Tierra Linda Monitoring Project

Preliminary findings from first heating season

08/23/19

slipstream

Background

Two new, 6-unit properties developed by LUCHA

Both certified under the ComEd Affordable Housing New Construction Program.

Same layout, same orientation, same location.

Constructed to two different energy efficiency standards

ENERGY STAR

Passive House Institute US (PHIUS+)

How do they compare?

Energy performance

Construction and operating costs

Indoor air quality (IAQ)

Photo credit: LUCHA

Purpose of this report

- Share interim analysis results from the first heating season
- Provide a basis for stakeholder-guided identification of issues and analyses to be explored in more detail for first- and second-year reports
- Provide a basis for stakeholder discussion of how results relate to prior design decisions for the properties (to provide appropriate context for final report)

Note: results provided here are preliminary and subject to revision pending additional analysis

Comparison of key property features

Feature	ENERGY STAR property	PHIUS+ property
Measured air leakage (ACH50)	1.90	0.52
Ceiling insulation	R-50	R-60
Wall insulation	R-14.5 assembly	R-29.4 assembly
Windows	Triple-pane U-value: 0.26 – 0.29 SHGC: 0.28 – 0.33	Triple-pane U-value: 0.15 – 0.17 SHGC: 0.31 – 0.37
Heating	High efficiency gas furnace	Variable-speed ducted heat pump
Cooling	SEER 16 central A/C	
Ventilation	Continuous bath exhaust (~40 cfm)	Energy recovery ventilator (~100 cfm)
Domestic hot water	Power-vented, 40-gal. gas water heater	
Cooking	Gas range w/ vented exhaust	Gas range w/ unvented exhaust (but ERV exhaust pickup in kitchen)
Laundry	Vented dryer w/ booster fan	Unvented compact dryer

Monitoring parameters

Electrical

1-second power draw for entire unit and for key circuits:

- heat pump / A/C compressor
- furnace / air handler
- water heater
- ERV
- kitchen range/oven
- clothes washer/dryer
- bath exhaust fan and clothes dryer booster fan

HVAC-related

1-second data for:

- system airflow
- supply/return temperature and humidity
- ERV pressure drops and temperature/humidity
- furnace gas-valve status
- heat pump refrigerant-line temperature

IAQ

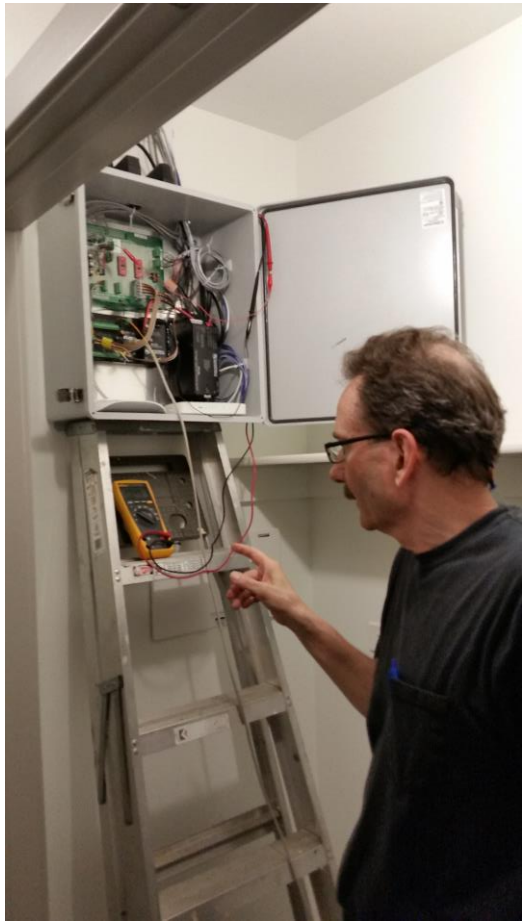
1-minute data for:

- indoor temperature/humidity
- CO2 (3 locations)
- PM2.5 and PM10
- total VOCs

Outdoor

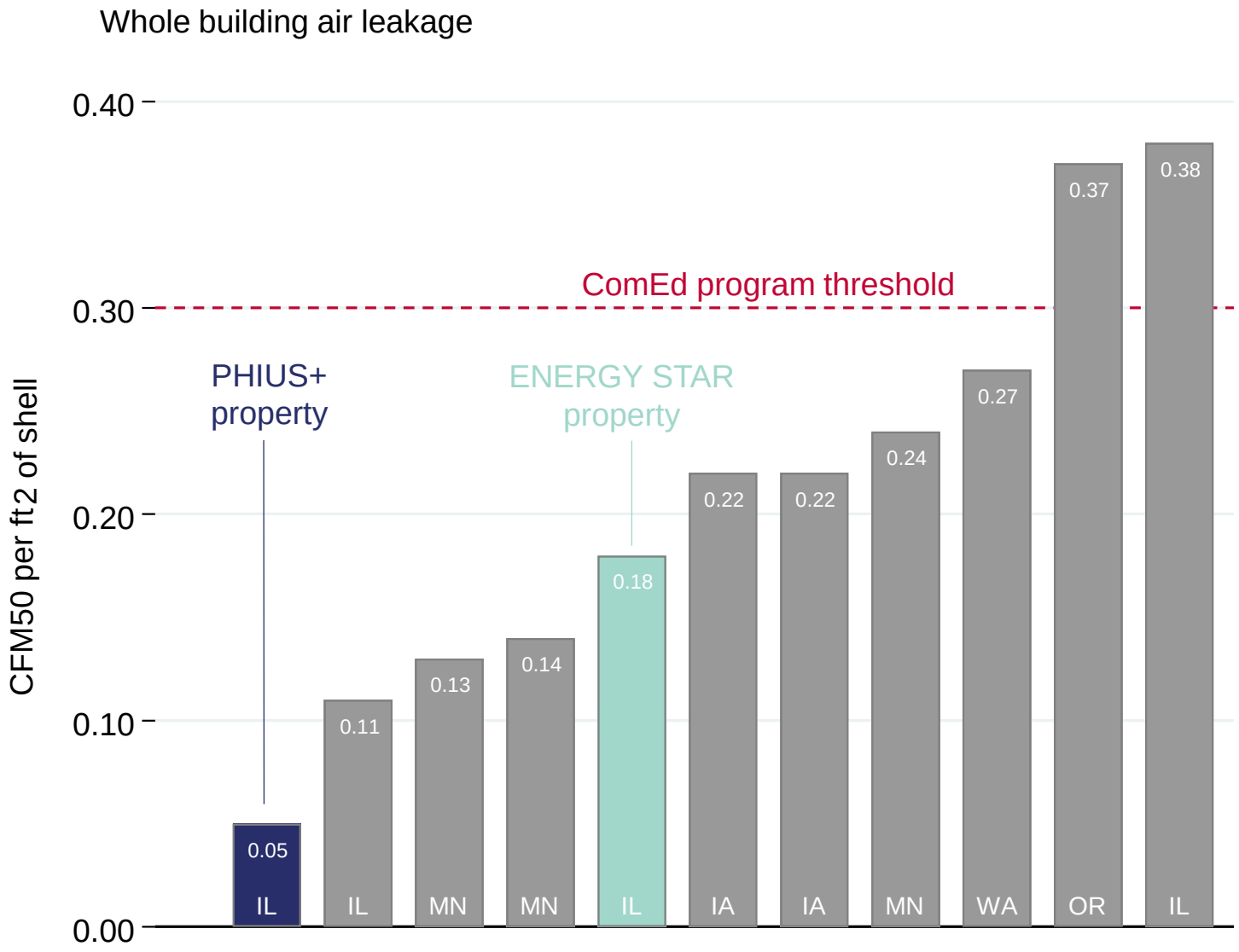
1-minute data for:

- temperature/humidity
- solar
- barometric pressure
- windspeed and direction
- IAQ parameters above



Air-leakage testing: the PHIUS+ property is very tight relative to similar low-rise multifamily properties

- Under standard air-leakage test conditions, the PHIUS+ property has 73% less air leakage than the ENERGY STAR property and 83% less than the maximum threshold for air leakage under the ComEd program.



