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Cold Climate Heat Pump Demonstration Results

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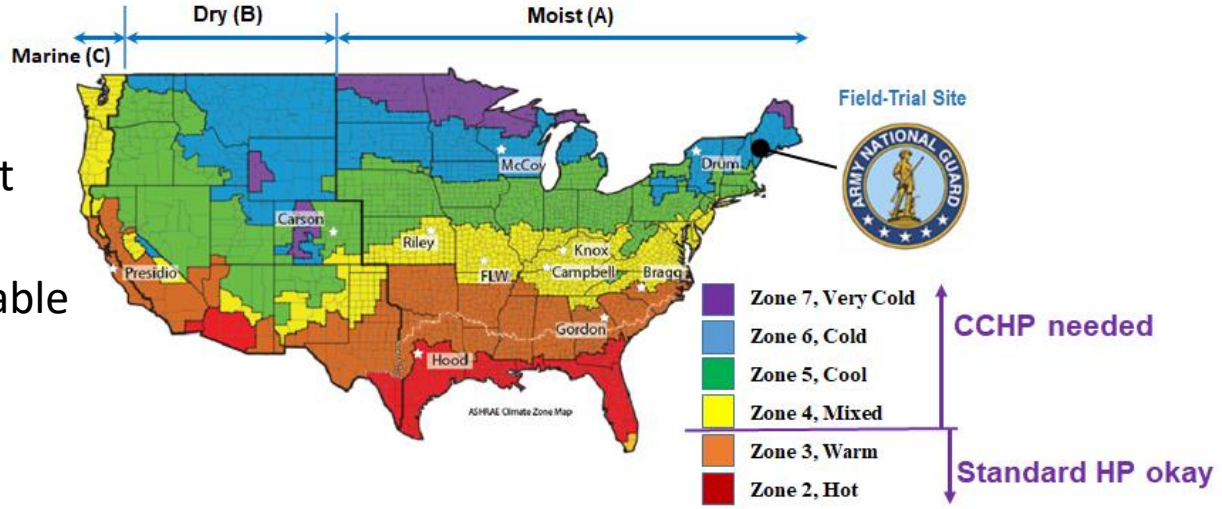
SERDP • ESTCP SYMPOSIUM 2019 | Enhancing DoD's Mission Effectiveness

Motivation

State-of-the-art commercial heat pumps significantly degrade in cold climates

Problem:

- State-of-the-art industry heat pumps degrade by up to 60% in capacity and 50% in system coefficient of performance (COP) at very low ambients.
- Cold blow effect further cements that heat pumps are not a viable technology for space heating in cold climates
- Scalable and cost-effective technologies as well as system optimization/integration are necessary to deploy CCHP



Target Market:

- Commercial building owners need a superior air-source HP that operates over extreme heating and cooling seasons
- U.S. Commercial buildings in cold climates represent 45% of the national building stock.
- 32% use electricity as the primary source of space heating representing 149 billion kWh and $9.2 billion
- 56% of DoD buildings fall in climate zones suitable for cold climate heat pumps

Expected DoD Benefit

- Quantitative
  - **Energy Savings:** 20% annually for electric-based space heating & cooling
    - Superior heating performance at moderate and extreme heating
    - Parity in cooling performance at design and part load conditions (IEER)
  - **Pricing:** Parity with State-of-the-art Carrier heat pumps
  - **Thermal comfort:** >95°F supply air temperature
  - **Institutional scalability:** 56% of DoD buildings
  - **Annual Cost Savings:** >$61M savings (electric heating solutions and supplement needs only)
  - **Annual energy savings:** ~14 trillion Btu
  - **Annual GHG Reductions:** 2,884,535 metric tons of CO2*

- Qualitative
  - Remote heating solution
  - Reduced operational costs (volatility and dependence) associated with using hydrocarbon fuels to remote bases
  - Increased visibility into electric-based air-source heat pumping equipment solutions
  - Easily scalable to larger packaged roof-top units - up to 40TR

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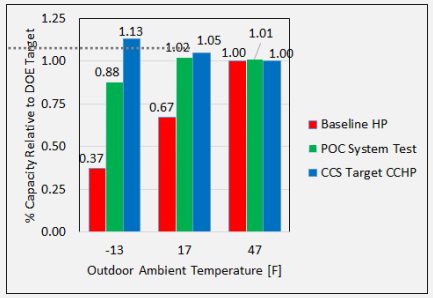
***7.03×10^{-4} metric tons CO_2 / kWh**
(eGRID, U.S. annual non-baseload CO_2 output emission rate, year 2012 data)

