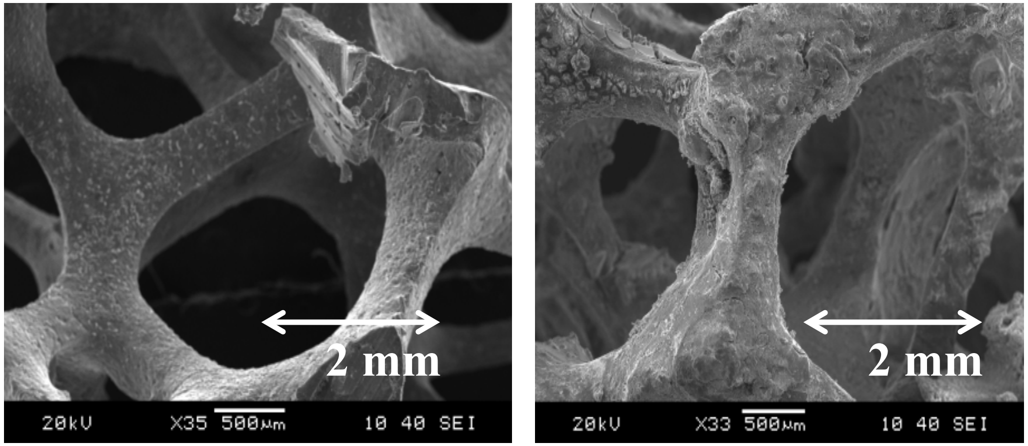
Separate Sensible and Latent AC System



Oak Ridge National Laboratory
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Project Summary

Timeline:

Start date: October 2019

Planned end date: September 2022

Key Milestones

1. Development of coated heat exchanger with at least 30% reduction in footprints
2. Demonstration of SSLC system based on DCHX with at least 20% higher COP

Budget:

	DOE funds	Cost share
FY20	250K	50K
FY21	270K	50K
FY22	300K	100K

Key Partners:

OAK RIDGE National Laboratory

Johnson Controls

PURDUE UNIVERSITY

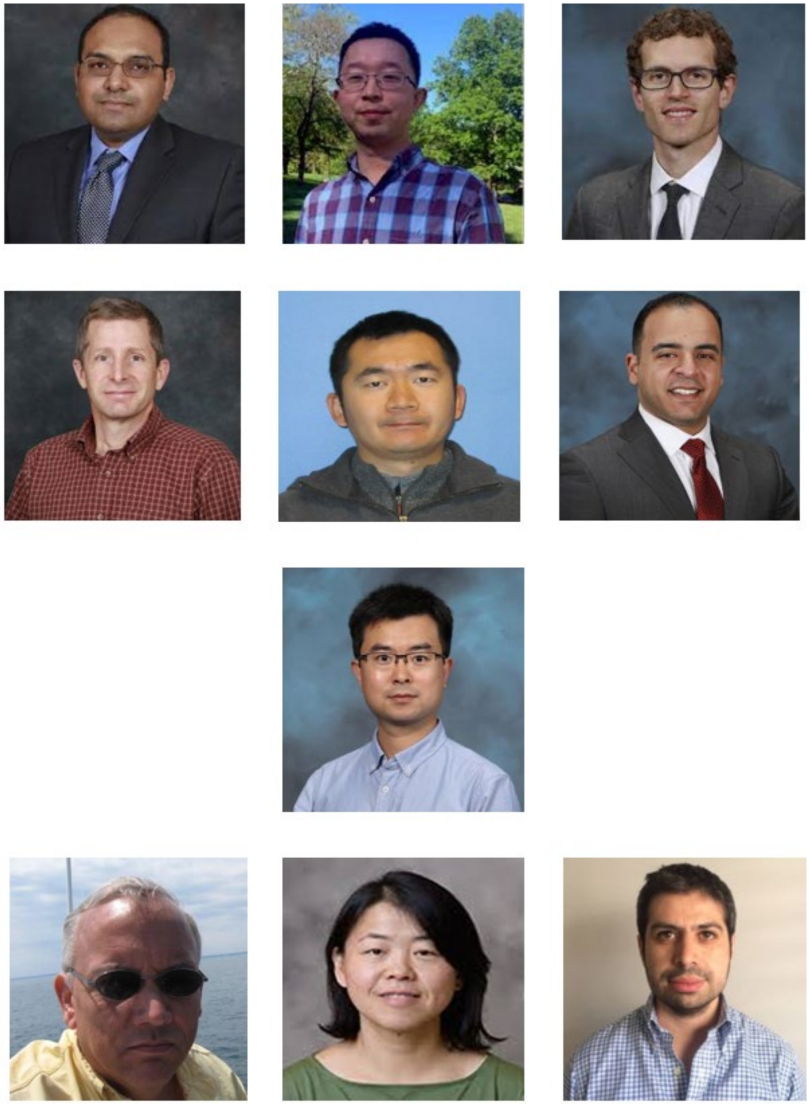
Project Outcome:

- Novel SSLC compatible for **small scale** deployments with unprecedented performance
- Demonstration of the system in a residential and light commercial platforms with 20% higher COP compared to the state-of-the-art technology.

A novel SSLC deployment for moisture management for improved efficiency and reduced CO_2 emissions (direct and indirect)

Project Team

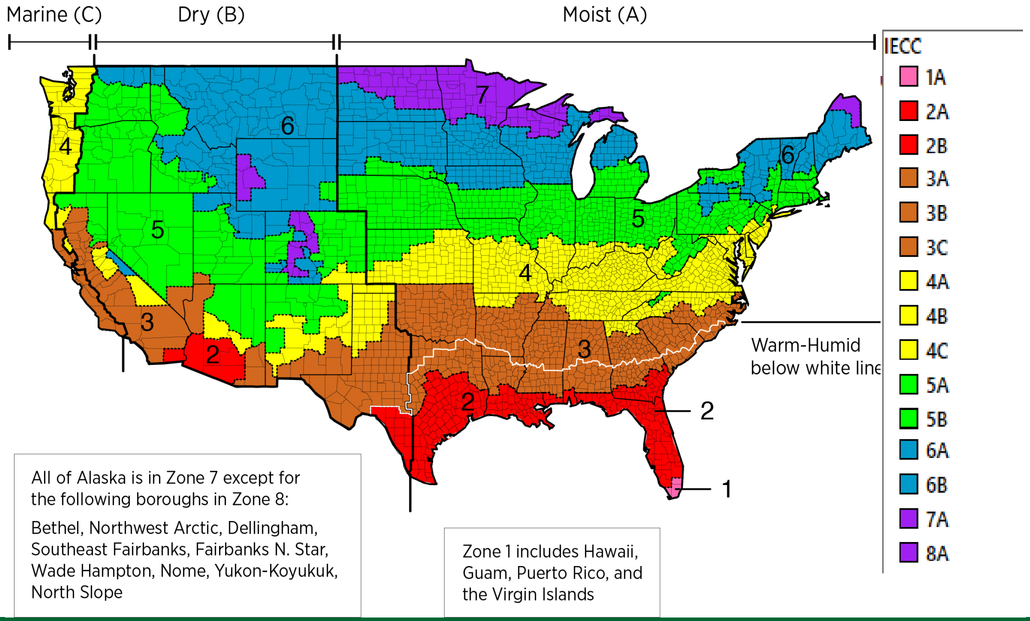
- **Oak Ridge National Laboratory**
  - Kashif Nawaz (Sr. R&D staff)
  - Kai Li (R&D staff)
  - Lingshi Wang (Post Doc associate)
  - Kyle Gluesenkamp (Sr. R&D staff)
  - Ahmed Elatar (R&D staff)
  - Tony Gehl (Senior technical professional)
  - Zhenning Li (Post Doc associate)
- **Johnson Controls Inc.**
  - Roy Crawford (Executive Director R&D)
- **Purdue University**
  - Ming Qu (Associate Professor)
  - Tomas Venegas (Graduate Research Assistant)



Challenge

- On average, ~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



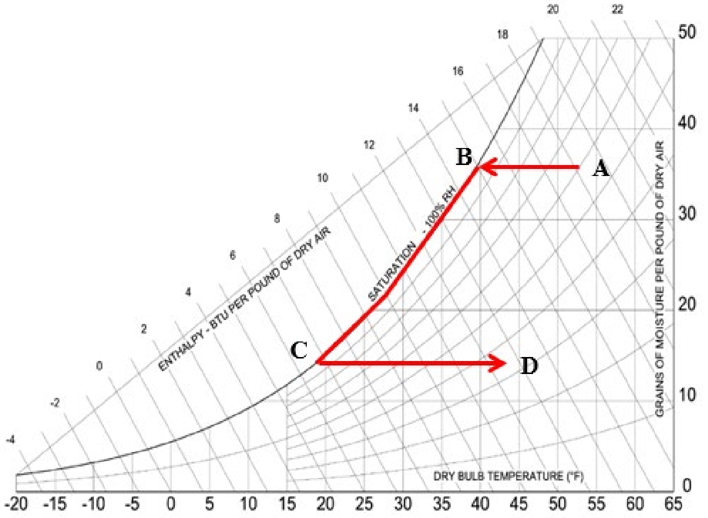
All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

