Reconfigure System Architecture for Low GWP Refrigerants

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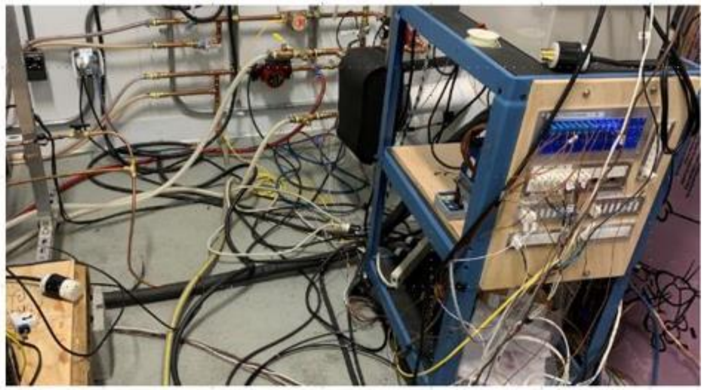
Project Summary

Objective and outcome

- Develop a versatile, energy-efficient hydronic heat pump using propane.
- Achieve high-performance cooling/heating (SEER > 16.0, HSPF > 9.5).
- Ensure >4.0 annual COP for water heating and performance in cold climates.



Team and Partners

CRADA: Emerson Commercial & Residential Solutions (the Helix Center)

EMERSON™

Stats

Performance Period: 10/01/2019 - 09/30/2022

DOE budget: $250K (FY20), $125K (FY21), $125K (FY22), Cost Share: $250K (FY20), $125K (FY21), $125K (FY22)

Milestone 1: Two-stage scroll compressor optimized for propane fabrication

Milestone 2: 3-ton rated cooling/heating capacity with SEER> 16.0, propane charge < 2.5 lbms

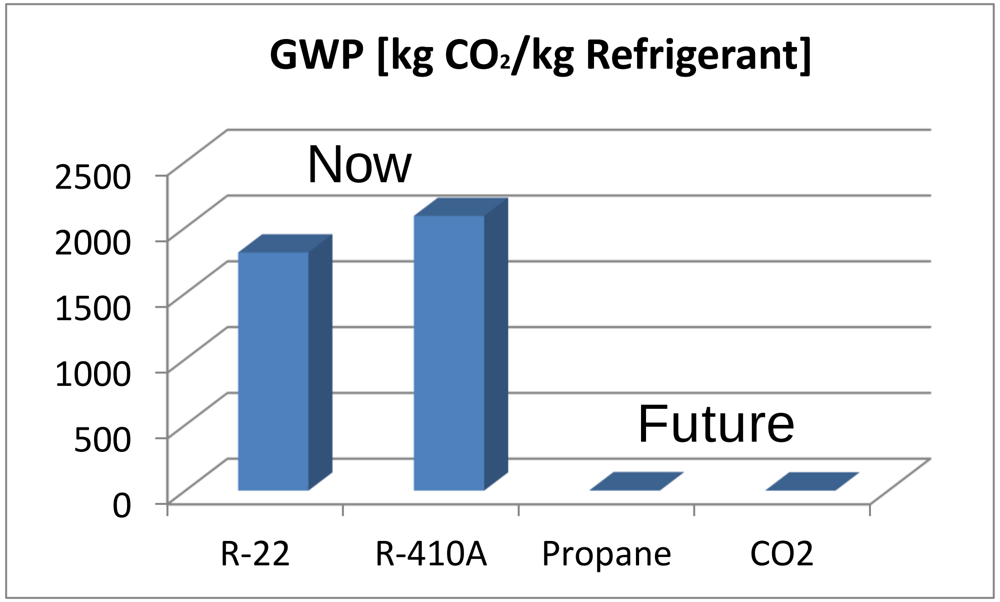
Milestone 3: HSPF > 9.5,

Milestone 4: Water heating with full condensing; calculated seasonal water heating COP > 4.0

Milestone 5: Prototype HP installed for a field demonstration

*No cost extension to Sep 30th 2023 to continue a field demonstration.

Problems Addressed



- The global HVAC market is projected to reach **$367.5 billion** by 2030, making energy-efficient and environmentally friendly solutions increasingly important;
  With propane's (R290) low GWP (3.3) and high efficiency, adopting it in all HVAC & WH applications could significantly reduce greenhouse gas emissions and energy consumption.
- However, propane is in **A3, highly flammable**

- Hydronic system puts propane outdoor and distributes indoor capacity using hydronic loop, to mitigate flammability
- Hydronic system is flexible in storing cooling/heating energy in response to grid demand

Alignment and Impact

Impacts:

- Energy justice: Significant energy savings in residential and commercial sectors, with potential annual site savings of 816 TBtu in the residential sector and 670 TBtu in the commercial sector.
- Greenhouse gas emission: Enhanced market adoption of efficient, environmentally friendly HVAC & WH systems utilizing propane (GWP of 3.3), supporting the growth of sustainable solutions in the industry.
- Power system decarbonization: Develop hydronic multifunctional heat pump system for space heating and water heating; Contribution to EERE/BTO goals by helping to achieve the target of reducing U.S. buildings' carbon emission per square foot by 30% by 2030 vs. a 2010 baseline.

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 (1)

Current solutions:

- Separate systems for space heating, cooling, and water heating
- R-410A as the refrigerant, which is less efficient and has higher carbon emissions compared with propane

Shortcomings:

- Current solutions often lack integration, leading to higher energy consumption, increased complexity, and higher costs;
- Many efficient refrigerants are either flammable or have safety hazards, limiting their applicability in residential use.

