2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

High-Efficiency Cold-Climate Integrated Heat Pump

High-Efficiency Cold-Climate Integrated Heat Pump (CCIHP)

Oak Ridge National Laboratory
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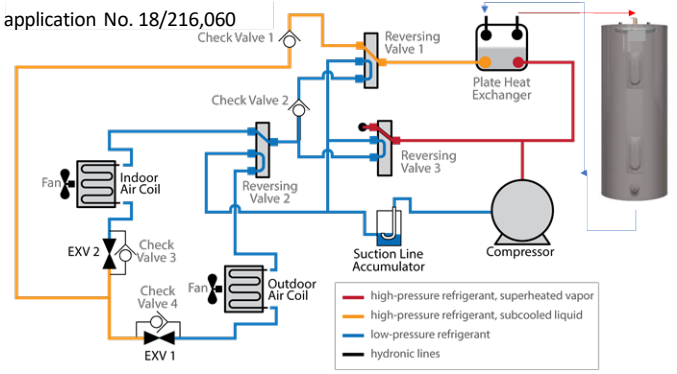
WBS#03.02.02.26.2003; HVAC&WH AOP

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

1. Decarbonize home comfort applications (i.e., space and water heating) via replacing resistance heating and fossil fuel heating
2. Develop a cost-optimized, residential multifunctional heat pump using lower-cost multistage compressors
3. Extend market of heat pumps to cold climates
4. Investigate low-GWP refrigerants in CCHPs
5. Enable hydronic hot water storage for grid-responsive heating

Patent application No. 18/216,060



TEAM & PARTNERS

- Nortek Global HVAC and Rheem: CRADA OEM Partners
- Copeland LP: Compressor
- Syracuse University: Field Test Cold-Climate Integrated Heat Pump (CCIHP)
- ORNL: Bo Shen, Jeff Munk, Jian Sun, Moonis Ally

STATS

Performance Period: 10/2020–09/2024

Budget: DOE, $700k; Nortek, $200k

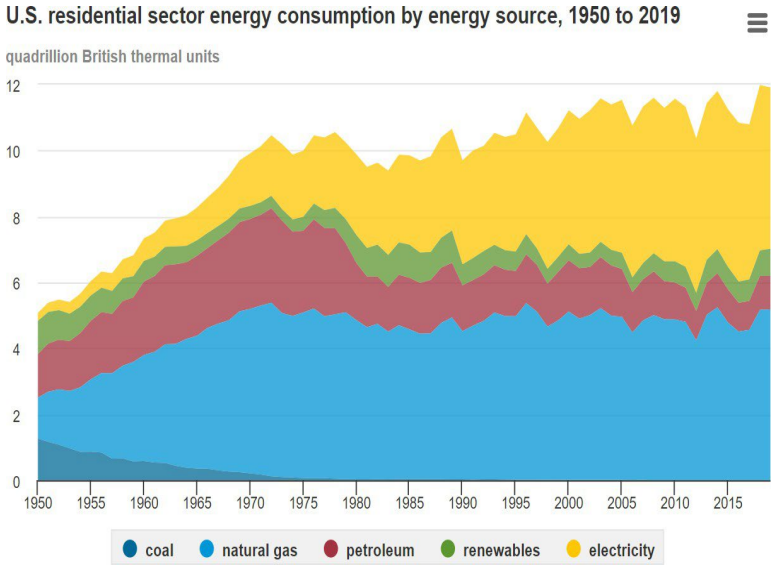
CRADA project completed:

- Final report, “High Efficiency Multifunctional Cold-Climate Integrated Heat Pump,” ORNL/TM-2023/2870

Ongoing activities:

- Completed 1 year field demonstration in Syracuse, NY
- Collaborate to start new field demo with modified Rheem unit and new Copeland multistage compressors

Problems



Reference:
https://www.eia.gov/energyexplained/use-of-energy/homes.php

- E3 (Energy, Emissions and Equity) initiative challenges HPWH and CCHP
- Decarbonization and electrification: heat pumps are most effective means to replace fossil burning; they should deliver the same functionalities with good efficiency and adequate capacity at low ambient temperatures
- Efficiency and capacity: Current heat pumps are inefficient and have inadequate capacity at low ambient temperatures; COP approaches 1.0 in subzero environments
- Low ambient and high supply temperatures cause high compressor discharge temperature and limit operation range
- Unit cost: heat pump must be cost-competitive with other means for heating; a single-set of components provide all home comforts, leading to high performance and lower cost
- Inverter-driven variable-speed compressors are expensive
- Grid-response: if achieving full electrification, peak heating loads will likely dominate soon; integrated heat pumps facilitate hydronic heating and storage
- Current CCHPs all use refrigerants with GWP >750

