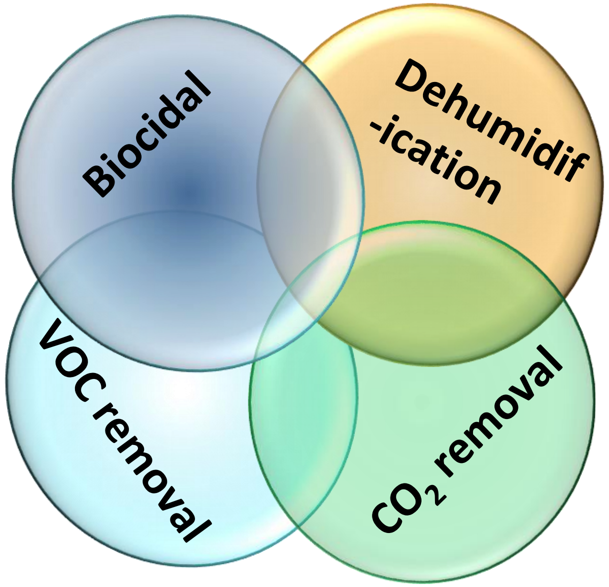
Multi-functional Equipment for Direct Decarbonization with Improved Indoor Air Quality (IAQ)



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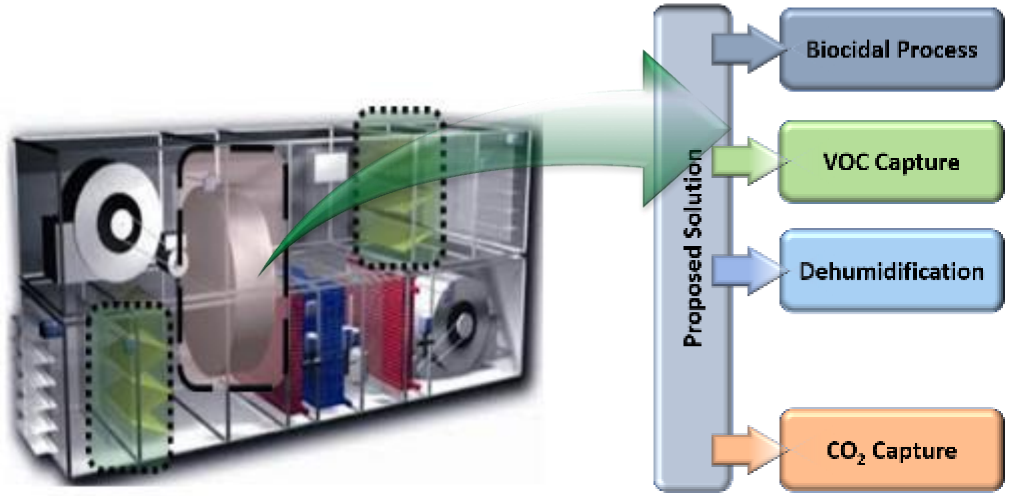
WBS: 03.02.02.26

Project Summary

Objective and outcome

Development and deployment of a *combined platform* to manage moisture, volatile organic compounds (VOCs) and CO_2 removal with effective biocidal capability. Ensuring a cost-effective approach for improved indoor air-quality achieved through building equipment.



Team and Partners

Oak Ridge National Lab

Kashif Nawaz, Kai Li, Jian Sun, Yunfei Li, Muneesh Murugan, Jamieson Brechtl, Keju An, Xiaoli Liu, Melanie DeBusk, Bill Partridge

Johnson Controls, Carrier, Rheem, TRANE TECHNOLOGIES

Stats

Performance Period: March 2022 –Dec 2025

DOE budget: $1.5M, Cost Share: $300k

Milestone 1: Materials characterization

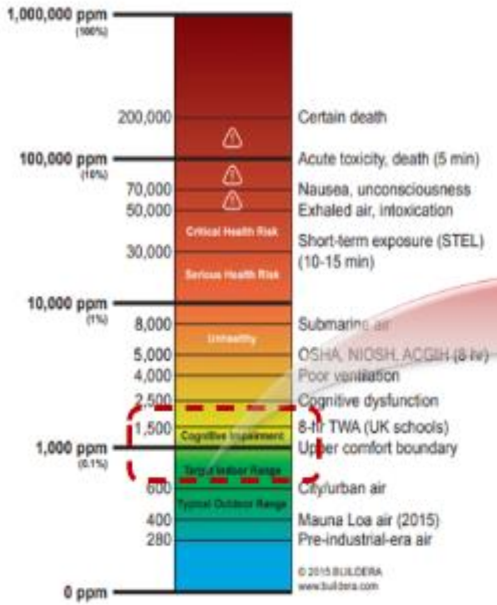
Milestone 2: Device development and analysis

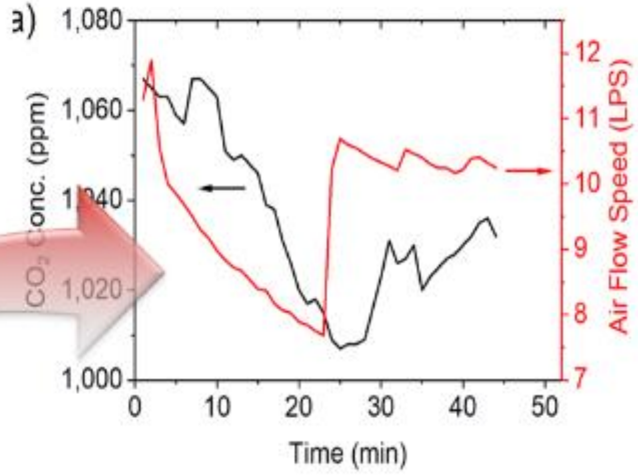
Milestone 3: System level process integration

Milestone 4: Field evaluation (Commercial building)

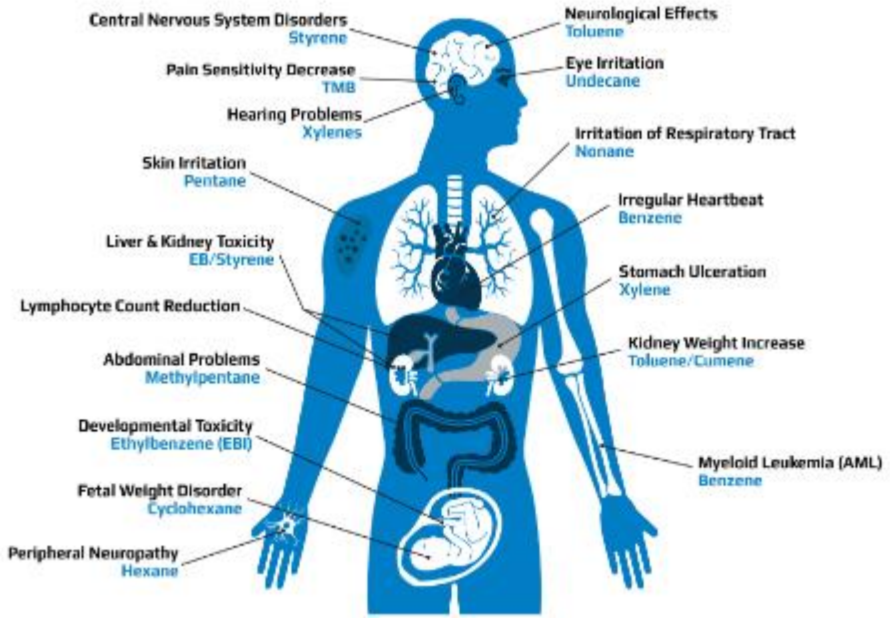
Problem

- Efficiency has been the primary goal with less emphasis to carbon emissions
- Rare efforts to achieve IAQ through building equipment.
- CO_2 concentration has been a measure to establish the ventilation requirements.
- Standalone equipment for moisture management poses performance challenges.
- COVID-19 has highlighted the challenges associated with IAQ.
- Rare efforts to manage volatile organic compounds (VOCs)





