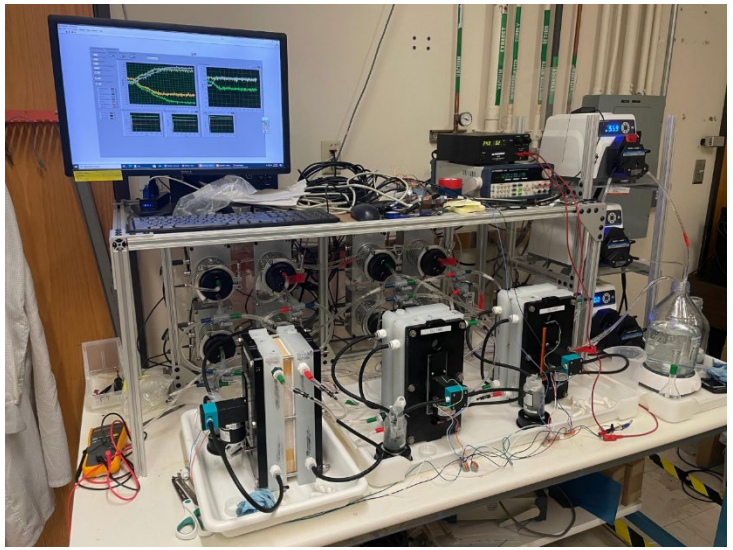
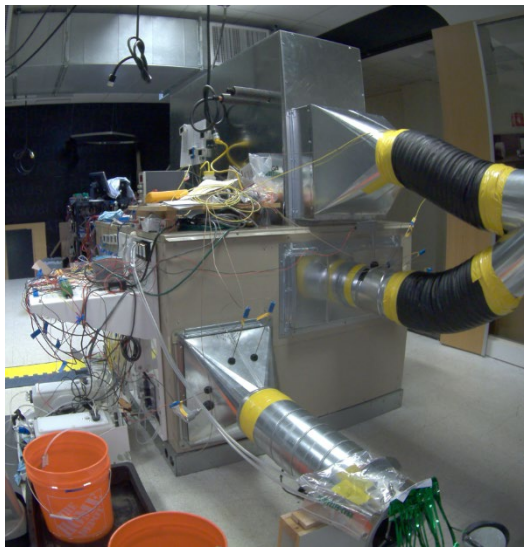
Reduced AC Loads using RAD-AC: an Efficient Electrochemical Dehumidification Cycle





Palo Alto Research Center
Aaron Meles, Product Manager
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Project Summary

Timeline:

Start date: June 1, 2019

Planned end date: February 28, 2022

Key Milestones

1. First test of electrochemically-regenerated dehumidifier; 12/31/20
2. Electrochemical regenerator RSEI <0.15 kbtu/lb

Budget:

Total Project $ to Date:

- DOE: $542k
- Cost Share: $154k

Total Project $:

- DOE: $897k
- Cost Share: $224k

Key Partners:

ORNL	
Daikin	

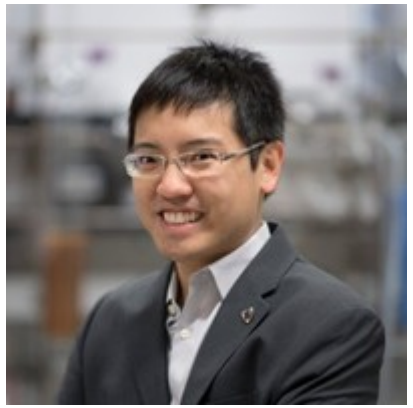
Project Outcome:

The Redox Assisted Dehumidification Air Conditioning (RAD-AC) project aims to reduce air conditioner energy usage by 55% by decoupling latent and sensible heat load in an AC unit by developing a liquid desiccant dehumidifier in tandem with PARC's novel redox-assisted electrodialysis-based liquid desiccant regenerator. The outcome of the project will be a demonstration of the key regeneration and desiccation technologies in a scaled, fully functional prototype.

