Variable Speed Heat Pumps
Advanced Features and Capabilities - Update

NEEA Product Council
August 1st, 2023

Presented by

Christopher Dymond	*NEEA*
Rick Huddle	*Cadeo Group*
Cory Luker	*Cadeo Group*

Outline

- Context and Vision
- Work Sessions and Workplans
- Improvement Updates
  - Low Load Efficient
  - Cold Climate Capable
  - Connected Commissioning
- Closing Comments and Discussion

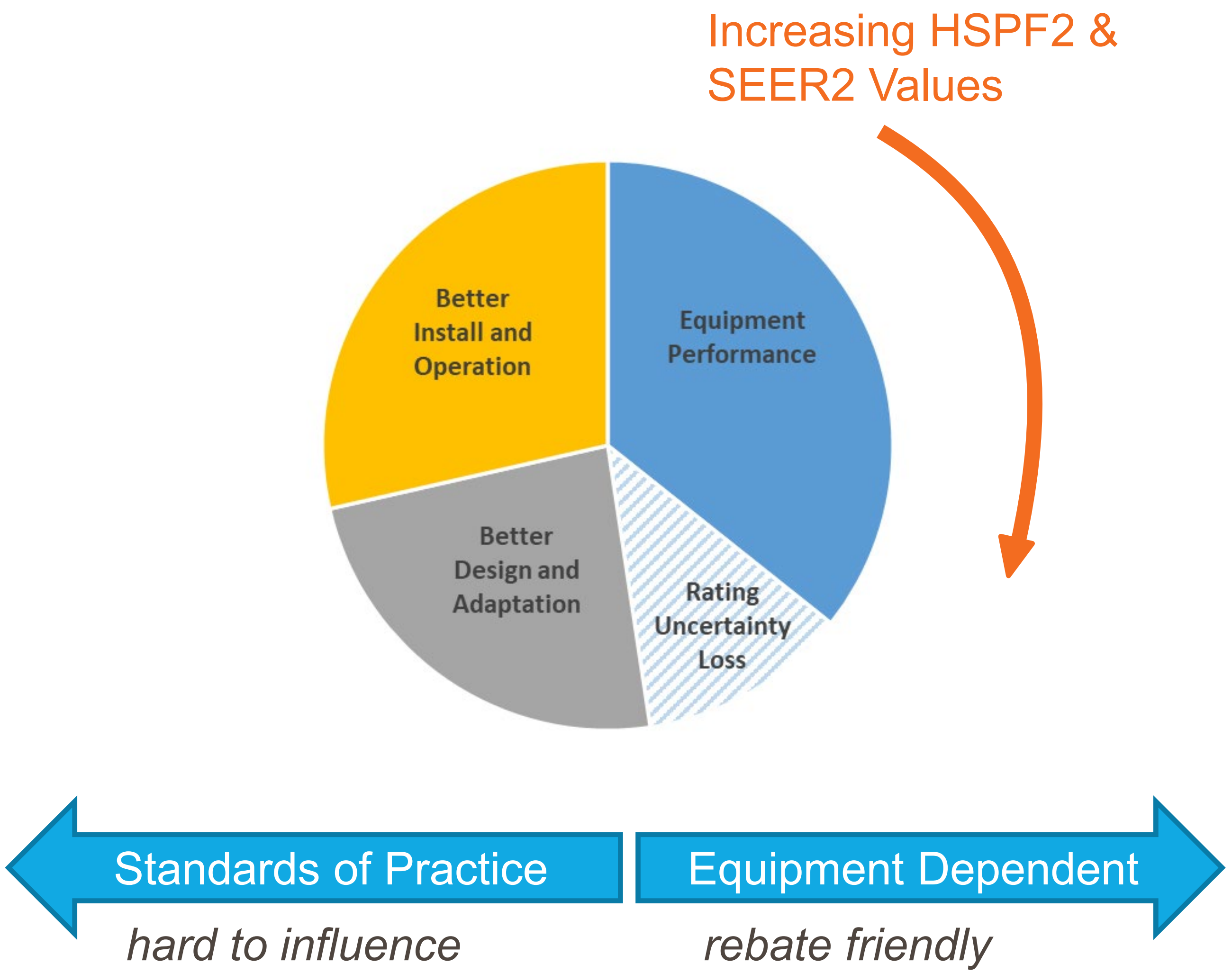
Desired Outcome

(of this presentation)

- You are up to date on what NEEA's Advanced Heat Pump Program progress
- You have an opportunity to share your insights
- You are interested in collaboration

Context & Vison

The Whole Energy Savings Pie



*Savings compared to current practice

What We Know

- Ratings do not reflect real world performance
  - Installation, adaptation for house, rating limitations
- Utility and Tax incentives are increasing
- Worldwide HPs are shifting to variable speed drives for compressors and fans with microprocessor controls
- Reducing a customer’s energy bill is not enough to motivate contractors to expend extra effort on design, customer education, installation, or filling out checklists

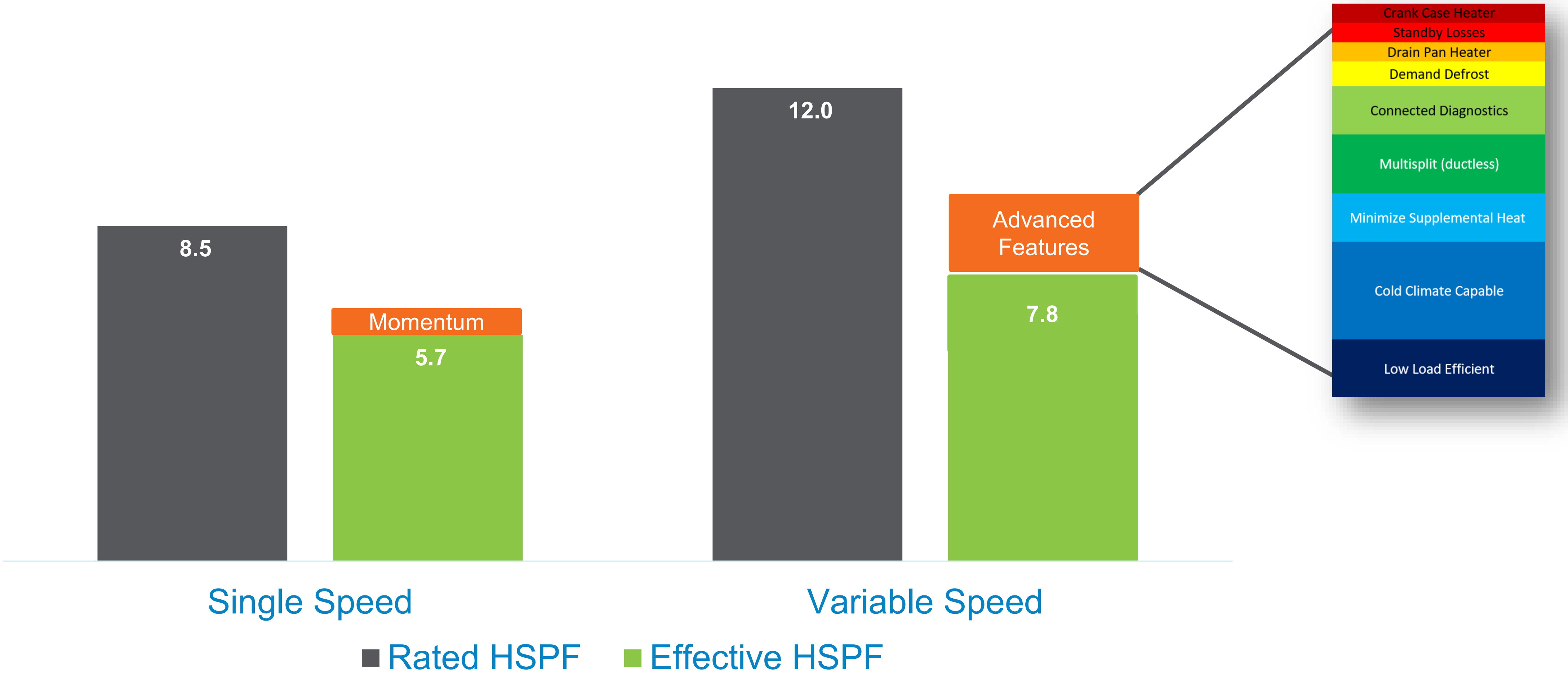
Current Trajectory

- Millions of heat pumps will be installed
- Contractors will be too busy to care much about efficiency
- Savings and comfort will not always meet expectations

Vision: Heat Pumps That . . .

- Made it easy for customers to ask for the house appropriate solution
- Help contractors commission and diagnose system
- Minimize the use of supplemental heat
- Integrate demand response

Vision


8.5
Momentum
5.7
12.0
Advanced Features
7.8
Crank Case Heater
Standby Losses
Drain Pan Heater
Demand Defrost
Connected Diagnostics
Multisplit (ductless)
Minimize Supplemental Heat
Cold Climate Capable
Low Load Efficient
Single Speed
Variable Speed
Rated HSPF
Effective HSPF

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Full List of Heat Pump Improvements

HP Improvement	Est. Energy Savings	Est. Peak Savings
Low Load Efficient	4-12%	small
Cold Climate Capable	7-11%	4+ kW
Connected Commisioning	5%	
Minimize Supplemental Heat	5%	medium
No Duct Losses	6%	small
Auto Demand Response	0%	medium
Adaptive Defrost	2.5%	
Drain Pan Heater	2%	
Standby Losses	2%	
Crankcase Heater	2%	

Today's Priority

HP Improvement	Est. Energy Savings	Est. Peak Savings
Low Load Efficient	4-12%	small
Cold Climate Capable	7-11%	4+ kW
Connected Commisioning	5%	

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Work Sessions and Workplans

Elements Needed

Definition	*General Description, Specification*
Savings	*Percent energy savings compared to market average HP, and how certain we are that these savings are real*
Identification	*How do we know it when we see it . . . Data for a QPL*
Incremental Cost	*Balance of material cost necessary for improvement*
Market Baseline	*What is the current market share, how fast is it growing*
Value Proposition	*Why would OEMs, Distributors, Trainers, Contractors and Consumers want (or dislike) the improvement*

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Cadeo Project Description

- Identify Secondary Research
  - Gather and synthesize
  - Calculate energy savings estimates
- Subject Matter Expert Work Sessions
  - Presentation, facilitation, follow-up 1:1 calls
  - Understand knowledge gaps
- Develop Workplans
  - Define what is needed to address knowledge gaps

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SME Work Sessions

- Low Load Efficient
  - November 2022
- Cold Climate Capable & Minimize Supplemental Heat
  - December 2022
- Connected Commissioning
  - April 2023

Low Load Efficient Update

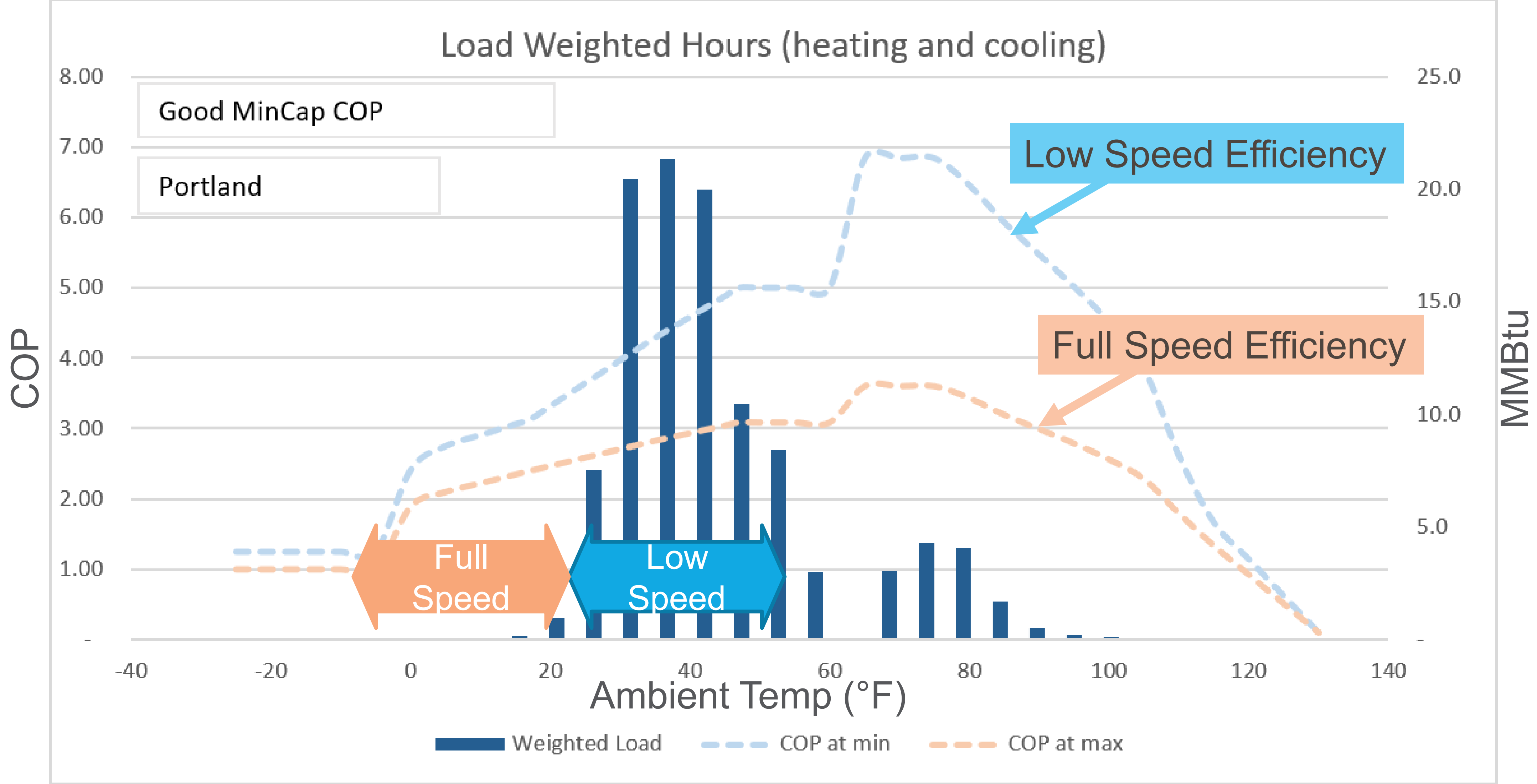
Low Load Efficient

When sized right, a variable speed heat pump spends most of its time running at part load.

