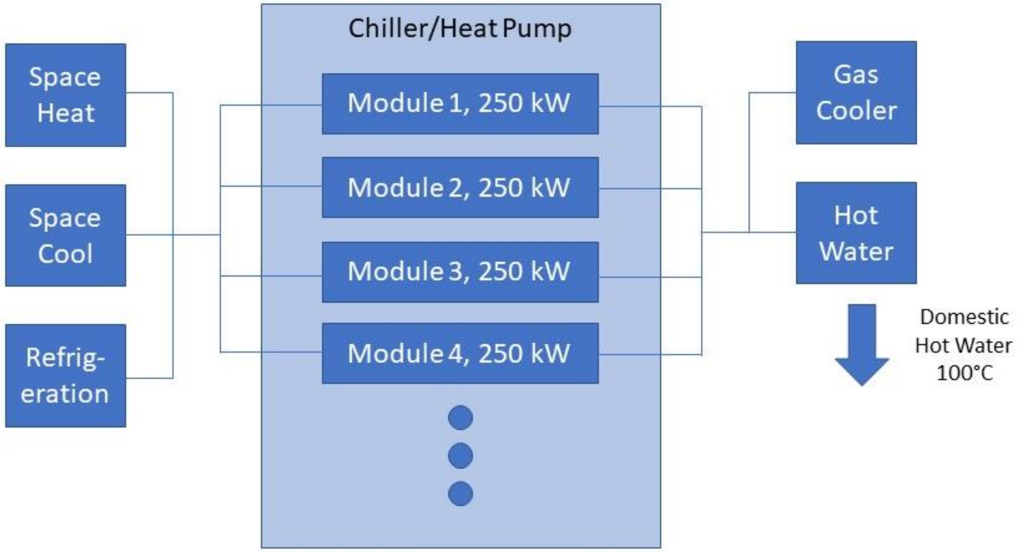
Development of a CO_2 Chiller Heat Pump for Multiple North American Applications



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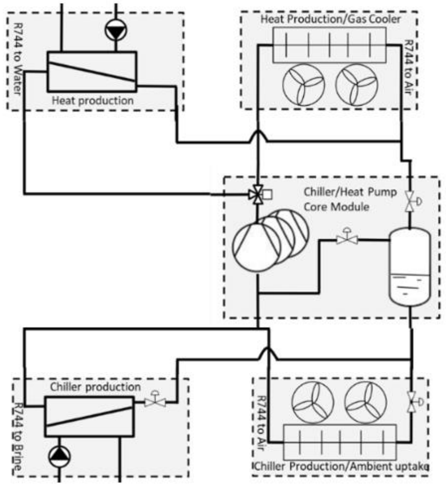
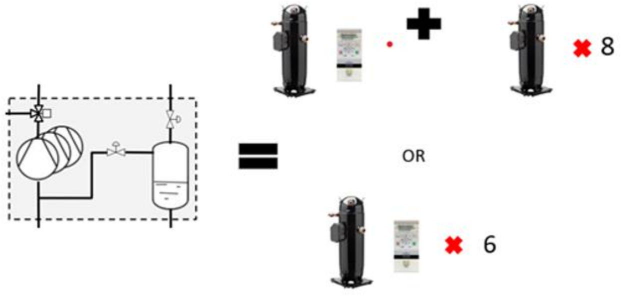
WBS: 03.02.02.55

Project Summary

Objective and outcome

The goal of this project is to develop and demonstrate a modular CO_2 refrigerant-based chiller/heat pump solution that enables the delivery of heating, cooling and domestic hot water for commercial building applications. The modular nature of the solution will allow for manufacturing and application efficiencies. This chiller/heat pump will displace conventional water heaters, downsize the need for conventional HVAC equipment and provide refrigeration and hot water for process use.





