BUILDINGENERGY NYC

Understanding VRF: Insights from Real-World Measured Performance

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Study Background

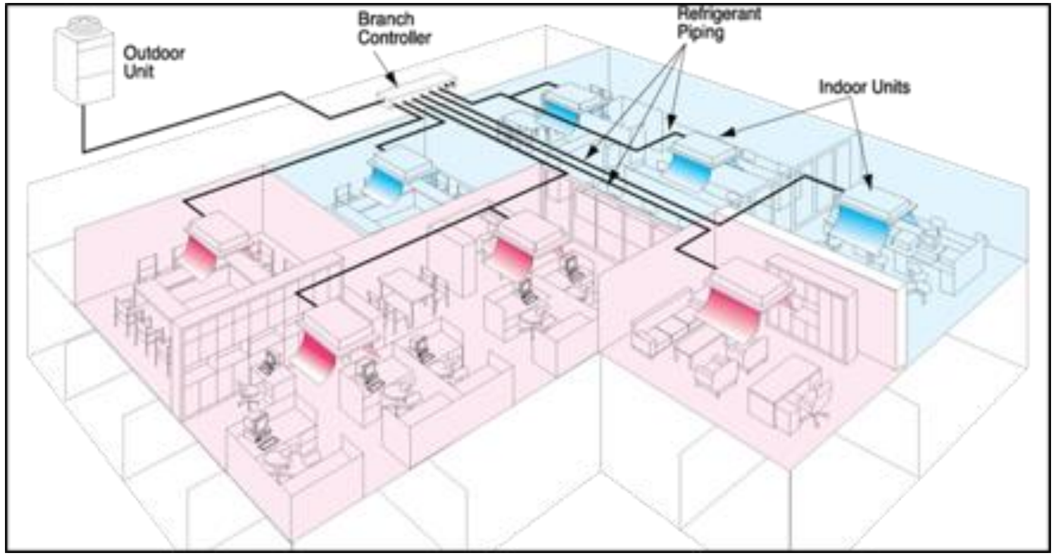
- Need
  - Application of VRF systems in cold climates has grown in recent years, with increased interest in electrification solutions
  - To further increase market confidence, 3rd party validation of VRF system performance in cold climates was needed
- Approach
  - Measure in-field performance of Variable Refrigerant Flow (VRF) systems in cold climates, (IECC Zone 5 and higher)
    - Efficiency performance
    - refrigerant leakage
- Study Funding/Participants
  - US DOE, NEEP, Ridgeline Energy Analytics, VEIC, NYSERDA, Mass CEC, NEEA, BPA, Mitsubishi, Daikin, VRF site owners

The Study and Its Limitations

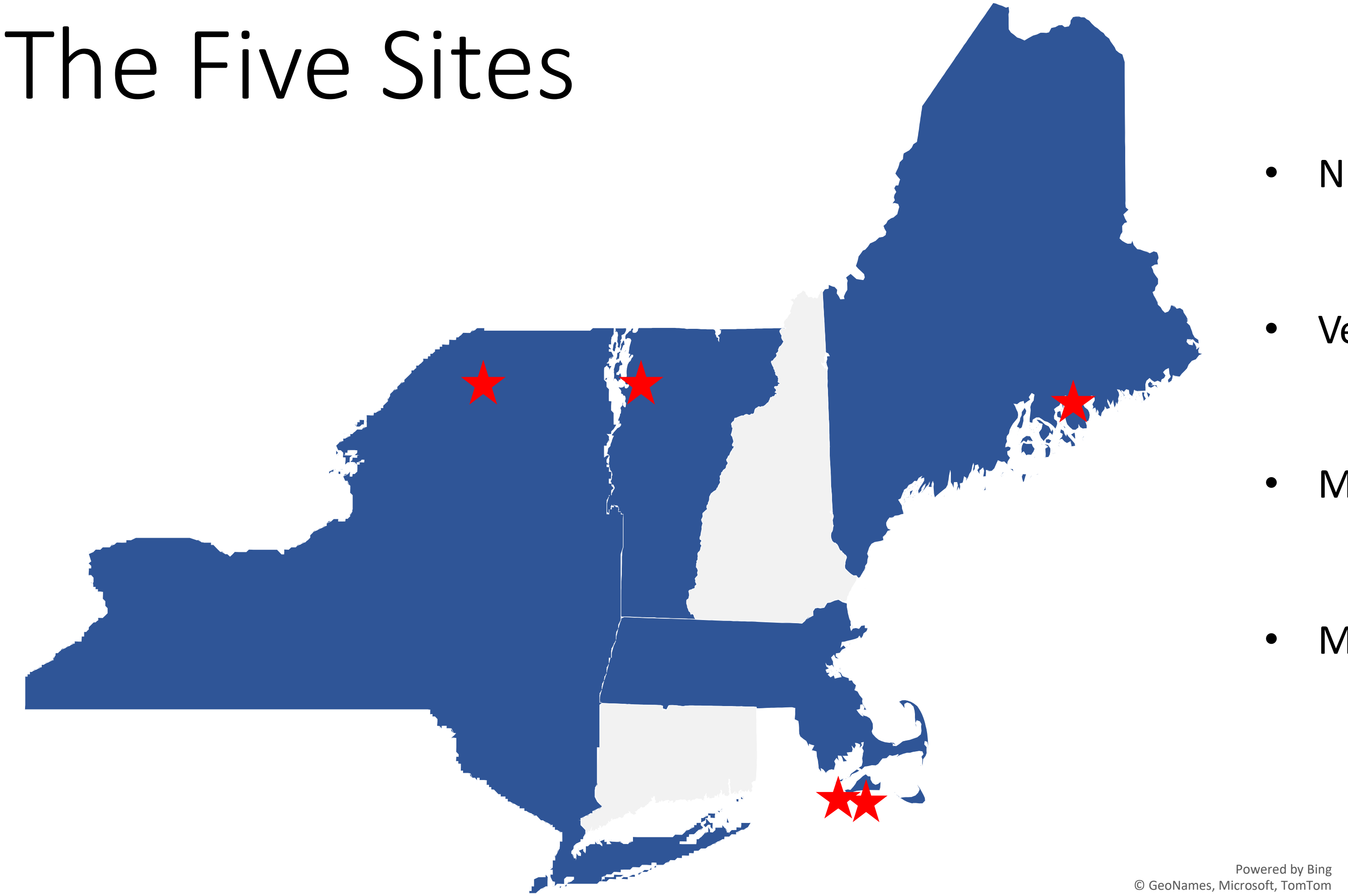
- Summary of work metering five VRF systems in the field
- It is **not** a significant enough sample size to draw definitive conclusions of VRF technology
- It **is** observational, educational, and directional
- Some additional data is provided by an additional study of 30 VRF units at 11 sites

Variable Refrigerant Flow (VRF)

- Variable refrigerant flow (VRF) is an HVAC technology that can provide both heating and cooling.
- VRF systems circulate refrigerant as the heat transfer medium. VRF systems generally include one or more air-source outdoor compressor units serving multiple indoor fan coil refrigerant evaporator units.
- DC inverters are added to the compressor to support variable motor speed and thus variable refrigerant flow rather than simply perform on/off operation.
- Systems selected with a heat recovery module have the added benefit of simultaneously heating and cooling from one condensing unit, transferring energy between zones.

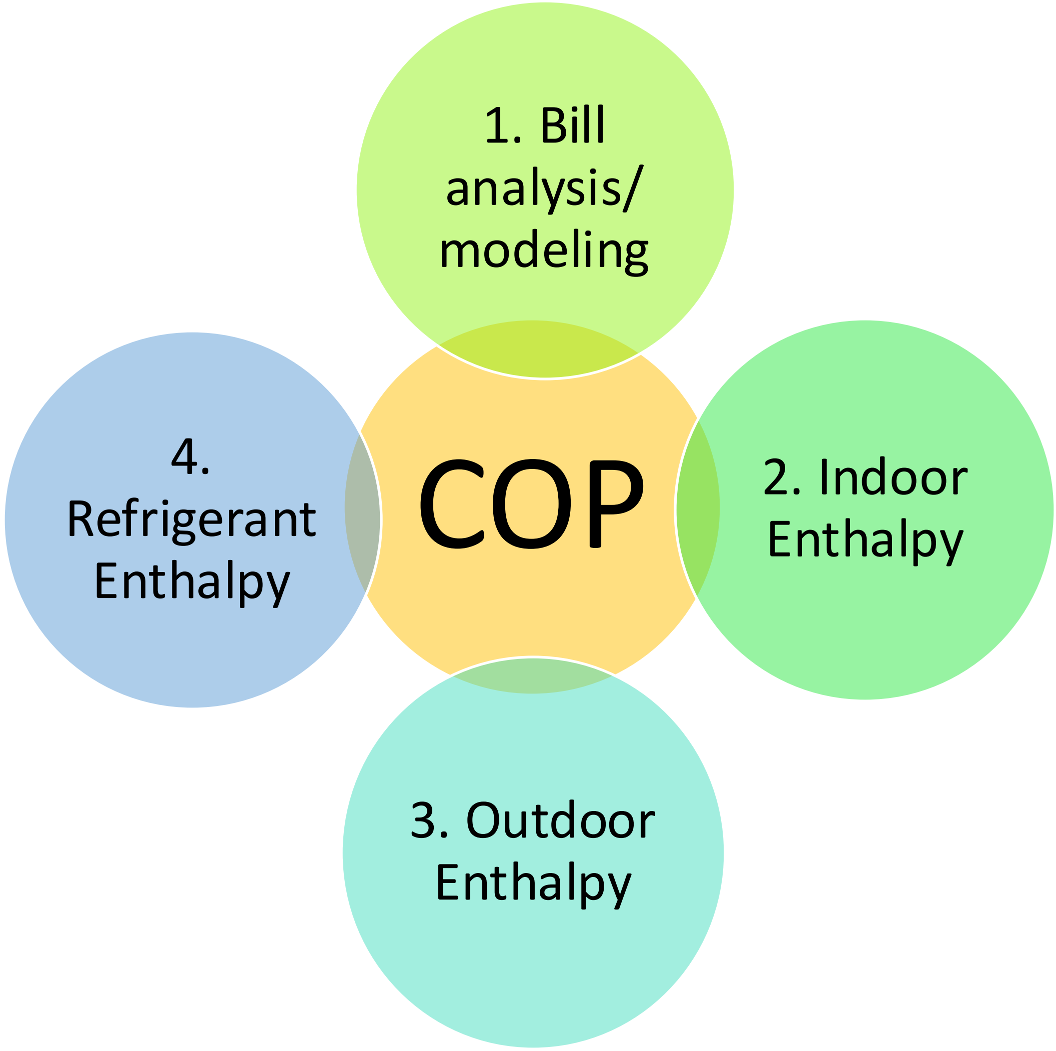


The Five Sites



- New York
  - Clarkson University
- Vermont
  - Camp Johnson (Army National Guard)
- Maine
  - College of the Atlantic
- Massachusetts-
  - West Tisbury Library
  - West Tisbury Police Station

Methods for Calculating COP



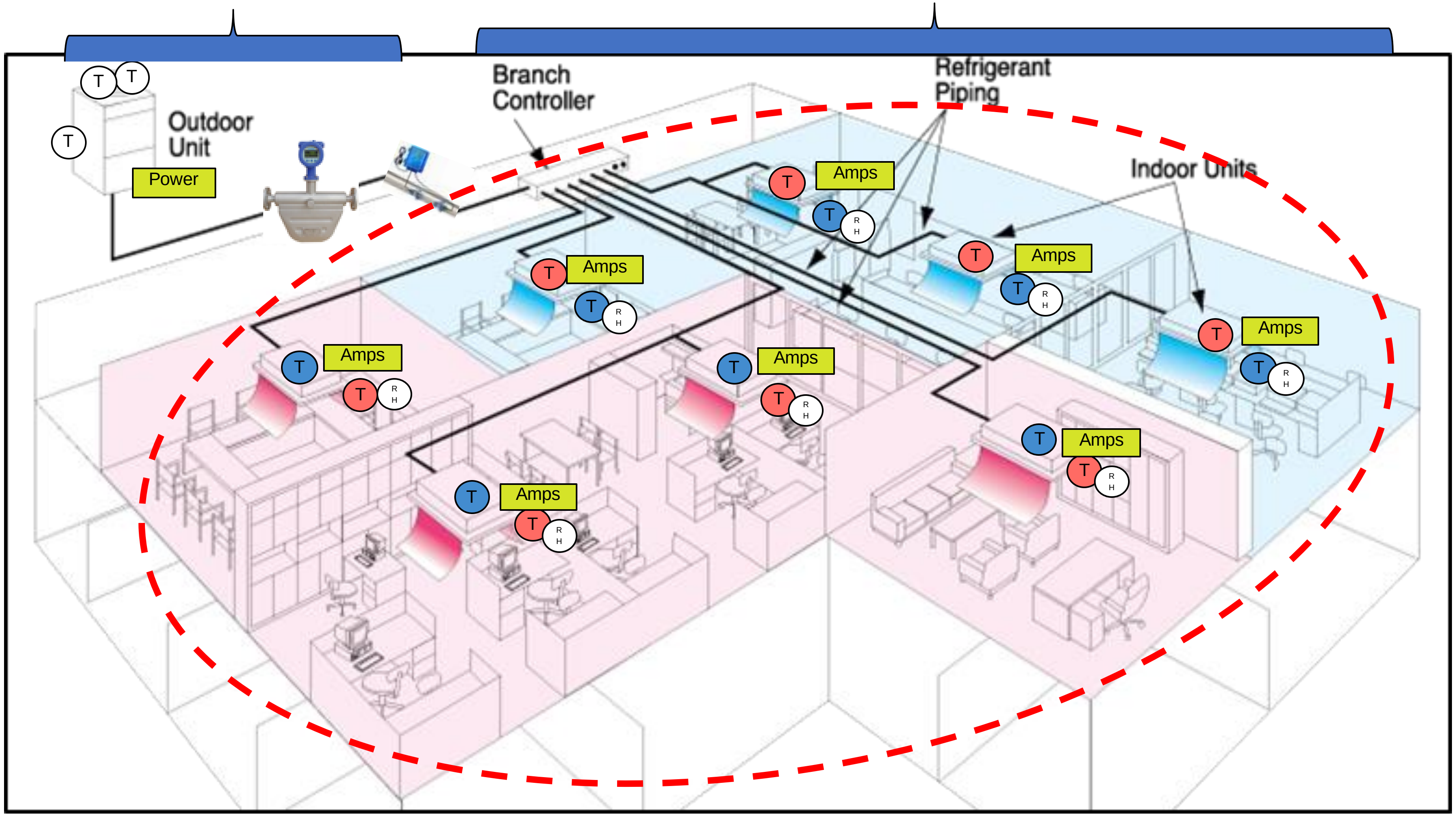
- $COP = \frac{energy\ benefit}{energy\ consumed}$

COP 1. Billing Analysis

- Retrofit fuel buildings
  - Pre/ post analysis can provide an approximate COP but delivery timing and DHW can create difficulties
    - Performed for Site 4
- All electric buildings
  - Works if the VRF provides all or a known and substantial portion of the building’s heat and submetering is in place
  - Heat loss model of known accuracy
    - Testing for Site 3

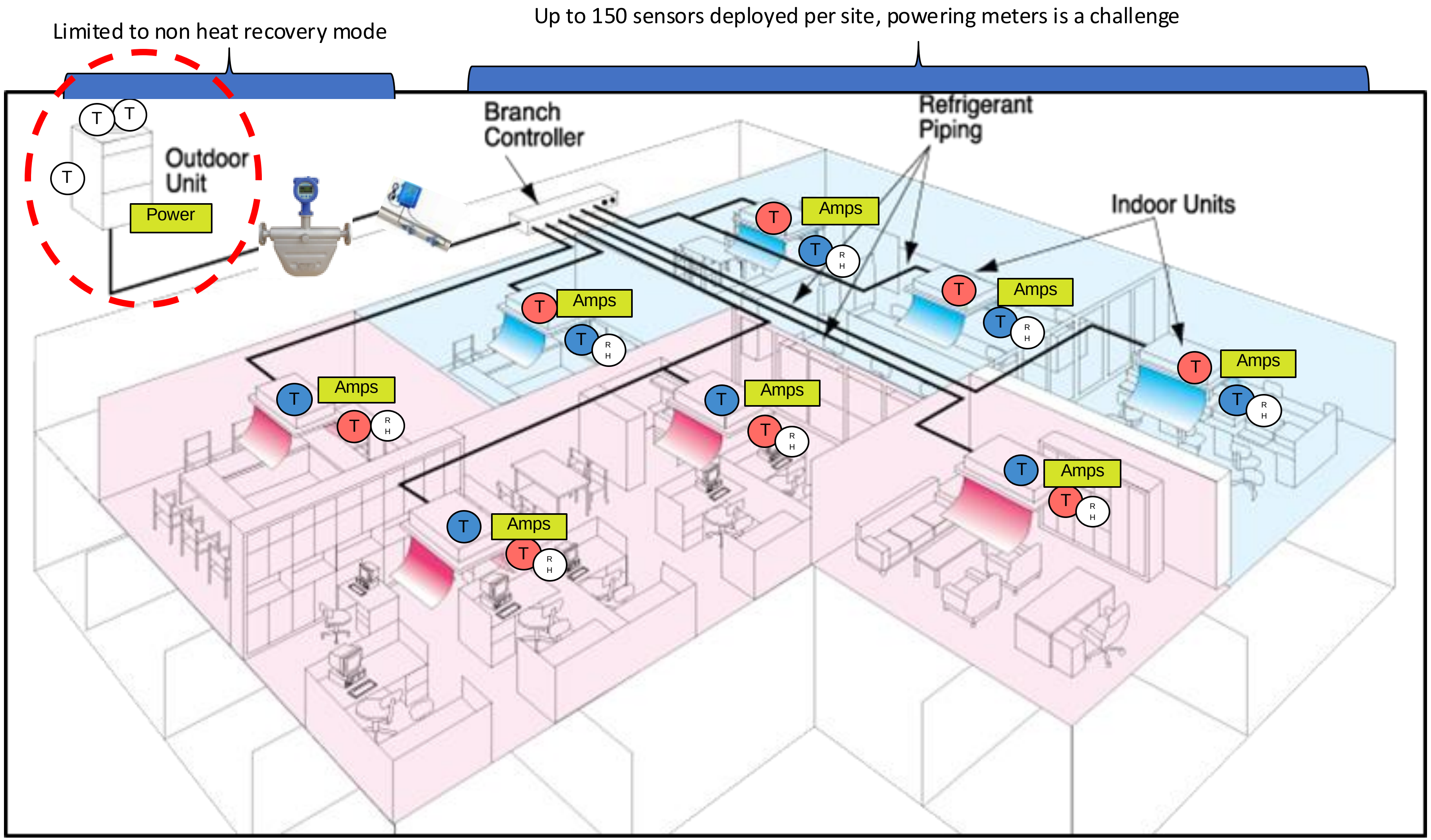
COP 2. Metering for Indoor Enthalpy Calculations

Up to 150 sensors deployed per site, powering meters is a challenge



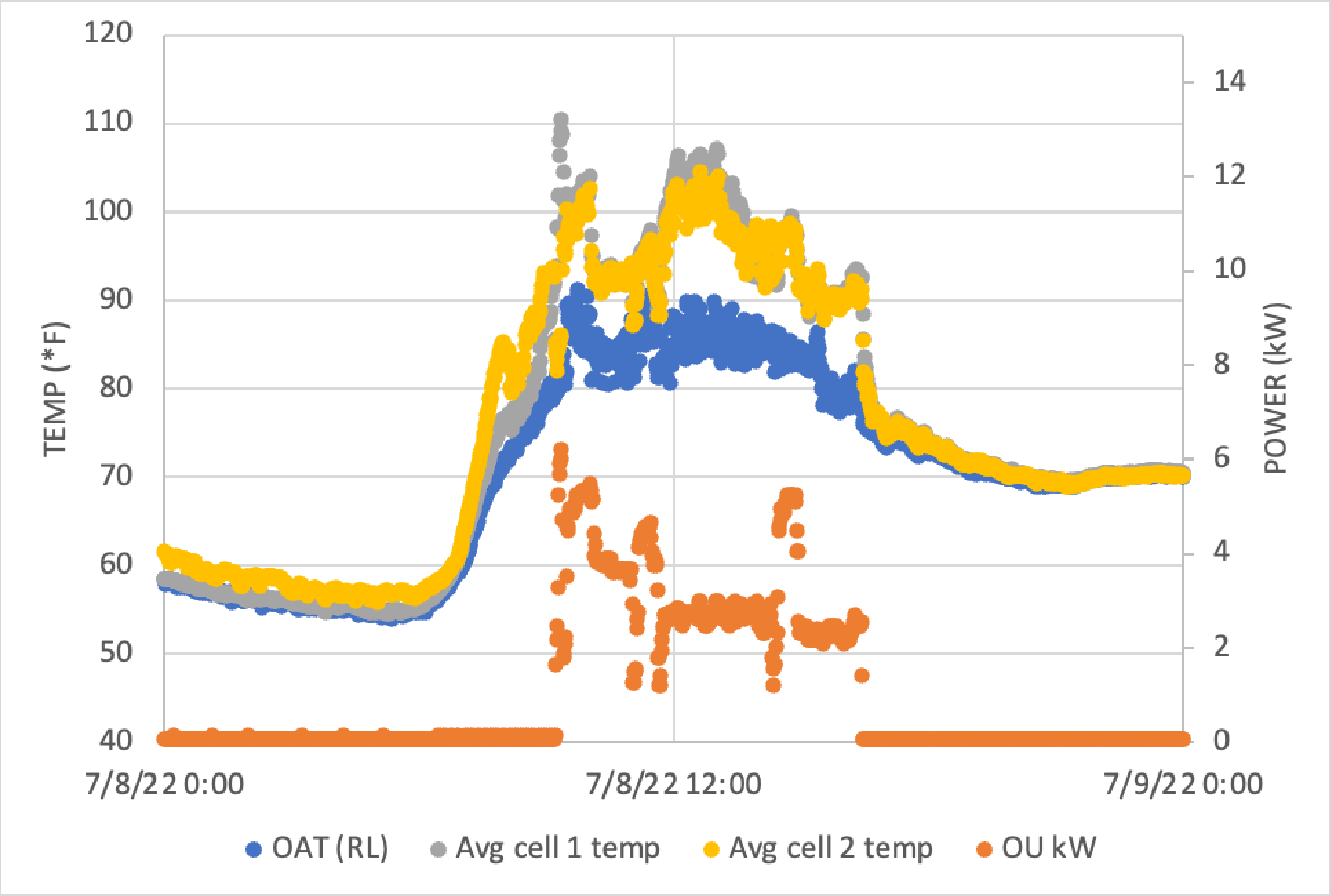
(Source: 2012 GSA VRF Systems Report / Mitsubishi)

COP 3. Metering for Outdoor Enthalpy Calculations

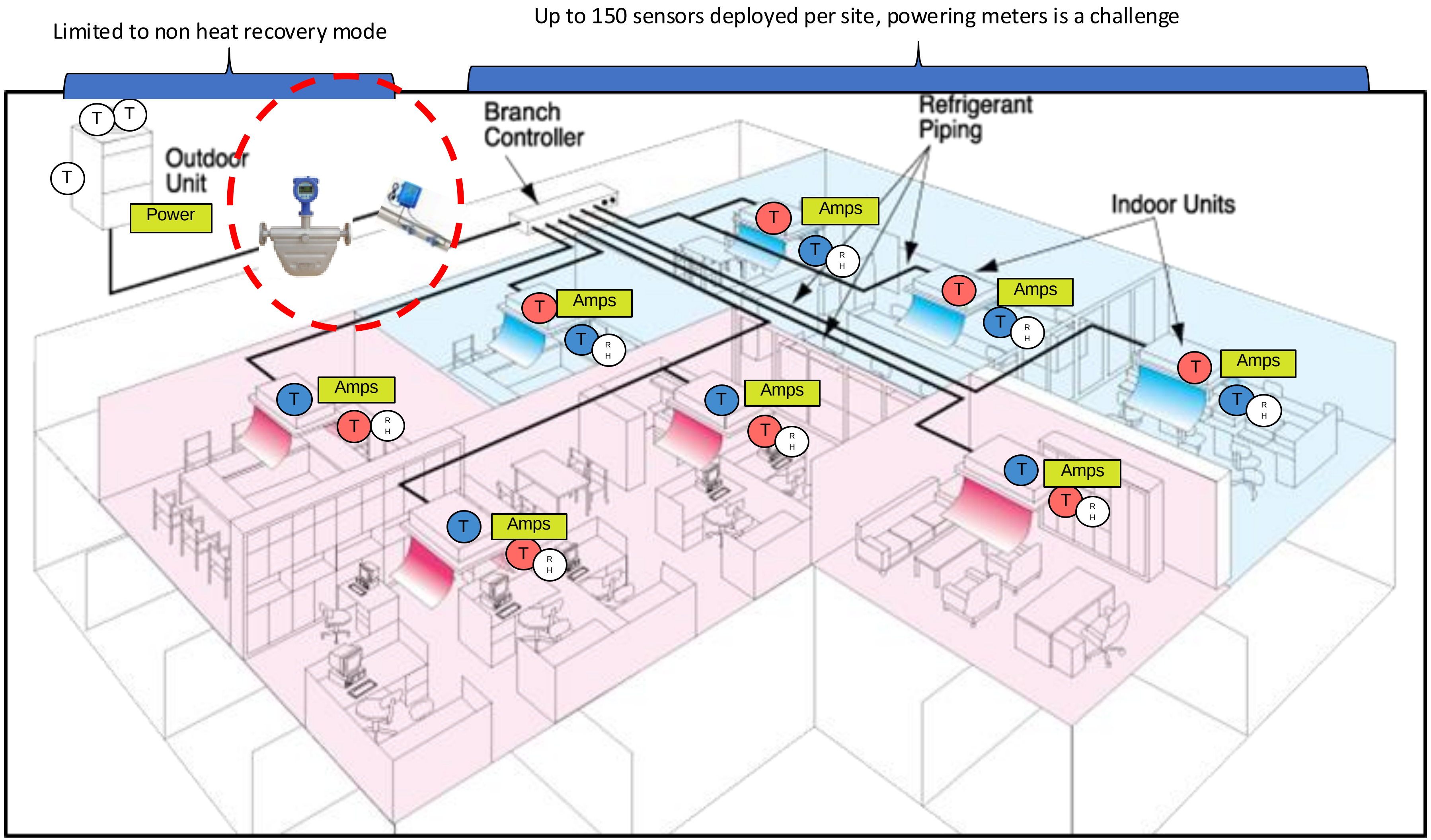


(Source: 2012 GSA VRF Systems Report / Mitsubishi)

COP 3. Outdoor Enthalpy Measurements



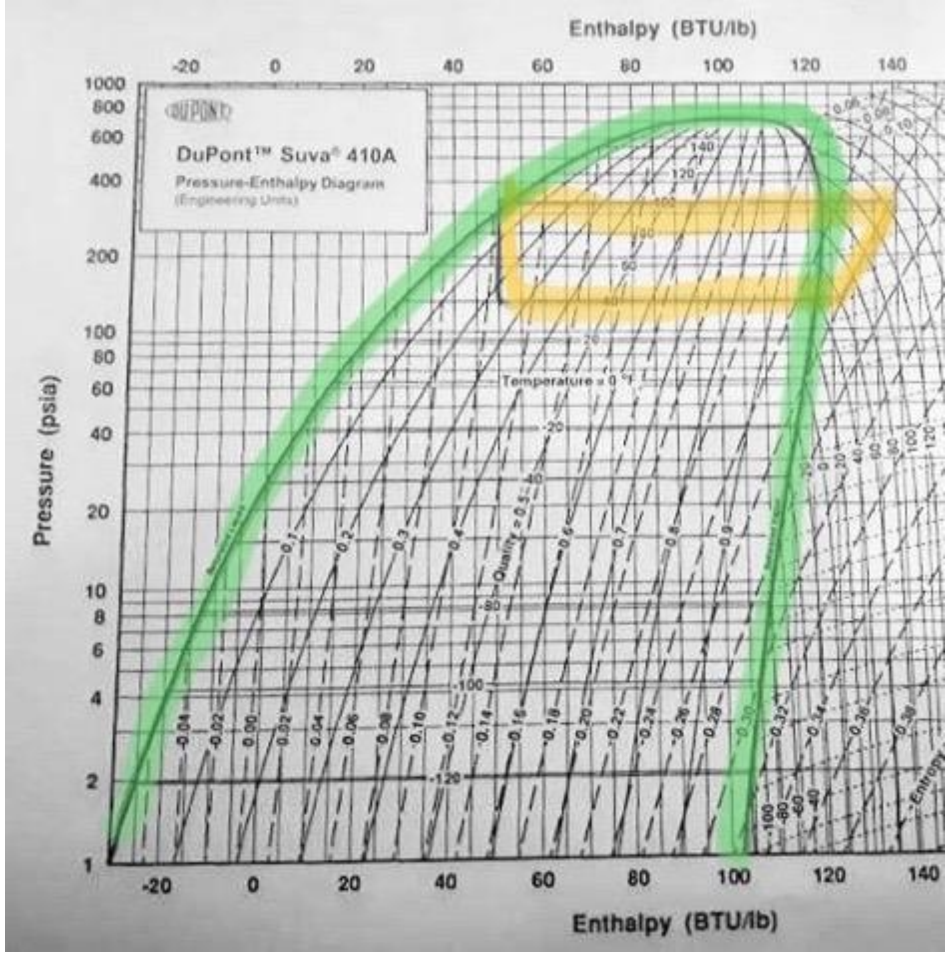
COP 4. Metering for Mass Flow Calculations



(Source: 2012 GSA VRF Systems Report / Mitsubishi)

COP 4. Refrigerant Enthalpy

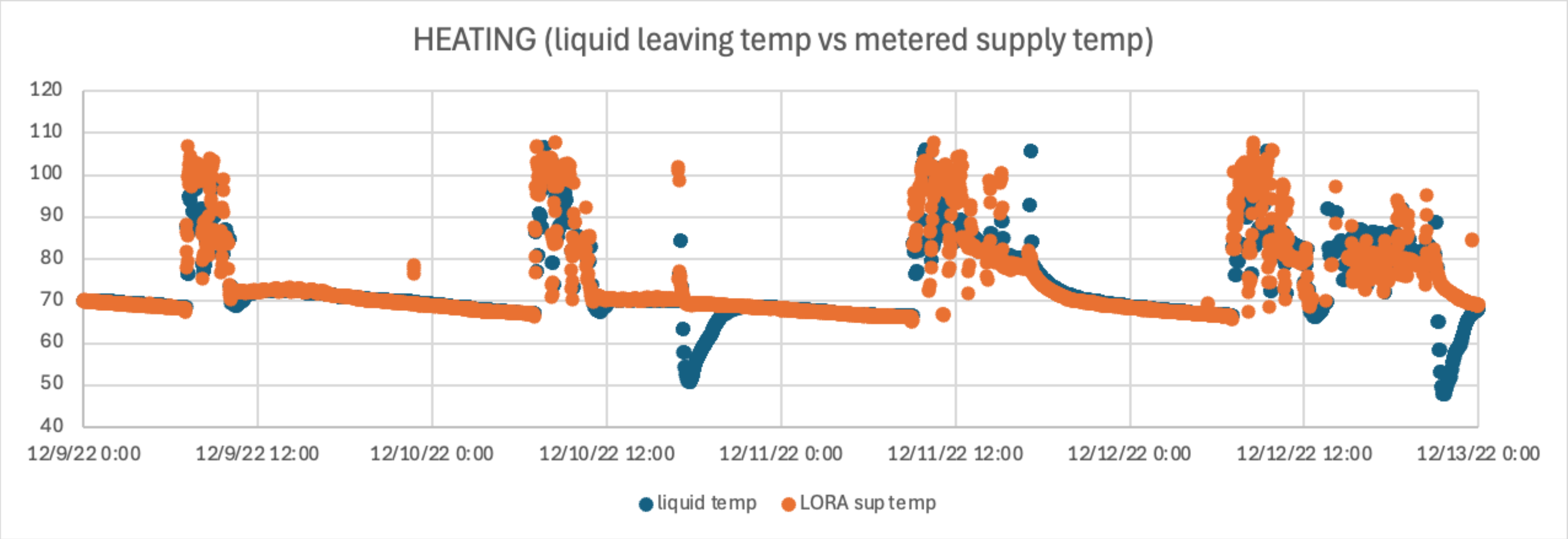
- Coriolis meter
- Ultrasonic meter
- Pressure temperature-based compressor mapping
- Methods require measuring
  - Refrigerant mass flow
  - Refrigerant pressures
  - Refrigerant temperatures
- These methods can only detect net heat rejected and absorbed and cannot work for periods of simultaneous heating and cooling

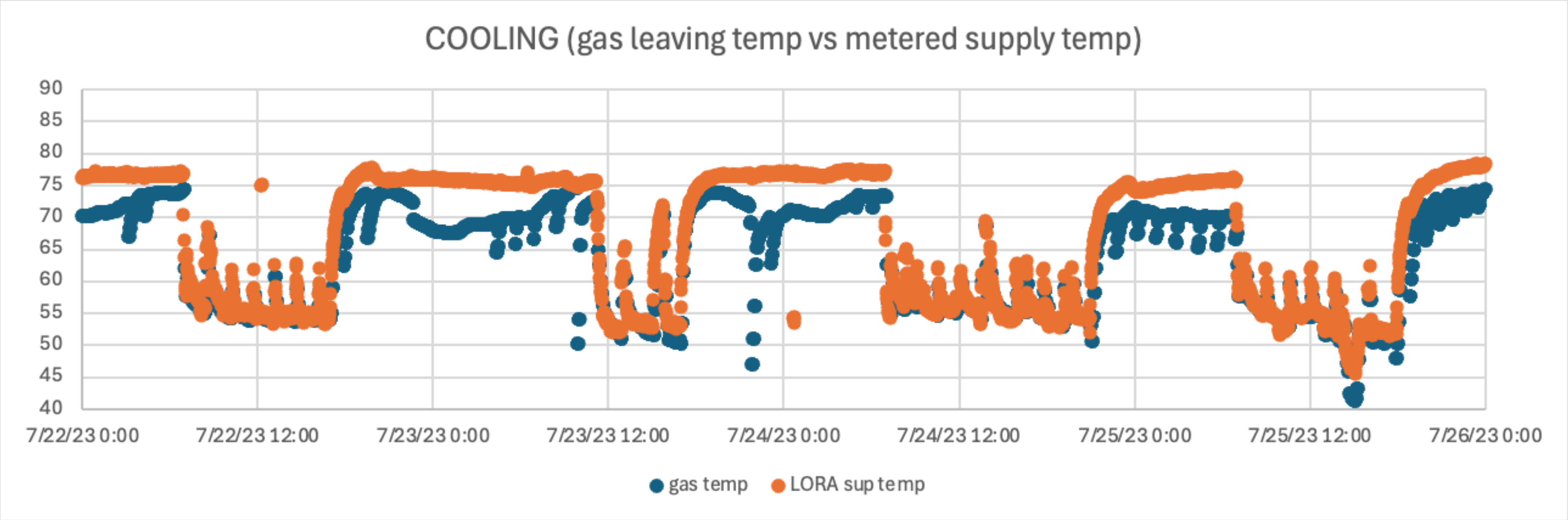


Data Sources—Metering Methods

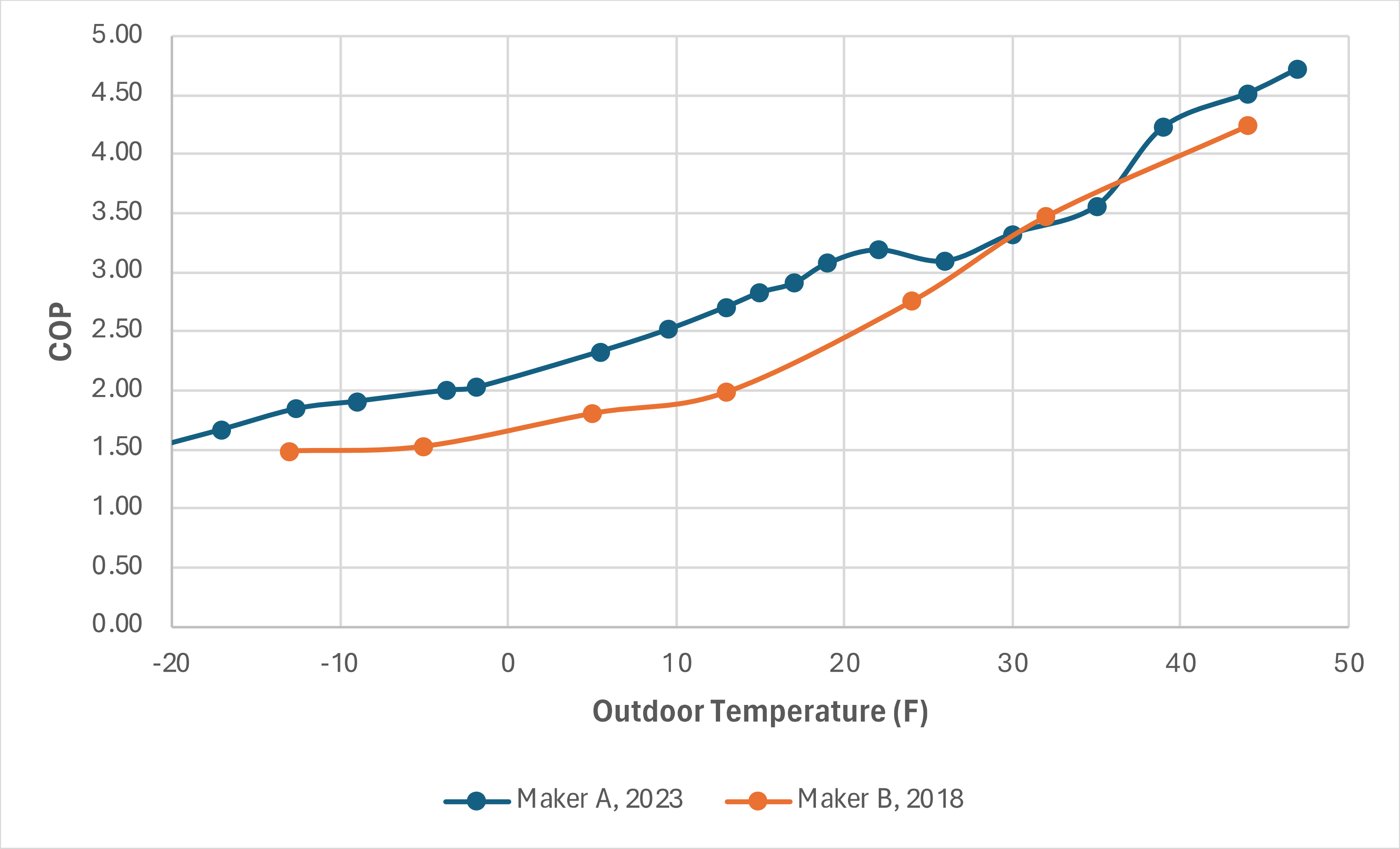
- External metering systems
  - Expensive, and labor intensive
  - Calculations currently require data from power meters, mass flow meters and thermistors yielding potential multiple points of error or failure
- DAS systems
  - Some elements require post processing by manufacturer
  - Intended for short term metering and need to be downloaded regularly to avoid outages
  - Good potential tool for long term metering if sensor gaps are filled
    - Gaps: FCU airflow, FCU supply and return humidity, true power, outdoor exhaust temperature

Leaving Coil Vs. Measured Air Temperatures

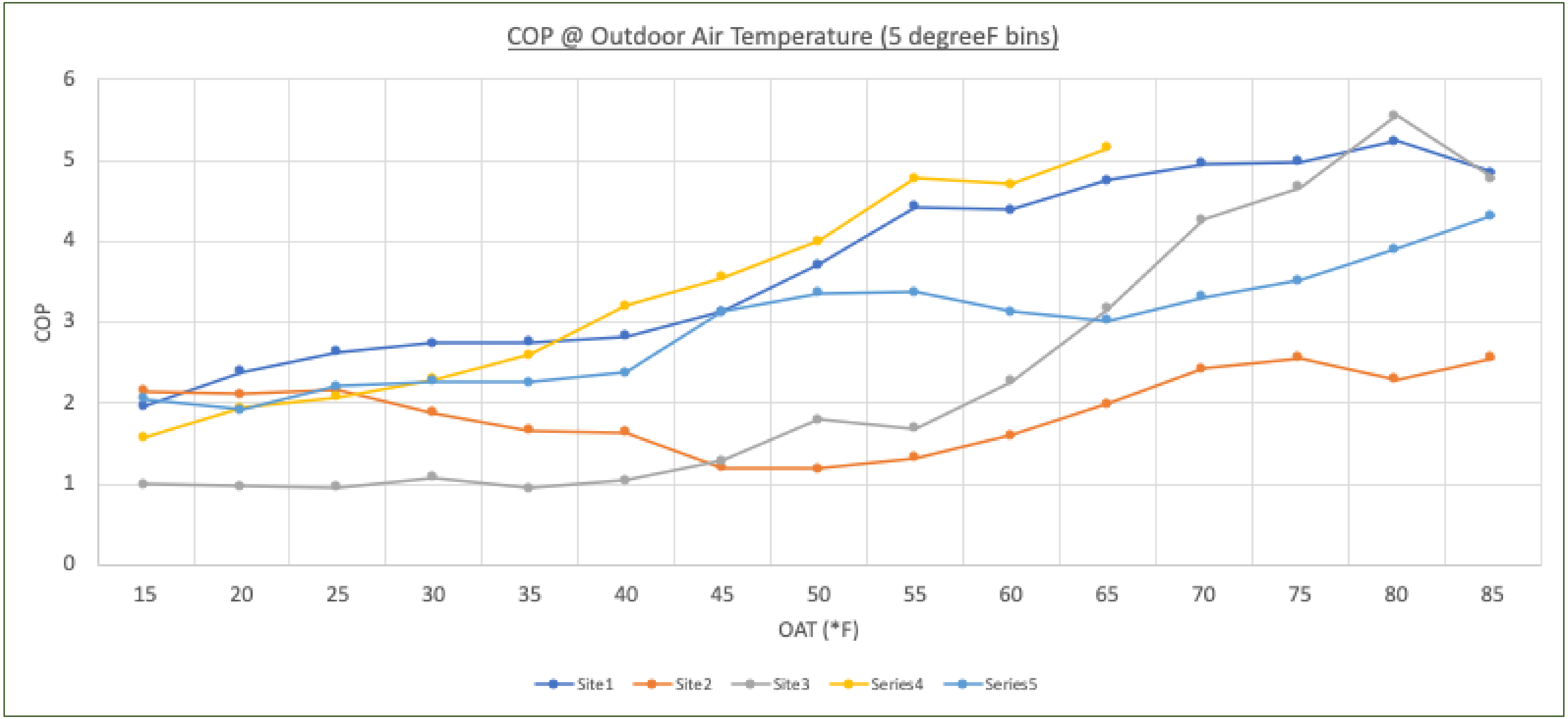




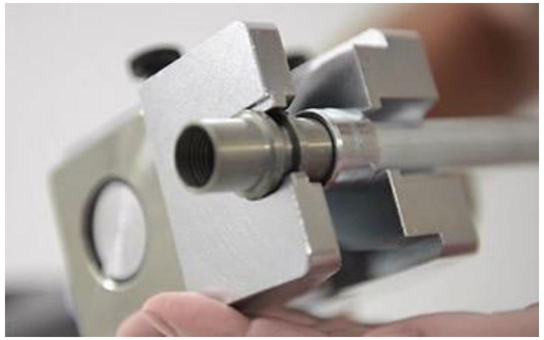
Rated Heating COP: 3-pipe

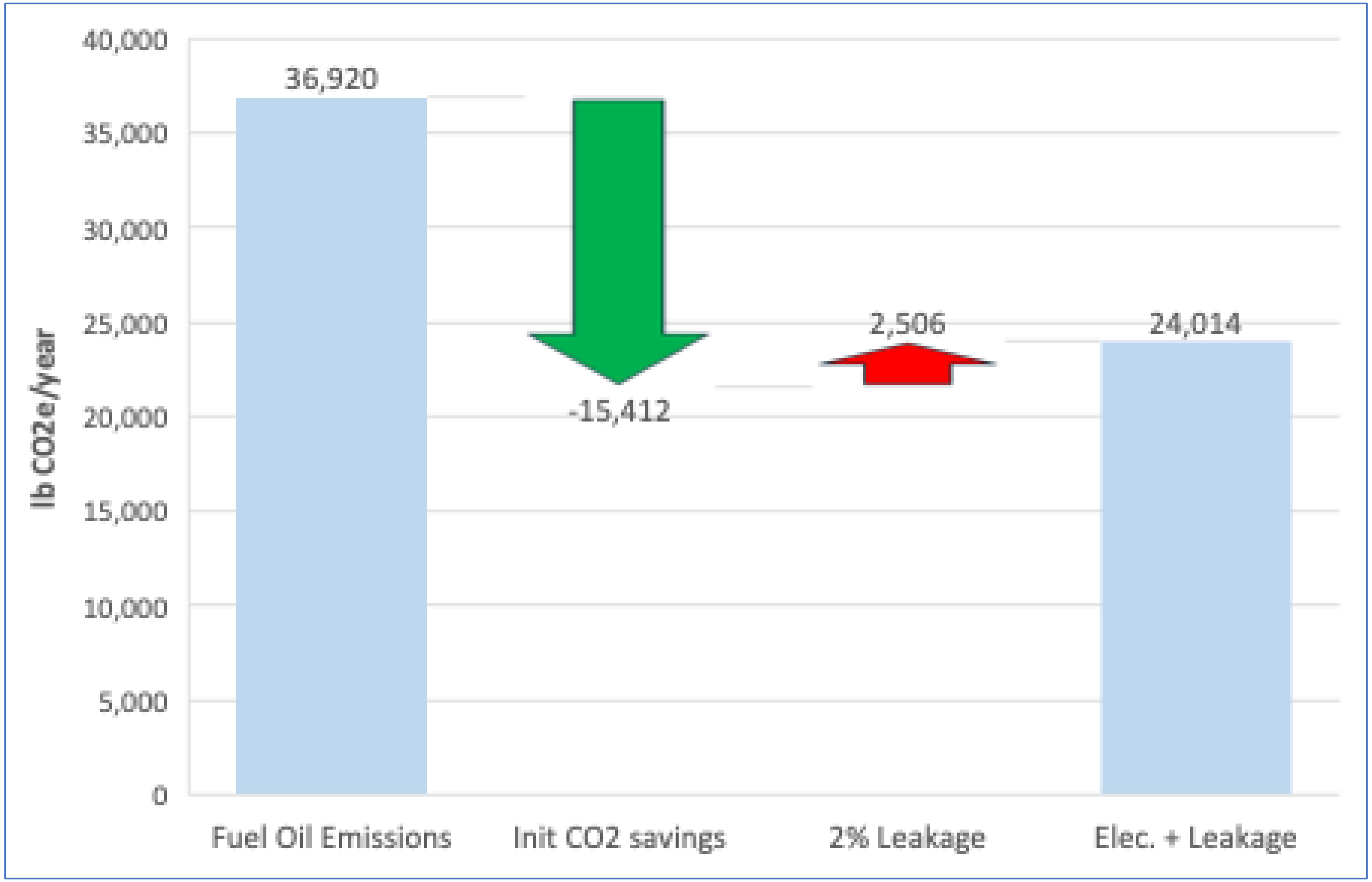


Measured COP at 5 Sites



Refrigerant Leakage





Hypothetical Carbon Balance—2% Leakage vs. Oil

Leakage Review of the 5 Sites

Site	Install year	Charge (lb.)/ # units	Leakage (lb.)	Leakage %	Evidence of Method	Notes
1	2012	150/ 3	65lb/yr	45%/ year	Service records, leak detector	Leaking Reflok fittings, an ongoing issue
2	2012	50/ 1	5 lb.	2.5%/ year	Service records	Multiple failing fan coil units. Length of leakage for replaced refrigerant assumed to be 4 years.
3	2020	336/ 3	No leakage	0%	Charge removal, subcooling	No leakage since installation in 2020
4	2021	130/ 2	30 lb.	0%	Charge weigh out/ in, sub cooling and other diagnostics	Physical damage to unit, no leakage for 1 year afterwards
5	2022	130/ 2			Not yet tested	System was installed new in 2022

Findings

- VRF are complex systems needing skilled support
- COPs vary across sites and outdoor temperatures, ranging from "expected" performance to under performance.
- Low heating COP correlated with very high over sizing, and high numbers of connected indoor units to outdoor unit.
- Onboard manufacturer DAS systems are evolving quickly and a promising method for cost effectively measuring performance
- Leakage in VRF appears to be limited, not common

Full Report Coming in Q1, 2025

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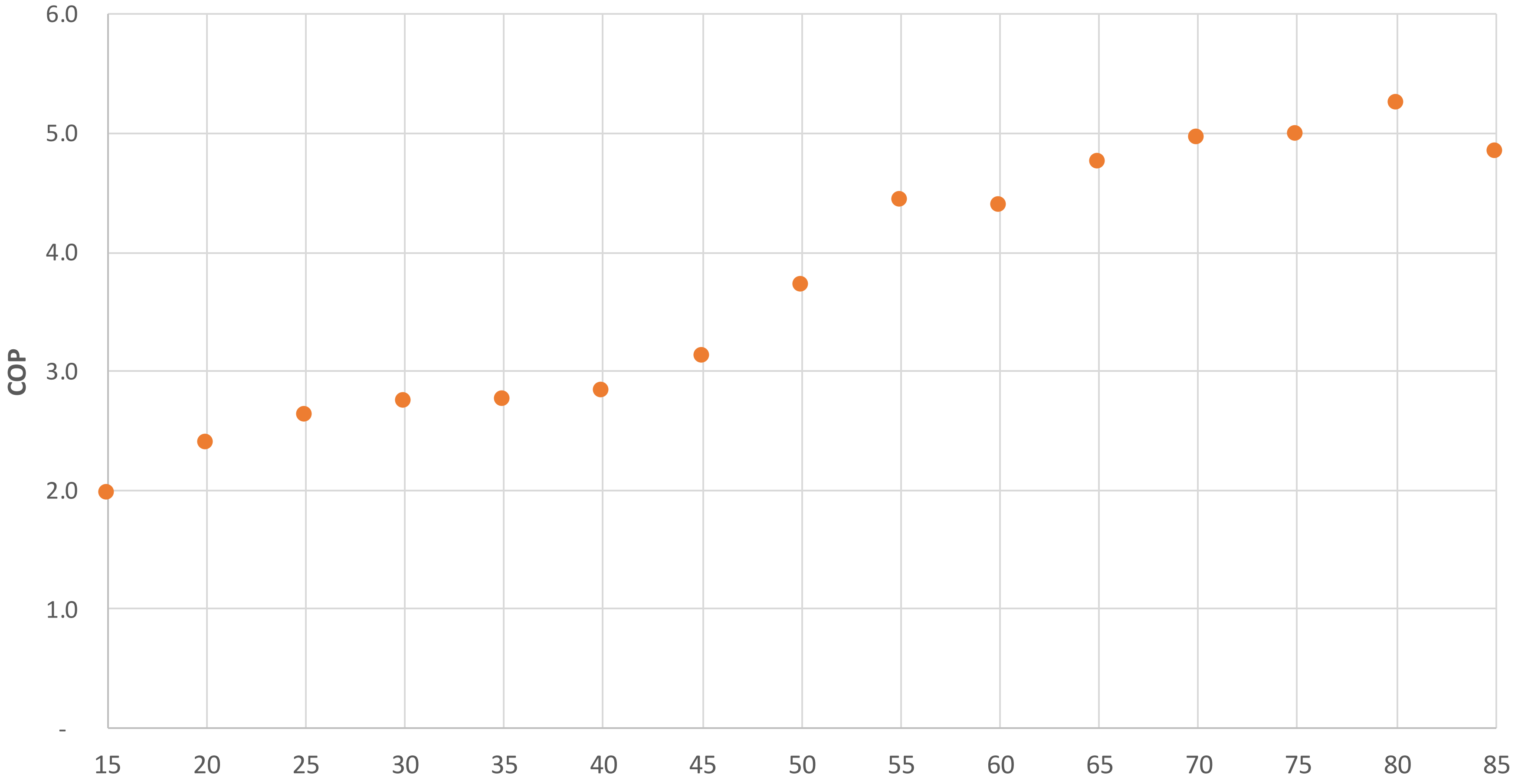
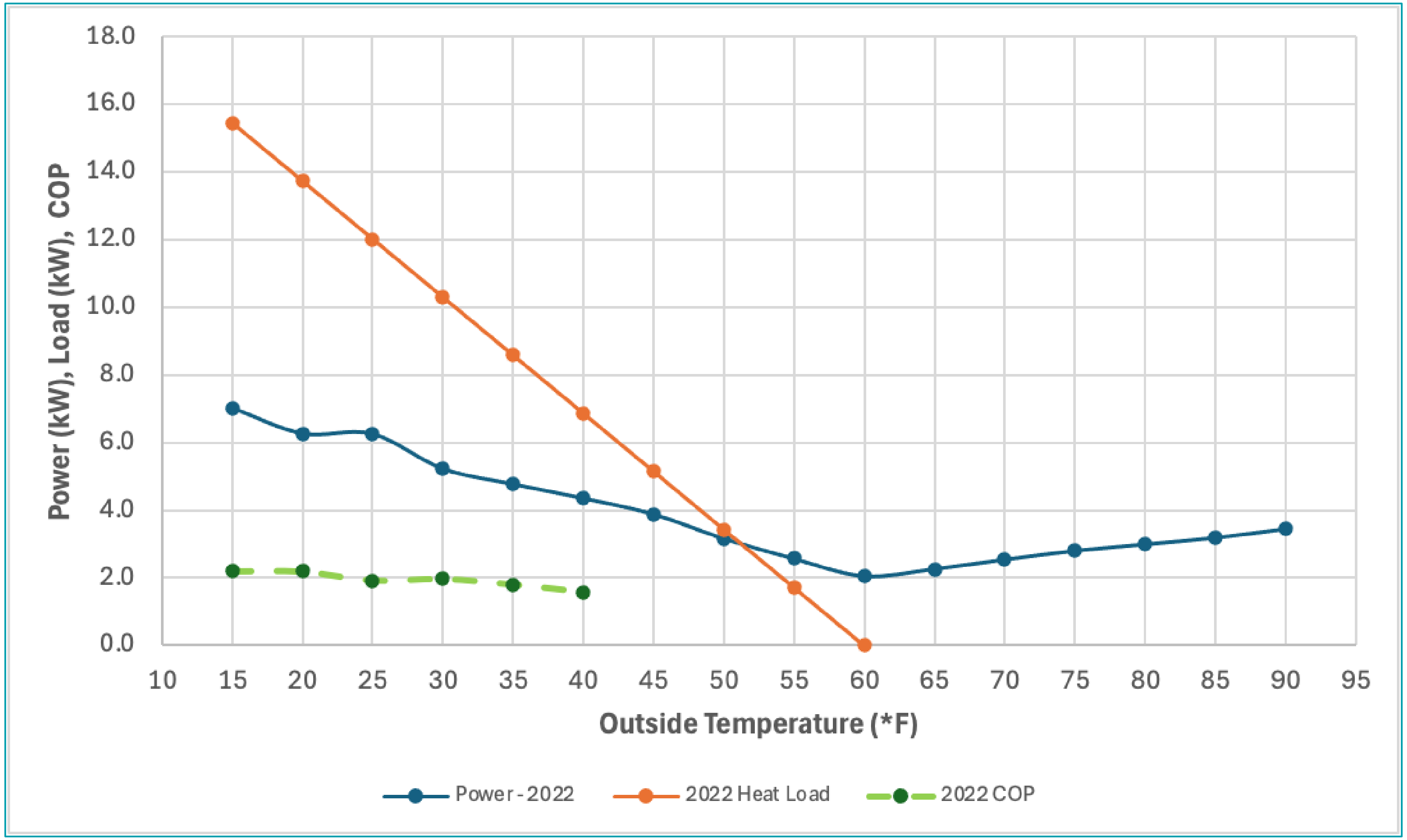
Site Details

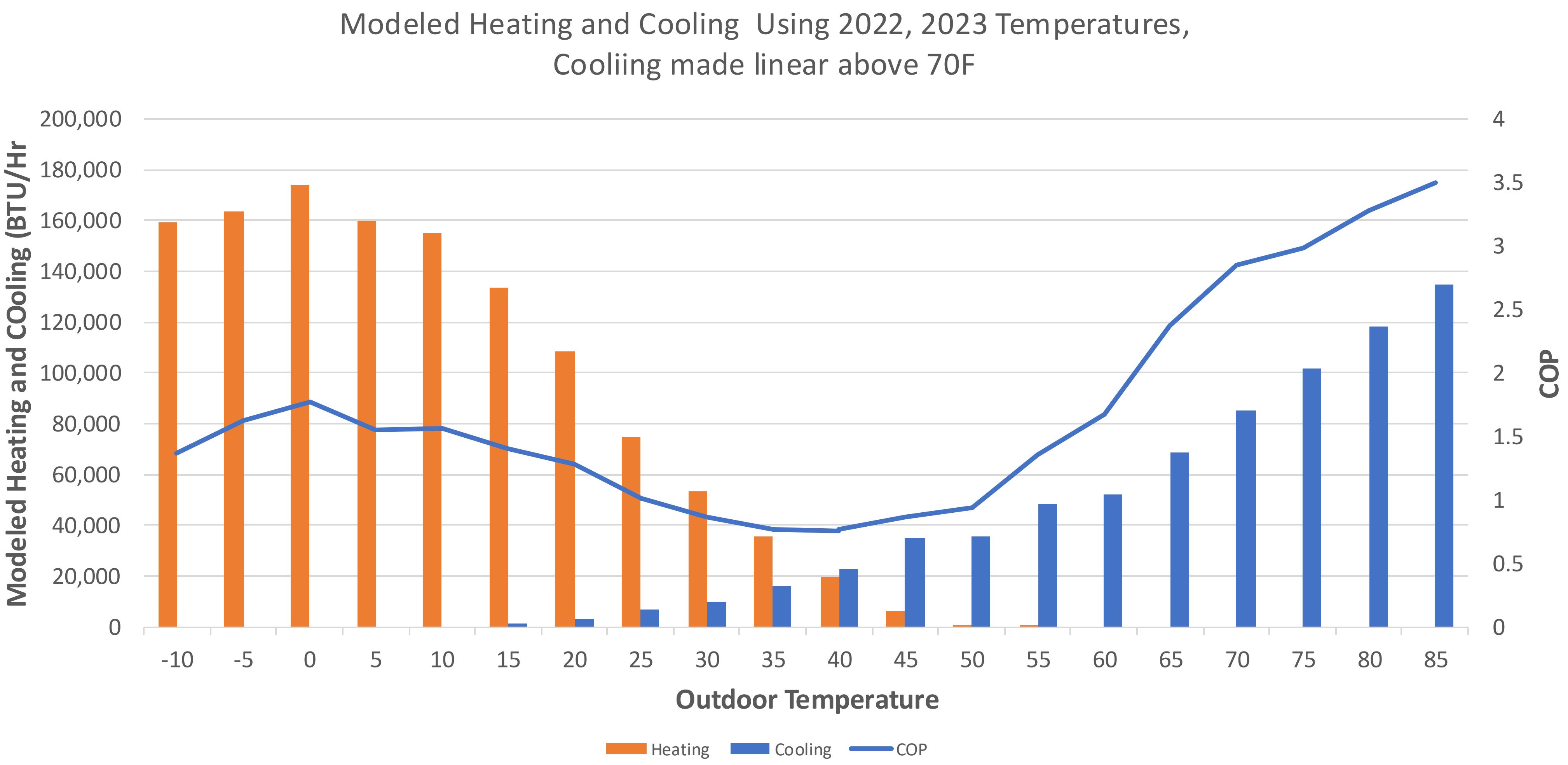
Site 1: COP Based on Indoor Enthalpy



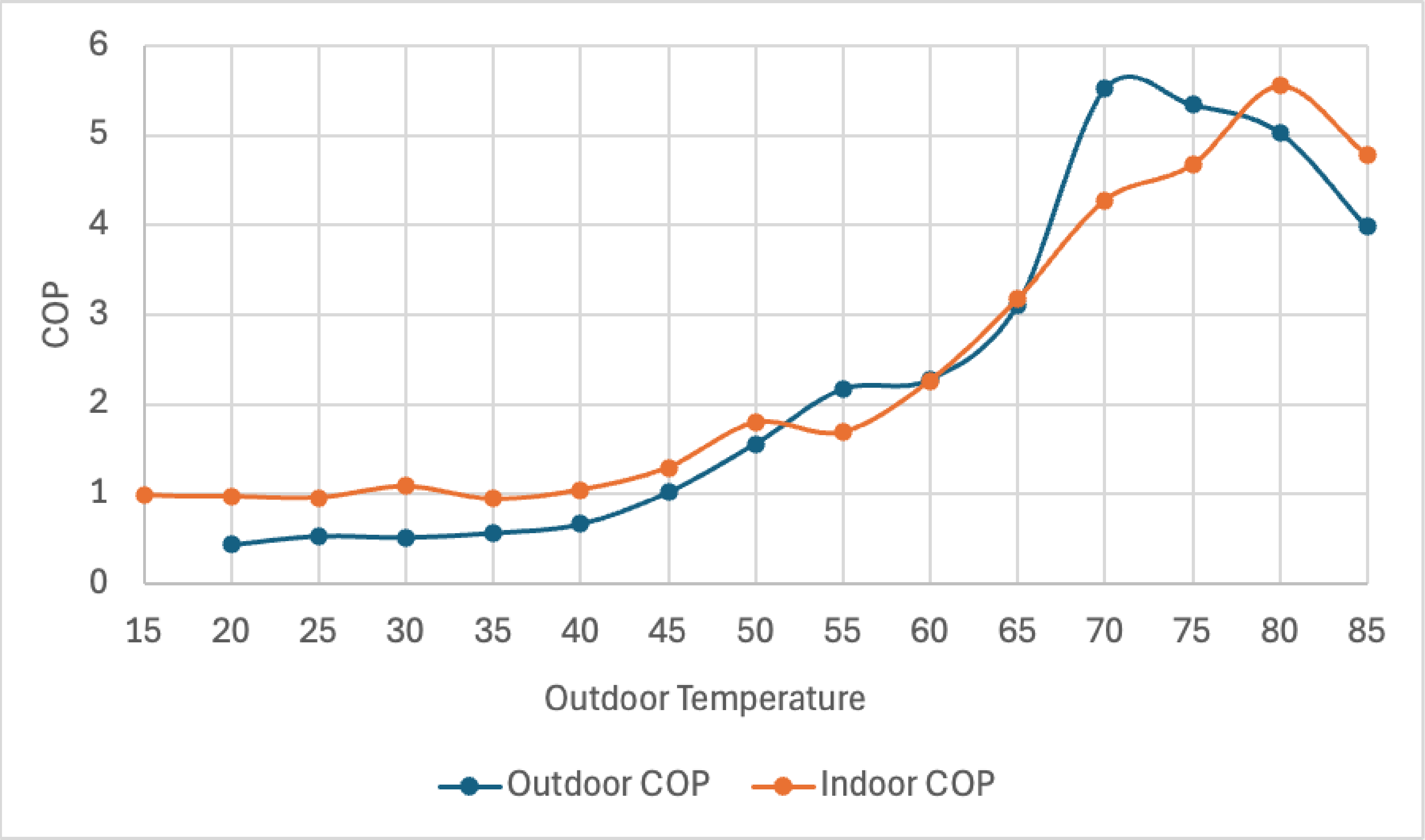
Site 1: COP Based on Power Metering



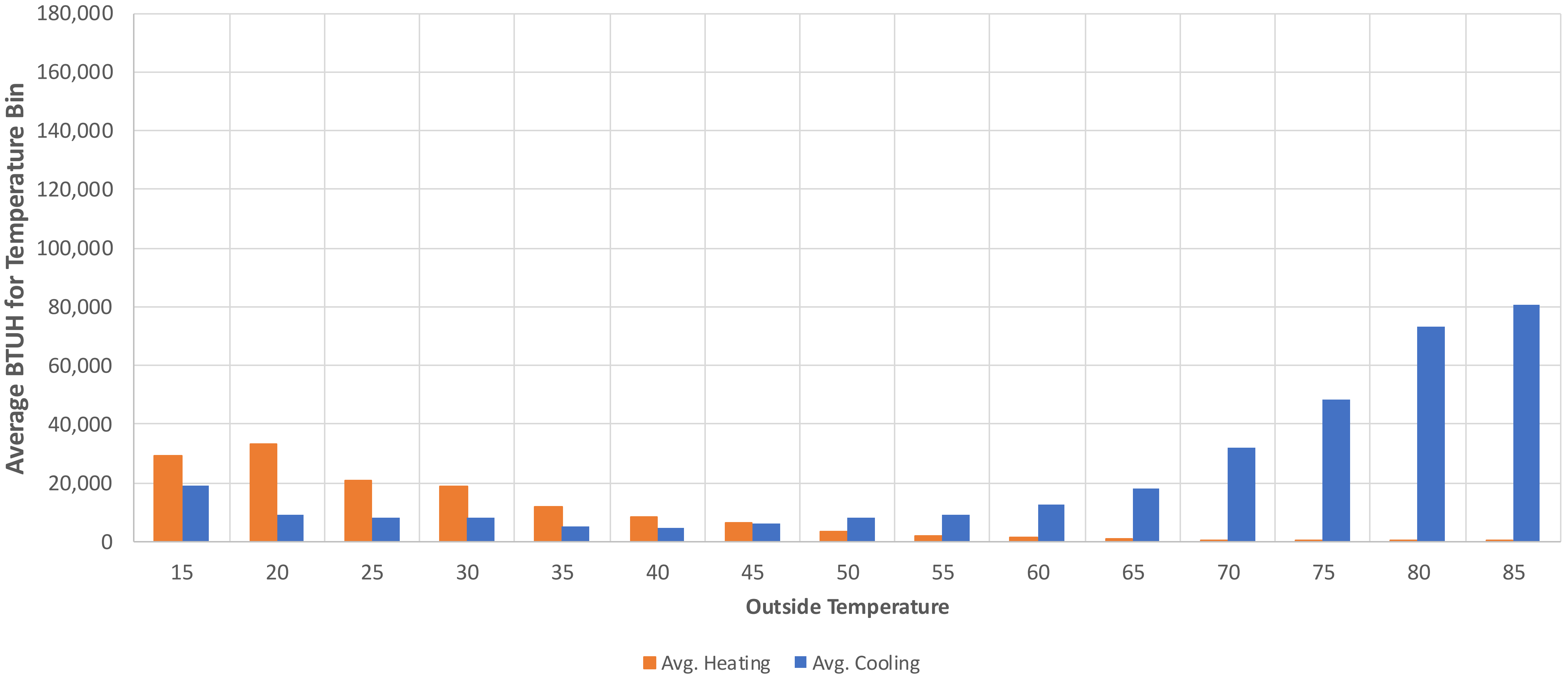
Site 3: COP Based on Modeling Shows Low Heating COP



Site 3: COP Based on Indoor/ Outdoor Enthalpy



Site 3: Heating Use at Very Low Capacity Due to PassivHaus Construction



Humidity and Variable Refrigerant Flow Operation in Multifamily Buildings

Published Report expected November 2024

Study Goals

Building America
U.S. DEPARTMENT OF ENERGY

- Explore **humidity** in new **VRF multifamily buildings**
  - Passive House (PH) and non-Passive House
  - Key drivers
  - Is it too high?
- Impact of **sizing**
- **Energy consumption difference** across PH and non-PH buildings
- Evaluate overall **efficiency** of VRF systems
  - Key drivers

Buildings Monitored

Building A

Passive House,
Affordable

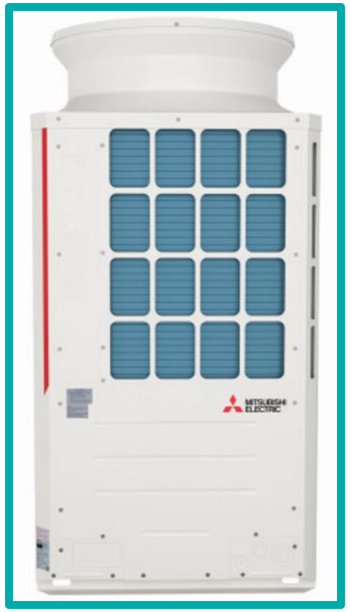
Building C

LEED NC,
Market Rate

Data Collection (7/1/2023 – 3/31/2024)

Thermostat with Humidity

Temperature and Humidity Sensor



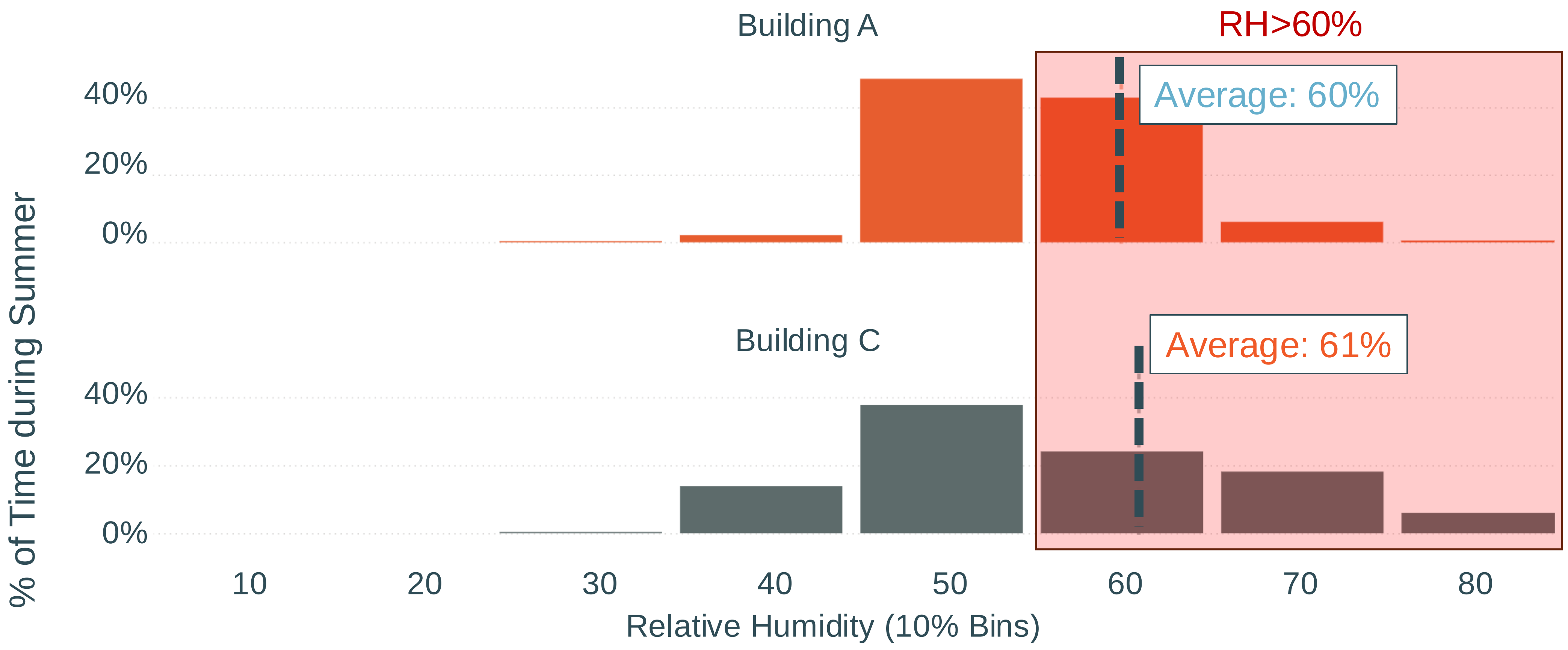
Heat Pump

Energy Recovery Ventilator (ERV)

Humidity Results

Research Question

How often was apartment humidity above 60% **in the summer**?



Research Question

How often was apartment humidity above 60% **in the summer**?

Building A:

43%

of Summer Hours above 60% RH

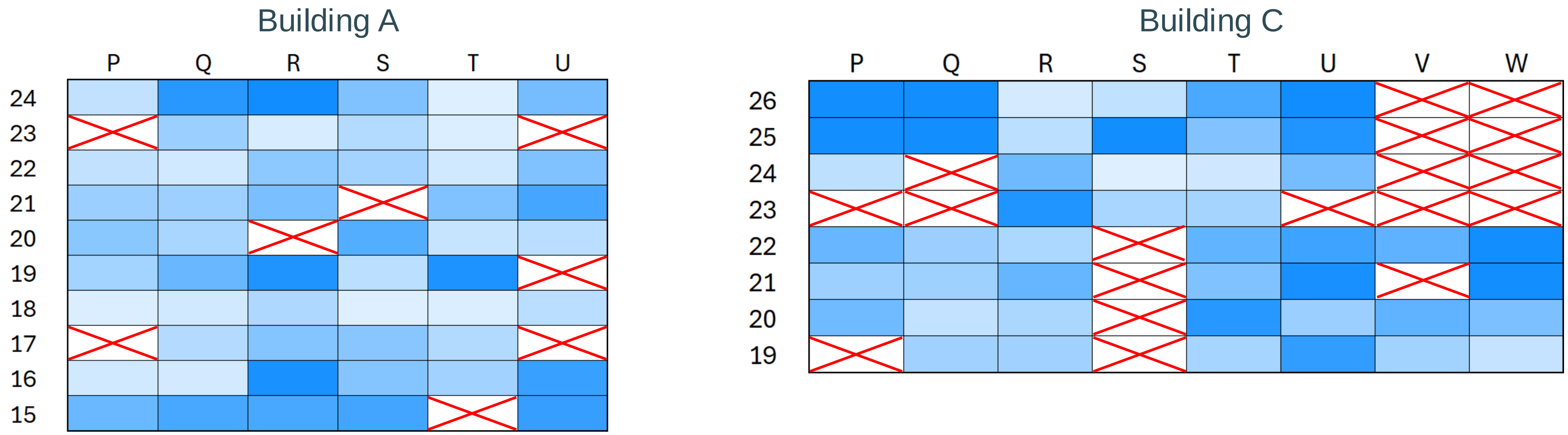
Building C:

44%

of Summer Hours above 60% RH

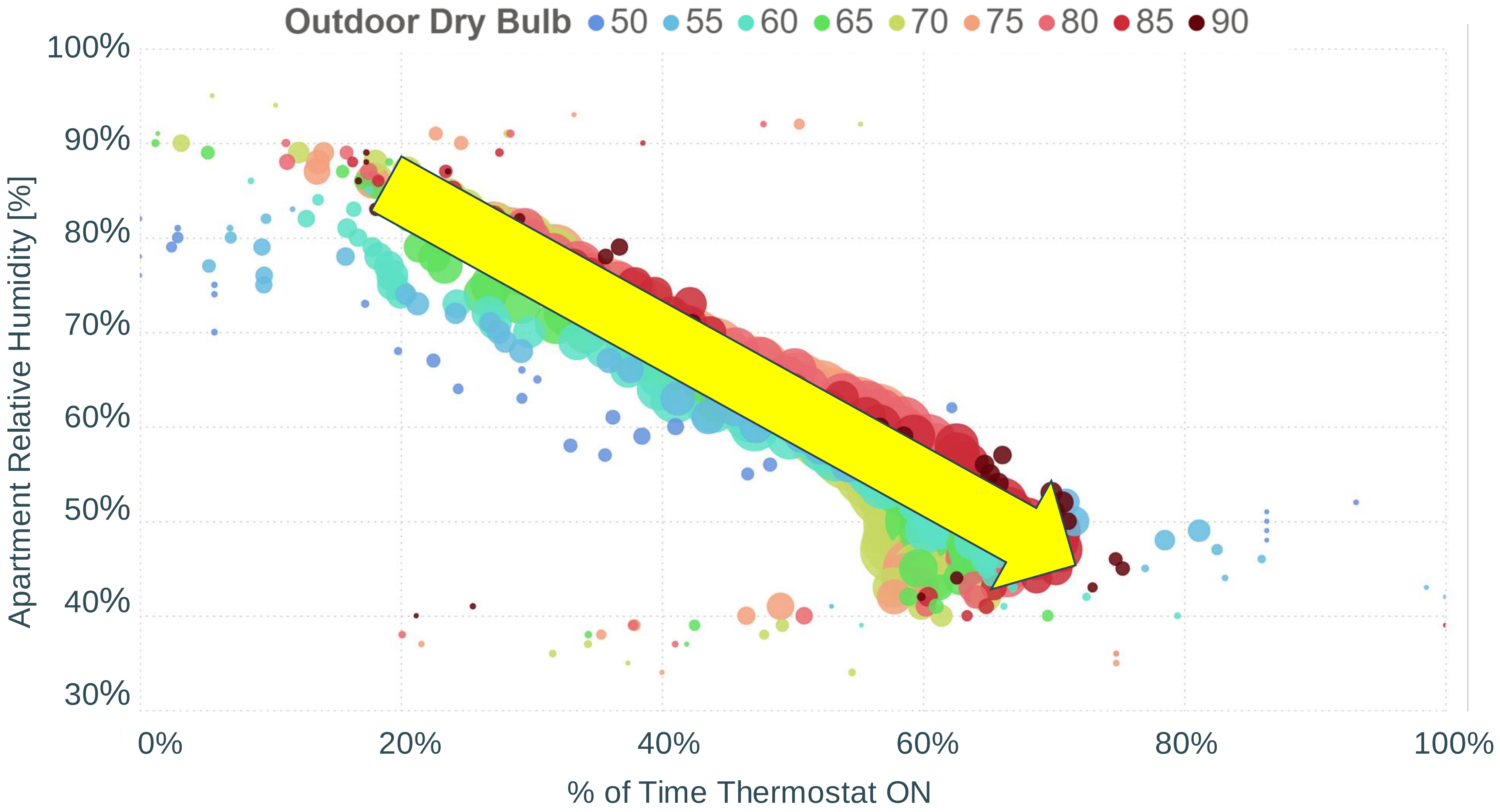
Occupant Behavior - Thermostat Use

Summer Cooling



Legend: Thermostat always ON | Thermostat never ON | Unoccupied

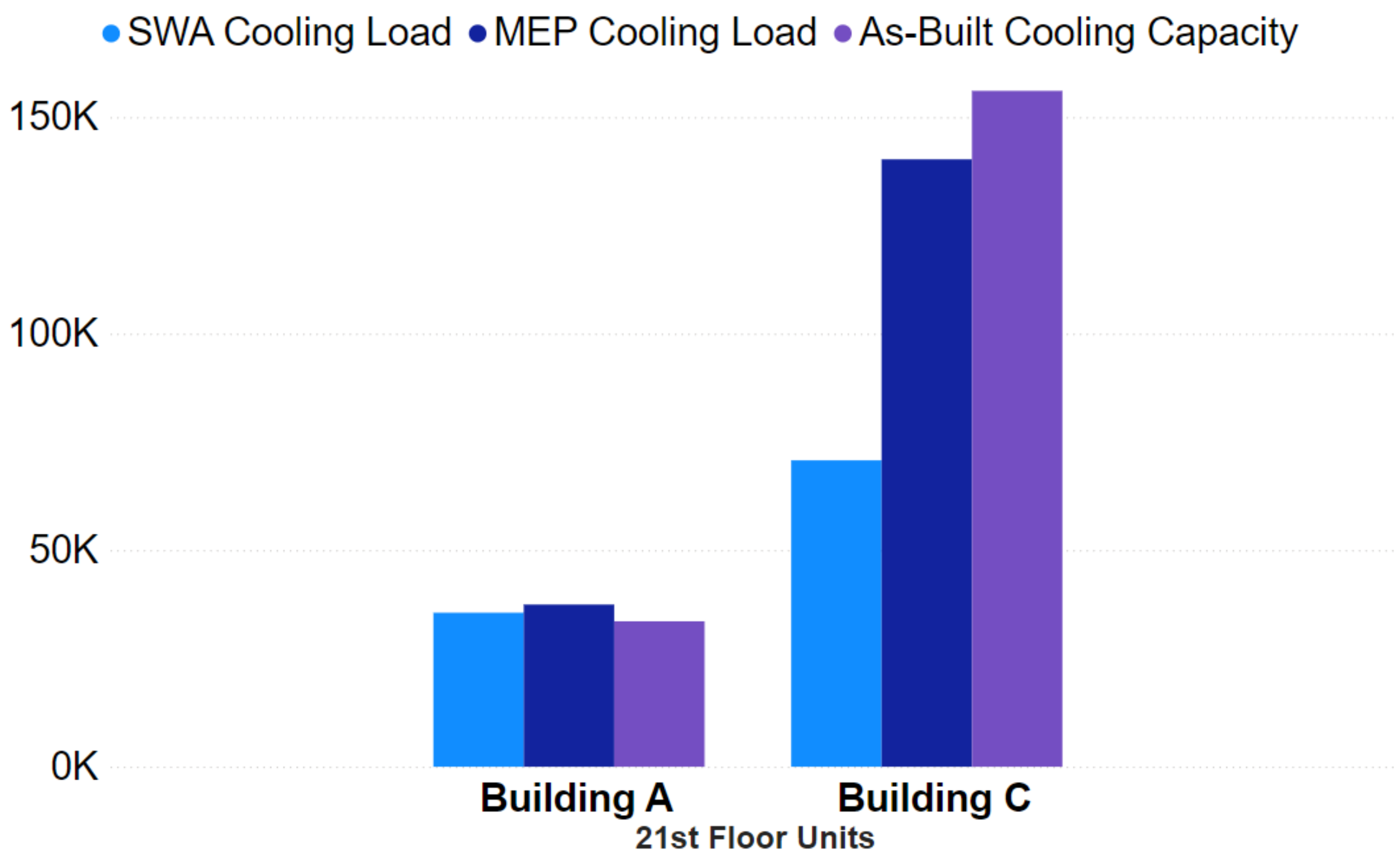
Importance of Thermostat On: **Building C**



Sizing and Efficiency

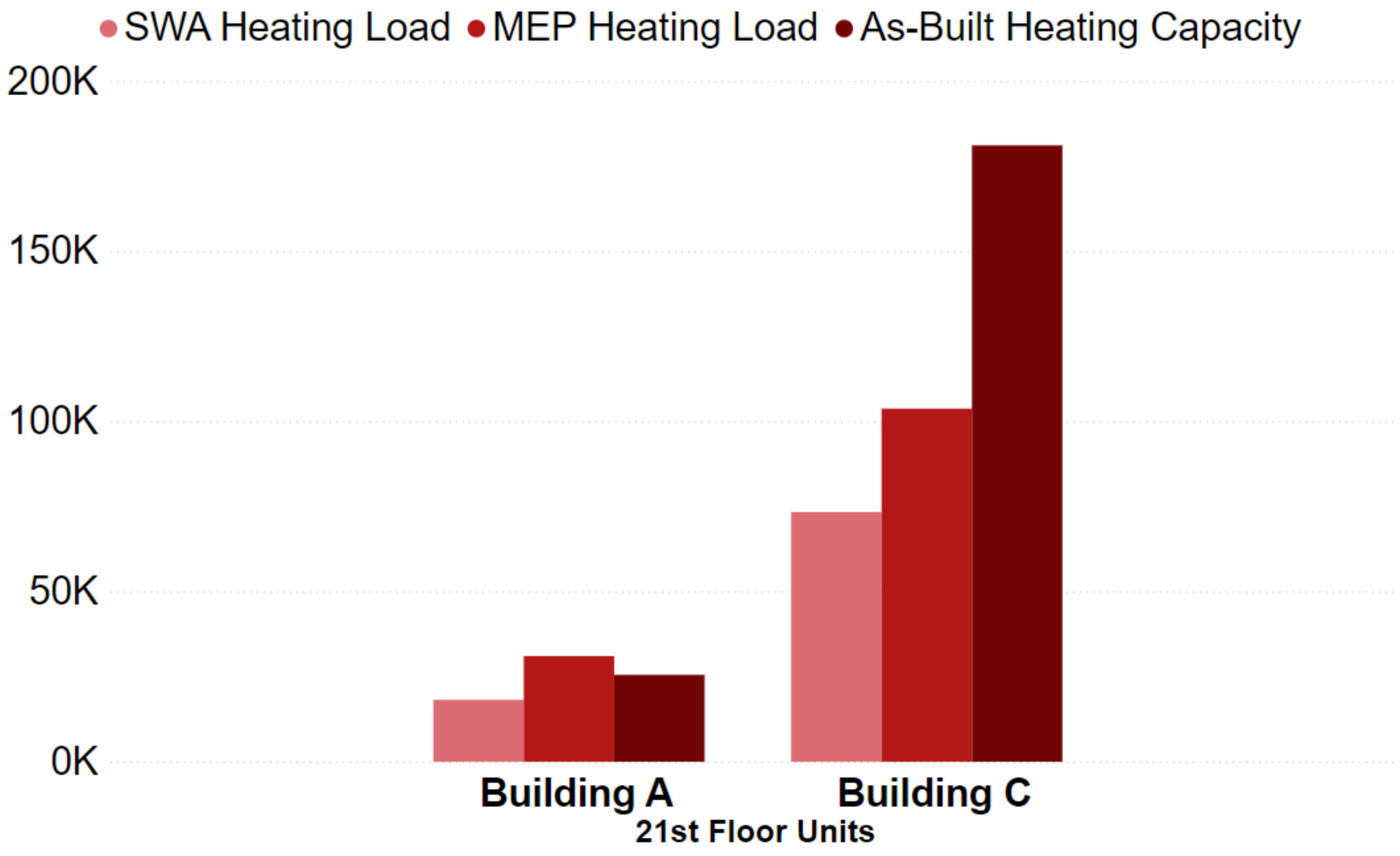
Sizing – Cooling

- SWA calculated loads for both buildings using consistent methodology
- Building A units are sized in line with or below SWA loads
- Building C is oversized

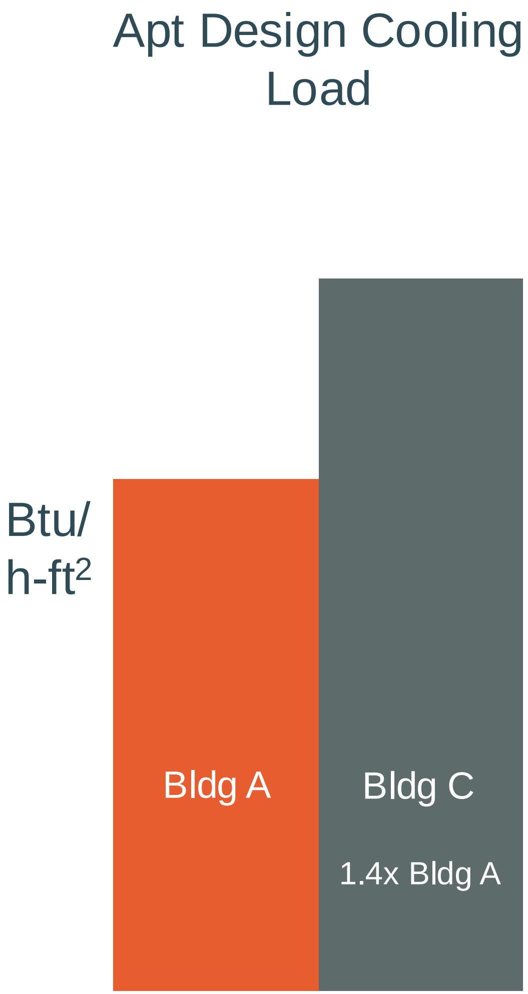


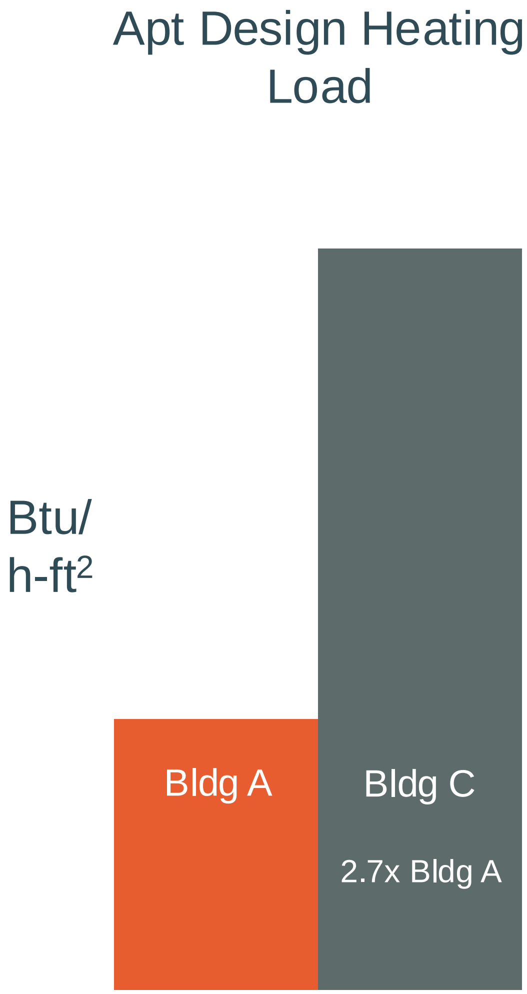
Sizing – Heating

- Same load calc process followed
- Building A is more right-sized
  - Custom implementation of software

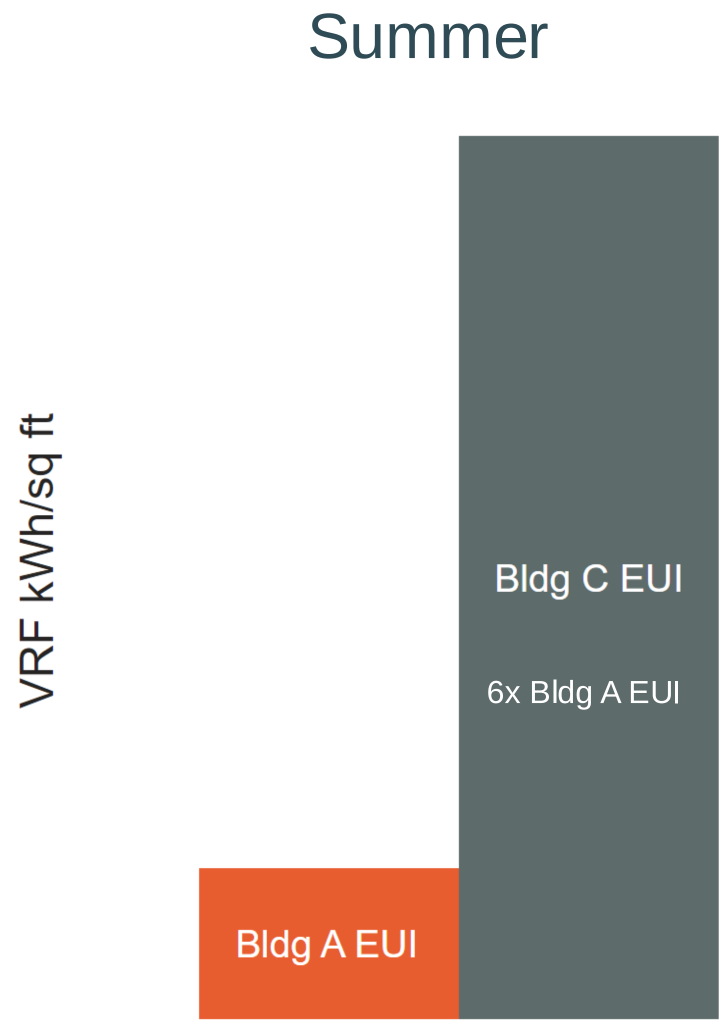


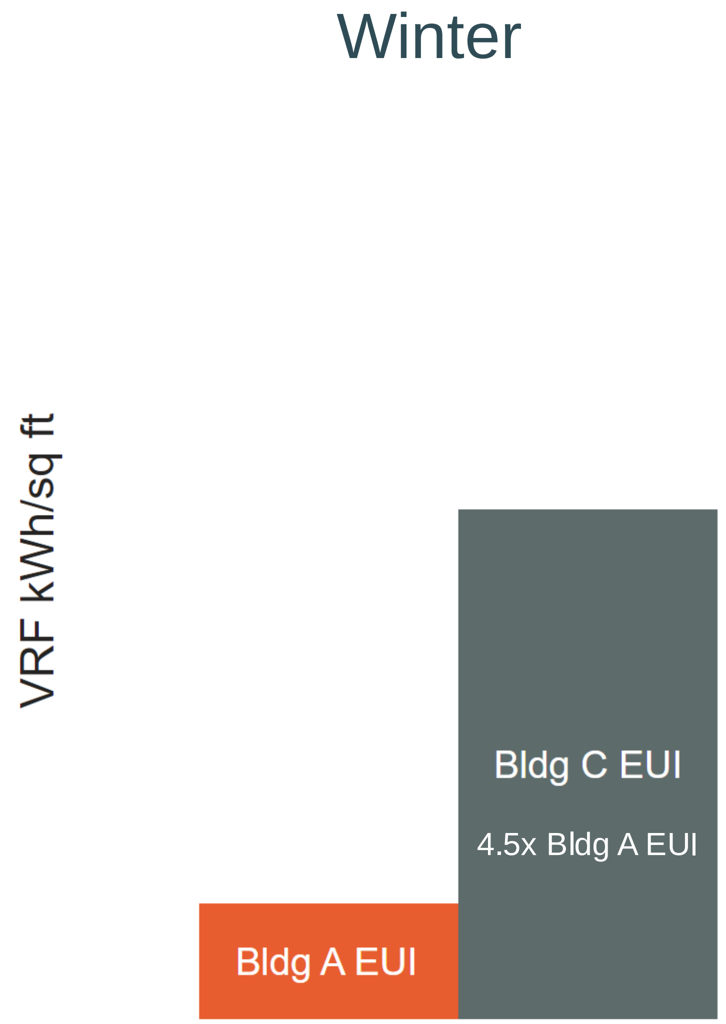
Load Comparisons





EUI – Overall


Summer
VRF kWh/sq ft
Bldg A EUI
Bldg C EUI
6x Bldg A EUI


Winter
VRF kWh/sq ft
Bldg A EUI
Bldg C EUI
4.5x Bldg A EUI

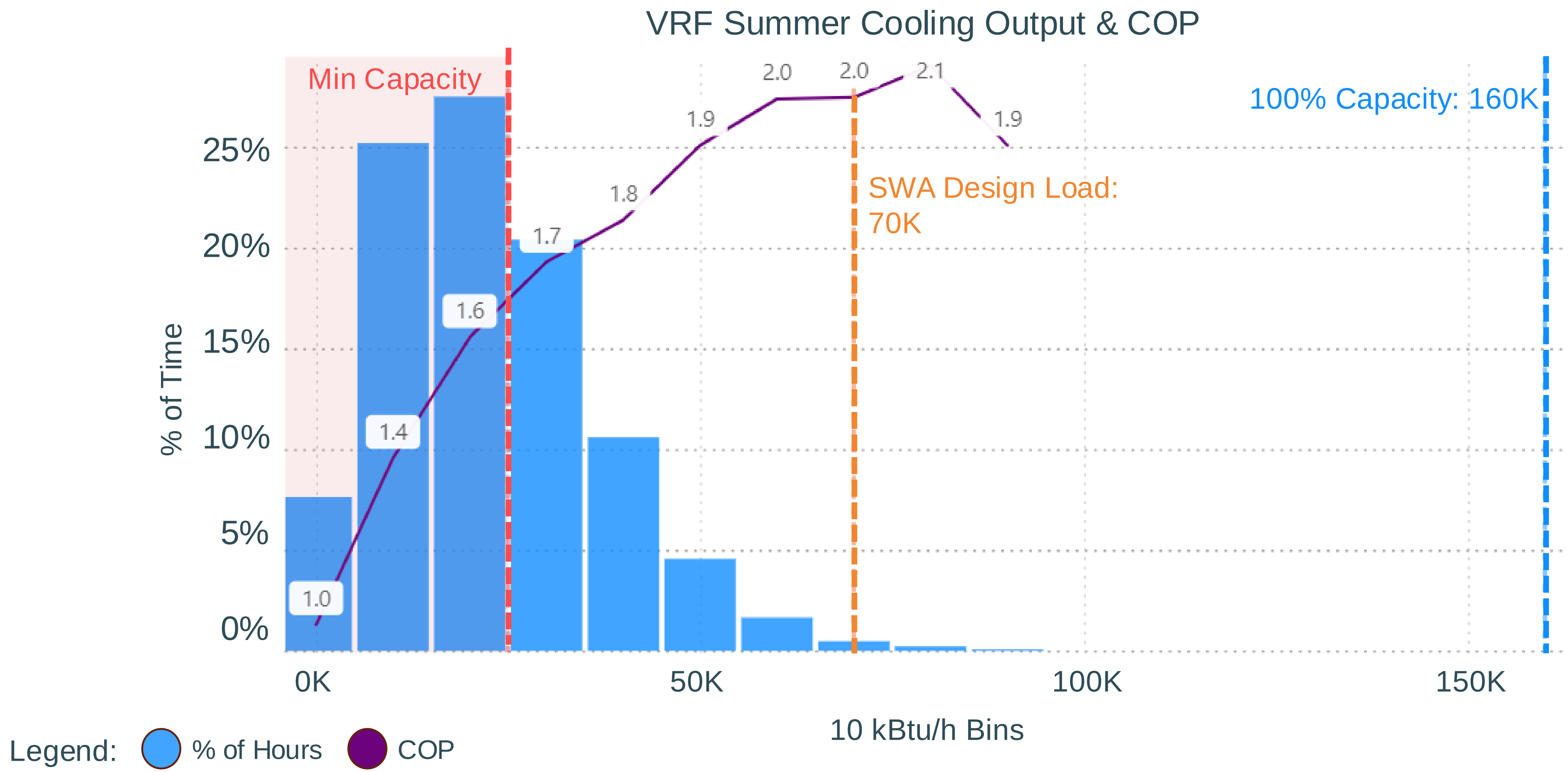
COP Results

Measured COP (Efficiency) – Bldg C

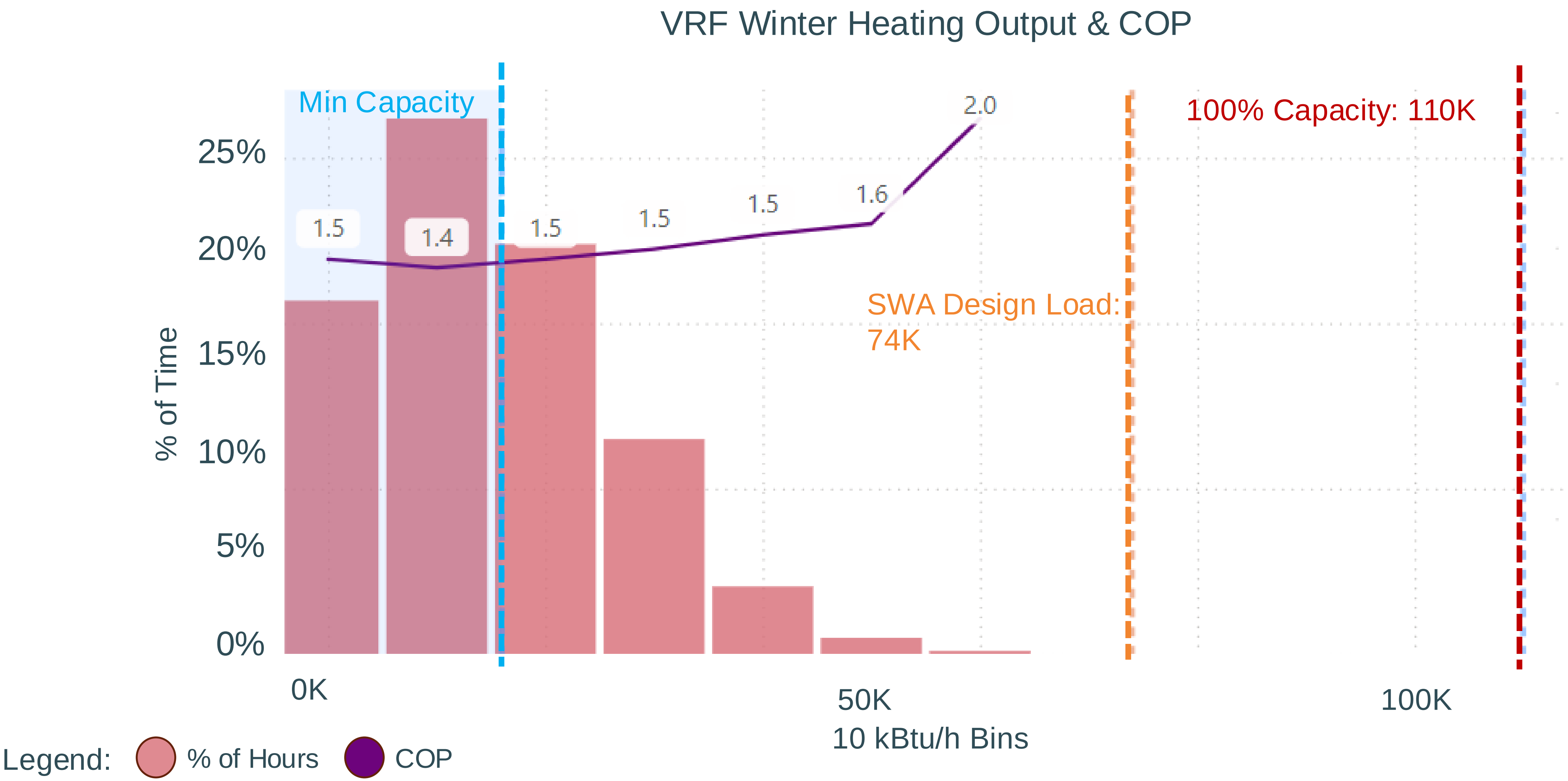
Average	Summer	Fall	Winter
1.6	1.8	1.0	1.5

- Rated COP: ~3.3

Oversized = Low COP (Efficiency)



Oversized = Low COP (Efficiency) Heating



Heat Recovery Energy Penalty (ODU)

- There are four ODU operating modes
  - Cooling Only
  - Cooling Main – Lowest COP
  - Heating Main – Lowest COP
  - Heating Only
- Penalty to efficiency
  - When heat recovery is active, COP decreases by 20-30%

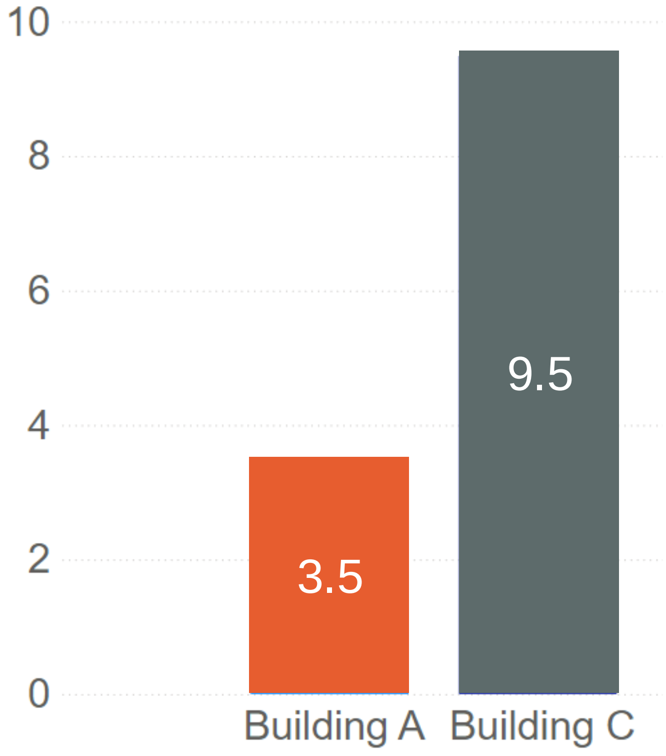
Measured COP (Efficiency) – Bldg C

Average

1.6

- Rated COP: ~3.3
- Potential causes
  - Thermostats off
  - Oversizing
    - Load below min capacity
    - Increased cycling
  - Heat recovery energy penalty

Average Cycles per Indoor Unit per Day (Summer)



Conclusions

Rightsizing Benefits/Risks

- Benefits
  - Improved efficiency
    - Operation above min capacity
    - Less cycling
- Risks
  - Resiliency
    - Is sizing appropriate for a warmer world?
  - Comfort

Recommendations

- Consider other heat pump technologies (WSHP, PTHPs, Unitized ASHPs)
  - Efficiently accommodate diverse load profiles
  - Low load operation
- Tenant Education
- Buildings take responsibility for cooling
  - Passive house = tighter buildings = extended cooling period

Thanks! Questions?

Aldrich, Robb, Kevin McDonald, Dylan Martello, Neale Misquitta, Eleanor Fulkerson, and Shari Rauls. 2024. *Humidity and Variable Refrigerant Flow Operation in Multifamily Buildings.* Steven Winter Associates for the U.S. Department of Energy's Building America Program.