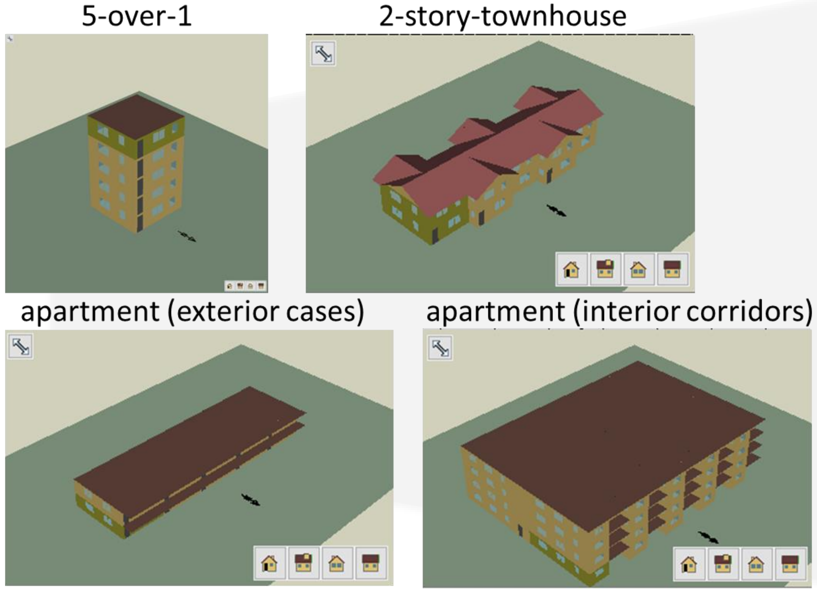
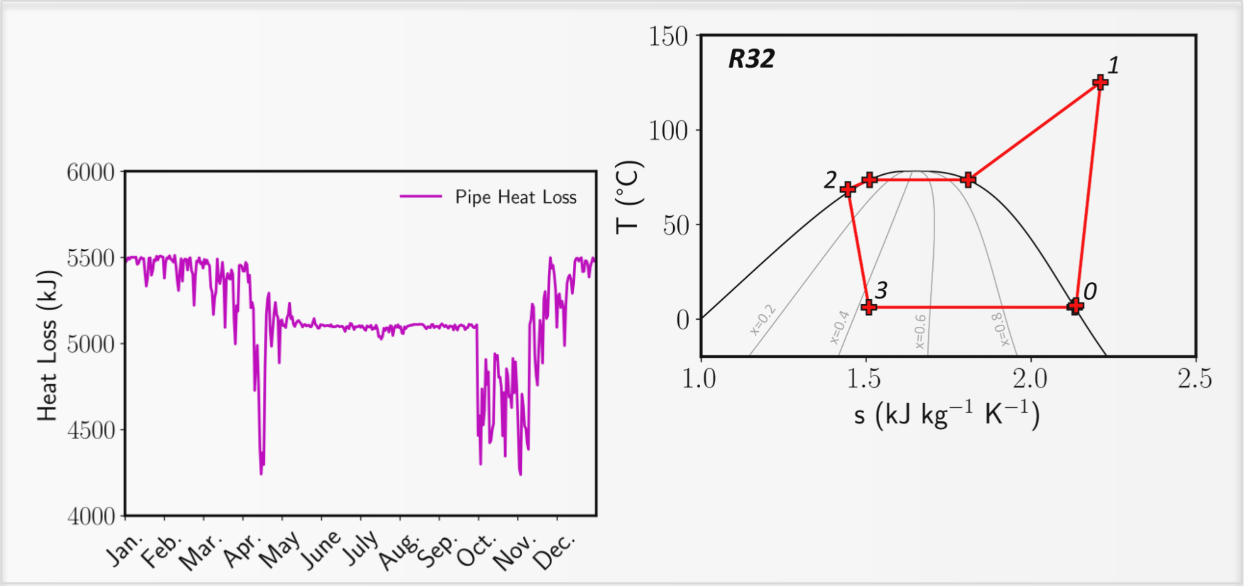
High-Temperature Combination Heat Pumps for Low-Cost Electrification





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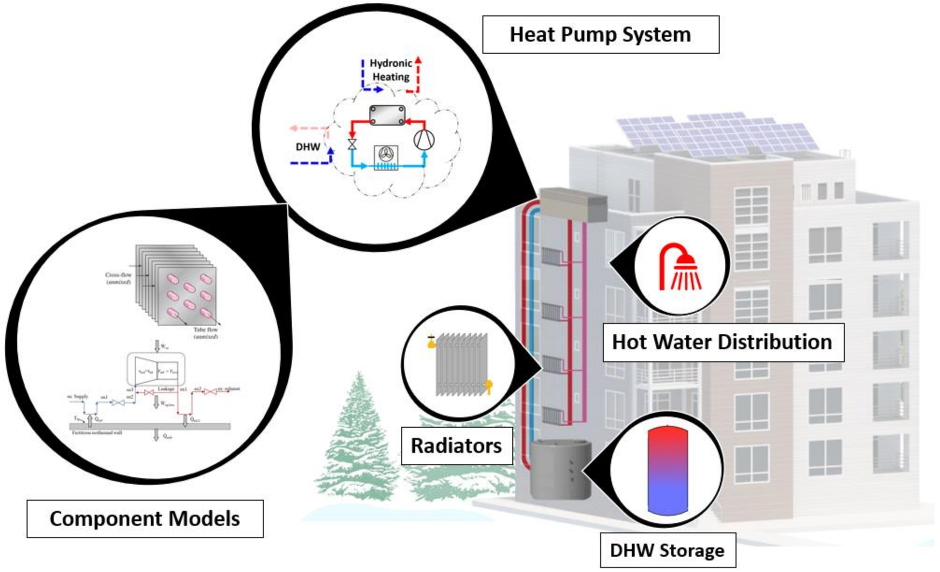
Project Summary

