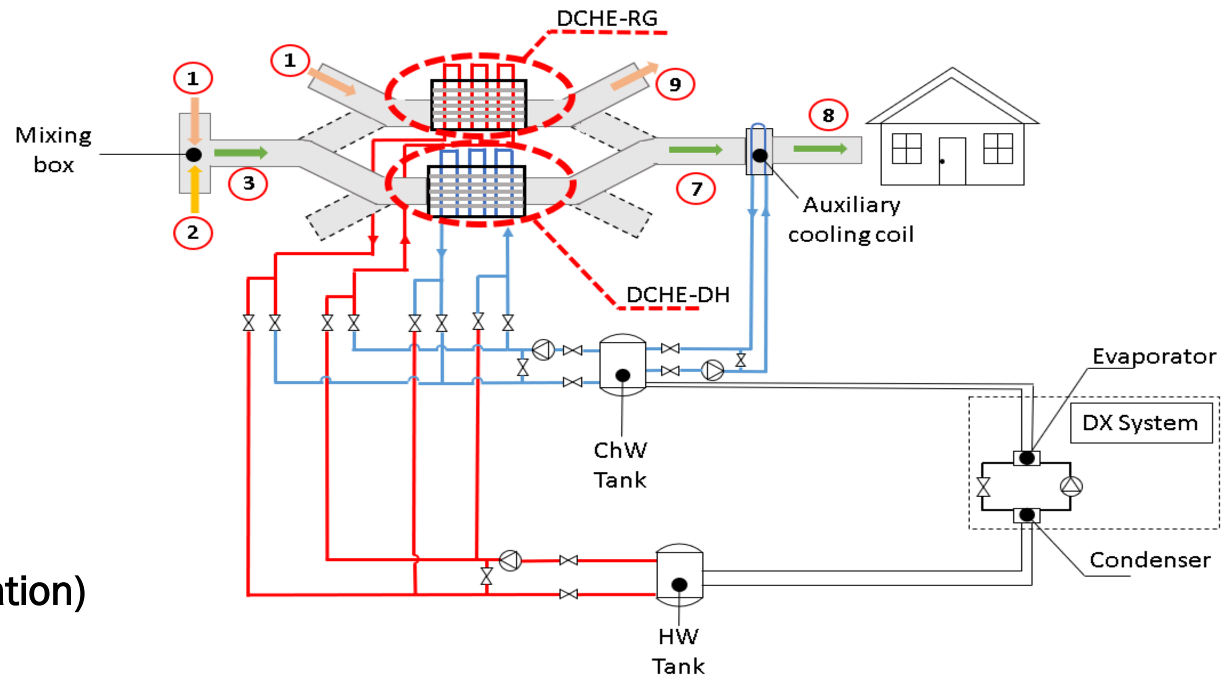
# Separate Sensible and Latent AC System





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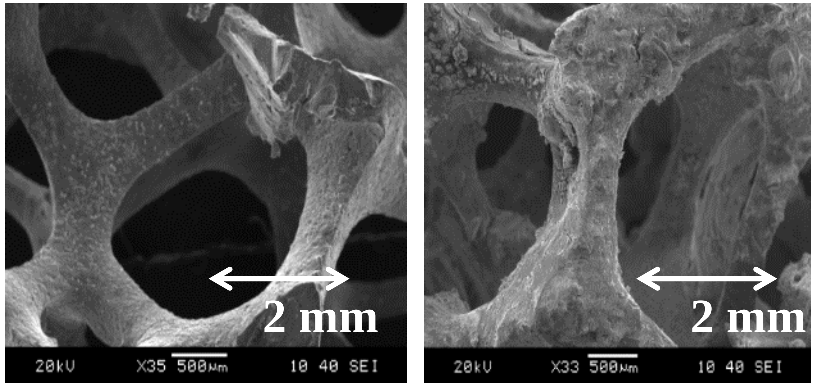
Oak Ridge National Laboratory
Presenter: Kai Li, Research Staff (Multifunctional Equipment Integration)

# Project Summary

## Objective and outcome

Development of an infrastructure to realize separate sensible and latent cooling in a cost-effective manner. The project team will develop desiccant coated heat exchangers and will demonstrate SSLC with 20% COP improvement compared to the state-of-the-art dehumidification systems.




## Team and Partners

**Oak Ridge National Lab**

Kashif Nawaz, Kai Li, Lingshi Wang, Kyle Glusenkamp, Ahmed Elatar, Tony Gehl, Zhenning Li

**Purdue University**

Ming Qu, Tomas Venegas

## Stats

Performance Period: Oct 2019 –March 2024

DOE budget: $250K/year, Cost Share: $75K/year

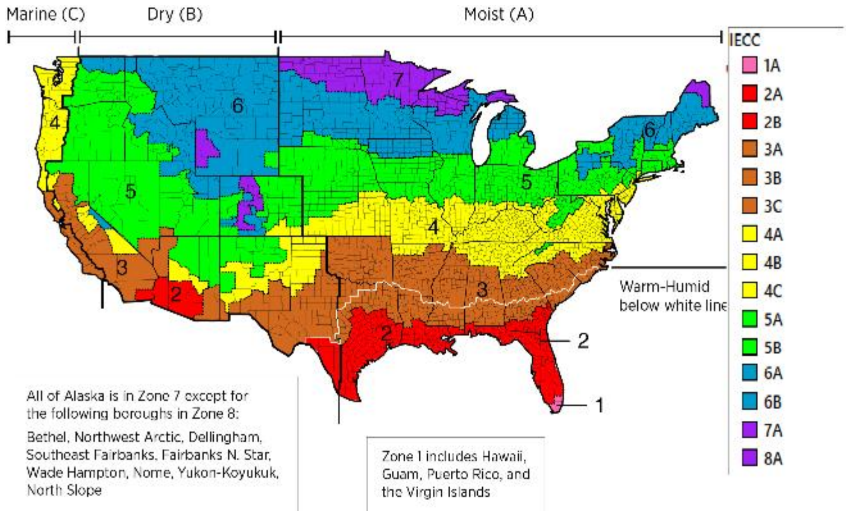
Milestone 1: Thermodynamic analysis of various configurations

Milestone 2: Development and performance evaluation of coated heat exchangers

Milestone 3: System level deployment

# Problem

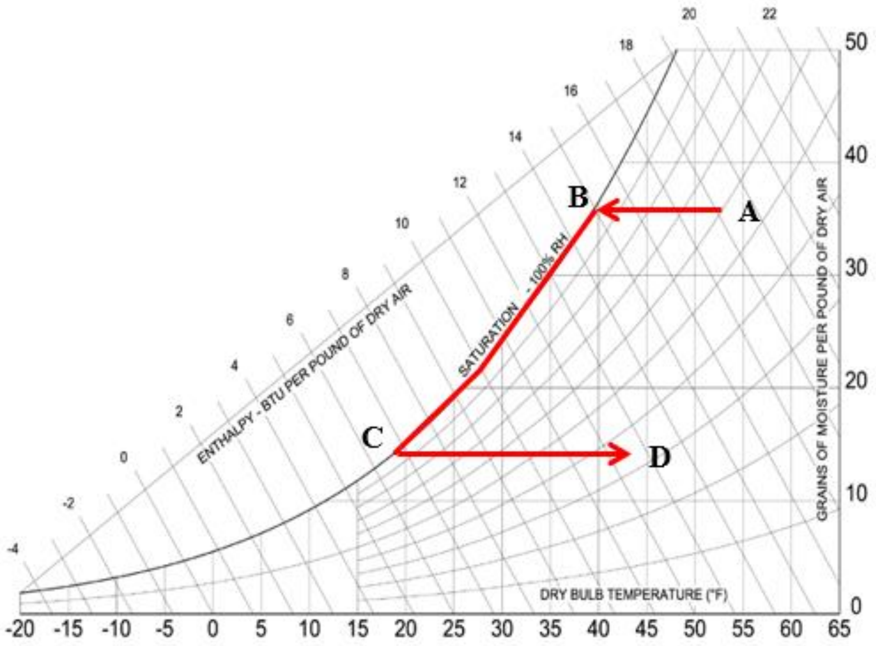
- On average, about 33% of energy consumption is attributed to dehumidification processes.
- Separate sensible and latent cooling (SSLC) systems offer significant improvements in the overall performance of cooling/dehumidification systems compared with conventional vapor-compression air-conditioning systems.
- Key to the energy efficiency of such systems is the performance of the heat and mass exchangers, which provide sensible cooling and dehumidification.
- The proposed work focuses on developing a novel technology to handle sensible as well as latent loads for buildings: a heat and mass exchanger deploying a metal foam as the substrate, coated with appropriate desiccant materials.

