Membrane Based Air Conditioning

2017 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: October 1, 2015

Planned end date: March 31, 2018

Key Milestones

1. System Design Review; March 2016
2. Compressor testing review; September 2017
3. Go/No-Go based on bench testing; March 2017
4. Experimental evaluation of V1 prototype; December 2017

Key Partners:

Oak Ridge National Lab (ORNL) *Building Technologies Research & Integration Center (BTRIC)*
Xergy Inc
SoftInWay, Inc

Budget:

Total Project $ to Date:

- DOE: $236,432.05
- Cost Share: $62,396.36

Total Project $:

- DOE: $1,200,000.00 (includes $500,000.00 to ORNL)
- Cost Share: $300,000.00

Project Outcome:

This project will develop, fabricate, and test a TRL-6 prototype of a membrane-based, non-vapor-compression HVAC system offering

- Up to 84% energy savings
- Water as a working fluid
- Independent humidity control

Purpose and Objectives

Problem Statement: Development of high performance, cost-effective non-vapor compression air conditioning system for the commercial sector.

Target Market and Audience: The target market is cooling provided by rooftop equipment; roughly half of the current commercial cooling load. We are targeting collaboration with equipment and component manufacturers. The total primary energy consumption for cooling in commercial buildings in 2030 is projected to be 0.57 quad (EIA, AEO)*.

Impact of Project: This project will result in the development of the first packaged, membrane-based air conditioning system with separate sensible and latent cooling.

- Eliminate ~20 lb refrigerants per unit
- 54 – 89% energy savings

* http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2015&subject=0-AEO2015&table=5-AEO2015&region=0-0&cases=ref2015-d021915a

Approach

Approach:

- Two strategies for vapor compression
  - Mechanical and electrochemical
  - Design, test, and evaluate
- Build a 7.5 ton, TRL-6 prototype RTU for testing at ORNL
  - Demonstrate primary COP = 2.00
  - 54 – 89% better than today

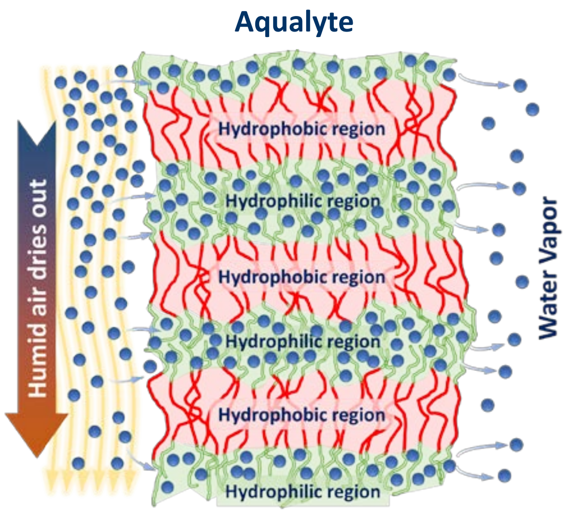
Key Issues:

- Techno-economic factors
- Optimal vapor compression
  - Extremely low density water vapor must be compressed efficiently
  - Vapor compressors are by far largest parasitic load

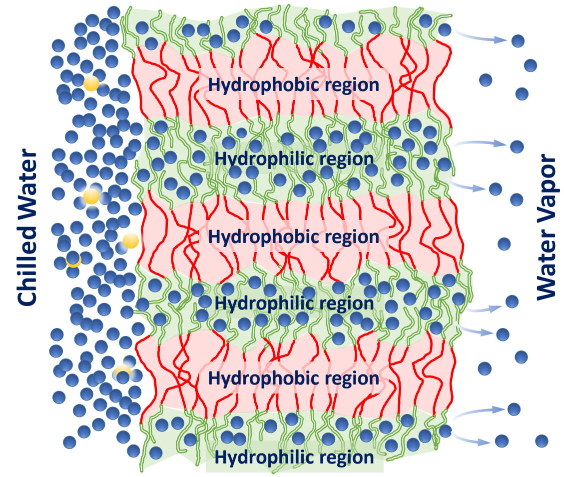
Approach

Distinctive Characteristics:

- Aqualyte™ = selective pervaporation material
  - Manipulate vapor pressure differentials
  - Low transport rates for N_2, O_2, other gases helps maintain vacuum
- Membrane dehumidifier & humidifier
  - Isothermal transport of water vapor = ***independent control of T and RH***
- Membrane chiller
  - Vacuum evaporation = sub-ambient refrigeration
  - Closed loop heat pump, water as working fluid
- Vapor compressors provide motive force
  - Electrochemical vapor compression (Xergy)
  - Mechanical vapor compression



Membrane Dehumidifier

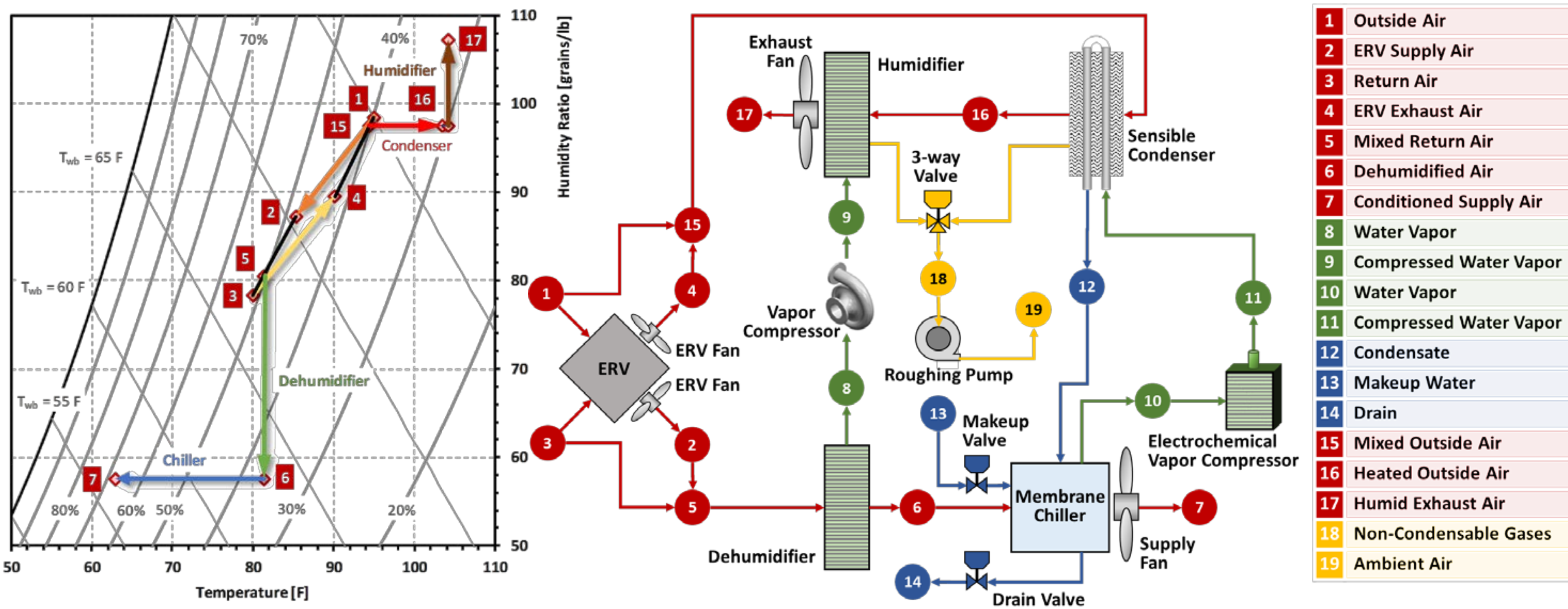


Membrane Chiller

Approach

System Overview:

- Process air is dehumidified, then chilled
  - Compression of water vapor moves excess humidity, heat outside