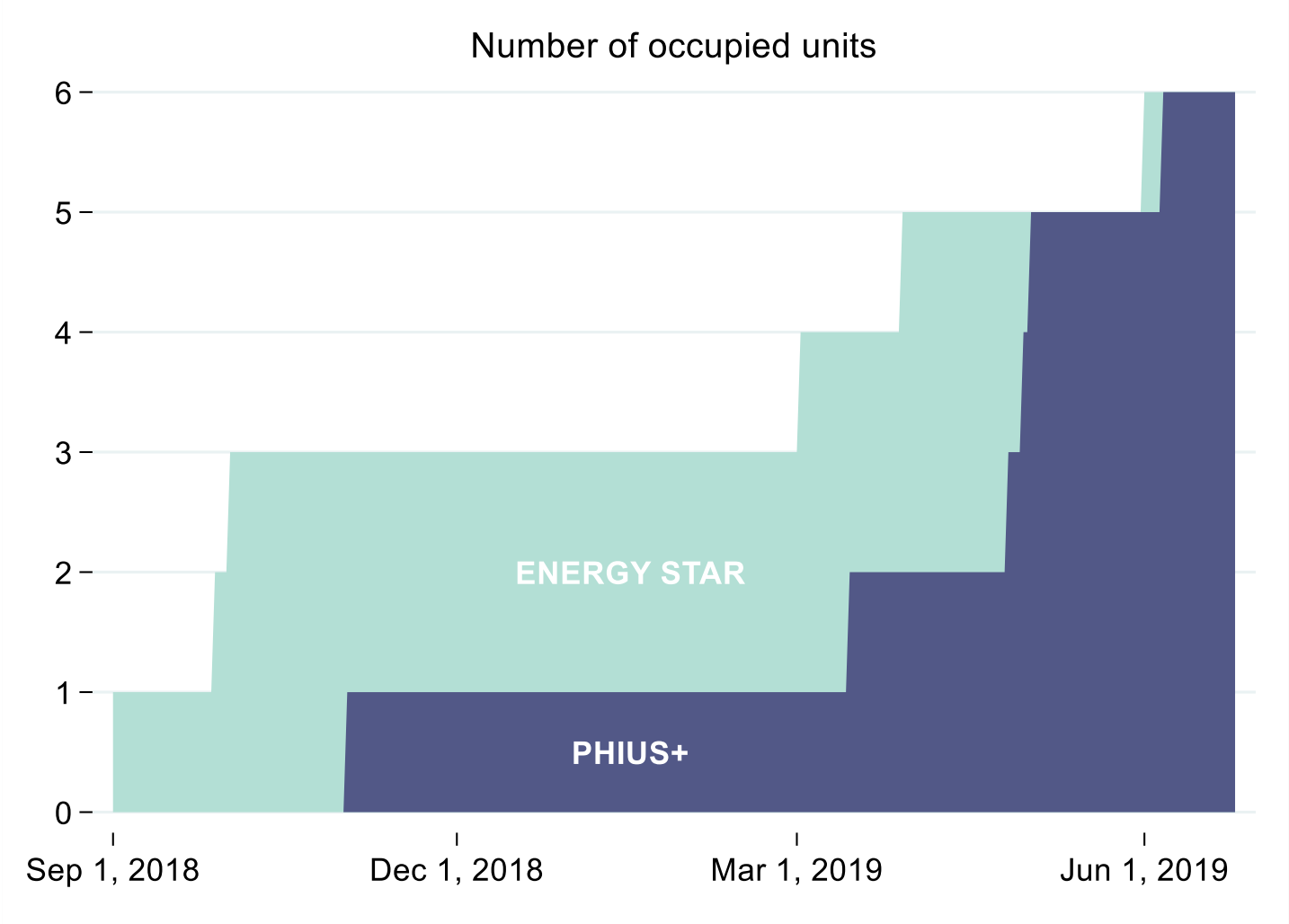
Source: preliminary data from DOE Low-Rise Multifamily Code Compliance Study

Analysis and interpretation of data from the first heating season is complicated by the fact that the properties were not fully occupied

- Construction and occupancy of the PHIUS+ property lagged behind the ENERGY STAR property. This has implications for:

- indoor temperature differences between properties (see next slide)

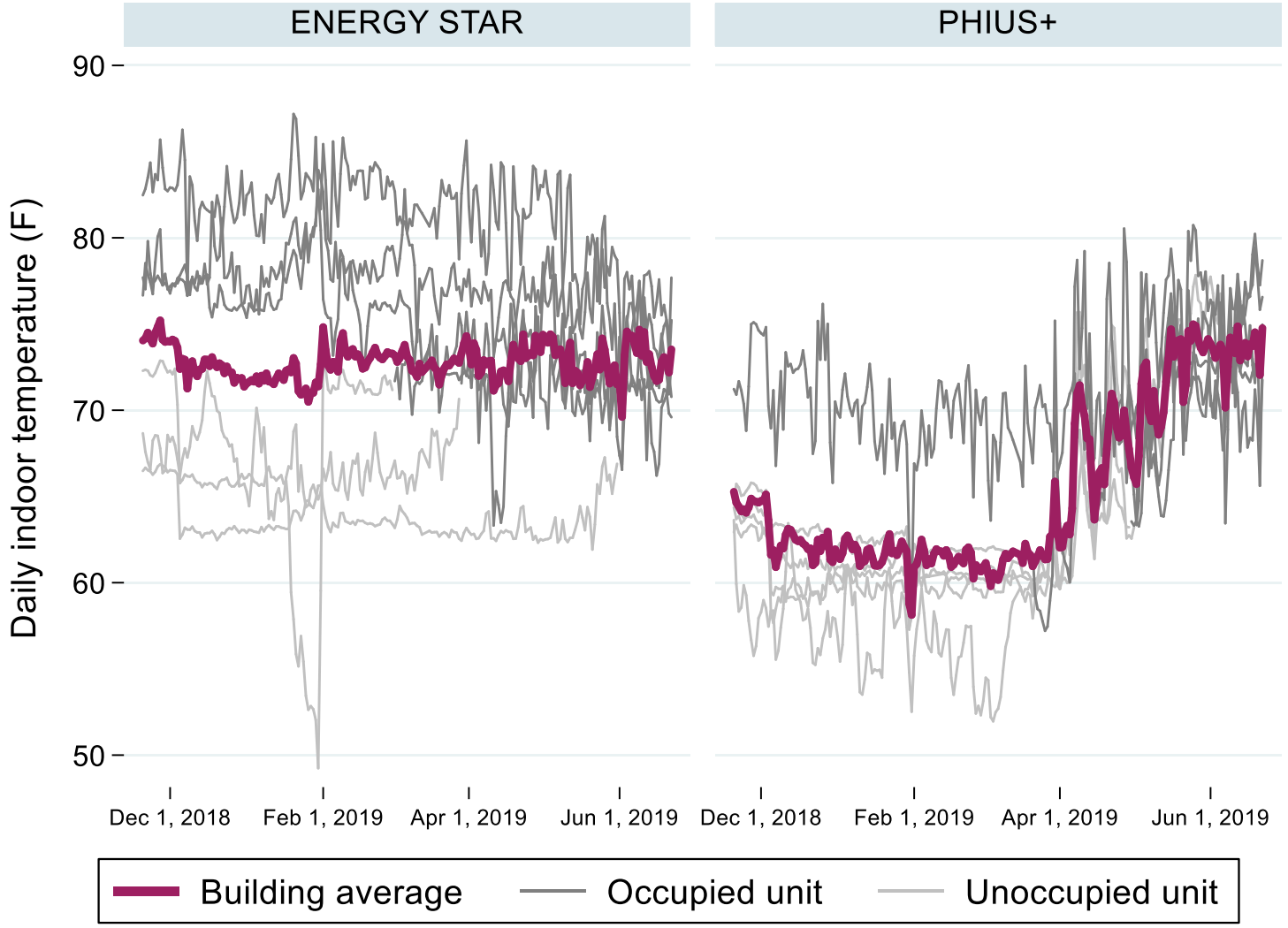
- the ability to analyze IAQ during first heating season



The ENERGY STAR property had higher indoor temperatures during the heating season

- Higher setpoints and higher occupancy meant the ENERGY STAR property averaged 8-14F higher indoor temperature during most of the heating season.
- We therefore analyzed energy performance as a function of indoor-outdoor temperature difference, and then normalized both buildings to an assumed common indoor temperature.

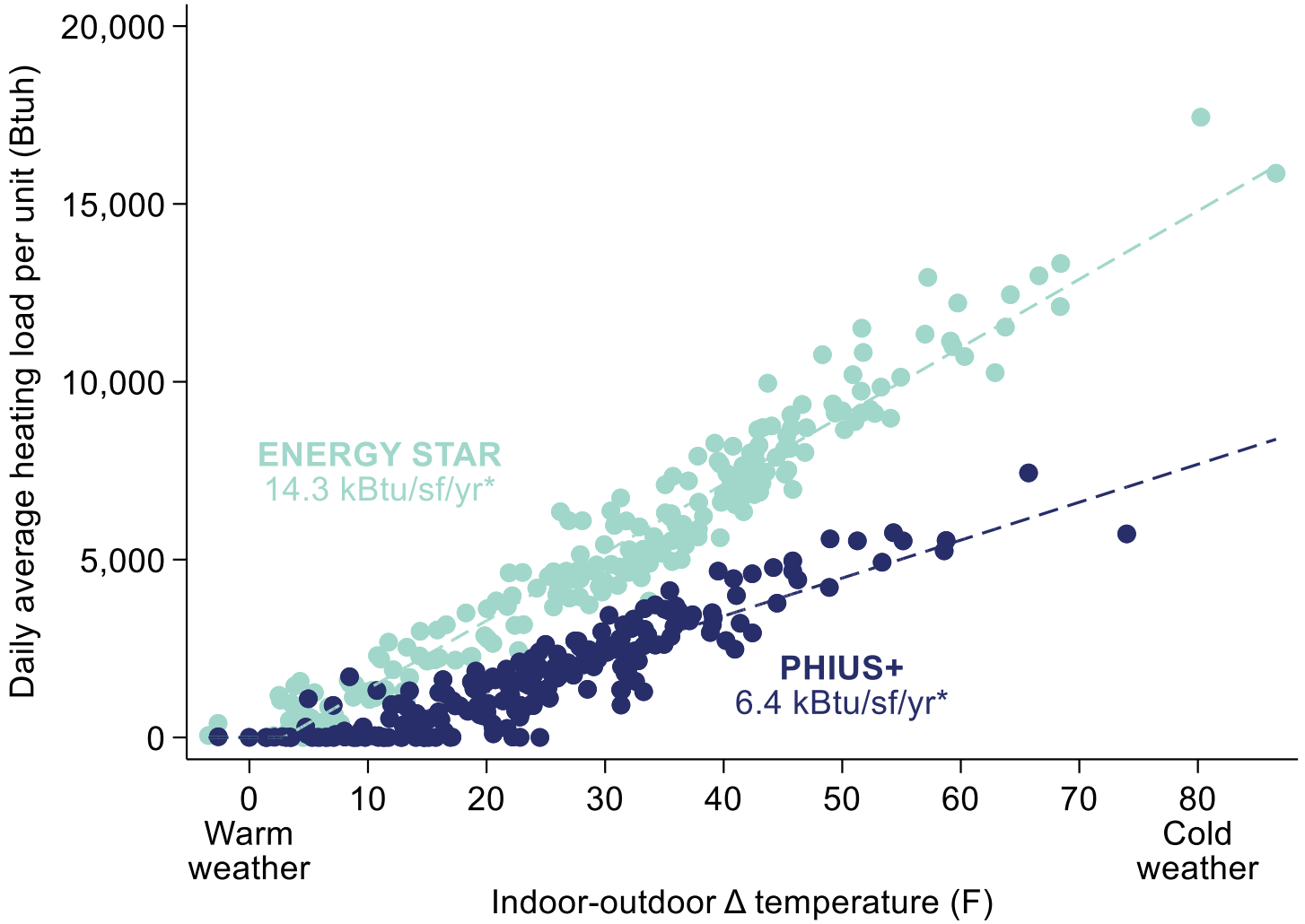
Note: indoor temperature is measured about 1 foot below the ceiling, so is likely higher than temperature at thermostat level