Good VSHPs are 20-30% more efficient at part load than at full load

Annual Heating vs COP

Portland, OR



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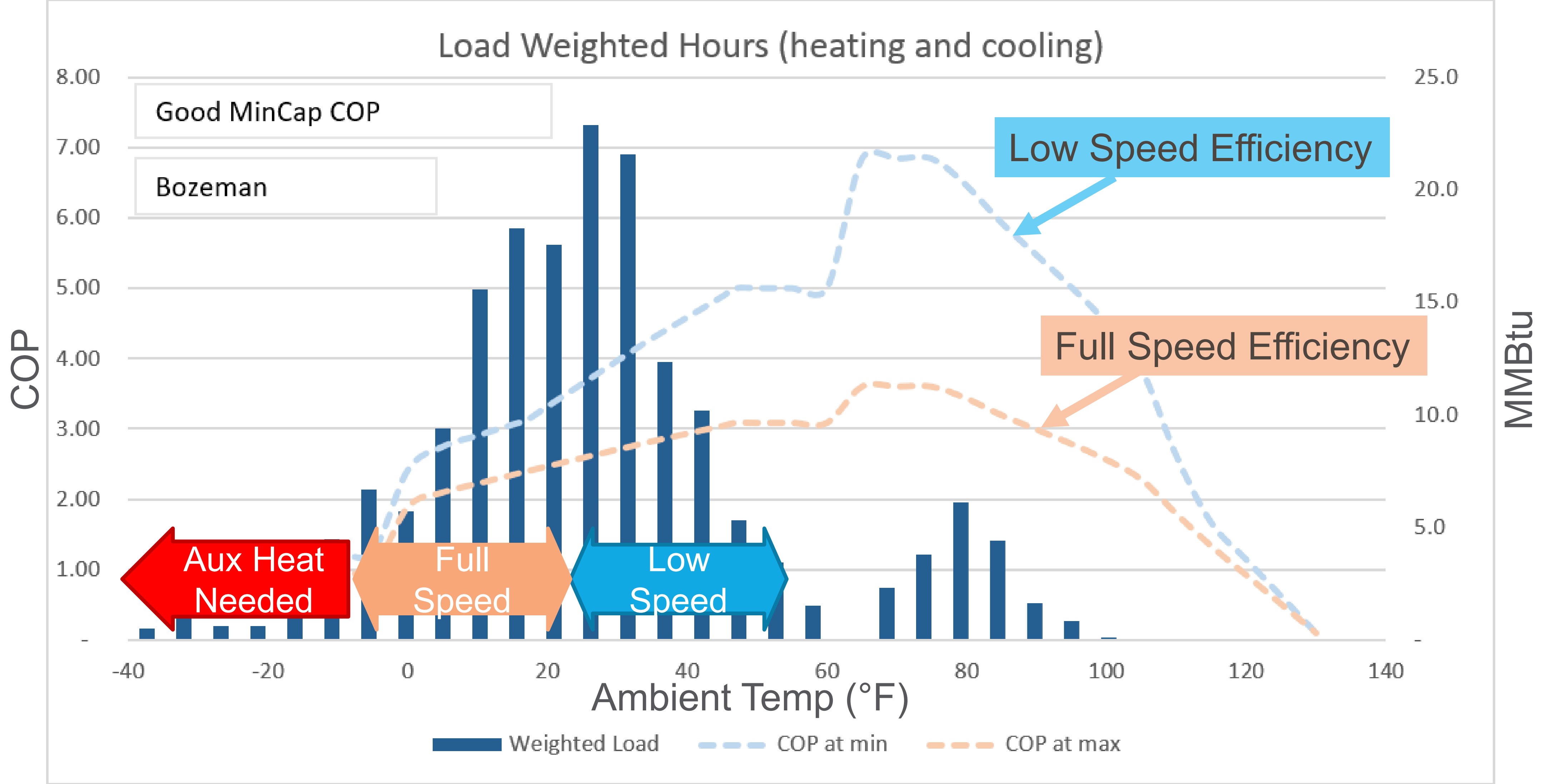
Annual Heating vs COP

Bozeman, MT



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What Enables Low Load Efficiency?

- Control Algorithm
- Metering Device (e.g. TXV vs EXV)
- Compressor Type (scroll, rotary)

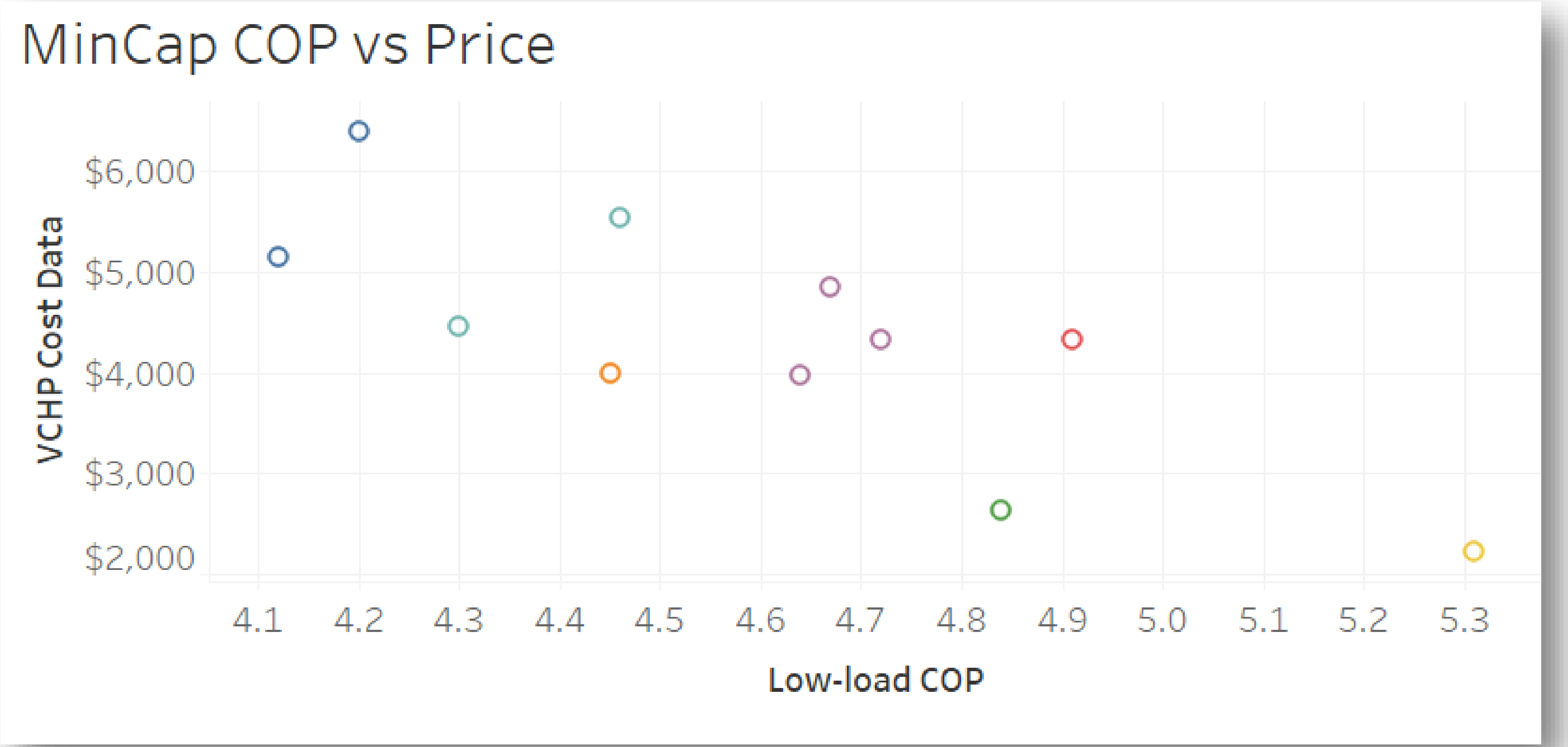
Graphs below show 2 heat pumps that are the same make, model and size, but different model year tested with load-based test method

COP = 2.03

+8%

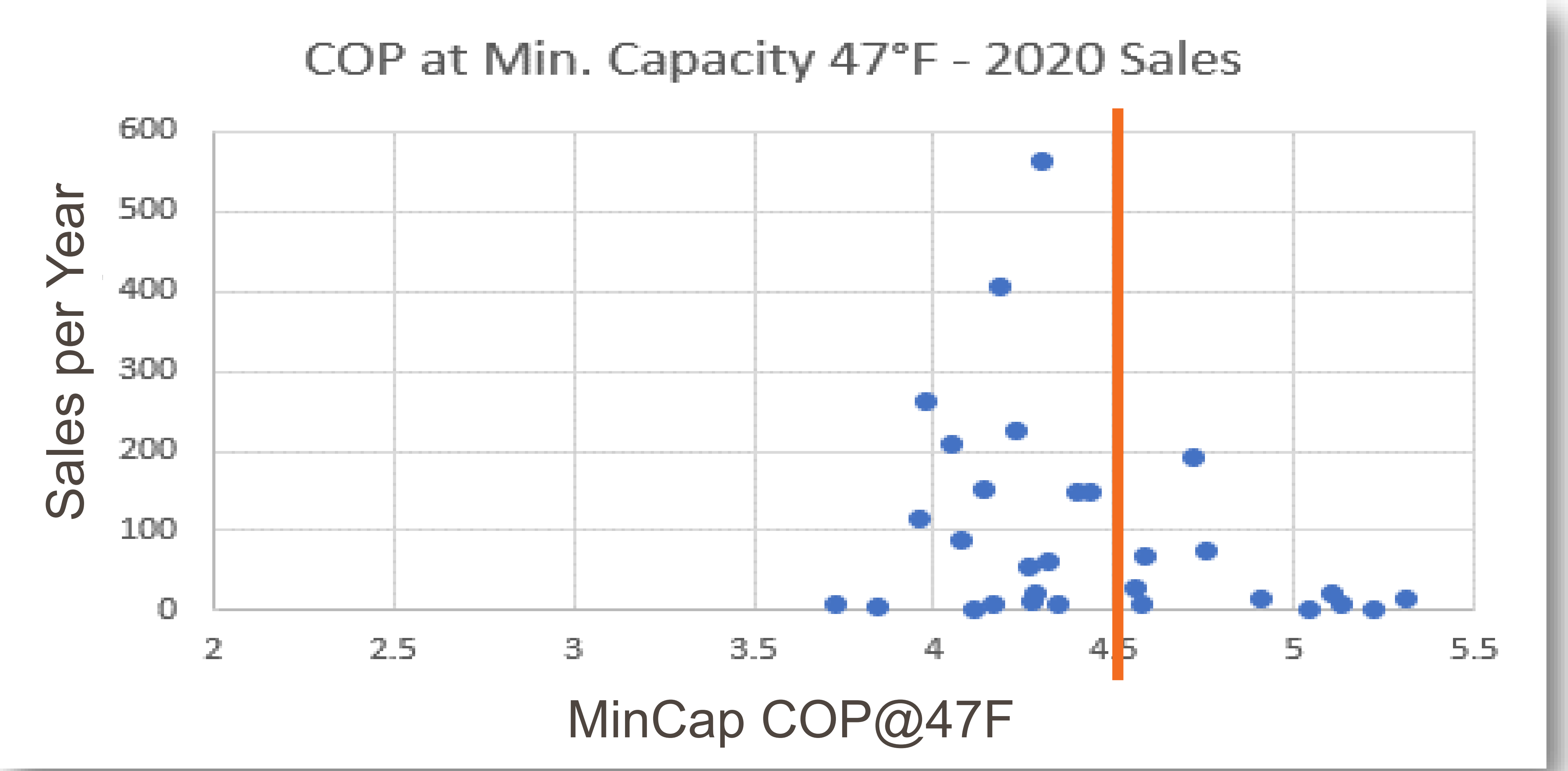
COP = 3.37 +66%

LLE doesn't appear to cost more

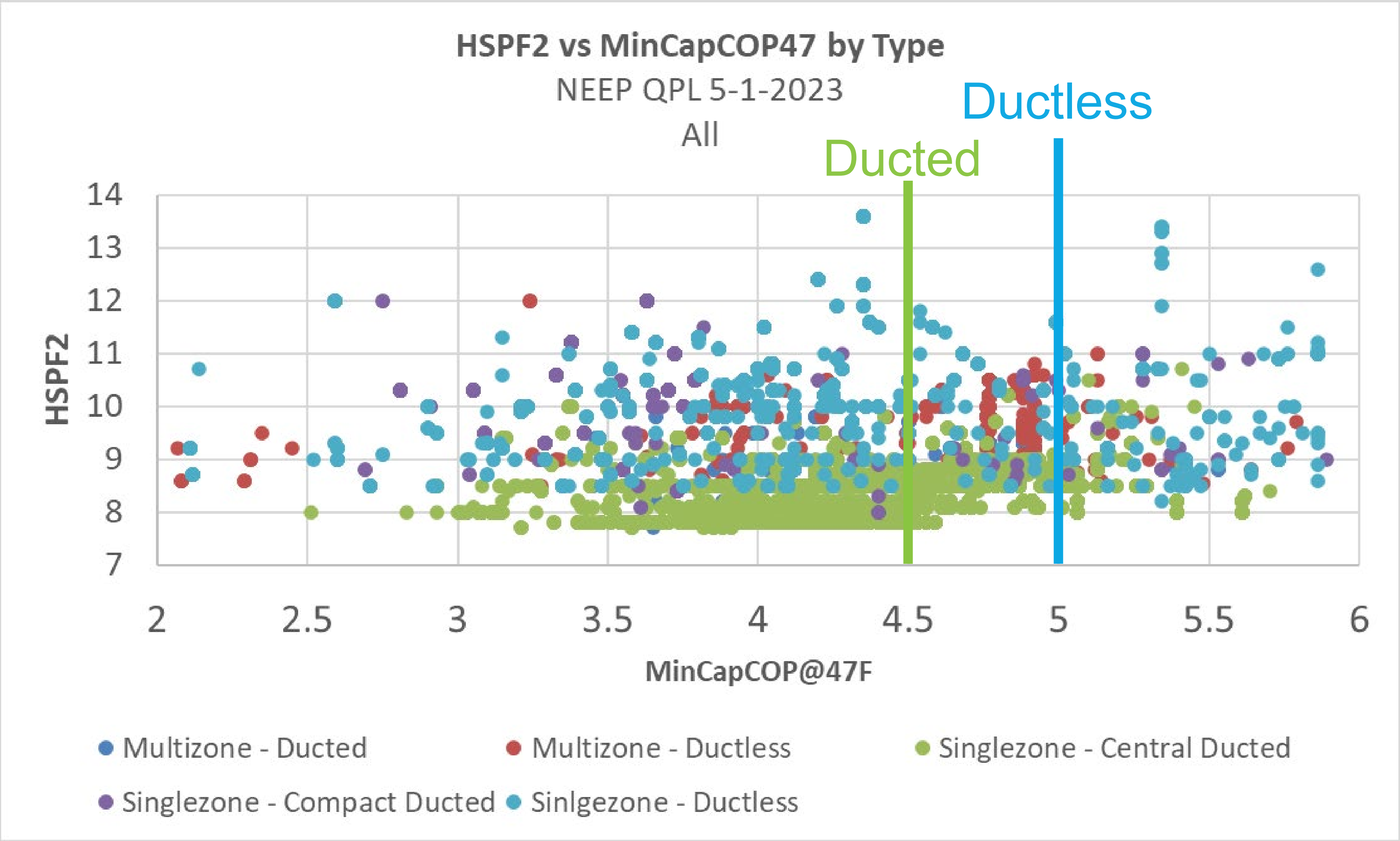


Source: MN CEE/NEEA Variable Speed Heat Pump Product Assessment and Analysis
https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis

BPA – 2020 Ducted Sales Data



NEEP Database - HSPF2 Rated Systems



Low Load Efficient

Definition	*Ducted* *Ductless*	*MinCapCOP47 ≥ 4.5* *MinCapCOP47 ≥ 5.0*
Savings	*Ducted* *Ductless*	*5-12% over average non-LLE ducted*[1] *4-9% over average non-LLE ductless*[1]
Identification	*Data in NEEP QPL*	
Incremental Cost	*TBD – current assumption is very little incremental cost*	
Market Baseline	*Ducted =* *Ductless =*	*4.1 → 4.8* *4.8 → 5.5* *(2/3 if NW market is > 4.75)*
Value Proposition	*TBD*	

[1] Compared to NW Market Average Units
Based on modeled results from MN CEE

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Knowledge Gaps

1. Is MinCapCOP47 a good independent indicator of LLE?
2. Will manufacturers embrace LLE?
3. Field verification of savings
4. How good is the NEEP data?

Workplan - LLE

Workplan Activity	Timeline
Test Procedure Analysis	Q4 2023
Manufacturer Engagement	Q4 2023
Analysis of Existing Field Data	2024
Comparative Field Testing	If needed
Lab Testing	If needed

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Cold Climate Capable

Cold Climate Heat Pumps

Two main capabilities:

1. ***Provide heat at cold temperatures***
   - Good **capacity**
     - Avoids use of supplemental heat
     - Helpful in reducing peak demand

2. ***Be efficient at cold temperatures***
   - High **COP**

These two mechanisms can achieve energy and demand savings of 5-10% over standard VSHPs

Proposed Spec = ENERGY STAR Northern Climate

- COP at 5°F ≥ 1.75
  Based on M1 H42 test
- Heating Capacity at 5°F ≥ 70%
  5°F capacity via Appendix M1 H42 compared to 47°F rated capacity, Appendix M1 H1N
- Confirmation of specs with Controls Verification Procedure

+

- *Sized for 17°F and No-Supplemental Heat above 25°F*

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Capacity Maintenance - NW Market Share

