PG&E HVAC Tool v2.2.03 Documentation

Contents

DEER Peak Calculation (General):

Calculation Engine

CZ2022 (hidden) tab:

- Uses CZ2022 weather data
- Uses DEER Peak Dates per Climate Zone and 4pm-9pm based on Resolution E-5152 to identify Peak Temperatures

Air Side System, Hot Water System, and Chilled Water System calculation tabs:

- In the "Calculation Engine" section, the number of "Peak hours" per temperature bin are broken out as to whether they correspond to "Occupied" or "Unoccupied" modes of operation (see "On-Pk Occ Hrs" and "On-Pk UnOcc Hrs").
- Peak kW is calculated as the average (sumproduct divided by 15 hours) of the number of "Occupied" and "Unoccupied" peak hours per OAT bin multiplied by the corresponding "Occupied" and "Unoccupied" equipment power consumption in that OAT bin.
    - For example: For Airside tabs, the sumproduct of the "On-Pk Occ Hrs" and the sum of the Occ SF kW, Occ RF kW, and Occ Load kW plus the sumproduct of the "On-Pk Unocc Hrs" and the sum of the Unocc SF kW, Unocc RF kW, and Unocc Load kW results in the total peak kW-hrs over the 15 hour peak period. This sum total is then divided by 15 to calculate the average peak kW over the 15 hour peak period.
- The above methodology follows the methodology outlined in Resolution E-5152.

General Calculation Comments (pertains to all equipment tabs)

The calculation flow in the HVAC Tool can be summarized as follows. In each of the tabs:

1. The user enters "Input" data (baseline data in green cells and proposed data in blue cells). Where measures are marked as disabled, the proposed data input cells are greyed out.
2. The Processing section takes the user "Input" selections and consolidates the active "Inputs" into this section for each "iteration" run.
    a. Switches: The Processing section contains "switches" which switch between "Baseline" and "Proposed". A macro is used to change the switches which start with all switches set to "Baseline" and then each iteration run going down the list of switches and one by one changing them to "Proposed".
3. The "Calculation Engine" section contains the formulas used to calculate energy use of the equipment based on the conditions set forth by the "Inputs" for each iteration run. As the "switches" change from "Baseline" to "Proposed", each iteration calculates the new equipment energy usage building upon the previous iteration. The difference in energy usage between each iteration results in the measure savings. This method results in a cascading of the measures so savings are not double counted.

EEM Data Entry:

- Inputs data entry section for energy usage calculations. Data typically can be entered as "Simple Data" or "Trend Data"
- Selecting "Disable" skips over any "proposed" inputs and re-uses the "baseline" inputs for the calculation.

Processing:

- Switches: Changes between Baseline and Proposed during each Macro run for each measure
    - Runs baseline (all) and then sequentially flips each switch to "Proposed" and re-runs calculation
    - Results are populated line by line in the "Consumption" table at the top of the tab
- Inputs change depending on "switch" and whether the measure is "enabled" in the measure section above

Inputs:

- When using Trended Data, if any bins are blank, they are forecasted based on the trend data that has been entered in. As a general practice, the forecasted values (in the calculated columns) should be checked to make sure that they make sense. In most cases, the easiest way to do this is to look at the generated graphs (while manually setting the switches to "Baseline" or "Proposed" depending on which data is being checked).

Other:

- Calculations need to be checked to make sure that savings aren't double counted between the different tabs (Chiller, HHW, and AHU) since the AHU tab calculates savings seen by the chillers and boilers and may even affect their loads.

AHU Calculation Tab

System Requirements and Exclusions:

- Single duct VAV or CAV systems with terminal box reheat (or no reheat boxes)
  - Example of exclusions:
    - Not applicable for dual duct systems
    - Not applicable for systems with fan powered terminal boxes or induction boxes or cooling coils at the zones
    - Not applicable for Package Unit with furnace section or AHU with heating coils (pre-heat coils are okay). Primary space heating should be provided at the zone level and not at the AHU/package unit.
- Single fans or multiple fans operating simultaneously
  - Not applicable when there are multiple fans that are staged on based on load. When multiple fans are present, they all must run simultaneously at all times at the same speed.
- AHU must have return fans and not relief/exhaust fans (with possible exception for labs where exhaust fans track supply fan)
- When served by chilled water plant, chilled water plant should not have a waterside economizer (WSE). The tool assumes that 100% of the cooling load from the AHU is seen by the chillers.
  - Note: If a site has a WSE, a conservative approach would be to determine the outside air temperature when the WSE operates and to set the "Cooling Lockout" in the AHU tab to that temperature. This will zero out any potential savings calculated due to cooling coil load reduction whenever the WSE is operating.

Key Assumptions:

- This calculation assumes that the return fan speed (flow) tracks with the supply fan speed (flow). This calculation tool may not be appropriate if the return fan controls to a duct static pressure <u>**and**</u> does not track well (linearly or proportionally) with the supply fan.
- The following inputs are shared between occupied and unoccupied modes of operation. If a single profile for any of the inputs below is not appropriate, separate tabs may need to be created for both the occupied and unoccupied modes of operation. Create as many "tabs" for a single AHU as necessary to appropriately model the system.
  - Duct static pressure operating profile
- Reduction in cooling load from any of the EEM's only affects chiller energy. Energy impacts on the pumps (chilled water and condenser water) as well as cooling tower fans are excluded. There may be additional savings on those ancillary components, but they are not captured in the Air Side System calculation tab.
- Space Cooling and Heating Loads (zone loads) are assumed and kept constant between the baseline and all EEM iterations. From the equations below, if Cooling Zone Temp is increased and/or SAT is decreased, the required cooling flow must decrease to maintain the same Building Cooling Load. Similarly, if Heating Zone Temp is decreased or DAT is increased, then reheat flow must decrease to maintain the same Building Heating Load. <u>The zone loads used in the calcs (and held constant throughout) are set based on the baseline inputs entered by the user.</u>
  - $Building\ Cooling\ Load\ (tons) = \frac{1.08 \times Cooling\ Only\ Flow\ CFM \times (Cooling\ Zone\ Temp - SAT)}{12{,}000\ Btu/ton}$

- $Building\ Heating\ Load\ (kBtu) = \frac{1.08 \times Reheat\ Flow\ CFM \times (DAT - Heating\ Zone\ Temp)}{1000}$

- For Constant Air Volume (CAV) systems, the airflow remains unchanged (unless it is manually overridden with Proposed inputs) and it is assumed that any changes to SAT or DAT result in changes to space temperatures since it is also assumed that building heating and cooling loads remain unchanged as well.
- For simplification, the seasonal average kW/ton (e.g. IPLV or NPLV or SEER) is used at all temperature bins to calculate cooling savings.

Description of Inputs/Measures:

Equipment Specifications & Replacements

- **Equipment Name:** Provide name of AHU unit
- **Equipment Vintage:** This is the year of original installation
    - Note: This input is not used for anything in the calculation but may be useful for documenting Remaining Useful Life of AHU.
- **Efficiency:**
    - **Seasonal average kW/ton:** Enter the <u>seasonal average</u> kW/ton
        - If cooling is provided by chillers, enter the chiller IPLV or NPLV
        - If cooling is provided by compressors directly (DX systems), enter the AC unit SEER/IEER converted to kW/ton
        - Note: This kW/ton is applied equally across all temperature bins in the calculation (i.e. every temperature bin calculates cooling load savings using this kW/ton value). This is a tradeoff between ease of use for the calculator versus ultimate accuracy (and complexity) of trying to capture the various part load kW/ton values across all temperature bins and loads. Using part load (e.g. seasonal) kW/ton values instead of full load kW/ton is therefore meant to minimize the likelihood of overestimating savings from these measures described below.
    - **Source of Heating:** Select either Gas or Electric
        - **Gas Efficiency:** If Gas (source) is selected, enter the nameplate efficiency of the gas fired equipment (e.g. boiler or furnace)
            - Note on Condensing Boilers: For condensing boilers, the efficiency may need to be “derated” if HW return temperatures are high (i.e. above dewpoint) and the boiler does not actually operate at peak nameplate efficiency. Consult the boiler data sheet to determine the appropriate efficiency to enter in here based on average observed hot water return temperatures.
        - **Electric Heating (HSPF):** If Electric (source) is selected, enter the rated HSPF.
            - For heat pumps, this value should be the rated HSPF of the unit.
            - For electric resistance heating, this value should be set to 3.412.
    - **Lockout Temp:** Enter in the heating and cooling lockout temperatures.
        - Heating lockout temp: At and above this value, no heating occurs and the heating coil load is set to 0.
        - Cooling lockout temp: At and below this value, no mechanical cooling occurs and the cooling coil load is set to 0.

- **Supply Fan (HP):** Enter in the nameplate horsepower (HP) of the supply fan motor.
    - Note: For multiple fans (in parallel) such as a fan wall, enter in the total HP of all the fans that operate.
- **Supply Fan (CFM):** Enter in the design Supply CFM of the AHU
- **Supply Fan Control:** Select from the following options:
    - Damper
    - Inlet Guide Vane (IGV)
    - VFD
    - Air-Foil or Backward-Inclined - Dampers Control Flow
    - Air-Foil or Backward-Inclined - Inlet Vanes
    - Vane-Axial - Variable Pitch Blades
- **Return Fan (HP):** Enter in the nameplate horsepower (HP) of the supply fan motor.
    - **Exclusion:** The HVAC Tool is applicable only for return fans and does not support relief/exhaust fan configurations (see "Exception" below for a scenario in which exhaust fans can be modeled).
    - **Exception:** 100% outside air systems with exhaust fans that run whenever the supply fans run can be modeled using the HVAC Tool.
        - Hybrid systems with both return air and dedicated exhaust (e.g. a building with an AHU that serves both office and lab spaces) may use the tool but likely need a separate, custom calculation for any dedicated exhaust fans (e.g. general exhaust or fume hood exhausts).
- **Return Fan (CFM):** Enter in the design Return CFM of the AHU
- **Return Fan Control:** Select from the following options:
    - Damper
    - Inlet Guide Vane (IGV)
    - VFD
    - Air-Foil or Backward-Inclined - Dampers Control Flow
    - Air-Foil or Backward-Inclined - Inlet Vanes
    - Vane-Axial - Variable Pitch Blades
- **Return Fan % of Supply:** Enter in the average return fan speed as a percentage of the supply fan speed.
    - Tip: This can be estimated by calculating the average return fan speed and dividing by the average supply fan speed in the trend data. Alternatively, if trend data is not available, it may be reasonable to estimate it as the design return CFM divided by the design supply CFM.
    - Note that the only current option is a % speed ratio (RF/SF) and not a speed/CFM fixed offset (e.g. return CFM stays constantly 500 CFM less than supply CFM as supply flow varies).
- **System Type (CAV/VAV):** Select whether the air distribution system is Constant Air Volume (CAV) or Variable Air Volume (VAV). Setting the system type to CAV keeps the airflow constant throughout the calculation iterations whereas VAV will automatically adjust the flow as SAT and/or zone temperatures are adjusted.