Objective and Outcome

- 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.
- **Low-GWP** heat pumping systems will be developed targeting **20% lower installed costs** for heat pump retrofits in multifamily homes using hydronic heating systems.



Team and Partners

NREL – Modeling & Performance Characterization

Rheem – Prototype Development

Group 14 Engineering – Stakeholder Engagement

Stats

Performance Period: 10/2022–09/2025

DOE Budget: $2,027k, Cost Share: $225k

Milestone 1: *Stakeholder engagement for design guidance*

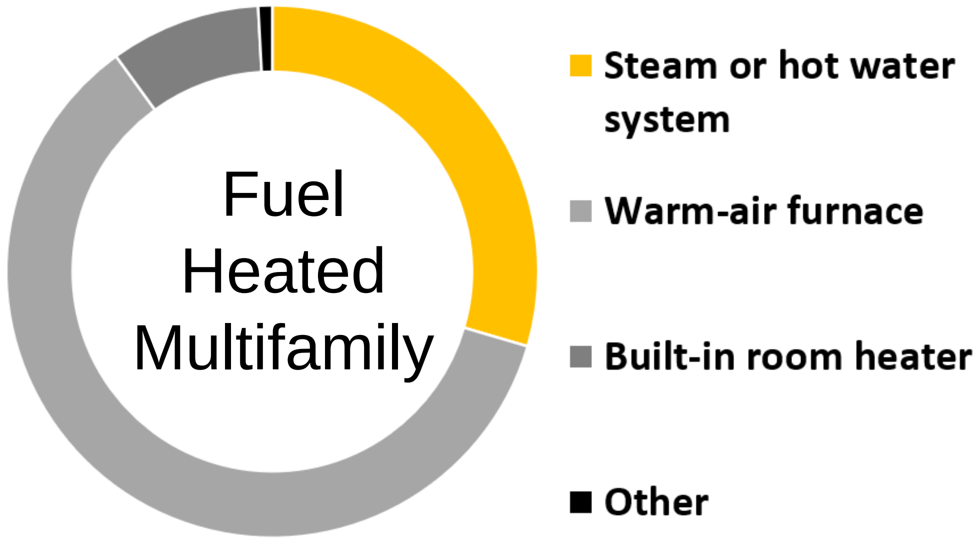
Milestone 2: *Techno-economic modeling and optimization of heat pumping systems*

Milestone 3: *Experimental characterization of prototype system*

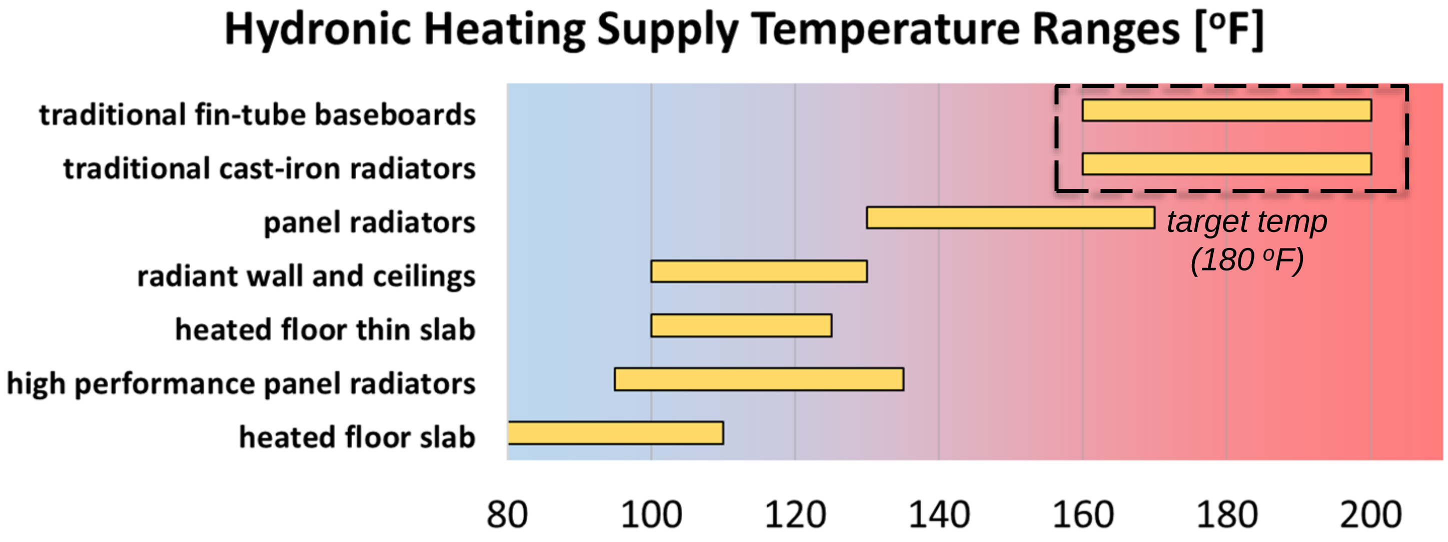
Problem

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**.

