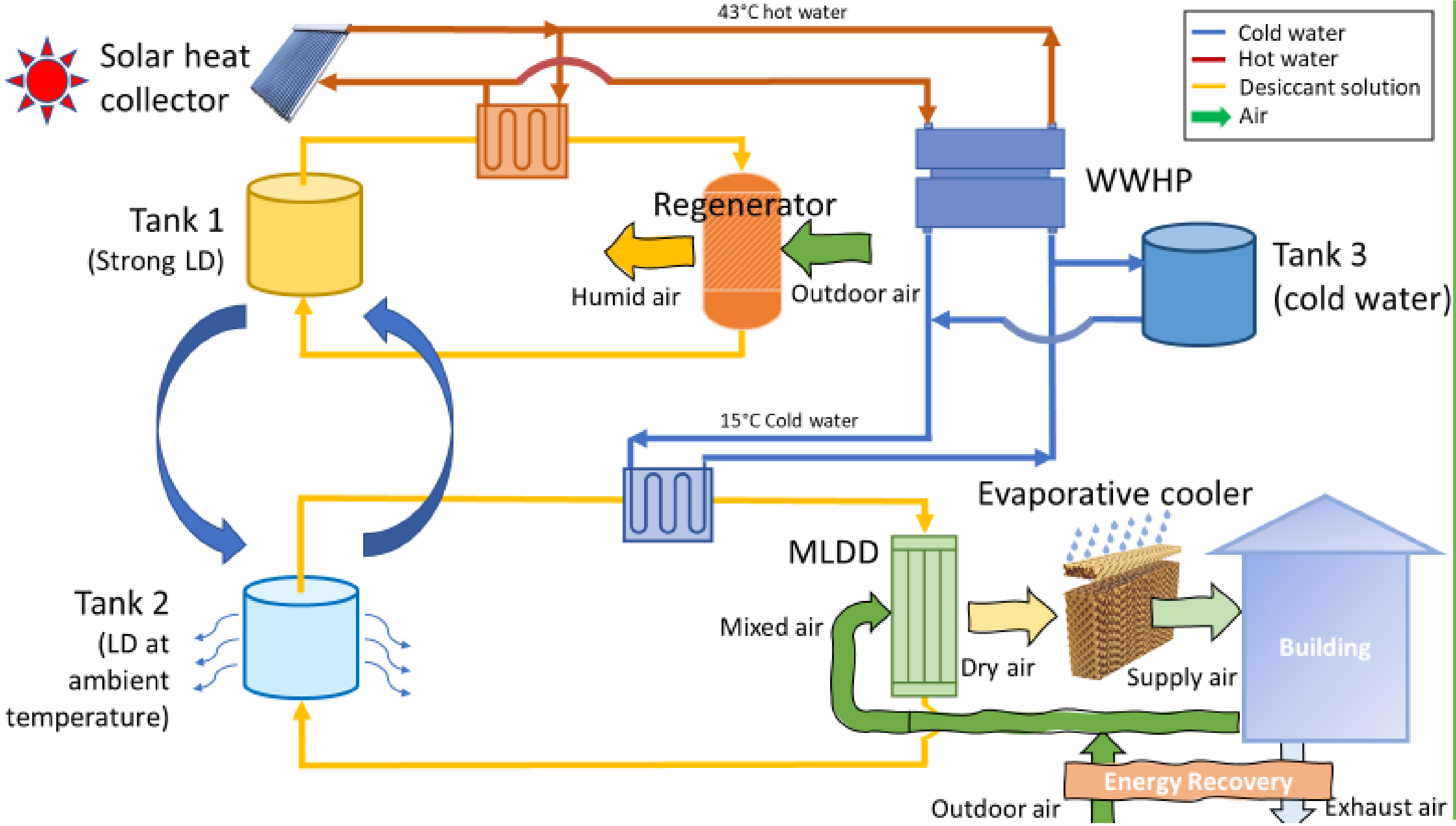
Grid Flexible and Energy Efficient Evaporative Cooling and Dehumidification System Integrated with Thermal Energy Storage



ORNL
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Project Summary

Timeline:

Start date: April 2021

Planned end date: March 2023

Key Milestones

1. Design an evaporative cooling system integrated with membrane-based dehumidifier using liquid desiccant and a thermal energy storage; 6/30/2021
2. Build a prototype of the proposed system with 3.5 kW cooling capacity; 3/31/2022

Budget:

Total Project $ to Date:

- DOE: $300K
- Cost Share: $0

Total Project $:

- DOE: $500K
- Cost Share: $0

Key Partners:

PURDUE UNIVERSITY

IEA EBC Energy in Building and Communities Programme

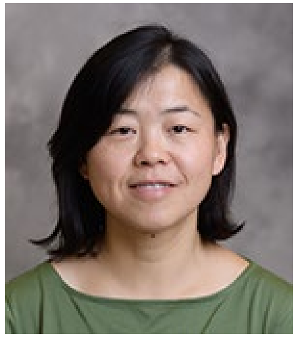
ANNEX 85 Indirect Evaporative Cooling

Project Outcome:

Develop a highly efficient sorption-assisted cooling system that separately controls temperature and humidity in residential and commercial buildings. Integrated with a thermal energy storage, this system also enables flexible behind-the-meter electricity demand.