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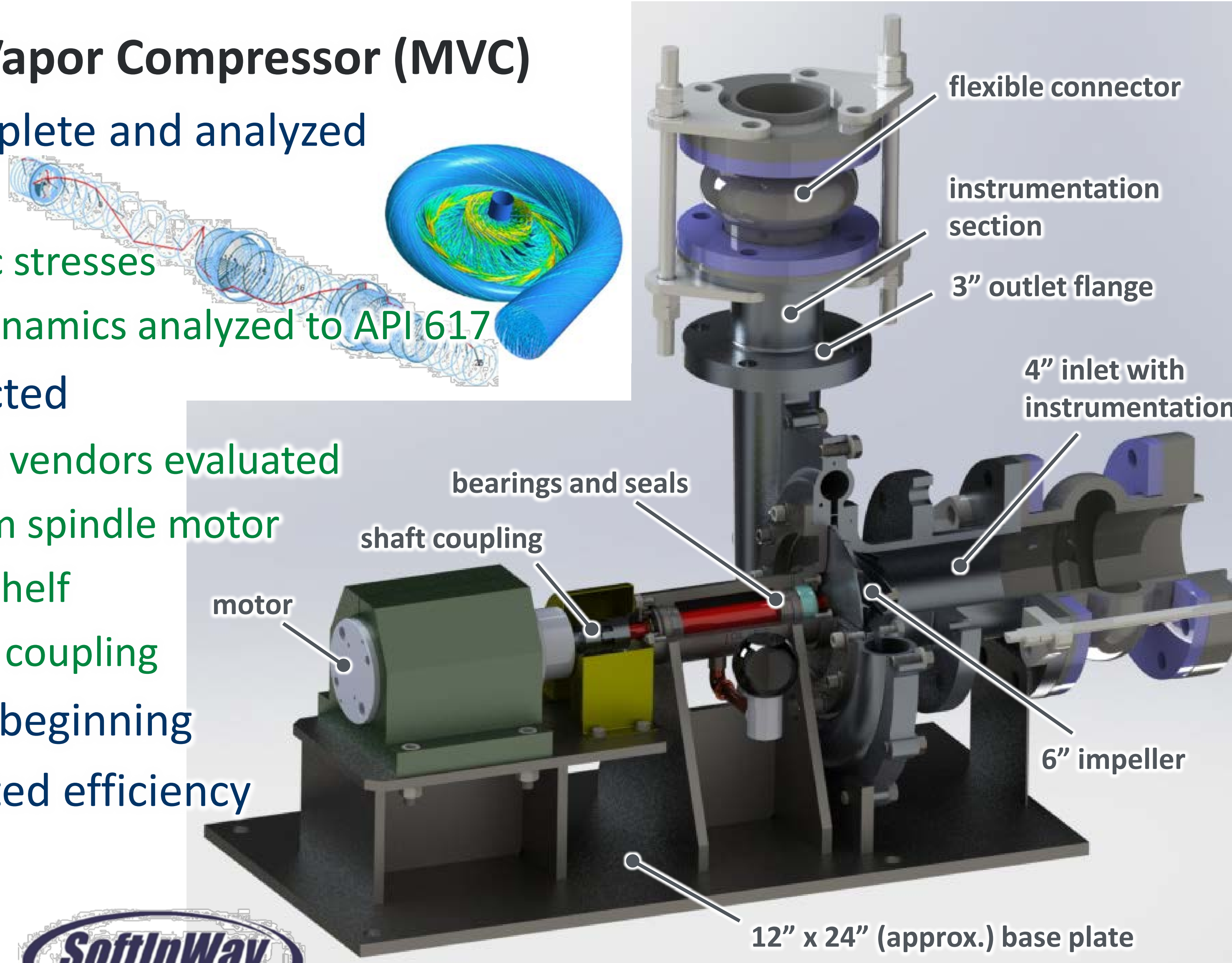
Progress and Accomplishments

Mechanical Vapor Compressor (MVC)

- Design complete and analyzed
  - 3D CFD
  - Dynamic stresses
  - Rotor dynamics analyzed to API 617
- Motor selected
  - Multiple vendors evaluated
  - High-rpm spindle motor
  - Off the shelf
  - External coupling
- Fabrication beginning
- 71% predicted efficiency



DAIS SoftInWay Incorporated

Progress and Accomplishments

Electrochemical Compressor (ECC)

- Bench testing at larger scale beginning
  - Sub-stack testing complete
  - Installation at ORNL
- Challenges
  - Low pressure kinetics
  - Current density vs. cell voltage
  - Mass flow throughput
- Next generation design
  - Proposed concept addresses challenges
  - Modeling performance now
  - Improve techno-economic performance vs. first generation
  - Demonstrate in next budget period