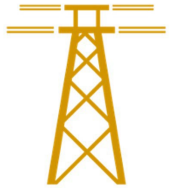
Alignment and Impact

- Energy justice: Complete E3 home comfort package, residential integrated heat pump for US cold climates; achieve the following:
  - SEER >16.0 (versus 14.0 ENERGY STAR)
  - HSPF >11.0 (versus 8.2 ENERGY STAR), HSPF2 (Region V) >8.5
  - Water heating annual efficiency >4.0 (versus electric heater, 1.0)
  - Water heater works to −15°F (versus stand-alone HPWH >40°F)
  - Explore low-cost capacity modulation using three-stage compressor with/without vapor injection
  - Multifunctional heat pumps with capacity modulation and recovering condenser waste heat for water heating proven to save annual energy up to 40%
- Power system decarbonization: Replace resistance/propane heating in near term and replace fossil fuel in long term
- GHG emissions reductions: Investigate R-454B (GWP <500) in CCHPs

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050



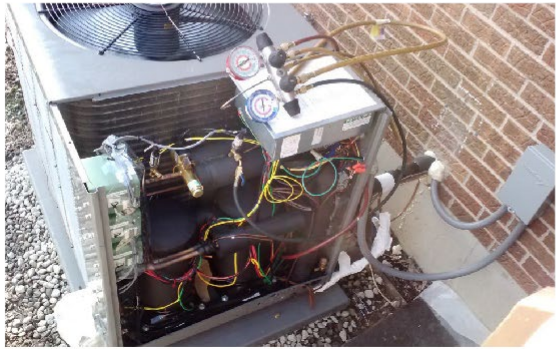
Power system decarbonization

100% carbon pollution-free electricity by 2035

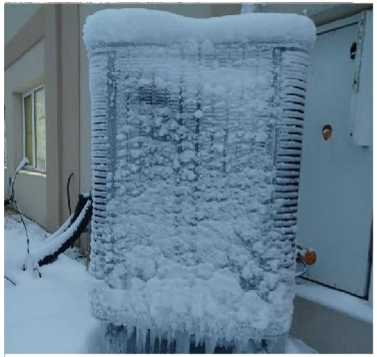
Energy justice

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

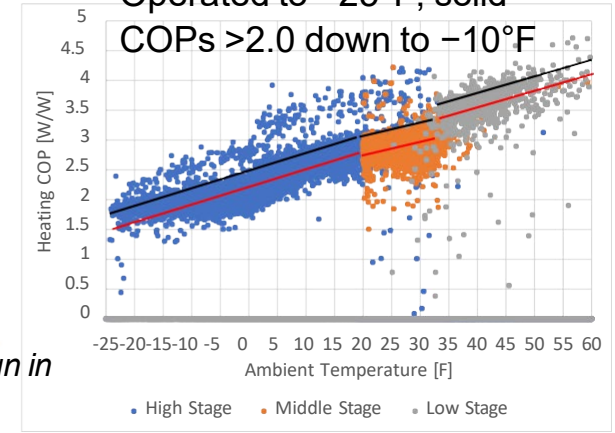
Approach: Legacy of ORNL's cold climate heat pumps and integrated heat pump development



Dual-compressor design in Ohio



Three-stage design in Fairbanks, Alaska



MAIN POINTS

- Pioneer cold-climate heat pumps and shorten US industry learning curves
- ORNL is developing new heat pumps suitable for cold weather
- Lessons learned from tests in harsh Arctic conditions are being applied

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OUTCOMES

- Develop and deploy three prototypes for field testing in severe Alaskan winters
- 40% energy saving in peak heating months in one field test
- BTO success story, 2014
- US manufacturers are applying technical strategies developed by ORNL 10 years ago

CURRENT DEVELOPMENT

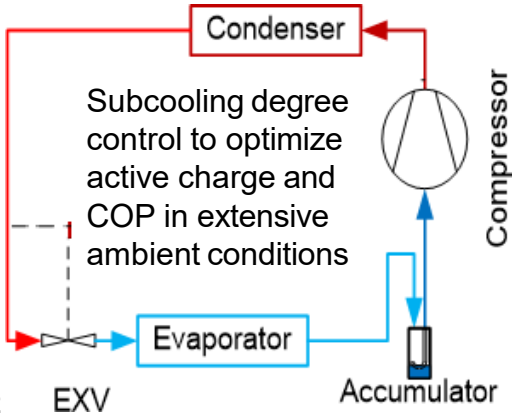
Whole decarb package—cold climate multifunctional heat pump for space cooling, heating, and water heating; seeking commercialization