Team

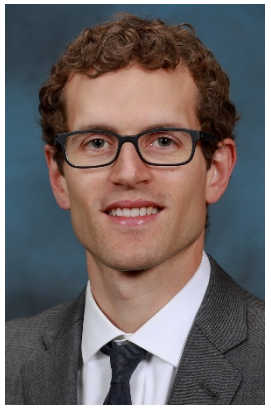
Mr. Aaron Meles
PARC
PI

- LDAC and HVAC industry veteran engineer
- Project management, systems engineering, productization



Dr. Eugene Beh
PARC
Lead Electrochemist

- Inventor of SUPER and RAD-AC
- Electrochemical system development



Dr. Kyle Gluesenkamp
ORNL
Equipment design & analysis

- Equipment and energy use modelling

Dr. Chun-cheng Piao
Daikin
Commercialization Partner

- Technology to Market and commercialization planning

Challenge

Problem Definition

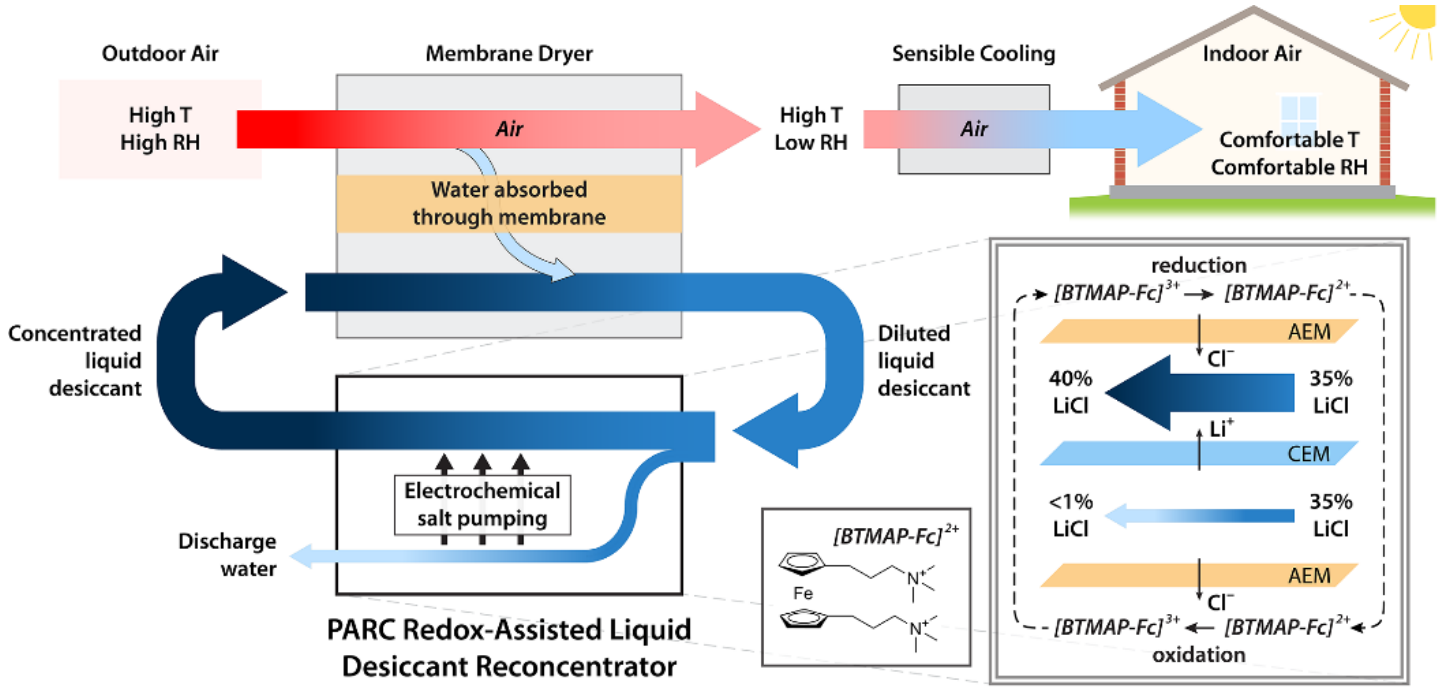
15% of commercial building electricity use is devoted to cooling. Energy efficiency improvements and increasing ventilation requirements have significantly increased the fraction of moisture load in modern buildings. A majority of existing HVAC systems meant to address this load dehumidify by overcooling the air to condense out the desired amount of water, resulting in high energy use and, in many cases, uncomfortably cool buildings.

