2024 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: High Energy Density Hydrogel Thermo-Adsorptive Storage

Massachusetts Institute of Technology (MIT)
Heat Transfer Technologies (HTT)
Rheem Manufacturing Inc.

Bachir El Fil – Assistant Professor
bachir.elfil@me.gatech.edu or belfil@mit.edu

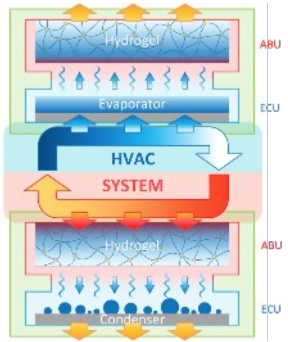
Project#: DE-EE0009679

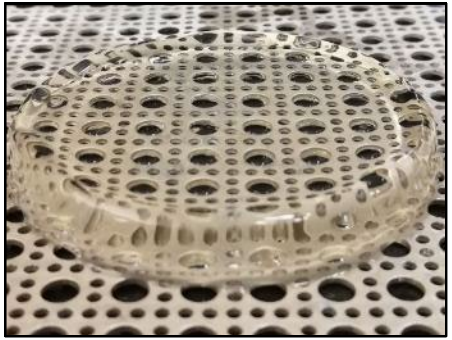
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

Novel thermal energy storage (TES) device based on the adsorption of a hydrogel/salt composite, promising the following performances:

- High energy density ≥ 200 kWh/m^3
- Regeneration temperature ≤ 70˚C
- Building energy savings of ≥ 50 kWh/m^3/day
- System cost ≤ \$13.8/kWh_{th}





TEAM & PARTNERS

MIT (Prime)	Device design, modeling, characterization, & integration
HTT	Component fabrication, characterization, & commercialization
Rheem Inc.	Device integration, characterization, & commercialization

STATS

Performance Period: 10/01/2021 – 9/30/2024 (NCE requested)

DOE Budget: \$2,623,595, Cost Share: \$661,500

Milestone 1: Thermodynamic and numerical models for system-level and component-level

Milestone 2: Component design, fabrication & material synthesis and engineering

Milestone 3: Device design, optimization, & demonstration

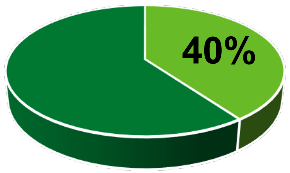
Energy consumed by buildings
Energy consumed by others

Problem Statement

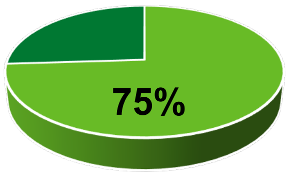
- Around **17 million** low-income households in the U.S. spend at least 15% of their income on heating and cooling. (ACEEE, US DOE, 2021)
- Buildings are responsible for 40% of total energy use in the U.S., including 75% of all electricity use and 35% of the nation's carbon emissions.
- Although today's decarbonization efforts often focus on renewable electricity or EVs, **decarbonizing the building stock is also essential**.

(Energy.gov/BTO, 2023)

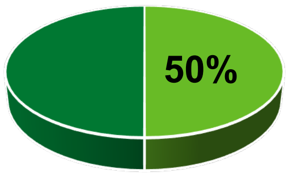
Overall Primary Energy Consumption



Overall Electric Energy Consumption



Heating and Cooling

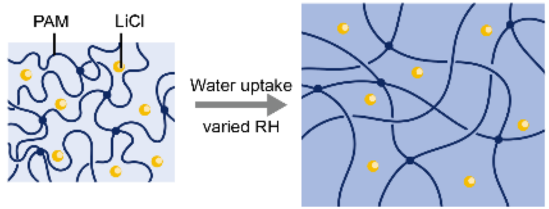


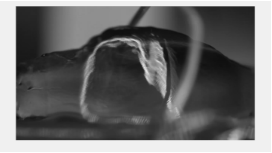
Inexpensive, retrofittable, and high-energy density thermal energy storage (TES) could help save significant energy for heating and cooling.

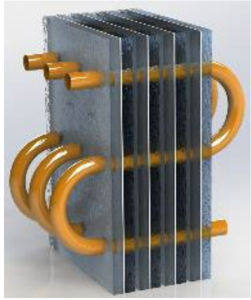
Alignment and Impact

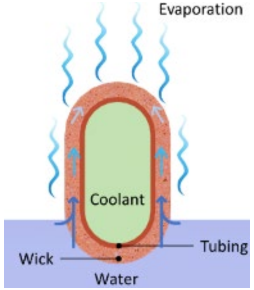
By end of project, we aim to innovate on material-level and system-level to enable:

- Customizable hydrogel-salt composite as adsorbent with high water uptake (>1.7 g/g at 30% RP) and kinetics (>10^{-10} m^2/s)
- Low desorption temperature *i.e.*, recycling building waste heat (65 $\leq T_{des} \leq$ 100°C)
- Integrated evaporator/condenser unit to ensure system compactness
- High energy density (> 450 kWh_{th}/m^3)
- Hydrogel-TES system (5 kWh) at cost < $\$15/kWh_{th}$

