ENERGY STAR Connected Thermostats

CT Metrics Stakeholder Meeting Slides

June 23, 2021

Attendees

Abigail Daken, EPA
Abhishek Jathar, ICF for EPA
Alan Meier, LBNL
Leo Rainer, LBNL
Ethan Goldman, Resilient Edge
Craig Maloney, Intellovations
Michael Blasnik, Google/Nest
Kevin Trinh, Ecobee
Michael Sinclair, Ecobee
Brad Powell, Carrier
David Frank, Carrier
Jason Thomas, Carrier
Theresa Gillette, JCI
Rohit Udavant, JCI
Bernard Clement, JCI
Diane Jakobs, Rheem
Carson Burrus, Rheem
Chris Puranen, Rheem
Glen Okita, EcoFactor
John Sartain, Emerson
Eric Ko, Emerson
Albert Chung, Emerson
James Jackson, Emerson
Daniel Stephan, Emerson
Tom Lorenz, Emerson
Mike Lubliner, Wash State U
Charles Kim, SCE
Dan Fredman, VEIC
Robert Weber, BPA
Phillip Kelsven, BPA
Casey Klock, AprilAire
Wade Ferkey, AprilAire
Ulysses Grundler, Trane
John Hughes, Trane
Mike Caneja, Bosch
Sarathy Palaykar, Bosch
Mike Clapper, UL
Alex Boesenberg, NEMA
Jon Koliner, Apex Analytics
Hassan Shaban, Apex Analytics
Michael Siemann, Resideo
Arnie Meyer, Resideo
Aniruddh Roy, Goodman/Daikin
Jia Tao, Daikin
Dan Baldewicz, Energy Solutions for CA IOUs
Dave Winningham, Lennox
Dan Poplawski, Braeburn
Natasha Reid, Mysa
Mustafa Elsisy, Mysa
Peter Gifford, Mysa
Vrushali Mendon, Resource Refocus
Riana Johnson, Illume Advising

Agenda

- Software updates V2.0
- Aux runtime
- Vendor anonymity update
- Setbacks v/s Savings
- Missing data updates (if time allows)

Software Updates: V2.0

- Clarification for how Temperature In / Temperature Out are interpolated.
  - Gaps of two or less hours are "healed" by interpolating (limit 1, forward and backward).
  - Larger gaps cannot be "healed", and any days with these larger gaps will be removed from consideration.
  - Changes are currently under the following branch:

`https://github.com/EPAENERGYSTAR/epathermostat/tree/feature/epa2.0_temperature_rules_fix`

  - *(Will be merged into the* `epathermostat_2.0` *branch pending discussion.)*

Auxiliary runtime vs. Emergency run time

- Currently do not count resistance heat run time when compressor is off in RHU metric.
- Decision made early in RHU development presuming resistance heat runtime without compressor run time occurs only when the compressor is not working.
- However, in the 30 – 45 °F bin that we've focused on for the RHU metric, algorithms can waste energy through needlessly cautious compressor lockout temperatures.
  - Products are not differentiated on this as long as the RHU metric excludes "emergency" resistance heat run time
  - Updated RHU metric filters outliers which should eliminate broken systems; also requires >30 hrs annual heating run time in the outdoor temperature bin to exclude systems working beyond their design temperatures
- A small adjustment to the software could include emergency heat run time in RHU. Shall we try it?

Discussion: Aux runtime

- Emergency heat is supposed to be a specific call for emergency heat when the compressor is broken. Eliminate distinction between emergency and aux heat, relying on filtering to eliminate broken systems. Also, true broken systems are rare.
- Can true emergency heat be ID'ed from the thermostat? Yes for some, not sure for others.
- Another 2 stakeholder acknowledges value.
- 3 distinctions: resistance heat with compressor, without compressor, and when compressor is broken.
- Are there problems with some compressors running at or below 30F? There may be economic reasons in a dual fuel situation, but dual fuel is not treated. Also, in that case, the aux heat would be off here.
- CONSENSUS: Yes we should try it – will request additional data to see effect on RHU scores.

Vendor Anonymity Update

- Have answers from seven of ten partners on these questions.
- EPA knowing which vendor submitted which statistics results file (containing aggregated results of annualized analysis for the entire sample of installations)
  - Only one partner said no
  - Will make one last effort to connect with partners and/or resolve concerns
- Submitting the metrics file (containing annualized analysis of individual installations)
  - Most partners thought it was worthwhile.
  - Minority needed to adjust contents and/or check with lawyers.
  - EPA will continue to seek clarity with partners.
- Partners evenly split about advisability of publishing metric scores, and some who said yes had reservations. No further action on this at this time.

EPA ENERGY STAR Performance Metric for Smart Thermostats

Setbacks vs. Savings

23-Jun-2021
mblasnik@google.com

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EPA ENERGY STAR Performance Metric

How to measure the "efficiency" of a thermostat in use?

Energy savings primarily from more efficient temperature settings

But comfort preferences may vary between thermostat models due to demographics

Solution: measure amount of setback achieved relative to a customer's "comfort temperature" and calculate % savings from that setback for each thermostat

General Methodology

- Define Comfort Temperature
  90th percentile of indoor temperatures on days with >30 minutes of heating and no cooling
- Fit linear model of 12 months of daily heating runtime based on indoor and outdoor temperatures
  $\text{runtime} = \boldsymbol{\alpha} * \Sigma_{1\text{-}24}[\ \max(0, (T_{in} - T_{out} - \boldsymbol{\tau}))\ ]$
- Calculate % savings for each device compared to constant baseline at $T_{in}=T_{comfort}$

EPA Energy STAR Performance Metric: Issues

Metric assumes that comfort temperature is not affected by thermostat

- Thermostat features may lead to more efficient comfort temps that save energy but reduce score

Unequal weighting + small samples + attrition -> fairly high variance

Real energy savings depend on baseline (no CT) score, which is unknown

Only includes setback savings, not savings from other features e.g., fan overrun, aux control, HVAC monitoring, etc.

Results vary with weather

Results screened to exclude poor fits (cv(rmse)>=60%) or "bad" parameters (tau not 0-25)

- attrition is fairly large (20%-25%)
- tau<=0 in 15%-20% of heating models but only 2% of cooling models

Attrition increases variance and may create bias -- can we reduce it?

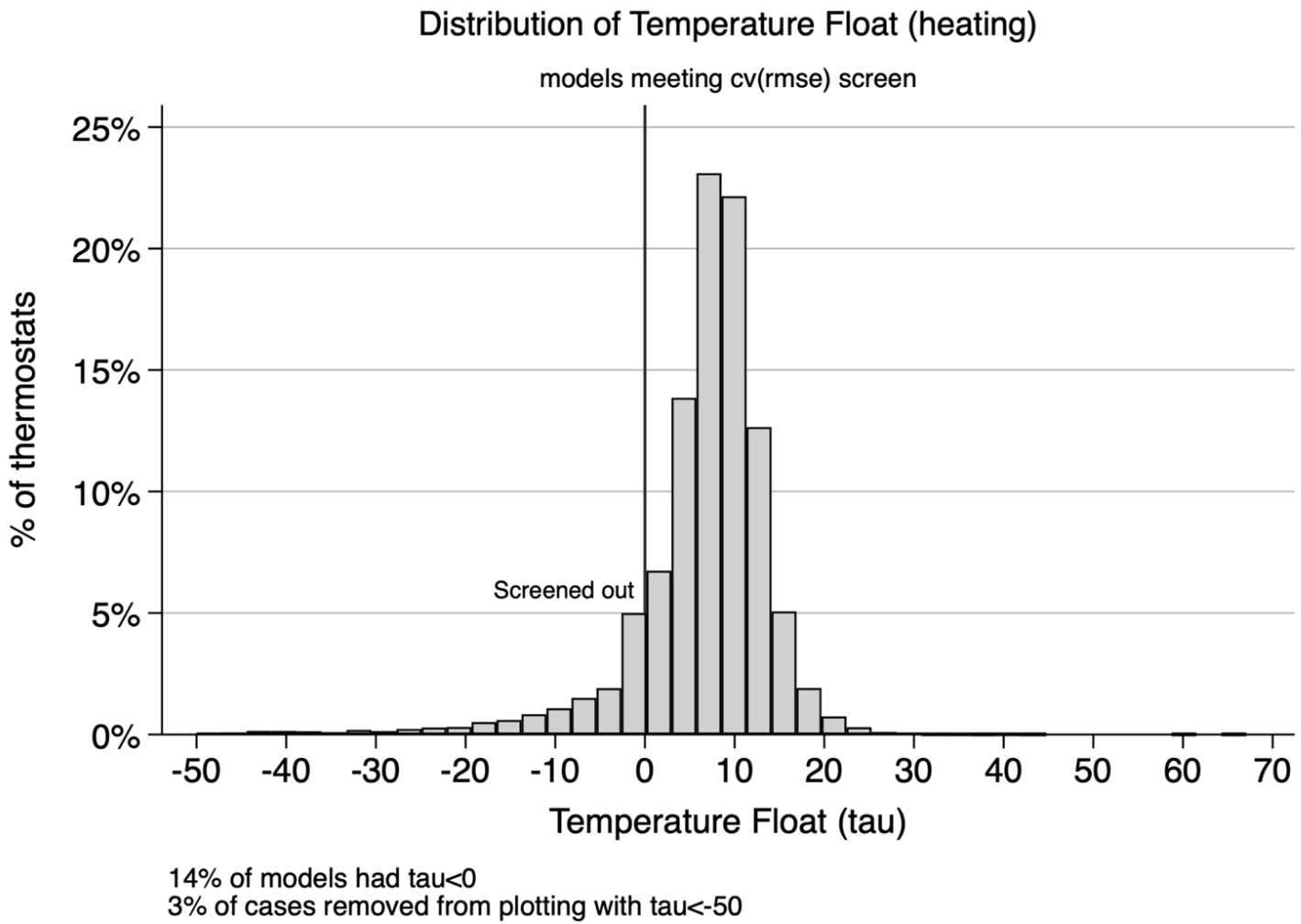
% Heating Savings/°F setback vs T float (tau): cold climate

