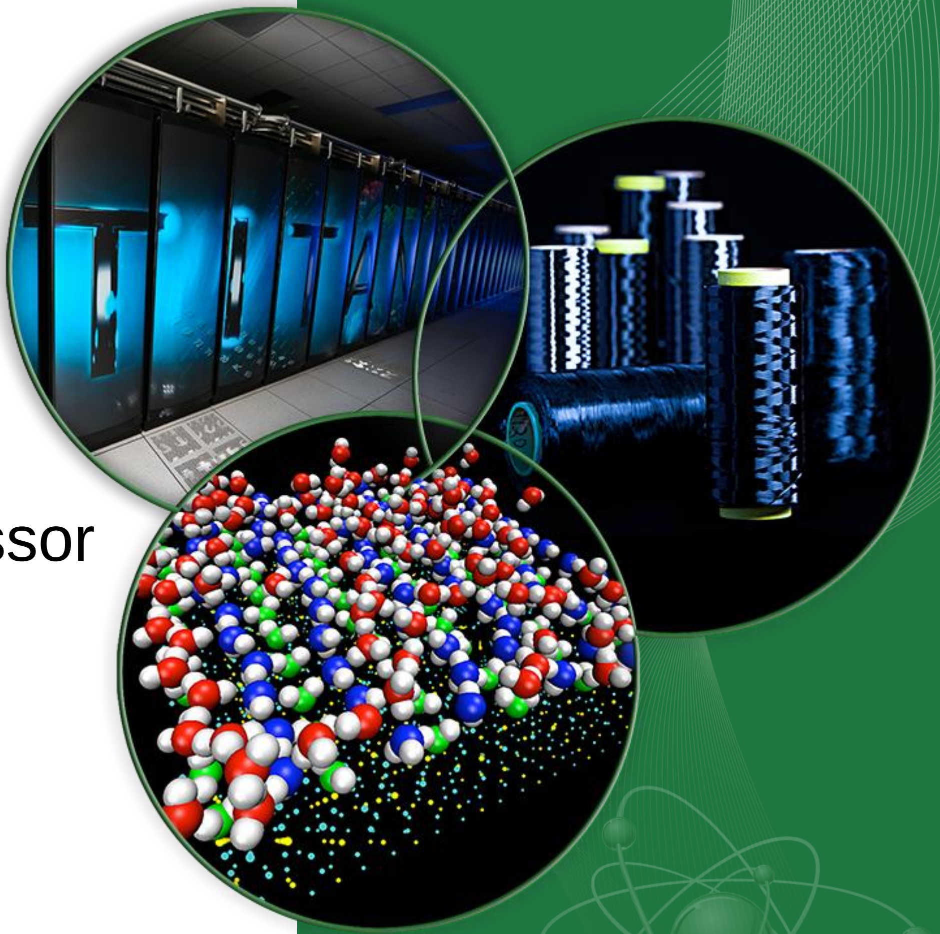
IEA HPP Annex 41 – Cold Climate Heat Pumps: Improving Low Ambient Temperature Performance of Air-Source Heat Pumps



Tandem, single-speed compressor air-source heat pump system laboratory and preliminary field test results

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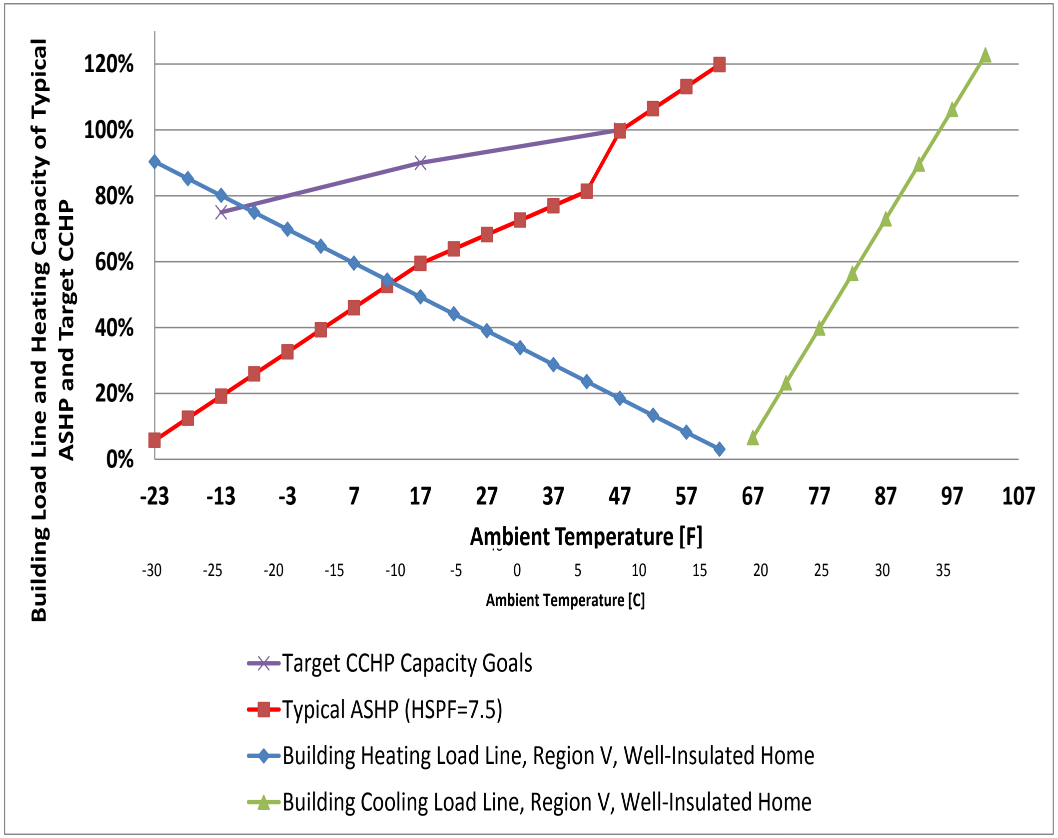
Target Market: Replace electric resistance heat in cold climates.

1.1 Background

Problem Statement:

- Typical ASHPs don't work well at low ambient temps due to very high discharge temp and pressure ratio
- Single-speed ASHP heating capacity not sufficient to match building load
- COP degrades significantly with ambient temperature



Technical Goals (Project outputs):

Develop a CCHP to minimize resistance heating

- COP@ 8.3°C > 4.0; HP capacity@ -25°C > 75% of rated capacity@ 8.3°C.
- Maximize COPs at -8.3°C and -25°C with acceptable payback period.

