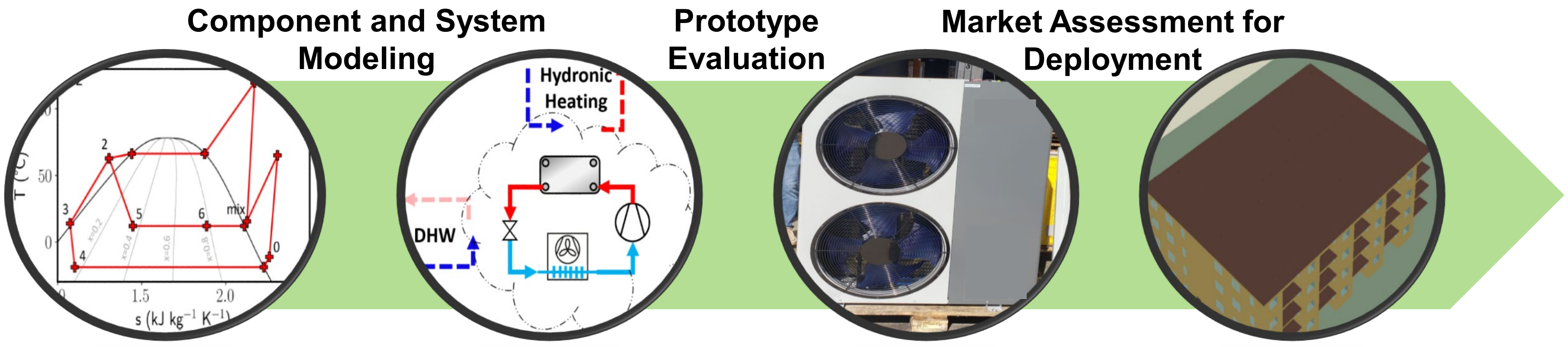
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: High-Temperature Combination Heat Pumps for Low-Cost Electrification

High-Temperature Combination Heat Pumps for Low-Cost Electrification



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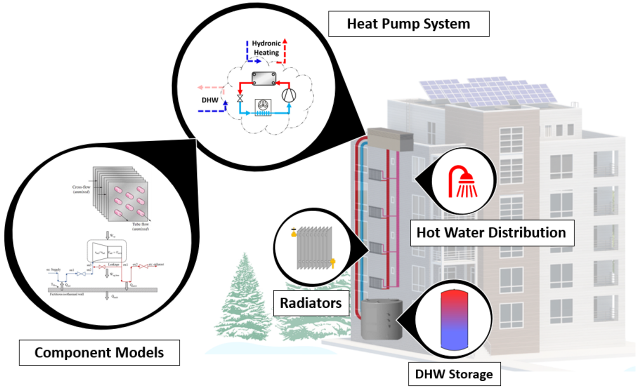
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

This project aims to **reduce barriers to decarbonization** in multifamily homes by developing combination electric heat pumping systems suitable for interfacing with legacy convective heat emitters. Prototype heat pumping systems will be developed targeting **20% lower installed costs** for heat pump retrofits in multifamily homes using hydronic heating systems.