Team and Partners

- Oak Ridge National Laboratory (Brian Fricke, Kashif Nawaz)
- Effecterra (Michael May)
- Emerson/Vilter (Andre Patenaude)
- Optimized Thermal Systems (Dennis Nasuta)

Stats

Performance Period: 10/01/2022 – 09/30/2025

DOE budget: $2,227k, Cost Share: $0

Milestone 1: Detailed integrated system and controls design completed (FY24)

Milestone 2: Laboratory evaluation of demonstration unit completed (FY25)

Milestone 3: Pilot unit field evaluation completed (FY25)

Problem

- Current US heating and cooling applications rely on either synthetic refrigerants or hydrocarbons/fossil fuels
  - Contribute significantly to climate issues
- Transition away from these methods of heating and cooling, and towards the use of heat pumps for heating, cooling, and domestic hot water production
  - Heat pumps deployed in the US use high global warming potential (GWP) refrigerants
    - Contribute to significant direct emissions
    - These refrigerants pose long term viability, safety, and societal concerns.
  - Most HVAC&R products are designed and purpose built for a specific application.
    - They are at best custom designs that do not allow for manufacturing efficiencies
    - Often predicated on central plant applications, thus not offering siting efficiency and flexibility
- Proposed chiller heat pump concept:
  - Deploys a CO_2 refrigerant solution
    - GWP = 1
    - No safety or environmental concerns
  - Enables the delivery of heating, cooling and domestic hot water at 100ºC
  - Modular concept
    - Allows for the inclusion of manufacturing and application efficiencies

Alignment and Impact

- The proposed chiller/heat pump concept will enable the displacement of traditional fossil fuel water heating systems with a CO_2 refrigerant system
  - System efficiency gain
  - Reduction of both direct and indirect emissions
- On the cooling side, the system will provide supplemental cooling and refrigeration capacity without the use of synthetic refrigerants
  - Significant reduction in direct emissions (greater than 99% reduction)
- Broad commercialization of the proposed system
  - Save millions of tons of CO_2 emissions (direct and indirect) per year
  - Demonstrate the viability of CO_2 as a refrigerant in HVAC&R applications
- Significant benefits to the US public
  - Creation of jobs to manufacture and produce the chiller/heat pump modules domestically
  - Intangible health and safety benefits through eliminating the need for fossil fuels or ammonia refrigerant in these types of applications

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Alignment and Impact

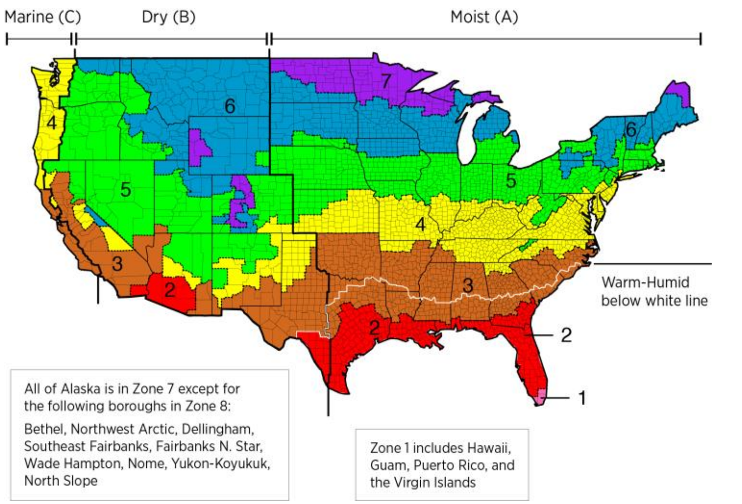
- Modular CO_2 chiller/heat pump concept has major implications for diversity, equity and inclusion.
  - Modular nature will be attractive to public housing authorities
    - Particularly for providing heat, cooling and domestic hot water in multifamily buildings
  - Cost-effective platform which is safe for deployment
  - CO_2 technology will minimize the environmental impact of the technology
  - Modularity and compactness and the use of an energy efficient design will keep associated costs at a minimum
- Technology is suitable for other commercial buildings that serve the community
  - Hospitals, civic centers, etc.
- During the field evaluation phase, the research team will seek the assistance of public housing authorities to identify test sites in underserved communities
  - Field demonstrations in these communities will accelerate the acceptance
  - Provide valuable feedback to the research team to ensure that the final design meets the needs of the community

Energy justice

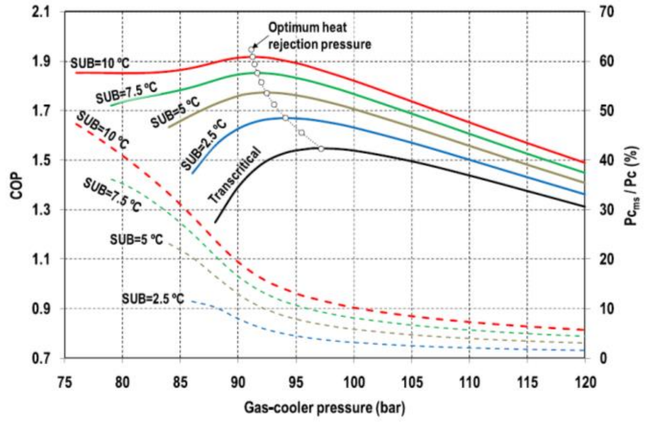
40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

