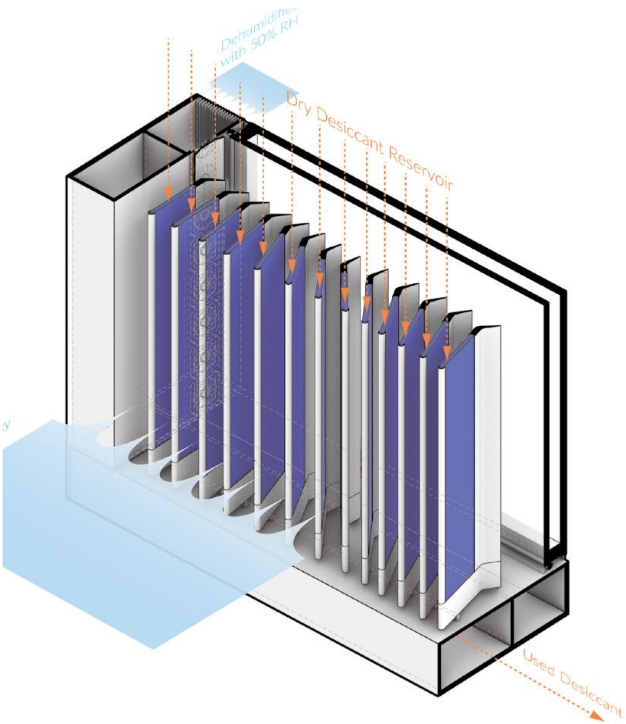
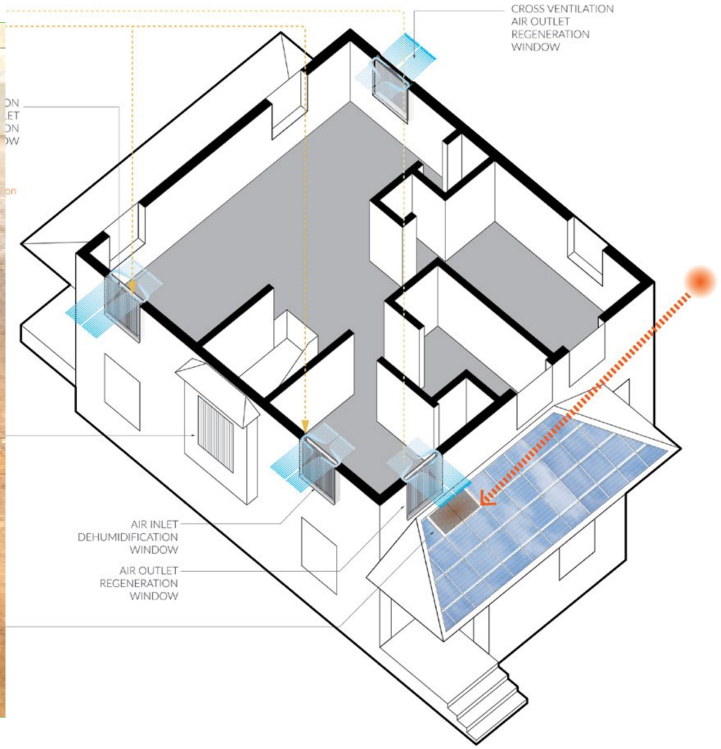
# “Dry Screen”

## Membrane Dehumidification as Facade-integrated Building Screens for Latent Cooling




Princeton, Harvard, MIT, NREL, AILR, Transolar
Dr. Forrest Meggers, Assistant Professor, Princeton University
fmeggers@princeton.edu , @fmeggers (Twitter, LinkedIN)

# Project Summary

## Timeline:

Start date: July 1, 2020

Planned end date: Phase 1: Mar 31, 2022

downselect for Phase 2 to Dec 31, 2024

Key Milestones

1. Applied Energy Covid ventilation publication Jan ‘21
2. Desiccant prototype producing 50% RH, Oct ‘20

## Key Partners:

| | |
|---|---|
| Princeton | Transolar |
| Harvard | Treau (Gradient) |
| MIT | Arkema (Pebax) |
| AILR | dPoint |
| NREL | Princeton HVAC Shop |

## Budget:

### Total Project $ to Date:

- DOE: $154,537
- Cost Share: $63,197

### Total Project $:

- DOE: $457,000
- Cost Share: $125,000

## Project Outcome:

We are developing an alternative HVAC retrofit solution to replace standard AC. Using membranes that can remove water vapor in air and can be constructed as high contact area screens we propose an integrated “dry screen” that produces dehumidified air. The solution is accompanied by research demonstrating how new comfort frameworks that enable higher fresh air rates and expanded temperature setbacks.

# Team

PRINCETON UNIVERSITY

HARVARD UNIVERSITY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Massachusetts Institute of Technology

AIL Research, Inc.

TRANSSOLAR KlimaEngineering

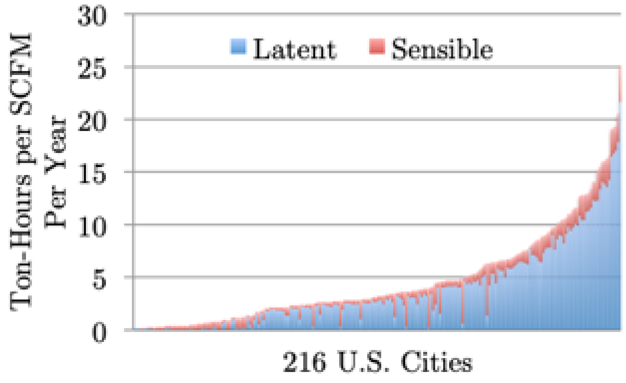
We combine world class research institutions, membrane sorption domain experts, and industry practitioners