Team

Modeling



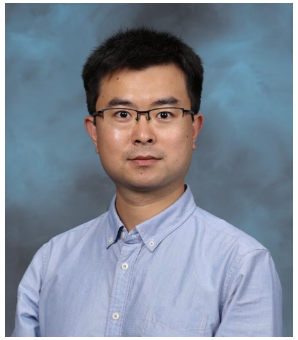
Professor Ming Qu
at Purdue University

Tomas Venegas
PhD student at
Purdue University

Prototype development, lab tests, and system integration

Project Lead

Dr. Xiaobing Liu
R&D Staff at ORNL
20 years experience in
R&D of HVAC systems



Dr. Lingshi Wang
Associated R&D Staff at ORNL

Tony Gehl
Senior Technical Staff at ORNL

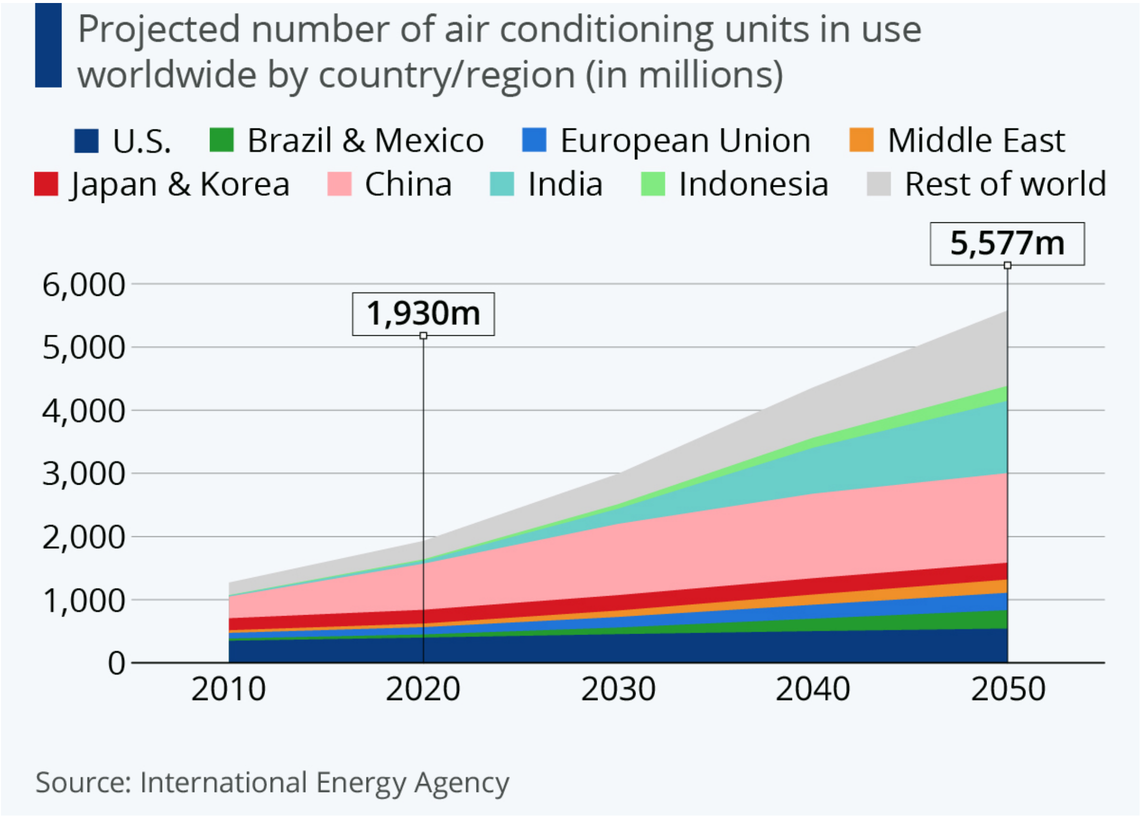
Industry partners

International Energy Agency

EBC
Energy in Building and
Communities Programme

ANNEX 85
Indirect
Evaporative
Cooling

Background

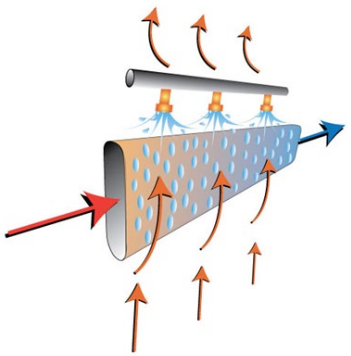


- Growing demands for air-conditioning
- Current vapor-compression (VC) based cooling systems result in huge demand for electricity and refrigerants with high global warming potential
- Few non-vapor-compression cooling technologies are commercially available
- Better indoor environment is needed to improve well-being of building occupants and reduce potential virus transmission

Technical Challenges of Promising Technologies

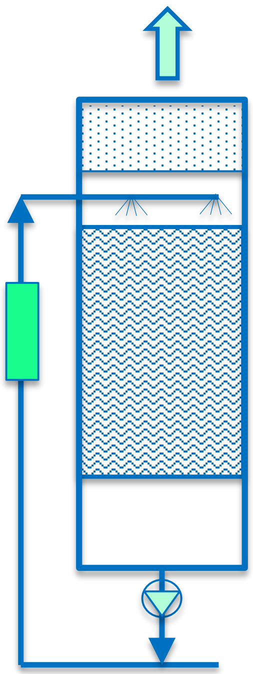
6 of the 8 finalists of the 2018 Global Cooling Price proposed variants of two technologies

Evaporative Cooling (EC)



- Only applicable in dry climate
- Consume water
- Limited control of indoor air condition

Liquid Desiccant Dehumidification (LDD)

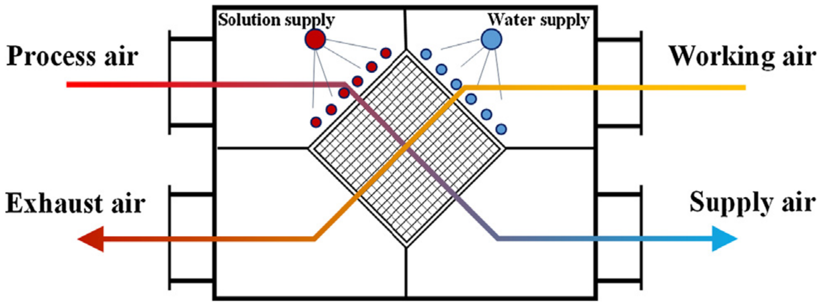


- Corrosion resulting from desiccant
- High energy consumption for regeneration
- Large size for heat and mass transfer

Available Technologies to Solve Problems

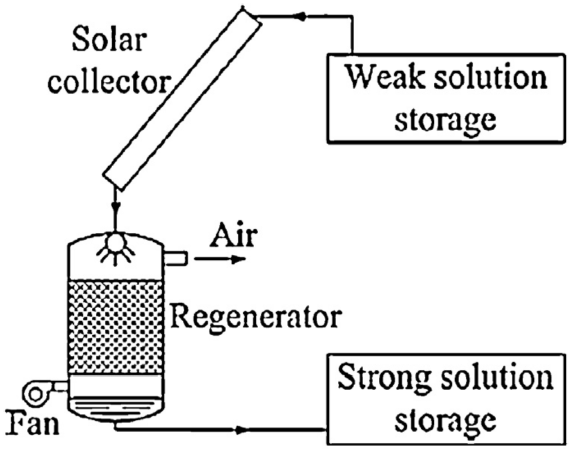
Problem	Solution
Limited applicability	Desiccant-assisted EC
Poor control of indoor air temperature and humidity	Separated sensible and latent cooling with a hybrid desiccant-assisted EC and VC cooling
Corrosion	Membrane-based dehumidifier
High energy consumption for regenerating desiccant	Recover heat from VC and use solar heat or other available waste heat
Mismatch between demand and supply of renewable power	Load shifting with thermal energy storage and desiccant-assisted EC

Internally cooled liquid desiccant dehumidifier



Park et al., Applied Energy 235 (2019)

Solar desiccant regeneration system with storage

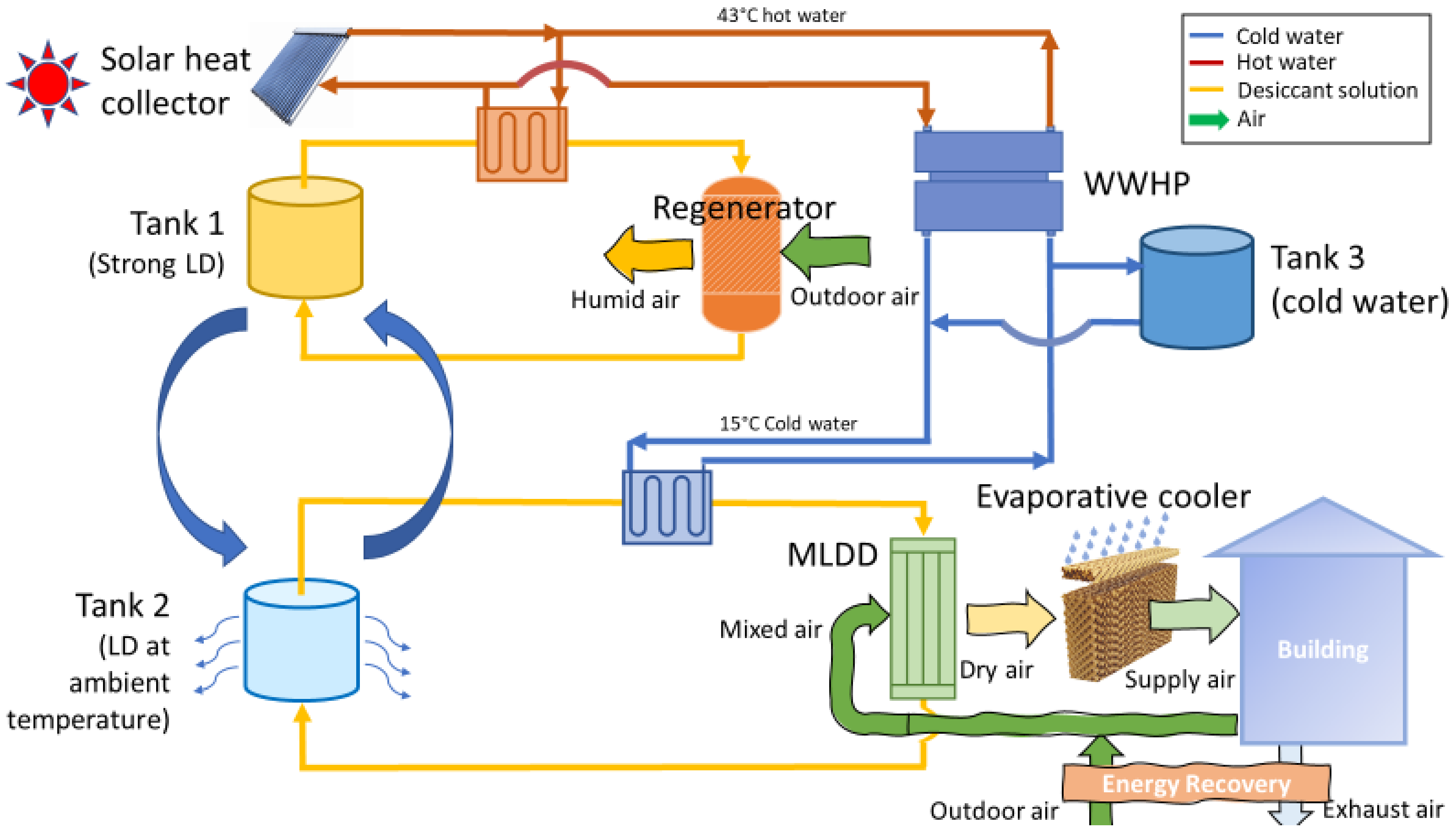


Cheng and Zhang, Energy and Buildings 67 (2013)

Approach: System Integration

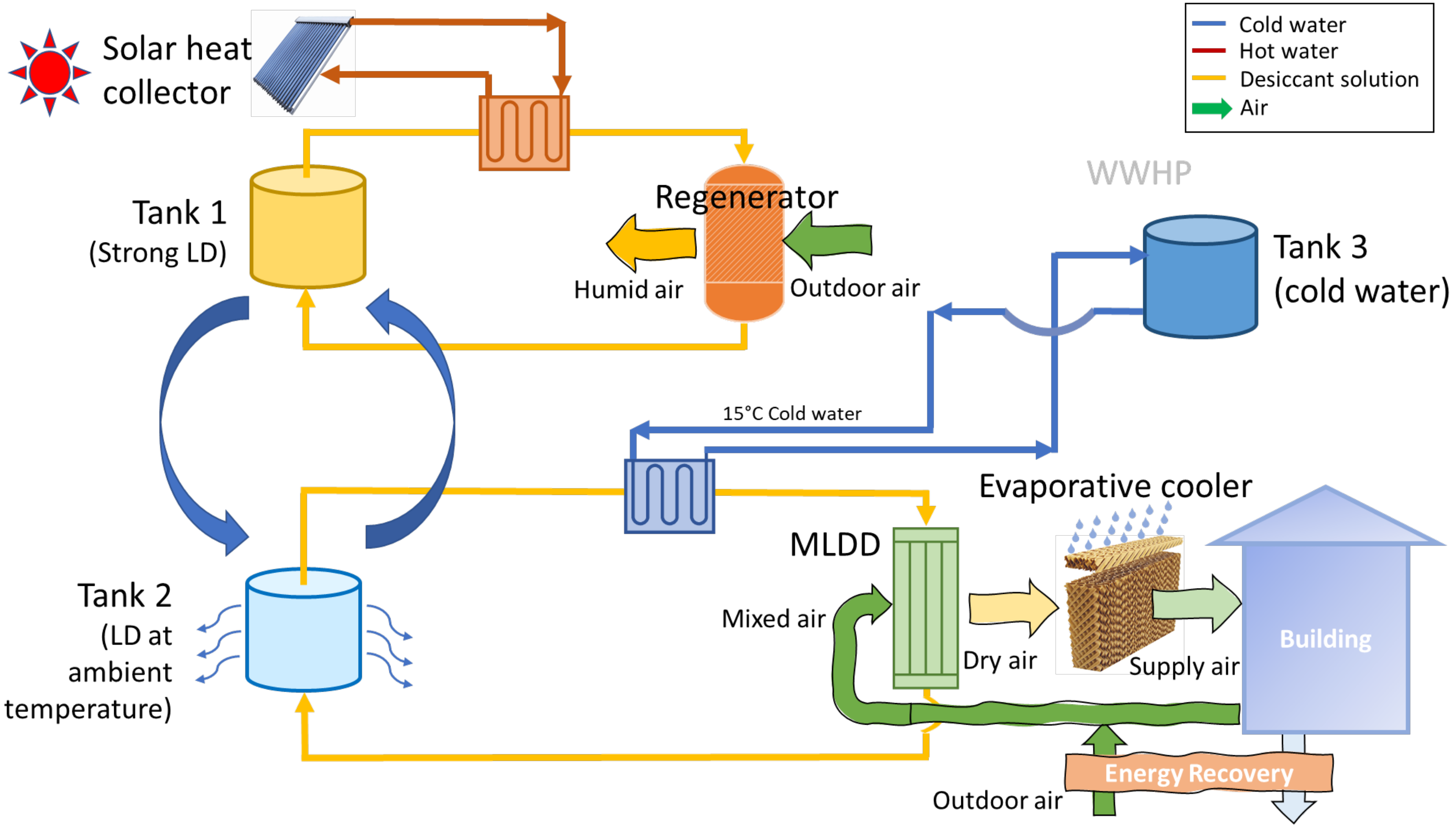
- A membrane-based liquid desiccant dehumidifier (MLDD) to enable EC at all climates
- A WWHP to provide both sensible cooling and the primary heat source for regenerating liquid desiccant
- Decouple dehumidification and regeneration processes using two tanks to store liquid desiccant (LD)

