ENERGY STAR® Smart Thermostat Products

Method to Demonstrate Field Savings
Draft 1 Version 2.0

1) OVERVIEW

This method shall be used to demonstrate field savings for ENERGY STAR Smart Thermostat (ST) Products.

2) APPLICABILITY

This ENERGY STAR Method is applicable to Smart Thermostat Products as defined in the ENERGY STAR Eligibility Criteria for Smart Thermostat Products.

3) DEFINITIONS

Unless otherwise specified, all terms used in this document are consistent with the definitions contained in the ENERGY STAR Eligibility Criteria for Smart Thermostat Products.

4) DEMONSTRATING FIELD SAVINGS

Field savings of ST Products shall be assessed for product certification as well as for periodic reporting as detailed in the Partner Commitments section of the ENERGY STAR Program Requirements for Smart Thermostat Products.

1. Install and configure the then current ***major release*** of the ENERGY STAR ST Field Savings Software using the open-source code and instructions available at:
   a. Documentation: https://epathermostat.readthedocs.io/en/latest/
   b. Source code: https://github.com/EPAENERGYSTAR/epathermostat

2. From the set of all instances of a fielded ST Product Family in the US, generate a randomly selected data set via the following procedure:
   a. Generate a metadata file that includes all instances of a fielded ST Product in the US, with the following information:
      i. included data: "thermostat_id", "heat_type", "heat_stage", "cool_type", "cool_stage", "zipcode", "utc_offset", and "interval_data_filename";
      ii. thermostat_id is a unique alphanumeric string;

      Important Note: thermostat_id shall be a pre-existing unique identifier associated with the ST Device (e.g., MAC address or serial number) or directly mapped from it using consistent rules (e.g., to remove non-alphanumeric characters or to eliminate duplicates).

      iii. heat_type: In each case this refers to heating equipment type controlled by the thermostat, with the understanding that there may be other heating devices in the home.
         1. furnace_or_boiler: Forced air furnace or boiler (any fuel)
         2. heat_pump_electric_backup: Only heating where thermostat controls heat pump with electric resistance heat (strip heat)
         3. heat_pump_no_backup: Only heating where thermostat controls heat pump without any backup.
         4. heat_pump_dual_fuel: Only heating where thermostat controls dual fuel heat pump (e.g., electric heat pump with a gas or oil-fired backup system)

5. electric_resistance: electric furnace or Line Voltage controlled heaters (baseboard, radiant etc.)
6. other: not included in any of the above.
7. none: Does not control a heating system

iv. heat_stage: This refers to how the primary heating equipment is wired at the thermostat, understanding that multi-stage or variable speed equipment may not be wired as such.

1. single_stage: Single capacity heater or single stage compressor, also called fixed capacity or fixed speed.
2. single_speed: Synonym for single_stage.
3. two_stage: Dual capacity furnace, dual stage compressor, or dual compressors.
4. two_speed: Synonym for “two_stage”
5. modulating: Modulating or variable capacity unit, or one with three or more capacity stages.

v. cool_type: In each case this refers to cooling equipment type controlled by the thermostat, with the understanding that there may be other cooling devices in the home.

1. heat_pump: Heat pump w/ cooling
2. central: Central AC
3. other: Mini-split, evaporative cooler, etc.
4. none: No central cooling system

vi. cool_stage: This refers to how the primary cooling equipment is wired at the thermostat, understanding that multi-stage or variable speed equipment may not be wired as such.

1. single_stage: Single stage compressor
2. two_stage: Dual stage compressor or dual compressors
3. single_speed: Synonym for single_stage.
4. two_speed: Synonym for two_stage.
5. modulating: Modulating or variable capacity compressor or having three or more capacity stages.

Note: In Version 2, EPA has implemented the ability to evaluate installations in which thermostats are controlling two stage equipment. The method uses an equivalent full load run time instead of simple run time. The equivalent full load run time is the sum of run time, weighted by the relative capacity of each stage. For instance, 10 run minutes in a stage with 50% of the full capacity would contribute 5 minutes of equivalent full load run time. In cases where the vendor knows the relative capacity of each stage, they may calculate such and include it in the input interval data file. In the more usual circumstance where vendors do not know the relative capacity of the stages, the software automatically assumes that stage 1 is 65% of full capacity for fossil fuel systems and 72% of full capacity for compressor-based systems. While not perfect, this will allow some installations with dual-capacity equipment to be included in the analysis. Those installations for which this represents actual behavior poorly are expected to be filtered out of the statistical calculations.