The novelty of this project:

- Integrated system addressing multiple HVAC & WH needs
- Using hydronic heat pump system
- Utilizing propane's benefits while mitigating flammability
- Scalable solution for various residential and commercial applications

Current VCC water heater

Current R-410A Residential Heat Pump

Approach (2)

Barriers and risks:

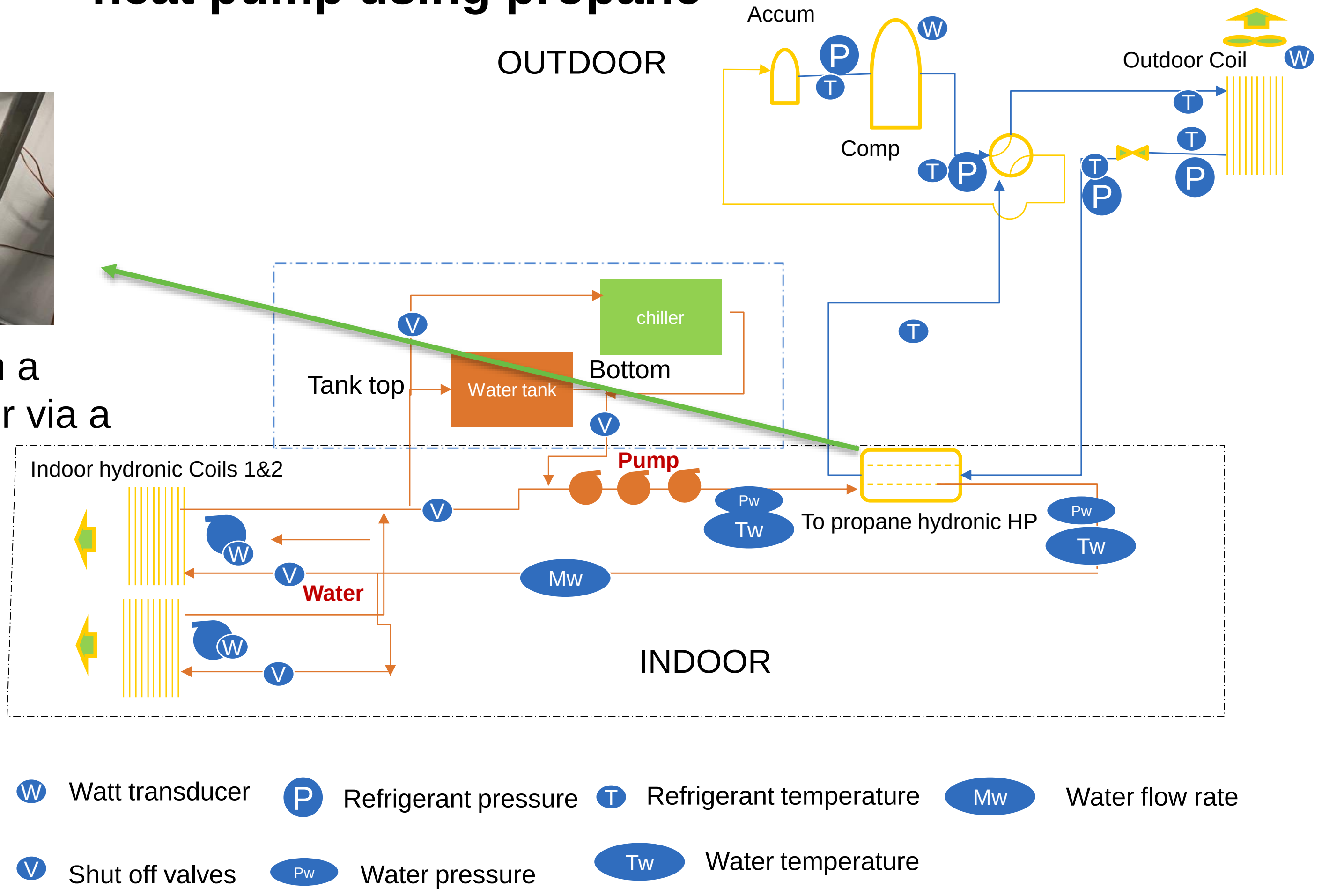
- System complexity and integration
- Heat transfer efficiency
- Flammability and safety concerns
- Cost competitiveness

Compact brazed plate HX (in a plastic box, vented to outdoor via a PVC pipe)

Mitigation strategies:

- Collaborating with industry partners like Emerson to leverage their expertise
- Employing a hydronic system that keeps propane leaked to outdoors if any
- Focusing on scalability and modular design
- Continuously refining the design and testing prototypes

- **System Diagram – multi-functional, hydronic heat pump using propane**

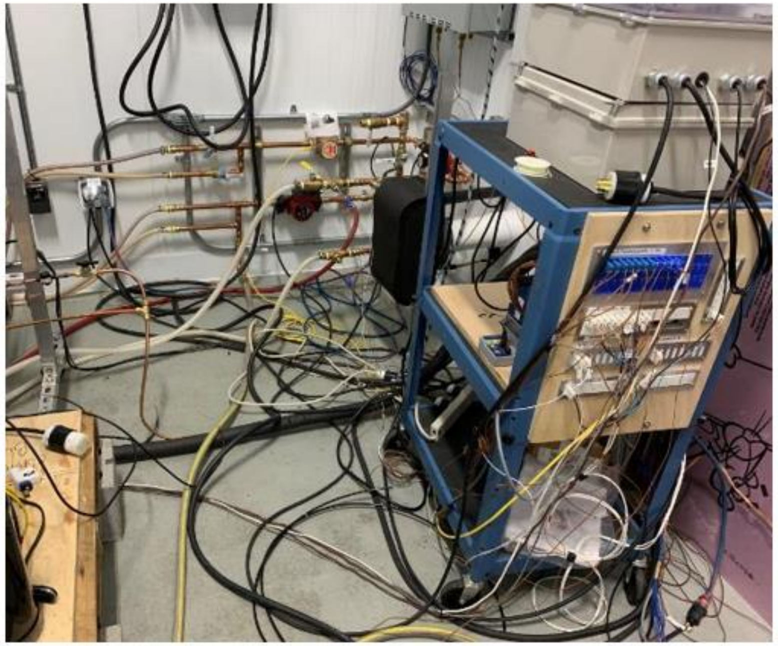


Laboratory hydronic and domestic hot water loops

Two-stage Propane Hydronic Heat Pump

- Emerson two-stage scroll compressor optimized for propane
- System charge: <2.5 lbm propane, (>3.5-Ton rated capacity)
- A bi-directional EXV controls superheat in cooling mode and subcooling in heating mode
- 3 serial pumps to alter the water flow rate from 4.0 GPM to 9.5 GPM