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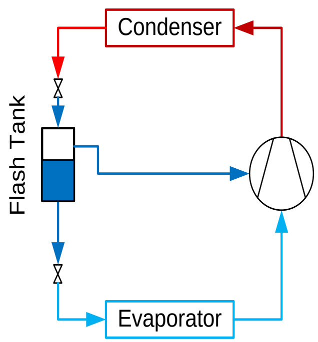
1.2 Extensive System Configurations

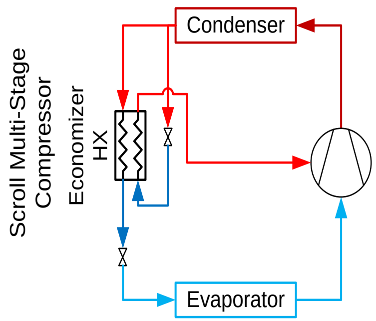
Copeland Scroll

Single-stage compression concepts:

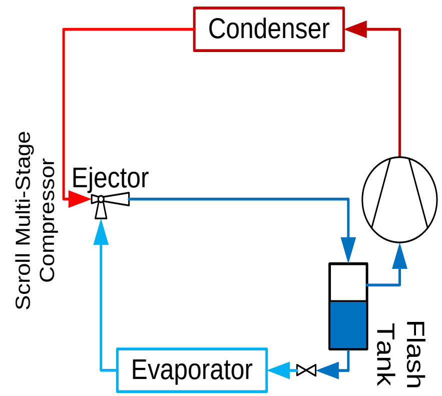
Vapor injection with flash tank



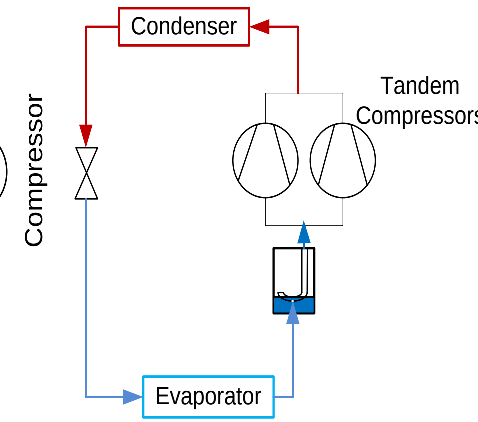
Vapor injection with economizer



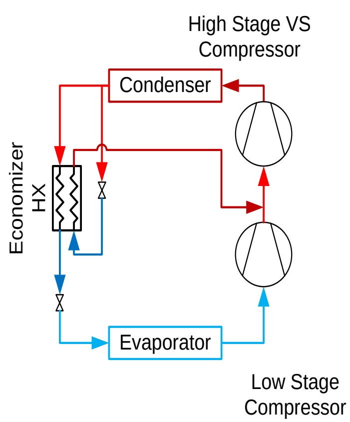
Ejector cycle



Tandem (parallel) and multi-capacity compressor(s)



Two-stage (series) compression w/ inter-stage economizing



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

ORNL to assist in modeling, analysis, component sizing, and performance verification testing

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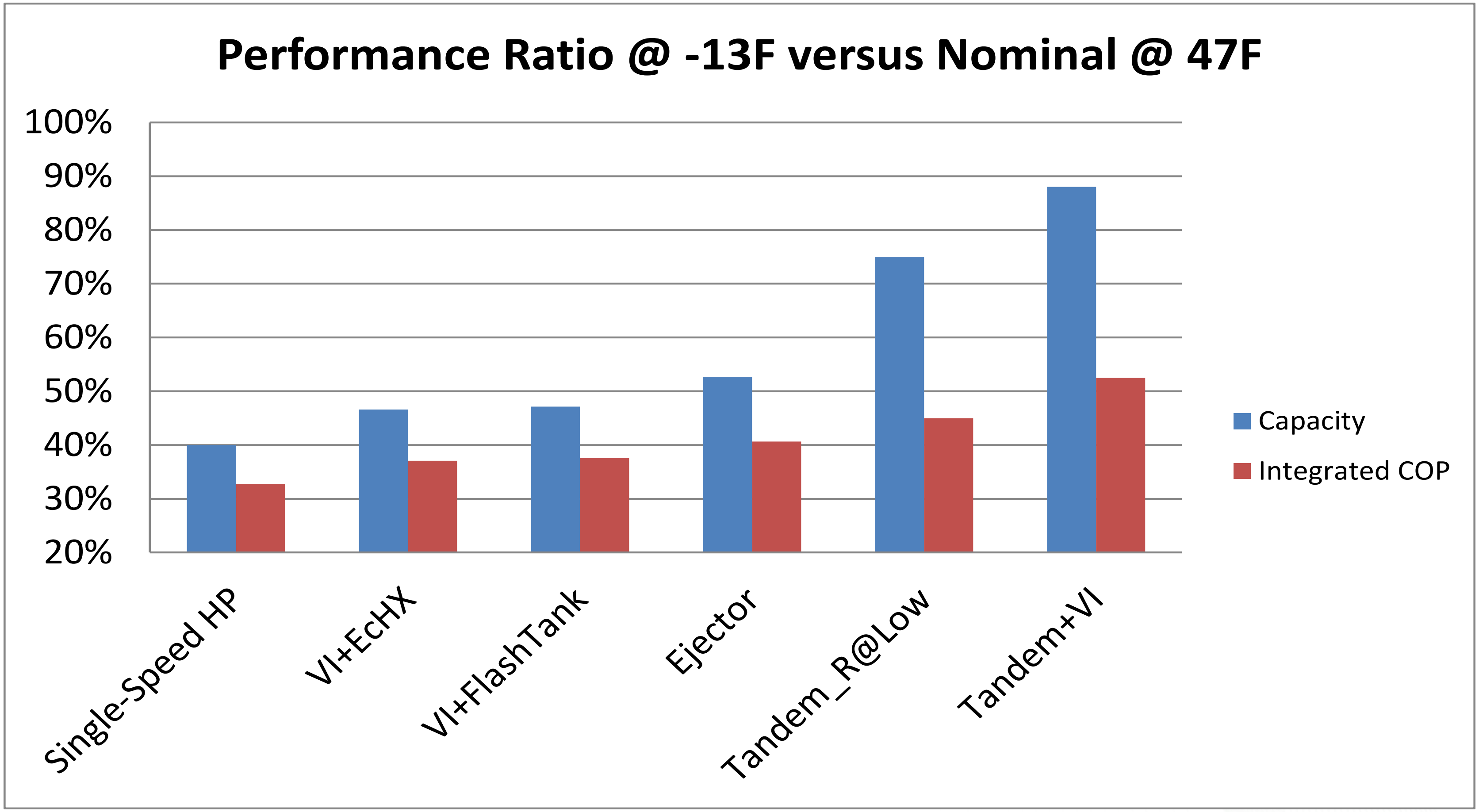
1.3 Compare Different Design Options



Over-capacity is the key to meet the 75% capacity goal, i.e. using tandem compressors.
Vapor injection boosts HP COP at -25°C.