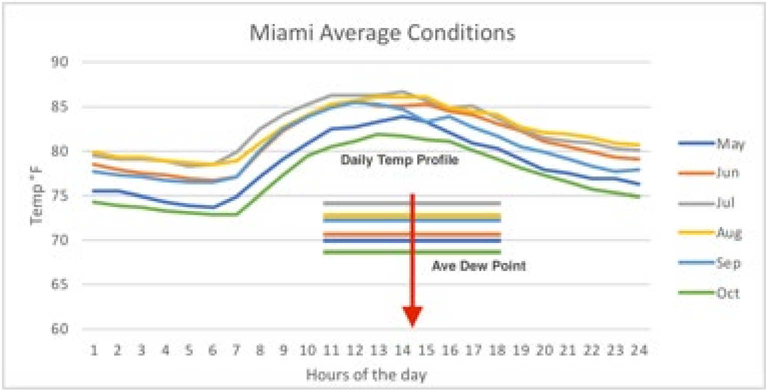
- The project is involved in **high-level technical development**– Princeton, Harvard, and MIT are three of the best places in the world to produce game-changing technology
- AILR and NREL membrane and sorption analyses provide ***decades of experience*** and are connected to the majority of market development in that space with ***numerous patents and licenses***
- Transolar one of the ***most well-known*** high-performance building design consultancy providing key demo site options
- The commercial gap will be addressed as phase 1 architectural demos with Transolar, and will transition to extended partnership with collaborators like Treau(now Gradient) as we scale the technology toward a window product for phase 2

# Challenge

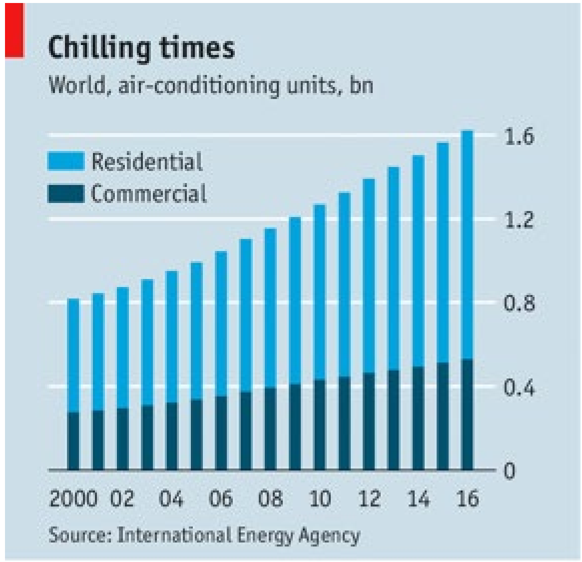
**Problem Definition:** Conventional air conditioning relies on brute-force mechanical <u>energy-intensive</u> dehumidification of air.

- In the United States nearly 2 million commercial buildings and 56 million households rely on central AC systems to cool and mainly dehumidify spending ***$26 Billion***
- **Dehumidification is the majority of air conditioning** in the form latent cooling, not the sensible temps thermostats read – see blue area for major US cities (below left)

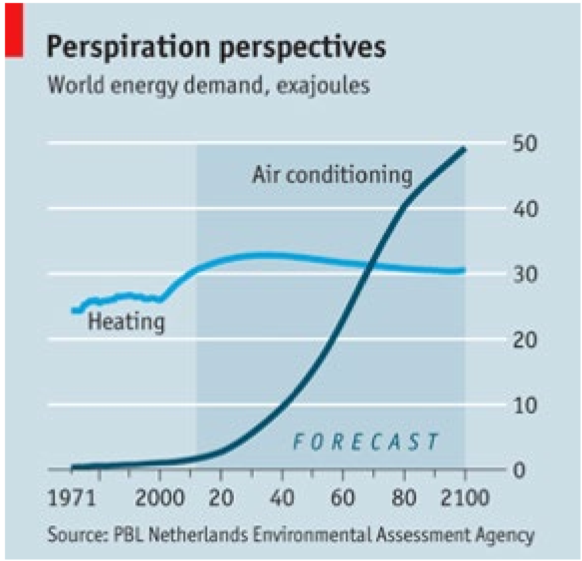



- In Miami the average air temps (sensible) are not that extreme, and by removing humidity thus reducing the average dew point (above right) produces comfort conditions.
- The current technological paradigm has created the ***"cooling crunch"*** where the development of the global south and the accompanied conventional AC use will cause enormous increases in global energy (see right)




