Low Load Efficient Heat Pumps – version 2 (shortened)

NEEA Advanced Heat Pump Program

NEEA Product Council
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Presenter

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Outline

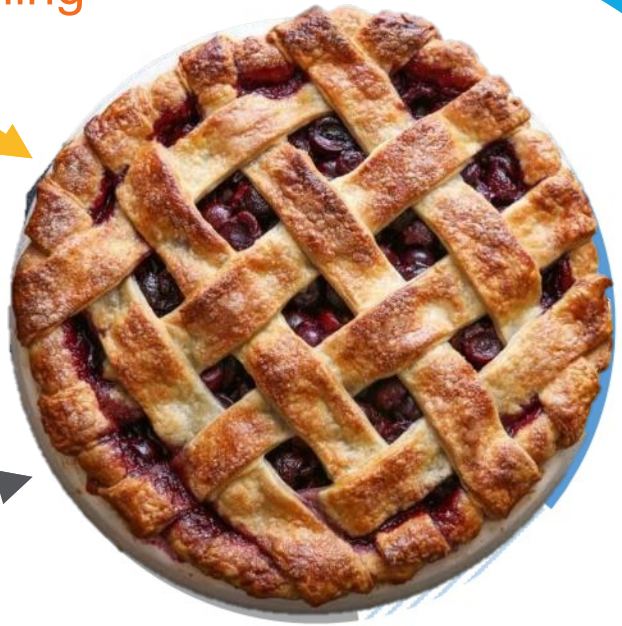
- Introduction – NEEA Advanced Heat Pump Program
- Metrics and Ratings
- What is a Low Load Efficient Heat Pump
- Source of Low Load Efficiency Investigation
- Where are Low Load Efficient heat pumps a good fit

Introduction

The Heat Pump Energy Savings Pie

Fix bad ducts,
good installation w/commissioning
+
good thermostat settings
and proper maintenance

Increasing HSPF2 &
SEER2 Values



Reduce oversizing and
eliminate unnecessary
ER heating

Standards of Practice | Equipment Dependent

*Savings compared to current practice

NEEA Advanced Heat Pump Program

CONTEXT and CONCEPT

- Real world energy metering consistently shows that heat pump performance often falls short of energy savings potentials. NEEA has identified a portfolio of technology and system improvements that meaningfully and cost effectively increase real world heat pump system efficiency.

APPROACH

- Use a mixture of analysis, lab testing and field research to refine our understanding of the improvement benefits (savings, comfort, etc) and differentiate products that have these improvements.
- Engage state, federal, utility and manufacturer partners to incorporate these improvements into their products, programs, trainings and incentives.
- Encourage continuous improvement of testing and ratings to provide representative metrics that inform customer and contractors about what heat pump solution delivers energy efficiency and load flexibility without negatively impacting customer comfort or lifecycle cost.

DESIRED OUTCOME

- All heat pumps incorporate one or more of the identified improvements.
- Increased energy savings without impacting customer cost or comfort

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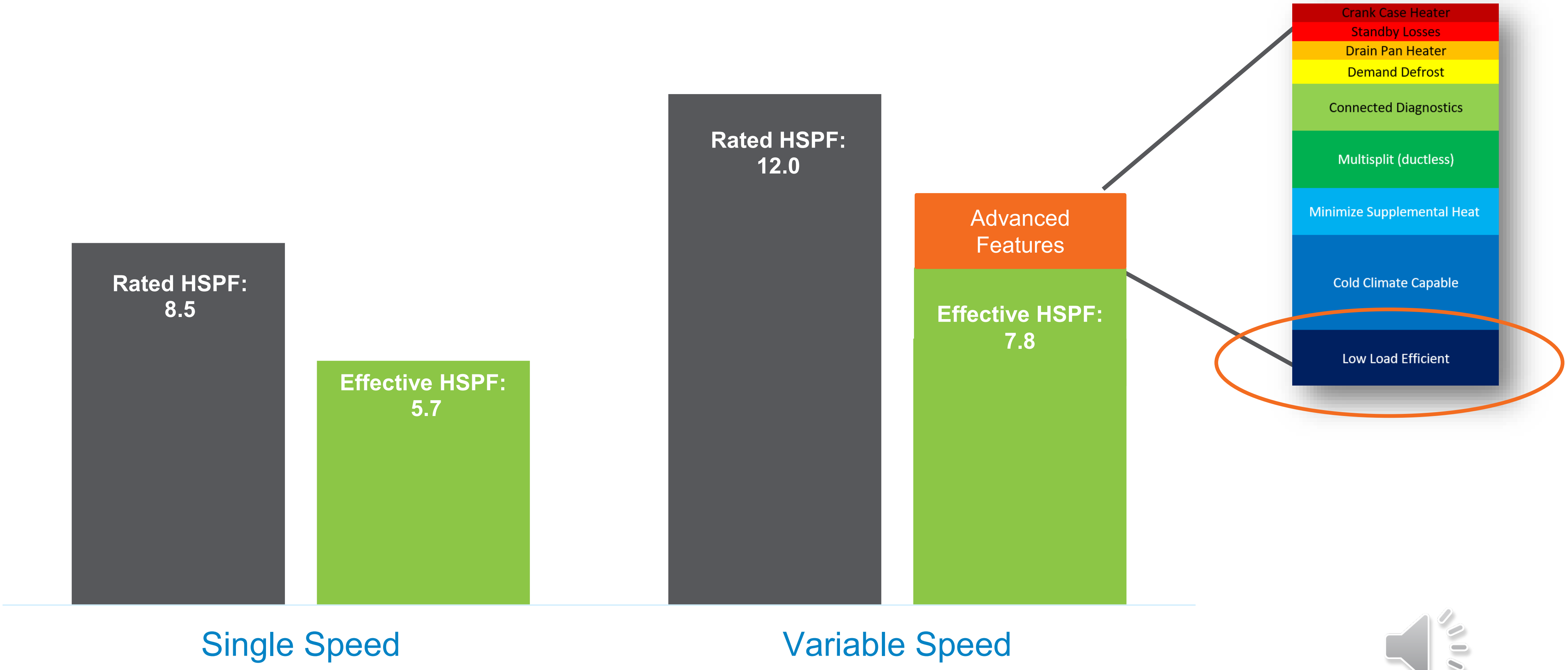
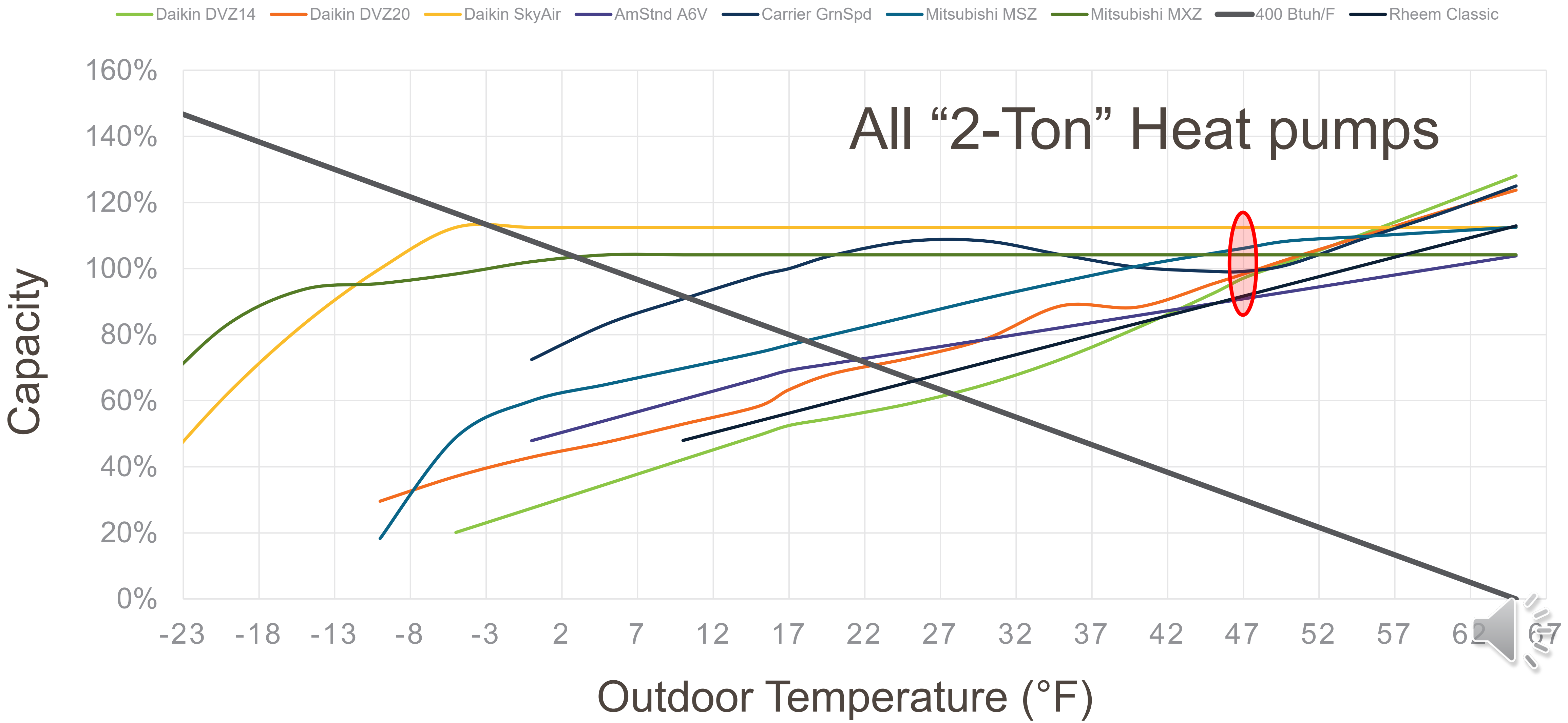
Heat Pump Improvements



Not all Heat Pumps are the same



Metrics & Ratings

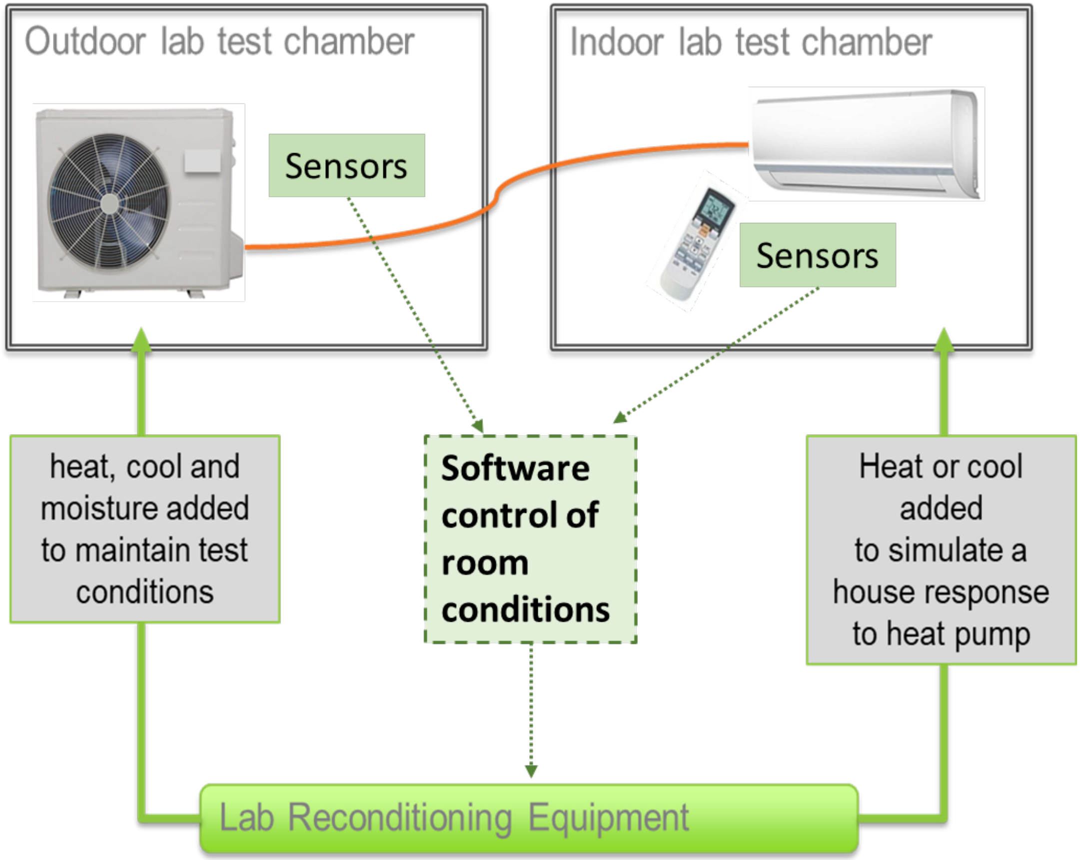
Heat Pump Ratings are Imperfect Proxies

Heat Pump Ratings

- SEER2 Seasonal Energy Efficiency Ratio (2023+)
- HSPF2 Heating Season Performance Factor (2023+)
- EER2 Energy Efficiency Ratio (2023+)
- COP Coefficient of Performance
- SCOP Seasonal Coefficient of Performance
- SCORE Seasonal Cooling and Off-hour Rated Efficiency
- SHORE Seasonal Heating and Off-hour Rated Efficiency