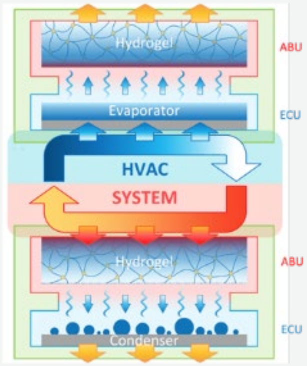




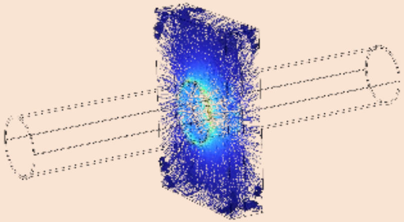




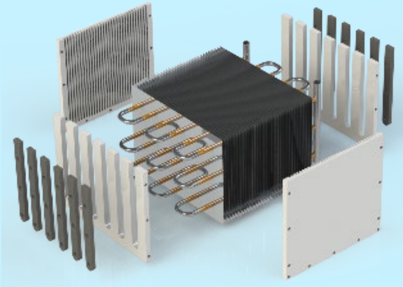
Outline



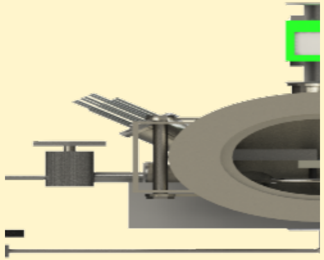
System



Design

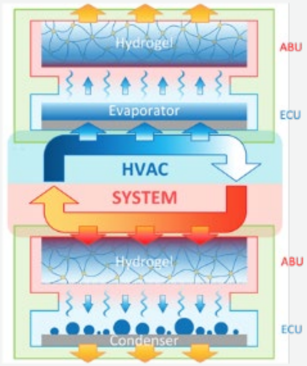


Scale up

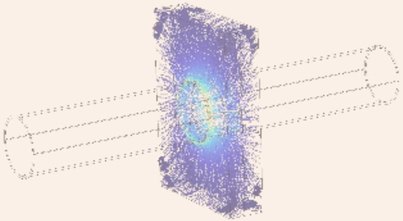


Experimentation

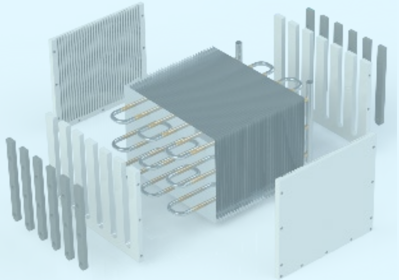
System



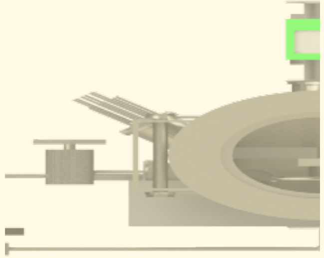
System



Design



Scale up

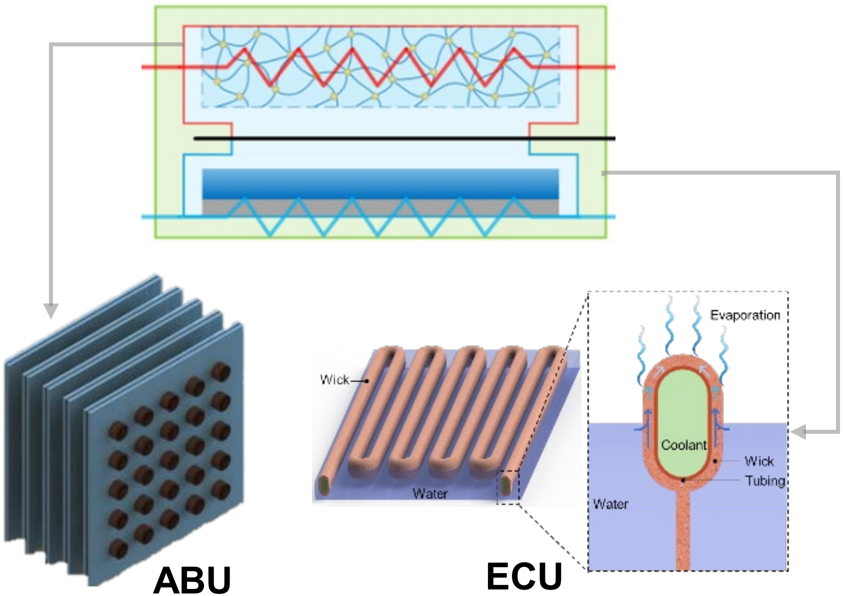


Experimentation

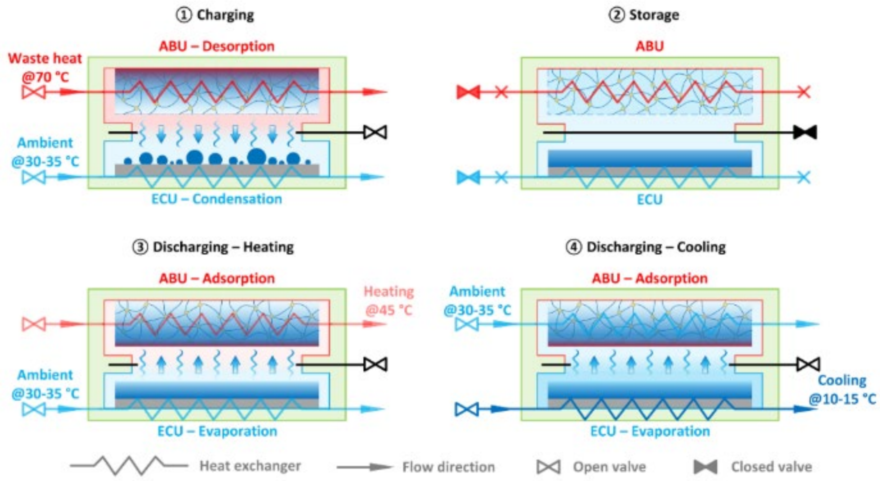
Approach: Hydrogel-based TES system

The TES device is composed of two components:

- Adsorbent Bed Unit (ABU)
- Evaporator/Condenser Unit (ECU)

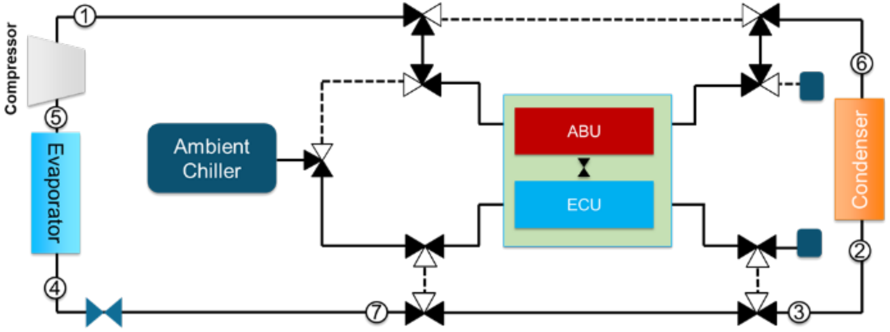


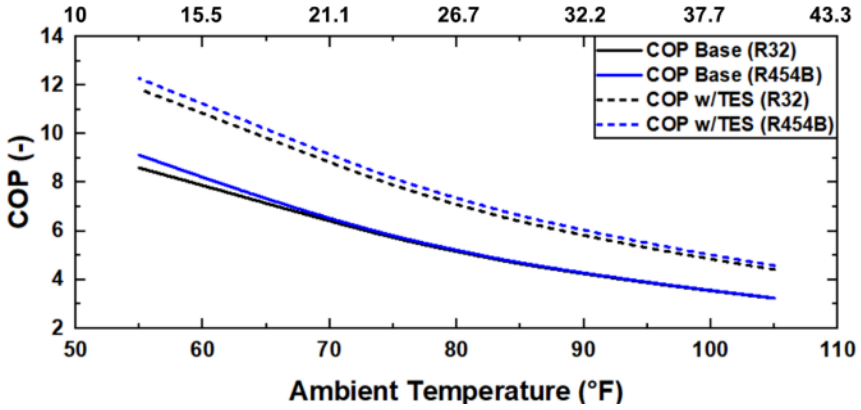
Operating principle of the TES system:

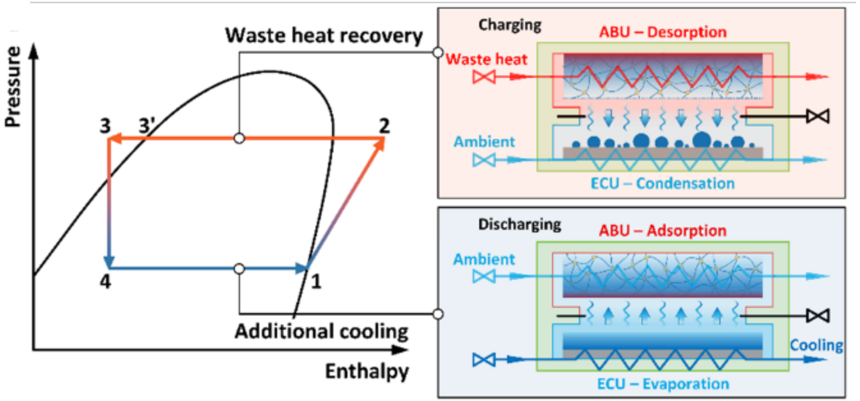


Hydrogel-TES system can provide energy savings in both cooling and heating mode when integrated with HVAC

Approach: Integrating TES system with HVAC



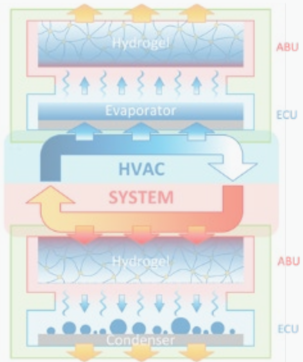




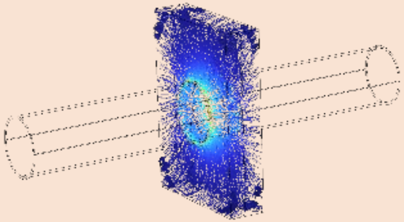
$$\mathrm{COP_{tot}} = \mathrm{COP_e} + \mathrm{COP_{th}}(1 + \mathrm{COP_e})$$

COP enhancement 37 – 41% when integrating TES with HVAC
40% SEER enhancement across the US