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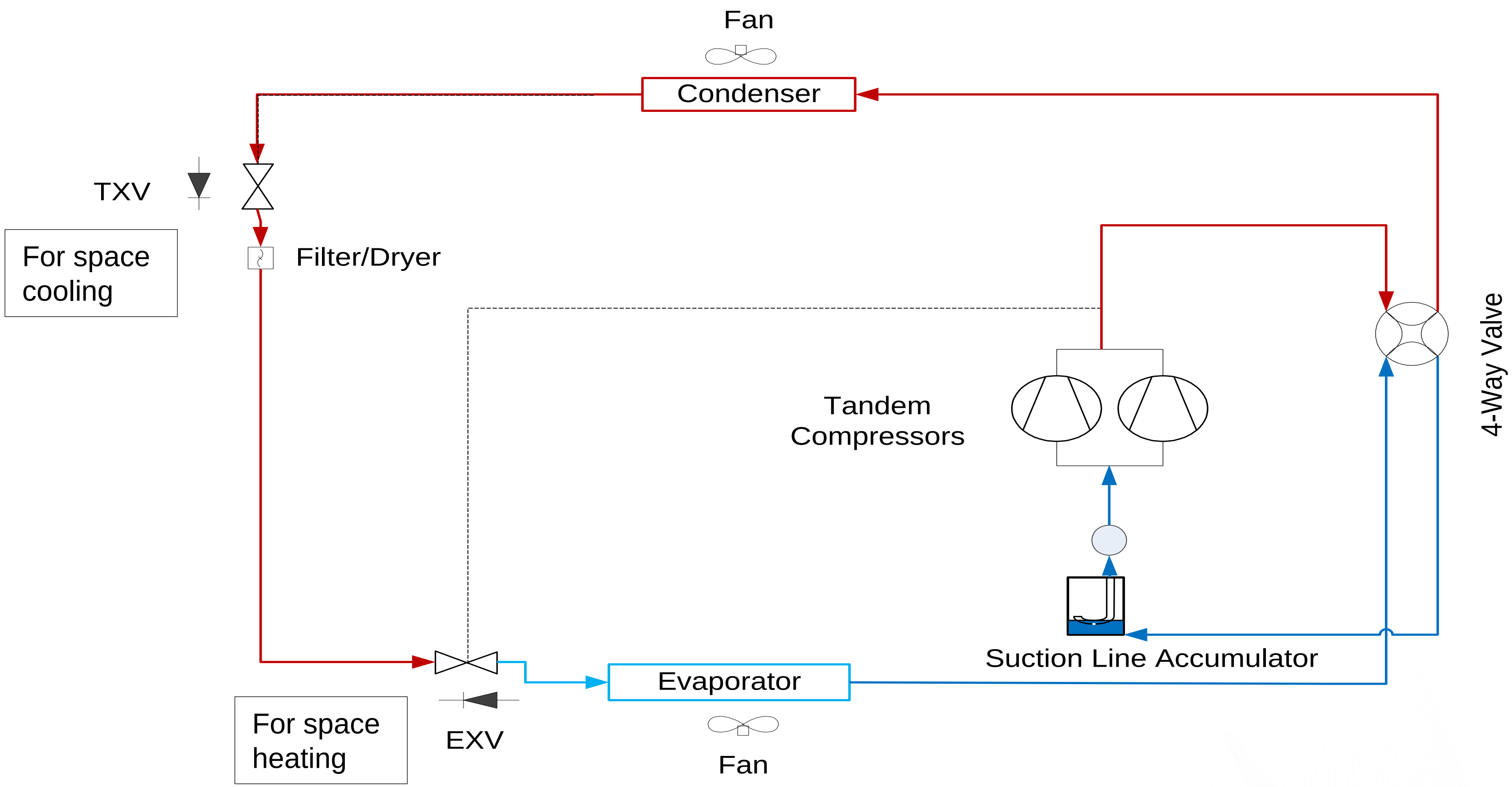
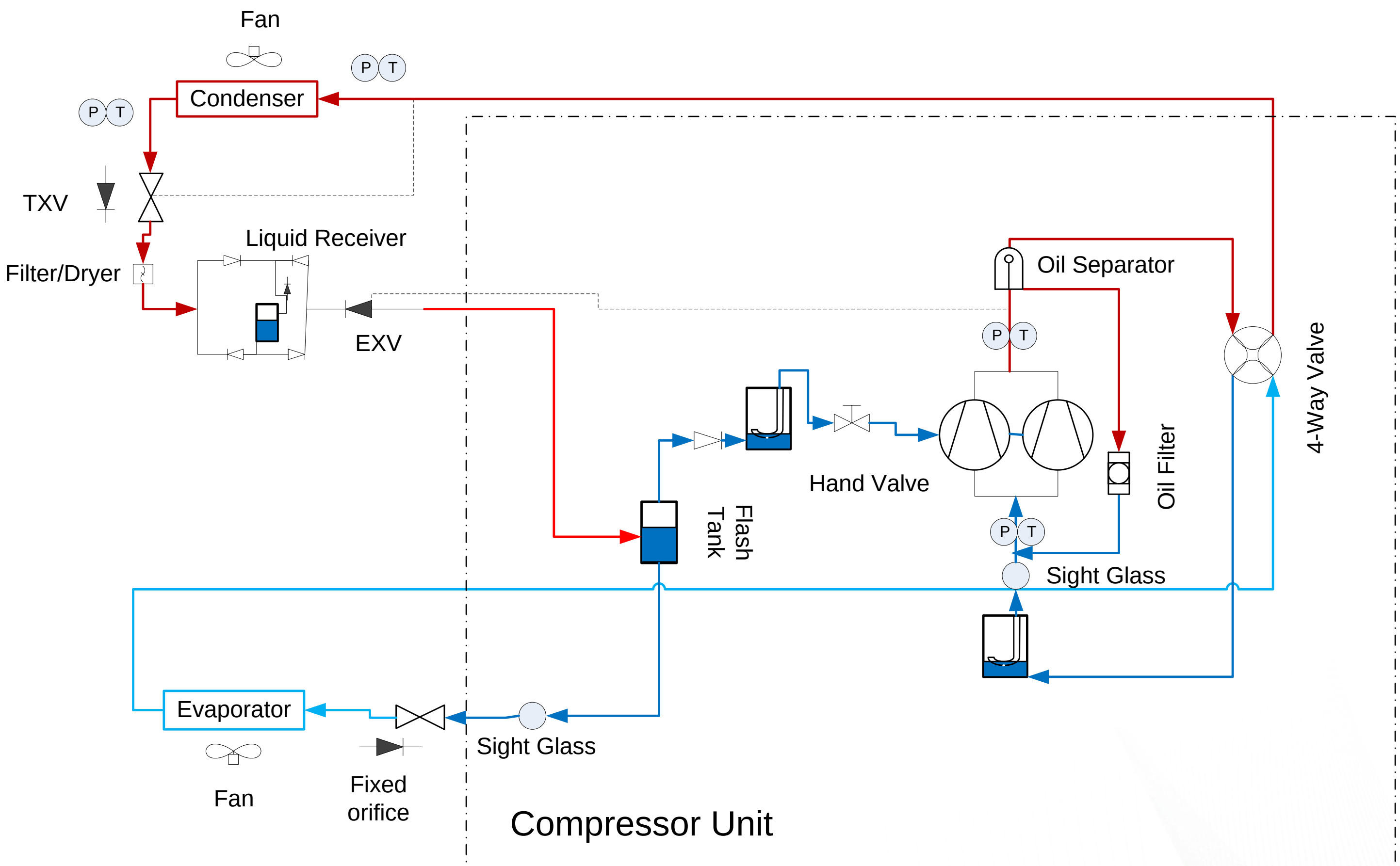
2.1 'More Cost Effective' Configuration



- *Use two identical, single-speed compressors, specially optimized for heating mode , tolerate up to 138°C discharge temperature.*
- *Use a single compressor to match cooling load, and heating load at moderately cold temperatures, turn on both compressors at low ambient temperatures when needed.*
- *(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.*

2.2 'Premium' Configuration



- ***Equal Tandem, Vapor Injection Compressors + Inter-stage Flash Tank + EXV Discharge Temperature Control .***

