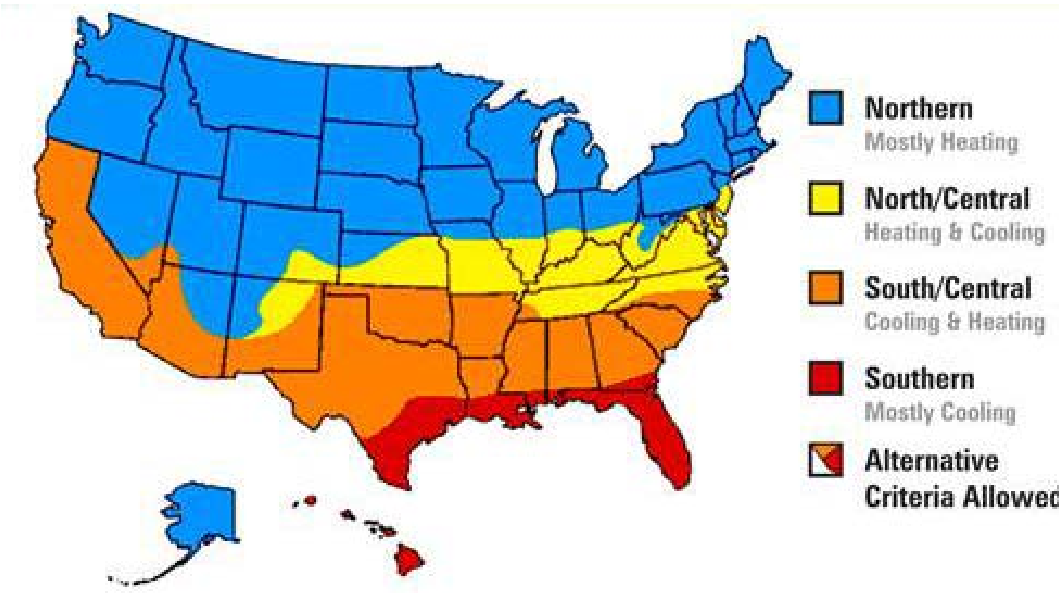
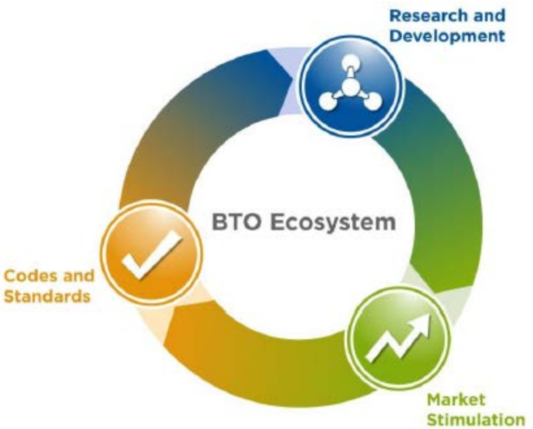
High Efficiency Cold Climate Heat Pump

2017 Building Technologies Office Peer Review





Copeland Scroll

EMERSON. Climate Technologies

The Unico System® Small-Duct Central Heating & Air Conditioning

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Project Summary

Timeline:

Start date: 10/01/2010

Planned end date: May-Sept. 2017

Key Milestones

1. Tandem fixed-speed system: meet 76% capacity at -13°F vs. 47°F; COP=4.2 at 47°F; March 2014
2. Tandem vapor injection system: meet 88% capacity at -13°F vs. 47°F; COP=4.4 at 47°F; June 2015
3. Field investigation of a prototype CCHP: eliminate auxiliary heat down to -13°F in an occupied home; April 2015.

Budget:

Total Project $ to Date:

- DOE: $2,839K
- Cost Share: partner in-kind cost share exceeds DOE cost

High Efficiency Cold Climate Heat Pump (CCHP) CRADA

Key Partners:

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EMERSON. Climate Technologies

The Unico System® Small-Duct Central Heating & Air Conditioning

Solution: Single-stage compression system development and assessment.

Project Outcome:

- Achieve COP@47°F > 4.0; achieve capacity at -13°F > 75%, vs. rated capacity@47°F.
- Maximize COP at 17°F and -13°F with acceptable payback period.

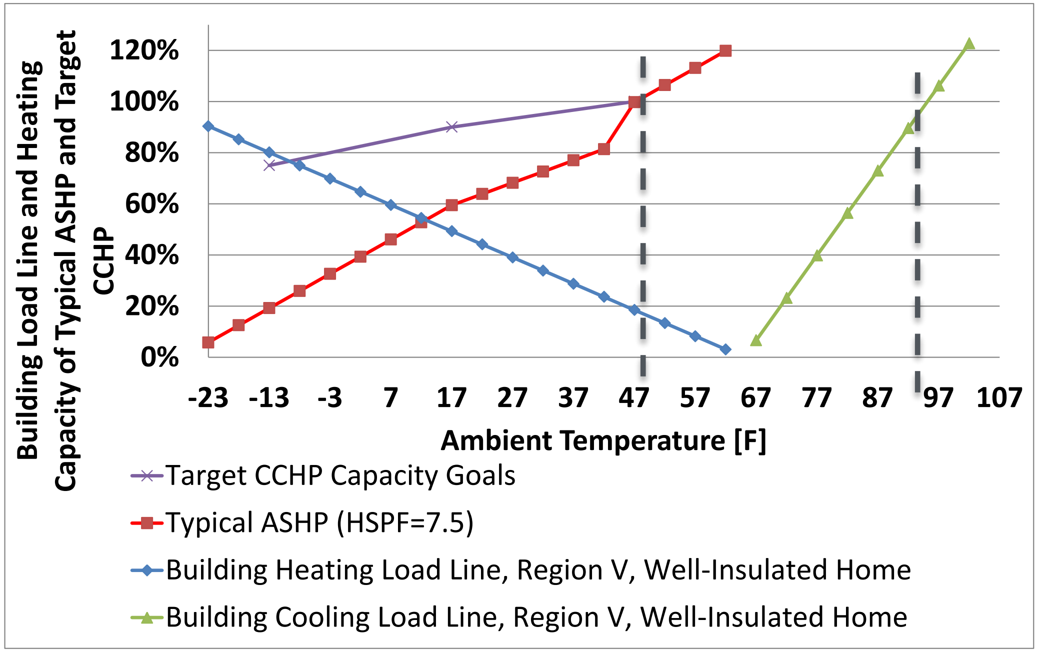
Two prototypes of 3-ton, split CCHPs achieved the project goals, verified in lab and field tests.

Purpose & Objectives

Target market/audience: The principal target market is 2.6M electric-heated dwellings in cold regions. It would contribute to annual site energy savings of 3,664,405 MMBTU and CO_2 emissions reduction of 470,000 Ton.