Solid and liquid desiccant air conditioning systems have attempted to address this by separating sensible and latent cooling in a single piece of equipment but have been limited by high heat requirements to regenerate the desiccant. In addition to the energy cost required to produce, this heat also “bleeds over” and warms the cool air stream, increasing the cooling load and diluting the equipment’s value proposition.

Approach

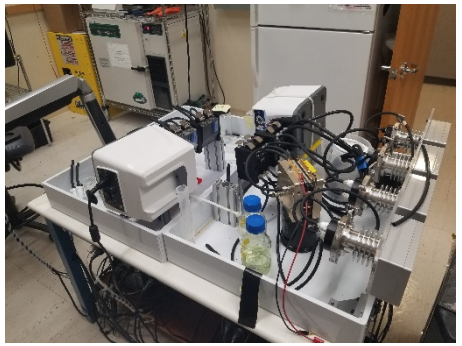
RAD-AC uses electrodialysis to regenerate liquid desiccants entirely in the liquid state

- Reduces minimum theoretical regeneration energy from 0.97 kBTU/lb (to evaporate water) to 0.05 kBTU/lb
- Unlocks full potential of liquid desiccants by eliminating parasitic heat crossover
- Compatible with any sensible cooling technology

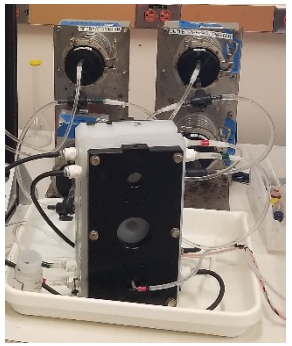


Approach

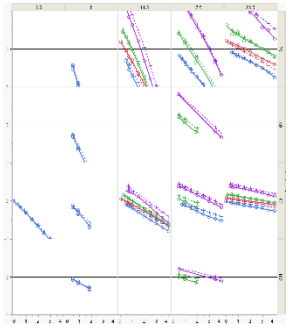
Project plan



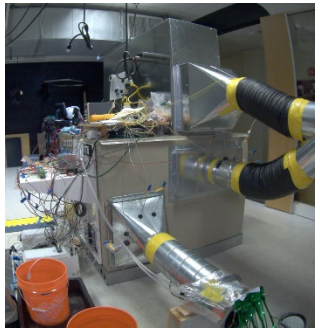
Material selection & characterization



Stack construction & testing



System modelling



Full system build & test

De-risk materials

What materials work best for this new application?

De-risk components

What design performs like material properties predict?