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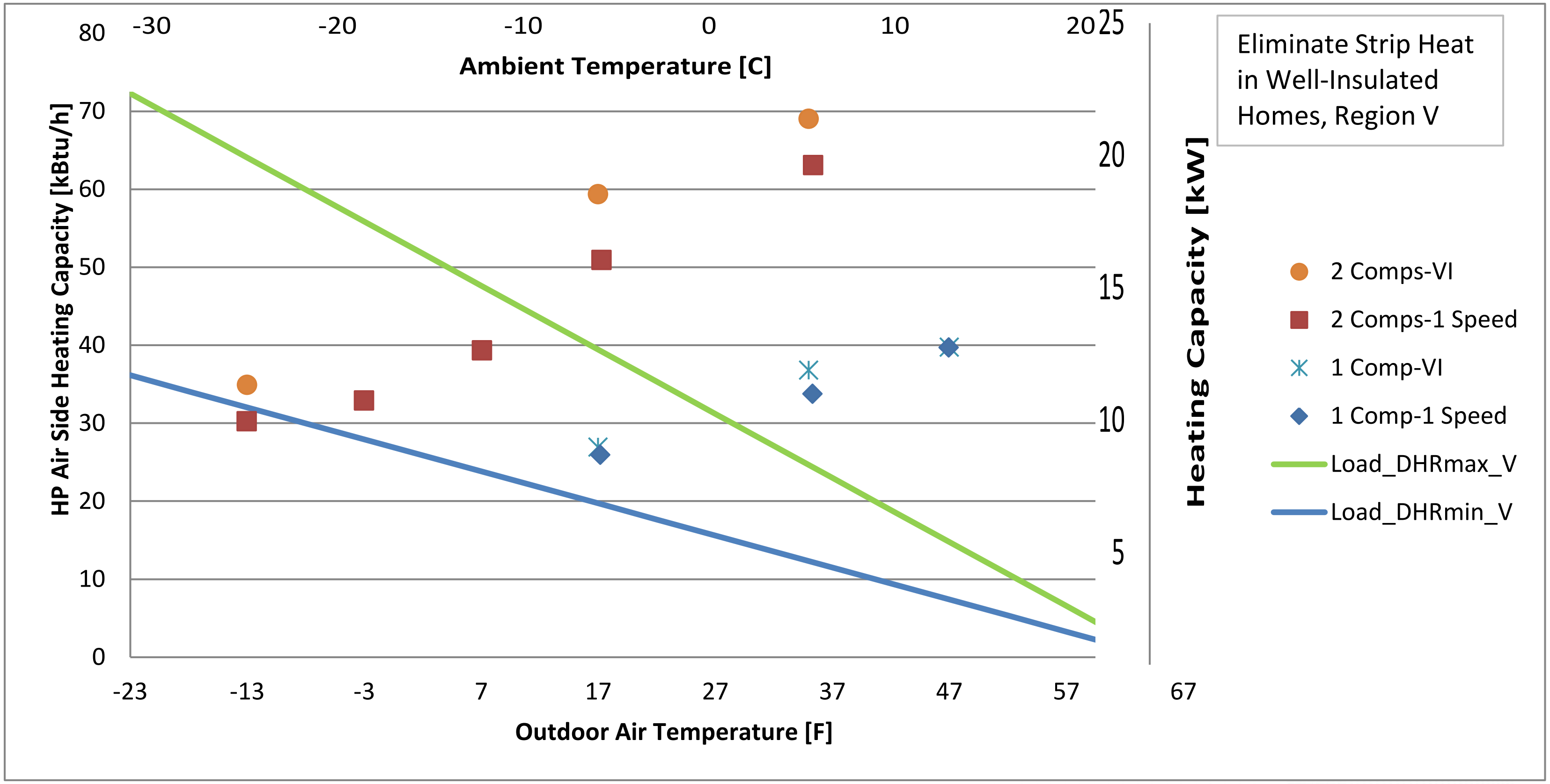
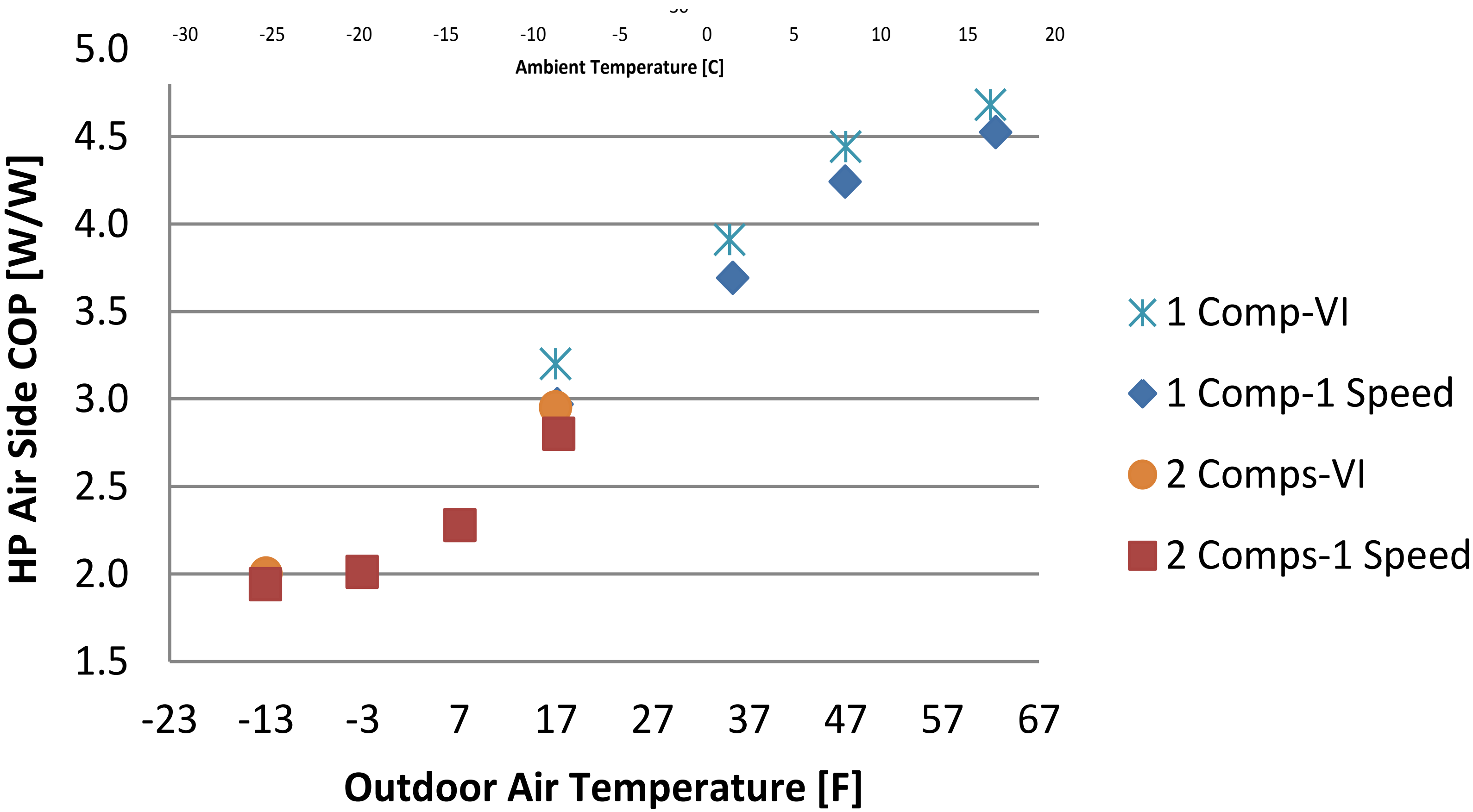
2.3 Lab Measured Heating Capacities



2.4 Lab Measured Heating COPs



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

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2.5 HSPF (DHRmin = 11.7kW) – AHRI 210/240

Heating Season Ratings, Region: IV [HSPF in W/W; OD design temperature → -15°C]		
'More Cost-Effective'	'Premium'	Case
3.29	3.47	Based on DHRmin
3.21	3.46	Based on DHRmax

Heating Season Ratings, Region: V [HSPF in W/W; OD design temperature → -23.3°C]		
'More Cost-Effective'	'Premium'	Case
2.94	3.13	Based on DHRmin
2.81	2.96	Based on DHRmax

