Super-efficient air conditioning unit

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FOA Project BENEFIT 2020 and/or any other Project 2196-1902

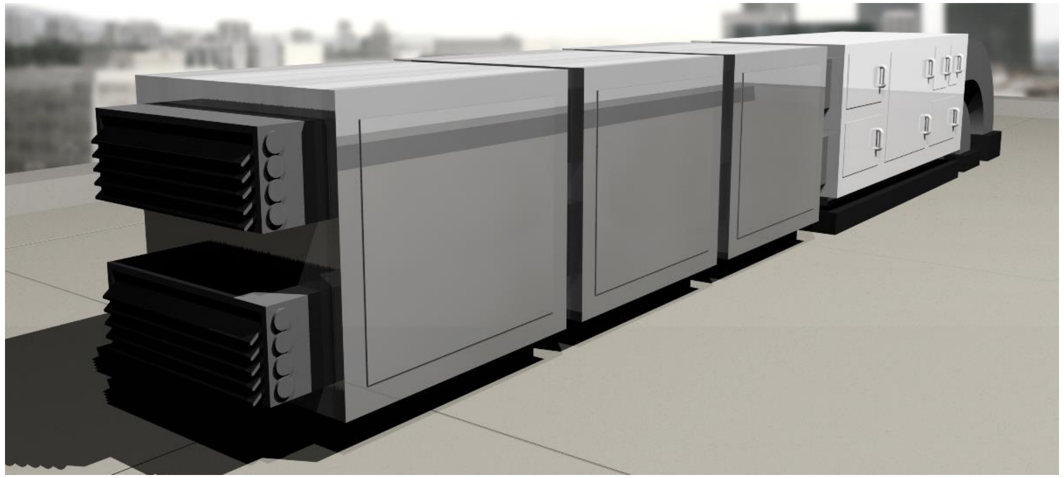
Project Summary

Objective and outcome

-ESCCC cooling technology which allows to save from 50 up to 90% energy for air conditioning

-The technology is based on an unique two phase cooling proces

-The technology is most efficient in humid climates



Team and Partners

-Baryon inc.