Load Based Testing – CSA SPE07

- Two test chambers
  - Constant outdoor conditions
  - Indoor room controlled in real time to reflect building response to load vs. heat pump capacity
- Test are run until:
  - COP converges, or
  - Elapsed time limit hit



Graphic by Parveen Dhillon, Purdue University

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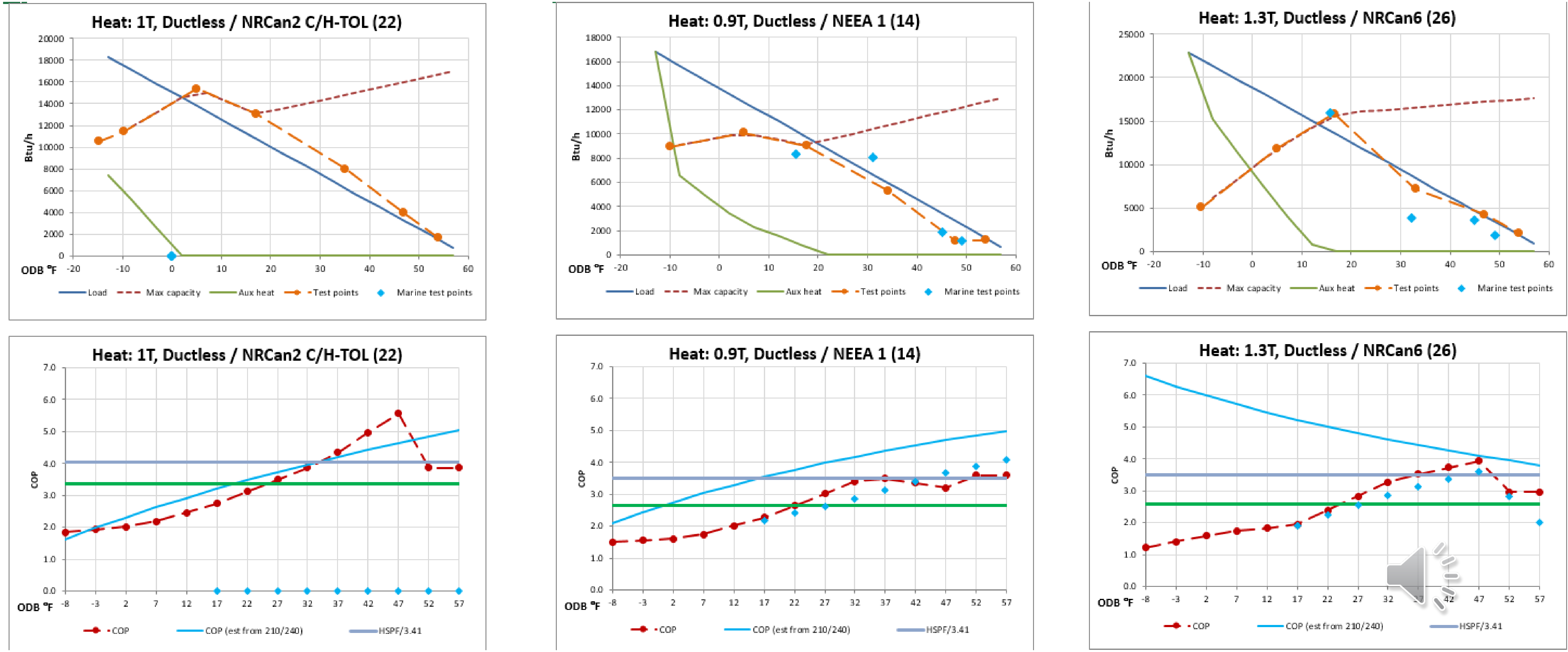
Load Based Testing Confirms Differences



Current Ratings

- HSPF and SEER are reasonably good basis for federal regulations, but do not reflect real world performance
- 2 Testing Methods
  - AHRI 210/240: static testing does not reveal heat pump algorithm differences
  - CSA SPE07: Load based is superior for variable speed, but less reproduceable
- Next generation metrics (SCORE and SHORE) should address the major shortcomings starting about 2030

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Heat pumps operate differently based on their internal control algorithms

What algorithms should Heat pumps have?

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Low Load Efficiency

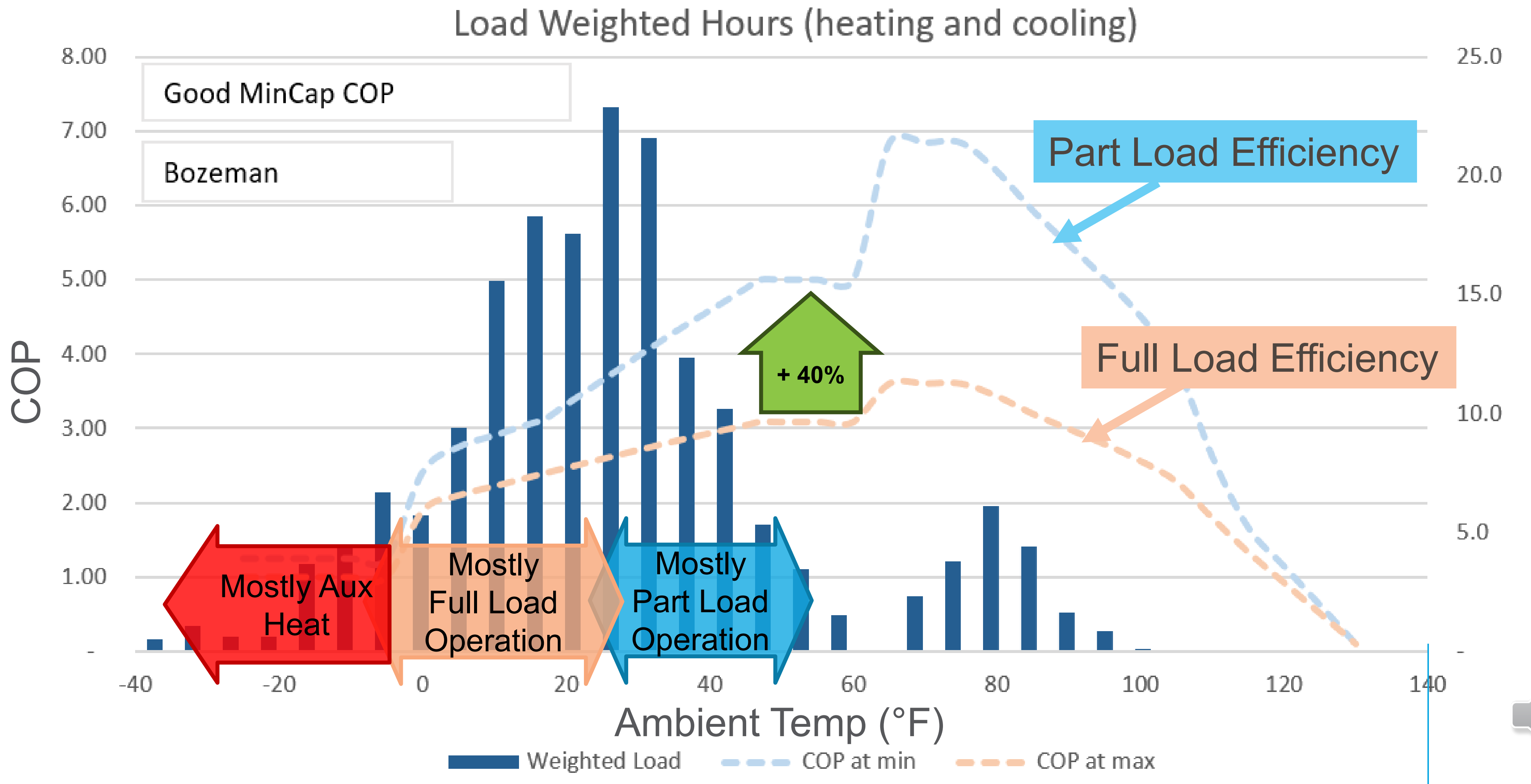
(aka part load performance)

Low Load Efficient (LLE) Heat Pumps

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

Good VSHPs are 40+% more efficient when running at minimum output than at full output. (lots of potential benefit)

Annual Heating vs COP



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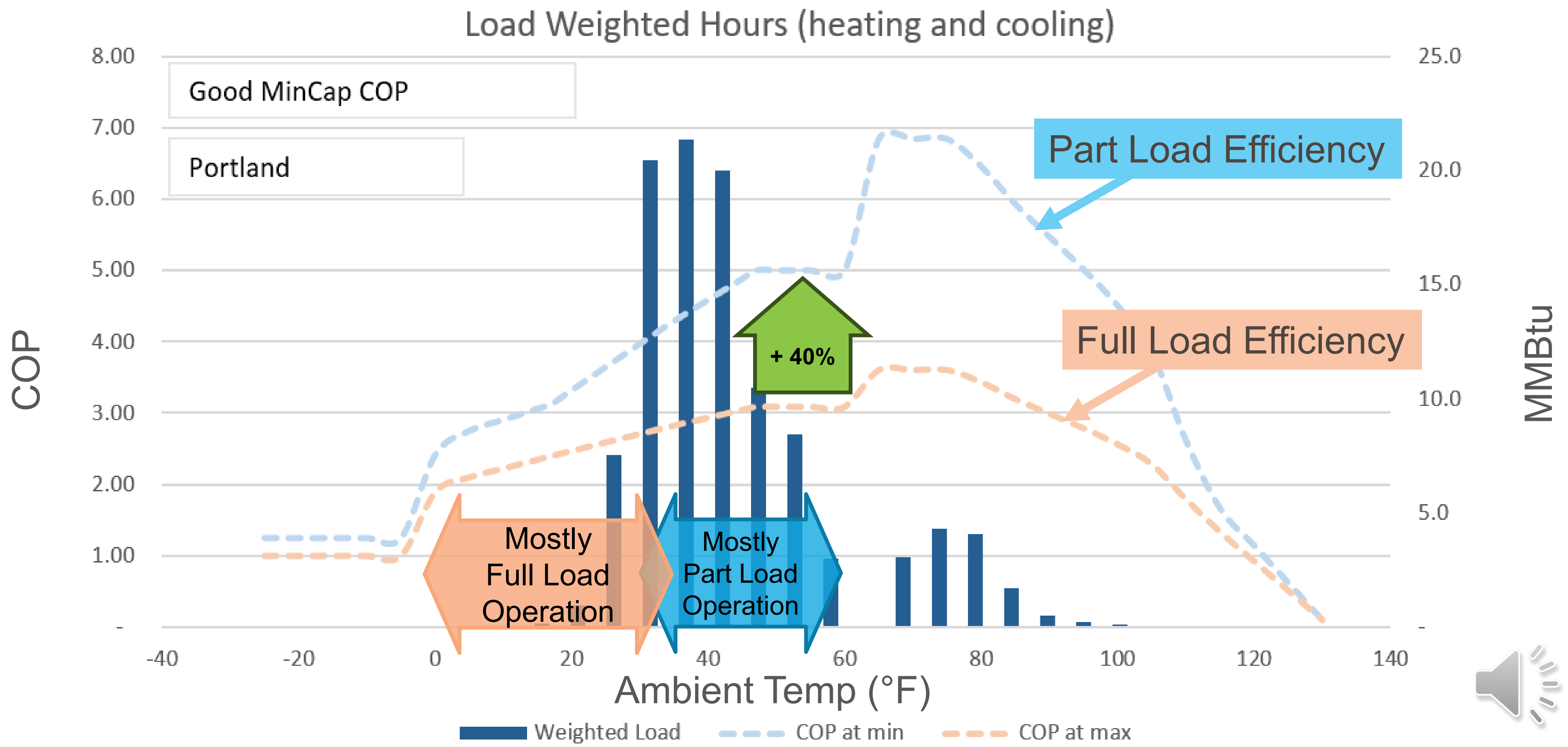
Annual Heating vs COP