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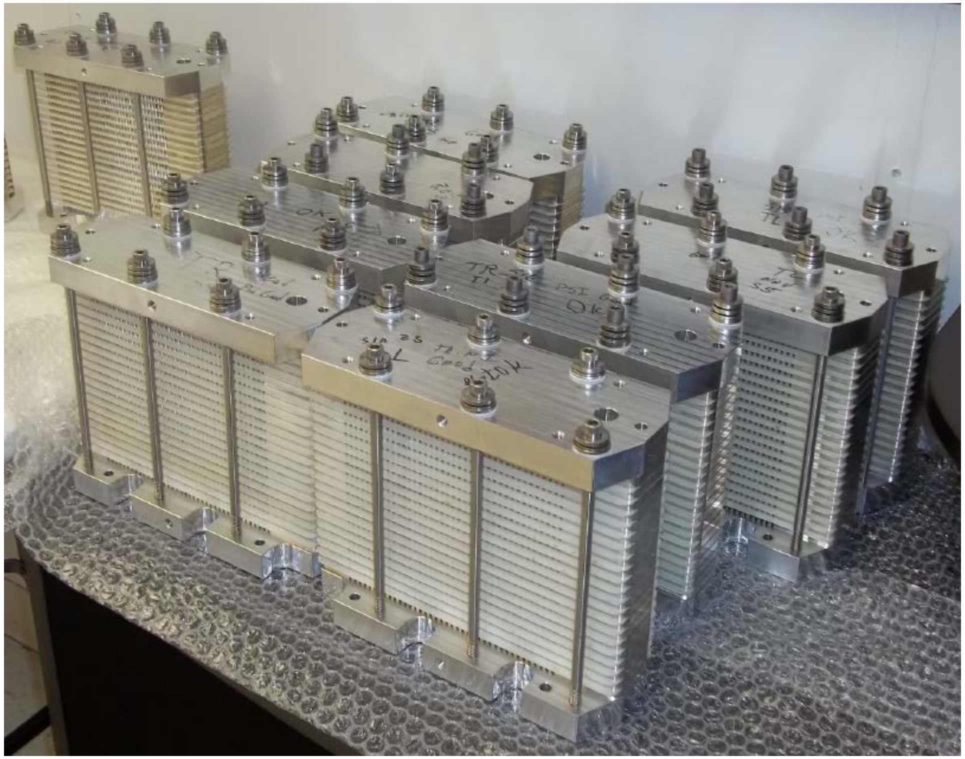

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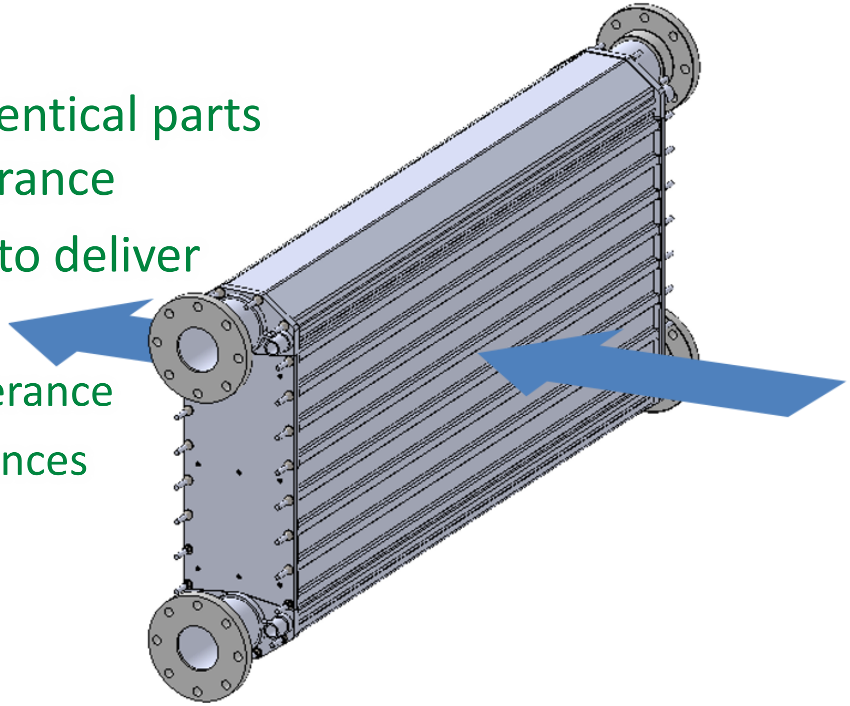
Progress and Accomplishments