In addition, with the inclusion of line voltage thermostats in the scope of the specification, EPA has included a heating equipment type appropriate for these products.

vii. zipcode is the US ZIP code where the thermostat is installed;
viii. utc_offset is the offset of the timestamps in the file; and
ix. interval_data_filename: the filename for the file containing the actual data.

b. from the above metadata file, generate a new metadata file that eliminates STs according to the following rules:

i. thermostat_id is null or invalid;
ii. heat_type, heat stage, cool_type, or cool_stage is beyond the scope of ENERGY STAR specification which cannot be analyzed by the software, or changes during the reporting period;
iii. zipcode is null, invalid, or changes during the reporting period;

c. from the above metadata file, split STs into 5 climate zone metadata files, using this file (EE weather), which maps U.S. ZIP codes with the following Energy Information Administration (EIA) climate zones:
   i. Cold/Very Cold
   ii. Hot Dry/Mixed Dry
   iii. Hot Humid
   iv. Mixed Humid
   v. Marine
d. Sort each climate zone metadata file by the unique thermostat_id assigned to each thermostat. (Refer to Appendix A for guidance on sorting method).[1]
e. Use numpy.random.RandomState(number) to set a local (not global) random seed for the selection of the sample of thermostats in each climate zone, using the seeds provided by EPA.

   Important Note: It is important to use a local seed because if other processes call on the seed (as might happed with a global seed), the selection will not be reproducible or auditable. Refer to the numpy documentation at https://numpy.org/doc/1.22/reference/random/generated/numpy.random.seed.html for more information and/or refer to the sample thermostat_selection.py code for more details on how best to set the seed for numpy.

f. For each of the five EIA climate zones, generate metadata files with a random sample of 1000 STs without replacement (i.e., no duplicate entries). If the Partner has fewer than 1000 thermostats in an EIA climate zone from which to sample, include all thermostats for that climate zone.[1]There must be at least 30 thermostats in each climate zone after automatic filtering during analysis.
g. Using the above metadata files, generate files that follow the requisite file format and content requirements in https://epathermostat.readthedocs.io/en/feature-epathermostat_2.0/data_files.html#input-data[1]
   i. a single metadata file that includes all STs from the above step; and
   ii. a separate interval data file for each included unique thermostat_id.
h. To generate an additional dataset for Resistance Heat Utilization, use the same seeds and sampling routine as above, but from a pool of only Heat type: heat_pump_electric_backup, heat_pump_no_electric_backup or heat_pump_dual_fuel.

Note: EPA reminds partners that our goal is for this Method to be as easy for partners to perform as possible, consistent with fairness, reproducibility, and auditability. All of the changes noted below were made with these principles in mind. EPA welcomes additional feedback about furthering these aims.

EPA seeks feedback on the metadata file generated for the full population of the product family in step 2).a.i. Its creation supports the auditability of the process, but we'd like to minimize the burden associated with creating and storing it. The "utc-offset" and "interval_data_filename" items are not needed for this step but will be needed in the metadata files for thermostats in the final sample that is analyzed. Would partners prefer that they be optional in this step? Note that we discourage partners from producing the actual interval data files at this step and presume (given the computing burden involved) that they are typically not generated.

Based on the stakeholder feedback in the discussion guide, EPA proposes to increase the maximum sample size to 1000 thermostats per climate zone. EPA proposes this value after thorough consideration to ensure that undue advantage isn't offered to large vendors due to narrowing confidence intervals while improving precision and stability of metric scores. Note that this is a maximum – as before, stakeholders are not required to include this many samples if they do not have them.

EPA also proposes requiring a minimum of 30 thermostats per climate zone to ensure the results reflect the performance of the thermostat rather than idiosyncrasies of the homes in the sample.

