TECHNICAL MANUAL

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HVAC and Refrigeration Tools

Contents

1 Description

The HVAC and Refrigeration Tools provide robust energy saving calculations for simplified and detailed inputs for the most common measures found in HVAC and refrigeration systems. The tools also include multiple parameters utilized by end-users to determine the financial impact of projects such as simple payback and Return-on-Investment (ROI). The tools consist of two different calculators with these respective capabilities:

HVAC Calculation Tool

- Calculation and analysis for four (4) retrofit measures related to upgrading equipment as well as equipment and system change outs such as going from rooftop units to air-cooled chillers
- Calculation and analysis for three (3) retrofit measures focused on water-cooled equipment such as large centrifugal chillers and circulation pumps.
- Calculation and analysis for a total of six (6) air-side RCx measures most commonly implemented for air side systems.
- Calculations and analysis for a total of nine (9) water-side RCx measures most commonly implemented for chilled water systems.
- Calculations and analysis for a total of five (5) water-side RCx measures most commonly implemented for hot water systems. All measures are properly cascaded to take into account measure interactions.
- All measures are properly cascaded to take into account measure interactions.
- Current Title-24 baselines for chiller replacement measures.
- Option to use simplified or trend data inputs depending on the information the user has available or to accommodate different levels of effort.
- An automated Engineering Report that collects all identified measures, their savings, the financial analysis and M&V requirements.

Refrigeration Calculation Tool

- Calculations and analysis for a total of seven (7) different measures for refrigeration systems which are combination of retrofit and RCx.
- All measures are properly cascaded to take into account measure interactions.
- Option to use simplified or detailed calculations depending on the information the user has available or to accommodate different levels of effort.
- An automated Engineering Report that collects all identified measures, their savings, the financial analysis and M&V requirements

Supported Measures

The HVAC and Refrigeration Tool supports the following measures listed in the following table:

HVAC	Refrigeration
▪ **Retrofit - High Efficiency Air-Cooled Units** ▪ High Efficiency AC ▪ High Efficiency Heat Pump ▪ **Retrofit - High Efficiency Water-Cooled Units** ▪ High Efficiency Chiller ▪ High Efficiency Cooling Tower ▪ High Efficiency Evaporative Coolers ▪ **Retrofit - Air-Side System Upgrade** ▪ CAV To VAV ▪ Advanced VAV Controls ▪ **RCx - Air-Side System Measures** ▪ Scheduling Optimization ▪ Supply Air Temperature Reset ▪ Static Pressure Reset ▪ Economizer Optimization ▪ VAV Flow Adjustment ▪ Temp/Flow Setback ▪ **RCx - Chilled Water Plant Measures:** ▪ Chilled Water Temperature Reset ▪ Chilled Water Differential Pressure Reset ▪ Chiller Staging Sequence Optimization ▪ Chiller Plant Lockout Control ▪ Condenser Water Temperature Reset ▪ Cooling Tower Staging Control ▪ Chilled Water Pump VFD and Speed Control ▪ Condenser Water Pump VFD and Speed Control ▪ Water-Side Economizer Sequence Optimization ▪ **RCx - Hot Water Plant Measures:** ▪ Hot Water Temperature Reset ▪ Hot Water Differential Pressure Reset ▪ Boiler Staging Sequence ▪ Hot Water Plant Lockout Control ▪ Hot Water Pump VFD And Speed Control	▪ VFD Control of Condenser Fans ▪ Floating Head Pressure/Reduce Minimum Condensing Temperature ▪ Evaporator Fan Variable Speed ▪ Replace Fixed Speed Compressor with VFD Compressor (or Add VFD) ▪ Suction Pressure Controls ▪ Compressor Staging

2 HVAC Calculation Tool

2.1 How to Use the Tool

The following section provides detailed instructions on how to use the HVAC and Refrigeration Calculation Tool.

2.1.1 Facility Information

To begin, input customer information and consumption data in the launched tab

Customer Information

Name		Phone	
Contact		Email	

Building Information

Address		Type	Convention Center
City		SQFT	
Zip	00054 Zone 1	Year Built	

Enter Customer Information and all available Building Information.