Hydronic Loop

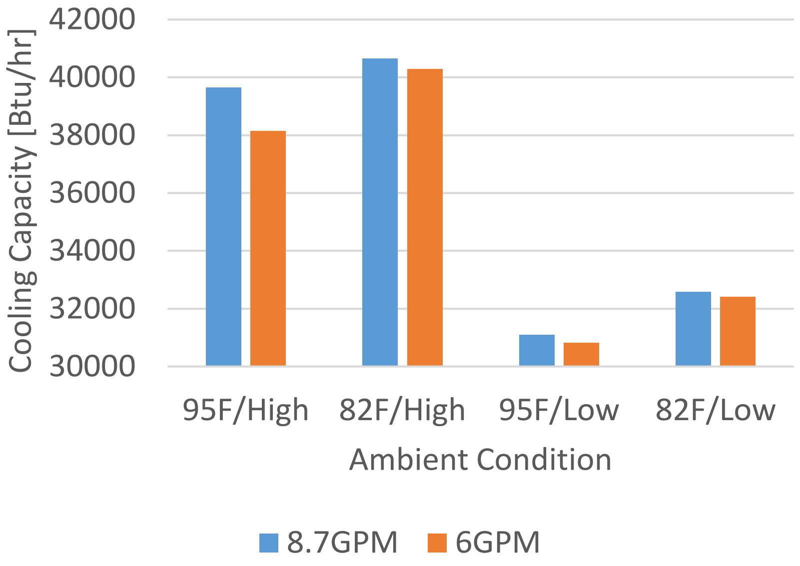

Brazed Plate HX, DAQ


Water Heater

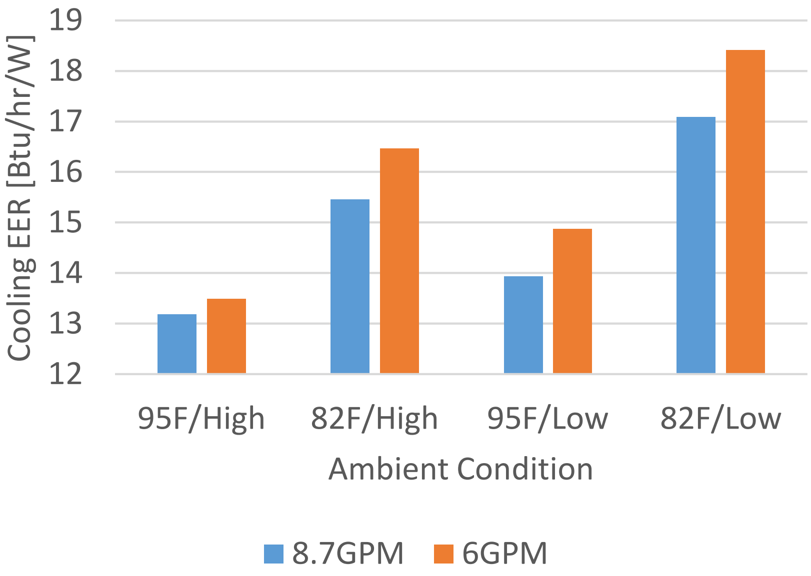

Outdoor Unit

Cooling Performance

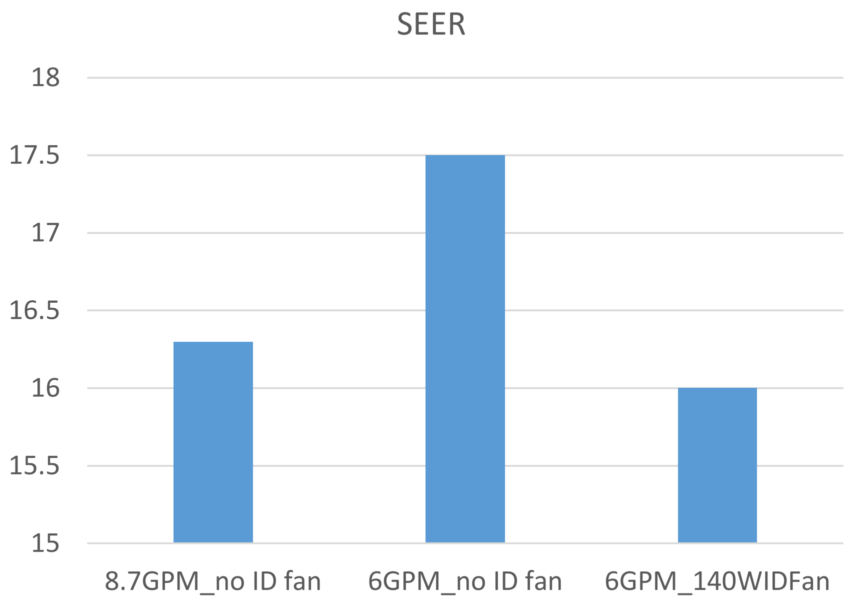
- Test performance at two indoor water circulation rates, i.e., 8.7 GPM with 330 watts pump power and 6.0 GPM with 160 watts pump power
- Larger GPM resulted in higher cooling capacity but lower EER
- The experimental results have accomplished the project goals, i.e.,@ 95˚F cooling capacity > 38 k BTU/hr (3-ton), EER > 13.0 (excluding pump power)
- 6 GPM led 10% higher SEER than 8.7 GPM due to the smaller pump power
- **With duct-less high-efficiency fan coils, SEER > 16 is achievable**