-Argonne National Laboratory

-Oak Ridge National Laboratory

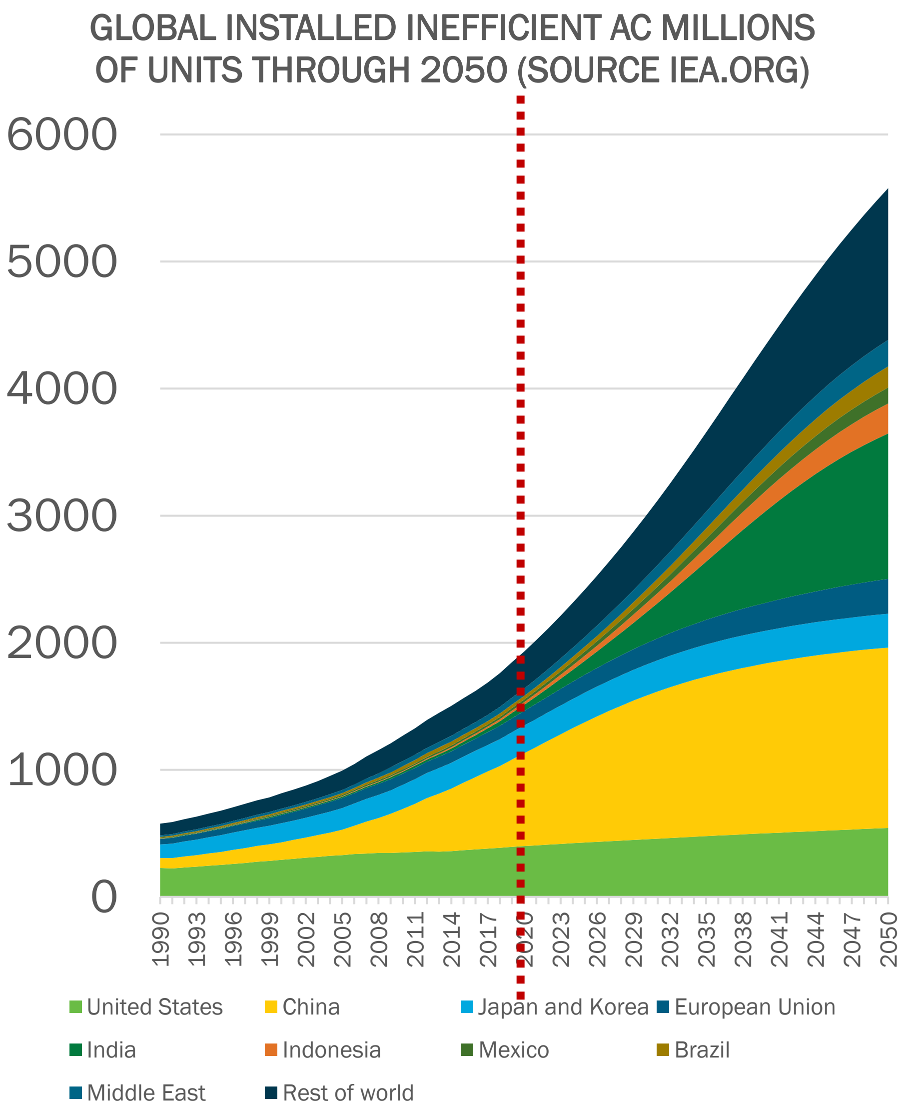
-University of Illinois at Chicago

Stats

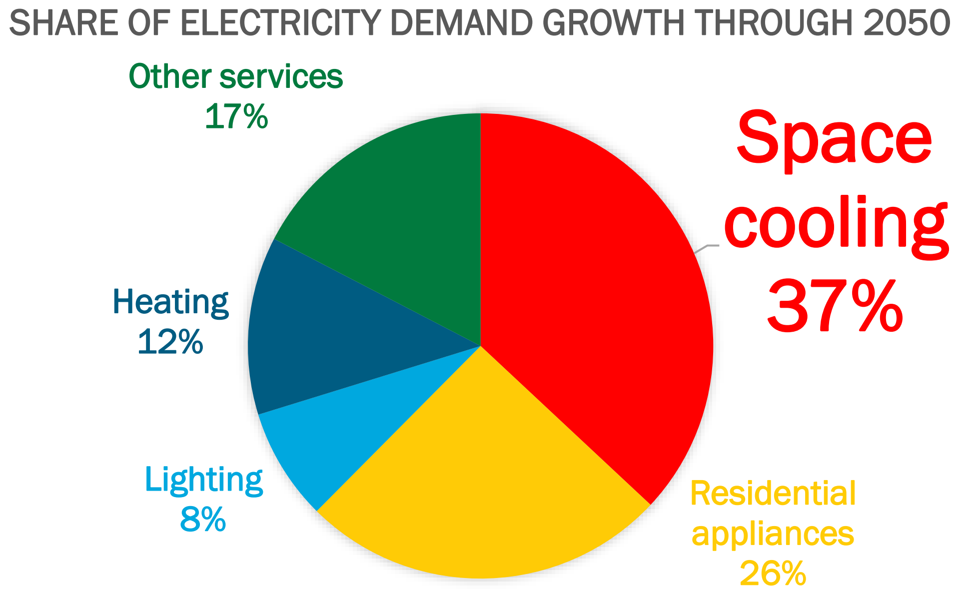
Performance Period: 10.2022-10.2025

DOE budget: $2,849,033, Cost Share: $750,000

Problem



GLOBAL INSTALLED INEFFICIENT AC MILLIONS OF UNITS THROUGH 2050 (SOURCE IEA.ORG)
6000
5000
4000
3000
2000
1000
0
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020
2023
2026
2029
2032
2035
2038
2041
2044
2047
2050
United States
China
Japan and Korea
European Union
India
Indonesia
Mexico
Brazil
Middle East
Rest of world



SHARE OF ELECTRICITY DEMAND GROWTH THROUGH 2050
Other services 17%
Space cooling 37%
Heating 12%
Lighting 8%
Residential appliances 26%

Alignment and Impact

1) **power consumption:** proposed unit is able to significantly decrease the energy consumed by air conditioning systems, with the cooling COP varying from 12.5 up to 30, which corresponds to 50-80% energy savings.,
2) **Highest effectiveness in humid climates:** the system is dedicated for humid climates, where most of the human population leaves and where AC is a necessity. Air conditioning systems are responsible for 40-60% of the energy consumption in buildings in humid climates. Proposed system uses a dedicated flow arrangement and tailor-designed elements to obtain water for its operation from outdoor air in closed cycle. The self-sustaining water system allows it to obtain very low energy consumption in humid climates,
3) **New type of air cooler:** Two phase cooler in ESCCC uses dedicated mini-channel structure, special synthetic materials and dedicated water distribution system, which allows it to obtain very high effectiveness (cooling outdoor air to ap.. 14° C),
4) **Novel membrane system:** the system uses dedicated ionic membranes with Chemours Nafion® (sulfonated polytetrafluoroethylene, PFSA) used as cationic ionomer, which allows to dehumidify the air at very low level of vacuum, which allows to achieve cooling COPs higher than 12.0,
5) **Universality:** the proposed system offers a complete temperature and humidity control solution which doesn't need any supplementary equipment (eg. Cooling towers, dry coolers etc.),
6) **Closed water cycle:** unique arrangement of the unit allows recover condensate from TPC and membrane unit for the purpose of evaporation, which allows to save 100% of the water needed,
7) **Synthetic materials:** the cooler has to operate in moist environment- due to this fact it will use new composite-like synthetic materials, which allow to prevent bacteria formation in the channels,
8) **No mineral deposition:** TPC in the unit uses unique water distribution system, which allows to completely prevent the mineral formation in the wet channels, by using self-cleaning mechanism,
9) **100% fresh air:** proposed device supplies 100% fresh air stream to the building with minimal energy consumption (typical AC systems use 10% of fresh air). Fresh air creates a much healthier indoor environment (effective room ventilation is essential in minimizing the spread of bacteria and viruses, such as COVID-19),
10) **No refrigerants:** the system doesn't use chemical refrigerants which are known as high potent greenhouse gases,
11) **Independent temperature and humidity control:** unit enables SSLC (separate sensible and latent cooling) at minimal energy consumption, which allows for precise control of room parameters,
12) **Easy retrofit:** the arrangement of the unit allows it to be applied to most type of buildings using typical AC configurations- room conditioners, window units or rooftop units (the size of the device will be similar to typical AC),
13) **Plug and play:** the unit has a plug-and-play structure, which makes it user-friendly,
14) **Lifetime:** the unit is passive, its made of synthetic materials, the only moving elements are fans and vacuum pump. Due to this fact its expected life expectancy is 30-40 years in compare to 10-20 of traditional AC.