Consumption

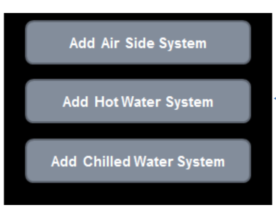
	Peak kW	kWh	Therms	Electric Cost	Therm Cost		
Jan	1,197	577,999	25,587	$70,173	$17,206		
Feb	1,149	566,599	26,362	$69,713	$13,637		
Mar	1,150	606,071	33,314	$73,817	$14,007		
Apr	1,190	564,308	25,563	$76,557	$11,763		
May	1,286	635,393	23,130	$101,162	$10,210		
Jun	1,279	630,541	24,098	$110,689	$10,982		
Jul	1,311	660,829	22,603	$113,919	$13,740		
Aug	1,282	699,343	25,318	$117,095	$17,215		
Sep	1,289	636,783	24,459	$111,569	$17,896		
Oct	1,250	647,780	25,156	$95,430	$21,295		
Nov	1,107	557,830	36,992	$70,065	$31,817		
Dec	1,033	588,953	36,726	$70,988	$30,956	$/kWh	$/Therm
Annual	1,311	7,372,429	329,308	$1,081,177	$210,724	$0.15	$0.64

Include Total Cost for customers that receive bundled service. If the customer is direct access and the commodity cost is available, it should be included. Otherwise the Total Cost can be omitted.

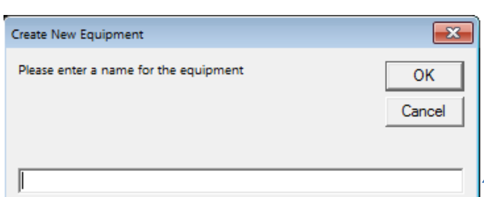
Enter Consumption data using building energy billing statements or manually enter $/kw and/or $/therm.