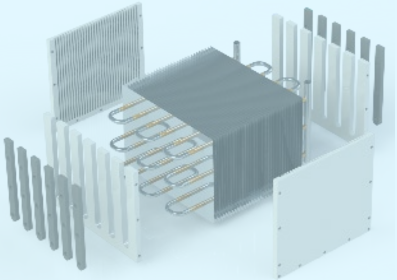
Device Design and Material Synthesis



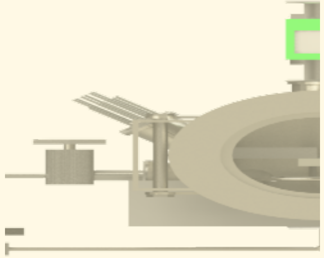
System



Design

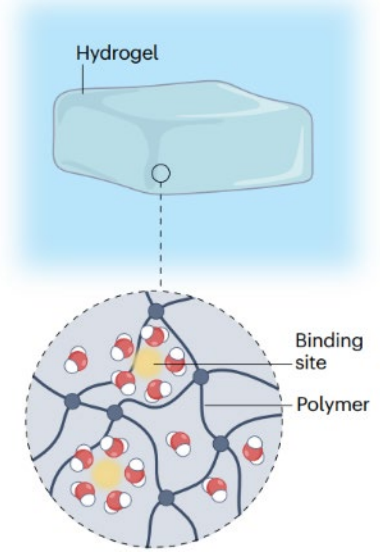


Scale up

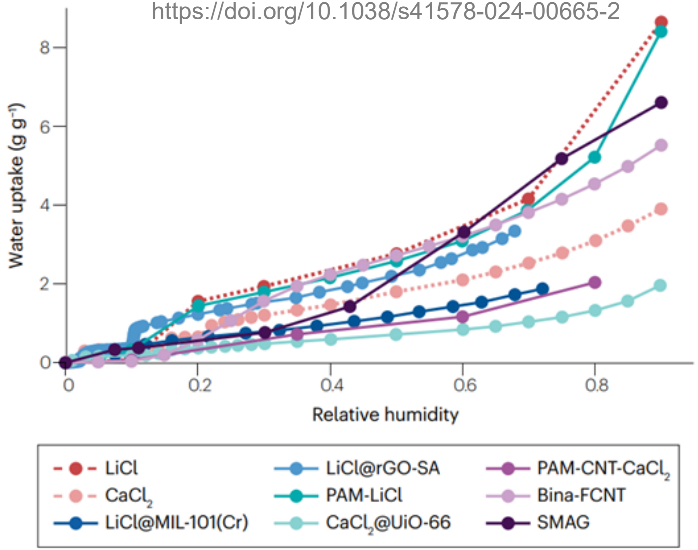


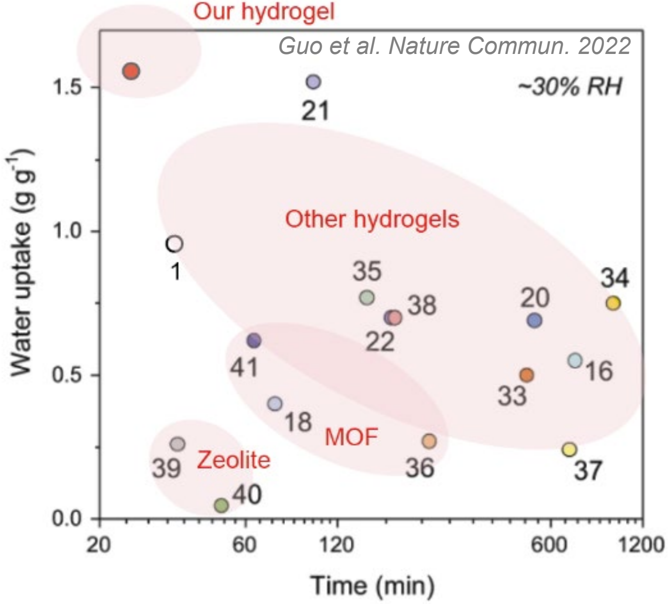
Experimentation

Hydrogel Synthesis and Characterization



Nat Mat Rev,2024
https://doi.org/10.1038/s41578-024-00665-2

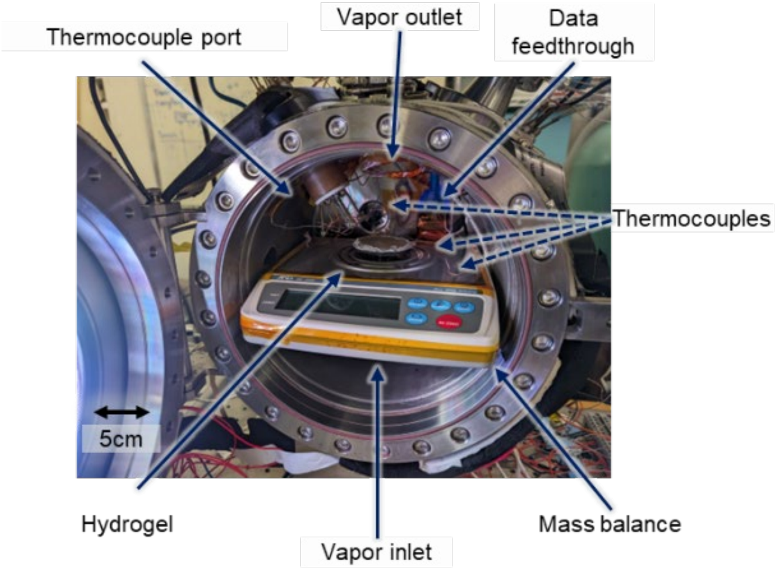


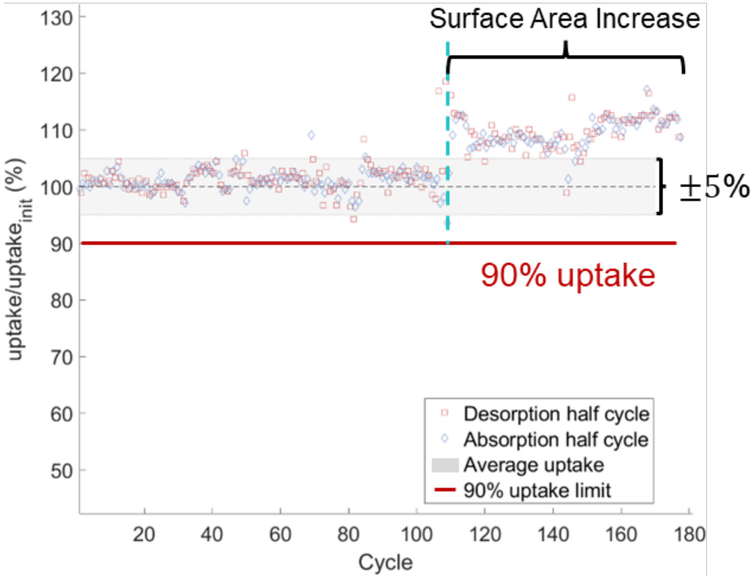


Exceptional water hygroscopicity:
Uptake: 15% higher than previous best hydrogels, 2× MOFs, 4 × zeolites
Kinetics: 4 × faster than previous hydrogels, MOFs and zeolites

Large Scale Cyclic Vacuum Dynamic Vapor Sorption System: Uptake

Concept: Large vacuum chamber integrated with automated chamber's vapor pressure control. During the experiment, we measure the mass change of a hydrogel placed on top of a mass balance and the temperatures.

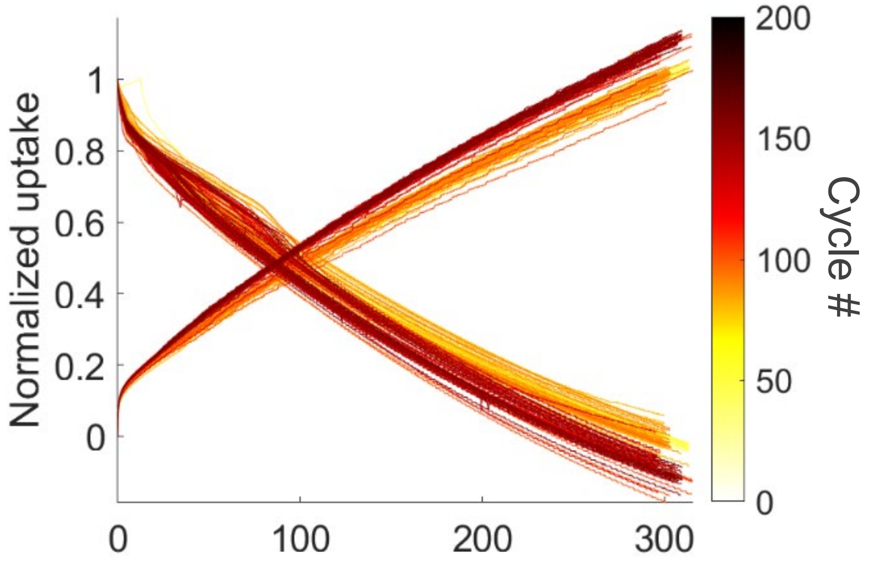




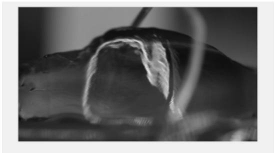
No degradation of the hydrogel uptake or kinetics over 180+ stable cycles (>3 months)