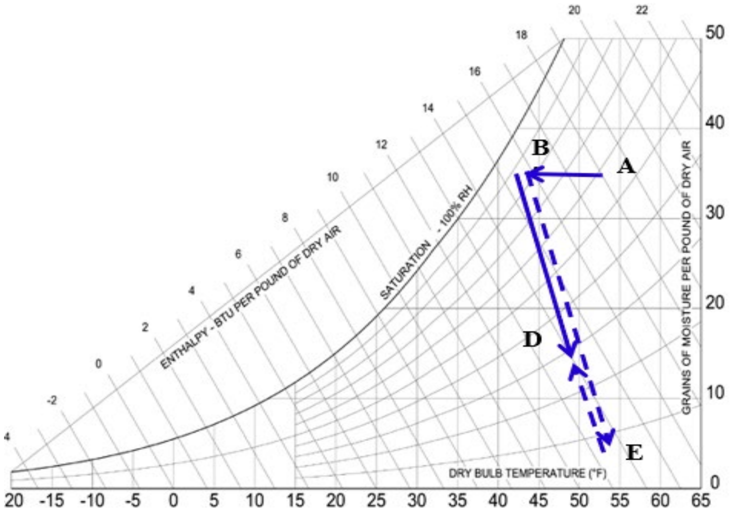
Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Challenge

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





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

Solution Approach

- **Phase 1** Market evaluation
- **Phase 2** Feasibility analysis
- **Phase 3** System integration

Phase 2- Feasibility analysis

- Characterization of substrate materials (dry, wet, frost performance)
- Desiccant characterization transient/ steady-state performance
- Performance modeling of heat and mass exchanger (coated HXs)

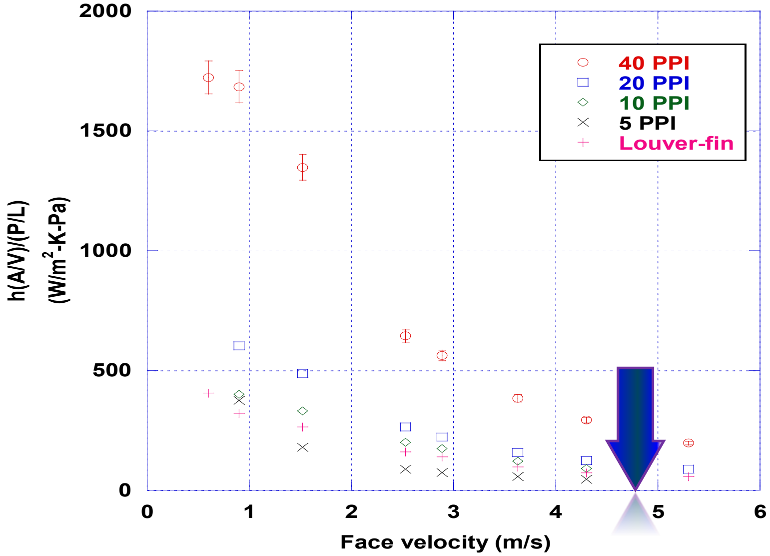
Phase 3- System integration

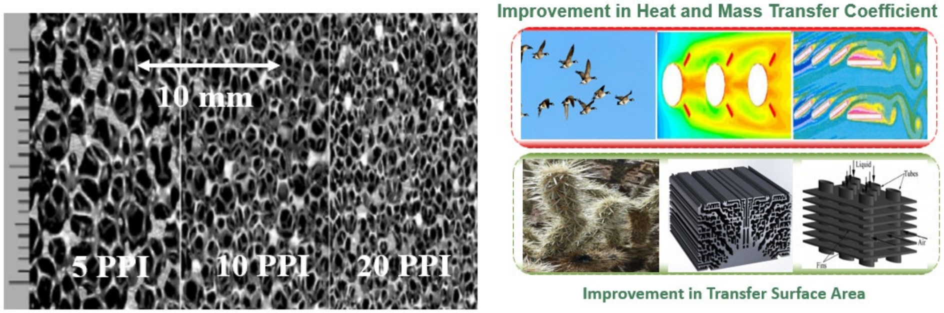
- Baseline system modeling (SSLC approach using VCS)
- SSLC system analysis (Hybrid approach, coated HX and VCS)
- Field evaluation and CRADA partnership

