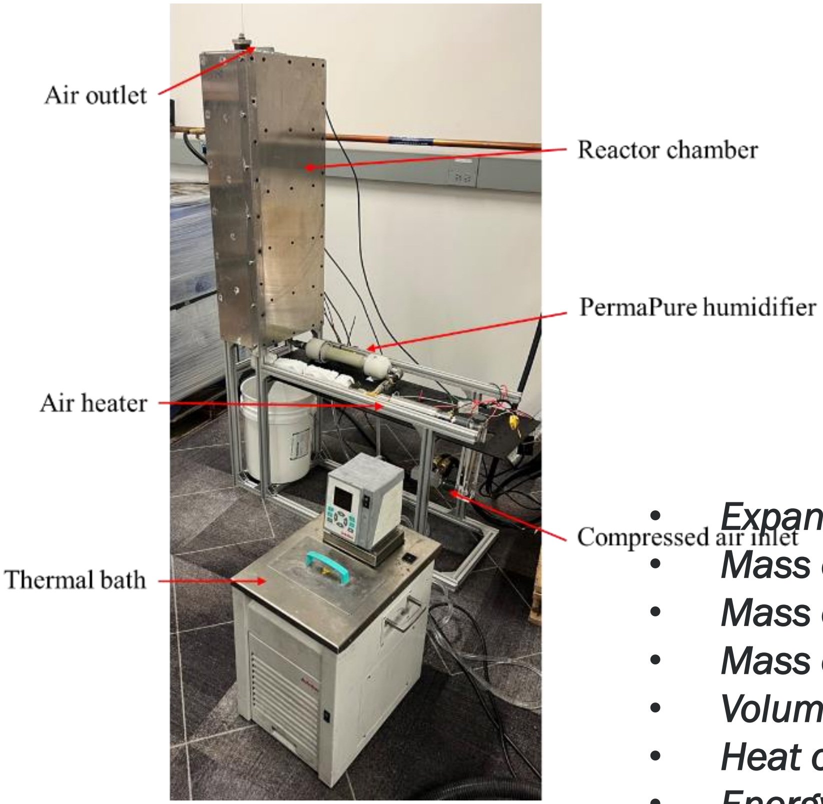
Expanded Graphite – Pre compressed Method used:

Wet Method

Benefit:

We are leveraging the existing product (pre compressed expanded graphite) of NetEnergy for TCM.

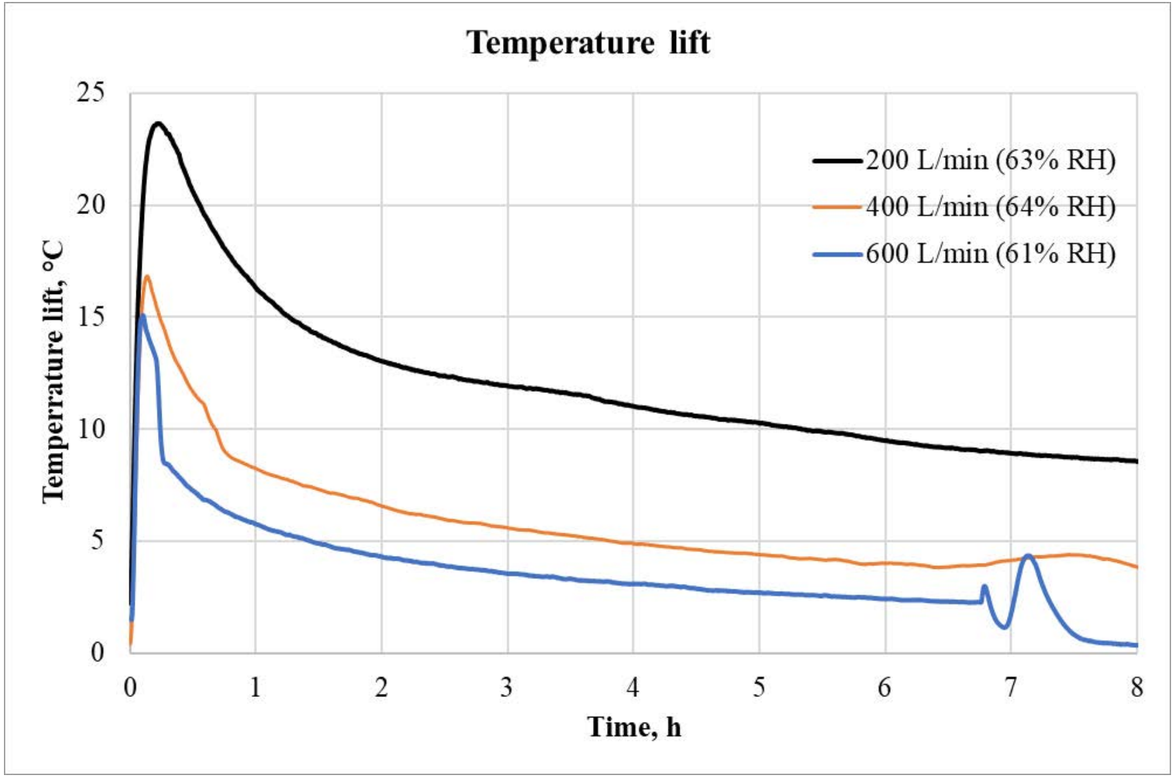
Reactor Prototype at NET Energy – Perforated brick design