Previous work, DoE and Carrier Sponsored

2013	2014	2015

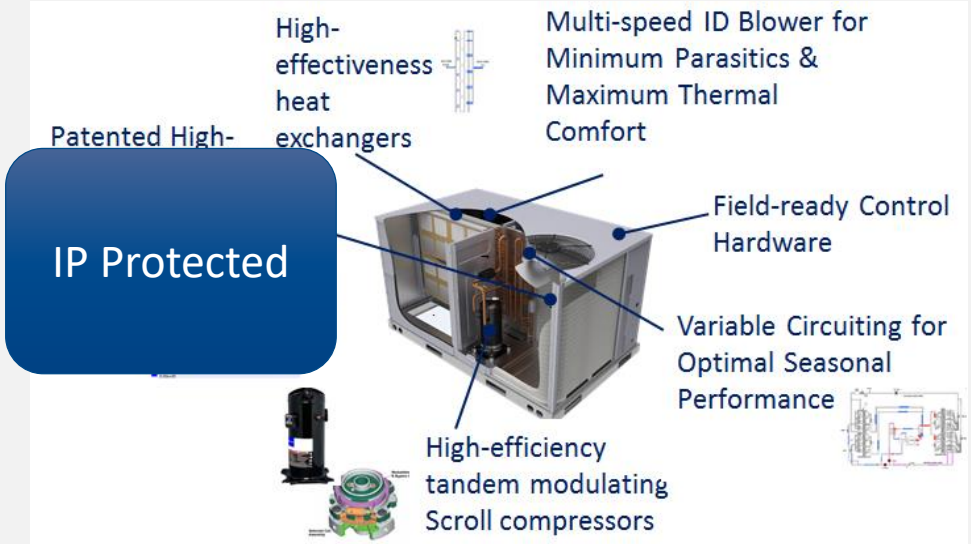
DoE Project (-13F Target)
Recip Compr, EBM Papst Fans



Performance Targets Achieved

2016

Focus on Cost Optimization



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ESTCP Project Objectives

Cold Climate Heat Pump

Key Enablers:

Optimized compression

Dynamic Models & Controls

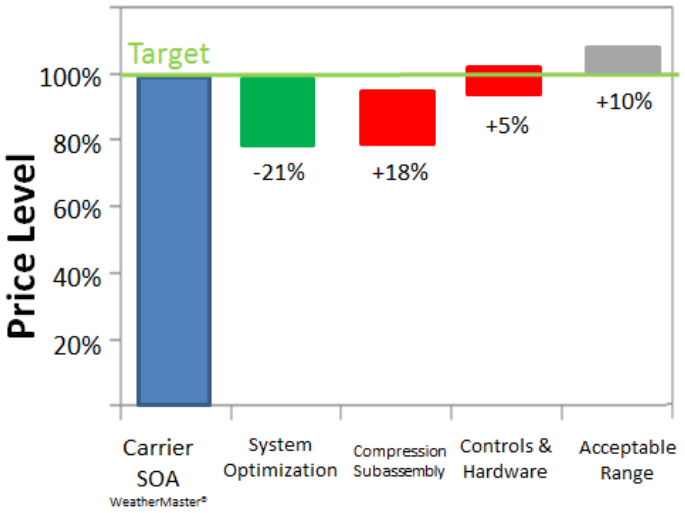
Chassis & HX optimization

KPI	10TR 50HCQ	10TR CCHP
Size	-	Smaller
Heating Performance at 0F	3.5TR	>9TR
Supply Air Temp at 0F	85F	>100F
Cooling IEER	13.6	14.6
Cost to Carrier	-	Parity

Field demonstrate cost-effective high performance cold climate heat pump

- ✓ Demonstrate heating and cooling performance of cost optimized CCHP
- ✓ Develop and deploy field ready controls for two field trial systems

Achieving Price Parity…



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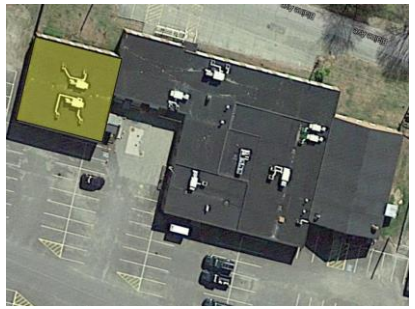
Approach

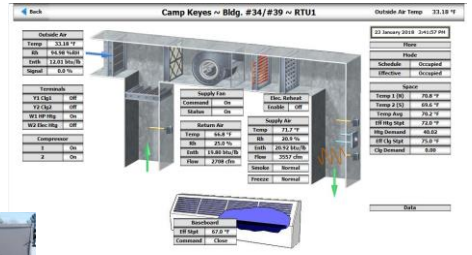
Program Phases at Camp Keys Maine (MEARNG)

Legacy System



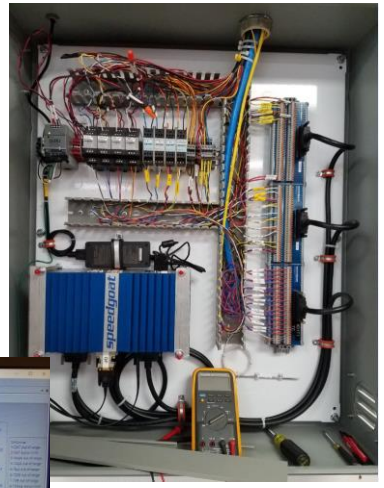
Two air-handler units,
Four residential style condensing units,
Baseboard heating.