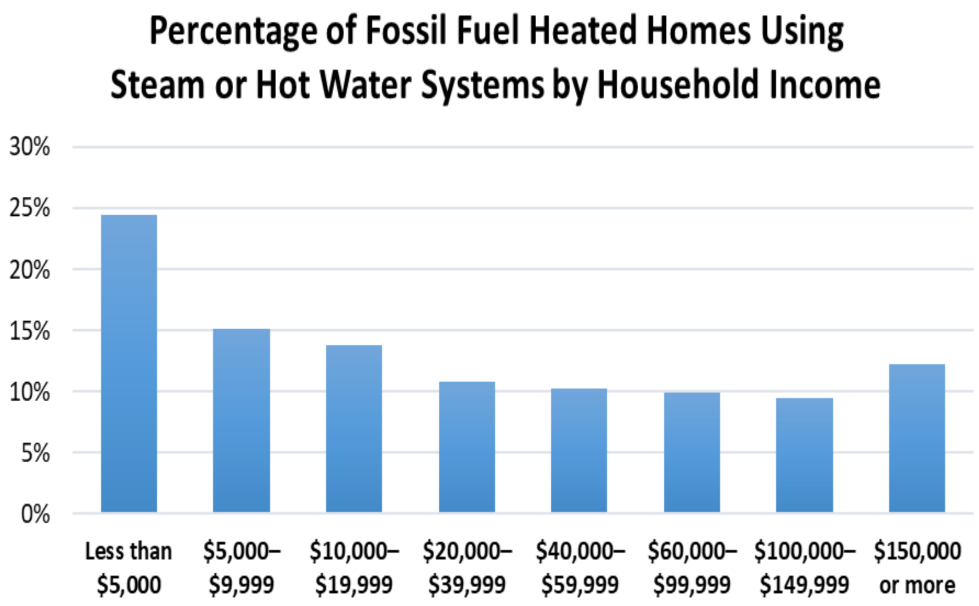


EIA RECS 2020



Alignment and Impact with BTO Goals

- **Increase energy efficiency**
  – Heat pump to achieve efficiency targets of UEF > 3.5, and COP_H of 2.1 at 5°F
- **Accelerate building electrification**
  – Provide efficient electrification option for millions of buildings using high-temperature hydronic systems
- **Prioritize equity and affordability**
  – Explore priorities of income-qualified housing and disadvantaged communities
- **Reduce cost of decarbonizing specific building segments**
  – Drop-in replacements with a lower installation and operating cost