Measured Cooling Capacities



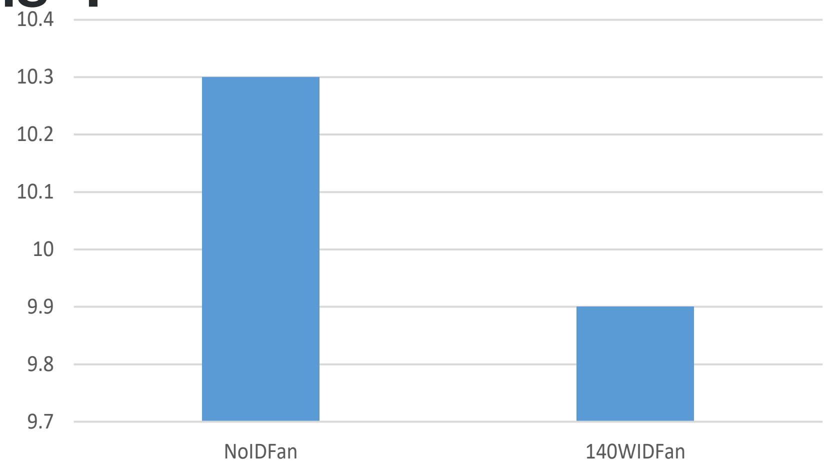
Measured Cooling EERs



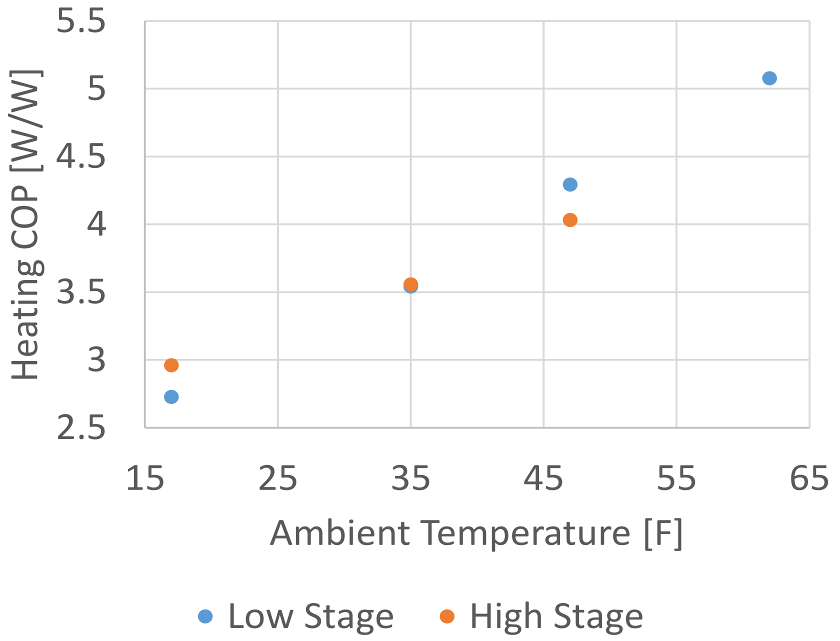
SEERs with Different Fan Powers

Space Heating Performance

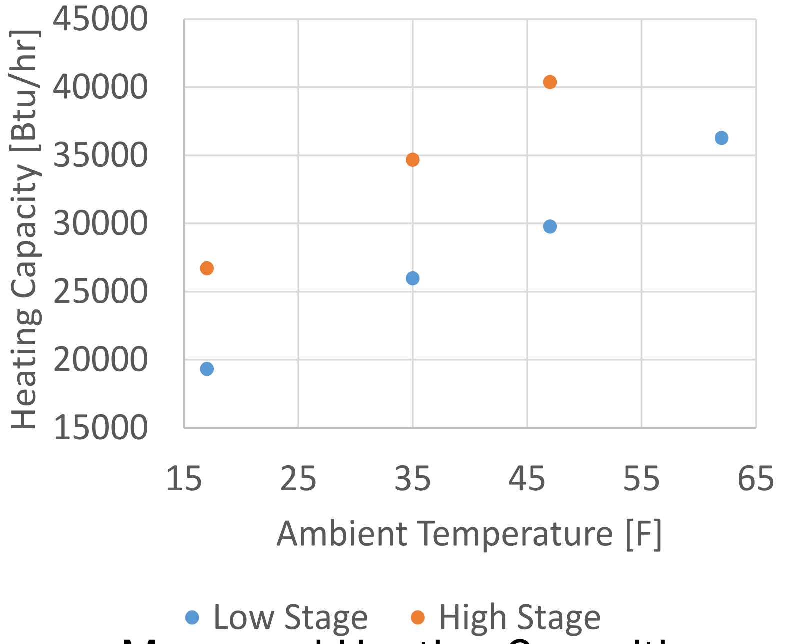
- **@ 47 °F the rated heating capacity is 40K Btu/hr, COP is 4**
- @ 17 °F, COP is 2.96 at the high stage
- @ 17 °F, supply water temperature > 90 °F, good for floor heating
- HSPF reached 10.0 if used for floor heating or high efficiency ductless terminal units