Tank 1 is charged with strong LD, cooled naturally, then swapped with Tank 2

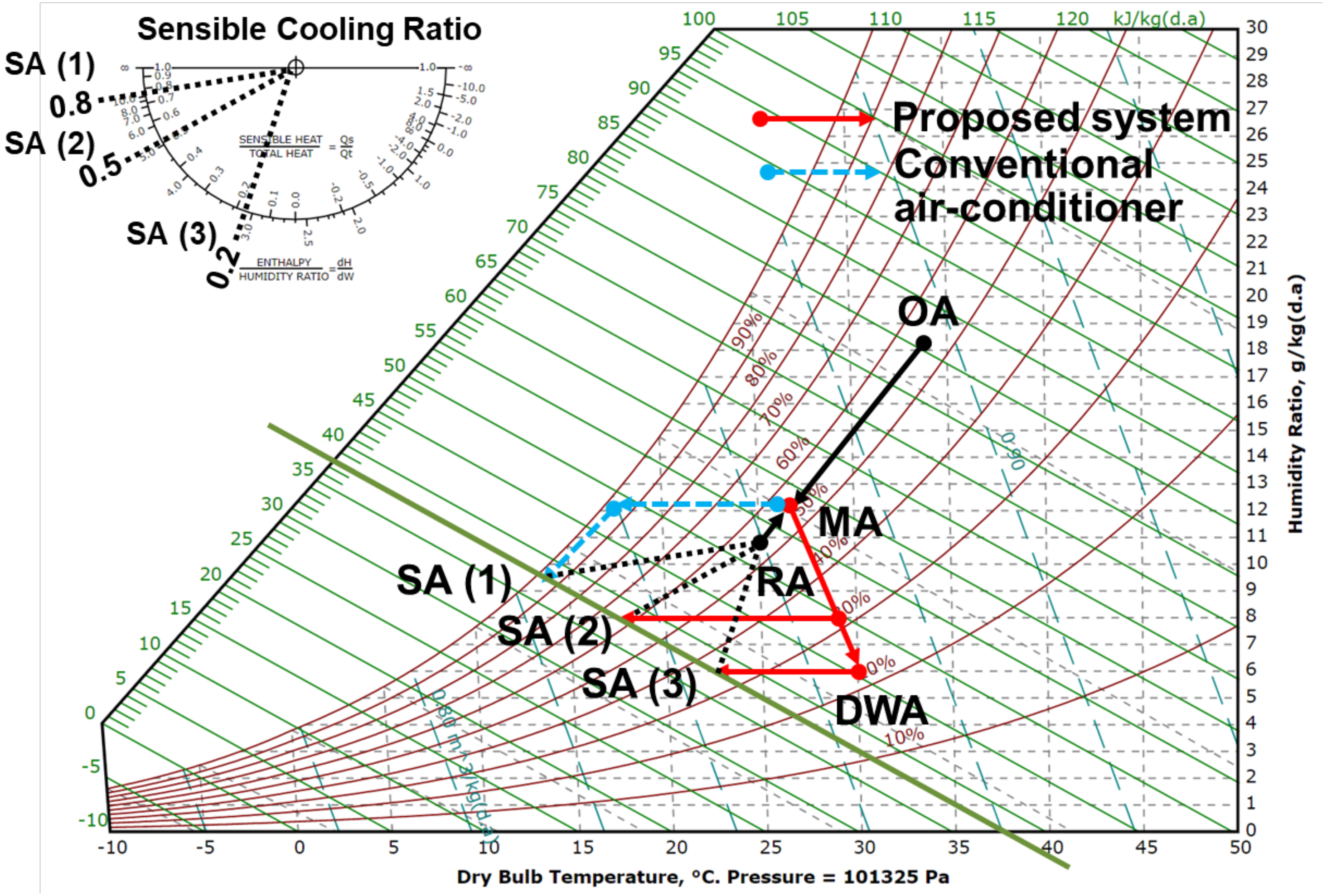


Approach: Load Shifting

- Operate WWHP at off-peak hours to store LD and cold water
- Use stored LD and cold water to dehumidify and cool air during peak hours **without running WWHP**



Approach: Flexible Temperature and Humidity Control



OA: Outdoor air
RA: Return air
MA: Mixed air
DWA: Dry warm air (leaving MLDD)
SA (1-3): Supply air