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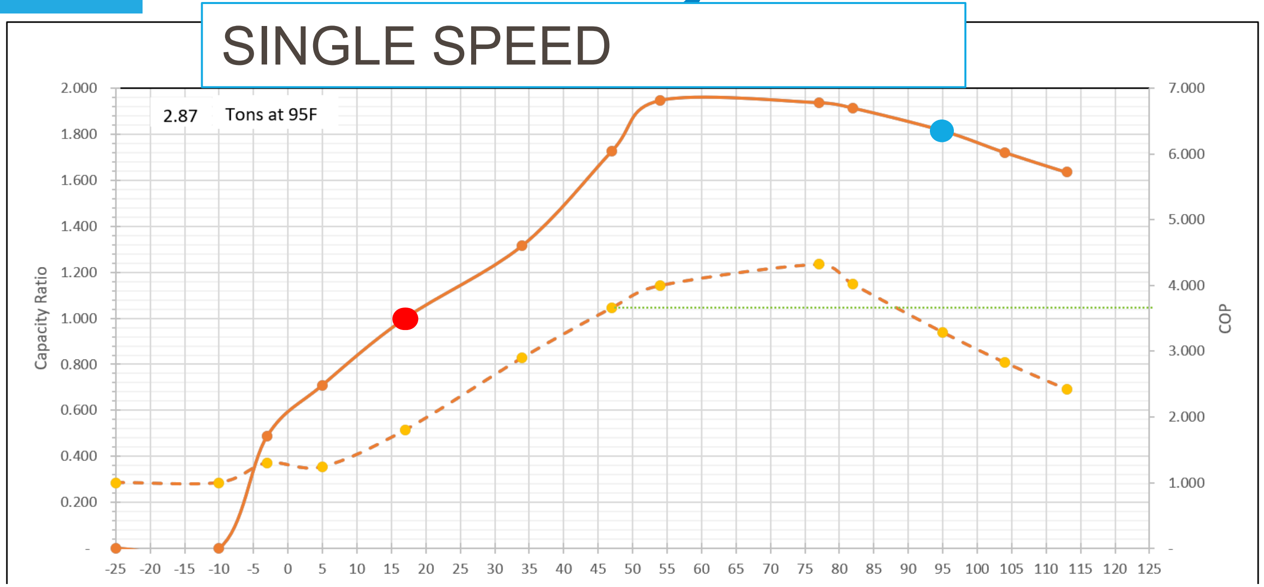
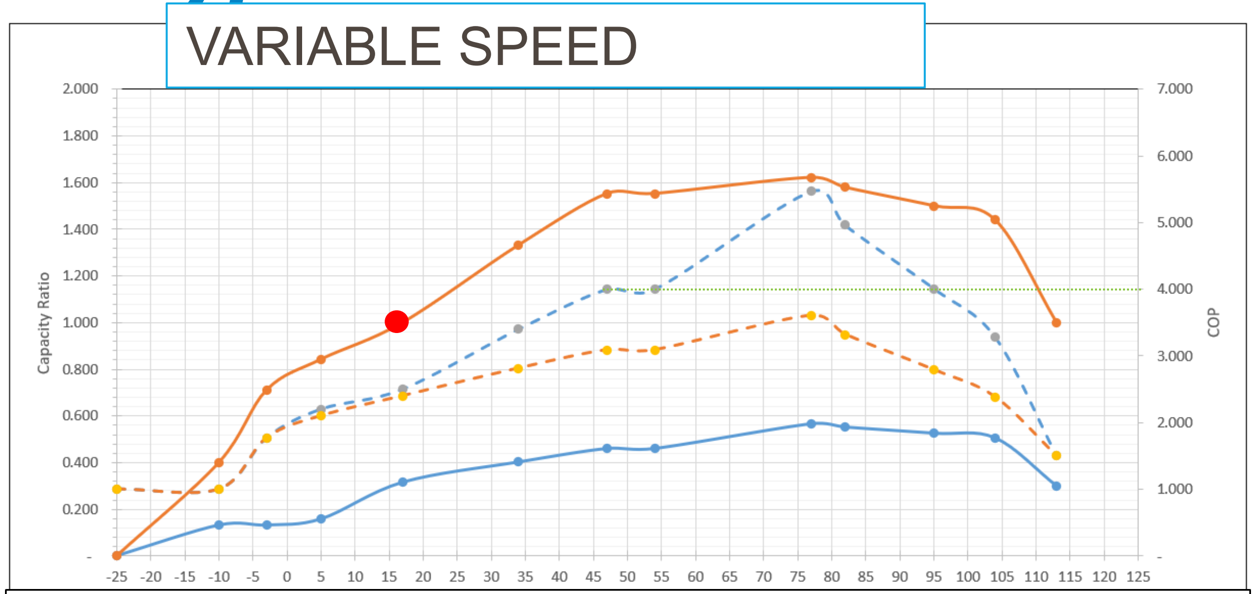
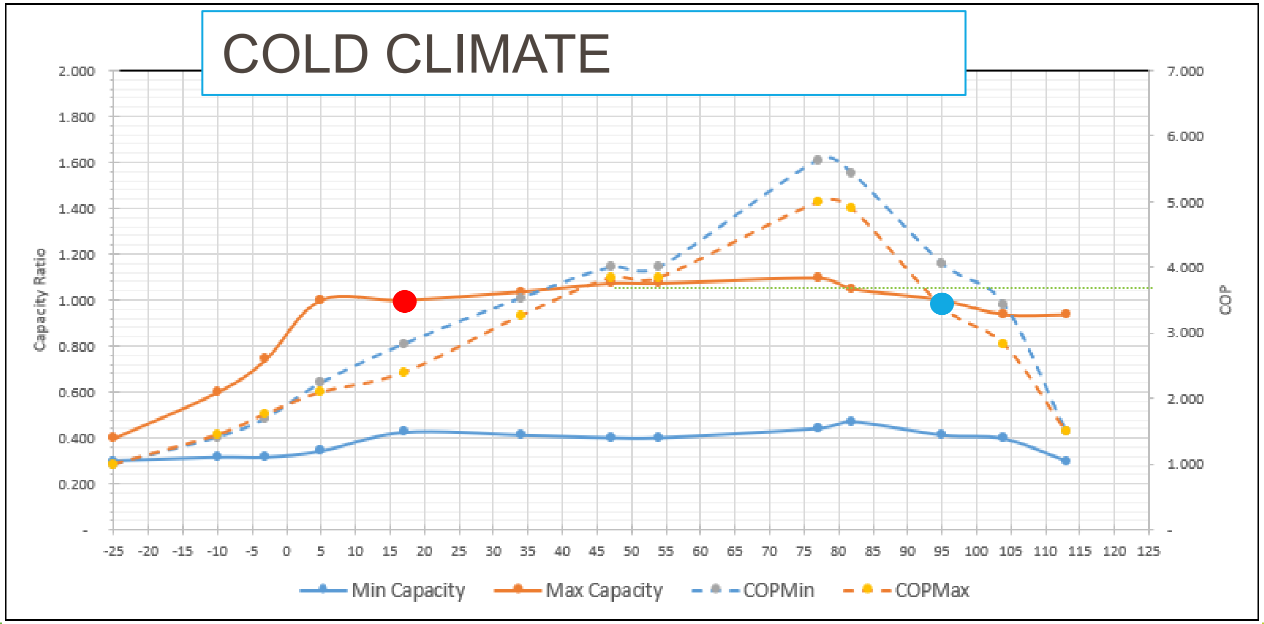
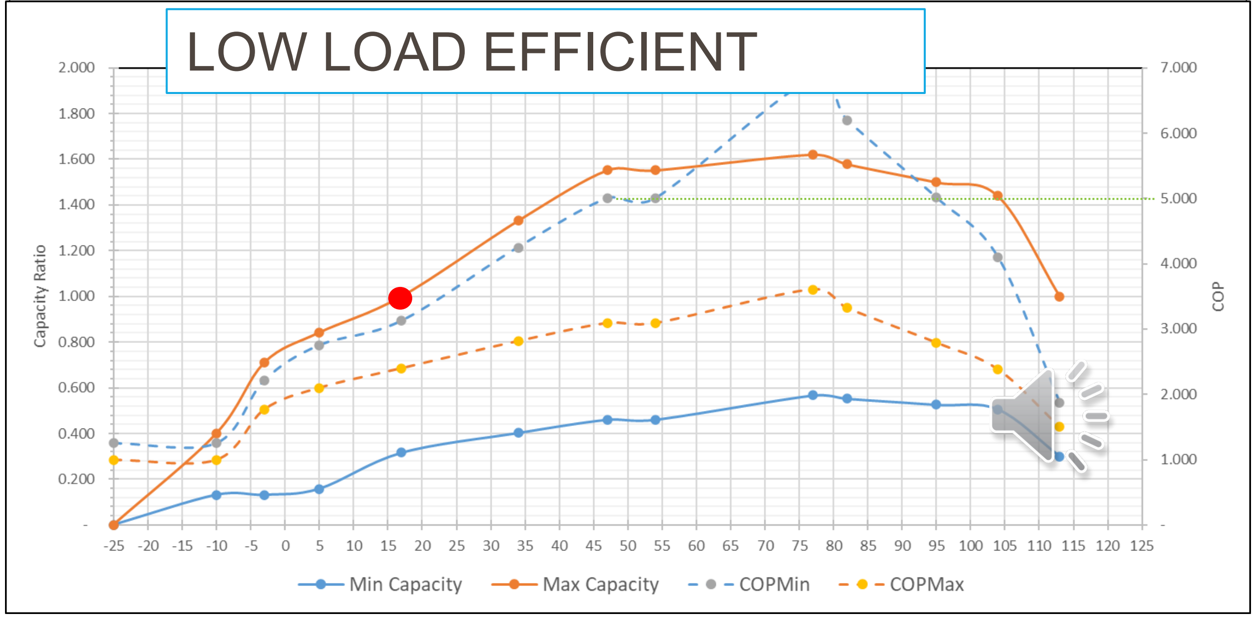
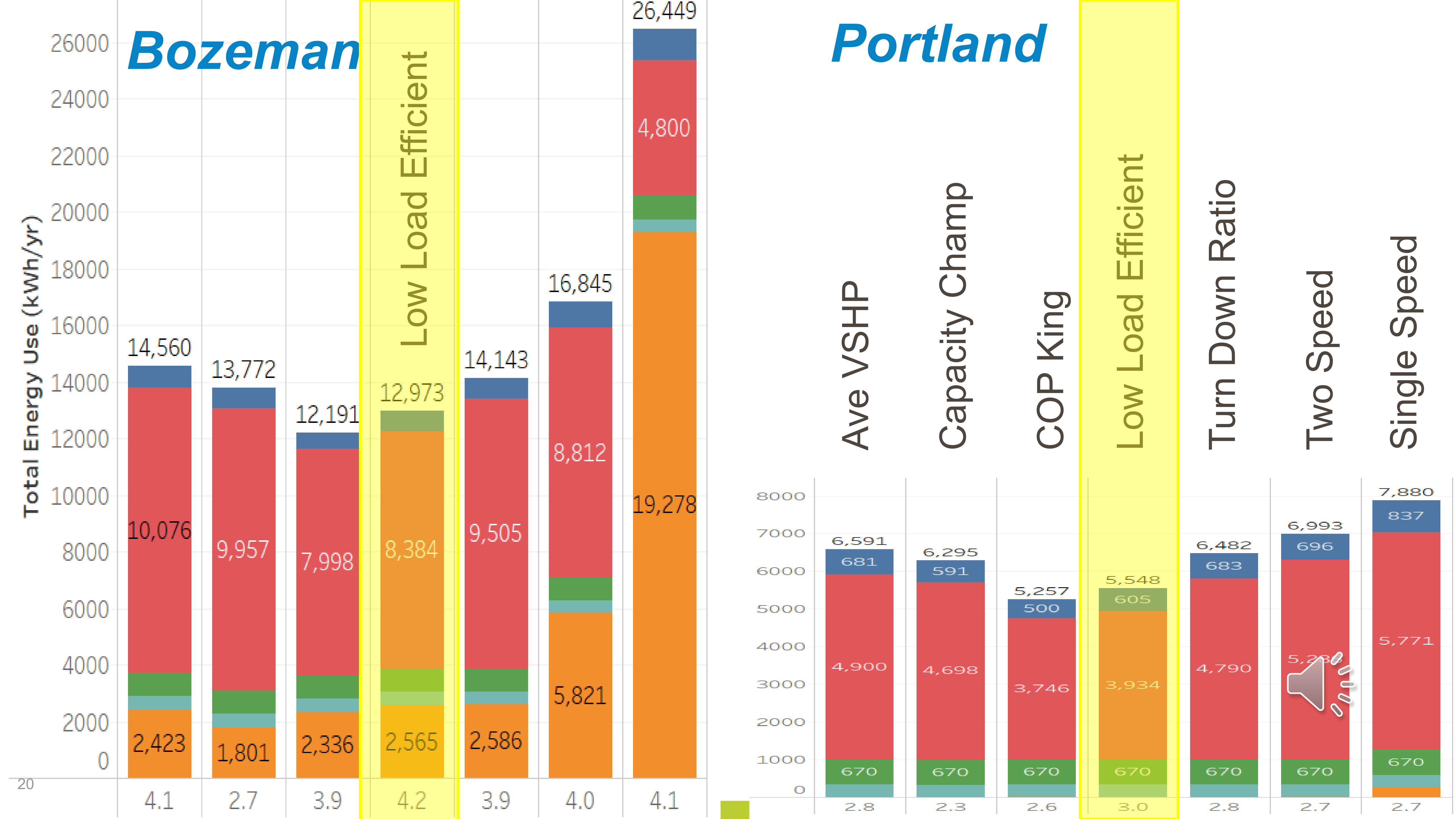
2022 - Analysis of HP Archetypes