De-risk system

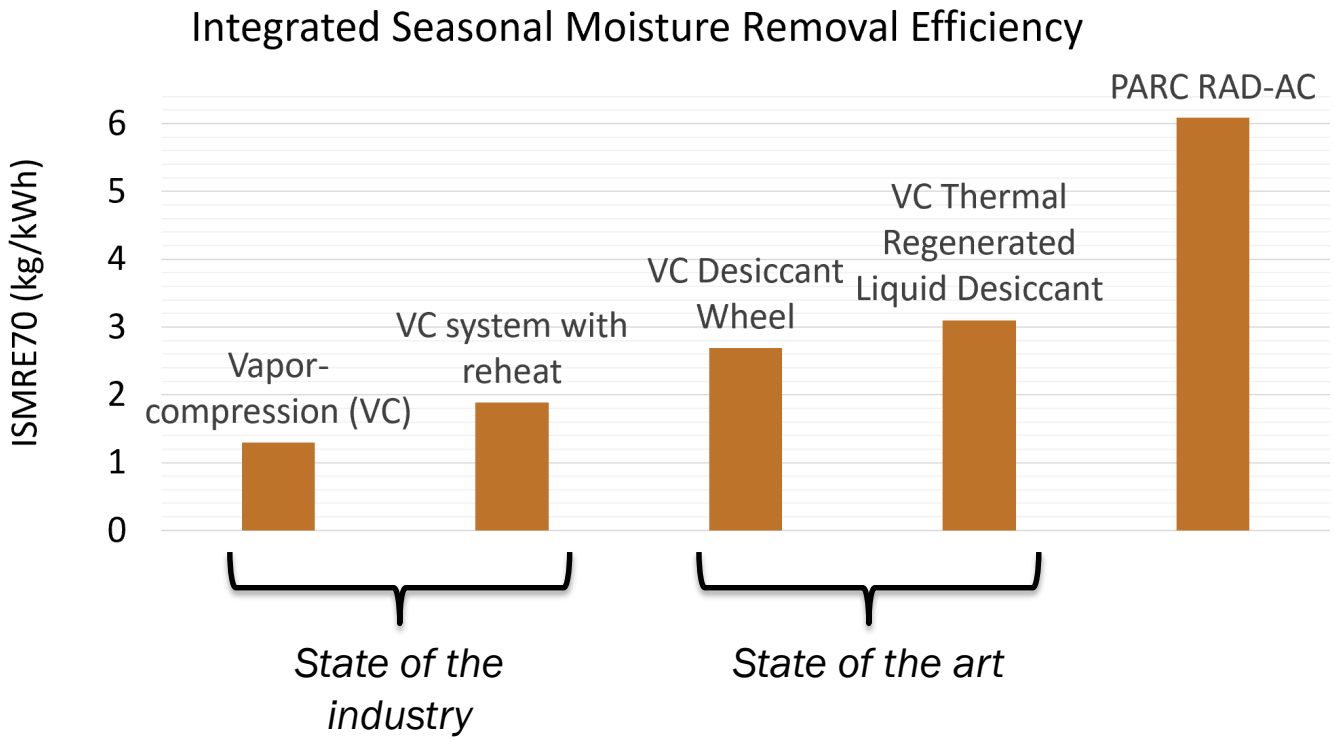
What efficiency can we expect from a liquid desiccant air conditioner using RAD-AC?

Systematic material/component/system progression mitigates project risks and addresses each technical challenge at the smallest possible scale

Impact

RAD-AC can achieve efficiencies 2x the state of the art

- Modelling of RAD-AC shows Integrated Seasonal Moisture Removal Efficiencies (per AHRI920) of >6 kg/kWh possible
- 100% electric regeneration enables energy storage and load shifting by concentrating desiccant during off-peak periods
- Enables separate sensible and latent cooling agnostic to heat pump technology