Scheduling Optimization

- **Schedule:** Set the corresponding "Occupied Time (Start)" and "Unoccupied Time(Stop)" (hours 0 to 24) for the AHU based on Weekday, Saturday, and Sunday operation.
  - Note: Occupied (Start) and Unoccupied (Stop) is not the same as on/off times. They refer to when the AHU enters occupied and unoccupied modes of operation, respectively. For example, when an AHU is set to unoccupied mode, it may either be shut down completely or run in a "setback" mode where space temperature deadbands are expanded and air flows are reduced. Use the "Fan and Space Temperature Setbacks" input section to have the model run in a "setback mode" or completely off during "unoccupied" hours.
  - *Tip #1: The "Occupied" start time is the beginning of the hour that the AHU enters occupied mode; the "Unoccupied" stop time is the beginning of the hour that the AHU enters unoccupied mode. See examples below:*
    - *7am to 6pm operation would be entered as "Start Time = 7" and "Stop Time = 18")*
    - *24 hour operation would be entered as "Start Time = 0" and "Stop Time = 24"*
    - *Off entire day would be entered as "Start Time = 0" and "End Time = 0"*
  - *Tip #2: Below are common scenarios in which a "scheduling" measure could be implemented.*
    - *Scenario 1: The AHU is running during occupied hours and shut down during unoccupied hours. The measure is to reduce the occupied hours schedule.*
    - *Scenario 2: The AHU is running both during occupied and unoccupied hours and have a distinct operating profile for each mode of operation. The measure is to shut down the AHU during unoccupied hours rather than run in an unoccupied setback mode.*

Economizer Optimization

- Note: The inputs in this section (Simple Data or Trend Data) are for total outside air fraction. For units that have a dedicated minimum outdoor air damper section and a separate 0-100% economizer section, the two must be combined to represent to total outside air fraction entering the AHU.
- **Data Type:** Outdoor Air (OA) Percentage Profile can either be entered in as "Simple Data" or "Baseline/Proposed Trend Data". See below for details of each.
  - Warning: If there is not an economizer measure being implemented, it is recommended to use "Simple Data" **AND NOT "Baseline Trend Data"**. Using "Baseline Trend Data" while leaving the Economizer Optimization measure as "Disable" will incorrectly model the economizer in the "proposed" calcs since it will apply the same baseline economizer positions from the trend data rather than dynamically re-calculating the economizer position based on other changes made to the system from the other measures.
- **For "Simple Data":** This method assumes ideal operation of the economizer based on the parameters input below. Using Simple Data, the calculator will always select the optimal Outdoor Air % within the bounds of the min and max percentages that are entered in (based on OAT, RAT, and SAT) to maximize free cooling.
  - Enter the minimum outdoor air % (fraction/damper position)

- Enter the maximum outdoor air % (fraction/damper position)
- Enter the "Enable OAT" (economizer lockout) temperature. Above this temperature, the economizer will be locked to minimum position.
- *TIP: This input is for outdoor air fraction/percentage. If outdoor air flow rate and total AHU flow rate are measured, this can be calculated directly. However, in most instances where either or both of those are not available, it can be estimated (in order of preference) by:*
  - *Calculating OA fraction using trended RAT, MAT, and OAT values*
  - *Using the economizer position/OA damper position (%) trend.*

- **For "Baseline/Proposed Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "OA Flow (%), Base (or Prop)". Enter in all available OA % trend data that has been binned to each corresponding OAT bin. It is highly recommended that the user manually fill in any missing points in the binned trend data as the HVAC Tool forecasting will likely not work properly for Economizer trends due to the non-linear nature of economizer operation through the OAT bin range.
- *Tip: View the "OA Flow %" graph to verify the final outside air profile looks correct.*

Static Pressure Reset

- **Static Pressure Inputs:**
  - Enter the minimum observed duct static pressure (DSP)
  - Enter the maximum observed duct static pressure (DSP)
  - Note: The min and max observed actual DSP should be used and not necessarily the DSP setpoint. For example, a minimum DSP setpoint may be set lower than the system is able to achieve due to zone airflow demand.
  - *Tip: The calculation uses the curve coefficients from the "Advanced Variable Air Volume System Design Guide" and selects the appropriate curve based on the lowest achieved DSP. A minimum DSP of 1.5" and above will select the "No Reset" curve which is mapped to a DSP of 1.5" through the plenum at 0 flow. Therefore, if the baseline and proposed minimum DSP are both 1.5" or higher, no savings will be calculated. There is a possible workaround to estimate savings in this case.*

Supply Air Temperature Reset

- *Tip: View the "Supply & Discharge Air Temperature" graph to verify the final SAT profile looks correct/reasonable compared to the trends.*
- **Data Type:** Supply Air Temperature (SAT) Profile can either be entered in as "Simple Data" or "Baseline/Proposed Trend Data". See below for details of each.
- **For "Simple Data":** This method assumes a linear change in SAT versus OAT.
  - Enter the Supply Air Temperature corresponding to the low limit (Min) OAT.
  - Enter the Supply Air Temperature corresponding to the high limit (Max) OAT.
  - *TIP: The Min and Max OAT sets the "knee" of the curve. Below the Min and above the Max, the SAT profile flattens out to the corresponding OAT entered for each low/high limit OAT input.*
- **For "Baseline/Proposed Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "SAT (°F), Base (or Prop)". Enter in all available SAT % trend data that has been binned to each corresponding OAT bin. If SAT data is unavailable for any particular OAT

bin, the calculation tool will linearly forecast or interpolate in the missing data with limits set at the minimum and maximum observed SAT in the trend data. See “Base SAT” and “Proposed SAT” sections in the “Calculation Engine” write-up below for details on the ruleset applied towards forecasting the missing data.

  - Note: In some instances, it may be necessary to manually forecast certain values if the trend data range available does not adequately capture the realistic operating range of the system. For example, if there is not enough hot weather data and the trend data only shows the SAT decreasing to 60 °F, the user may be required to fill out the profile manually to have the SAT decrease down to 55 °F if that is the actual expected lowest SAT when the weather is hottest.
- **Pre-Heat Coil:** This section must be filled out whether Simple Data or Trend Data is selected above
  - **Pre-Heat Coil?:** Select “Yes” or “No” depending on if the system has a pre-heat coil
  - **Pre-Heat Setpoint Temp:** This is the setpoint for the pre-heat coil and is considered as a separate setpoint than the SAT setpoint. The pre-heat coil will heat the supply air to this temperature if the MAT is less than this value.
  - **Fan Heat °F Added:** This input allows the user to add fan heat to offset some of the pre-heat load. If the user finds the pre-heat energy to be too high, this value can be used to reduce the amount of pre-heat energy calculated. The calculation assumes that if the MAT plus the Fan Heat equals or is above the Pre-Heat Setpoint Temp, then the pre-heat coil will not be active.

Fan and Space Temperature Setbacks

- *Tip: View the “Supply Fan Flow %” and “RH Box VAV Flow % and Avg DAT” graphs to verify the final airflow and terminal box discharge air temp profiles look reasonable compared to the trends or expected operation.*
- **Data Type:** Fan Flow and Space Temp Profile can either be entered in as “Simple Data” or “Baseline/Proposed Trend Data”. % Fan Flow is defined as the ratio of operating CFM versus design airflow CFM. See below for details.
  - Note: For the “Proposed” inputs, there are drop-downs that specifically enable changing the “Occupied” proposed flows, “Unoccupied” proposed flows, and/or “Heating/Cooling” setpoints.
- **Supply Fan Flow(Simple Data):** This method assumes a linear change in Fan Flow % versus OAT
  - **Occ/UnOcc Fan Flow % - Cool:** Enter the minimum and maximum Fan Flow % when the building is primarily in cooling mode during the “Occupied” or “Unoccupied” period, respectively.
  - **Occ/UnOcc OA Cooling Temp Range:** Enter the OAT range (from low to high) corresponding to the Fan Flow % - Cool inputs.
  - **Occ/UnOcc Fan Flow % - Heat:** Enter the minimum and maximum Fan Flow % when the building is primarily in heating mode during the “Occupied” or “Unoccupied” period, respectively.
  - **OA Heating Temp Range:** Enter the OAT range (from high to low) corresponding to the Fan Flow % - Heat inputs.

- Note: The ranges for “Fan Flow % - Cool” and “Fan Flow % - Heat” do not mean that in the OAT range for “Cool” and the OAT range for “Heat” that the AHU is only providing Cooling or Heating, respectively. These are merely used to set the fan airflow profile for the building. Rather, for heating specifically, the heating profile is determined by the Heating Lockout input and the “VAV Reheat” inputs described further below.

- **VAV Reheat (Simple Data)**
  - **Fraction of Zones with RH:** This is the fraction of zones with reheat. Ideally, this should represent the estimated fraction of total reheat box CFM versus total system CFM. Other possible options are to use approximate area (sqft) of reheat space versus total conditioned space.
  - **@OAT (No Reheat):** This is the Outside Air Temp when there is no space reheating in any of the zones anymore.
    - This value represents the outside air temperature (OAT) when the VAV boxes begin to reheat the supply air. This input value sets the start point of the linear slope of the DAT profile from the "@OAT (No Reheat)" to the "Design Heating OAT".
  - **Select Closest City:** Select the closest city in the available list to this facility.
  - **Design Heating OAT Lookup:** Based on the city selected above, this is the “Design Drybulb (0.6%)” temperature from Title 24 JA2.2.
    - The Design Heating OAT sets the OAT value when all VAV boxes operate at the Max DAT entered below. This input value sets the end point of the linear slope of the DAT profile from the "@OAT (No Reheat)" to the "Design Heating OAT".
  - **Override Lookup?:** Select “yes” or “no” to override the temperature selected from Title 24 JA2.2. This can be used as one of the means to “calibrate” the calculated baseline therms usage if the tool is severely over or under estimating the baseline gas usage compared to historical usage/meter data.
  - **Override Design Heating OAT:** If “Override Lookup?” is set to “yes”, enter in the temperature.
    - Tip: Increasing this value will make the DAT curve steeper and increase gas usage. Decreasing this value will make the DAT curve less steep and decrease gas usage.
  - **Max DAT (Avg of All RH Boxes):** This is the maximum average discharge air temperature (DAT) when all the reheat VAV boxes are at their maximum heating observed.
    - Tip: Since this value is likely to be based on engineering judgment, it can also be used as a variable to “calibrate” the baseline gas/therm usage to be reasonable when compared to historical usage/meter data.
  - **Proposed VAV Reheat Inputs:** Note that the above inputs are only available for the “Baseline”. For the proposed, the options are “Auto Calc” or “Proposed Trend Data”. Auto-calc is the equivalent of “Simple Data” and tells the calculation to automatically adjust the reheat flow and average DAT based on changes from other measures and keeping the calculated baseline space heating and cooling loads constant throughout the calculation. See “RH Box Flow %” and “RH VAV DAT °F” in “Calculation Engine” write-up below for additional details.
- **Space Temp and Return Air Temp (Simple Data)**

- **Occ Space Temp:** Enter the space heating and cooling temperature setpoints when in “Occupied” mode.
- **Unocc Space Temp:** Enter the space heating and cooling temperature setpoints when in “Unoccupied” mode.
  - Notes: Space Temperature inputs are only available in this “Simple Data” format here.
- **Return Air Temp:** When “Use Space Temp” is selected, the RAT is equal to the Space Temperatures entered above.
  - Note: When “Use Space Temp” is selected, the calculation assumes that the RAT is at the “Heating” temperature setpoint when OAT is at or below the “Heating” space temperature. The calculation assumes that RAT is at the “Cooling” space temperature setpoint when OAT is at or above the “Cooling” space temperature. When OAT is between the heating and cooling space temperature setpoints, the calculation assumes that the RAT is equal to OAT.