tau <=0 is largest source of heating model attrition

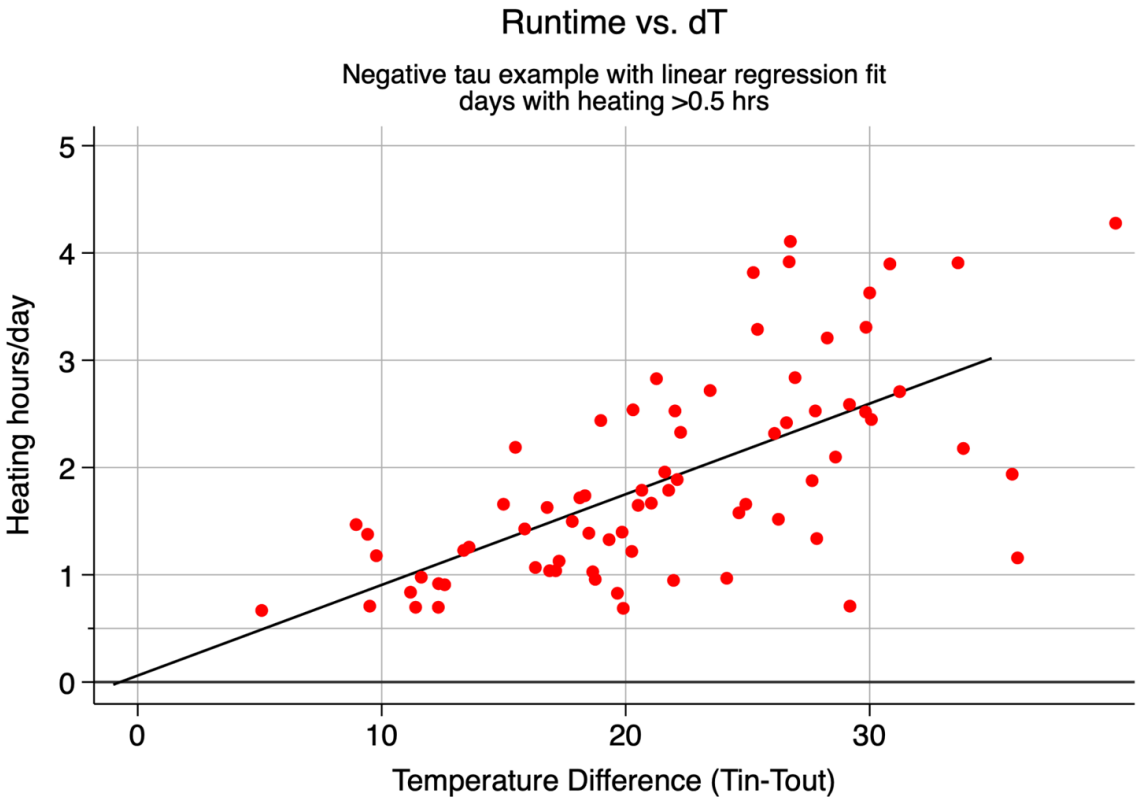
noisy data can lead to tau<=0

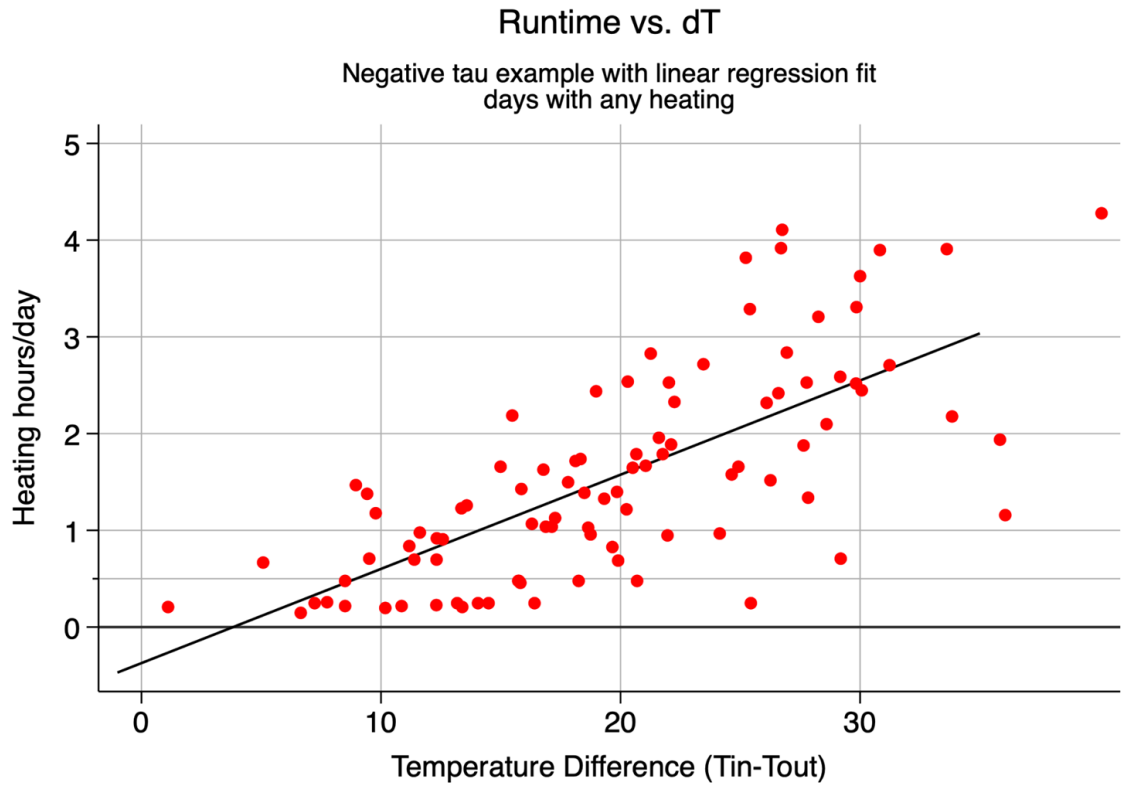
heating day required 30 minute runtime can also lead to low tau

Low tau in:
25% of hot dry climate
21% of hot humid climate
11% of cold climate
33% of vacation homes
25% of multi-thermostat homes



Heating runtime vs. temperature difference





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EPA ENERGY STAR Performance Metric: closer look

Model: daily heating runtime = $\boldsymbol{\alpha} * \Sigma_{1\text{-}24}[\ \max(0, (T_{in} - T_{out} - \boldsymbol{\tau})\ )\ ]$

where $\boldsymbol{\alpha}$ = heating slope = runtime hours /°F temperature difference to overcome

$\boldsymbol{\tau}$ = temperature float = °F of non-HVAC heating above outdoor temperature
= (internal gains + solar gains) / building heat loss rate

% savings = $1 - (\ runtime_{actual} / runtime_{comfort}\ )$

$= 1 - [\alpha * \Sigma_{1\text{-}24}[\ \max(0, (T_{in} - T_{out} - T_{float}))\ ]] / [\alpha * \Sigma_{1\text{-}24}[\ \max(0, (T_{comfort} - T_{out} - T_{float}))\ ]\ ]$

$= 1 - \Sigma_{1\text{-}24}[\ \max(0, (T_{in} - T_{out} - T_{float}))\ ] / \Sigma_{1\text{-}24}[\ \max(0, (T_{comfort} - T_{out} - T_{float}))\ ]$

approximate hourly sum using averages (true for cold days), then

% savings = $1 - (T_{in} - T_{out} - T_{float}) / (T_{comfort} - T_{out} - T_{float})$

$= (T_{comfort} - T_{in}) / (T_{comfort} - T_{out} - T_{float})$

define $T_{setback} = (T_{comfort} - T_{in})$, then

% savings = $T_{setback} * (1 / (T_{comfort} - T_{out} - T_{float}))$

Performance Metric: % savings/°F setback

% savings = $T_{setback}$ * (1 / ($T_{comfort}$ - T_{out} - T_{float}))

Thermostat provides savings by increasing $T_{setback}$, primarily by reducing T_{in}

Second term defines the scaling factor of % savings/°F setback

- equals reciprocal of the float-modified temperature difference
- primarily f(weather, home characteristics)
- not affected by the thermostat (could argue about $T_{comfort}$)

% savings/°F setback increases with

- warmer outdoor temperatures
- more temperature float
- lower comfort temperature (but reduces $T_{setback}$)

Q1: Should a thermostat get a better score because their customers have more internal gains or better insulated homes or live in warmer parts of the climate zone?

Q2: Do we need to drop 10%-15% of thermostats because the model estimated T_{float} <0?

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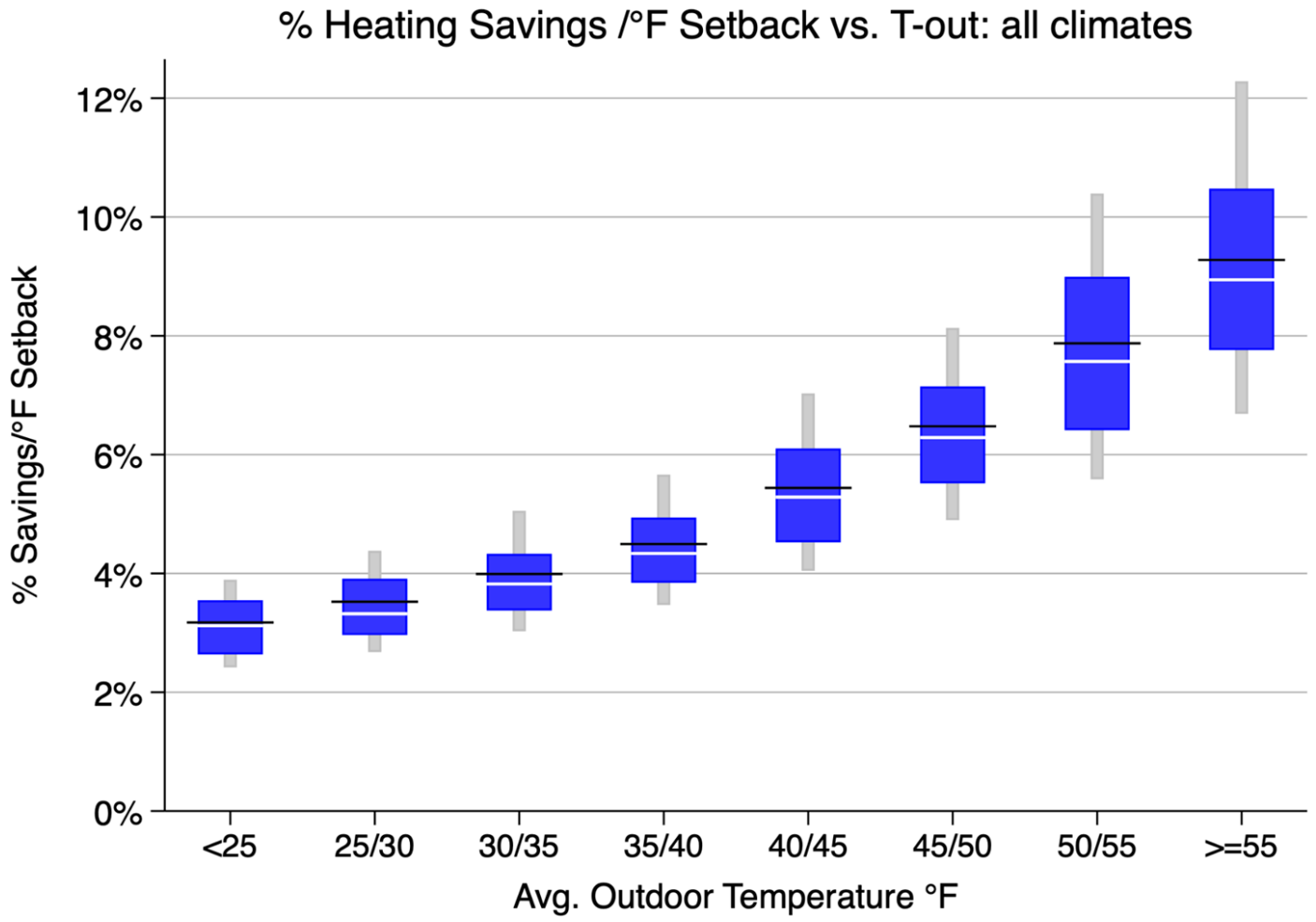
% Heating Savings/°F setback vs Outdoor Temp