Not many systems have good capacity maintenance

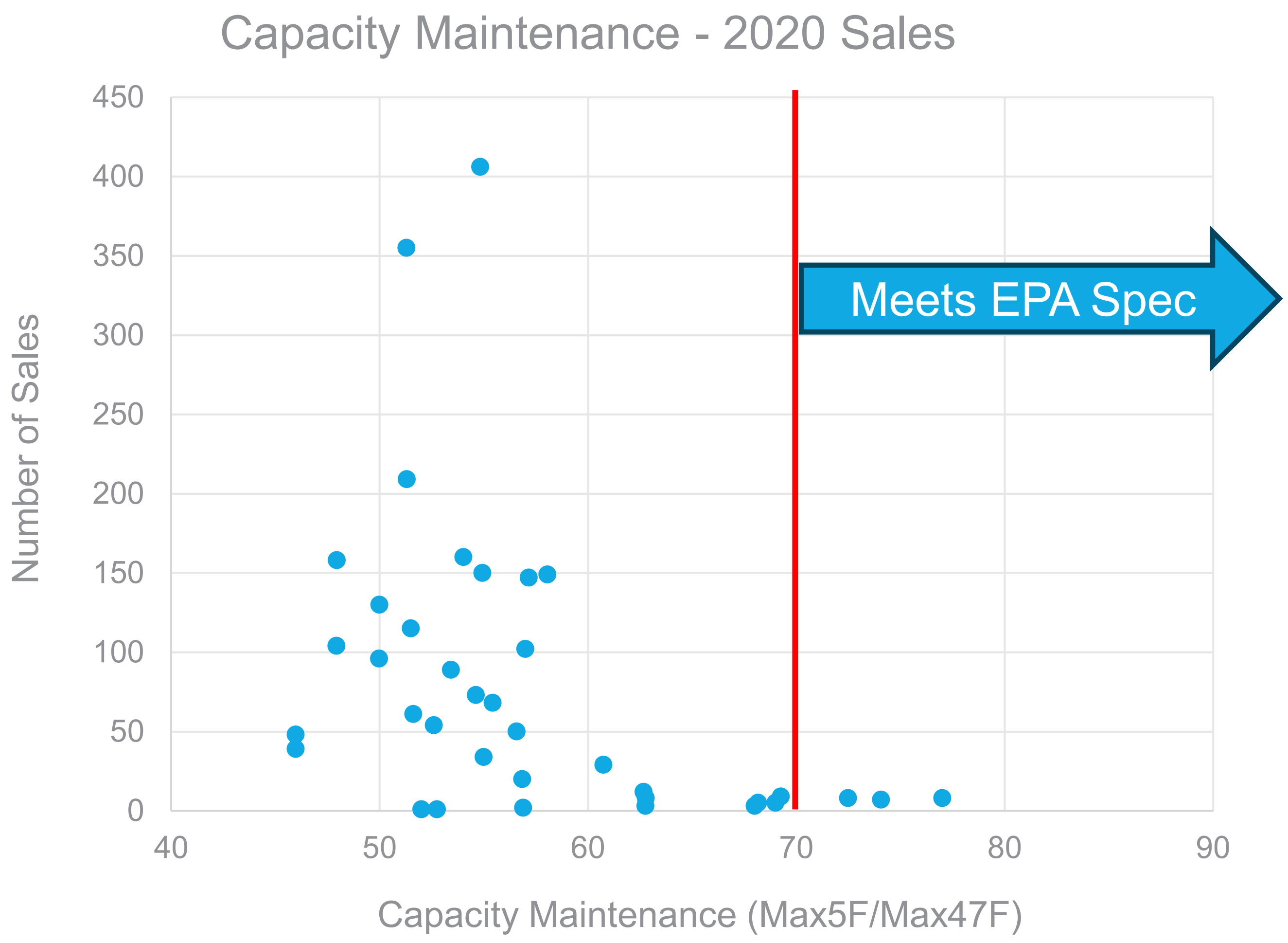
NW Ducted VSHP Sales

2020 Market Average

MaxCap5F/MaxCap47F = 53%

Source:
BPA Market Data Analysis of Northwest Ducted VSHP 2020 Sales

Representing ~3,000 sales



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COP at 5F - NW Market Share

many systems have good COP

Ducted VSHP Sales
2020 Market Average

Source:
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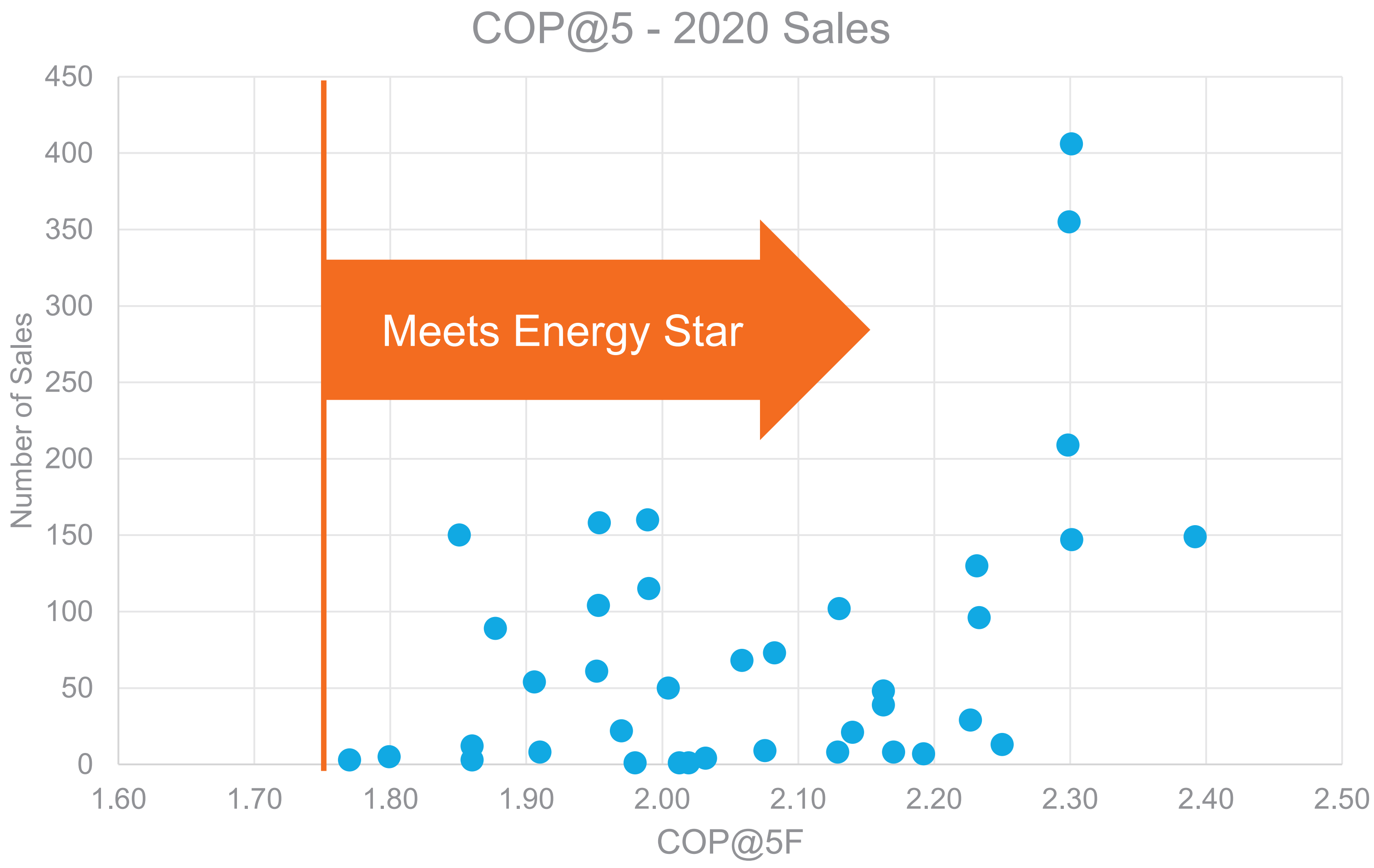
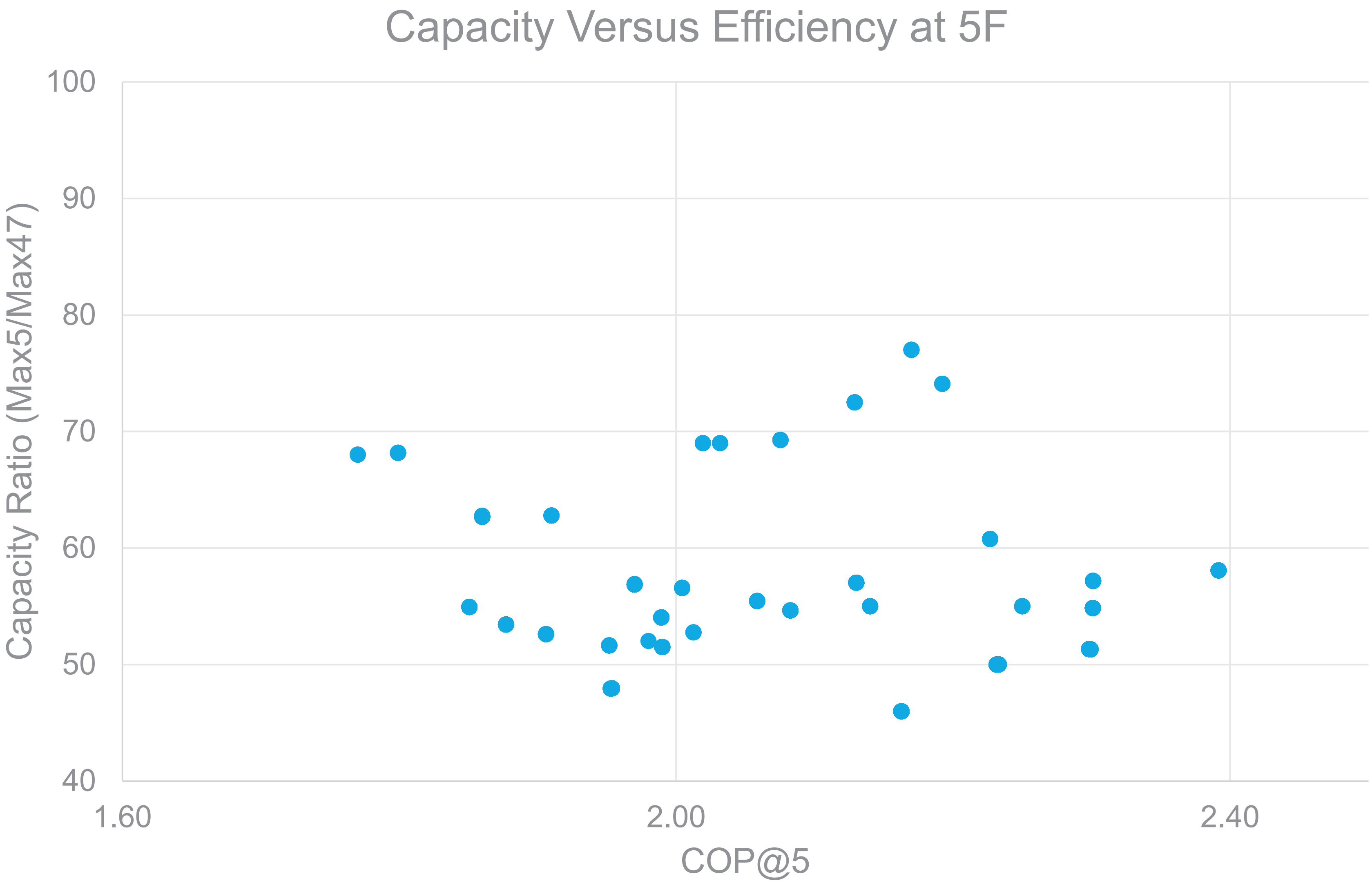


No Clear Connection Between Capacity Ratio and COP



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Incremental Savings Studies

Study	Energy Savings	Peak Power Savings	Method	Baseline
2021 MN CEE- “Capacity Champ”	4-5%	0.6 kW	modeling	“Average” VSHP
2021 MN CEE- “COP King”	16-20%	0.4 kW	modeling	“Average” VSHP
2020 Energy Trust	17%	0.4–0.8 kW	Pilot Program	Varies
2021 NREL/ComEd	22%	Not studied	Field Test	Single Speed HP
2021 NRCan	12%	Not studied	Lab Test	Good Capacity CCC HP
2022-2025 BPA Field Study	TBD	TBD	Field Test	Mixture

There are other studies, but none were identified that provided incremental savings estimates

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Cold Climate Capable

Definition	*Energy Star Northern Climate* *----- Supplemental heat limit - TBD*
Savings	*7% - 11% energy savings[1]* *---- Peak demand savings - TBD*
Identification	*ENERGY STAR Northern Climate certification* *---- Verification of supplemental heat limit - TBD*
Incremental Cost	*TBD*
Market Baseline	*TBD*
Value Proposition	*TBD*

[1]w/o minimizing supplemental heat control

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Knowledge Gaps

1. Need clarity on balance between capacity and COP
   - Is 70% capacity maintenance the right value?
   - Should a supplemental heat limit be set?
2. Need better clarity on sizing
   - Size for 17F?
3. How do we verify supplemental heat limit?

Workplan- Cold Climate

Workplan Activity	Timeline
Help RTF define a CCC measure	Q4 2023
Gather available field data	2024
Calibrate models with field data & refine savings	2024
Estimate incremental costs	2024

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Connected Commissioning Update

Connected Commissioning

Contractors use Bluetooth diagnostic tools and smart phones as part of their installation and commissioning process

Do tools that provide commissioning guidance and feedback improve system performance?

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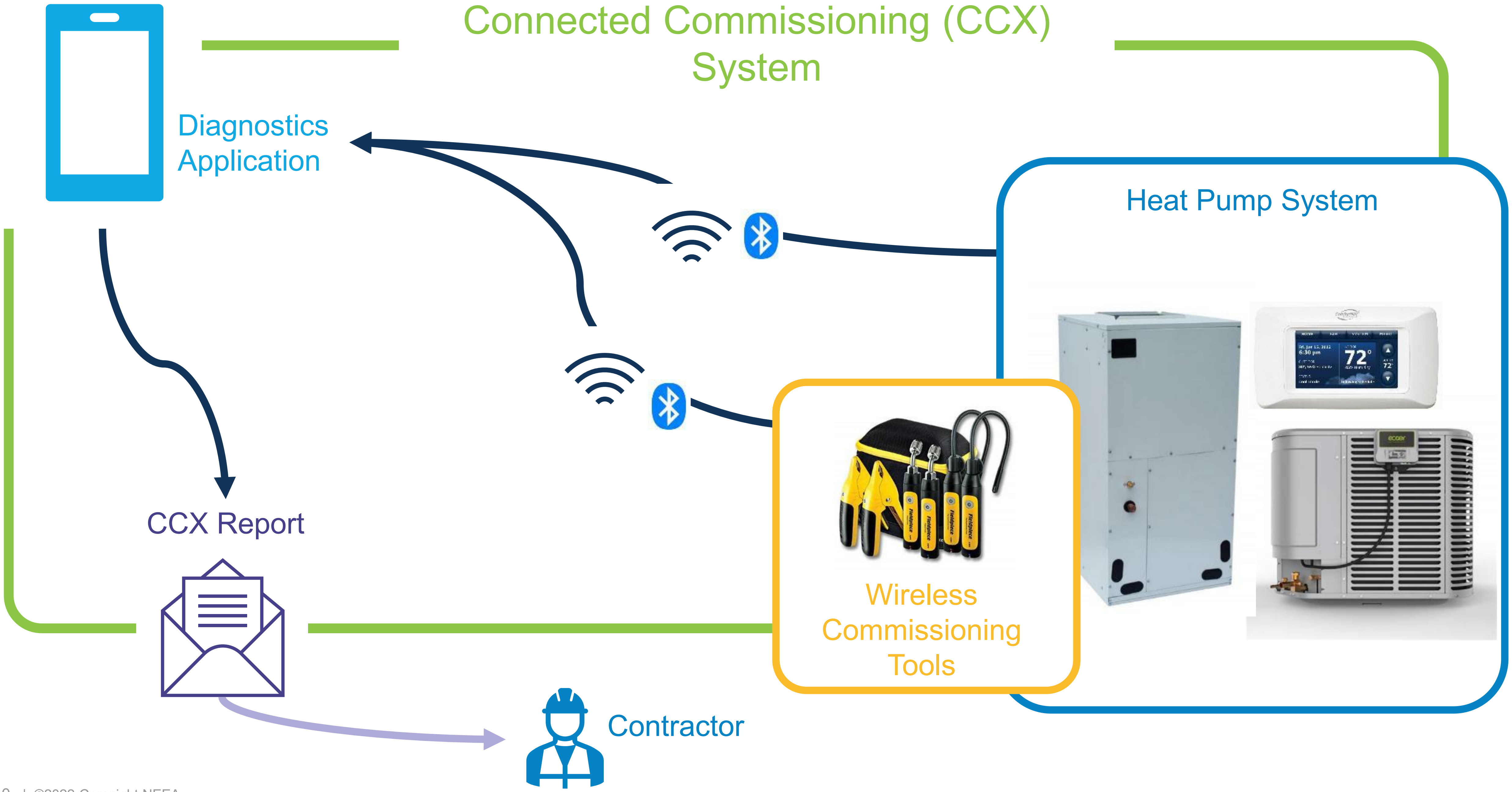
Connected Commissioning Vision

- Contractors can connect to the heat pump and generate a report that confirms the system is setup and operating correctly
- Data collected during commissioning will be stored remotely so that it can be retrieved during service visits and aid diagnosis of system operation
- Utility checklists will no longer be a thing
- Systems will last longer and perform better


Connected Commissioning (CCX) System
Diagnostics Application
Heat Pump System
72°
Wireless Commissioning Tools
CCX Report
Contractor

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We can Leverage EPA

(From Installation Capabilities EPA ENERGY STAR v6.1)

Refrigerant charge

- System can self-verify that the refrigerant charge is within manufacturer recommended tolerances at a range of conditions including outdoor temperatures at least as low as 65ºF or can estimate and report refrigerant charge level. An alert that only initiates when the charge is critically low does not satisfy this requirement.

Airflow measurement or external static pressure

- System shall have some capability to self- estimate and report airflow and/or confirm that it is within the OEM recommended settings, or to self-measure and display external static pressure and the fan speed setting. For split systems, this capability may be contingent on the recognized product being paired with a specific furnace or air handler. (Capability not applicable to ductless units.)

Blower fan power draw

- System shall have the capability to self-measure and report the watt draw of the blower fan. For split systems, this capability may be contingent on the recognized product being paired with a specific furnace or air handler. (Capability not applicable to ductless units.)

Test mode for manual measurements

- The system provides an easily accessible test mode that locks the system into an appropriate fan speed and compressor capacity setting for testing refrigerant change, airflow/external static pressure, and blower fan power draw available in that installation.

