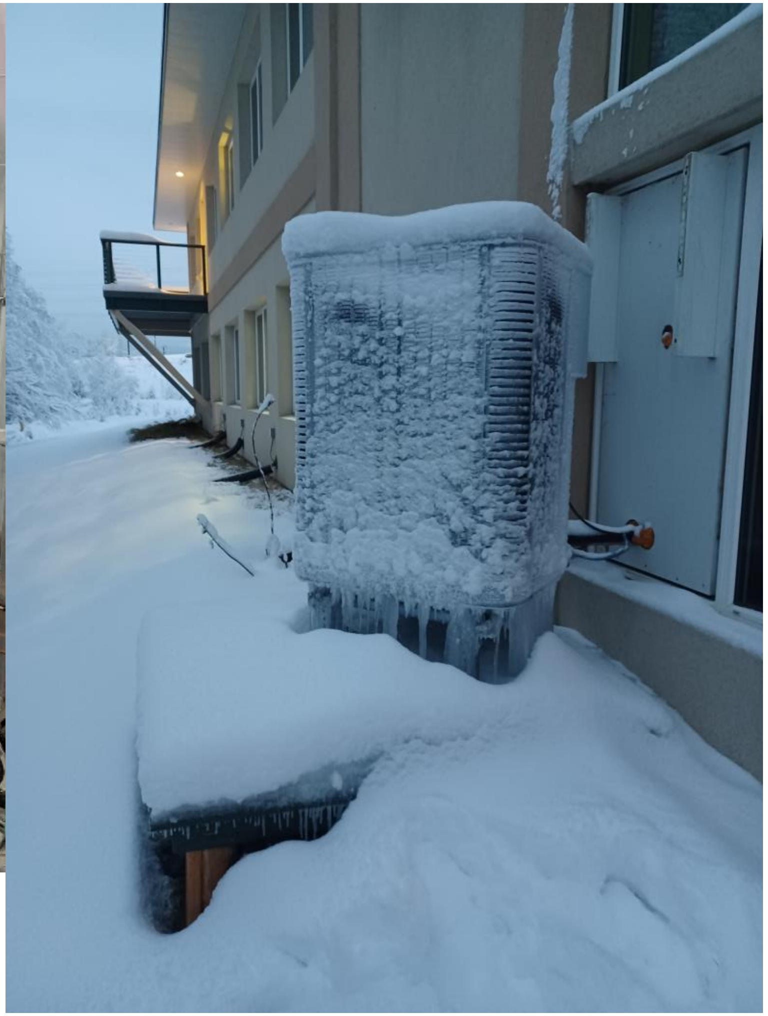
High Efficiency Cold-Climate Integrated Heat Pump (CCIHP)



Oak Ridge National Lab

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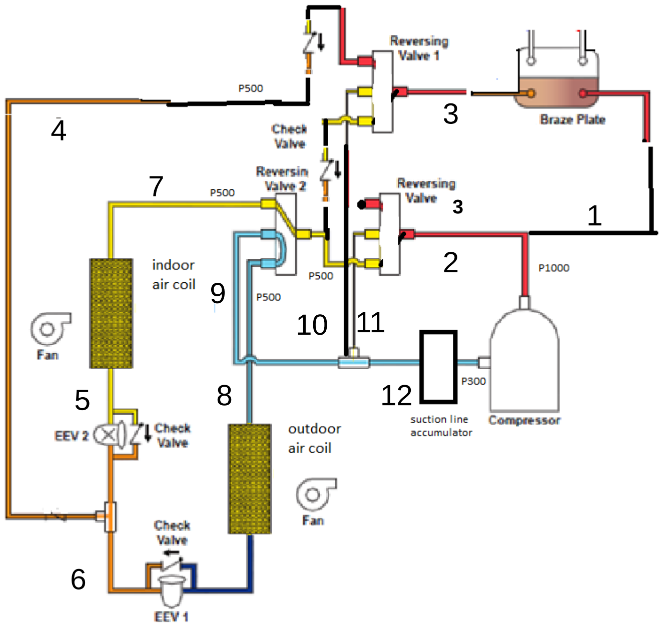
WBS#03.02.02.26.2003; HVAC&WH AOP

Project Summary



Provisional application 63/358,298 filed 05 Jul 2022

Objective and outcome

1. Decarbonize home comfort applications, i.e. space heating and water heating, via replacing resistance heating and fossil fuel heating.
2. Develop a cost-optimized, residential multi-functional heat pump using a multi-stage compressor.
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.

Team and Partners

- Nortek Global HVAC – CRADA OEM Partner
- Emerson Commercial and Residential Solutions - Compressor
- NREL – Cold climate Housing Research Center in Fairbanks, AK – Field Test Cold Climate Heat Pump (CCHP)
- Syracuse university – Field Test Cold Climate Integrated Heat Pump (CCIHP)

Stats

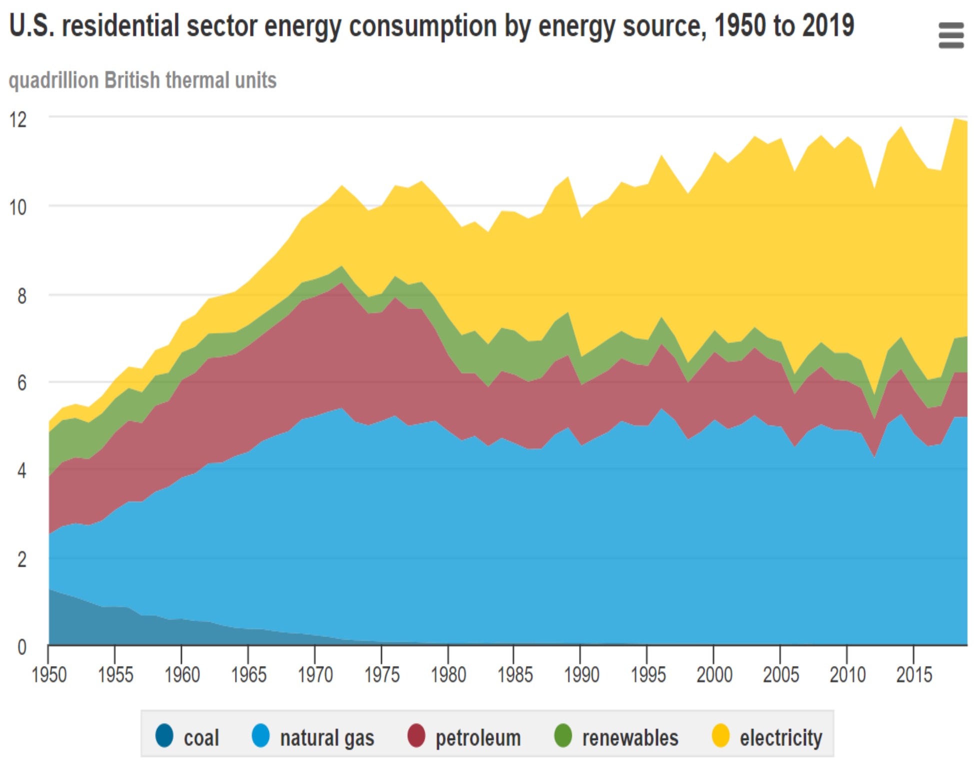
Performance Period: 10/2020 – 09/2023

Budget: DOE – $700K; Nortek - $200K

Key milestones

1. Verify space cooling/heating performances in laboratory and field tests – 01/2021
2. Integrate water heating function – 09/2021
3. Verify the CCHP performance using R-454B – 06/2022
4. Install a field test unit with full space cooling/heating/water heating functions – 04/2023
5. Developed cost-reduced CCHP using two-stage vapor injection compressor – 09/2023