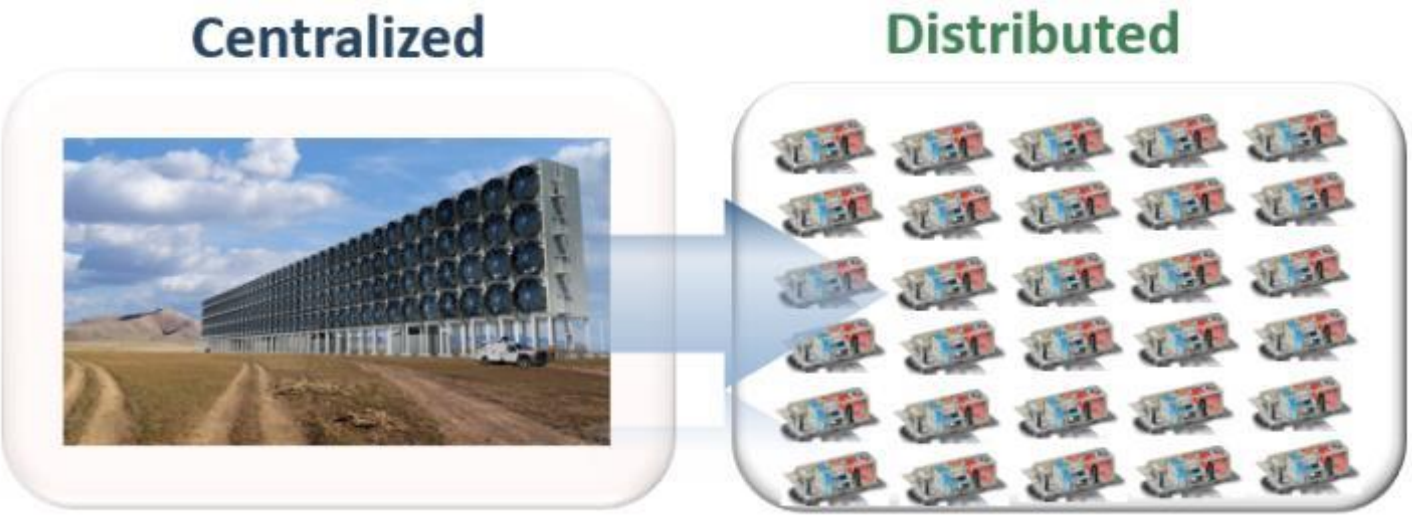
Indoor CO_2 concentration can be critical



ASHRAE Standard for Indoor Air Quality 62.1 and 62.2

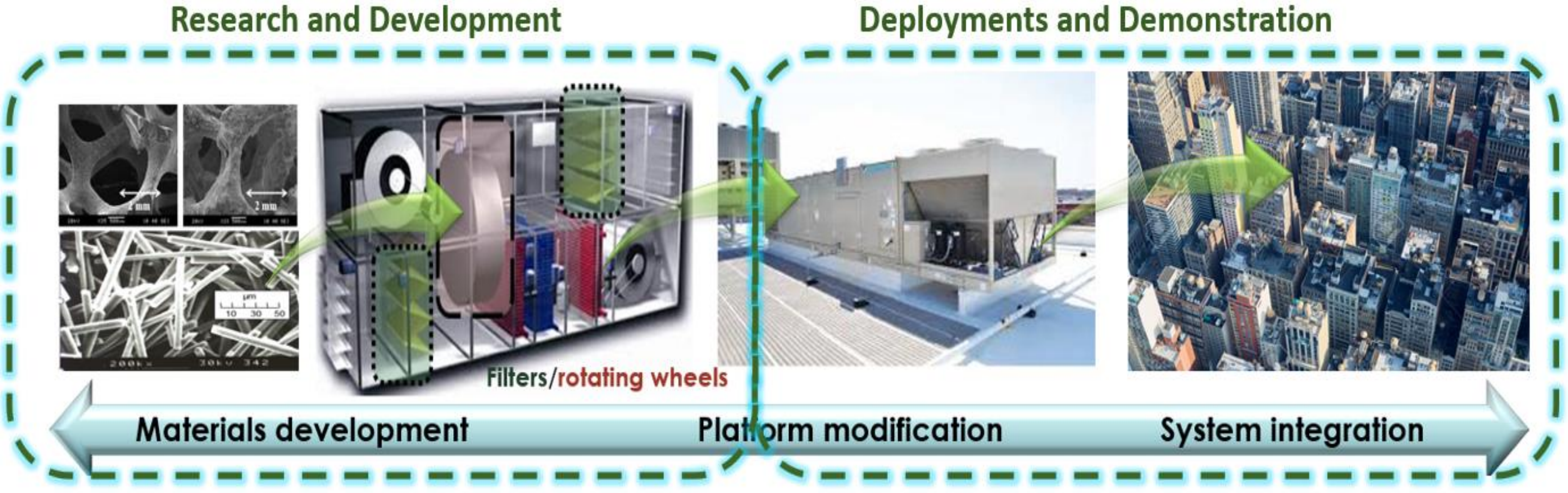
Problem

- Direct Air Capture has been noted as a major initiative for decarbonization.
- Dedicated DAC system have extensive capital (CapEx) and operational (OpEx) costs.
- Over 120 Million buildings across the US and are responsible for 600 Mt CO2/year.
- Existing building equipment moves large amounts of air that can enable a distributed DAC