The seasonal heating requirement for the PHIUS+ property appears to be about half that of ENERGY STAR property

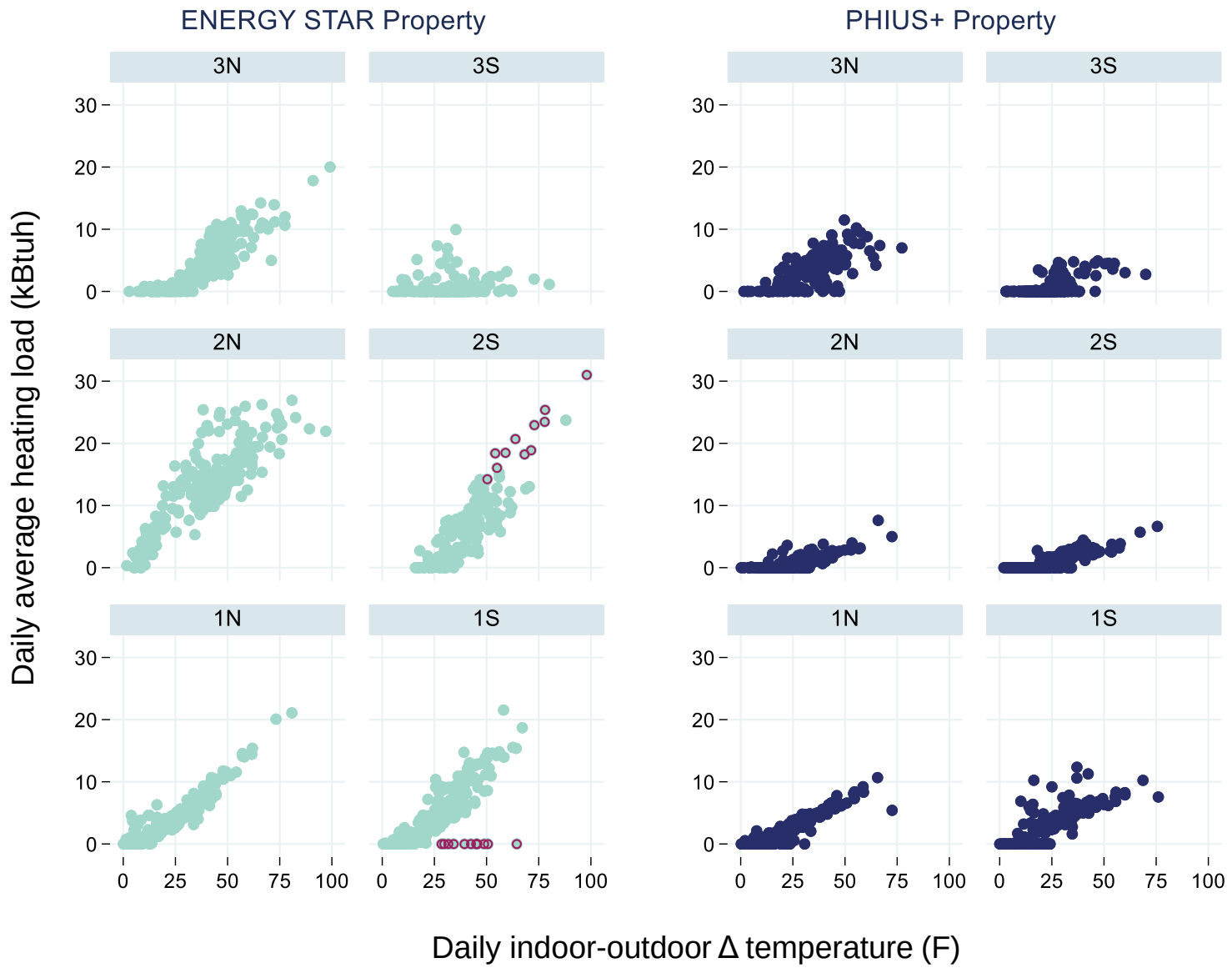
- At the building level, the PHIUS+ property needs to be supplied with 55% as much heat seasonally as the ENERGY STAR property.
- The analysis is based on daily measured heat output for all heating systems in each building as a function of daily indoor-outdoor temperature difference. The relationship at the building level is reasonably linear for both properties.
- Seasonal heating-requirement estimates are based on an assumed indoor temperature of 70F and Sep 15 – May 31 outdoor temperature distribution for O'hare between 2003 and 2018.

Note: These results have higher uncertainty due to difficulty measuring system output, and are subject to future revision.



The situation is more complicated for individual apartment units

- The relationship between daily heating requirement and indoor-outdoor Δ temperature is less linear at the unit level, especially for the third floor, south (3S) units at each property, where solar gain may play a larger role.
- Occupancy status may play a role here, because unoccupied units tend to have lower setpoints than occupied units. Preliminary statistical analysis suggests that differences in setpoint temperatures between vertically-adjacent units is a statistically-significant predictor of unit-level heating load.
- An extreme example of the above is a 12-day period in January when the furnace in unit 1S at the ENERGY STAR property was out of commission (red-circled days in graph). The heating requirement for the unit above (2S) increased during this period.



Utility rates vary between the two properties due to difference in heating fuels

- ComEd and Peoples Gas rates vary depending on the heating fuel.
- **The ENERGY STAR property has natural gas space heat and has higher customer and per-therm charges for natural gas**
- **The PHIUS+ property has electric space heat, and has a slightly higher ComEd electric customer charge but lower per-kWh charges.**

		ENERGY STAR	PHIUS+
Electricity*			
Monthly charge		$17.00	$18.80
Per kWh	Winter	12.4 cents	10.4 cents
	Summer	11.9 cents	9.9 cents
Gas**			
Monthly charge		$44.70	$22.60
Per therm***		66.0 cents	61.1 cents

*ComEd BES rate, includes riders and taxes
**Peoples Gas Rate 1, includes riders and taxes
***based on gas costs for Jan-July 2019

HVAC operating costs for the PHIUS+ property are less on average—if fixed customer charges are considered

- Direct costs for space heating and ventilation are higher for the PHIUS+ property due to reliance on electricity for space heating and higher electricity consumption for the ERVs compared to the bath fans at that ENERGY STAR property.
- But annual customer gas charges for the PHIUS+ property are considerably lower because of the non-heating gas rate.

Potential questions to explore:

(1) how would operating (and construction) costs for the PHIUS+ property have been affected if it had been scoped as an all-electric building?

(2) How would operating costs be affected is PHIUS+ accounts were on ComEd hourly rate

Average annual costs per housing unit…		ENERGY STAR	PHIUS+
Space heating	Electricity	$21	$291
	Gas	$201	$0
	Subtotal	*$222*	*$291*
Space cooling (electricity)*		*TBD*	*TBD*
Ventilation (electricity)		$6	$37
Annual customer charges	Electricity	$204	$226
	Gas	$536	$271
	Subtotal	*$740*	*$537*
Total		**$968**	**$865**