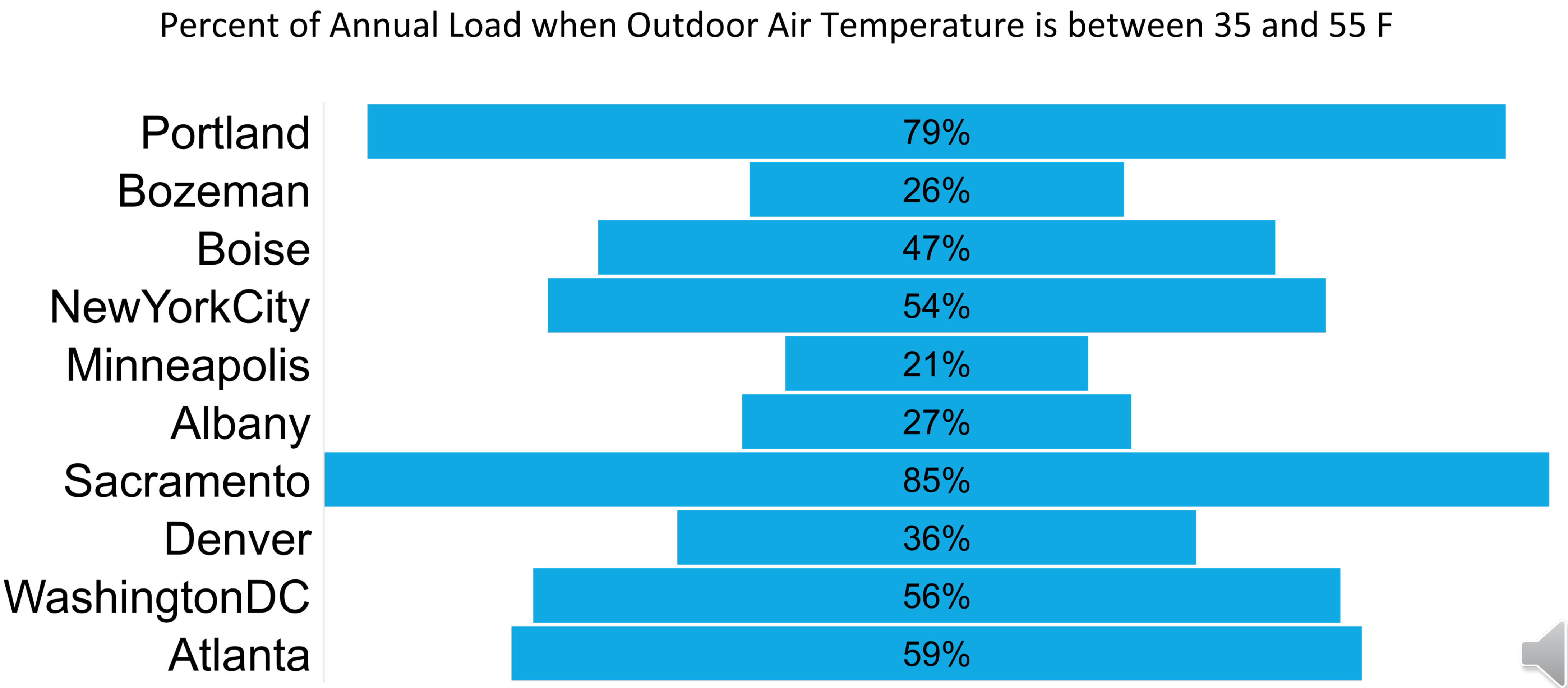






Bozeman
Total Energy Use (kWh/yr)
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Low Load Efficient
14,560
10,076
2,423
4.1
13,772
9,957
1,801
2.7
12,191
7,998
2,336
3.9
12,973
8,384
2,565
4.2
14,143
9,505
2,586
3.9
16,845
8,812
5,821
4.0
26,449
4,800
19,278
4.1
Portland
Ave VSHP
Capacity Champ
COP King
Low Load Efficient
Turn Down Ratio
Two Speed
Single Speed
8000
7000
6000
5000
4000
3000
2000
1000
0
6,591
681
4,900
670
2.8
6,295
591
4,698
670
2.3
5,257
500
3,746
670
2.6
5,548
605
3,934
670
3.0
6,482
683
4,790
670
2.8
6,993
696
670
2.7
7,880
837
5,771
670
2.7

Part Load Operation is Significant in Most Climates[1]



[1]Based on the heating load in typical home when ambient temperatures above 35°F and below 55°F - TMY3 climate data

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4-8% Annual LLE Savings

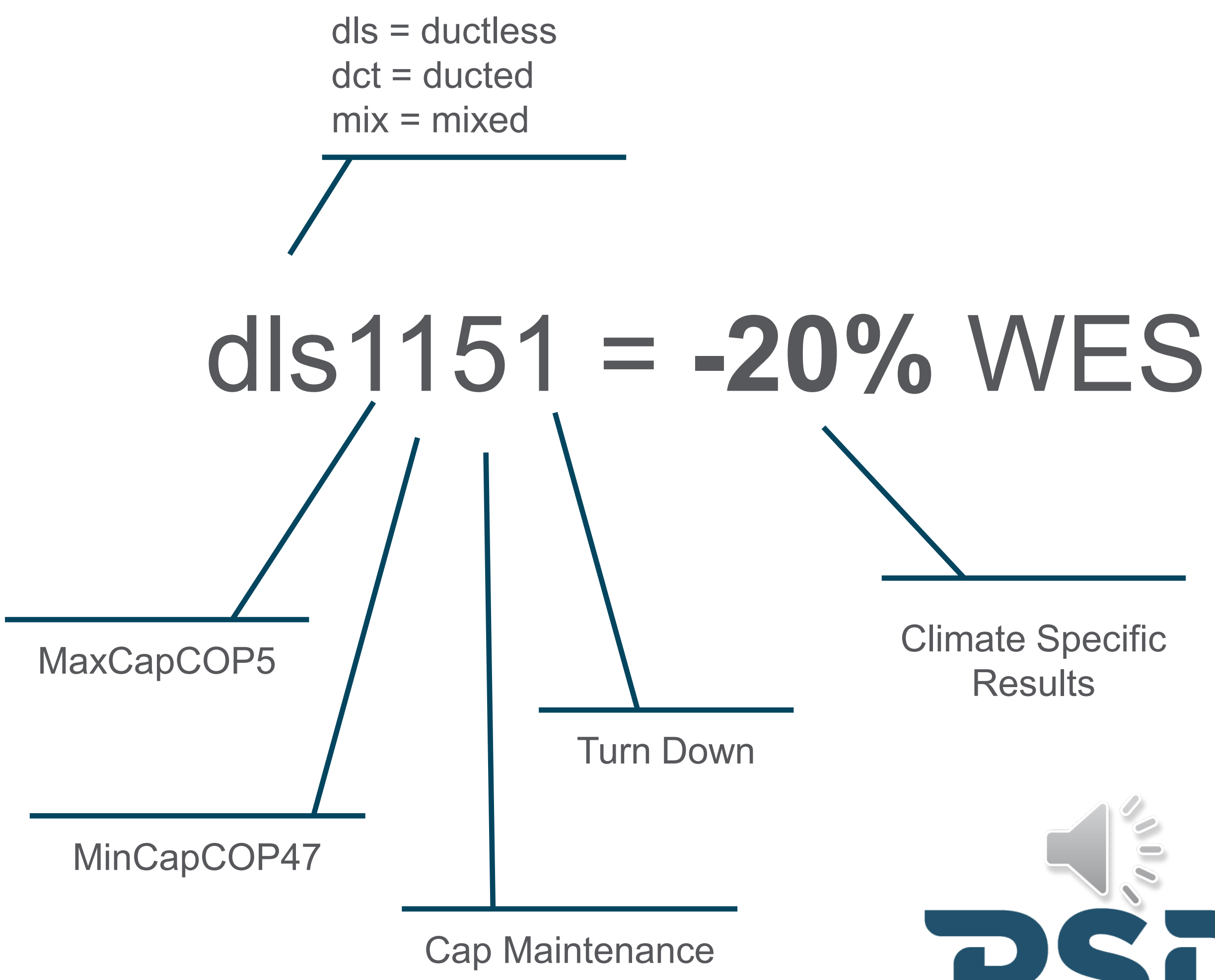
- Energy modeling by the Center for Energy & Environment (CEE) demonstrated that a **12.5% increase in efficiency at moderate outdoor temperatures** led to the following annual energy savings, by location.[1]

	Annual Savings
Portland	7.9%
Boise	7.4%
Bozeman	4.4%
Sacramento	8.4%
Denver	6.8%
Minneapolis	3.8%
New York City	8.6%
Washington DC	8.2%

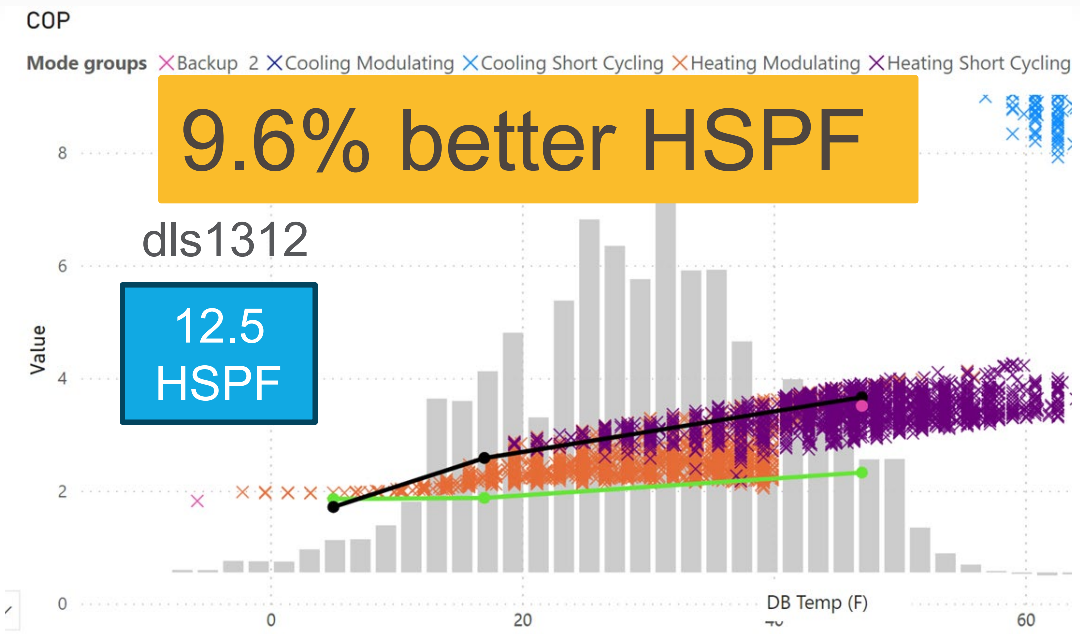
[1]Variable Speed Heat Pump Product Assessment and Analysis (*Note values in report for 25% increase*), NEEA 2022, https://neea.org/resources/variable-speed-heat-pump-product-assessment-and-analysis

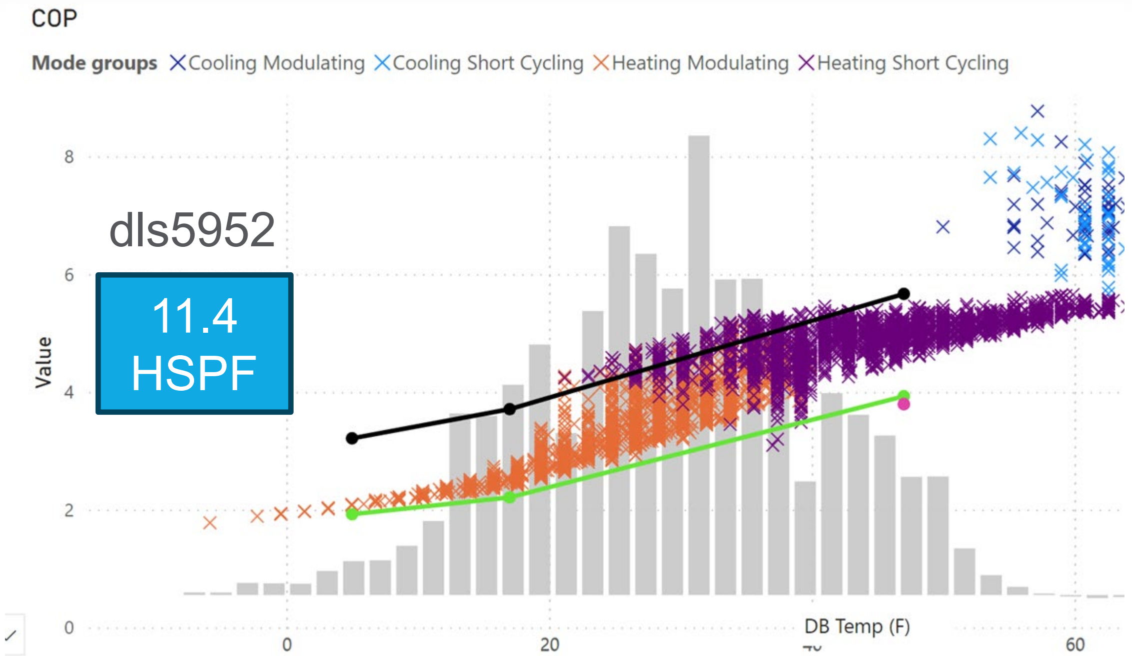
Equipment Profile Code and Performance Score

- PSD Consulting developed equipment codes to make climate specific comparisons easier
- Every code type is modeled with ENERGYPlus to generate annualized energy use of heating and cooling
- A score is then generated that indicates annual energy use compared to the average NEEP database listed heat pump for that system type
- Code consists of 5 inputs
  - (Type)(code 1)(code 2)(code 3)(code 4)