- **For “Baseline/Proposed Trend Data”:** The data is entered in the “Calculation Engine” section below under the following headings.
  - **Occ (or UnOcc) SF Flow (%), Base (or Prop) Trend**
    - For missing trend data points, the calculation performs a linear extrapolation/interpolation using the entered trend values. The upper limit is set to 100% and the lower limit is set to the minimum observed SF Flow % trend value.
  - **Occ (or UnOcc) RH Box VAV Flow (%), Base (or Prop) Trend**
    - For missing trend data points, the calculation performs a linear extrapolation/interpolation using the entered trend values. The upper limit is set to the SF Flow % (for that OAT bin) and the lower limit is set to the minimum observed RH Box VAV Flow % trend value.
  - **Occ (or UnOcc) RH VAV DAT (°F), Base (or Prop) Trend**
    - For missing trend data points, the calculation performs a linear extrapolation/interpolation using the entered trend values. The upper limit is set to the maximum observed RH Box DAT trend value and the lower limit is set to the SAT (for that OAT bin).
  - **Occ RAT (°F), Base (or Prop) Trend**
    - For missing trend data points, the calculation performs a linear extrapolation/interpolation using the entered trend values. The upper limit is set to the maximum observed RAT trend value and the lower limit is set to the minimum observed RAT trend value.
  - Note: When “Prop” (proposed) trend is used, this overwrites any “auto calculations” done to balance baseline and proposed conditions intended to balance space heating/cooling loads. Use of proposed trend data, therefore, is intended to represent the final conditions of the project and include any interactive effects from other measures (e.g. SAT reset affecting required supply air flow).

Calculation Engine:

- **Base SAT °F:** Source from Simple Data linear model or Trend Data as specified in "Supply Air Temperature Reset" measure input.
  - **Simple Data:** The SAT is interpolated linearly between the min and max SAT at the high and low OAT limits entered in the "Simple Data" input. The SAT is limited to the min and max SAT inputs.
  - **Baseline Trend Data:** Forecast linearly for missing trend data points with SAT high limit set at maximum observed SAT value in trends and SAT low limit set at minimum observed SAT value in trends.
- **Prop SAT °F:** Source from Simple Data linear model or Trend Data
  - Same as above for "Base SAT" except for "Proposed" inputs and only when "Supply Air Temperature Reset" is set to "Enable". Otherwise, set to "Base SAT" if measure is disabled.
- **Delta SAT °F:** Calculated as: SAT – Baseline SAT
- **SAT °F:** SAT value depending on whether calculation is in "Baseline" or "Proposed" based on the "Supply Air Temperature Reset" switch in the "Processing" section. This is the active SAT for the iteration run.
- **RH Box Flow %:** Source from Simple Data linear model or Trend Data
  - **Simple Data (Base):** Calculated as:

    $$RH\ Box\ Flow\ \% = SF\ Flow\ \%\ \times Fraction\ of\ Zones\ with\ RH$$

    For subsequent iterations, RH Box Flow % is adjusted
  - **Trend Data (Base/Prop):** From Trend Data inputs. Missing trend data points are forecasted linearly with the low limit set to the lowest observed trend value and the high limit set to the total SF Flow %.
    - Note: "Proposed Trend Data" overwrites any auto-calculations of the RH Flow.
  - **Auto Calc (Prop):** See conditions below
    - If SF Fan Flow % has been manually changed using the Proposed in EEM "Fan and Space Temperature Setbacks", the RH Flow is calculated as $(Proposed\ SF\ Flow\ \%) \times (RH\ to\ SF\ Ratio, Base)$. For this simplified calculation approach, it is assumed that the Proposed SF Flow % is the final flow inclusive of all the EEM interactive effects and that the % RH Flow to SF Flow ratio stays the same as in the baseline.
    - Otherwise, if there is no manual change to the SF Fan Flow % in the Proposed inputs, calculate using "EEM Iteration Adjustments" as described below.
  - **EEM Iteration Adjustments:** As the macro cycles through the EEM iterations, the airflow is adjusted under the following conditions:
    - For tempered cooling, if SAT is increased at any point above the baseline VAV box DAT, RH Box flow is increased using the following equation:

      $$Prop\ Flow\ Adj\ \% = \frac{Max\ of\ \left(0\ or\ \frac{Tempered\ Cooling\ Load\ Btuh, Base}{1.08 \times (Prop\ Cool\ Space\ Temp - Prop\ SAT)} - Tempered\ Cooling\ Flow, Base\right)}{Design\ CFM}$$

      Note: This calculation is found in the columns named "Occ/Unocc Prop Fan Flow Adj (Tempered Cooling)"
    - For RH VAV boxes in cooling only (no tempering of supply air), RH Box flow is adjusted when SAT or space cooling temp setpoint changes. The overall "Prop

Fan Flow Adj (Cooling Only)" percentage is proportioned based on the RH Box VAV cooling only flow versus the VAV boxes that are cooling only (i.e. no reheat). "Prop Fan Flow Adj (Cooling Only)" is calculated as:

$$Prop\ Flow\ Adj\ \% = \frac{\left(\frac{Space\ Cooling\ Only\ Load\ Btuh, Base}{1.08 \times (Prop\ Cool\ Space\ Temp - Prop\ SAT)} - Cooling\ Only\ Flow, Base\right)}{Design\ CFM}$$

- **RH VAV DAT °F:** Source from Simple Data or Trend Data
  - **Simple Data (Base):** Baseline DAT is calculated using the equation below. The HVAC Tool references the "Occ/Unocc DAT Adj" column which effectively applies the below equation for the Baseline iteration run (see also "Occ/Unocc DAT °F, Base" description below)

    $$DAT = SAT + (Max\ DAT - SAT) \times \frac{NoRHTemp - OAT}{NoRHTemp - OAT@MaxDAT}$$

    The DAT calculation is set with a low limit corresponding to the SAT and a high limit corresponding to the "maximum DAT" entered in the inputs.
  - **Trend Data (Base, Prop):** Forecast linearly for missing trend data points with a low limit of the SAT and a high limit of the maximum observed value in the included trends.
    - Note 1: If the user believes the maximum DAT should go higher than the maximum observed in the trends, the range of the trend inputs should be extrapolated manually by the user and then entered into the HVAC Tool's trend data input section. An explanation to justify the manual extrapolation and why it is reasonable should be included in the project documentation.
    - Note 2: Baseline Trend Data (as entered by the user) is only used for setting the initial "Baseline" iteration. Once the first EEM iteration is run, the DAT is automatically recalculated for the calculation to maintain the same space loads for each EEM iteration run. However, proposed Trend Data overwrites any auto-calculated DAT values for the final EEM iteration run.
  - **Auto Calc (Prop):** The adjusted DAT is re-calculated when SAT is changed and heating space temperature setpoint is changed. It is calculated using the equations shown in "RH DAT °F Adj" below.
- **RAT °F:** Source from Simple Data ("Use Space Temp") model or Trend Data
  - **Simple Data ("Use Space Temp"):** RAT is estimated using the following ruleset:
    - If OAT >= Cooling Space Temp, RAT = Cooling Space Temp
    - If OAT <= Heating Space Temp, RAT = Heating Space Temp
    - If OAT is between Cooling Space Temp and Heating Space Temp, RAT = OAT
  - **Trend Data:** From Trend Data inputs. Missing trend data points are forecasted linearly with the low limit set to the lowest observed trend value and the high limit set to the highest observed trend value.
- **OA Flow %:** Source from Simple Data linear model or Trend Data
  - **Simple Data:**
    - If OAT > OA Enable, set to minimum % in Simple Data range
    - Otherwise, calculated ideal % based on combination of SAT, RAT, and OAT up to Max OA % (high limit) or down to Min OA% (low limit) as set in Simple Data range using the following equation:

$$OA\ Flow\ \% = MEDIAN\left(Min\ OA\ \%, Max\ OA\ \%, \frac{SAT - RAT}{OAT - RAT}\right)$$

- **Trend Data:** From Trend Data inputs. Missing trend data points are forecasted linearly with the low limit set to the lowest observed trend value and the high limit set to the highest observed trend value.
  - Note: If there is not enough "weather coverage" where the user believes the limits set in the linear forecasting is too high (for the low limit) or too low (for the high limit), the user should perform a manual forecasting in their trend analysis file with proposed limits and provide justification in the project documentation as to why those high/low limits are appropriate.

- **MAT °F:** Calculated based on OA Flow %, OAT, and RAT

$$MAT = (OA\ Flow\ \% \times OAT) + (1 - OA\%) \times RAT$$

- **Pre-Heat?:** Marked "Yes" when the following conditions are met (otherwise "No"):
  - "Pre-Heat Coil?" input is marked as "Yes"
  - SAT > MAT + Fan Heat
  - Hour (Occ or UnOcc) > 0
- **Pre-Heat Load, kBtu:** Calculated as follows when "Pre-Heat?" is marked as "Yes":

$$Pre - Heat\ Load, kBtu = 1.08 \times SF\ Flow\ CFM \times [SAT - (MAT + Fan\ Heat)]$$

- **SF Flow %:** Source from Simple Data linear model or Trend Data as specified in "Fan and Space Temperature Setbacks" measure input.
  - **Simple Data:** SF Flow % is interpolated linearly within the OAT bounds set in the measure input for both "Occ/Unocc Fan Flow % - Cool" and "Occ/Unocc Fan Flow % - Heat". This results in a piecewise linear fan flow profile.
    - Note: If there is a "gap" in the temperature range between the Cooling Temp Range and Heating Temp Range, the SF Flow % is set to the minimum cooling fan flow % during that period.
  - **Trend Data:** Use entered trend data values. When trend points are missing, forecast linearly for missing trend data points with high limit set to 100% and low limit set to the minimum observed trend value.
  - Note:
    - The Baseline iteration run is calculated using either the "Simple Data" or "Baseline Trend Data" inputs. The airflow profile generated from these inputs are automatically re-calculated in subsequent EEM iteration runs when either SAT and/or Space Temperature Setpoints are changed. Unless overridden with manual "Proposed" data entry (see bullet below), the fan flow % for each EEM iteration run is calculated as:
      - $SF\ Flow\ \% = SF\ Flow\ \%, Base + Prop\ Net\ Fan\ Flow\ Adj$
        - Where "Prop Net Fan Flow Adj" is calculated below in the section "Baseline Space Load and Measure Interactive Effects Calcs"
    - Manual Entry of Proposed Fan Flows: When "Fan and Space Temperature Setbacks" is set to "Enable" and the Occupied/Unoccupied are set to "Sub-Enable" (respectively), the automatic calculations are overridden by the user inputs of either Proposed Simple Data or Proposed Trend Data. These Proposed

inputs are intended to be inclusive of any fan flow increases or decreases resulting from other EEM's such as SAT reset and/or Space Temperature Setpoint changes which should be seen embedded in the post-install trend data.