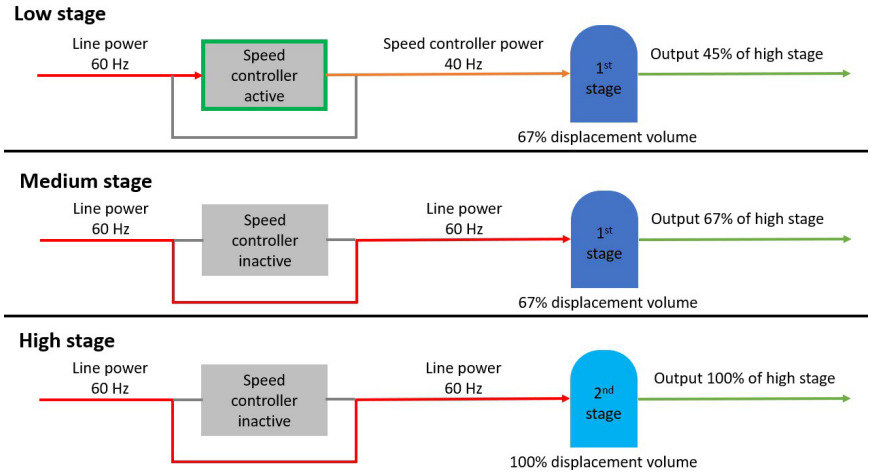
Rheem

Approach: Develop residential triple-capacity heat pump with rated cooling capacity at 3.5-ton/2.5-ton with subcooling degree control

Low-cost capacity modulation (use a low-cost inverter; change driving frequency from 60 HZ to 40 HZ)

- Three-stage scroll compressor (100%, 67%, 45%)—enhanced version of two-stage compressor
- 67% or 45% is used for rated capacity of cooling mode; 100% capacity used for enhanced heating at low ambient temperatures
- Compatible with two-stage thermostat

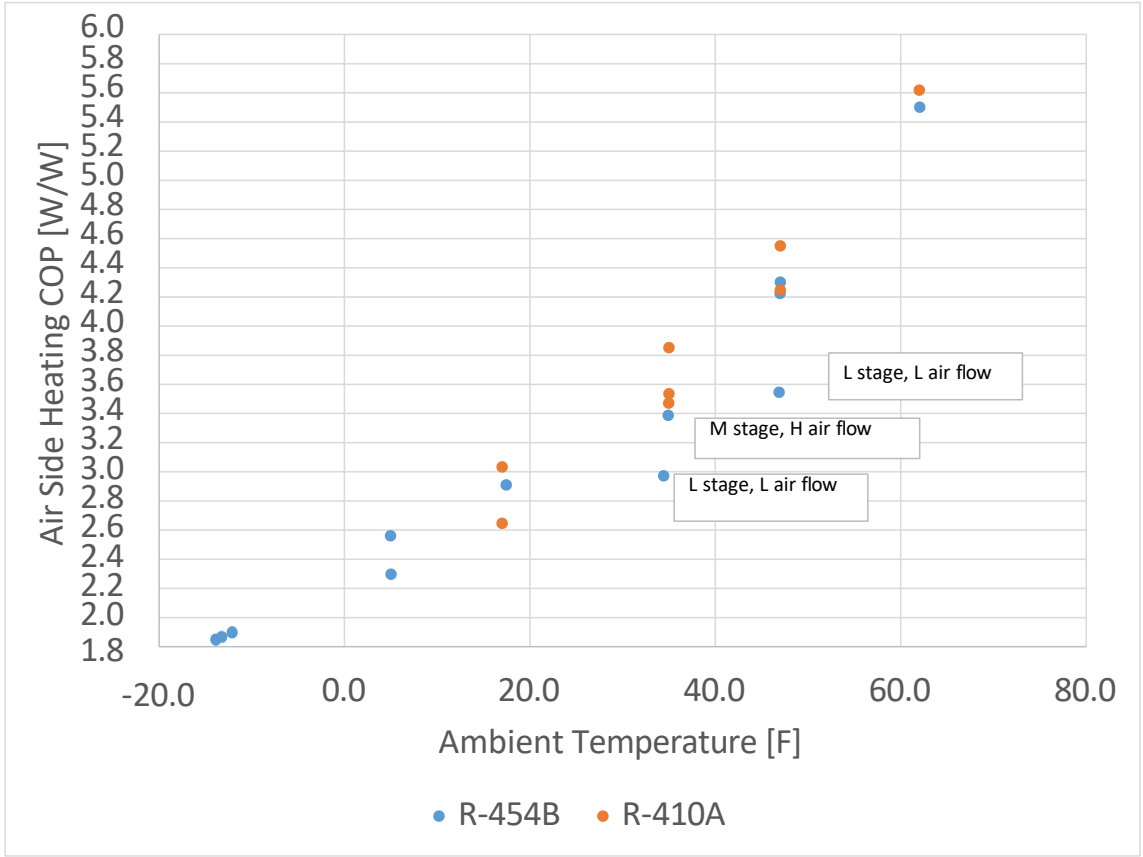




	3.5-ton nominal cooling 2-stage cooling 3-stage heating	2.5-ton nominal cooling 1-stage cooling 3-stage heating
SEER (Btu/Wh)	17.15	16.38
HSPF Region IV (Btu/Wh)	10.97	10.54
HSPF Region V (Btu/Wh)	9.47	8.96
HSPF2 Region IV (Btu/Wh)	10.15	10.29
HSPF2 Region V (Btu/Wh)	8.19	9.03

Low GWP CCHP using R-454B (GWP <450)