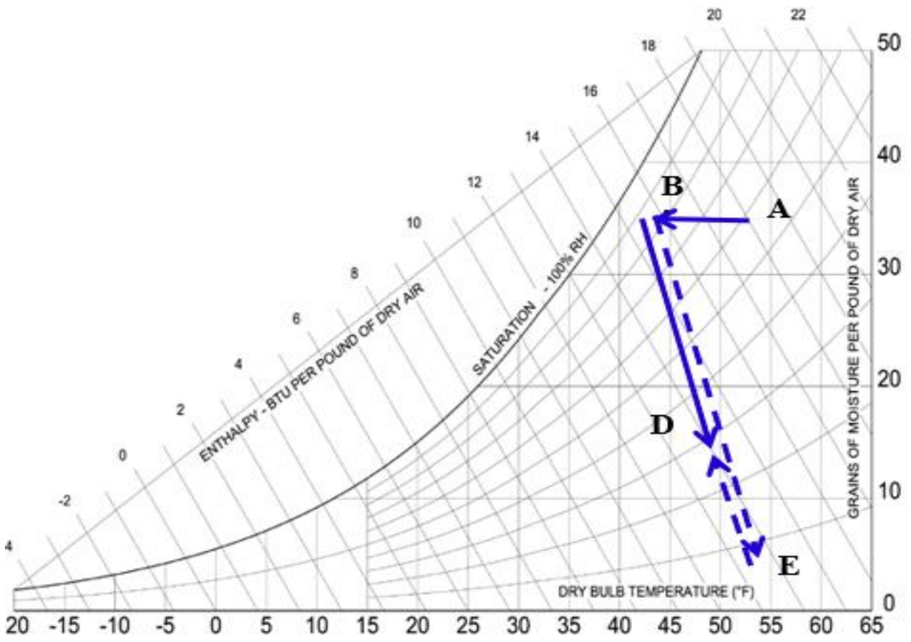



National climate map

# Approach

- Conventional dehumidification technology relies on a single vapor compression system to handle both sensible and latent loads.




- <u>Desiccant-coated enthalpy wheels</u> have some inherent disadvantages, including large size, inefficient process, and no effective control mechanism.
- The substrate is merely a support structure (polymer-based materials).

# Approach

**Phase 1**
Market evaluation

**Phase 2**
Feasibility analysis

**Phase 3**
System integration

Characterization of substrate materials (dry, wet, frost performance)

Desiccant characterization transient/ steady-state performance

Performance modeling of heat and mass exchanger (Coated HXs)

**Phase 2**- Feasibility analysis

Baseline system modeling (SSLC approach using VCS)

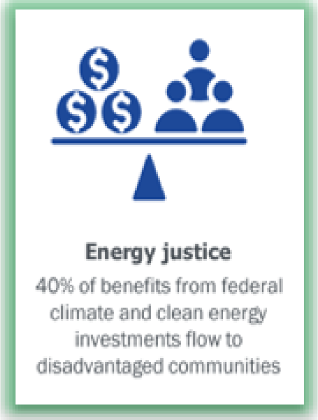
SSLC system analysis (Hybrid approach, coated HX and VCS)

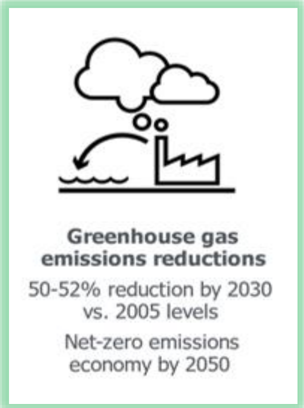
CRADA partnership

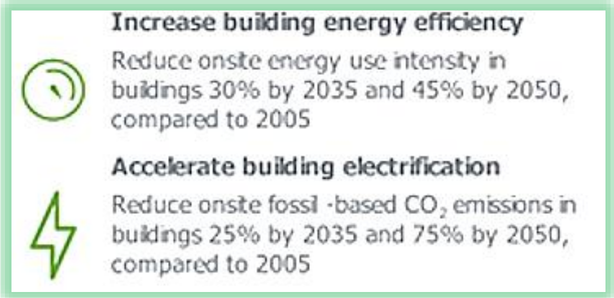
**Phase 3**- System integration

# Impact of Technology

- An improved dehumidification system deploying SSLC
  - Ultra-compact infrastructure to control the moisture content of supply air (>30% reduction in size)
  - At least 20% improvement in COP is expected compared with existing systems (single vapor compression).
  - At least 25% $CO_2$ emissions (>80 MMton) reduction due to improved performance
  - At least 40% cost saving compared to state of the art
- Enabling development for deployment of small-scale residential systems
  - Reduced cost of the working fluid
  - Reduced required maintenance due to compact design
- At least 800TBtu energy saving in air conditioning technologies