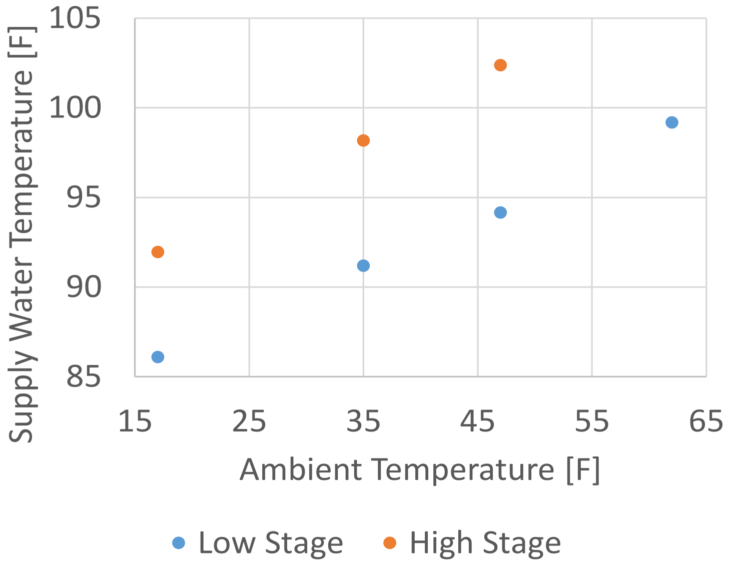
Heat Seasonal Performance Factors



Measured Heating COPs



Measured Heating Capacities



Supply Water Temperatures

Water Heating Performance Test Conditions

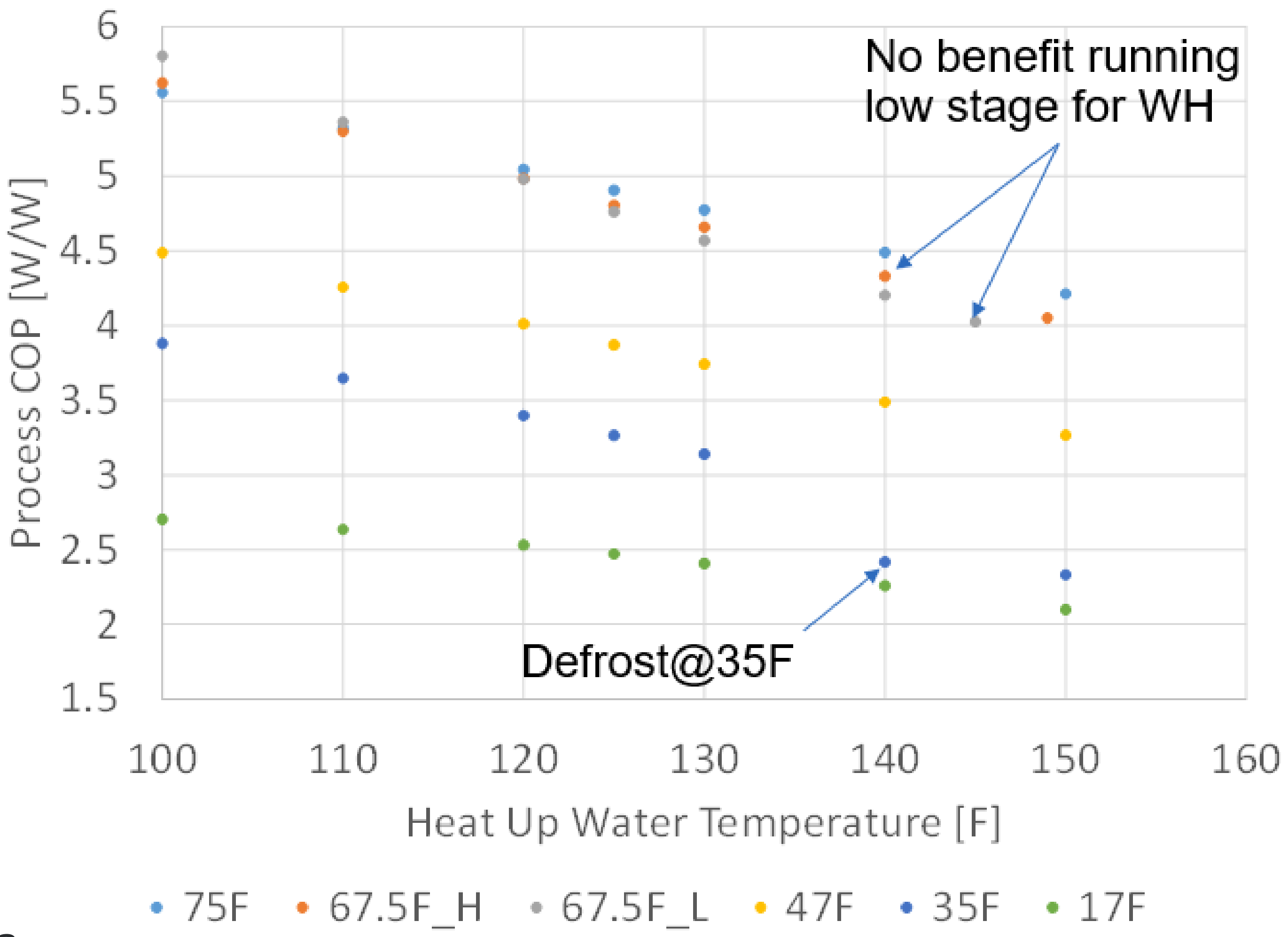
- Indoor air was controlled at 70°F
- For cooling season, the ambient conditions are set at 75°F/50%RH and 67.5°F/50%RH
- For heating season, the ambient conditions are AHRI conditions i.e., 47°F/70%RH, 35°F/70%RH, 17°F/70%RH
- Start initial tank water temperature at 58°F (50-gallon, 90% EF tank)
- Heat the tank until the water heater supply water temperature reaches 150°F
- Constant pump circulation water rate at 3.6 GPM at 150 Watts pump power

50-Gallon Water Tank and Chiller to recover 58˚F water

Water Heating Performance Results

- **The system provides high efficiency water heating**
  - In cooling season, it maintains the process heating **COP > 4.0** up to **150°F** supply water temperature.
  - In heating season, down to **17°F** ambient temperature, it can heat the water to **150°F** with a **COP > 2.0**
- **@ 35°F ambient temperature, defrosting operations degrades water heating COP by 10% to 15%**

Process COP: total capacity delivered/total power consumption in the process of heating a tank of water from 58F to a target top temperature