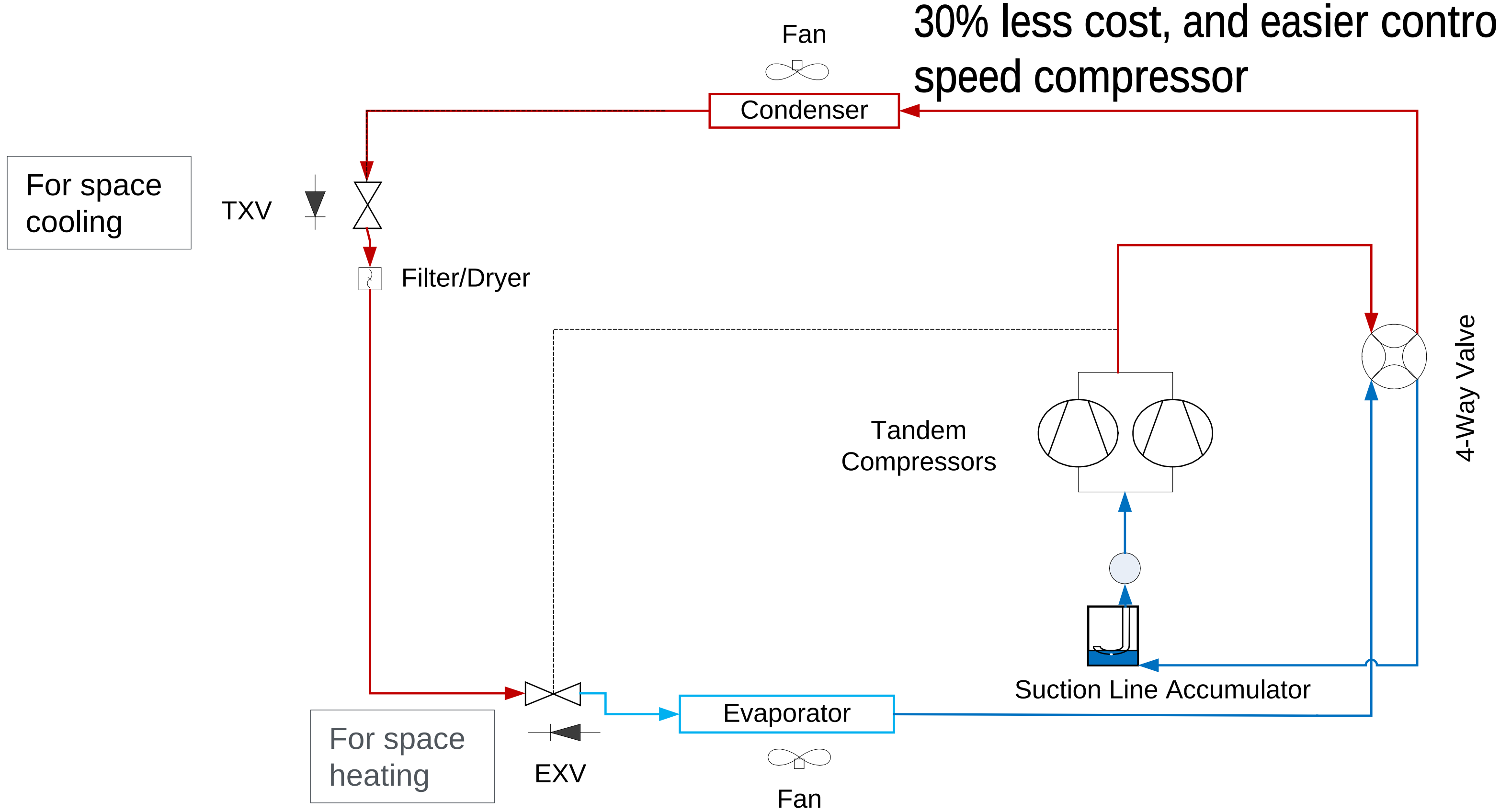
Problem Statement:

1. Typical HPs don't work well at low ambient temps due to very high discharge temp and pressure ratio.
2. HP heating capacity not sufficient to match building load.
3. COP degrades significantly with ambient temperature.



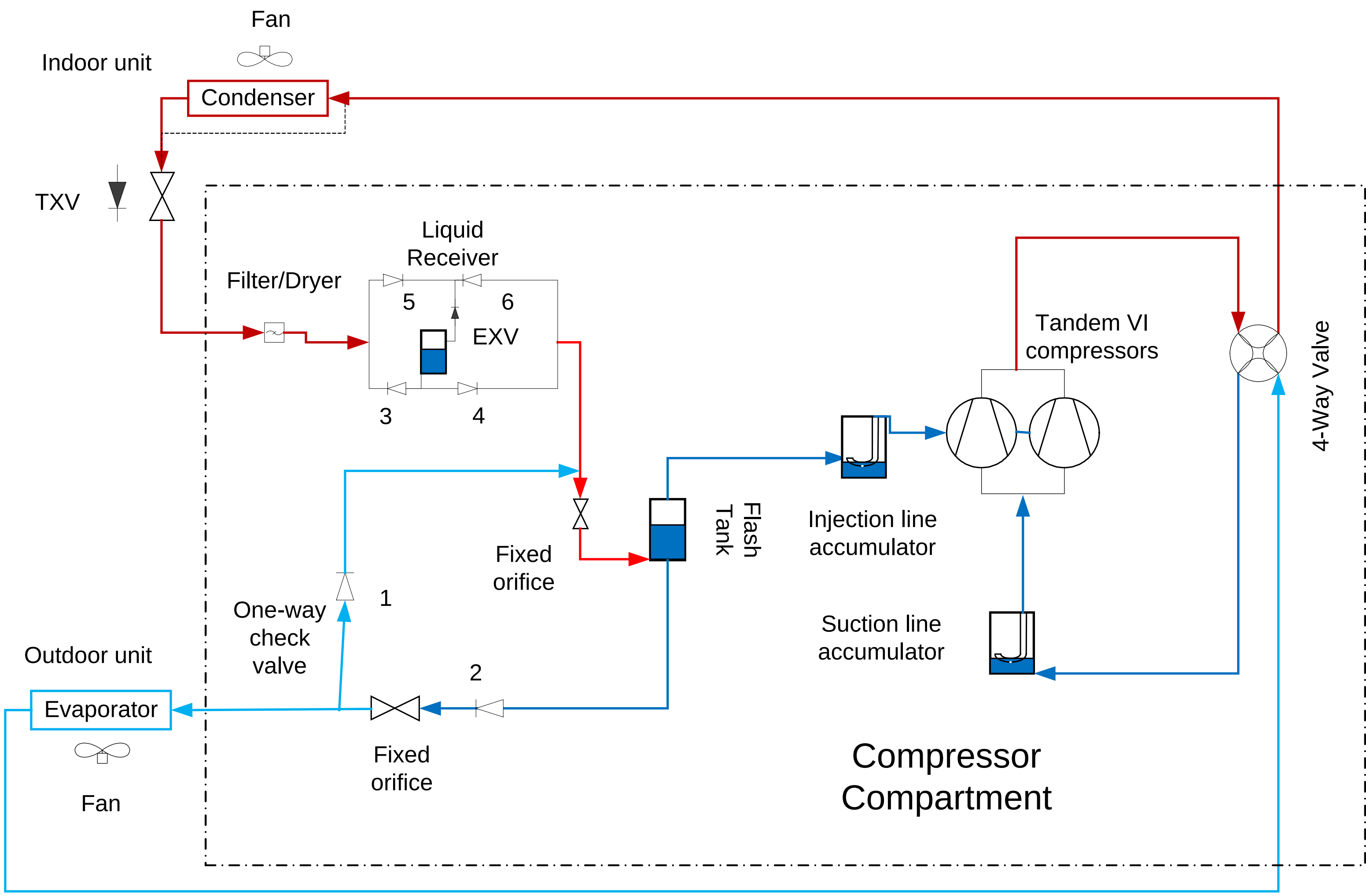
Approach - 'More Cost Effective' Configuration

30% less cost, and easier control than variable-speed compressor



1. ***Two identical, fixed-speed compressors, specially optimized for heating mode, tolerate up to 280°F discharge temperature.***
2. ***A single compressor to match cooling load and heating load at moderately cold temperatures, turn on both compressors at low ambient temperatures when needed.***
3. ***Suction line accumulator + EXV discharge temperature control facilitates charge optimization in a wide ambient temperature range → using TXV and optimizing charge for heating mode is an alternative.***

Approach - 'Premium' Configuration



- *Equal Tandem, Vapor Injection Compressors + Inter-stage Flash Tank + EXV Inter-stage Pressure Control*