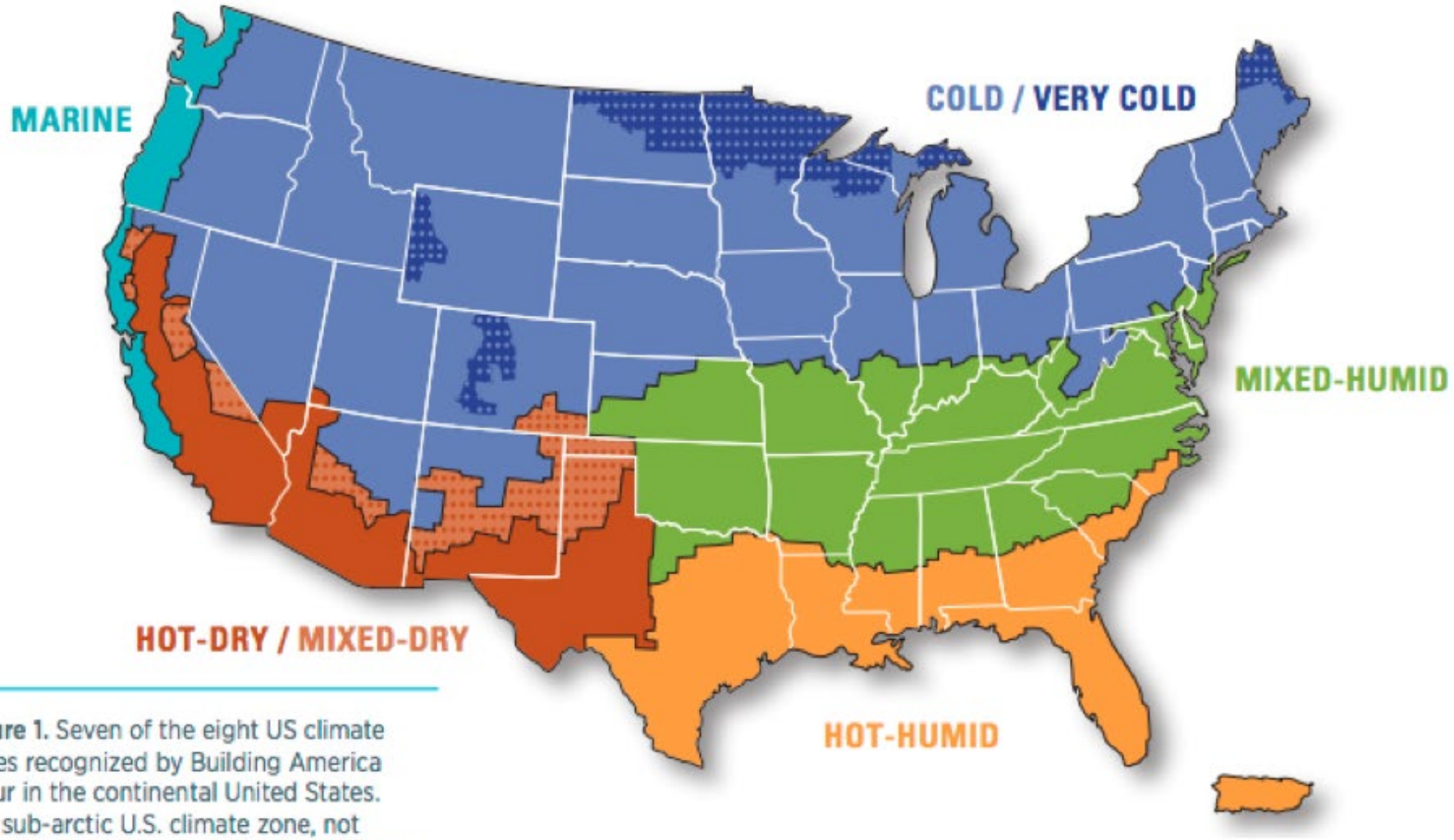


Figure 1. Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

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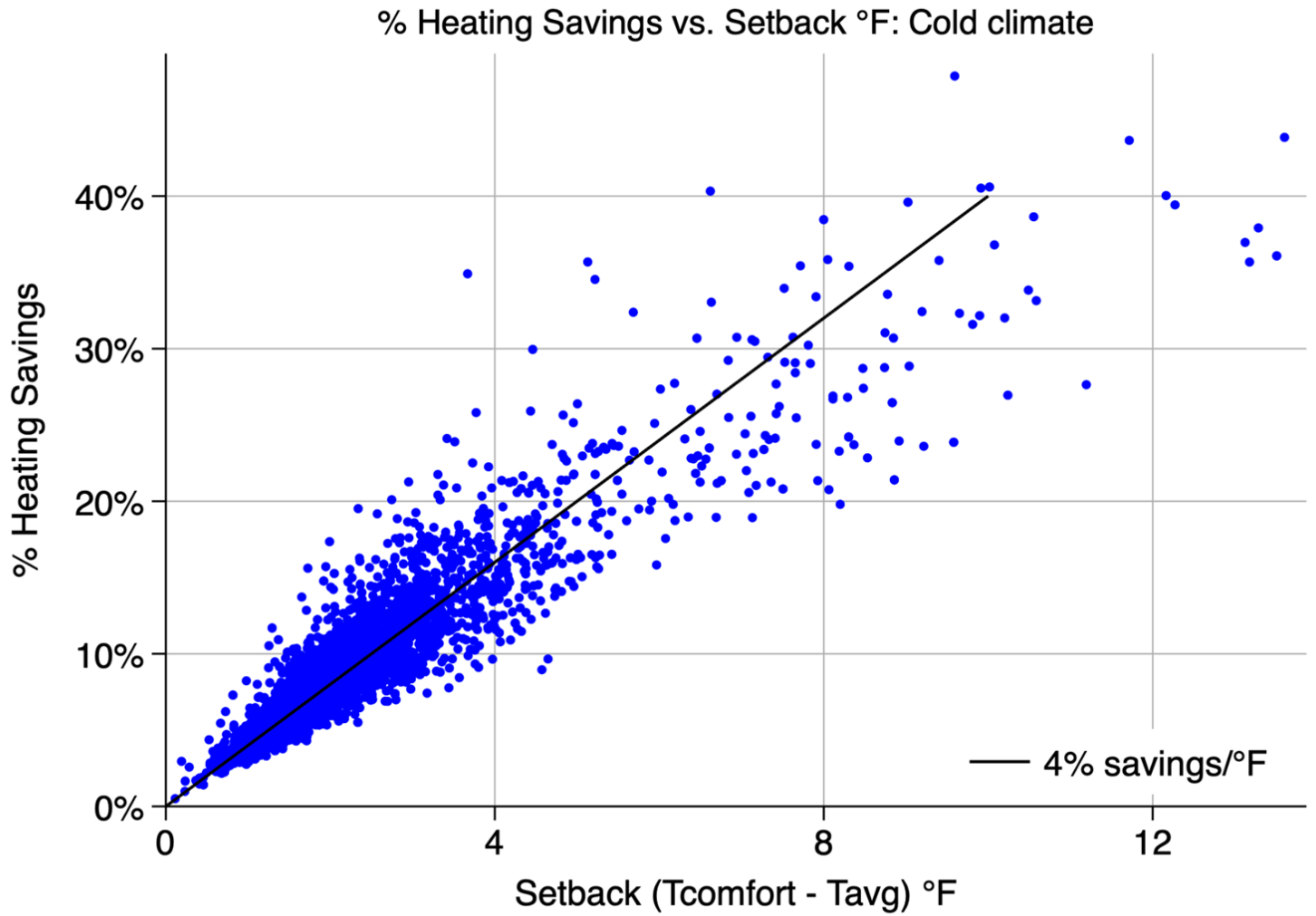