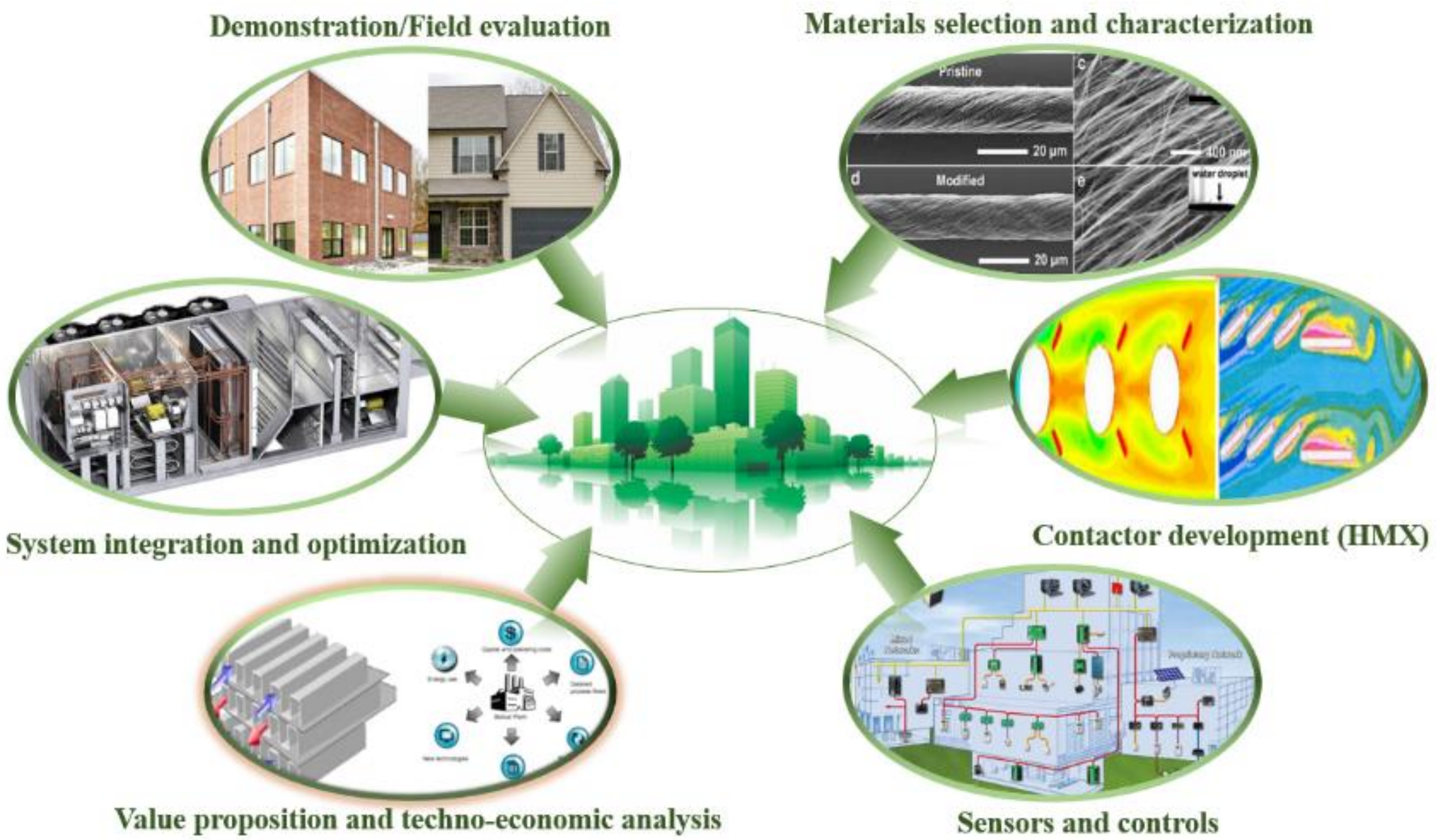
Approach

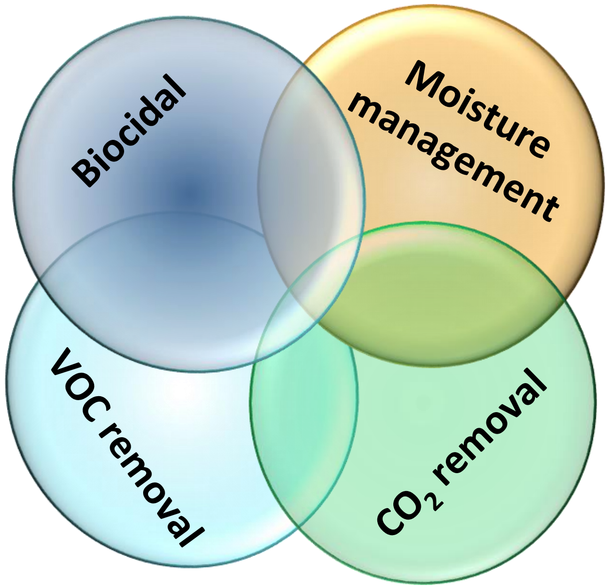
- A combined infrastructure to manage moisture, VOC, biocidal and CO_2 capture
- Separate sensible and latent cooling for *moisture management*
- *A comprehensive approach for Research, Development, Development and Demonstration (RDD&D)*



Net-negative carbon buildings with improved indoor air quality and comfort

Approach





A cross-cut approach is needed to develop a sustainable solution!!

Approach

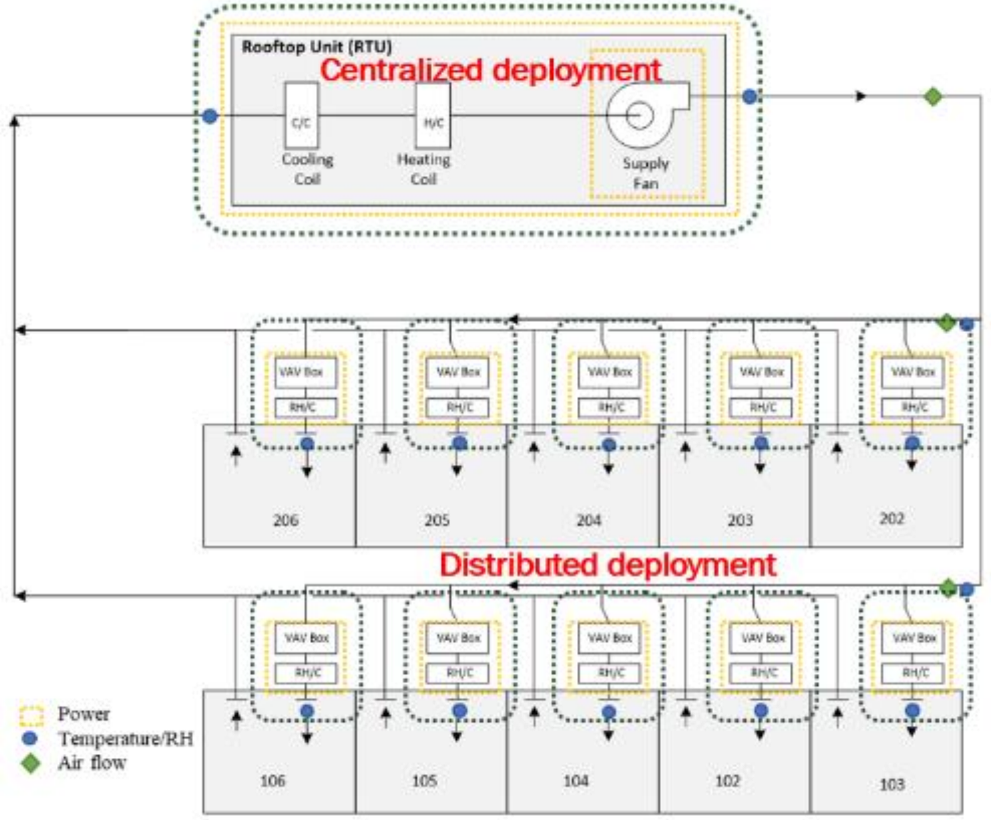
- CO_2 management
- VOC management
- Biocidal solutions
- Moisture management

Process controls

Lab scale demonstration (FRP II)

Field demonstration (Commercial building)