Progress and Accomplishments

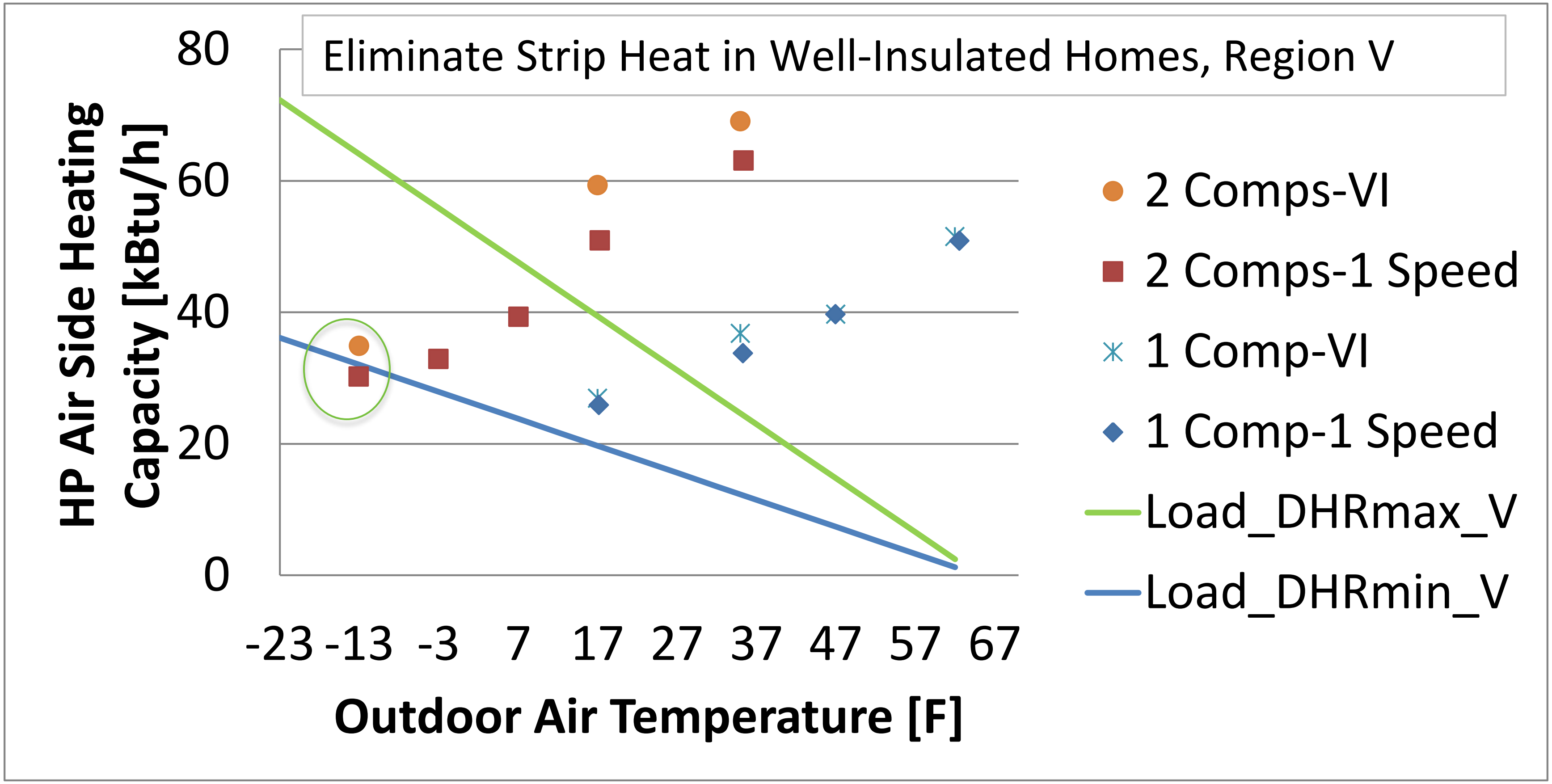
Market Assessment	Concept Design	Lab Prototyping	Optimization	Field Verification

Accomplishments:

Achieved the project goals, i.e. >75% capacity at -13^{O}F, COP >4.0 at 47^{O}F

1. Lab prototype with tandem fixed-speed (76% capacity at -13^{O}F vs. 47^{O}F; COP=4.2 at 47^{O}F)
2. Lab prototype with tandem vapor injection (88% capacity at -13^{O}F vs. 47^{O}F; COP=4.4 at 47^{O}F)
3. ***Field prototype in OH (tandem fixed-speed) operated down to -12^{o}F without auxiliary heat, achieved >40% energy saving versus a baseline fixed-speed HP in the peak heating month***
4. ***Field prototype in AK (tandem VI compressors) operated down to -30^{o}F, achieving 75% capacity and 1.8 COP***
5. Project final report complete