Problems



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

- <u>E3 (Energy, Emissions and Equity) initiative challenges HPWH and CCHP.</u>
- <u>Decarbonization and Electrification</u>: heat pumps are the most effective means to replace fossil burning. It 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 working at low ambient temperatures, COP approaches 1.0 at sub-zero environments.
- Low ambient temperature and high supply temperature causes high compressor discharge temperature and limits its operation range.
- Unit cost: heat pump must be cost-competitive with other means for heating. <u>A single-set of components provide all the home comforts, leading to high performance and lower cost.</u>
- Grid-response: if achieving full electrification, peak heating loads will likely dominate in the near future. Integrated heat pumps facilitate hydronic heating and storage.
- Current CCHPs all use refrigerants having GWP > 750

Alignment and Impact

- <u>Energy Justice:</u> **Complete E3 Home Comfort Package: residential integrated heat pump for US cold climates, achieve**

  →SEER > 16.0 (versus 14.0 EnergyStar)

  →HSPF > 11.0 (versus 8.2 ENERGY STAR) , HSPF2 (Region V) > 8.5

  →water heating annual efficiency > 4.0 (versus electric heater, 1.0)

  →WH works down to -15˚F (versus stand-alone HPWH > 40° F)

  →Explore low-cost capacity modulation using a 3-stage compressor.

  →Multi-functional heat pumps with capacity modulation and recovering condenser waste heat for water heating were proven to save annual energy up to 40%

- **<u>Power system decarbonization:</u> Replace resistance/propane heating in near term and replace fossil fuel in long term.**
- **Greenhouse Gas 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

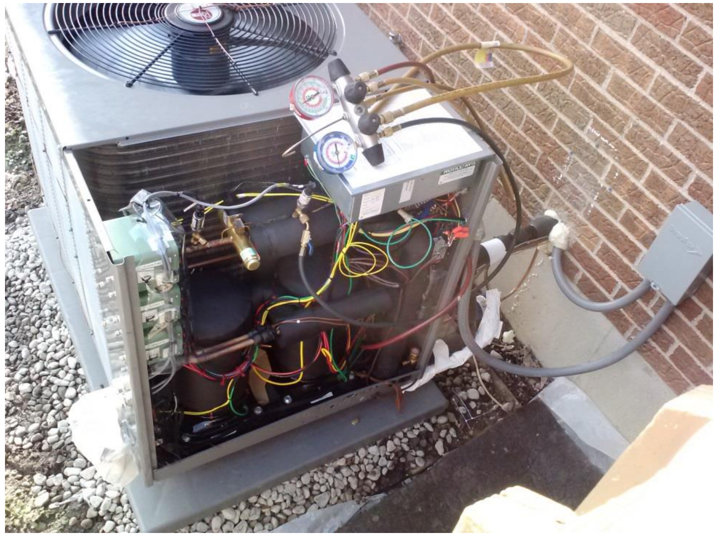
100% carbon pollution-free electricity by 2035

Energy justice

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

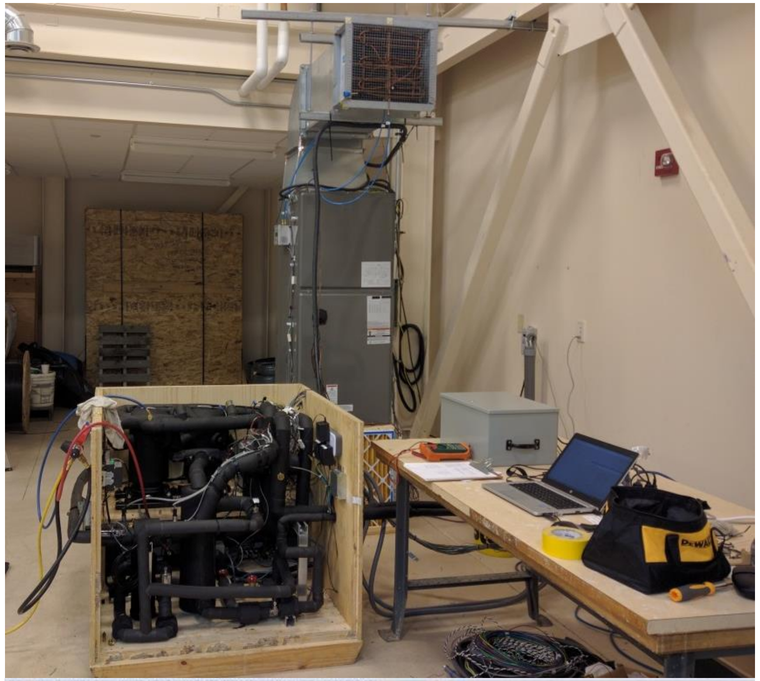
Approach: Built upon past projects in CCHP (BTO and ORNL have been persistently advancing CCHP and IHP technology)

CCHP



Field testing in Ohio using a pair of single-speed compressors;
Achieved 75% rated capacity down to -13˚F;
40% energy bill reduction in a peak heating month

- Prior prototypes used parallel compressors
- New development uses 3-stage compressor