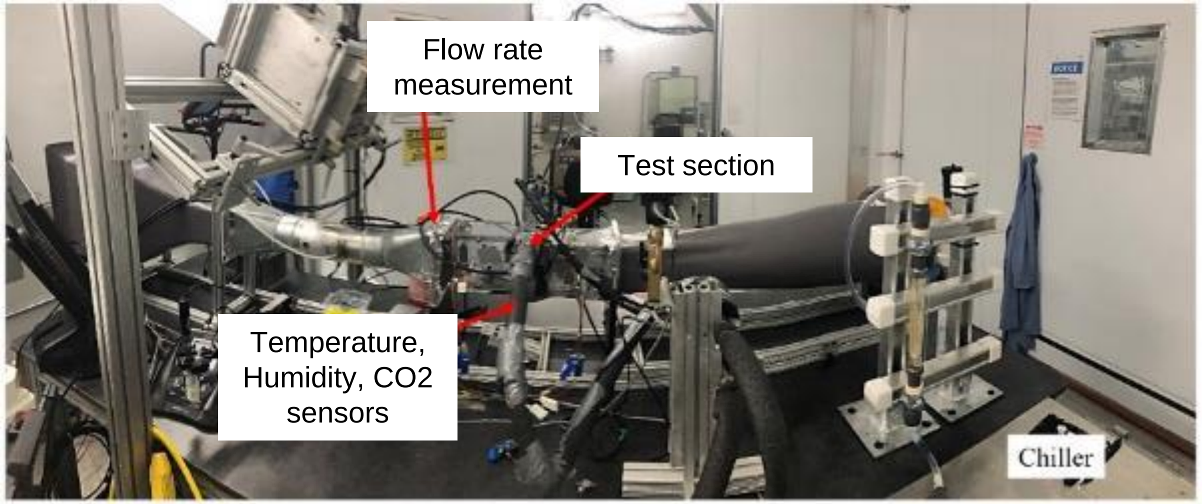
Phase I | Phase II | Phase III



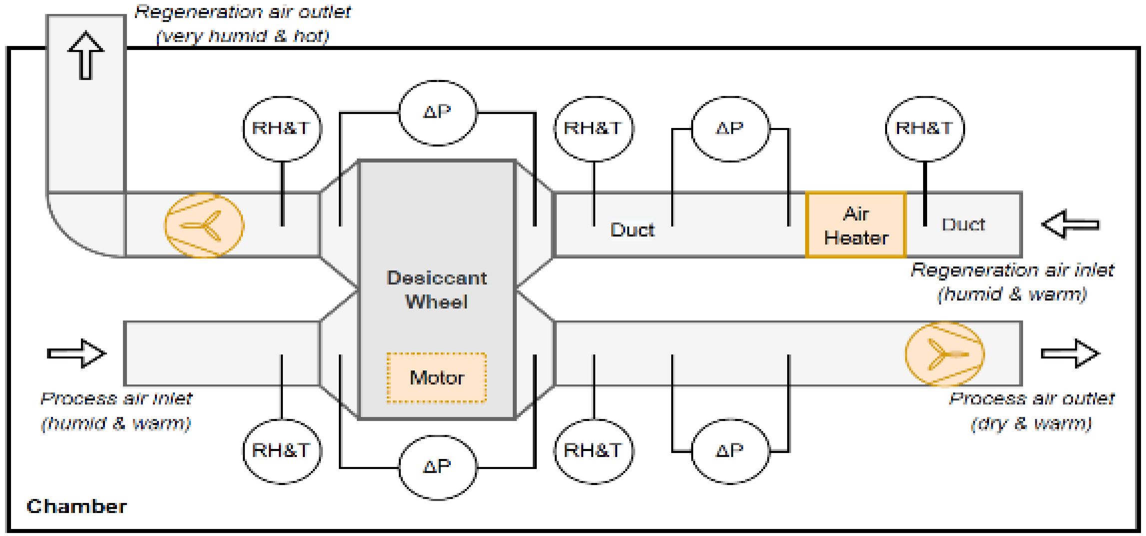
Flexible Research Platform II

- Temperature
- Relative Humidity
- CO_2 concentration
- VOC concentration
- Flow rate

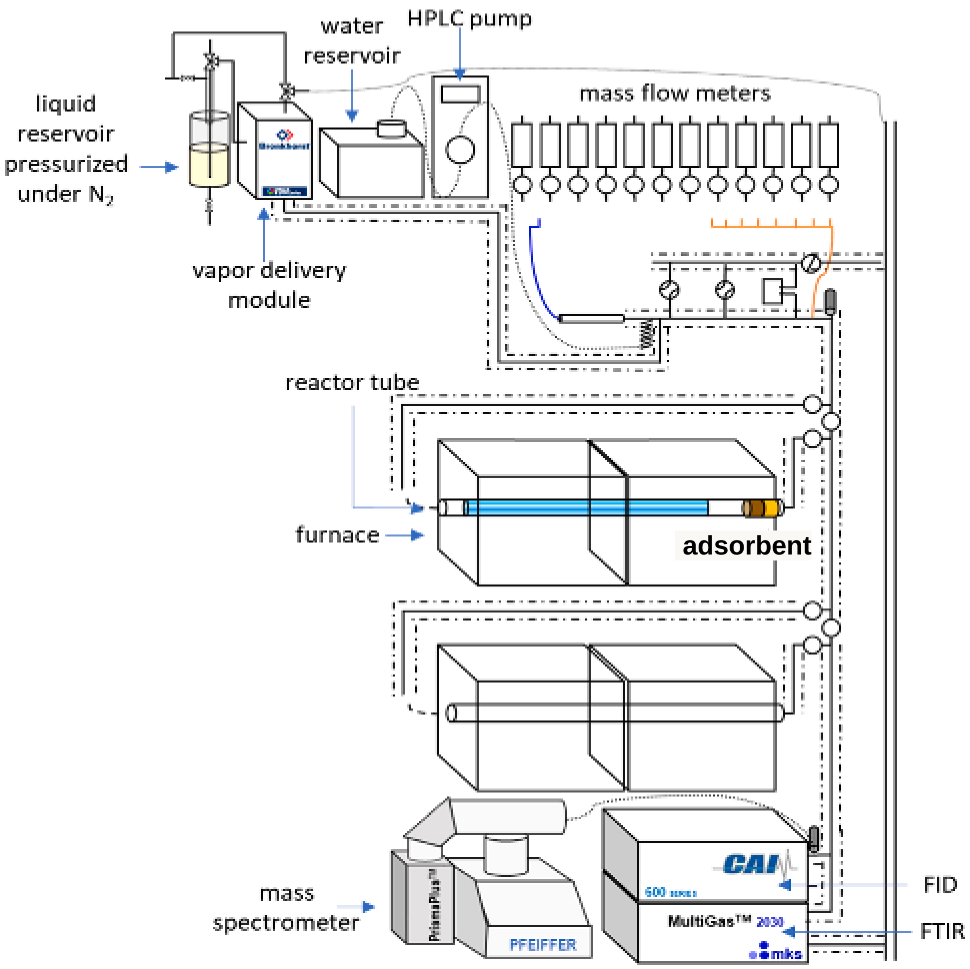
Approach



Open-loop wind tunnel device level evaluation (stagnant device)



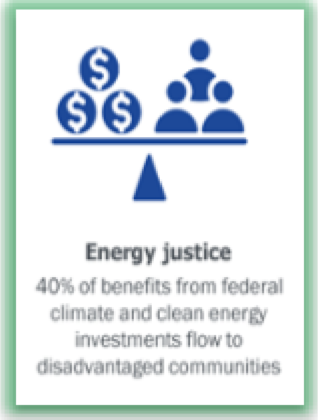
Test bed for rotating wheel's performance evaluation

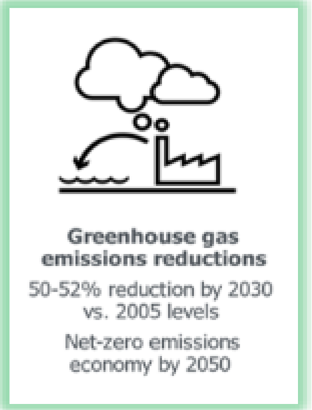


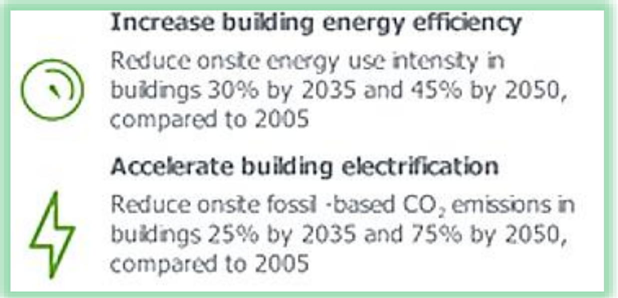
Test bed for VOC capture performance analysis

Impact and alignment

- *Direct and indirect* reduction in CO_2 emissions
    - Non-vapor compression technology (direct) >500 MT/year
    - CO_2 capture from exhaust stream (direct) >250 Mt/year
    - Improved process efficiency -SSLC (indirect) >170 Mt/year
- A cost-effective heat utilization of “waste heat” for regeneration
- Carbon tax benefits for US manufacturers- Global business opportunities
- Implications for underserved communities- Energy justice