2.1.2 Measure Information

To begin, select the type of system you would like to implement on the main tab



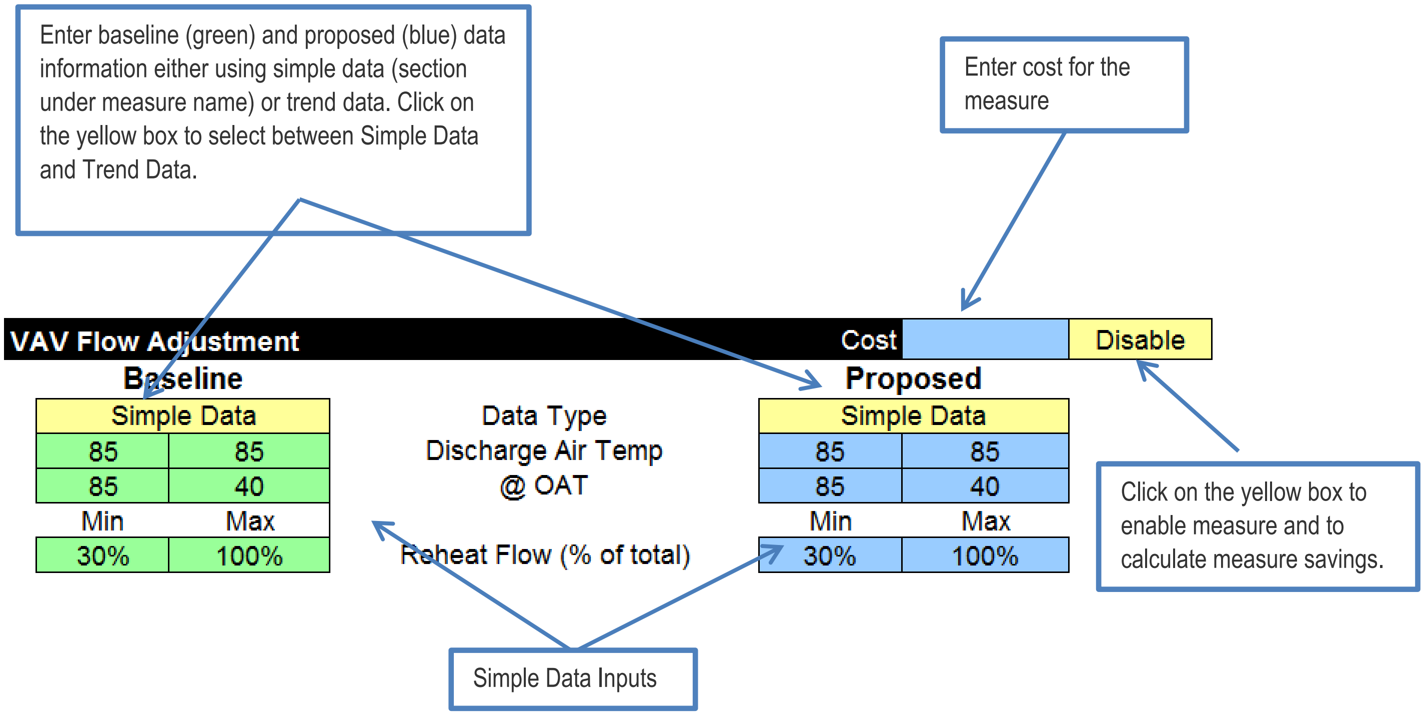
Select System



Once a system is selected, a dialog box will appear. Enter a name for the equipment or system and click on OK.

Once the equipment has been named, two new tabs will appear in the calculator: the calculation tab and the engineering report tab.

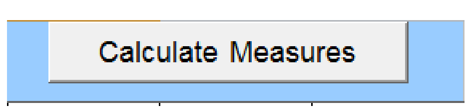
To continue, complete the following information for all measures under for that system, please note that an asterisk will appear by categories where the baseline and proposed parameters are different.



For users who choose to use the baseline and /or proposed trend data option, enter the required trend data into the table under the Calculation Engine.

Baseline Trend Data							Proposed Trend Data						
SAT °F	DAT °F	RH Flow %	Occ SF Speed %	Occ RAT °F	Unocc SF Speed %	UnOcc RAT °F	SAT °F2	DAT °F2	RH Flow %2	Occ SF Speed %3	Occ RAT °F	Unocc SF Speed %3	UnOcc RAT °F2

Once all information is entered, click on the Calculate Measures button at the top of the sheet to complete the calculator.



The macros use the inputs under the Processing section to run the calculations. Basically, the calculations under the Calculation Engine section are updated with the inputs under the Processing section. These inputs are updated based on measures being enabled and the inputs provided by the user.

The macros will change these switches from Baseline to Proposed.

If the measure is enabled, the measure inputs will change values when the measure switch is updated from baseline to proposed.

Processing

Switches	
Proposed	**Equipment Specifications & Replacements**
Proposed	**Scheduling Optimization**
Proposed	**Economizer Optimization**
Proposed	**Static Pressure Reset**
Proposed	**Supply Air Temperature Reset**
Proposed	**Temperature And Fan Setback**
Proposed	**VAV Flow Adjustment**

Inputs

Equipment Specifications & Replacements

1.5	Seasonal average kW/Ton
Gas	Source of Heating
0.8	Gas Efficiency
7	Heat Pump (HSPF)
65	Heating Lockout Temp
50	Cooling Lockout Temp
65	Supply Fan (HP)
60000	Supply Fan (CFM)
VFD	Supply Fan Control
25	Return Fan (HP)
60000	Return Fan (CFM)
VFD	Return Fan Control

Supply Air Temperature Reset

Scheduling Optimization

Occupied	Unoccupied	
1	24	Weekday
1	24	Saturday
1	24	Sunday

Economizer Optimization

Min	Max	
0.3	1	Out Door Air %
65	Enable OAT	

VAV Flow Adjustment

Simple Data	Data type	
85	85	harge Air Temp

Static Pressure Reset

Min	Max	
2.5	2.5	In H2O

Peak

5

Temperature And Fan Setback

Simple Data	Data type	
Min	Max	
0.4	1	Occ Fan Speed % - Cool
0.3	0.7	Unocc Fan Speed % - Cool
55	95	OA Cooling Temp Range
0.6	1	Occ Fan Speed % - Heat
0.4	0.6	Unocc Fan Speed % - Heat
50	15	OA Heating Temp Range
Heating	Cooling	

The calculations are reviewable by the user under the Calculation Engine Section. If the user wants to review a specific measure they need to disable all the other measures and enable the measure that they want to review and click on Calculate Measures. If the user wants to review the baseline calculations, then disabling all the measures and clicking on Calculate Measures will show the baseline hourly calculations.

The consumption and energy savings for each measure can be reviewed on the top right corner of the calculator.