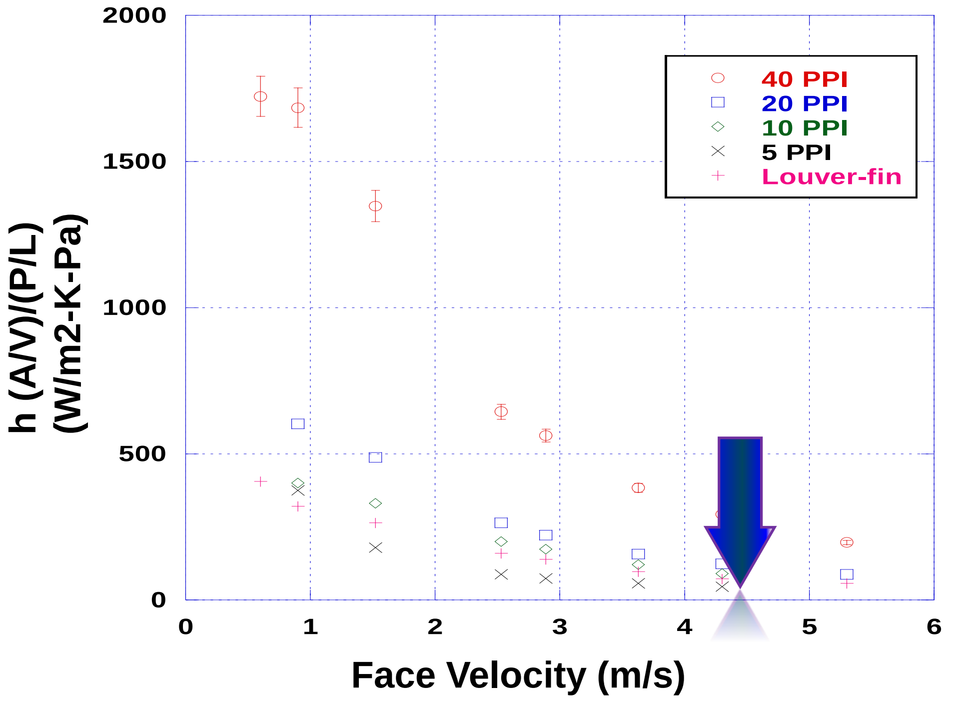


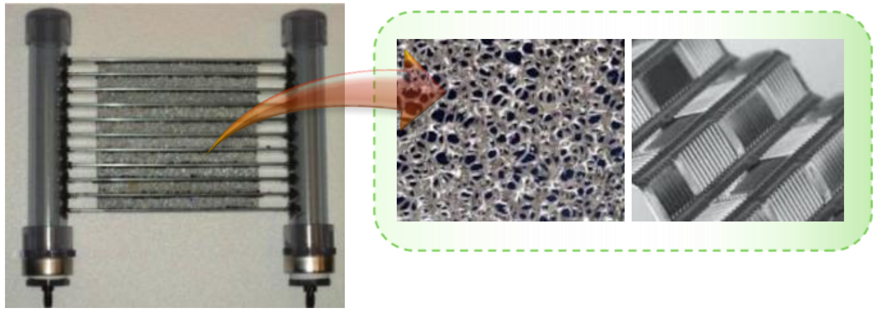



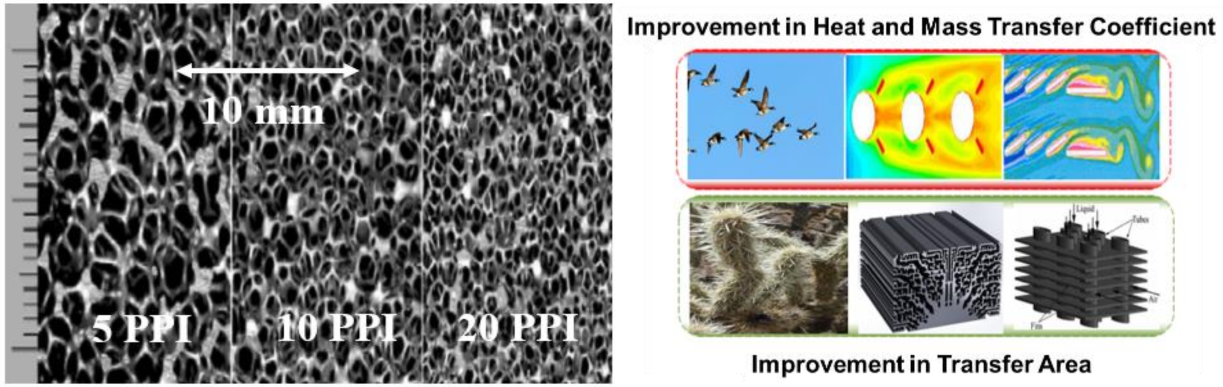

Aligned with BTO goal to develop energy efficient technology to cause 50% energy saving by 2030 compared to 2010 technologies and zero carbon foot-prints by 2050.

# Project Progress — Substrate Evaluation

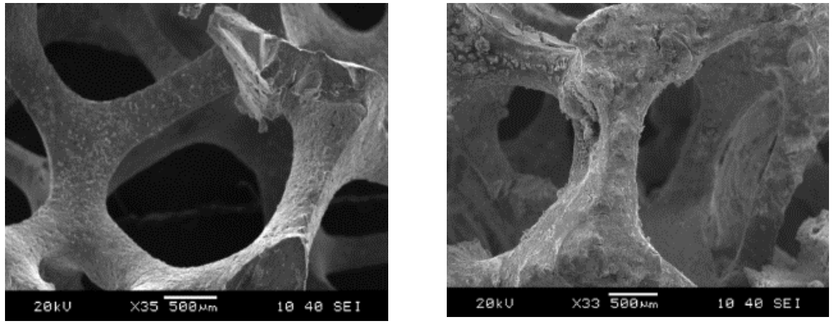


Heat exchangers developed at ORNL deploying high surface areas substrates




Metal foams with varying porosity (irregular porous media)

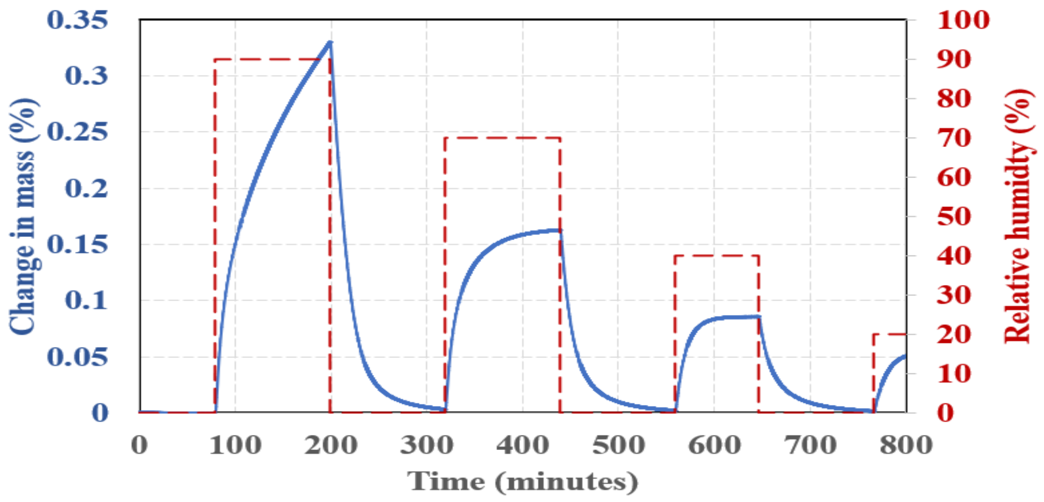


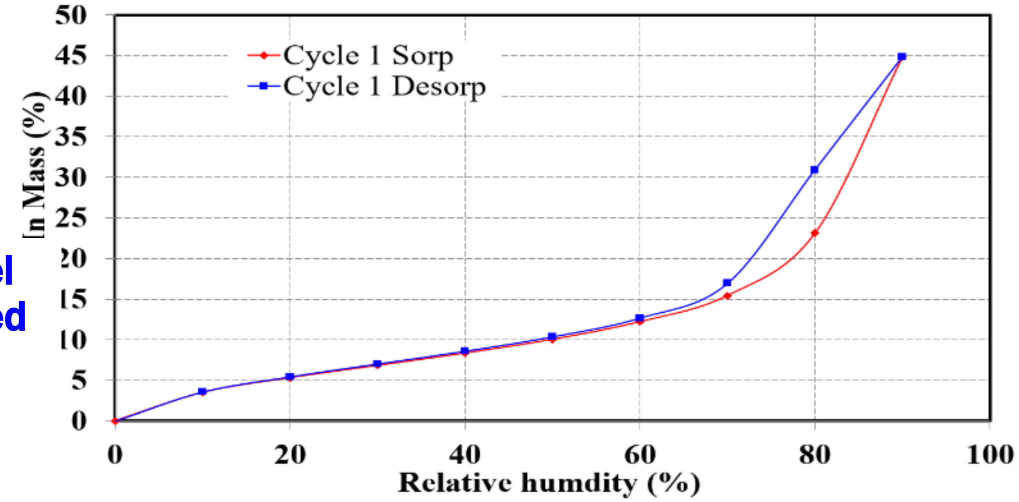
Coated vs. uncoated metal foam samples

$$f_{D_p} = \frac{\Delta P}{L}\frac{\bar{\rho}}{G^2}\frac{D_p}{2} = 1.975\,\mathrm{Re}_{D_h}^{-0.1672}\left(D_p/D_h\right)^{-3.708}$$

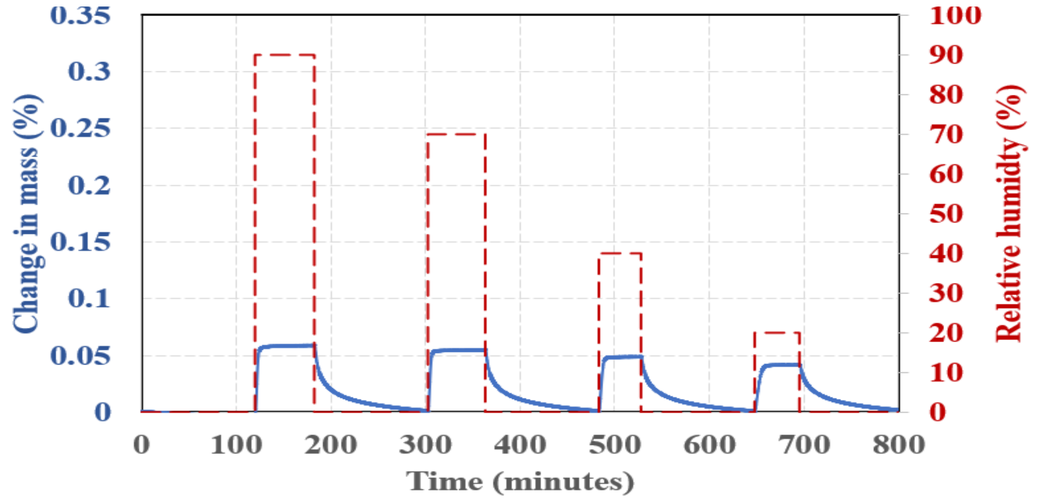
$$j_{Dp} = \frac{h}{\bar{\rho} c_p V}\frac{D_p}{D_h}\mathrm{Pr}^{2/3} = 2\,\mathrm{Re}_{Dh}^{-0.5611}\left(D_p/D_h\right)^{0.3213}$$