Project Impact

- An improved dehumidification system deploying SSLC
  - Ultra-compact infrastructure to control the moisture content of supply air (>30% reduction in size)
  - At least 50% 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
- Implications for additional processes
  - Energy and water harvesting
- 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

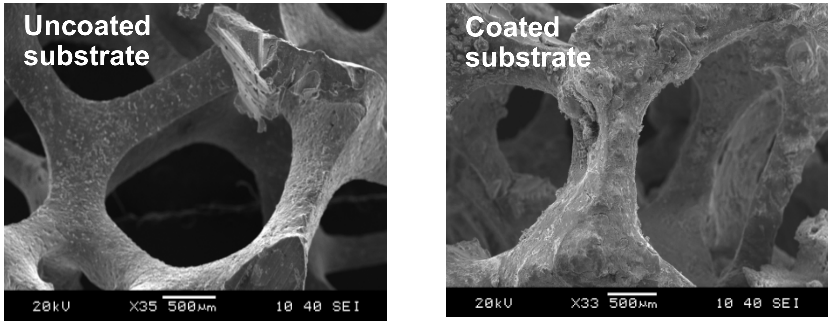




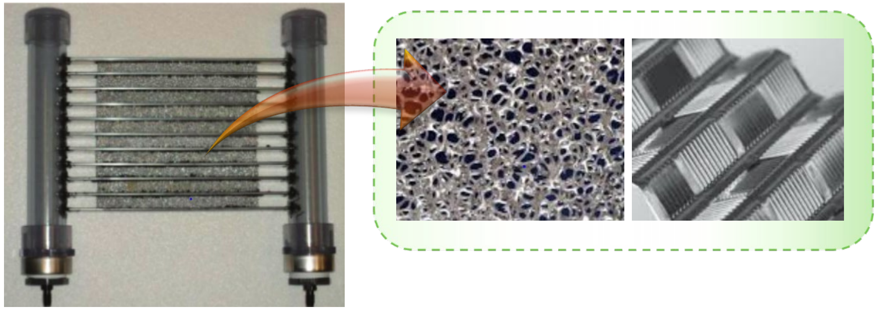
Improvement in Heat and Mass Transfer Coefficient

Improvement in Transfer Surface Area

Metal foams with varying porosity (irregular porous media)