- *Expanded graphite density: 100 g/L*
- *Mass of the block (graphite before soaking): 217.7 g*
- *Mass of the block after soaking and drying : 587.4 g*
- *Mass of anhydrous salt = 369.7 g*
- *Volume of the composite: 1,709,565 mm^3 or 0.001709565 m^3*
- *Heat of reaction =3200 kJ/kg*
- *Energy content = 3200 x 0.369.7 = 1183 kJ or 0.329 kWh*
- *Theoretical energy density = 0.329/0.001709565 = 192.5 kWh/m^3*

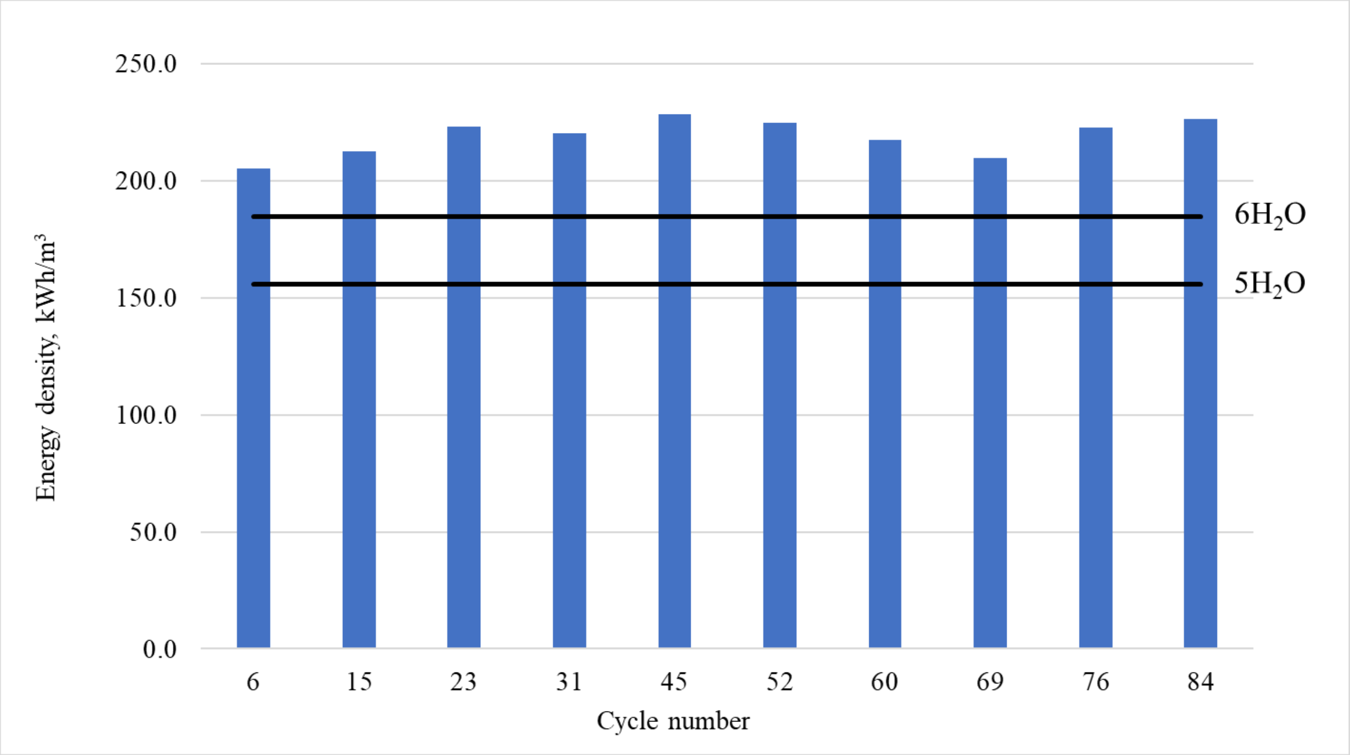
Results

Temperature lift during 8h of hydration reaction