Phase I
Carrier 50HCQ



16SEER 10TR Carrier heat pump with auxiliary electric heat.
BMS system control

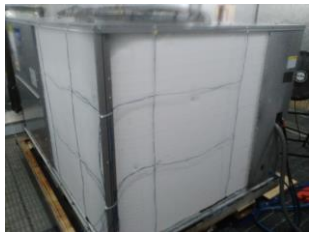
Phase II
CCHP field trial



10TR CCHP field trial unit with SpeedGoat Controls

Approach

Program Phases at UTRC Psychrometric Laboratory



Lab has >10TR capacity
Outdoor room controls from -20F to 130F
Controlled Frost/Defrost Testing

2018: Control Development and Lab Verification

Winter 2019 data from MEARNG used to improve control code and cost-optimize system.

Verified in Lab, and code updated at MEARNG.

Results

Data Processing

Things to note:

- Steady COP in lab can be much higher than integrated COP at the site:
  - Cycle Degradation
  - Frosting
  - Defrost cycle
  - Unnecessary electric heat
- Outdoor air ventilation can add significantly to the load, or reduce it (economize), depending on conditions.
- Use of zone set-back (unoccupied) causes large scatter in load as a function of temperature
- Use of zone set-back can increase the use of electric heat upon recovery, and actually hurt integrated COP.

Integrated COP over set number of hours is used to process the data:

$$\overline{COP} = \frac{\int_{t1}^{t2} Q_{therm}\, dt}{\int_{t1}^{t2} Pow\, dt}$$

$$t2 - t1 = 4hr$$

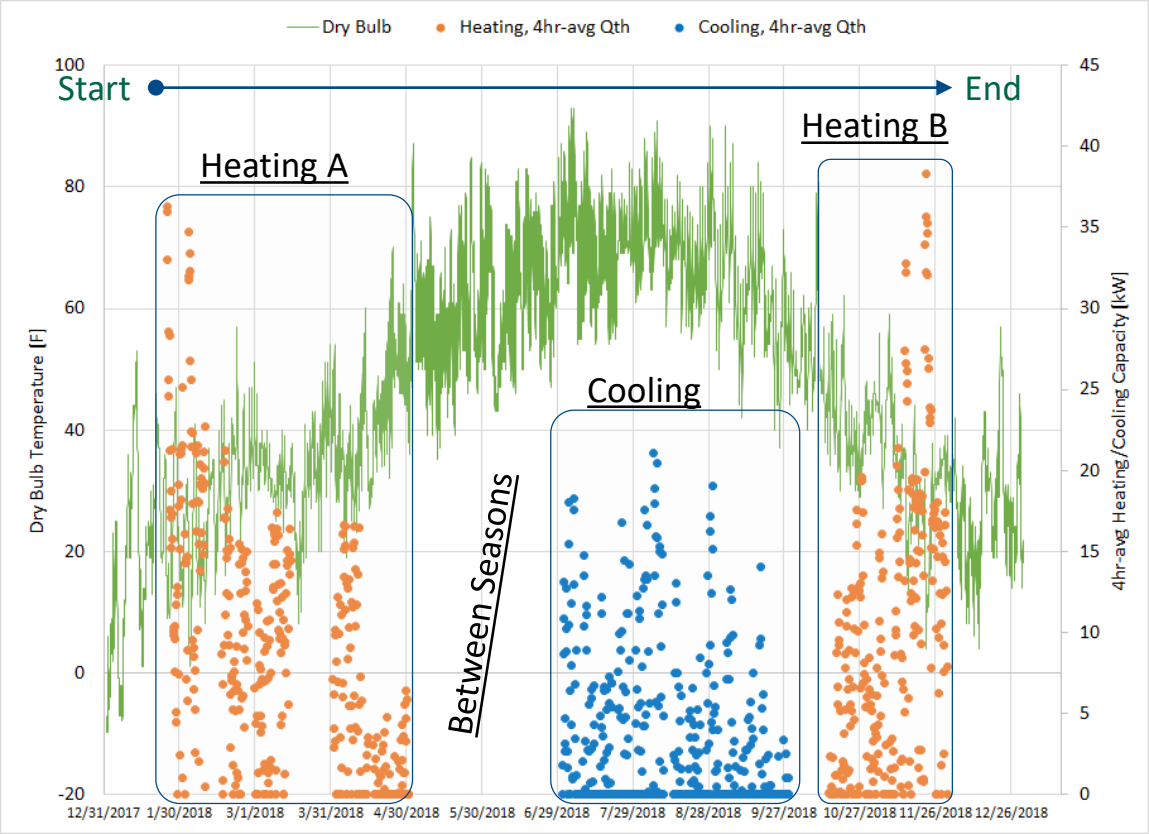
Siemens Power Meter

Instantaneous Q_{therm} is determined from calibrated flow stations installed in the supply and return ducts.

Return Air Flow Station (T, Dew, CFM)

Outdoor air flow rate is the mass-flow difference from supply and return.