Alignment and Impact

Due to the unique system arrangement its **energy consumption is minimal**. The only elements which consume the energy are the vacuum pump, which dehumidifies the air on the membrane and fans which pass the air through the unit. **The total cooling COP of the system** (i.e, the cooling capacity divided by the electrical energy consumed by the vacuum pump and fan (Btu/Btu) for very humid conditions is estimated as 12.0. The COPs of most effective AC system nowadays is equal to 6,0. This means that the proposed technology **can generate at least 50% of the savings** (in many cases the savings can reach 80%). Since AC is responsible for 40-60% of energy consumption in buildings in humid climates, the ability to reduce this amount over two times corresponds to significant sustainability impact.

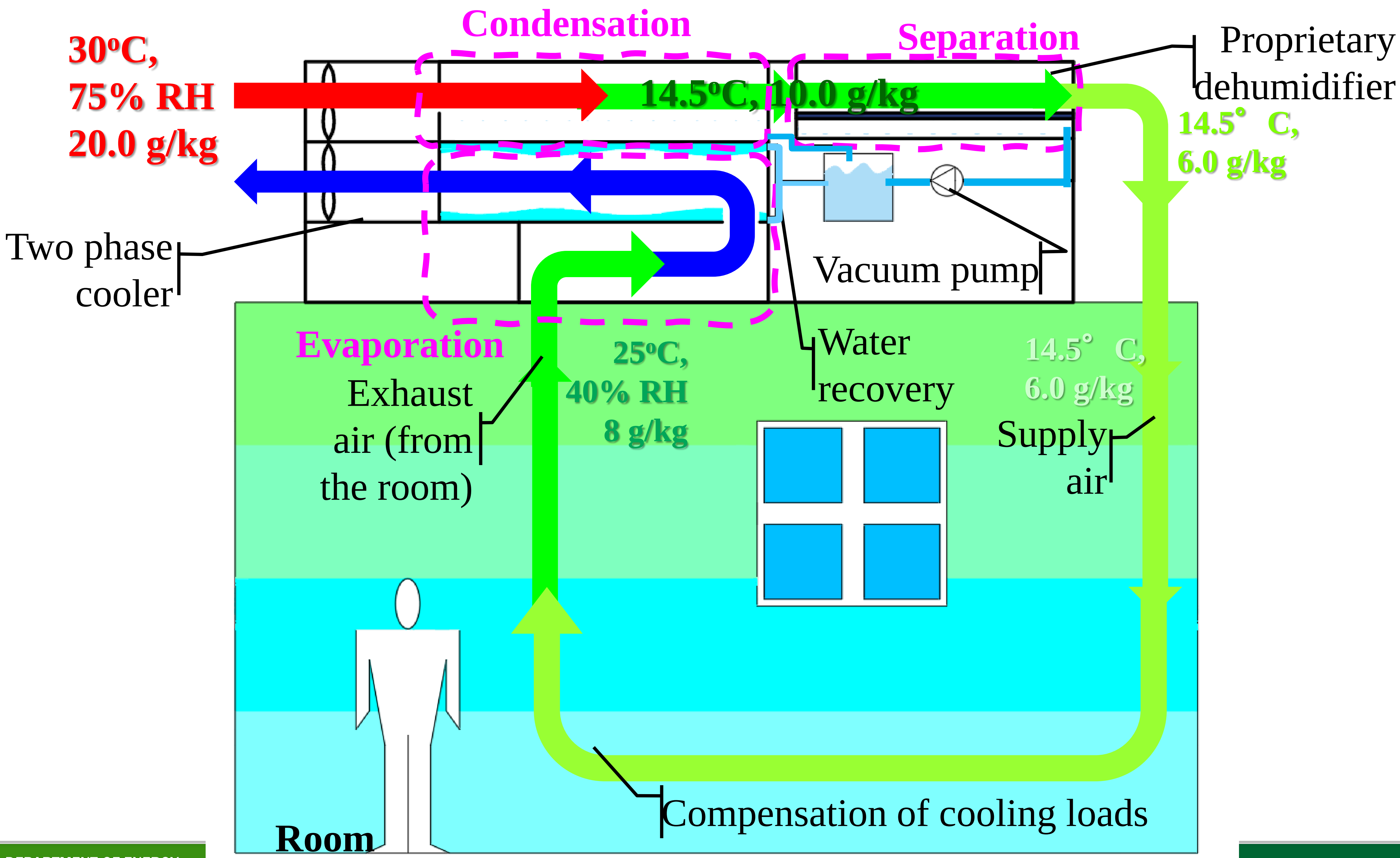
The system **does not use chemical refrigerants** which are known to be extremely potent greenhouse gases (e.g. 1 kg of the refrigerant R410a has the same greenhouse impact as two tonnes of CO_2).