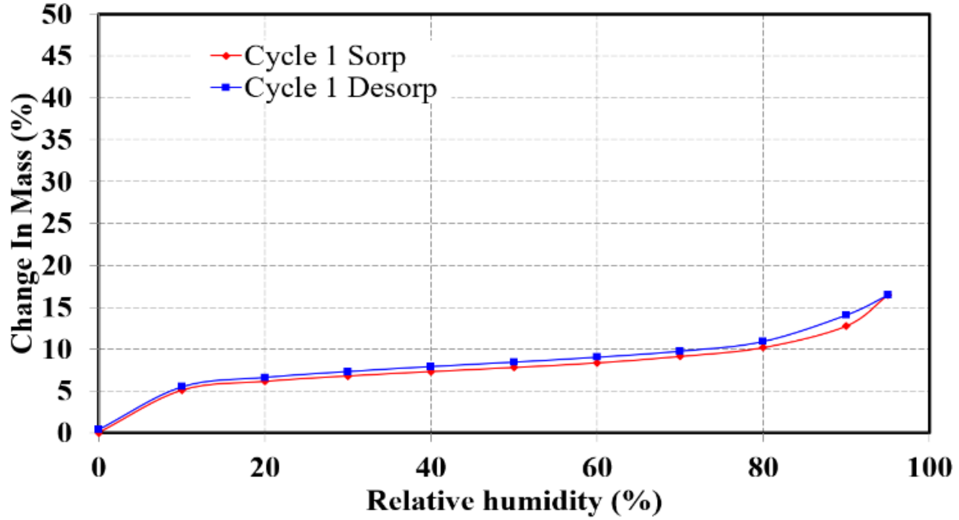
# Project Progress — Desiccant Evaluation




**Silica aerogel (manufactured at ORNL)**




**Zeolite 13X (Procured)**

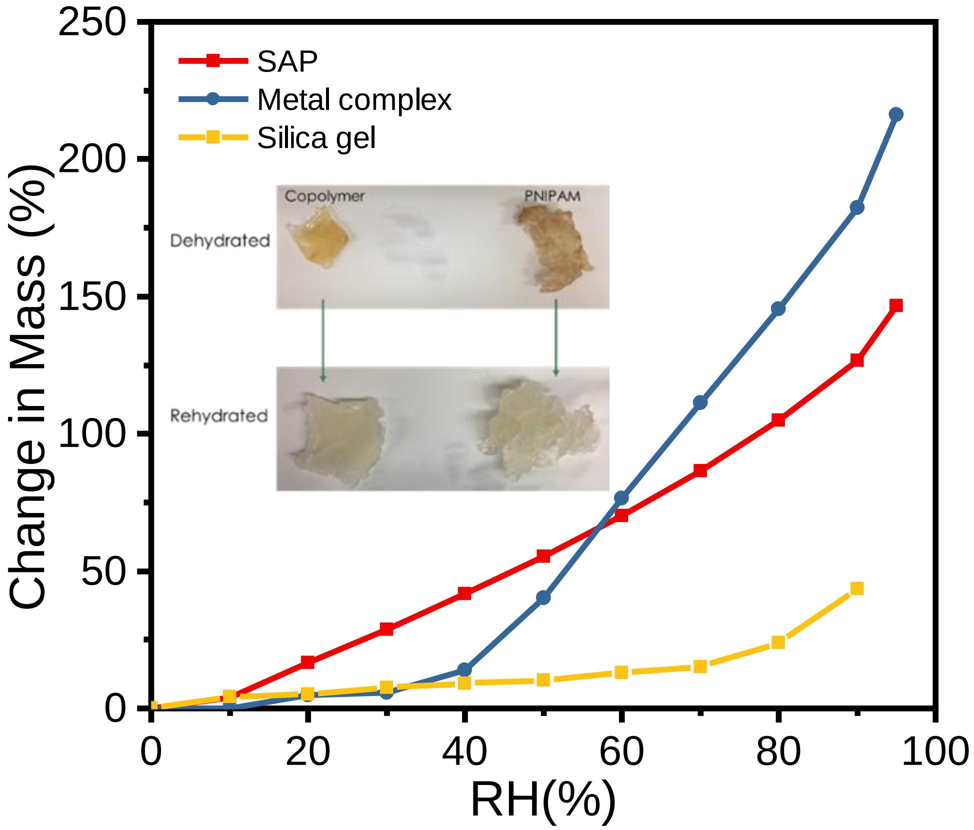
**Transient Response**

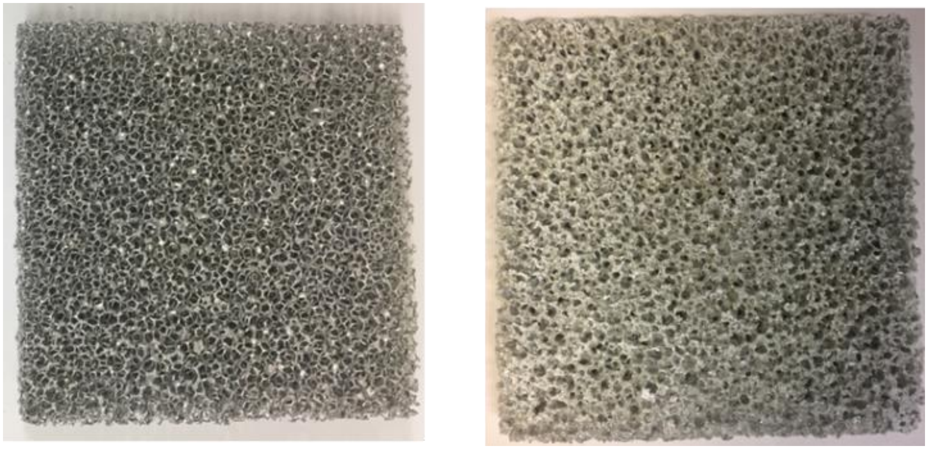
**Steady-state Response**

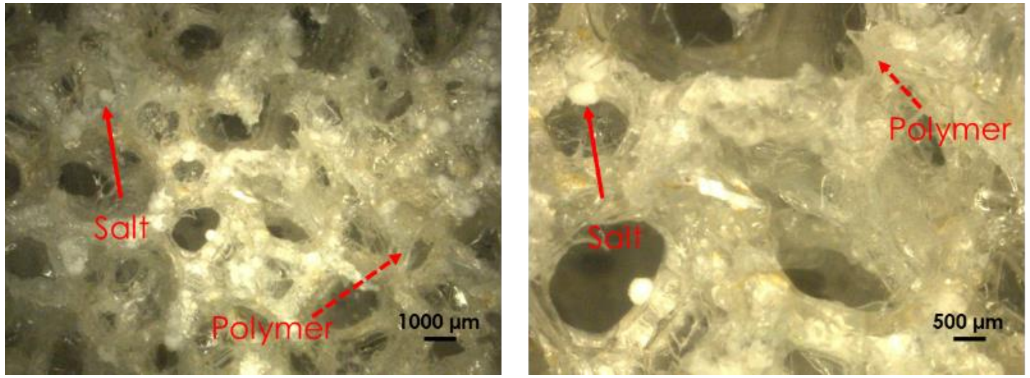
Project team has analyzed more than 15 materials including zeolites, aerogels, activated carbon fibers and hybrid materials!!