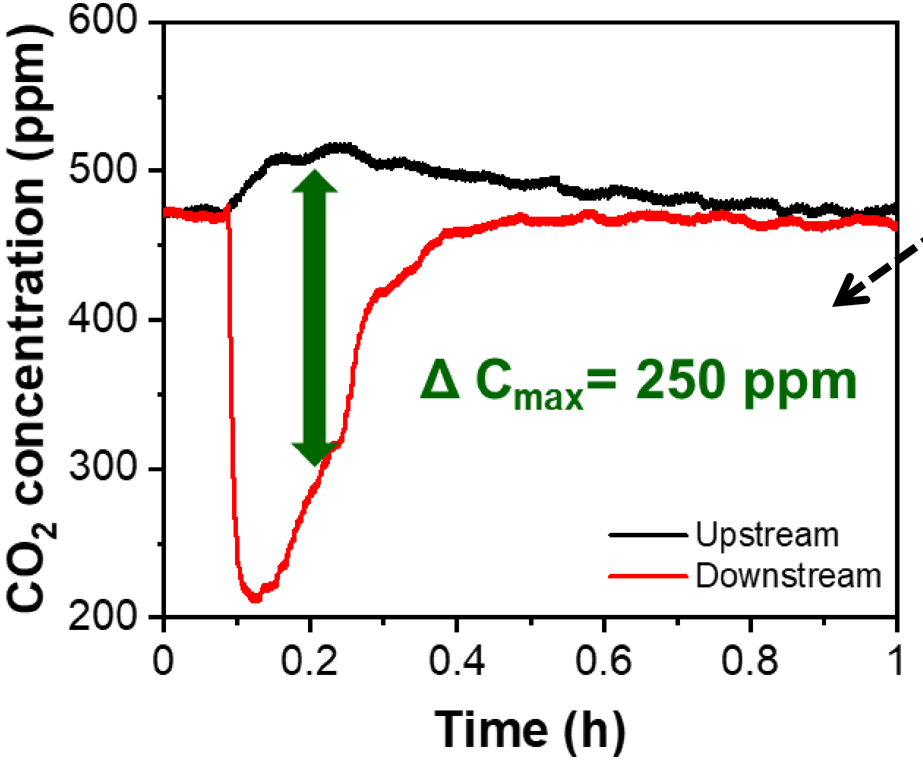




A comprehensive realization of decarbonization framework while ensuring comfort!!

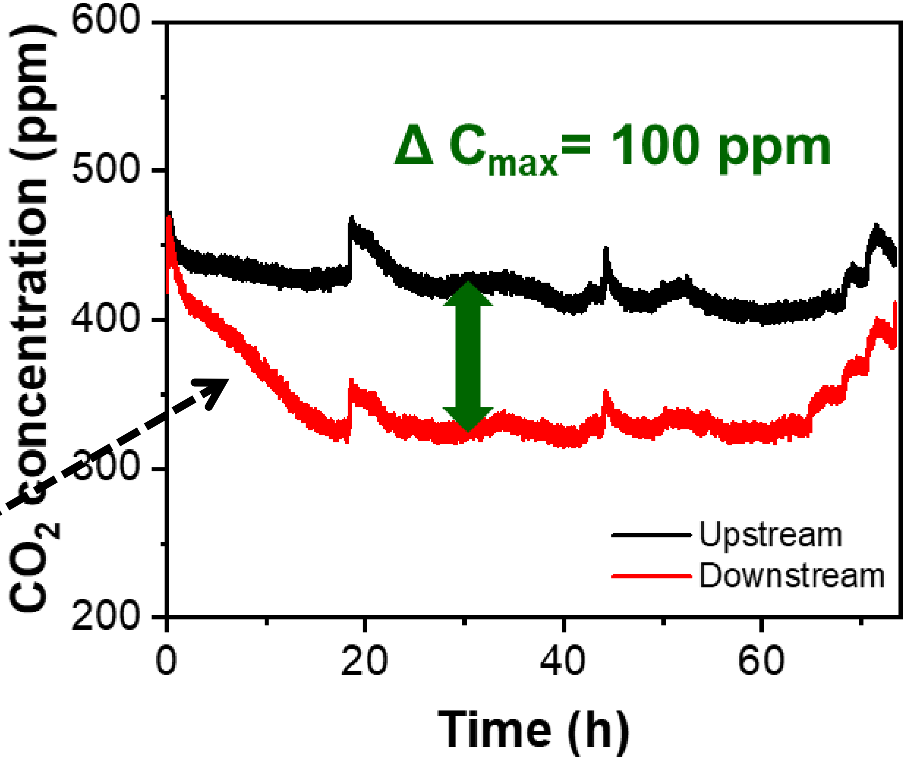
Thrust 1- CO_2 Management

- Development and characterization of different CO_2 adsorbents.



Cellulose acetate-SiO_2-PEI

PAN-TETA



The CO_2 removal performance is a function of base material, treatment process, ambient conditions and flow rates. The performance data is essential to establish the deployment strategy.

Thrust 2- Moisture Management

Inputs → **Numerical models** → **Outputs**

Operating conditions
- Process air temperature/humidity
- Regeneration air temperature/humidity

Control variables
- Air flow rate
- Wheel rotational speed
- Regeneration heat

Design parameters
- Diameter/thickness
- Wheel channel size
- Area split ratio
- Material properties
- Purge angle

Transient heat & mass transfer models

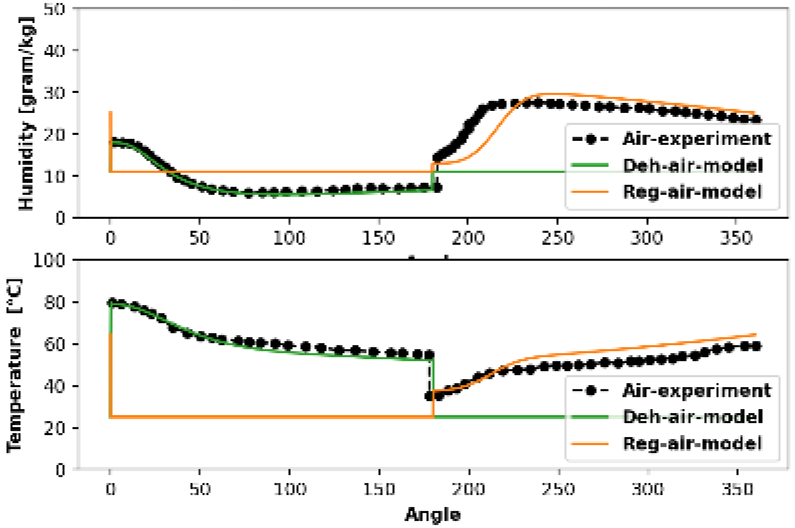
Performance
Air/desiccant temperature/ humidity

Derived metrics
Humidity change (Δx), MRC, RSHI, DCOP, COP, effectiveness

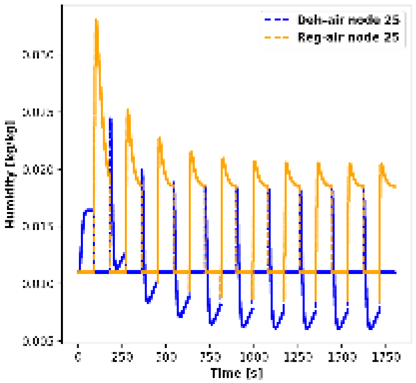
Parametric study & optimization

Better sizing and operating variable selection

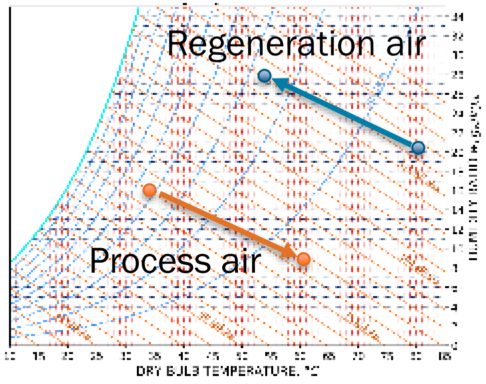
Validation result



Transient

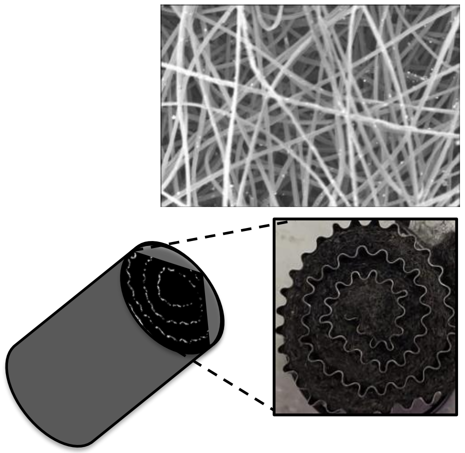


Steady-state



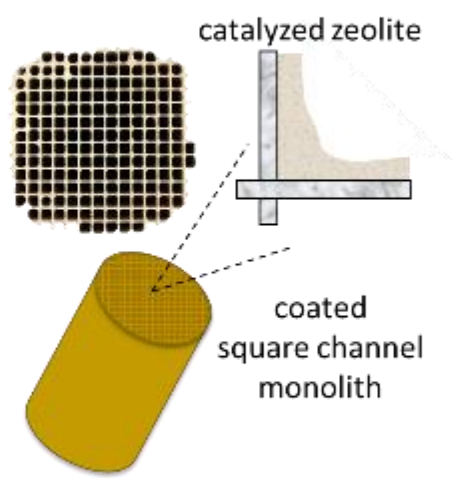
The development of a model-based evaluation framework to predict the dehumidification performance for control and design optimization.