The heat balance for the outdoor air is equal to zero (the air is taken from the outside, it is cooled and dehumidified on the cooler, it passes the building and it is heated and humidified again to similar conditions). This means that the system **does not have negative impact on the outdoor environment** (unlike traditional AC, which heat the outdoor air with their condensing units which results in increased temperature in dense urban areas). The system also **does not change the amount of water vapour** (which is a greenhouse gas) in the outdoor air.

Due to the above-described advantages, ES3C has incomparably lower climate impact than best traditional, mechanical compression units.

Building cooling systems

- Energy consumption 50-90% less than traditional AC/HVAC
- Lower CO2 footprint
- Free dehumidification

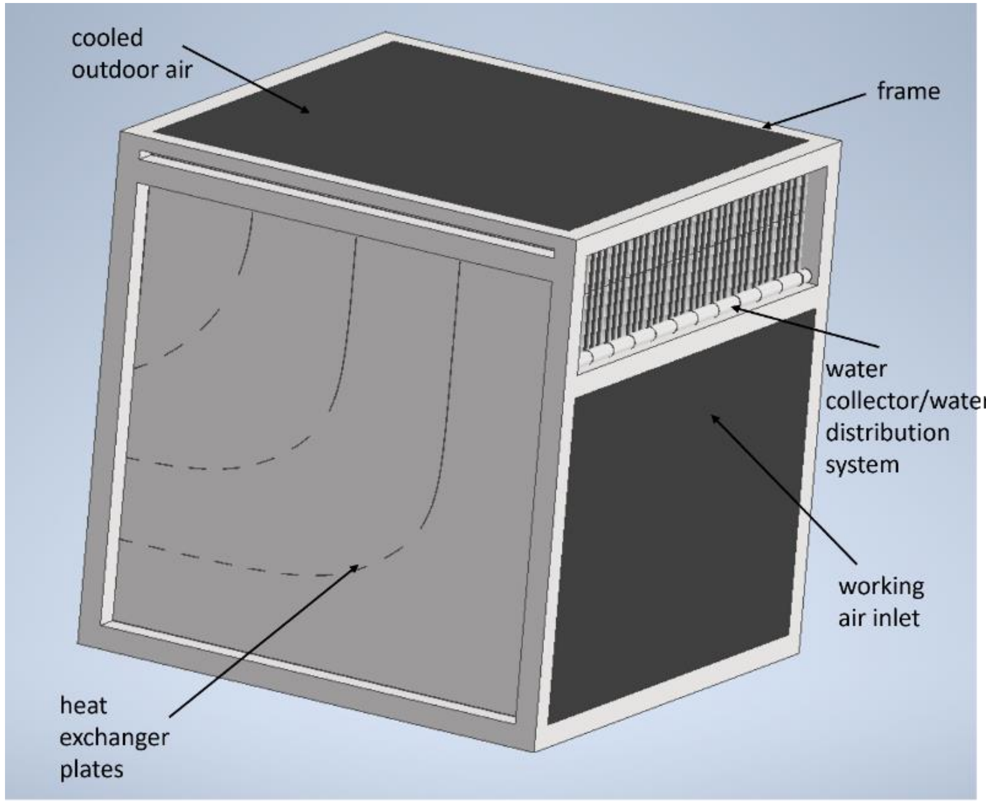


Condensation
Separation
30°C,
75% RH
20.0 g/kg
14.5°C, 10.0 g/kg
Proprietary
dehumidifier
14.5° C,
6.0 g/kg
Two phase
cooler
Vacuum pump
Evaporation
25°C,
40% RH
8 g/kg
Water
recovery
14.5° C,
6.0 g/kg
Exhaust
air (from
the room)
Supply
air
Compensation of cooling loads
Room