# Project Progress — Desiccant development and coating

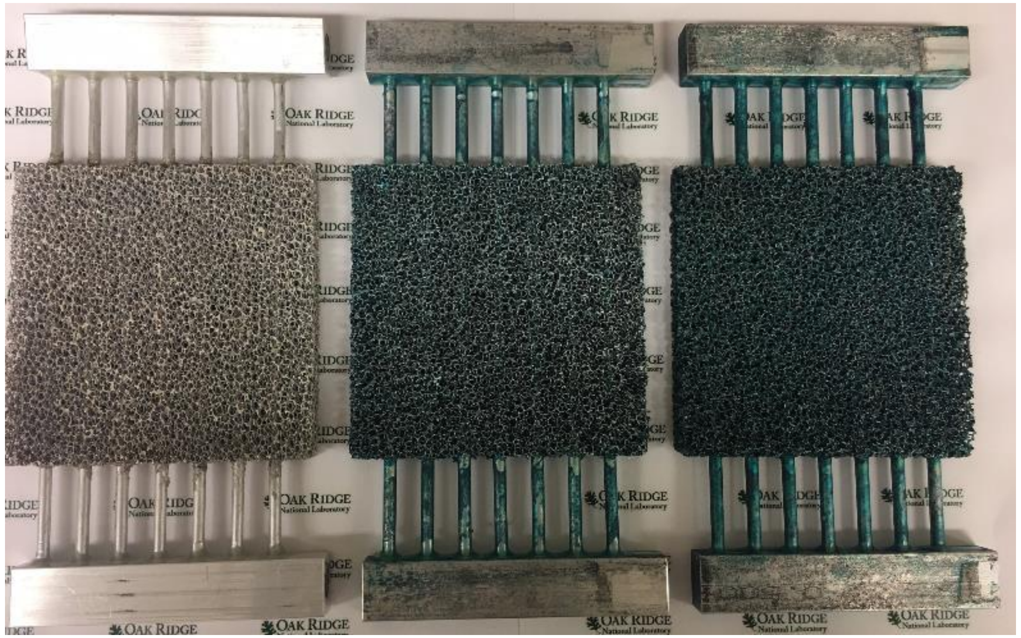
- Developed <u>new desiccant materials</u> with high moisture absorption capacity and low regeneration temperature
- Development one step polymerization induced desiccant coating on metal foam



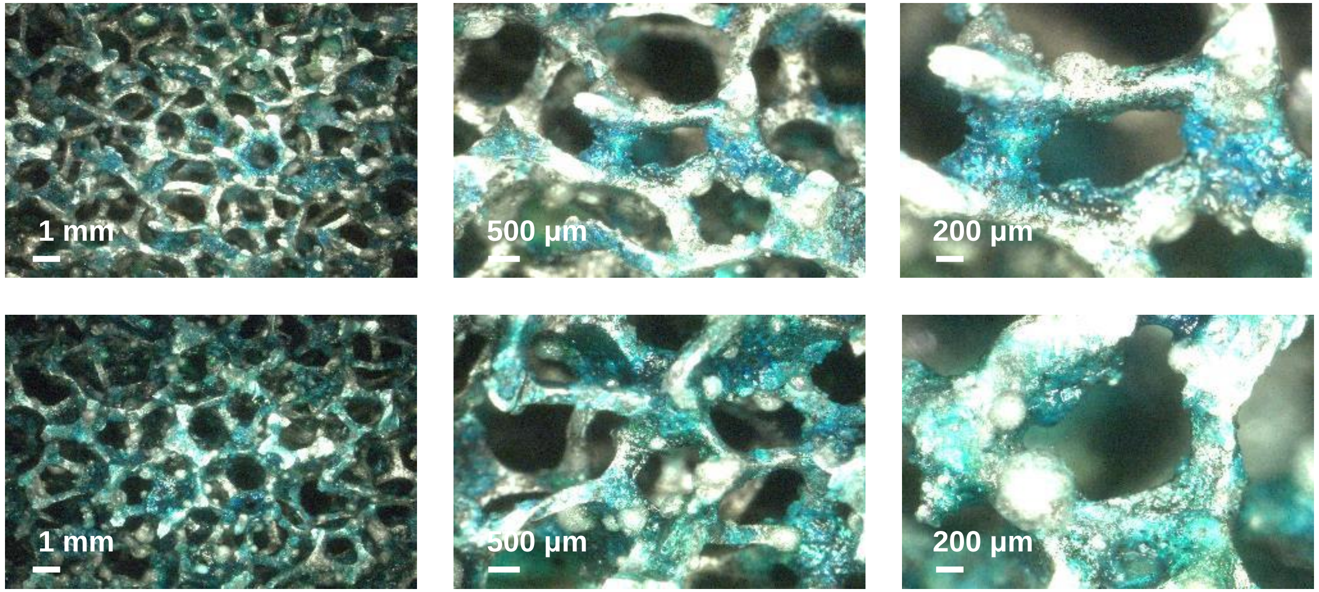





# Project Progress — Desiccant development and coating



Uncoated and coated heat exchanger

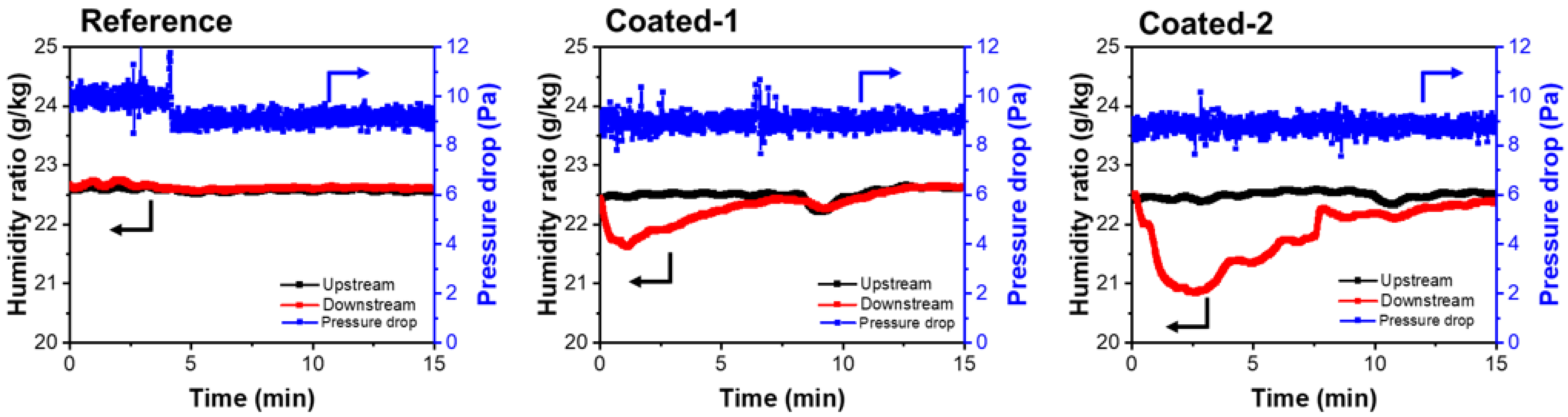



Close-up views of coated heat exchangers

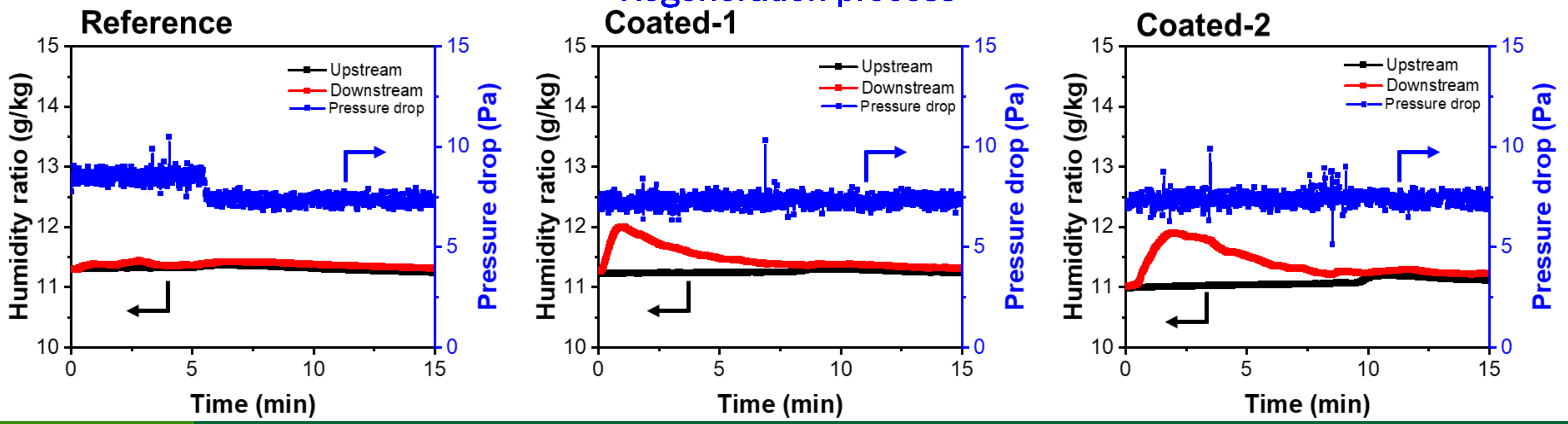
- Development of appropriate surface morphology for coating process
- Uniform coating without blocking the pores is critical for successful deployment
- The coatings should be durable in order to ensure sustainable process