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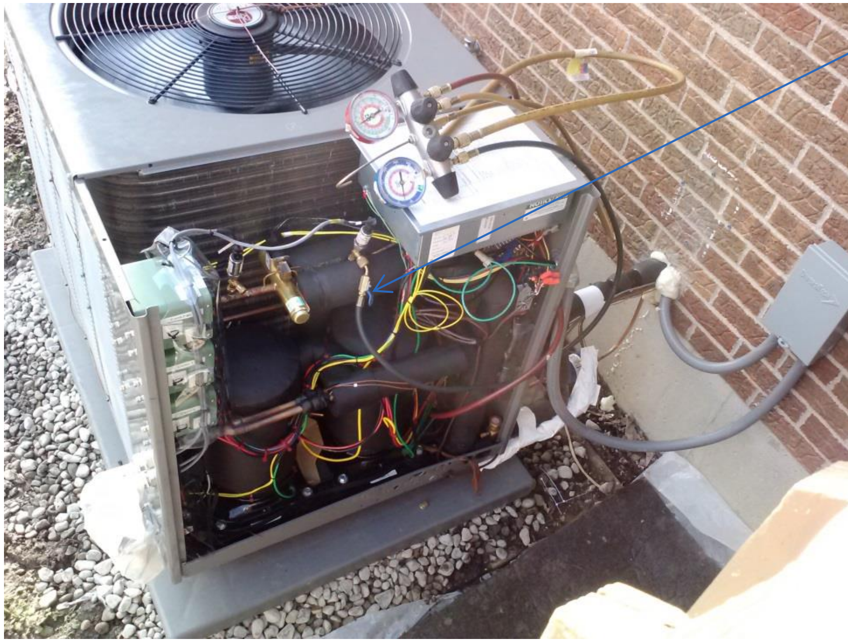
3.1 Field Testing of a ‘More Cost-Effective’ System

Insulated compressors’ shell



Field testing in OH-outdoor unit, at a residential home having a design cooling load of 3-ton (10.6 kW)

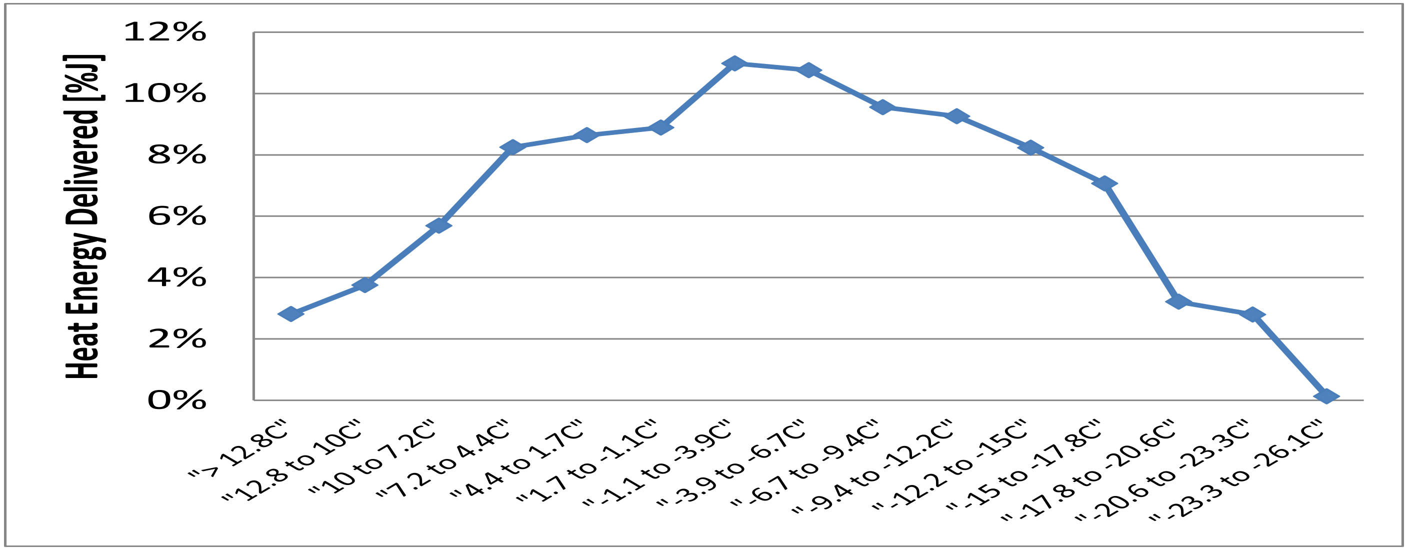
-Indoor Unit and Data Acquisition, record data point every half minute.

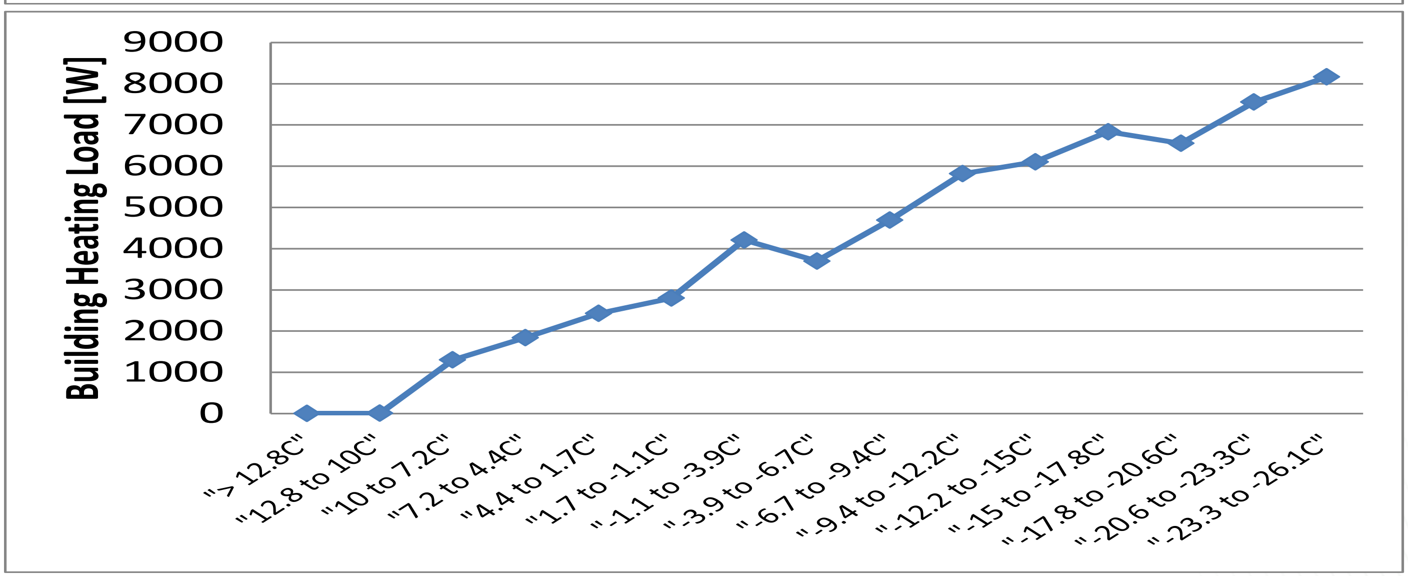
3.2 Parameters of Field Testing Unit

Parameters (heating mode)	Indoor Fin-&-Tube Coil	Outdoor Fin-&-Tube Coil
Face area, ft^2 (m^2)	3.30 (0.307)	22.3 (2.07)
Total Tube Number	84	64
Number of rows	3 (cross counter-flow)	2 (cross counter-flow)
Number of parallel circs	9	6
Fin density, fins/ft (fins/m)	168 (551)	264 (866)
	Indoor Blower (High/Low[1])	Outdoor Fan
Flow Rate, cfm (m^3/s)	1500/1250 (0.708/0.590)	3500 (1.652)
Power [W]	322/203	300

-the indoor and outdoor heat exchangers originally used for a 5-ton (17.7 kW) heat pump, i.e. oversized for single-compressor operation (3-ton/10.6 kW).
-Power source: 240 V, 60 HZ, single-phase.