Approach

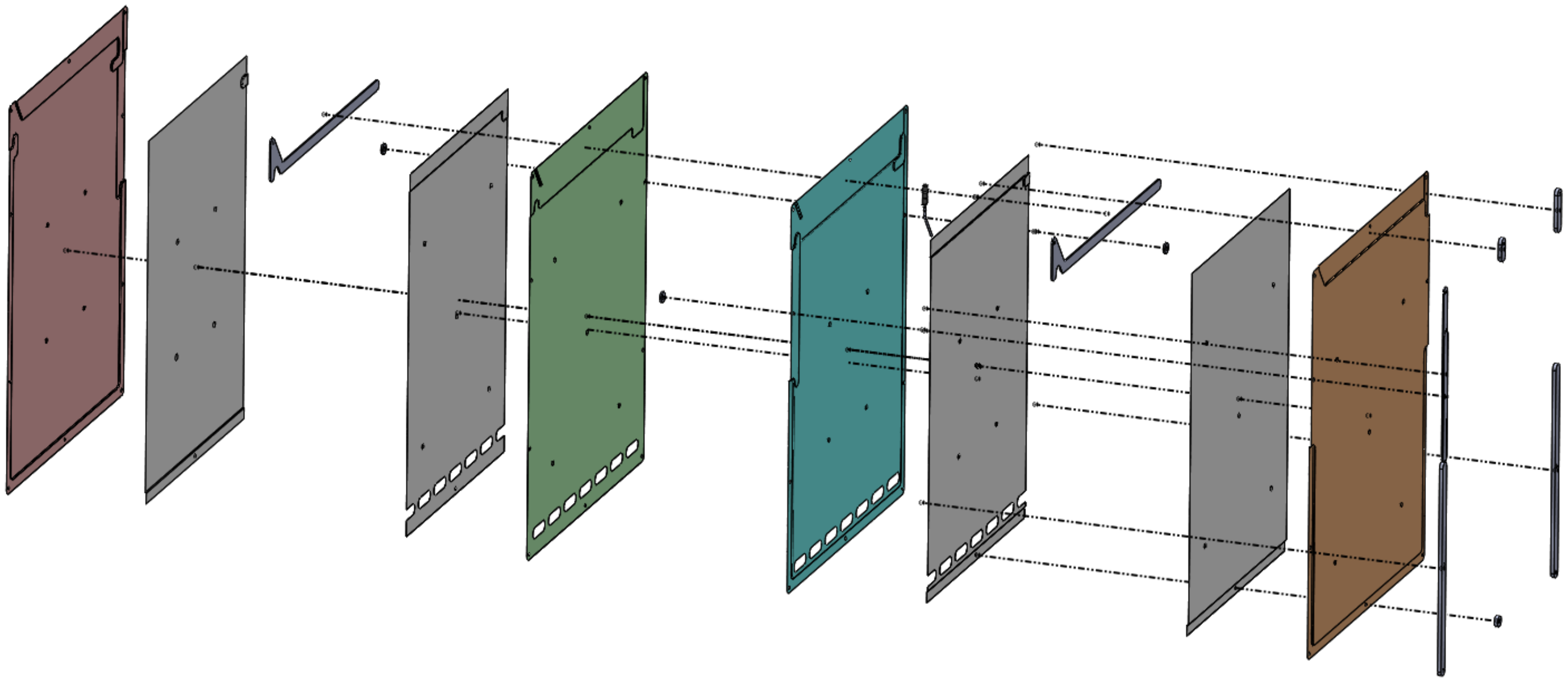
Theoretical research
- Numerical simulation of the crucial components
- Initial validation of the models
- Numerical simulation of the integrated system

Experimental research
- Material testing
- Water distribution testing
- Crucial components testing
- Prototype testing
- Integrated system testing



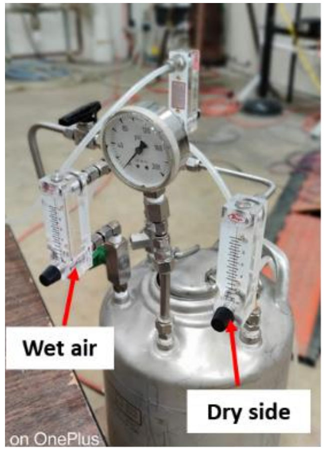
Approach

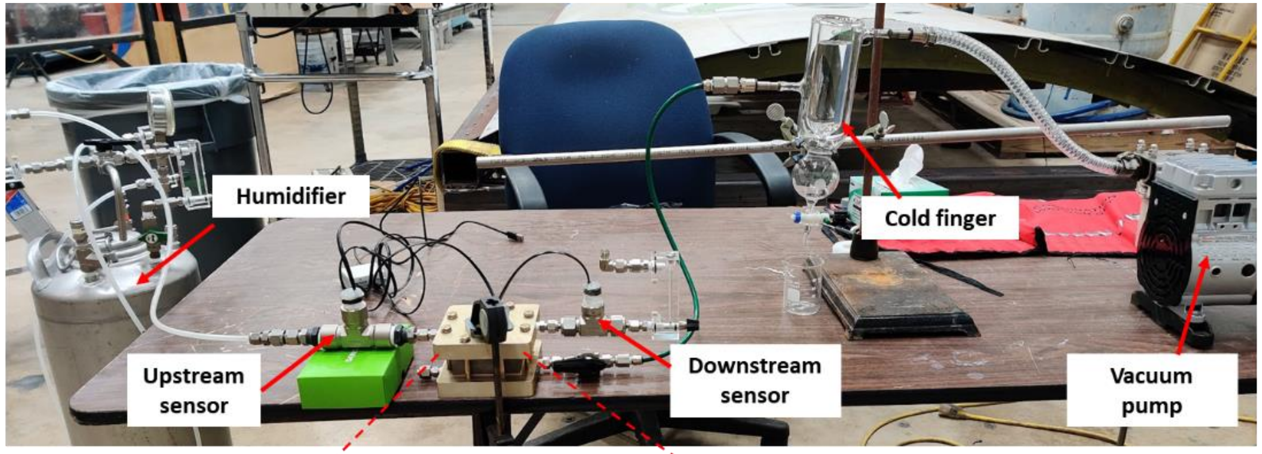
Novel approach on the heat exchanger structure