> The thermostat team is aware that the new output sample size requirement will make it harder for new entrants to the smart thermostat space to demonstrate field savings and earn the ENERGY STAR. EPA welcomes stakeholder feedback on this proposal.
>
> EPA has learned of the importance of the seeds distributed by EPA being specific to the selection process (rather than being used as global seeds), because otherwise they will be used by other processes and updated, making the selection non-reproducible and therefore unable to be audited. The proposed method change and corresponding changes to the suggested random selection code (see Appendix A) implement this change.
>
> EPA and Natural Resources Canada (NRCan) have discussed including installations in Canada in the analysis. If they were, the “zipcode” field would include postal codes for Canadian locations that would allow outdoor temperature lookup similar to procedures using US zip codes. In this scenario, installations in the US and in Canada in similar climates could be included in one zone. The possibility exists of automatically calculating different heating and cooling savings metrics for Canada, with the various climate zones weighted as appropriate for Canadian energy use. As of yet, this work has not been funded and therefore has not proceeded.

3. Verify that this data set:
    a. consists of one metadata file and *n* interval data files (one interval data file for each ST in the sample)
    b. includes ST Products in each of the five EIA climate zones: Very Cold/Cold, Hot Dry/Mixed Dry, Hot Humid, Mixed Humid, and Marine
    c. adheres to the relevant reporting period criteria as detailed in the Partner Commitments section of the ENERGY STAR Program Requirements for Connected Thermostat Products; and
    d. includes only ST Products that control HVAC equipment types as noted in 2.a.iii – vi above which can be analyzed by the software and fall within the scope of the specification.

4. Process the data set using the ENERGY STAR ST Field Savings Software. To be valid, these quantities must be based on at least 30 thermostats per climate zone after filtering. In addition, at least 30% of thermostat files must be retained through the process. The output includes:
    a. Mean cooling and heating savings scores (% run time reduction) with associated standard error of the mean, and decile bins, in each of five EIA climate zones.
    b. The lower 95% confidence interval of the mean cooling and heating savings scores (% run time reduction) with decile bins in each of the five EIA climate zones.
    c. Weighted national average cooling and heating savings scores (% run time reduction) with associated standard error of the mean.
    d. Weighted national average of the lower 95% confidence interval of the mean cooling and heating savings scores (% run time reduction).
    e. Mean resistance heat utilization for heat pumps with backup electric resistance heating, in 5°F outdoor temperature bins from 60°F to 0°F across all climate zones with and without filtering.
    f. Mean resistance heat utilization for heat pumps with backup electric resistance heating, in a singular bin from 30°F to 45°F across all climate zones with and without filtering.

5. Submit the ST Field Savings Software certification zip file comprising of metric scores for filtered data and a summary statistics file to evaluate performance metric and RHU
    a. to the Certification Body for initial product certification, or
    b. to EPA for ongoing reporting.

    EPA requests that additional output files such as advanced statistics filtering, metrics output file and error log file also be submitted to further refine metrics quality but the submission of the same is not mandatory as per partnership requirements. Vendors may anonymize the additional output files further as necessary before submitting it.

6. Retain the following data for a period not less than five years from the associated file submission:

a. raw input data files for each thermostat_id in the ST data set used to assess savings.
b. all metadata files created in step 4.2. and all random seeds with a reference to the metadata files for which each seed was used.
c. ST interval data file, generated in step 4.2.g., and used with the ENERGY STAR ST field savings software to assess reported savings; and
d. All output files generated by the software and submitted to EPA or to certification bodies.

Note: EPA proposes that at least 30% thermostats are retained after filtering to ensure quality of fit to the linear model and credibility of metric scores published. Many vendors have more than 50% of their samples filtered out of the statistics calculation. EPA and our partners have spent considerable time investigating the same and the Version 2 software includes logging functionality to the importer script. This documents thermostats that were present in the metadata file but were not imported, which can help partners troubleshoot why particular thermostats were rejected. The tool also generates a separate log file with the thermostat ID and the reason why the thermostat was rejected to aid in tracing any issues with importing the thermostat.

In addition, EPA and partners have discussed that a significant number of thermostats are eliminated from the statistical calculations because parameters of the model of the home's response to heating (or cooling) run time come out as slightly outside what makes physical sense. Updating how the model is derived might allow slightly different parameters that makes physical sense and also result in a good correlation with the data. If so, that thermostat could be used in deriving the statistical results. EPA continues to be interested in this update but currently is unable to fund the bulk of the work to update the software. We would welcome more thorough participation by partners in solving this problem and would be able to incorporate suggested software changes into Version 2 once they are tested.