The Economist

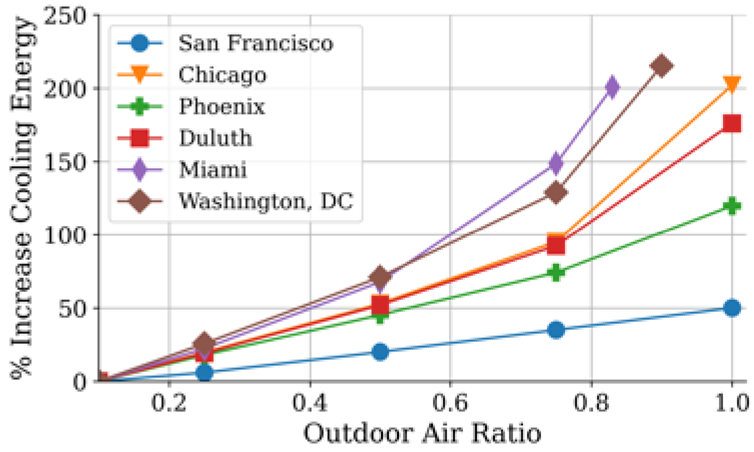


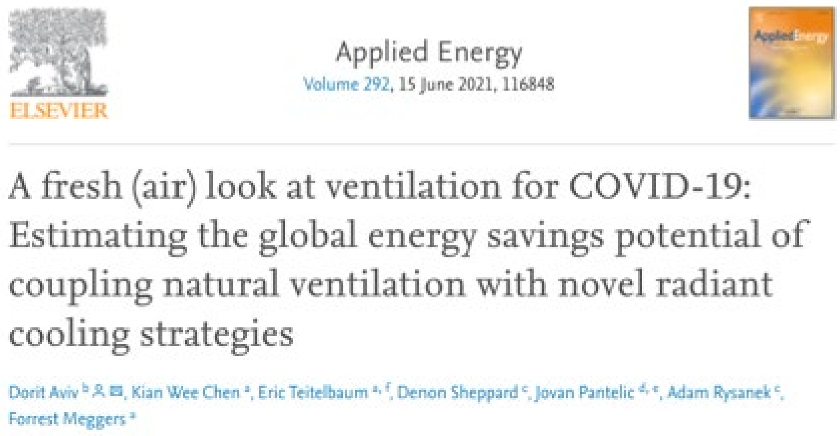
# Challenge – and then there was COVID

**COVID Ventilation Problem:** Conventional air conditioning puts fresh air in direct competition with energy efficiency, and indoor air is a primary COVID transmission pathway

- Commercial recirculated central systems are often only 10% fresh air
- Residential systems typically offer no fresh air at all
  - The appearance of a window air conditioner through the window often gives the false impression of fresh air delivery
- Common strategies to seal and insulate buildings are based on minimum ventilation requirements.
  - Our *Applied Energy* paper (below) showed how active systems like Dry Screen can increase both fresh air and performance by expanded consideration of thermal comfort variables
  - Our ”expanded psychrometric” comfort model eliminates comfort zones on the psychrometric chart (right)

”Air should be conditioned for breathing, not heating and cooling”



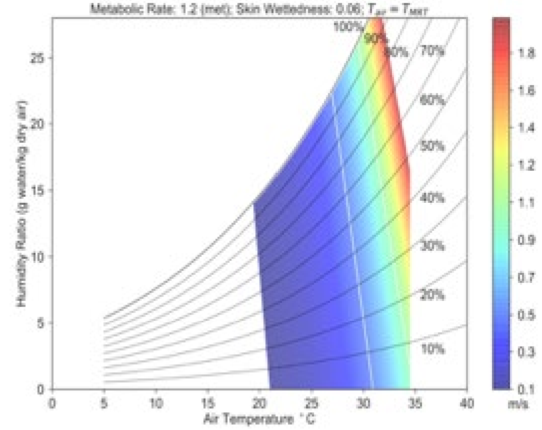



ELSEVIER
Applied Energy
Volume 292, 15 June 2021, 116848

A fresh (air) look at ventilation for COVID-19: Estimating the global energy savings potential of coupling natural ventilation with novel radiant cooling strategies

Dorit Aviv [b], Kian Wee Chen [a], Eric Teitelbaum [a, f], Denon Sheppard [c], Jovan Pantelic [d, e], Adam Rysanek [c], Forrest Meggers [a]

Expanded Psychrometrics
Teitelbaum et al. *Energy and Buildings*

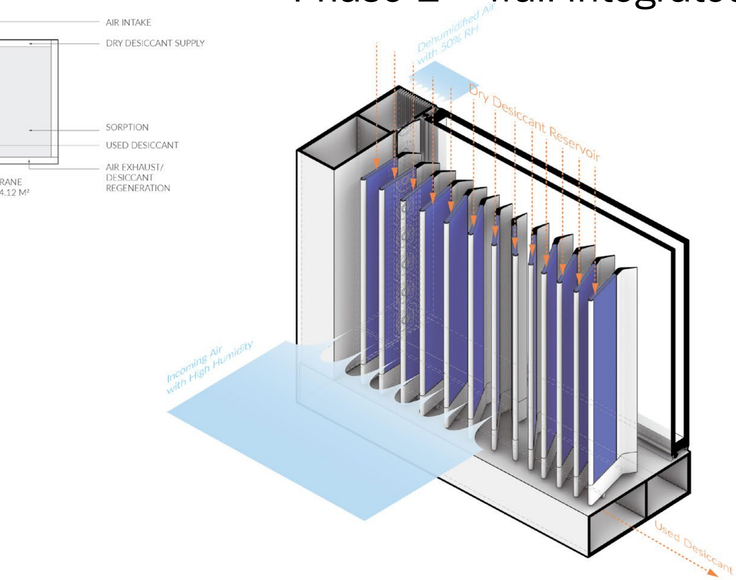



www.comfortch.art

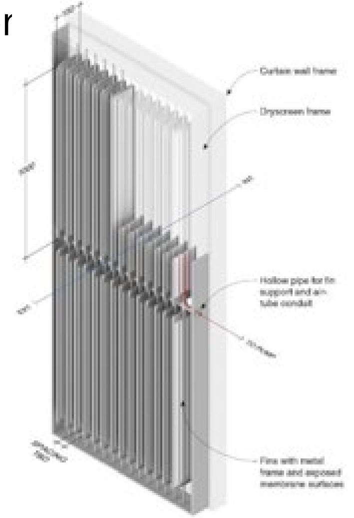
# Approach “it’s not the heat, It’s the humidity”

**Our Solution:** Membrane based dehumidification that reduces relative humidity through an energy-efficient system that can be easily integrated into building windows, and exposes how we can be comfortable by addressing the fact that “it’s not the heat, it’s the humidity”

- An HVAC retrofit that challenges the standard paradigms for both system design and comfort definition, filling major gaps in air quality and efficiency of the current system.
- High novelty = High risk so we proposed to research 2 system embodiments
  - Liquid Desiccant Membrane system (Princeton/AILR) thermally regenerated desiccant dehumidificatior
  - Vacuum Membrane separation (Harvard/MIT) selectively removing water vapor through vacuum
  - Phase 1 – wall integrated system with Transolar for whole building retrofit to gain market traction