Savings	Fan kW	Fan kWh	Load kW	Load kWh	Therms	Total kW	Total kWh	Cost	Incentives
Equipment Specifications & Replacements	0	0	0	0	0	0	0	$0	$0
Scheduling Optimization	0	0	0	0	0	0	0	$0	$0
Economizer Optimization	0	0	0	-2,370	15,099	0	-2,370	$10,000	$5,000
Static Pressure Reset	0	0	0	0	0	0	0	$0	$0
Supply Air Temperature Reset	0	0	15	43,587	13,751	15	43,587	$15,000	$7,500
Temperature And Fan Setback	0	0	0	0	0	0	0	$0	$0
VAV Flow Adjustment	0	0	0	0	0	0	0	$0	$0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**$25,000**	**$12,500**

Consumption	Fan kW	Fan kWh	Load kW	Load kWh	Therms	Total kW	Total kWh
Baseline	24.0	242,658	15	77,353	100,105	39	320,012
Equipment Specifications & Replacements	24.0	242,658	15	77,353	100,105	39	320,012
Scheduling Optimization	24.0	242,658	15	77,353	100,105	39	320,012
Economizer Optimization	24.0	242,658	15	79,723	85,005	39	322,382
Static Pressure Reset	24.0	242,658	15	79,723	85,005	39	322,382
Supply Air Temperature Reset	24.0	242,658	0	36,137	71,254	24	278,795
Temperature And Fan Setback	24.0	242,658	0	36,137	71,254	24	278,795
VAV Flow Adjustment	24.0	242,658	0	36,137	71,254	24	278,795
Proposed	24.0	242,658	0.0	36,137	71,254	24	278,795

2.2 System Equations, Assumptions and Details

2.2.1 Equations

The following are the equations used in each of the calculators.

Air Side System

- **Cooling kW:**

$$Cooling\ kW = \frac{1.08 \times CFM \times (MAT - SAT)}{12{,}000} \times \eta_{kW/ton} \qquad \text{Eq.1}$$

Where:

CFM = supply fan cfm defined by the user.

SAT = supply air temperature, leaving air handler unit. Calculated by linear regression created from trend data or from inputs provided by the user.

$\eta_{kW/ton}$= efficiency of the cooling system in kW/Ton defined by the user

MAT = mixed air temperature. Calculated based on Equation 2:

$$MAT = RAT \times (1 - OA\ Flow\ \%) + OAT \times OA\ Flow\ \% \qquad \text{Eq.2}$$

Where:

RAT = return air temperature. Calculated by a linear regression from trend data or calculated as the median temperature between heating and cooling space temperature setpoints and OAT.

OA Flow %= Outside Air Flow %. Calculated based on Equation 3 and within the minimum and maximum values provided by the user:

$$OAT\ Flow\ \% = \frac{(SAT - RAT)}{(OAT - RAT)} \qquad \text{Eq.3}$$

- **Fan KW:**

$$Fan\ kW = a + b \cdot FR + c \cdot FR^2 + d \cdot FR^3 \qquad \text{Eq.4}$$

Where:

a, b,c,d = Fan Curve Coefficients from ASHRAE 90.1 for all fans except VFD

FanType	a	b	c	d
Damper	0.25	1.11	-0.36	10%
IGV	0.62	-0.74	1.11	25%
Air-Foil or Backward-Inclined - Dampers Control Flow	0.23	1.18	-0.41	45%
Air-Foil or Backward-Inclined - Inlet Vanes	0.58	-0.58	0.97	30%
Vane-Axial - Variable Pitch Blades	0.21	-0.57	1.35	20%

For VFD Fans the following coefficients are used:

Plenum Pressure (inches)	a	b	c	d
0	0.02782788	0.03	-0.09	1.03
0.3	0.03417126	0.06	-0.06	0.97
0.4	0.03744257	0.07	-0.06	0.95
0.5	0.04075989	0.09	-0.07	0.94
0.6	0.04403459	0.11	-0.09	0.94
0.7	0.04718282	0.13	-0.12	0.94
0.8	0.05025414	0.16	-0.15	0.94
1	0.05611853	0.21	-0.23	0.96
1.5	0.07042885	0.39	-0.46	1.01

From: https://energydesignresources.com/media/2651/EDR_DesignGuidelines_VAV.pdf?tracked=true

FR = Flow Ratio calculated is assumed to have a linear relationship with fan speed.