- **Cooling Load, Ton:** Calculated based on:
  - If OAT < Cooling Lockout, 0
  - Else, calculated as: $Cooling\ Load, Ton = \frac{1.08 \times SF\ Flow\ CFM \times (MAT - SAT)}{12{,}000}$
- **Re-Heating Load, kBtu:** Calculated based on:
  - If OAT > Heating Lockout, 0
  - Else, calculated as: $Heating\ Load, kBtu = \frac{1.08 \times RH\ Box\ Flow\ CFM \times (RH\ VAV\ DAT - SAT)}{1{,}000}$
    - Where SAT is determined as follows:
      - If "Pre-Heat?" = "Yes", SAT = Pre-Heat SAT setpoint
      - If "Pre-Heat?" = "No", SAT = MIN (SAT, MAT)
- **Total Heating Load, kBtu:** Calculated as:
  - $Total\ Heating\ Load, kBtu = Pre\text{-}Heat\ Load, kBtu + Re\text{-}Heat\ Load, kBtu$
- **RF Flow %:** Return Fan flow is calculated as:
  - $RF\ Flow\ \% = SF\ Flow\ \% \times Return\ Fan\ \%\ of\ Supply$
- **SF kW:** Calculated as:
  - $SF\ kW = \frac{0.746 \times SF\ Fan\ HP}{Motor\ Eff \times VFD\ Eff} \times \%\ Fan\ Full\ Load\ Power$
    - Where motor efficiency is pulled from default table in "Processing" section
    - Where curve coefficients are determined based on fan capacity control type
    - Where % Fan Full Load Power is calculated using fan coefficients from ASHRAE 90.1 or the EDR Advanced VAV Design Guide Appendix 5.
      - Fan Curve Coefficients equation uses SF Flow % as the independent variable in the polynomial equation using the appropriate fan curve coefficients
- **RF kW:** Same calculation as for Occ SF kW except using return fan values (e.g. return fan speed, hp, curve coefficients, etc…)
- **Total Fan kW:** Calculated as
  - $Total\ Fan\ kW = SF\ kW + RF\ kW$
- **Load kW:** Calculated using the following:
  - $Load\ kW = Cooling\ Load, Ton \times Seasonal\ Avg\ \frac{kW}{ton}$
  - If applicable (electric heating), add also:
    - $Total\ Heating\ Load, \frac{kBtu}{hr} \div HSPF, \frac{kW \times hr}{kBtu}$
- **Unoccupied calculations** are the same as for Occupied but using the Unoccupied inputs
- **Fan Total kWh:** Calculated for both occupied and unoccupied as:
  - $Fan\ kWh = (SF\ kW + RF\ kW) \times hours$
- **Load Total kWh:** Calculated for both occupied and unoccupied as:
  - $Load\ kWh = Load\ kW \times hours$
- **Heating Total Therms:** Calculated for both occupied and unoccupied as:
  - $Therms = \frac{Total\ Heating\ Load, kBtu/hr}{Boiler\ Eff} \times \frac{1\ therm}{100\ kBtu} \times hours$

<u>Baseline Space Load and Measure Interactive Effects Calcs:</u>

This section in the calculation engine calculates the baseline space heating, cooling only, and tempered cooling loads. For “automatic” theoretical calculations, these loads are held constant through each EEM iteration. The theoretical impacts on the airflow and/or DAT from the EEM’s are then calculated based on the assumption that the zone loads do not change from baseline to proposed. The description below is for each variable generally, and the calculation breaks these down further into “occupied” and “unoccupied” periods using their respective inputs.

- **SF Flow %, Base:** Calculated as described previously but only using baseline inputs
- **RH Box Flow %, Base:** Calculated as described previously but only using baseline inputs
- **RH to SF Ratio, Base:** Calculated as
  - $RH\ to\ SF\ Ratio, Base = \frac{RH\ Box\ Flow\ \%, Base}{SF\ Flow\ \%, Base}$
- **DAT °F, Base:** Calculated as above but only using baseline inputs
- **RAT °F, Base:** Calculated as above but only using baseline inputs
- **Heating Only Flow %, Base:** Calculated as the “RH Box Flow %, Base” when DAT>Space Heating Setpt
- **Cooling Only Flow %, Base:** Calculated as
  - $Cooling\ Only\ Flow\ \%, Base = SF\ Flow\ \%, Base - Heating\ Only\ Flow\ \%, Base - Tempered\ Cooling\ Flow\ \%, Base$
- **Tempered Cooling Flow %, Base:** Calculated as the “RH Box Flow %, Base” when DAT<=Space Heating Setpt and DAT>SAT
- **Sum of Flow %, Base:** Calculated as the sum of Heating Only Flow %, Cooling Only Flow %, and Tempered Cooling Flow %.
  - Used only to check that Flow % allocations to each sum up to the total SF Flow %.
- **Space Heating Only Load kBtu/h, Base:** Calculated as

$$Space\ Heating\ Load = \frac{1.08 \times Heating\ Only\ Flow \times (DAT - Heating\ Zone\ Temp)}{1{,}000\ BTU/kBtu}$$

- **Space Cooling Only Load kBtu/h, Base:** Calculated as

$$Space\ Cooling\ Only\ Load = \frac{1.08 \times Cooling\ Only\ Flow\ (CFM) \times (Cooling\ Space\ Temp - SAT)}{1{,}000\ Btu/kBtu}$$

- **Space Tempered Cooling Load kBtu/h, Base:** Calculated as

$$Space\ Tempered\ Cooling\ Load^{1} = \frac{1.08 \times Tempered\ Cooling\ Flow\ (CFM) \times (Heating\ Space\ Temp - DAT)}{1{,}000\ Btu/kBtu}$$

- **SF Manual Prop Airflow Adj to Base Ratio:** This is calculated only when the EEM “Fan and Space Temperature Setbacks” is enabled that changes the SF Flow % between the baseline and proposed via Simple Data or Proposed Trend Data inputs. When the EEM is enabled:

$$Ratio = \frac{Supply\ Fan\ Flow\ \%,\ Prop}{Supply\ Fan\ Flow\ \%,\ Base}$$

- **Prop Fan Flow Adj (Cooling Only):**

  If AHU system type is selected as “Constant Air Volume”:

  - Set to 0% (meaning airflow stays constant and DAT will need to be adjusted when appropriate)

[1] Should accurate delta T be calculated as: MAT-DAT?
This calculation doesn’t seem to include the impact of OAT.

If AHU system type is selected as “Variable Air Volume”, calculated as:

$$Prop\ Flow\ Adj\ \% = \frac{\left(\frac{Space\ Cooling\ Only\ Load\ Btuh, Base}{1.08 \times (Prop\ Cool\ Space\ Temp - Prop\ SAT)} - Cooling\ Only\ Flow, Base\right)}{Design\ CFM}$$

- **Prop Fan Flow Adj (Tempered Cooling):**

  If AHU system type is selected as “Constant Air Volume”:

  - Set to 0% (meaning airflow stays constant and DAT will need to be adjusted when appropriate)

  If AHU system type is selected as “Variable Air Volume”, calculated as:

$$Prop\ Flow\ Adj\ \% = \frac{Max\ of\ \left(0\ or\ \frac{Tempered\ Cooling\ Load\ Btuh, Base}{1.08 \times (Prop\ Cool\ Space\ Temp - Prop\ DAT)} - Tempered\ Cooling\ Flow, Base\right)}{Design\ CFM}$$

- **Prop Net Fan Flow Adj:**
  - If AHU system type is selected as “Constant Air Volume”:
    - Set to 0% (meaning airflow stays constant and DAT will need to be adjusted when appropriate)
  - If AHU system type is selected as “Variable Air Volume”:
    - Calculated as the sum of the Prop Fan Flow Adj for cooling only and tempered cooling
- **RH DAT °F Adj:** This is the calculated and adjusted if certain inputs are expected to change the DAT. It is calculated as follows:

  For Tempered Cooling Mode:

$$Prop\ DAT = Prop\ Heating\ Space\ Temp - \frac{Tempered\ Cooling\ Load\ Btuh, Base}{1.08 \times Base\ Tempered\ Cooling\ Flow}$$

  For Heating Mode:

$$Prop\ DAT = \frac{Heating\ Load\ Btuh, Base}{1.08 \times Base\ Heating\ Flow} + Prop\ Heating\ Space\ Temp$$

  Note: It is assumed that in both tempered cooling and heating modes, the airflow is at its minimum and does not change from baseline to proposed conditions. The exception to this is if the SF flow % is changed using the proposed inputs (Simple Data or Proposed Trend Data). In this case, the “Base Tempered Cooling Flow” and “Base Heating Flow” are multiplied by the % change from baseline to proposed SF flow.

Chiller Calculation Tab

System Requirements and Exclusions

- Maximum of three (3) chillers and/or three (3) cooling towers
- For water-cooled chillers only (air-cooled option expected to be added in the future)
- For positive displacement (e.g. screw), centrifugal, and centrifugal with VFD chillers only. Magnetic bearing chillers may be added at a future date but would need to be modeled as centrifugal with VFD for now.
- For primary-only or primary-secondary systems only
- For primary-secondary system, one primary chilled water pump operates per chiller and at constant flow
- All chilled water pumps (primary in primary only configuration or secondary pumps) must be of equal size with the same design parameters (head and flow rate).
- Primary pumps (in primary-secondary configuration) are constant speed/flow and operate one per chiller.
- Condenser water pumps operate one per chiller and at constant flow and head
- Water-side economizer is for non-integrated (piped in parallel) economizers only

Key Assumptions

- When multiple chilled water pumps (primary-only or secondary) operate, they are treated as a single large pump (horsepower summed together) with the DOE-2 generic pump curves (% power as a function of % total flow). This prevents the calculations from calculating energy savings when splitting the flow between fewer VFD pumps to more VFD pumps in operation in a closed loop pumping system. In other words, the calculation assumes no difference in energy whether running multiple pumps concurrently or staging up pumps sequentially.
- When pump flow measurements are unavailable, pump speed may be used as a direct proxy for pump flow % of total design flow.
- Cooling Tower Fan % is estimated based on the ratio of Cooling Tower Heat Rejection Load versus Cooling Tower Available Heat Rejection Capacity. Cooling towers stage up based on load vs available capacity.
- For systems with various cooling tower sizes, it is assumed all fans operate at the same speed when multiple CT's are in operation and that the load is effectively proportioned amongst the operating CT's based on their respective capacities.
- Chillers use default chiller curve coefficients from the Title 24 ACM Manual Appendix 5.7. The ability to enter custom chiller curve coefficients based on manufacturer data may be added in the future.