- The performance of R-454B is comparable to (slightly lower than) that of R-410A; at 17°F:
  - COP of R-410A is 3.0
  - COP of R-454B is 2.9
- The performance of R-454B at low and middle stages drops faster than that of R-410A with an increasing pressure ratio



Integrated Heat Pump Provides All Home Comfort Needs

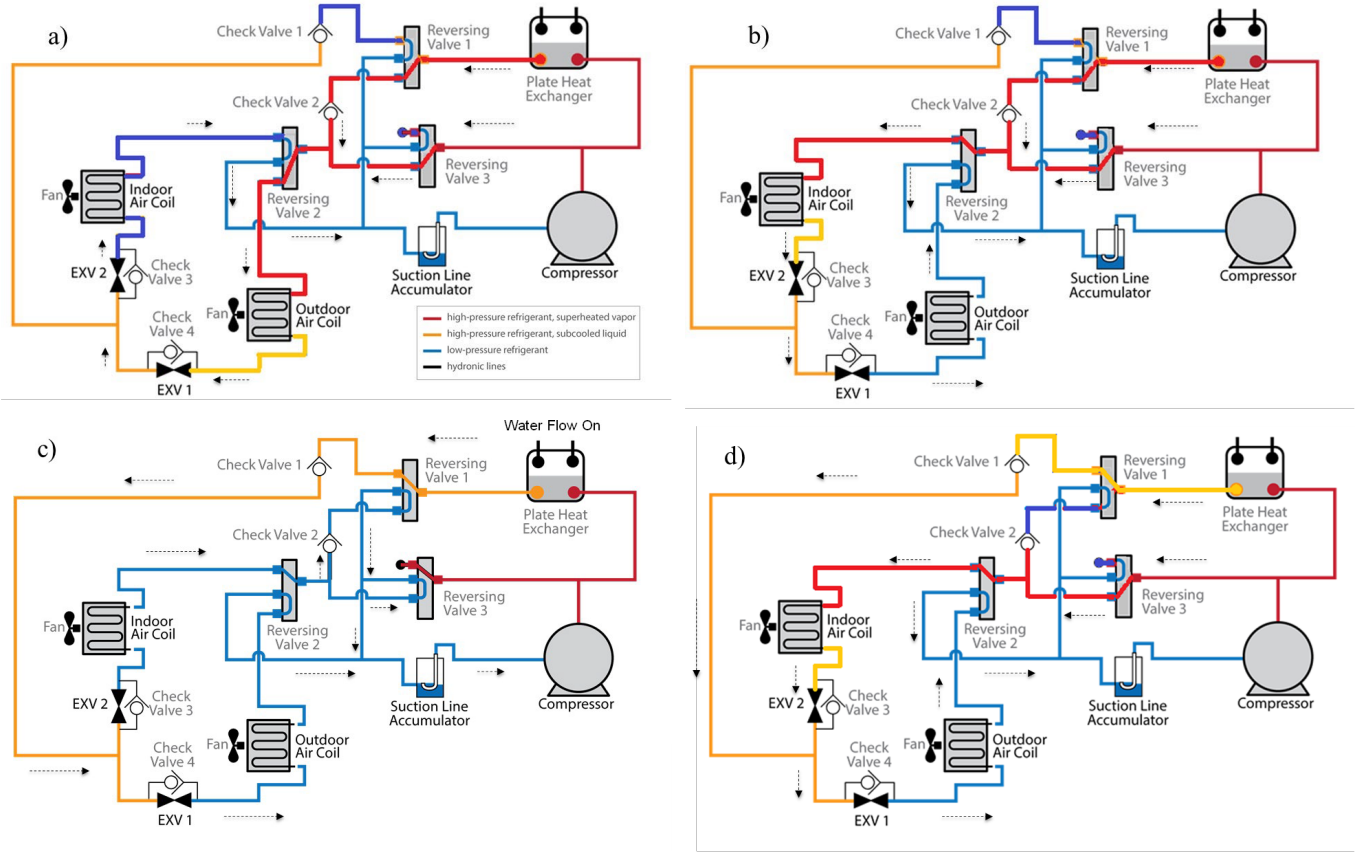
Seven modes

a) Space cooling + combined space cooling/water heating with desuperheating

b) Space heating + combined space heating/water heating with desuperheating

c) Dedicated water heating + combined space cooling/water heating with full condensing