TEAM & PARTNERS

NREL – NATIONAL RENEWABLE ENERGY LABORATORY

Modeling & Performance Characterization

Group 14 ENGINEERING

Stakeholder Engagement

STATS

Performance Period: 10/2022 – 09/2025

DOE Budget: $2,027k, Cost Share: $0k

Milestone 1: Stakeholder engagement for design guidance

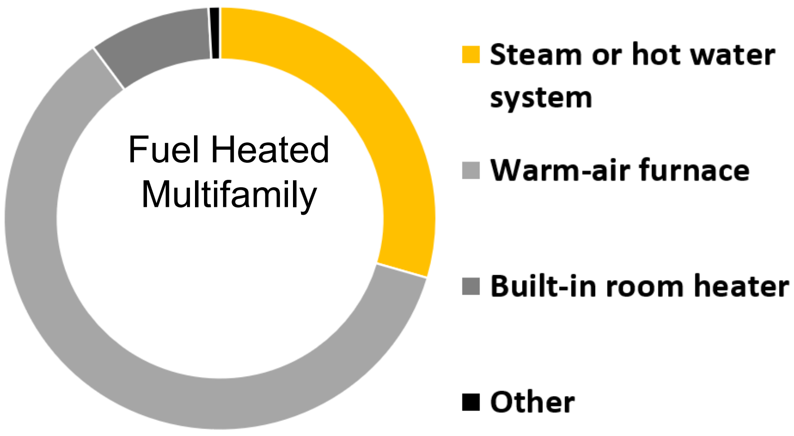
Milestone 2: Techno-economic modeling and optimization of heat pump system.

Milestone 3: Prototype experimental characterization

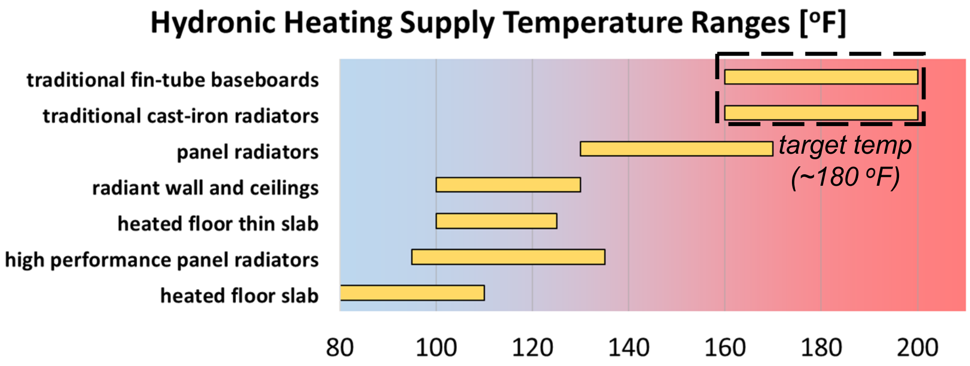
Problem

More than **3.8 million multifamily housing units** rely on gas-driven steam or hot water systems to provide space heating. These legacy systems generally utilize **high-temperature radiators** that present challenges for electrification with heat pumps.

Cost-effective heat pumping solutions for these buildings can help ensure that all segments of the population reap the benefits of **equitable decarbonization**.

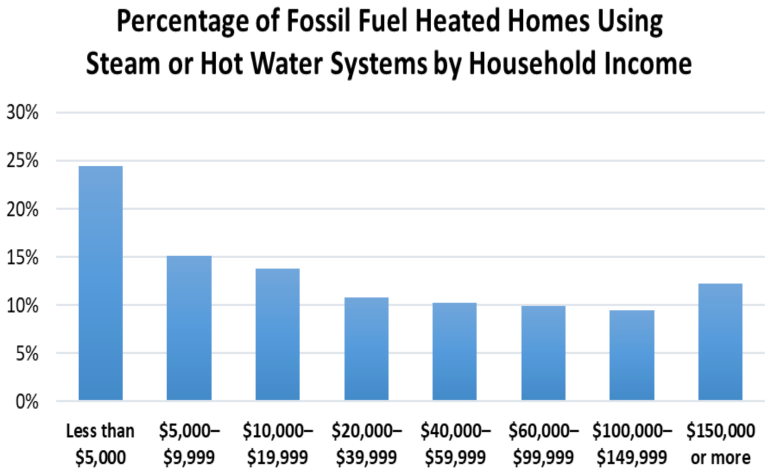


EIA RECS 2020



Alignment and Impact

- **Increase building energy efficiency**
  - Heat pump to achieve efficiency targets COP_H of 2.1 at 5°F
- **Accelerate onsite emissions reductions**
  - Provide efficient electrification option for millions of buildings using high-temperature hydronic systems
- **Prioritize equity**
  - Explore priorities of income-qualified housing and disadvantaged communities
- **Prioritize affordability**
  - Drop-in replacements with a lower installation and operating cost