Automatic system discovery

- System is capable of automatically recognizing compatible communicating indoor/outdoor units, furnaces. Automatic discovery of humidifiers and dehumidifiers is encouraged

Preprogrammed system tests

- System shall automatically prompt the installer to run preconfigured system tests following the initial setup. These tests should verify, at a minimum, fan blower, cooling-mode, heat pump only heating, and auxiliary heating tests as applicable to the product and season of installation. The system shall store all faults recognized during these tests until the installer corrects the related issues.

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Two Sources of Justifiable Savings

1. **Fix commissioning faults**
   - Improper airflow
   - Refrigerant undercharge/overcharge
   - Non-condensable gas infiltration

We can attribute savings from helping the contractor fix faults with known impact on performance

2. **Verifying control settings**
   - Supplemental heat controls

We can also attribute savings from verifying system control settings are appropriate

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How frequently do faults and improper controls occur?

In 2019, BPA assessed heat pump commissioning, controls, and sizing practices through 95 site visits in the Northwest region[3] (about half of which were in a utility program)

Percent of Systems that meet BPA's PTCS* Specifications

	Airflow	External Static Pressure	Refrigerant Charge	Auxiliary Heat Lockout	Compressor Lock Out	Sizing	HSPF
PTCS	67%	89%	68%	65%	84%	41%	95%
Other Utility Program	70%	91%	73%	14%	50%	44%	86%
No Program	67%	97%	75%	25%	72%	45%	56%
All Sites	67%	93%	72%	43%	72%	42%	78%
	Commissioning faults			Control settings			

*PTCS (Performance Tested Comfort Systems) is a BPA-funded heat pump quality-install program.

[3]2019 BPA, Air Source Heat Pump Commissioning, Controls & Sizing Baseline Field Study Report https://www.bpa.gov/-/media/Aep/energy-efficiency/momentum-savings/2019-bpa-heat-pump-field-study-final-report.pdf

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How Much Energy can be Saved from Fixing Faults?

The table below shows fault impacts based on building energy simulations from the 2014 NIST study: *Sensitivity Analysis of Installation Faults on Heat Pump Performance*[1]

Fault Type	Moderate Fault	Moderate Fault Increased Energy Use (%)	Significant Fault	Significant Fault Increased Energy Use (%)
Reduced Indoor Coil Airflow	-15% airflow	3%-5%	-36% Airflow	11%-14%
Refrigerant Undercharge	-20% undercharge	6%-10%	-30% undercharge	17%-23%
Refrigerant Overcharge	20% overcharge	4% - 7%	30% overcharge	10%-14%
Refrigerant Subcooling	100% excess subcooling	6%-8%	200% excess subcooling	16%-19%
Non-Condensable Gases	10% NCG	1%-2%	20% NCG	1%-4%

Estimated Savings = 5% for flow, 10% for charge

[1]Sensitivity Analysis of Installation Faults on Heat Pump Performance, NIST, 2014, https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1848.pdf

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Supplemental Heat Control

Type	Current practice	Improved, HP Controls
Compressor Lockout	• Compressor Lockout below 30 F	• No Compressor Lockout, unless COP<1.0
Comfort Assist	• ER Lockout set at 40F • ER in parallel if HP to boost delivered air temp even if it can meet load	• No ER Lockout • Controls avoid ER when HP can meet load within 60 minutes • No simultaneous ER & HP operation when HP can meet load alone
Setback Recovery	• Thermostat turns on ER when DeltaT is greater than 4 degrees	• Controls anticipate setback recovery • HP comes on 1-2hr before setback recovery to meet target setpoint using only HP

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Ben Larson Research

SEEM Modeling based on calibrated RTF approach

- Basecase
  - Compressor Lockout below 30 F (applies only to fraction of population)
  - Comfort Assist - Tstat turns on ER when HP can't meet load in 1 hr
  - Setback Recovery - Tstat turns on ER to help with recovery at all temperatures
  - Auxilliary - ER used when too cold for HP to meet load
- Efficient Case
  - No Compressor Lockout
  - No simultaneous ER & HP operation when HP can meet house load alone
  - ER used in setback recovery only when temperature 10 deg F above design or colder
  - Same - ER used when too cold for HP to meet load

City	% Savings
Portland	9%
Sacramento	7%
NewYorkCity	10%
Denver	11%
Minneapolis	7%
Bozeman	8%
Boise	10%

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How do controls affect energy consumption?

The table below describes the base case and efficient case for a building energy simulation study that assessed the impact of supplemental heating controls on energy consumption

Control Issue	Base Case	Efficient Case	PDX	Bozeman
Compressor Lockout	Compressor lockout below 30°F	No compressor lockout.	0.4%	7.7%
Comfort Assist	Electric resistance (ER) lockout set at 40°F, ER operates in parallel if HP can't meet 100% of load	No ER lockout, controls avoid ER when heat pump can meet load within 60 minutes.	11.2%	5.0%
Setback Recovery	Thermostat turns on ER during setback recovery (when ΔT is greater than 4°F)	Controls anticipate need for setback recovery. “soft setback” enabled. Modeled as HP comes on before setback returns to daytime temperature	1.7%	0.6%
Heat Pump is used more instead of ER	ER used	Greater use of heat pump	- 4.2%	- 5.6%
		Net Impact	**9.1%**	**7.7%**

Estimated Savings = 8%

Ben Larson Research Memo 1/5/23

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Potential Savings

	Fault Name	Estimated Savings[1,2]	Likelihood of Error[3]
Commissioning faults	Reduced Indoor Coil Airflow	5%	33%
	Refrigerant Undercharge/ Overcharge	10%	28%
	Refrigerant Subcooling	8%	Missing Data
	Non-Condensable Gases	2%	Missing Data
Control Settings	Appropriate Aux heat control settings	8%	57%

$$Commisioning\ Savings = \sum_{Fault=i}^{n} Savings_i * Likelihood_i$$

= 9%

(5%*10% + 10%*28% + 8%*57%)

1. 2014 NIST fault impact study
2. 2023 Ben Larson Research memo
3. 2019 BPA's CC&S ASHP field study

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Our Conservative Estimate of Savings

The fraction of CCX systems that are *actually* commissioned using a certified verification report

9% x 80% x 75% ~ **5%**

Potential savings assuming that all faults are fixed

The fraction of faults that CCX systems correctly identified and resolved during commissioning

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Connected Commissioning

Definition	*The capability of a HVAC system to use onboard and/or 3rd party probes to guide proper commissioning of a system. Requires product specific information, internet connection and generation of a certified commissioning report.*
Savings	*5% energy savings* *0% peak power savings*
Identification	*Certified commissioning report* *(meet ENERGY STAR installation criteria?)*
Incremental Cost	*Negligible, these elements are part of standard system*
Market Baseline	*Currently no certified report exists (0%)*
Value Proposition	*Likely very strong benefits for: contractors, OEMs, distributors, trainers and end customers*

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Knowledge Gaps

1. What commissioning criteria need to be verified?
2. Does commissioning improve equipment longevity?
3. What is the required accuracy of measurements?
4. How will we certify the commissioning report?
5. What is the value proposition to the contractor (time, cost, effort, etc.)

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Workplan - CCX

Workplan Activity	Timeline
Establish a CCX Technical Committee	Q4 2023
Develop a CCX Report Test Procedure and Spec	2024
Characterize and Field Test Current CCX Systems	2024
Lab Testing of Commissioning Fault Impacts	2025
Field verification of CCX	2025
Establish CCX QPL	2026?

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Summary

Desired Outcomes

- Consistent Savings
- Low Incremental Cost
- Make Saving Easy

HP Improvement	Est. Energy Savings	Est. Peak Savings
Low Load Efficient	4-12%	small
Cold Climate Capable	7-11%	4+ kW
Connected Commisioning	5%	

How Can You Participate in NEEA's Work

- Active Participation in HP Collaborative
  - Advanced Heat Pump Coalition
  - Consortium for Energy Efficiency
  - DOE National Field Validation Partnership
  - EPA ENERGY STAR
  - ACEEE Hot Air Forum
  - NEEP Database
- Contribute Field Data Sets
  - BPA, EULR, Tech Clean CA, NREL, etc.

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Closing Comments & Discussion

Thank You

Christopher Dymond

cdymond@neea.org

Rick Huddle

rhuddle@cadeogroup.com

Cory Luker

cluker@cadeogroup.com

Extra Slides

LLE Studies

Year	Author / Company	Title	Key Finding(s)
2021	NEEA/MN CEE	Variable Speed Heat Pump Product Assessment and Analysis, https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis	MinCap COP@47 appears to be a good indicator of HP savings and performance, good market and performance knowledge, Analysis tool developed
2022	NEEA	AHRI HSPF/SEER Calculator, https://seerhspf2.ahrianalytics.org/app/seerhspf2	Analysis of inputs that affect HSPF and HSPF2 confirm MinCap47COP has little effect on HSPF and HSPF2.
2022	NEEA/MN CEE	Additional VSHP modeling analysis	Using the VSHP LCtool CEE compared an average VSHP with data from NEEPs cold-climate ASHP list. While keeping all other metrics the same (capacity, max COP) the min COP values were set to be 25% higher than the average VSHP archetype. This resulted in a COP of 5 at the original key metric of MinCOPat 47. This Archetype, GoodMinCapCOP was then modeled against the average VSHP, with the results for 3 cities shown below.
2020-2021	NEEA & BPA	NEEA & BPA Sales Data Analysis	Analysis shows the range of performance data and sales using MinCap47COP
2022	NEEP	NEEP Database Analysis	Analysis indicates many otherwise good performing units on the NEEP list using HPSF have poor MinCap47COP. Analysis included data at the manufacturer level as well.
2021	Natural Resources Canada	Studying the impact factors influencing variable-capacity heat pump energy performance through simulation, report here	Explores selection tradeoff between part load performance and cold climate performance. The better part load performer used less energy overall, even though it used more backup, strip heat.
2016	CEC	Central Valley Research Homes Variable Compressor Speed Heat Pump Performance, report here	California based, but has rated vs measured performance data for four test homes. Has standby data (crank case heater and fans) ranging from 43-237 kWh per year, but doesn't call out which is crank case, which is fans.
2022	ACEEE - NYSERDA, Steven Winter Associates, TRC	Air Source Heat Pumps: Metrics and Tools for Cold Climate Programs, report here	There are issues with all the rating systems. Contractor education and training may be the most important for success. Metrics based off rated values can be gamed by manufacturers

CCC Studies

Year	Author / Company	Title	Key Finding(s)
2013	BPA / Ecotope	Residential Variable Capacity Heat Pump Field Study	Gathered data used to calibrate RTF SEEM model. 15% better then Single speed, higher losses in ducts, sizing is still very important as are controls
2018	MN CEE	Field Test of Cold Climate Air Source Heat Pumps	annual COP 1.84
2020	Energy Trust	Extended Capacity Heat Pump Pilot	ECHPs save an extra 1300 kWh/yr, regardless of heating zone
2021	NEEA / MN CEE	Variable Speed Heat Pump Product Assessment and Analysis	Goldilocks Zone is defined by MinCap COP@47, lots of good market and performance knowledge, Analysis tool developed
2022	Cadmus	Residential ccASHP Building Electrification Study	Very high satisfaction of HPs, 4+head ductless systems severely underperformed, average seasonal VSHP COP ~2.4 (does not include hours when ER is used) , single head Ductless ~ 3.1
2022	Slipstream	Dual Fuel ASHP Pilot	has data about defrost
2022	Tacoma Power	TPU Heat Pump Capacity Modeling Project	Peak power of setback recover is at 5+kW higher with standard heat pumps than cold climate HP
2021	Natural Resources Canada	Studying the impact factors influencing variable-capacity heat pump energy performance through simulation	Explores selection tradeoff between part load performance and cold climate performance. The better part load performer used less energy overall, even though it used more backup, strip heat.
2021	Natural Resources Canada	Simulation based assessment on representativeness of a new performance rating procedure for cold climate air source heat pumps	CSA07 is more promising to be representative of actual field performance
2022	ACEEE - NYSERDA, Steven Winter Associates, TRC	Air Source Heat Pumps: Metrics and Tools for Cold Climate Programs	There are issues with all the rating systems. Contractor education and training may be the most important for success. Metrics based off rated values can be gamed by manufacturers
2022	NREL / ComEd	Performance Assessment of High Efficiency Variable Speed Air-Source Heat Pumps in Cold Climate Applications	22.1% overall savings between CCC HP and single speed in Chicago's climate

CCX Studies

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Two Approaches

Heat Pumps w/ 24VAC Thermostats*

- Models have limited/no embedded sensors used for diagnostics
- Models have limited/no onboard diagnostic reporting capabilities
- Requires 3rd party probes and diagnostic applications to verify commissioning

**Includes systems controlled by "Traditional" and "Smart (Wi-Fi connected)" thermostats*

Heat Pumps w/ Communicating Thermostats

- Models may include various embedded sensors used for diagnostics
- Models may include various onboard diagnostic reporting capabilities
- Models may have embedded sensors and diagnostic capabilities to verify commissioning, whereas others some require additional 3rd party probes and diagnostics applications