d) Combined space heating and water heating with parallel condensers

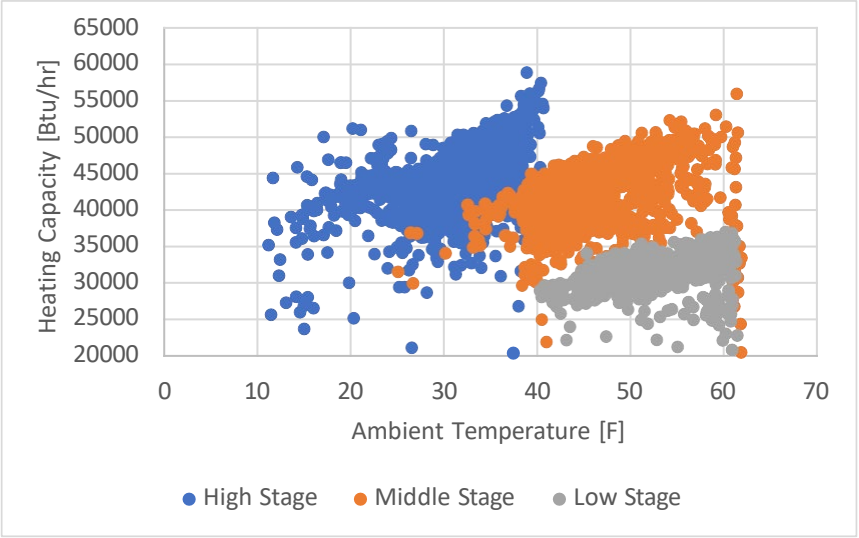


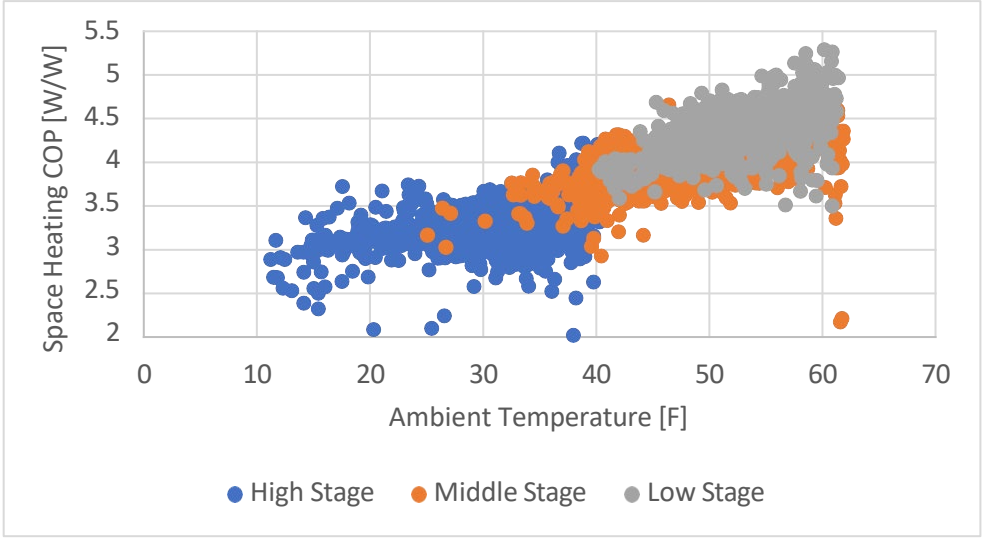
Progress Field demonstration in Syracuse, New York

Compressor box, indoor air handler, and 50 gal water tank; circulation water flow rate measured using a flow meter, 10 min hot water draw, every hour, 24/7; >200 gal hot water use

Outdoor unit containing a fan and a microchannel coil

Progress Space heating performance (hourly average)