Coated vs. uncoated metal foam samples

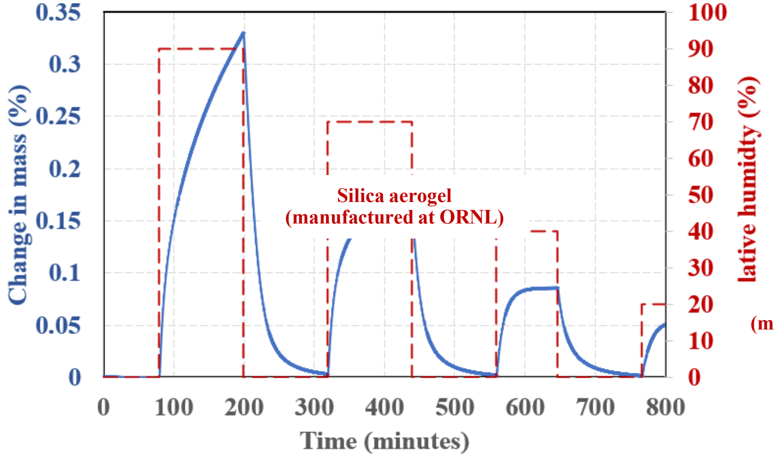


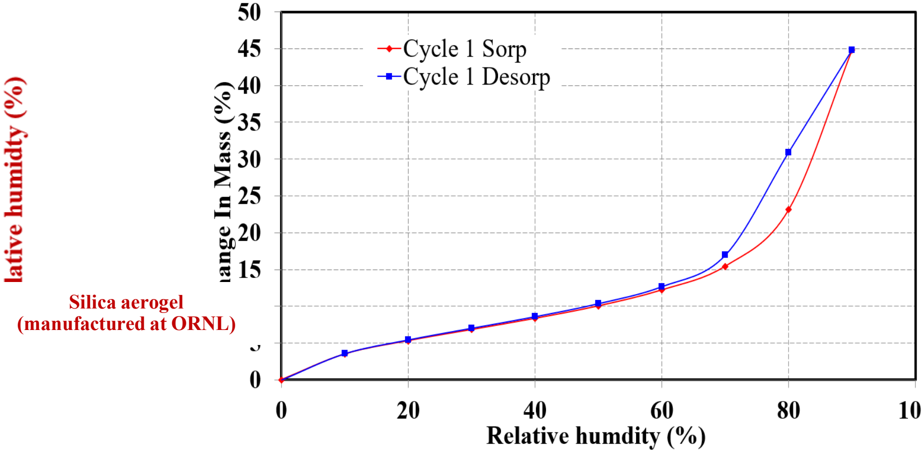
Heat exchangers developed at ORNL deploying high surface areas substrates

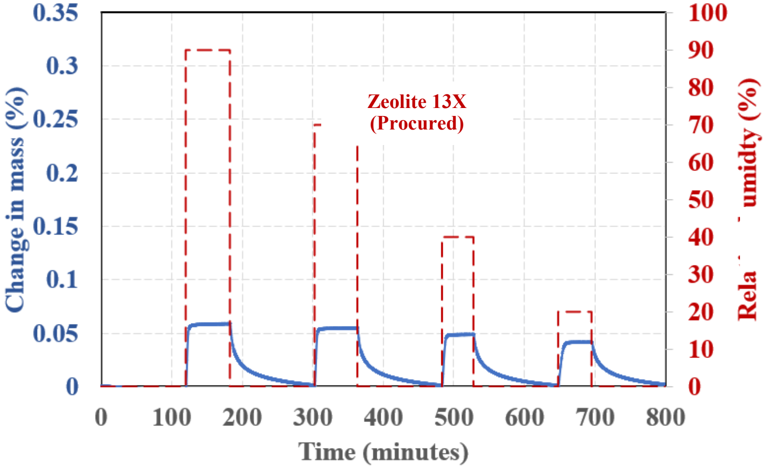
$$f_{D_p} = \frac{\Delta P}{L}\frac{\bar{\rho}}{G^2}\frac{D_p}{2} = 1.975\,\mathrm{Re}_{D_h}^{-0.1672}\left(D_p/D_h\right)^{-3.708}$$

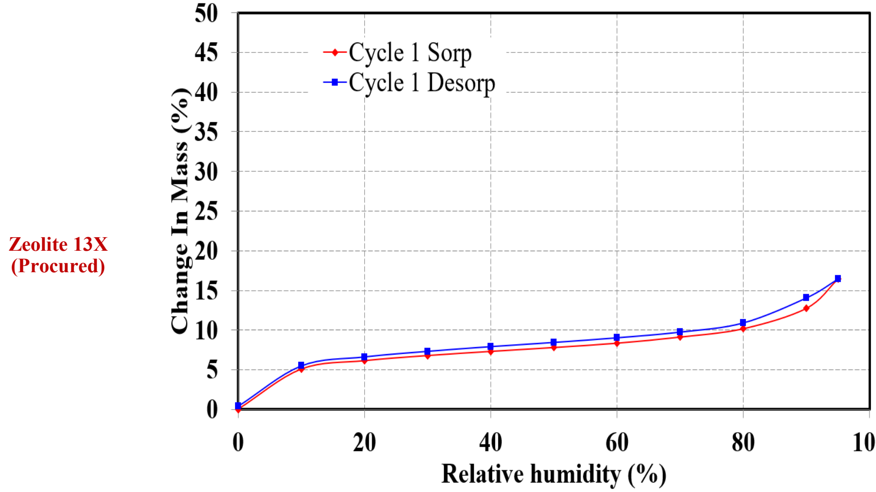
$$j_{Dp} = \frac{h}{\overline{\rho c_p}V}\frac{D_p}{D_h}\mathrm{Pr}^{2/3} = 2\,\mathrm{Re}_{Dh}^{-0.5611}\left(D_p/D_h\right)^{0.3213}$$