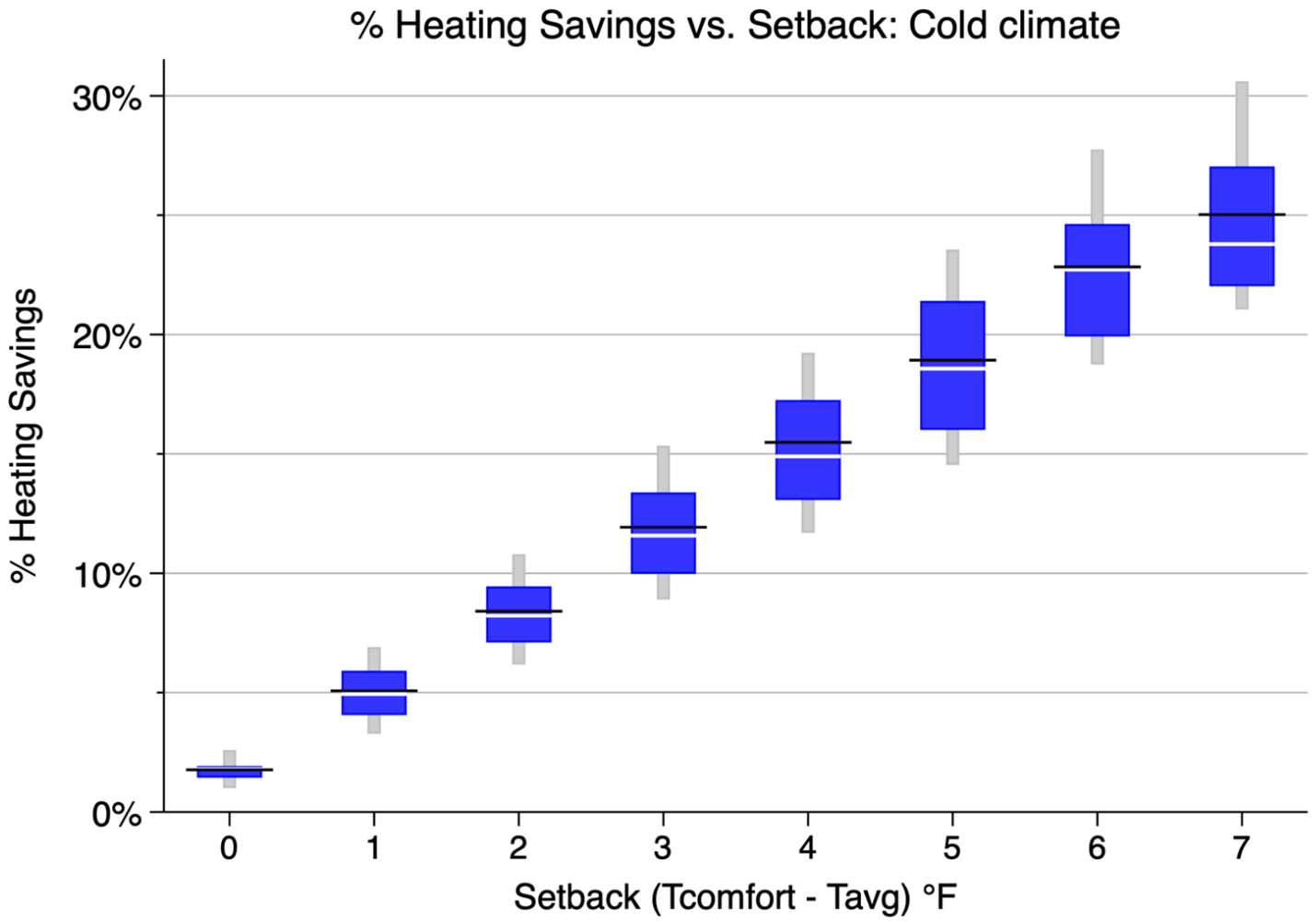
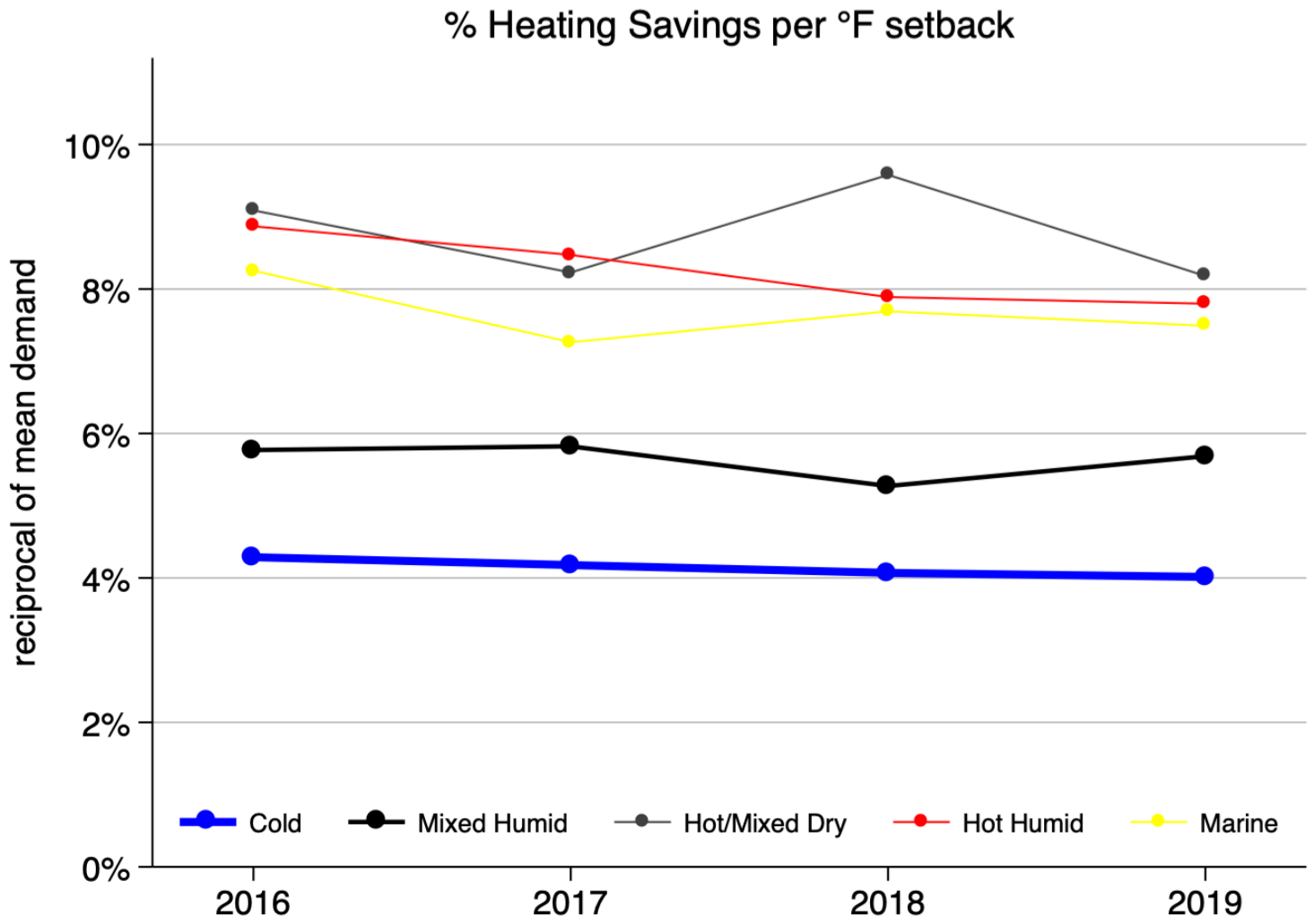
% Heating Savings vs $T_{setback}$ in cold climate



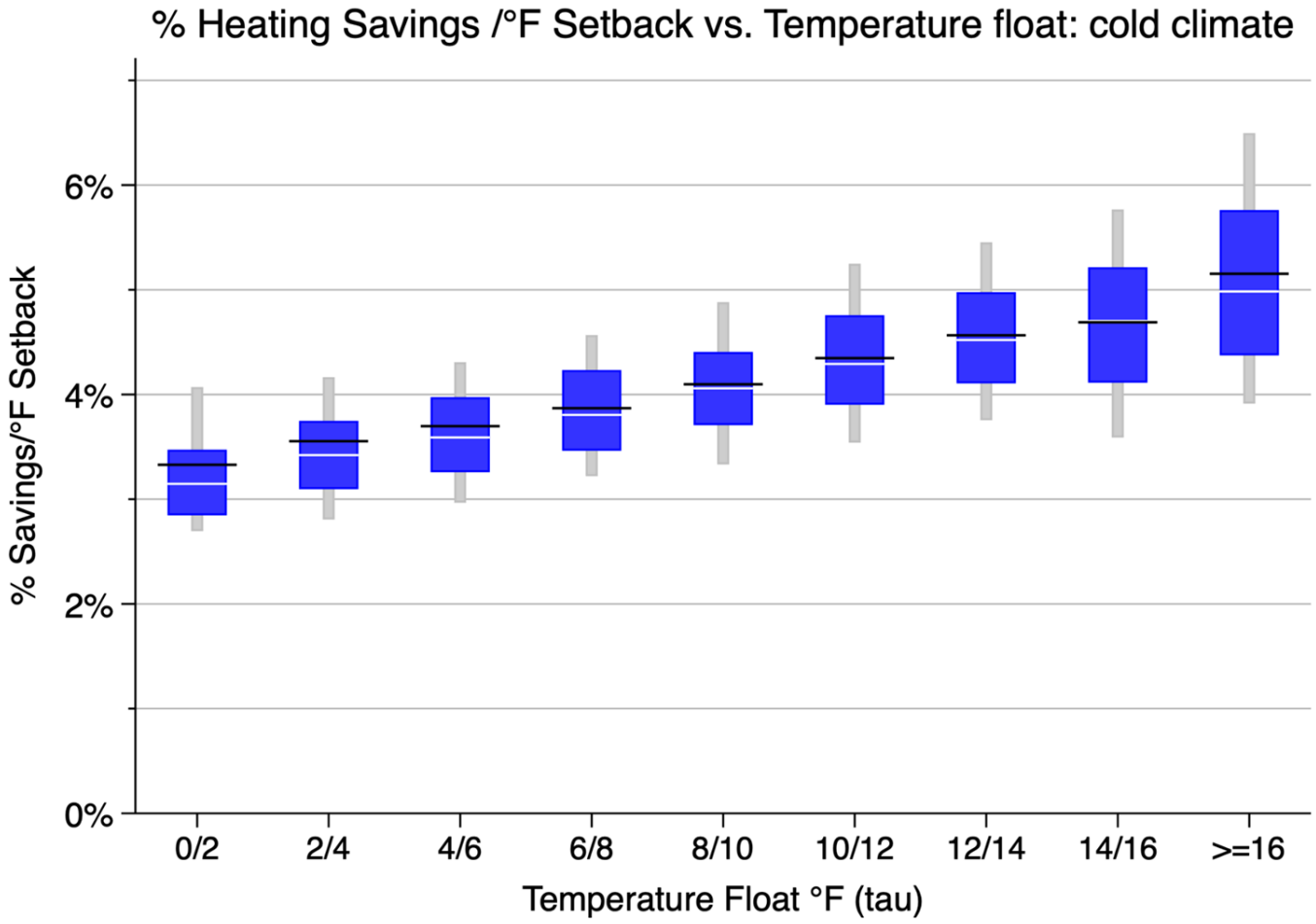
% Heating Savings vs $T_{setback}$ in cold climate