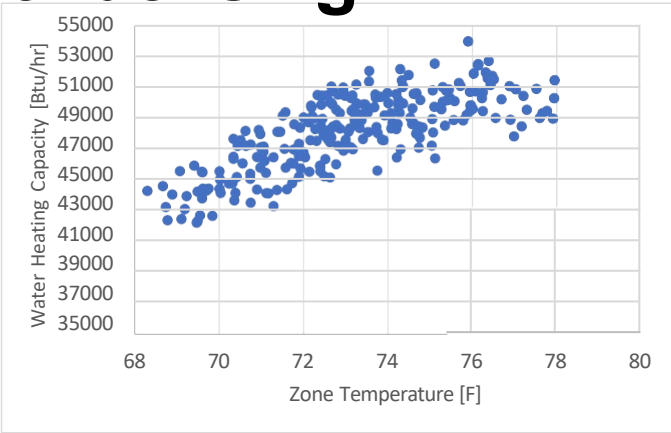


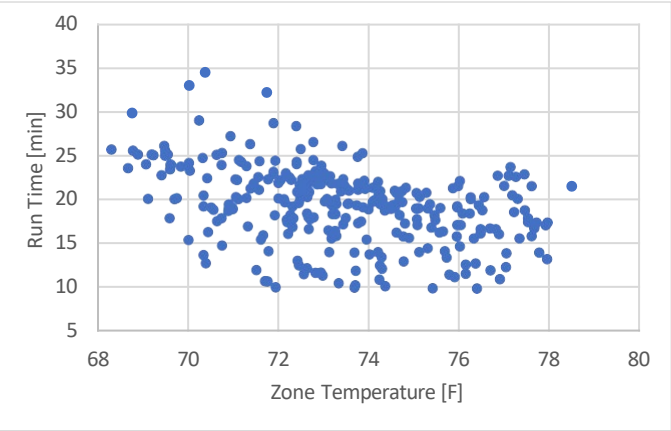


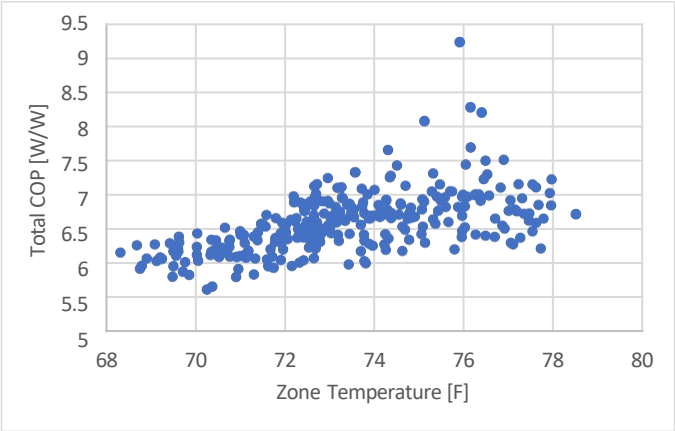
- Each point represents average capacity and COP in each hour when the unit is ON for space heating
- Dispersed points are due to real field conditions (i.e., cyclic, frost formation, raining)
- Ambient temperature down to 10°F in winter 2023 in Syracuse, NY

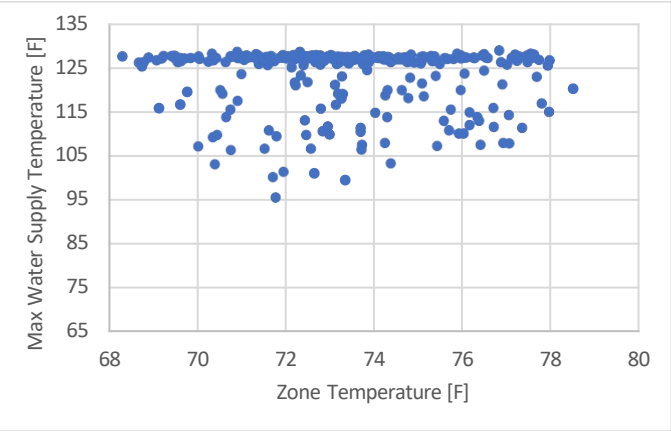
Combined Space Cooling/Water Heating with Full Condensing

- 10 times water heating capacity
- Recovery time within half hour to heat 50 gal tank from 95°F to 125°F@top
- Combined seasonal COP >6.5