Thrust 3- VOC Management



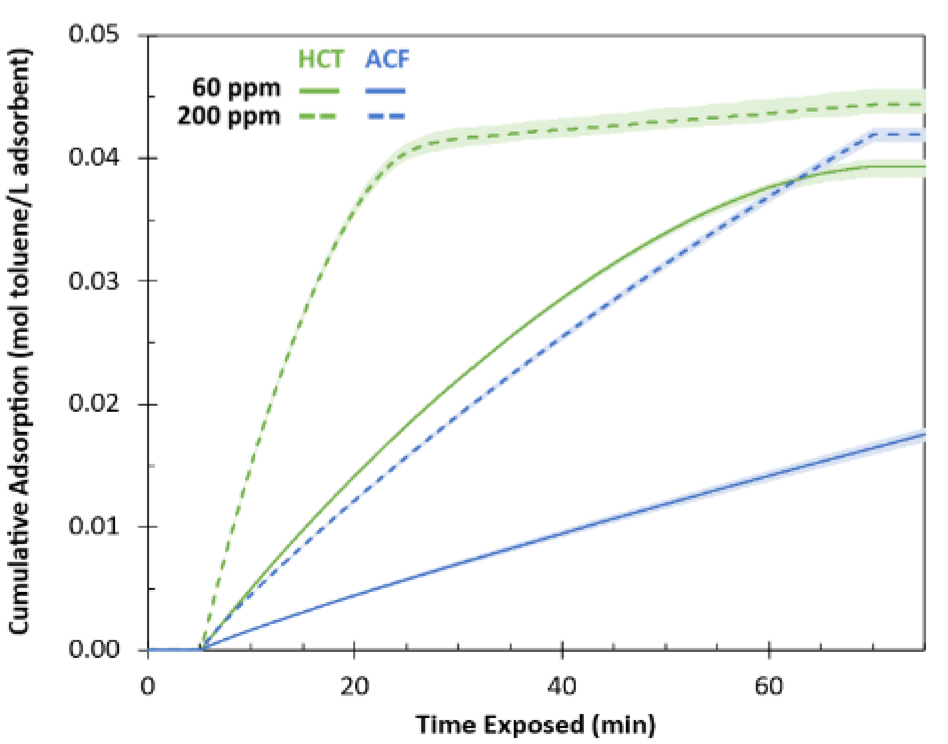
Grade	ACF1600
Specific Surface Area (M2/g)	1500
Micropore Volume (ml/g)	0.8-1.2
Density per Sq meter (g/m2)	250 +- 30
Micropore Diameter (A)	17-20
Benzene Adsorption Capactiy %	53-58
Iodine Adsorption Value (Mg/g)	1400-1500
Methylene Blue Absorption Value (Ml/g)	250
pH Valute	5-7
Fire Point Centigrade	500 min

Activated Carbon Fiber (ACF-1600)



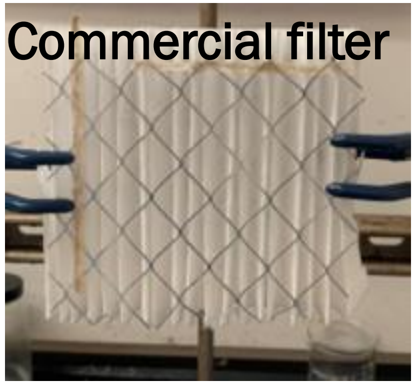
HCT: Zeolite Monolith

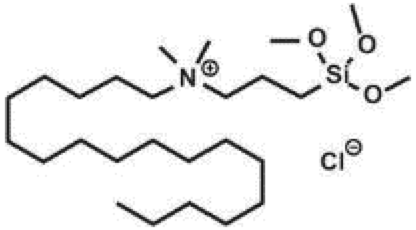
-VOC type: Toluene
-Flow rate: 7.5 LPM
-Temperature: 25 ^{o}C
-Relative Humidity: 60%



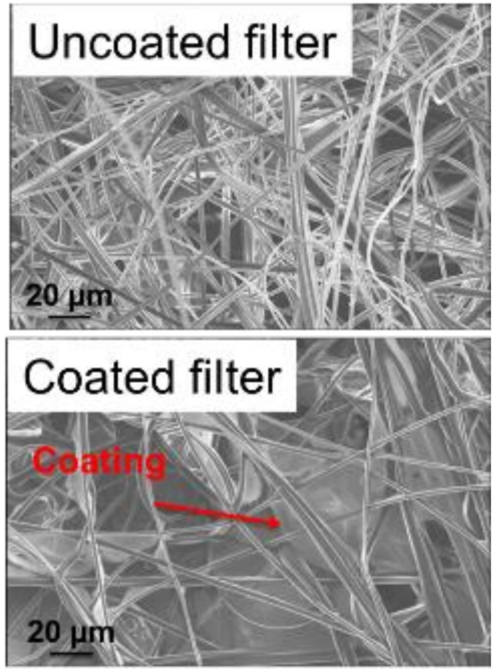
The material performance is a function of humidity, inlet concentration and temperature