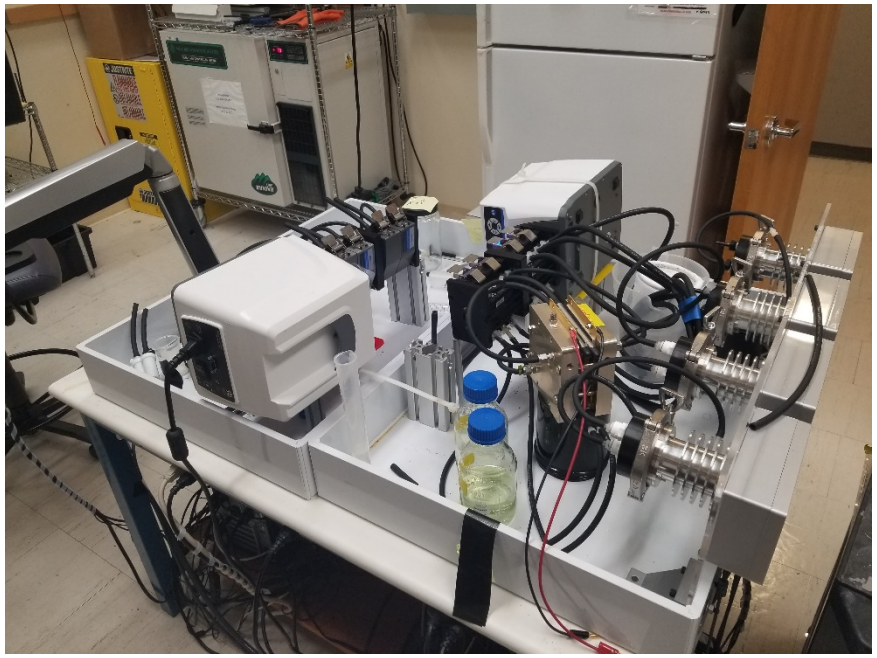


RAD-AC can contribute > 0.5 Quad/year in savings toward BTO program goals

Progress

Material selection & characterization

- ✓ *Over 25 commercially available membranes characterized*
- ✓ *Compatible wetted components identified*
- ✓ *Flow field visualizations completed*
- ✓ *Mechanical design of stack completed*

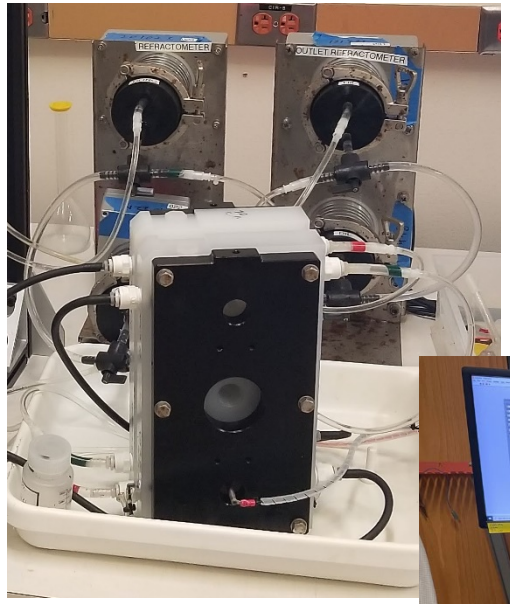


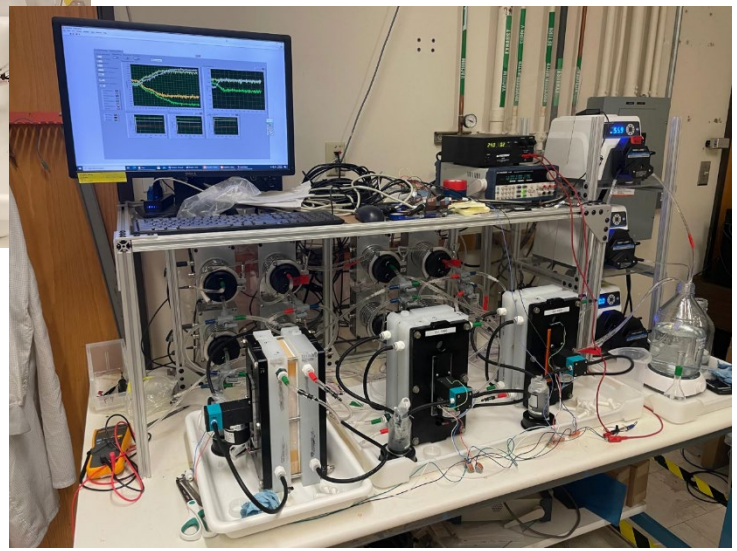
Deep knowledge of critical materials established