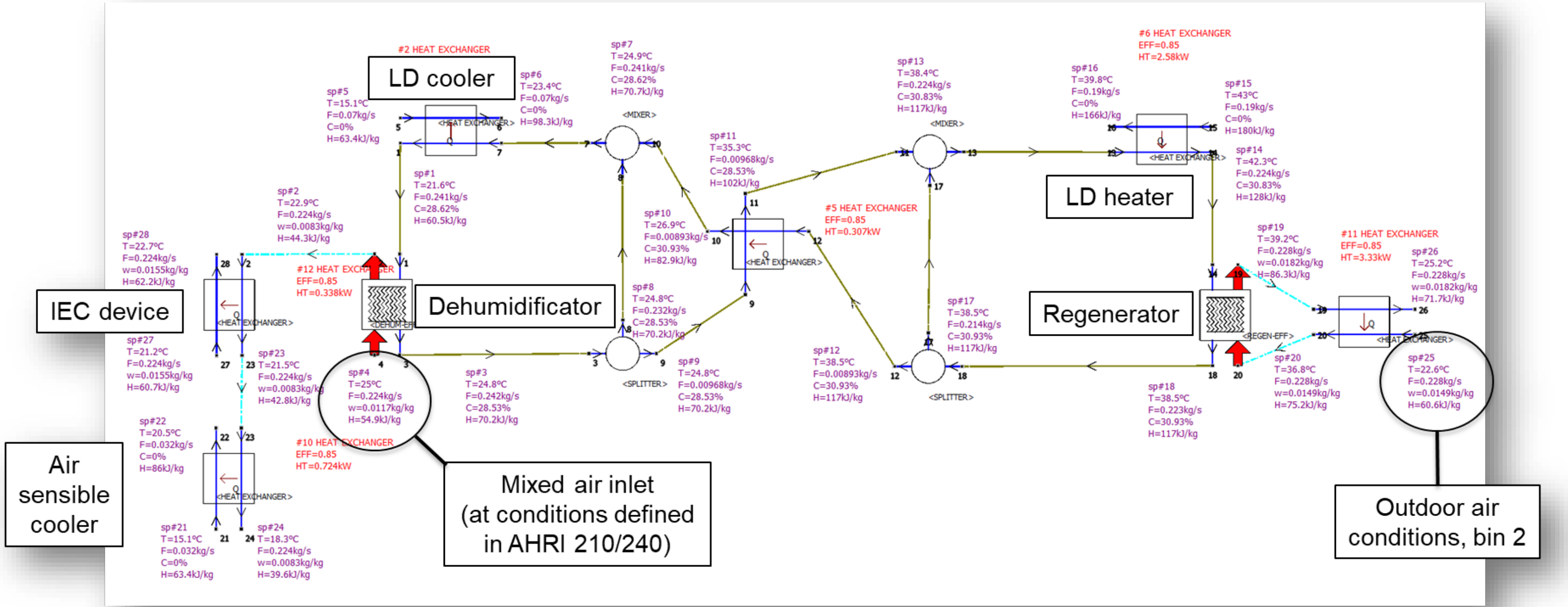
- Provide a range of supply air conditions to match both the latent and sensible cooling loads (variable sensible cooling ratio) by adjusting dehumidification and sensible cooling
- Improve occupant thermal comfort and VC system efficiency by increasing supply air temperature closer to thermal comfort range

Impact

- **20% higher efficiency than SEER 14 → reduction in electricity consumption and carbon emissions for air-conditioning in the US each year**
  - 119 TWh electricity consumption
  - 84 Million Metric tons of CO_2
- **Smaller vapor-compression systems with lower GWP refrigerants**
- **Reduce summer peak electric demand by using non-VC cooling and desiccant dehumidification during peak hours**
- **Improve thermal comfort with separated temperature and humidity control**

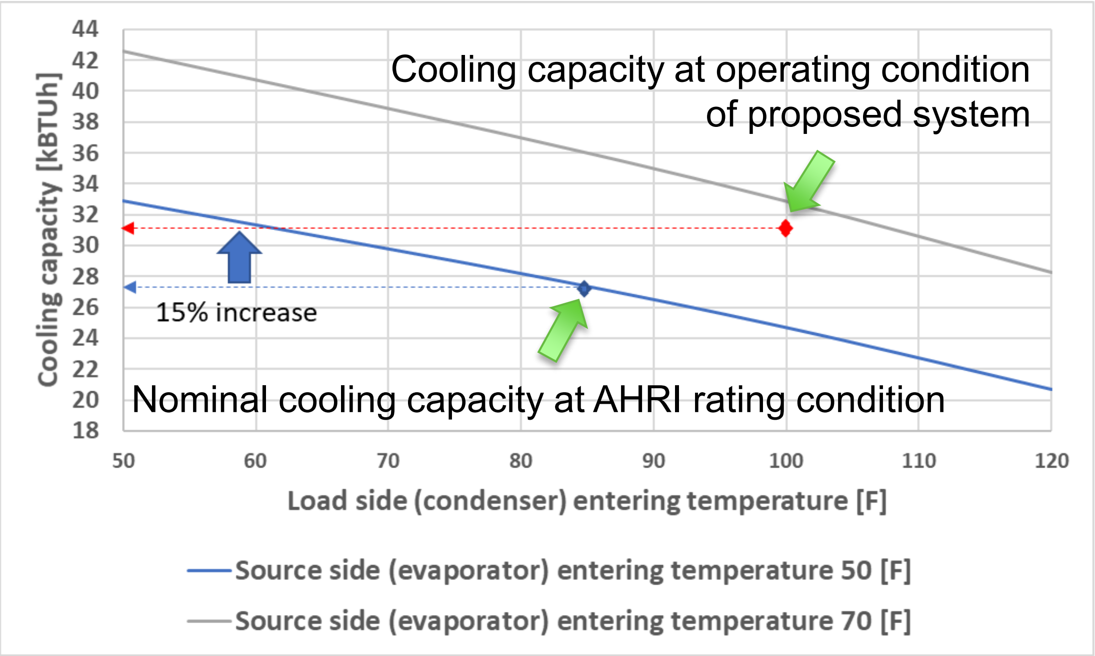
Progress (Early-Stage): System Design & Efficiency Calculation