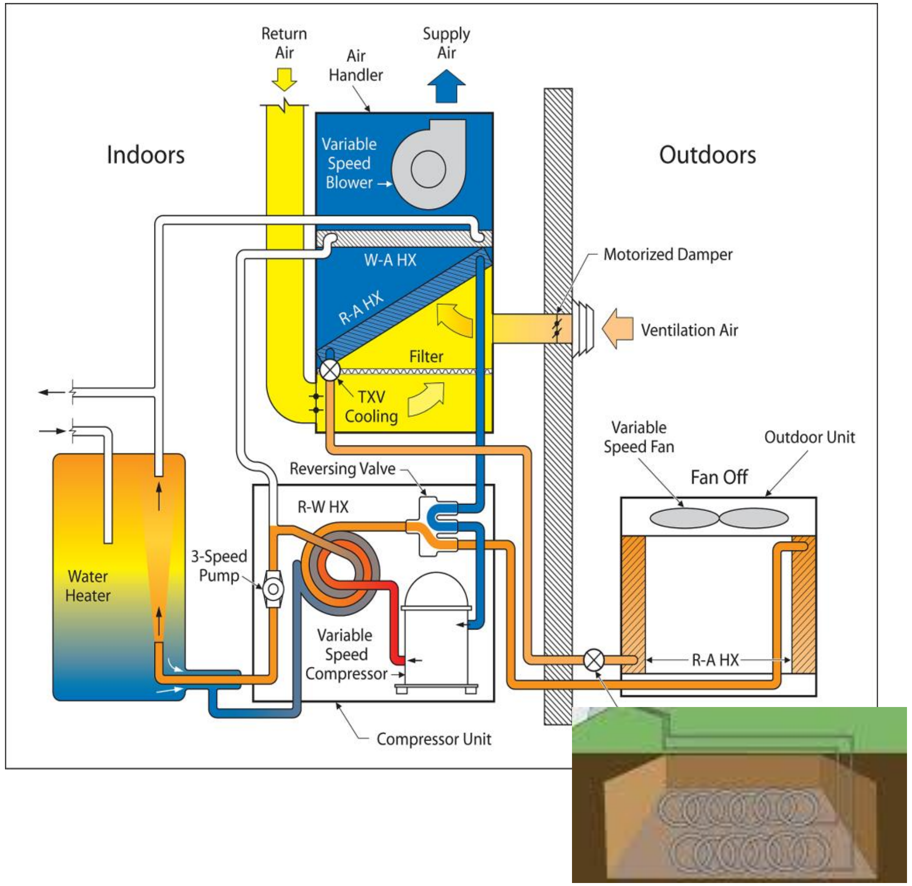


Field testing in Alaska, using a pair of vapor-injection compressors

- Work in most extensive and extreme ambient range, from -30 ˚F to 60 ˚F
- >1.6 COP at -30 ˚F.

ORNL delivers R&D success!

Approach: Built upon past success in integrated heat pumps



Integrated heat pumps recover condenser waste heat for domestic hot water.

NORTEK GLOBAL HVAC — Air-source

CLIMATEMASTER — Ground-source

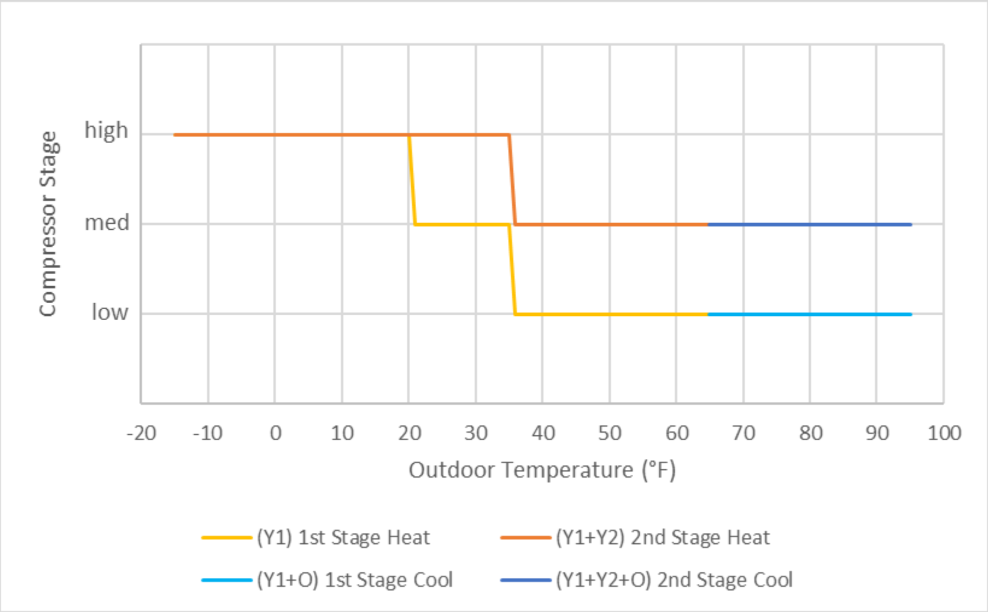
Climatemaster trilogy ground source integrated heat pump won an R&D 100 award.

ORNL delivers R&D success!

Approach - Develop a residential triple-capacity heat pump having a rated cooling capacity at 3.5-ton/2.5-ton

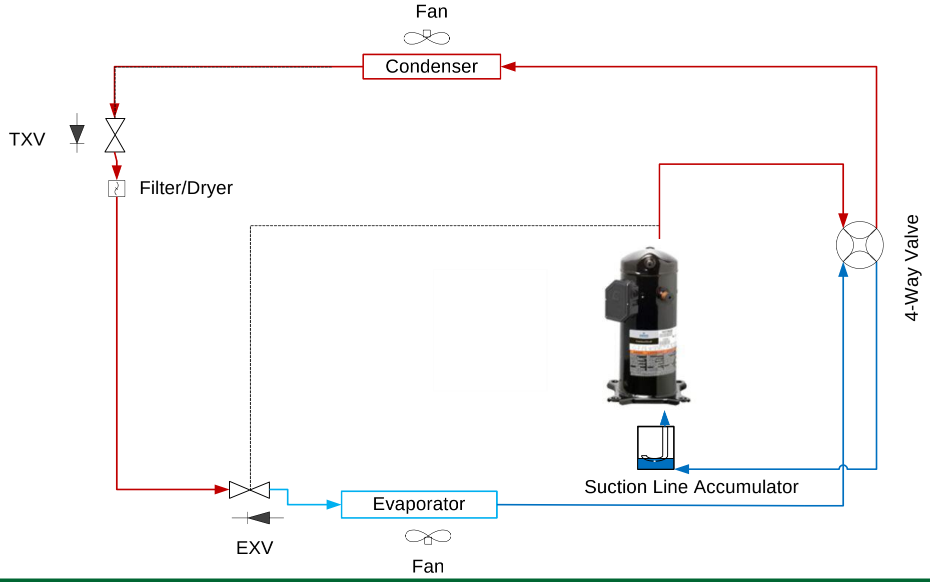
Low-Cost Capacity Modulation (use a low-cost inverter, only change driving frequency from 60 HZ to 40 HZ)

- 3-stage scroll compressor (100%/67%/45%) – an enhanced version of 2-stage UltraTech Compressor
- 67% or 45% is used for rated capacity of cooling mode, 100% capacity for enhanced heating at low ambient temperatures.
- Compatible with 2-stage thermostat



Electric expansion valve coupled with suction-line accumulator for head pressure control

- Optimize active system charge in a wide-range of ambient temperatures
- Mitigate compressor discharge temperature, and enlarge the compressor working range



Approach – Integrated Heat Pump Provides All the Home Comfort Needs.