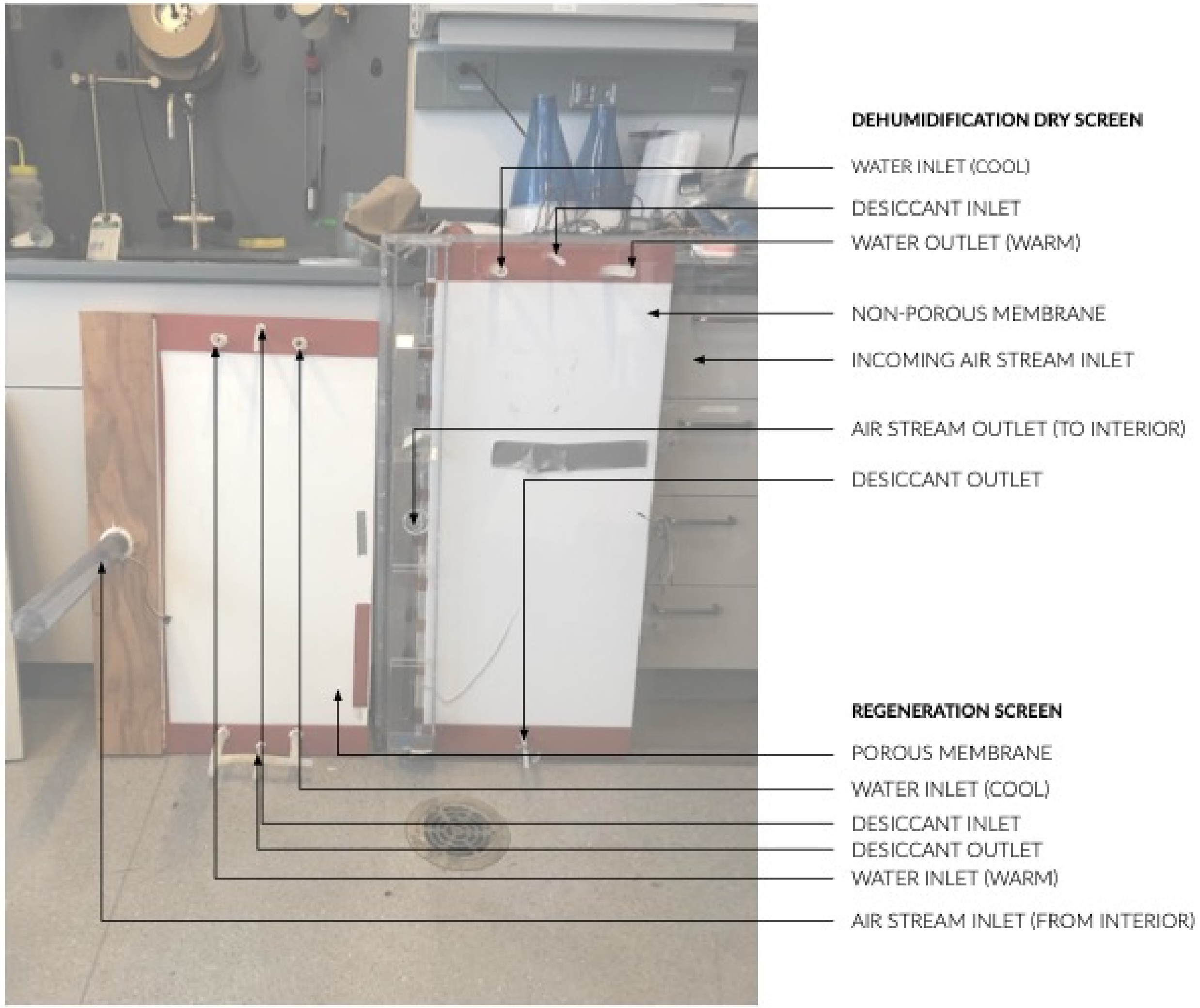



Liquid desiccant membrane (Princeton lead)