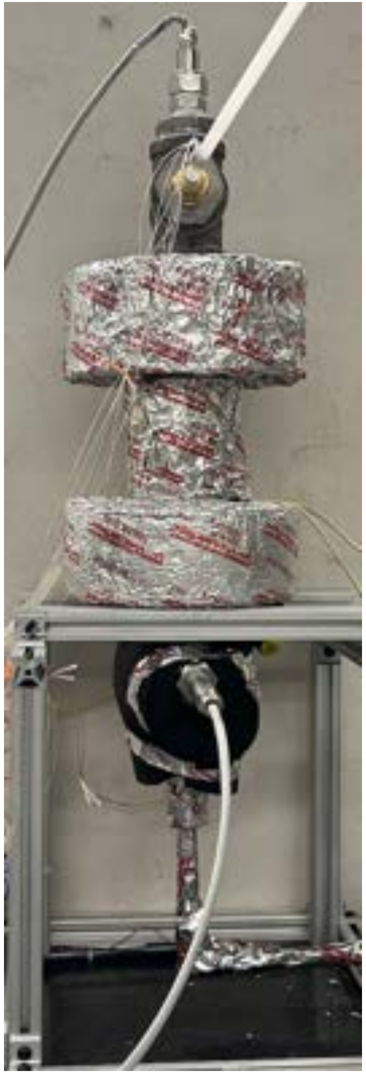
- >80 cycles
- Majority at 400 L/min
- Showing the comparison between different air flow rates

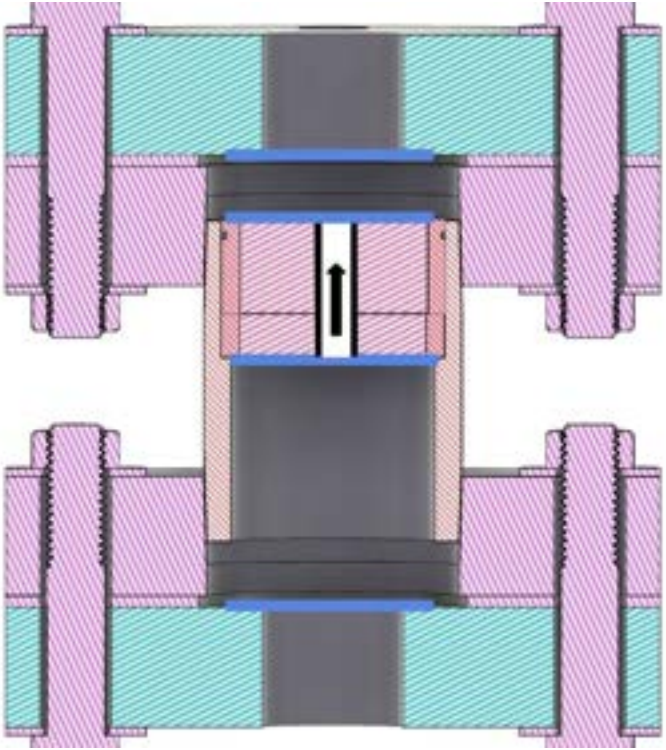
Composite block energy density



LBNL-Benchtop Reactor

- System configuration provides control of flow rate through reactor, and the relative humidity and temperature of that flow
- Measures temperatures across the reactor, relative humidity at inlet and outlet, flow rate, and pressure drop across the composite