Timeline

Market is Moving Rapidly

Collaborative Efforts

- Advanced Heat Pump Coalition
- DOE Heat Pump Partnership
- AHRI USE STC
- NEEA and Bonneville Power
- CEE ResHVAC Committee
- Midwest HP Collaborative
- EPRI

Heat Pumps Harvest Fusion Energy

They Improve Grid Resilience


The Technology and Practice
Will Grow dramatically
over the next 20 years

LLE backup

Low-Load efficiency is important to seasonal performance in all climates

- Minimum Capacity COP@47°F appears to be the best indicator

Savings if MinCapCOP@47°F is increased by 25% (Modeled Results)	
City	**Savings**
Portland	16%
New York City	17%
Bozeman	11%
Minneapolis	8%

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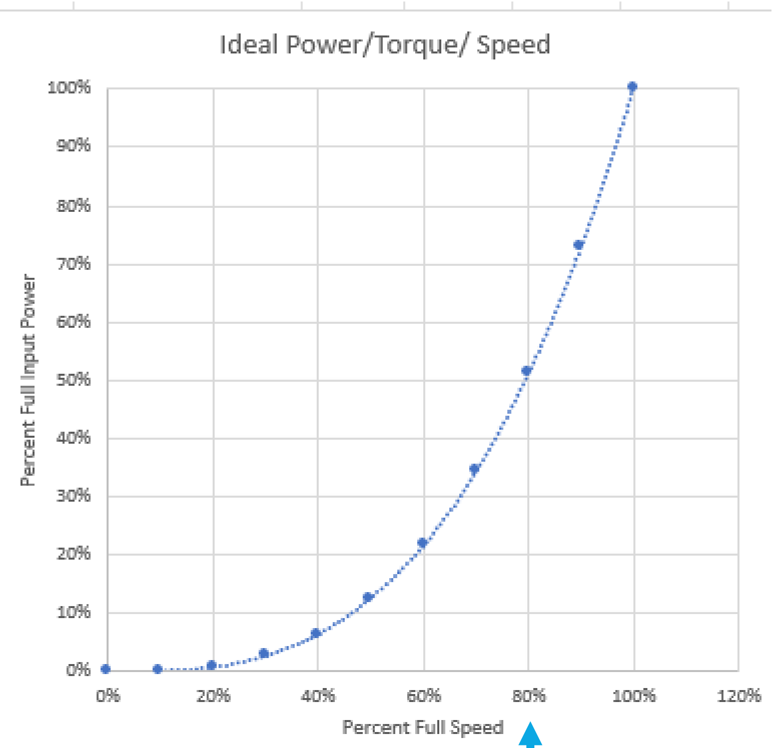
The Physics of LLE

1. Pumps (fans, compressors) use much less energy per unit moved when operating at low speed



FAN LAW 1

$$CFM_2 = CFM_1 \times \left(\frac{RPM_2}{RPM_1}\right)$$

FAN LAW 2

$$SP_2 = SP_1 \times \left(\frac{RPM_2}{RPM_1}\right)^2$$

FAN LAW 3

$$HP_2 = HP_1 \times \left(\frac{RPM_2}{RPM_1}\right)^3$$

2. At low speed, the heat exchanger coils are much larger than they need to be – increasing the heat transfer effectiveness

At 80% flow, only use 50% Power

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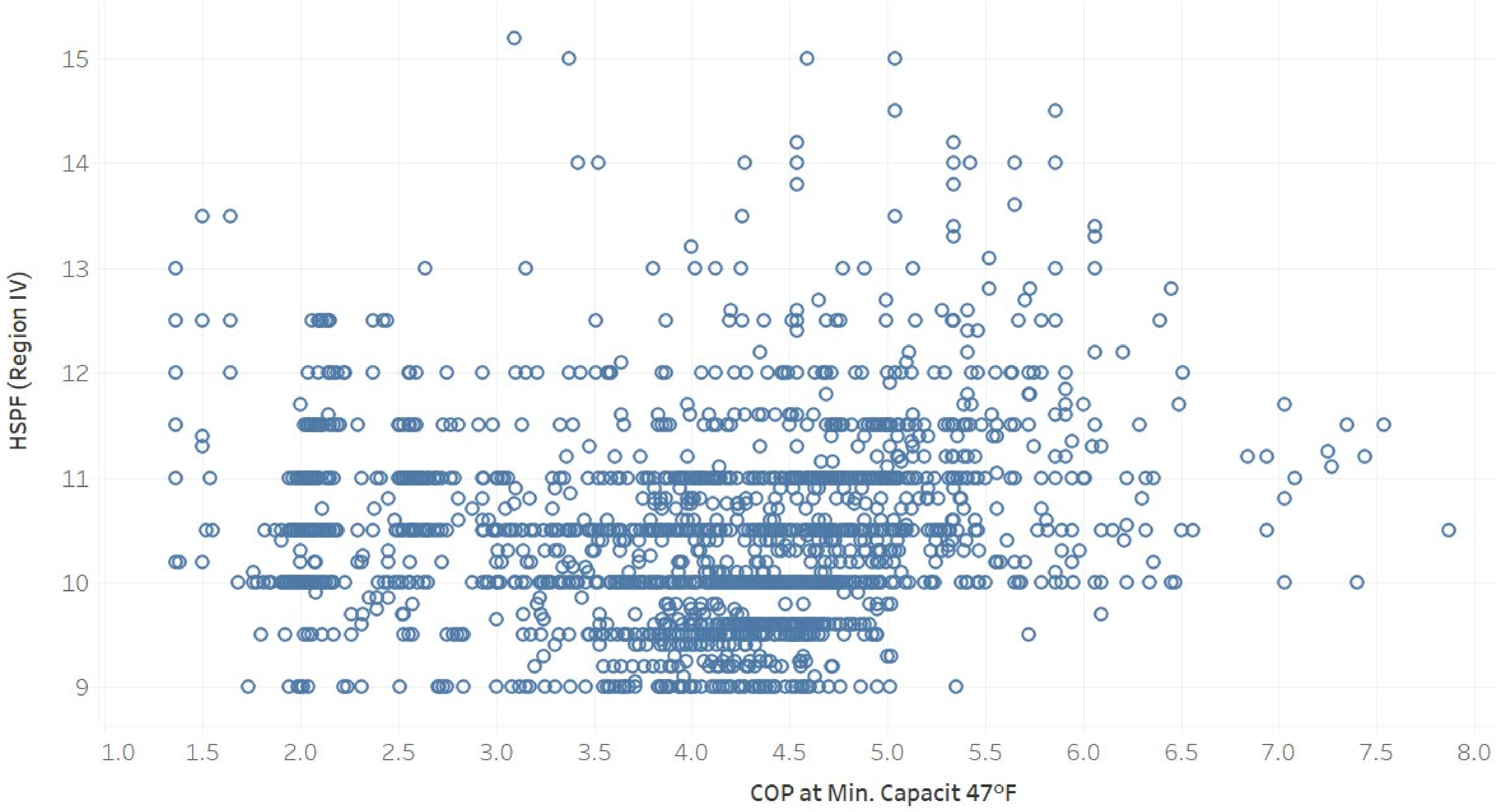
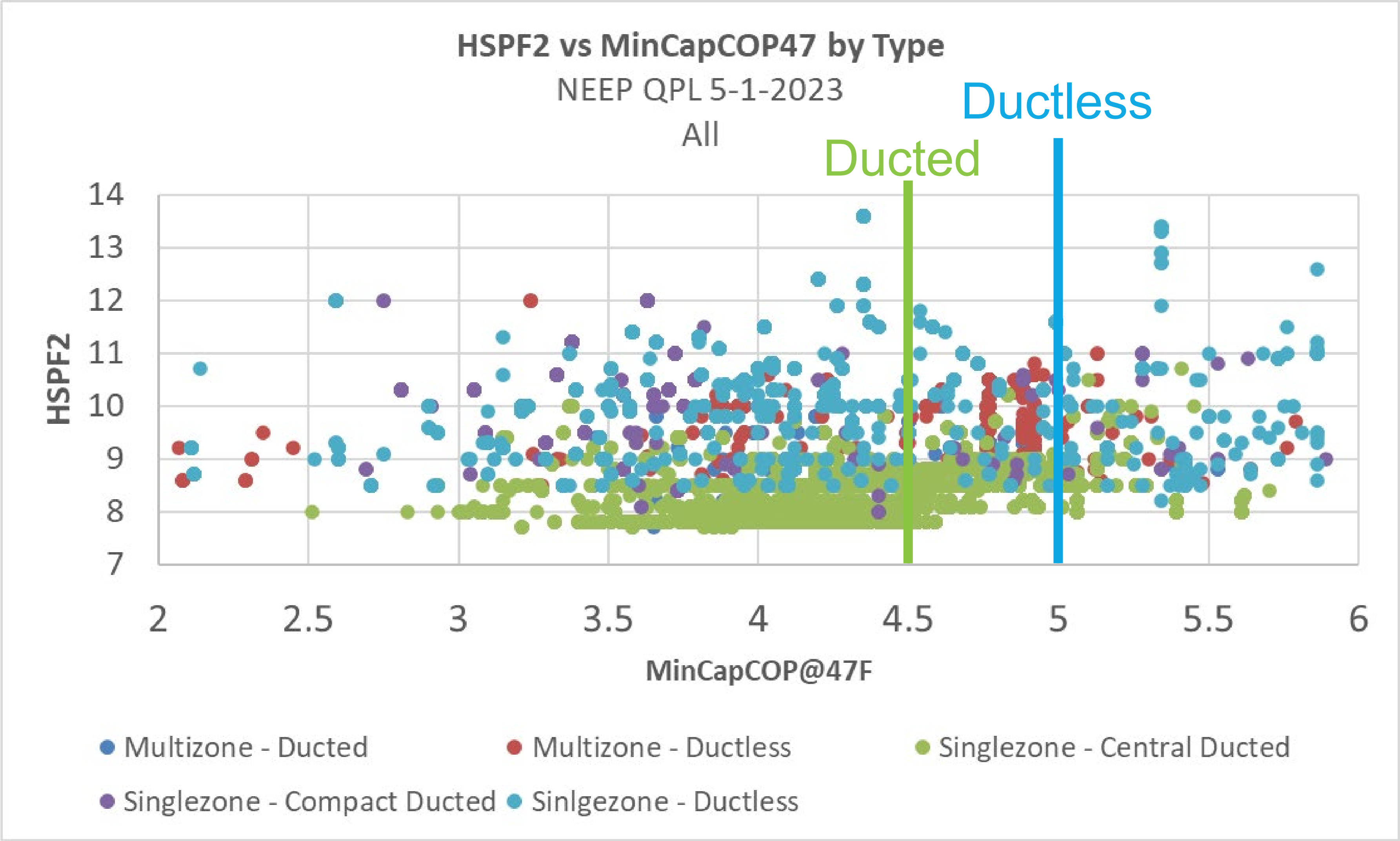
NEEP Database

These are self reported data – not AHRI certified



HSPF2 Rated Systems as of May 1, 2023



Latest update on MinCapCOP47 Investigation

- HSPF2 does include Min Capacity COP values

$$HSPF = \frac{\sum_{j=1}^{18} n_j BL(t_j)}{\sum_{j=1}^{18} \frac{n_j HLF(t_j)\delta(t_j)E(t_j)}{PLF(t_j)} + \sum_{j=1}^{18} RH(t_j)} \cdot F_{def}$$

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CCC backup

Proposed Specification

ENERGY STAR Northern Climate:

- COP at 5°F ≥ 1.75
  Based on M1 H42 test
- Heating Capacity at 5°F ≥ 70%
  5°F capacity via Appendix M1 H42 compared to 47°F rated capacity, Appendix M1 H1N
- Confirmation of specs with Controls Verification Procedure

	Federal Minimum		EPA ENERGY STAR		CEE Tax Credit	
Split System Type	**HSPF2**	**SEER2**	**HSPF2**	**SEER2**	**HSPF2**	**SEER2**
Non-Ducted	7.5	14.3	8.5	15.2	8.5	15.2
Ducted	7.5	14.3	8.1	15.2	8.1	15.2

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Cold Climate Savings

4-10% energy savings[1]

- NREL/ComEd – 22.1% savings for CCHP vs a single-speed HP baseline
- MN CEE – 4%-16% savings based on climate and VCHP archetype vs ref VCHP
- Energy Trust Oregon – 1,300 kWh savings extended capacity HP vs VCHP

- Isolation of savings by feature
  - Efficiency versus capacity
  - Cold temperature efficiency versus mild temperature efficiency