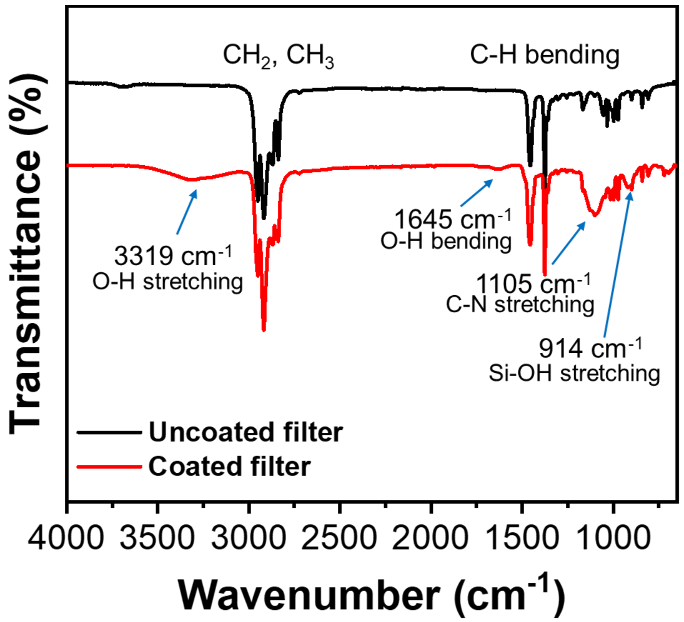
Thrust 4- Biocidal Management

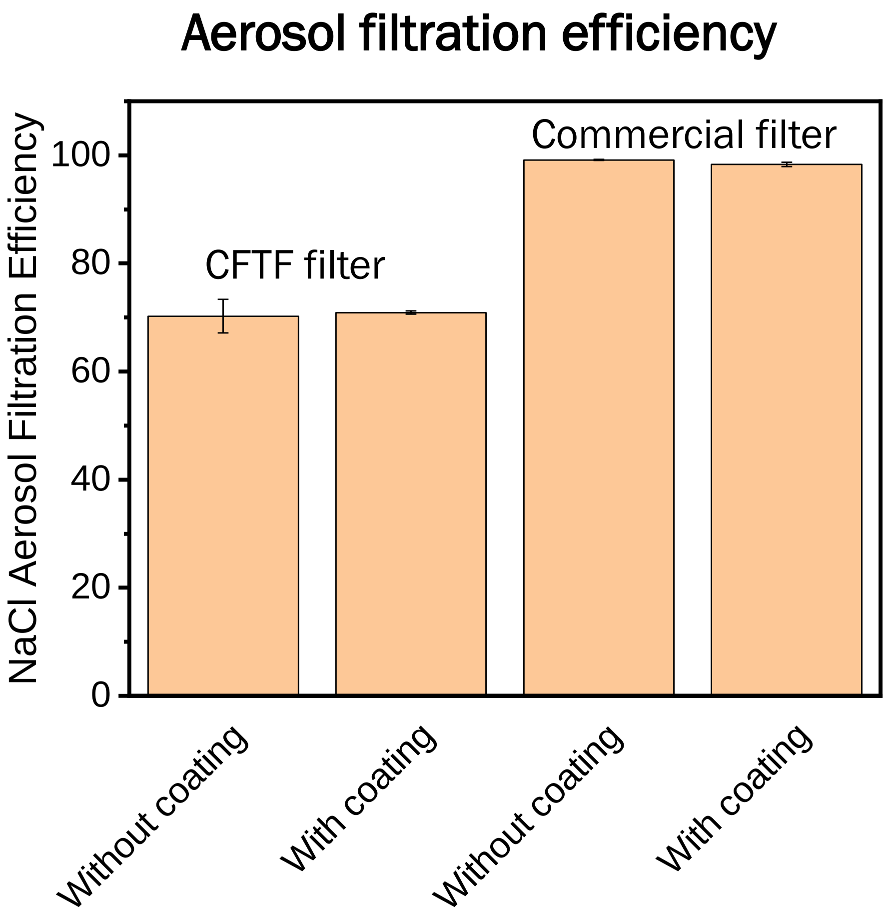




Biocidal agent





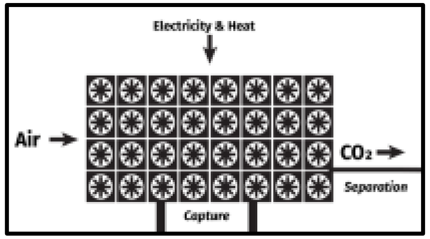


Prior developments at ORNL have been critical to scale-up the technology

https://www.ornl.gov/news/powerful-polymers-ornl-study-provides-new-insights-n95s-covid-19-filter-efficiency

Thrust 5- Process Control

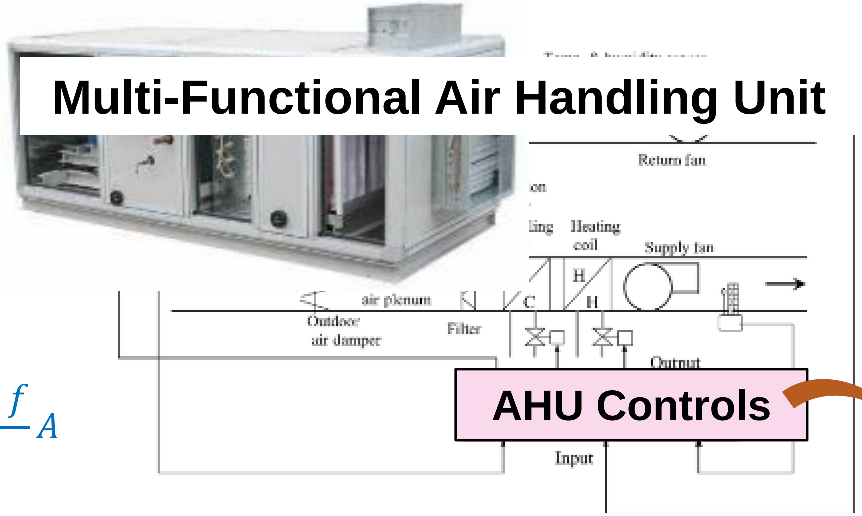
Direct Air Capture Device



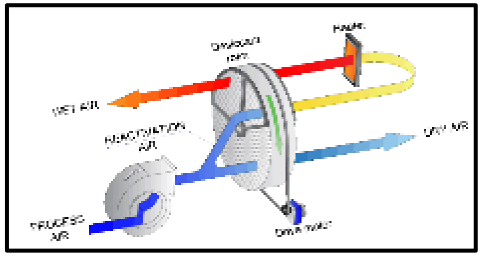
Integration

$$V_{zone}\frac{dC_{zone}}{dt}=Q_{oa}(C_{zone}-C_{oa})-\mathrm{C(t)}-Q_{oa}\frac{1-f}{f}A$$

Multi-Functional Air Handling Unit

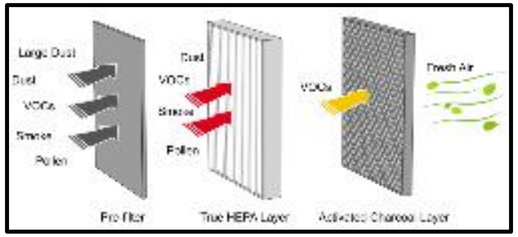


Discant Dehumidification



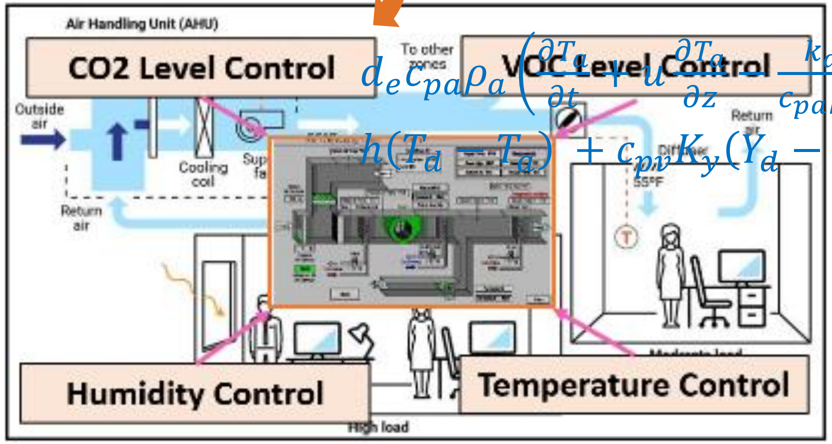
Integration

VOC Filter Device



Integration

$$V_{zone}\frac{dX_{zone}}{dt}=Q_{oa}(X_{zone}-X_{oa})-\mathrm{XG(t)}-Q_{oa}\frac{1-f}{f}A$$



$$d_e c_{pa}\rho_a\left(\frac{\partial T_a}{\partial t}+u\frac{\partial T_a}{\partial z}-\frac{k_a}{c_{pa}\rho_a}\frac{\partial^2 T_a}{\partial z^2}\right)=h(T_d-T_a)+c_{pv}K_y(Y_d-Y_a)(T_d-T_a)$$

- Control-oriented component models development (Carbon capture, VOC, humidification)
- Component model validation: ongoing with experiments
- System integration: Ongoing with EnergyPlus and PythonEMS