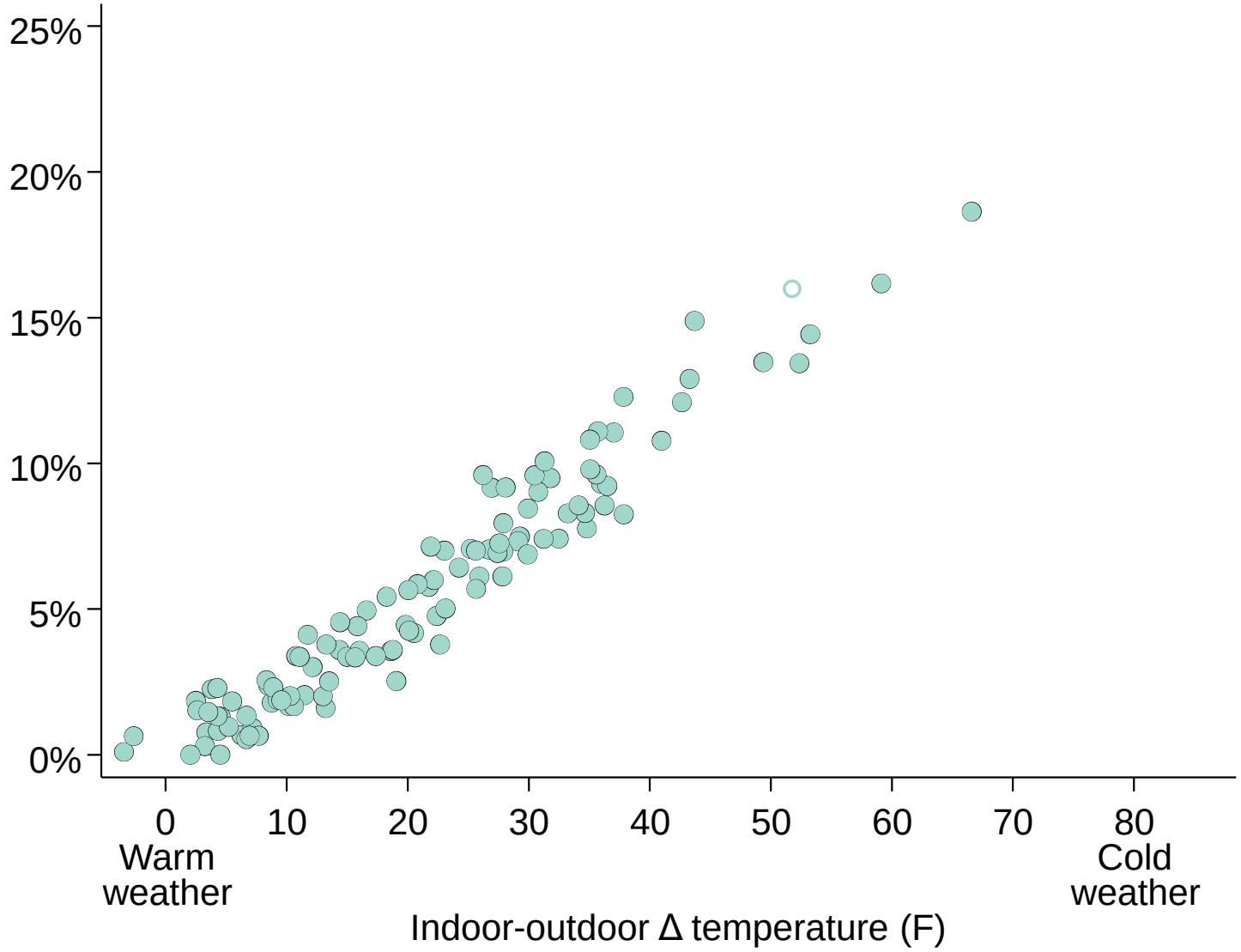
*Note: space-cooling costs are omitted in these preliminary results – these will be analyzed at the conclusion of the 2019 cooling season

The furnaces in the ENERGY STAR property are considerably oversized

- Furnaces in the ENERGY STAR property are 2-stage 80-kBtuh units. Only 2.6% of aggregate furnace operation was in high stage during the heating season.
- At the building level, only 25% of the total furnace firing capacity was needed under polar vortex event conditions, which was well below design temperature (see graph).
- No furnace ran at more than 40% of full capacity on any day during the heating season.
- Across ~41,000 firing cycles for all 6 units, the median firing time was 4.2 minutes. No furnace firing cycle exceeded 60 minutes.

Potential question to explore: what led to the selection of this furnace equipment?

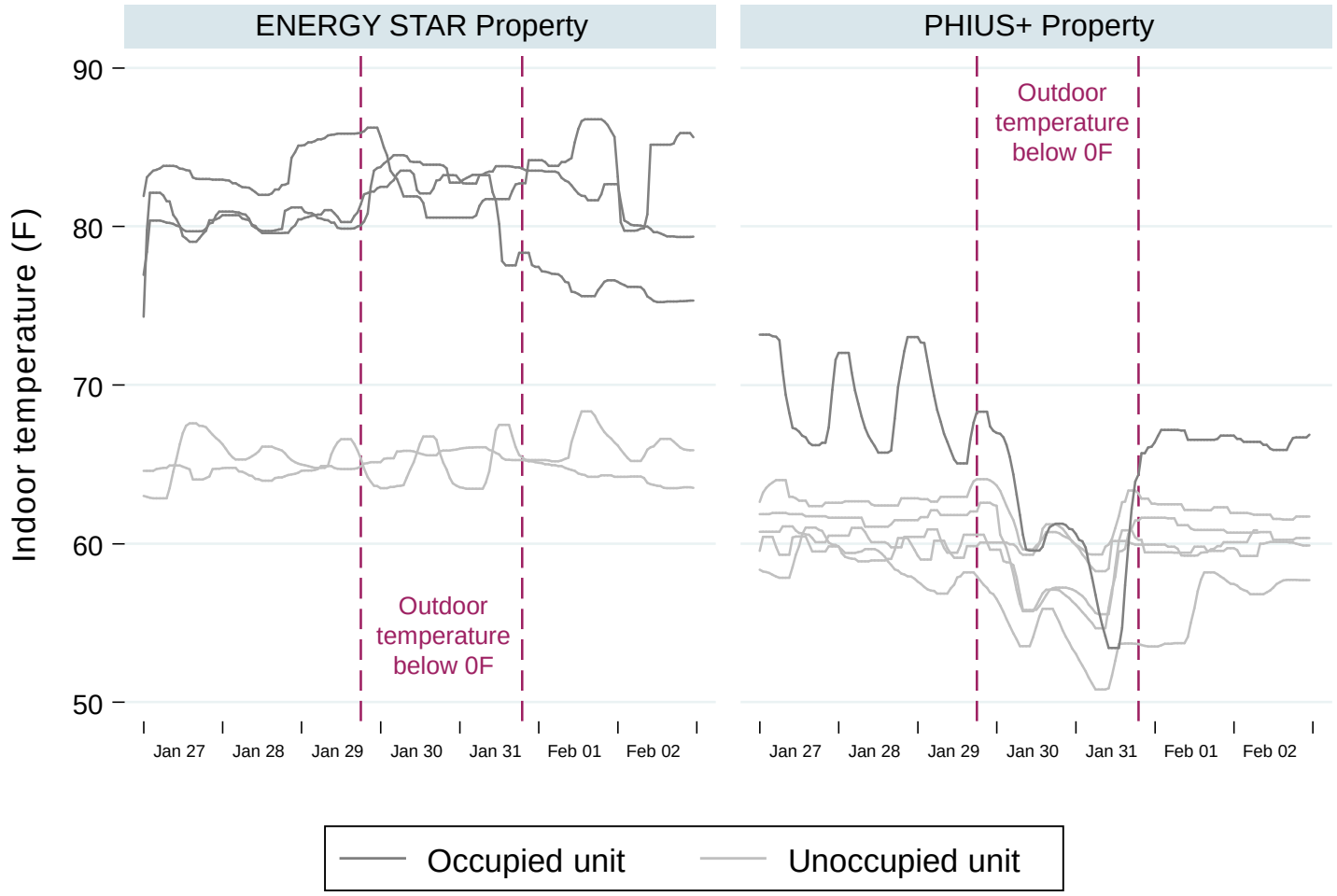
Daily percent utilization of total building furnace firing capacity



The heat pumps at the PHIUS+ property could not maintain setpoint during a polar-vortex event at the end of January

- Outdoor temperature remained below 0F from the evening of January 29 through late on January 31—and dropped to a low of -22F at one point.
- Setpoint temperatures were maintained at the ENERGY STAR property, but drooped by as much as 15F at the PHIUS+ property.
- The 2.5-ton PHIUS+ property heat pumps have no backup provisions. It is likely that the heat pumps could not meet the load on the building during the event, which was well below design temperatures.
- The situation was likely exacerbated by freezing of the ERV exhaust-side flow during this period (next slide).