Innovative system configuration and control enable seamless mode transition and optimize charge allocation among numerous operation modes

New Configuration solved issues of prior air-source integrated heat pumps

Prior

- Charge migration operation is needed
- Dedicated water heating (use outdoor air) can't work at low ambient temperatures
- Extra water heating components may degrade main space cooling/ heating performance

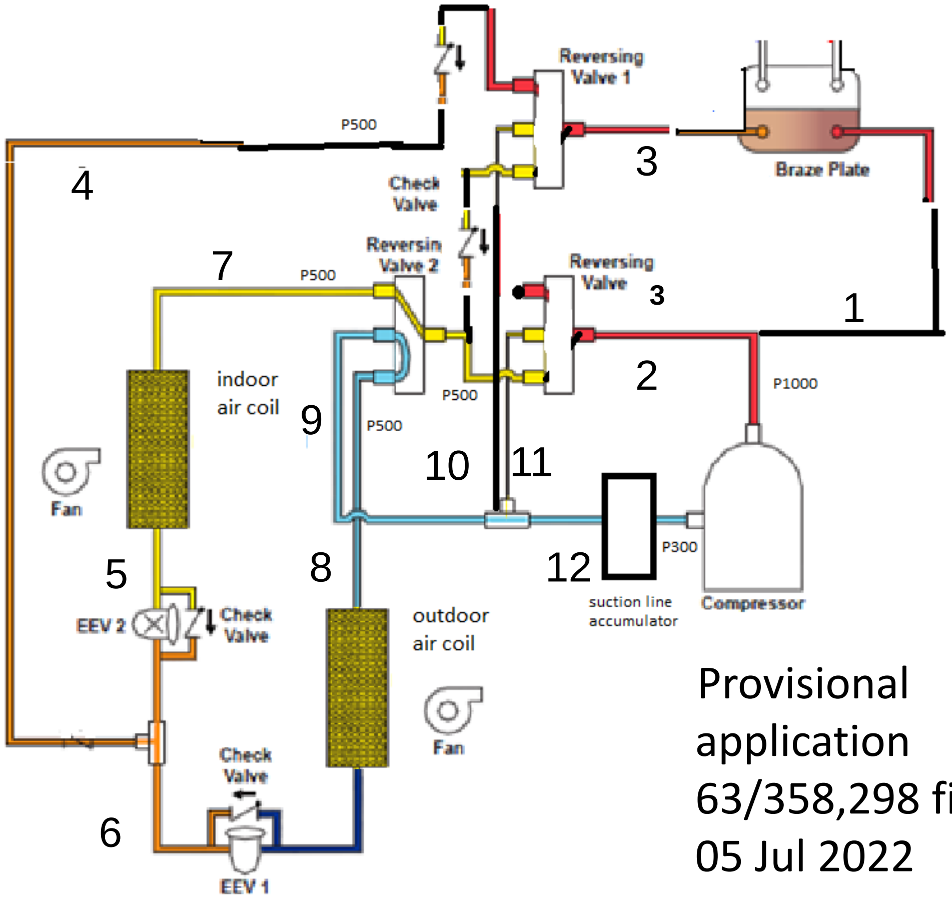
New

→Mode transition within 1 minutes

→Proven to work down to 17˚F, and can go lower

→No extra flow resistance caused by the new components; charge allocations are automatically optimized in each mode.

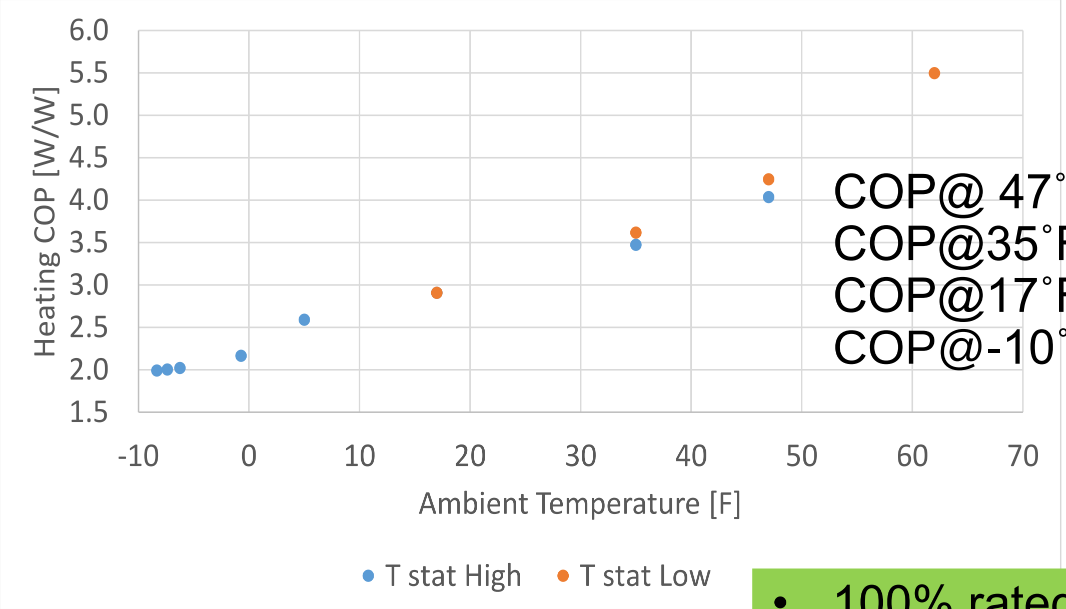
→desuperheating mode heats hot water down to -20 ˚ F



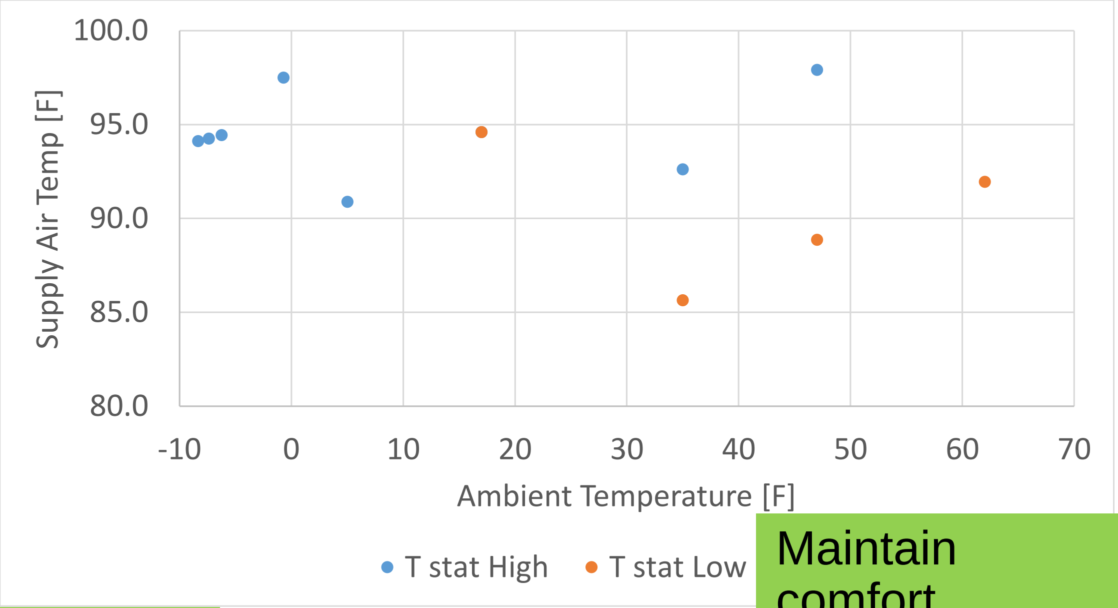
Provisional application 63/358,298 filed 05 Jul 2022

<u>Seven</u> working modes to satisfy good energy efficiency and comfort simultaneously