These measures may be continually improved, and others implemented, as the Version 2 software evolves. EPA looks forward to continuing to work with stakeholders on this issue.

APPENDIX A: CODE FOR SORTING AND REPRODUCABLE RANDOM SAMPLING OF THERMOSTATS

This section provides guidance for selecting thermostats for the sample. Source code and detailed documentation are available at the following locations:

The code for selecting thermostats for sampling is available on our GitHub repository. The `thermostat_selection.py` code is available at the following location under the `scripts` directory.

> **Note:** Previous versions of this code required the use of Python's `natsort` module. This module is no longer required for sorting identifiers. Based on the partner feedback, EPA determined that the use of the module complicated the selection process for vendors with large datasets. Some vendors were adversely affected by the requirement to use `natsort`. EPA is relaxing this requirement to alleviate any friction for submissions. If vendors are currently using `natsort` they are free to continue using `natsort` for sorting identifiers. The aim of this proposal is to remove any unnecessary overhead in the sampling process. If the sampling process is not adversely affected by downloading data locally and using `natsort` then vendors are free to continue using it.

EPA requires that stakeholders use a reproduceable sorting method for their data. Many databases (such as those using a SQL-based query language) have the ability to order data prior to selection. Stakeholders should sort their identifiers using whatever methodology is convenient and reproduceable. Sorting methods that are not reproduceable or give varying results are not acceptable. In the cases where database sorting is not predictable or reproduceable EPA recommends using another methodology such as Python's built-in sorting or `natsort`.

Certain databases may have issues with repeatable sorting because of techniques like sharing or other methodologies to store large sets of data. EPA recommends doing several tests to ensure that the thermostat ids are consistently sorted between runs. If the sorting is inconsistent you may need to contact your database vendor or other support forums to determine how to achieve a consistent sorted dataset.

Example:

This simple example uses the syntax for a typical SQL database. The sort order is ascending:

```
select ct_identifier from tstats order by ct_identifier asc;
```

> **Note:** This is a basic example. It does not have any of the other filtering a vendor might need such as climate zones, time-periods, or other filtering that may be required for selecting data from your thermostat database.

Documenting this process can be as simple as documenting the query that is being used for doing the selection / sorting. EPA's aim is for stakeholders to be able to replicate the process should there be an issue with their data or should they be required to resubmit data.

Sample selection code

The sample selection code provided demonstrates the following steps:

1. Downloading data from a database or files for sampling (based on Climate Zone)
2. Randomly select a few thermostats (currently 1000) per climate zone based on a provided seed.
3. Sort the thermostat IDs to aid in detecting reproducibility issues.
4. Combine the thermostat IDs and output the results.

This code needs to be modified for your specific environment and serves as a template for above tasks.

https://github.com/EPAENERGYSTAR/epathermostat/blob/feature/epathermostat_2.0/scripts/thermostat_selection.py

APPENDIX B: DESCRIPTION OF SAVINGS METHODOLOGY & ALGORITHMS USED IN THE ENERGY STAR ST FIELD SAVINGS SOFTWARE

This description pertains to the V2.0 release. Source code and detailed documentation are available at the following locations:

Documentation: https://epathermostat.readthedocs.io/en/latest/index.html
Source code: https://github.com/EPAENERGYSTAR/epathermostat

OVERVIEW OF SOFTWARE METHODOLOGY

The software consists of two modules (*thermostat* and *statistics*) which assess ST savings expressed as the run time reduction relative to the baseline and resistance heat utilization (RHU) expressed as a percentage in a specific temperature bin for heat pump systems only.

- *Thermostat Module* - The thermostat module separately assesses savings due to setback (for heating and cooling separately) and RHU for each thermostat in the data set, as well as identifying the data quality for each thermostat.

  1. *Read in input files* – a metadata file with a record for each ST in the data set and an interval data file for each ST in the data set with a record for each hour[1].
  2. *Check ST interval data* – reject ST data files that are missing too much data, or if corresponding outdoor temperature data is not available. Indoor and outdoor temperature data gaps of up to 2 hours are interpolated. After interpolation, any days with gaps are excluded from the analysis. If more than 5% of days are missing HVAC run time data, the ST is excluded.
  3. *Read in outdoor temperature data* - use the ZIP Code included in the metadata file to determine the closest NOAA weather station that is in the same climate zone as the ST and read in hourly outdoor temperatures;
  4. *Determine Baseline Comfort Temperatures* –parse the ST indoor temperature history to determine the occupants' preferred temperatures for heating and cooling;
  5. *Develop Thermal/HVAC Model* –construct a model of the relationship between heating and cooling HVAC run time, outside temperature, and indoor temperature;
  6. *Assess Baseline Run Times* –use the thermal/HVAC model to assess baseline heating and cooling run times for the ST, i.e., what run times would have been under 24/7 use of baseline comfort temperatures;
  7. *Assess ST Savings* –calculate ST savings; expressed as percent run time reduction relative to the baseline.
  8. *Assess Resistance Heat Utilization (RHU)* – calculate the fraction of total heating run time that includes auxiliary or emergency heating (heat pumps only).
  9. *Produce the metrics output file* – generate a thermostat metrics file that includes a row for each ST in the data set[2].

[1] For a detailed list of the file structure and contents refer to: https://epathermostat.readthedocs.io/en/latest/data_files.html

[2] *Ibid*

> **Note:** Version 1 of the software did not implement checks for missing data. In Version 2 EPA has implemented missing data checks based on a series of discussions in stakeholder metrics meetings. The data checking includes two criteria: 1) Any data set including valid data (i.e., with run time data gaps of not > 1 hour) for 95% of days in the reporting period is considered complete. 2) For data sets with valid data from less than 95% of days in the reporting period, if they have at least 50 core days they are considered complete and may be included in the analysis. Note that for this second criterion, a thermostat may be included in a heating sample but not a cooling sample or vice versa. Version 2 alpha releases of the software will include this feature for vendors to test on their data in future. EPA welcomes feedback on this proposed method to test for missing data.

- *Statistics Module* - The statistics module assesses aggregate national and regional savings using the metrics file output from the thermostat module and produces two output files as follows*:*

    1. Read in the thermostat modules metrics output file.
    2. Produce the statistics file.
        - The statistics file contains summary statistics for each output variable in the metrics file, including 23 quantile bins, means, and standard errors of the mean.
    3. Produce the certification file.
        - *Regional ST savings* – average regional HVAC savings in the five EIA[3] climate zones, along with the weighted average decile bins, weighted average standard error of the mean, and the lower 95% confidence limit of the weighted average.
        - *National ST* savings – national heating and cooling savings as a weighted average of regional savings, along with associated statistics. Regional savings are weighted by the proportion of national heating or cooling energy consumed in each of the five EIA climate zones.
        - *Resistance heating utilization (RHU)* – average regional and national RHU and associated statistics (ST's with heat pumps only).

THERMOSTAT MODULE IMPLEMENTATION DETAIL

Assess Heating Savings

1. Add hourly outdoor temperature ($Tout$):
    - Using the ZIP Code included in the metadata file, determine the closest NOAA weather station that is in the same climate zone as the ST and add the outdoor temperature for each hour ($Tout_{d.h}$ $(^\circ F)$)
2. Calculate core heating days
    - Core heating days are days where the total heating runtime is greater or equal to 30 minutes and there is no cooling runtime. Only primary heating source runtimes are assessed to determine core heating days. That is, auxiliary and emergency electric resistance heat run times associated with heat pumps are not included.
3. Develop the ST/home's unique thermal/HVAC heating run time model
    - Calculate the Baseline Heating Setpoint ($Tbaseheat$) – the occupant's preferred comfort

[3] https://www.eia.gov/consumption/residential/reports/images/climatezone_eere-lg.jpg

temperatures for heating[4]:

$Tbaseheat\ (°F)$ = 90th percentile of indoor temperature on *core heating days*

- Calculate the average hourly indoor minus outdoor temperature difference ($\Delta T_{d.h}$) for each core heating day:

$$\Delta T_{d.h}\ (°F) = Tin_{d.h} - Tout_{d.h}$$

where
$Tin_{d.h}$ is the indoor temperature for core heating day d and hour h

$Tout_{d.h}$ is the outdoor temperature for core heating day d and hour h

(from the closest NOAA weather station)

- Starting with an assumed value of zero for Tau ($\tau_H = 0$), calculate the daily Heating Thermal Demand (HTD_d):

$$HTD_d\ (°F) = \frac{\sum_{h=1}^{24} max\left[\Delta T_{d,h} - \tau_H, 0\right]}{24}$$

where

τ_H is the ΔT associated with $HTD = 0$ (zero heating run time), reflecting that, homes with no heat running tend to be warmer than their surroundings.

- For the set of all core heating days in the ST interval data file, use ratio estimation to calculate the home's responsiveness to heating (α_H), which will be expected to be positive for well-behaved thermostats.

$$\alpha_H \left(\frac{minutes}{°F}\right) = \frac{\sum_{d=1}^{x} HRT_d}{\sum_{d=1}^{x} HTD_d}$$

where
HRT_d is the actual heating runtime for core heating day d

- For the set of all core heating days in the ST interval data file, optimize τ_H so that it results in the minimization of the sum of squares of the difference between daily run times reported by the ST, and calculated daily heating run times.:

$\sum_{d=1}^{x}(HRTactual_d - HRTdaily_d)^2$ is minimized[5]

where
$HRTdaily_d = \alpha_H * HTD_d$
$HRTactual_d$ is the total daily heating run time reported by the ST for core heating day d.

Next recalculate α_H (using the above step) and record the model's parameters (τ_H, α_H). Note that α_H characterizes the response of the home to heating and τ_H is the difference between inside and outside temperatures when heating run time = 0

[4] Based on method described in paragraph 3.1.2 of "A DATA-DRIVEN FRAMEWORK FOR COMPARING RESIDENTIAL THERMOSTAT ENERGY PERFORMANCE," Bryan Urban and Kurt Roth, Fraunhofer USA, July 2014.

[5] The thermostat module calls Scipy Function leastsq

> **Note:** EPA and ST stakeholders have been working together to update the method of deriving the model, to constrain tau such that fewer thermostats are eliminated from the analysis due to having a non-physical tau. Instead, the analysis will constrain the optimization such that tau is guaranteed to be physically meaningful, and any thermostat with an acceptable fit under this constraint will be included in statistical calculations. The thermostat team and our stakeholders continue to work on this and will update this section as appropriate once changes have been finalized.

4. Calculate the cumulative baseline run time for the collection of all core heating days in the ST interval data file (i.e., what would have occurred over the set of all core heating days in the reporting period, had the home been held constant at the preferred heating comfort temperature).
   - Calculate the difference between the occupant's preferred comfort temperature for heating and the average outside temperature for each hour of each core heating day ($\Delta Tbaseheat_{d.h}$):

$$\Delta Tbaseheat_{d.h}\ (°F) = Tbaseheat - Tout_{d.h}$$

   - Calculate baseline daily Heating Thermal Demand ($HTDbase_d$) for each core heating day:

$$HTDbase_d = \frac{\sum_{h=1}^{24} max[\Delta Tbaseheat_{d.h} - \tau_{H,0}]}{24}$$

   - Calculate baseline run time as the sum of daily baseline run times for the set of core heating days:

$$RTbaseheat\ (minutes) = \sum_{d=1}^{x} \alpha_H * HTDbase_d$$

   where
   α_H , determined above, is a constant that is part of ST/home's thermal/HVAC heating run time model
   $HTDbase_d$ is the baseline daily Heating Thermal Demand

5. Calculate the ST heating savings (HS), the percent heating run time reduction, for the reporting period in the ST input file:

$$HS\ (\%) = \frac{100 * (RTbaseheat - RTactualheat)}{RTbaseheat}$$

   where

   $RTbaseheat$ is the sum of modeled baseline heating run times for all core heating, and

   $RTactualheat$ is the sum of heating run times for all core heating days.

Assess Cooling Savings

1. Add hourly outdoor temperature *($Tout$):*
   - Using the ZIP Code included in the metadata file, determine the closest NOAA weather station that is in the same climate zone as the ST and add the outdoor temperature for each hour ($Tout_{d.h}$ ($°F$))

2. Calculate core cooling days
   - Core cooling days are days where the total cooling runtime is greater or equal to 30 minutes and there is no heating runtime. Only primary cooling source runtimes are assessed to determine core cooling days.
3. Develop the ST/home's unique thermal/HVAC heating run time model
   - Calculate the Baseline Cooling Setpoint ($Tbasecool$) – the occupant's preferred comfort temperatures for cooling[6]:

     $Tbasecool\ (°F)$ = 90th percentile of indoor temperature on *core cooling days*

   - Calculate the average hourly indoor minus outdoor temperature difference ($\Delta T_{d.h}$) for each core cooling day:

$$\Delta T_{d.h}\ (°F) = Tin_{d.h} - Tout_{d.h}$$

     where
     $Tin_{d.h}$ is the indoor temperature for core cooling day d and hour h

     $Tout_{d.h}$ is the outdoor temperature for core cooling day d and hour h

     (from the closest NOAA weather station)

   - Starting with an assumed value of zero for Tau ($\tau_C = 0$), calculate the daily Cooling Thermal Demand (CTD_d):

$$CTD_d\ (°F) = \frac{\sum_{h=1}^{24} max\left[\tau_C - \Delta T_{d,h}, 0\right]}{24}$$

     where

     τ_C is the ΔT associated with $CTD = 0$ (zero cooling run time), reflecting that homes with no cooling running tend to be warmer than their surroundings.

   - For the set of all core cooling days in the ST interval data file, use ratio estimation to calculate the homes responsiveness to cooling (α_C), which will be expected to be positive for well-behaved thermostats.

$$\alpha_C \left(\frac{minutes}{°F}\right) = \frac{\sum_{d=1}^{x} CRT_d}{\sum_{d=1}^{x} CTD_d}$$

     where
     CRT_d is the actual cooling runtime for core cooling day d

   - For the set of all core cooling days in the ST interval data file, optimize τ_C so that it results in the minimization of the sum of squares of the difference between daily run times reported by the ST, and calculated daily cooling run times.:

     $\sum_{d=1}^{x}(CRTactual_d - CRTdaily_d)^2$ is minimized[7]

     where
     $CRTdaily_d = \alpha_C * CTD_d$
     $CRTactual_d$ is the total daily cooling run time reported by the ST for

[6] Based on method described in paragraph 3.1.2 of "A DATA-DRIVEN FRAMEWORK FOR COMPARING RESIDENTIAL THERMOSTAT ENERGY PERFORMANCE," Bryan Urban and Kurt Roth, Fraunhofer USA, July 2014.

[7] The thermostat module calls Scipy Function leastsq

core cooling day d.

Next, recalculate α_C (using the above step) and record the model's parameters (τ_C, α_C). Note that α_C characterizes the response of the home to cooling and τ_C is the difference between inside and outside temperatures when cooling run time = 0

Note: In cooling as well as in heating, the method of deriving the model is in the midst of improvement. Software doesn't check for negative alpha, but we expect the software to filter out thermostats with negative alpha.

4. Calculate the cumulative baseline run time for the collection of all core cooling days in the ST interval data file (i.e., what would have occurred over the set of all core cooling days in the reporting period, had the home been held constant at the preferred cooling comfort temperature).
   - Calculate the difference between the occupant's preferred comfort temperature for cooling and the average outside temperature for each hour of each core cooling day ($\Delta Tbasecool_{d.h}$):

$$\Delta Tbasecool_{d.h}\ (°F) = Tbasecool - Tout_{d.h}$$

   - Calculate baseline daily Cooling Thermal Demand ($CTDbase_d$) for each core cooling day:

$$CTDbase_d = \frac{\sum_{h=1}^{24} max[\tau_C - \Delta Tbasecool_{d.h}, 0]}{24}$$

   - Calculate baseline run time as the sum of daily baseline run times for the set of core cooling days:

$$RTbasecool\ (minutes) = \sum_{d=1}^{x} \alpha_C * CTDbase_d$$

   where
   α_C , determined above, is a constant that is part of ST/home's thermal/HVAC cooling run time model
   $CTDbase_d$ is the baseline daily Cooling Thermal Demand

5. Calculate the ST cooling savings (CS), the percent cooling run time reduction, for the reporting period in the ST input file:

$$CS\ (\%) = \frac{100 * (RTbasecool - RTactualcool)}{RTbasecool}$$

where

$RTbasecool$ is the sum of modeled baseline cooling run times for all core cooling and

$RTactualcool$ is the sum of cooling run times for all core cooling days.