Project Progress







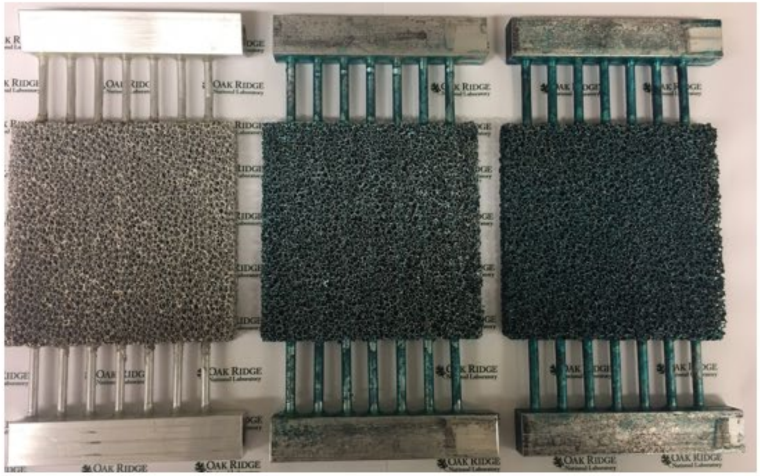


Transient Response

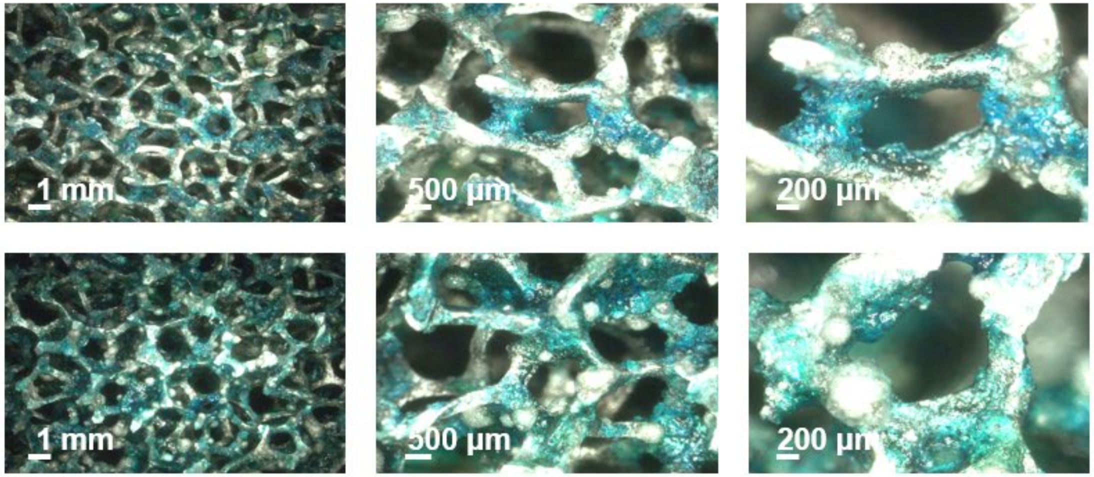
Steady-state Response

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

Project Progress



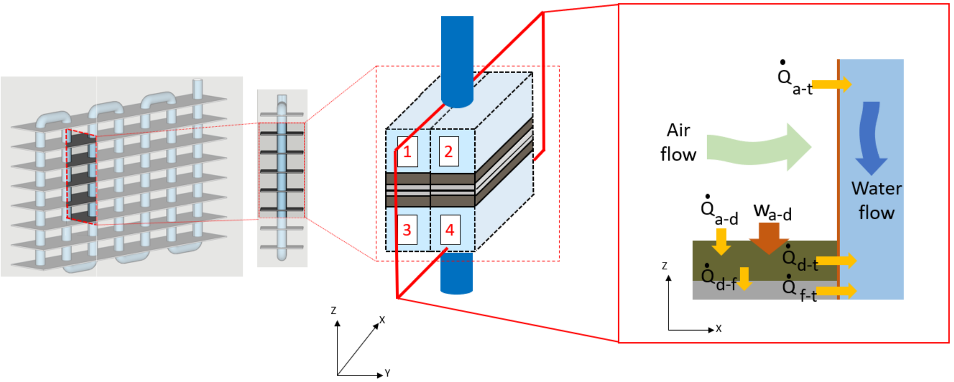
Uncoated and coated heat exchanger



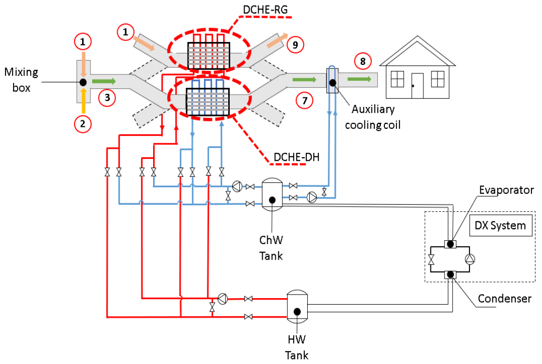
Close-up views of coated heat exchangers