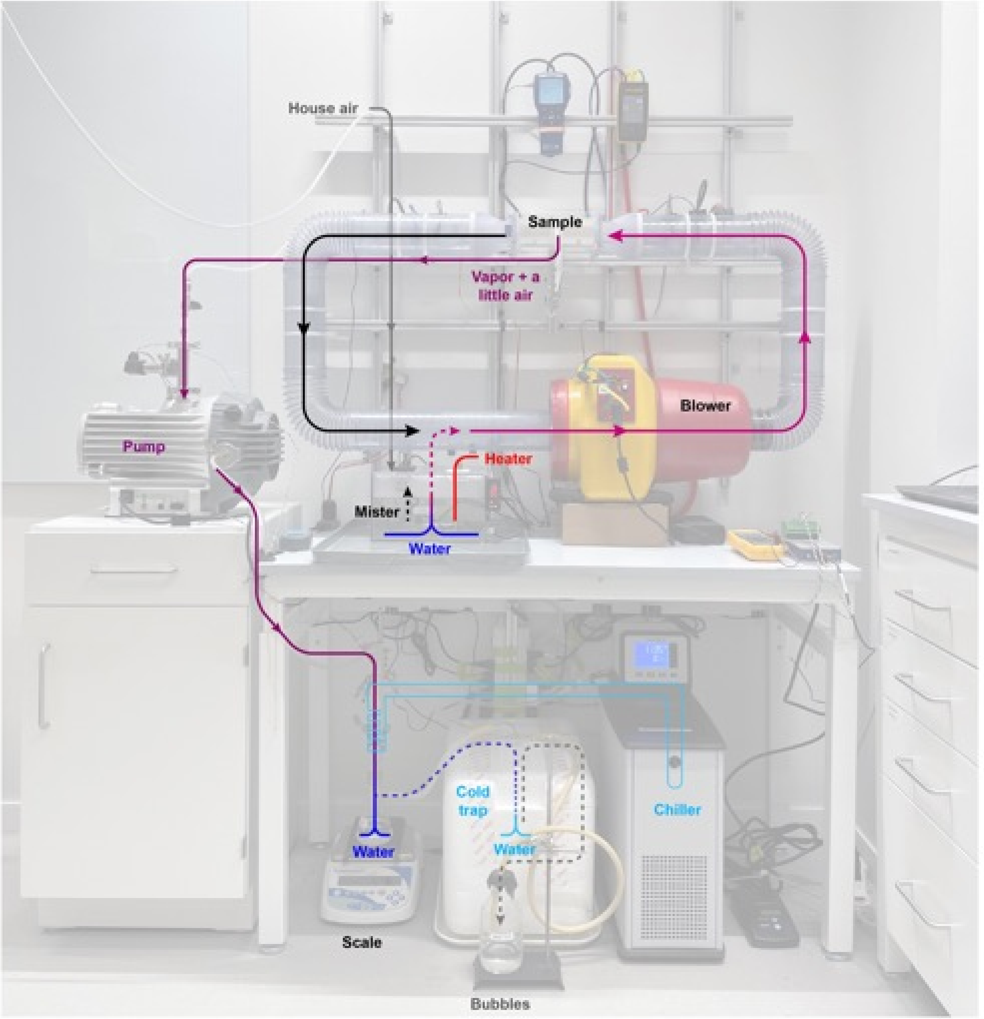


Vacuum membrane (Harvard lead)

# Approach Experimental prototypes



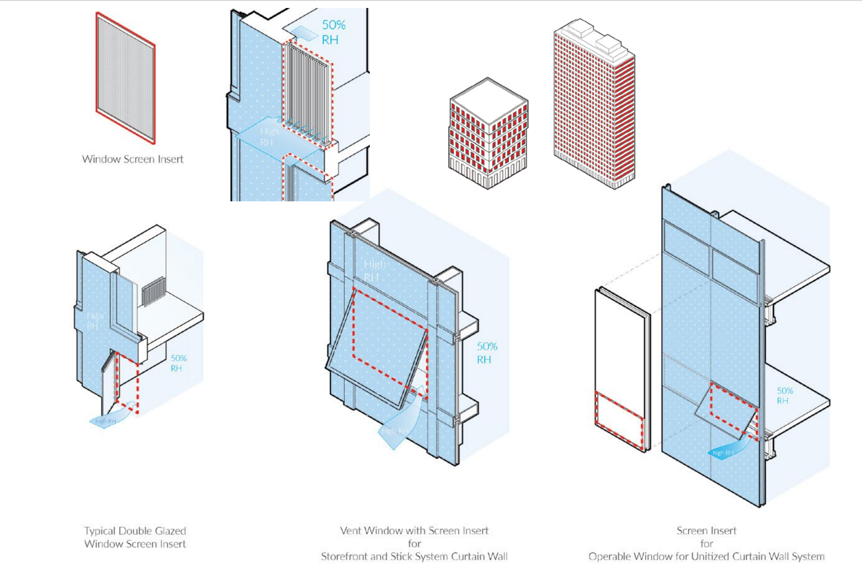

Desiccant



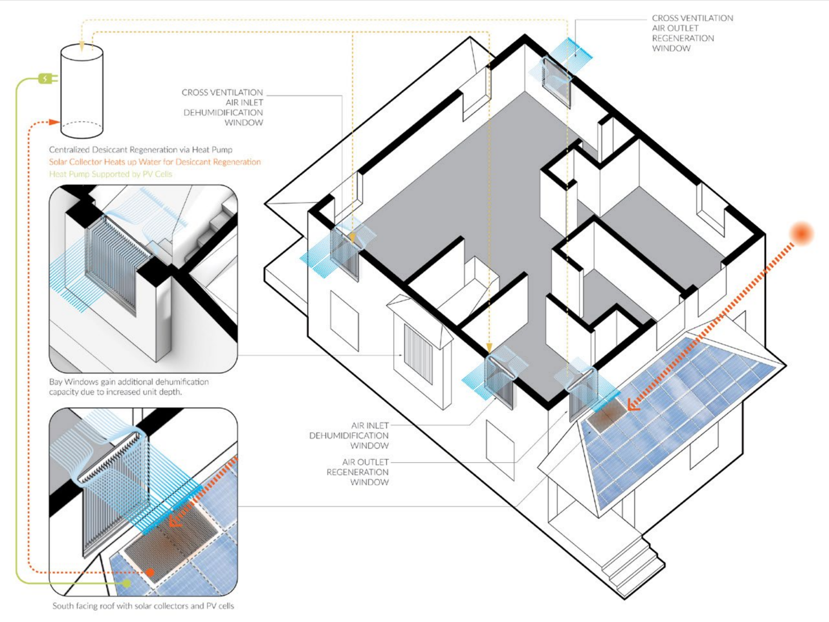

Vacuum

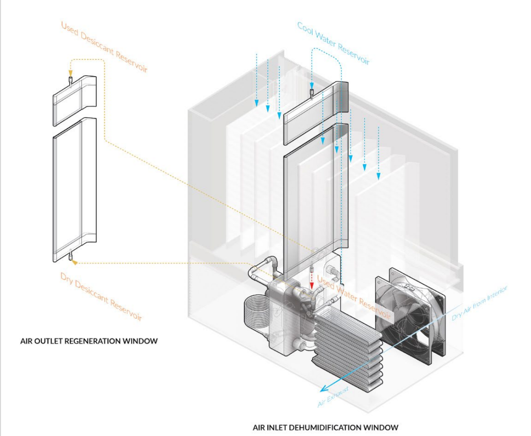
# **Approach** Building system integration and commercialization strategy