Lab-Measured Heating Capacities



- *CCHPs eliminate auxiliary strip heating down to -13°F in US cold regions.*

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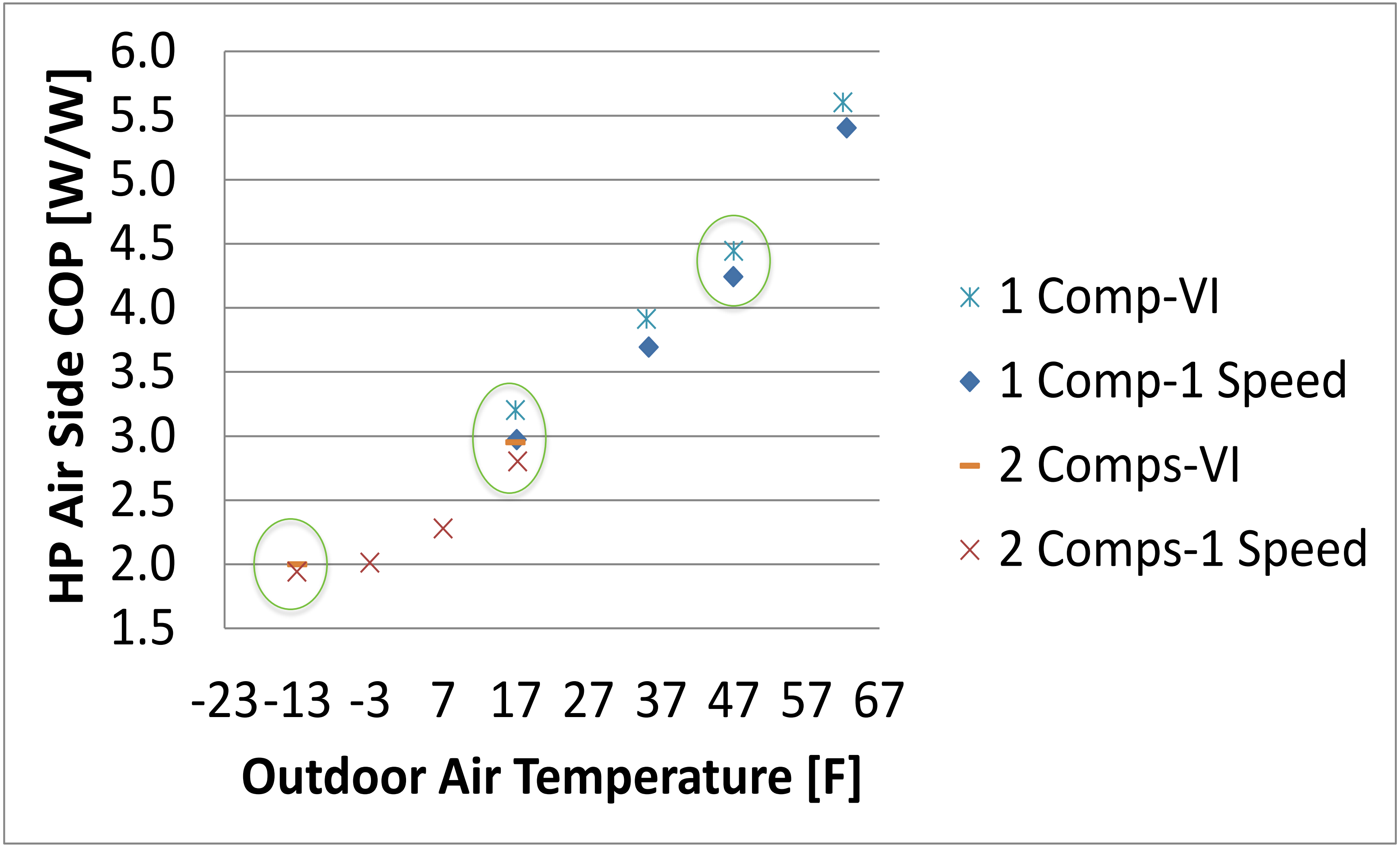
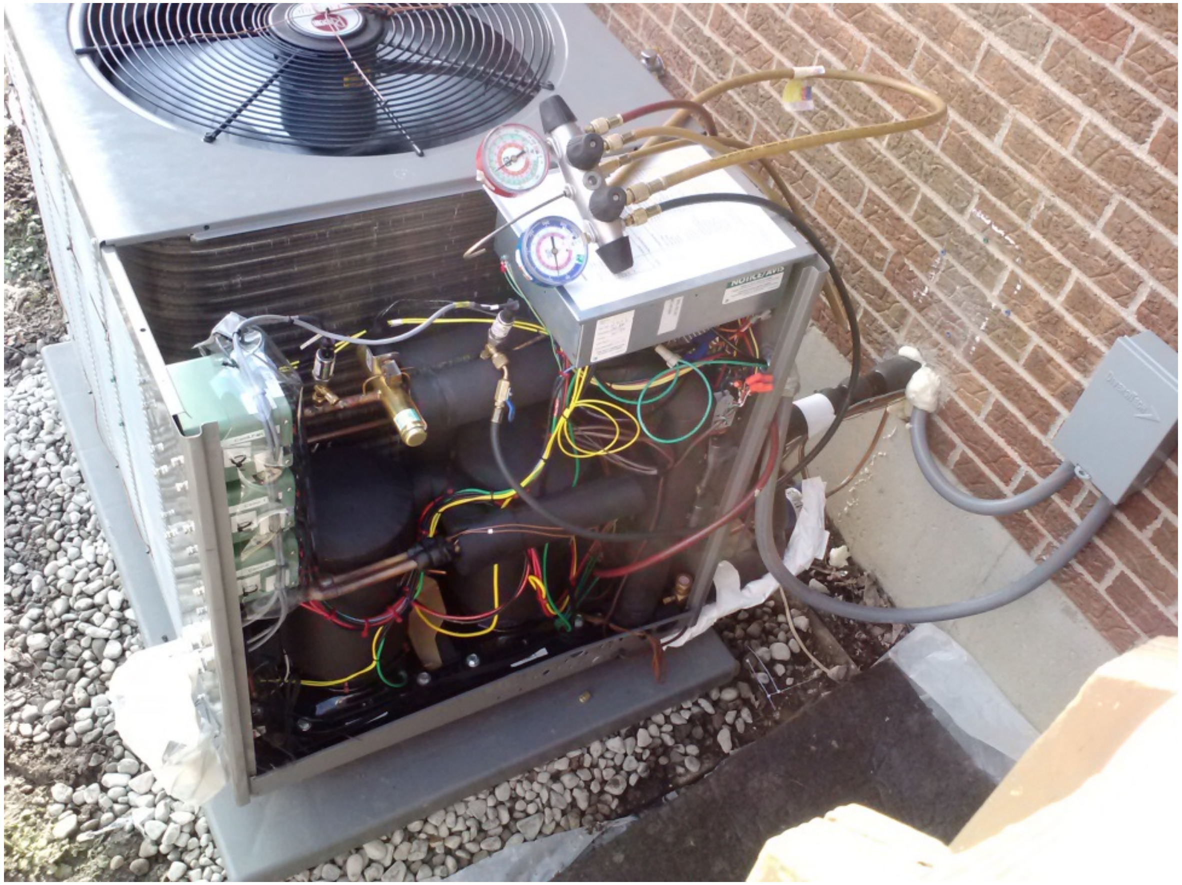
Lab-Measured Heating COPs



- ***The 'premium' system with tandem VI compressors achieved 5% better COPs than the 'more cost-effective' fixed-speed compressor version at various ambients.***

Field Testing of a ‘More Cost-Effective’ System since February 2015, in Sidney, Ohio

Field testing in an occupied Ohio home



Field testing in Ohio. Outdoor unit at a residential home having a design cooling load of 3-ton