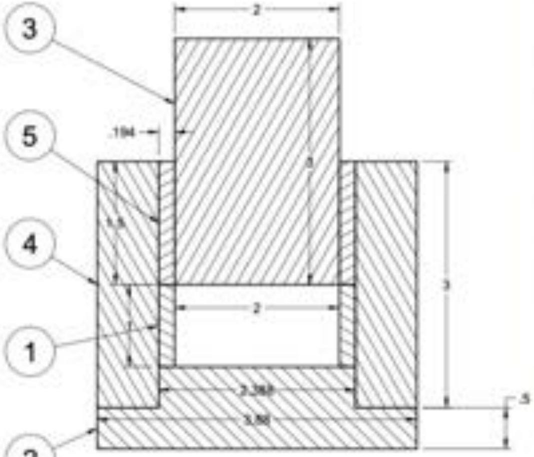


TCM Composite

- $SrCl_2*6H_2O$ dehydrates at 80ºC 0%RH and hydrates at 20ºC 65%RH providing a pure salt energy density of 563 kWh/m^3

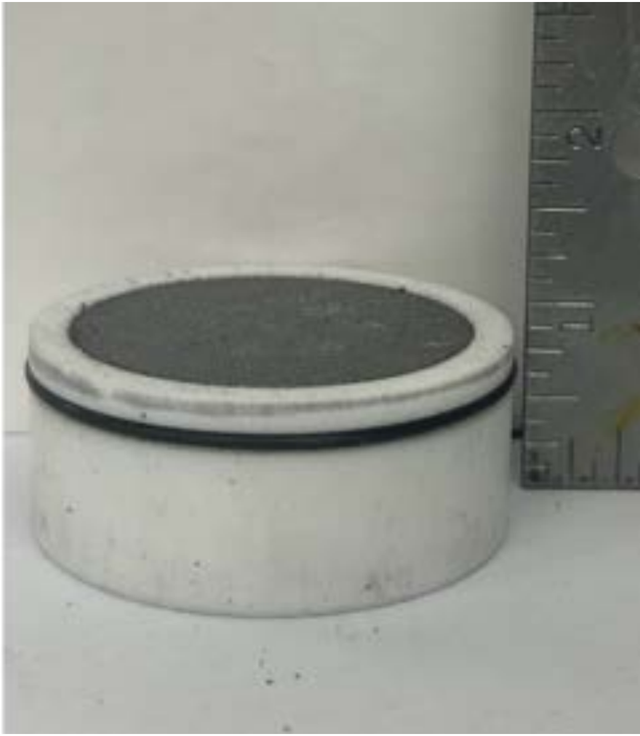
- Composite recipe: Salt 75% wt, Binder 5% wt, Carbon 20% wt

- Using expanded graphite, 150 lbs pressing force and 20g of material achieved a porosity of 80% and a theoretical material energy density of 87 kWh/m^3



SECTION A-A
SCALE 1:1

PARTS LIST		
ITEM	QTY	PART NAME
1	1	CUSTOMER'S RING
2	1	BOTTOM
3	1	PRESSIG ROD
4	1	OUTER SLEEVE
5	1	INNER SLEEVE



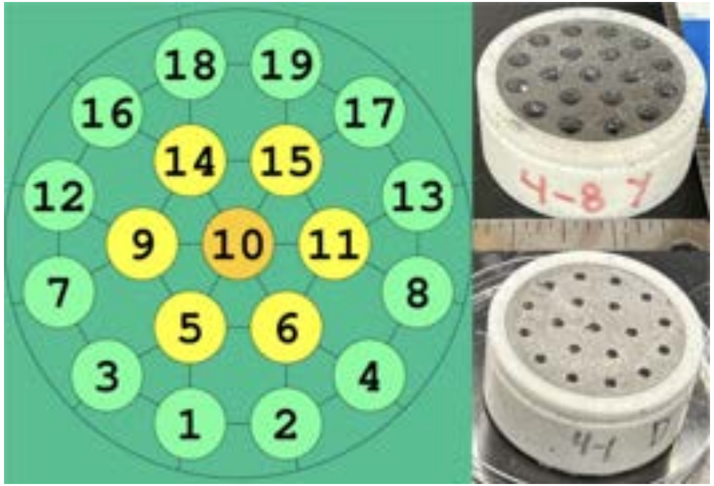
TCM Composite Hole Design

- To reduce pressure drop (at least <0.036 psi, goal <0.018psi) and improve moisture transport, we added 19 through holes as air flow channels

- The design nicknamed "Tiny Holes" has a hole diameter of 3.175mm, pitch of 7.3mm, and retains 90% of the initial mass

- The design nicknamed "Opt-D" has a hole diameter of 6.35mm, pitch of 4mm, and retains 65% of the initial mass

- The theoretical energy density on a composite level is 78.4 kWh/m^3 for "Tiny Holes" and 55.9 kWh/m^3 for "Opt-D"

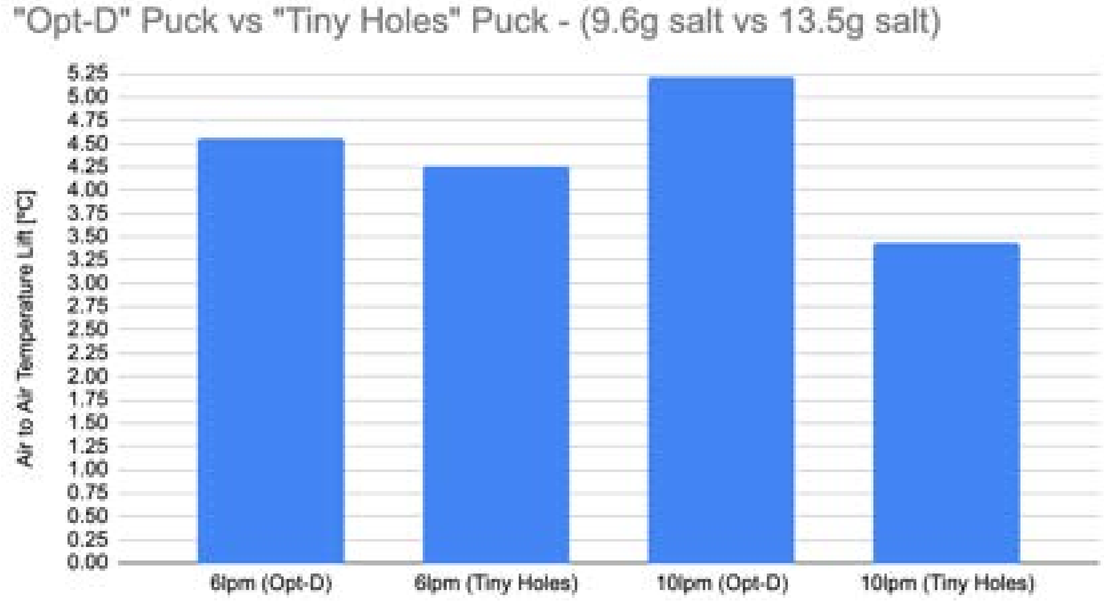


Credit: E. Specht 2010

Geometry Optimization

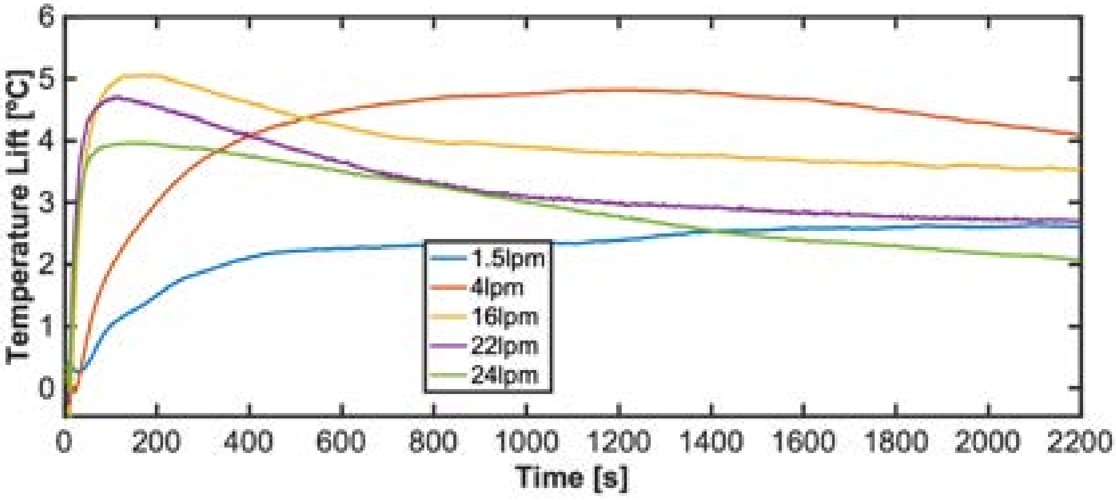
- For both 6lpm and 10lpm the "Opt-D" geometry provided a higher air-to-air temperature lift than the "Tiny Holes" geometry

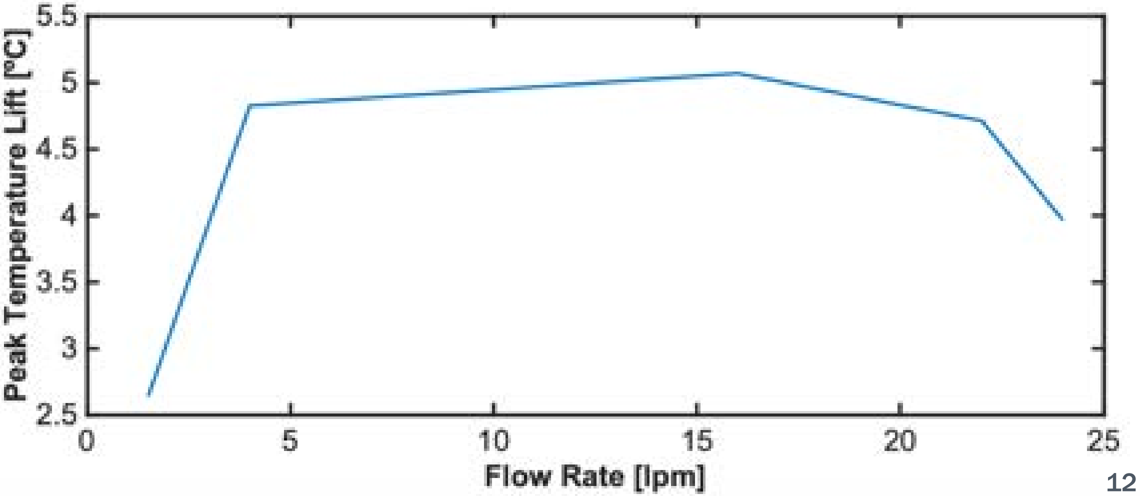
- While "Tiny Holes" had a higher theoretical energy density, moisture transport and reaction kinetics are slow



Flow Sweep

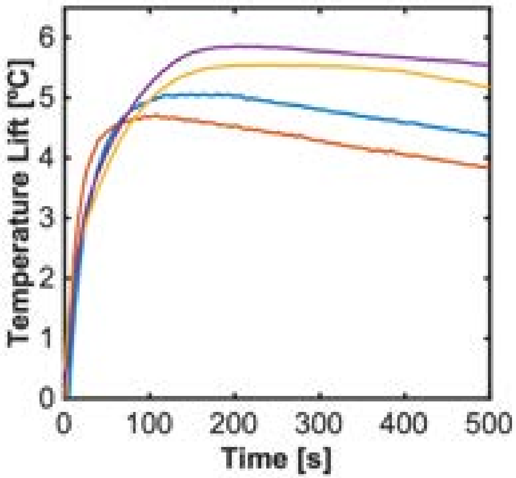
For our “Opt-D” puck we performed multiple 65% RH experiments at different flow rates, measuring the temperature lift