Fan speed is calculated by a linear regression from trend data or by a linear regression of the heating or cooling flow inputs provided by the user (under the Fan and Space Temperature Setbacks measure). For return fans the speed is assumed to be 90% of the supply fan.

- **Heating Therms:**

$$Heating\ Therm = \sum \frac{1.08 \times CFM \times (DAT - minimum\ of\ MAT\ or\ SAT)}{Boiler\ Efficiency} \times Hr \qquad Eq.5$$

Where:

Boiler Efficiency= defined by the user.

DAT = discharge temperature, leaving VAV box. Calculated by linear regression created from trend data or from inputs provided by the user.

Chilled Water Side System

- **Chiller kW**

$$Chillers\ kW = Cooling\ Load \times \eta_{kW/ton} \quad \text{Eq.6}$$

Where:

Cooling Load = Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

$\eta_{kW/ton}$ = efficiency of the chiller. The efficiency is calculated using Equation 7.

$$\eta_{kW/ton} = \eta_{kW/ton_{standard\ condition}} \times 1.4 * (1 - (CHWST - CHWST_{design}) + (CWST - CWST_{design})) \quad \text{Eq.7}$$

Where:

CHWST = is the supply chilled water temperature. Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

$CHWST_{design}$ = is the design chilled water temperature provided by the user.

CWST = is the supply condenser water temperature. Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

$CWST_{design}$ = is the design condenser water temperature provided by the user.

1.4 = assumed chiller efficiency performance improvement per degree increase in chilled water supply temperature, or degree decrease in condenser water temperature

- **Primary Pump kW**

$$Pump\ kW = \frac{0.746 \times GPMdesign \times head\ in\ ft}{3960 \times \eta_p \times \eta_m} \quad \text{Eq.8}$$

Where:

GPM = design flow in gallons per minutes. Provided by the user.

Head in ft = provided by the user.

η_p = efficiency of the pump. Provided by the user.

η_m = efficiency of the pump motor. Provided by the user.

- **Secondary Pump kW**

$$Pump\ kW = \frac{0.746 \times GPMdesign \times head\ in\ ft \times Speed}{3960 \times \eta_p \times \eta_m \times \eta_{VFD}} \quad \text{Eq.9}$$

Where:

GPM = design flow in gallons per minutes. Provided by the user.

Head in ft = provided by the user.

η_p = efficiency of the pump. Provided by the user.

η_m = efficiency of the pump motor. Provided by the user.

η_{VFD} = efficiency of the VFD motor. Assumed 97% if pump is controlled with a VFD, otherwise 100%.

Speed = Speed of the secondary pump. Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

Hot Water Side System

- **Heating Therms**

$$Heating\ Therms = \frac{Building\ heating\ load}{\eta_b} \quad \text{Eq.10}$$

Where:

Building heating load= Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

η_b = efficiency of the boiler. Provided by the user.

- **Primary Pump kW**

$$Pump\ kW = \frac{0.746 \times GPM \times head\ in\ ft}{3960 \times \eta_p \times \eta_m} \quad \text{Eq.11}$$

Where:

GPM = design flow in gallons per minutes. Provided by the user.

Head in ft = provided by the user.

η_p = efficiency of the pump. Provided by the user.

η_m = efficiency of the pump motor. Provided by the user.

- **Secondary Pump kW**

$$Pump\ kW = \frac{0.746 \times GPMdesign \times head\ in\ ft \times Speed}{3960 \times \eta_p \times \eta_m \times \eta_{VFD}} \quad \text{Eq.12}$$

Where:

GPM = design flow in gallons per minutes. Provided by the user.

Head in ft = provided by the user.

η_p = efficiency of the pump. Provided by the user.

η_m = efficiency of the pump motor. Provided by the user.

η_{VFD} = efficiency of the VFD motor. Assumed 97% if pump is controlled with a VFD, otherwise 100%.

Speed = Speed of the secondary pump. Calculated by a linear regression from trend data or by a linear regression based on the inputs provided by the user.

2.2.2 Difference between Simple and Trend Data Calculations

For the HVAC tool there are two different types of calculations for each measure: Simple and Trend Data. For each measure the user can choose to calculate the baseline and proposed with simple inputs or trend data inputs. The user can also use trend data to calculate the baseline energy usage and simple inputs for the proposed if the user is working on pre-installation calculations.