Indoor unit and DAQ

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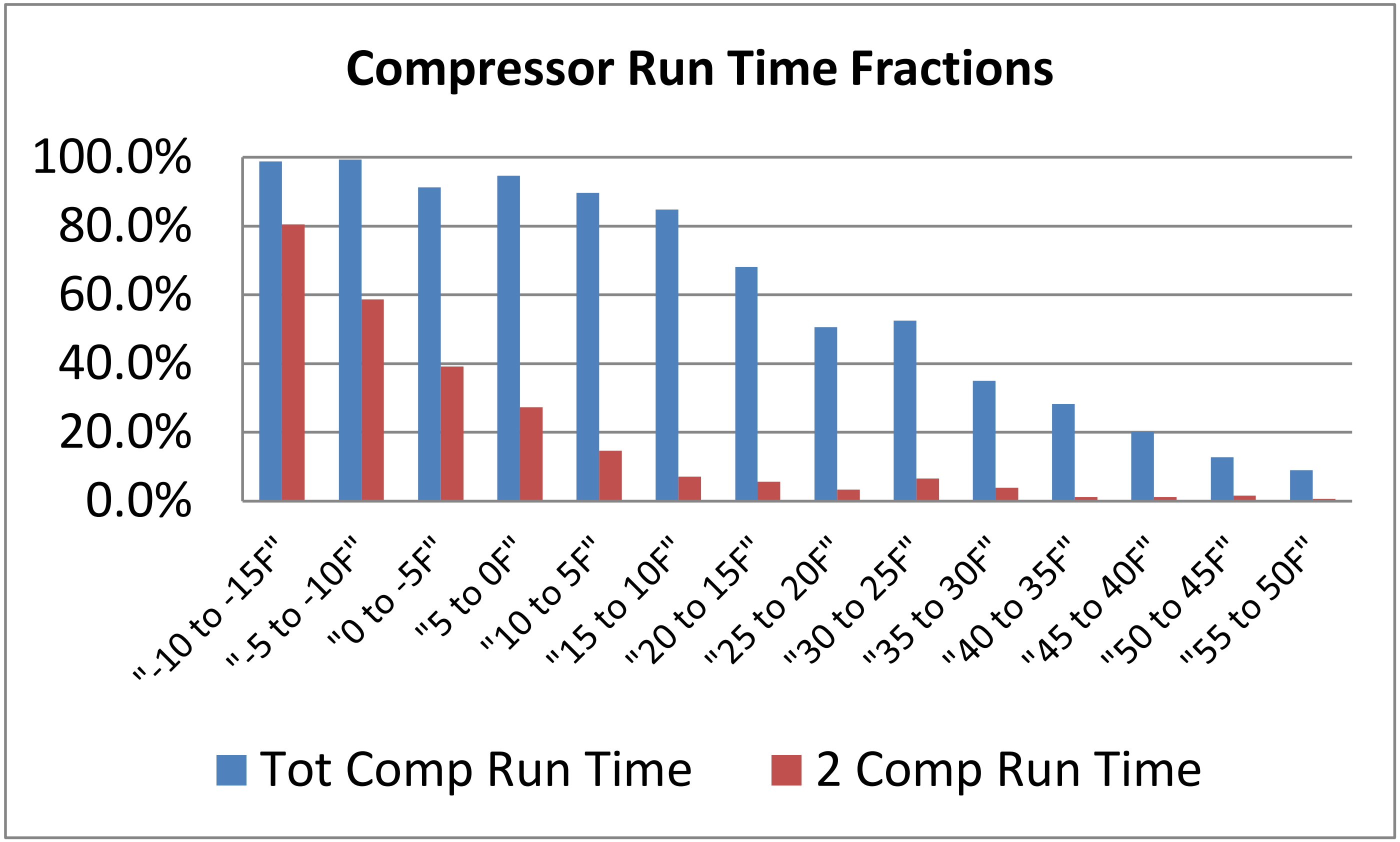
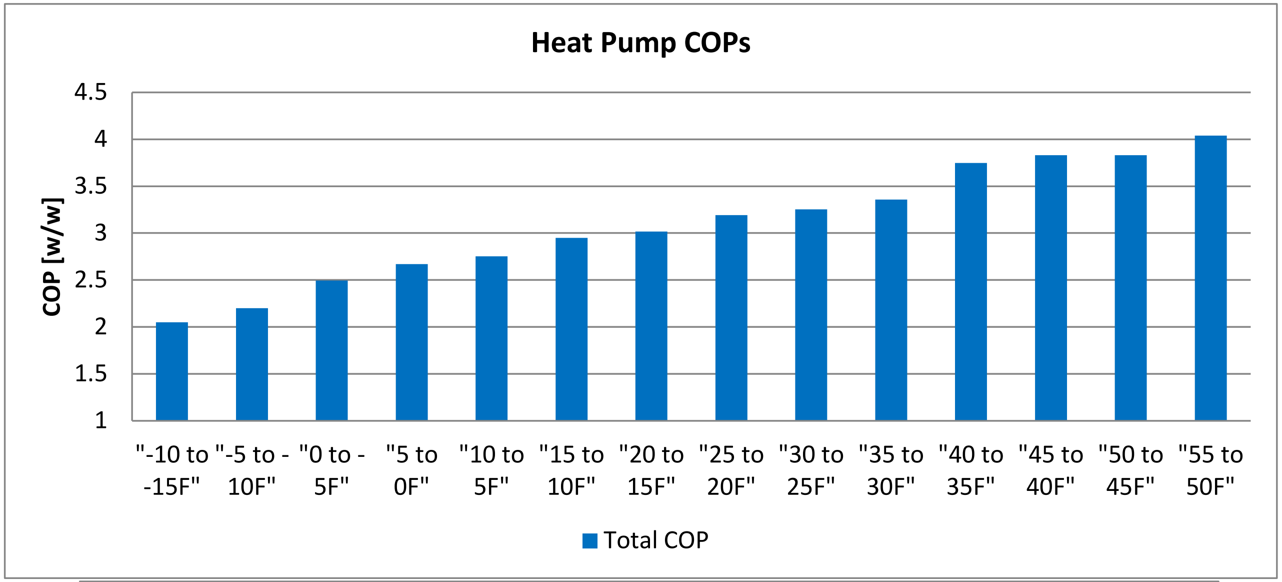
Compressor Running Time Fractions



1. Field ambient temperature went down to -12°F.
2. The second compressor cycled with 80% running time, even at -12°F (having room for more capacity).

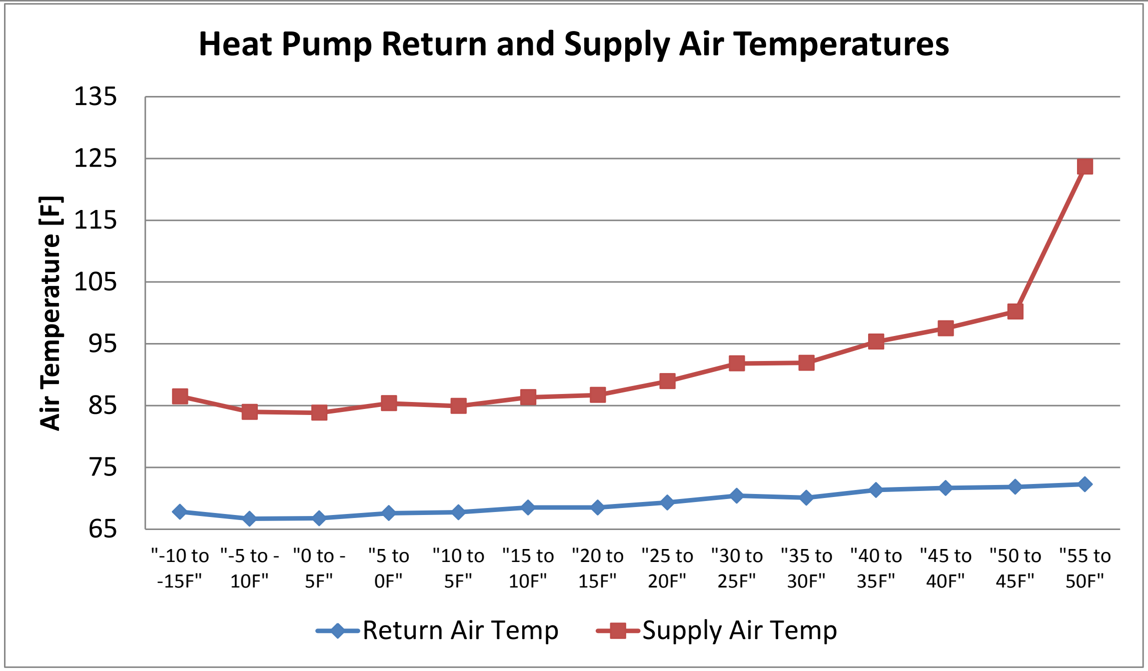
No auxiliary heat needed down to -13°F.