EIA RECS 2020

Deliverables: Laboratory demonstration of heat pump suitable for legacy hydronic systems

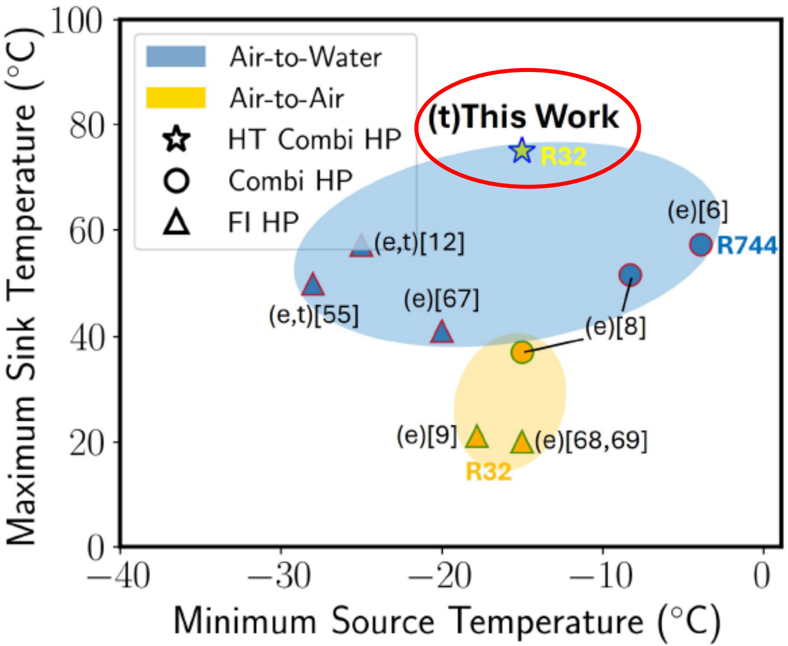
Approach

Current Solutions

- Reduce hot water temperature requirements:
  - Replace heat emitters with larger devices.
  - Reduce building load via envelope retrofits.
  - Replace heat emitters with fan-coils.
  - Adding radiant panels.

- Retrofit with in-unit heating
  - Mini-splits
  - Window units
  - PTACs

- Heat Pump Drop-In Replacements
  - Numerous air-source product offerings for water delivery temperatures < 160 °F.
  - Limited offerings for water delivery temperatures > 160 °F.



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Approach

NREL
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- System and Component Modeling.
- Techno-Economic Optimization.
- Prototype Development:
  - Modify equipment for high temperature combination heat pumping.
- Experimentation:
  - Steady-state prototype characterization.
  - Hardware-in-the-loop evaluation.

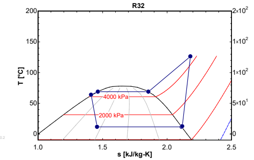
Group 14 ENGINEERING

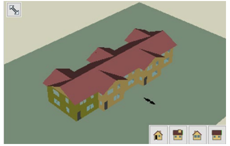
- Stakeholder Engagement:
  - Outreach interviews.
  - Regional assessments.
  - Design Guidance

A holistic approach to deploying combination heat pump systems suitable for convective heating in multifamily buildings

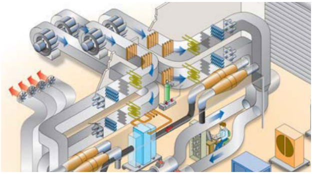
Approach

Modeling

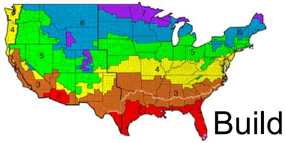




Laboratory experimentation



Target markets



Climate Zones

Utility Structures

Building Characteristics

OBJECTIVES

- Develop low-cost combination heat pumps for multifamily buildings
- Reduce electrification retrofit cost by easily integrating with legacy hydronic infrastructure
- Substitute system components with lower cost alternatives to drive down hardware costs