Progress

Stack construction and testing

- ✓ *Over 50 electrochemical stacks built*
- ✓ *Fully characterized over expected operating regime*
- ✓ *Over 2000 hours of run time on one stack with no performance degradation*
- ✓ *Multi-stack testing commenced*

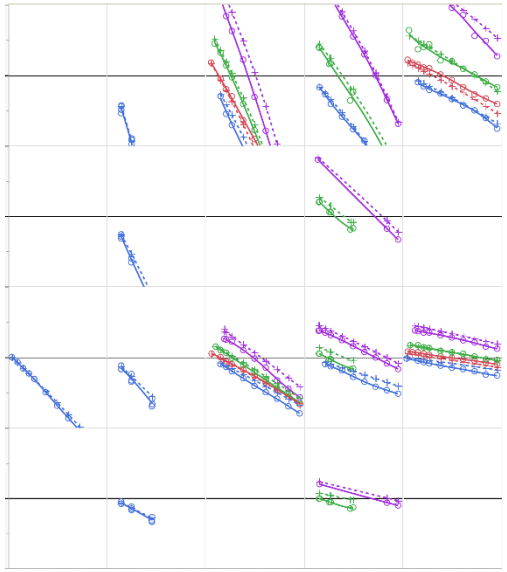


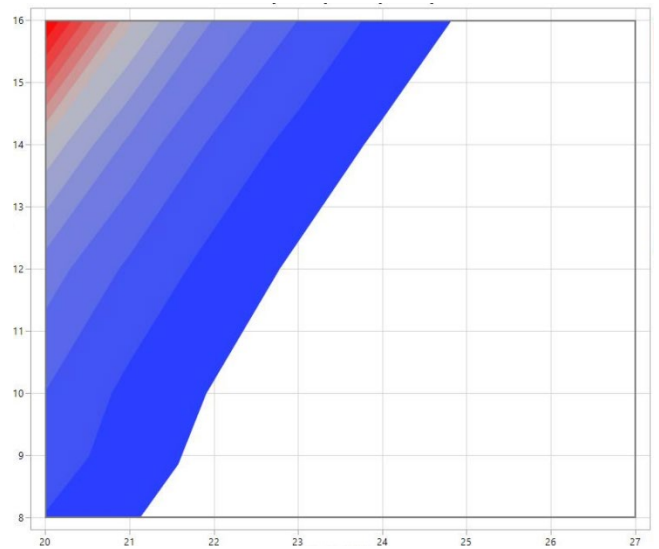


Strong expertise developed in electrochemical stack design, build, and operation

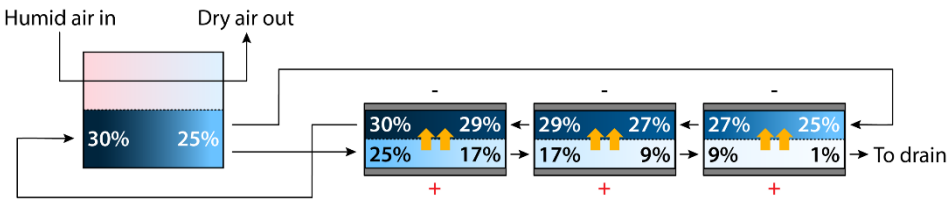
Progress

System modelling





- ✓ *Stack model matches characterization data set within 6%*
- ✓ *Multi-stack staging topology selected*
- ❑ *Integrated thermodynamic model of dehumidifier*