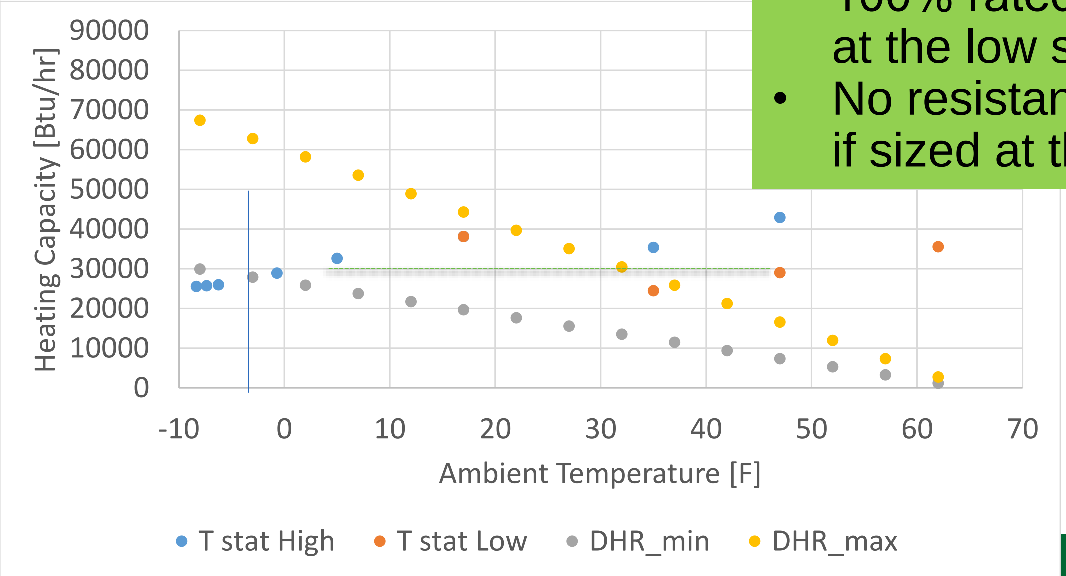
Progress – Laboratory Prototype using R-410A



COP@ 47˚F > 4.0
COP@35˚F > 3.5
COP@17˚F > 2.9
COP@-10˚F >=2.0



Maintain comfort temperature > 93˚F down to -10˚F



- 100% rated capacity@5˚F if sized at the low stage
- No resistance heat needed > -5˚F if sized at the middle stage

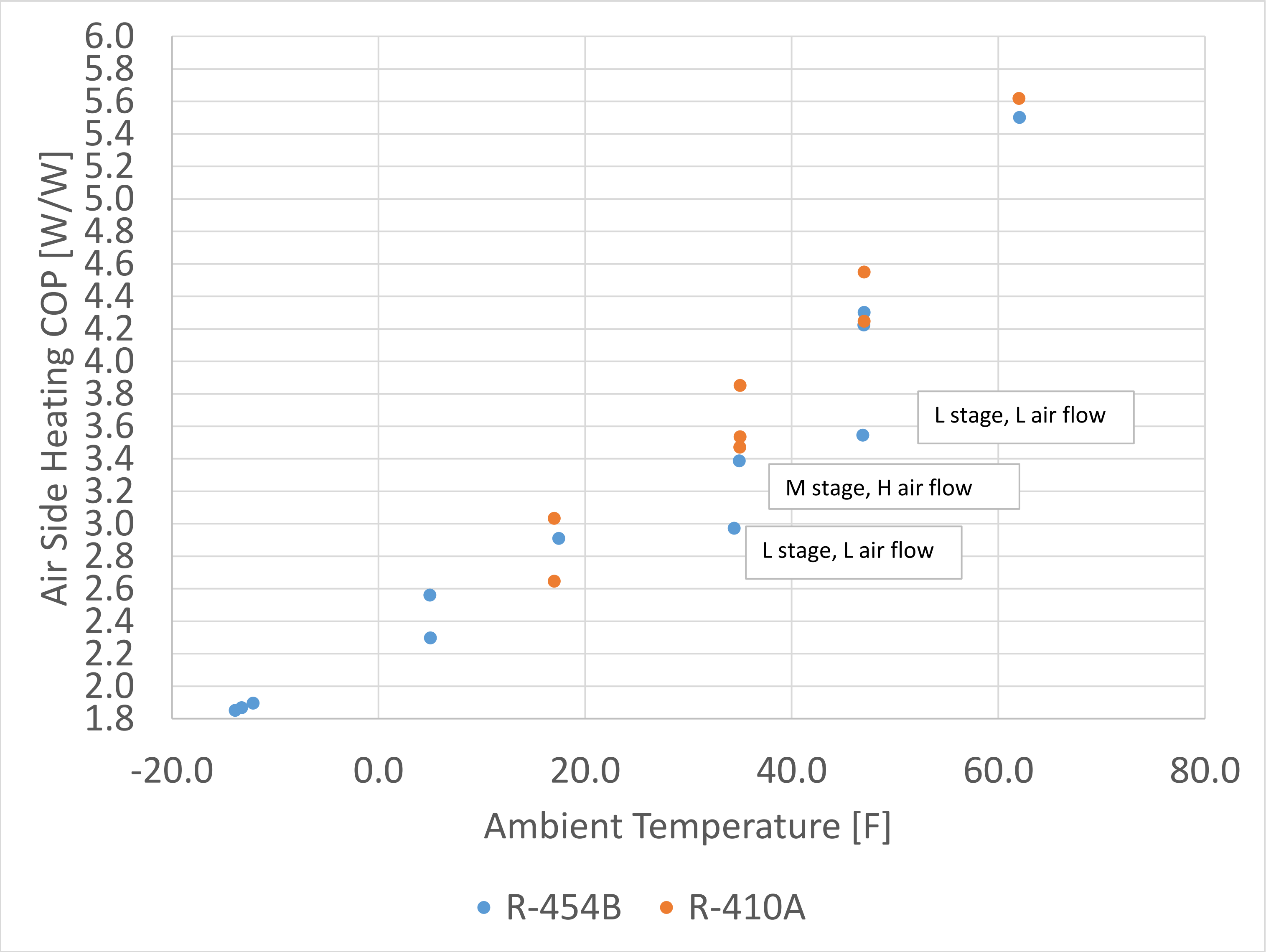
*DHR_min represents well-insulated buildings.
*DHR_max represents poorly-insulated buildings.