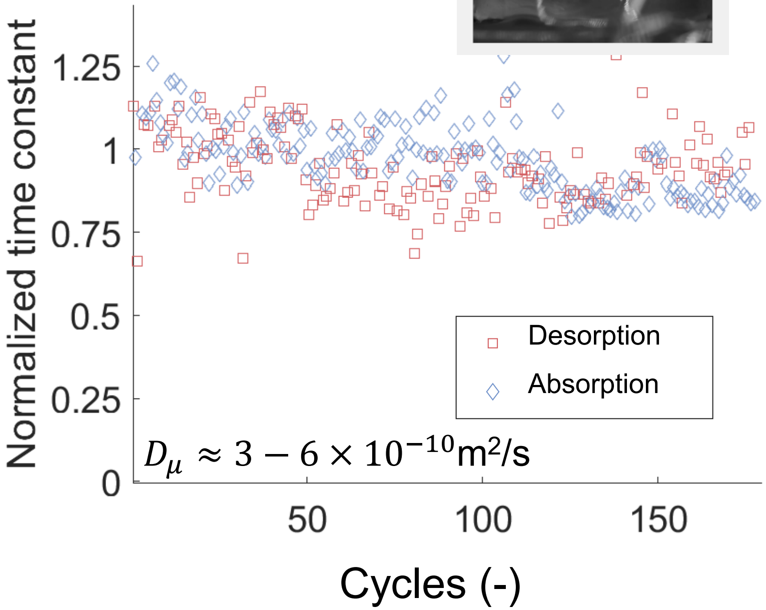
Large Scale Cyclic Vacuum Dynamic Vapor Sorption System: Kinetics

No visual degradation of the hydrogel kinetics over 3+ months



Overlay of adsorption and desorption uptake curves



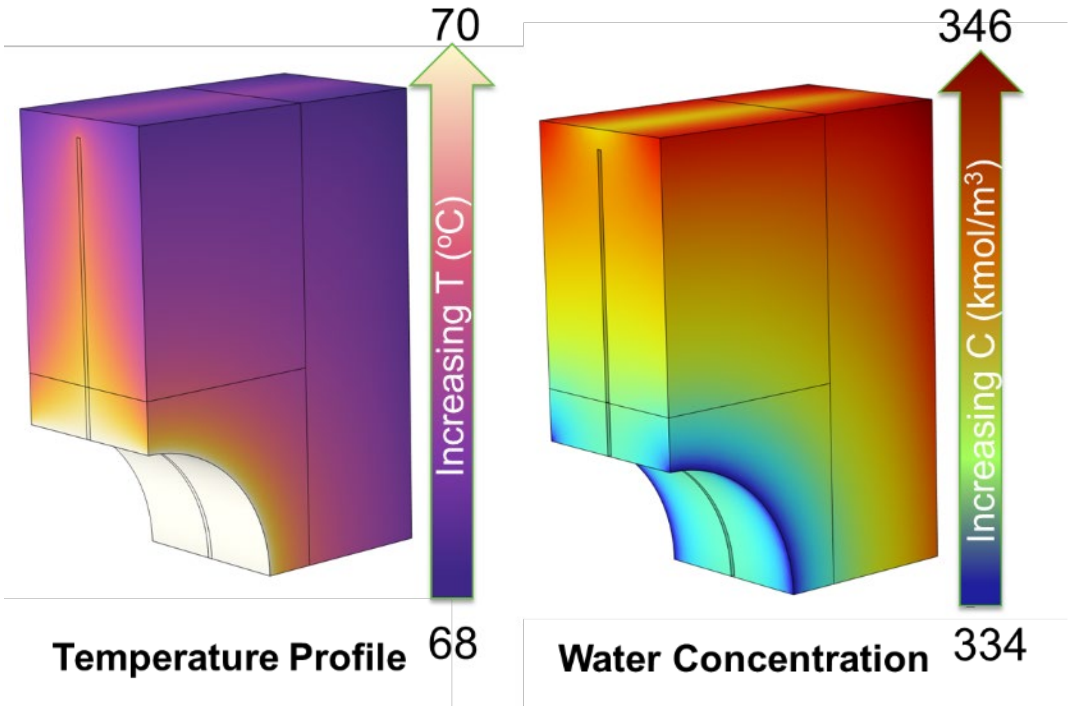


Time constant of desorption and adsorption over time

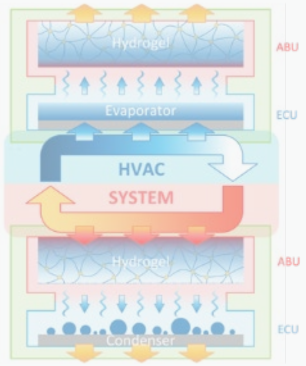
Thermo-fluidic models for the device

Highlights:

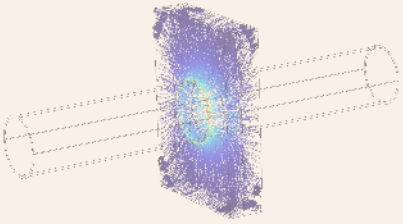
- Our system design is based on fundamental modeling of material, component, and system-level
- Water uptake swing is >1 g/g
- Heat and mass transport model of hydrogel coated fin
- Predicting temperature and water concentration profiles