### *1. Screen Insert Scenario for Existing Enclosure Systems*



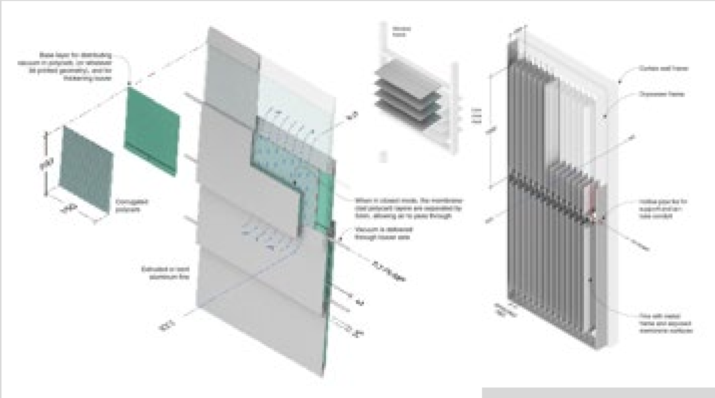

### *2. Window Replacement: Centralized Regeneration System*



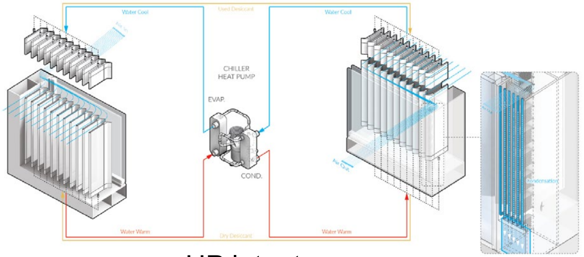




**liquid desiccant** based system with option for active regeneration micro heat pump system with auxiliary sensible heat management

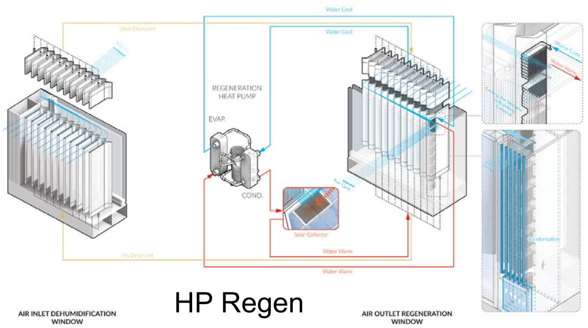
**Vacuum** development design systems for louvre integration and mullion pumping



Desiccant micro heat pump integration for active control




HP latent chiller




HP Regen

# Impact

**Energy Performance:** Eliminate sensible ventilation loads and increase latent cooling COP

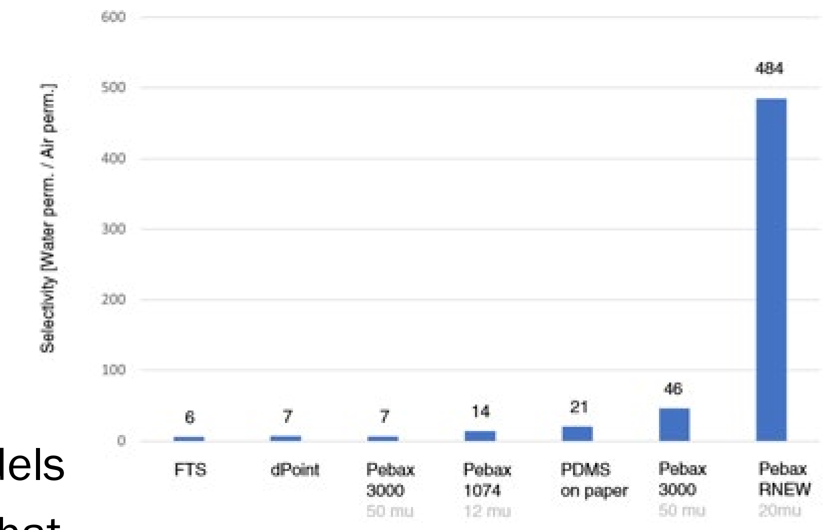
- Eliminate the need for standard AC cooling system operation in the shoulder season
- Elimination of 90% of standard AC cooling for hot and humid climates
- Contribute to significant EUI reduction 75% for hot humid and mixed humid climates
  - Unique pathway to EUI improvements toward BTO goal of 30% reduction by 2030
- Avoid the COVID ventilation >200% energy penalty for fresh air delivery

**HVAC Technology Innovation:** Researching new materials and system design

- Characterize new membrane technology performance capabilities for water vapor removal and provide <50% RH
- Develop new vacuum and desiccant cycling techniques with <10% electricity demand compared to standard dehumidification systems
- Integrate novel heat pump and compressor hybrid control systems

**New Comfort Paradigms:** Demonstrating the failure of standard comfort models

- Demonstrate through physiological models and thermal comfort studies that 85°F and <50% RH can maintain comfort
- Demonstrate how RH and air movement can offer more efficient/effective pathways to comfort than sensible air temperature




New application of Polyether Block Amides
In collaboration with Arkema

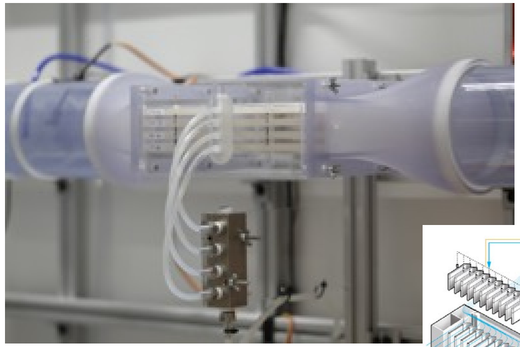
# Progress

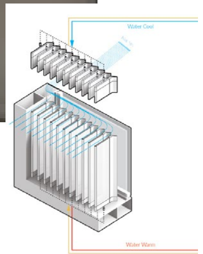
**Overall Progress**: *Doing it all for free*! Getting to lab and funds in COVID