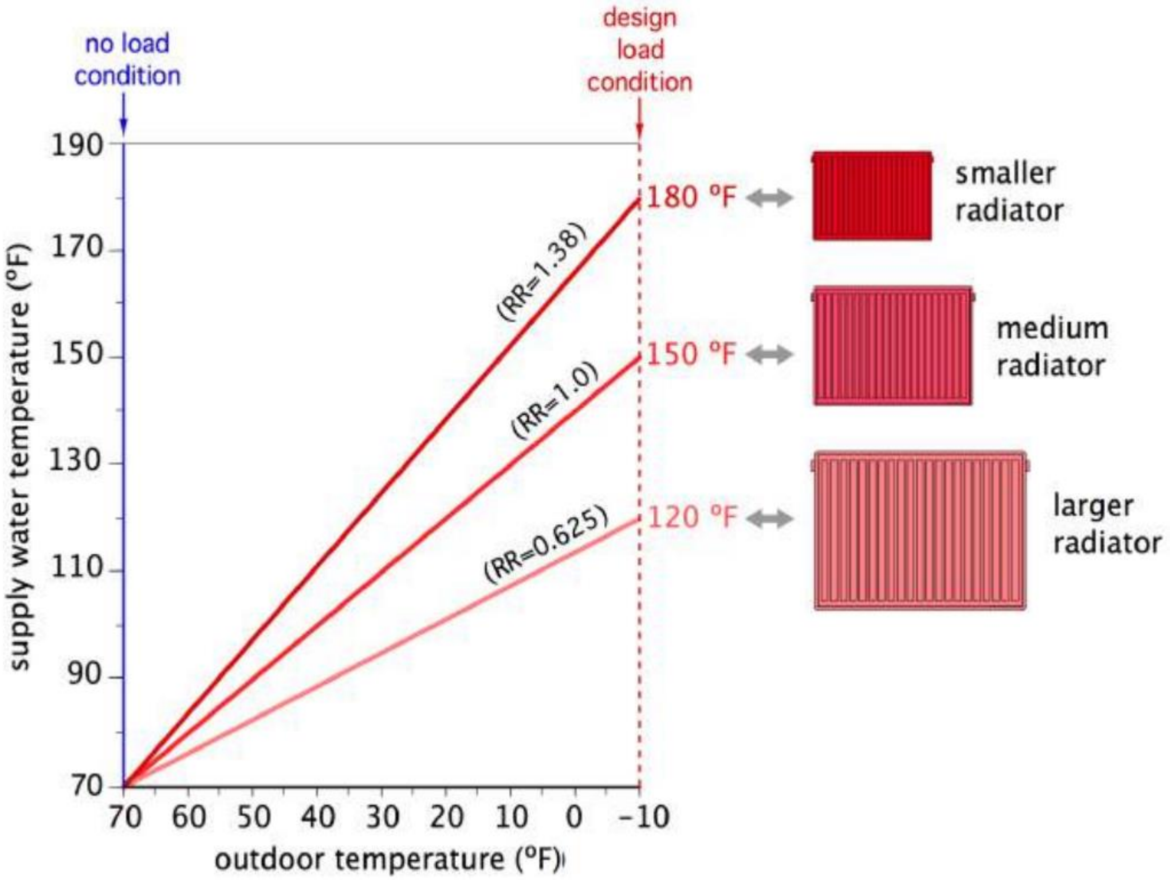


EIA RECS 2020

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

Current Electrification Options For Hydronic Systems

- **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:**

Group14 Engineering: https://www.chfainfo.com/getattachment/4d9f70a2-6fb3-4077-9c5d-677e9edeab01/HTC-Building-Electrification-Report.pdf
CALEFFI: https://www.caleffi.com/sites/default/files/file/idronics_25_na.pdf

Approach to Delivering Outcomes Aligned with BTO Goals

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- **System and Component Modeling.**
- **Techno-Economic Optimization.**
- **Experimentation:**
  - Steady-state prototype characterization.
  - Hardware-in-the-loop evaluation.

+

Rheem
Group 14 ENGINEERING

- **Prototype Development:**
  - Component sourcing and assembly.
- **Stakeholder Engagement:**
  - Outreach interviews.
  - Regional assessments.

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

Approach to Delivering Outcomes Aligned with BTO Goals

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

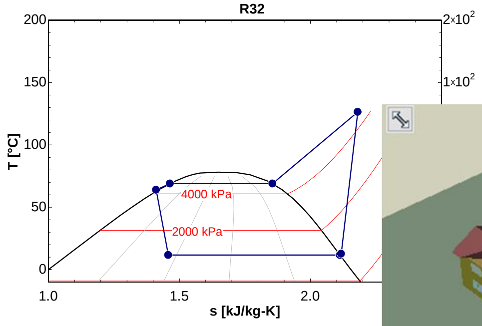
OUTPUTS

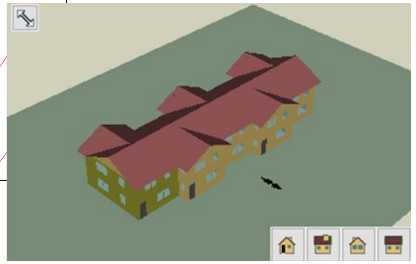
- Guidance for designing low-cost high temperature lift combination heat pumps
- Simulation tools to aid in system design for performance and cost targets
- Pre-commercial prototype system
- Market assessment to aid in targeted system deployment

OUTCOMES

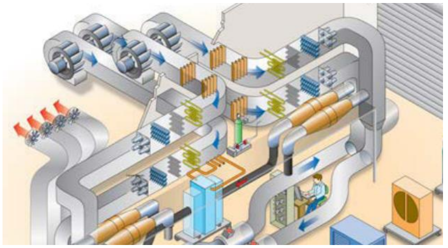
- **Reduced barriers to decarbonization in multifamily homes**
- **Expanded product offerings for electrification**
- **Increased use of space and water heating systems with refrigerant GWP <750**
- **20% lower installed cost multifamily heat pumps**