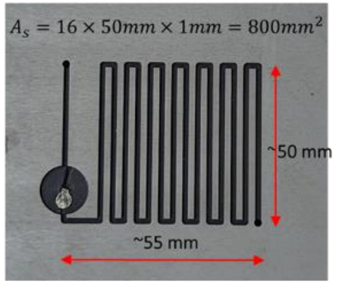


Approach

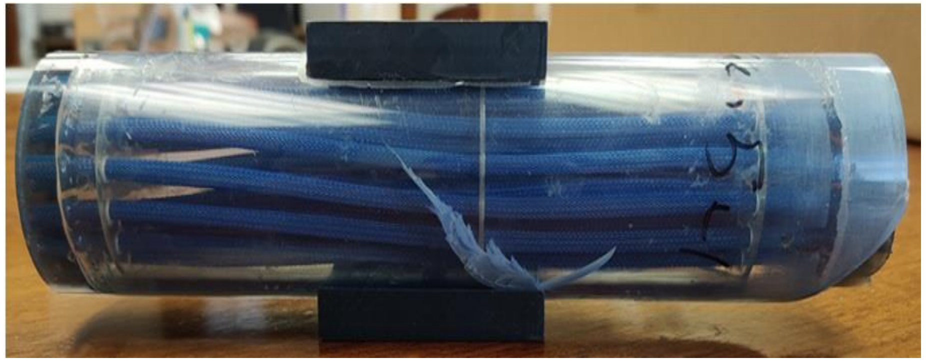
Novel approach on the membrane dehumidification







Relative humidity: ± 1.5%
Temperature: ±0.2 C
Flow rate: ±4% of range



Approach

Project risks

- -*Stiffness and strength of the plate materials:* To realize a prototype with the assumed capacity the proposed heat and mass exchangers will have to be relatively large. Due to this fact they will have to remain very stiff and strong, a structure will be designed to meet these requirements while keeping a highly effective water distribution and thermal effectiveness.

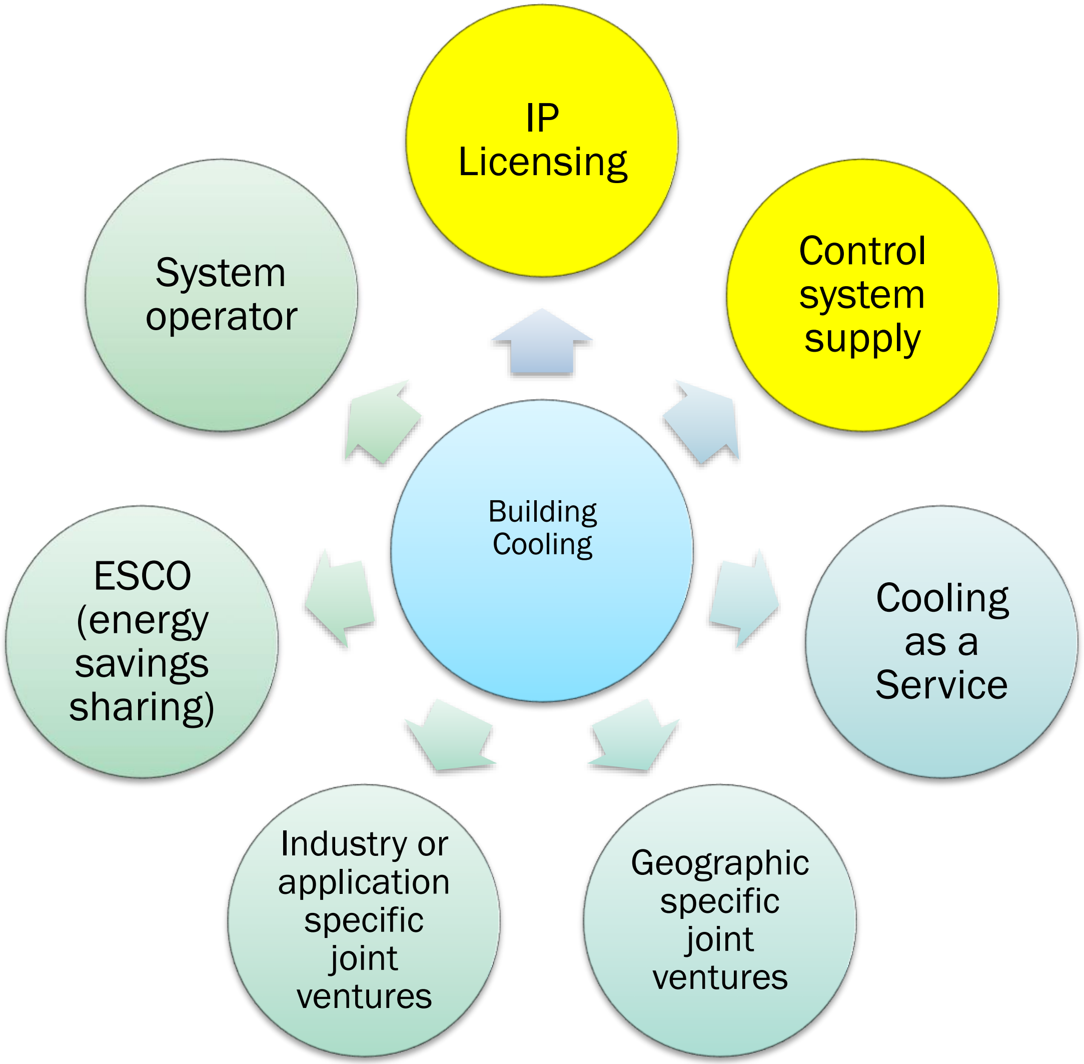
- *Water distribution effectiveness*: water has to be distributed very evenly on the plates and the system needs to deliver the exact amount needed, to keep the water recovery rate as high as possible to minimize the thermal energy needed.

- *Integration of the system:* BDC cooler and membrane unit have to be integrated into one device, which generates integration problems, both in terms of the optimal performance and control system requirements.