- Designed and evaluated various system configurations using the SorpSim program
  - Run simulations at various outdoor air conditions at Atlanta, GA in cooling season
  - Calculate SEER of the proposed system based on AHRI standard 210/240 (2008)
  - **Simulation result indicates the proposed system reaches a 15.7 SEER (a 12% increase over SEER 14)**



Screenshot of SorpSim model of the proposed system with calculated operating state of each component
(SorpSim is an open-source sorption simulation software, co-developed by ORNL and Purdue University)

Progress (Early-Stage): VC Capacity Reduction

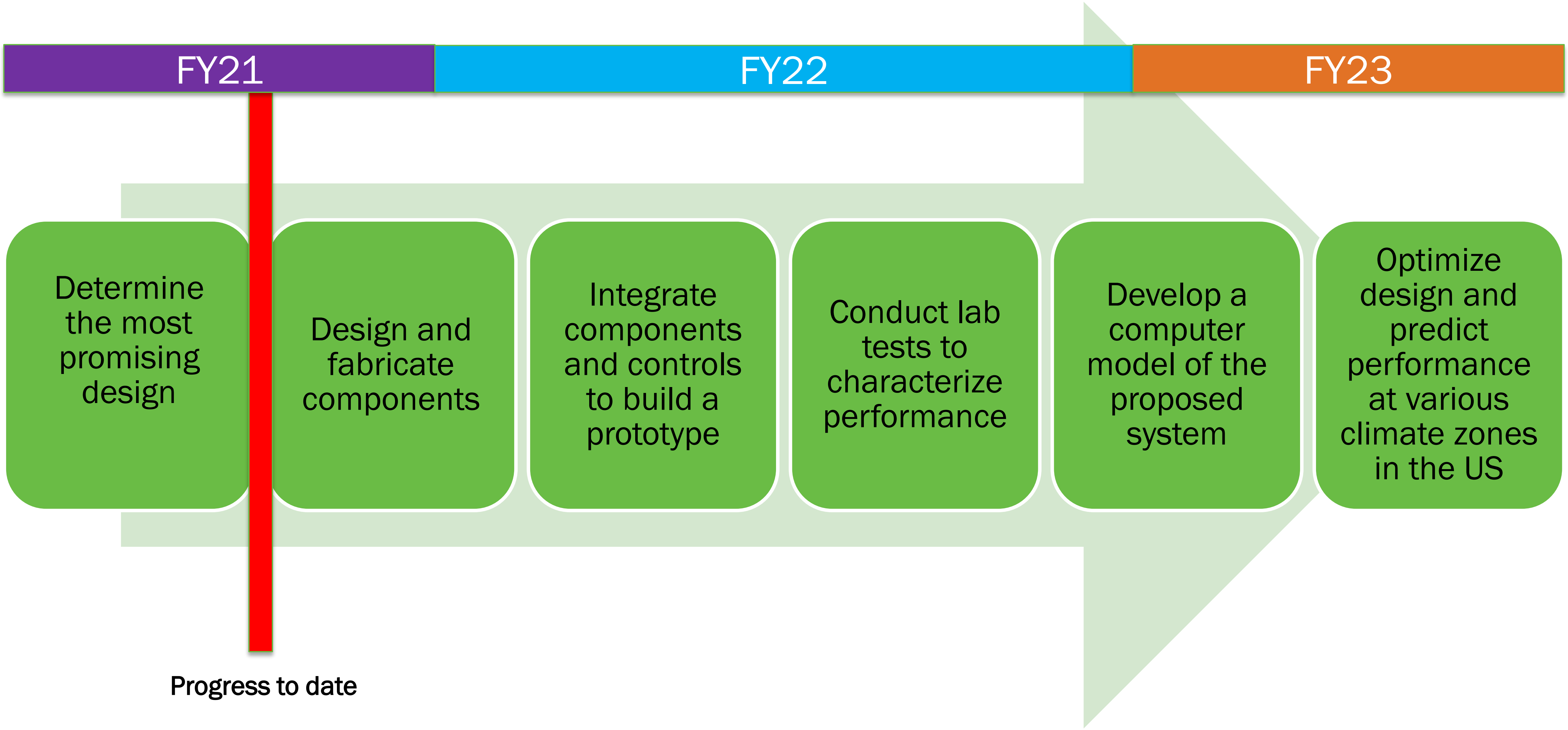


- WWHP provides more cooling at operating condition of the proposed system (15°C/59°F cold water and 43°C/109°F hot water) than at typical air-conditioning condition (i.e., 7°C/45°F cold water and 35°C/95°F hot water)
- **The size of VC in the proposed system can be 15% less than the conventional air-conditioner for delivering the same total cooling capacity**
- Needed VC capacity may be further reduced by using indirect evaporative cooling to reduce cooling demand of the WWHP