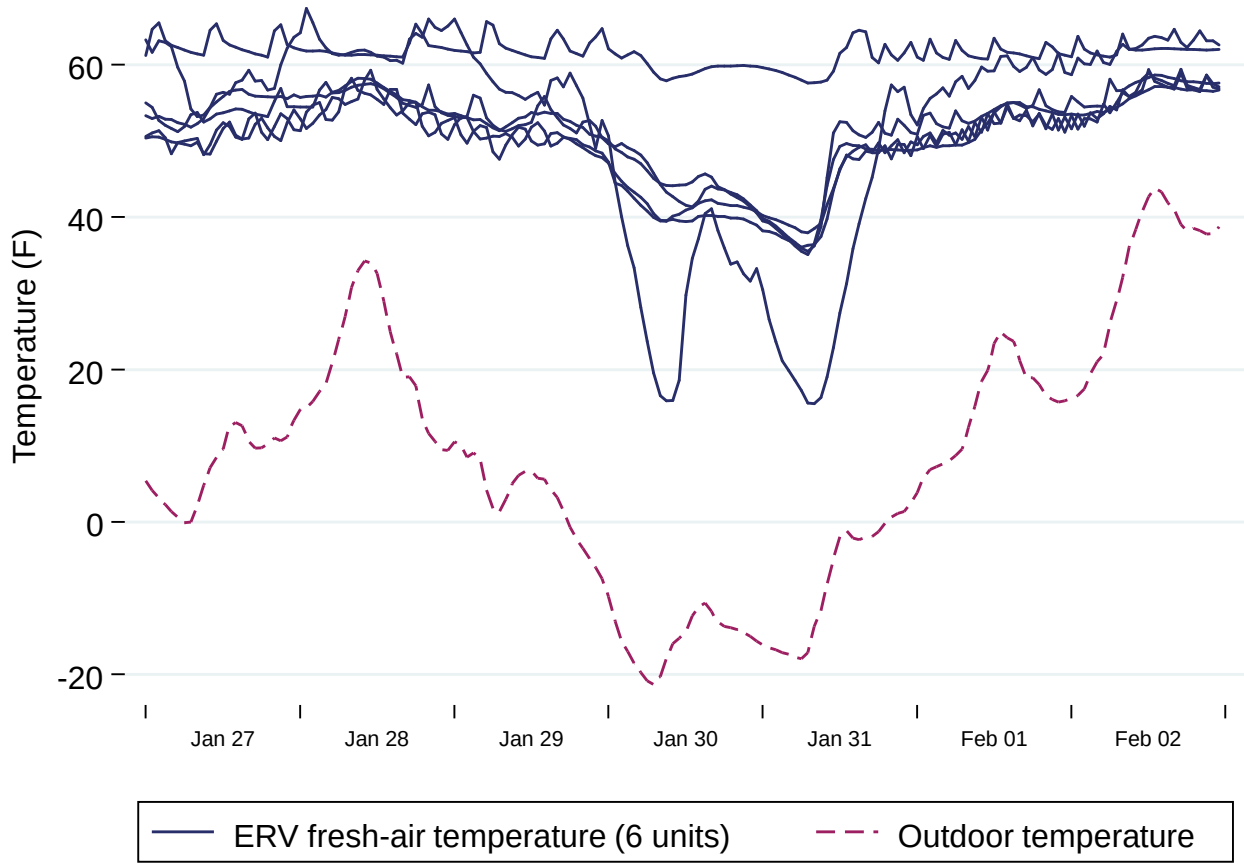
Potential question to explore: what led to the decision to forgo backup heat?



The exhaust side of most of the PHIUS+ ERVs appear to have partially or completely frozen during the January polar-vortex event

- Normally, exhaust and inlet flows are balanced, heat exchange is maximized and delivered fresh air is within 5-8F of indoor temperature.
- Under very cold conditions, moisture in the exhaust air can freeze in the heat exchanger, and thus reduce or completely stop exhaust airflow. Monitoring data shows elevated exhaust-side pressure drop during the polar-vortex event, indicating partial or complete blockage.
- Without balanced flow, there is less heat exchange and delivered fresh air is much colder. One of the units experienced brief periods with delivered fresh-air temperatures below 20F.

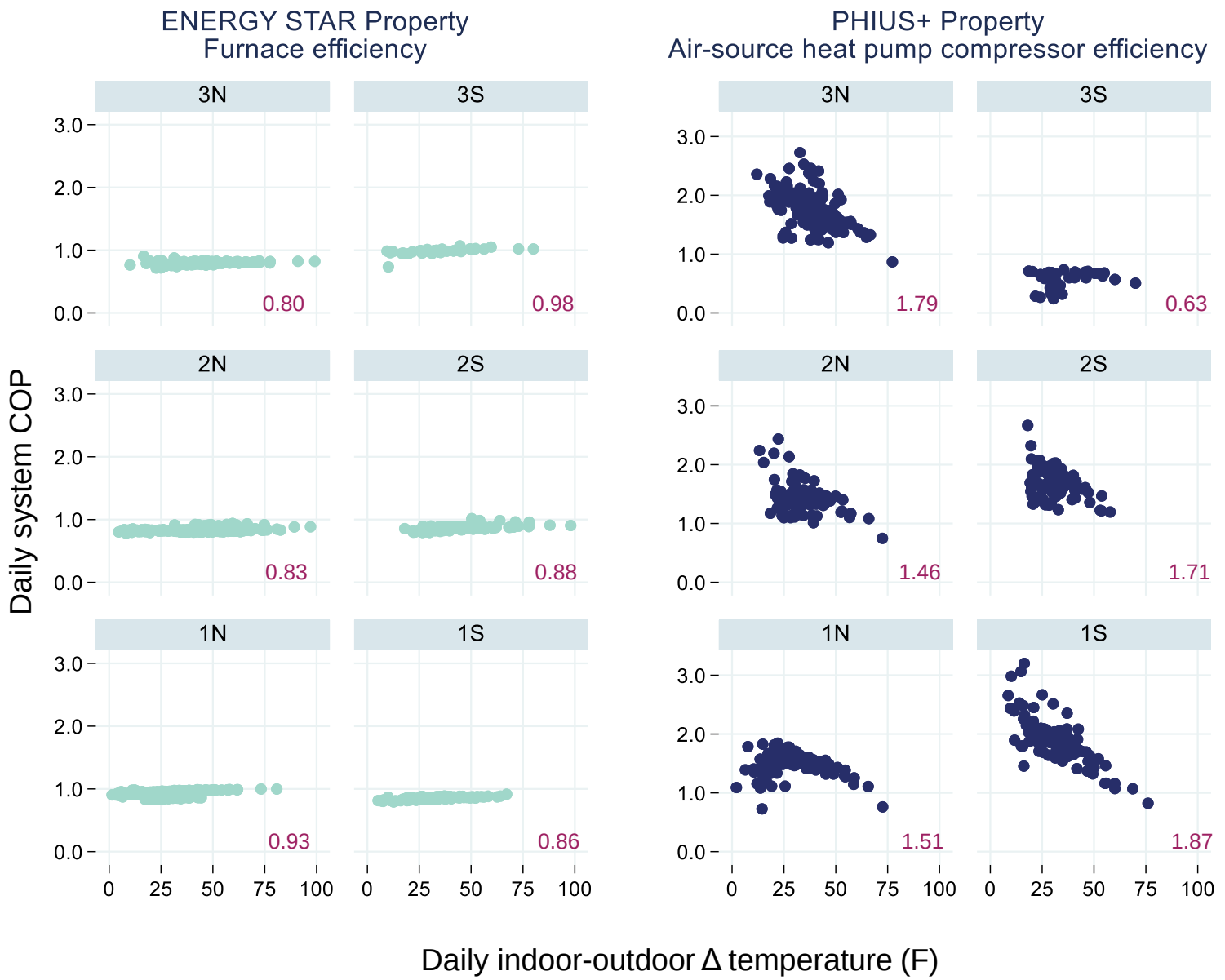
Potential question to explore: what strategies could be used to avoid exhaust-side freeze-up and cold fresh-air delivery?



Estimated heating system efficiencies are somewhat lower than expected

- Coefficient of performance (COP) is the ratio of system output energy (heat) to energy input (gas for a furnace; electricity for a heat pump)
- The furnaces at the ENERGY STAR property have a gas efficiency rating (AFUE) of 96%, so should show a COP of about 0.96. Calculated seasonal values are somewhat below this value for four of the six units.
- COP for heat pumps varies with outdoor temperature, but would be expected to be above 3.0 in mild heating conditions and around 2.0 in moderate conditions. As with the furnace results, calculated COPs are somewhat below expectations.
- These results suggest further diagnostic work related to heating output measurements
- PHIUS+ Unit 3S stands out as a clear outlier in need of additional investigation (see next slide)

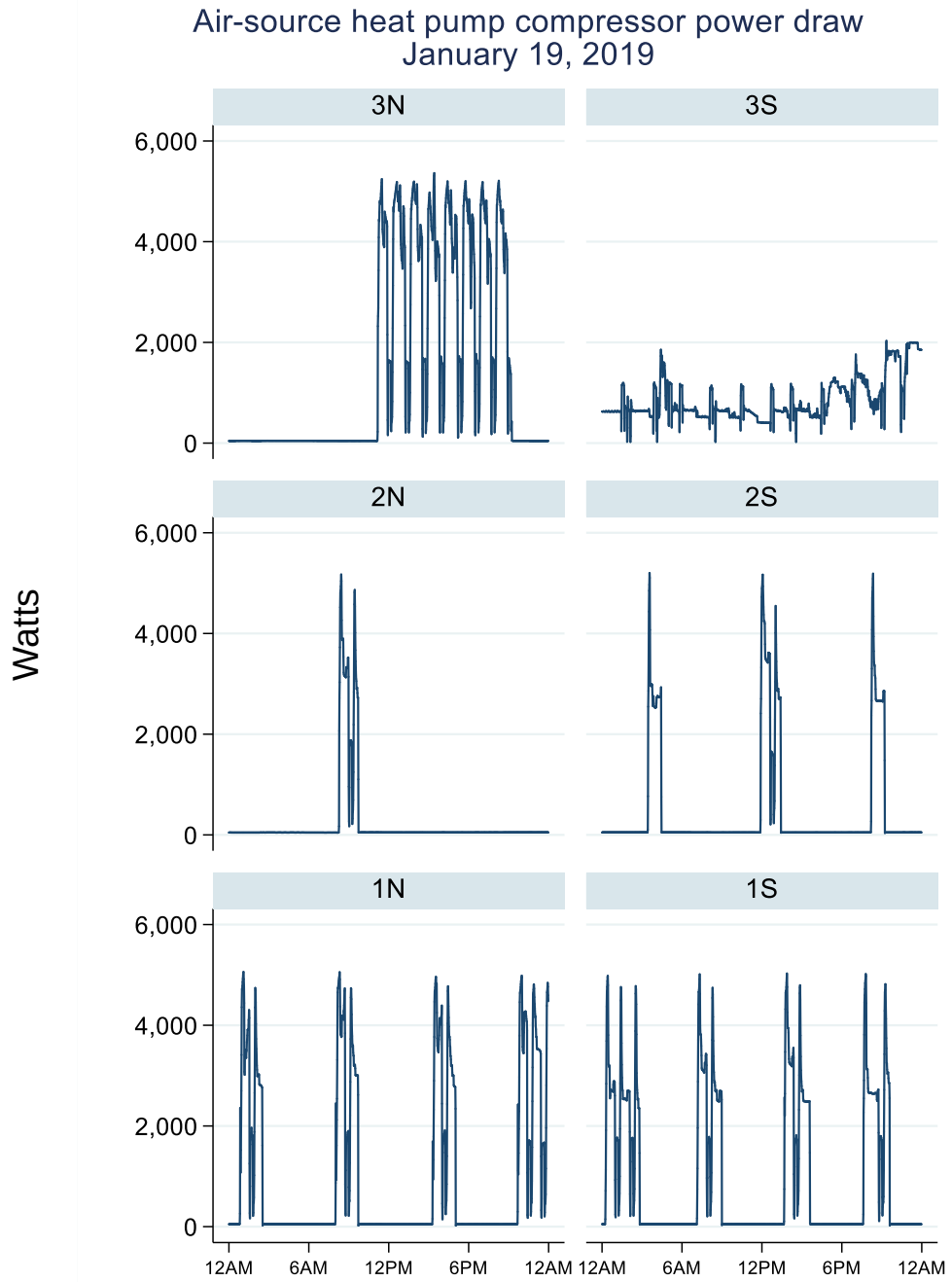
Question to explore: are these estimates accurate, and if so, why are efficiencies lower than expected?