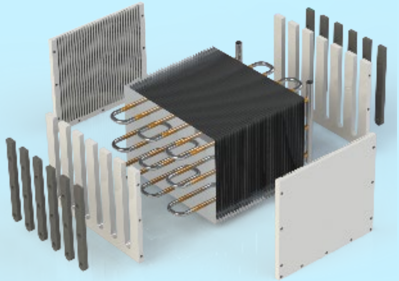
Scale Up



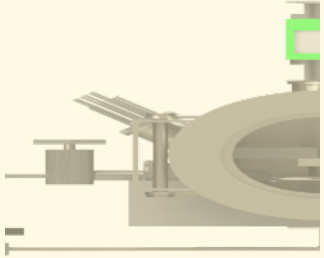
System



Design

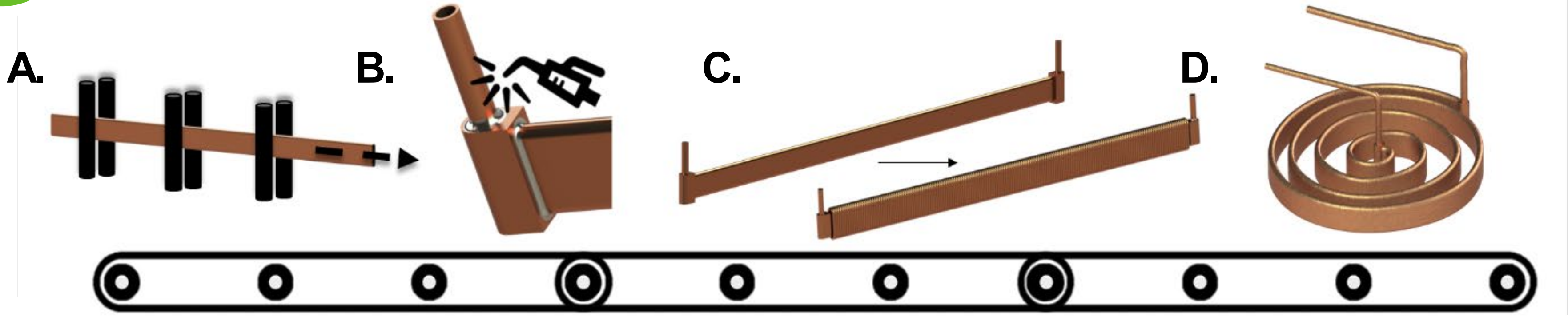


Scale up

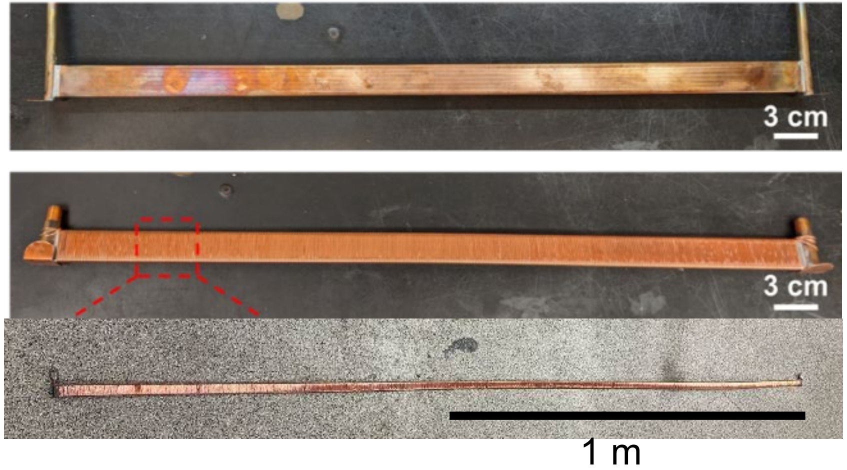


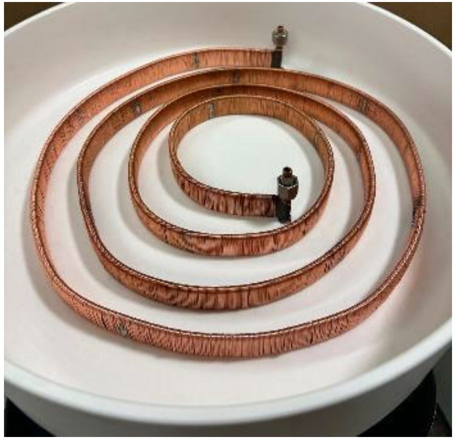
Experimentation

ECU Fabrication and Scale up

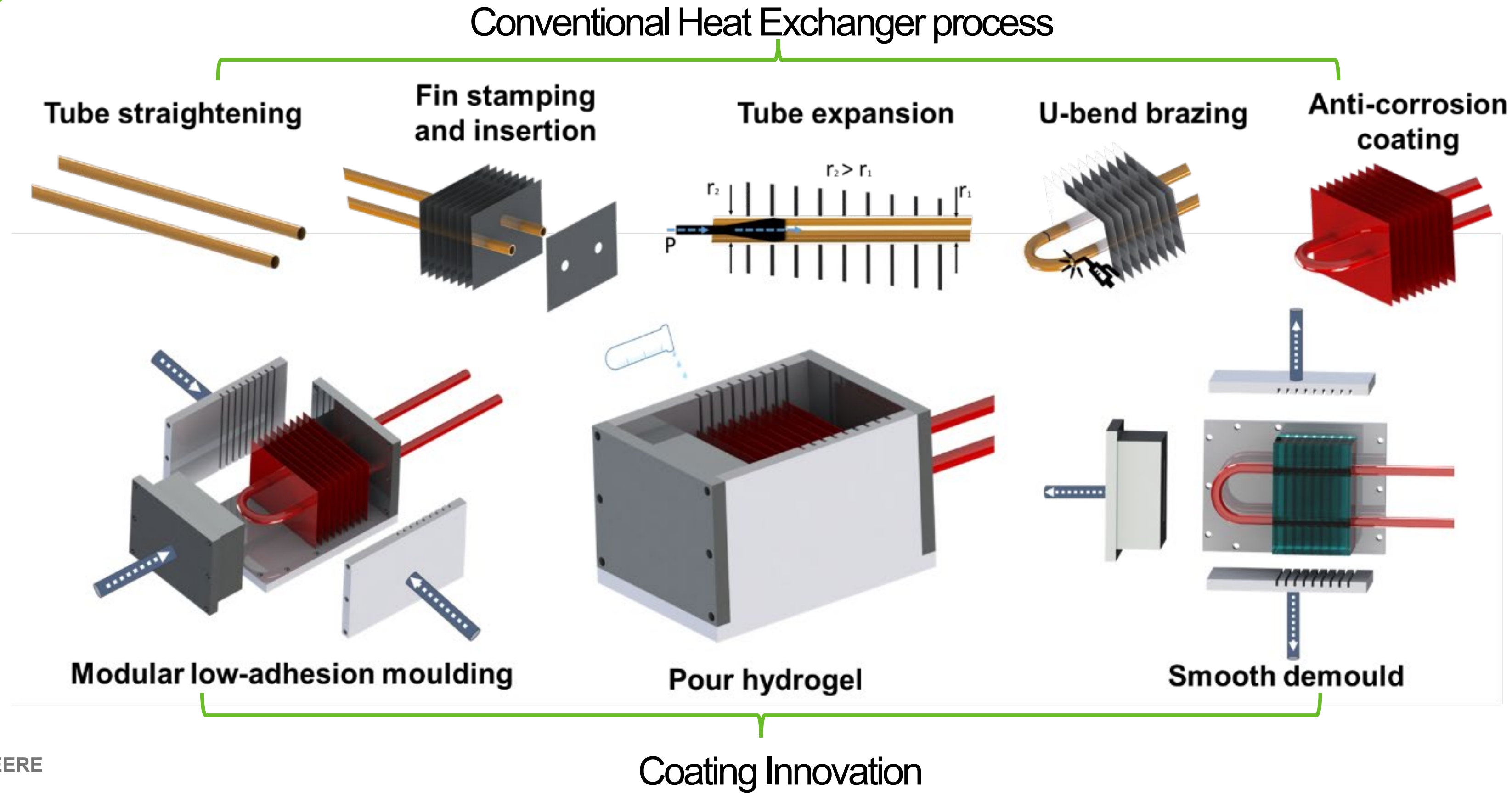


	Process
A.	Straighten and size
B.	Braze end
C.	Add wicking structure
D.	Form to shape

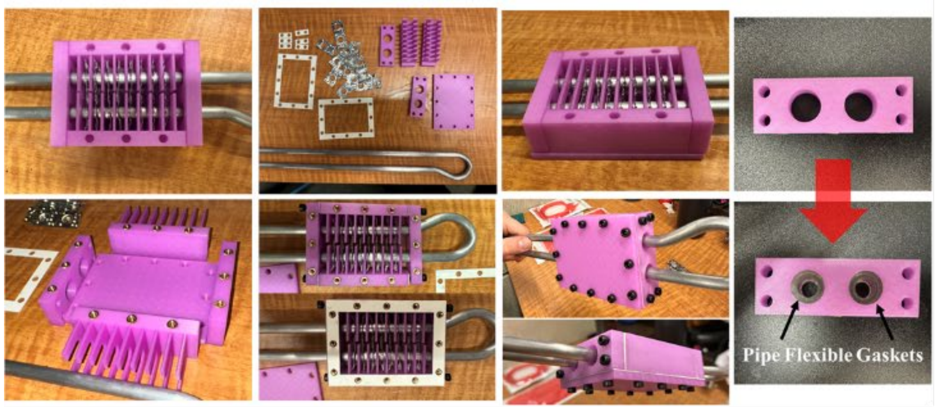


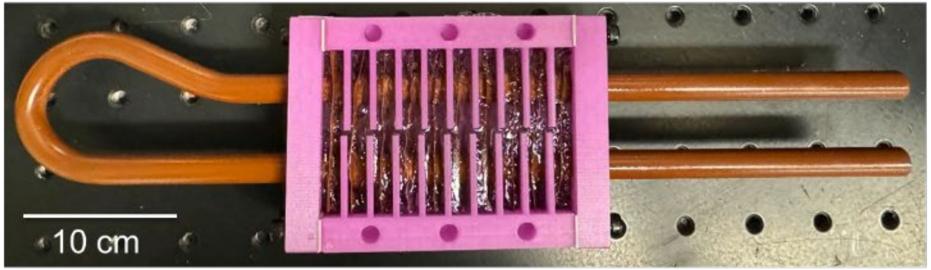


ABU Concept Fabrication and Moulding Procedure



Small Scale ABU Hydrogel Coating Repeatable

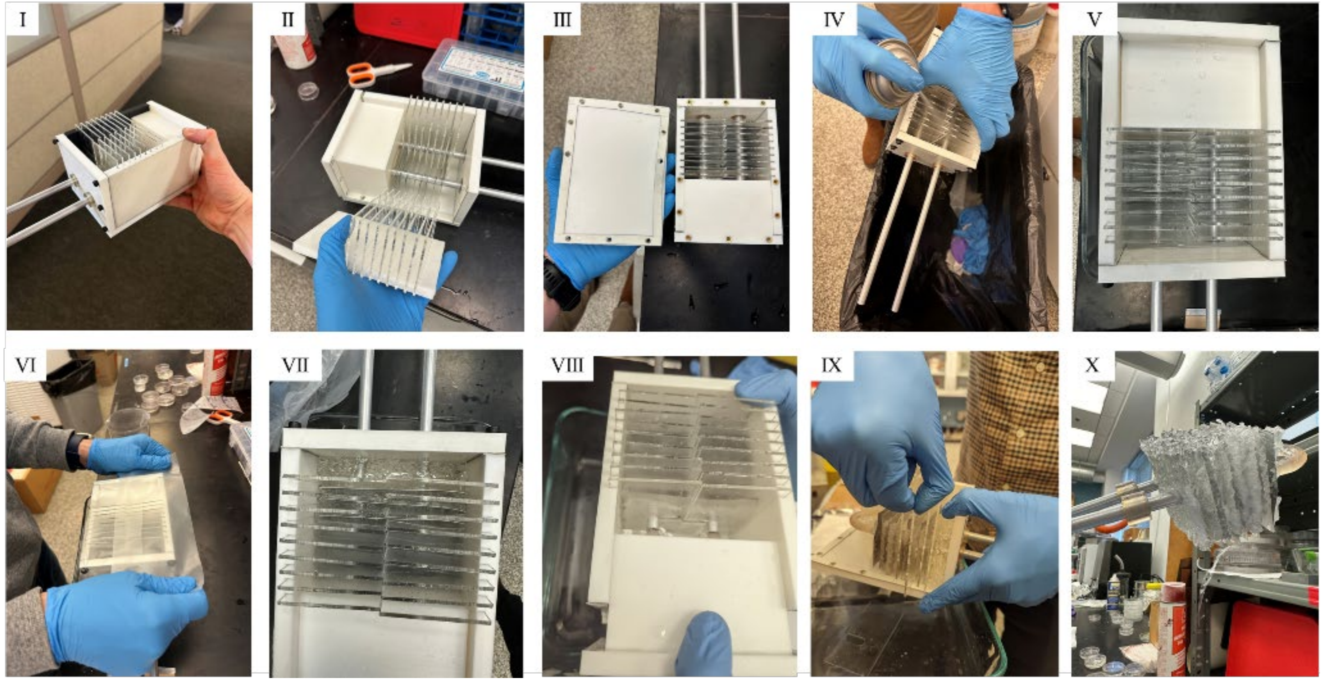




The following characterization setup is currently being tested under actual operating conditions

We demonstrate high quality, leak tight, and repeatable hydrogel ABU coating process

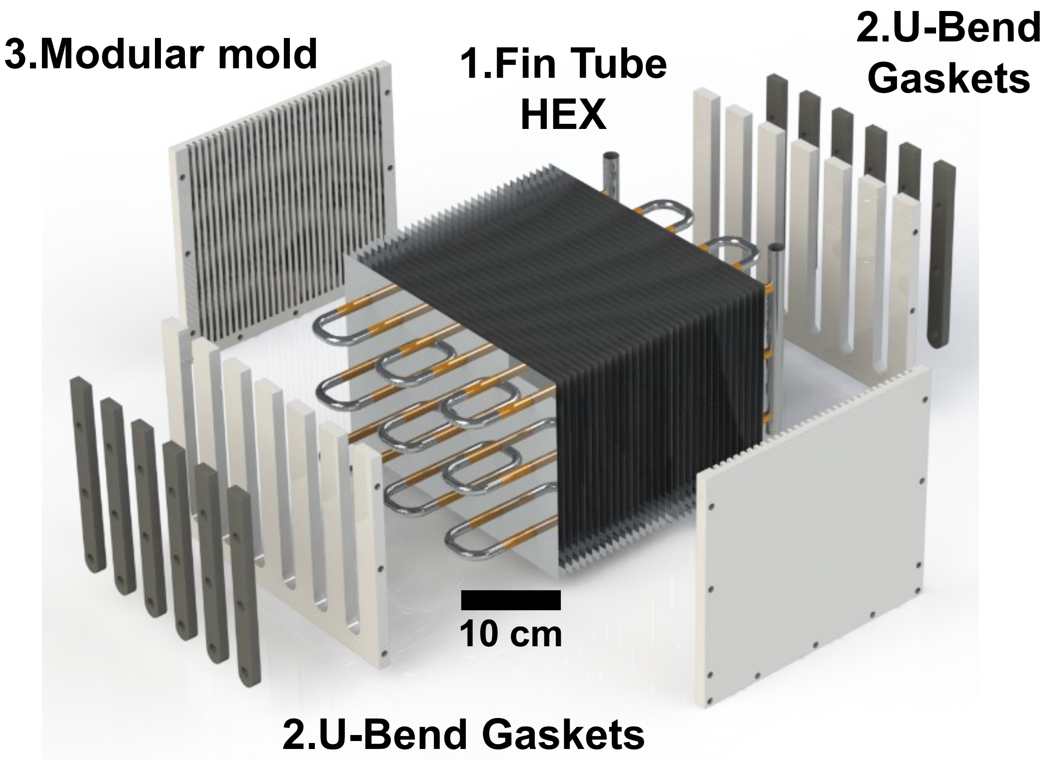
1/8th Medium Scale ABU Hydrogel Coating Repeatable

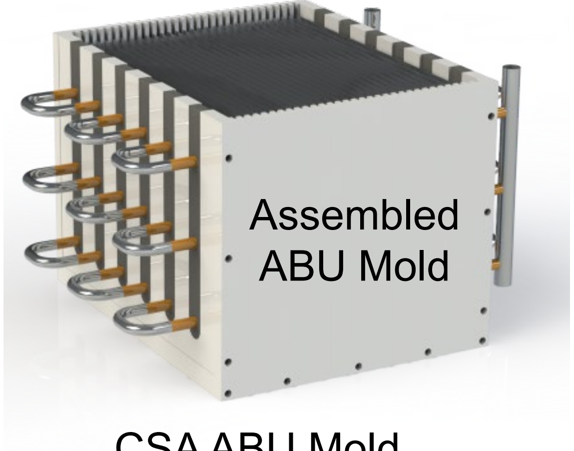


	Steps
I	Assembled mold
II	Modular panels
III	Eco gaskets
IV	Mold release spray
V	Pour gel
VI	Cover
VII	Gelate overnight
VIII	Demold
IX	
X	Gelated 1/8th ABU

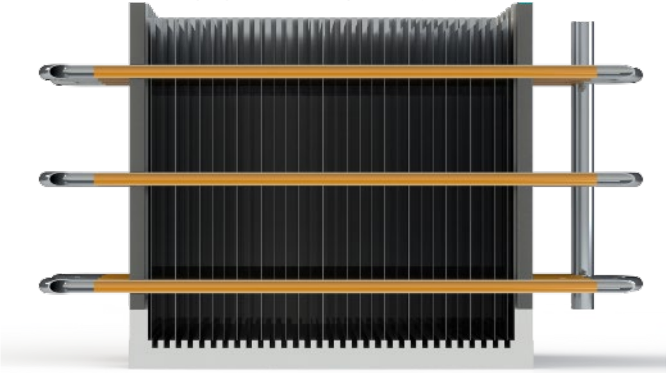
We successfully demonstrate scale up of hydrogel ABU coating process

Full-Scale 16 L ABU Hydrogel Coating Mold





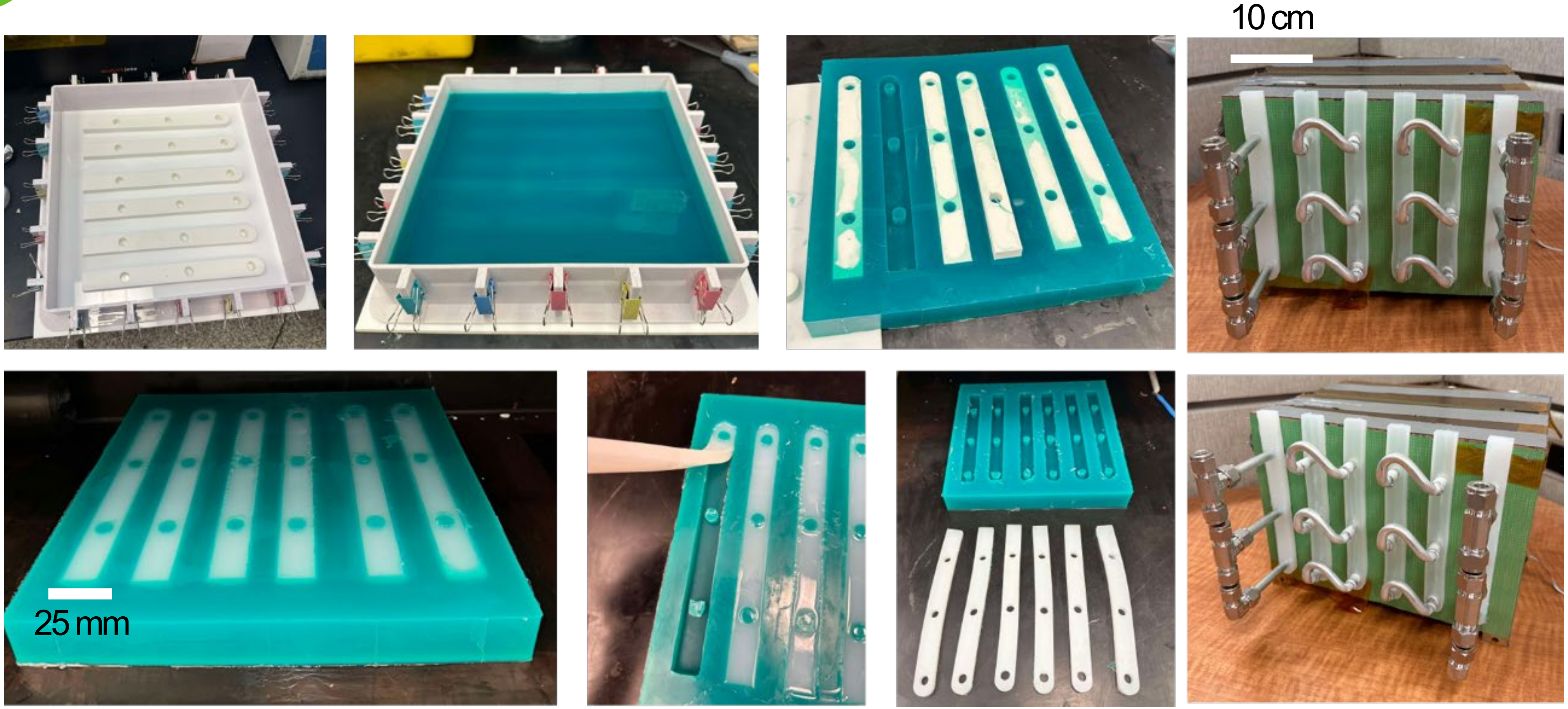
CSA ABU Mold



1. Full Scale ABU Heat Exchanger Fabrication

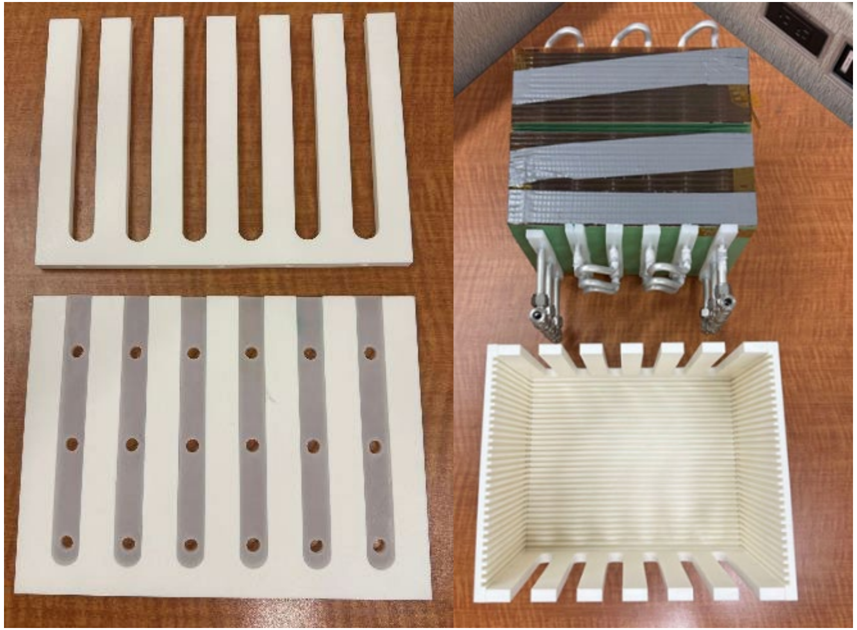
Demonstration of conventional low-cost heat exchanger fabrication for ABU component

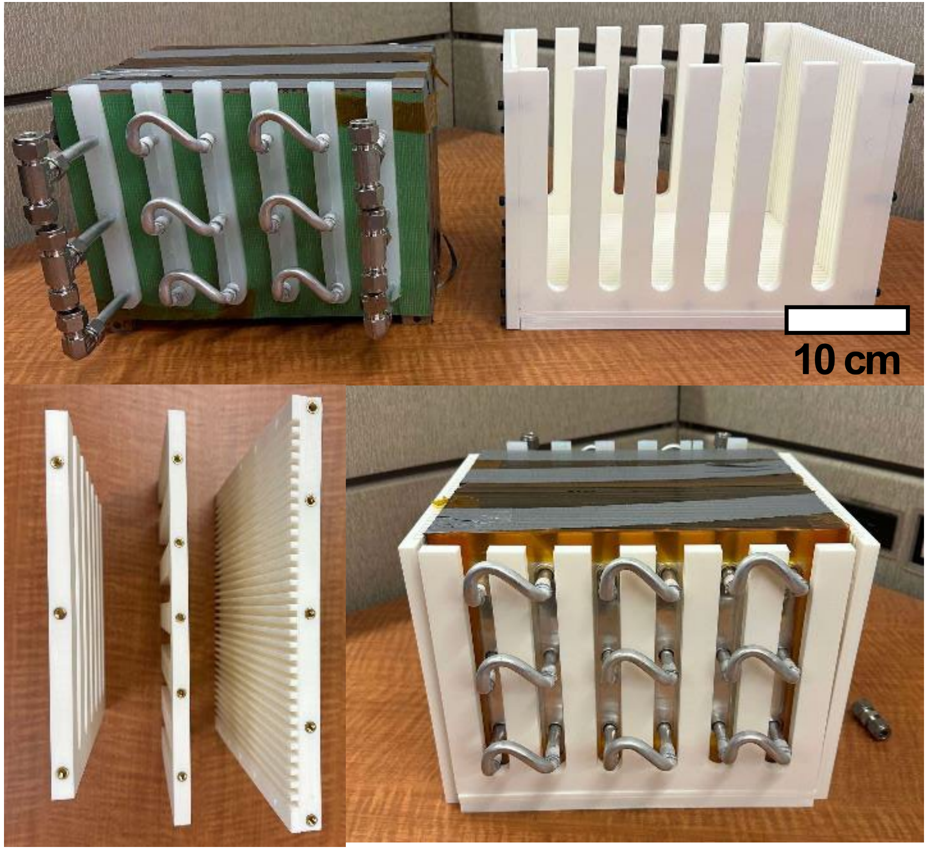
2. Fabrication of Custom Mold Silicone Gaskets



Scalable, low-cost & repeatable fabrication of mold gaskets - >600 gaskets per mold

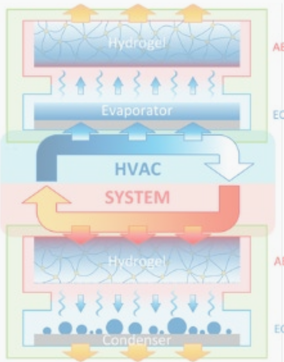
3. Modular ABU Mold



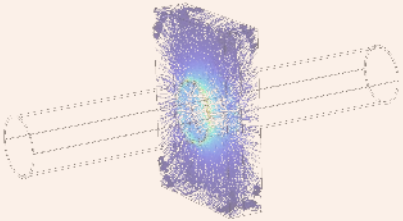


Low-cost leak tight and modular ABU mold

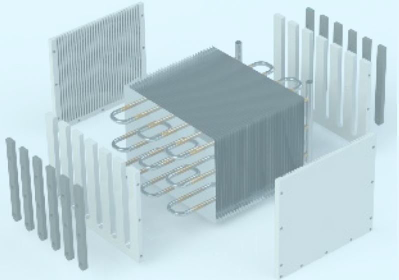
Experimentation



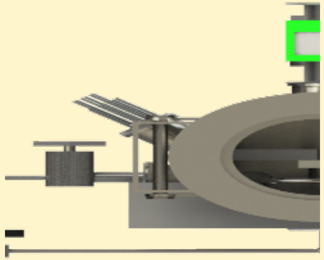
System



Design

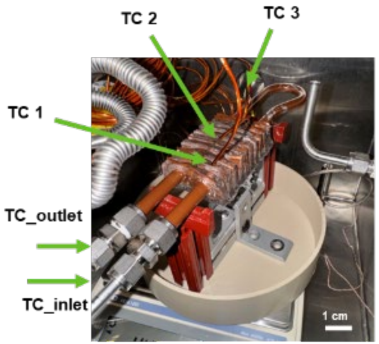


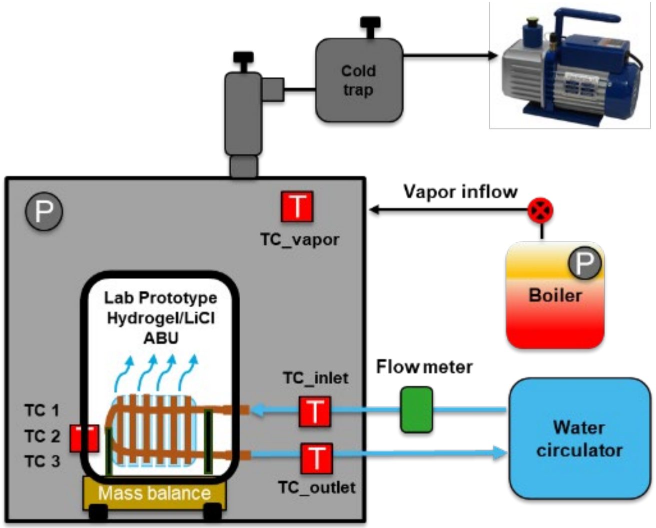
Scale up

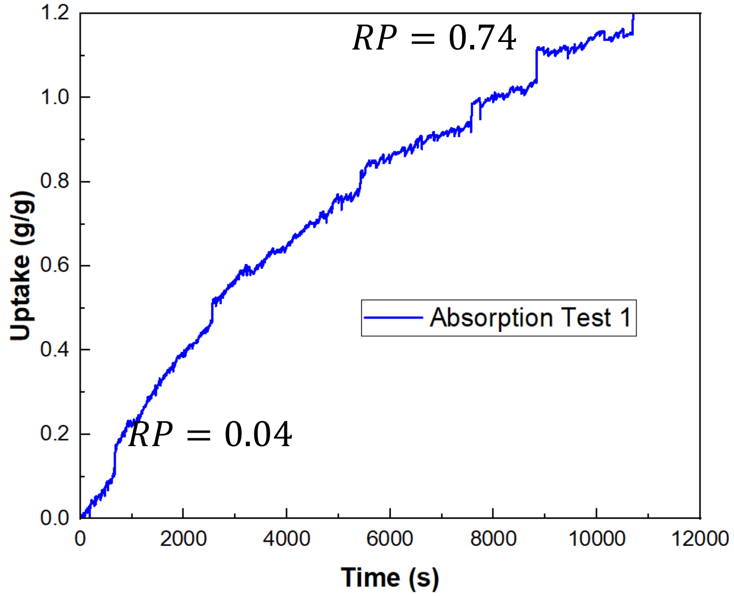


Experimentation

ABU – Experimental Characterization Setup

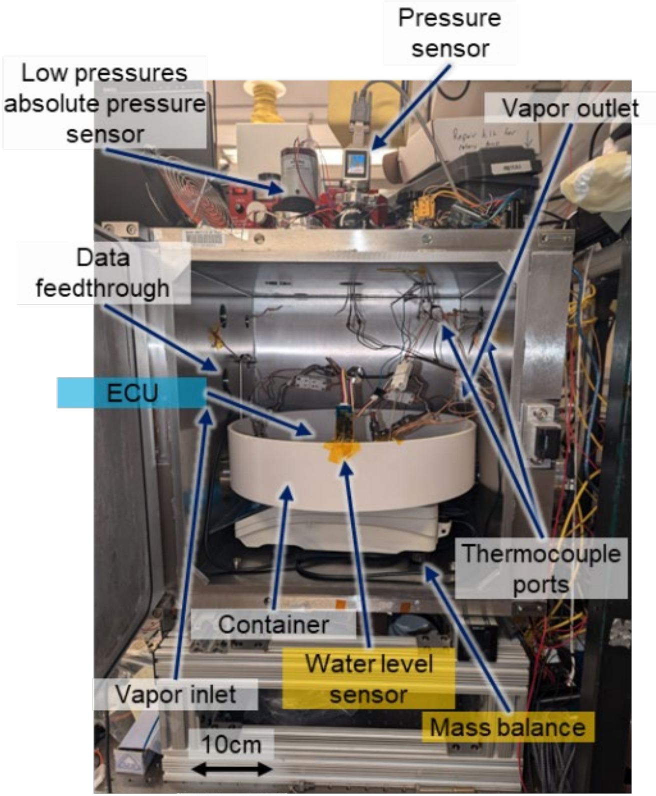




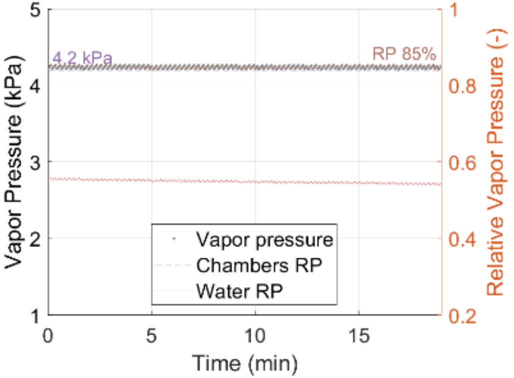


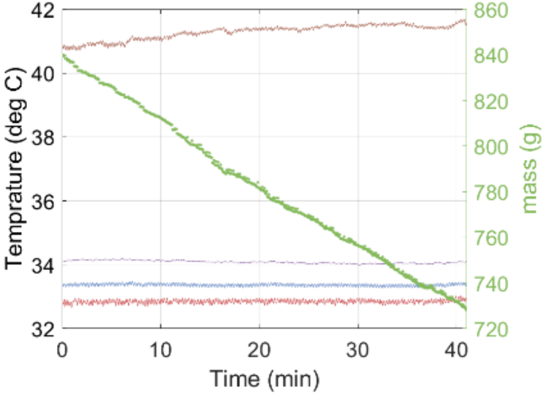
Hydrogel/salt coated heat exchanger shows repeatable performance. Temperature profiles, uptake, and kinetics validated experimentally.

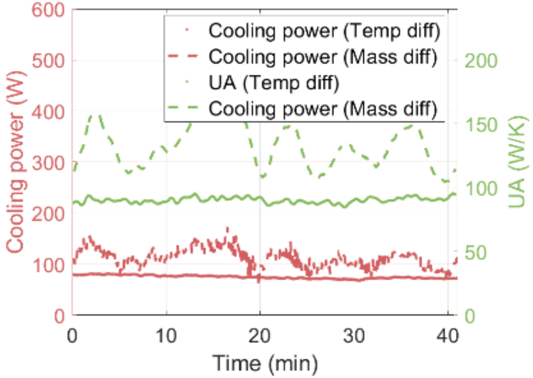
Experimental Setup for Full Scale Testing of ECU



Experiments of the full-scale ECU were performed in a large scale dedicated vacuum chamber







- Temperature and flow rate are equivalent to a 3-RT HVAC system operating at 25°C

- Achieved the designed performance at scale

Cost Model and Market Analysis

	Cost
ABU	44.04
ECU	24.72
Connector tubes & valve	10.00
Total cost ABU/ECU unit	**78.76**
Payback time - run 6 mo, (yr)	**2.12**
Cost, $ per kWh	**15.75**

ABU

- All aluminum tube/fin HX structure
- Lower-cost salt sourcing

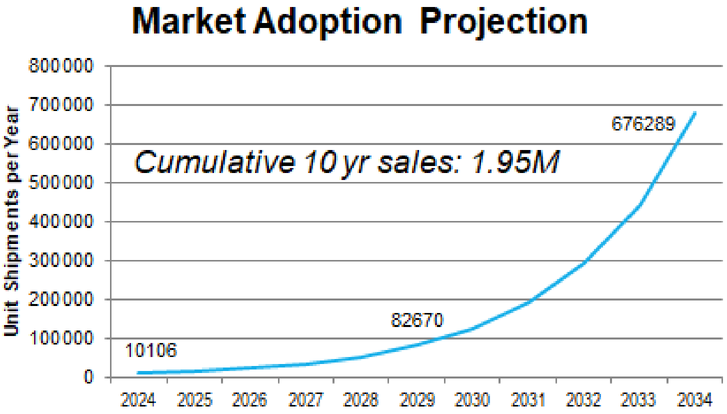
ECU

- Copper microchannel tube
- Replaced expensive copper foam with copper wire for wicking water on microchannel tube

U.S. Addressable Market: 8.7 M units (AC+HP)[1]

Market Adoption Rate:

- *Year 1, 0.1% rising to 4.1% in Yr 10*
- U.S. AC/HP Market growth - 5% CAGR



Source: MIT team cost estimates and market projections, AHRI Release, Feb 10, 2023[1]

Summary and Future work

Full Scale ABU

- Experimental characterization and optimization
- Minimize cost

System Integration

- Testing ABU+ECU (full scale)
- Risk assessment

Cyclic Testing

- Continue cycle testing to ensure stability > 1000 cycles

Field testing

- Integrating device to HVAC system
- Assess performance

Current Team

Dr. Joseph Mooney

Postdoctoral Fellow

MIT

Liliosa Eyang Cole

Graduate Student

MIT

Prof. Bachir El Fil

Assistant Professor

Georgia Tech/ MIT

Dr. David Keisar

Postdoctoral Associate

MIT

Briana Cuero

Graduate Student

MIT

Yoram Shabtay

HTT

Dr. John Black

HTT

Dr. Harshad Inamdar

Rheem

Thank you for your attention

Acknowledgements:

- Device Research Lab (MIT)

- DOE EERE:
- Sven Mumme and Joseph Mogyoros

For questions:

Bachir El Fil
bachir.elfil@me.gatech.edu
belfil@mit.edu
DE-EE0009679