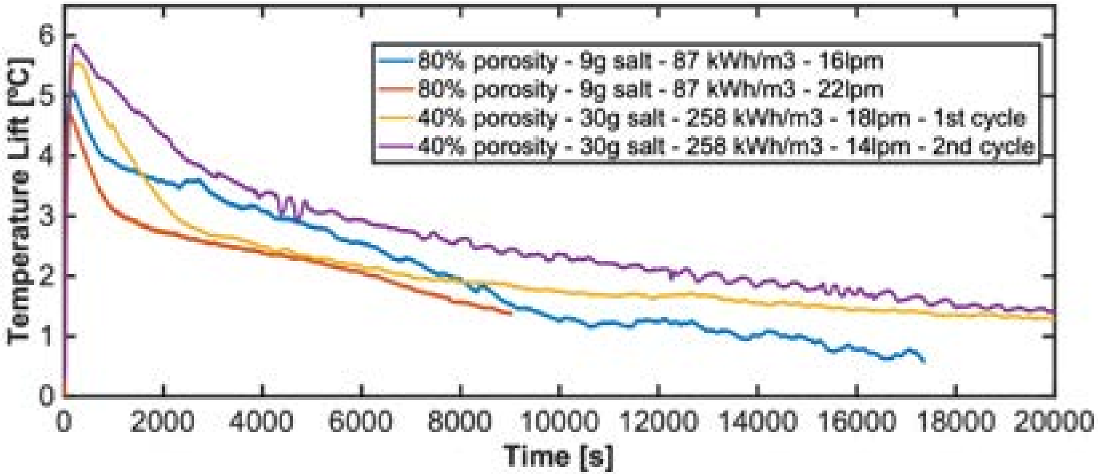




Improving Energy Density

- At 7000 lbs pressing force and 60g of material we achieved a porosity of 40% and a theoretical material energy density of 258 kWh/m^3
- After adding holes in the “Opt-D” design, the theoretical energy density on a composite level is 168 kWh/m^3

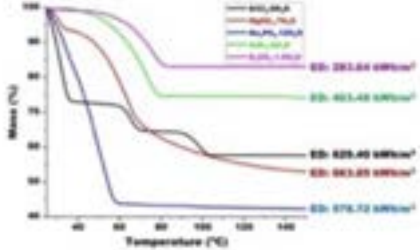




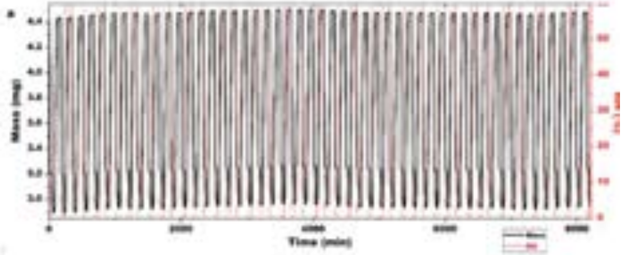
Next Steps

- Ragone Plots for TCM: working with NREL team
- Testing of new composite materials and design (work in Progress)
- Design Gen 2 Reactor based on the learnings from two reactors (LBNL and NETEnergy)

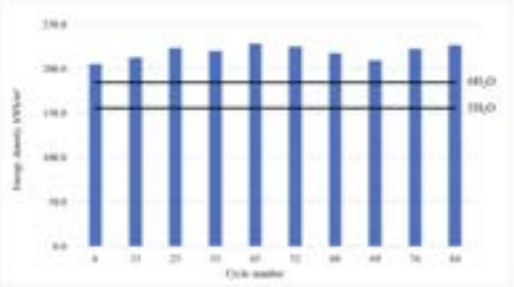
Down selection of TCMs for building



Cyclability (Salt) (Sample size –mg)



Cyclability of composite (275 x120x73 mm)



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Back up- Energy Balance

- For an "Opt-D" puck with 9g of salt, we measured a 3.2ºC temperature lift for 12lpm of 60%RH gas flow
- For 9g of salt, we would expect to react 3.0406g of water. We measured that the reaction absorbed 2.917g meaning that 95.9% of our salt is reacting during hydration.
- Qreaction (red) is the reaction power output based on the water absorbed with a total energy output of 9.2820 kJ. The initial reaction from monohydrate to dihydrate has the highest water absorption rate and power output
- Qv (blue) is the power used to heat the air based on the air to air temperature lift with a total energy input of 6.5856 kJ. The air is receiving 70.95% of the reaction energy after 20,000 seconds or 5.55 hours.