Stakeholder Engagement (Early-Stage)

- Collaborate with IEA EBC Annex 85 to develop EC technology and keep up to date of the latest development and market needs for EC
- Will work with Emerson and other industry partners to develop a prototype of the proposed system
- Seek opportunities for a CRADA project to further develop, field test, and commercialize the proposed system
- Work with ASHRAE and DOE's Building Energy Simulation program to develop modeling tool for the proposed system
- Publish papers and present results at related conferences

Remaining Project Work



Thank you

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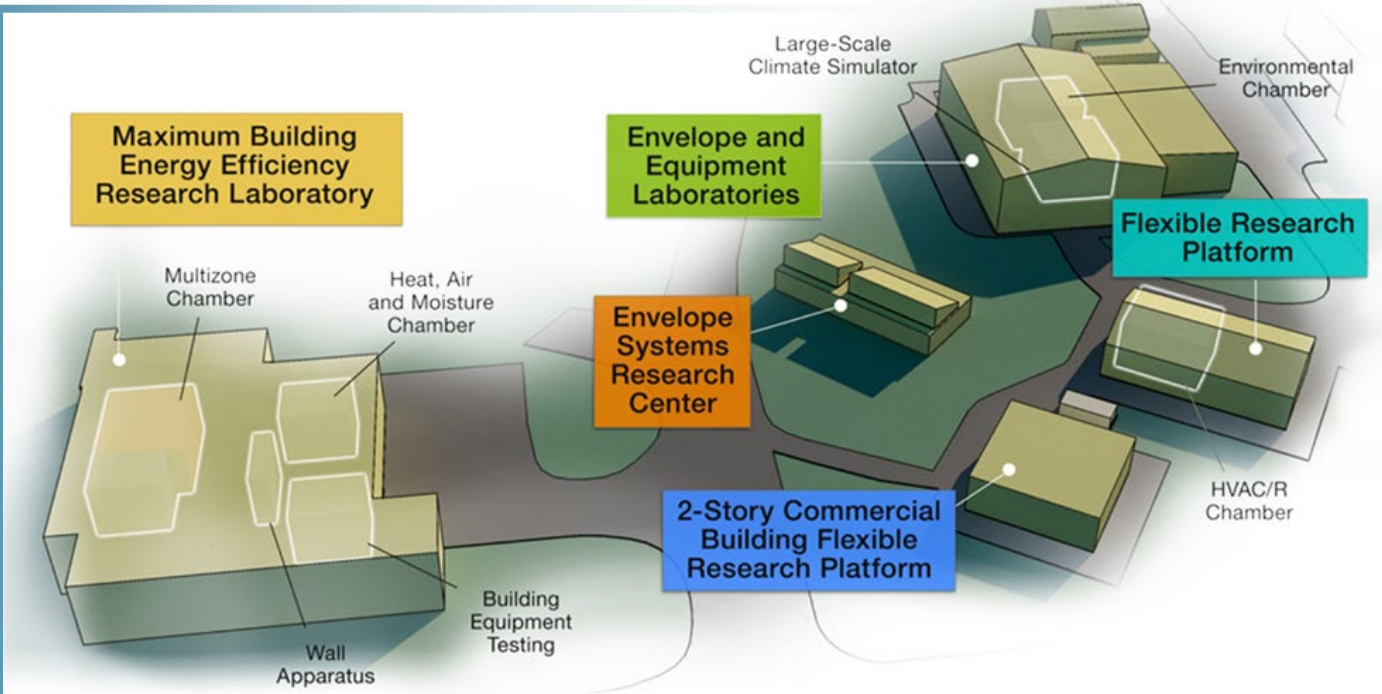

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free 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: FY21: $300K; FY22: $200K
Variances: Due to a late start, the end date will be extended to Q2 of FY23
Cost to Date: 10% ($50K)
Additional Funding: No

Budget History					
FY 2020 (past)		FY 2021 (current)		FY 2022 – FY2023 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$0	$0	$300	$0	$200	$0

Project Plan and Schedule

Project Schedule													
Project Start: April 2021		Completed Work											
Projected End: March 2023		Active Task (in progress work)											
	◆	Milestone/Deliverable (Originally Planned) use for missed											
	◆	Milestone/Deliverable (Actual) use when met on time											
	FY2021				FY2022				FY2023				
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													
Task 1: First order analysis for system design													
Current/Future Work													
Task 2: Component design for targeted performance													
Task 3: Fabricate componens													
Task 4: Develop control system													
Task 5: Build a prototype with 3500 W total cooling capacity													
Task 6: Conduct lab tests to characterize performance													
Task 7: Create simulation of the proposed system													
Task 8: Assess performance for targeted applications													