Field Heating COPs and Comfort Level



1. Heat pump COP at -13°F > 2.0.
2. Seasonal, average, heating COP was 3.1, i.e. 10.5 HSPF.

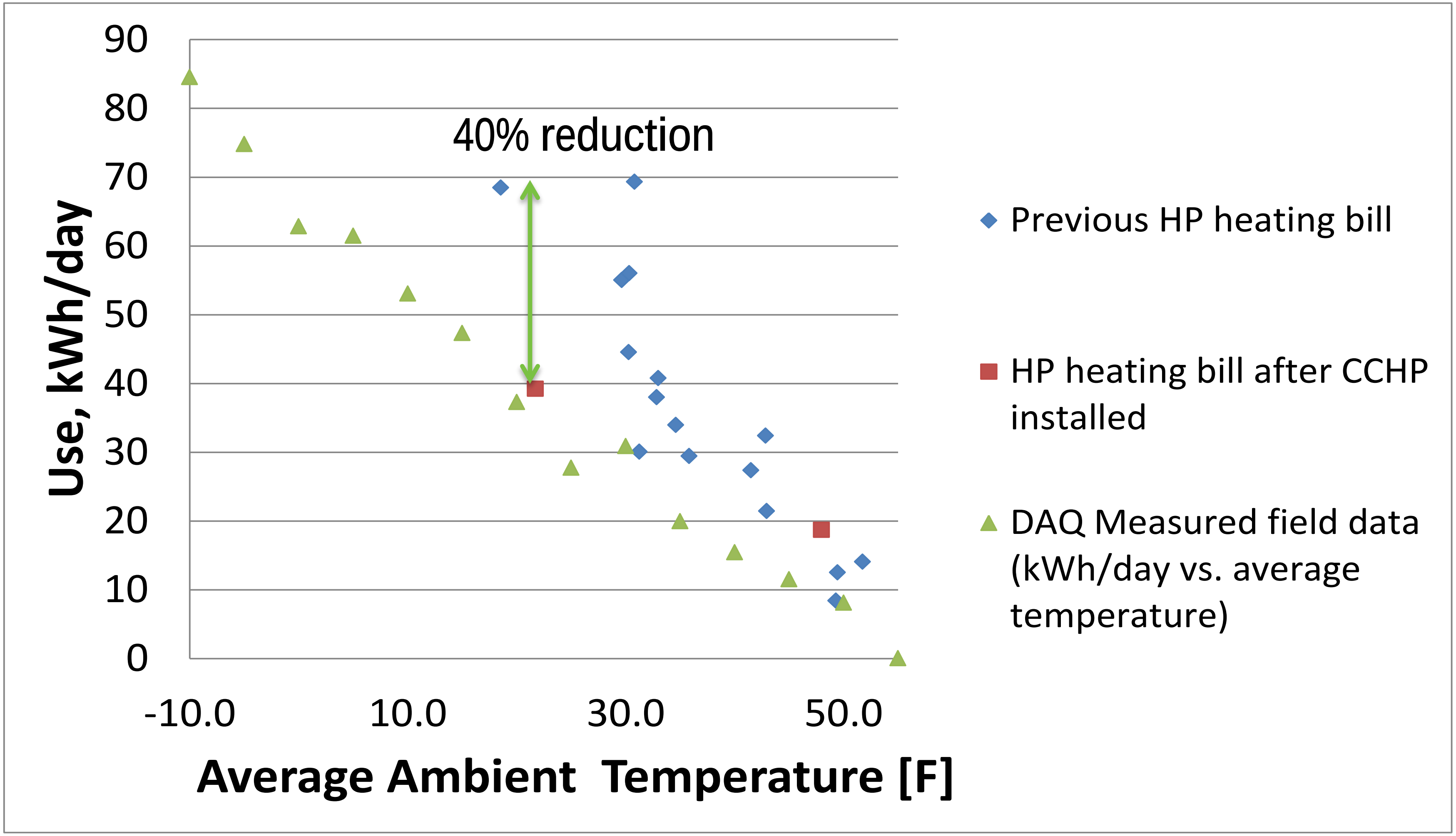
Note: Total COP includes cyclic and frost/defrost losses, etc.



Maintain 20°F air temperature increase at low ambient temperatures.

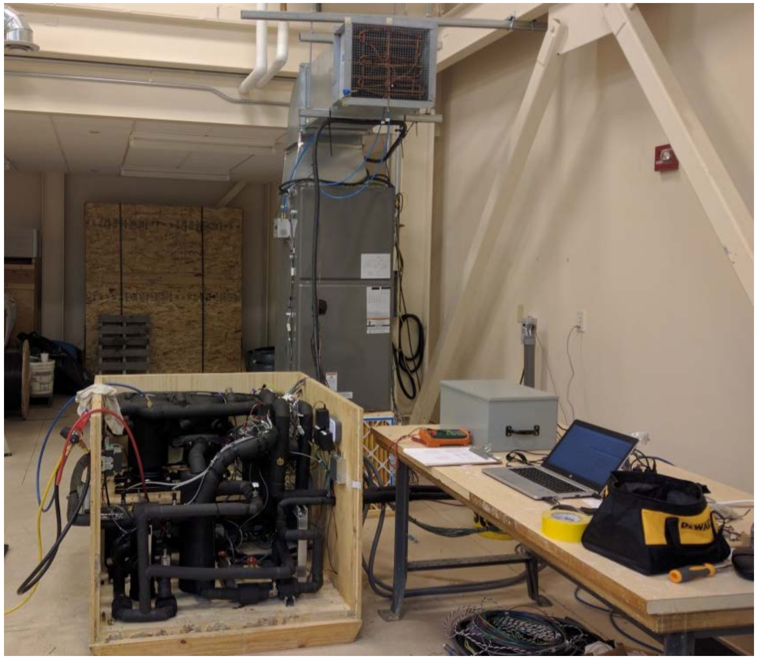
*Temperature setting at 68°F with 2R dead band.

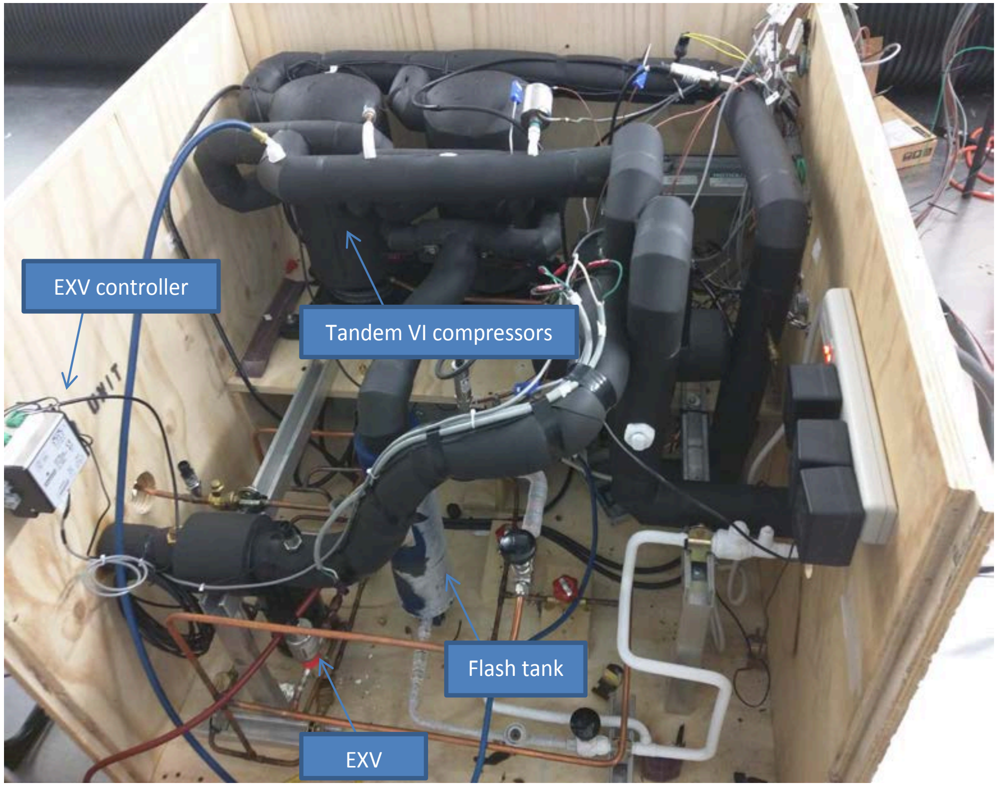
Huge Energy Reduction in Coldest Months Compared to Previous Conventional HP (13.0 SEER/8.0 HSPF)



>40% energy reduction vs. previous HP with similar average temperatures of 20°F

Field Testing of a ‘Premium’ System since September 2016 in Fairbanks, Alaska





Three boxes, put compressor box indoor.