Modeling

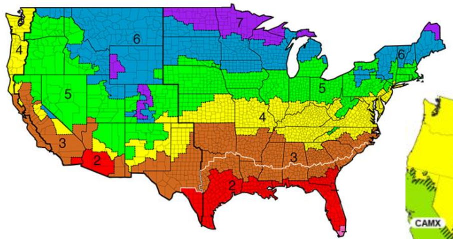




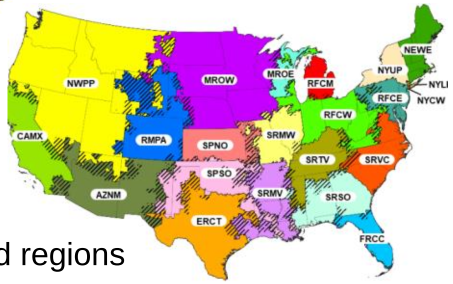
Laboratory experimentation



Target markets



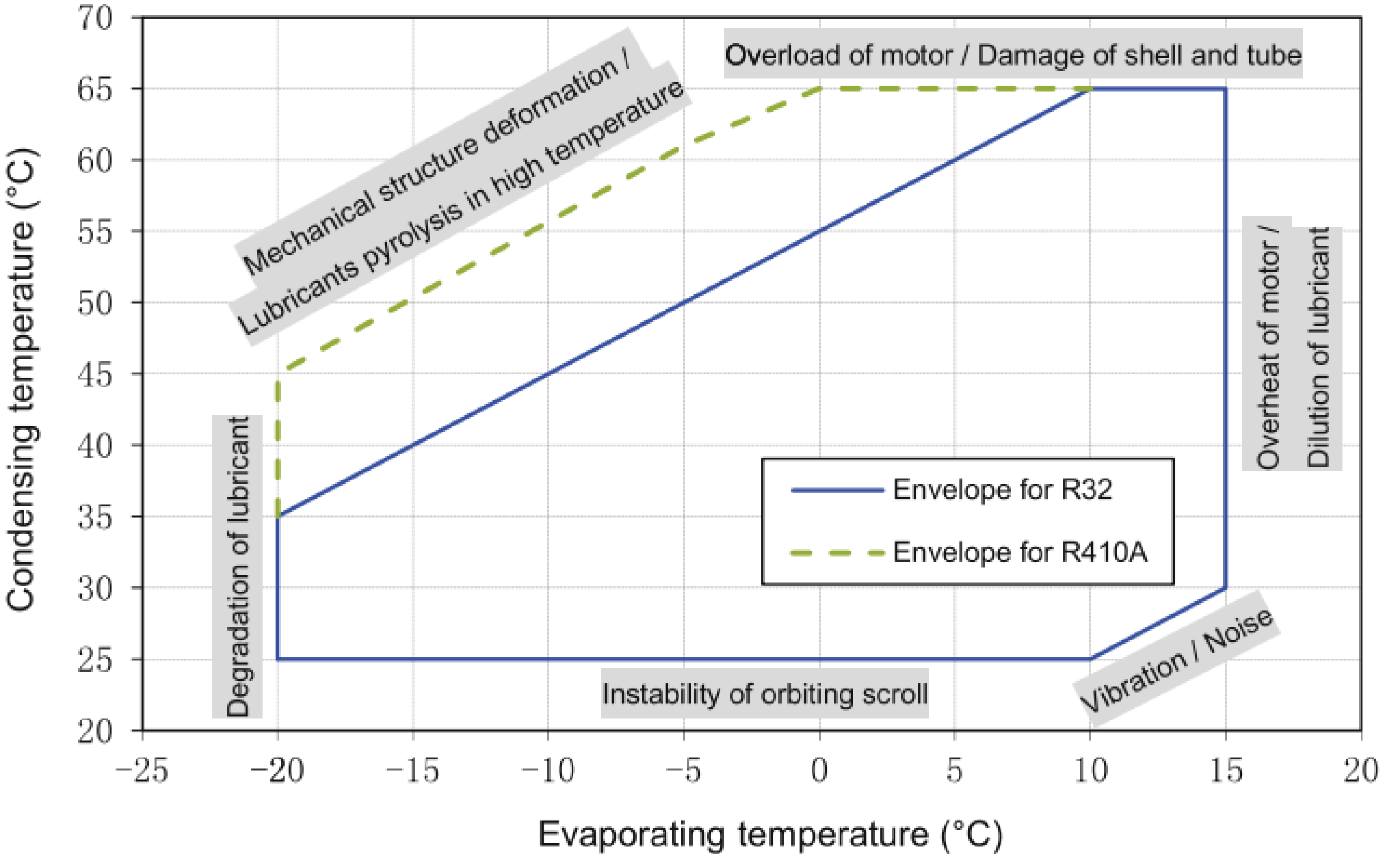
climate zones



grid regions

Technical Challenges

	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.



Yang et al. 2015. *Int J Refrig.* https://doi.org/10.1016/j.ijrefrig.2015.08.004

Risk Mitigation Strategies

#	Risk	Mitigation
1	**Compressor overheating**, preventing 180°F supply temperature.	- Investigate the use of **multistage compressors.** - Explore **dual fuel options** as a bridge between fossil fuel and full electrification.
2	**Capacity drops** at low ambient temperatures preventing meeting heating loads.	- Investigate **supplemental heating options** for meeting building loads during low ambient temperature conditions.
3	**Limited deployment** of proposed technology solutions.	- Explore **installed cost reducing** measures, identify and address **stakeholder needs** during design, and evaluate potential roles for **utility programs** and other sources to aid deployment.

Progress: Stakeholder Engagement

Group14 Engineering

Engage with stakeholders to better understand needs of hydronic systems in multifamily buildings.

Potential stakeholders: Housing developers, maintenance staff, general contractors, mechanical contractors, etc.

Planned themes to investigate:

- Constructability.
- Design/Infrastructure.
- Maintenance.
- Operational Expenses.
- Rebates/Incentives.
- Regulatory Compliance.

NREL Advisory Panel

Provide input that can be used across a range of HVAC projects supporting electrification at NREL.

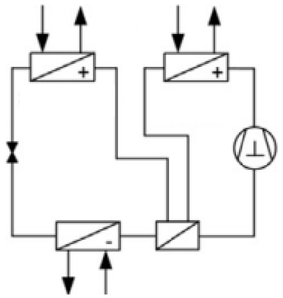
Stakeholders interviewed: Multifamily building owners, co-op utility, large utility, community-based organization.

Current themes discussed:

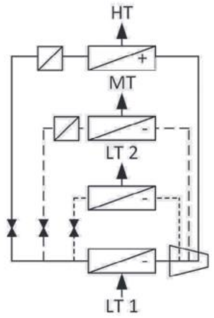
- Initial cost of high importance.
- ROI must make sense for building owners to adopt.
- Adding cooling could justify extra costs.
- Concerns over electrical capacity limitations.