Phase I Results, Benchmark RTU

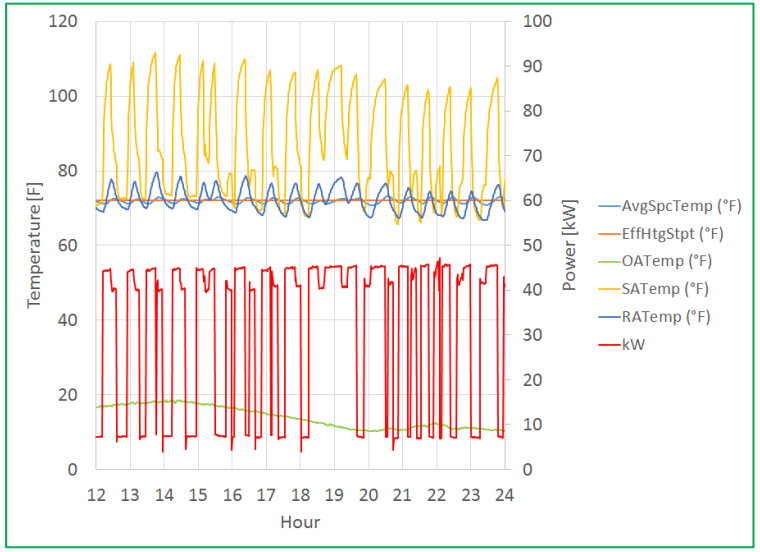


Capacity

- Two heating seasons and a cooling season analyzed.
- Between seasons had little load (and sometimes heating and cooling in same day)
- Peak heating load (4hr average) was 39kW (11Tons)
- Large variation in load at a given ambient.

Example of Cold-Ambient operation

- OAT 10-18F
- Unit runs continuously, electric heat cycles on and off to meet load.
- With electric heat off, SAT < 80F!



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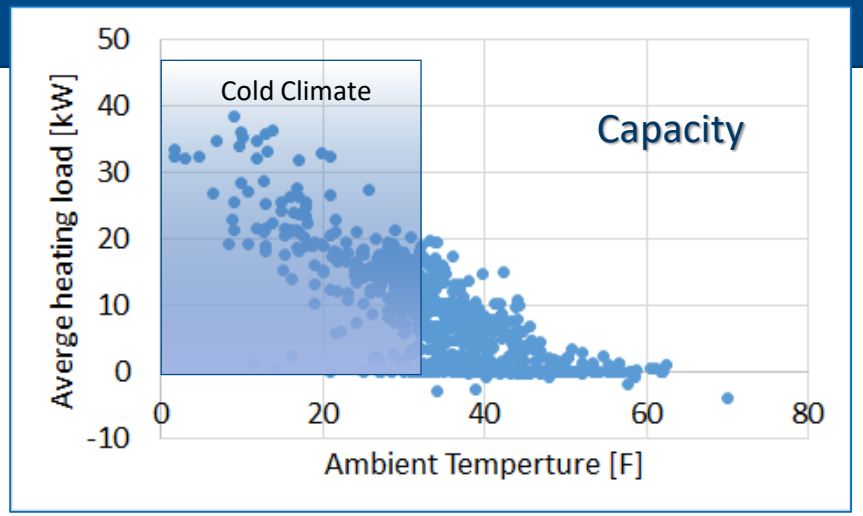
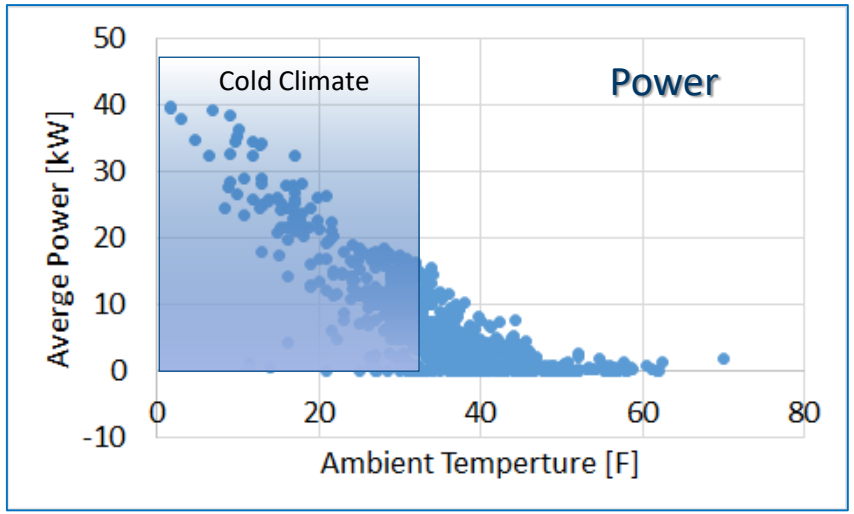
Phase I Results, Benchmark RTU





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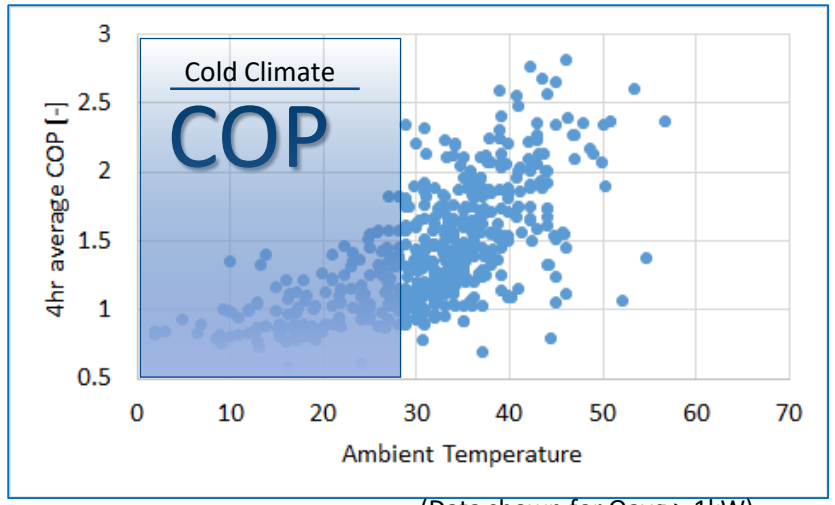