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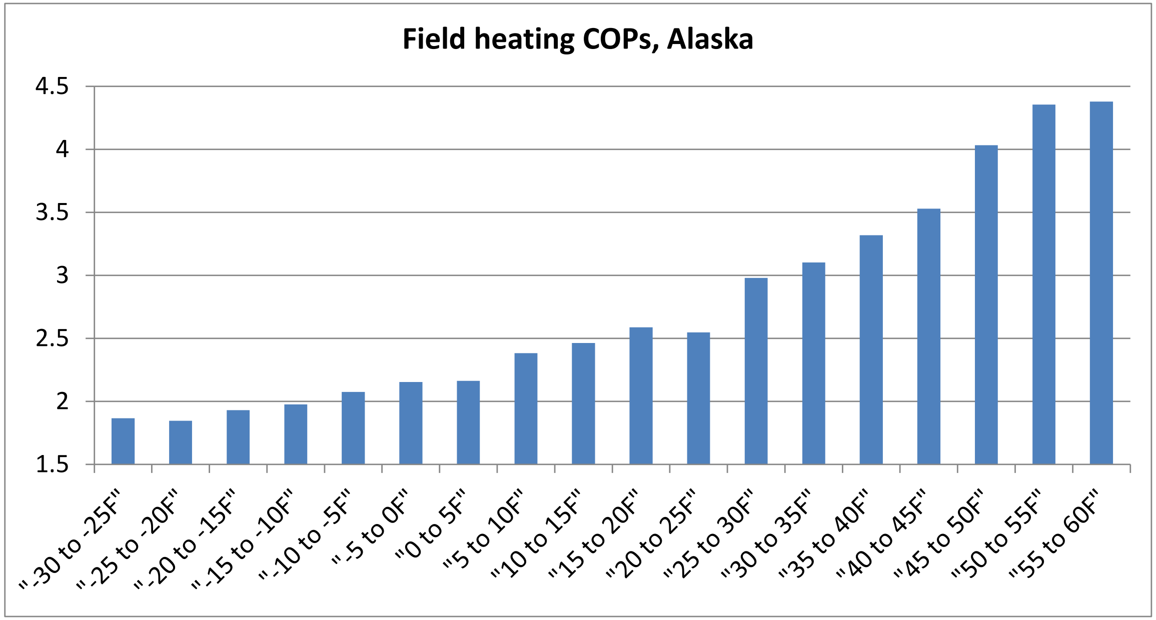
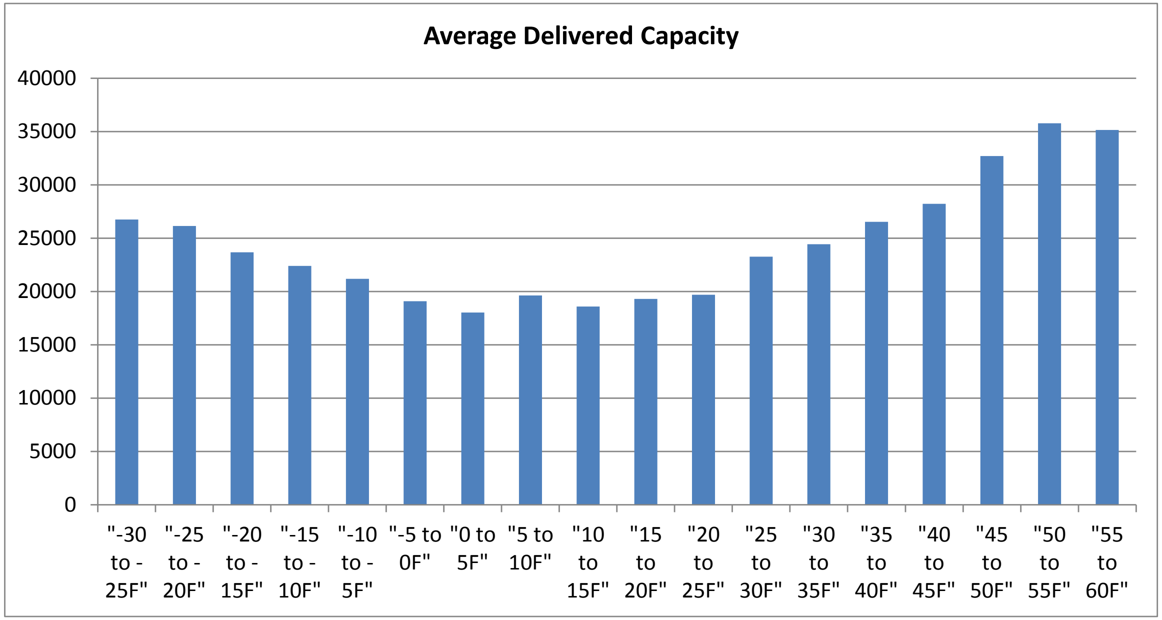
Field Heating COPs and Capacities, Alaska



- Work in most extensive and extreme ambient range.
- 1.8 COP at -30°F



- The second compressor turned on below 5°F.
- Running two compressors provides 75% of rated capacity at -30°F.

Project Integration and Collaboration

Project Integration:

Compressor solutions: Collaborative R&D agreement (CRADA) with Emerson Climate Technologies (US component and control). World leader of compressor technologies. Outcomes of the project will be transferred to US OEMs.

Heat pump development: Provide design, analysis, laboratory and field testing support to Unico Inc. (CRADA).

Partners, Subcontractors, and Collaborators: CRADA partners Emerson Climate Technologies and Unico Inc.

Communications:

- Market assessment report (ORNL research report, http://info.ornl.gov)
- Four presentations for Annex 41, International Energy Agency.
- Six conference papers and ORNL reports, one journal paper.
- Two ORNL invention disclosures (201703856; 201603739).
- Project final report.

Next Steps and Future Plans

Next Steps and Future Plans:

- Collaborate with OEM to make production-ready CCHPs under a new project of the Technology Commercialization Fund.

Market Impact:

Emerson Climate Technologies to provide compressor solutions to US OEMs interested in developing CCHPs.

Publications:

- Bo Shen, Omar Abdelaziz, Van Baxter and Keith Rice, 2015, "High Performance Cold Climate Heat Pump (CCHP) – Final Report", ORNL Report, ORNL/TM-2015/784.
- Bo Shen, Omar Abdelaziz, Keith Rice, Van Baxter and Hung Pham, "Cold Climate Heat Pumps Using Tandem Compressor", Conference Paper in 2016 ASHRAE Winter Conference.
- Van Baxter, Eckhard Groll and Bo Shen, 2014, "Air Source Heat Pumps for Cold Climate Applications: Recent U. S. R&D Results from IEA HPP Annex 41", Journal Article in Federation of European Heating, Ventilation, and Air Conditioning Associations (REHVA) European HVAC Journal.
- Bo Shen, Omar Abdelaziz, Van Baxter and Keith Rice, 2014, "Compressor Selection and Equipment Sizing for Cold Climate Heat Pumps", Conference Paper in 11th International Energy Agency Heat Pump Conference.
- Van Baxter, Eckhard Groll, Omar Abdelaziz and Bo Shen, 2013,"IEA HPP Annex 41 – Cold Climate Heat Pumps: Task 1 Report – Literature and Technology Review – United States", ORNL Report, ORNL/TM-2013/472.
- Omar Abdelaziz and Bo Shen, 2012,"Cold Climates Heat Pump Design Optimization", Conference Paper in ASHRAE 2012 Winter Conference.
- Omar Abdelaziz and Bo Shen , 2011, "Development of a High Performance Air Source Heat Pump for the US Market", Conference Paper in 10th International Energy Agency Heat Pump Conference.
- Gannate Khowailed, Karen Sikes, and Omar Abdelaziz, 2011, "Preliminary Market Assessment for Cold Climate Heat Pumps", ORNL Report, http://info.ornl.gov/sites/publications/files/Pub32941.pdf.