Climate Specific Performance Differentiation





-6%
Total EnergyPlus Performance Score
An average $2000 energy bill increases to $2120/year

+19%
Total EnergyPlus Performance Score
An average $2000 energy bill decreases to $1620/year

$500 per Year Savings

Elmira NY Weather

The Low Load Efficiency Metric

- **MinCapCOP47** is the coefficient of performance (COP) of a heat pump at an outdoor air temperature of 47°F while the compressor operates at its minimum capacity under its own native controls

- It is intended reflect the AHRI 210/240 test procedure $H1_{low}$ test condition operating

$$MinCapCOP47 \sim \mathrm{H1}_{\mathrm{low}} = \frac{Heat\ Capacity_{H1low}}{Input\ Power_{H1low}}$$

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NEEP Database

- Extended Performance Data
- Voluntary reported
- COP@ 5˚F ≥ 1.75
- Public Access
- Searchable
- Consistent format

MinCapCOP47

Note, the NEEP database calls this value MinCOP47

Central Air Conditioning Heat Pump (HP)
Singlezone Ducted, Centrally Ducted
AHRI Cert #+: **201754546**
Outdoor Unit Model #+: **PUZ-A30NHA7*****
Indoor Model #+: **PVA-A30AA***
Maximum Heating Capacity (Btu/h) @5°F: **17,200**
Rated Heating Capacity (Btu/h) @47°F+: **32,200**
Rated Cooling Capacity (Btu/h) @95°F+: **30,000**

Information Tables

Brand	MITSUBISHI ELECTRIC
Series	P-Series
Ducting Configuration	Singlezone Ducted, Centrally Ducted
AHRI Certificate #+	201754546
Outdoor Unit Model #+	PUZ-A30NHA7***
Indoor Model #+	PVA-A30AA*
Indoor Unit Type+	Mini-Splits
Furnace Model+ #	
EER+	10
SEER+	19
HSPF (Region IV)+	10
EER2+	9.9
SEER2+	19.4
HSPF2 (Region IV)+	8.9

Performance Specs

Heating / Cooling	Outdoor Dry Bulb	Indoor Dry Bulb	Unit	Min	Rated+	Max
Cooling	95°F	80°F	Btu/h+	10,000	30,000	30,000
			kW	0.54	3	3
			COP	5.43	2.93	2.93
Cooling	82°F	80°F	Btu/h+	10,200	-	32,000
			kW	0.44	-	2.7
			COP	6.79	-	3.47
Heating	47°F	70°F	Btu/h+	12,000	32,200	34,000
			kW	0.65	2.64	2.82
			COP	5.41	3.57	3.53
Heating	17°F	70°F	Btu/h+	6,700	18,000	20,700
			kW	0.6	2.11	2.23
			COP	3.27	2.5	2.72
Heating	5°F	70°F	Btu/h+	6,000	[illegible]	17,200
			kW	0.5	[illegible]	2
			COP	3.52	-	2.52

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MinCapCOP47 Possible Issues

- **Manufactures agree** that MinCapCOP@47 is the best available metric for identifying low load efficiency
- AHRI's "low speed" definition allows manufacturers flexibility in what speed is actually reported. **Manufacturers suggested** we should normalize MinCapCOP@47 with consistent “speed” (turndown ratio)
- MinCapCOP@47 is likely based on the static test of H1low, and may not reflect how a system operates under its own control algorithm

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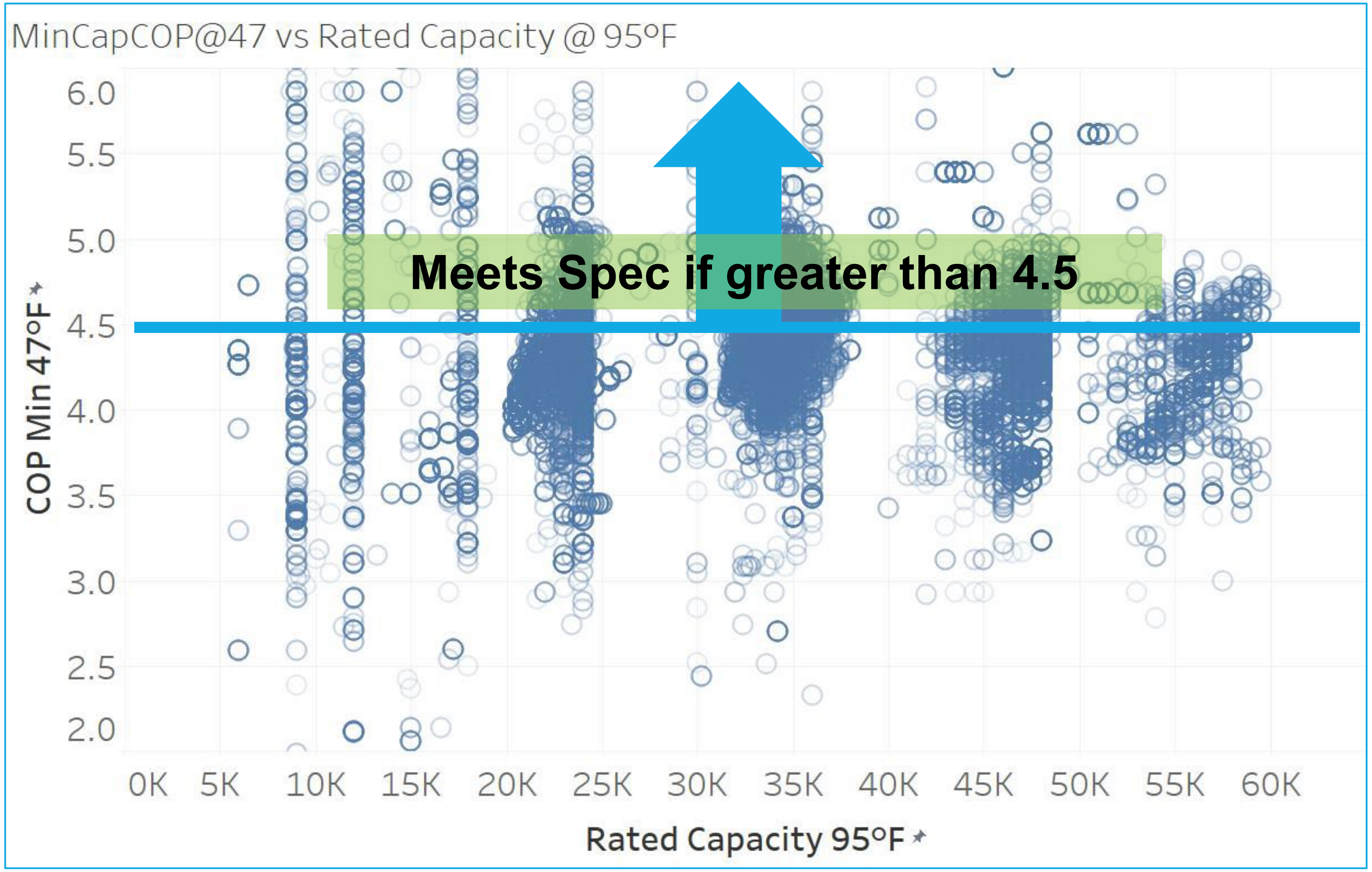
MinCapCOP47



- There is **significant variation** in MinCapCOP@47 in the market today
- NEEA LLE Specification
  - Tier1 ≥ 4.5
  - Tier2 ≥ 5.0

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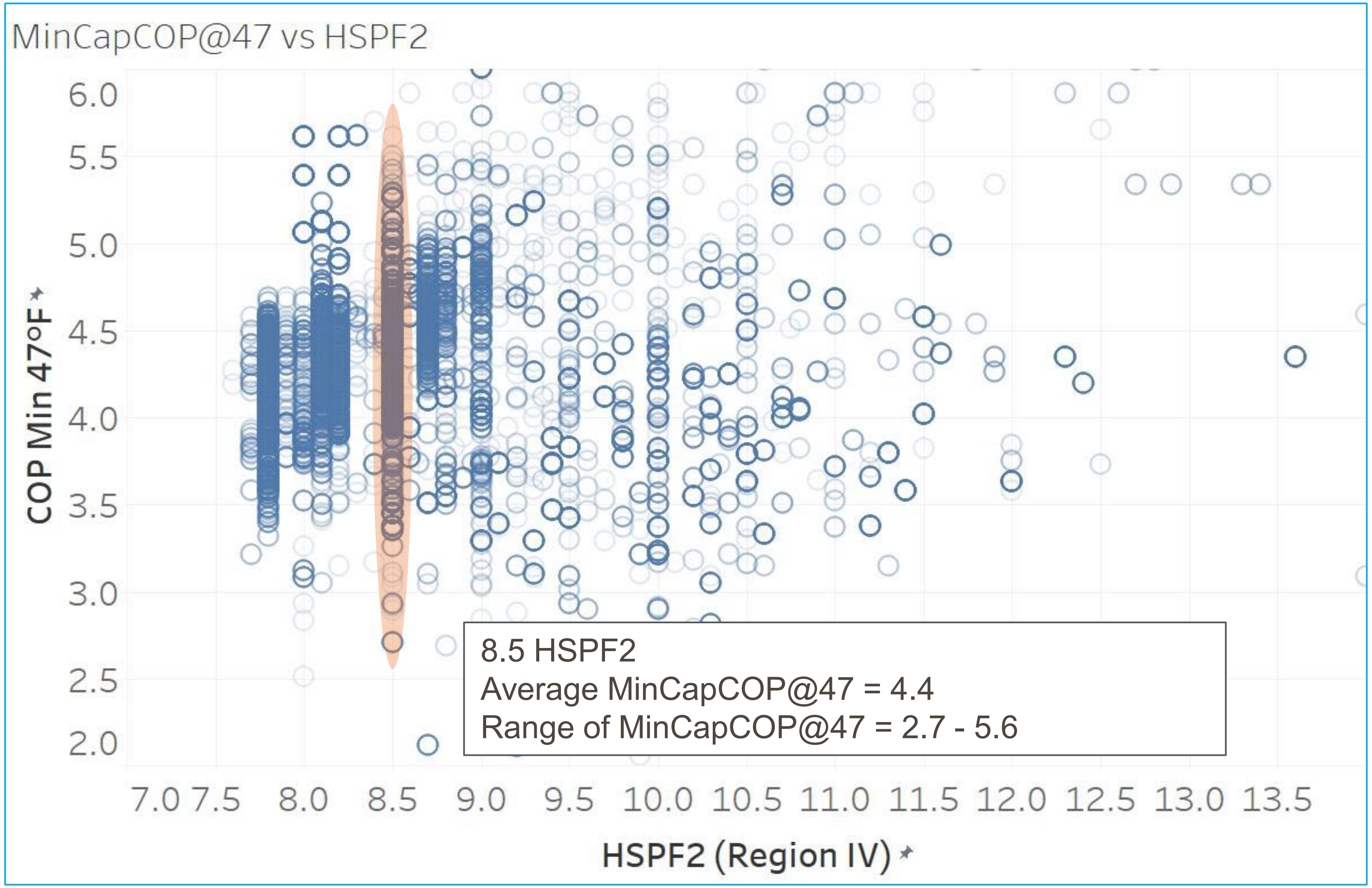
HSPF2 does not tell you which machine is has good part load efficiency



- HSPF2 does not indicate LLE
- The potential for energy savings through LLE has been unrecognized until now
- OEM have shown minimal interest in optimizing for LLE due to the absence of incentives and clear guidelines.