The heat pump for PHIUS+ Unit 3S operates differently than the other units

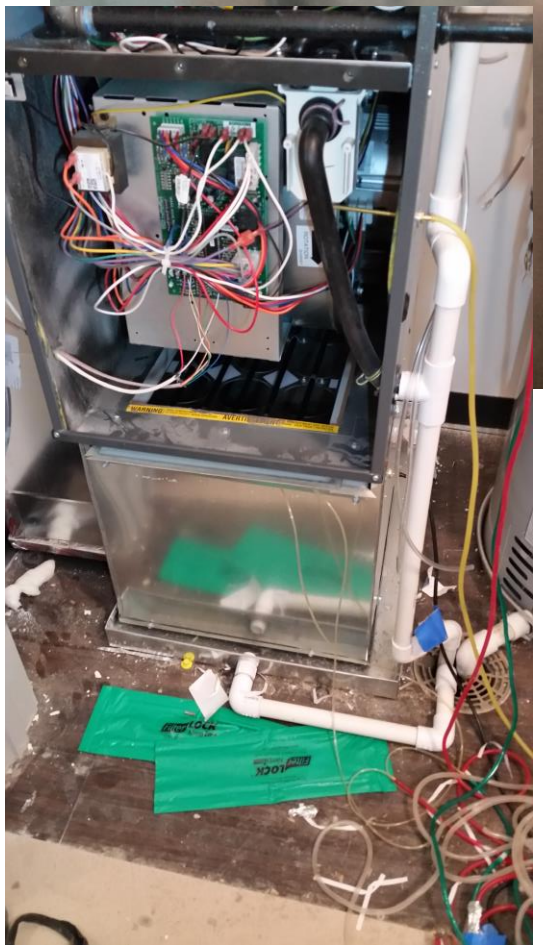
- Most of the units show clear heating cycles that each ramp up to full system power input (see example day at right).
- The compressor for Unit 3S shows nearly continuous operation at low power draw. Heat output (not shown) is also much lower.

Question to explore: why does the heat pump at this unit operate differently?



Is duct leakage at filter slot (or elsewhere) affecting calculated system output?

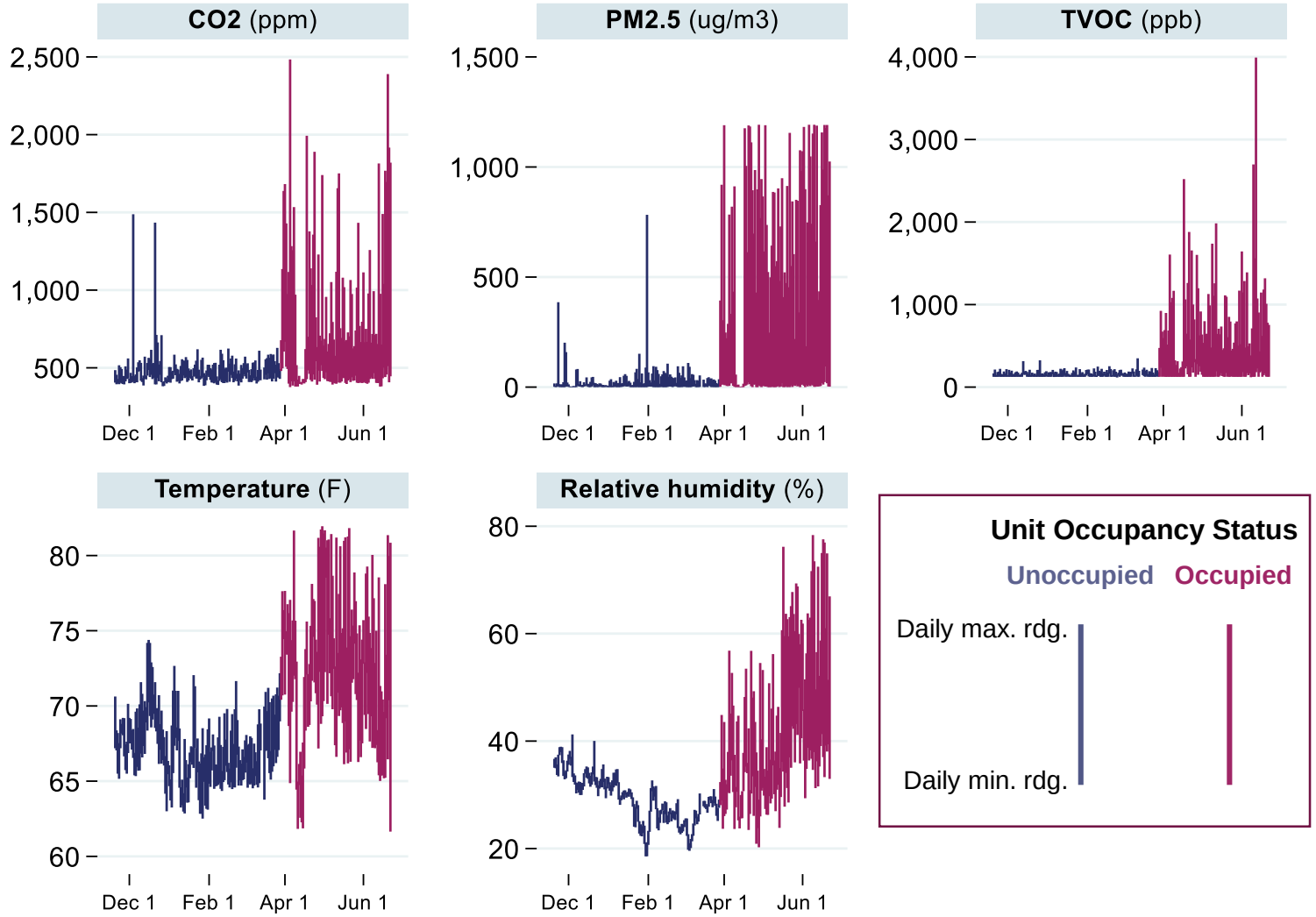
- System airflow is measured in the return duct near the air handler.
- Any air that leaks into the system downstream of the airflow sensor but upstream of the air handler will cause an undermeasurement of airflow and thus an underestimate in heating/cooling output
- The most likely candidate for return-side duct leakage is at the filter slot, which is sealed by magnetic covers that are easily dislodged.
- We may want to use alternative means to seal the filter slots prior to the second heating season.



Unit occupancy has a large effect on IAQ parameters

- As the example at right shows, unit occupancy has a large impact on the daily range of IAQ parameters such as particulates (PM2.5) and total volatile organic compounds (TVOCs). This indicates that these pollutants are mainly occupant-generated and not inherently sourced in the building itself.