ACTIVITIES

- Generate stakeholder driven design criteria
- Model heat pumping and water distribution systems
- Integrate cost and performance system modeling
- Construct and characterize prototype system
- Evaluate grid-interactive controls

OUTPUTS

- Guidance for designing low-cost high temperature lift combination heat pumps
- Simulation tools to aid in system design for performance and cost targets
- Pre-commercial prototype system
- Market assessment to aid in targeted system deployment

OUTCOMES

- **Reduced barriers to decarbonization in multifamily homes**
- **Expanded product offerings for electrification**
- **Increased use of space and water heating systems with refrigerant GWP <750**
- **20% lower installed cost multifamily heat pumps**

Approach

Challenges	
1	**Large Temperature Lift:** • Prevent compressor overheating. • Achieve efficiency targets.
2	**Cost Reduction:** • Establish baseline costs. • Reduce costs of material inputs. • Simplify retrofit/installation procedure.
3	**System Installation:** • Space and electrical capacity constraints.
4	**Control Optimization:** • Simulating realistic building behavior.

Risk	Mitigation Strategy
Compressor Overheating	- Multi-stage Compression - Dual Fuel Systems
Capacity loss at low outdoor temperature	- Supplemental heating integration
Limited Deployment of Proposed Solution	- Explore cost reducing measures - Identify and address stakeholder needs - Explore role of utility programs to aid deployment

Progress and Future Work: Stakeholder Engagement

- Results of interviews with stakeholders compiled into 39-page report on challenges and needs for electrifying affordable multifamily housing and delivered to BTO.

Stakeholder Demographics

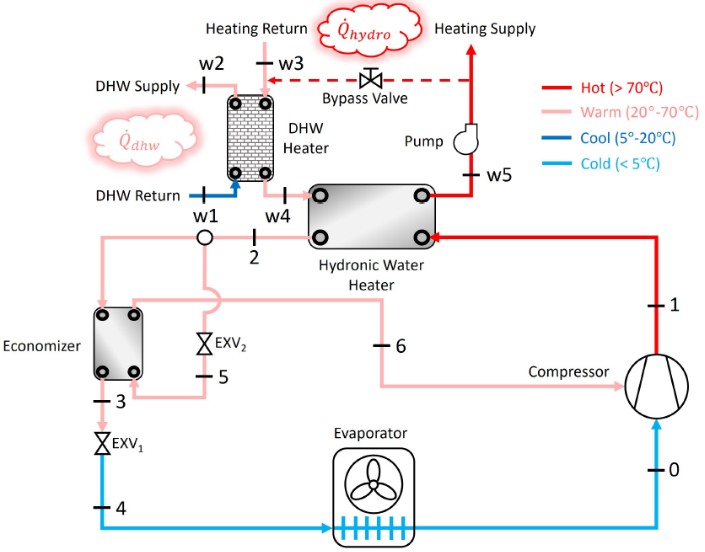
Stakeholders by Location	
CA	5
CO	15
FL	4
Stakeholders by Type	
Affordable Housing Developer/Owner	7
Architect	3
Design Engineer	5
Design Engineer/Installing Contractor	2
General Contractor	1
Housing Finance Authority	2
O&M Contractor	1
Utility/Rebate Program Administrator	3