Approach

Key differentiators to drive adoption

- Advanced IOT control systems – unlocking value!
  - Calculate and report cooling loads in real time for cooling as a service business model option.
  - Carbon accounting and real time liquidation and clearing of carbon credits in real time.
  - Ability to provide demand response service across multiple installation sites.
- **Market by stages:**
  - Big box retailers
    - Single buyers with large footprints
    - Target the replacement cycle
    - Helps achieve ESG goals
  - Indoor agriculture
  - Gyms, malls, restaurants, gas stations, convenience stores



Progress and Future Work

Recommendation: 5-6 slides

- **Accomplished work**

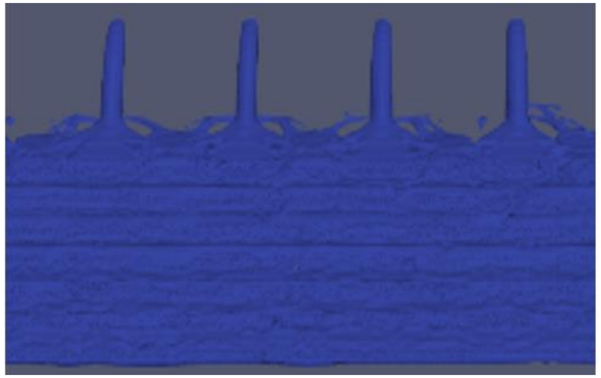
Milestone	Verification Method (Method for verifying success)	Status (accomplished/not accomplished/ partly completed)
1.1. Detailed thermal models of the BDC cooler which provide agreement within 5-10% with the literature data (Establishing detail design of the heat and mass exchangers for testing)	Confirmation email to Federal Project Officer+ provides the test methods and conditions for testing. Verification conditions will be selected based on materials available In the most recent and adequate literature after approval from DOE.	**Accomplished Q1**
1.2. Detailed CFD model of the water distribution system which provides agreement within 10% with the simple experiments performed (Design of the arrangements of the water distribution system for testing)	Confirmation email to Federal Project Officer+ provides the test methods and conditions for testing. Verification conditions will be determined based on selected plate shape, which will be selected based on a heat transfer model and confirmed with DOE.	**Accomplished Q2**
Mathematical model of the membrane system which provides agreement within 10% with the experimental data	Confirmation email to Federal Project Officer+ provides the test methods and conditions for testing. Verification conditions will be selected based on materials available. In the most recent and adequate literature after approval from DOE.	**Accomplished Q2**
Selection of at least one pair of plate material (porous layer and impenetrable coating)	Confirmation email to Federal Project Officer+ provides the test methods and conditions for testing. The plate materials will be selected for the plate shape determined during research Task 1. Verification conditions will be confirmed with DOE.	**Accomplished Q1**

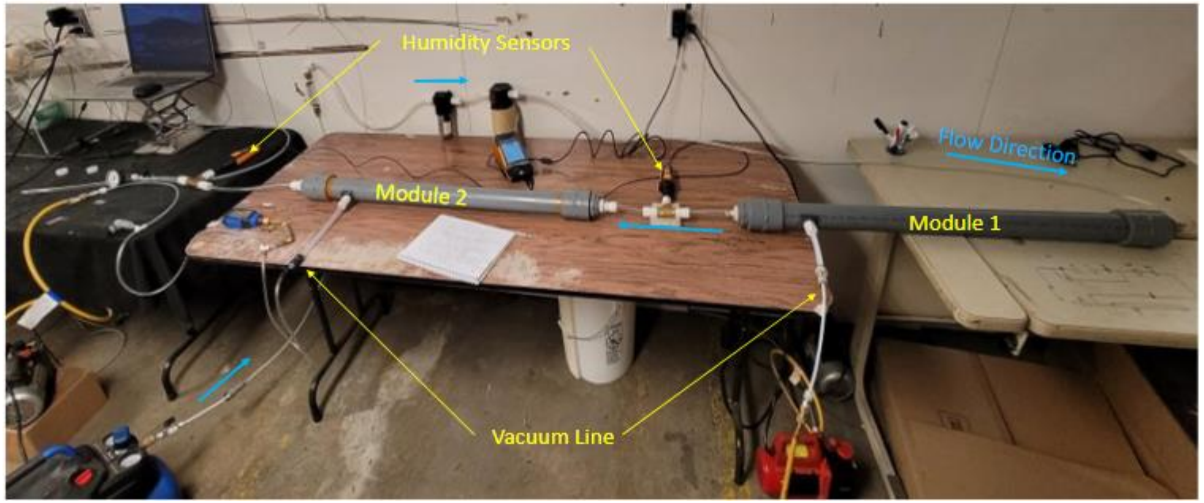
Progress and Future Work

Recommendation: 5-6 slides

- **Accomplished work**

GO NO GO 1:
Complete the BDC, water system, and dehumidification system models, achieving agreement within 10% of literature and laboratory data, and complete fabrication and testing of the BDC, water system, and dehumidification system. The water distribution system is able to distribute water with the diffusion rate of at least 0.3 cm2 on the plate materials of BDC cooler. The dehumidifier is able to reduce the humidity level of airflow of 0.6 CFM with a temperature equal to 25 °C from 60% to 50%.