Project Milestones

Milestone No.	Associated Task	Milestone Description
Milestone 1	Market assessment	Evaluation of current procedures and value proposition for existing indoor air quality measured and associated technologies has been completed.
Milestone 2	Stakeholder engagement and compliance with E3 Initiative	The proposed work plan has been discussed with appropriate stakeholders in dehumidification, indoor air quality, and ventilation industries, and engagement protocols have been determined. Cooperative research and development agreement partnerships have been finalized, and a potential demonstration facility has been identified. The potential for implementation in large-scale deployment has been assessed.
Milestone 3	CO_2 and VOC management	Analysis and evaluation of adsorbent based capturing of CO_2 and VOCs from return and/or supply air has been completed and regeneration requirements have been established.
Go/No-Go 1	Based on the available data, the potential for removing CO_2 from the return and/or supply air has been established. The framework allows for the reduction at least 100 ppm in CO_2 concentration from the return air for at least one deployment strategy.	
Milestone 4	Moisture management	Analysis and evaluation of various technologies for moisture management from return and/or supply air has been completed. Deployment approaches, such as filter, monolith, and coating on metallic and nonmetallic substrates, have been evaluated.
Milestone 5	Evaluation of biocidal implications	Analysis and evaluation of various technologies for biocidal behavior from return and/or supply air has been completed.
Go/No-Go 2	Based on the available data, the potential of removing excess moisture from the return and/or supply air has been established. The framework allows for at least 20% reduction in relative humidity for at least one deployment strategy.	
Milestone 6	Platform integration	A compatible framework has been demonstrated for a typical commercial building where various deployment approaches have been studied. This framework includes combined and separated platforms for separation processes and centralized and distributed frameworks.
Milestone 8	Commercialization strategy and evaluation of impact on air quality	With the assistance of various stakeholders, a comprehensive commercialization plan has been developed, identifying major market barriers, and an associated mitigation strategy has been developed. The effect on the indoor air quality has been established for various climate zones. In addition, appropriate utilization strategies for captured CO_2, including direct use and conversion to useful products, have been assessed.
Go/No-Go 3	The potential for direct and indirect CO_2 emission reduction has been established. The framework allows for at least 50% reduction in greenhouse gas emissions (>30 MT) owing to the multifunctional platform managing carbon capture, moisture, and VOC removal.	

Dissemination and Engagement

- Advances in biocidal implication for improving indoor air quality: A critical review (In progress)
- Numerical modeling of a rotary desiccant wheel using super absorbent polymer for air dehumidification (In progress)
- A critical review of desiccant wheel for air dehumidification in buildings: module design, operation, and system integration (In progress)
- US patent 63/272,351, "Multi-functional Equipment for Direct Decarbonization with Improved Indoor Air Quality"

Johnson Controls   Carrier   Rheem   TRANE TECHNOLOGIES

Thank you

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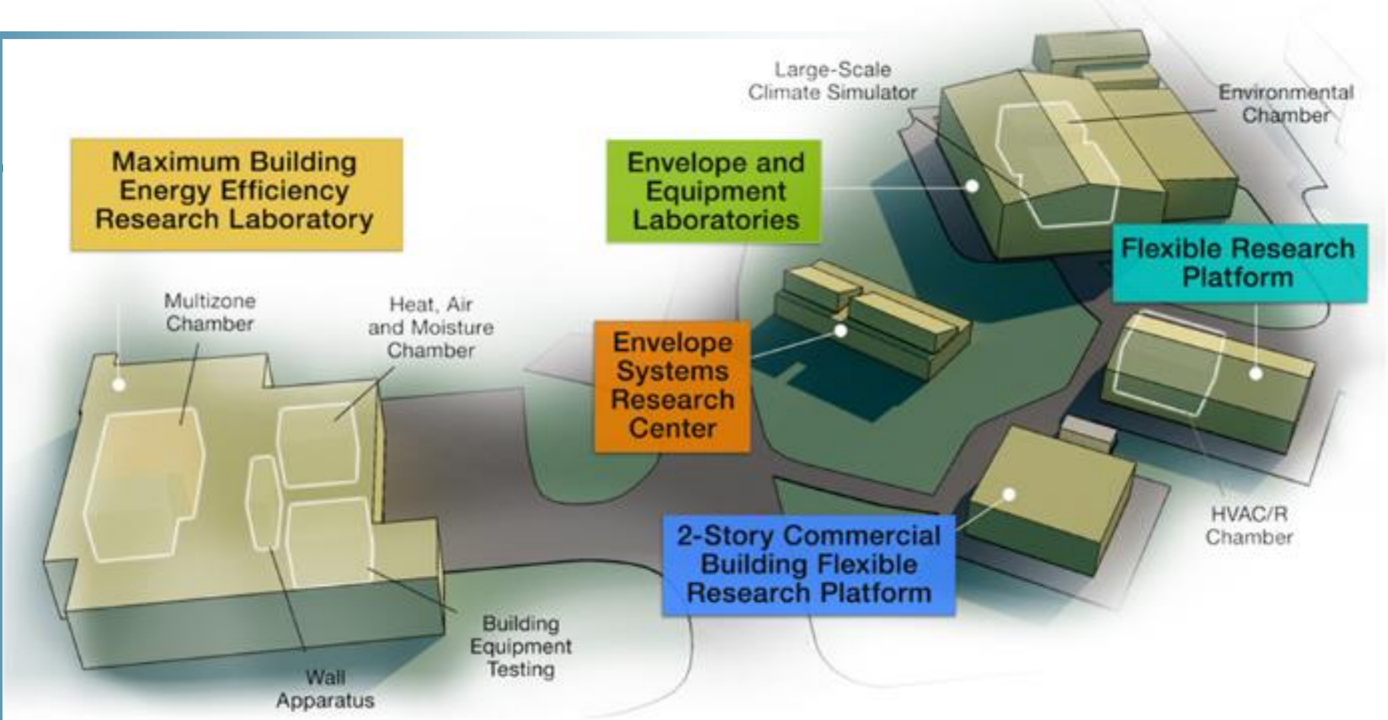


ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

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

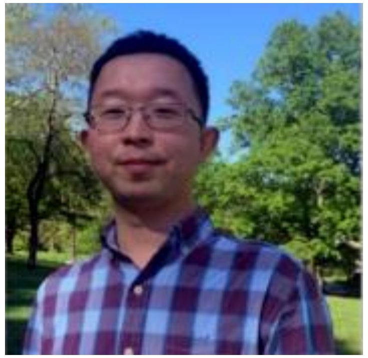
REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024		
Planned budget	1,500,000				1,500,000				1,500,000		
Spent budget	1,000,000										
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Market analysis and OEM engagement											
Materials characterization (CO2 and VOC removal)											
Materials characterization (Mositure removal)											
Materials characterization (biocidal)											
Process controlsand integration											
Lab scale evaluation											
Data analysis and establishment of integration											
Field evaluation											

Team


Kashif Nawaz
Project management
CO2 and moisture team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VOC team


Anna Jiang
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Muneesh Mururgan
Moisture team


Xiaoli Liu
Moisture and controls team


Melanie DeBusk
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Bill Partridge
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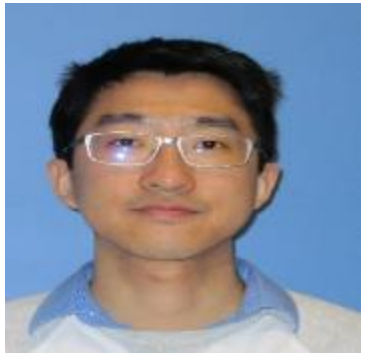
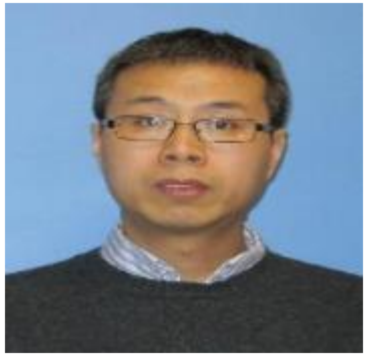
Keju An
VOC team


Borui Cui
Controls team


Jian Sun
Controls team


Yanfei Li
Controls team