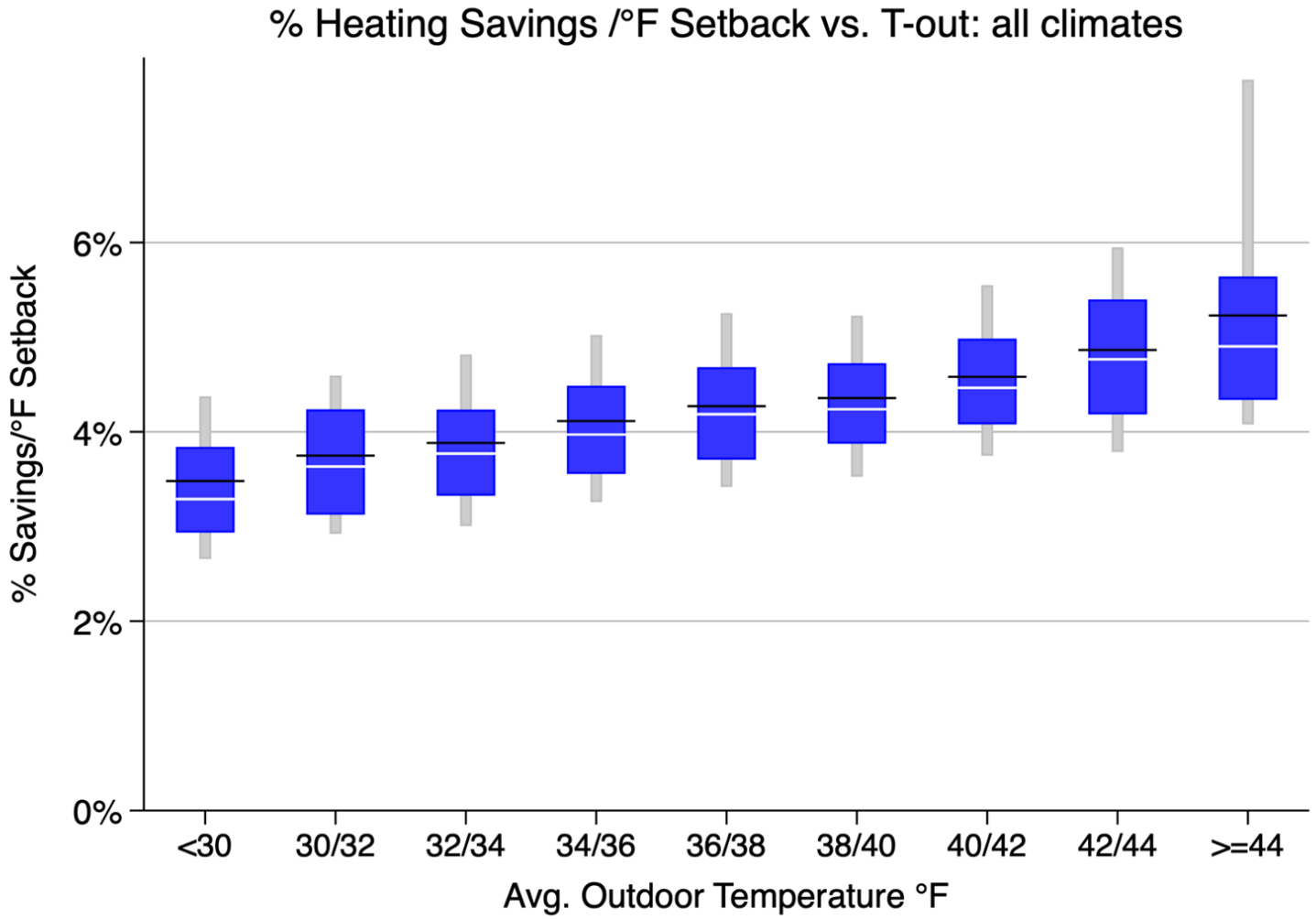
% Heating Savings per degree setback by climate



% Heating Savings/°F setback vs T float (tau): cold climate

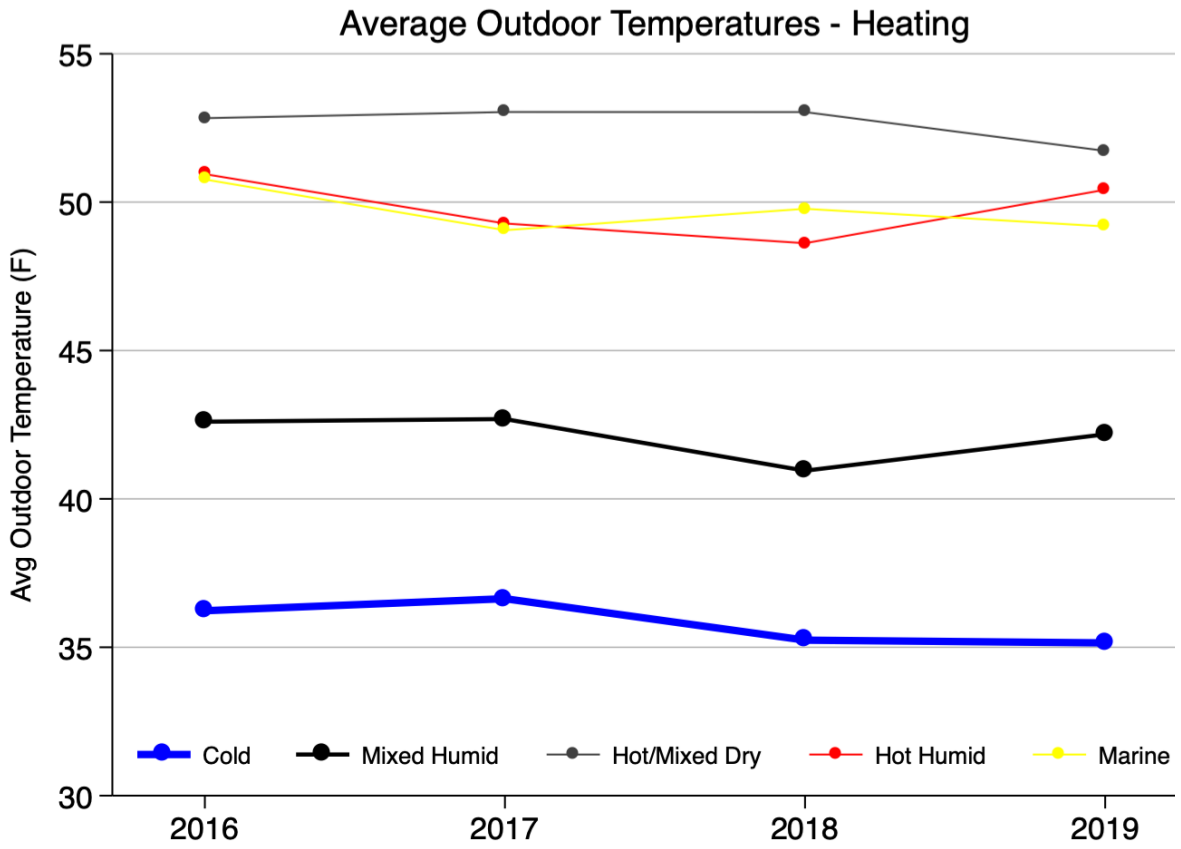


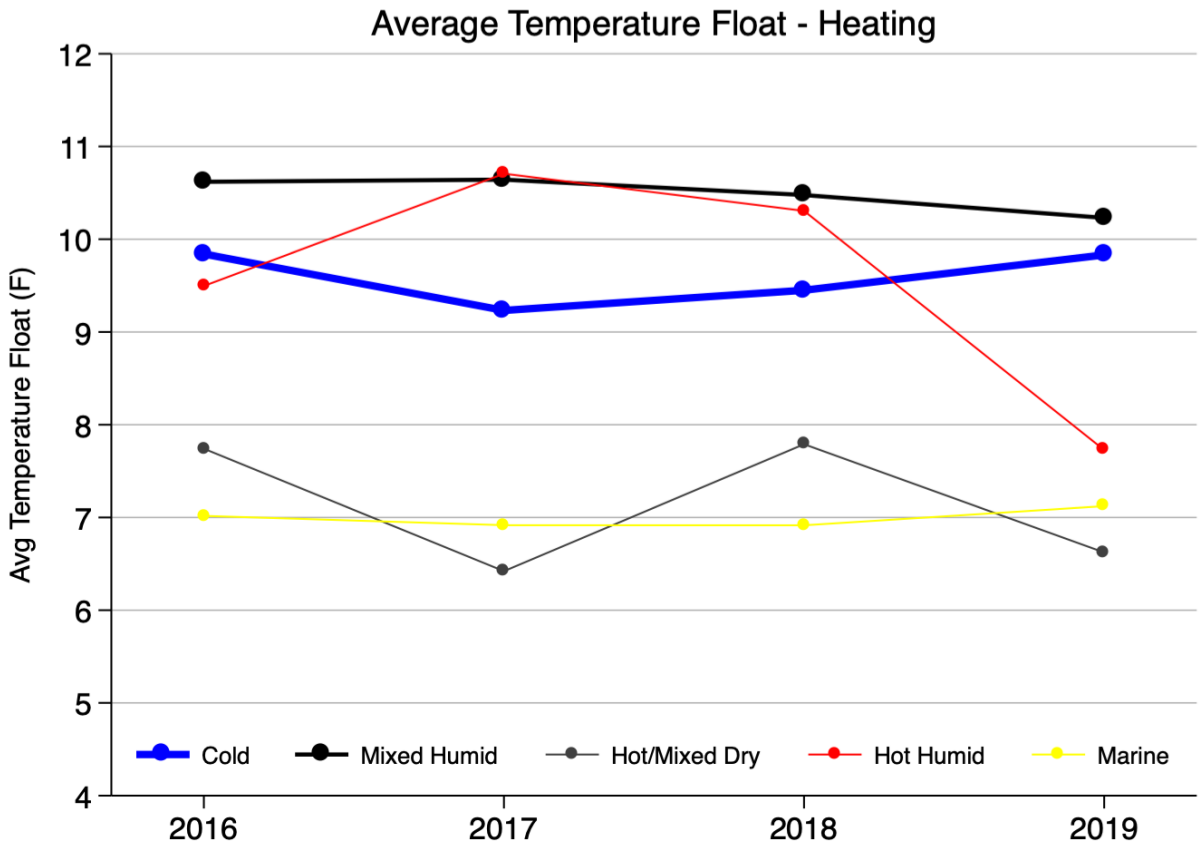
% Heating Savings/°F setback vs Outdoor Temp: cold climate



T-out and Temperature Float

Should variations in weather or average tau values year-to-year affect savings scores?





Options to Reduce Attrition / Improve Metric

Change screening criteria for heating models and allow tau <0 (maybe >-5?)

Change model fitting approach to penalize unusual tau

full Bayesian

or simply add residuals from (tau - mean tau)/(std dev of mean tau) to least squares fit

Don't use fitted model when tau<= and instead use average % savings/setback for climate zone or weather bin

Drop the statistical modeling and make metric based on achieving certain setback

Leave things as is

Other?

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Discussion: Average vs Comfort temperature

- If the fit comes off as <0, you can pin it as zero and refit
- Can also do a grid search for values of tau from 0 to 15 (fit at each tau) and choose the best one
- Is the T difference meaningful if the home responds very differently than what we expect?
- Some thermostats include a large number of points with less than half an hour of runtime, which will kill the CVRMSE.
- Interested in either Bayesian or grid search models, but would expect goodness of fit to suffer somewhat
- EPA considered a pure setback metric but didn't use it because we were concerned about pinning to an absolute simple indoor temperature, and because we were unsure about relating it to savings. Could be reconsidered with more subtlety.
- Fixed baseline temperature may introduce bias between vendors based on user populations.