ENERGY STAR Unit 3S



Adaptation of the RESET standard forTierra Linda

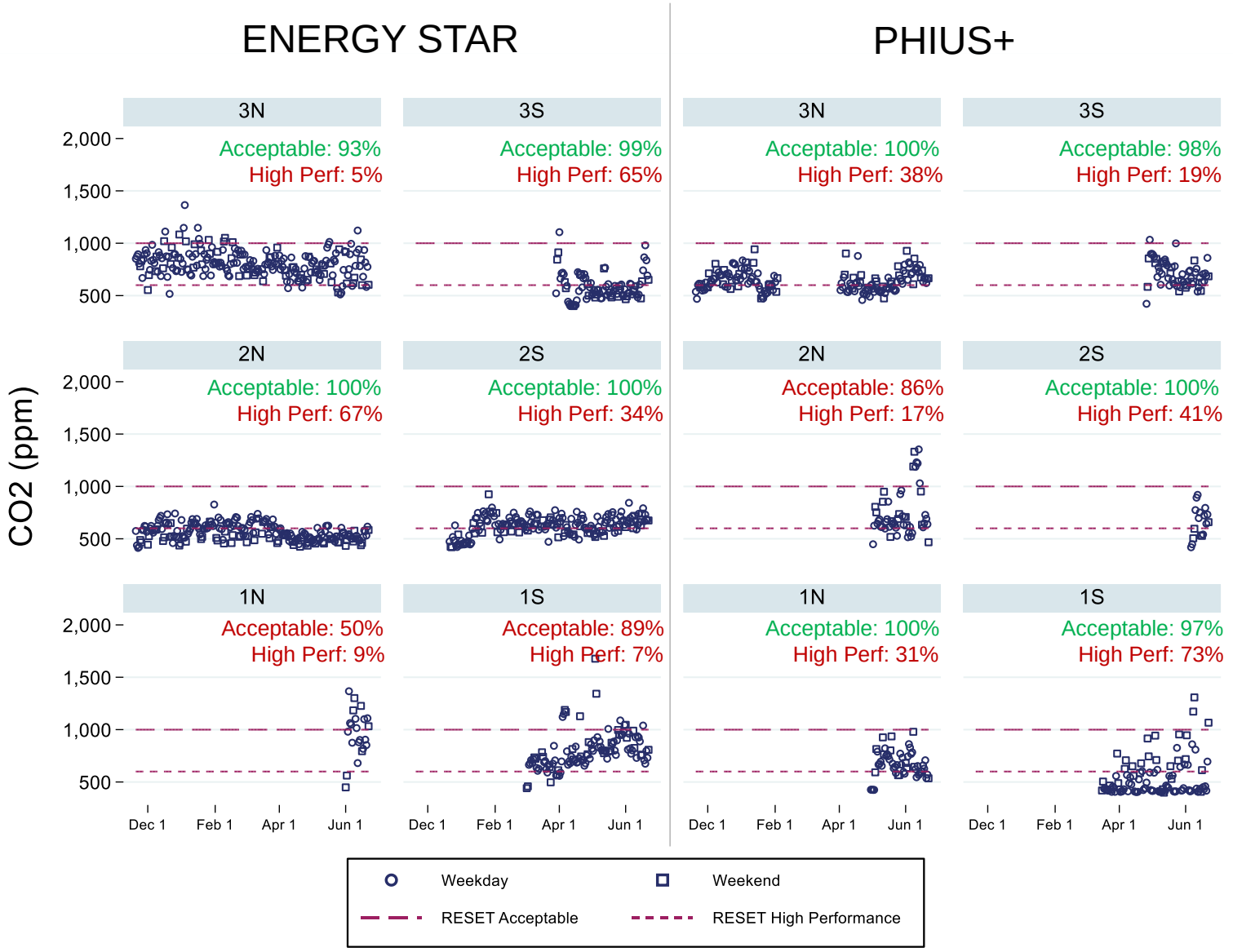
- RESET is a monitoring-based standard that is intended for commercial spaces but provides useful benchmarks for residential.
- For application at Tierra Linda, limit to periods when unit is rented and occupied. Further exclude weekdays between 8:00 am – 5:59 pm when people tend to be away from home. Hourly CO2 profiles confirm that this is the case for at least some of the Tierra Linda units.
- Calculate the average daily values for PM2.5, TVOC and CO2 for each unit, and evaluate against RESET “acceptable” and “high performance” thresholds.
- RESET calls for no more than 10% “fail” days relative to these thresholds.

PM2.5 Particulate Matter	TVOC Total Volatile Organic Compounds	CO_2 Carbon Dioxide
Acceptable < 35 µg/m³	Acceptable < 500 µg/m³	Acceptable < 1000 ppm
High Performance < 12 µg/m³	High Performance < 400 µg/m³	High Performance < 600 ppm

https://www.reset.build/standard#std__download

CO_2

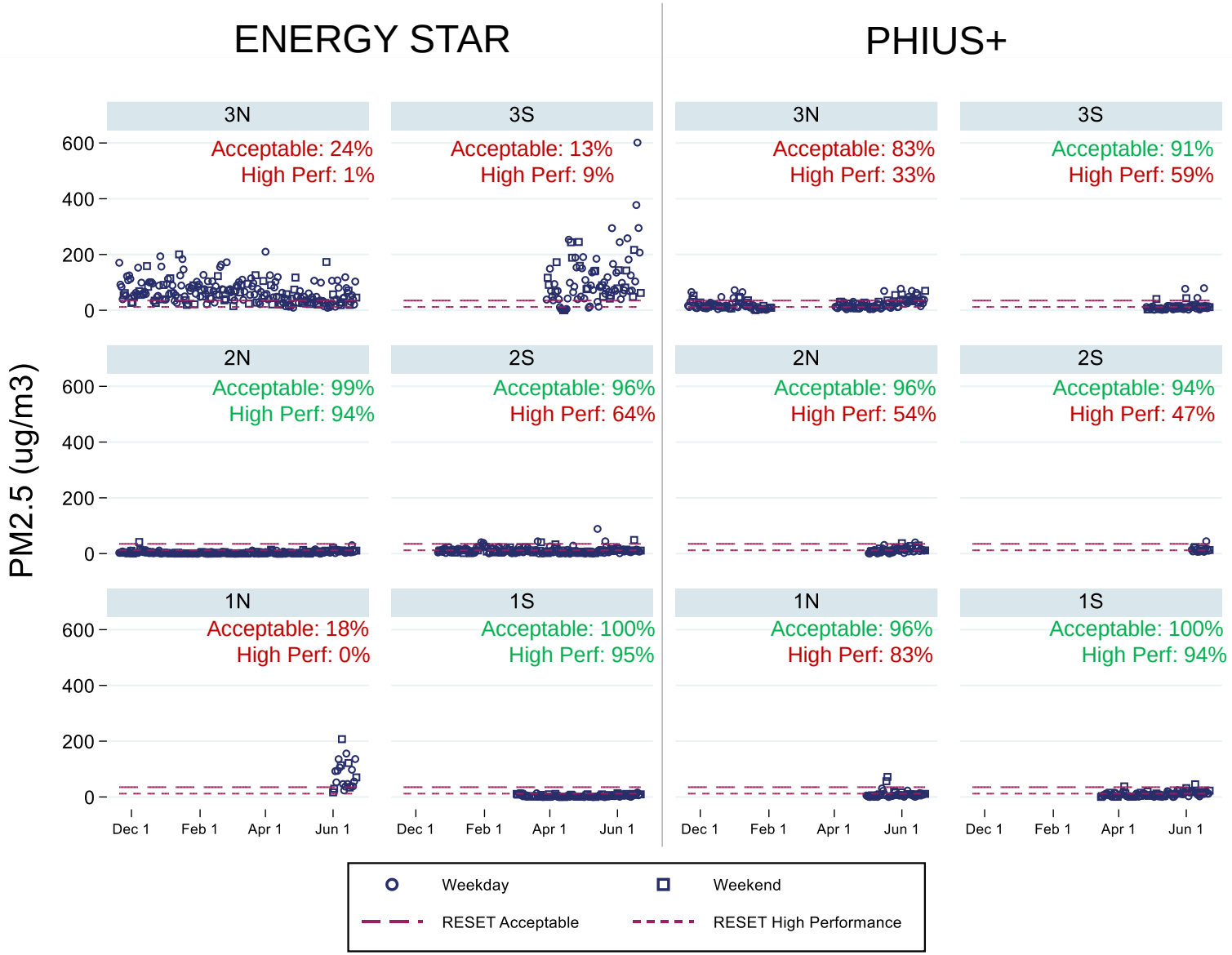
Most units pass the Acceptable threshold but none meet the High Performance threshold



Values shown are daily averages during defined occupied periods. Data omitted for periods when unit was not rented and occupied. Percentages represent the fraction of days that pass the “Acceptable” and “High Performance” thresholds.