REFERENCE SLIDES

Project Budget

Project Budget: DOE total $2,839K- FY11-16
Cost to Date: ~$2,839k through March 2017
Additional Funding: None expected

Budget History					
FY 2011 to FY 2015 (past)		FY 2016 (current)		FY 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$2,439K	*	$400k	*	NA	NA

- In-kind contribution from CRADA partner –exceeds DOE funding level; exact total is confidential information

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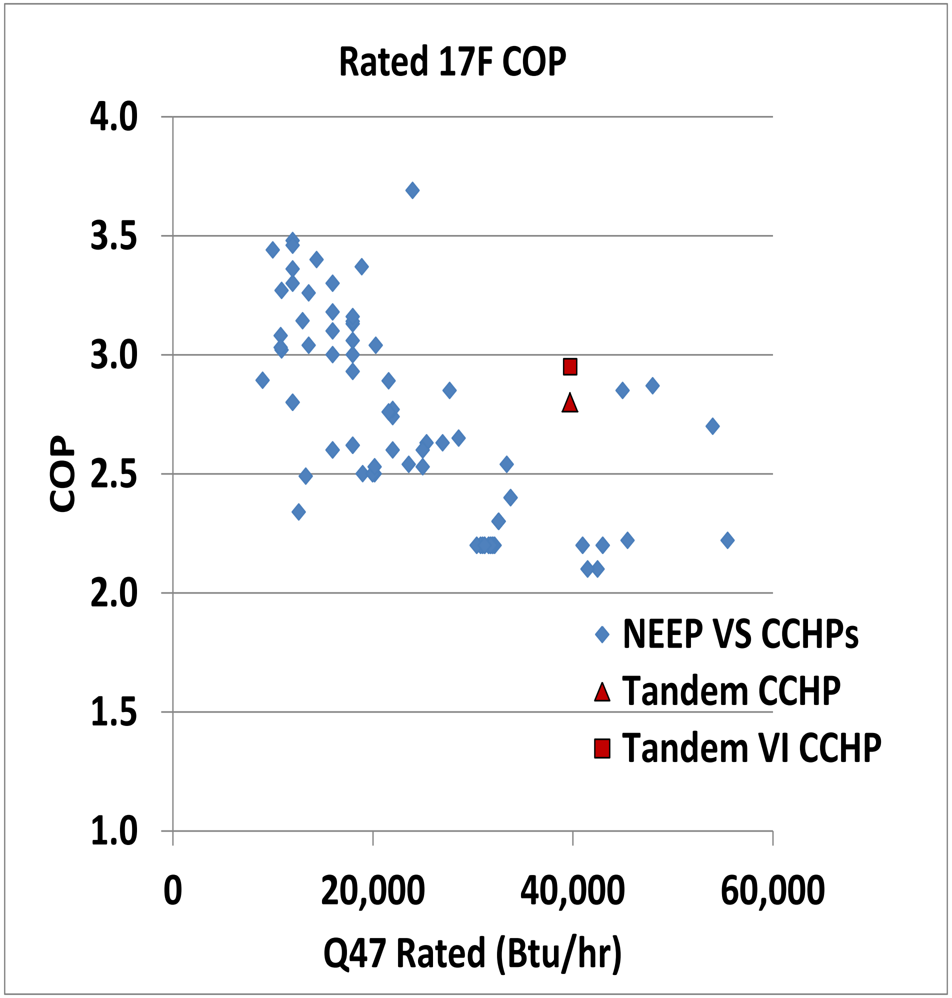
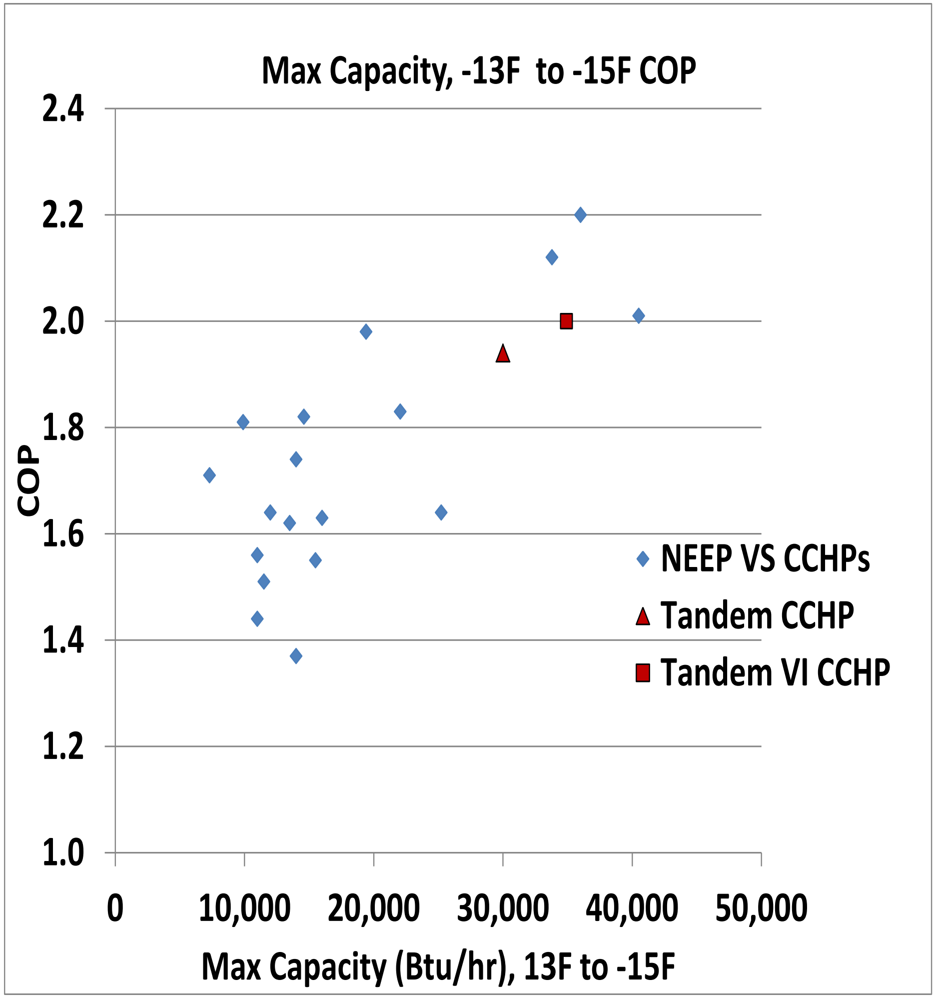
Project Plan and Schedule

Original initiation date: 01-Oct-2010 -- Planned completion date: 30-May-2017
(minor delays in lab prototype fabrication and testing schedules)
Go/no-go decision points
* March '14 Tandem fixed-speed lab prototype met project goals– ***Passed***
* Sept'15 Field testing of HP using tandem fixed-speed compressors– ***Passed***
* June'15 Tandem vapor-injection lab prototype met project goals– ***Passed***

	Milestone/Deliverable (Originally Planned) use for missed											
	Milestone/Deliverable (Actual) use when met on time											
	FY2014				FY2015				FY2016			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Fab. CCHP prototype, install, begin tests												
G/ng: tandem single-speed prototype met project goals												
Develop control strategy and design control board												
Fabrication of Ohio field test units and initiate installation												
G/ng: tandem VI prototype met project goals												
G/ng: Complete field testing report for tandem single-speed												
Complete CRADA final report with Emerson												
Fabrication of HP using VI compressors for Alaska field testing												
Complete field testing in Alaska by May, 2017												

Compared to other CCHPs on the market (Northeast Energy Efficiency Partnerships, CCHP Listing)





1. ***ORNL prototypes reached top efficiency level in the target capacity range, as compared to Japanese VRF mini-split and multi-split units.***
2. ***ORNL prototypes are much less expensive (estimated cost: $4K for a 3-ton split CCHP).***