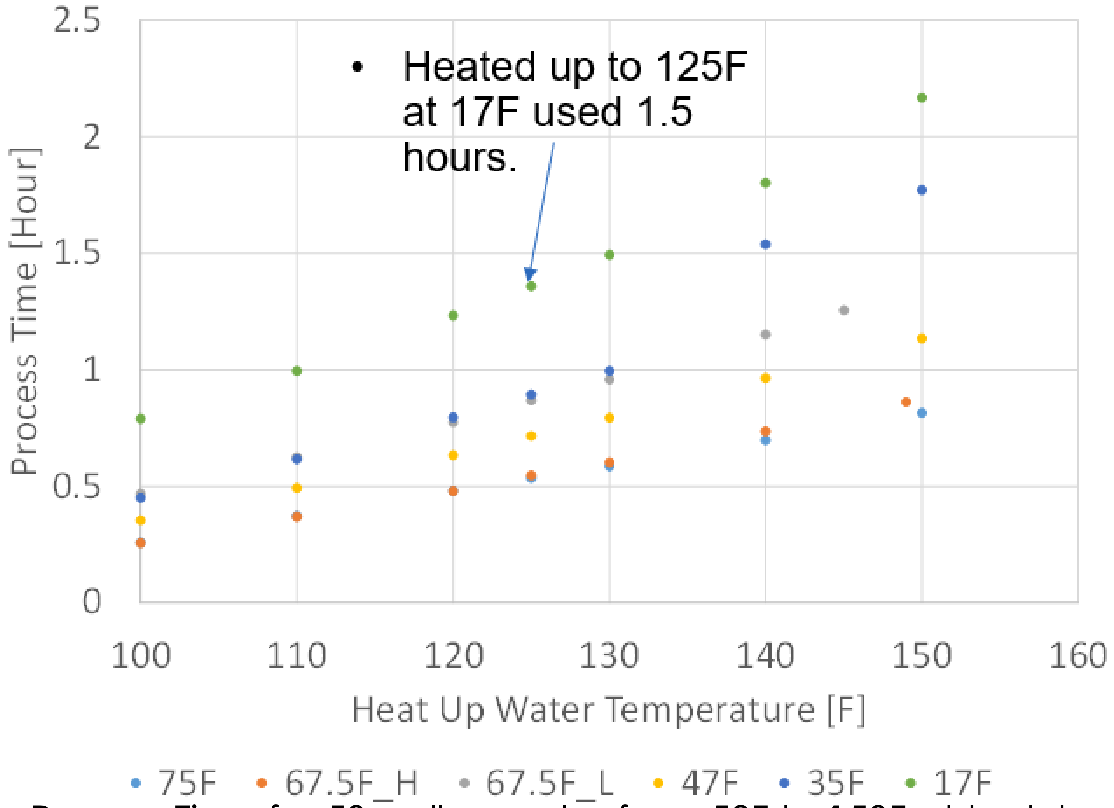


Process COPs versus Water Supply Temperature

Water Heating Performance (Cont'd)

- **The system demonstrates large water heating capacity**
  - Heat 50-gallon water to 125°F within 0.55 hour, as a comparison, a typical stand-alone water heater which may heat the tank using 4-5 hours.
  - @ 17°F ambient temperature, the propane heat pump was able to heat the water to 125°F in 1.5 hours

- Water heating using compressor low stage should be avoided
  - @ 67.5°F ambient temperature, running compressor at low stage shows no efficiency benefit compared with high-stage operation
  - Low-stage operation results in much longer heating time



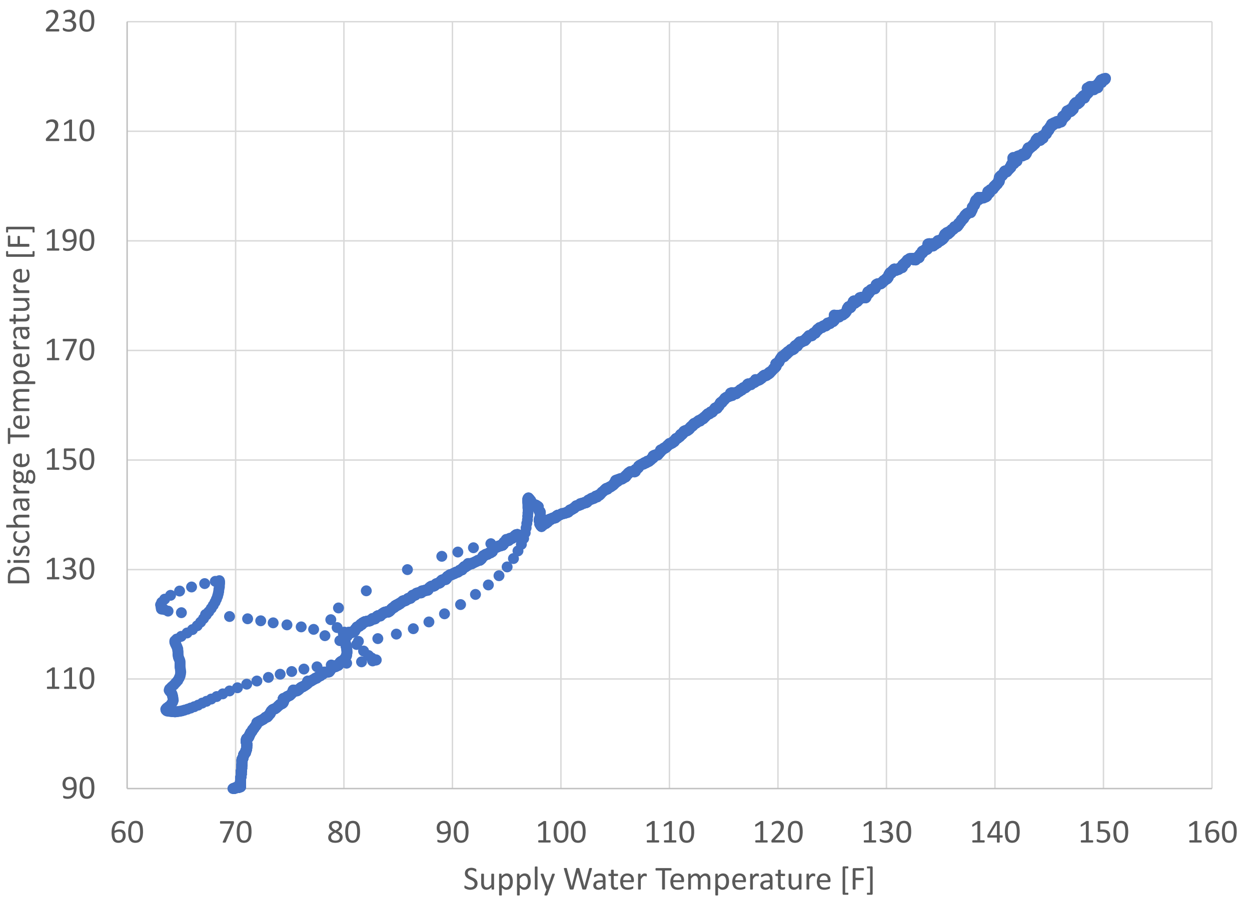
Process Time for 50-gallon water from 58F to 150F at tank top