Discussion: Average vs Comfort temperature

- Side conversation about the weighting of the various zones in the national metric.
- Btu savings (in terms of load) of 1F change in delta T is similar in all climates on heating days for a given building (UA), but the % savings differ.
- Simpler temperature correction available based on the actual weather experienced by the thermostats in the sample, rather than on TMY. If there is a correlation between total HDD for season and % savings, maybe we could do a correction for a given year for how the HDD/CDD compare to typical. Some subtlety about how we do the HDD/CDD calculation.
- Correct each installation per the climate it actually experienced.
- UK created temperature bins. Could do that for our metric also? Need to think about this in more detail. (Can we get that method presented to our stakeholders?)
- Homes with lower tau tended to have larger setback and lower % savings than other homes.
- Would a larger sample reduce the year-to-year variation? (Or filtering out fewer installations). Variation in samples vs. variation in the weather.

Discussion: Average vs Comfort temperature

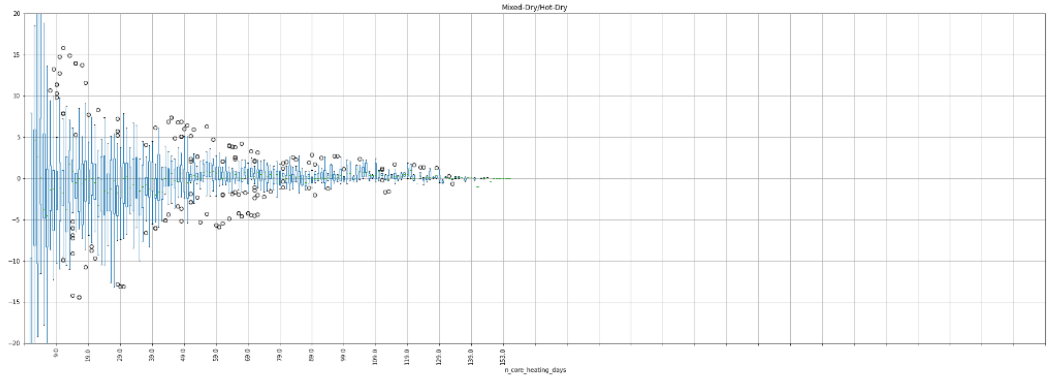
- Do you code set up to run the same sample of thermostats through both E* and UK metrics? Yes, but they're not comparable. In some ways they're using a simpler model, but they are also using all thermostats.
- Reminder: helpful to have something relatable and transparent for consumers, as well as something technically appropriate. Note UK label is not designed for consumers, but for energy modelers and home improvement contractors.

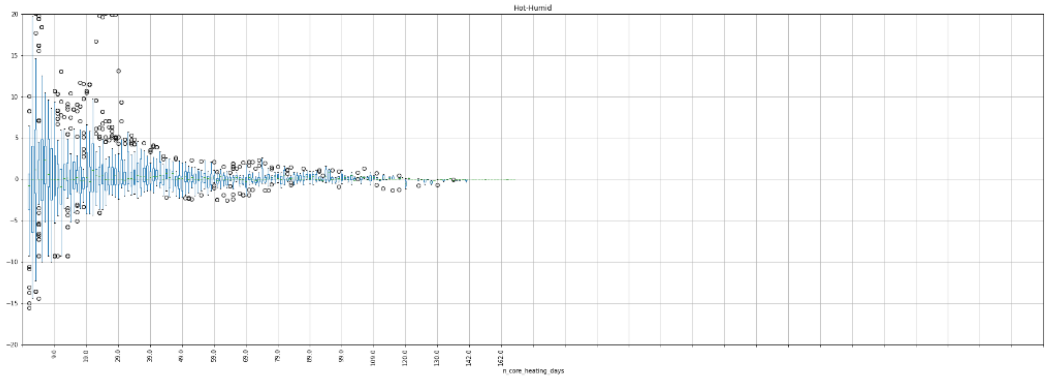
Missing data updates

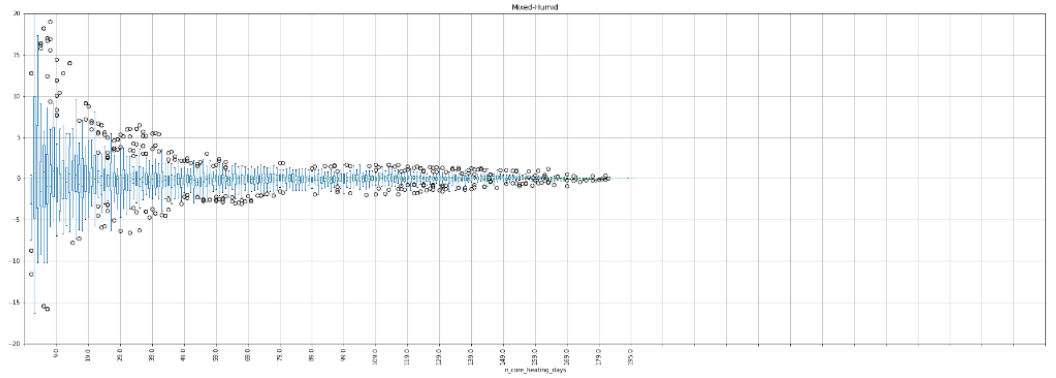
- Problem: too many thermostats are being disqualified due to failing data quality tests
- Possible solution: relax the standard for max number of missing days
- Question: how many days are needed to accurately calculate savings?
- Test: remove random days and compare savings scores
- Results: number of core days remaining vs. absolute change in percent-savings metric
  - By heating/cooling
  - By climate zone

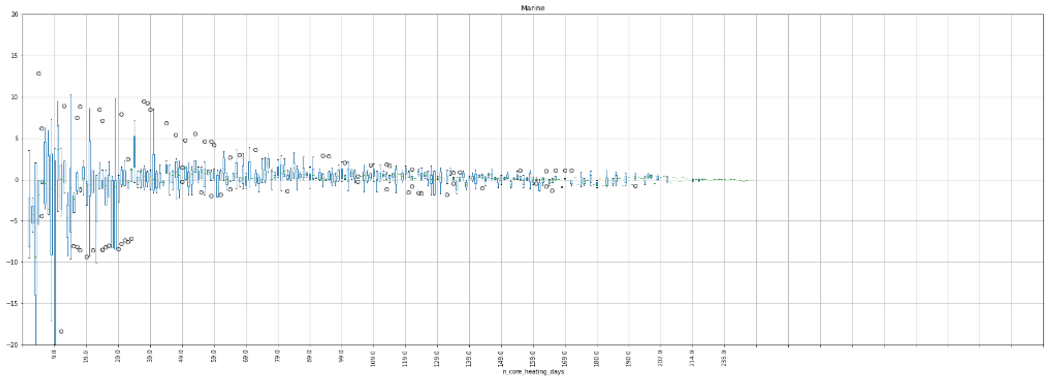
- Remaining open question: how many of the tstats that drop out are affected by missing data?

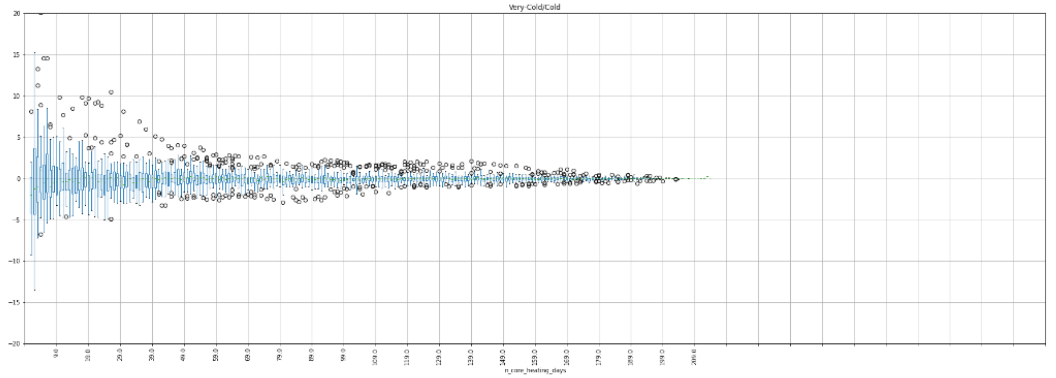
Heating Savings: Change vs. Remaining Core Days