Special Notes:

- For modeling Primary-Only systems, the primary pumps are modeled using the "Secondary Chilled Water Pumps (SCHWP)" inputs in the "Chillers, Cooling Towers & Pumps Specifications" section and the "Secondary Chilled Water Pump VFD And Speed Control" section. Energy usage and savings on the Primary-Only PCHWP pumps are calculated in the "SCHWP" columns in the "Calculation Engine".

Description of Inputs/Measures

Chillers, Cooling Towers & Pumps Specifications

Chiller Specifications

- **Chiller Type:** Select between Positive Displacement (e.g. screw), Centrifugal, or Centrifugal (VFD)
- **Heat Rejection:** Only the Water-Cooled option is currently available. Air-cooled may be added in the future.
- **Capacity:** Enter the nominal design capacity (tons) of each chiller
- **kW/ton (full load):** Enter in the full load kW/ton of each chiller (Do not use part load kW/ton)
- **Design CHWT:** Enter the design chilled water supply temperature. If unavailable, default to 44 °F.
- **Design CWT:** Enter the design entering condenser water temperature. If unavailable, default to 75 °F.
- **Schedule:** Set the corresponding "Start Time" and "Stop Time" (0-24) for the boiler plant based on Weekday, Saturday, and Sunday operation.
    - *Tip: The start time is the beginning of the hour that the HHW plant turns on; the stop time is the beginning of the hour that the HHW plant turns off. See examples below:*
        - *7am to 6pm operation would be entered as "Start Time = 7" and "Stop Time = 18")*
        - *24 hour operation would be entered as "Start Time = 0" and "Stop Time = 24"*
        - *Off entire day would be entered as "Start Time = 0" and "End Time = 0"*

Chiller Plant Cooling Load Change

- **Data Type:** Cooling Load Profile can either be entered in as "Simple Data" or "Baseline Trend Data". See below for details of each.
- **For "Simple Data":**
    - Enter the maximum load corresponding to the highest OAT
    - Enter the minimum load corresponding to the lowest OAT.
    - Select either a "Baseload" or "Goes to Zero" load profile.
        - "Baseload" sets the load profile to remain at the minimum load that is input when OAT exceeds the high OAT input.
        - "Goes to Zero" sets the load profile to continue linearly to 0 when OAT exceeds the high OAT input.
- **For "Baseline Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "Cooling Load (tons), Base". Enter in all available Cooling Load trend data that has been binned to each corresponding OAT bin.
    - Note: If cooling load data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data.
        - The load will increase linearly (as OAT bin increases) up to the total OUTPUT capacity available for the CHW Plant.
        - The load will decrease linearly (as OAT bin decreases) up until the Chiller Lockout OAT or it reaches 0 tons.
    - *Tip: View the "Cooling Load" graph to verify the final load profile looks correct.*

Chilled Water Pumps

- **Chilled Water Pumps System Configuration:** Select either “Primary Only” or “Primary-Secondary”
- **Primary Chilled Water Pumps** (PCHWP) (Note: This input section is only for primary pumps in a primary-secondary configuration. For primary pumps in a primary-only configuration, use the “Secondary Chilled Water Pumps/Primary-Only Chilled Water Pumps” inputs):
  - Requirements:
    - The Primary CHW Pumps input is for constant speed primary pumps only in parallel configuration. The Primary CHW Pumps are assumed to operate at constant flow and head.
    - The Primary CHW Pumps operate one per chiller. That means PCHWP1 operates when CH1 operates, PCHWP2 operates when CH2 operates, etc…
    - For Primary-Only Variable Flow systems, enter in primary pumps under the “Secondary CHW Pumps/Primary-Only CHW Pumps” section and leave the Primary Pump Inputs blank.
  - **General Instructions:**
    - Leave columns blank when there is no pump.
    - There should be one primary pump assigned to operate with each chiller (2 chillers means there should be 2 primary CHW pumps).
    - Only enter in the number of operating pumps. For example, if there are 3 pumps but one is backup/redundant (n+1), then only enter in two pumps.
  - **Select Inputs for Power Calc:** Select either calculating full load pump power using either 1) nameplate horsepower and estimated load factor or 2) Design Flow GPM and Feet of Head
  - **For “Design Flow and Head”:** Enter
    - **Flow (gpm):** Enter in the Design Flow (GPM) for each pump
    - **Head (ft) per pump:** Enter in the design head of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Pump Eff (%) per pump:** Enter the estimated pump efficiency. Typically 70-80% is reasonable if unknown.
  - **For “Nameplate Horsepower”:** Enter
    - **Size (HP) per pump:** Enter in the nameplate hp of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Load Factor (%):** Enter in an estimated load factor %. The default load factor is set to 80%. If design information for the pump is available, Load Factor may be estimated as follows:
      - Determine Load Factor using Design BHP

$$Load\ Factor = \frac{BHP}{Nameplate\ HP}$$

- Secondary Pumps (or Primary-Only Pumps in a primary-only system configuration):
  - **General Instructions:**
    - Input fields represent one pump. The calculation requires that all secondary CHW pumps be identical. Modeling multiple pumps is described below.

- **Select Inputs for Power Calc:** Select either calculating full load pump power using either 1) nameplate horsepower and estimated load factor or 2) Design Flow GPM and Feet of Head
  - **For "Design Flow and Head":** Enter
    - **Flow (gpm):** Enter in the Design Flow (GPM) for each pump
    - **Head (ft) per pump:** Enter in the design head of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Pump Eff (%) per pump:** Enter the estimated pump efficiency. Typically 70-80% is reasonable if unknown.
  - **For "Nameplate Horsepower":** Enter
    - **Size (HP) per pump:** Enter in the nameplate hp of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Load Factor (%):** Enter in an estimated load factor %. The default load factor is set to 80%. If design information for the pump is available, Load Factor may be estimated as follows:
      - Determine Load Factor using Design BHP

$$Load\ Factor = \frac{BHP}{Nameplate\ HP}$$

- **Maximum Pump Qty Operating:** Enter the maximum number of operating secondary CHW pumps (i.e. all pumps excluding redundant pumps)

Cooling Tower Specs

- **General Instructions:** Enter in the data for each cooling tower that operates (i.e. exclude any back-up/redundant cooling towers)
- **Capacity (tons):** Enter the rated capacity of each cooling tower
- **Fan (hp):** Enter the nameplate horsepower of each cooling tower fan
- **Motor eff (%):** Enter the motor efficiency for the cooling tower fan
- **Min Fan Speed (%):** Enter the minimum allowable fan speed for the cooling tower fan. If calculated required flow is below this value, CT fans are set to operate at minimum speed.

Condenser Pumps

- **General Instructions:**
  - Input fields represent a single condenser water pump. The calculation requires that all condenser water pumps be identical and that one operates per chiller. Modeling multiple pumps is described below.
- **Select Inputs for Power Calc:** Select either calculating full load pump power using either 1) nameplate horsepower and estimated load factor or 2) Design Flow GPM and Feet of Head
  - **For "Design Flow and Head":** Enter
    - **Flow (gpm):** Enter in the Design Flow (GPM) for each pump
    - **Head (ft) per pump:** Enter in the design head of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Pump Eff (%) per pump:** Enter the estimated pump efficiency. Typically 70-80% is reasonable if unknown.

- **For "Nameplate Horsepower":** Enter
  - **Size (HP) per pump:** Enter in the nameplate hp of each pump
  - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
  - **Load Factor (%):** Enter in an estimated load factor %. The default load factor is set to 80%. If design information for the pump is available, Load Factor may be estimated as follows:
    - Determine Load Factor using Design BHP

$$Load\ Factor = \frac{BHP}{Nameplate\ HP}$$

- **# of CW Pumps Available:** This is the total number of CW pumps available and is used solely for calculating CW pump energy when the WSE is operating (if enabled).

Chilled Water Pump Lockout Control

- **Cooling Lockout Temp:** Enter the cooling lockout temperature. Below this temperature, the cooling load is 0 and there is no corresponding chiller plant (pumps, chiller, cooling tower) energy. The waterside economizer (if enabled) is also locked out below this temperature.

Chiller Staging Sequence Optimization

- **Chiller Staging Table Entry:** This allows for up to 7 stages for chiller sequencing. For each stage, change the cell to "on" for all chillers operating at that stage. This feeds the "Chiller Staging Sequence" table in the Processing section of the calculation tab.
- **Stage Up Tons:** For each stage, enter the cooling load tons at which point the chiller plant stages up to the next stage. This allows for sequencing the chillers to stage up prior to reaching 100% load for the stage.

Chilled Water Temperature Reset

- **Data Type:** CHWST Profile can either be entered in as "Simple Data" or "Baseline Trend Data". See below for details of each.
- For **"Simple Data":**
  - Enter the high limit CHW Supply Temp corresponding to the Min OAT
  - Enter the low limit CHW Supply Temp corresponding to the Max OAT.
- For **"Baseline Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "CHWST (°F), Base (or Prop)". Enter in all available CHWST trend data that has been binned to each corresponding OAT bin. If CHWST data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data. See "CHWST" section in the "Calculation Engine" write-up below for details on the ruleset applied towards forecasting the missing data.
- Tip: View the "CHWST" graph to verify the final load profile looks correct.

Water Side Economizer Optimization

- **General Instructions:** This is for non-integrated waterside economizers (WSE) only. That means that either the chillers operate or the WSE operates, but not both at the same time (i.e. no partial free cooling of the chilled water).
- **Non-Integrated WSE?:** Enter "Yes" or "No" if there is an integrated WSE in the system. If yes, proceed with the inputs below.

- **CT Approach for WSE (°F):** This is the approach temperature between the ambient wet bulb and the condenser water supply temperature.
- **WSE Enable OAT Wet Bulb (°F):** The WSE operates when the outside air wet bulb temperature is less than or equal to the temperature entered here.
- **HX Approach (°F):** This is the approach temperature at the WSE heat exchanger between the condenser water supply (entering) temperature and the chilled water supply (leaving the HX) temperature.
- **Avg Condenser Water Flow (GPM):** This is the average operating condenser water flow required when operating the WSE. It is used to determine the number of condenser water pumps operating and calculating condenser water pump energy when operating the WSE.

Cooling Tower Staging Sequence Optimization

- **Data Type:** Simple Data only currently. Trend Data option may be added at a future date.
- **For "Simple Data":**
    - **Cooling Tower Staging Table Entry:** This allows for up to 7 stages for cooling tower sequencing. For each stage, change the cell to "on" for all chillers operating at that stage. This feeds the "Cooling Tower Staging Sequence" table in the Processing section of the calculation tab.

Secondary (or Primary Only) Chilled Water Pump VFD and Speed Control

- Note that this is also the data entry section for primary-only primary chilled water pumps.
- **Data Type:** Secondary CHW Pump VFD and Speed Control Profile can either be entered in as "Simple Data" or "Baseline Trend Data". See below for details of each.
- **For "Simple Data":**
    - Enter the maximum Pump Flow % corresponding to the highest OAT
    - Enter the minimum Pump Flow % corresponding to the lowest OAT.
- **For "Baseline Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "SCHWP Flow (%), Base (or Prop)". Enter in all available SCHWP pump flow % trend data that has been binned to each corresponding OAT bin. If SHWP pump flow % data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data. See "SCHWP Flow %" section in the "Calculation Engine" write-up below for details on the ruleset applied towards forecasting the missing data.
- **Pump Control:** Select from either Constant – Variable Flow, VFD – no DP reset, or VFD - with DP reset.
- **IMPORTANT:** The input is Pump Flow % and not Pump Speed %. The calculation is based on % of Design Pump Flow. In instances where pump flow data is unavailable, Pump Speed % can be used as a proxy for Pump Flow %. However, the preference will always be to use actual pump flow % which can be calculated as measured flow divided by design flow.
- *Tip: View the "SCHWP Pump Flow" graph to verify the final load profile looks correct.*

Calculation Engine

- **CHWST degF:** Source from Simple Data linear model or Trend Data
    - Note: When using trend data, missing data points are forecast/interpolated linearly with limits set at the highest and lowest observed trend data points.
- **CWST degF:** Source from Simple Data linear model or Trend Data

- If Econ Engaged = TRUE, CWST is wet bulb temp + CT Approach for WSE. This also overwrites any trend data entries at those OAT bins.
- Note: When using trend data, missing data points are forecast/interpolated linearly with limits set at the highest and lowest observed trend data points.

- **Cooling Load tons:** Source from Simple Data linear model or Trend Data
  - Note: When using trend data, missing data points are forecast/interpolated linearly with the limits set at the maximum rated chiller plant capacity (high limit) and 0 tons (low limit).
- **CT Load tons:** Cooling Tower Load (tons) is calculated as the cooling load plus the work of the compressor using the formula:
  - $CT\ Load\ Tons = Cooling\ Load\ Tons + \left(Chiller\ kW \times \frac{Ton}{3.517\ kW}\right)$
  - If "Econ Engaged" is TRUE, then CT Load Tons = Cooling Load Tons (i.e. no compressor work is added).
- **SCHWP Flow:** Source from Simple Data linear model or Trend Data
  - Note: When using trend data, missing data points are forecast/interpolated linearly with the limits set at 100% (high limit) and the minimum observed trend data value (low limit)
- **CWP Qty:** Set based on "Chiller Staging". One CW pump operates per chiller.
  - When in WSE Mode ("Econ Engaged" = TRUE), the number of CW pumps is calculated as the "Avg Condenser Water Flow (GPM)" with the WSE operating divided by the design GPM of each CWP and rounded up to the nearest whole number.
- **CWP Flow:** No longer used; calculation assumes one pump operates per chiller and pump operates at constant design flow and head.
- **Econ Engaged:** True (on) if all conditions below are met:
  - "Non-Integrated WSE" is marked as "Yes"
  - Average WBT bin + CT Approach + HX Approach is less than or equal to CHWST
  - Average WBT bin is less than or equal to "WSE Enable OAT Wet Bulb" from data entry
  - Note: Waterside economizer engaged is for non-integrated WSE only; **this calculation will not work for integrated WSE's.** When WSE is engaged, there is no chiller energy being used.
- **CH Stage:** Lookup from chiller staging sequence optimization and "Cooling Load (tons)"
- **CT Stage:** From cooling tower staging sequence optimization inputs and "CT Load (tons)". Actual capacity available for each stage is adjusted based on changes to the condenser water supply temperature using the calculation for "CAPfAPP&WB ratio" (capacity as a function of approach temp and wet bulb temp). The stage is selected where the CT Load (tons) is less than or equal to the available adjusted capacity.
- **Chiller Load kW:** Calculated as follows
  - If economizer (WSE) engaged or no bin hours, set to 0 (non-integrated WSE only)
  - Otherwise, calculate Chiller kW following Title 24 ACM Manual methodology.
    - Default chiller curve coefficients from the ACM Manual (Appendix 5.7) are used based on selected chiller type (Positive Displacement, Centrifugal, and Centrifugal with VFD)

    - A custom excel function is created to run through the ACM Manual methodology. The function is named "acm_Calc".
    - See ACM Manual methodology
- **Chiller Load kWh:** Calculated as follows:
  - $Chiller\ Load\ kWh = Chiller\ Load\ kW \times Hours$
- **PCHWP kW:** Calculated as follows based on inputs of either "Design Flow and Head" or "Nameplate HP" in the "Processing" section. In the "Calculation Engine" section, the total PCHWP kW is calculated by summing up each pump that is operating corresponding to the Chiller Stage in the OAT bin (assumes one dedicated pump tied to each chiller). The primary pumps are assumed to be constant speed and flow and, therefore, operate at full load power continuously when they are running.
  - For Design Flow and Head:

$$Pump\ kW = 0.746\ x\ \frac{Design\ Flow\ \times\ Design\ Head}{3960\ \times\ Motor\ Eff\ \times\ Pump\ Eff\ \ \times\ VFD\ Eff}$$

  - For Nameplate HP:

$$Pump\ kW = 0.746\ x\ \frac{Nameplate\ HP\ \times\ Load\ Factor}{Motor\ Eff\ \times VFD\ Eff}$$

- **PCHWP kWh:** Calculated as follows:
  - $PCHWP\ kWh = PCHWP\ kW \times Hours$
- **SCHWP kW:** Calculated as follows
  - SCHWP kW = Pdesign x CIRC-PUMP-FPLR
    - Where P_{design} is the Total SCHWP Full Load Power (kW) as calculated in the "Processing" section based on the inputs of "Design Flow and Head" or "Nameplate HP" and total number of operating pumps at full load
      - For Design Flow and Head:

$$Pump\ kW = 0.746\ x\ \frac{Design\ Flow\ \times\ Design\ Head}{3960\ \times\ Motor\ Eff\ \times\ Pump\ Eff\ \ \times\ VFD\ Eff}$$

      - For Nameplate HP:

$$Pump\ kW = 0.746\ x\ \frac{Nameplate\ HP\ \times\ Load\ Factor}{Motor\ Eff\ \times VFD\ Eff}$$

    - Where CIRC-PUMP-FPLR is calculated following the ACM Manual methodology and the coefficients in Appendix 5.7 and DOE 2.2.
      - $Circ - Pump - FLR = a + b(PLR) + c(PLR)^2 + d(PLR)^3$
        - Where PLR is the ratio of operating flow rate in GPM to design flow rate in GPM (i.e. SCHWP Flow %)
- **SCHWP kWh:** Calculated as follows:
  - $SCHWP\ kWh = SCHWP\ kW \times Hours$
- **Chiller and Pumps kW:** This is really chiller, PCHW pump, and SCHW pump kW.
  - $Chiller\ kW = Chiller\ Load\ kW + PCHWP\ kW + SCHWP\ kW$
- **Chiller and Pumps kWh:** Calculated as follows:
  - $Chiller\ kWh = Chiller\ kW \times Hours$
- **CT Fan Qty:** Lookup of number of cooling tower fans operating at active CT Stage. This is used only for graph visualization of how the CT's are operating.

- **Avg CT Fan % Speed:** The average CT Fan % Speed is calculated based on the cooling tower (heat rejection) load divided by the cooling tower capacity (adjusted based on changes to the condenser water supply temperature). It is calculated with the following equation:
  - $Avg\ CT\ Fan\ \%\ Speed = \frac{CT\ Load\ (Tons)}{CT\ Capacity\ \times CAPfAPP\&WB\ ratio}$
    - Where
      - "CT Capacity" is determined based on the CT Stage and the number of cooling towers running in that stage multiplied by each's nominal tonnage rating
      - "CAPfAPP&WB ratio" is calculated further below
      - If calculated "Avg CT Fan % Speed" value using the above equation is less than the minimum fan speed input, use the minimum fan speed input.
      - If calculated "Avg CT Fan % Speed" value is above 100%, cap at 100%
- **CT Fan kW:** Calculated as follows:
  - $CT\ Fan\ kW = \sum\left((Avg\ CT\ Fan\ \%\ Speed)^{2.5} \times \frac{0.746 \times CT\ Fan\ HP_{operating}}{Motor\ Efficiency\ \times VFD\ Efficiency}\right)$
    - Where only the operating CT Fans at the corresponding OAT bins are summed in the total
    - CT Fan % Speed is capped at minimum input value (min CT fan speed) or a maximum of 100%
- **CT Fan kWh:** Calculated as follows:
  - $CT\ Fan\ kWh = CT\ Fan\ kW \times Hours$
- **CWP kW:** Calculated as follows:
  - $CWP\ kW = CWP\ Qty \times CW\ Pump\ Design\ kW$
  - Where CW Pump Design kW is calculated as:
    - For Design Flow and Head inputs:

$$Pump\ kW = 0.746\ x\ \frac{Design\ Flow\ \times\ Design\ Head}{3960\ \times\ Motor\ Eff\ \times\ Pump\ Eff\ \ \times\ VFD\ Eff}$$

    - For Nameplate HP inputs:

$$Pump\ kW = 0.746\ x\ \frac{Nameplate\ HP\ \times\ Load\ Factor}{Motor\ Eff\ \ \times VFD\ Eff}$$

- **CWP kWh:** Calculated as follows:
  - $CWP\ kWh = CWP\ kW \times Hours$
- <u>**Energy Penalties**</u>
  - **CWST, Base:** This is the CWST used in the baseline run iteration
  - **Approach, Base:** Calculated as follows:
    - $Approach, Base = CWST, Base - Avg\ WBT$
  - **Approach, Prop:** Calculated as follows:
    - $Approach, Prop = CWST - Avg\ WBT$
      - Where "CWST" is the active CWST used for the current iteration run
  - **CAPfAPP&WB ratio:** This is a calculated adjustment factor for cooling tower capacity. It calculates the change to the cooling tower capacity based on change in the approach temperature when condenser water supply temperature reset is implemented. Calculated as follows:

        - $CAPfAPP\&WB\ ratio = \frac{a+b\times Approach,Prop+c\times Approach,Prop^2+d\times Avg\ WBT+e\times Avg\ WBT^2+f\times Approach,Prop\times Avg\ WBT}{a+b\times Approach,Base+c\times Approach,Base^2+d\times Avg\ WBT+e\times Avg\ WBT^2+f\times Approach,Base\times Avg\ WBT}$
        - Where the coefficients a-f are the default coefficients taken from eQUEST v3.65
    - **CHWST, Base:** This is the CHWST used in the baseline run iteration
    - **Clg Coil EAT:** This is the assumed average entering air temperature (EAT) at the cooling coil (heat exchanger) in the AHU. It assumes an economizer with a minimum position of 20% and an average return air temperature of 70 degF. The EAT is calculated as follows:
        - If OAT>70 degF,
            - $EAT = (70\ degF \times 80\%) + (OAT \times 20\%)$
        - If SAT<OAT<70 degF,
            - $EAT = OAT$
        - If OAT<SAT
            - $EAT = 55\ degF$
    - **SCHWP Penalty:** This is calculated as a % flow penalty multiplier for the secondary chilled water flow.
        - $SCHWP\ Penalty\ (Flow\ \%\ change) = \frac{EAT_{Base}-CHWST_{Base}}{EAT_{Prop}-CHWST_{Prop}}$
        - Where $EAT_{Base} = EAT_{Prop}$

HHW Calculation Tab

System Requirements:

- Maximum of 3 hot water boilers; not for steam systems
- Pumping Configurations Allowed:
    - Primary-Only
        - Constant Speed[2] and must have one pump dedicated to each boiler (i.e. when one boiler runs, it has a corresponding pump that runs with it).
        - Variable Speed (See workaround. Enter in primary pumps in "Secondary Pumps" input section.
    - Primary-Secondary
        - Constant Speed Primary Pumps where:
            - 1) pumps are configured in parallel
            - 2) one pump operates per boiler (i.e. PHWP1 operates with B1, PHWP2 operates with B2, etc…)
            - 3) Must have one pump dedicated to each boiler (i.e. when one boiler runs, it has a corresponding pump that runs with it).
        - Constant or Variable Speed Secondary Pumps where secondary pumps operate in parallel and stage up with load

Key Assumptions:

- Condensing boilers are assumed to operate at peak efficiency[3].
    - Note: A possible workaround would be to manually trend the return water temperature for the baseline and proposed, get an average return water temperature, determine the baseline and proposed operating boiler efficiencies, and then "Enable" the Boilers and Pump Specifications section and input the different baseline and proposed boiler efficiencies.
- When staging and sequencing boilers, each stage assumes that the operating boilers ramp up to 100% output capacity before staging up to the next[4].
- When multiple boilers run in a stage, the operating load is split proportionally between the chillers based on their individual output capacities. For example, two equally sized boilers will split the load 50/50. If two boilers are operating at any particular load and one boiler is twice the size of the other, the operating load will be split 67/33 between the two boilers (with the larger boiler receiving 67% of the operating load).
- For constant speed, constant flow pumping, the pump operates continuously at full load design power.

Special Notes:

- For modeling Primary-Only systems, the primary pumps are modeled using the "Secondary Chilled Water Pumps (SCHWP)" inputs in the "Chillers, Cooling Towers & Pumps Specifications"

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[2]Why not variable speed pumps?

[3] Efficiency is not derated based on return water temperature (makes the calculation generally more conservative).

[4] Boiler efficiency does not change based on part load.

section and the “Secondary Chilled Water Pump VFD And Speed Control” section[5]. Energy usage and savings on the Primary-Only PCHWP pumps are calculated in the “SCHWP” columns in the “Calculation Engine”.

Description of Inputs/Measures:

Boiler & Pump Specifications

- Boilers (up to 3 boilers)
  - **Input Capacity (kBtu/h):** Rated Input Capacity of each boiler in kBtu/h. If there are less than (3) boilers, only enter in the number of boilers and leave the remaining columns blank.
  - **Efficiency (%):** This should be nameplate efficiency of the boiler(s)
    - Note: the tool does not adjust efficiency based on return water temperature for condensing boilers. The nameplate efficiency should be used in this case for the most conservative savings estimate.
  - **Equipment Vintage:** This is the year of original installation
    - Note: This input is not used for anything in the calculation but may be useful for documenting Remaining Useful Life of boilers.
- Building Heating Load
  - **Data Type:** Heating Load Profile can either be entered in as “Simple Data” or “Baseline Trend Data”. See below for details of each.
  - **For “Simple Data”:**
    - Enter the maximum load corresponding to the lowest OAT
    - Enter the minimum load corresponding to the highest OAT.
    - Select either a “Baseload” or “Goes to Zero” load profile.
      - “Baseload” sets the load profile to remain at the minimum load that is input when OAT exceeds the high OAT input.
      - “Goes to Zero” sets the load profile to continue linearly to 0 when OAT exceeds the high OAT input.
  - **For “Baseline Trend Data”:** The data is entered in the “Calculation Engine” section below under the heading “Heating Load (kBtu/h), Base”. Enter in all available Heating Load trend data that has been binned to each corresponding OAT bin.
    - Note: If heating load data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data.
      - The load will increase linearly (as OAT bin decreases) up to the total OUTPUT capacity available for the HHW Plant.
      - The load will decrease linearly (as OAT bin increases) up until the HW Lockout OAT
  - *Tip: View the “Building Heat Load” graph to verify the final load profile looks correct.*
  - Note: “Proposed” Building Heat Load is currently disabled as an option in order to ensure current calculations calculate energy savings using the same baseline and proposed loads. Future updates can re-enable this feature if there are applicable measures that reduce the actual heating load (currently reduction in heating load is

[5] This seems to be for chilled water, not hot water

accounted for in the "Airside" tabs already and should not be double counted in the "Hot Water" tab).

- Boiler Location and Room Temperature
  - **Main Location of Boilers:** Select either "Indoor" or "Outdoor".
  - **Air Temperature if Indoor:** Enter in assumed average temperature of unconditioned mechanical room. Set to 60 degF by default.
- Schedule:
  - **Schedule:** Set the corresponding "Start Time" and "Stop Time" (0-24) for the boiler plant based on Weekday, Saturday, and Sunday operation.
  - *Tip: The start time is the beginning of the hour that the HHW plant turns on; the stop time is the beginning of the hour that the HHW plant turns off. See examples below:*
    - *7am to 6pm operation would be entered as "Start Time = 7" and "Stop Time = 18")*
    - *24 hour operation would be entered as "Start Time = 0" and "Stop Time = 24"*
    - *Off entire day would be entered as "Start Time = 0" and "End Time = 0"*
- **Hot Water Pumps System Configuration:** Select either "Primary Only" or "Primary-Secondary"
- Primary Pumps (Note: This input section is only for primary pumps in a primary-secondary configuration.
  - Requirements:
    - The Primary Pumps input is for constant speed primary pumps only in parallel configuration. The Primary HW Pumps are assumed to operate at constant flow and head.
    - The Primary Pumps operate one per boiler. That means PHWP1 operates when B1 operates, PHWP2 operates when B2 operates, etc.
    - For Primary-Only Variable Flow systems, enter in primary pumps under the "Secondary Pumps" section and leave the Primary Pump Inputs blank.
  - **General Instructions:**
    - Leave columns blank when there is no pump.
    - There should be one primary pump assigned to operate with each boiler (2 boilers means there should be 2 primary pumps).
    - Only enter in the number of operating pumps. For example, if there are 3 pumps but one is backup (n+1), then only enter in two pumps.
  - **Select Inputs for Power Calc:** Select either calculating full load pump power using either 1) nameplate horsepower and estimated load factor or 2) Design Flow GPM and Feet of Head
  - **For "Design Flow and Head":** Enter
    - **Flow (gpm):** Enter in the Design Flow (GPM) for each pump
    - **Head (ft) per pump:** Enter in the design head of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
    - **Pump Eff (%) per pump:** Enter the estimated pump efficiency. Typically 70-80% is reasonable if unknown.
  - **For "Nameplate Horsepower":** Enter
    - **Size (HP) per pump:** Enter in the nameplate hp of each pump
    - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor

- **Load Factor (%):** Enter in an estimated load factor %. The default load factor is set to 80%. If design information for the pump is available, Load Factor may be estimated as follows:
  - Determine Load Factor using Design BHP

    $$Load\ Factor = \frac{BHP}{Nameplate\ HP}$$

- Secondary Pumps (or Primary Pumps in a primary-only system configuration):
  - **General Instructions:**
    - Input fields represent one pump. The calculation requires that all secondary hot water pumps be identical. Modeling multiple pumps is described below.
  - **Select Inputs for Power Calc:** Select either calculating full load pump power using either 1) nameplate horsepower and estimated load factor or 2) Design Flow GPM and Feet of Head
    - **For "Design Flow and Head":** Enter
      - **Flow (gpm):** Enter in the Design Flow (GPM) for each pump
      - **Head (ft) per pump:** Enter in the design head of each pump
      - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
      - **Pump Eff (%) per pump:** Enter the estimated pump efficiency. Typically 70-80% is reasonable if unknown.
    - **For "Nameplate Horsepower":** Enter
      - **Size (HP) per pump:** Enter in the nameplate hp of each pump
      - **Motor Efficiency (%):** Enter in the Motor Efficiency (%) for each pump motor
      - **Load Factor (%):** Enter in an estimated load factor %. The default load factor is set to 80%. If design information for the pump is available, Load Factor may be estimated as follows:
        - Determine Load Factor using Design BHP

          $$Load\ Factor = \frac{BHP}{Nameplate\ HP}$$

  - **Maximum Pump Qty Operating:** Enter the maximum number of operating pumps (i.e. all pumps excluding redundant pumps)

Hot Water Plant Lockout Control

- **Heating Lockout:** Enter in the lockout temperature for the HW plant. Above this temperature, there will be no therm usage or pumping kW/kWh calculated.

Boiler Staging Sequence

- **Boiler Staging Table Entry:** This allows for up to 7 stages for boiler sequencing. For each stage, change the cell to "on" for all boilers operating at that stage. This feeds the "Boiler Staging Sequence" table in the Processing section of the calculation tab where you can see how the boilers stage up based on capacity along with which boilers are running at each stage/capacity.