[1] depending on climate zone and baseline/efficient case

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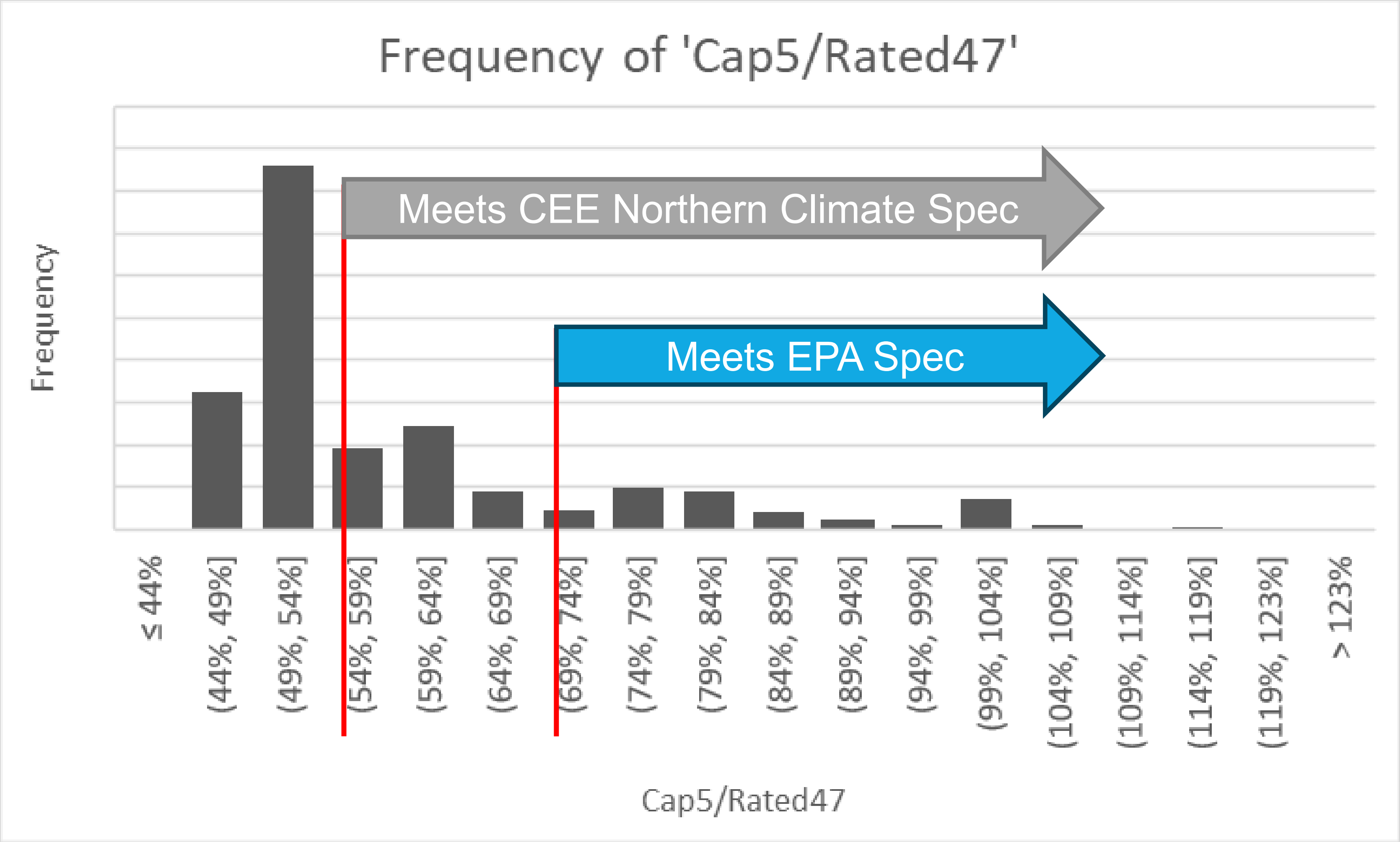
Most units on NEEP's cold climate list lose around ½ their capacity at 5F



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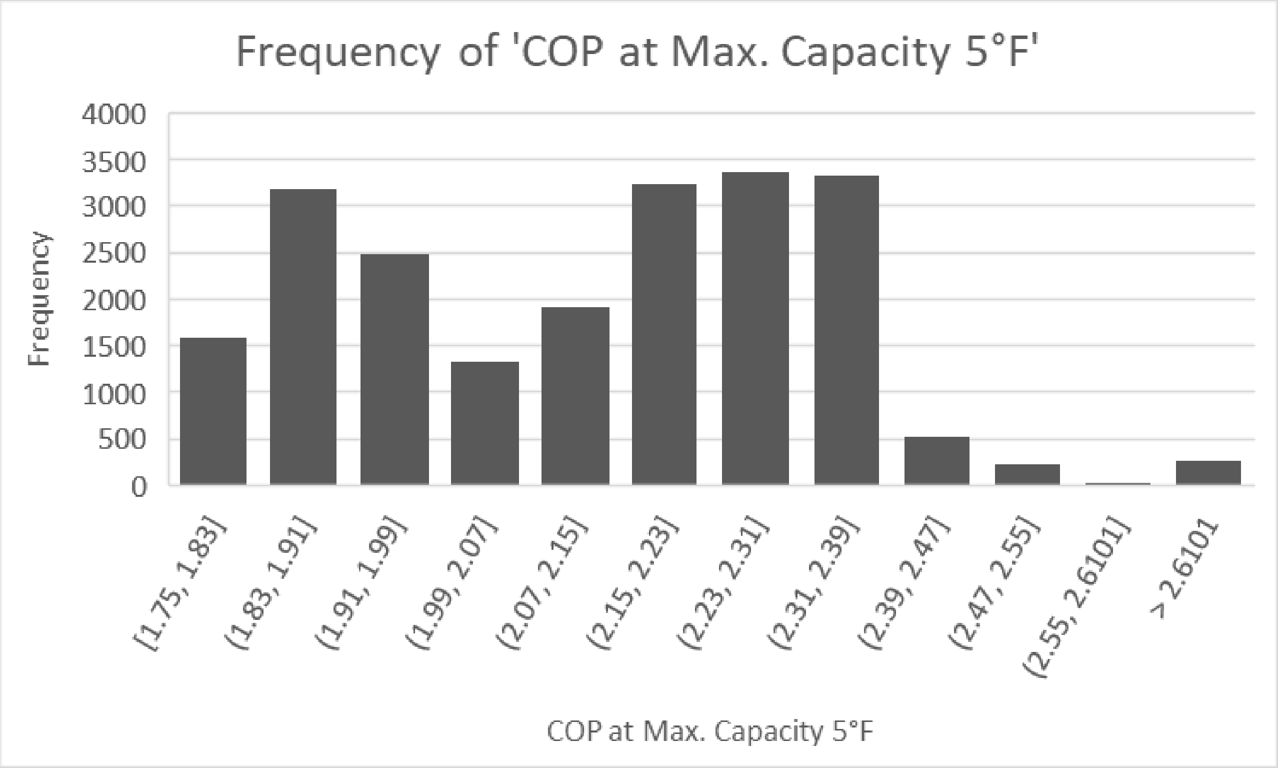
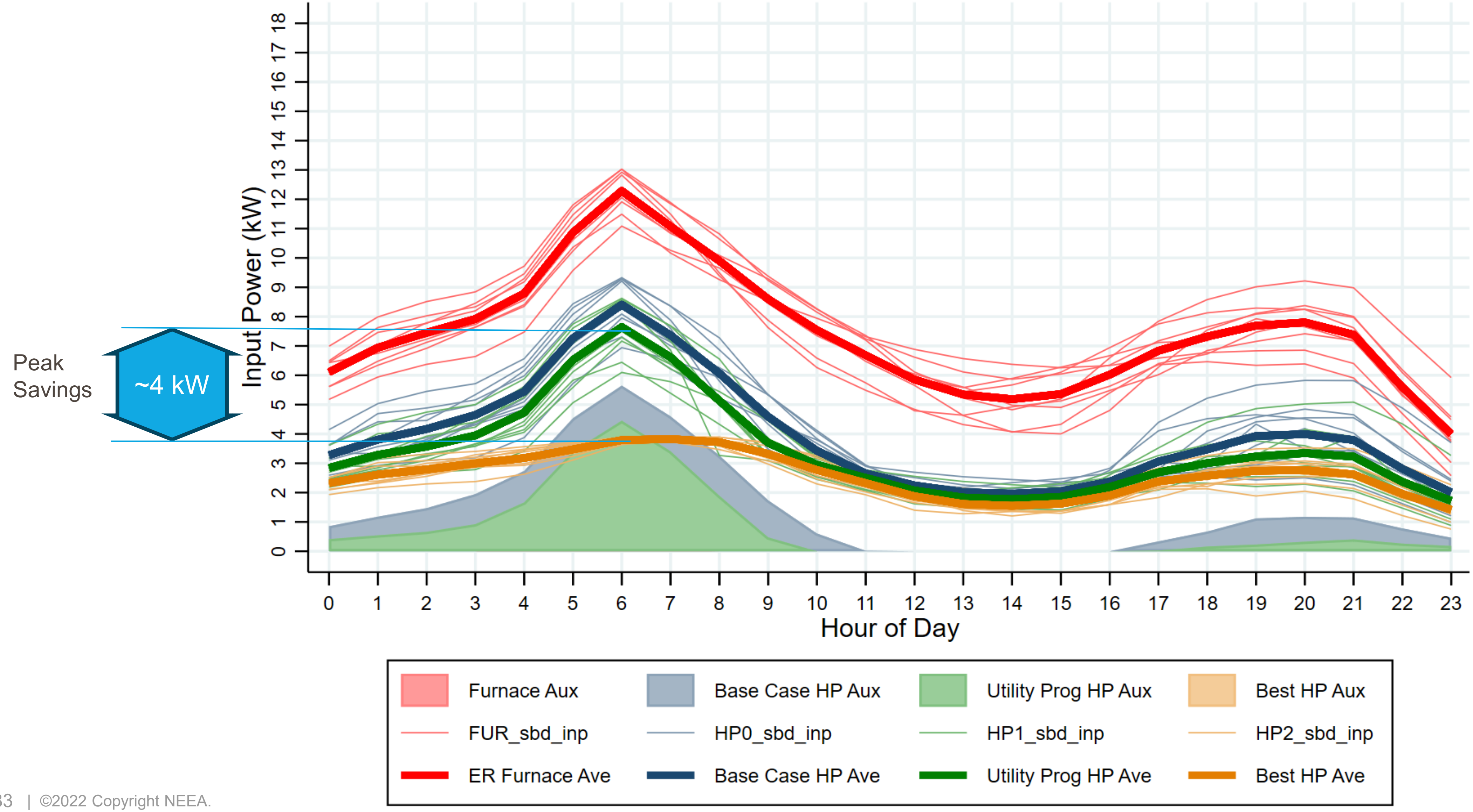
The NEEP database shows COP diversity

- 40,000+ Listed units w/COP@5 ≥ 1.75
- Note bimodal distribution



Connected Cx backup

Good heat pump with supplemental heat control reduces peak power demand



Source: 2021 Ben Larson Analysis

Coldest day of the year modeling of a diversified group of systems in Tacoma WA

What is Connected Commissioning?

The capability of a HVAC system to use onboard and/or 3rd party probes to guide proper commissioning of a system. Requires product specific information, internet connection and generation of a certified commissioning report.

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3 Tiers of Commissioning Reports

CCX provides the contractor commissioning guidance that sets the heat pump into a defined test mode with and uses current OEM product information (downloaded). Data is used to generate a commissioning report that is uploaded to the cloud where it can be recovered at any time by installing contractor and forwarded on to others as needed.

- Tier 1
  - Identification of heat pump system details (e.g. AHRI #, Location, Date)
  - Verification of refrigerant charge levels
  - Verification of indoor airflow through heat exchangers
- Tier 2
  - Verification of fan power, static pressure
  - Verification of auxiliary heat settings
- Tier 3
  - DR capabilities confirmed/enabled (presence of CTA2045)
  - Continuous connection to cloud services for ongoing fault detection

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What we Need to Know to Quantify Savings

1) How much energy can be saved by
   a) Fixing faults
   b) Setting controls to minimize auxiliary heat usage

2) How frequently do faults and improper control settings occur?

3) How well will the connected commissioning specification result in faults and improper control settings being addressed by contractor?