(Data shown for Qavg > 1kW)

- Huge variations in integrated COP
- COP is often < 1

- Q and P generally increase with decreasing temperature. Little to no load above 50F.
- Large scatter at given temperature.
- Variations in COP are due to:
  - Frosting
  - Defrosting, and the amount of defrost time that happens to fall within the 4-hr integral
  - Cycling
  - Fraction electric heat (affected by set-back)

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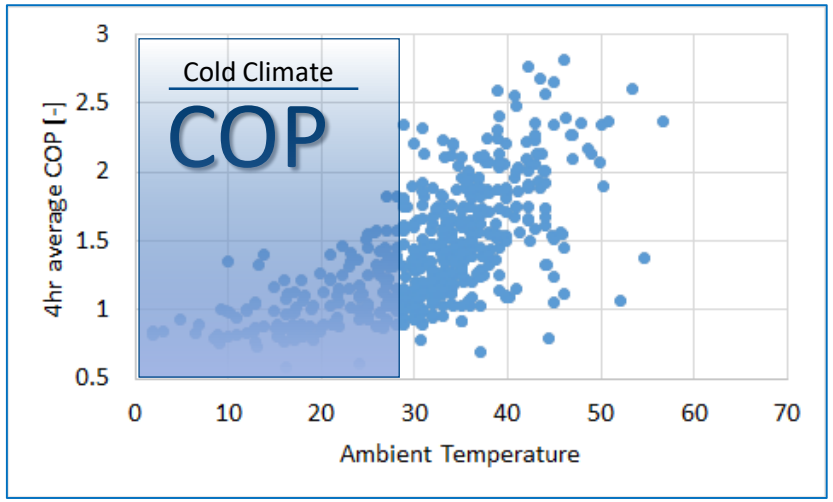
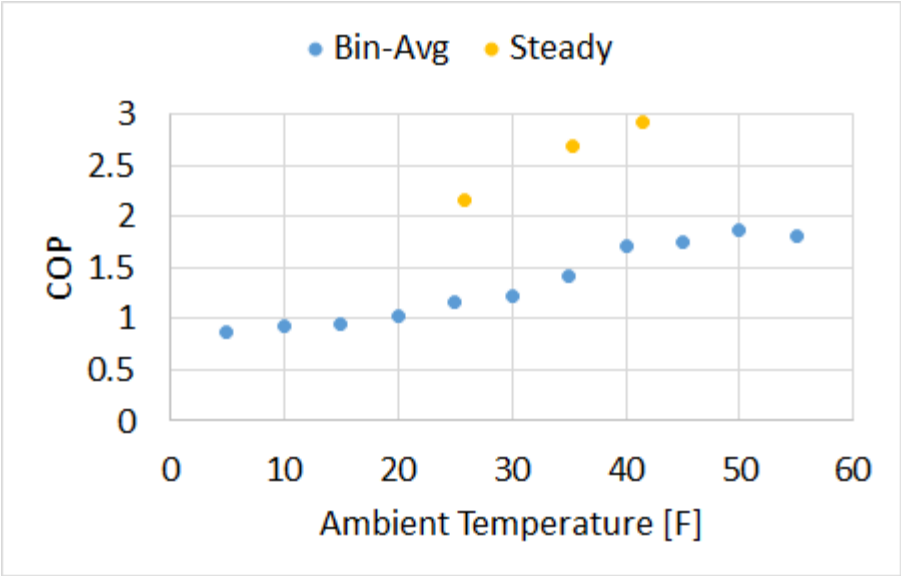
Phase I Results, Benchmark RTU



Δ5F temp bins,
Sum all Q and P per bin,
Divide to find overall COP as a function of temperature.

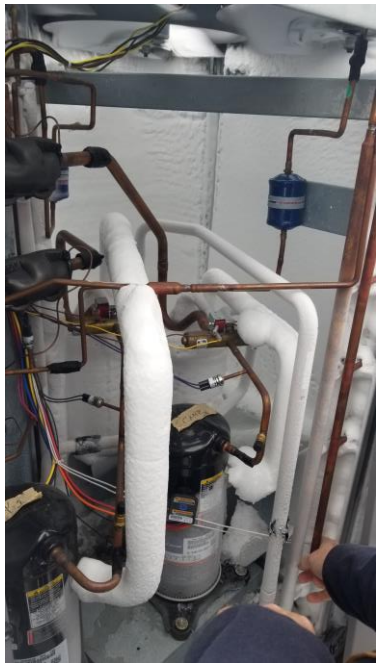


- Effective COP is <1 below 20F
- Three steady operating points shown for comparison (with neither frost nor cycling effects) are much higher.

Phase I Results, Benchmark RTU

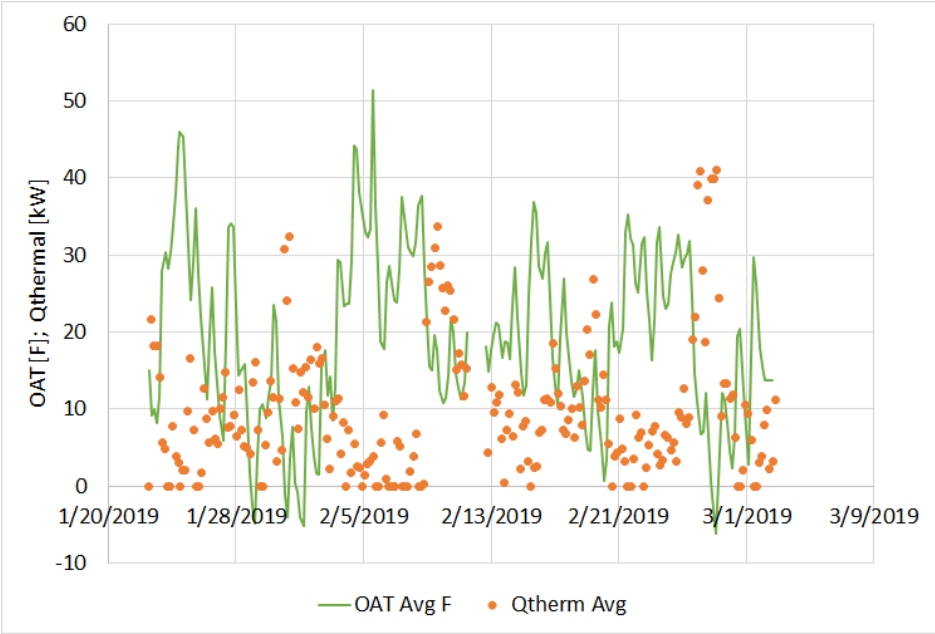
Frosting!

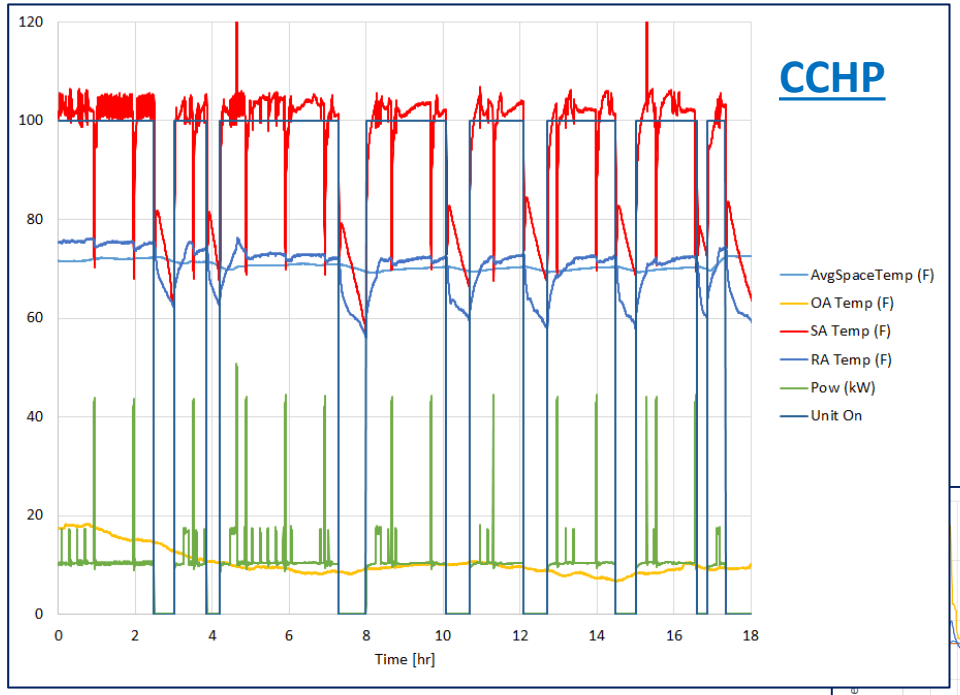
- Normally heat pumps are not run to 0F ambient. We changed the factory-set cut-out from 30F to -20F for this demonstration.
- Several times the baseline unit did not defrost on its own, but needed intervention.
- When frosted the instantaneous capacity and COP are very low, but defrosting (which runs in cooling mode with electric heat) is even worse.



Phase II Results, CCHP Field Trial

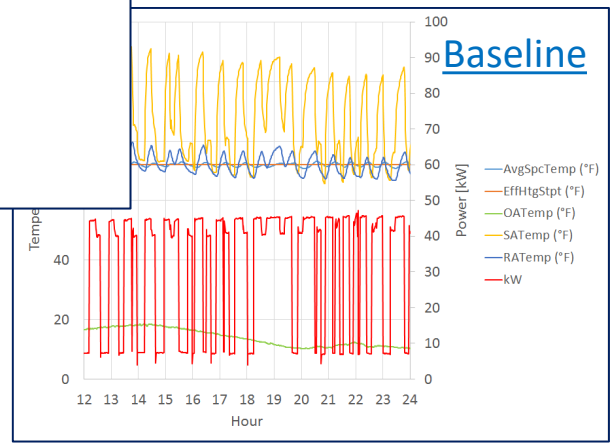
Start





Example of Cold-Ambient Operation

- OAT 8-18F
- Supply Air T > 100F without electric heat.
- Unit cycles on and off meeting load.
- No electric heat needed except during defrost.



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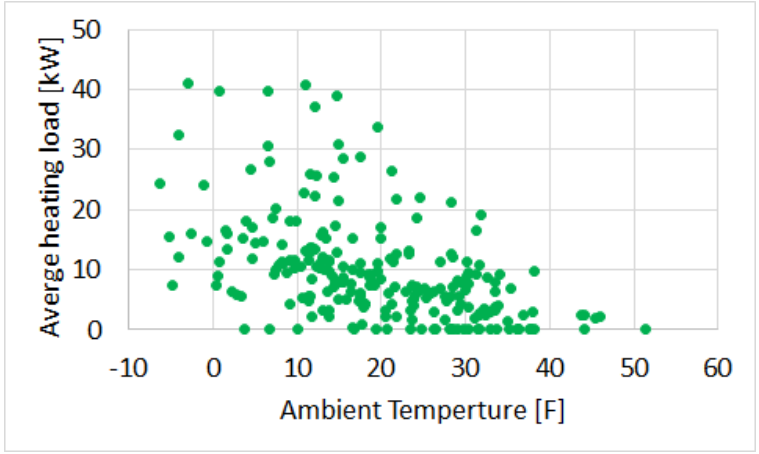
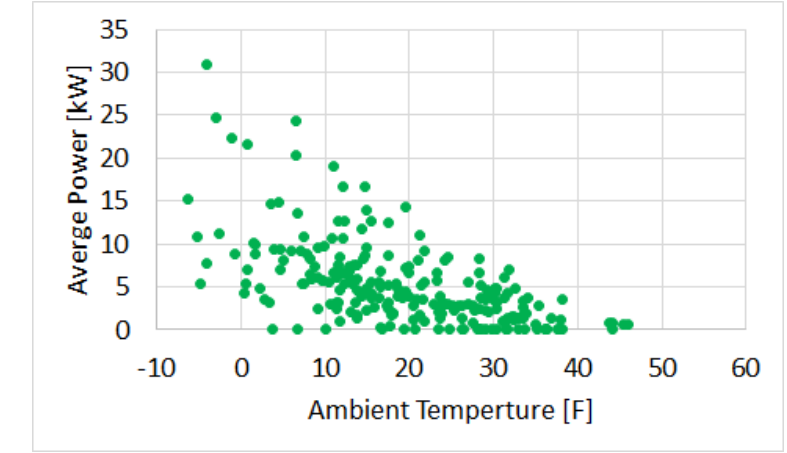
Results Phase II, CCHP Field Trial





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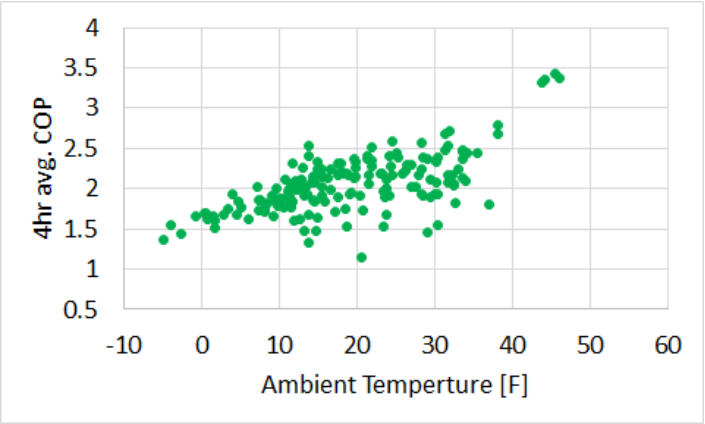

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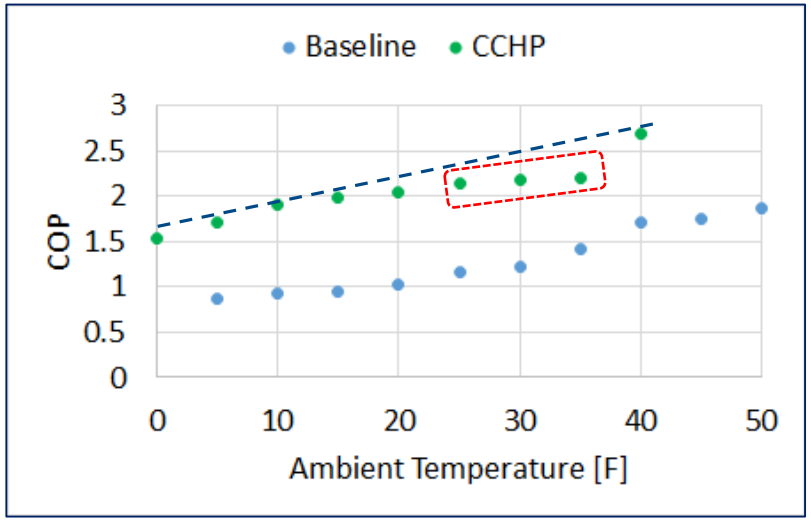

CCHP significantly better than baseline

- Integrated COP > 2 times higher at low ambient.
- But dip at 30-35F.
- A look at this data indicates significant frosting (next slide).

