Enabling Vapor Injection Compressors in Next Generation Heat Pumps

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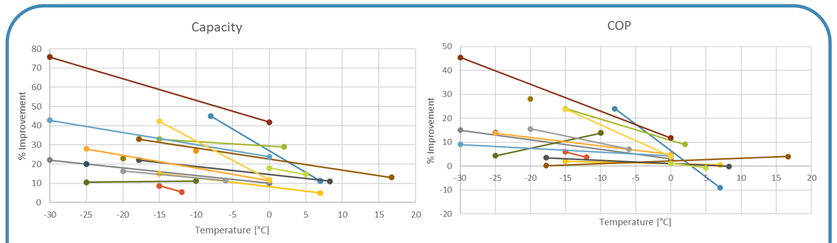
Working Group of 7 Member Companies

Period of Performance: 36 months
DOE Funds $964,573
Cost Share: $250,920
BP1: Design and build compressor test stand
BP2: Complete compressor testing and modeling
BP3: Design and test prototype system

Residential space heating in climate **zones 1 and 2** (AIA) will consume 2.2 Quads in 2035 (41% of the national total) and emit 111MtCO$_{2e}$ (45% of national total) despite housing ~30% of the population. **Less than 5%** of these homes use heat pumps as their primary source of heat.

Vapor injection can:
- Improve efficiency of heat pumps (10- >50%)
- Enable electrification of cold climate regions that are slower to shift from fossil fuel sources
- Reduce reliance on electric resistance backup heating and resulting winter peaking
- Reduce size/cost of heat pumps due to improved low temperature performance

However, these systems remain difficult to design and optimize because **the industry has not standardized protocols for testing, curve-fitting, and reporting compressor performance needed for modeling.**



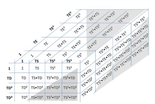
AHRI 540 10-coefficient maps are effective for communicating and modeling compressor performance, but they cannot be extended to vapor injection, especially when considering additional important variables.

Fixed speed

	1	TS	TS^2	TS^3
1	1	TS	TS^2	TS^3
TD	TD	TS•TD	TS^2•TD	TS^3•TD
TD^2	TD^2	TS•TD^2	TS^2•TD^2	TS^3•TD^2
TD^3	TD^3	TS•TD^3	TS^2•TD^3	TS^3•TD^3

2 variables
10 coefficients

Fixed speed, VI



3 variables
23 coefficients

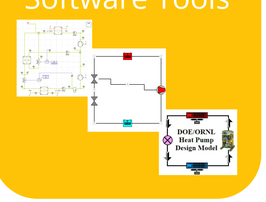
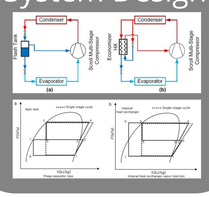
(Cambio, 2016)

Variable speed, VI
+Ambient temp
+Superheat

6 variables
262 coefficients?

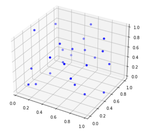
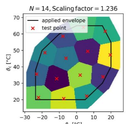
Vapor-Injection compressors hold immense promise for cold-climate heat pumps, but system designers lack resources to model and implement them.

Design of Experiments → Experimental Testing → Model Development and Evaluation → Software Tools → System Design → Prototype Demonstration

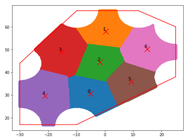

Project Outcomes:
- Develop and utilize **test facility** for variable speed, vapor injection compressors
  - At **arbitrary injection pressure** and superheat
  - At **low ambient** temperatures relevant for cold climates
  - Including **A2L and A3** flammable refrigerants
- Develop compressor **models/maps** that allow engineers to design VI systems
- Design, fabricate, and test **prototype system** with VI to validate modeling methodology

Design of Experiments – where to perform tests to minimize effort and maximize model accuracy

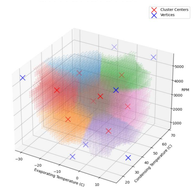



Compressor envelope, Desired # Tests → DoE Tools → Test Matrix

Mode: include vertices, fill interior:



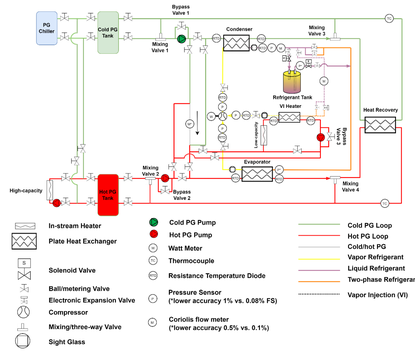
Example variable speed map constrained in 3 dimensions:



Latin hypercubes cannot be readily applied to constrained compressor envelopes

Other authors have developed clustering-based approaches to solve this (e.g. Aute 2015, Christ 2023)

Compressor Test Facility:



Novel capabilities:
- Very low ambient testing (-26°C / -15°F)
- A3 flammable refrigerants
- Flexible vapor injection pressure

Parameter	Min	Max
Operating Conditions		
Suction Dew Point [°C]	-40	20
Discharge Dew Point [°C]	-20	60
Injection Ratio [-]	0	50%
Nominal Capacity* [kW]	7	17.6
Accurate Capacity Range [% Nominal]	25%	200%
Ambient Temperature [°C]	-26.1**	35
Suction Superheat [K]	5	40
Maximum Measurement Uncertainty		
		Max
Mass Flow Rate [% of measurement]		±1%
Power [% of measurement]		±1%
Saturation Temperature [°C]		±0.3

*Defined by heating capacity at -15°C/35°C condition
**Environmental chamber improvements will be carried out into BP2 to allow for safe handling of A3 flammable refrigerants and low ambient temperature operation.


Construction in Progress: