Low-Load Efficient Heat Pumps

2023-4 Investigation

NEEA Product Council

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Outline

- What is LLE and why is it important
- What Causes LLE
- 2024 – LLE Lab Testing
- 2024 – BPA Field Data Analysis
- Conclusions

Low Load Efficiency Investigation History

- Early Field data from Next Step Home projects
- 2020-2 VCHP assessment and modeling,
  Load based test procedure development
- 2023 Manufacturer Interviews,
  Database Evaluation and Virtual teardown
- 2024 Lab Testing, BPA field data analysis
  teardown workshop, NEEP & AHRI database
- 2025 Savings Rate Validation Project

What is LLE
Why is it important

Low Load Efficient (LLE) Heat Pumps

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

LLE HPs have been found to run 40+% more efficient when running at minimum output than at full output.

NEEA LLE Specification

- Variable Speed Heat Pump
- MinCapCOP @ 47°F **≥ 4.5**

Minimum Capacity COP at 47°F provided by the NEEP Database
It should be the same as the AHRI 210/240 $H1_{low}$ test condition

NEEP Database

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**

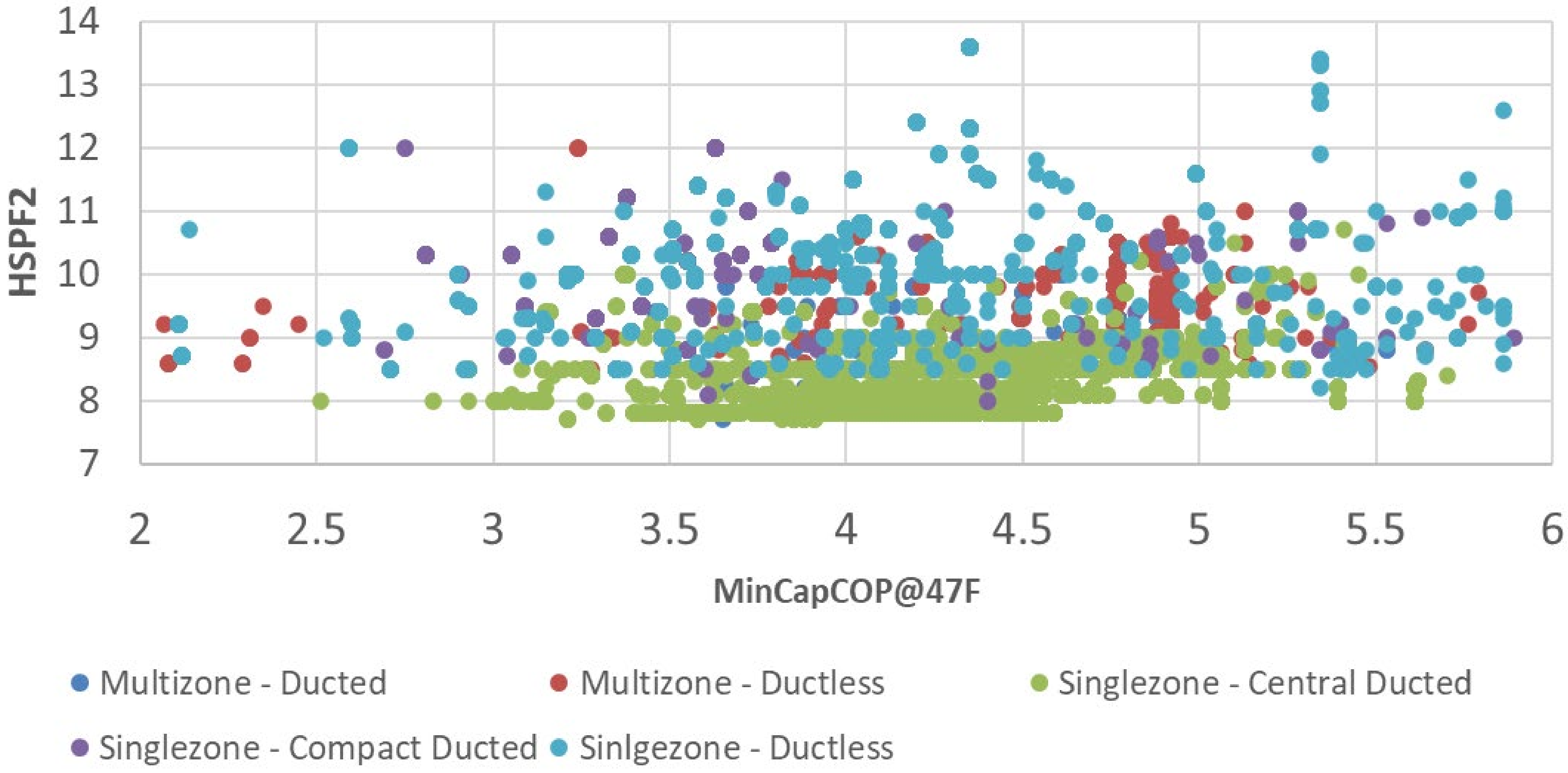
Information Tables

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

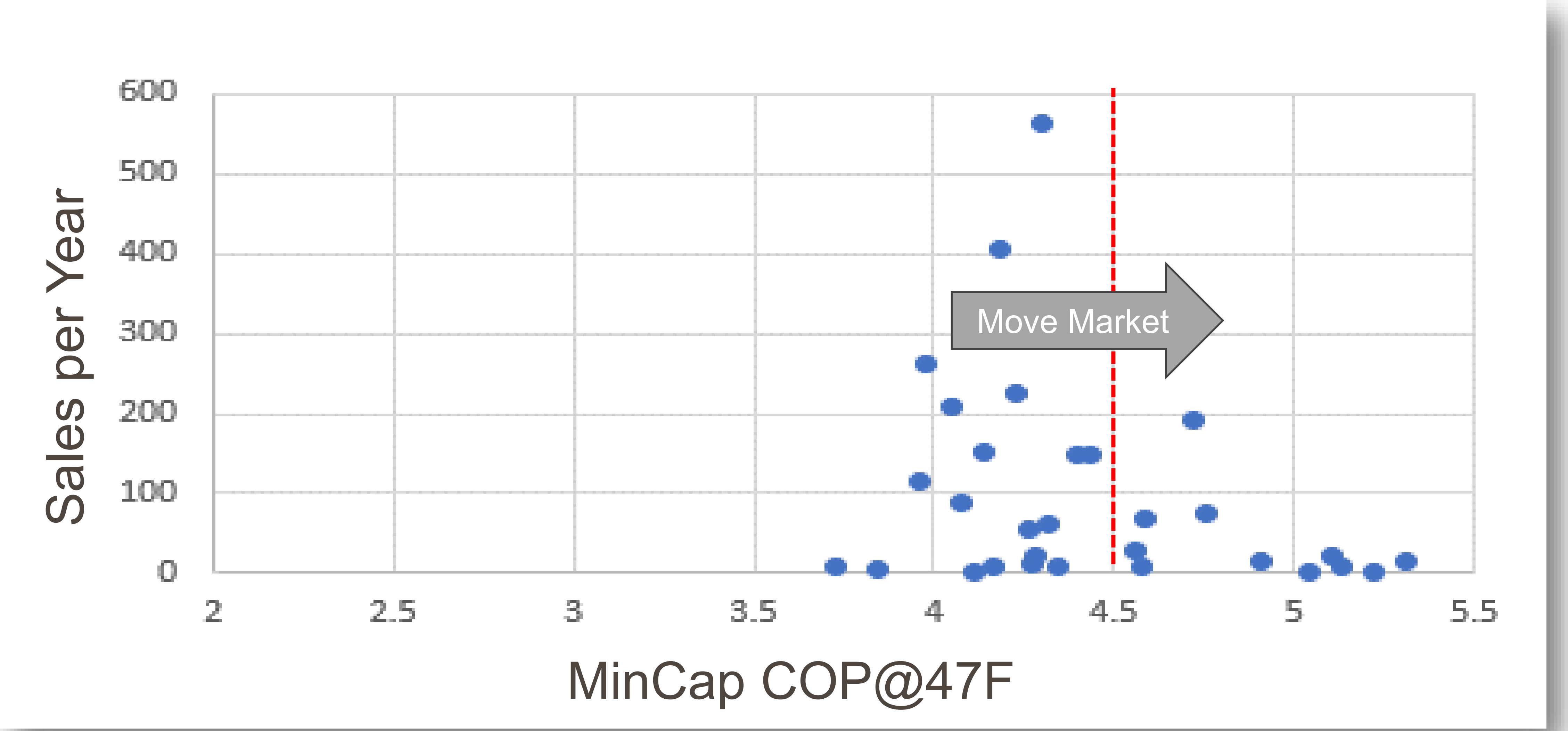
Performance Spe

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	-	17,200
			kW	0.5	-	2
			COP	3.52	-	2.52

NEEP Database - HSPF2 Rated Systems

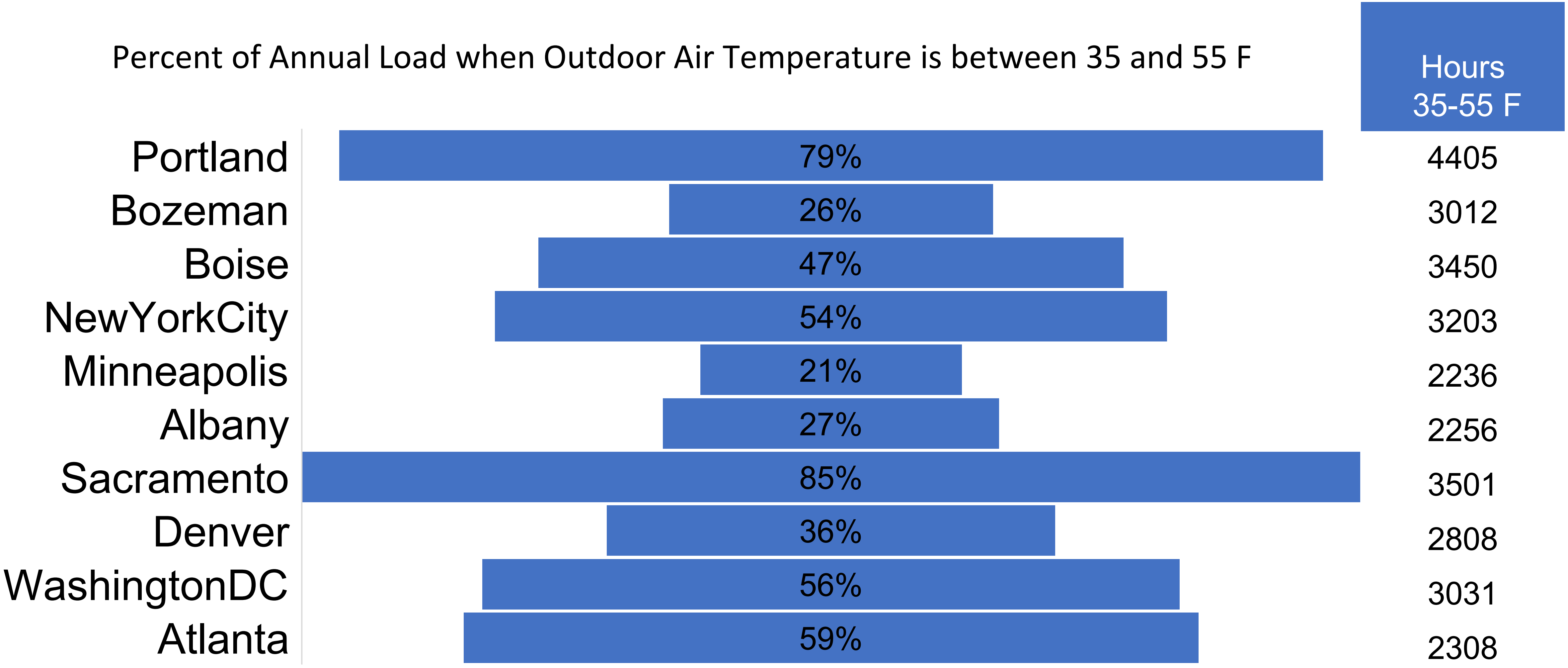


Northwest 2020 Ducted HP Sales Data



Part Load is Important all Climates[1]

Percent of Annual Load when Outdoor Air Temperature is between 35 and 55 F



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

Energy Savings Estimate

Performance Gain compared to average VSHP

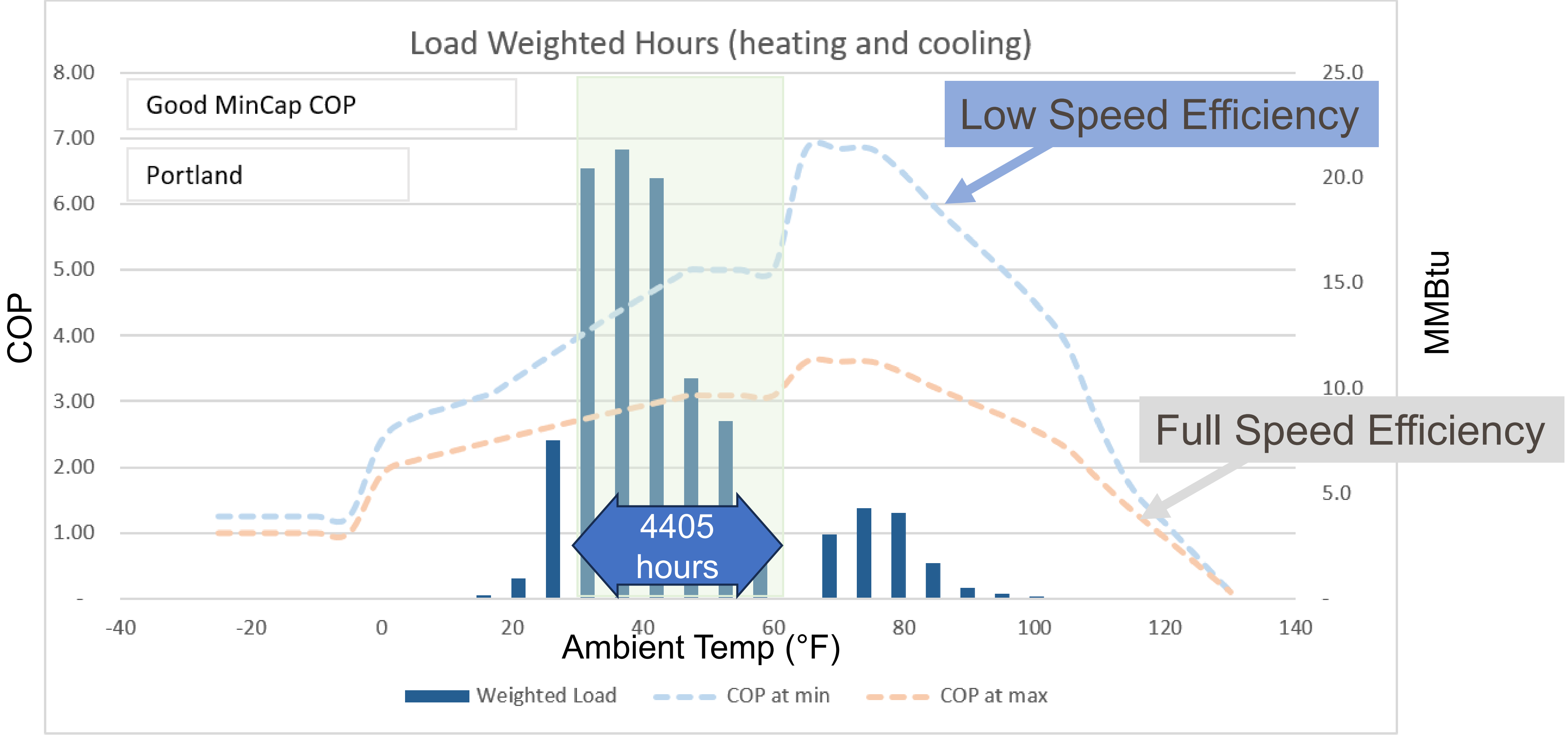
	2022 LLE[1]	2025 LLE[2]	*Update Notes*
Portland	7.9%	6.6%	*3 Ton*
Boise	7.4%	3.4%	*3 Ton*
Bozeman	4.4%	0%	*5 Ton*
Sacramento	8.4%	4.6%	*4 Ton*
Denver	6.8%	4.1%	*4 Ton*
Minneapolis	3.8%	3.3%	*4 Ton*
New York City	8.6%	5.6%	*4 Ton*
Washington DC	8.2%	4.4%	*3 Ton*

[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

[2] Updated tool with COP curves modified from Field and Lab data – LLE only increased 12.5% in heating in temperature bins 34, 47 and 54 – Size of HP was chosen for best annual heating and cooling.

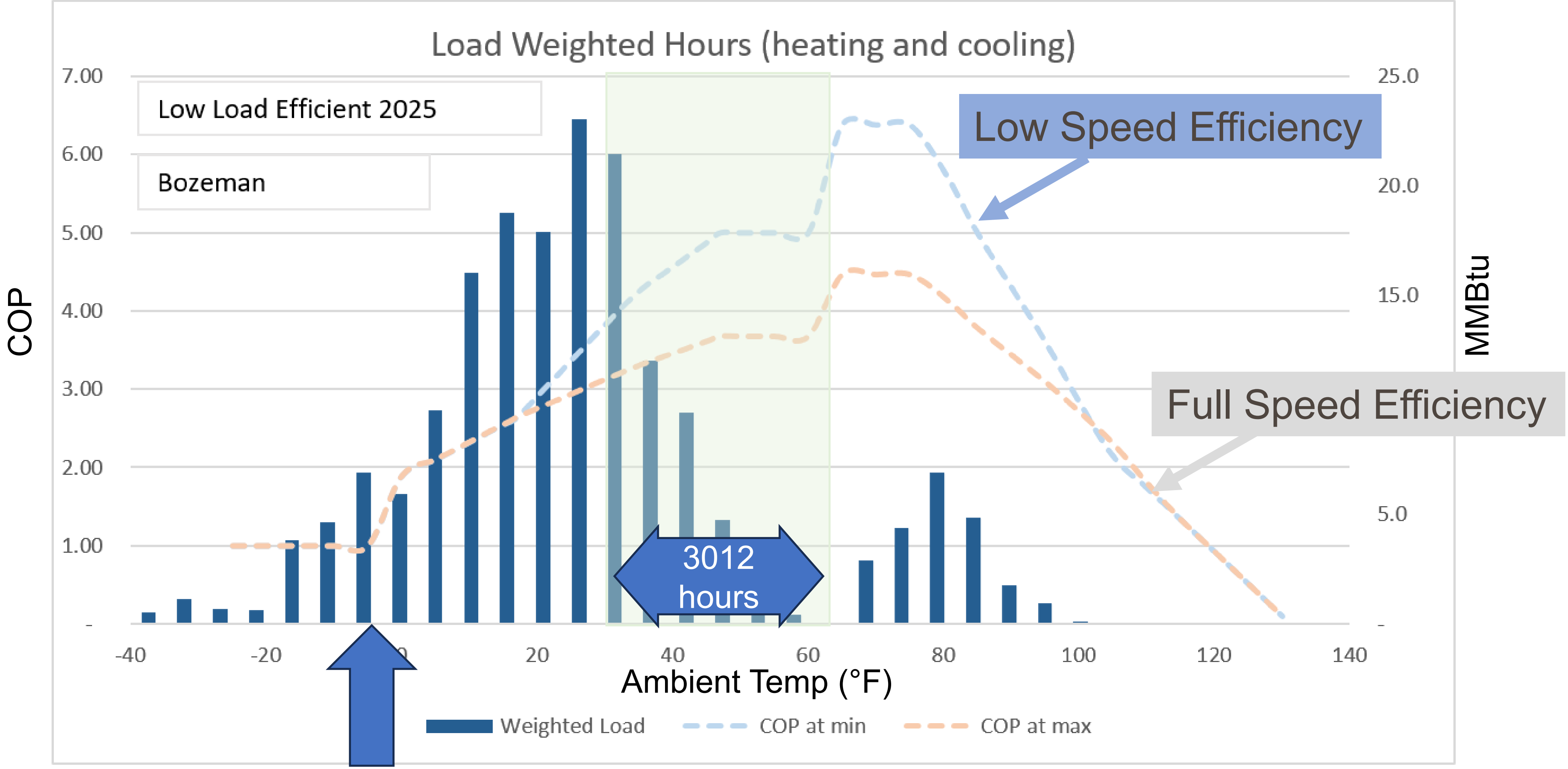
Annual Heating vs COP

Portland, OR



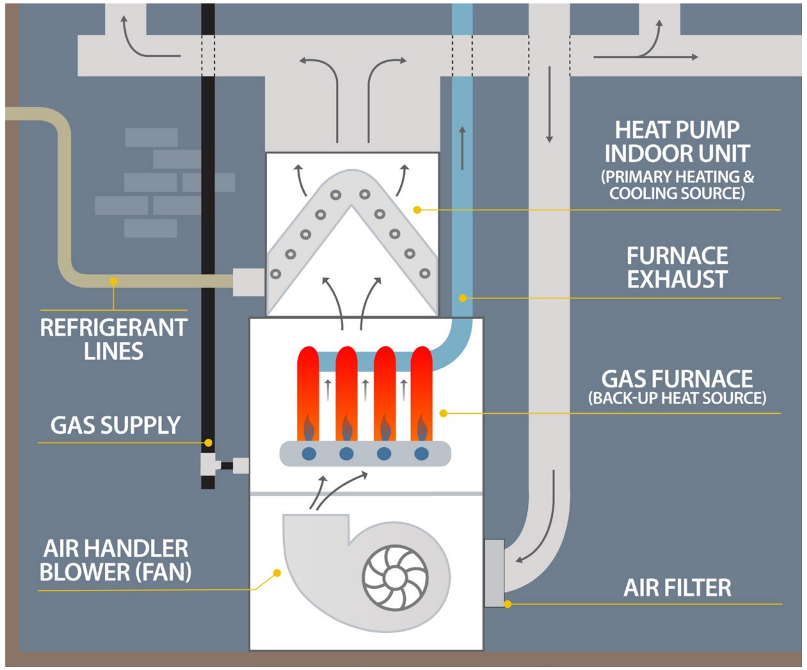
Annual Heating vs COP

Bozeman, MT



Dual Fuel Systems Need LLE Heat Pumps

- Dual fuel heat pumps don't operate the heat pump and the furnace at the same time*
- The majority of the time, the heat pump will operate in an unloaded condition

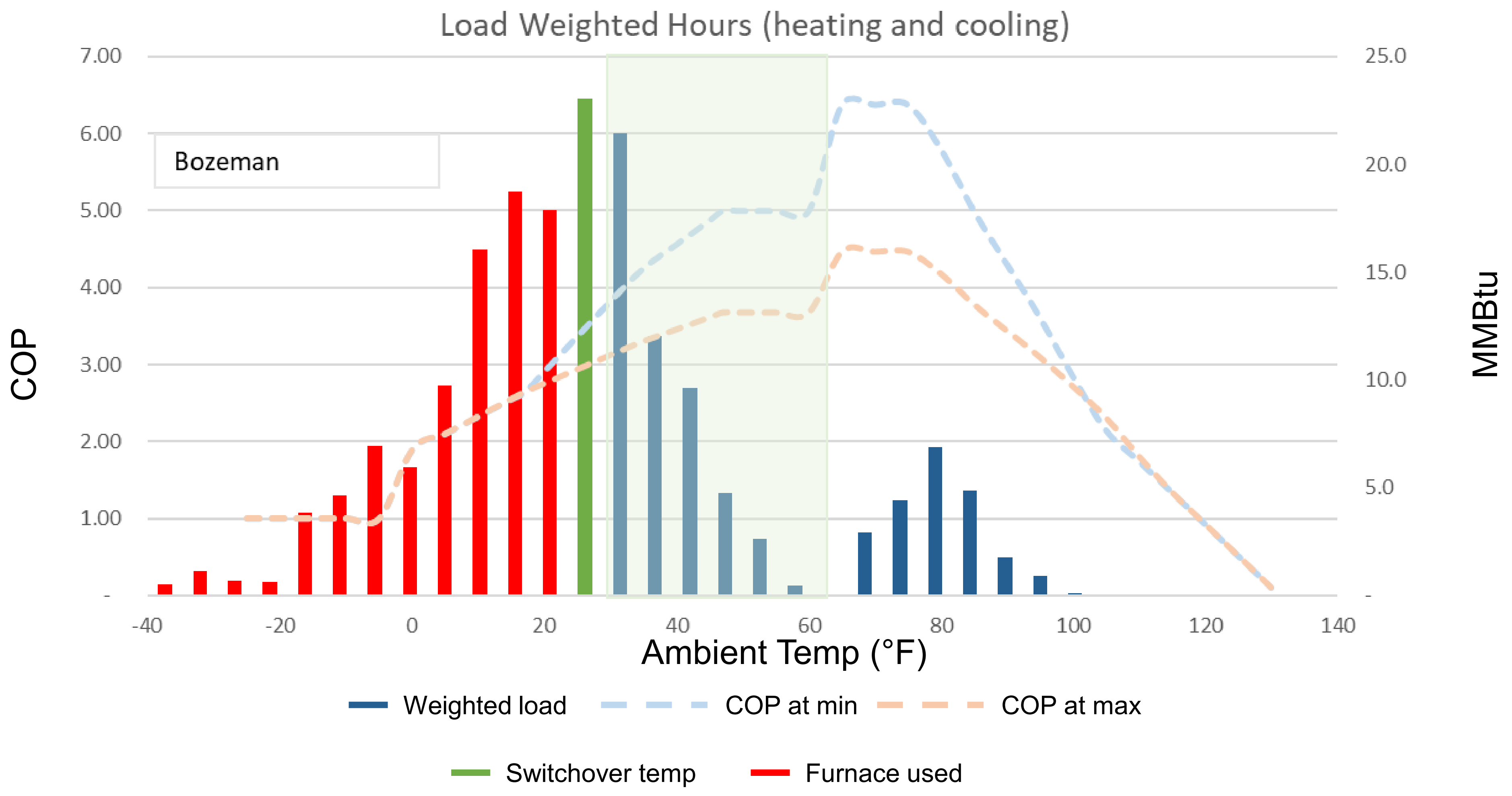


graphic by Slipstream Inc.

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

LLE is good for Dual Fuel

Bozeman, MT



What causes LLE?

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What Enables Low Load Efficiency?

Approach Used

- Metrics analysis
- Test procedure analysis
- Virtual teardown
- OEM interviews
- Physical teardown

What Was Looked At

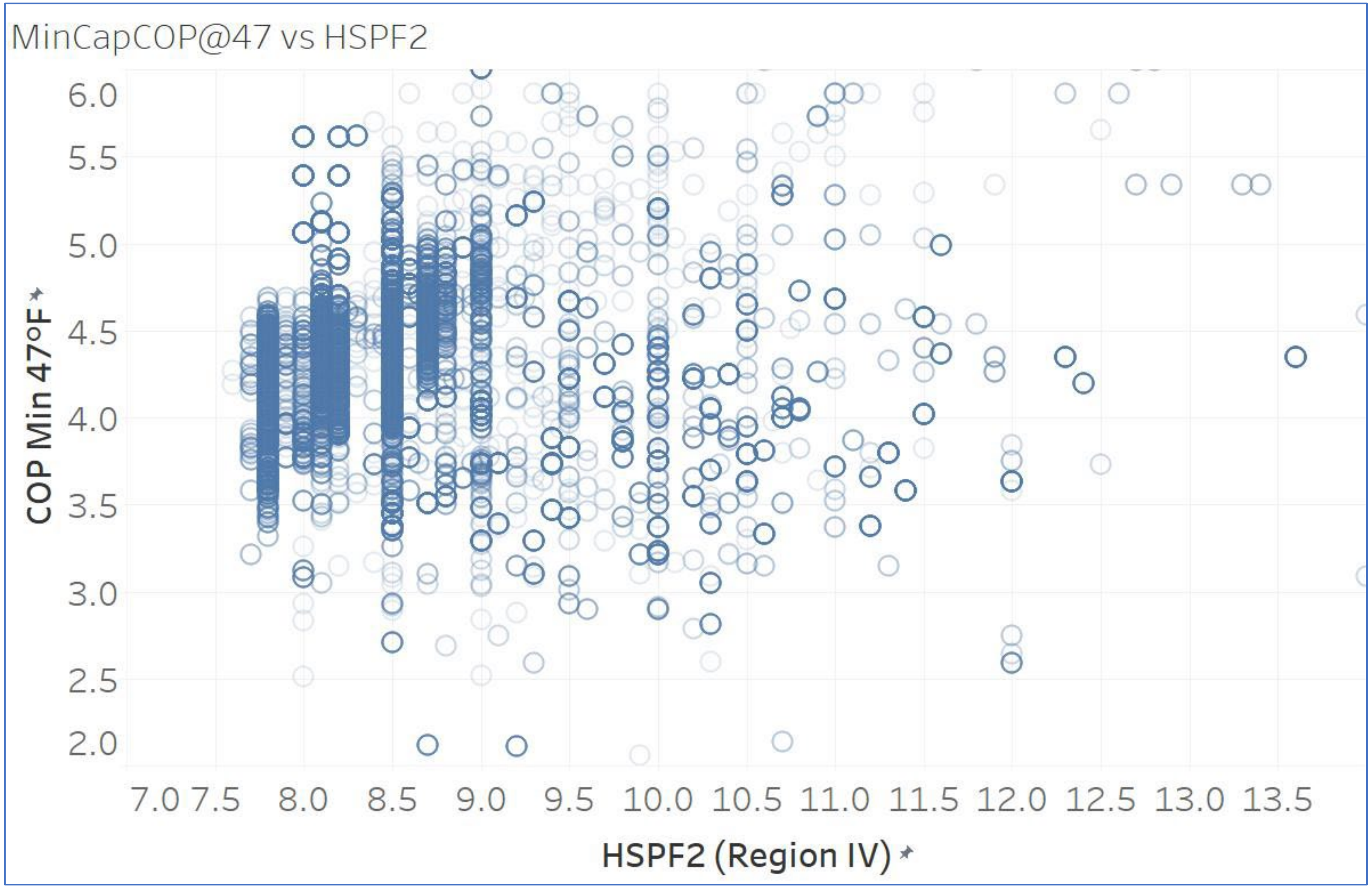
- Control Algorithm
- Heat Exchanger Size
- Metering Device Type
- Compressor Type
- High Turn Down Ratio

Metrics Analysis

HSPF does not fully reflect part load efficiency

- HP modeling revealed 2-3 times more incremental savings per increment in MinCapCOP47 as is reflected by HSPF2
- HSPF2 is based on national climate bins and dominated by full load test results at 17 and 47F
- For undersized the heat pumps, MinCapCOP47 does not reveal much new information

HSPF2 is not a good indicator of LLE

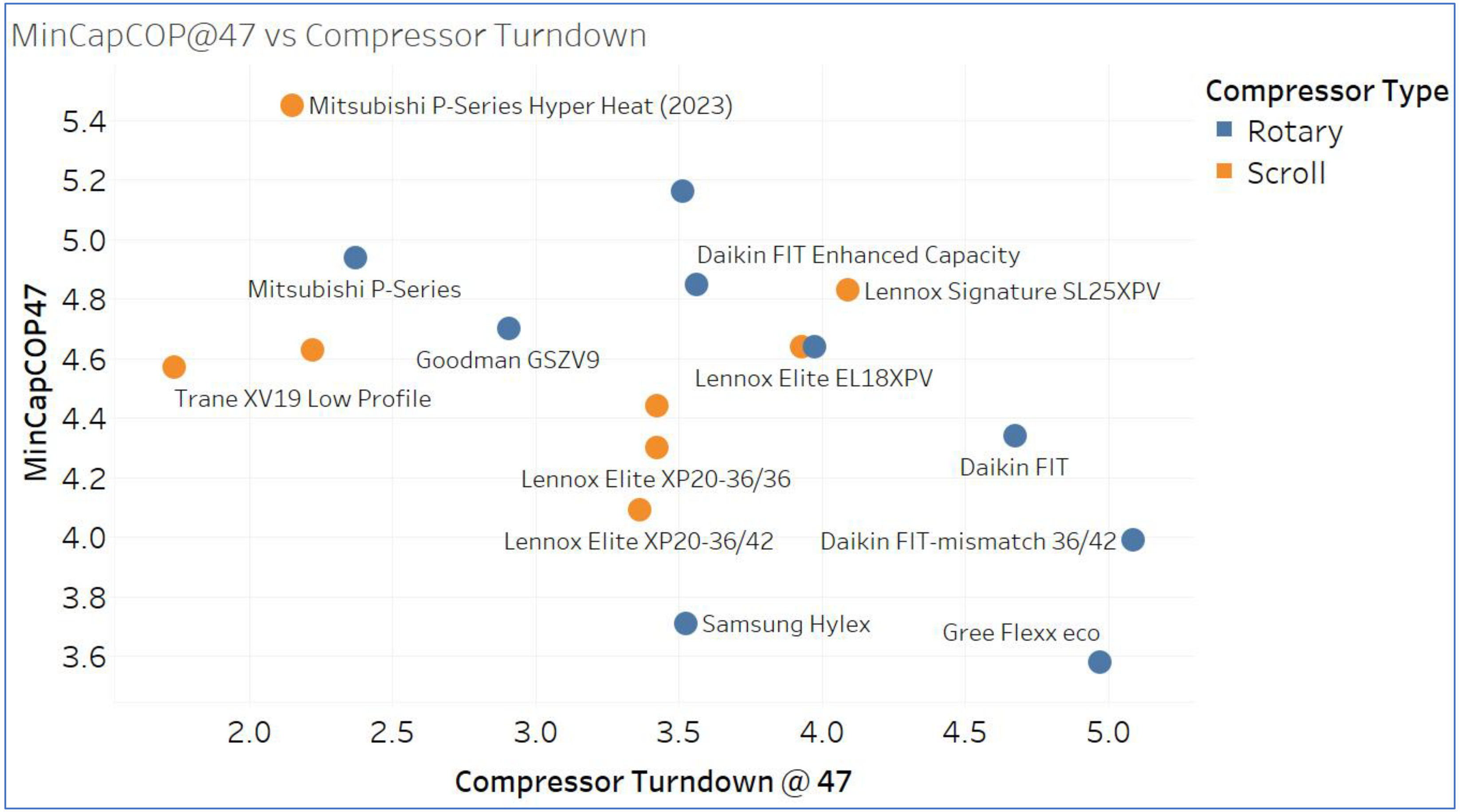


- The potential for energy savings through LLE has not been recognized
- OEMs do not feel motivation to pursue LLE in heating mode.

This is NEEP Data

Compressor Type

does not appear to be significant contributor to part load efficiency



Manufacturers

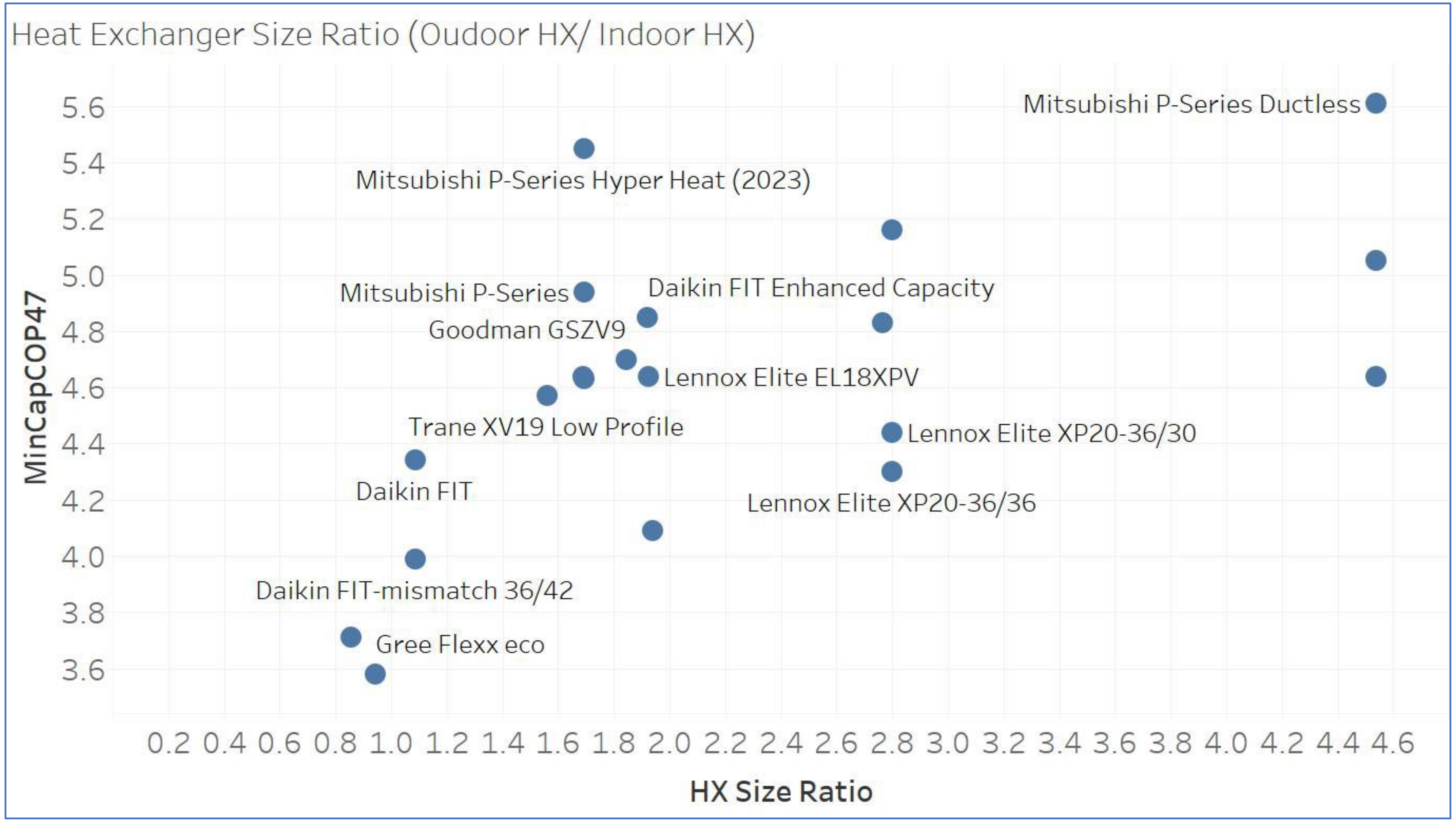
- Rotary compressors have wider optimal output range
- Discharge pressure needs to remain fairly constant to ensure good HX flow characteristics

Data

- compressor type does not significantly impact part load efficiency.

Heat Exchanger Sizing

seems to affect part load efficiency, but is not a primary factor



Manufacturers

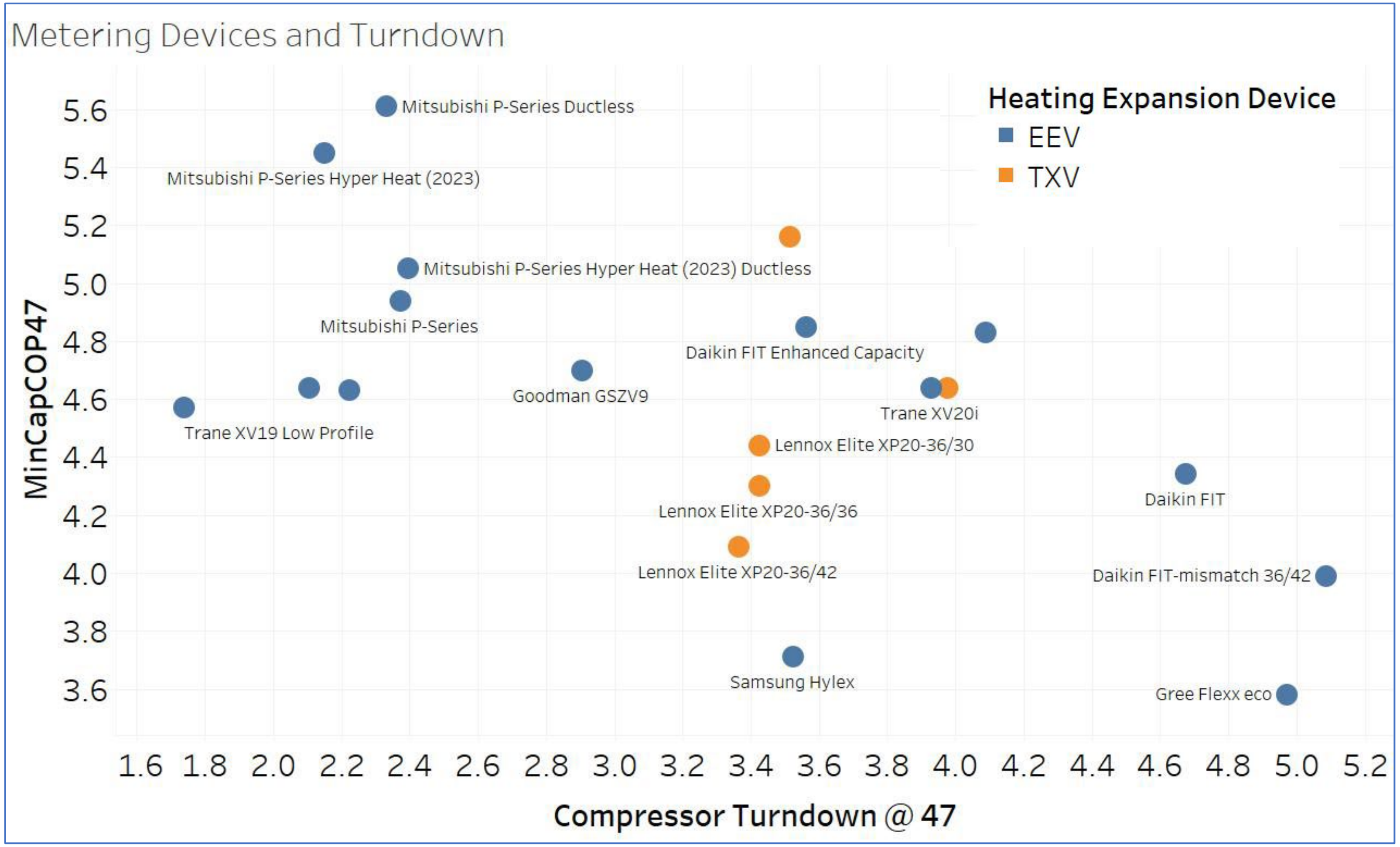
- Primary driver of HP efficiency is heat exchanger effectiveness
- At part load a HP operates as if it has an oversized HX (greater effectiveness)

Data

- Shows slight trend, but LLE is still achievable without large HX

Metering Device Type

does not appear to be significant contributor to part load efficiency



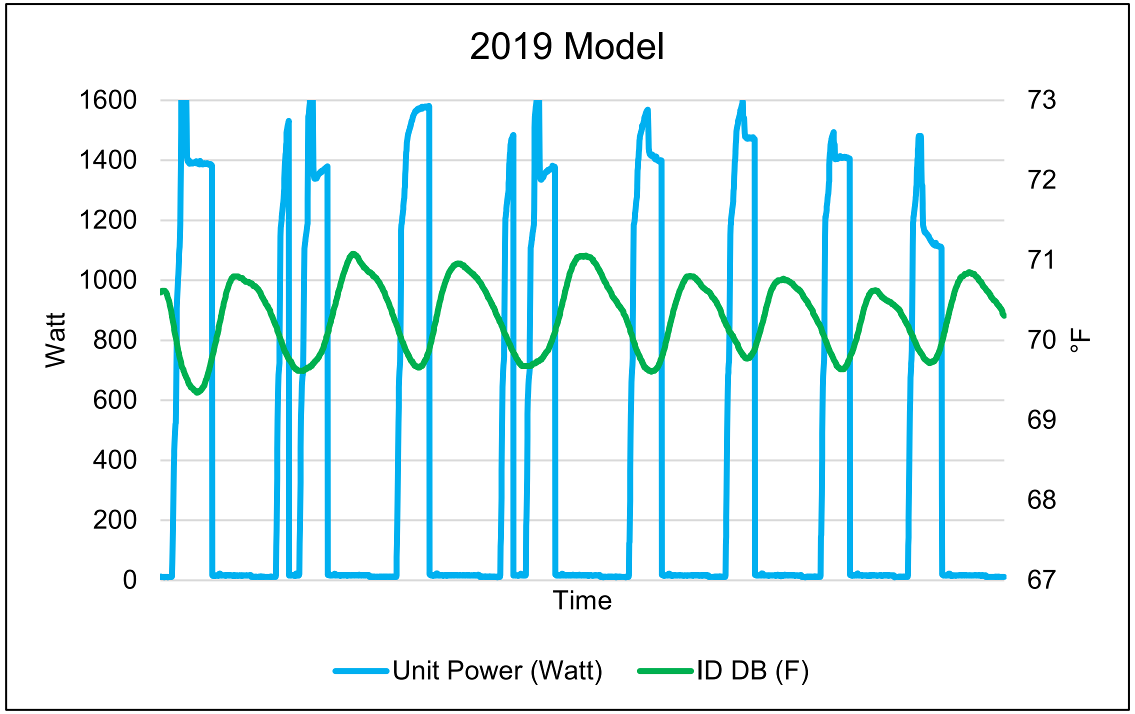
Manufacturers

- EEVs offer greater control of subcool and superheat at part load conditions

Data

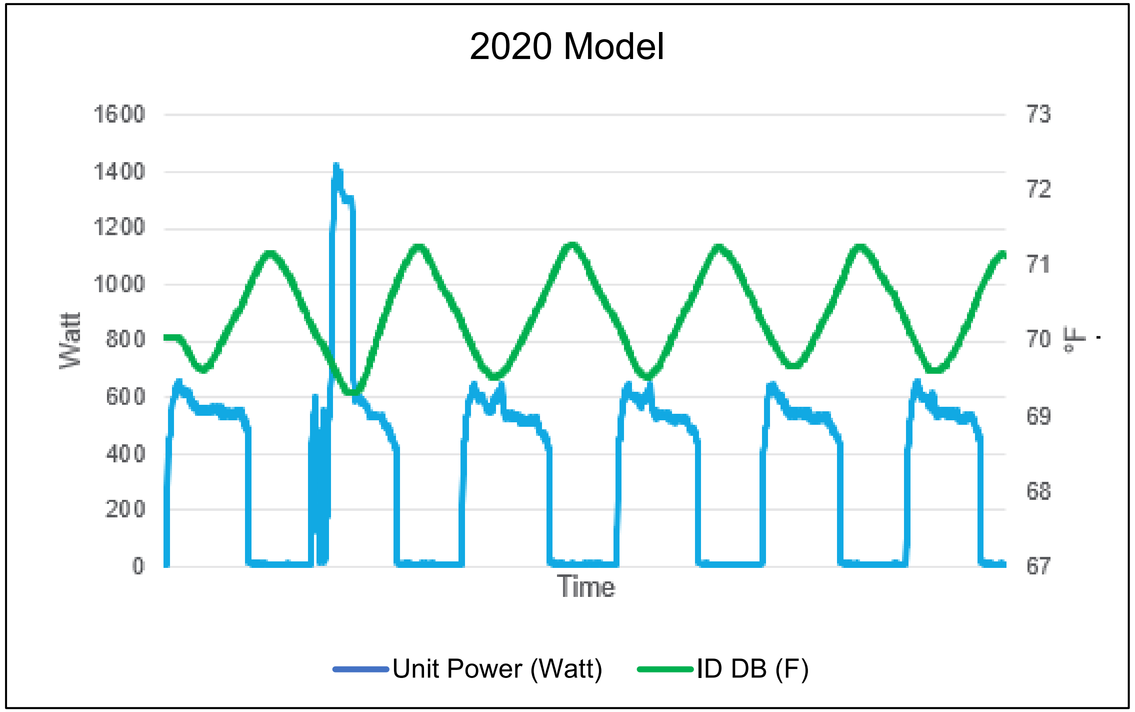
- metering device type is not a significant contributors to part load efficiency
- There are no systems with TXVs with high compressor turndown ratios

Control Algorithm Can Have A Big Impact



HSPF 12

COP = 2.03



HSPF 13 +8%

COP = 3.37 +66%

Load based testing of 2 heat pumps that are the same make, model and size, but different model year

The main difference was a new control algorithm

Good Control of Fans

are likely significant contributors

- Good control of ECM fan motors can shift COP by ~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

What Enables Low Load Efficiency?

Approach Used

- Metrics analysis
- Test procedure analysis
- Virtual teardown
- OEM interviews
- Physical teardown

2023-24 Findings

- Control Algorithm
- Heat Exchanger Size
- ~~Metering Device Type~~
- ~~Compressor Type~~
- ~~High Turn Down Ratio~~

2024
LLE Lab Testing

Bruce Harley
Bruce Harley Energy LLC

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Low Load Efficiency Lab Testing

NEEA funded part load efficiency lab testing of 6 variable speed heat pumps tested in the UL Lab 7 during the summer of 2024.

Research Questions:

1. Can use the MinCapCOP47 rating as a reasonable indicator or part load efficiency?
2. How should we model part load performance?
3. Should we evaluate this LLE at a standard turn down?
4. Are the performance values reported consistent with data in NEEP database?

Test plan, guidance, analysis and technical support provided
by
Bruce Harley Energy LLC

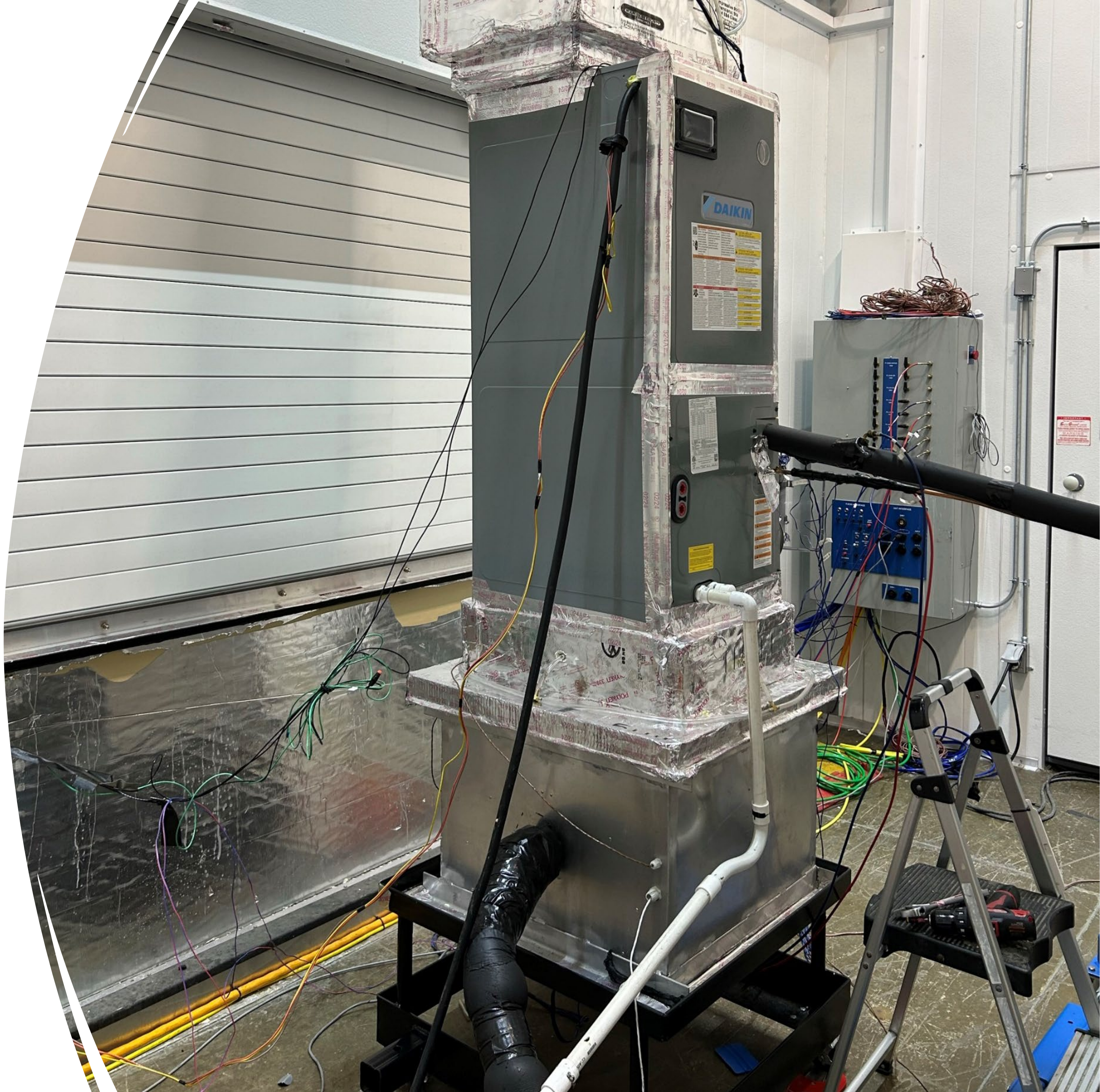
Equipment Tested

small size too small to make conclusions about all systems

Unit	Test Dates	Type	Nominal Capacity	HSPF2	MinCap COP47	Rated Cap 47F
NEEA LLE1	June 19-June 26	Ductless	12,000 Btuh	11.7	4.5	3,100
NEEA LLE2	June 27-July 15	Ductless	18,000 Btuh	10.2	1.4	3,070
NEEA LLE3	July 16-July 24	Ductless	14,000 Btuh	11.0	7.0	4,800
NEEA LLE4	July 25-August 1	Ducted	22,000 Btuh	8.5	5.1	6,300
NEEA LLE5	August 2-August 12	Ducted	22,000 Btuh	9.2	4.2	6,500
NEEA LLE6	August 13-August 20	Ducted	23,000 Btuh	10.0	4.7	7,100

Testing was conducted in the UL Lab 7 in Plano TX
Managed by Mark Baines with Lab Engineering support by Titus Mowry

Indoor Test Chamber



Outdoor Test Chamber

Thermostat Environmental Emulator (TEE)

aka the "RAT Trap"

A bit about Load Based Testing

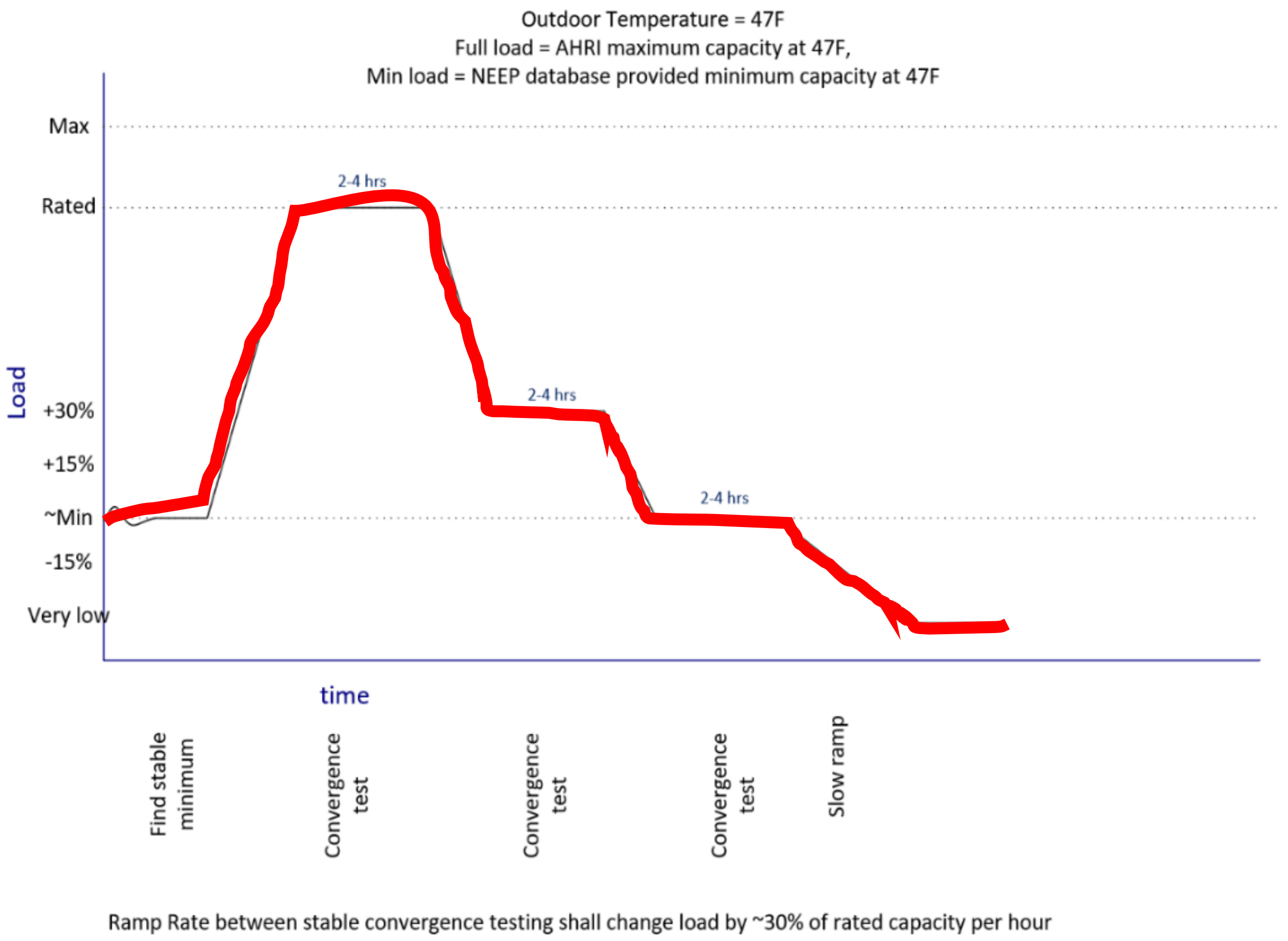
- The load-based test procedure imposes a target building load on the indoor chamber by the reconditioning equipment. As the machine heats and cools the space, the imposed load varies based on a calculation of a virtual building load minus the heat delivered by the unit under test. The reconditioning equipment changes the indoor chamber temperature to meet the “RAT” which is a temperature which a room would be at for a home under the outdoor chamber conditions.

- The unit under test senses the RAT at its own thermostat. There is a risk of measuring the wrong RAT value (location in psych chamber can have a significant effect: big room, lots of air movement, non-uniform temperatures). So the thermostat is located inside a Thermostat Environmental Emulator (TEE) that delivers a constant low air velocity across the thermostat at the correct RAT so that the unit under test can respond appropriately.

- In the graphs shown in this deck you will notice that the “building load” (BL) line varies considerably at times. The reason for this is that the “target” BL is constant, but the short-term “virtual” BL value used in the virtual model varies. As the room temperature RAT varies, and the tested system manages the indoor conditions, the model adjusts accordingly. This deviation from the “target” BL is largest when the unit shuts off, because the room temperature drops (or rises) most quickly when the unit capacity is 0, and then adjusts in the opposite direction for the first few minutes when the unit starts running again.

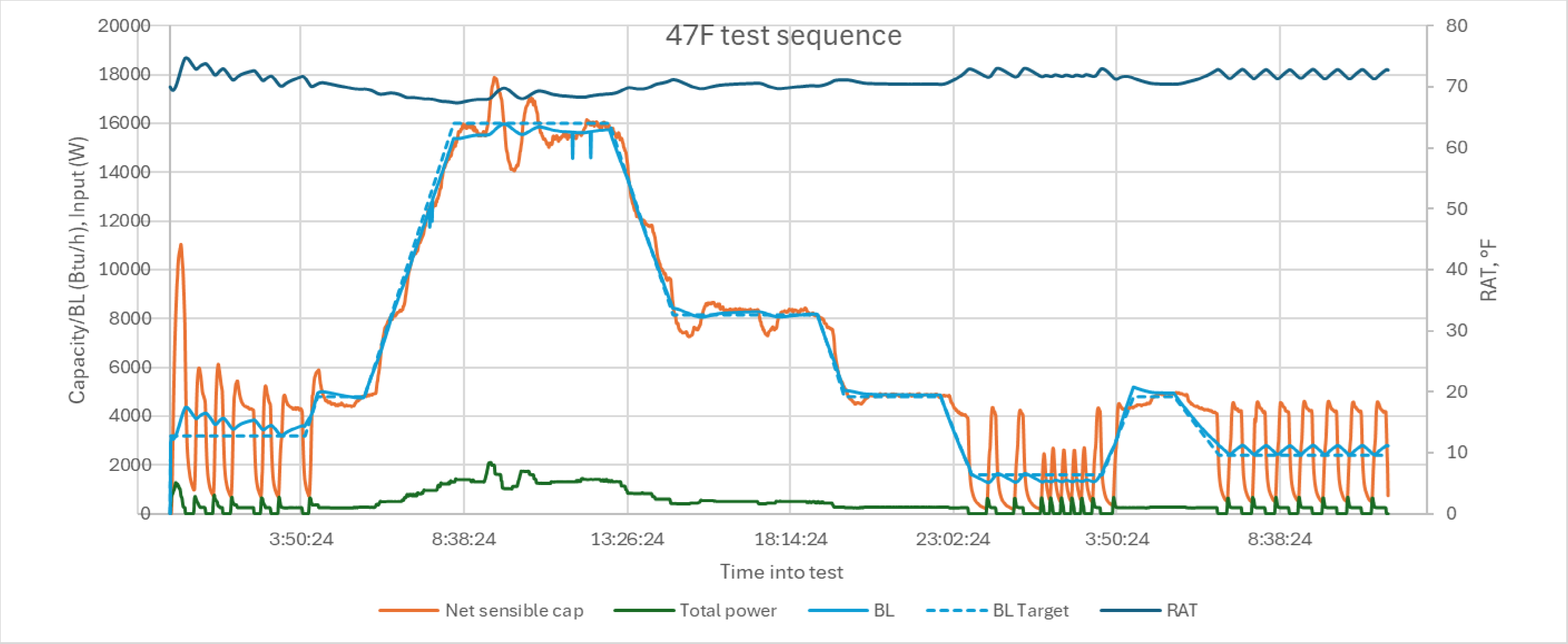
Test Sequence
(not all tests followed this exactly)

- Outdoor chamber temperature is fixed
  - 47F, 17F, and 62F
- Indoor load varies over 20-30hr test
- Test starts at 3% above the NEEP-listed low capacity
- Load ramps up and down
- 47F test stops for 2-4 hrs for a convergence test at the following loads:
  - Rated
  - Low
  - 30% above Low



47F – entire sequence

Unit #1
16,000 Btuh
ductless



47°F COPs
during ramping periods and convergence tests

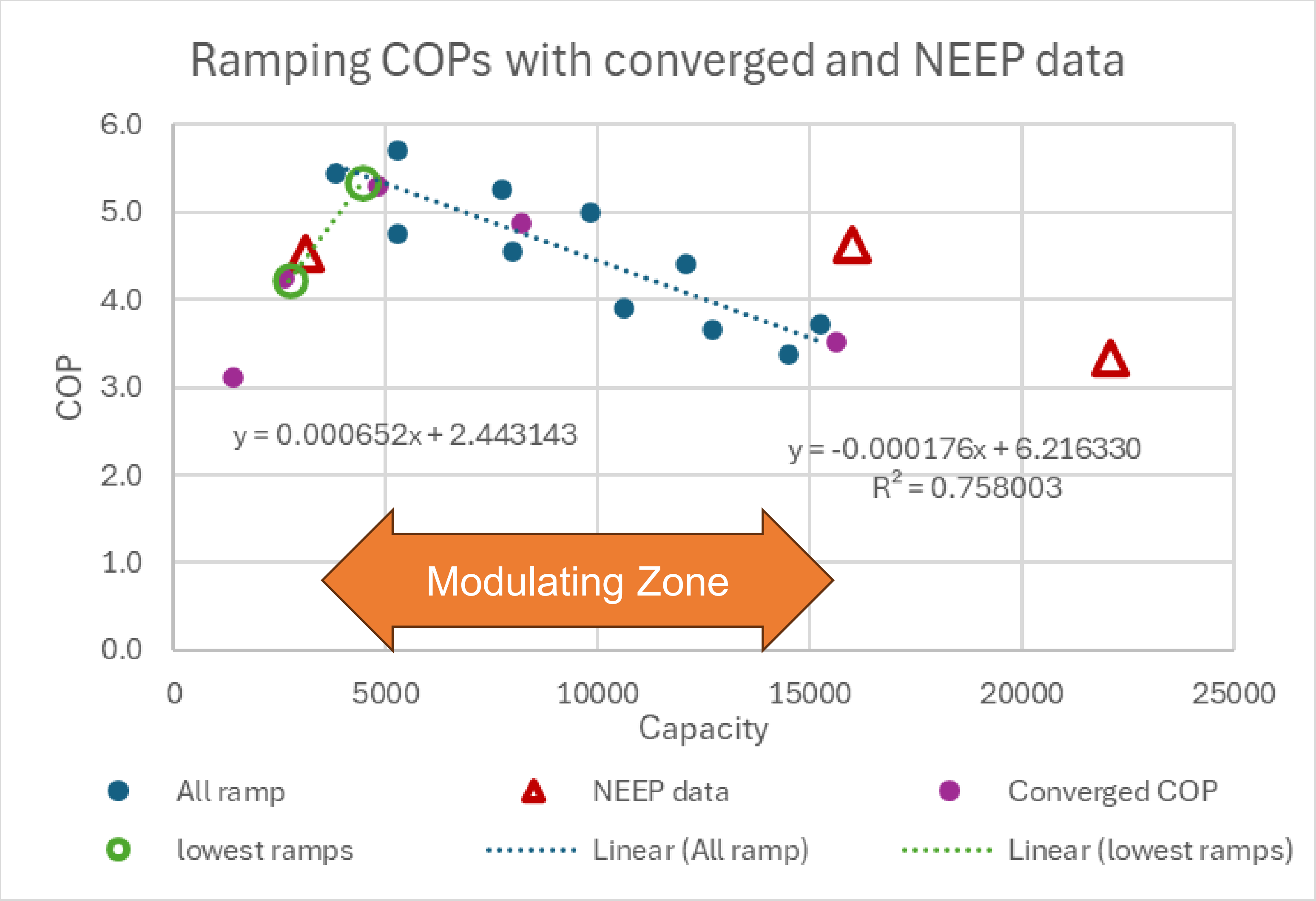
Unit #1
16,000 Btuh
ductless

Converged tests fit well with ramping data

COP drops during cycling behavior as expected

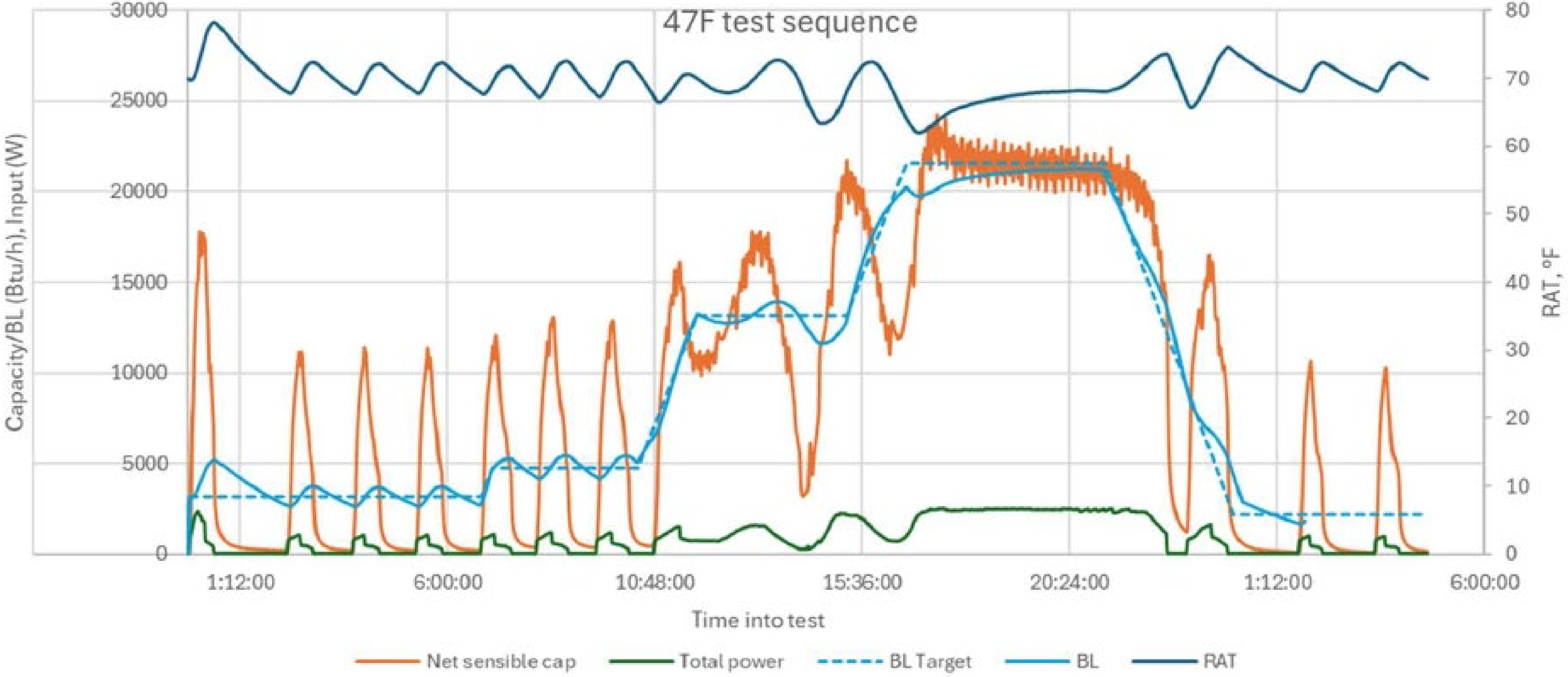
COP outperforms NEEP data near min capacity, though min capacity seems a bit higher.

C_D ~ 0.55
 = 1- (2.4/5.3)
Using COP at inflection point;



47F – Entire Sequence

Unit #2
18,000 Btuh
ductless

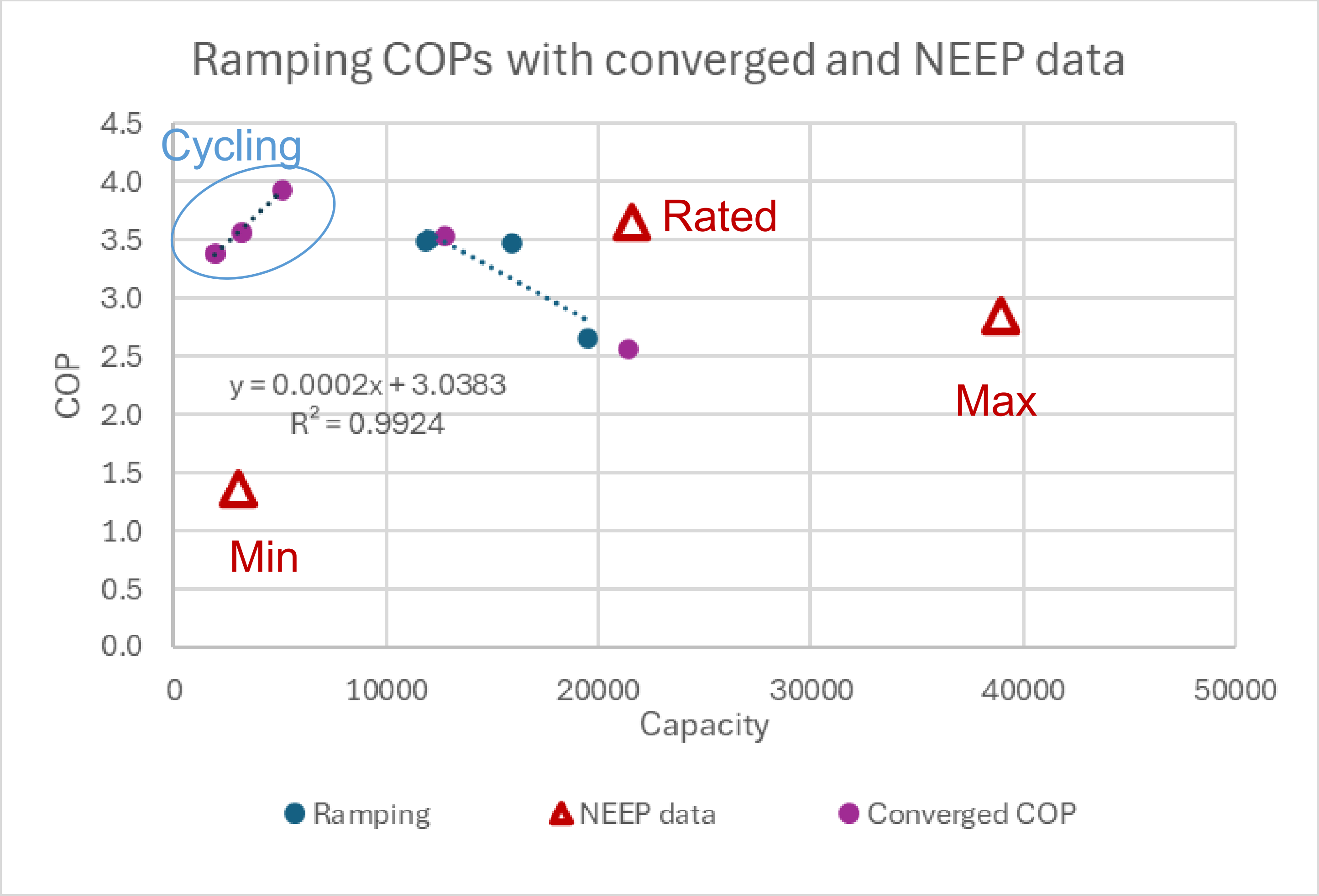


47°F COPs
during ramping periods and convergence tests

Unit #2
18,000 Btuh
ductless

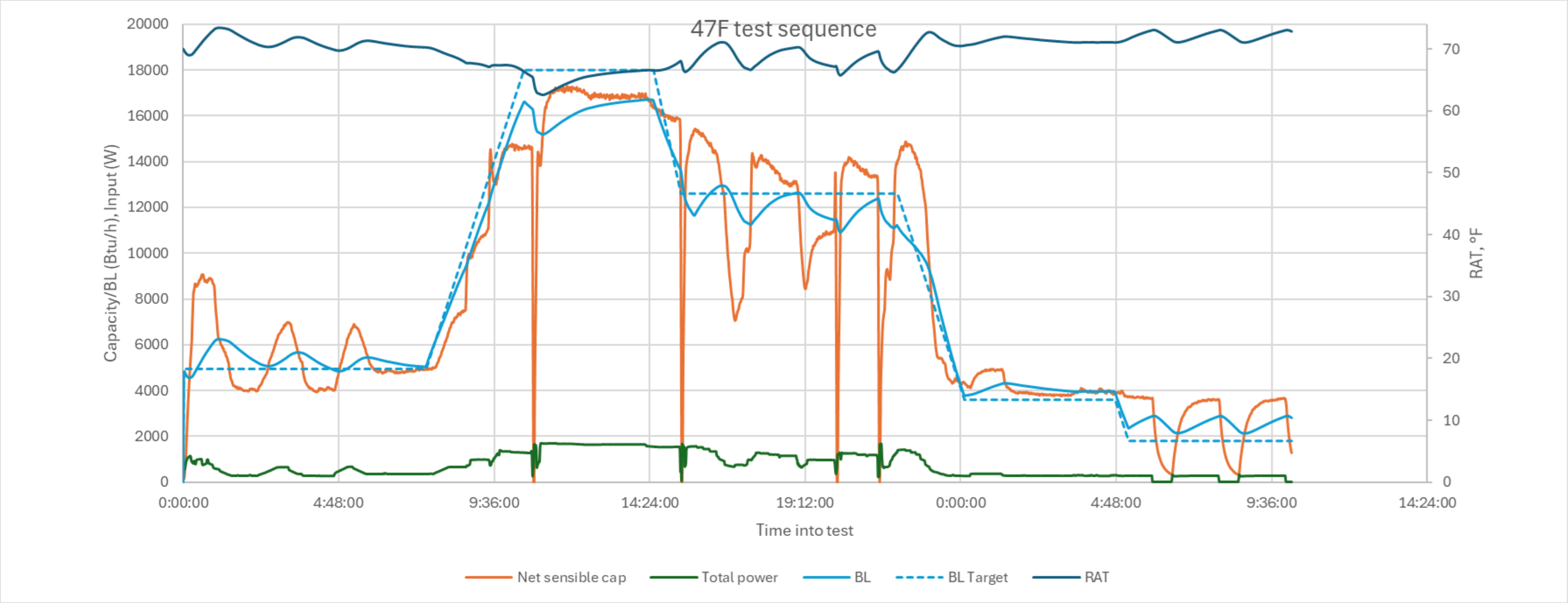
NEEP data for "min" is anomalously low relative to test results and to other products. Rated (& max?) seem to overstate performance substantially.

$C_D \sim 0.23$
$= 1- (3.9/3.0)$
(high uncertainty)



47F – entire sequence

Unit #3
21,600 Btuh
ductless



Analysis excluded off-cycle, but note that room temperature is low for most of “rated” condition

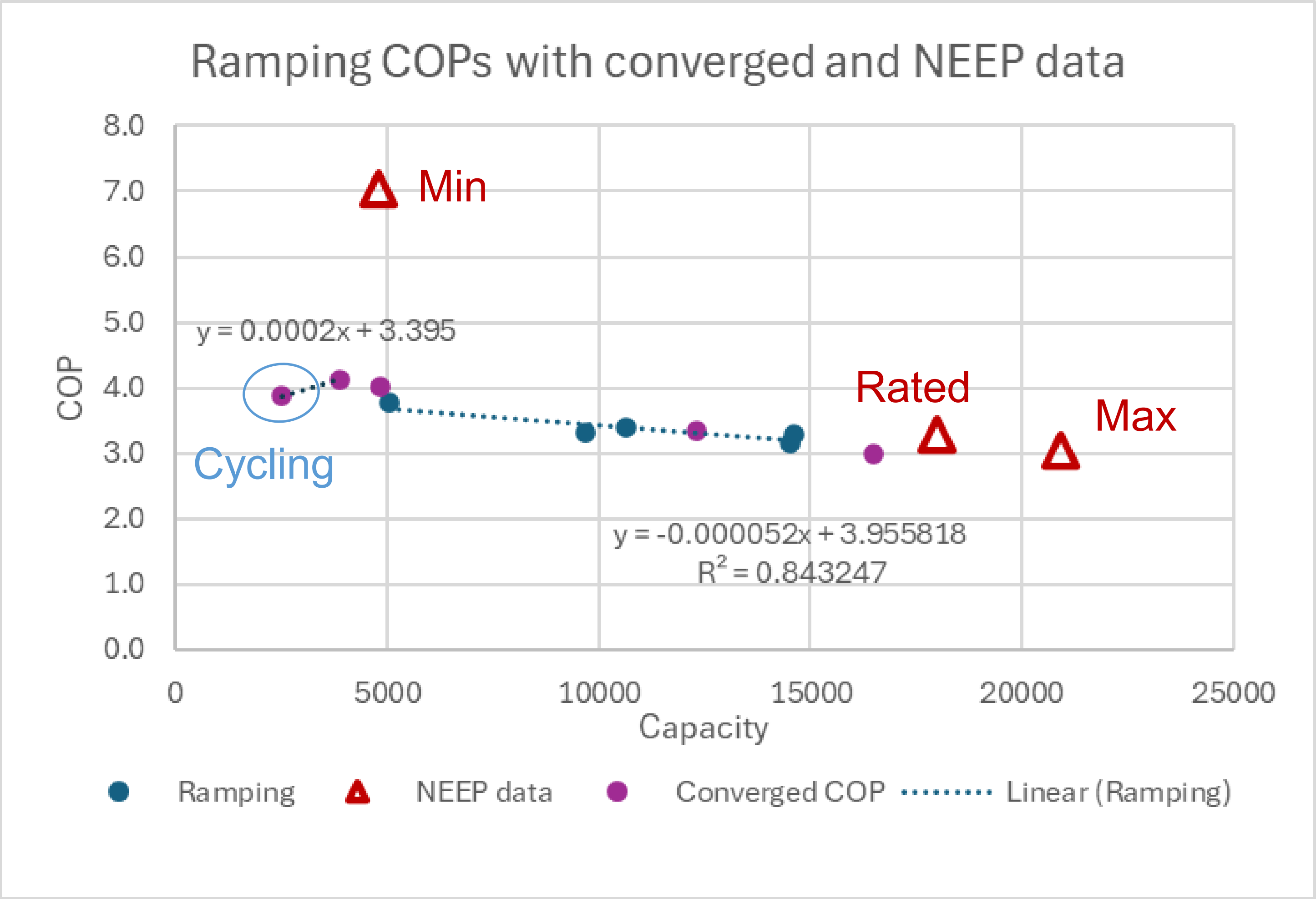
47°F COPs
during ramping periods and convergence tests

Unit #3
21,600 Btuh
ductless

Converged tests agree well with ramping data. COP drops (a bit) during cycling only at the lowest capacity.

NEEP data for “min” is anomalously high relative to test results and to other products. Rated & max are aligned well.

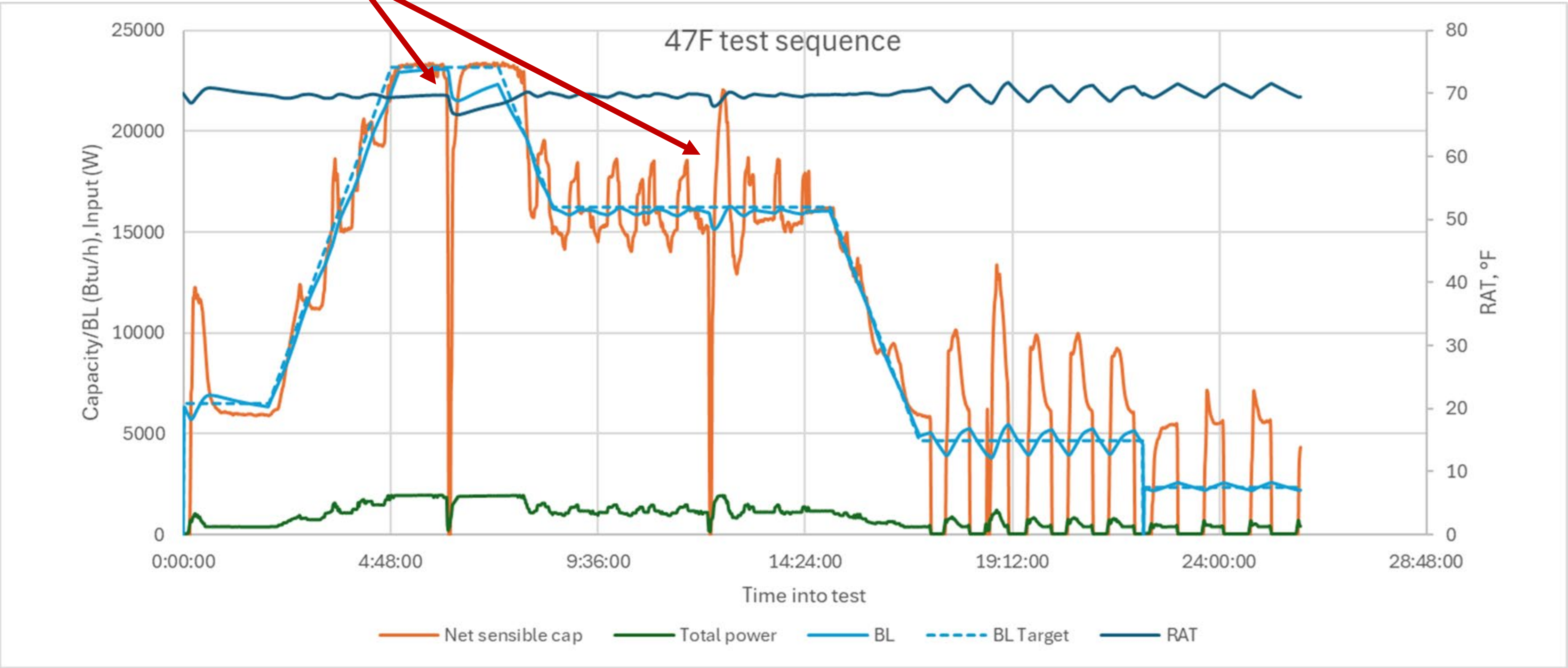
$C_D \sim 0.18$
$= 1 - (3.4/4.1)$ (high uncertainty)



47F – entire sequence

Unit #4
22,000 Btuh
Ducted

Unexpected defrosts were *excluded* from converged COP/capacity



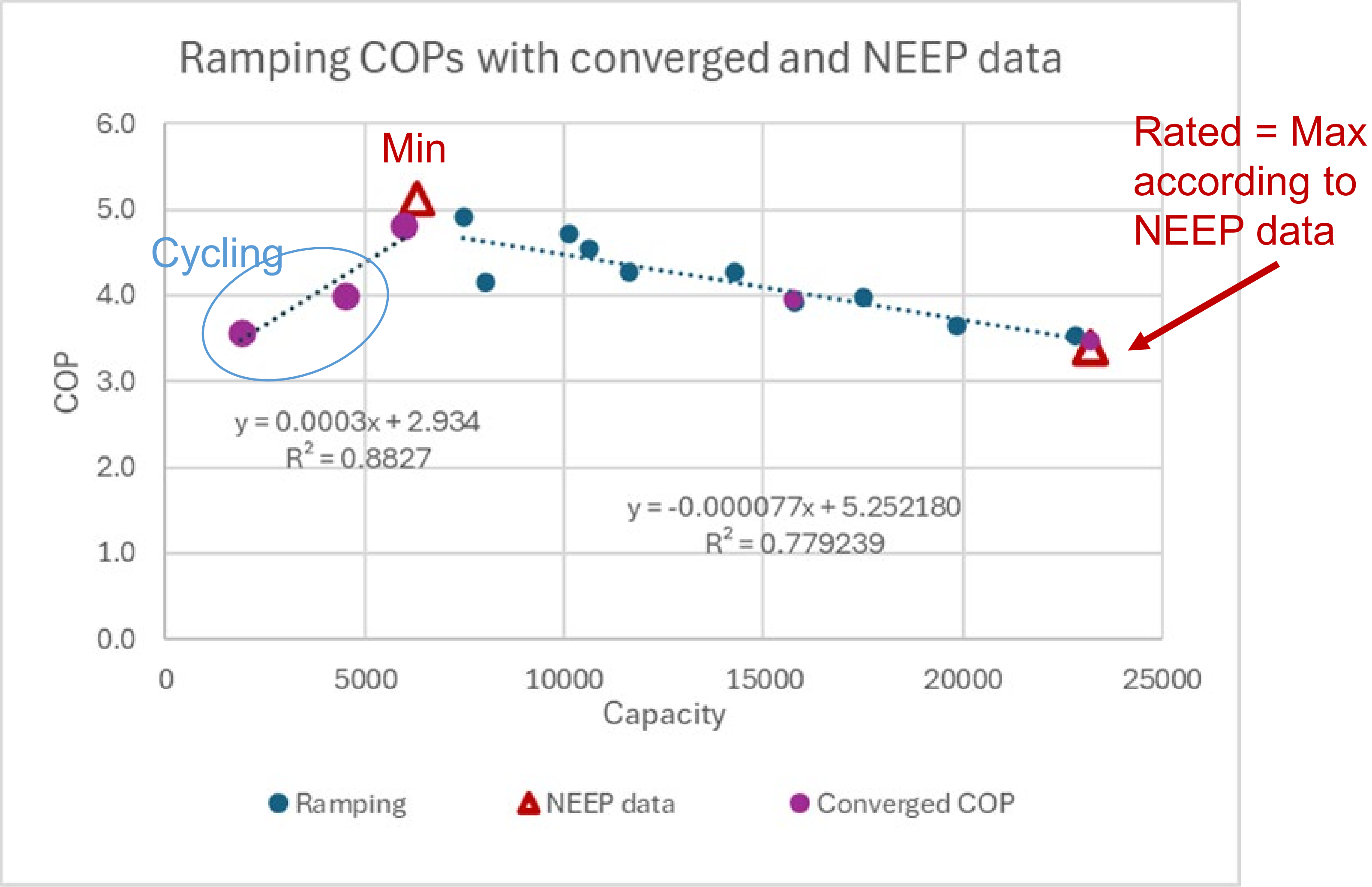
47°F COPs
during ramping periods and convergence tests

Unit #4
22,000 Btuh
Ducted

Converged tests agree well with ramping data. COP drops rapidly during cycling tests.

Test and NEEP data align well.

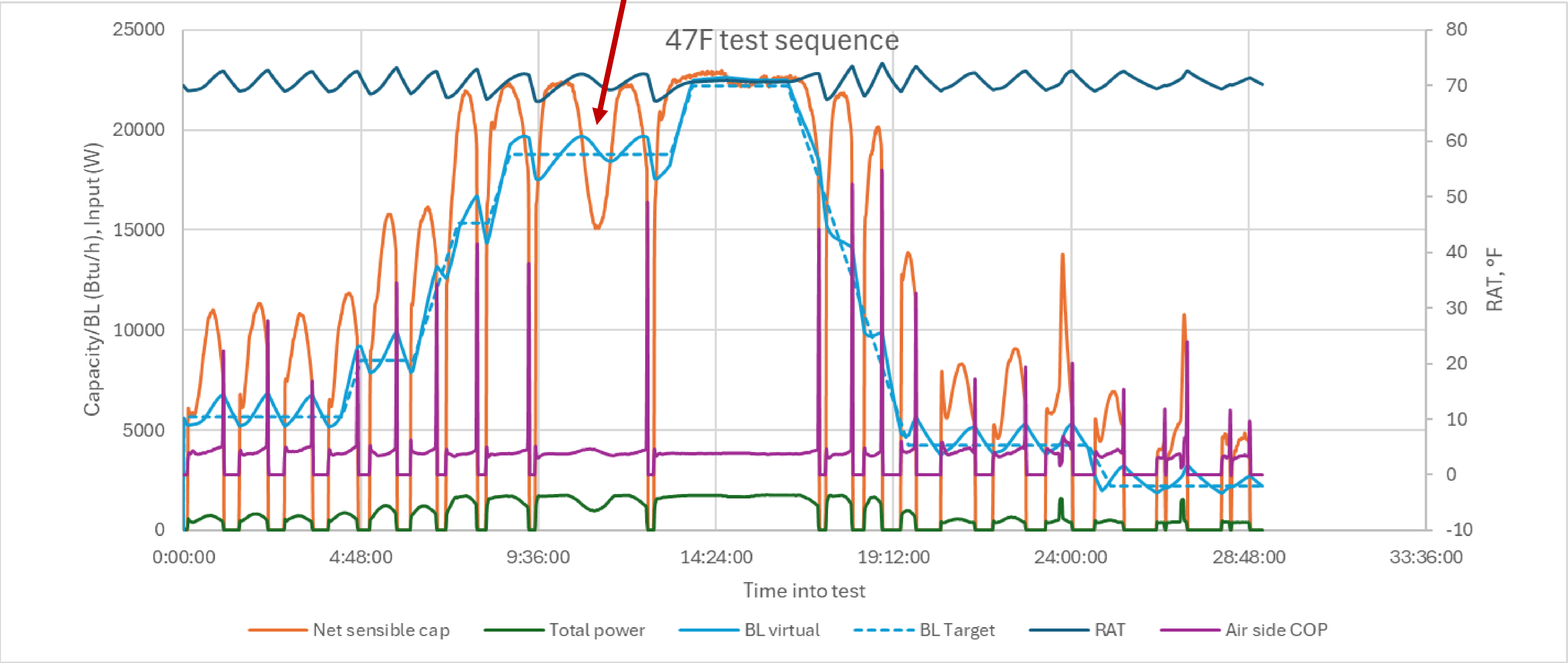
C_D ~ 0.4
= 1- (2.9/4.8)



47F – entire sequence

Unit #5
22,000 Btuh
Ducted

Unit cycled at every test condition except B2" and Rated



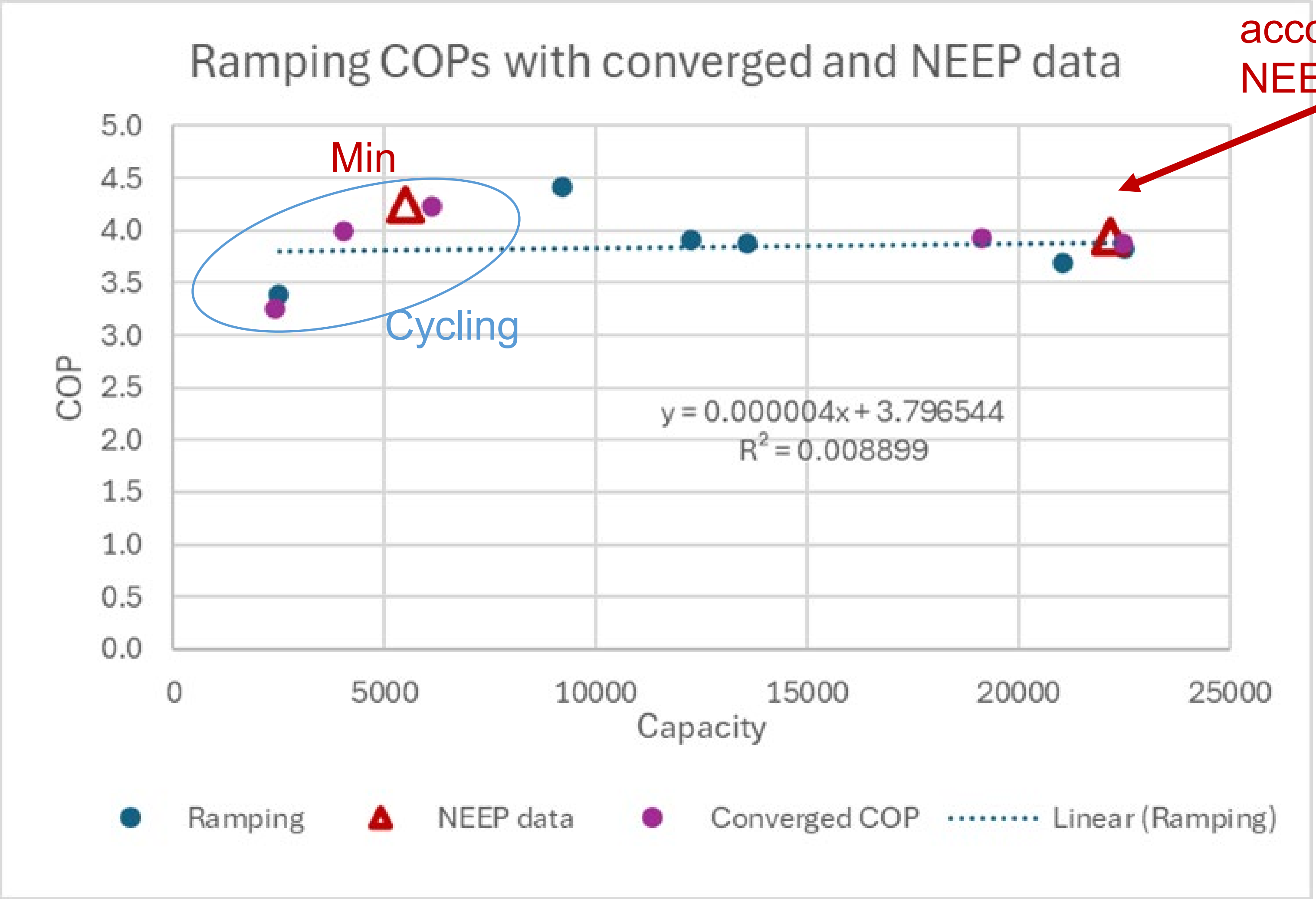
47°F COPs
during ramping periods and convergence tests

Unit #5
22,000 Btuh
Ducted

Test and NEEP data align well. COP is fairly flat across wide range of loads

Cycling doesn't seem to reduce COP much until very low loads

Rated = Max according to NEEP data

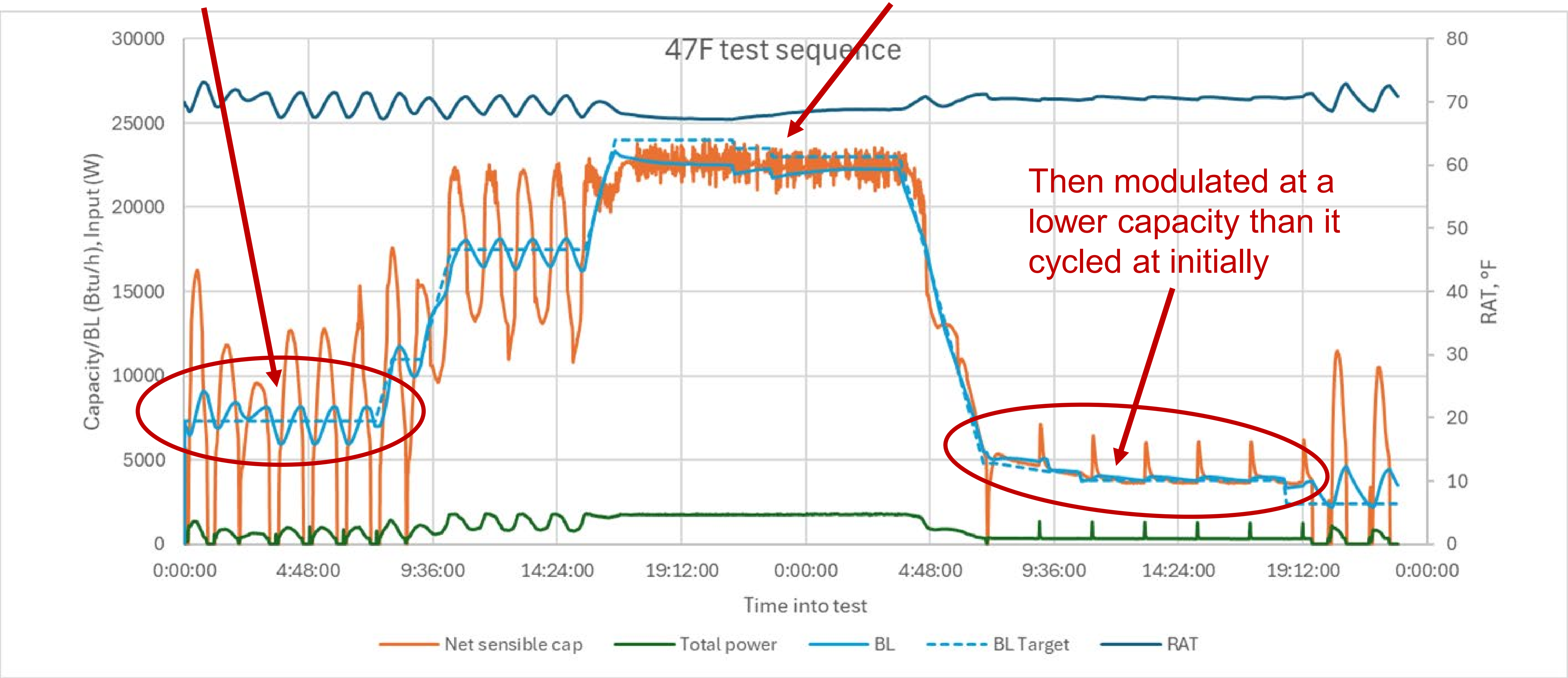


47F – entire sequence

Unit #6
23,500 Btuh
Ducted

Unit defrosted at 1st load (convergence excludes DF)

Didn't quite meet load at rated

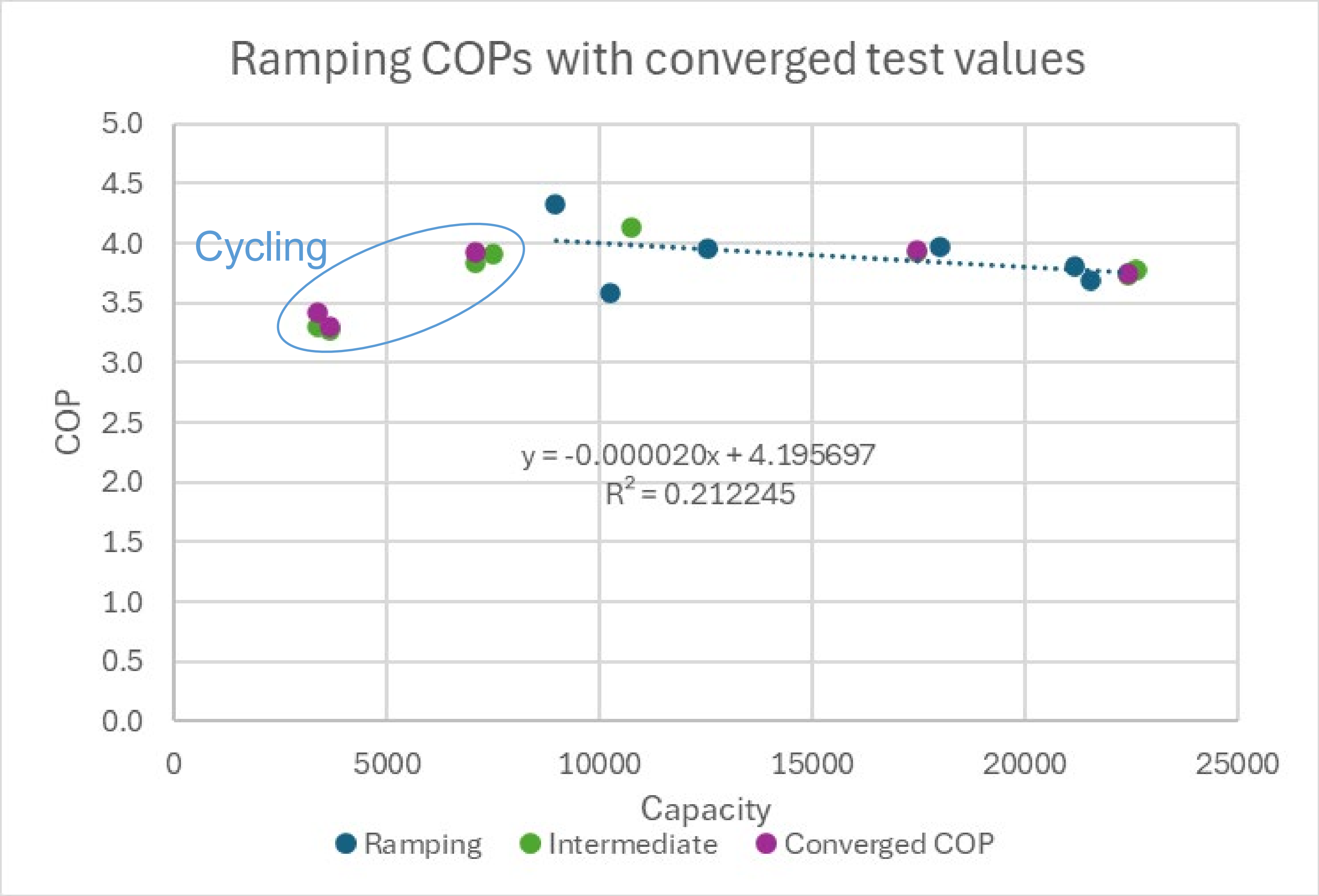


Then modulated at a lower capacity than it cycled at initially

47°F COPs
during ramping periods and convergence tests

Unit #6
23,500 Btuh
Ducted

Converged tests agree well with ramping data.
COP drops during cycling behavior.



2024
Field Data Analysis

John Bush, OTS Energy

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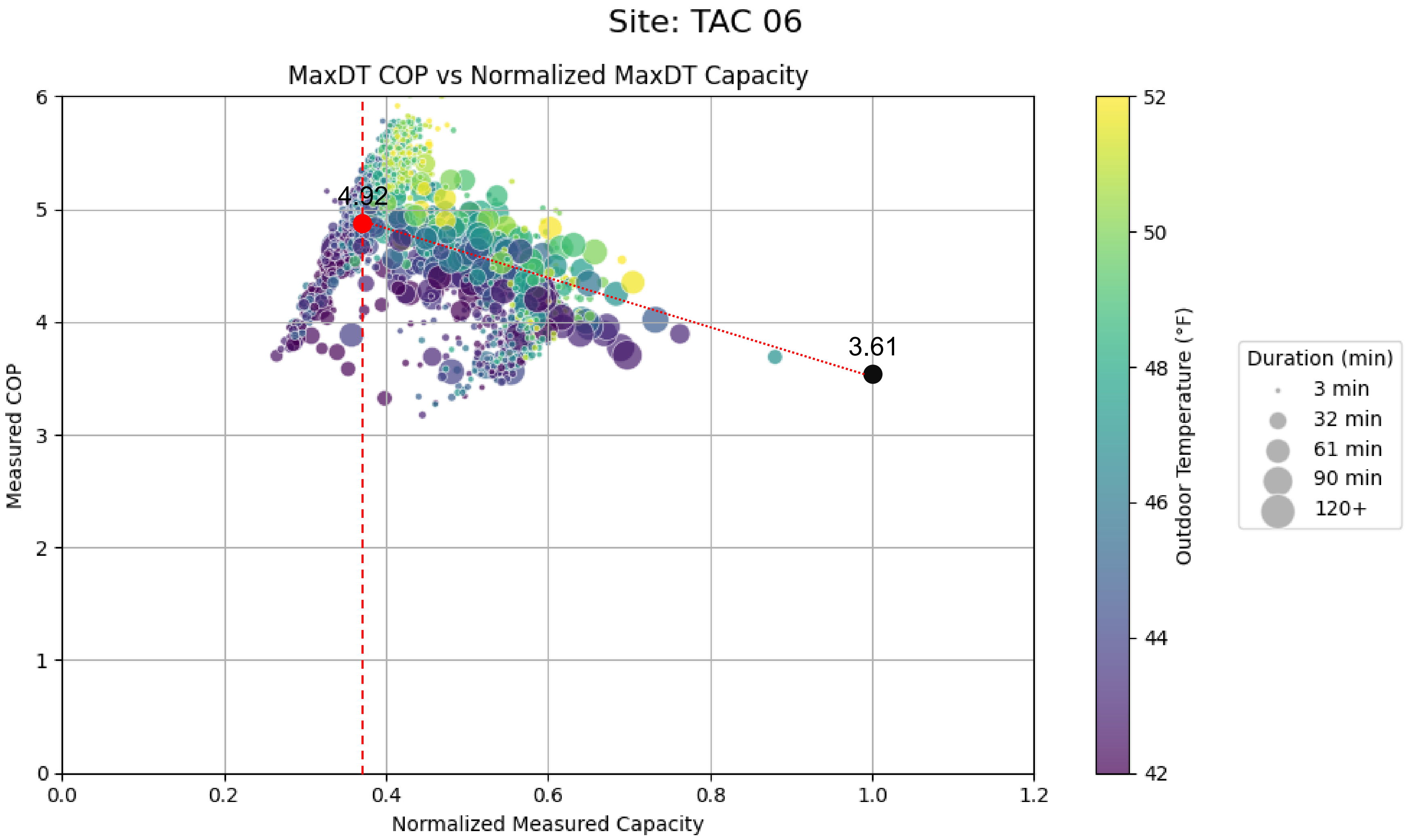
BPA High Performance High Capacity Field Test

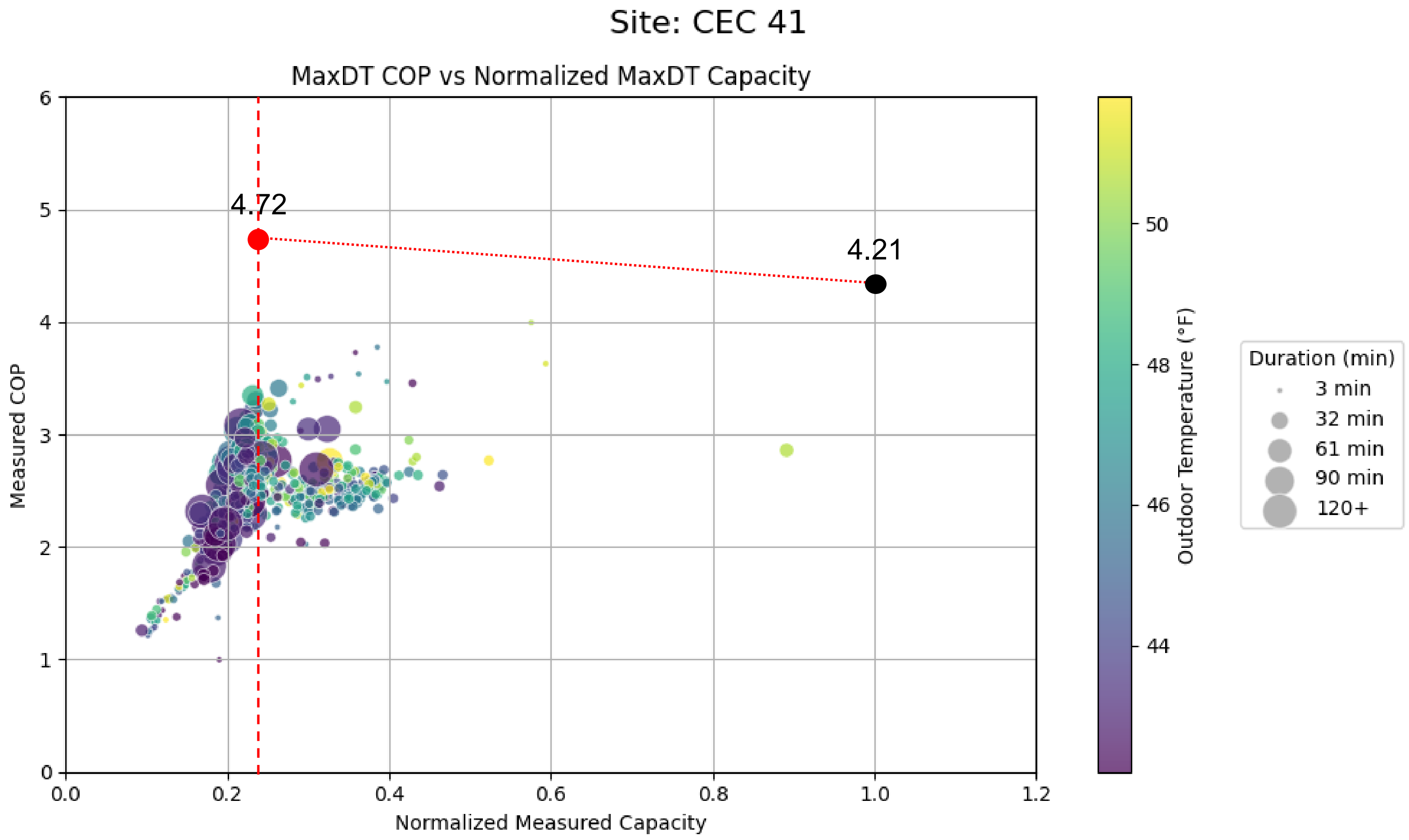
- 50 heat pump systems
  - ~50/50 ducted/ductless
- Minute level data monitoring
- Calibrated air flow measurements for ducted

Site	NEEP Capacity,MinCap 47°F	Measured Avg. Capacity (Diff%)	NEEP COP,MinCap 47°F	Measured Ave COP
CEC 41	9500	9335 (-2%)	4.72	2.23
INL 02	6200	11856 (91%)	4.33	2.97
INL 41	20400	19841 (-3%)	4.71	3.98
INL 42	17000	21341 (26%)	5.14	4.74
INL 44	21200	26056 (23%)	4.23	3.47
SNO 41	12000	21485 (79%)	3.86	3.35
SNO 43	7900	10770 (36%)	4.37	3.71
SNO 44	16000	17998 (12%)	4.64	4.97
TAC 01	20700	19913 (-4%)	4.53	4.14
TAC 02	20700	23312 (13%)	4.53	5.67
TAC 03	21000	21942 (4%)	4.56	4.23
TAC 04	20700	23588 (14%)	4.53	5.01
TAC 05	20700	18027 (-13%)	4.53	3.79
TAC 06	17300	20108 (16%)	4.92	4.89
TAC 08	13000	26309 (102%)	4.7	3.79
TAC 09	21000	20485 (-2%)	4.56	3.87
TAC 10	14273	12143 (-15%)	3.87	2.94

Good LLE Performance

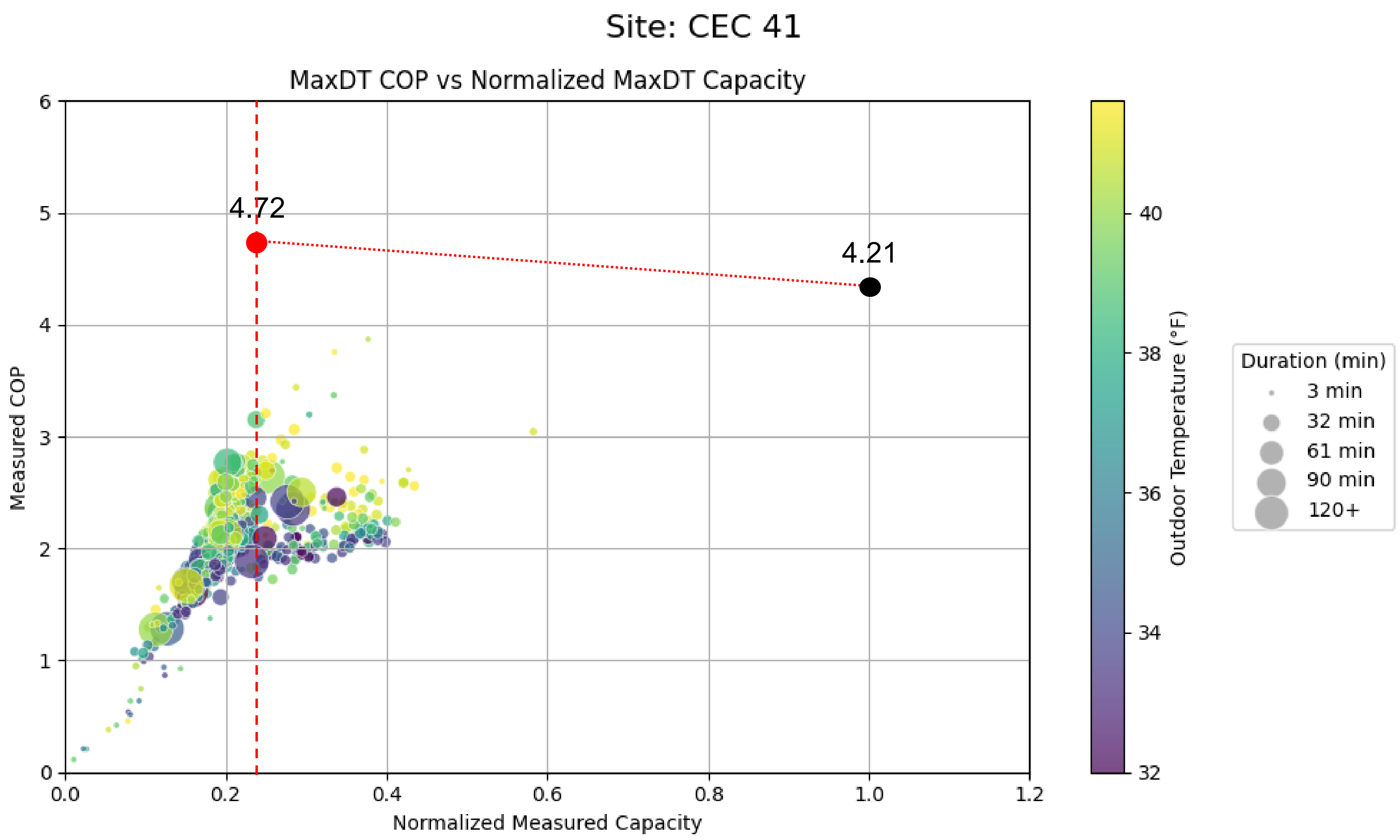


Oversized

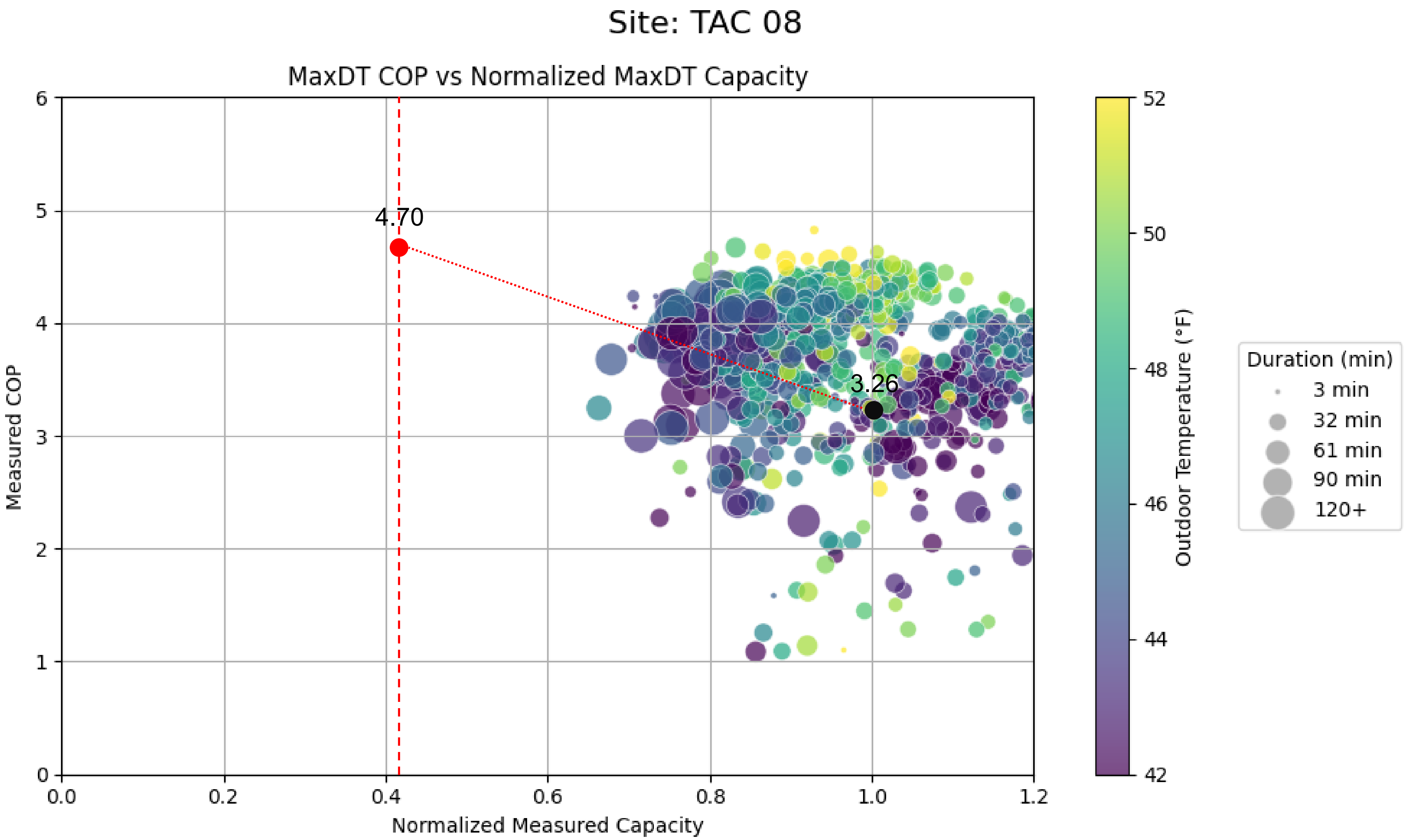


Site: CEC 41
MaxDT COP vs Normalized MaxDT Capacity
4.72
4.21
Measured COP
Normalized Measured Capacity
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
1
2
3
4
5
6
Outdoor Temperature (°F)
44
46
48
50
Duration (min)
3 min
32 min
61 min
90 min
120+

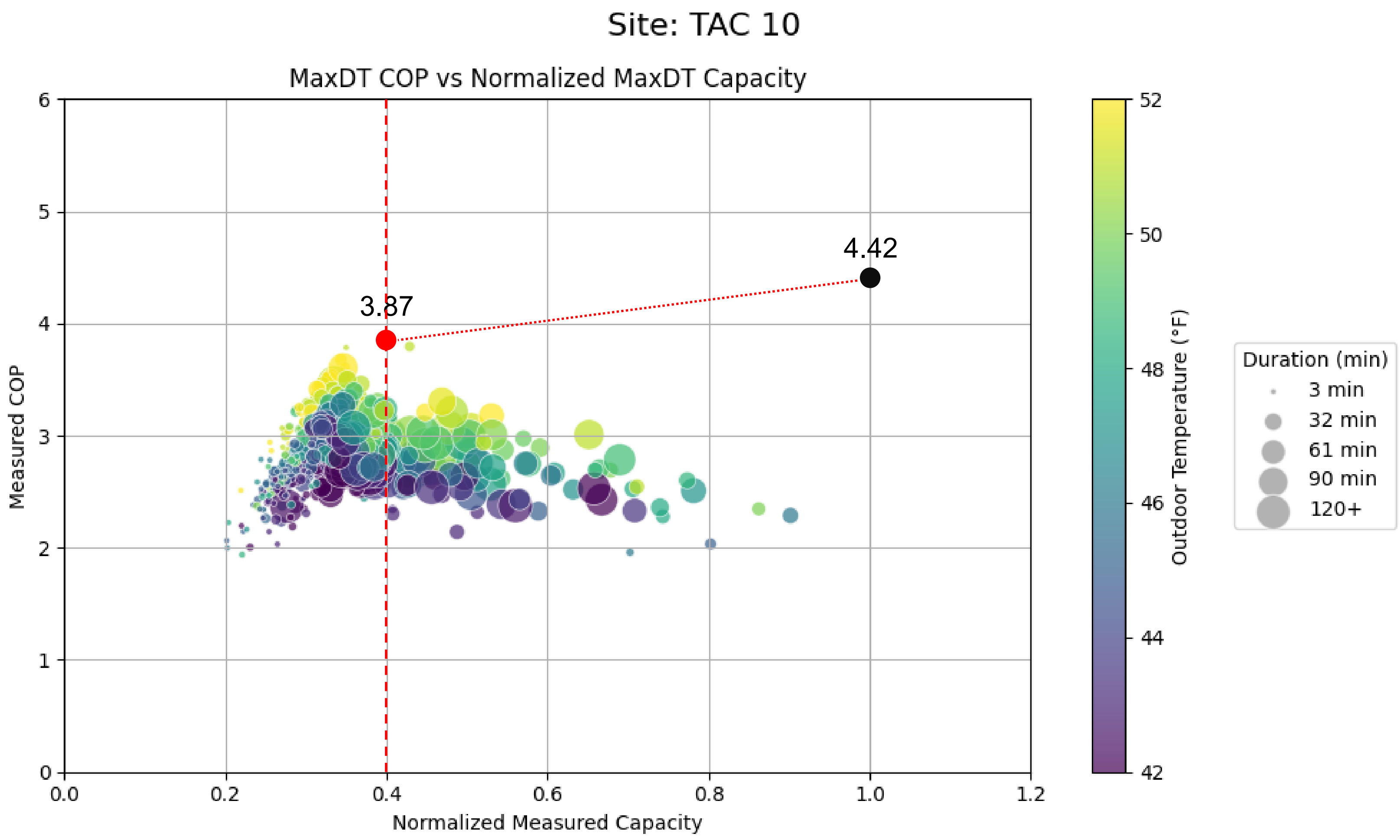
Oversized


Site: CEC 41
MaxDT COP vs Normalized MaxDT Capacity
4.72
4.21
Measured COP
Normalized Measured Capacity
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
1
2
3
4
5
6
Outdoor Temperature (°F)
32
34
36
38
40
Duration (min)
3 min
32 min
61 min
90 min
120+

Possibly Undersized or Instrumentation Error

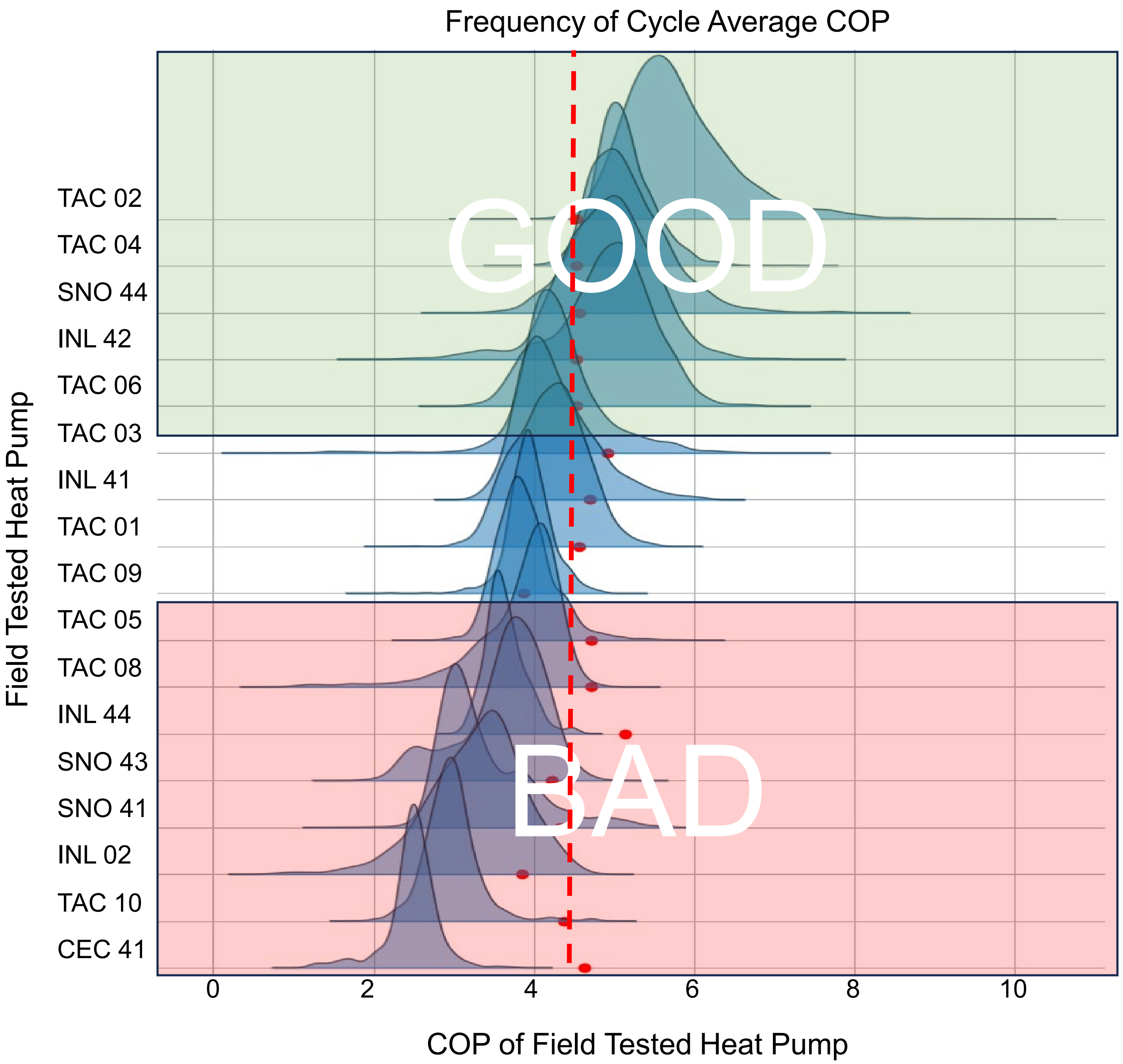


Possibly Incorrect Input Data



BPA Field Data

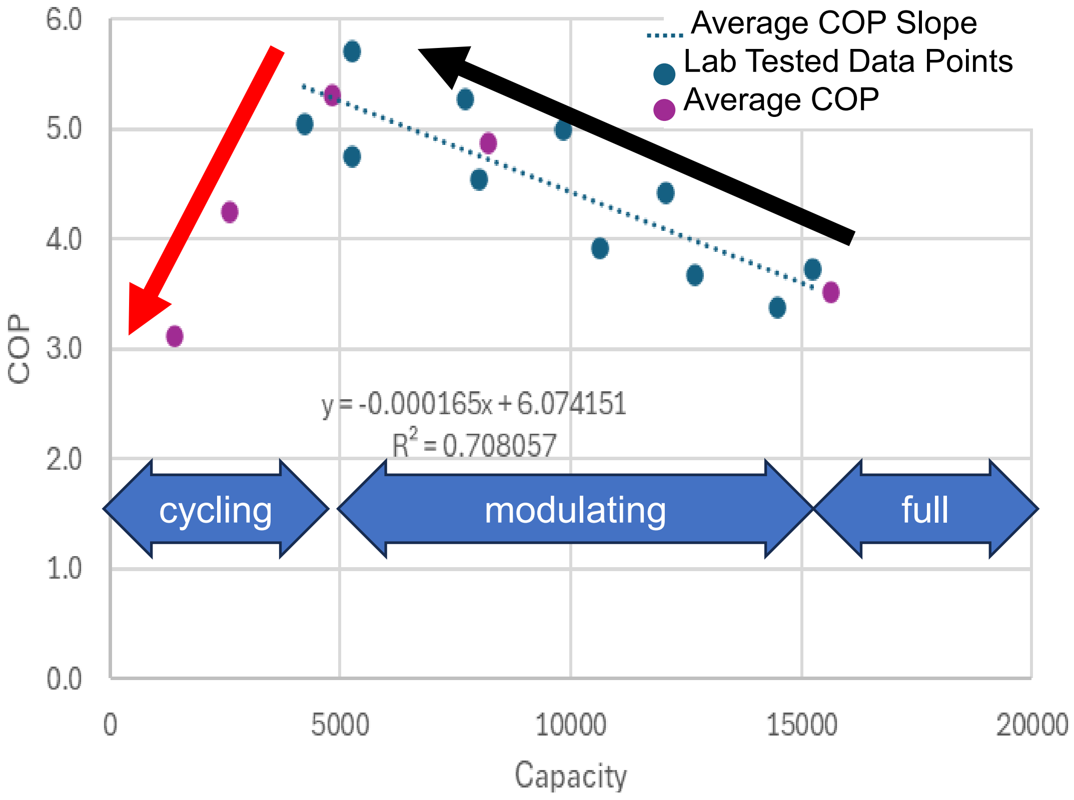
- Plot shows the frequency distribution of COP
- Red dot = NEEP MinCapCOP47 value
- Systems chosen were:
  - "high performance"
  - superior cold climate
  - mild climate performance