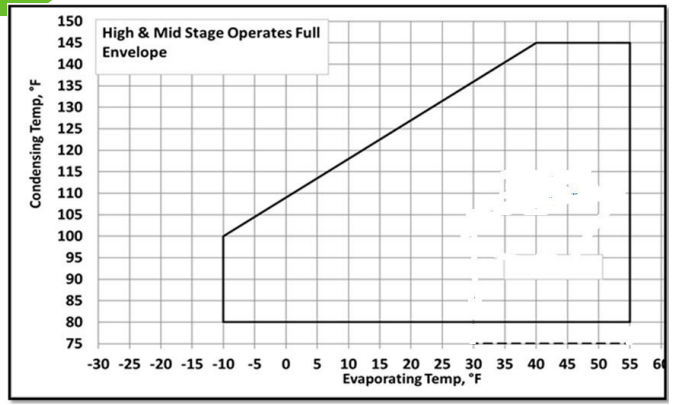


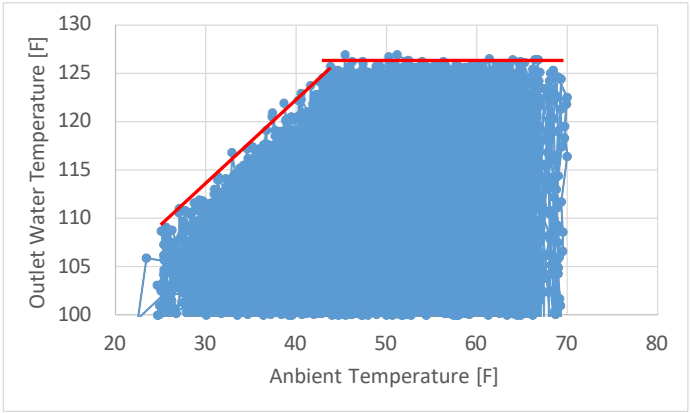


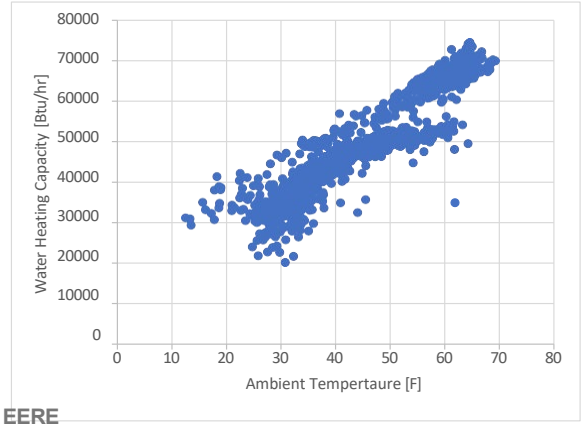


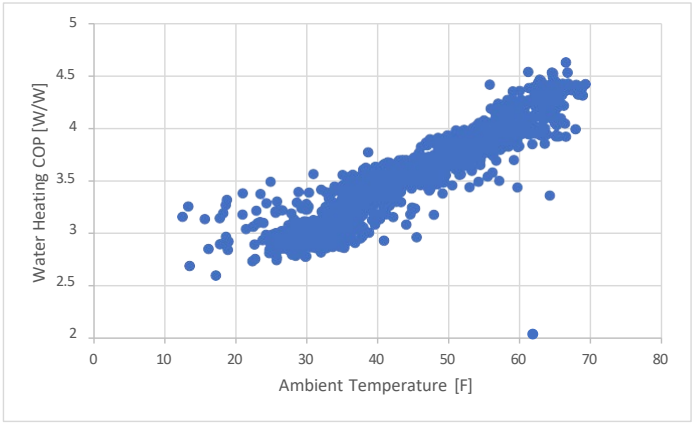


Dedicated Water Heating



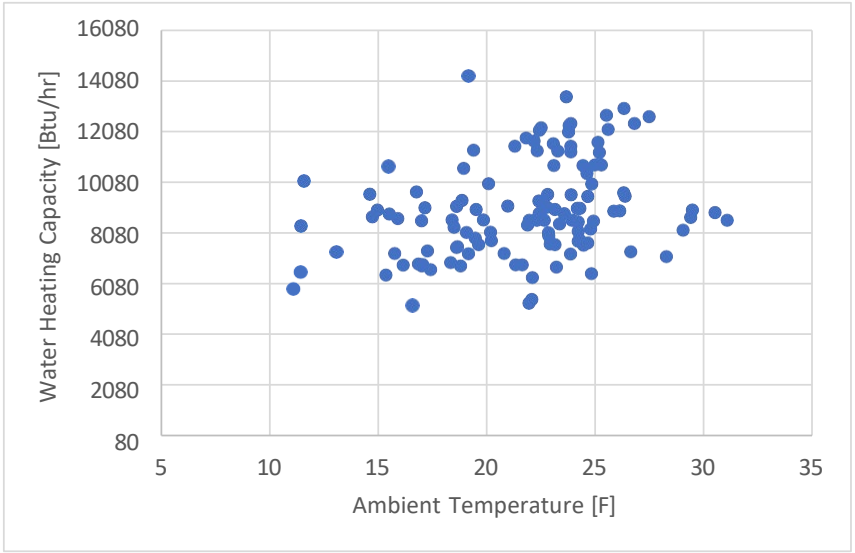




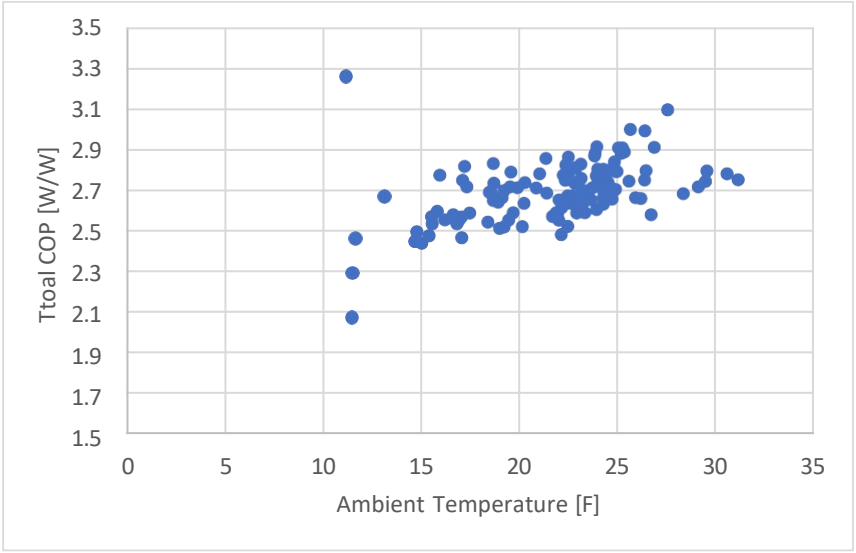


- Field control strictly followed the compressor envelope
- Worked down to 25°F to provide 110°F hot water, >40 K Btu/h
- Worked down to 10°F to provide 80°F hot water >30 K Btu/h, then switched to combined space heating and water heating in desuperheating

Combined Space Heating/Water Heating in Desuperheating



Water heating capacity >6,000 Btu/h to heat water to 140°F



Combined COP lower than that of single space heating COP owing to reduced indoor air flow rate and elevated condensing pressure