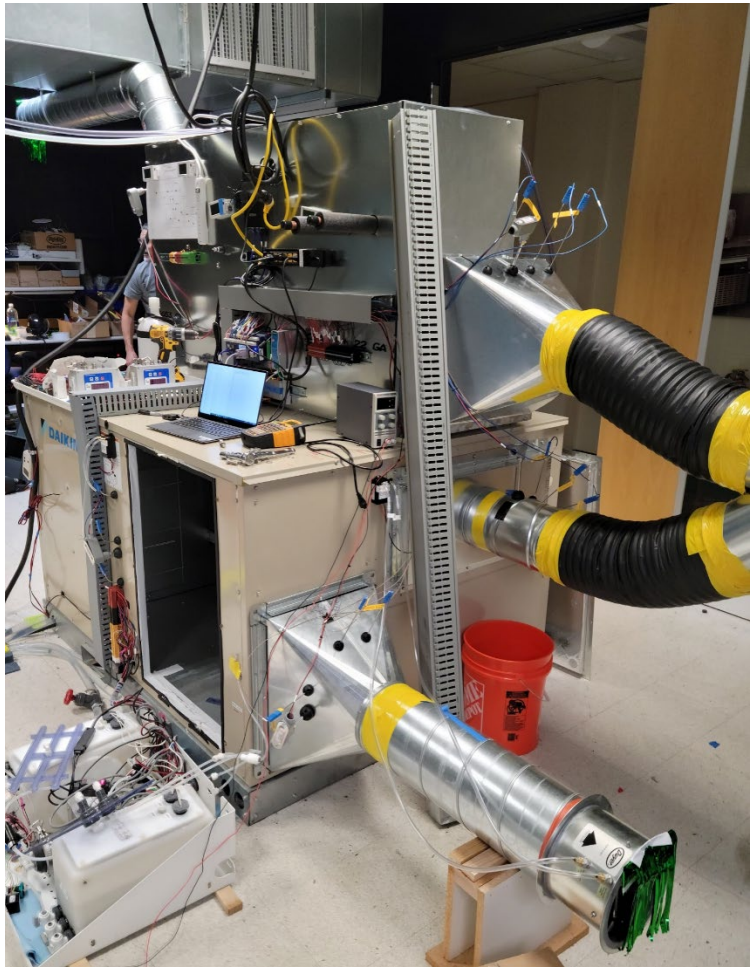


Validated system model shows regenerator achieving project goals

Progress

Full system build & test

- ✓ *Build LDAC unit (minus regenerator)*
- ❑ *Build and integrate RAD-AC regenerator*
- ❑ *Performance test dehumidifier*
- ❑ *Feed back results to TEA and commercialization plan*



Stakeholder Engagement

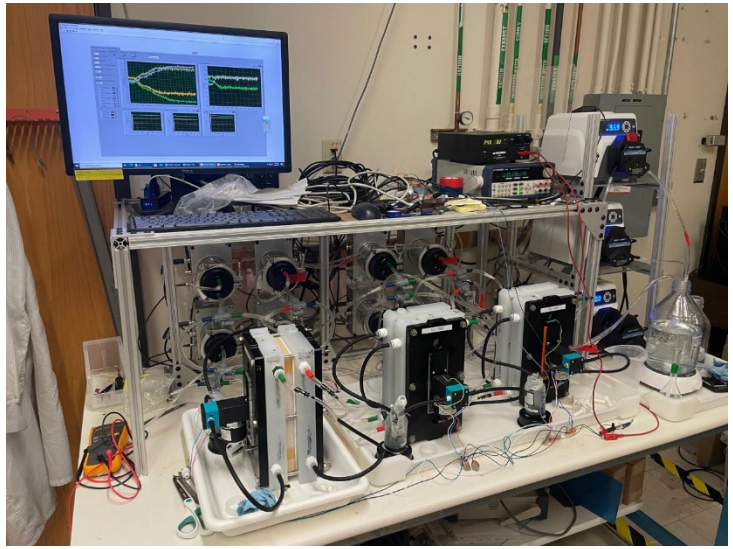
Initial target applications for RAD-AC are commercial dehumidification and dedicated outdoor air systems