Progress: Preliminary System Performance Assessment

- Domestic hot water (DHW) and hydronic water heating integration:



Series heat exchangers



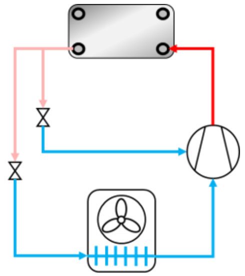
Multiple condensers

Arpagaus et al. 2018. *Energy* https://doi.org/10.1016/j.ijrefrig.2016.05.014

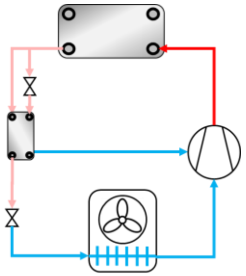
Arpagaus et al. 2016. *Int J Refrig.* https://doi.org/10.1016/j.ijrefrig.2016.05.014

- Compressor cooling strategies:

Liquid Injection



Vapor Injection



- GWP <750 refrigerant selection.

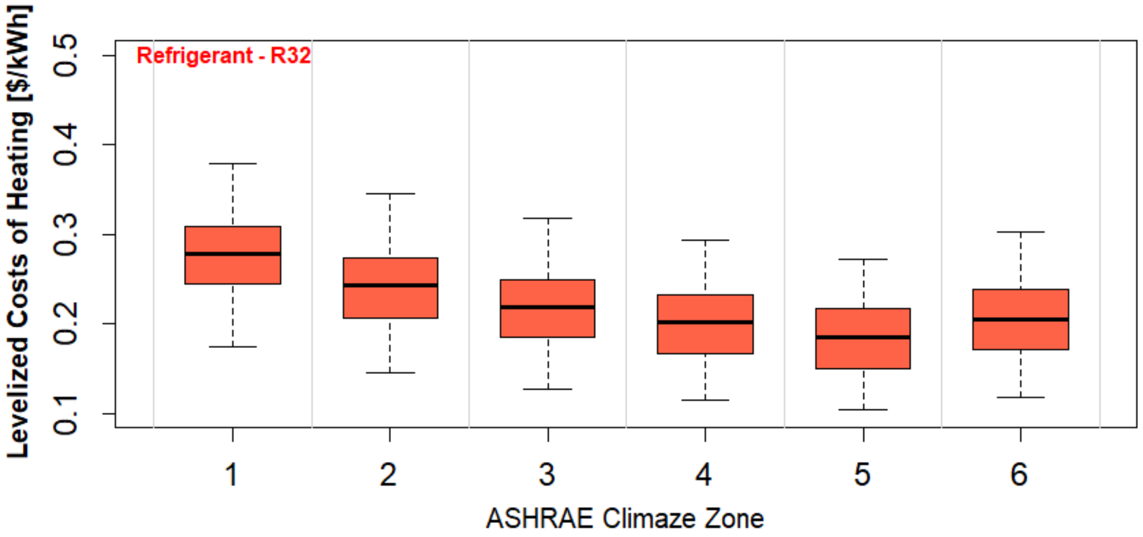
ANSI/ASHRAE Standard 206-2013 (RA 2017)
(Reaffirmation of ANSI/ASHRAE Standard 206-2013)
Includes ANSI/ASHRAE Addenda a, b, and c to ANSI/ASHRAE Standard 206-2013

Method of Testing for Rating of Multipurpose Heat Pumps for Residential Space Conditioning and Water Heating

<u>Evaluating:</u>

- System first costs.
- Annual COP.
- Levelized cost of heating (LCOH).

$$LCOH = \frac{a \cdot Cap_{\$} + E_{kWh} \cdot \frac{\$}{kWh}}{Q_{kWh}}$$



Plots show min, max, median, and interquartile range. | Electricity price range: 0.08 – 0.20 $/kWh

Progress: Water Distribution Modeling to Aid System Design

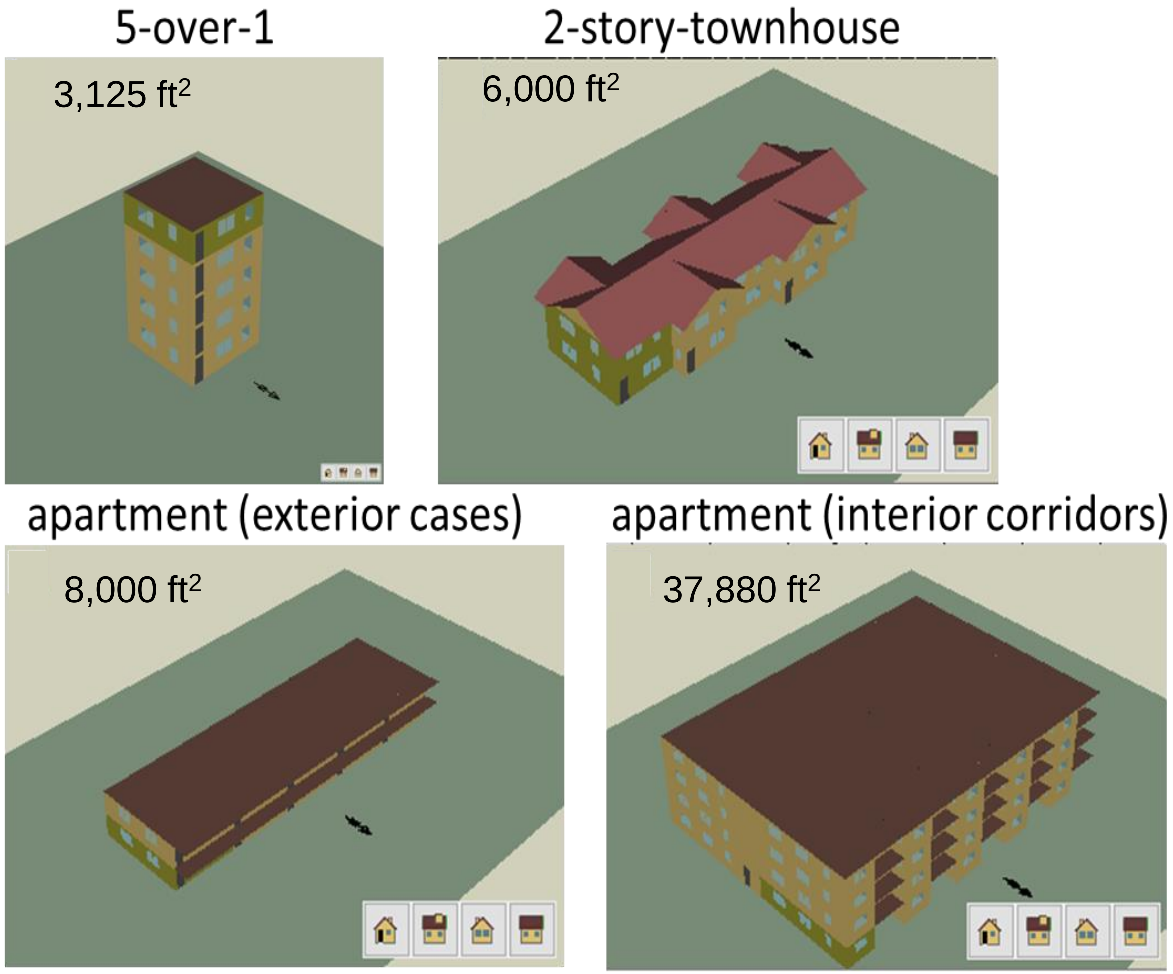
DHW distribution modeling:

- Multiple climate zones.
- Multiple building layouts.
- Central distribution system.
- Detail parameters:
  - Pipe materials.
  - Pipe layout.
  - Recirculation loop location.
  - Insulation thickness.

Hydronic distribution modeling:

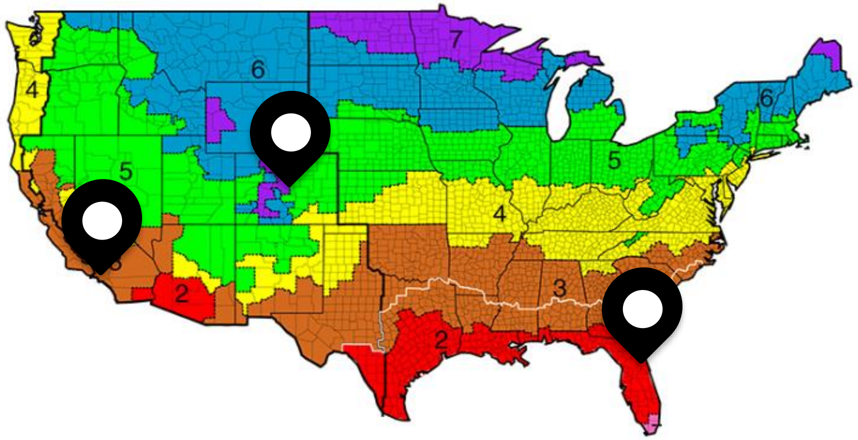
- Customized version of BEopt™.

Water distribution modeling results will be integrated with heat pump system models.



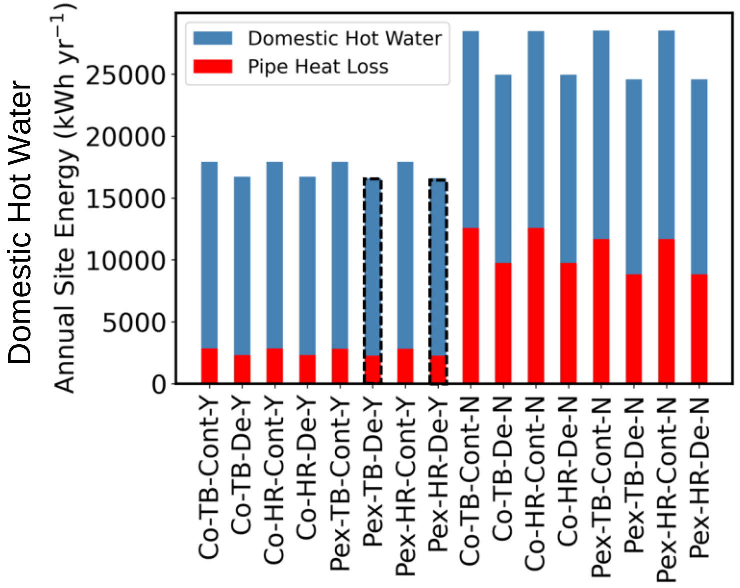
Progress: Quantifying Regional Heating Loads and Losses

Regions: Denver (CO), Los Angeles (CA), Orlando (FL)