Approach

- Chiller/heat pump systems are under development and are being deployed in the European Union (EU), primarily in Nordic countries
  - The basic technology is well understood
  - Technology development risk is low
- Issue with application of this technology to US market
  - Cooling dominated with more extreme hot ambient temperatures
  - CO_2 as a refrigerant suffers from inefficiency when deployed in hot climates
- Advantages
  - CO_2 is an excellent refrigerant for heating cycle applications
  - Overall system COP of a chiller/heat pump module can be higher than the combined COP for multiple devices deployed in the same independent functions



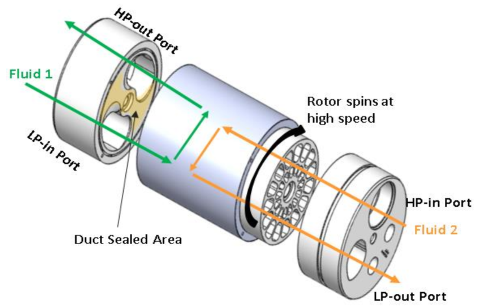
IECC Climate Zone Map



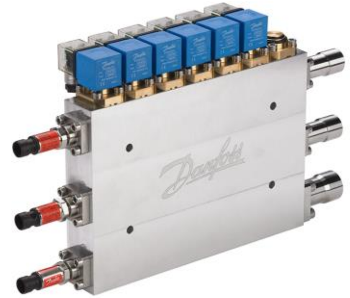
Effect subcooling and discharge pressure on CO_2 cycle COP (Dai *et al.* 2019. *Energy Convers. Manag.* 192: 202-220).

Approach

- Investigate several advanced CO_2 vapor compression technologies and develop a CO_2 chiller/heat pump concept with the following functionalities:
  - Chilled water and direct expansion (DX) evaporators for HVAC&R applications
  - Heating for both water and space needs
- Include advanced CO_2 technologies to improve cycle efficiency:
  - Ejectors, pressure exchangers, and advanced compression methods such as Direct Vapor Injection (DVI)
- Designed to accommodate North American requirements in the commercial HVAC&R application areas
- A consortium will be used to develop and deploy the concept:
  - Oak Ridge National Laboratory (national laboratory)
  - Effecterra (private company)
  - Optimized Thermal Systems (private laboratory)
  - Emerson/Vilter (original equipment manufacturer) – compression & manufacturing
  - US owner/operators (Google, Hemlock Semiconductor, etc.)



Pressure Exchanger (Energy Recovery, Inc.)



Ejectors (Danfoss)

System Controls (Carel)

Approach

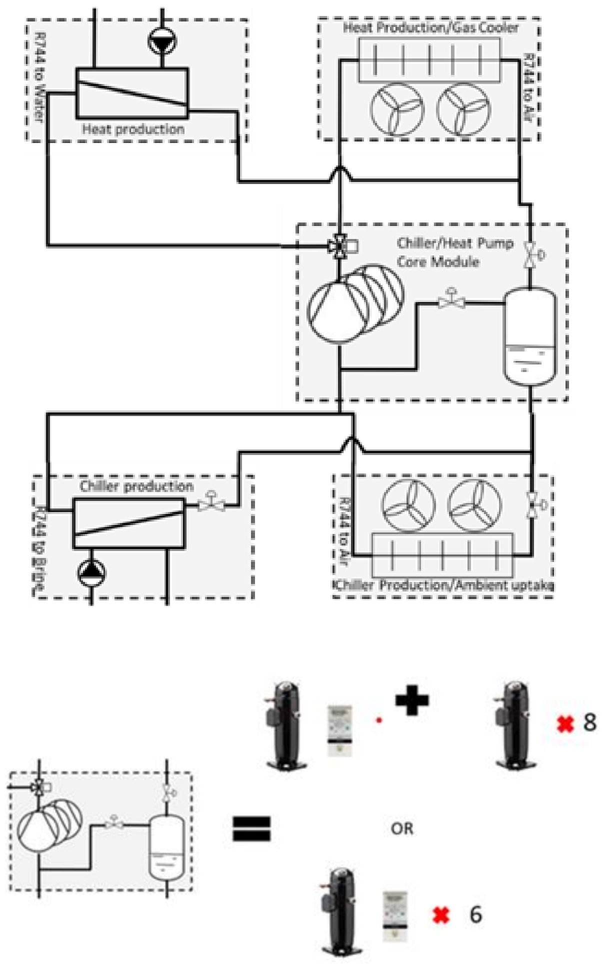
- The CO_2 chiller/heat pump development will occur in three phases.
  - Phase 1: CO_2 chiller heat pump conceptual design and technology insertion evaluation (6 months).
  - Phase 2: CO_2 chiller heat pump detail design, manufacture and verification testing of a development unit operating in a laboratory (18 months).
  - Phase 3. CO_2 chiller heat pump deployed in a commercial building application and associated validation testing (12 months).
- Goals:
  - We expect to achieve a base cooling system COP greater than 3.3 by implementing advanced CO_2 system technologies (ejectors, DVI)
    - Deployment of CO_2 chiller heat pumps in Nordic countries have demonstrated a seasonal summer COP of 3.2
  - Produce hot water for domestic use at approximately 100ºC