- Daikin is the commercialization partner for RAD-AC (Dr. Chun-cheng Piao, SVP Technology Alliances)
- Application requirements, TEA, and commercialization strategy informed by Daikin insights
- Manufacturing guidance from Xerox (PARC's parent company)

Remaining Project Work

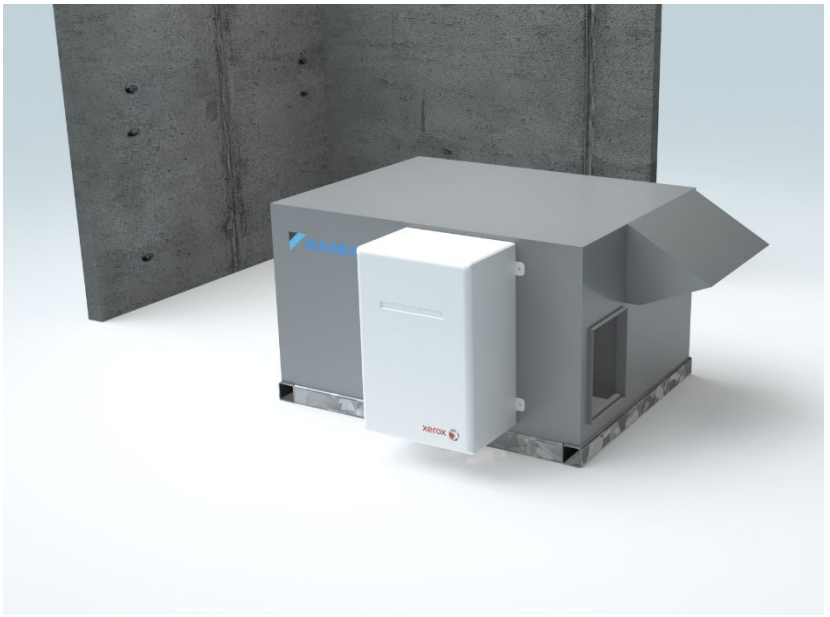
This project

- Build and integrate multi-stage regenerator into dehumidifier
- Performance test dehumidifier
- Transition activities



Beyond this project

- Lab performance & efficiency mapping
- Field testing
- Component continuous improvement
- Design for manufacturing



Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: Project total budget is just over $1m dollars, with period of performance of 26 months.
Variances: The only budget variances that arose during the project were underspending due to COVID delays, resulting in no-cost extensions.
Cost to Date: 80% of the budget has been expended to date.
Additional Funding: There was additional intercompany investment in this area as well as CRADA activities with National Labs.

Budget History			
6/01/2019 – FY 2020 (past)		FY 2021 (current)	
DOE	Cost-share	DOE	Cost-share
$318k	$80k	$478k	$145k

Project Plan and Schedule

Task Name	Start	Finish	% Complete	Du...
RADAC	06/01/19	02/28/22	81%	717d
1.0 Material selection	06/01/19	08/30/19	100%	66d
2.0 ED stages testing and modeling	06/01/19	05/20/20	100%	254d
3.0 ED stack construction	09/01/19	08/31/20	100%	262d
4.0 ED stack testing	01/01/20	12/30/20	100%	261d
5.0 System level modelling	11/01/19	12/31/20	100%	305d
6.0 Market transformation plan	08/01/19	12/31/20	100%	371d
7.0 ED stack testing	12/01/20	12/31/21	90%	284d
8.0 Building impact envelope	12/01/20	03/31/21	100%	87d
9.0 System level design	12/01/20	05/31/21	100%	130d
10.0 System build	12/01/20	12/31/21	83%	284d
11.0 System testing	05/01/21	12/31/21		176d
12.0 System level modeling	06/01/21	01/31/22	50%	175d
13.0 In-situ testing	07/01/21	02/28/22		173d
14.0 Market transformation plan	12/01/20	02/28/22	75%	325d