Calculate Resistance Heating Utilization (RHU)

- For heat pump systems only, calculate RHU in 12 (daily average) outdoor temperature bins (0 ≤ T < 5°F, 5 ≤ T < 10°F,…, 55 ≤ T ≤ 60°F). For example, RHU_{0-5F} is calculated as follows:

$$RHU_{0-5F}\ (\%) = \frac{\left(t_{emerg_{0-5F}} + t_{aux_{0-5F}}\right)}{\left(t_{emerg_{0-5F}} + t_{comp_{0-5F}}\right)}$$

where,

$t_{emerg_{0-5F}}$ is the total emergency resistance heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F. t_{emerg} is in lieu of compressor operation, e.g., use of electric resistance strip heat under fault conditions or when the outside temperature is very low,

$t_{aux_{0-5F}}$ is the total annual auxiliary resistance heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F. t_{aux} is supplemental to compressor operation, e.g., use of electric resistance strip heat to increase heating capacity, and

$t_{comp_{0-5F}}$ is the total compressor heating run time in the interval data file that occurs on core heating days where 0°F ≤ average daily outdoor temperature < 5°F. A proportion of t_{comp} may occur when auxiliary resistance heating also occurs.

Note: In 2017 – 2019 EPA and stakeholders carefully considered the appropriate metric to identify thermostats that avoided saving heat pump run time through excessive use of backup resistance heat. The interval from 30 to 45 F was identified as the outdoor temperature with the most distinction between use of backup heat. In this interval, most heat pumps can deliver significant heating with careful management. Thus, the metric on which we propose a requirement concentrates on this bin. In addition, the calculation of RHU was made more robust by eliminating installations that appeared to have compressors that weren't working properly (indicated by statistics section that filters out the top 5% installations) and those for which 30 – 45F appeared to be far from the system's design temperature (indicated by minimum runtime of 30 hours for the bin).

STATISTICS MODULE IMPLEMENTATION DETAIL

After the thermostat module generates an output file for the sample set, the statistics module summarizes these files to assess average savings, expressed as percent run time reduction.

- Assess average heating savings, cooling savings, and RHU for each of the five EIA climate zones. For example, the average heating savings in climate zone cz (HS_{cz}) is calculated as:

$$HS_{cz}\ (\%) = \frac{\sum_{i=1}^{n} HS_{cz,i}}{n}$$

where

n is the number of STs in the climate region cz

$HS_{cz,i}$ is the heating savings for ST i in climate zone cz.

- Nationally – from regional savings, national savings are calculated as weighted averages for heating and cooling. (see below for details on Climate Zone weightings). Statistics associated with nationally weighted savings estimates include the mean, standard error of the mean, decile bins (q10-q90) and the Lower Bound of the 95th Percentile Confidence Interval (LB95). The Nationally Weighted LB95 is calculated via the following formula:

$$SE_{National} = \sqrt{\sum_{CZ=1}^{5} (W_{CZ} * SE_{CZ})^2}$$

where

SE_{CZ} are the standard errors in each climate zone, calculated as the standard deviation in the climate zone divided by the square root of the number of STs analyzed in that climate zone

W_{CZ} are the climate zone weightings

$SE_{National}$ is the standard error of the weighted mean

The Nationally Weighted LB95 ($LB95_{National}$) is calculated from $SE_{National}$ as follows:

$$LB95_{National} = Mean_{National} - 1.96 * SE_{National}$$

Key performance metrics, Nationally Weighted LB95 and 20[th] decile bin q20 are specifically labelled and placed in the output file for ease of reference.

- Weighting for heating and cooling is by the proportion of national heating or cooling energy used in each of the five EIA climate zones, as follows:

Heating	
Climate Region	*%BTU vs National*
Very Cold/Cold	54.9%
Mixed-Humid	31.2%
Mixed-Dry/Hot-Dry	5.4%
Hot-Humid	4.9%
Marine	3.6%

Cooling	
Climate Region	*%BTU vs National*
Very Cold/Cold	9.6%
Mixed-Humid	34.0%
Mixed-Dry/Hot-Dry	14.4%
Hot-Humid	42.0%
Marine	Not included

- All other National outputs, including National RHU, are calculated as an unweighted average over all CTs in the sample set.