Outcomes

- Patent application No. 18/216,060, 2023
- *High Efficiency Multi-Functional Cold Climate Integrated Heat Pump—Final Report NFE-19-07889*, project final report, ORNL/TM-2023/2870
- “Cold Climate Integrated Heat Pump,” Bo Shen, Jeff Munk, Kyle Gluesenkamp, International Refrigeration and Air Conditioning Conference at Purdue, 2022
- “Residential Integrated Heat Pump to Meet All Home Comfort Needs,” ACEEE Summer Study, 2024
- “Development and Field Demonstration of Residential Air Source Integrated Heat Pump Using a Three-Stage Compressor,” *Energy & Buildings*, submitted 08/2024

Future Work and Commercialization Plan

- Cost reduction for cold climate heat pumps
  - Copeland developed a new three-stage scroll compressor, with all mechanical capacity modulation and elimination of the inverter
  - ORNL will conduct system development and field demonstration
- Engage Rheem for commercialization
  - Modify a Rheem heat pump and start a new field demonstration

Thank you

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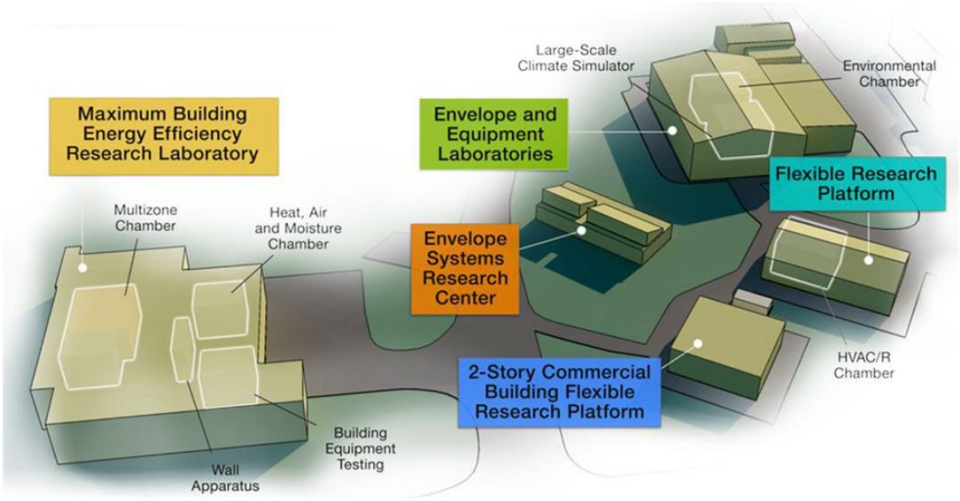
WBS#03.02.02.26.2003; HVAC&WH AOP



The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

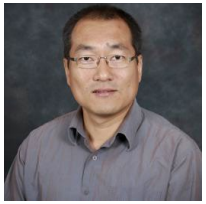
BTRIC is a DOE-Designated National User Facility

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	300K				200K				100K			
Spent budget	300K				200K				100K			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Three-stage cold-climate HP field demonstration							◆					
Integrated HP (IHP) laboratory performance verification		◆										
Develop control and fabricate IHP field test prototype					◆							
IHP field prototype installation and commission						◆						
IHP field test in heating season												
Current/Future Work												
Monitor IHP field cooling performance and complete 1 year field demonstration											◆	
System development and prototyping using three-stage compressor with all mechanical modulation												

- Success in field demonstration in FY24
- Awaiting new three-stage compressor to build a new system prototype

Team Significant Industry Involvement



Dr. Bo Shen
- System design and modeling
- Laboratory testing

Jeff Munk
- Field testing
- Unit control

Dr. Jian Sun
- Dynamic modeling

Dr. Moonis Ally
- Energy efficiency and exergy analysis

COPELAND

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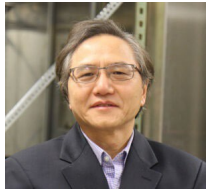
COLD CLIMATE HOUSING RESEARCH CENTER

Syracuse University

Brian Butler
Lead Innovation Technologist
- Coordinating advanced compressor development

Dr. Jie Chen
Senior Director of Engineering Technology
- Lead Nortek team for system development
- Provide all microchannel heat pumps

Robbin Garber-Slaght
Research Engineer
- Host field test of a CCHP in Fairbanks, Alaska



Jianshun Zhang
Associate Professor
- Host field test of a CCIHP in New York State

OAK RIDGE National Laboratory

Stakeholder Engagement Close Collaboration with Industry

- Debut case for the Copeland three-stage compressor (with a low-cost inverter) to the market
- Explore Nortek/Rheem's all microchannel heat pumps in cold climate with reduced charge (40% less); prepare for next-generation low-GWP A2L refrigerants
- CCHRC (NREL) monitored the 2021–2023 CCHP field demonstrations under extreme conditions in Fairbanks, Alaska
- Syracuse University hosted the 2023–2024 CCIHP field demonstration to showcase for New York customers