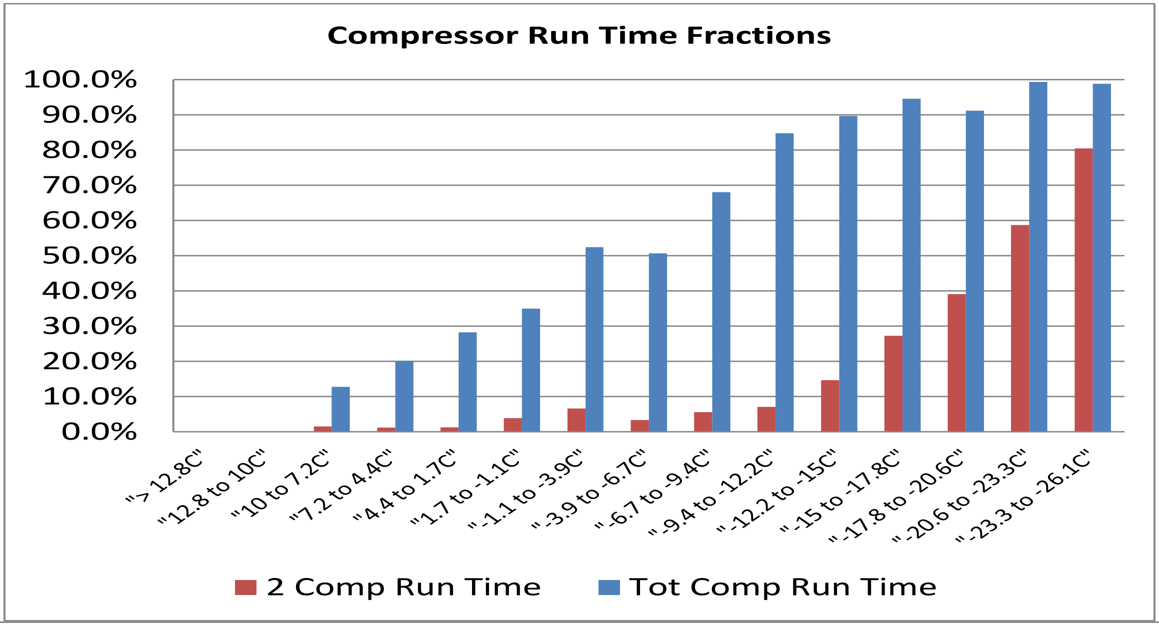
3.3 Field Testing from February to May, 2015 (half winter)





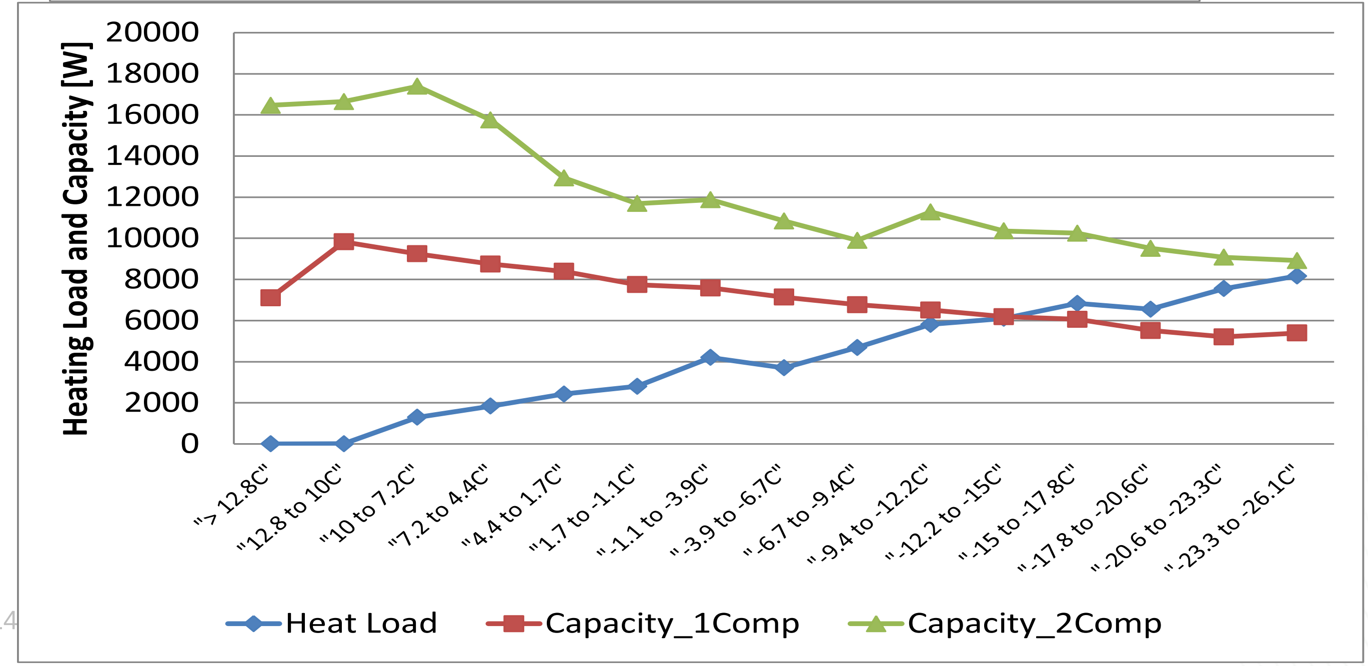
-Field ambient temperature went down to -24.4°C (-12°F).
-Seasonal, average, heating COP was 3.16, i.e. 10.8 HSPF.
-supplemental resistance energy use was 1.3% in total heating energy.