Heating Seasonal Performance Factors @ Different Sizing Options

	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

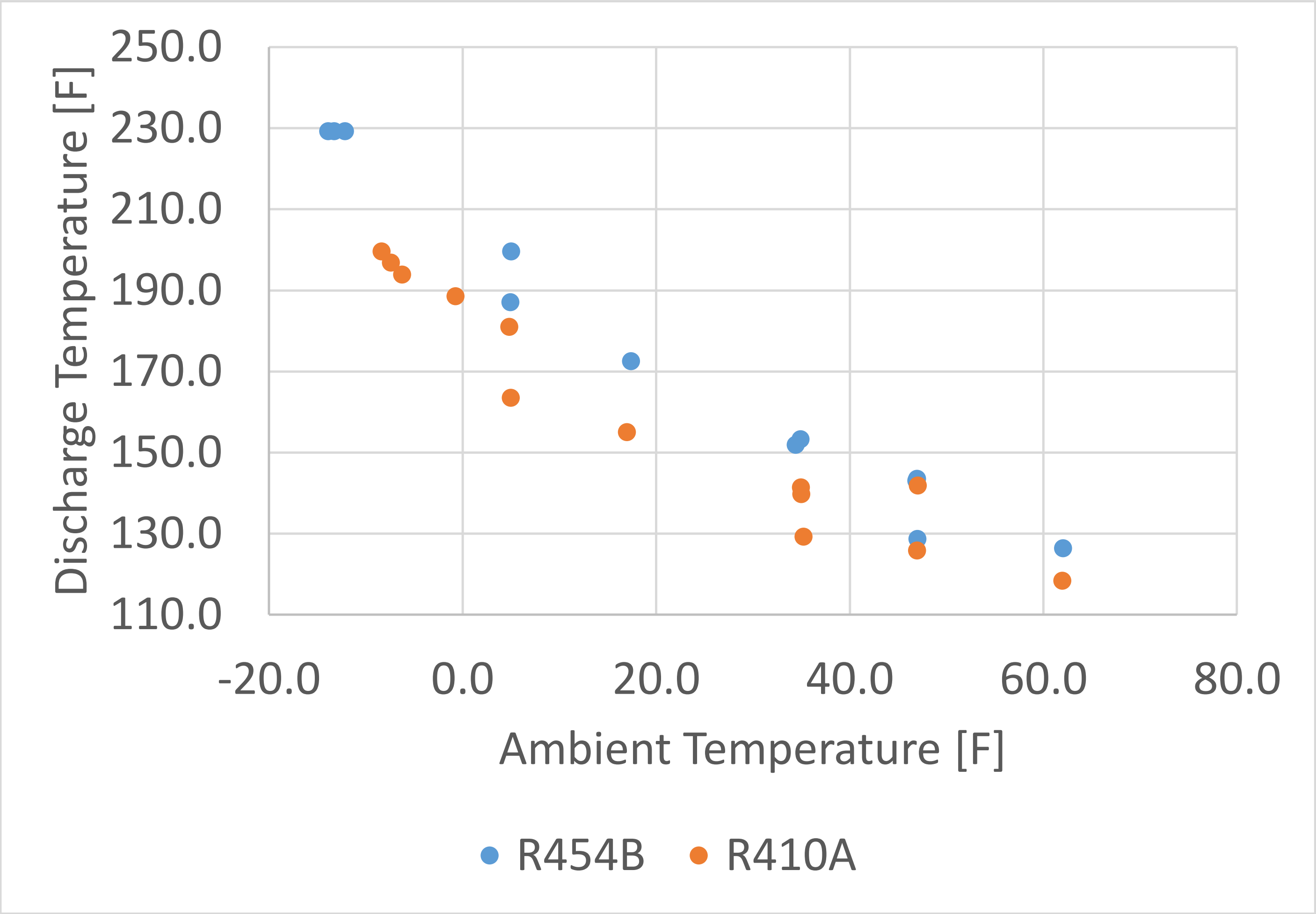
Met the DOE CCHP Challenge if sized for 2.5-ton cooling rated capacity at the lowest stage (1-stage cooling, 3-stage heating)

Progress – Low GWP CCHP using R-454B



- Comparable to R-410A performances (slightly lower, e.g., COP of R410A is 3.0@17 ˚F, COP of R454B is 2.9.
- The performance of R-454B at low and middle stages drop faster than R410A with increasing the pressure ratio.

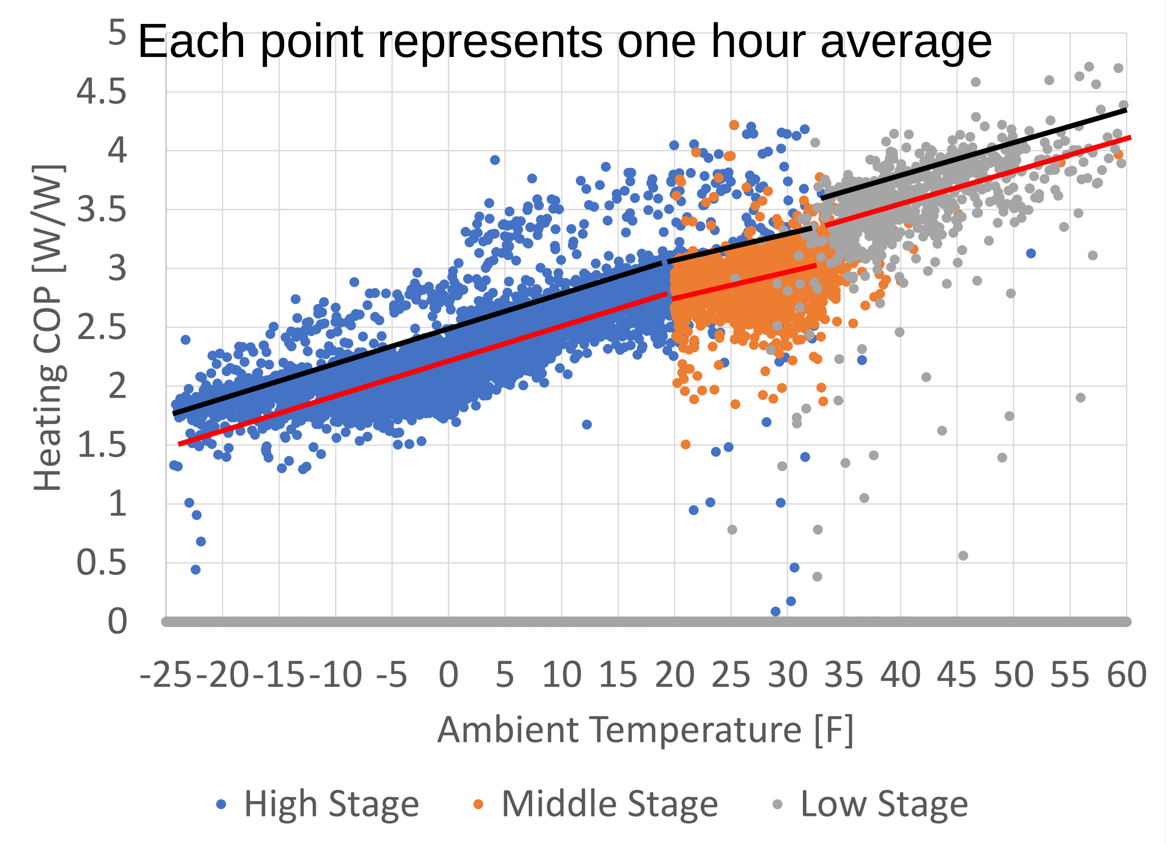
Progress – CCHP using R-454B



Question answered: discharge temperature of R-454B is 20R higher than R-410A, however, it can operate down to -15˚F if using EXV coupled with suction line accumulator for subcooling degree control

Progress

- Field trial in Fairbanks Alaska, collaborating with CCHRC (NREL), started in 2021 winter and operated well until 03/2023



Solid COPs > 2.0 down to -10˚F.