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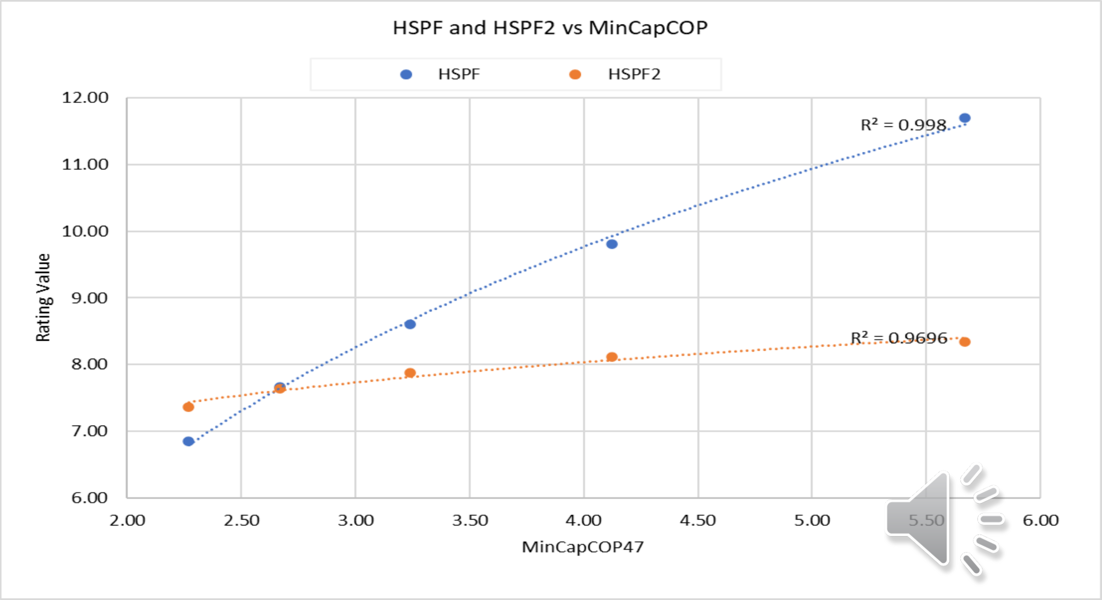
MinCapCOP47 has minimal impact on HSPF2

- MinCapCOP47 role in AHRI 210/240
  - $H1_{low}$ directly part of rating, the equations rely on a the "coefficient of degradation" to capture low load efficiency
- AHRI Calculator
  - 25% increase in MinCapCOP47 results in a 3% increase in HSPF2
  - It should be more like 8-17% depending on climate



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HSPF2 Calculation

- $H1_{low}$ is included but not heavily weighted
- 47_{max} and 17_{max} are dominant conditions
- HSPF is more impacted by full load efficiency
- SEER is more impacted by part load efficiency
- EER is a full load test at 95F

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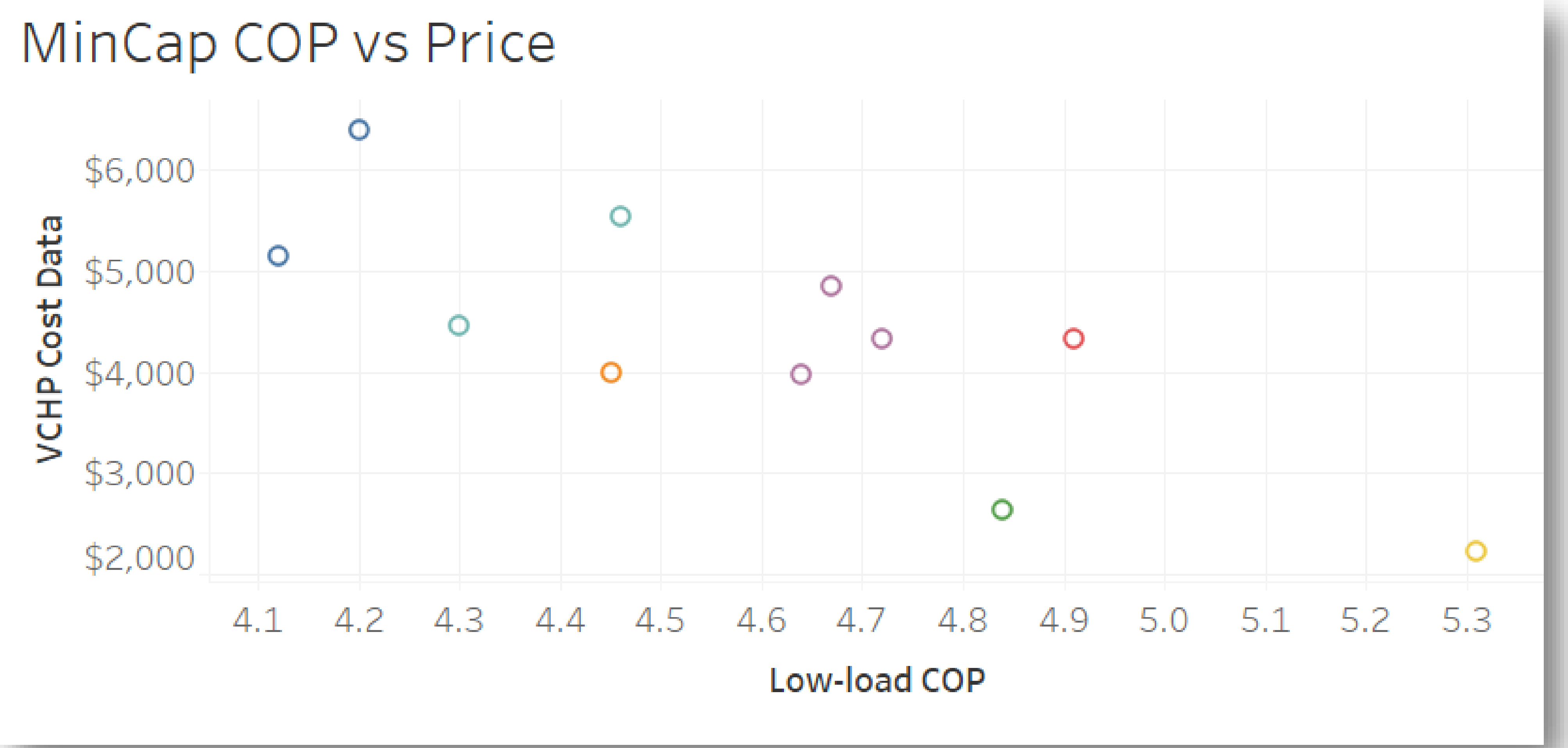
LLE doesn't appear to cost more



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

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Source of Low Load Efficiency Investigation

Possible Causes Low Load Efficiency

- Control algorithm?
- Metering device (e.g. TXV vs. EXV)?
- Compressor type (scroll vs. rotary)?
- Heat exchanger size?
- Heat exchanger miss-match?

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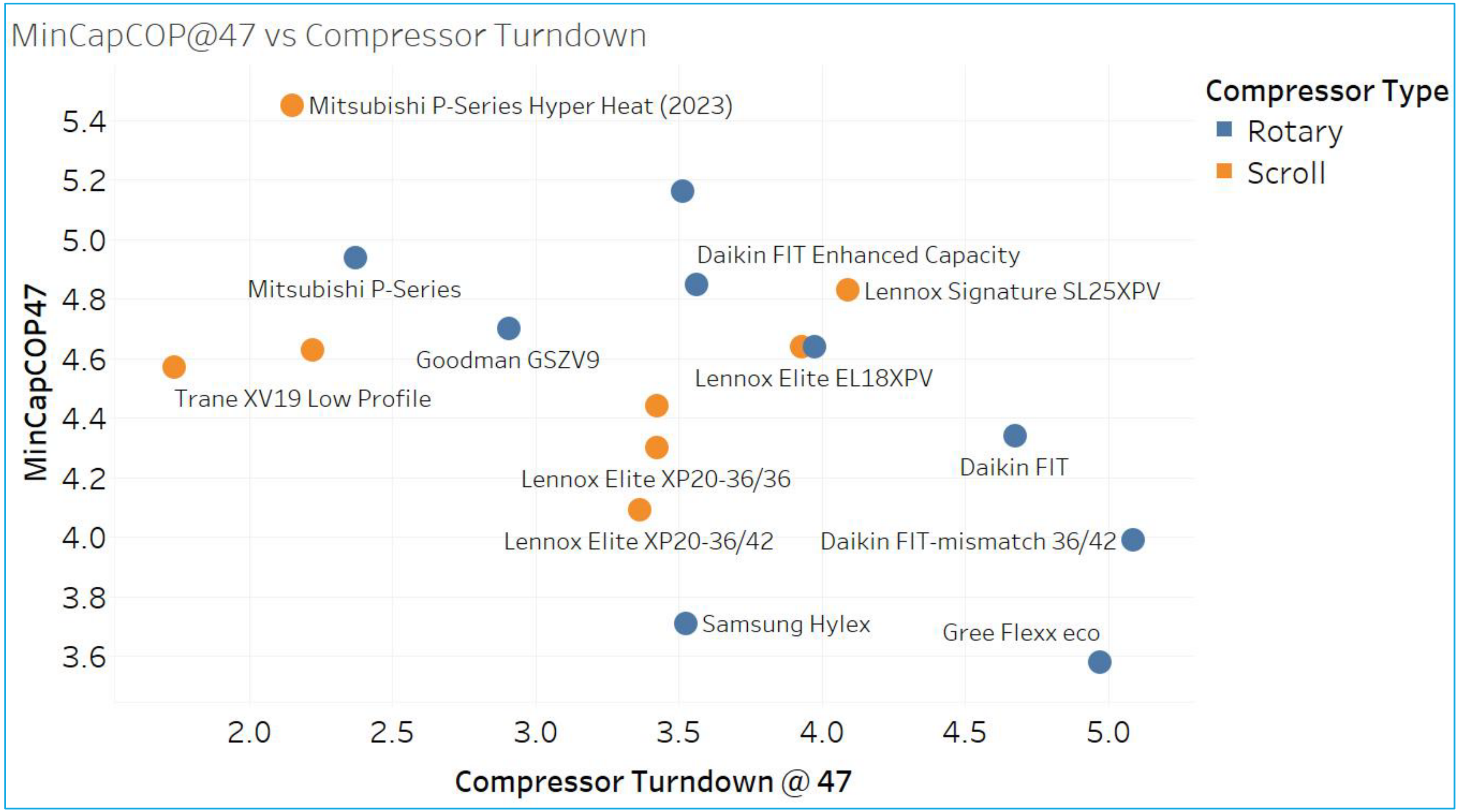
Methodology

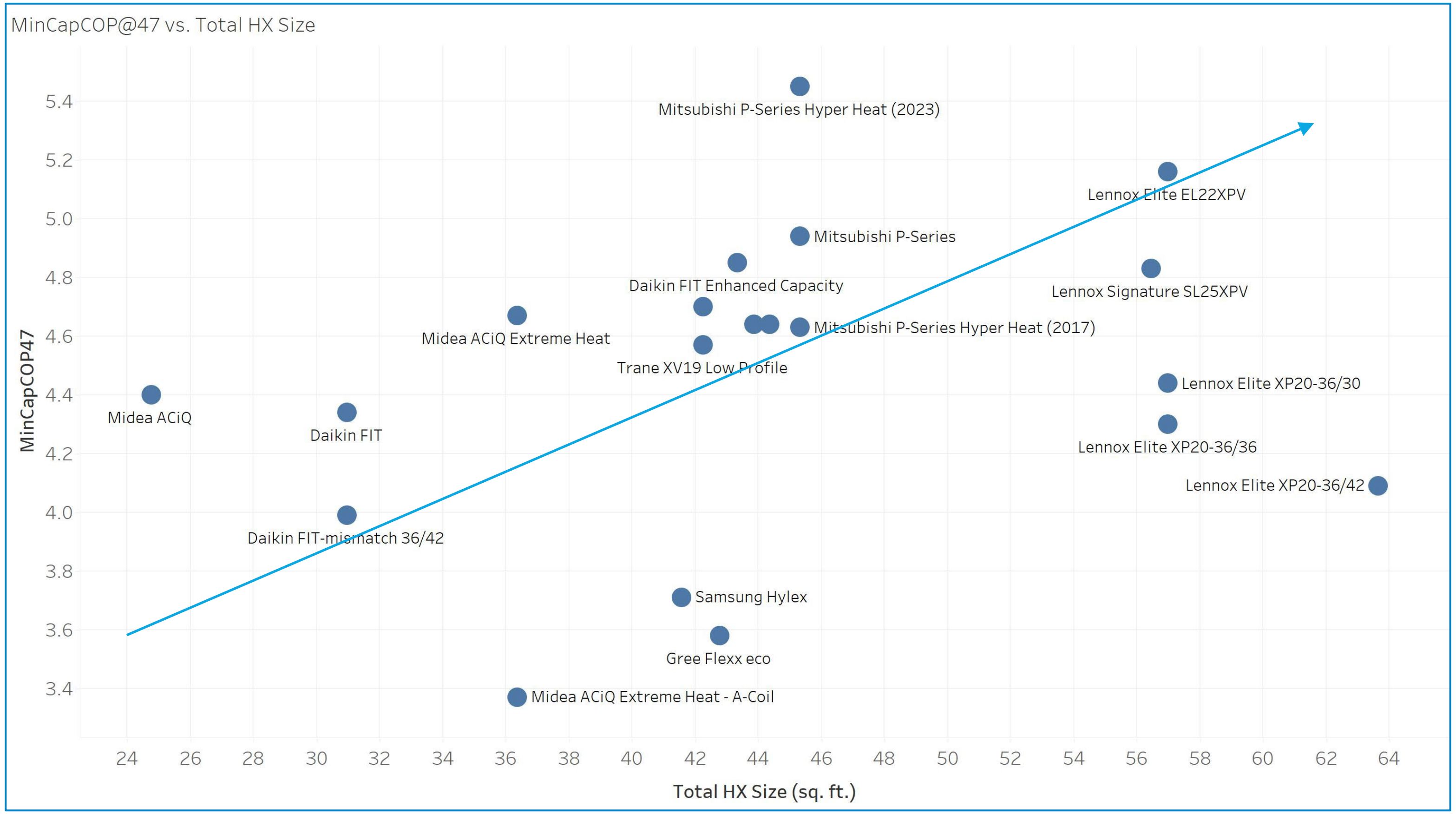
- We interviewed manufacture engineers and SMEs
- We investigated the reliability of the NEEP Database
- We also conducted a “paper teardown” of heat pumps
  - We tested theories discussed during the OEM discussions about features that lead to improved low load efficiency.
  - We assessing trends in NEEP values for MinCapCOP@47 associated with various technologies and design decisions

Compressor type does not appear to be significant contributor to part load efficiency