3.4 Compressor Running Time Fractions

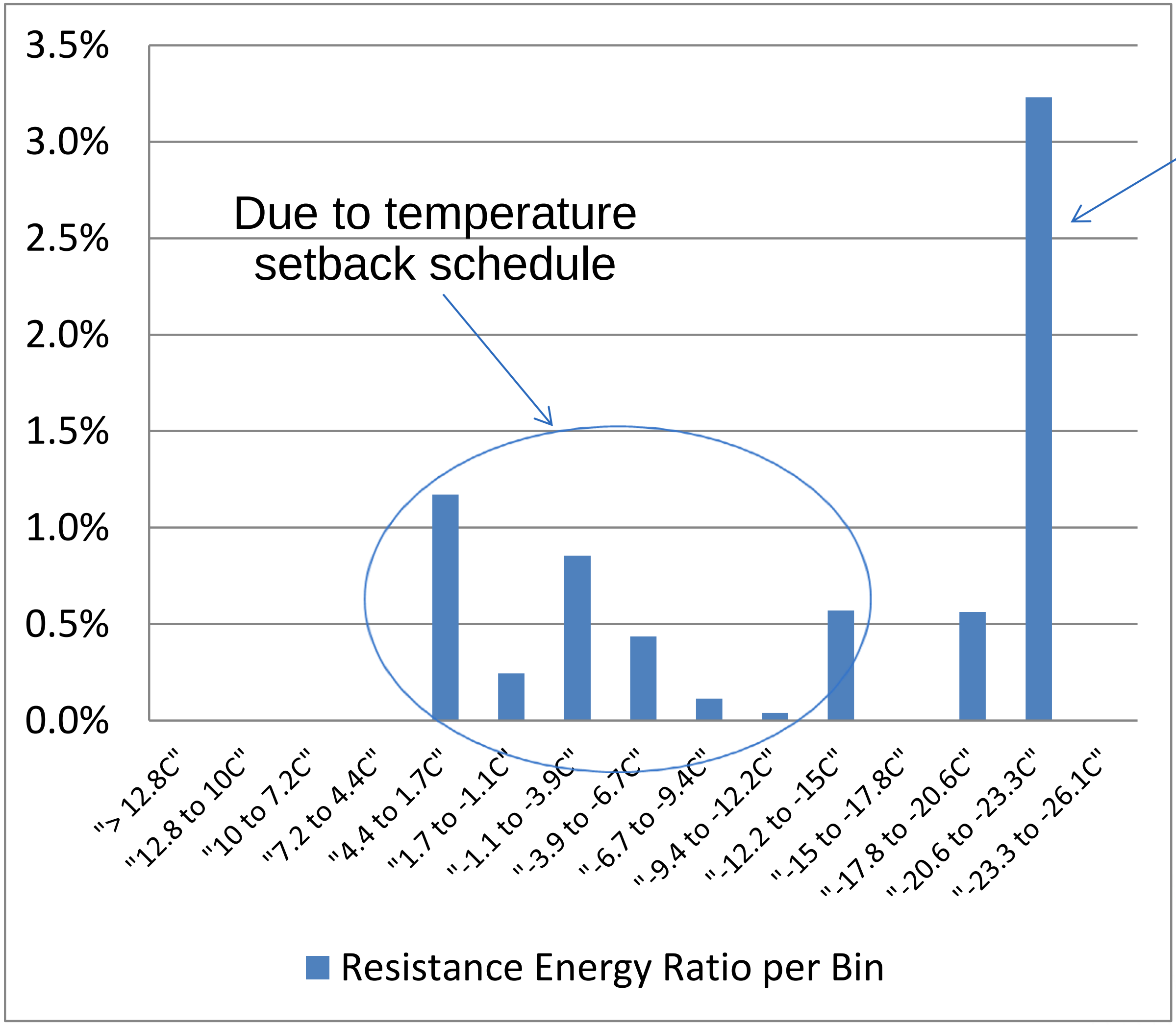


-The second compressor cycled with 80% running time, even at -25°C (having room for more capacity).

-The second compressor was needed at ambient temperatures below -12°C.

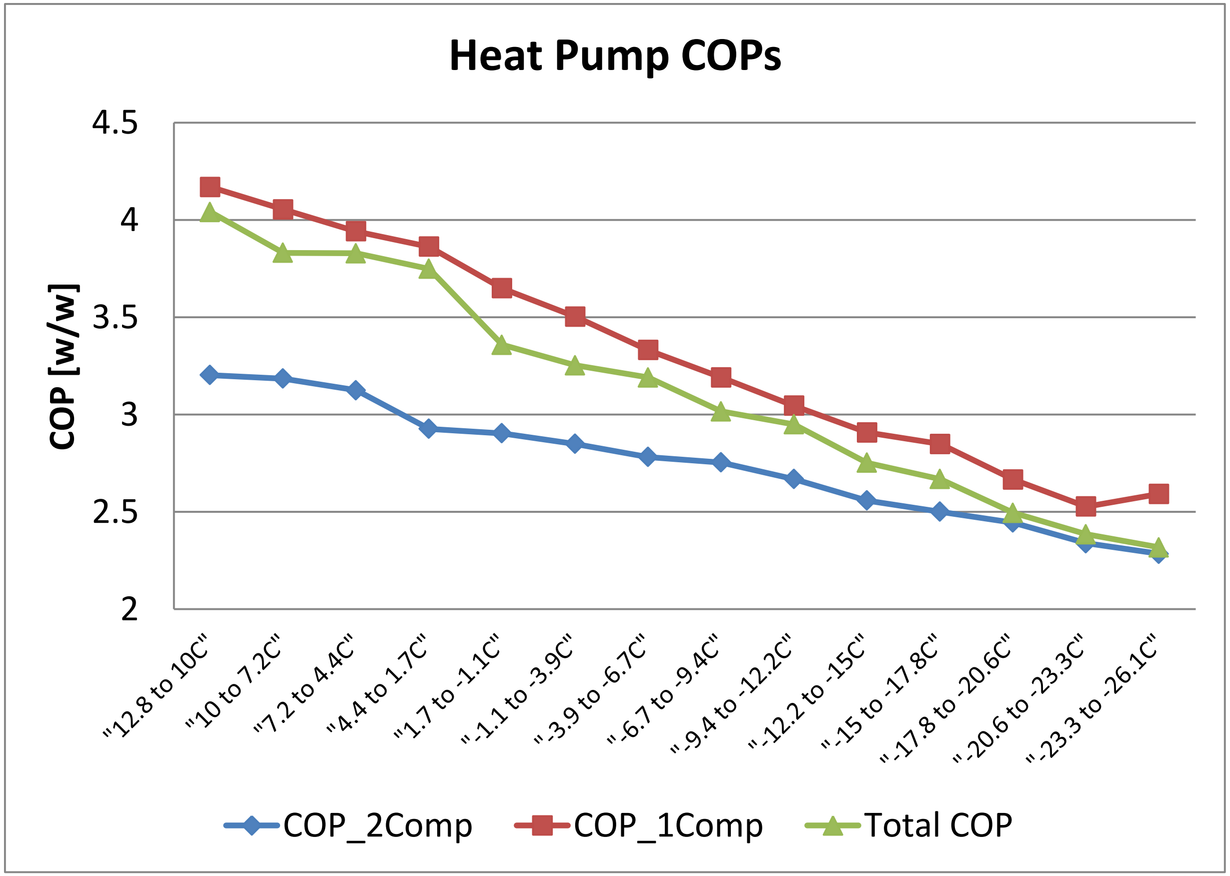


3.5 Resistance Energy Uses



-can be eliminated by changing the control and letting the second compressor run longer to match the temperature setting point.