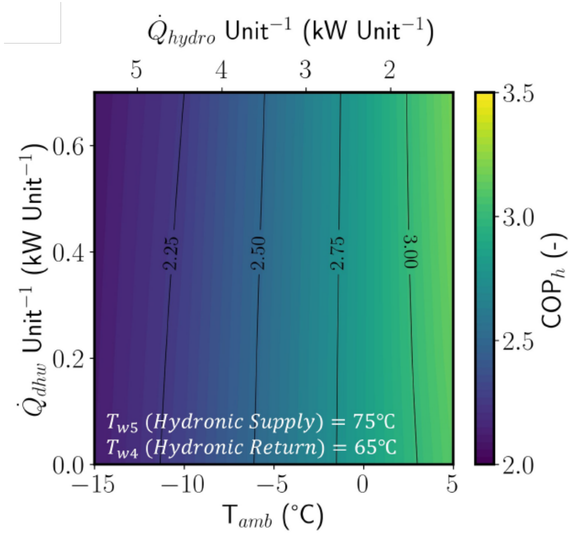
Feedback Excerpts

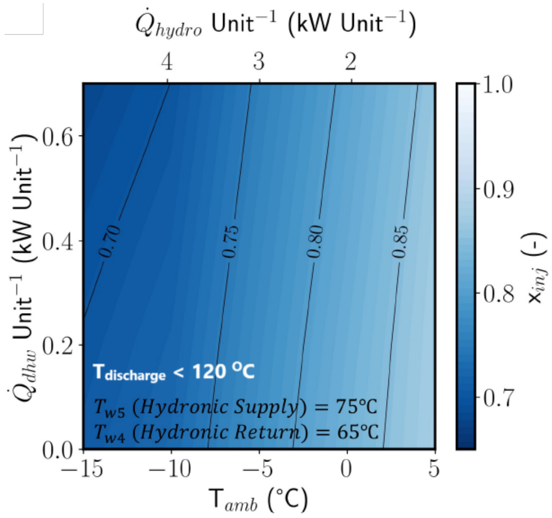
Constructability
• Older buildings with larger/bulkier existing equipment may have more space availability for heat pumping devices. • Sufficient outdoor air access required for interior mechanical rooms
Design/Infrastructure
• Lower capacity/temperature heat pumps may uncover issues that were previously compensated for by boiler systems. • There is a lot of variation in central water heating systems. Flexibility in configuring the equipment would help during the retrofit process

Progress and Future Work: System Modeling

- R32, 2-phase injected air-to-water vapor compression heat pump cycle with series heat exchangers for hydronic and DHW heating







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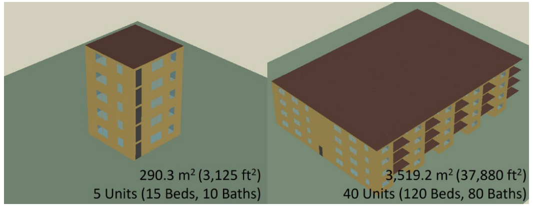
Progress and Future Work: Regional Assessment



BEopt
Building Energy Optimization
with Hour-by-Hour Simulations

ResStock

$$SCOP_h = \frac{\sum_{t=0}^{8760}\left(\dot{Q}_{hydro}(t_{hr}) + \dot{Q}_{dhw}(t_{hr})\right)}{\sum_{t=0}^{8760}\left(\dot{W}_{comp}(t_{hr}) + \dot{W}_{pump}(t_{hr}) + \dot{W}_{fan}(t_{hr}) + \dot{W}_{elec}(t_{hr})\right)}$$

$\dot{Q}_{hydro}(t_{hr})$: Hourly sensible space heating load.