Hot Water Temperature Reset

- **Data Type:** HWST Profile can either be entered in as "Simple Data" or "Baseline Trend Data". See below for details of each.
- **For "Simple Data":**
  - Enter the <u>maximum</u> HW Supply Temp corresponding to the <u>lowest</u> OAT
  - Enter the <u>minimum</u> HW Supply Temp corresponding to the <u>highest</u> OAT.
- **For "Baseline Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "HWST (°F), Base (or Prop)". Enter in all available HWST trend data that has been binned to each corresponding OAT bin. If HWST data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data. See "HWST" section in the "Calculation Engine" write-up below for details on the ruleset applied towards forecasting the missing data.
- *Tip: View the "HWST" graph to verify the final load profile looks correct.*

Secondary Hot Water Pump VFD and Speed Control

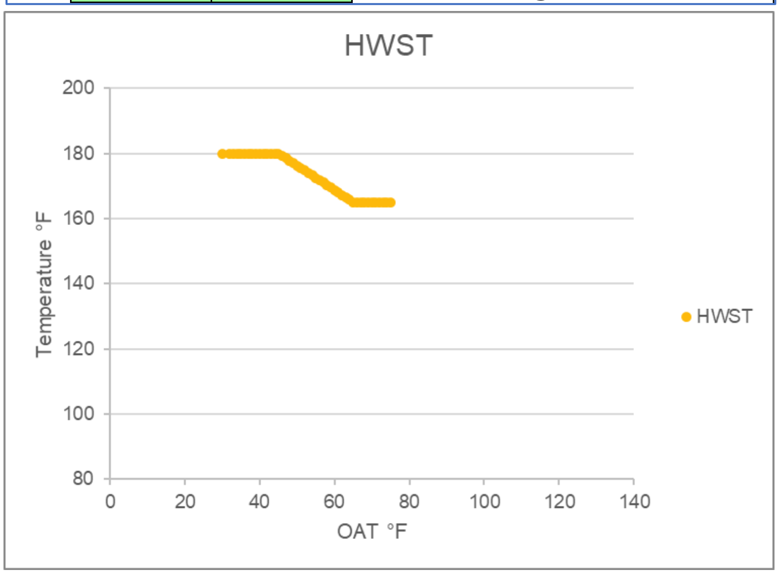
- Note that this is also the data entry section for primary-only primary hot water pumps.
- **Data Type:** Secondary HW Pump VFD and Speed Control Profile can either be entered in as "Simple Data" or "Baseline Trend Data". See below for details of each.
- **For "Simple Data":**
  - Enter the <u>maximum</u> Pump <u>Flow</u> % corresponding to the <u>lowest</u> OAT
  - Enter the <u>minimum</u> Pump <u>Flow</u> % corresponding to the <u>highest</u> OAT.
- **For "Baseline Trend Data":** The data is entered in the "Calculation Engine" section below under the heading "SHWP Flow (%), Base (or Prop)". Enter in all available SHWP pump flow % trend data that has been binned to each corresponding OAT bin. If SHWP pump flow % data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data. See "SHWP Flow %" section in the "Calculation Engine" write-up below for details on the ruleset applied towards forecasting the missing data.
- **Pump Control:** Select from either Constant – Constant Flow, Constant – Variable Flow, VFD – no DP reset, or VFD - with DP reset.
- **IMPORTANT:** The input is Pump Flow % and <u>not</u> Pump Speed %. The calculation is based on % of Design Pump Flow. In instances where pump flow data is unavailable, Pump Speed % can be used as a proxy for Pump Flow %. However, the preference will always be to use actual pump flow % which can be calculated as measured flow divided by design flow.
- *Tip: View the "SHWP Flow & Qty" graph to verify the final load profile looks correct.*

Calculation Engine

- **Heating Load:** Source from Simple Data or Trend Data; Load is set to 0 if above "Hot Water Plant Lockout"
  - **Simple Data:** Heating Load is calculated linearly between the min and max Load/OAT inputs. At the low OAT end, temperatures below the min OAT entered have the heating load capped at the Max HW Plant Capacity. At the high OAT end, temperatures above the max OAT entered either flatten at the corresponding Min Load entered (if "Baseload" is selected) or continue linearly to 0 (if "Goes to Zero" is selected).

    - **Baseline Trend Data:** Heating Load is pulled directly from the corresponding “Baseline Trend Data” entered at each OAT bin. If heating load data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data using the following ruleset:
        - The load will increase linearly (as OAT bin decreases) up to the total OUTPUT capacity available for the HHW Plant.
        - The load will decrease linearly (as OAT bin increases) up until the HW Lockout OAT
- **HWST:** Source from Simple Data or Trend Data; Set to 0 if above “Hot Water Plant Lockout”;
    - **Simple Data:** HWST is calculated linearly between the min and max HW Temp/OAT inputs and flattens above and below the min/max OAT inputs. See example below of load profile generated:

Hot Water Temperature Reset		
Simple Data		Data Type
Min	Max	
180	165	HW Temp
45	65	@ OAT



    - **Baseline Trend Data:** HWST is pulled directly from the corresponding “Trend Data” (baseline or proposed) entered at each OAT bin. If HWST data is unavailable for any particular OAT bin, the calculation tool will forecast or interpolate in the missing data using the following ruleset:
        - As OAT increases (hot weather), the HWST will decrease linearly but be capped at the lowest observed temperature in the trend data.
        - As OAT decreases (cold weather), the HWST will increase linearly but be capped at the highest observed temperature in the trend data.
        - *TIP: Because of how the forecasting functions, it is important to get a sufficient range in OAT within the trend data to accurately capture the min/max HWST. Alternatively, for smaller savings projects or larger savings projects where necessary, the user may perform manual calculations to reasonably “fill in” the inputs where trend data does not provide adequate OAT coverage. Any manual*

manipulation outside of standard trend analysis should be thoroughly documented and explained.

- **Stage:** The Boiler Stage is determined by comparing the Heating Load (kBtu/h) the available capacity at each stage (see Processing section under "Boiler Staging Sequence"). When the Heating Load exceeds the capacity at any given stage, the stage moves up to the next stage that can meet that Heating Load (kBtu/h). The stage is set to 0 if the boiler is locked out or there are no hours of operation in that OAT bin.
- **Therms:** Calculated as follows:

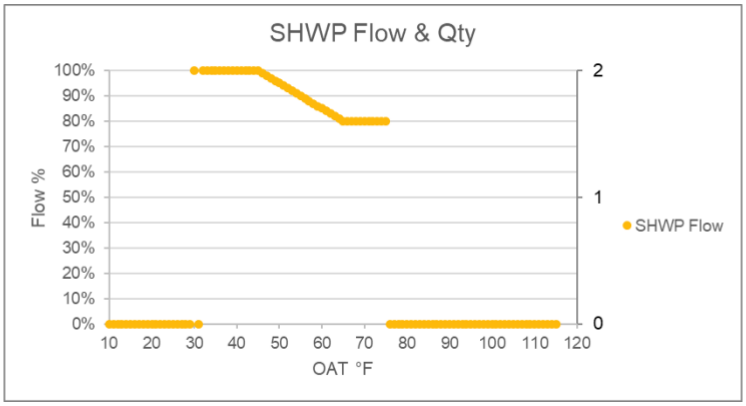
$$Therms = \left(\sum_{i=1}^{3} \frac{Heating\ Load\ x\ Boiler\ i\ \%\ Load}{Boiler\ i\ \%\ Efficiency}\right) \times \frac{1\ therm}{100\ kBtu/h} \times hours$$

  - Where:
    - i = Boiler #
    - Heating Load = total heating load at OAT bin calculated previously in Column O
    - Boiler i % Load = % of total heating load distributed to Boiler (i) as determined by the current operating "Boiler Stage"
    - Boiler i % Efficiency = % efficiency of Boiler (i)
- **Therms Lost:** Calculated as follows

$$Therms\ Lost = Boiler\ Output\ Capacity \times Boiler\ Load\ \%\ Split \times \frac{(HWST - Air\ Temp)^2}{(Design\ HWST - Ref\ Temp)^2} \times \frac{0.010\ kBtu}{therm} \times 1\%\ Jacket\ Losses \times Hours$$

  - Where
    - Where Air Temp is either the specified indoor air temp (if boiler location "Indoor" is selected) or the OAT (if boiler location "Outdoor" is selected)
    - Where Reference Standard Temp is either "standard boiler room temp" of 90 degF (if boiler location = "indoor") or OAT (if boiler location = "outdoor")
- **SHWP Flow %:** Source from Simple Data linear model or Trend Data; Set to 0 if above "Hot Water Plant Lockout". Note that for Primary Only systems, SHWP Flow % is the flow for the Primary-Only pumps.
  - **Simple Data:** SHWP Flow % is calculated linearly between the min and max Pump Flow (%)/OAT inputs and flattens above and below the min/max OAT inputs. See example below of load profile generated:

Secondary Hot Water Pump VFD And Speed Control		
Simple Data		Data Type
Min	Max	
100%	80%	Pump Flow (%)
45	65	@ OAT
VFD - no DP reset		Pump Control



  - **Trend Data:** Forecast linearly for Trend Data if outside of entered data range (i.e. missing data points for any OAT bin). When forecasting, minimum is set to 0% flow and maximum to 100% flow.
- **PHWP kW:** Primary HW pump kW is taken from the "Processing" section where the kW is calculated for each primary pump corresponding to each boiler. Based on the staging and number of boilers operating in that stage, the corresponding kW based on the number of PHWP's operating is summed. Primary Pump kW is calculated as follows:
  - For Design Flow and Head Inputs:

$$Pump\ kW = 0.746\ x\ \frac{Design\ Flow\ \times\ Design\ Head}{3960\ \times\ Motor\ Eff\ \times\ Pump\ Eff\ \ \times\ VFD\ Eff}$$

  - For Nameplate HP Inputs:

$$Pump\ kW = 0.746\ x\ \frac{Nameplate\ HP\ \times\ Load\ Factor}{Motor\ Eff\ \ \times VFD\ Eff}$$

  - Note: If "Hot Water Pumps System Configuration" is set to "Primary Only", then PHWP kW is 0.
- **PHWP kWh:** Primary HW Pump kWh is calculated as follows:

$$PHWP\ kWh = PHWP\ kW \times hours$$

  - Note: If "Hot Water Pumps System Configuration" is set to "Primary Only", then PHWP kWh is 0.
- **SHWP kW:** Secondary (or Primary-Only) HW Pump power is calculated using curve coefficients from the Title 24 Non-Residential Alternative Calculation Method (ACM) Method Manual. The appropriate curve coefficients are selected based on the Input selection (Const – Var Flow, VFD – no DP reset, or VFD – with DP reset). See screenshot below from ACM:

Definition	A part-load power curve for the pump: $CIRC - PUMP - FPLR = a + b(PLR) + c(PLR)^2 + d(PLR)^3$ $P_{pump} = P_{design}(CIRC - PUMP - FPLR)$ Where: PLR — Part-load ratio (the ratio of operating flow rate in gpm to design flow rate in gpm) P_{pump} — Pump power draw at part-load conditions (W) P_{design} — Pump power draw at design conditions (W) Refer to Appendix 5.7 for a specification of the default pump part-load curve, and the pump part-load curve if there is differential pressure reset (if DDC controls are present).

Where:

- VFD (w/ and w/o DP reset) curve coefficients “a-d” are taken from Appendix 5.7 of the ACM Manual. Constant Speed (variable flow) curve coefficients are from DOE 2.2.
- PLR is SHWP Flow (%)
- P_{design} is the sum of the design full load power of all SHWP operating at design conditions

- **SHWP kWh:** Secondary (or Primary-Only) HW Pump kWh is calculated as follows:
$$SHWP\ kWh = SHWP\ kW \times hours$$
- **Total Therms:** Total therms used is calculated as:
$$Total\ Therms = Therms + Therms\ Lost$$
- **Total kW:** Total kW used is calculated as:
$$Total\ kW = PHWP\ kW + SHWP\ kW$$
- **Total kWh:** Total kWh used is calculated as:
$$Total\ kWh = PHWP\ kWh + SHWP\ kWh$$