Potential under Cold Climate

- At 150°F supply water temperature. 17 ° F ambient, the discharge temperature is 220°F (<< 280°F), showing a great potential for cold climate

<u>**Protect lubricant from carbonized**</u>

- Suction saturation temperature increases with water supply temperature. At 150°F supply water temperature, 75 ° F ambient, it hits the 60°F limit

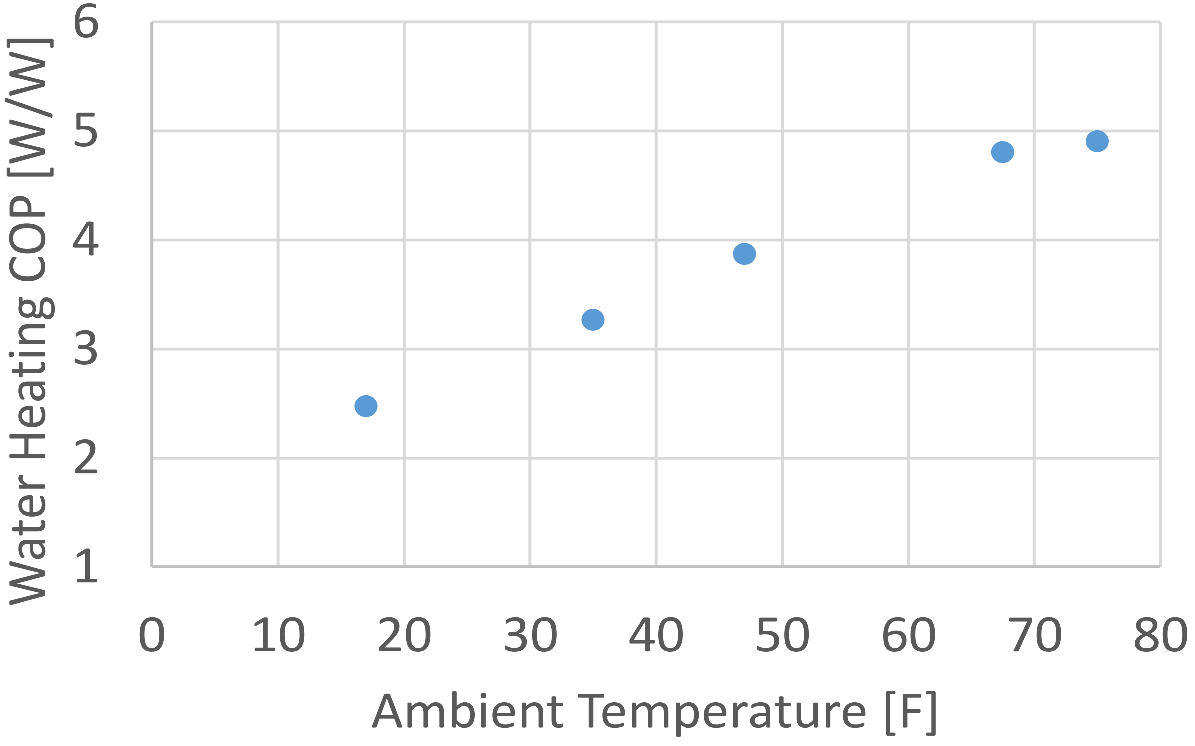


$T_{discharge\ saturation}$ vs $T_{water,supply}$ @ 17° F ambient

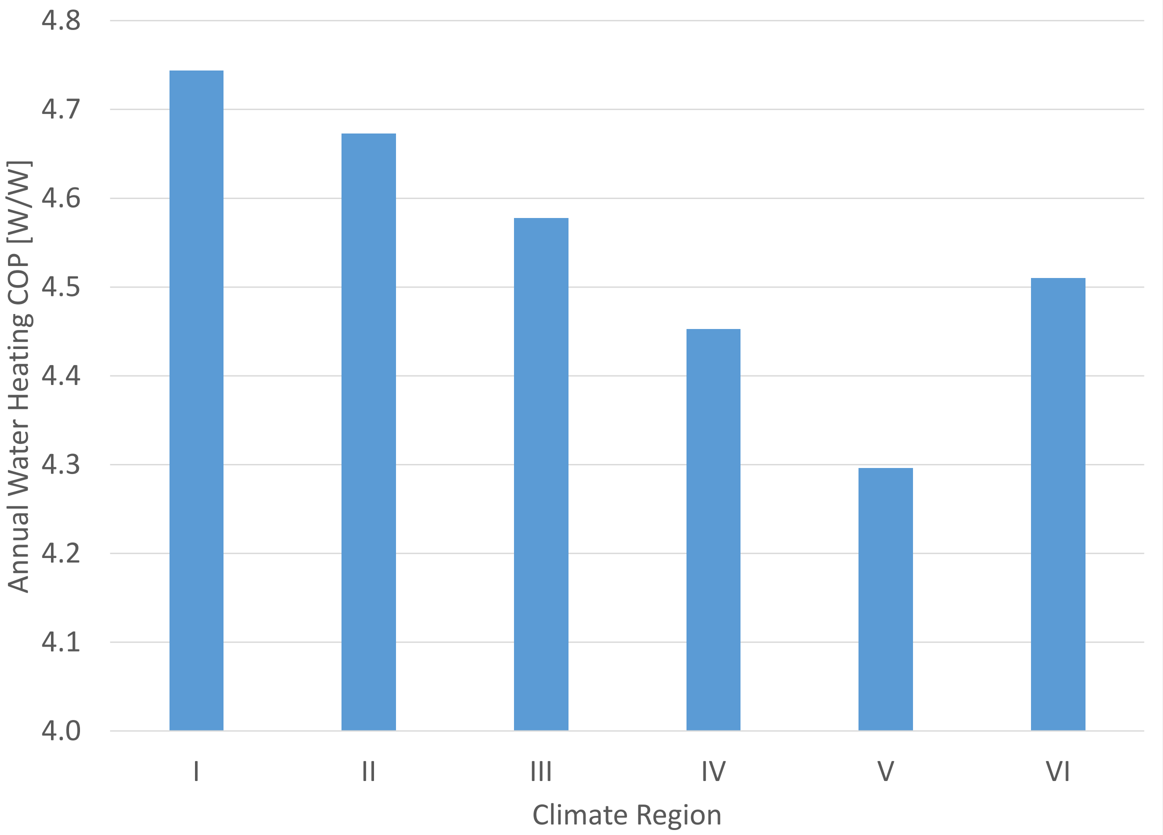
*Compressor operation limits: $T_{suction\ saturation} < 60°$ F, $T_{discharge\ saturation} < 150°$ F, $T_{discharge\ temperature} < 280°$ F