Field unit

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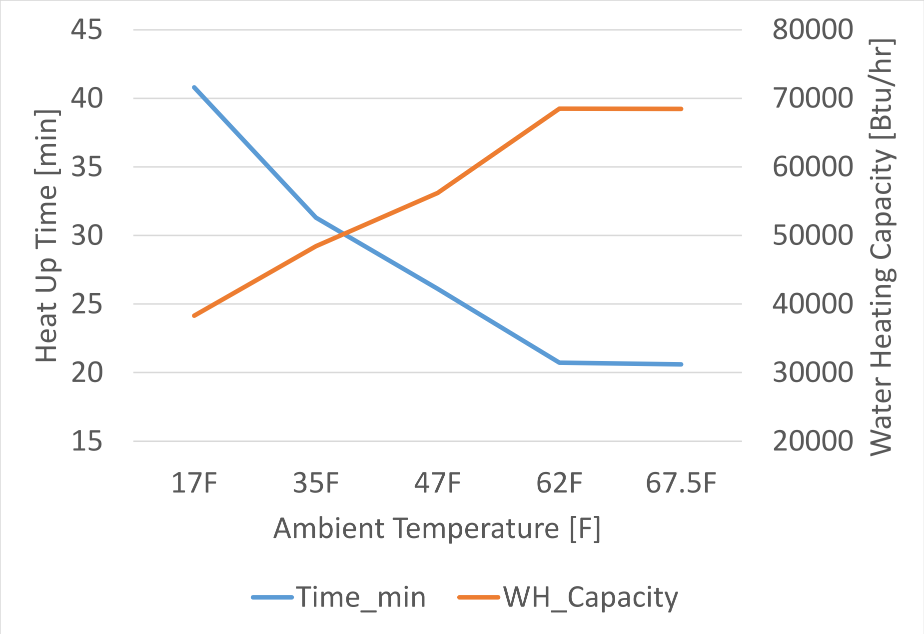
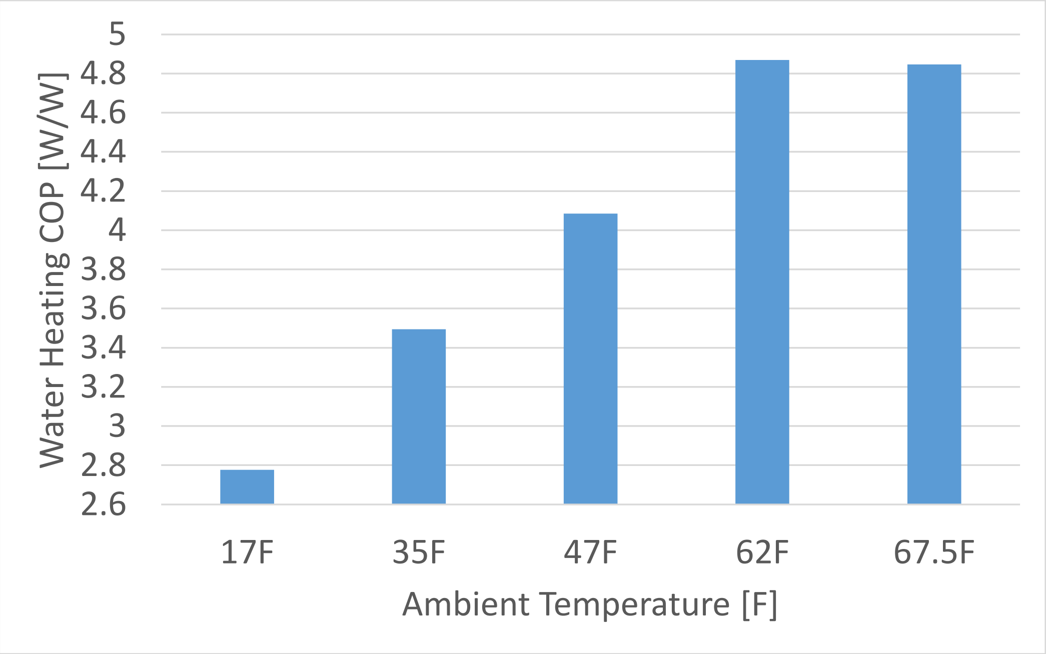
Progress – Outstanding water heating performance

Heat a 50-gallon tank of water from 58˚F to 125˚F

- Combined space cooling and water heating mode reached a total energy efficiency of **35.0 EER**, (cooling capacity + water heating capacity) / compressor and indoor blower. Took only 25 minutes heated to 125˚F.

- Fast and efficient dedicated water heating mode



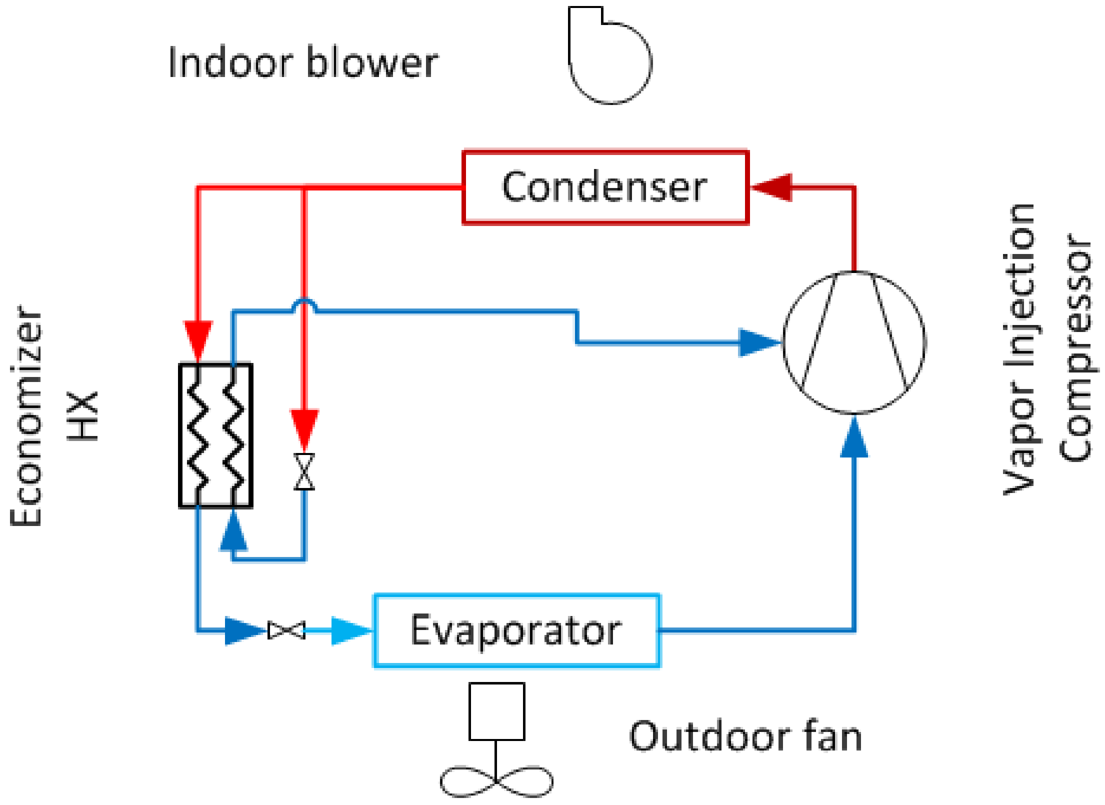


- Tankless HPWH: The CCIHP can heat 1.7 GPM water (max water draw for the medium draw UEF rating procedure) from 58 to 125˚F in a direct flow-through, when the ambient temperature is above 47˚F→**10 times faster than stand-alone HPWHs (4000 kBtu/hr)**