Progress and Future Work

Recommendation: 5-6 slides

- Future work

Milestone	Planned Completion Date
Simple system testing complete and verification of the assumed characteristics under simulated heat (achieving at least 70% of the target performance).	08/01/23
Operating laboratory-based system made of the BDC cooler and MDPlus dehumidifier. Performance to achieve at least 70% of model predictions for the same geometry.	08/01/23
Thermal and mass transfer characteristics of the entire system (accuracy of 0.2°C and 2% RH).	12/01/23
Optimal configuration for the value proposition.	03/01/24
Air conditioning module with a capacity of 10 kW (34,120 Btu/hr) operating in a real environment achieving 60-80% energy savings in comparison with the traditional system.	10/01/2024

Progress and Future Work

Recommendation: 5-6 slides

- **Future work**

G/NG 2: Demonstrate a laboratory-based prototype that will achieve ≥70% of the target effectiveness during the experimental tests (42% energy savings in comparison with the traditional air conditioning system

The end of the project goal is fully functional and validated 10 kW (34,120 Btu/hr) air conditioning unit prototype, with a cooling coefficient of performance (COP) >12.5 in humid climatic conditions, net zero water consumption, scalable up to medium and large-scale units for different building types, and an installed cost of ≤$12/kBtu/h.

Progress and Future Work

Recommendation: 5-6 slides

- Future work

Thank You

Performing Organization(s)

PI Name and Title

PI Tel and/or Email

WBS #, FOA Project # and/or any other Project #

Project Execution

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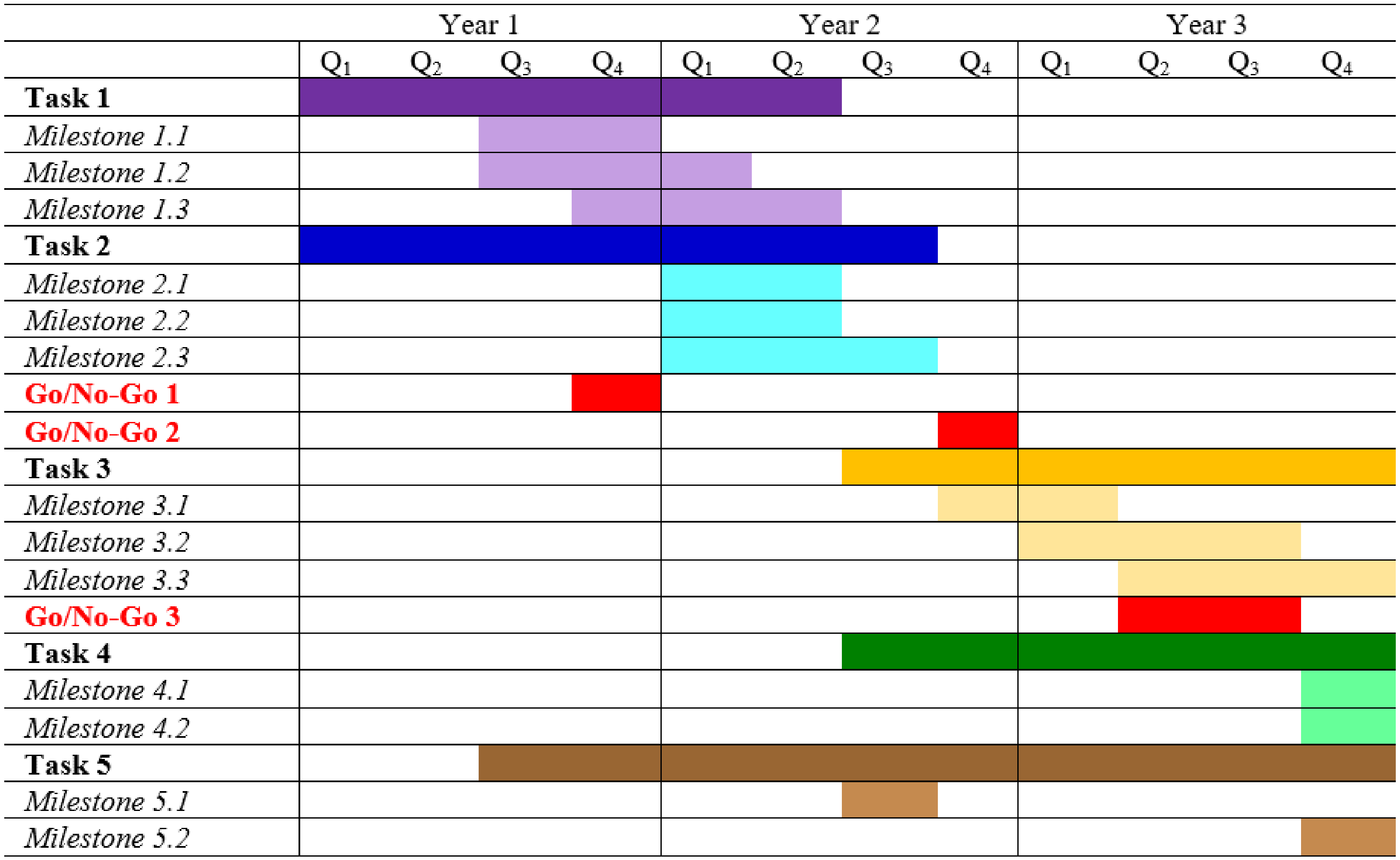

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