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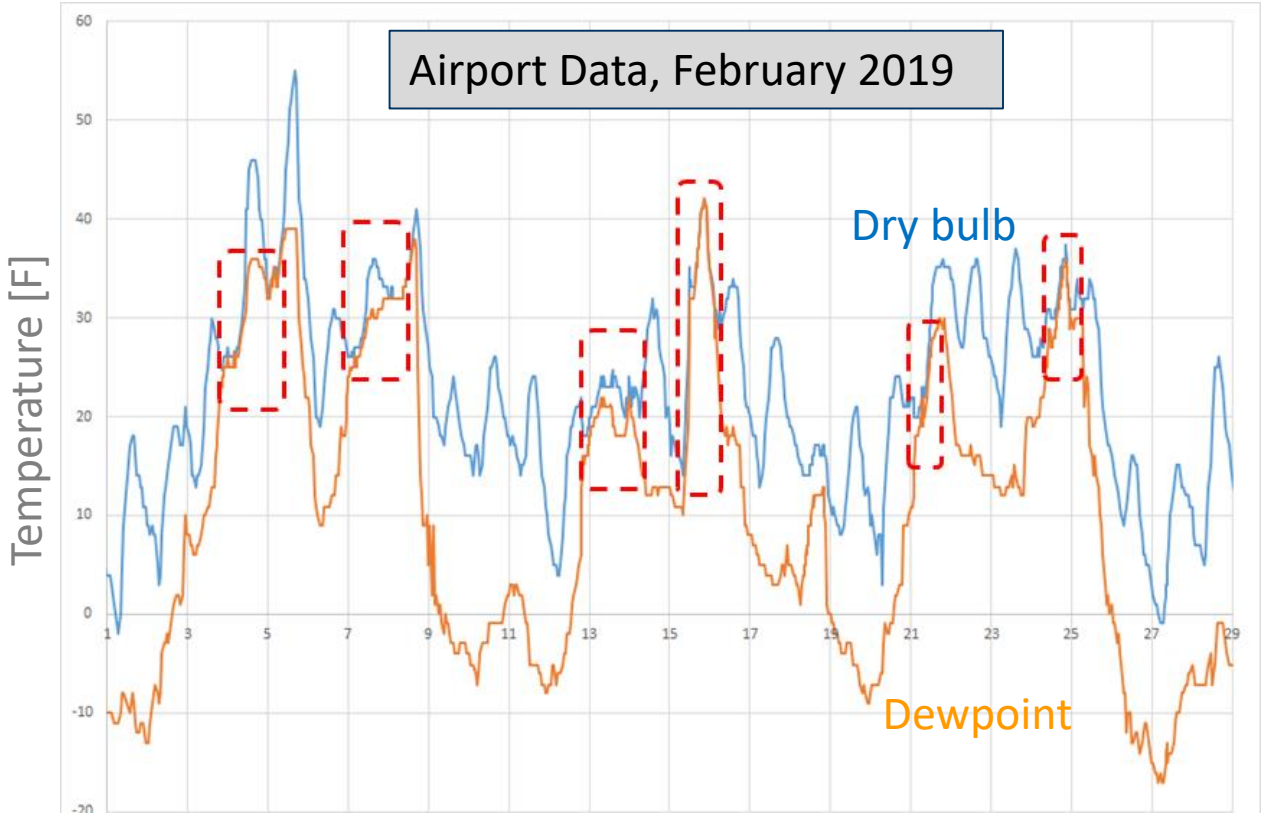
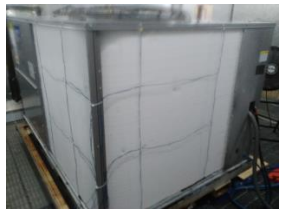
Results Phase II, CCHP Field Trial



- Many warmer periods in this data set had nearly 100% humidity.
- This results in lower integrated performance. The unit was found to be running with very low suction pressure.
- COP can be improved with better defrost logic.

Code Improvement and Cost Optimization (UTRC)



Defrost:

- The CCHP unit was noted to defrost more quickly than the baseline, typically in less than 3 minutes. No interventions were required.
- But even still, frost and defrost cycles were seen to significantly lower integrated COP.
- A new sensor-based logic was developed from the winter 2019 data and verified in the UTRC psychrometric laboratory.
  - Avoids unnecessary defrost cycles
  - Defrosts sooner if needed.

High Ambient:

- The field trial unit did not see temperatures over 100F. High ambient (up to 125F) operation was lab verified

Cost Optimization:

- The proprietary compressor control actuators were simplified by adjusting the control logic while maintaining performance.

Acknowledgement & Disclaimer

Acknowledgment:

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