Annual Water Heating Performance (Cont'd)

- Heating COPs in Six Climate Zones are all above 4.0
- Annual heating COP is higher in warm climate zones (I, II, III, VI) and lower in cold climates (IV and V)



Water heating COP changing with ambient at 125° F supply water temperature



Annual Water heating COPs in Six Climate Zones

Future Works

Funded project term has completed but a field demonstration is ongoing.

Propane hydronic heat pump to charge/discharge a 200-gallon water tank for sensible cooling/heating energy storage

Conclusions

- Environmental friendliness: GWP of 3.3 versus 1924 of R-410A
- Deliver > 3.5-ton rated capacity with propane < 2.5 lbms; develop a series of technologies to mitigate flammability
- Superior energy efficiency, SEER > 16.0 (vs. 14.0), HSPF > 9.5 (vs. 8.2), annual water heating COP > 4.0 (vs. 1.0)
- Zonal load control via hydronic terminals (vs central air flow)
- Multi-functional heat pump achieve annual energy savings > 40%
- Hydronic energy storage facilitates grid-responsive operation

Publication

"A Propane Hydronic Heat Pump with Energy Storage" International Congress of Refrigeration , ICR2023 | 26th International Congress of Refrigeration, Paris, France

Thank you

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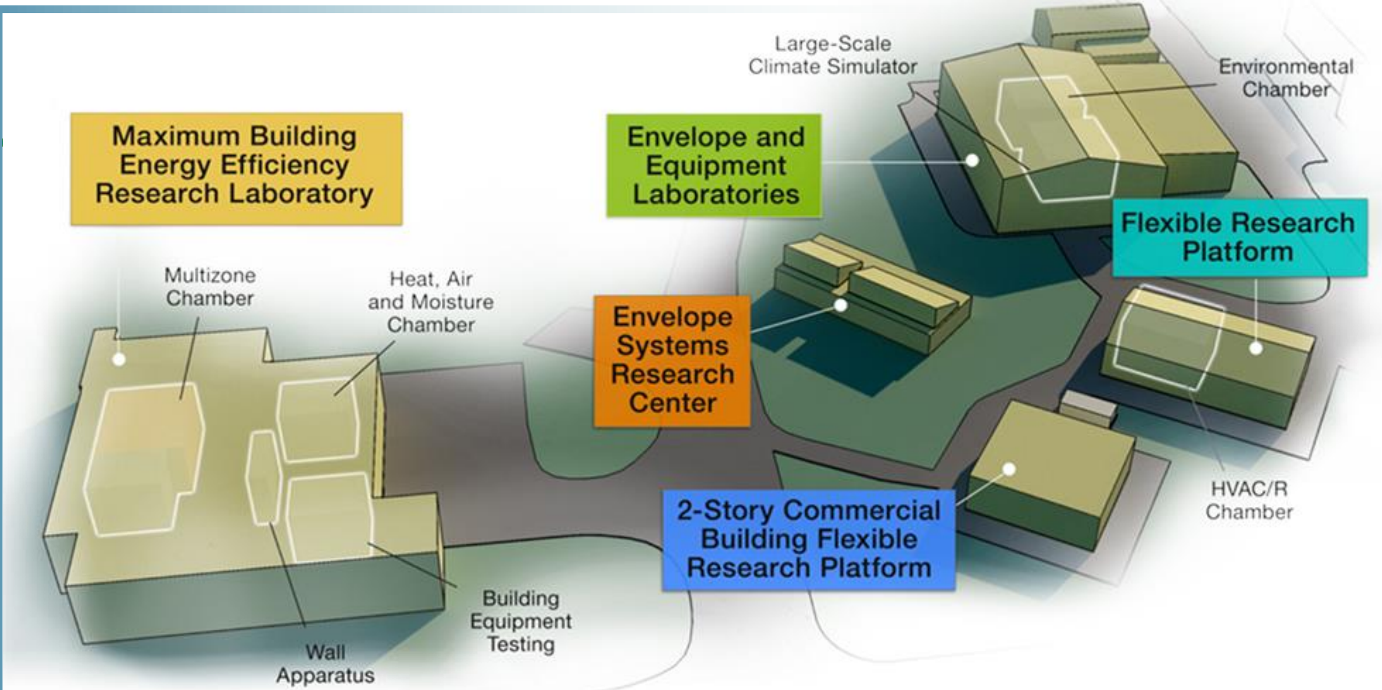

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free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

Industry Partner – Emerson Commercial & Residential Solutions

- Developed two-stage scroll compressor optimized for propane
- Develop leak-proof case to vent propane leak to outdoor
- Weekly meetings with Emerson engineers to monitor the progress.

Space Cooling and Heating Performance Test

- Test condition: AHRI 210/240 for two-speed heat pump system

Cooling Test Conditions

$T_{dry,bulb}$ outdoor	$T_{drybulb}$ indoor	$T_{wetbulb}$ indoor
95°F – High Speed	80°F	67°F
82°F – High Speed	80°F	67°F
95°F – Low Speed	80°F	67°F
82°F – Low Speed	80°F	67°F

Heating Test Conditions

$T_{dry,bulb}$ outdoor	$T_{wetbulb}$ outdoor	$T_{drybulb}$ indoor
47°F – High Speed	43°F	70°F
35°F-High Speed	33°F	70°F
17°F-High Speed	15°F	70°F
62°F-Low Speed	56.5°F	70°F
47°F-Low Speed	43°F	70°F
35°F-Low Speed	33°F	70°F
17°F-Low Speed	15°F	70°F