# Project Progress — Performance evaluation

Adsorption process

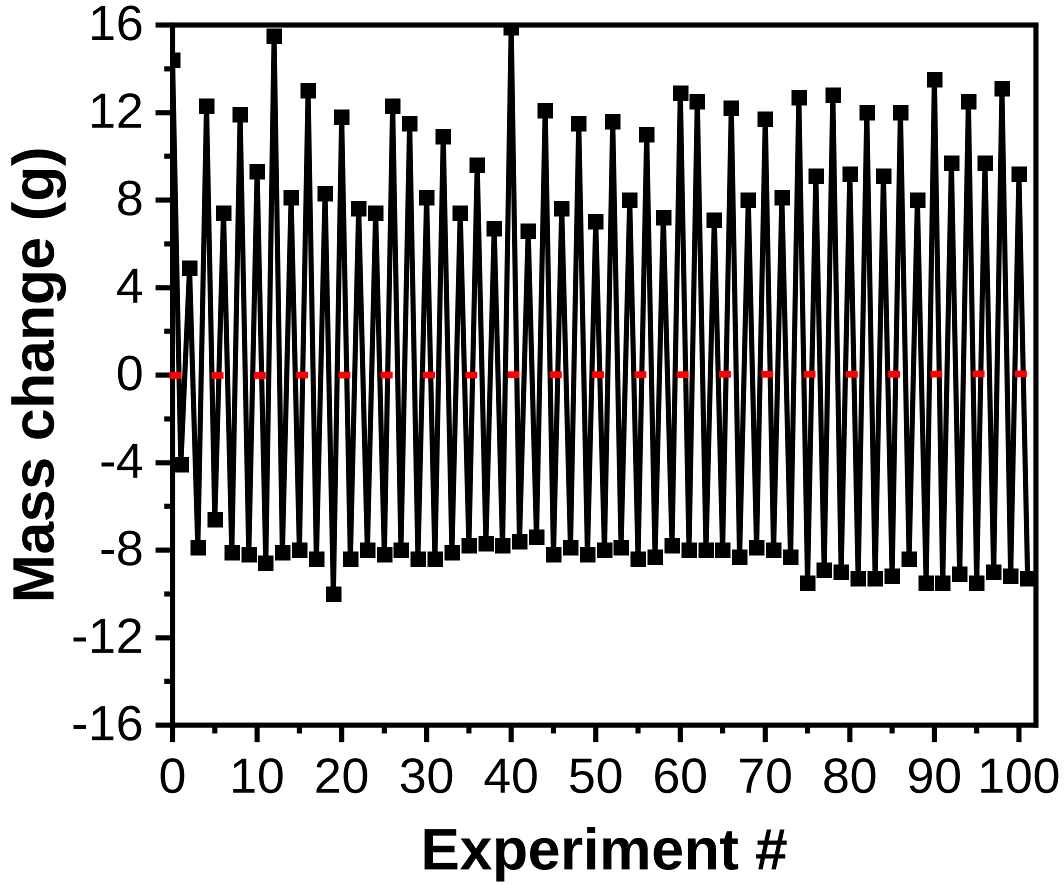


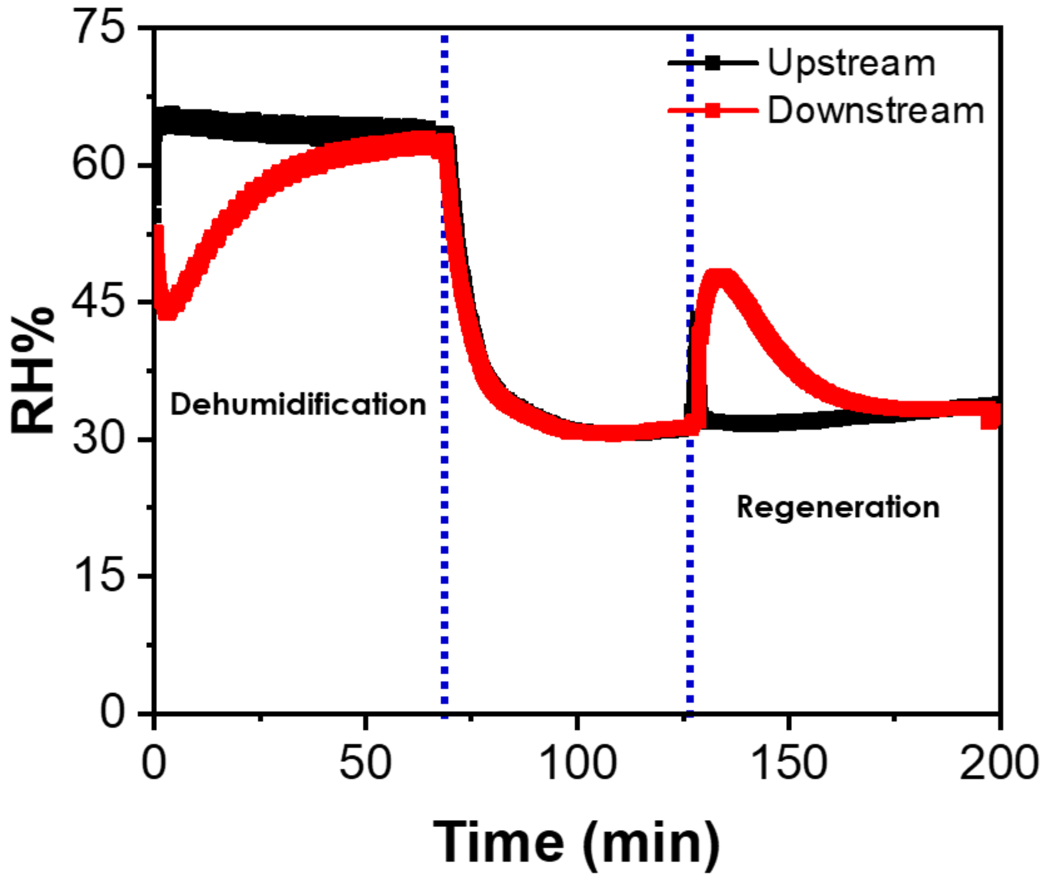

Regeneration process



# Project Progress – Performance evaluation

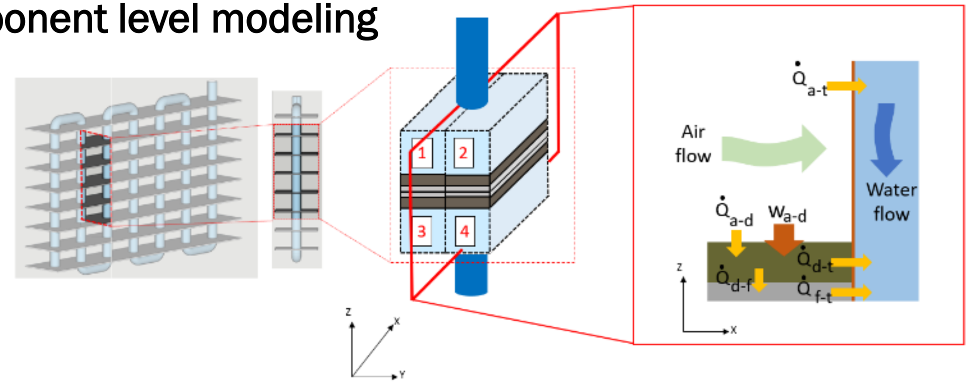
- SAP coated metal foam shows stable desorption and absorption behavior during **50 cyclic regeneration and dehumidification cycles**
- Coating are durable in the during the cyclic desorption and absorption experiments