Two ways to generate a CCX Report

- Path A – 3rd party “works with” Heat Pump
  - Product is verified to work with third party diagnostics applications.
  - Third party application is verified to meet CCX specification
- Path B – OEM complete
  - Product is verified to meet CCX specification

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Existing Capabilities: Market Summary

Capability	3rd Party Support	OEM Complete
Measurements of air-side and refrigerant-side parameters	X (3rd party probes)	X (Embedded probes)
Control setting identification		X
System identification	X (images/QR codes)	X (automatic system discovery)
Diagnostic checks to identify various fault types	X	X
Summarize data into commissioning report	X	X
Upload data to the cloud for long term storage	X	X

Existing 3rd party diagnostic apps

- MeasureQuick: https://old.measurequick.com/measurequick-hvac-app/
- Manifold; https://imanifold.com/imanifold/imanifold-app-2_0/
- Field Piece Job Link: https://www.fieldpiece.com/product-category/job-link-system/

Existing OEM Solutions with diagnostic capabilities

- Amana and Goodman: CoolCloud, https://www.coolcloudhvac.com/
- Ecoer MobileApp; https://www.ecoer.com/mobile-app/
- Trane Link; https://www.trane.com/residential/en/resources/smart-home-app/diagnostics/

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Knowledge Gaps Full List

- What are the commissioning criteria that a CCX-certified diagnostics application must meet for each tier?
- How will diagnostics application specification be adopted by CEE and/or ENERGY STAR?
- What are the possible consequences of tying heat pump system registration and warranty to completion of a CCX specification?
- What research exists that indicate methods and savings from other faults (e.g., defrost settings, liquid line restrictions, non-condensable gases)
- What research exists that demonstrates how correcting faults during commissioning can improve the longevity of the equipment and affect life-cycle cost?
- What research exists that shows the impact of commissioning faults on variable speed equipment?
- What fraction of systems installed by factory authorized contractors register an installed system to ensure it is eligible for manufacturer warranty requirements?
- What information does a CCX-certified diagnostics application need to know about a CCX-certified heat pump in order to verify design criteria?
- What commissioning criteria need to be verified?
- What is the required accuracy of the design criteria measurements?
- How will we verify measurement accuracy?

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Low Temperature COP Contributes to Savings

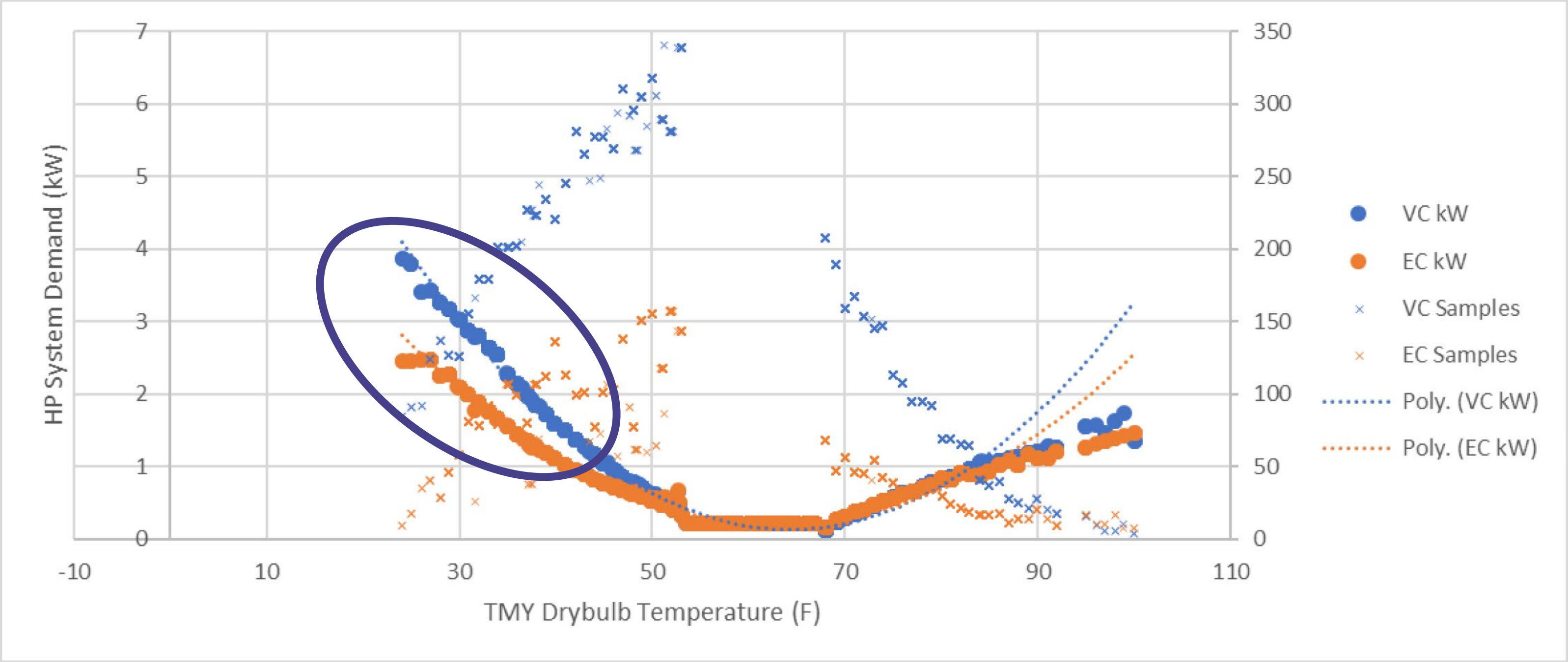

Figure 5 Normalized Hourly Demand – Portland, OR

Orange COP@5F = 2.24

Blue COP@5F = 1.81

- Metering
  - Small sample
  - Savings from 15F to 45F
  - **1,450 kWh** West of Cascades (mild);
  - **3,350 kWh** East of Cascades (cold climate)

Energy Trust pilot required a **good capacity ratio**, but also metered units with **good COP@5**

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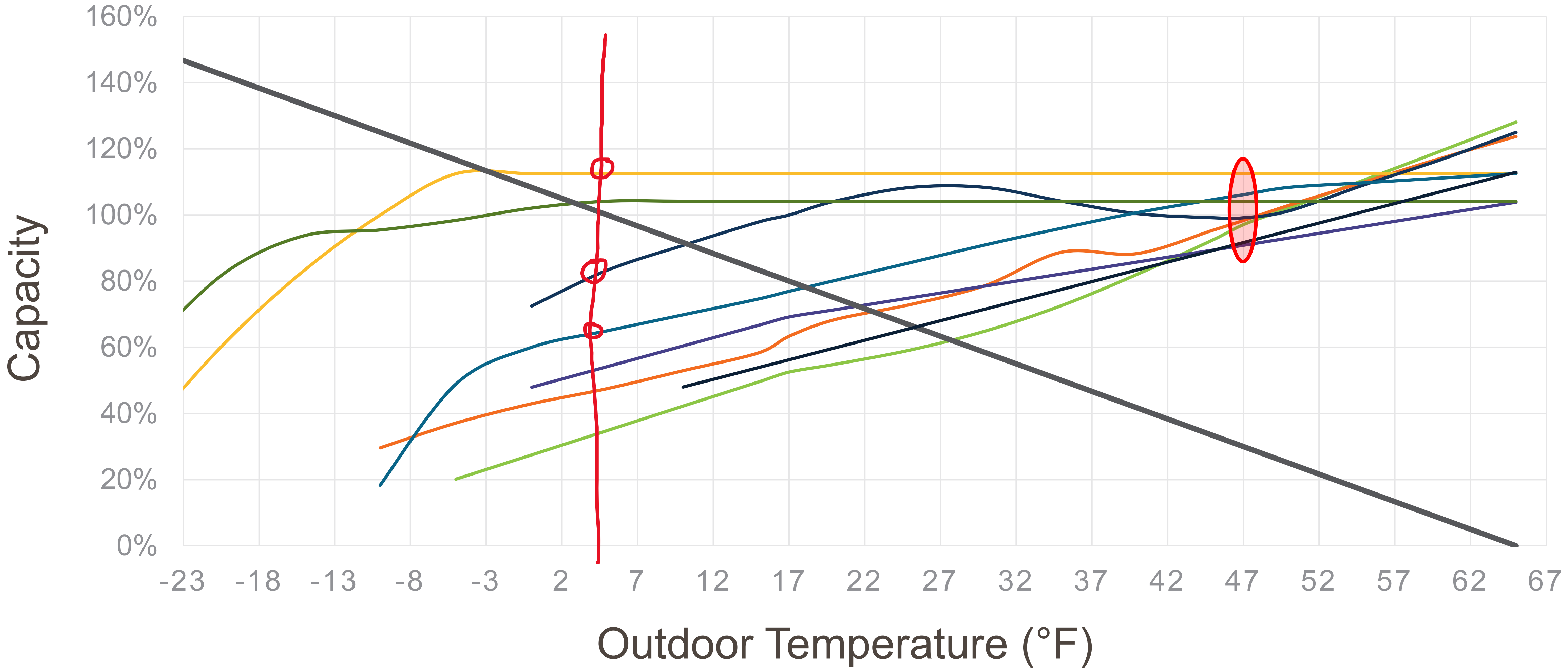
Not all Heat Pumps are the same



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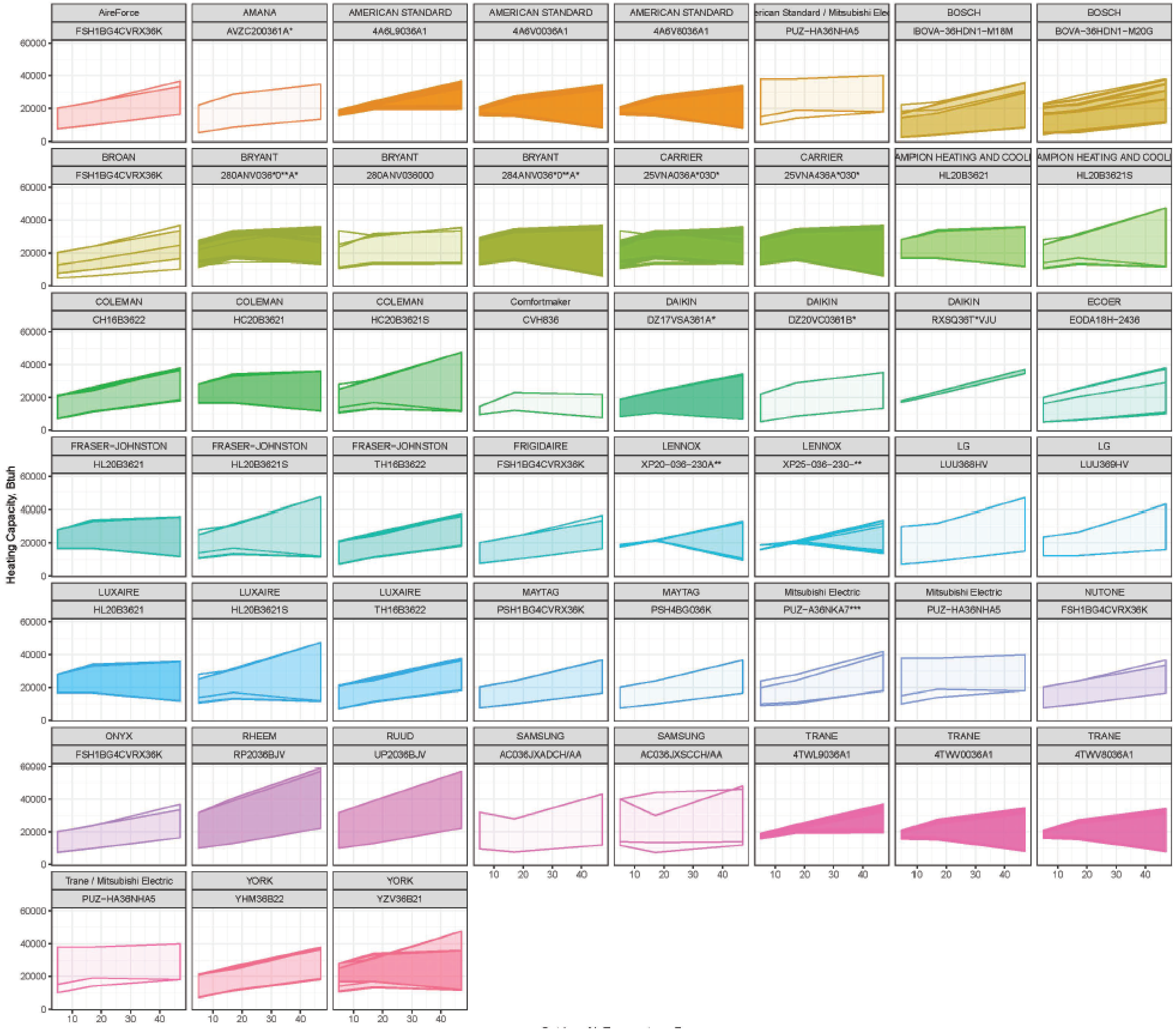
Capacity Curves

Nominal 3-Ton units

- AireForce
- AMANA
- AMERICAN STANDARD
- American Standard / Mitsubishi Electric
- BOSCH
- BROAN
- BRYANT
- CARRIER
- CHAMPION HEATING AND COOLING
- COLEMAN
- Comfortmaker
- DAIKIN
- ECOER
- FRASER-JOHNSTON
- FRIGIDAIRE
- LENNOX
- LG
- LUXAIRE
- MAYTAG
- Mitsubishi Electric
- NUTONE
- ONYX
- RHEEM
- RUUD
- SAMSUNG
- TRANE
- Trane / Mitsubishi Electric
- YORK



Archetypal HP Curves