- COVID kept us out of the labs for the first 6-9 months
- AILR was still able to develop prototype in isolated warehouse
- Membrane and systems simulations carried out independently

**Prototype progress**:

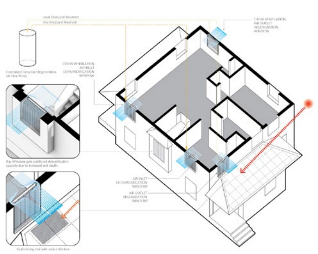
- Desiccant prototype integrated in a 1 m2 window opening
- 50% RH achieved with 80% RH outdoor wind driven ventilation
- Multi layer cassets and louvre formats built for increased area (right)

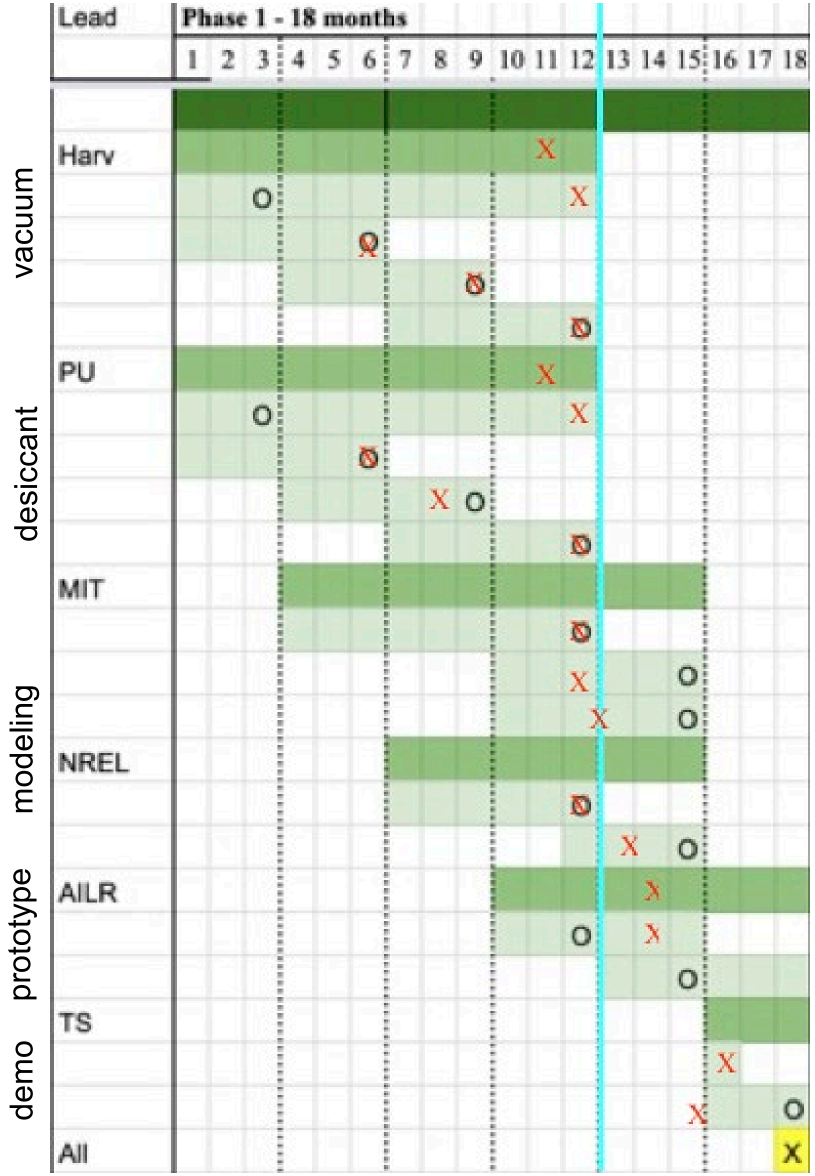




**Demo progress:**

- Demonstration sites identified in New Jersey and Miami.
- Transolar created whole building TRNSYS model



# Stakeholder Engagement

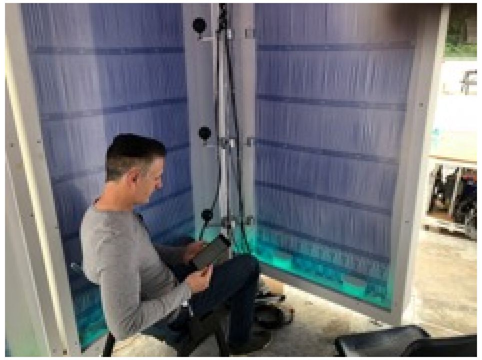
**Tech to market status:** We are moving form working prototypes to demonstration level pilots, and are partnering with HVAC innovators and validating comfort models while promoting alternative comfort paradigms

**AC innovation space:** Pathways to drive new pardigms

- We are in conversation with Treau (now Gradient) Inc. on strategies for disruptive AC technologies (right)
- Using previous market experience from AILR and NREL projects

**Thermal comfort studies**

- Evaluating comfort models using data form thermal comfort analysis
- Interviewing occupants on humidity sensations


Previous thermal comfort survey

**HVAC trade professionals**

- Gaining professional perspective from Princeton HVAC shop experts


Treau CTO working with AILR team member on  micro heat pump

# Remaining Project Work

**Phase 1 Work:** 12 months of first 18 months before ABC downselect

- Final 6 months focused on prototype demonstrations and testing
- Humidity and comfort tests in situ window tests
  - Aug/Sept tests in NJ Lab window
  - Vacuum and Desiccant benchmarking
  - Wind driven passive performance and active control with auxiliary systems analyzed
- Demonstration planning/deployment
  - Oct/Nov/Dec analysis and testing for Miami
  - Installation into office rooms at University of Miami

vacuum

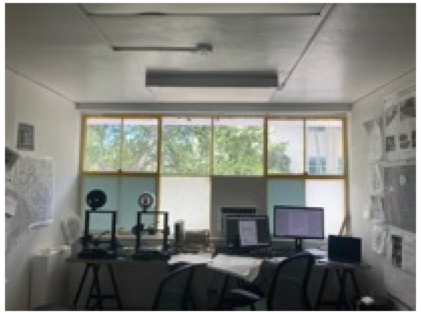
+

desiccant

**Phase 2 Work:** ABC downselect yr 2-4

- Residential and Commercial demonstrations
- Scale toward consumer market "dry is the new cool" and
- Integrate with fans and shading as more whole building solution

NJ Lab



Miami Office

PI's residence


# Thank You


## "Dry is the new cool!"

Princeton University
Dr. Forrest Meggers, Assistant Professor
fmeggers@princeton.edu @fmeggers (Twitter, LinkedIn)

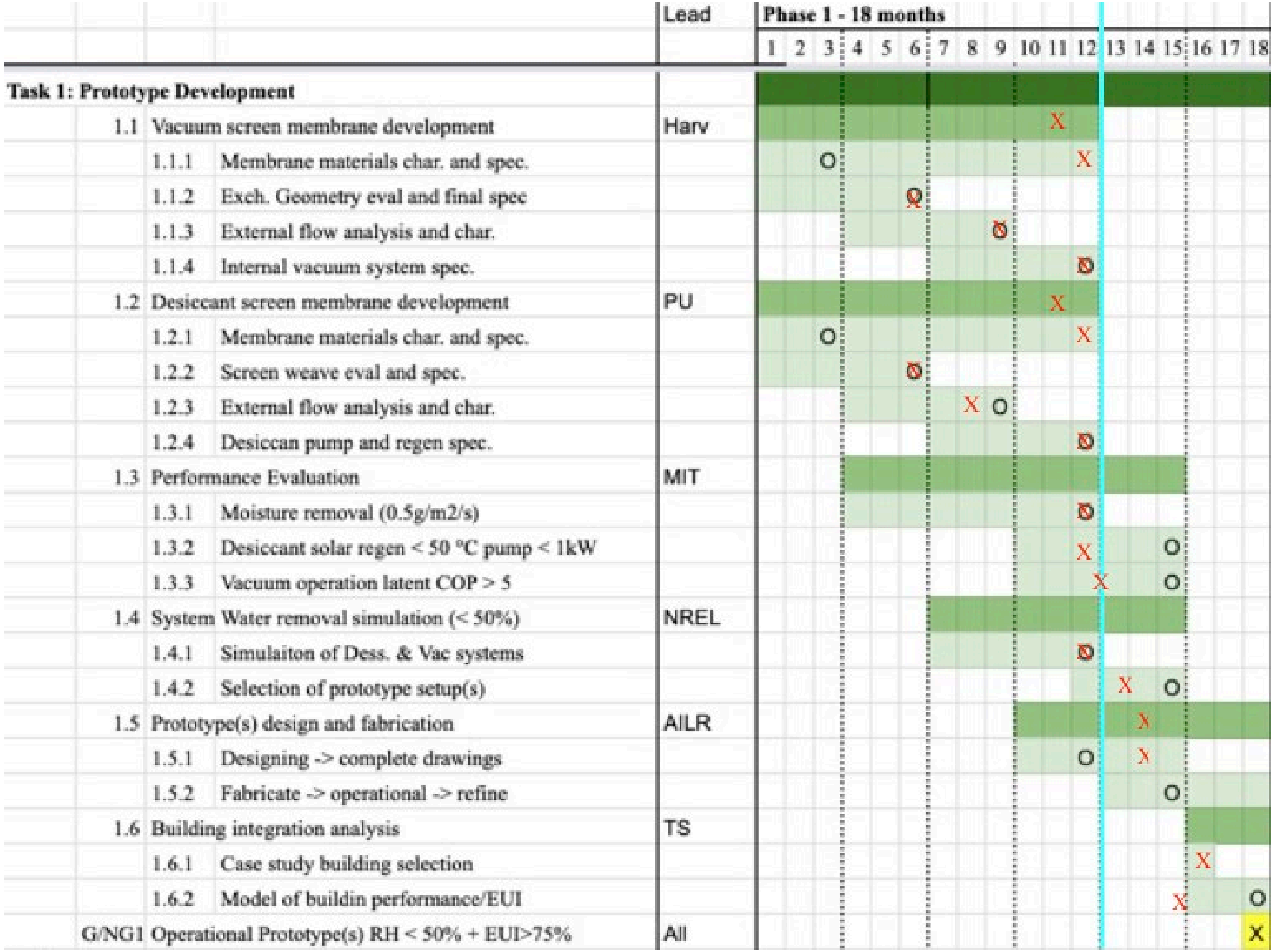
# REFERENCE SLIDES

# Project Budget

**Project Budget**: Proposed budget was $500K + $125K cost share
**Variances**: Contract negotiations were extremely drawn out so funding did not get to Princeton until end of spring 2021 and subawards had to be setup after. This slowed hiring at MIT, but all other team members were able to operate on temporary spending account
**Cost to Date**: 1/3 of the funding has been spent, but the temporary spending is all being backdated and applied to the project so we should catch up.
**Additional Funding**: Temporary accounts and a parallel atmospheric water harvesting sorption project funded by the Schmidt Fund helped support parallel synergistic sorption system work

| Budget History | | | | | |
|---|---|---|---|---|---|
| FY 2020 (past) | | FY 2021 (current) | | FY 2022 –FY2024 (planned) | |
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| 0 | 0 | 457,000 | 125,000 | TBD downselect | |

# Project Plan and Schedule




## Challenges

- We were slow on some of the membrane characterization at the beginning due to COVID access restrictions and material delays, but are mostly caught up
- Hiring a researcher to complete modeling at MIT has been slowed due to contract and funding delays
  - has been compensated with additional modeling support from Transolar