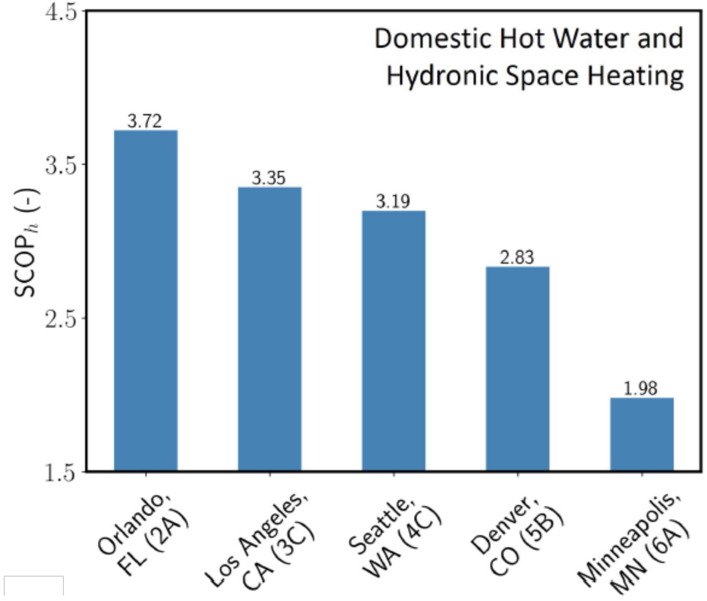
$\dot{Q}_{dhw}(t_{hr})$: Hourly domestic hot water (DHW) load.

$\dot{W}_{comp}(t_{hr})$: Hourly electrical load of the compressor.

$\dot{W}_{liquid}(t_{hr})$: Hourly electrical load of the liquid pumps.

$\dot{W}_{fan}(t_{hr})$: Hourly electrical load of the fan.

$\dot{W}_{elec}(t_{hr})$: Hourly electrical load of the electric heater.



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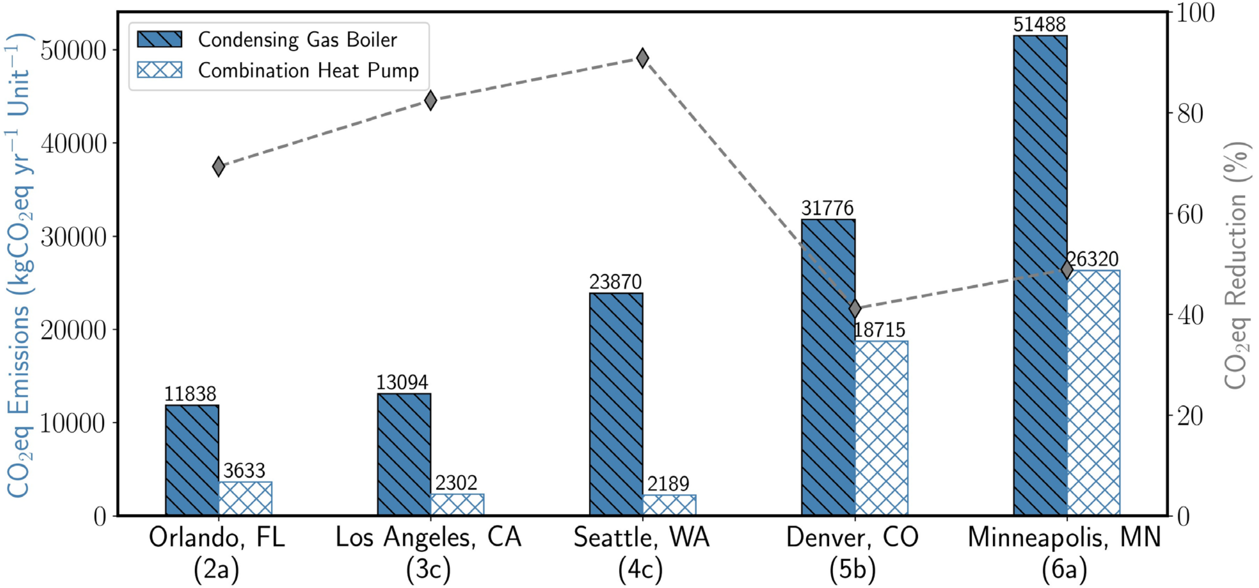
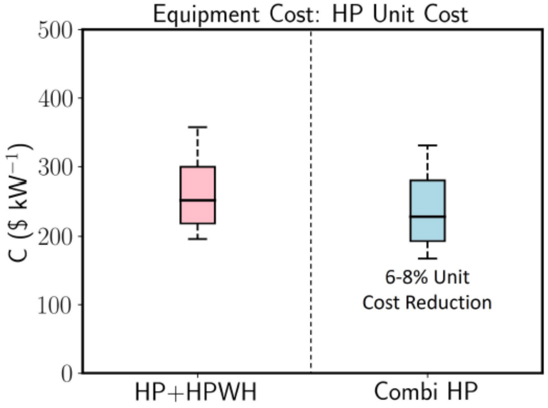
Progress and Future Work: Emissions and Costs