- 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

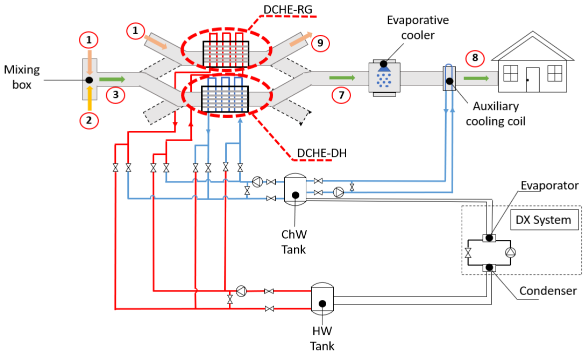
Project Progress



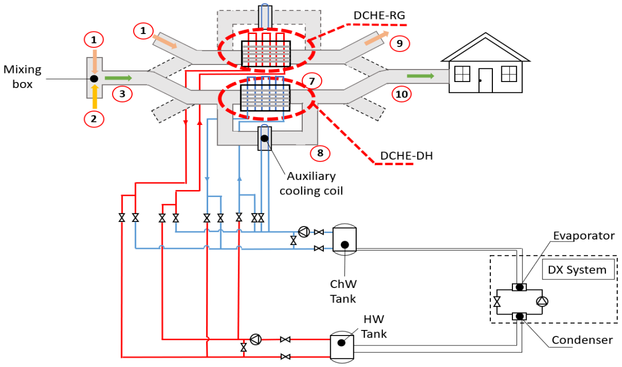
Component level modeling



Configuration 1



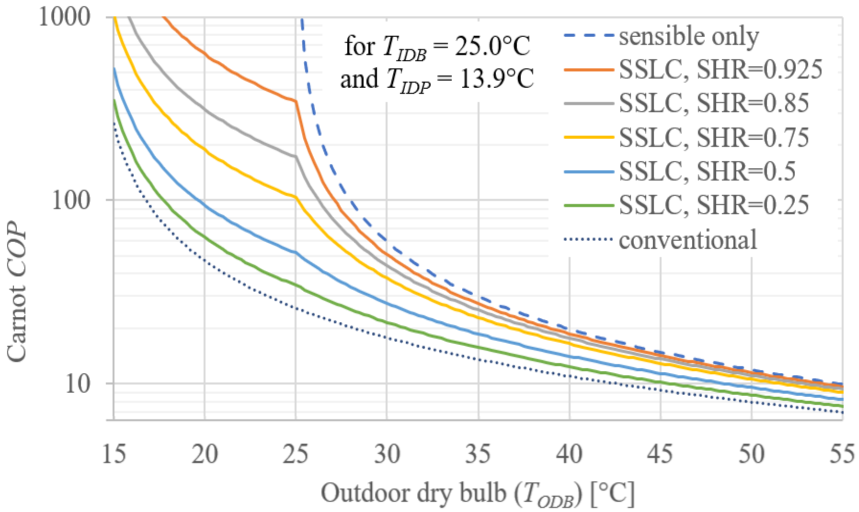
Configuration 2



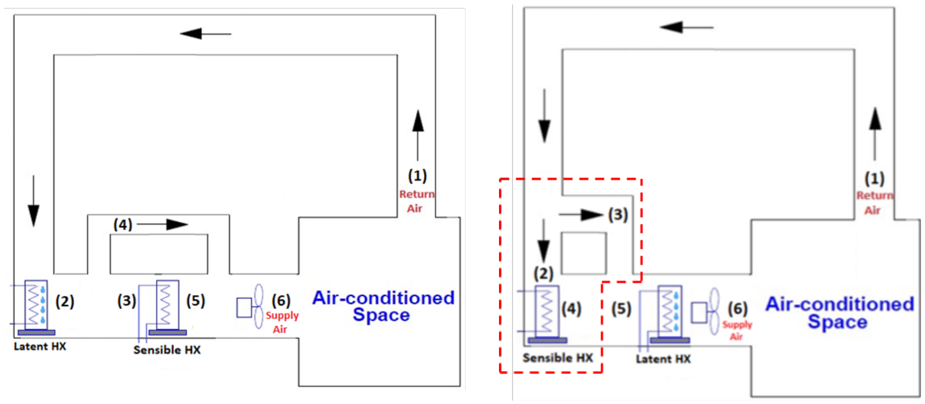
Configuration 3

System level modeling

Project Progress



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



Evaluation of various SSLC configuration

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

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

Stakeholder Engagement

- **Development of the technology**
  - Selection and characterization of desiccants
  - Coating process on substrates materials
  - Process controls
  - Independent latent load management
- **Meetings with experts at technical platform**
  - ASHRAE (TC 8.5, TC 1.1)
  - Purdue
- **Two of four GPRA milestones** for FY 2021 (Q1 and Q2)
- More than seven **journal articles** published
- One non-provisional patent applications
- More than twelve conference papers and presentations!!
- New IEA Annex and workshop “Comfort and Climate Box solutions for warm and humid climates”.
- OEM engagement with Daikin, Trane, Johnson Controls and Carrier Corp.