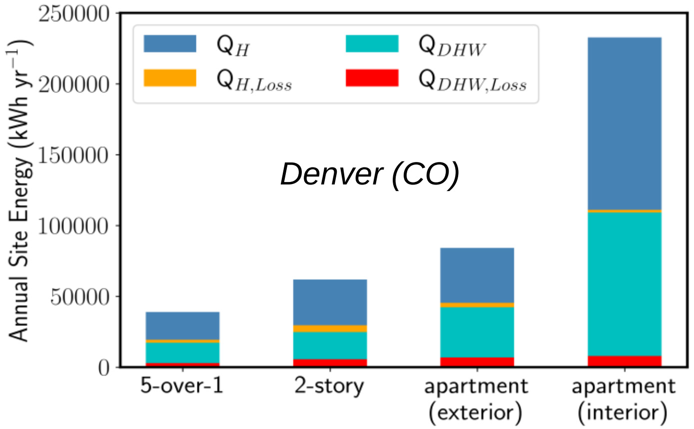


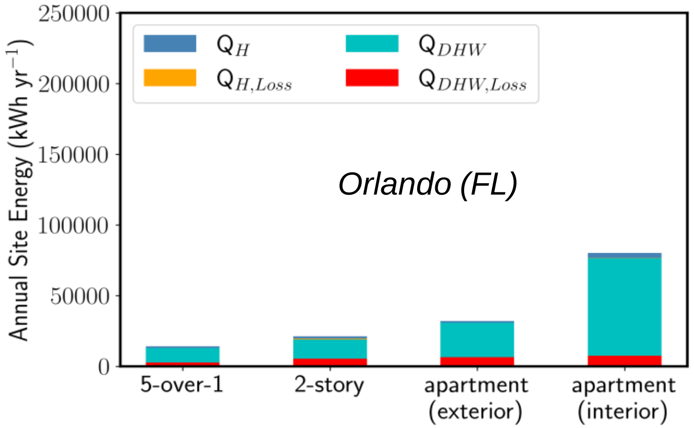
Pipe Material (2) – Pipe Layout (2) – Recirculation Type (2) – Insulation Layer (2)

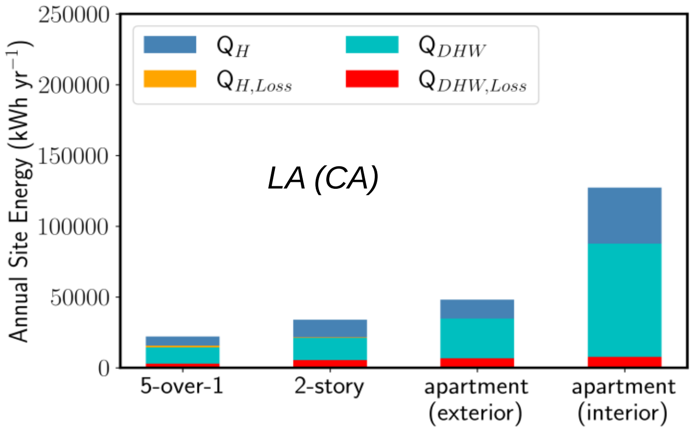
Copper/Pex TB/Homerun Cont'/Demand Yes/No



- DHW and hydronic distribution using continuous control circulation.
- The magnitude of site energy is a function of the size of a building and space heating load.
- Total pipe heat losses account for nearly 5% of the total site energy.







$\boldsymbol{Q_H}$: Site energy associated with hydronic heat delivered

$\boldsymbol{Q_H}$: Site energy associated with DHW

$\boldsymbol{Q_{H,Loss}}$: Site energy associated with hydronic pipe heat losses

$\boldsymbol{Q_{DHW,Loss}}$: Site energy associated with DHW pipe heat losses

FY23 Project Schedule

Q1

Complete preliminary analysis using heat pump thermodynamic model:

- Evaluate three different system architectures able to achieve 180°F water supply temperature.

Q2

Complete hot water distribution modeling:

- Model at least two distribution scenarios for multifamily buildings that quantify heat losses and inefficiencies.

Q3

Complete models capturing cost vs. performance tradeoffs in system design:

- Compare trade-offs of cost and performance for at least two system configurations achieving COP of >2.1 at 5°F.

Q4

Prototype design selection:

- *Select prototype design with model projected cost savings of 20%, water heating efficiency of UEF > 3.5, and COP_H of 2.1 at 5°F.*

Status of Milestone Completion:
- *Completed*
- *Ongoing FY23*

Future Work

- Experimental setup design and construction.
- Prototype development.
- Experimental characterization.
- Design optimization.
- Market assessment.

Thank You

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REFERENCE SLIDES

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	675k				675k				675k			
Spent budget	160k				0k				0k			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Initial thermodynamic modeling												
DHW storage and distributiong modeling												
Current/Future Work												
Costs. vs. performance modeling												
Model projected saving and performance targets												
Stakeholder engagement report												
Fabrication of prototype system												
Preliminary test data on prototype system												
Experimentallay achieve performance target												
Hardware-in-the-loop plan developed												

Team

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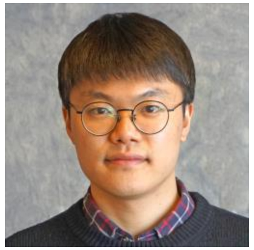
Researcher III, NREL



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