Future Work

Continue CCIHP field trial in Syracuse, NY in 2023 – March 2024

Further cost reduction - working with Emerson to explore two-stage vapor injection (EVI) compressors in CCHPs versus expensive variable-speed heat pumps



Two-stage EVI provides three capacity levels and eliminates inverter:
1st Low stage wo EVI; 2nd High stage wo EVI;
3rd High stage w EVI

EVI compressor has higher efficiency and lower discharge temperature at low ambient temperatures, and thus, can be coupled with reduced size heat exchangers to achieve the same efficiency of CCHPs using variable-speed compressor wo EVI and oversized heat exchangers.

Outcomes

- Provisional patent application 63/358,298 filed 05 Jul 2022
- “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
- Presentation: “Compressor Sizing and Modulation Strategies for Residential Cold Climate Heat Pumps”, 2023 ASHRAE Winter Conference

Thank you

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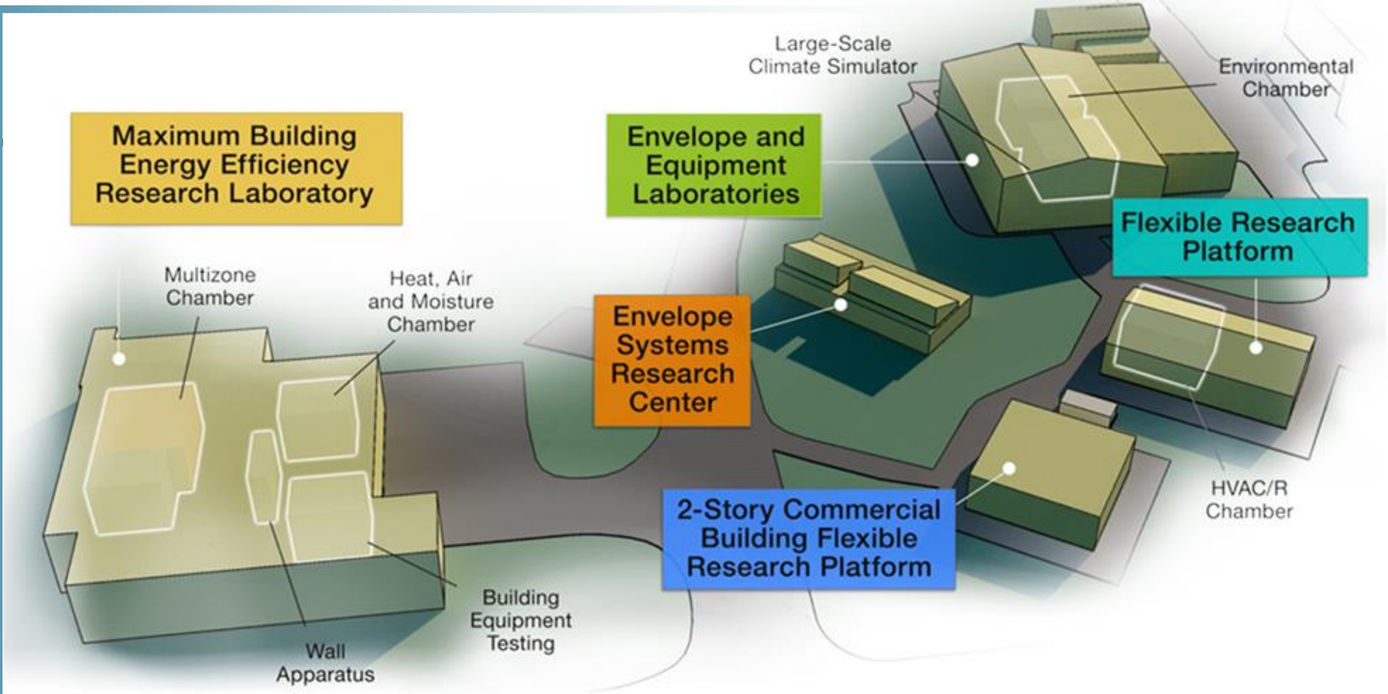


ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

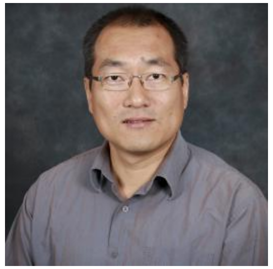
Scientific and Economic Results
238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

Stakeholder Engagement – Close Collaboration with Industry

- Debut case for the Emerson 3-stage compressor to the market.
- Explore Nortek's all microchannel heat pumps in cold climate with reduced charge (40% less), and prepare for next generation low GWP, A2L refrigerants.
- CCHRC (NREL) monitors the CCHP field demonstrations from 2021 to 2023 under the extreme conditions of Fairbanks, AK.
- Syracuse University will monitor the CCIHP field demonstration in 2023 to show case for New York customers.

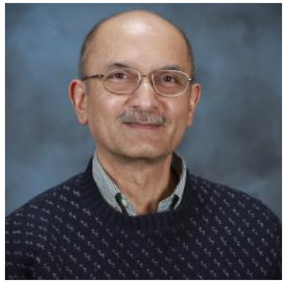
Team – Heavy industry involvement



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

Jeff Munk
- Field testing
- Unit control

Dr. Jian Sun
- Dynamic modelling



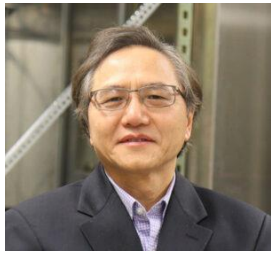
Dr. Moonis Ally
- Energy efficiency and exergy analysis

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

Milestones in FY23

Milestone Name For Sub-Projects - Input PI initials (i.e. VB_short name_milestone name)	Milestone type (internal) Select for a CRADA, AOP, TDM reporting)	Milestone Description	Original Planned End Date	Milestone Type Select from dropdown menu
BS_designCCHPw2stageVI	AOP	design a cold climate heat pump using two-stage vapor injection compressor and procure all the parts	1/30/2022	Quarterly Progress Measure (Regular)
BS_InstallCCIHPprototype	AOP	Install the cold climate integrated heat pump and start field test	3/30/2023	Quarterly Progress Measure (Regular)
BS_labverification	AOP	build a laboratory heat pump using a two-stage vapor injection compressor, meeting the CCHP challenge	9/30/2023	Quarterly Progress Measure (Regular)

REFERENCE SLIDES

Project Budget

Project Budget: $680K (DOE)
Variances: NONE
Cost to Date: $680K
Additional Funding: $200K for FY23

Budget History							
FY 2020		FY 2021		FY 2022		FY 2023	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$340K	$340	$170K	$170K	$170K	$170K	$200K	$200K