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.

Moving the technology from TRL 2 to TRL 5!!

Thank you

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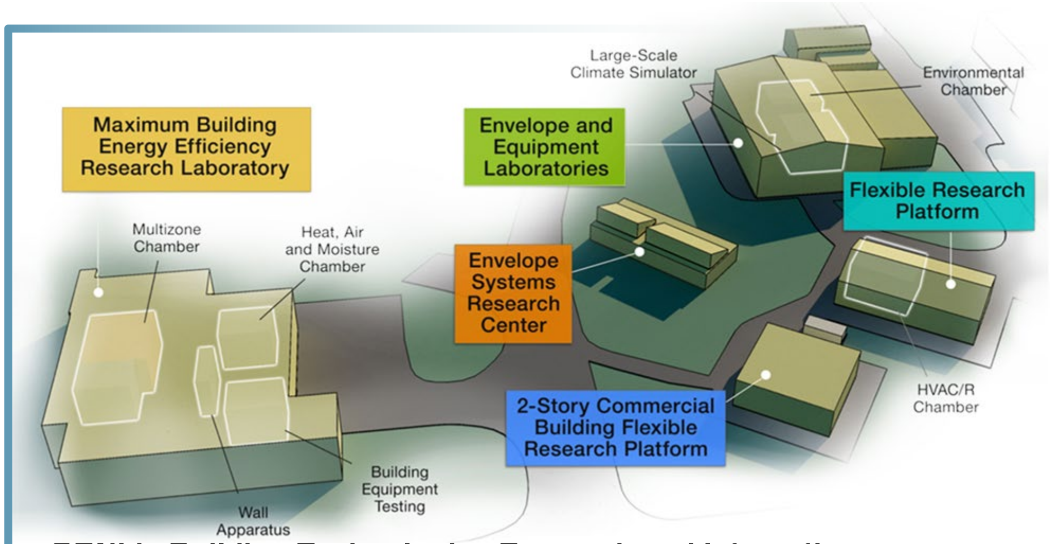

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: $820K, $100K cost share
Variances: None
Cost to Date: $480K
Additional Funding: None

Budget History					
FY2019 - FY 2020		FY 2021 (current)		FY 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$250K	$50K	$270K	$50K	$300K	$100K

Project Plan and Schedule

Project Schedule												
Project Start: 2020	🟦	Completed Work										
Projected End: 2023	■	Active Task (in progress work)										
	◇	Milestone/Deliverable (Originally Planned)										
	◆	Milestone/Deliverable (Actual)										
	FY2020				FY2021				FY2022			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Desiccant characterization	🟦 ◆											
Test facility for heat/mass exchanger performance evaluation		🟦 ◇	🟦 ◆									
Thermal-hydraulic characterization of metal foam heat exchangers			🟦 ◆									
Performance modeling			🟦	🟦 ◆								
Thermal-hydraulic characterization of coated conventional and metal foam heat/mass exchangers					🟦 ◇	🟦 ◆						
Parametric analysis												
Scale up analysis							■ ◆					
Commercialisation analysis							■	■ ◆				