Approach

Risk	Mitigation
The cost-effectiveness of the proposed solution does not meet expectations	There are trade-offs between cost and energy-efficiency. During the initial design phase, a variety of technologies will be evaluated, and hence the design can be modified to reduce the cost while achieving the required efficiency level.
Cooling performance of the CO_2 system at warm ambient conditions does not meet expectations	There are two primary technologies that we will use in our development efforts aimed at improving cooling performance at warm ambient conditions. The first is the inclusion of Emerson's DVI technology which allows the direct injection of flash gas into the compression cycle and the second is ejector technology from Danfoss that allows an overall increase in CO_2 system efficiency in both extreme hot and cold environments.
Integration of all functions (cooling, heating, water heating) leads to poor overall performance	Integration of all functions (cooling, heating and water heating) requires proper coordination of the sequence of operations of the chiller/heat pump unit. A task dedicated to developing control algorithms is included in the project to ensure seamless and efficient operation.

Progress and Future Work

- Work has recently been initiated
- Compressor and other component selection
  - Base configuration using DVI compressor technology
  - Alternative design using ejector components
  - Both configurations will be evaluated in heating and cooling/refrigeration modes
- Heat exchanger design to support both cooling and heating modes
  - Standard base technology (plate/tube & fin) configurations
  - Alternative heat exchanger designs and technologies will be evaluated
- Integrated module design
  - Ensure proper functioning of the overall combined system including the hot water booster module.



Initial layouts of the component selection for the modular concept

Thank you

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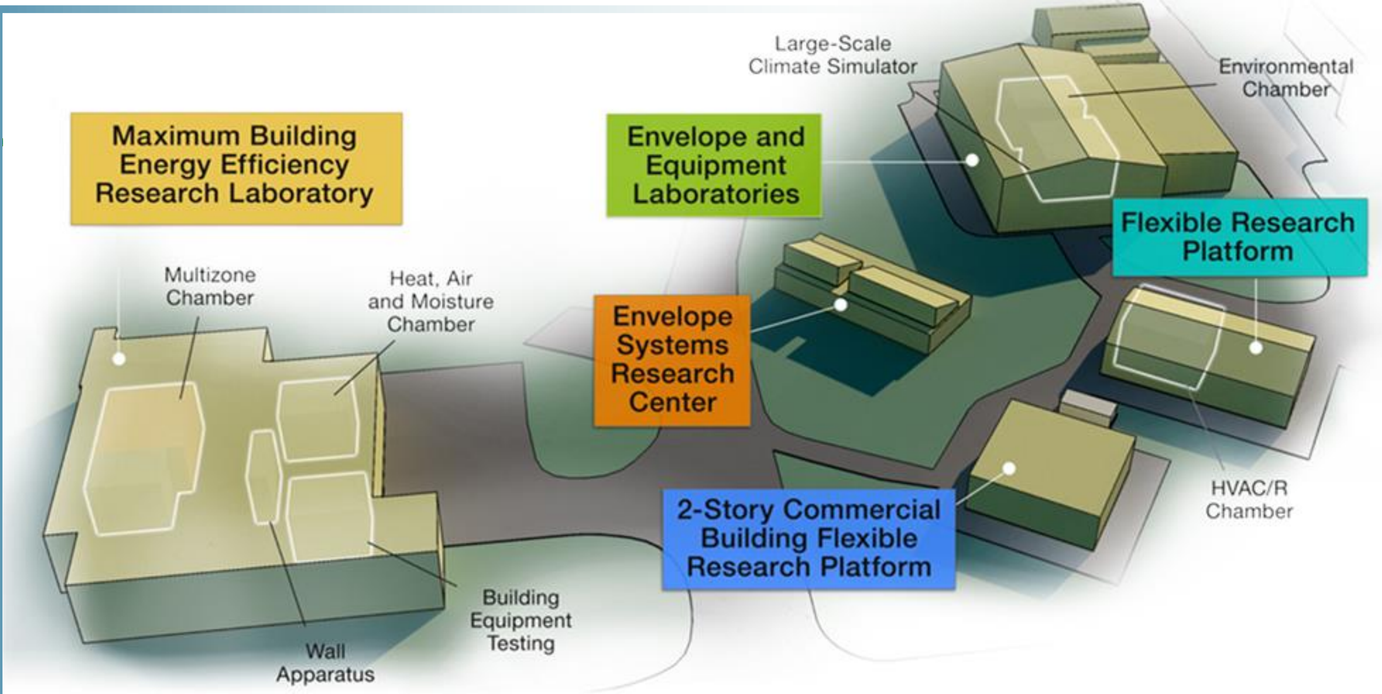