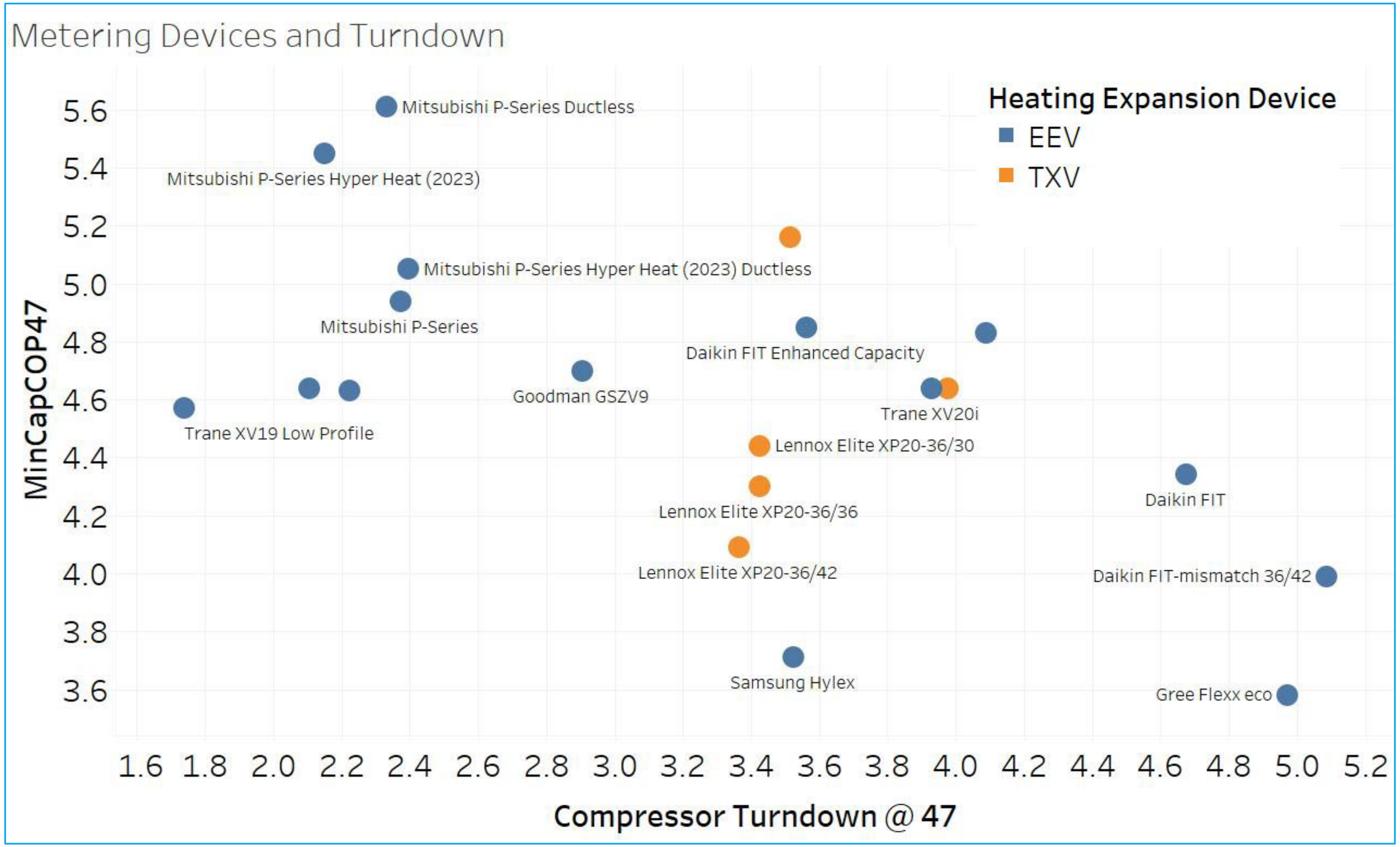
- Mfgrs suggested that rotary compressors maintain better efficiency at partial loads compared to scroll compressors.
- Data suggests that compressor type does not significantly impact part load efficiency.

Heat Exchanger Size Dependency



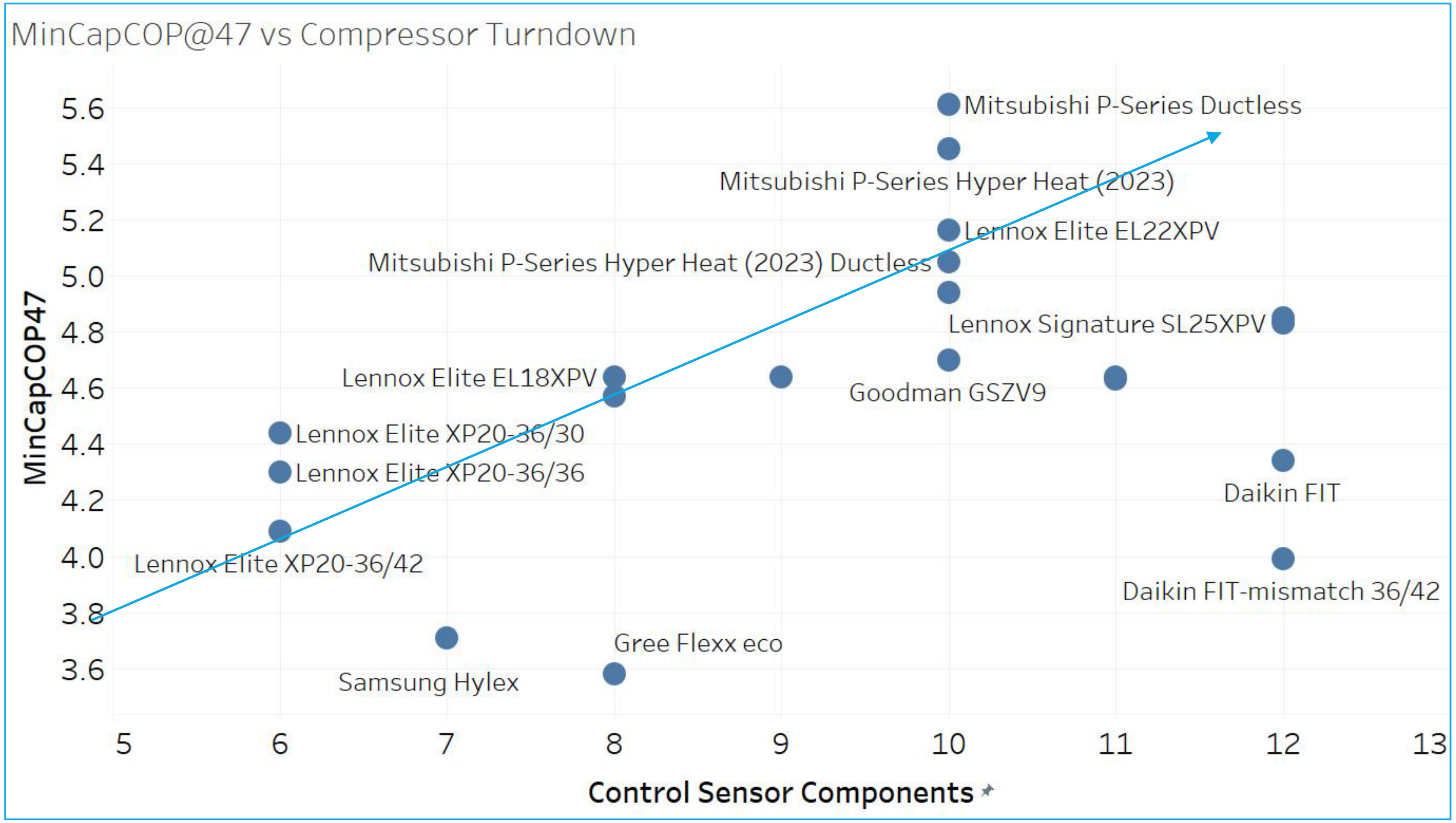
- Mfgrs suggested that larger heat exchanger size increases the opportunity to have better efficiency at low loads
- Data demonstrates this trend, but shows high LLE is still achievable without larger heat exchangers

Metering device type does not appear to be significant contributor to part load efficiency



- Mfgrs suggested that TXVs face challenges in effectively regulating flow at part load conditions
- Data suggests that metering device type is not a significant contributors to part load efficiency.
- However, there were no systems with TXVs with high compressor turndown ratios

Refrigerant controls are likely contributors of part load efficiency



- Manufactures suggested that optimized refrigerant controls improve LLE
- Data shows improved LLE with systems with more Control sensor components
- Previous load-based lab testing supports this hypothesis as well

Variable Speed Indoor and outdoor fans are likely significant contributors of part load efficiency

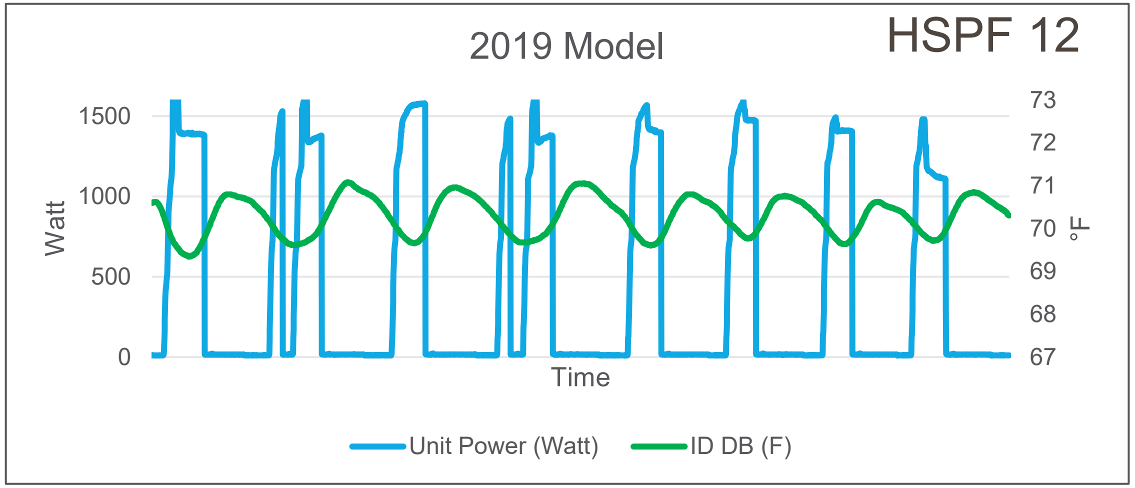
- A well paired indoor and outdoor unit with ECM fan motors could potentially result in a COP increase of more than 0.5 under part load conditions.
- Illustrative example: 3-Ton Unit w/ and w/o effective fan turndown

Load	Heating capacity (W)	Fan Power (W)	Standby + Compressor Power (W)	COP
100%	10,511	622	2,377	3.5
50% - No fan turndown	5,275	622	1,209	2.9
50% - Good fan turndown	5,275	144	1,209	**3.9**

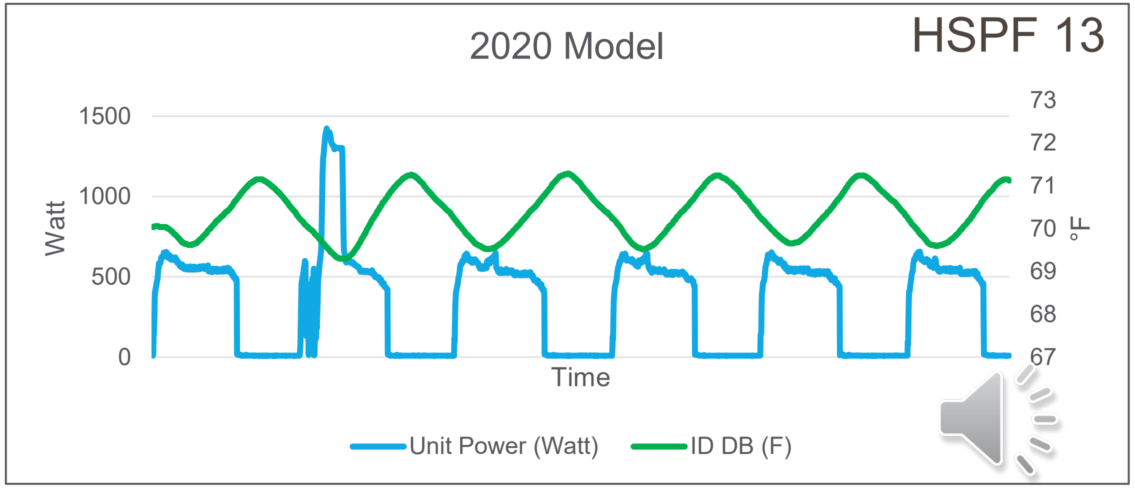
Full load fan and compressor watts based on average nameplate ratings across the 22 heat pumps analyzed as part of the paper teardown

Controls are likely contributors of part load efficiency

- 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%

Where are LLE heat pumps a good fit?