PM2.5

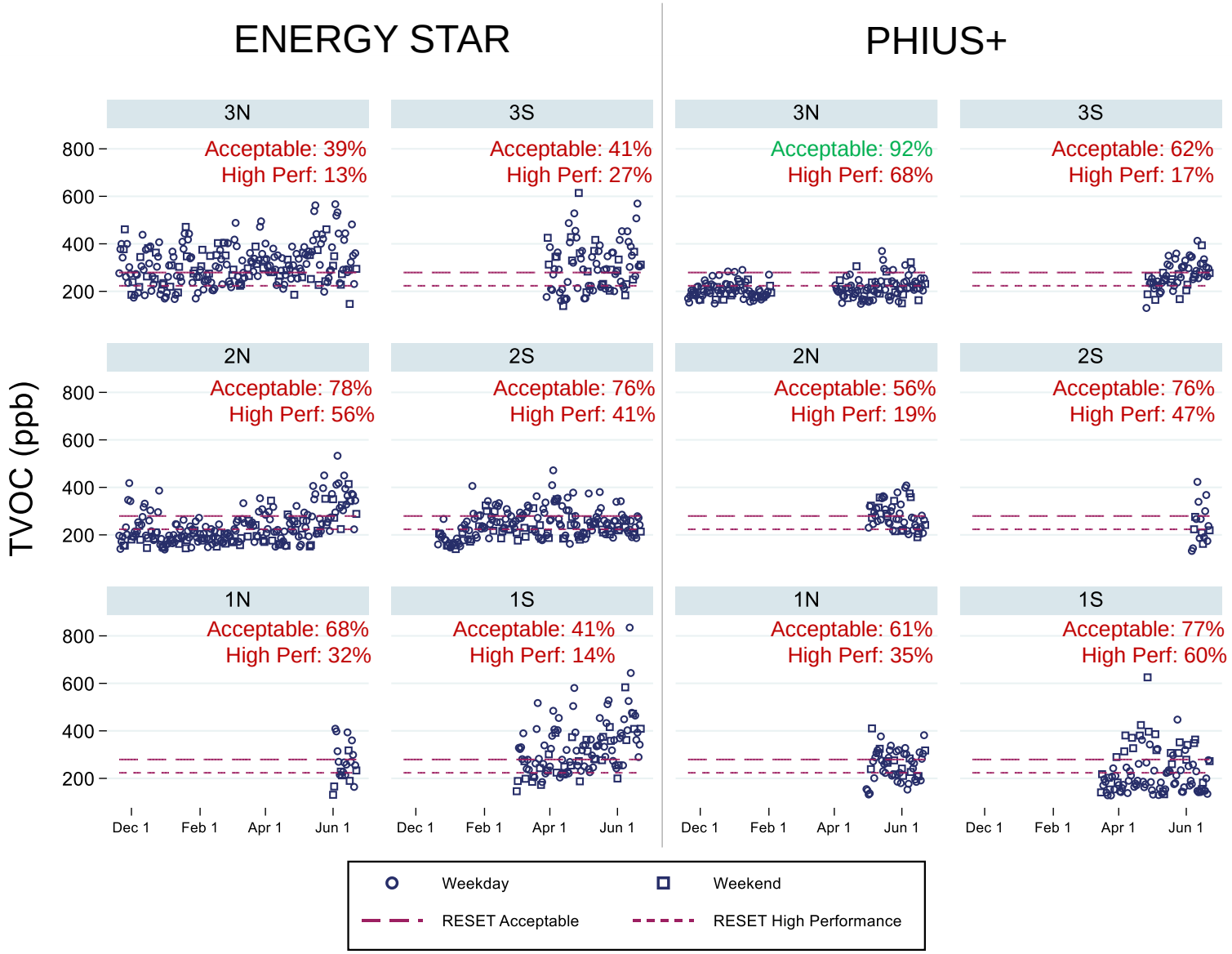
Two-thirds of units pass the Acceptable threshold and some meet the High Performance threshold



Values shown are daily averages during defined occupied periods. Data omitted for periods when unit was not rented and occupied. Percentages represent the fraction of days that pass the “Acceptable” and “High Performance” thresholds.

TVOCs

Only one unit passes the Acceptable threshold and none meet the High Performance threshold

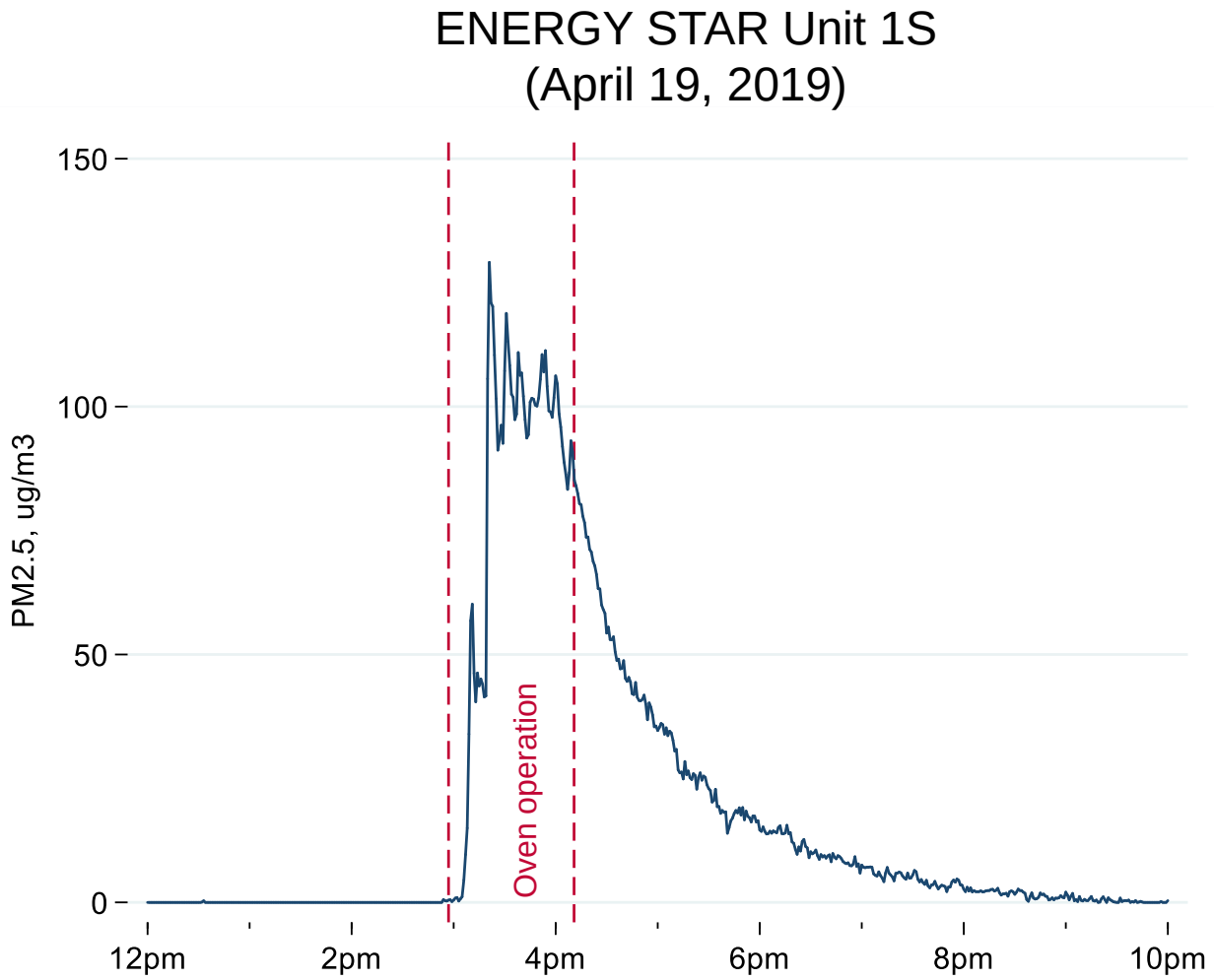


Note: the RESET standard for TVOC is expressed in terms of µg/m^3 but the instrument used for the study reports TVOCs in parts per billion (ppb). Converting between the two requires knowledge of the molecular weight of the VOCs involved, which is unknown in this case. For preliminary analysis, we used a vendor-provided conversion factor of 1.79 µg/m^3 per ppb and are looking into the literature on this subject.

Values shown are daily averages during defined occupied periods. Data omitted for periods when unit was not rented and occupied. Percentages represent the fraction of days that pass the “Acceptable” and “High Performance” thresholds.

Oven use is associated with IAQ “pulse” events

- Oven and range hood use can be determined from the range/oven electric data. Ovens in the units are used on average about once every 5 days in both buildings.
- The ENERGY STAR property has vented ranged hoods, but these may not be used consistently.
- The PHIUS+ property has recirculating range hoods and an ERV exhaust pickup that is located about 8 feet away from the oven.
- Oven use generally produces an observable pulse of CO2, PM2.5, TVOCs and humidity.
- The first-year analysis will look at the differential impact of oven use on IAQ in the two properties.



Winter Occupant Survey

4 completions for ENERGY STAR property; 2 for PHIUS+ (other units were unoccupied—will survey those next winter).

Key findings

- High occupancy: 3 to 5 household members per unit (mean 4.2) – mostly single-adults with children
- Most people gone for the majority of the day
- Range/oven used “Most or all days” – 4 ; “Some days” – 2; “Rarely or never” – 0
- “How would you describe the temperature in your apartment in the winter?”

	Very Cold	Cold	Comfortable	Hot	Very Hot
ENERGY STAR	0	**1***	**2**	**1**	0
PHIUS +	0	**2**	0	0	0

* “When it is extremely cold outside I have to turn my heat all the way up to 90 and the temp on the [thermostat] only says 77o and [it’s] still cold in my unit”

- One ENERGY STAR resident reports opening windows every day because “I’m used to it, and I like cool air.”
- Some reports of noise issues between units; one report of cross-unit odors “some of the time”

Key Interim Take-Aways

- The PHIUS+ property has substantially lower heating load than the ENERGY STAR property
- HVAC operating costs (excluding cooling) appear to be comparable – and are a strong function of utility monthly charges and presence of gas service
- There are issues related to heating-system sizing at both properties
- Calculated heating system efficiency is lower than expected at both properties – this needs more investigation
- Post-occupancy IAQ data are limited at this point, but no strong differences so far between the two properties

Remaining tasks for Year 1 report

- Analysis of cooling-season energy performance and IAQ
- Implement summer occupant survey
- Building modeling and cost analysis
- Analyze ERV efficiency
- Interview stakeholders regarding incorporating PHIUS+ into the AHNC program
- Conduct additional comparison of Tierra Linda to similar low-rise multifamily properties in DOE code-compliance study

Summary of identified issues to explore further

- Accuracy of heating/cooling output measurements—especially return-side duct leakage impacts on measured airflow
- Figure out why Unit 3S heat pump operates differently
- Better understand design decisions related to heating system sizing, backup heat and provision of gas service at the PHIUS+ property
- Better understand what leads to freezing of ERV exhaust and how to prevent it
- Better understand impact of gas range/oven on IAQ at the two properties
- Possibly look at vertical stratification of indoor temperature
- Possibly look at house electric meter for stairwell heater consumption

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