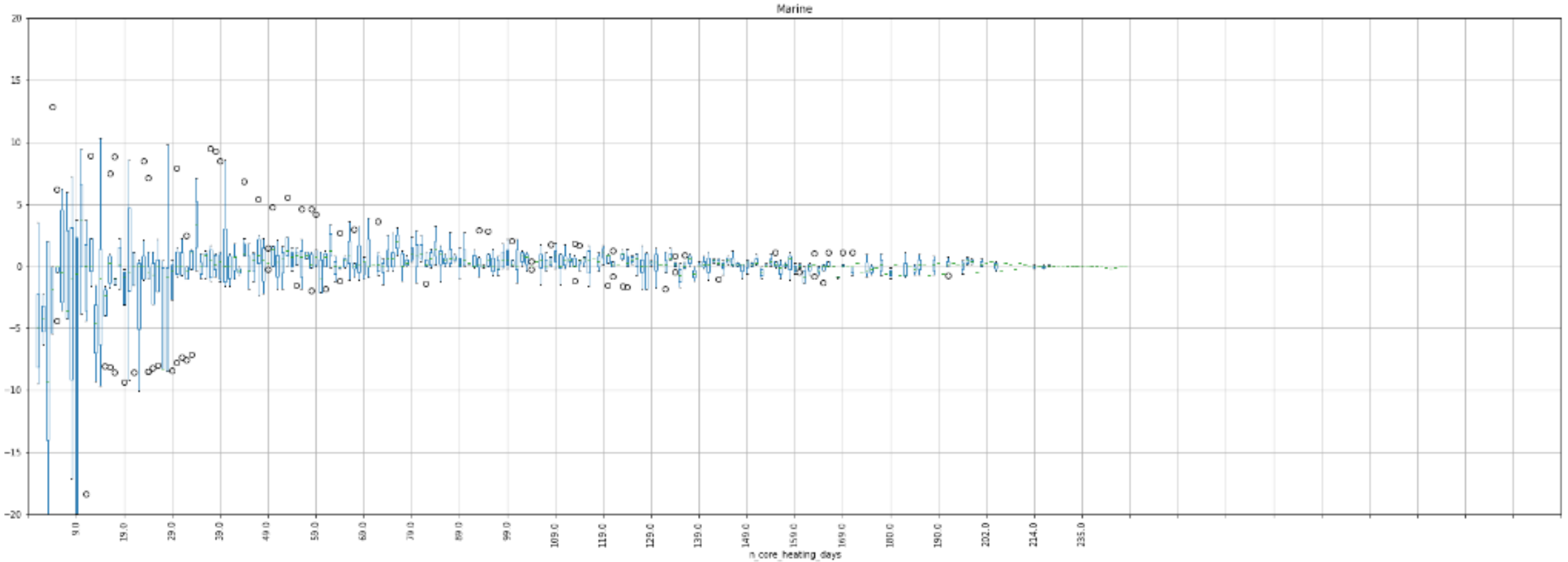




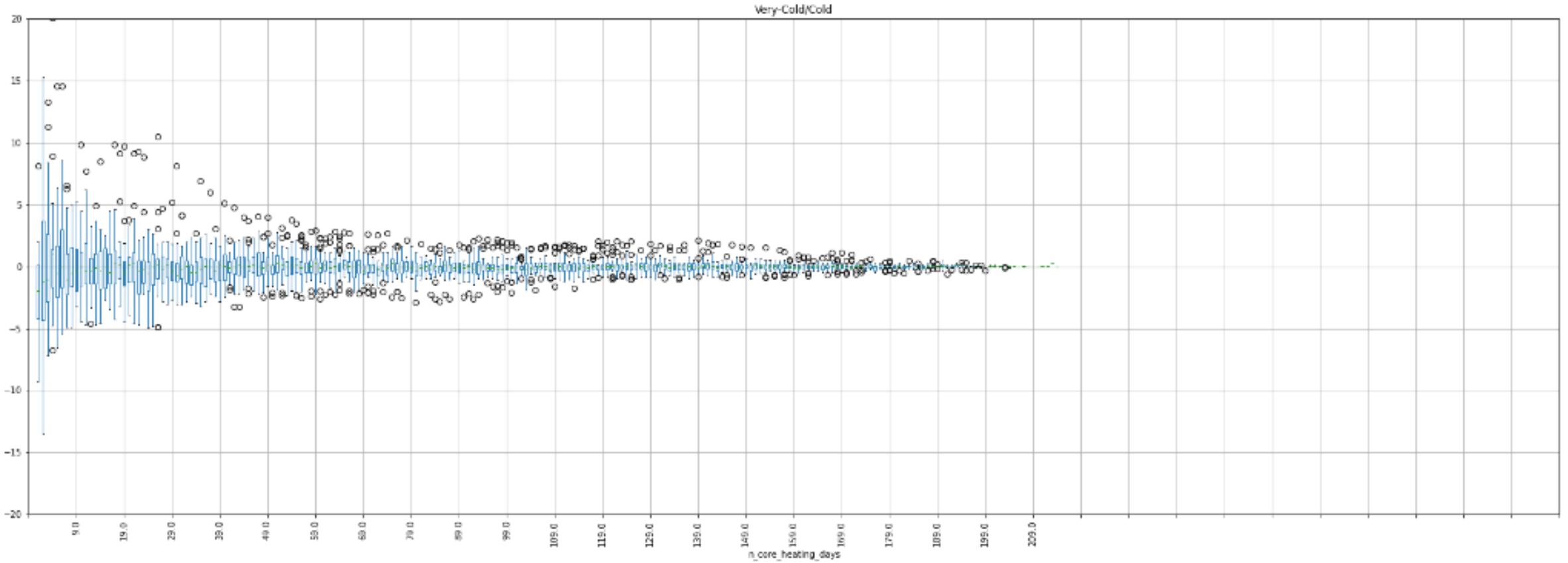




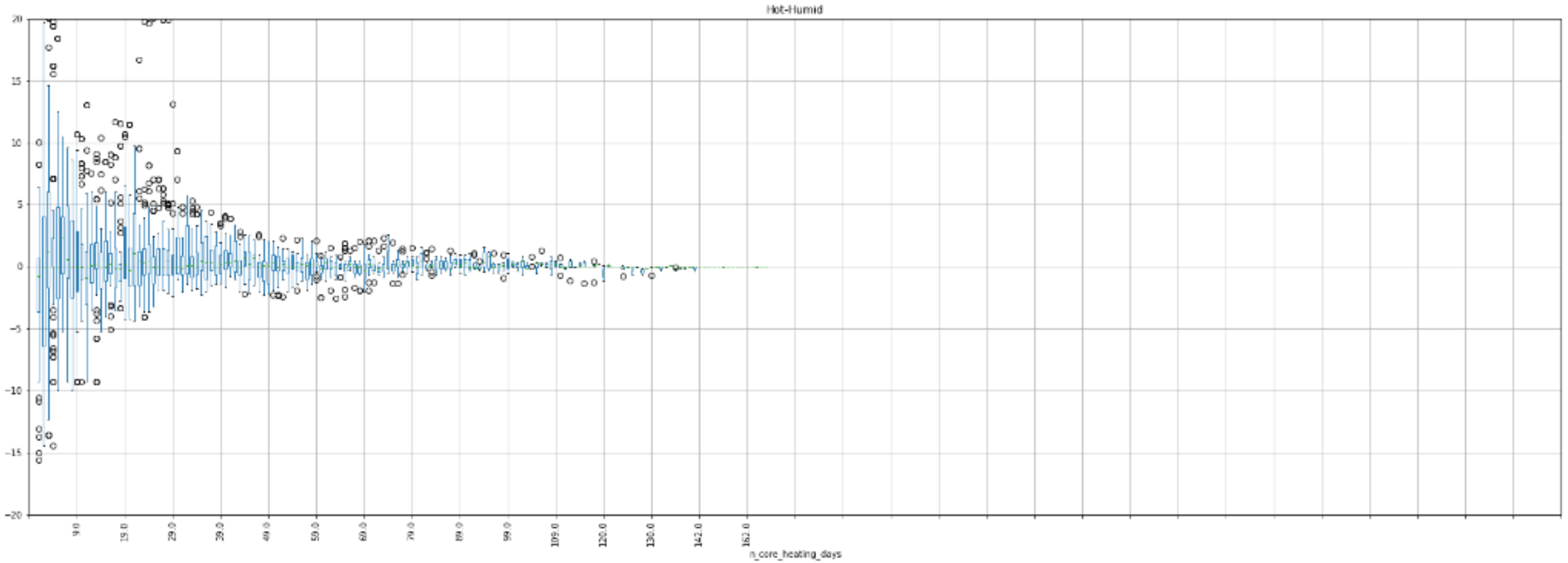
Change in heating savings, Marine



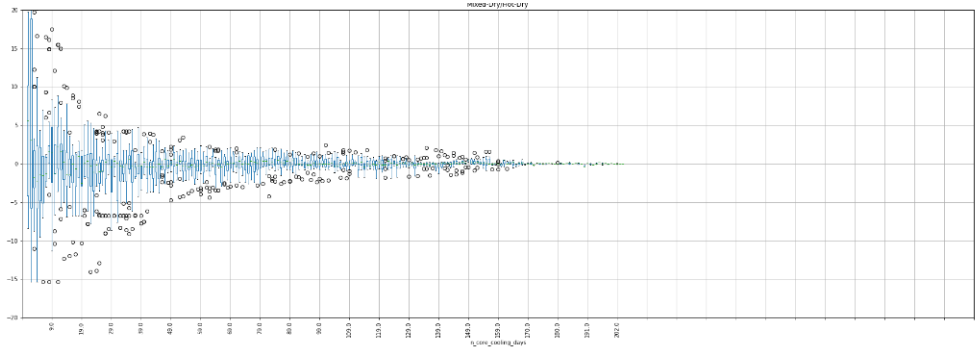
Change in heating savings, Very Cold/Cold

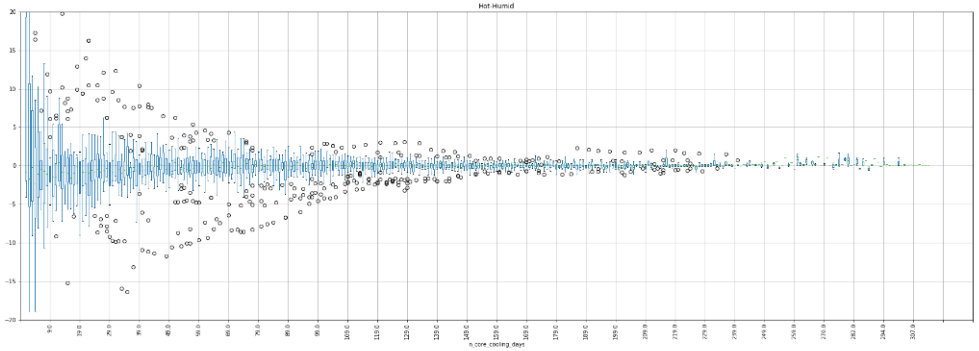


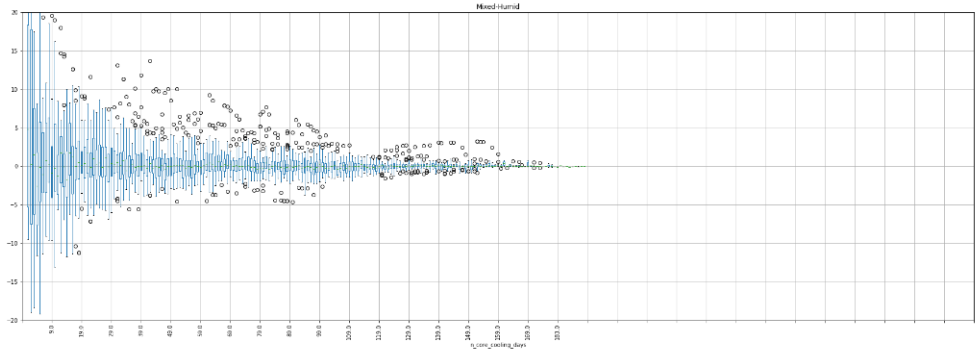
Change in heating savings, Hot-humid

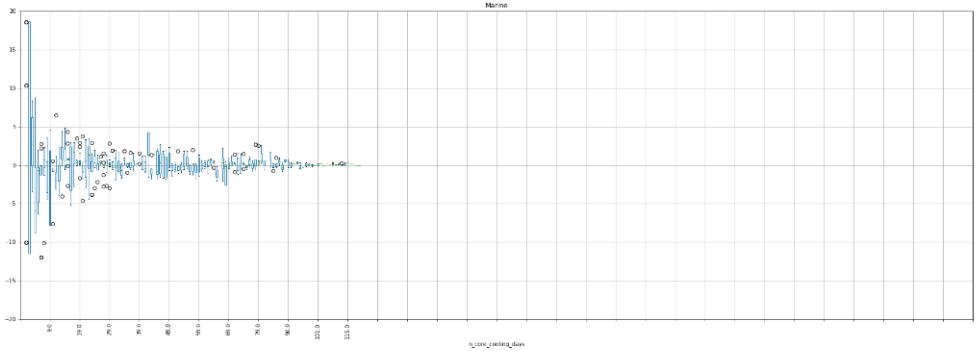


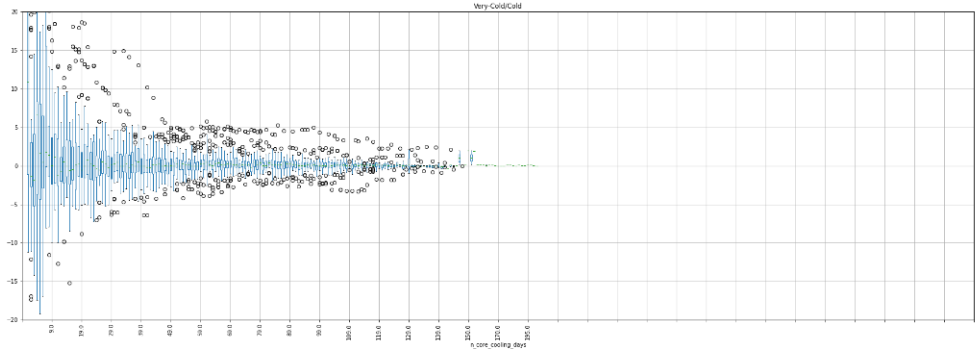
Cooling Savings:
Change vs. Remaining Core Days