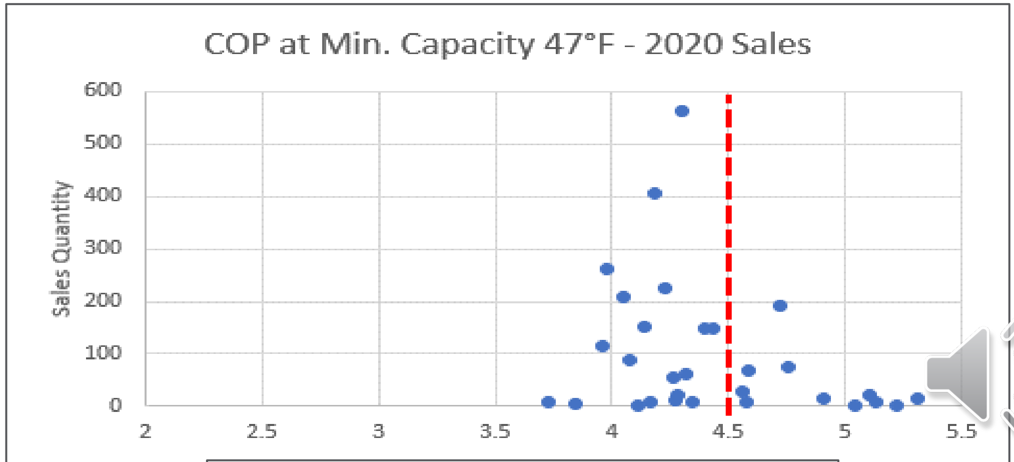
1. *Mild Climates*
2. *Dual Fuel Heat Pump Systems*

LLE is great in Mild Climates

	Annual Savings
Portland	7.9%
Boise	7.4%
Bozeman	4.4%
Sacramento	8.4%
Denver	6.8%
Minneapolis	3.8%
New York City	8.6%
Washington DC	8.2%

Based on MN CEE modeling work of 2022 for part load efficiency improvement

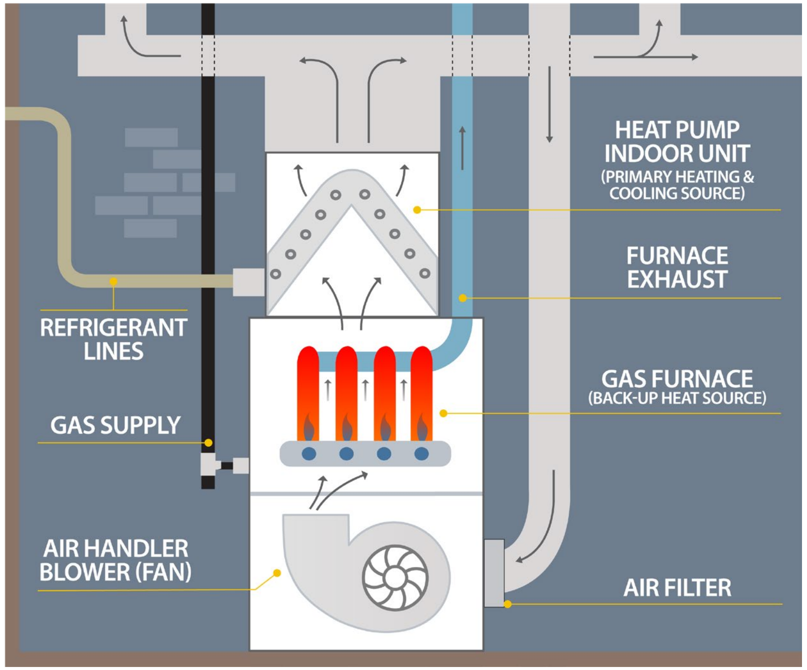
- Increasing part load efficiency by 12.5% in a mild climate should produce a 7-8% decrease in annual energy use.
- 2020 sales data shows roughly a quarter of sales already achieve this target.
- 250-500 kWh/yr incremental savings for typical existing home



MinCapCOP47

Dual Fuel Systems Need LLE Heat Pumps

- Dual fuel heat pumps cannot operate the heat pump and the gas furnace at the same time*
- The heat pump never runs at full load, it always runs at part load



graphic by Slipstream Inc.

* Because the gas burner is upstream of the heat pump coil

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Dual Fuel Cost Balance Point

for cold climate HPs

Natural gas rate, $/therm, (furnaces and boilers)

Electric rate, $/kWh (ASHP)	$0.60	$0.65	$0.70	$0.75	$0.80	$0.85	$0.90	$1.00	$1.15	$1.33	$1.50	$2.00	$2.50	$2.75
$0.05	25°	20°	15°	10°	5°	0°	-5°	-10°	-10°	-10°	-10°	-10°	-10°	-10°
$0.06	35°	30°	25°	20°	15°	15°	10°	0°	-10°	-10°	-10°	-10°	-10°	-10°
$0.07	45°	40°	35°	30°	25°	25°	20°	10°	0°	-10°	-10°	-10°	-10°	-10°
$0.08	50°	45°	40°	40°	35°	30°	25°	20°	10°	0°	-10°	-10°	-10°	-10°
$0.09	60°	55°	50°	45°	40°	40°	35°	30°	20°	10°	0°	-10°	-10°	-10°
$0.10	60°	60°	55°	50°	50°	45°	40°	35°	25°	15°	10°	-10°	-10°	-10°
$0.11	60°	60°	60°	60°	55°	50°	45°	40°	30°	25°	15°	-5°	-10°	-10°
$0.12	60°	60°	60°	60°	60°	55°	50°	45°	35°	30°	20°	0°	-10°	-10°
$0.13	60°	60°	60°	60°	60°	60°	55°	50°	40°	35°	25°	5°	-10°	-10°
$0.14	60°	60°	60°	60°	60°	60°	60°	55°	45°	35°	30°	10°	-5°	-10°
$0.15	60°	60°	60°	60°	60°	60°	60°	60°	50°	40°	35°	15°	0°	-5°
$0.16	60°	60°	60°	60°	60°	60°	60°	60°	55°	45°	40°	20°	5°	0°
Propane rate, $/gallon, (furnaces and boilers)										$1.22	$1.37	$1.83	$2.29	$2.52

3 Minnesota Air Source Heat Pump Collaborative, "Economic Balance Point for Dual Fuel," accessed May 8, 2023, https://static1.squarespace.com/static/5eebc734f52c736dceefa2ec/t/613a49d2020e0922d1401af1/1631209939451/Economic_Balance_Point_ASHP _Chart.pdf.

Better Part Load Efficiency Increases Range

Natural gas rate, $/therm, (furnaces and boilers)

Electric rate, $/kWh (ASHP)	$0.60	$0.65	$0.70	$0.75	$0.80	$0.85	$0.90	$1.00	$1.15	$1.33	$1.50	$2.00	$2.50	$2.75
$0.05	25°	20°	15°	10°	5°	0°	-5°	-10°	-10°	-10°	-10°	-10°	-10°	-10°
$0.06	35°	30°	25°	20°	15°	15°	10°	0°	-10°	-10°	-10°	-10°	-10°	-10°
$0.07	45°	40°	35°	30°	25°	25°	20°	10°	0°	-10°	-10°	-10°	-10°	-10°
$0.08	50°	45°	40°	40°	35°	30°	25°	20°	10°	0°	-10°	-10°	-10°	-10°
$0.09	60°	55°	50°	45°	40°	40°	35°	30°	20°	10°	0°	-10°	-10°	-10°
$0.10	60°	60°	55°	50°	50°	45°	40°	35°	25°	15°	10°	-10°	-10°	-10°
$0.11	60°	60°	60°	60°	55°	50°	45°	40°	30°	25°	15°	-5°	-10°	-10°
$0.12	60°	60°	60°	60°	60°	55°	50°	45°	35°	30°	20°	0°	-10°	-10°
$0.13	60°	60°	60°	60°	60°	60°	55°	50°	40°	35°	25°	5°	-10°	-10°
$0.14	60°	60°	60°	60°	60°	60°	60°	55°	45°	35°	30°	10°	-5°	-10°
$0.15	60°	60°	60°	60°	60°	60°	60°	60°	50°	40°	35°	15°	0°	-5°
$0.16	60°	60°	60°	60°	60°	60°	60°	60°	55°	45°	40°	20°	5°	0°
Propane rate, $/gallon, (furnaces and boilers)										$1.22	$1.37	$1.83	$2.29	$2.52

Part Load Operation Range

3 Minnesota Air Source Heat Pump Collaborative, "Economic Balance Point for Dual Fuel," accessed May 8, 2023, https://static1.squarespace.com/static/5eebc734f52c736dceefa2ec/t/613a49d2020e0922d1401af1/1631209939451/Economic_Balance_Point_ASHP _Chart.pdf.

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Dual Fuel with a LLE Heat Pump

- Better savings than a cold climate heat pump*
- No additional cost
- No change in system design
- Same crossover temperature

Type	Relative Savings
Single Speed	-
Ave VSHP	12%
Low Load Efficient	17%
Cold Climate	15%

These preliminary results based on simple bin-hour model in climate zone 4, with cross over temperature of 32F and similar HSPF2 values. More careful analysis and field or lab testing is needed.

* crossover point

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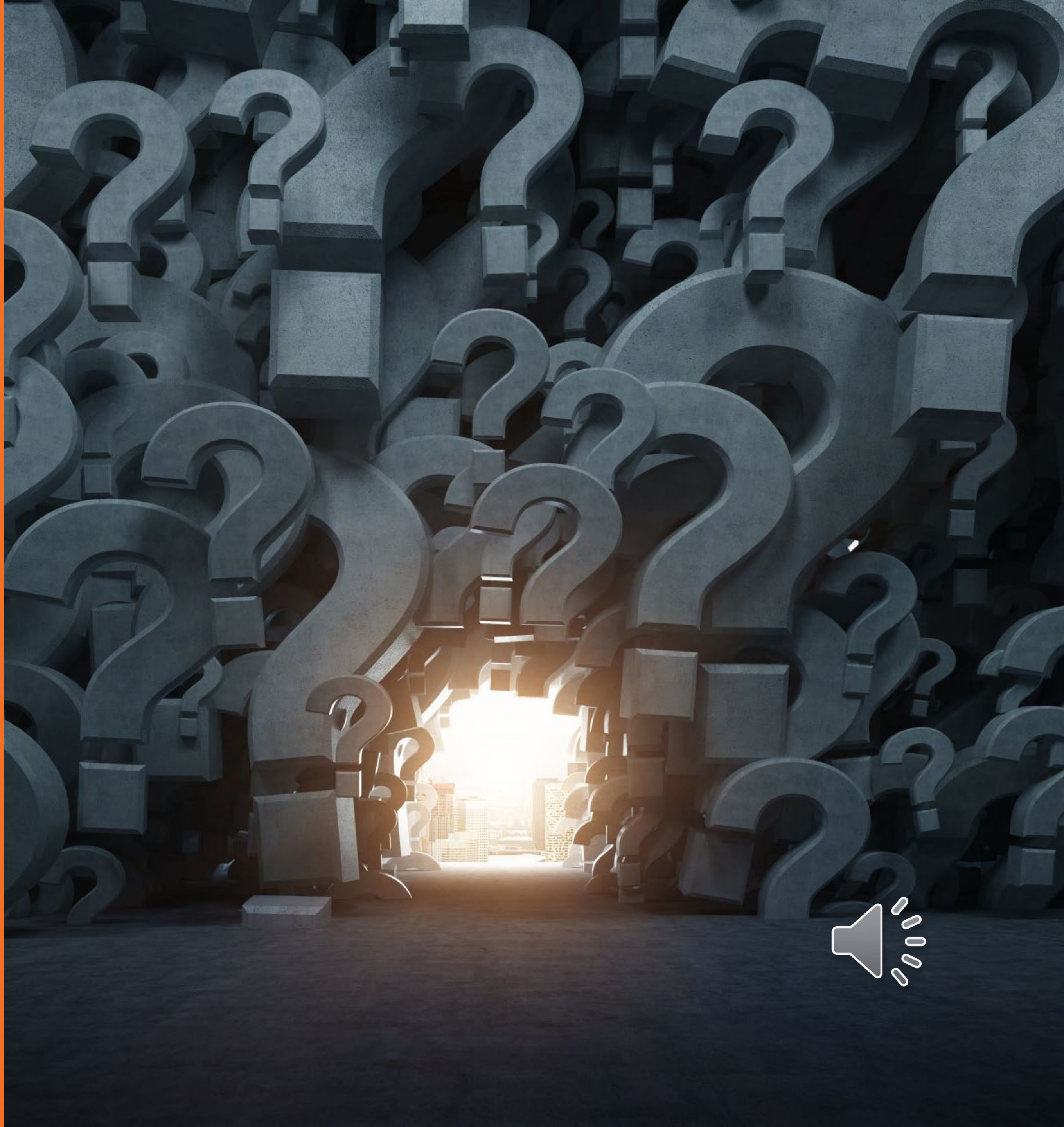
Summary

- What We Have Learned
  - LLE can provide low-cost efficiency gains in HPs
  - Not driven by hardware
  - Likely limiting factors
    - matching of indoor and outdoor units
    - Adequate HX size
    - EEV needed for top performance
- Next Steps
  - Part load lab testing explore control algorithm impact and potential differences between NEEP and AHRI data (June 2024)
  - Physical teardown workshop to see manufacturing differences (Sept 2024)

Questions and Discussion



Thank You

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