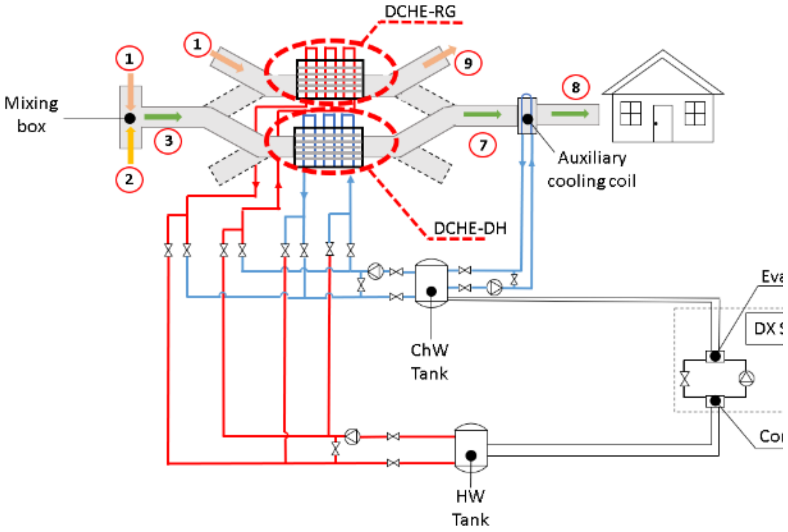



# Project Progress – Modeling

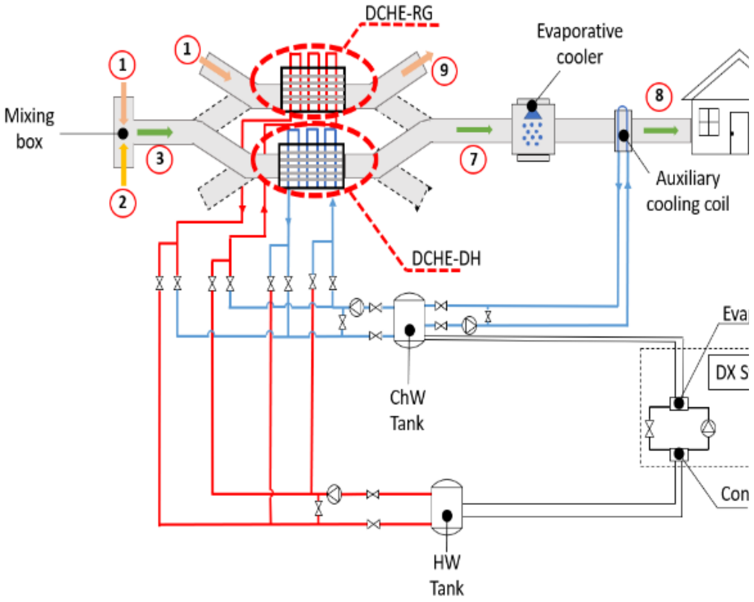
## Component level modeling



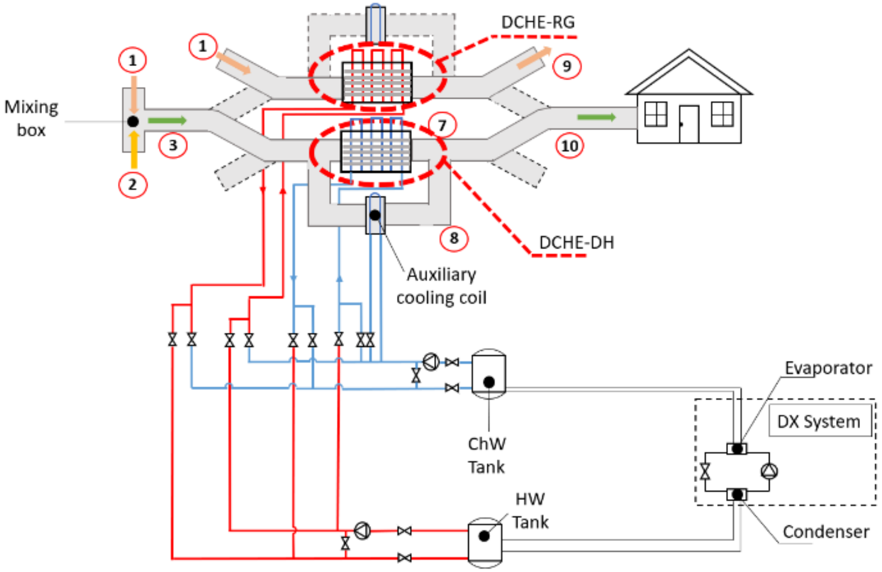

## System level modeling




Configuration 1

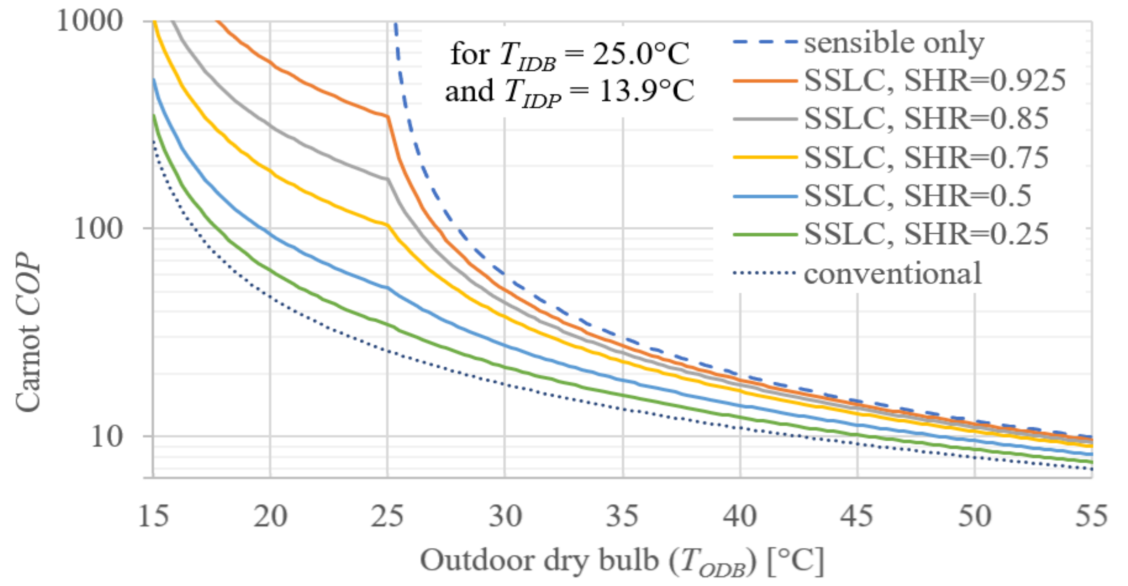



Configuration 2

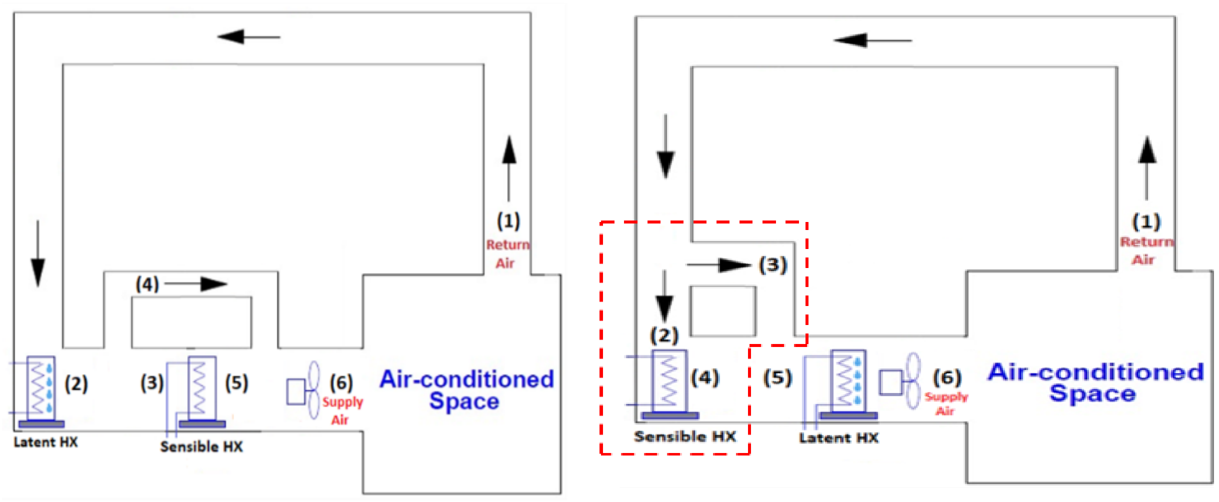



Configuration 3

# Project Progress – Modeling




Carnot COP limits for conventional, SSLC, and sensible-only cooling




Evaluation of various SSLC configuration

$$COP_{\max} = \frac{\dfrac{\Delta h_{tot}}{c_p}}{2\sqrt{T_{IDB}T_{ODB}(1+C_2)} - (T_{IDB} + T_{ODB} + C_2 T_{LHX}) + \dfrac{C_1 C_2}{c_p}}$$

$$C_1 = h_{fg}(w_{ID} - w_{LHX}) \qquad C_2 = \frac{T_{ODB} - T_{LHX}}{T_{LHX}}$$

# Publications and Implications

- Several conference/journal publications
- T. Venegas, M. Qu, K. Nawaz, L. Wang, "Effect of Geometry and Operational Parameters on the Dehumidification Performance of a Desiccant Coated Heat Exchanger", Science and Technology for the Built Environment, 2022, 28, 6, 729-741 (https://doi.org/10.1080/23744731.2022.2077595)
- T. Venegas, M. Qu, K. Nawaz, L. Wang, "Critical review and future prospects for desiccant coated heat exchangers: materials, design, and manufacturing," Renewable and Sustainable Energy Reviews, 2021, 151, 111531 (https://doi.org/10.1016/j.rser.2021.111531).
- M. Qu, K. Nawaz, T. Venegas, L. Wang, "Effect of geometry and operational parameters on the dehumidification performance of a desiccant coated heat exchanger," 2020 Building Performance Analysis Conference and SimBuild (Virtual- co-organized by ASHRAE and IBPSA-USA).
- K. R. Gluesenkamp, K. Nawaz, "Separate sensible and latent cooling: Carnot limits and system taxonomy," International Journal of Refrigeration, July 2021, 127, 128–136 (https://doi.org/10.1016/j.ijrefrig.2021.02.019).
- Z. Li, K. R. Gluesenkamp, K. Nawaz, "Analysis of basic airflow configurations for separate sensible and latent cooling systems with indoor air recirculation," International Journal of Refrigeration, July 2021, 127, 78–88 (https://doi.org/10.1016/j.ijrefrig.2020.12.026).
- K. Nawaz, K. Gluesenkamp, "Separate sensible and latent cooling systems: a critical review of the state-of-the-art and future prospects," 17th International Refrigeration and Air Conditioning Conference at Purdue, July 9–12, 2018, Purdue University, Lafayette, IN.
- K. Li, J. Brechtl, K. Nawaz, Desiccant coated heat exchanger for moisture management, ACS Spring 2023, March 26-30, Indianapolis, IN
- Separate sensible and latent cooling using Metal complex coated metal foam (In progress)
- Salt-in-hydrogel coated metal foam for dehumidification (In progress)
- US nonprovisional patent application 16/942,853, "Metal Foam Heat Exchangers for Air and Gas Cooling and Heating Applications."

# Stakeholders Engagement

- New IEA Annex and workshop “Comfort and Climate Box solutions for warm and humid climates”.

# Major Tasks

| Task name: | Task description: |
|---|---|
| Desiccant characterization | This task will focus on the procurement, development, and deployment of various desiccants, and on evaluating their performance as solids and coatings. |
| Test facility for heat/mass exchanger performance evaluation | A dedicated test facility will be established to conduct thermal-hydraulic testing of HXs. The same facility will be used for mass exchanger analysis as well. |
| Thermal-hydraulic characterization of metal foam heat exchangers | Metal foam HXs will be tested under various operating conditions, and their performance will be summarized as correlations. |
| Performance modeling | Based on findings from the previous tasks, a performance model will be developed to predict the performance of a coated mass exchanger. |
| Thermal-hydraulic characterization of coated conventional and metal foam heat/mass exchangers | This task will focus on extensive experimentation in a wind tunnel to observe the moisture adsorption capacity of the coated mass exchanger. In addition, characteristics such as sensible heat transfer rate and regeneration process will be analyzed. |
| Parametric analysis | Various parameters of the substrate and desiccant coating thickness will be investigated for potential effects on coated mass exchanger performance. |
| CRADA partnership | Engagement with OEMs to evaluate the performance in field |

# Thank you

Oak Ridge National Laboratory

Kashif Nawaz, Section Head of Building Technologies Research; Group Leader of Multifunctional Equipment

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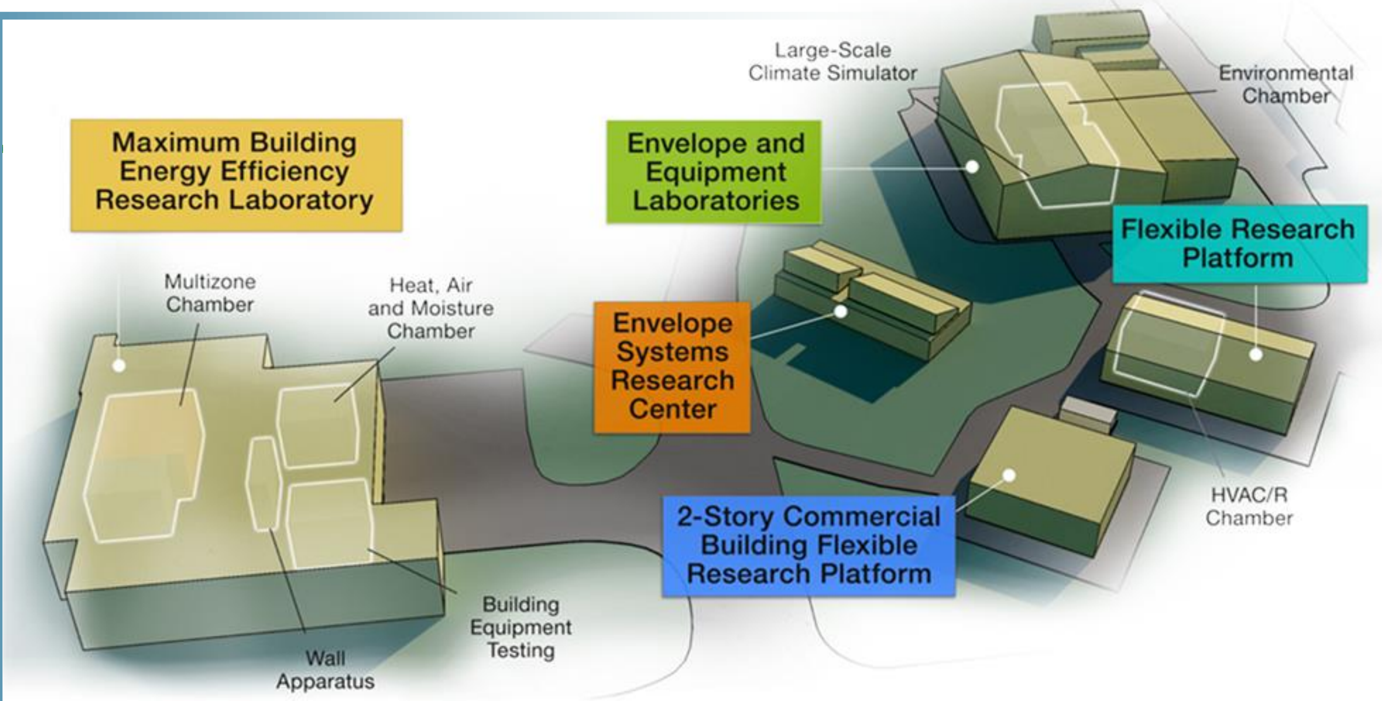


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**Scientific and Economic Results**

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

***BTRIC is a DOE-Designated National User Facility***

# REFERENCE SLIDES

# Project Execution

| | FY20XX | | | | FY20YY | | | | FY20ZZ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planned budget | | | | | | | | | | | | |
| Spent budget | | | | | | | | | | | | |
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **Past Work** | | | | | | | | | | | | |
| Q1 Milestone: Example 1 | | | | | | | | | | | | |
| Q2 Milestone: Example 2 ( ◆ is planned date of milestone) | | | | | | | | | | | | |
| Q3 Milestone: Example 3 | | | | | | | | | | | | |
| Q4 Milestone: Example 4 | | | | | | | | | | | | |
| Q1 Milestone: Example 5 | | | | | | | | | | | | |
| **Current/Future Work** | | | | | | | | | | | | |
| Q3 Milestone: Example 6 | | | | | | | | | | | | |
| Q4 Milestone: Example 7 | | | | | | | | | | | | |
| Insert more Milestones as needed | | | | | | | | | | | | |

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