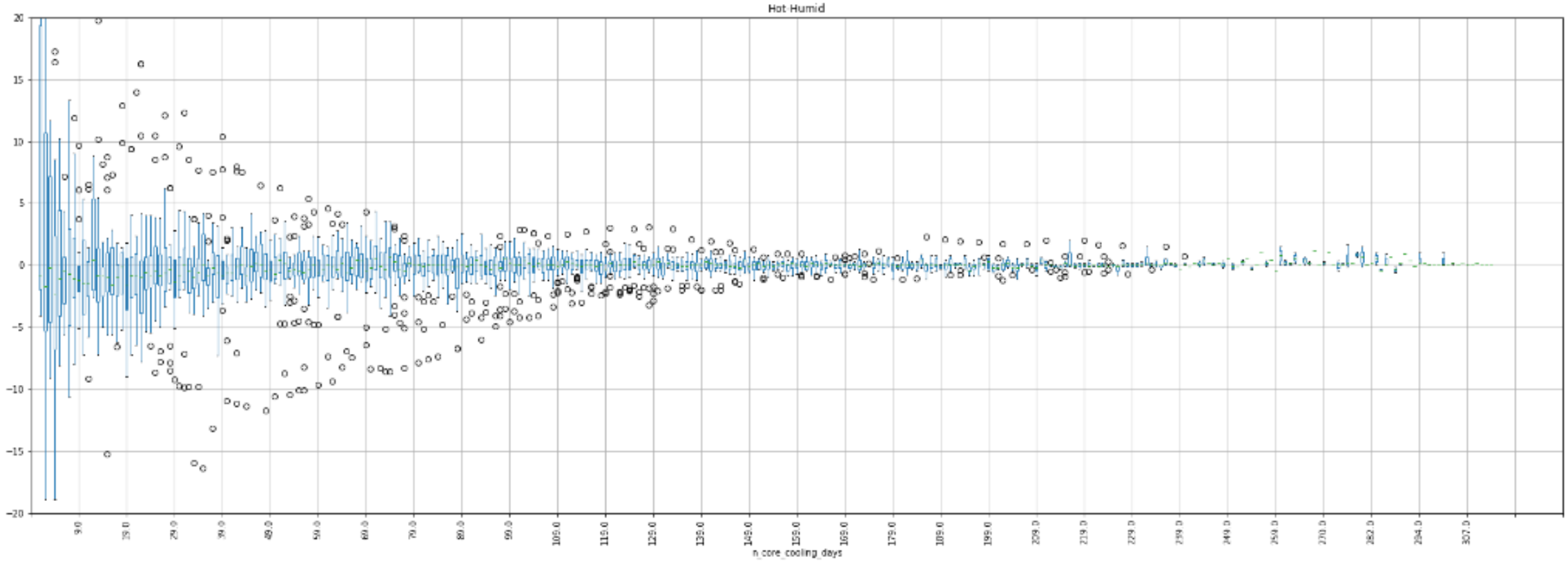




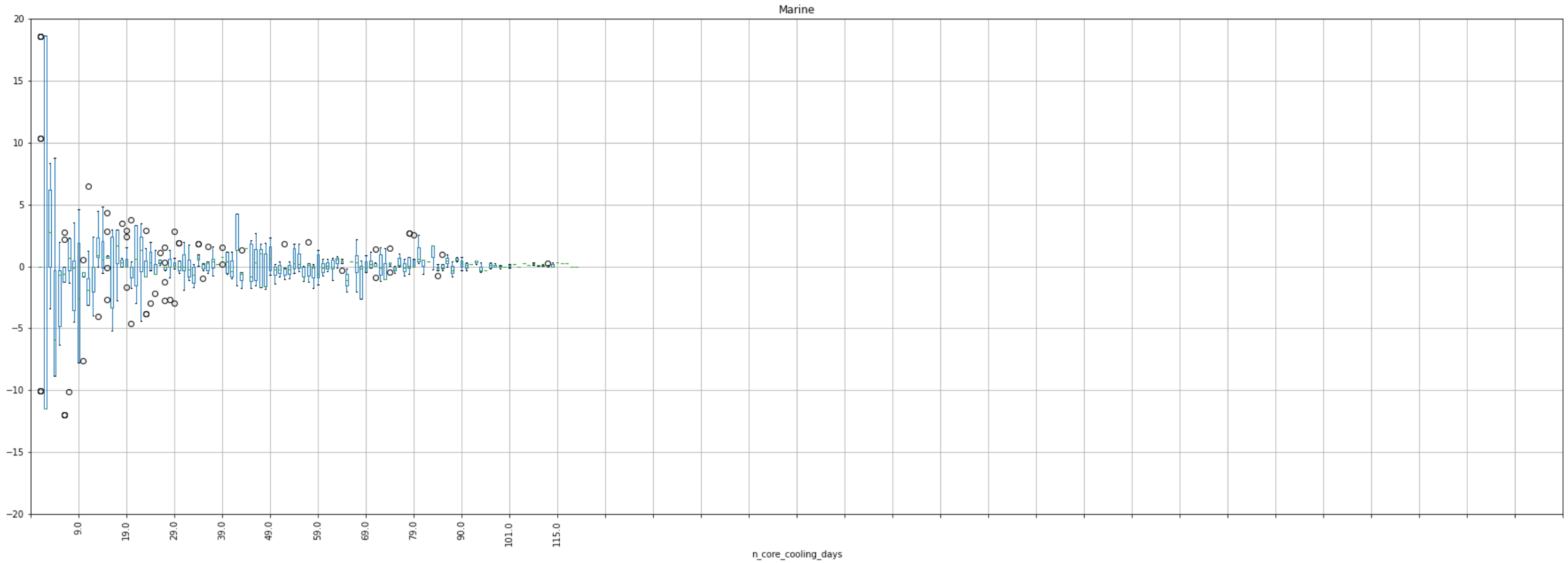




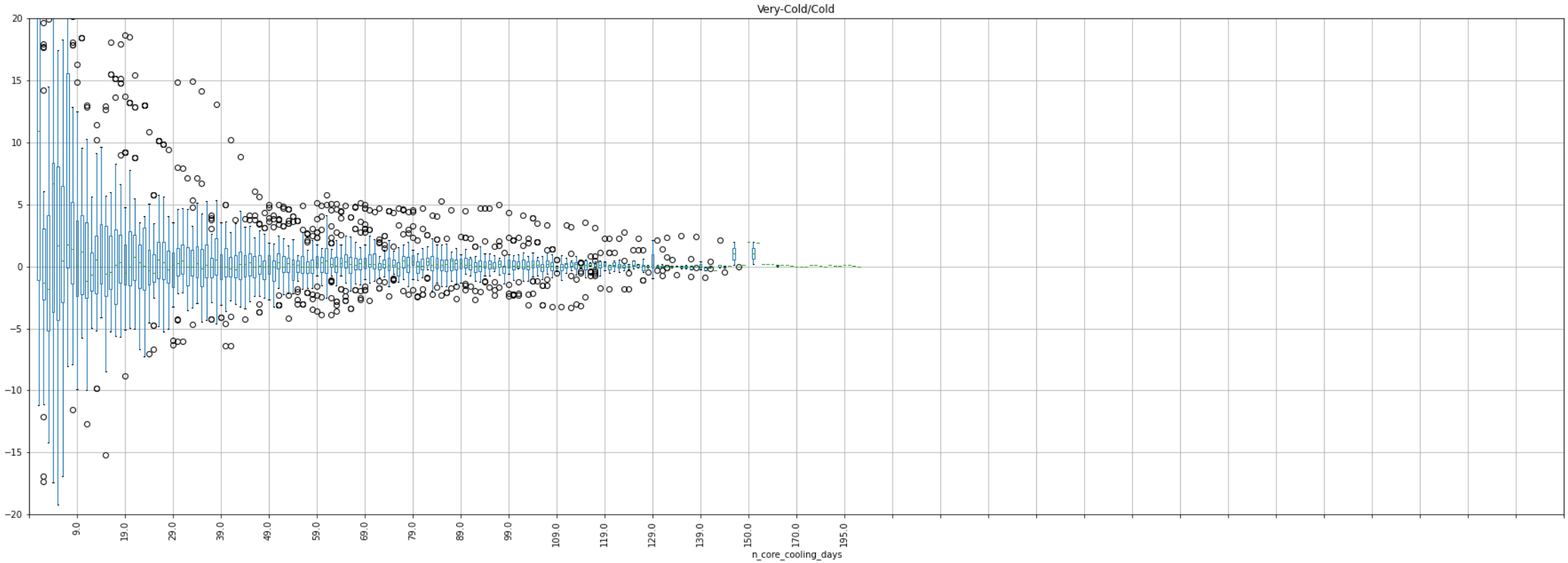
Change in cooling savings, Hot Humid



Change in cooling savings, Marine



Change in cooling savings, Very Cold/Cold



Discussion: Missing data

- Overall takeaway: We can relax our data standard significantly
- Questions: Other things we should look at? How do we set a standard for how much can be missing, since it seems to be that it's the % of core season is what matters.
- How/where are installations with missing data screened out? EPA team will need to check. Would be helpful to see installations that are missing data to see if they have systematically different scores. Hard to know this, because its hard to distinguish systematically different homes and scores that are less meaningful.
- Could screen both on % of season and on number of days. (Keep either if you have > X days or > Y% of the season)