Are internet connected thermostats agents of change?

Long-term trends in connected thermostat performance

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Alan Meier and Leo Rainer

Lawrence Berkeley National Laboratory

Abigail Daken, U.S. Environmental Protection Agency

International Context for eceee

- Internet-connected thermostats (CTs) now control heating and cooling systems in about 30% of U.S. and Canadian homes (compared to about 4% in Europe) and capture half of annual thermostat sales.
- Cloud-based control algorithms take into account how outdoor temperature, humidity, and insolation are likely to affect a particular home.
- American homes benefit more than European homes from daily temperature set-backs (and set-ups during the summer)
  - low-mass, wood frame construction
  - Heating and cooling are typically supplied from a central system through ducted air (rather than water or refrigerant)
  - Single-speed units are common
  - More AC, also dealing with latent load

Each thermostat collects data every 15 minutes

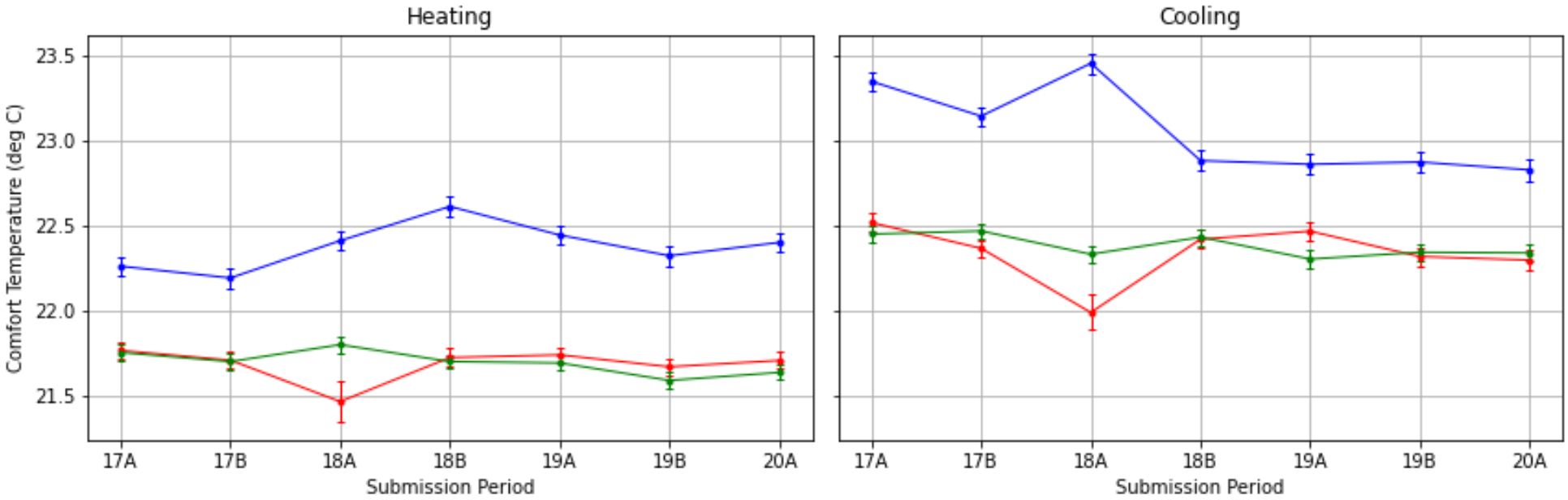
- Indoor temperature(s) [°C] from 1 – 5 sensors
- Desired temperature – the “setpoint” [°C]
- Heating run-time [min/15-min]
- Cooling run-time [min/15-min]
- Motion/occupancy (1 – 5 sensors)
- Sometimes also: humidity, ventilation, other

- The data are collected and transmitted to the cloud
- Depending on settings, the vendors (e.g. nest, ecobee) will adjust temperatures to save energy or optimize operation

Energy Star's connected thermostat program began in 2016

- New approach to savings verification
  - Relies on field data (rather than laboratory tests)
  - EPA developed software to estimate heating/cooling energy savings
    - Estimates HVAC runtime to outside temperature for each home
    - Uses local weather
    - Self-referential counterfactual to estimate savings
    - Generates a "savings metric" in %
  - Vendors use software on their customers to protect privacy
    - Vendors test random sample of thermostats (~ 1200/vendor every 6 months)
    - Vendors report only aggregated results to EPA
- Up to 6 years of data (12 submissions)
- 13 thermostat vendors participate in 2022

Inside temperatures* for 10M+ homes

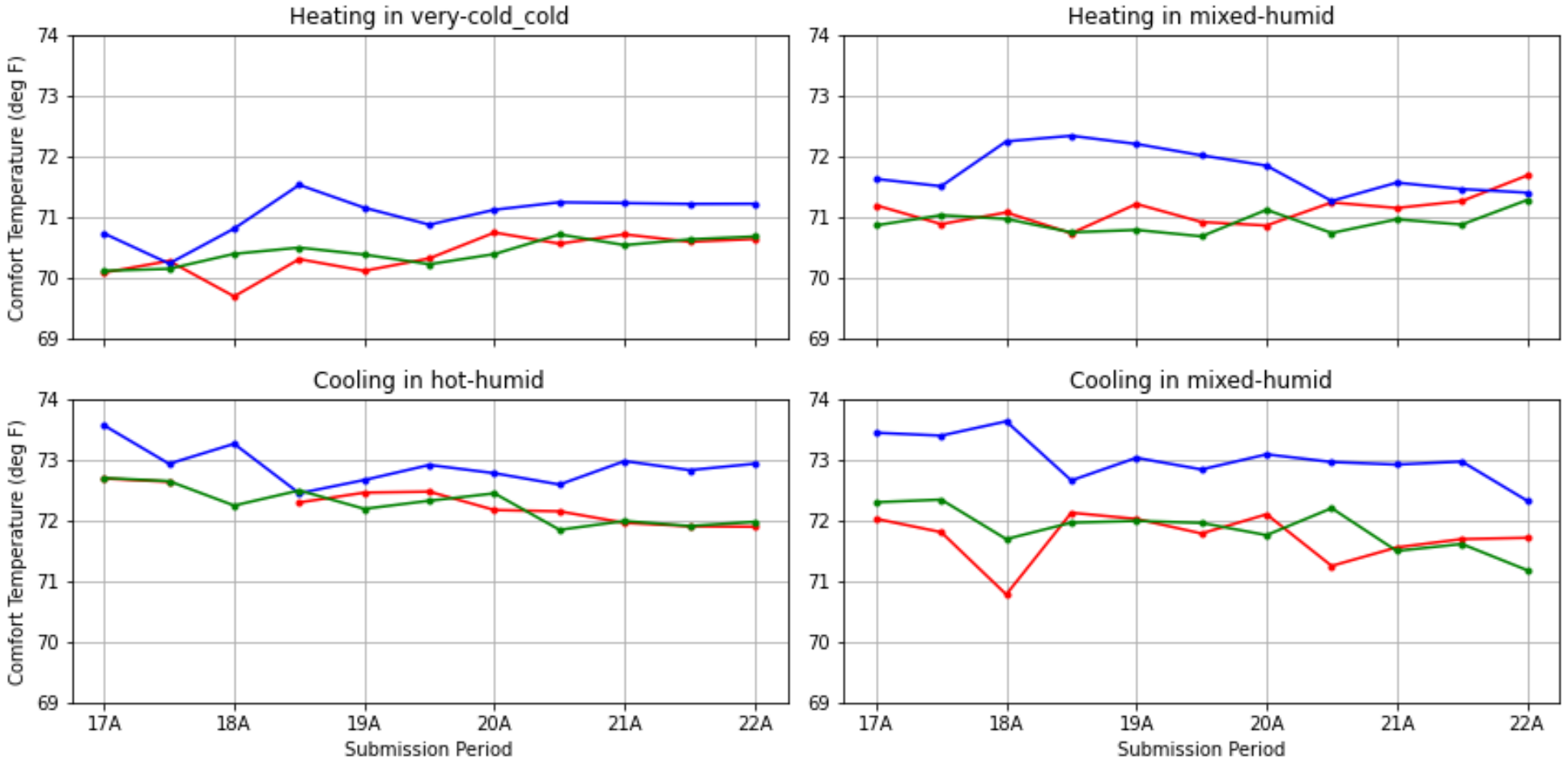


- *Constancy* (even during the pandemic)
- *Consistency* across vendors (ignore **BLUE** and a few data glitches)
- Small difference (0.7°C) between heating and cooling temperatures!
- Note small uncertainties in estimates

*See paper for procedure used to estimate inside temperatures

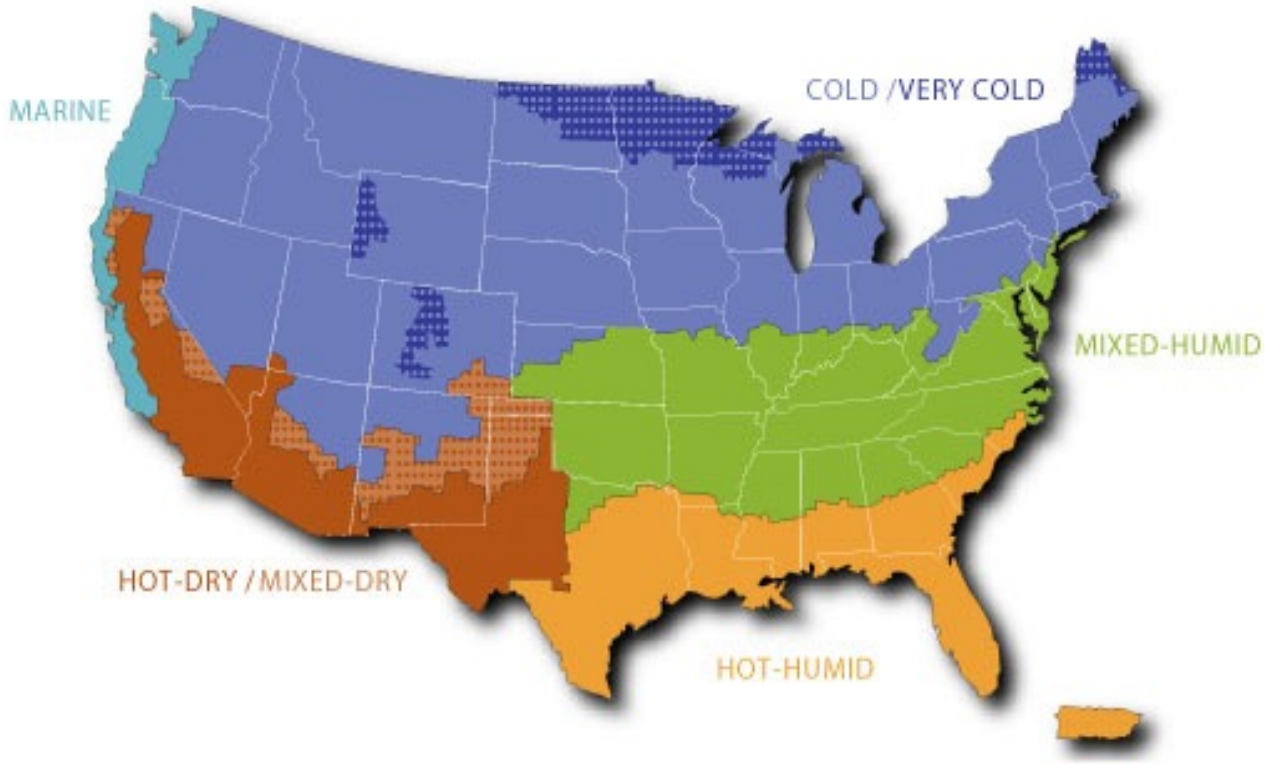
Few signs of a pandemic in these homes

(Inside Temperatures through 2022 in °F)

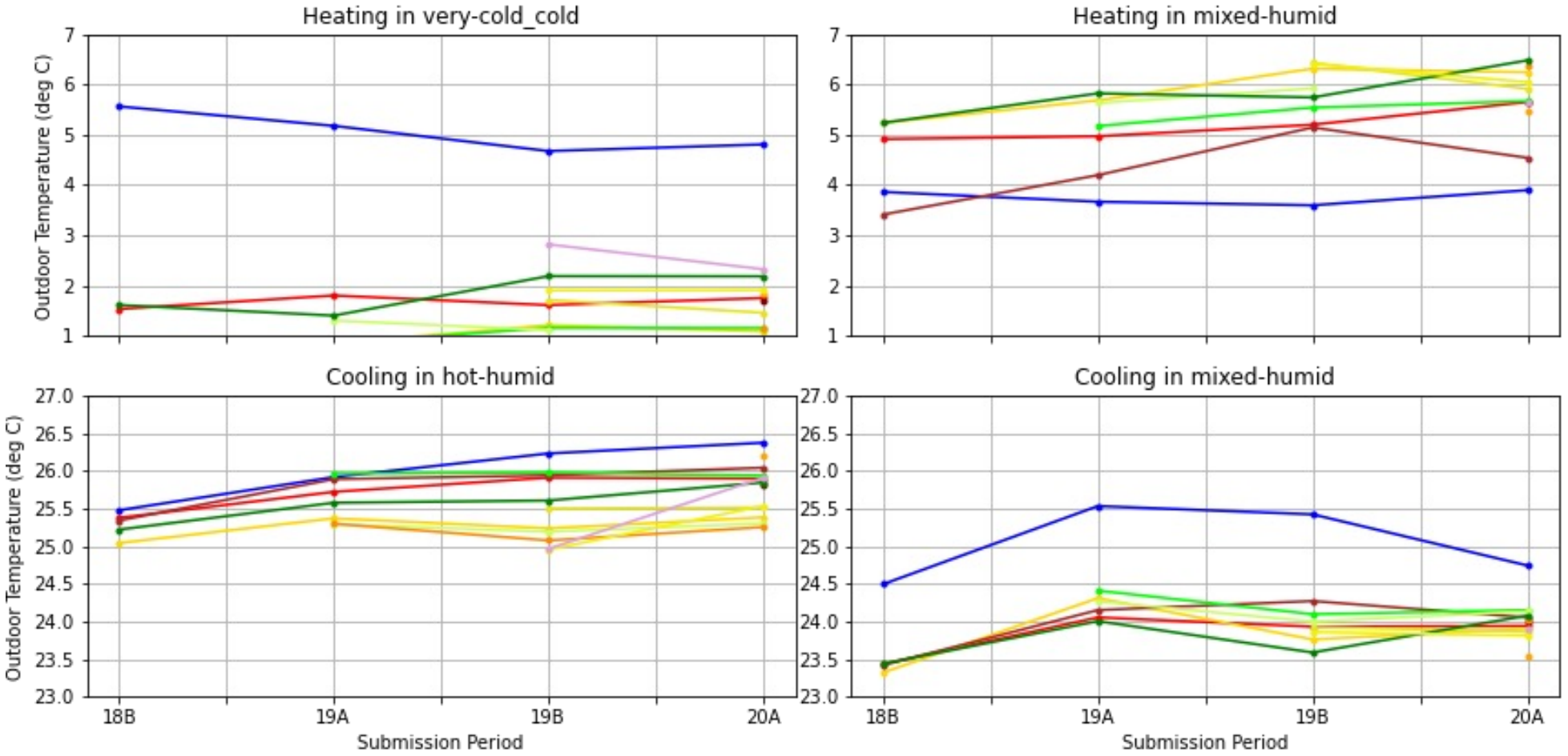


Vendors Reported Results by Climate Zone

- 5 climate zones
- ~250 homes/zone
- Majority of heating and cooling energy use occurs in just 3 zones

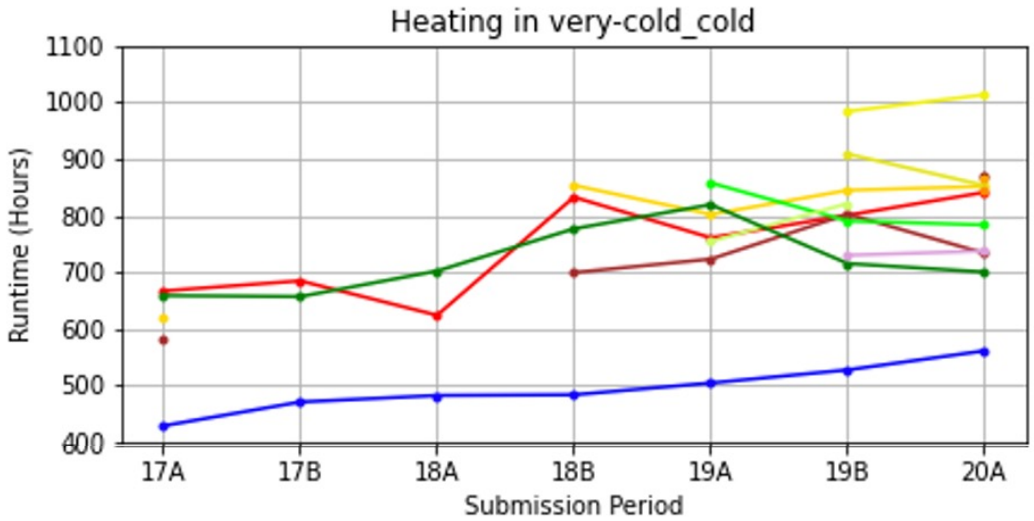


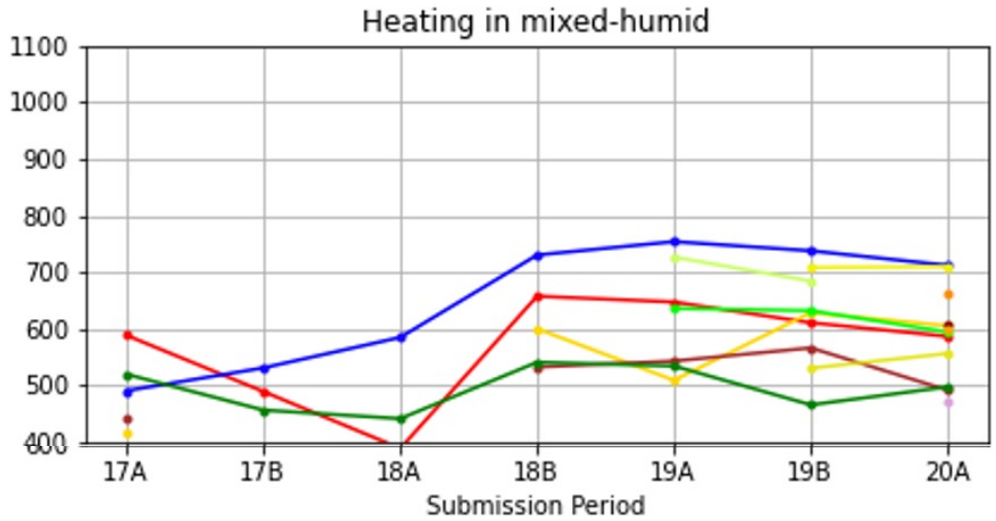
Reality Check: Are the vendors' thermostats in similar homes? Answer: Yes and No



Heating system runtimes

Majority of national heating energy occurs in these 2 zones



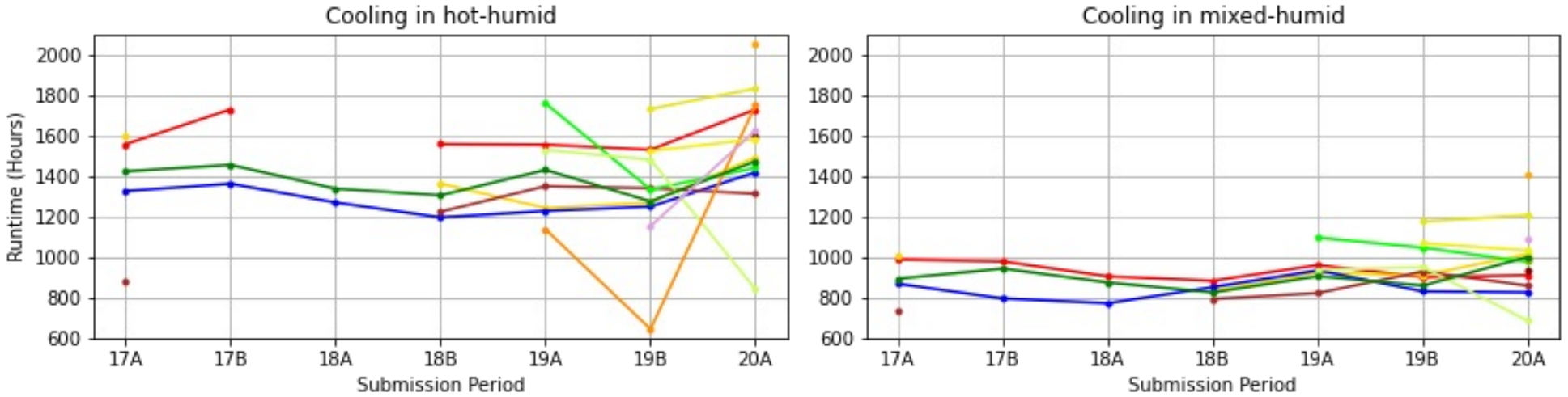


- Submissions capture national fluctuations in winter severity?
- Pandemic impact not visible. Why?
- Runtimes increased in cold zone and fluctuated in mixed-humid climate, Why?
- Energy ≠ runtime because we don't know system capacities

Ignore BLUE

Cooling system runtimes

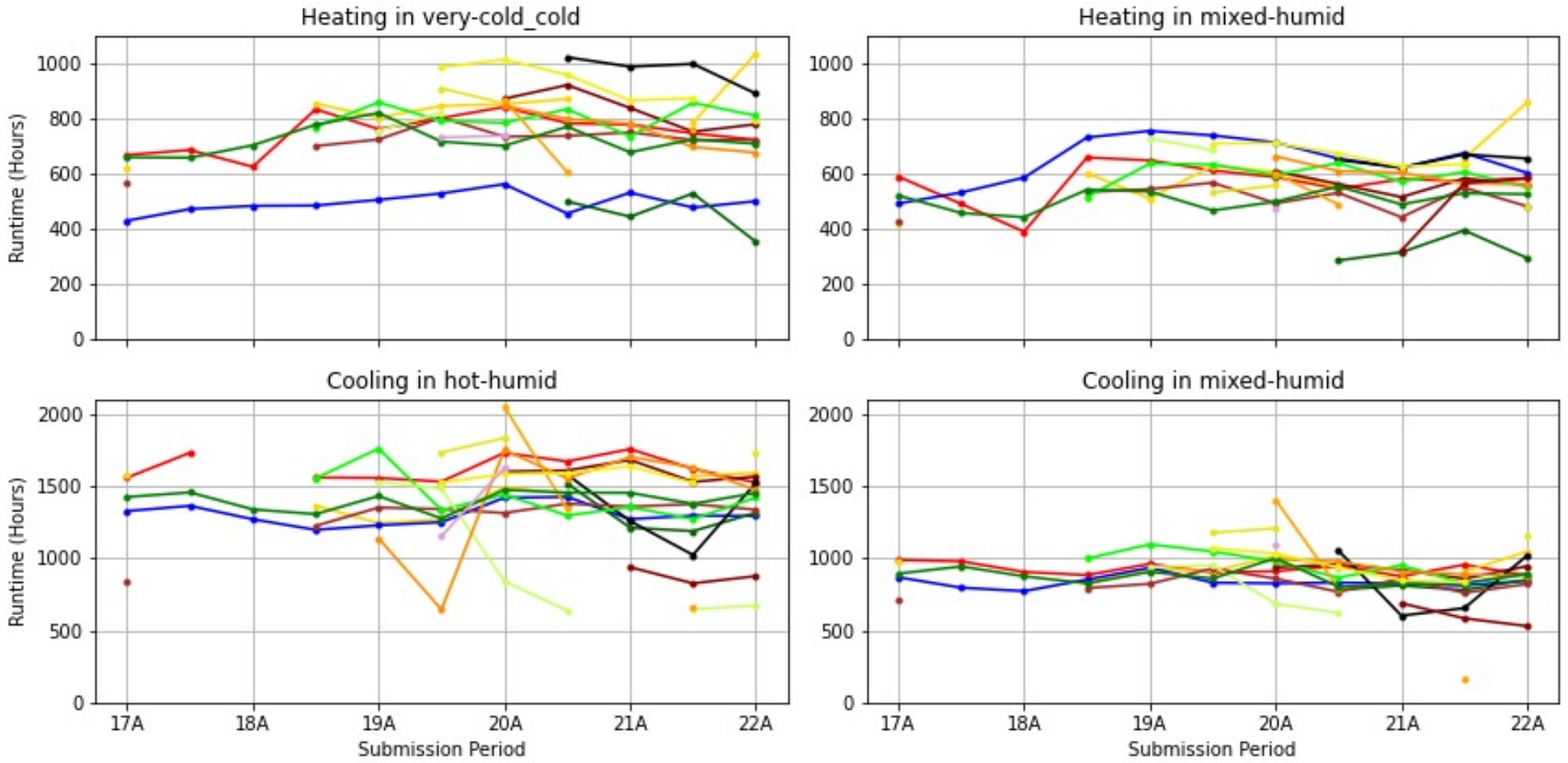
Majority of national cooling energy use occurs in these 2 zones



- AC used almost 2x more hours in warm climates (no surprise)
- *Constancy* (though pandemic impact might be visible)
- *Consistency* across vendors (ignore **BLUE** and a few data glitches)
- No long-term trends
- Energy ≠ runtime because we don't know system capacities

Ignore BLUE

Runtimes: more years and thermostats



What's With Blue?

- Different business model
- Customer base may be in limited regions and connected to other programs.
- Few thermostats (possibly the same ones every year)
- Vendor used a more aggressive energy savings approach, including lowering temperature settings (in the winter) without occupants' knowledge
- EPA model may calculate savings differently

Findings

- The HVAC runtimes submitted by the vendors are surprisingly stable from year to year and are not particularly responsive to variations in outside temperatures.
  - heating systems in the very cold climate zone typically run 700 hours/year
  - hot-humid climate AC runtimes average about 1400 hours/year.
- Indoor temperatures
  - Broadly similar temperatures for the heating season.
  - In contrast, differences in comfort temperatures during the cooling season among the vendors sometimes exceeded 1°C for samples of homes in the same climate zone.
    - May reflect varying effectiveness of technologies and algorithms employed by the thermostats.
  - Surprisingly little difference in temperatures for heating and cooling

Conclusions: some answers but more questions

- We now have accurate data on temperature settings, schedules, runtimes
  - No longer need to rely on occupant reports
  - Simulations: more realistic assumptions of settings, schedules, potential savings
- Data were used for evaluating energy savings (in %) of thermostats
  - 5 – 15% savings compared to baseline of constant temperature
  - Small savings with large uncertainties
  - How realistic is baseline?
- Policies
  - Customize operating advice to climate zones
  - Increase differences between heating and cooling setpoints
  - How many people never change their thermostat settings?
- Still can't convert runtimes to energy
  - What are HVAC capacities?

I didn't discuss this

Are connected thermostats agents of change?

We don’t know if they save energy because we lack before/after comparisons

- **Yes**
  - Enable new strategies to save energy:
    - Optimizing performance of building and equipment
    - Demand response and other actions needing high time-resolution
  - Facilitate nudges through information and “tweaks”
- **No**
  - More people “set and forget”
  - Greater disassociation between action and effect

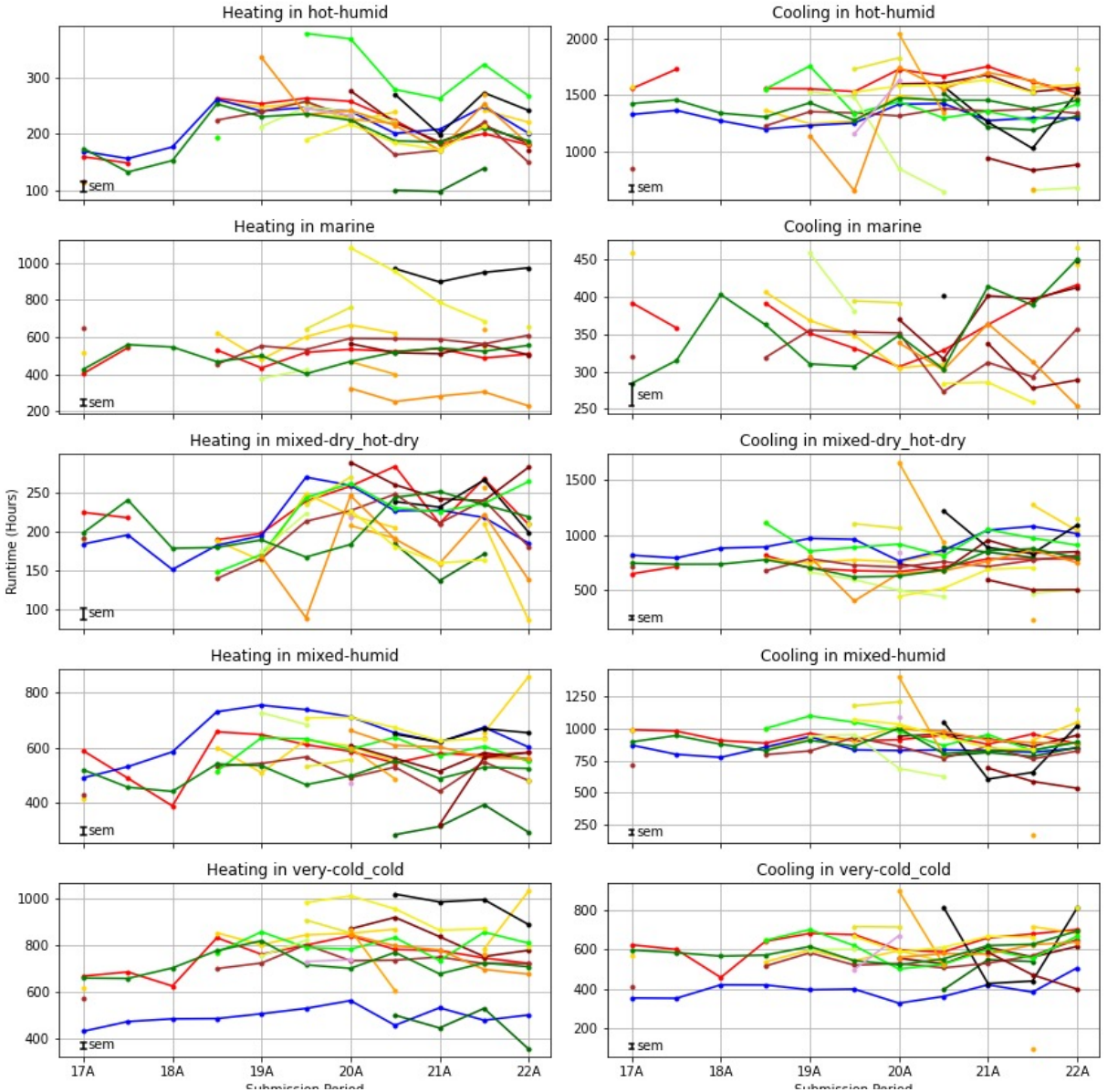
END

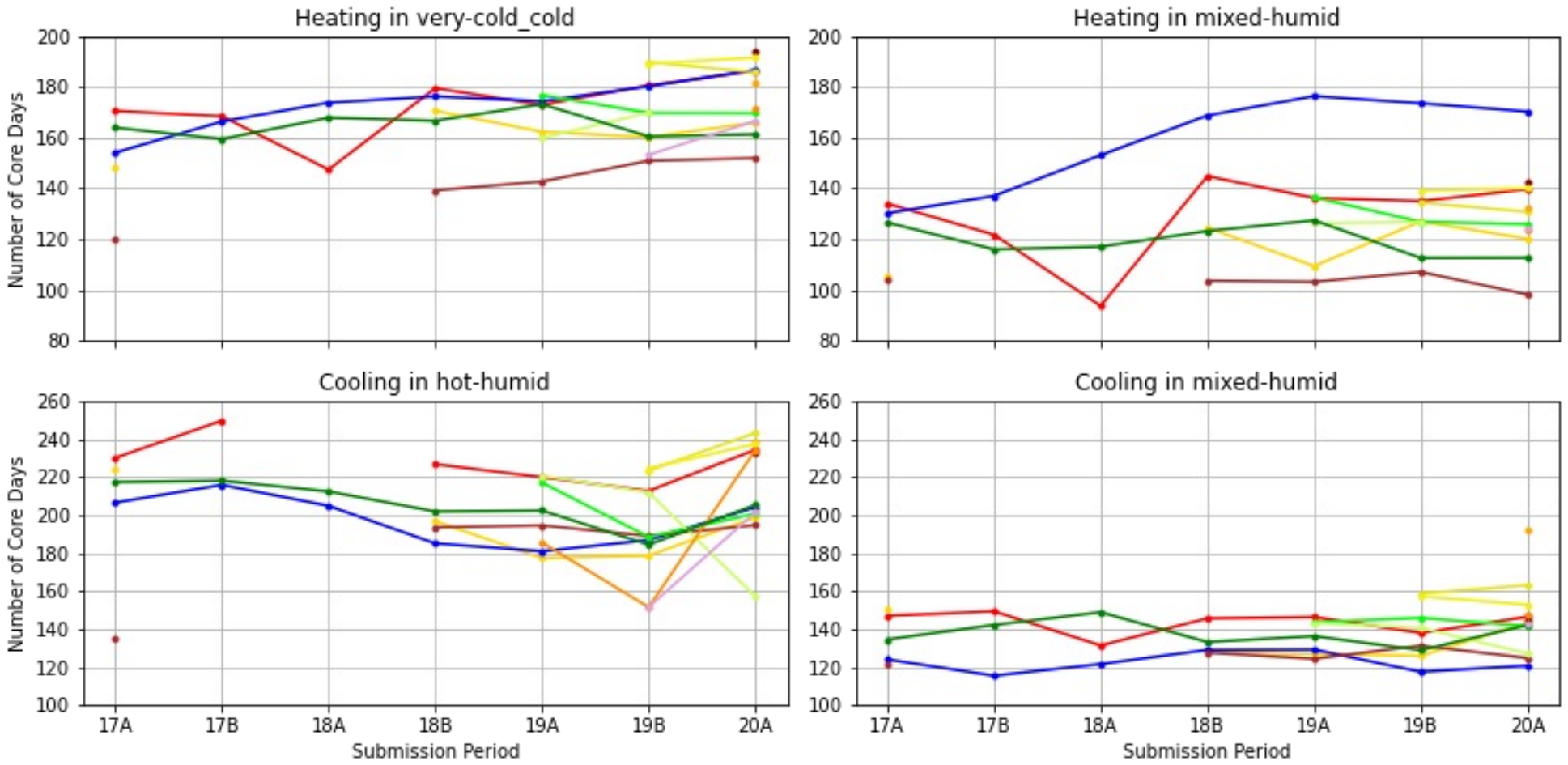
Thank you

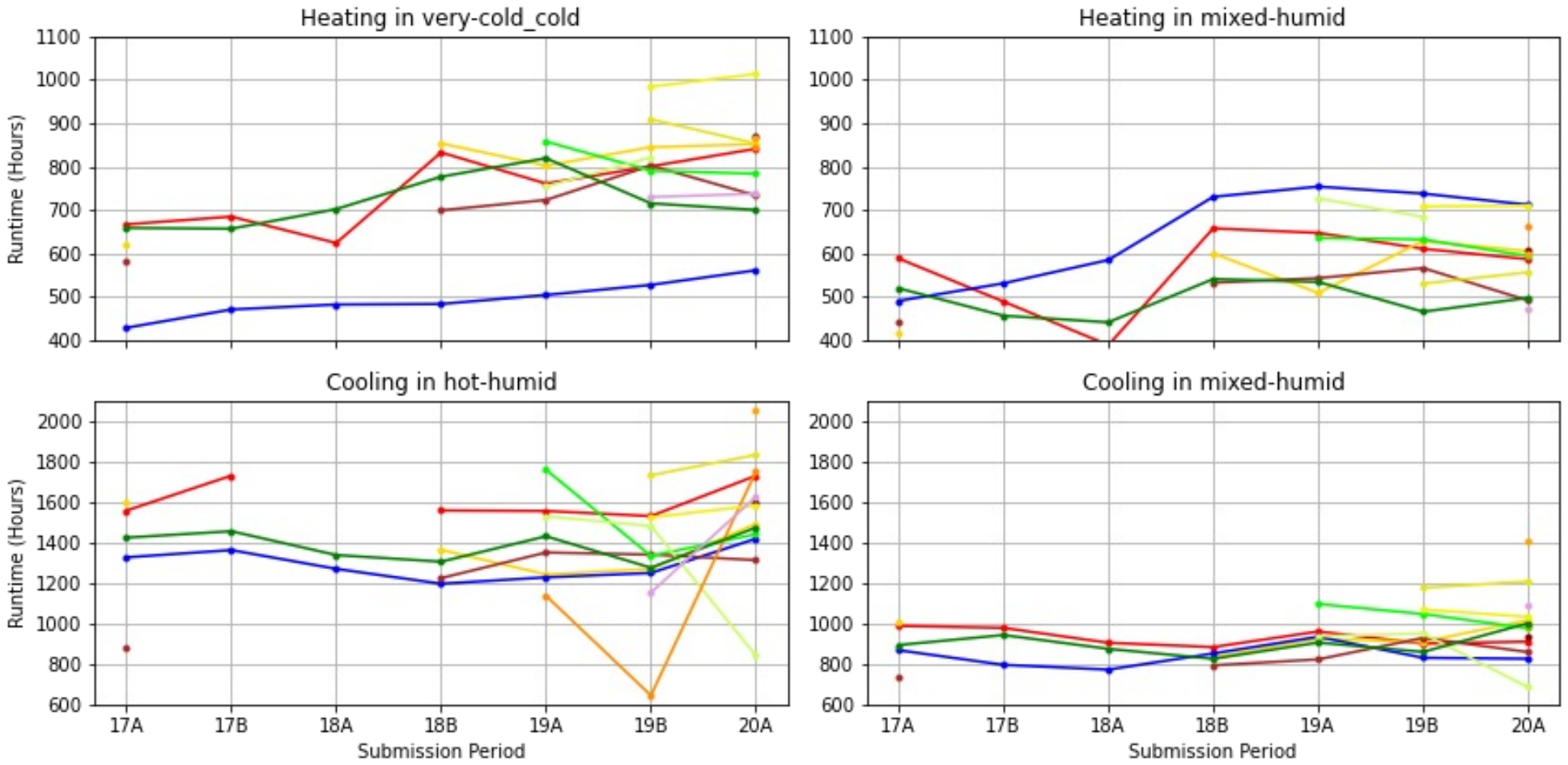
Alan Meier

akmeier@lbl.gov

More years, regions, and thermostats




Heating in very-cold_cold
Heating in mixed-humid
Cooling in hot-humid
Cooling in mixed-humid
Number of Core Days
Submission Period
17A
17B
18A
18B
19A
19B
20A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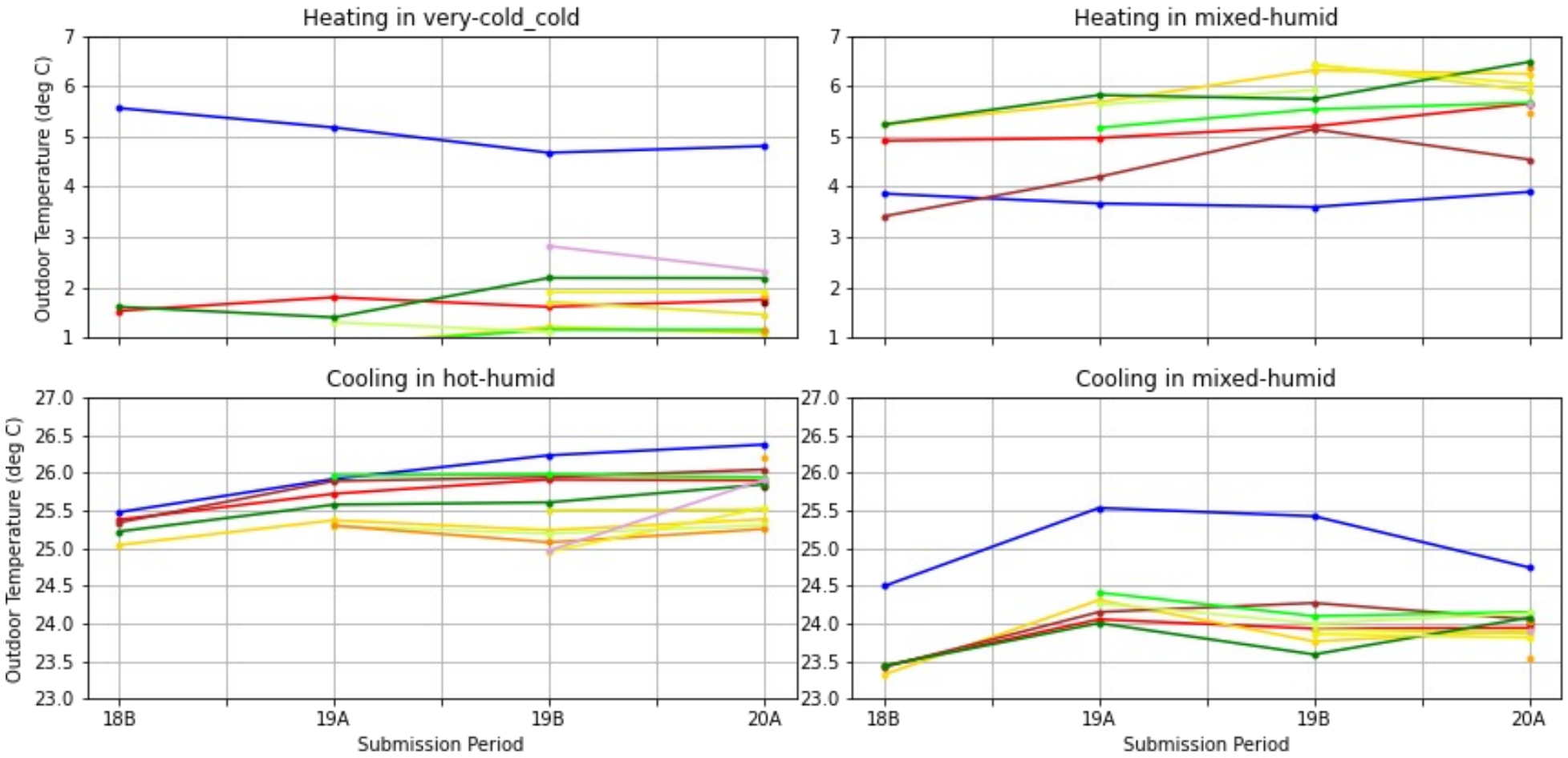
Cooling in mixed-humid
Runtime (Hours)
Runtime (Hours)
Submission Period
Submission Period
17A
17B
18A
18B
19A
19B
20A
400
500
600
700
800
900
1000
1100
1200
1400
1600
1800
2000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Cooling in mixed-humid
Outdoor Temperature (deg C)
Outdoor Temperature (deg C)
Submission Period
Submission Period
18B
19A
19B
20A
1
2
3
4
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6
7
23.0
23.5
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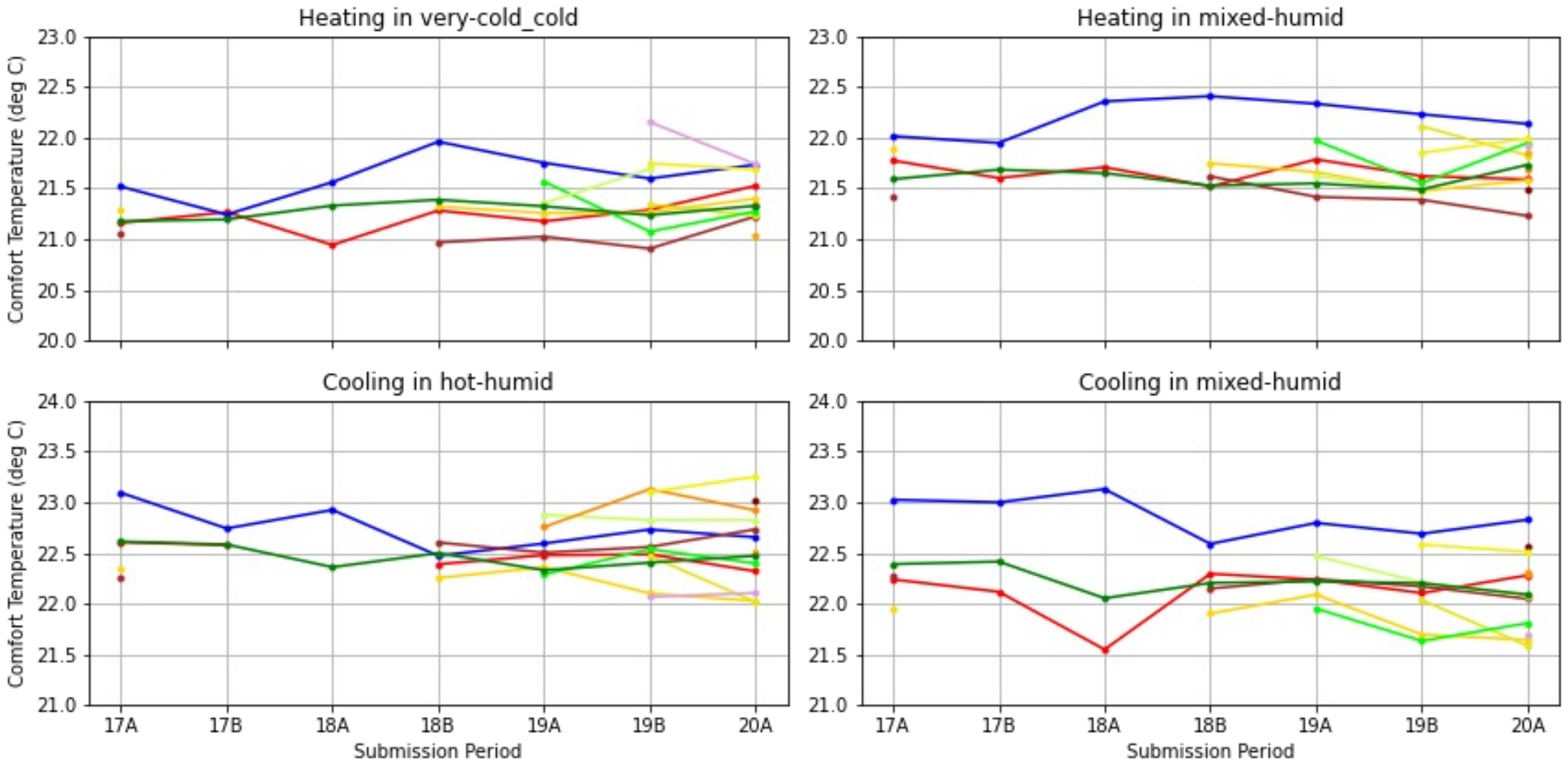
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Comfort Temperature (deg C)
Comfort Temperature (deg C)
23.0
22.5
22.0
21.5
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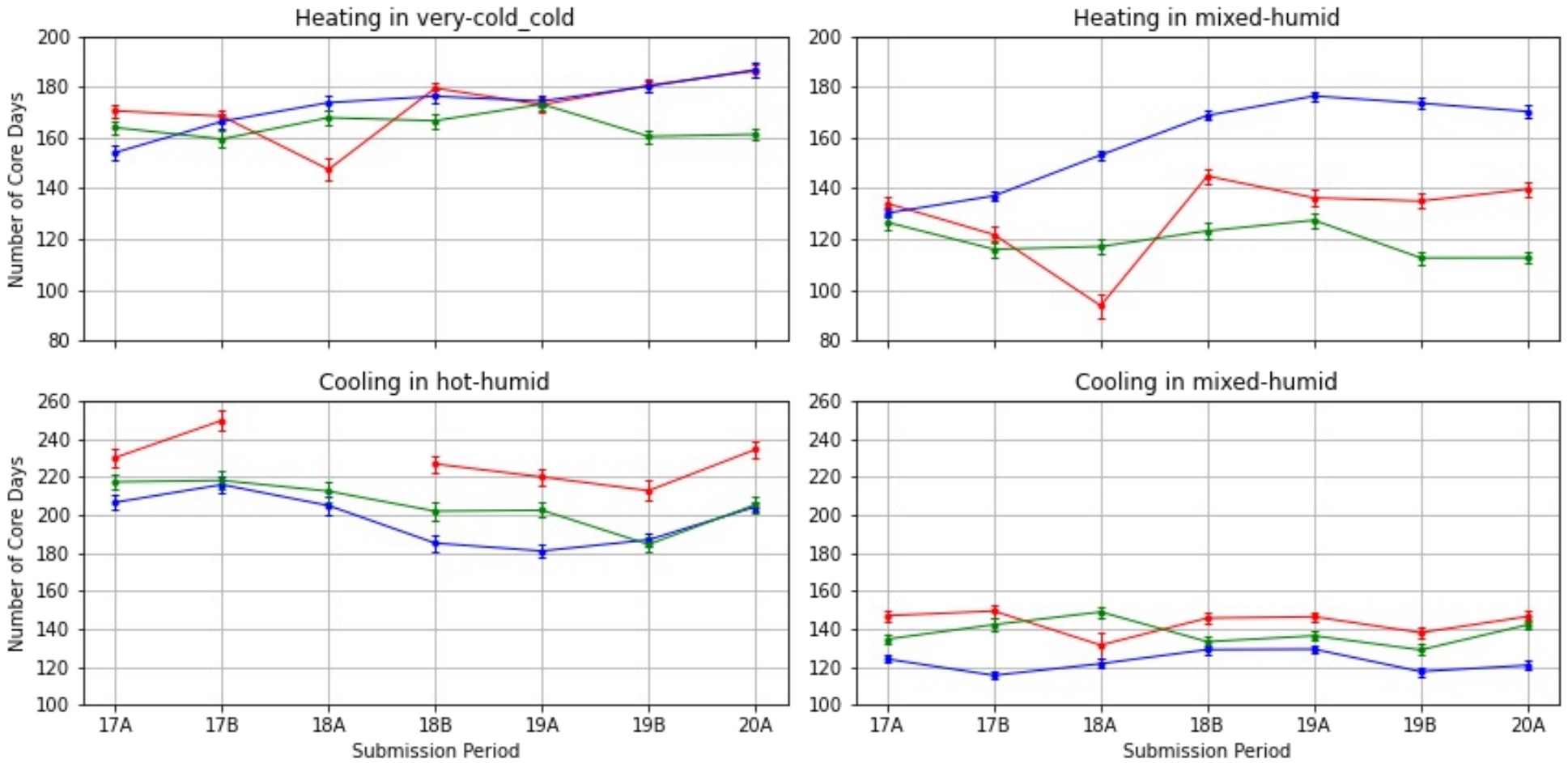
17A
17B
18A
18B
19A
19B
20A
Submission Period
Submission Period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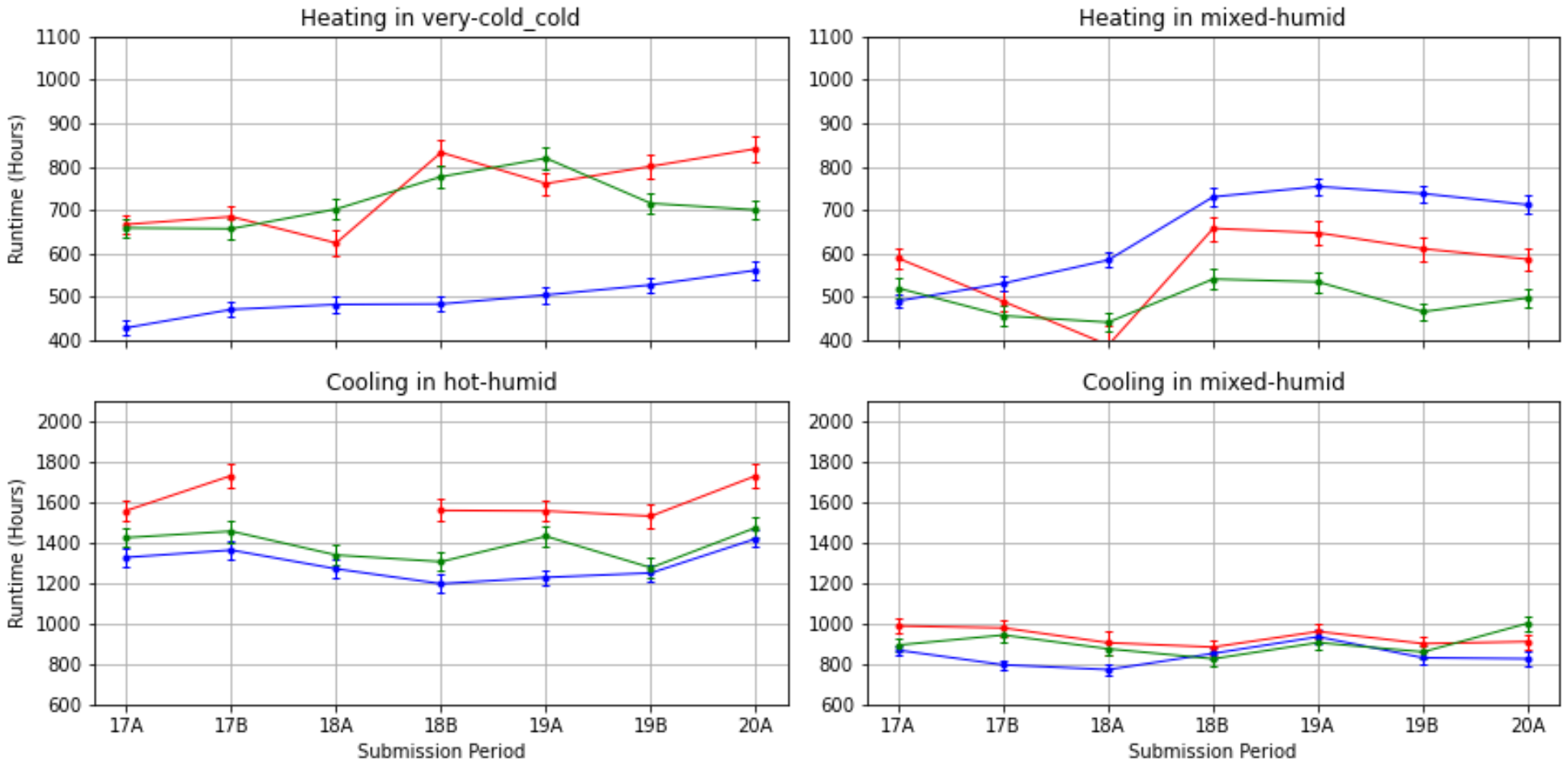
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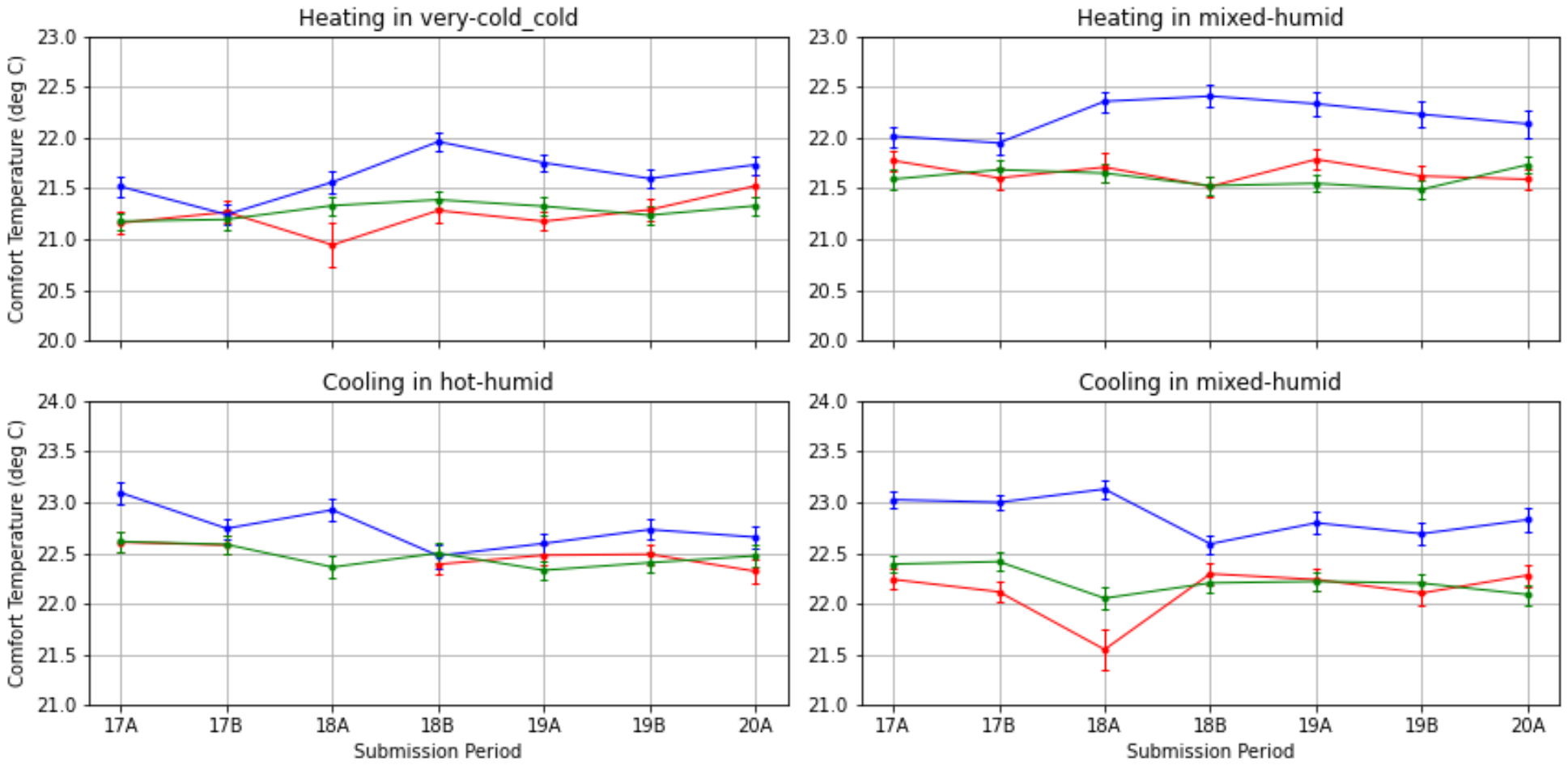
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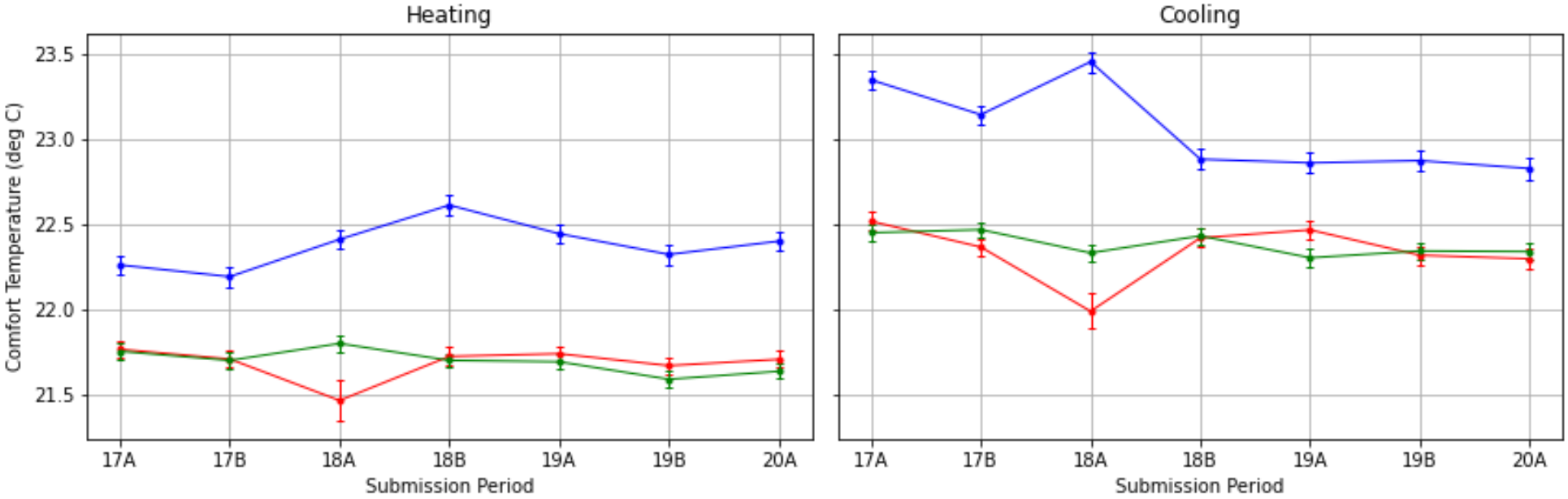
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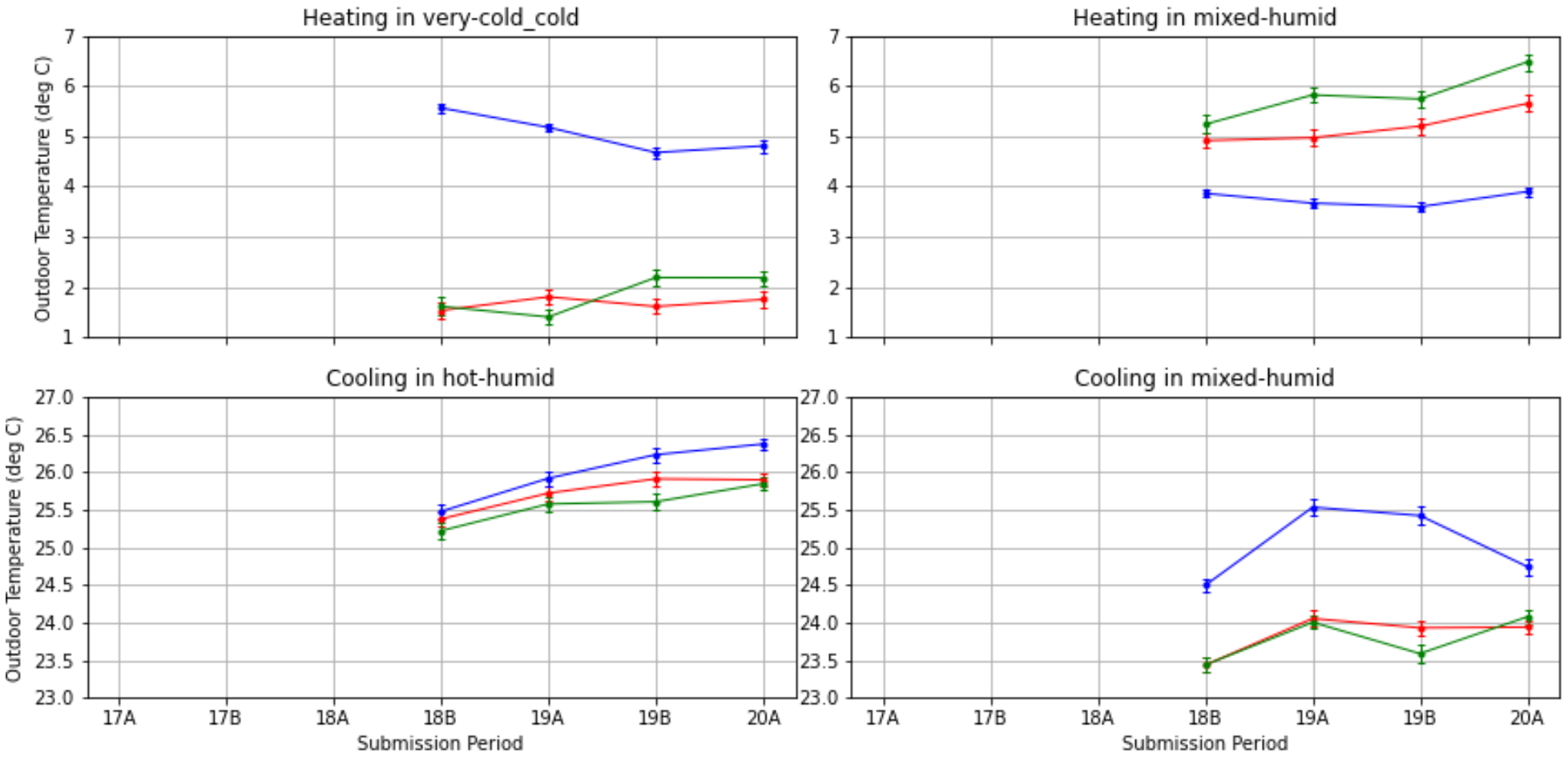
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