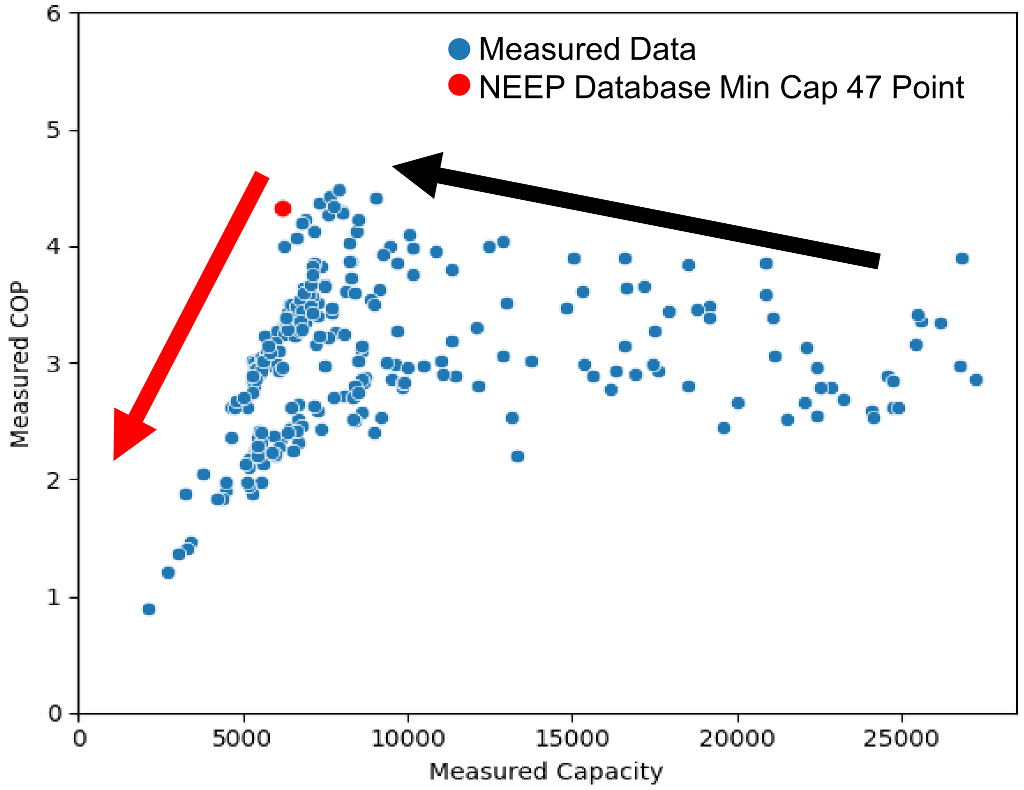
2024 Conclusions

This is what good LLE looks like

Lab Data
- NEEA LLE1
- Outdoor Tamb = 47F



Field Data
- INL 02
- Outdoor Tamb = 42-52F
- Removed first 3 minutes operation

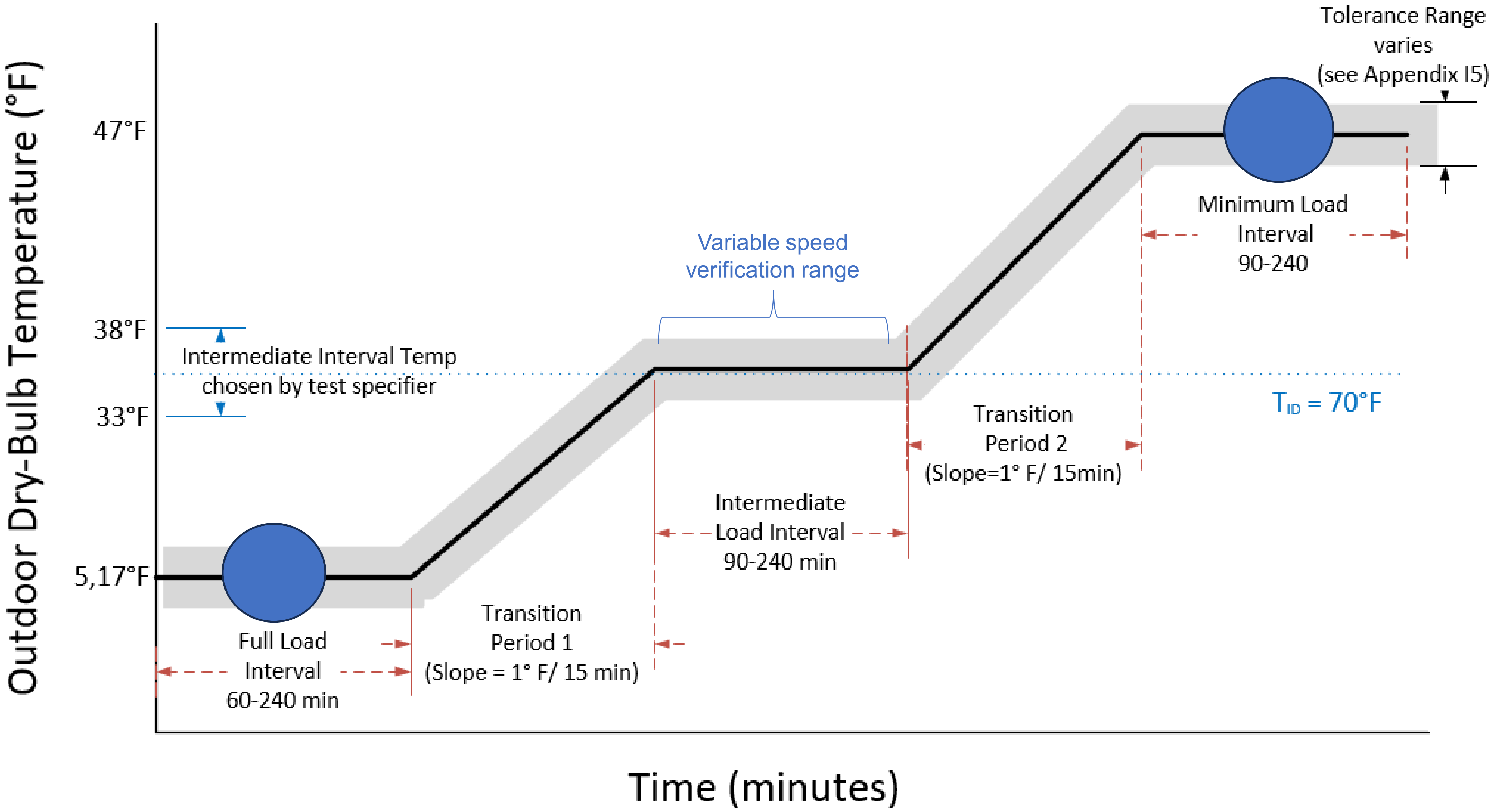


Lab Data

- Good News
  - Machines that did not cycle had good low load efficiency.
  - This suggest the CVP will catch most of the worst performers
- Bad News
  - Not all reported data (NEEP) is accurate
  - 6 Tested Systems
    - 4 showed reasonable alignment with NEEP data
    - One significantly over predicted performance – looks like bad reporting
    - One significantly under predicted performance – looks like bad testing

CVP Load Based Testing of Controls

An addition to the AHRI 210/240 Test Procedure

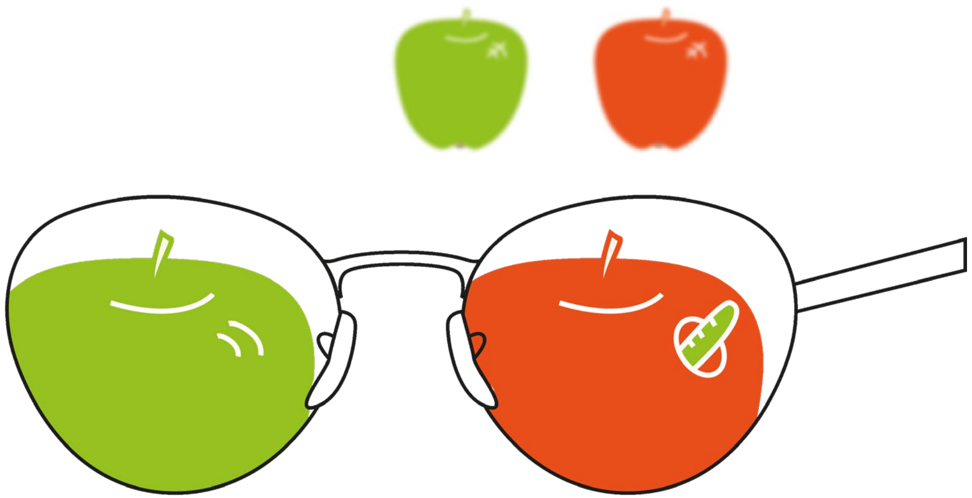


Field Data

- Good News
  - LLE Heat Pumps had Low Load COP values that were 143% of rated COP
  - ~1/3rd of machines overperformed NEEP reported data
- Bad News
  - Oversizing appears to undermine LLE
  - ~1/3rd of machines significantly underperform NEEP reported data

 |

Summary



- LLE heat pumps exist!
  - On paper --- definitely
  - In the Lab --- frequently
  - In the field --- yes, but it can be undermined
- MinCapCOP47
  - It's a good, but not perfect proxy for LLE
  - New CVP test procedure mid 2025 will catch worst performers

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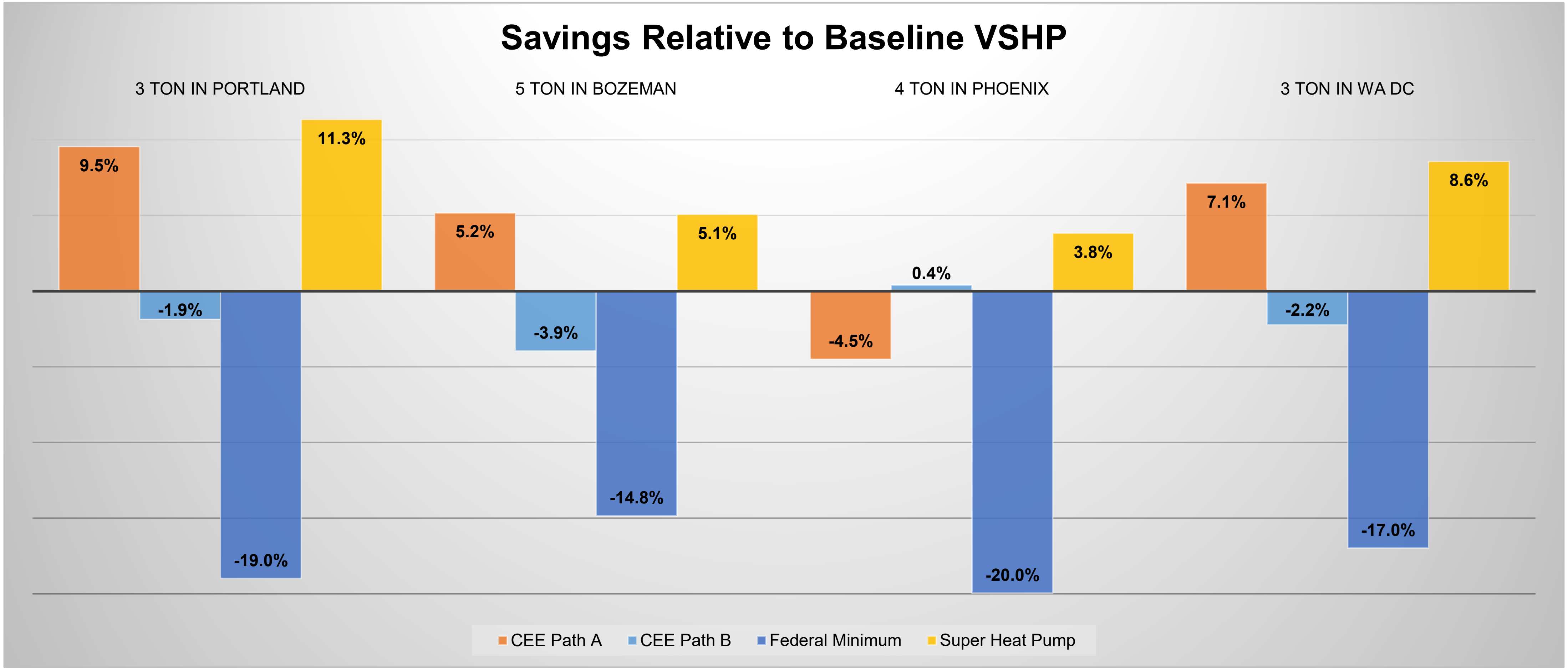
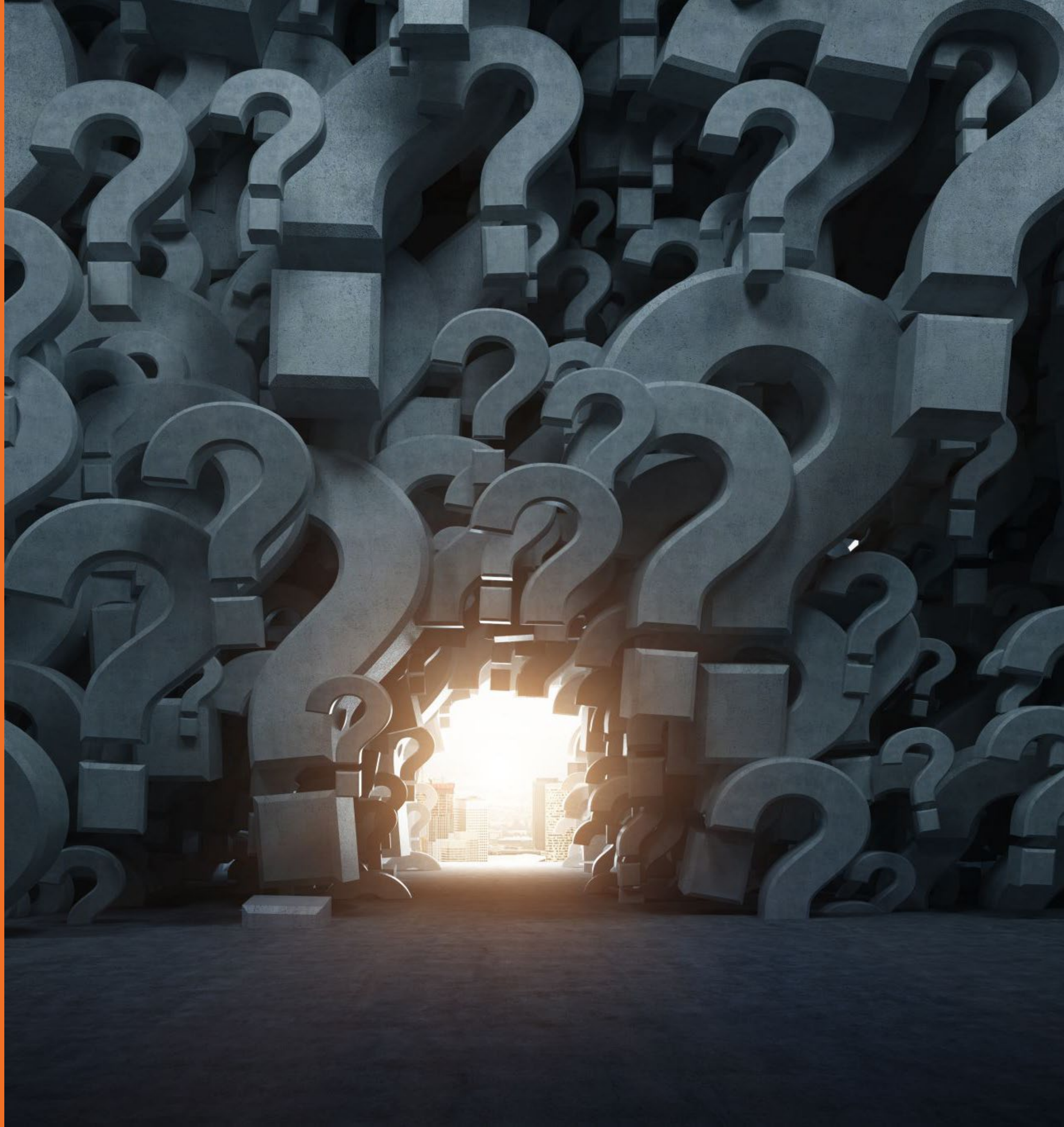
Performance Comparison

(updated modeling results analysis – future calibration work pending)



Questions and Discussion



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Thank You!

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