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution – Year 1 (M1 thru M12)

Budget $743K

Technology Development Period 1A		Technology Development Period 1B	
Project Start (3 months)	Conceptual Design (3 months)	Preliminary Design (3 months)	Final Design (3 months)
Collaboration and Team Structure, Research, Concepts	System Mechanical Design, Base P&ID	System Mechanical Design, Prototype Unit P&ID, Component Selection	System Mechanical Design, Final P&ID, Detailed BOM
Conceptual P&ID	P&ID Trade Studies	Prototype Unit P&ID	Final System P&ID
System Level Modeling, COP Targets	System COP Analysis	System COP Targets	
Technology Gap Analysis	Technology Development Roadmaps: Compression, Ejectors, Controls, System Integration	Technology Development Insertion: Compression, Ejectors, Controls, System Integration	Technology Development Selection: Compression, Ejectors, Controls, System Integration
Milestones			
DOE Kickoff meeting	Technology Development Roadmap	Technology Insertion Plan	Prototype Technology Selections
System & Component Requirements	Conceptual Design Review	Preliminary Design Review	Detailed Design Review
Draft Commercialization Plan	Integrated Development Plan	System Development Plan	Prototype Manufacturing Plan
Program Review (Phase End)	Program Review (Phase End)	Program Review (Phase End)	Prototype Verification & Validation Plan
			Draft Commercialization Plan
			Program Review (Phase End)

Project Execution – Year 2 (M13 – M24)

Budget $743K

Technology Development Period 2		
Development Unit Fabrication (4 months)	Development Unit Testing (8 months)	
Project Management	Development Unit Plan	
Design/Manufacturing Coordination	Development Unit FMEA	
Supply Chain Management	System COP Verification	
	Performance Verification	
		Pilot Unit Site Selection (3 months)
		Pilot Site Selection
		Pilot Application Design
		Pilot System Analysis
		Technology Assessment
Milestones		
Development Unit Delivery	Development Test Plan	Pilot Site Defined
Design Verification Plan	Development Unit FMEA	Application Design
	Development Test Report	Verification & Validation Plan
	Integrated Development Plan	

Project Execution – Year 3 (M25 – M36)

Budget $743K

Technology Development Period 3		
Pilot Unit Install & Commissioning (4 months)	Pilot Unit Verification & Validation (8 months)	
Pilot Unit Install	System COP Verification & Validation	
Pilot Unit Commissioning	System Performance Verification & Validation	
Pilot Unit Verification & Validation Plan	Remote Monitoring & Site Support	
		Final Report (3 months)
		Final Design Document
		Final Performance Assessment
		Completed Verification & Validation
		Final Report
Milestones		
Pilot Unit Installed	Pilot Testing Reports	Design Documents
Pilot Unit Commissioned	Final System Verification & Validation Report	Performance Report
Final Verification & Validation Plan		Final Verification & Validation Report
Commercialization Plan		Final Project Report

Team

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