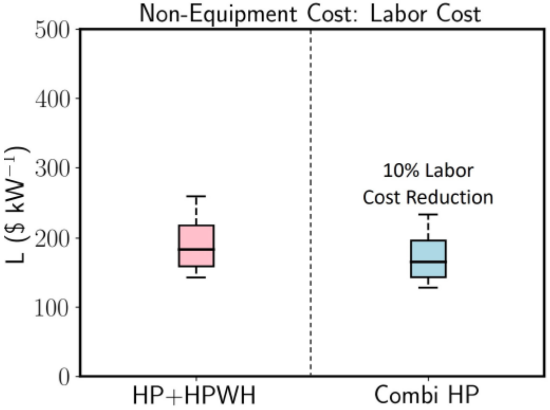
Total equivalent warming impact (TEWI)

$$TEWI_{hp} = C \cdot (L \cdot ALR + EOL) \cdot GWP + \bar{\alpha}_{hp} \cdot W_{hp} \cdot L$$

$$TEWI_{gas} = \bar{\alpha}_{gas} \cdot Q_{gas} \cdot L$$







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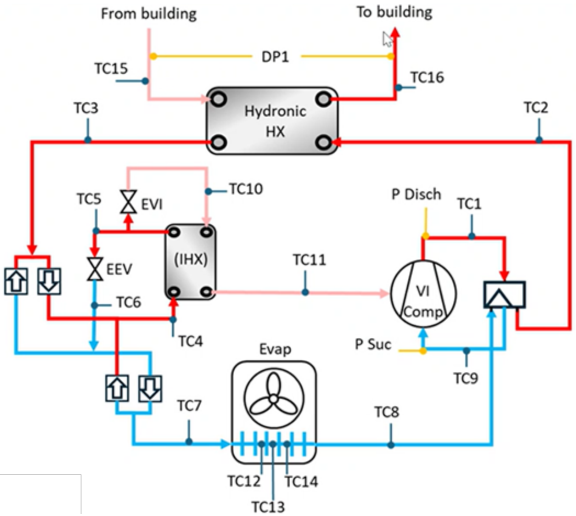
Progress and Future Work: Prototype Testing

- In-house modifications to off-the shelf vapor injected air-to-water heat pump unit



- Planned Modifications
  - Adding secondary heat exchanger for DHW
  - Imposing 2-phase injection
  - Refrigerant replacement

- CRADA negotiation with heat pump OEM underway to evaluate alternative compressor, refrigerant, and system designs

Future Work

- Steady-state testing of prototype heat pump
- Hardware-in-the-loop testing of prototype heat pump
- Material Substitutions and Design Optimization
- Techno-economic and target market assessment

Thank you

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Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	675k				675k				675k			
Spent budget	675k				392k				0k			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Initial thermodynamic modeling												
DHW storage and distributiong modeling												
Costs. vs. performance modeling												
Model projected saving and performance targets												
Stakeholder engagement report												
Current/Future Work												
Fabrication of prototype system												
Preliminary test data on prototype system												
Experimentallay achieve performance target												
Hardware-in-the-loop plan developed												

- Challenges in CRADA execution led to the need to replace OEM project partner for prototype characterization and technoeconomic assessment.

Team

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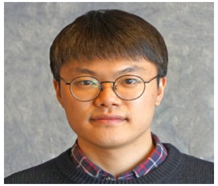

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