Selective Membrane Components

- Design of plastic frames to attach membrane
  - Chiller to incorporate chilled water and supply air flows
  - Shared part design with dehumidifier and humidifier
- Challenges
  - Fabrication process to join/seal two identical parts requires tight control of thickness tolerance
  - Prototype fabrication of frames failed to deliver required tolerances
    - Production tooling should achieve tolerance
    - Redesign instead to allow lower tolerances
- Next generation design
  - In progress



Progress and Accomplishments

Market Impact:

- Discussions with targeted OEM companies to explore market
- Outside study of market impact by CSRA underway
  - Draft complete, pending ECC revision for final analysis

Lessons Learned:

- Mechanical vapor compressor design is not straightforward
  - Chose detailed design and simulation vs. rapid fabrication
  - Motor selection was a winding path before finding off-the-shelf vendor
- Techno-economic reality of the ECC is critical
  - Low pressure kinetics & large mass flow dominate design
  - Additional design elements can yield desired size, cost, and input power
- Membrane component tolerances need to be liberal
  - Fabrication methods need to be appropriate to production costs

Project Integration and Collaboration

Project Integration: Both Dais and ORNL maintain industry contacts, ORNL through R&D projects and symposia, Dais thru 14 years as an HVAC OEM.

Partners, Subcontractors, and Collaborators:

- ORNL Building Technologies Research & Integration Center (BTRIC)
  - Full scale testing, performance modeling, rapid prototyping
- Xergy Inc. [Seaford, DE]
  - Electrochemical vapor compressor design & production
- SoftInWay Inc. [Burlington, MA]
  - Mechanical vapor compressor design
- ROBRADY Design [Sarasota, FL]
  - Mechanical design of components and systems

Communications: None applicable.

Next Steps and Future Plans

Next Steps:

- Fabrication and testing of bench scale prototypes
  - Membrane dehumidifier, humidifier, and chiller
  - Mechanical vapor compressor for use with dehumidification section
  - Electrochemical compressor for use with chiller section
- 7.5 ton V1 prototype system to be revised
  - Membrane dehumidification married to conventional low-GWP chiller
  - Bridge to allow testing while next gen ECC is proven, not final path
- Optimization based on lessons learned with V1
- Improvements generate V2 prototype system

Future Plans:

- Evaluate commercial markets and select initial target for entry

REFERENCE SLIDES

Project Budget

Project Budget: $1,500,000.00 total, including $300,000.00 cost share.
Variances: A six month no-cost extension has been granted and included from October 1, 2016 to March 31, 2017.
Cost to Date: Thru February 2017 (Month 17 of 30), Dais has spent $339,204.17 of $1,000,000.00. $500,000.00 to ORNL is being accounted for separately.
Additional Funding: None

Budget History					
FY 2015 - 2016 (past)		FY 2017 (current)		FY 2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$236,432	**$62,396**	**$432,599**	**$223,210**	**$30,969**	**$14,394**

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Project Plan and Schedule

Project Start: 10/1/2015
Project End: 3/31/2018
Project Length: 30 months

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
System and component design review	1	2	1	5	100%
Final design review based on bench testing results	3	2			0%
T2M strategy/commercialization plan	1	3	1	8	75%
Listing of potential manufacturers	1	3	1	8	25%
Mechanical compressor design & evaluation	1	3	1	7	75%
Electrochemical compressor design review	1	2	1	7	100%
Compressor testing review	8	1			0%
Go/No-Go: Performance ≥ vapor compression	6	1			0%
Fully operational V1 prototype RTU	9	1			0%
Experimental evaluation of V1 prototype RTU	9	1			0%
Redesign and optimization of V1 prototype	9	1			0%
Review optimized component designs for the V2	9	1			0%
Experimental evaluation of V2 prototype RTU	10	1			0%