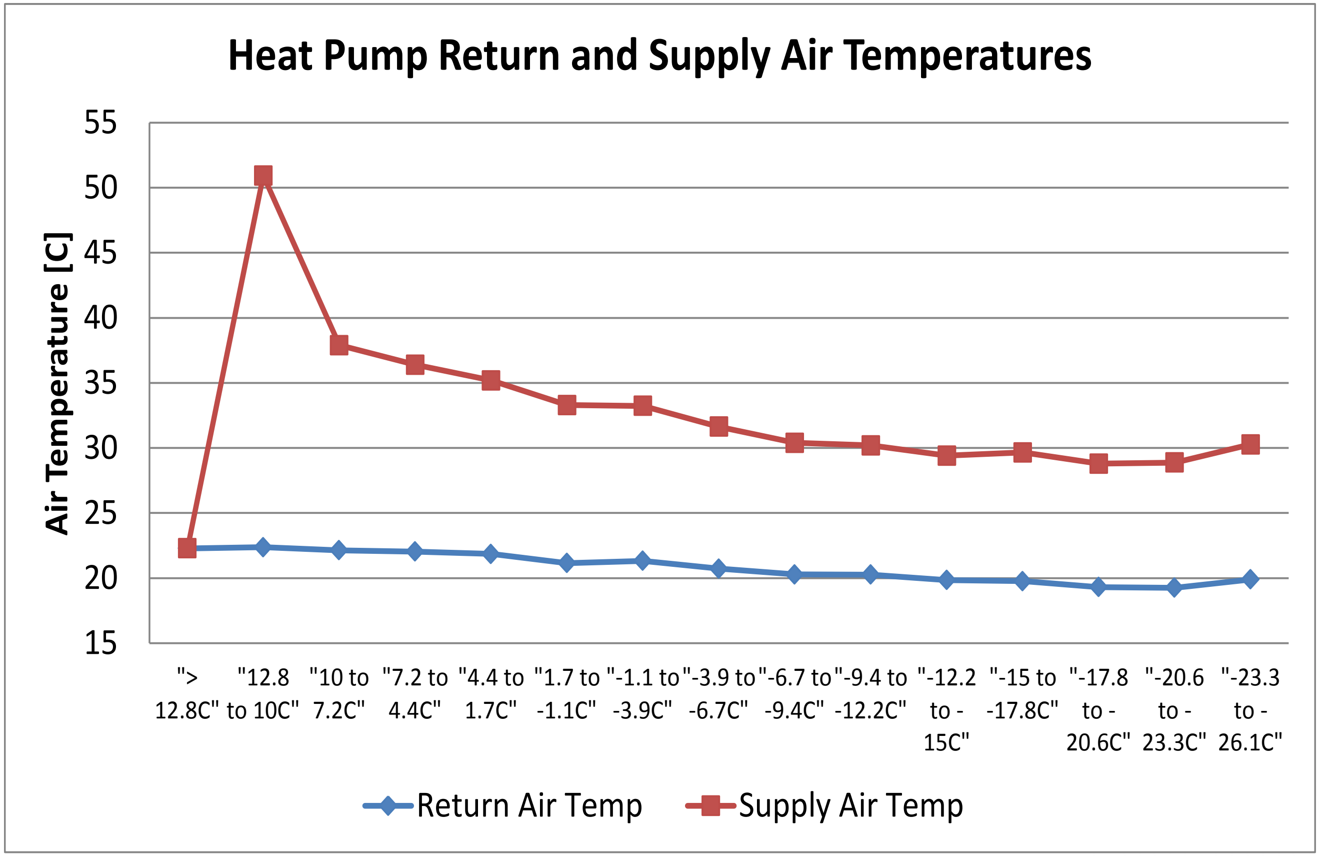
3.6 Heating COPs



-Heat pump COP at 47°F (8.3°C) >3.5.
-Heat pump COP at -13°F (-25°C) > 2.0.

* Total COP includes resistance heat, cyclic and frost/defrost losses.

3.7 Return and Supply Air Temperatures



-Maintain 30°C supply air temperature at low ambient temperatures.

* Temperature setting at 20°C (68°F) with 1.1K (2R) dead band.

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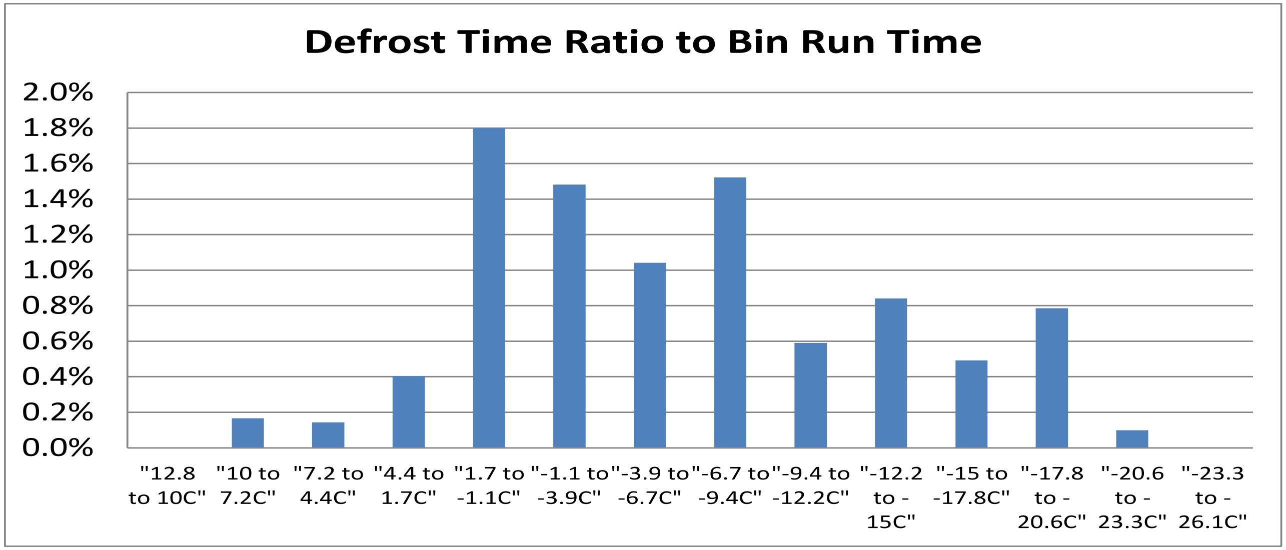
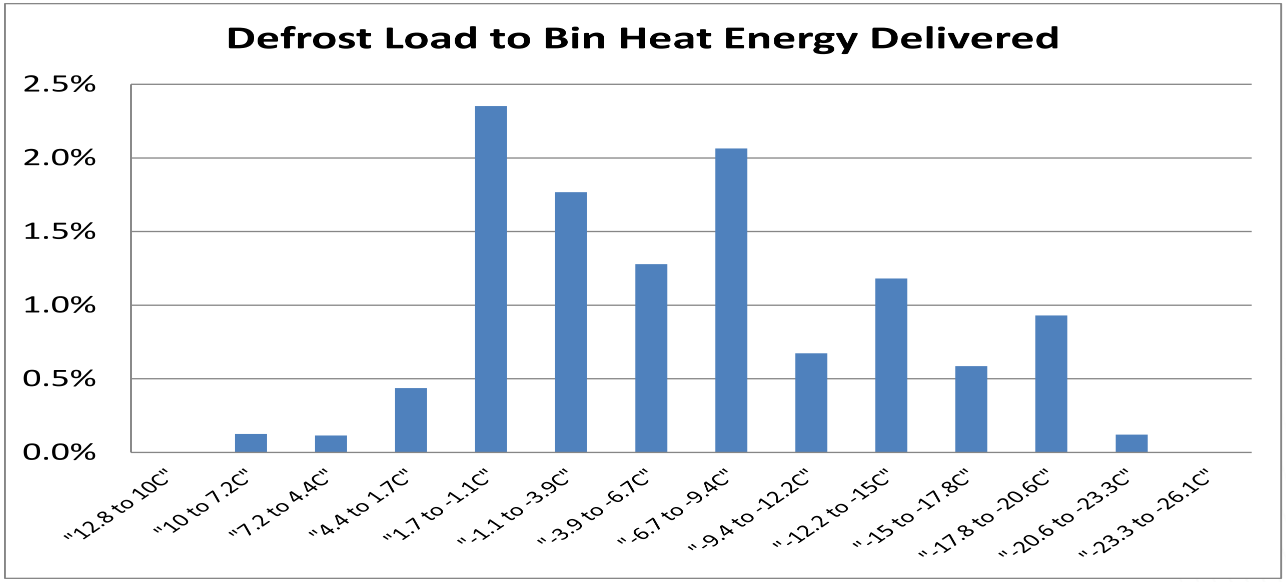
3.8 Defrost Frequency and Energy





Defrost frequency and energy were minimum for CCHP
-With running one compressor, frost formation was slow, due to the oversized outdoor HX.
-When the two compressors were needed at low ambients, the ambient humidity level was very low.

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4. Summary

- Over-capacity capability in a heat pump is the key to match the 75% capacity goal – tandem or variable-speed compressors are required.
- The tandem single-speed compressors had sufficient capacity to eliminate resistance heat down to -25°C during the field testing in Ohio.
- Proper charge control strategy is necessary to optimize heat pump operations at low ambient temperatures.
- Defrost losses were minimum during the field investigation.