Simple Inputs

- With simple inputs, the user inputs the low and high values of an OAT range (dry bulb for all inputs except for condenser water temperature) and the corresponding upper and lower values occurring at these temperatures.
- The data is interpolated or extrapolated linearly, based on the inputs

Trend Data Inputs

- With trend data inputs, there are columns under the Calculation Engine section. The first column shows OA temperature bins, from 10 degrees to 115, where corresponding values can be entered.
- The tool creates trends from the values if entered. If there is no value for a particular OAT bin or range of OAT bins, the tool linearly extrapolate the data/value.
- It is recommended to leave cells blank if the trend data is not available for some OAT bins.

2.2.3 Assumptions

General

- California DEER climate zone data is used for weather.
- Data input by users is assumed to be accurate and representative for the entire temperature range.
- Outside air temperature refers to dry bulb temperature unless specified otherwise.
- DEER average temperatures are used for peak kW reduction.
- Approach temperatures are assumed to be constant.
- Load is a linear function of outside air temperature.
- Load extrapolation is not capped.
- All equipment is adequately sized to meet the load.
- All interpolation or extrapolation is linear. Extrapolation is sometimes limited by minimums and maximums.
- VFDs are assumed to be 97% efficiency.

System Related

- Requested efficiencies are part-load efficiency values at stated conditions.
- Cooling requirements below lockout temperature are met through economizer, or other non-mechanical means.
- The cooling lockout temperature is the temperature below which there is no cooling load, and below which no towers, chillers, or cooling-related pumps operate.
- Runtime schedules are when the equipment is available to run if there is load (e.g. chillers turn off below lockout, even if during a scheduled time period).

- Economizer enables below the Enable OAT point, above this it goes to the minimum.
- If there is a cooling load, heat exchanger enables based on WBT.
- VAV box level reheat flow does not differentiate between occupied and unoccupied modes.
- Primary chilled water pumps run with their corresponding chillers.
- Chiller efficiency improves by 1.4% per degree increase in chilled water supply temperature .
- Chiller stages are in order of increasing capacity.
- Cooling tower fan affinity factor is 2.5.
- Pump and fan flows have linear relationship with VFD speed.
- Load rejected by the cooling towers is 125% of the load handled by the chillers.
- Secondary hot and chilled water pumps run according to inputs, irrespective of load.
- Primary hot water pumps run with their corresponding boilers.
- Boilers and pumps turn off above lockout temperature.
- Boiler stages are in order of increasing capacity.
- Boilers are all assumed to be in the same location (indoor vs outdoor).

2.2.4 Details about Air Side System Measures

Equipment Specifications and Replacements

- Equipment efficiency is adjusted using the Seasonal Average efficiency in kW/ton. For all units, including heat pumps, the efficiency must be converted to kW/ton.
- Direct evaporative cooling systems may be simulated by entering the appropriate efficiency in kW/Ton, making the Supply Fan control constant speed, and setting the heating lockout temperature to zero.
- Simulate the absence of a return fan by setting return fan HP to zero.

High-Efficiency A/C

- Equipment efficiency is adjusted using the Seasonal Average efficiency in kW/ton. For all units, including heat pumps, the cooling efficiency must be converted to kW/ton.

High Efficiency Heat Pump

- Heat pump cooling efficiency is adjusted using kW/ton. Heat pump heating efficiency is adjusting using Heat Pump (HSPF). Source of heating must be electric for heat pumps.

Constant Air Volume to Variable Air Volume (VAV)

- Select the type of supply fan control from the dropdown menu. If the supply fan is constant volume, choose VFD control, and then in the Temperature and Fan Setback section (further down in the tool) set the maximum and minimum fan speeds equal to each other.

Advanced VAV Controls

- Advanced VAV controls can be implemented in the Temperature and Fan Setback section by specifying the fan speeds in cooling and heating modes, and the temperatures of these modes.
- To set a constant fan speed for heating or cooling mode, set the min% and max% to the same value.

Scheduling Optimization

- Adjust the hours that the system will run. Occupancy schedule is assumed to align with equipment runtime schedule.

Economizer Optimization

- When 'Control' is set to OAT, the economizer will open to 100% between the SAT and enable temperatures, go to the minimum above the enable temperature, and modulate to achieve SAT when OAT < SAT.
- To simulate a 'stuck' damper, set the maximum damper position equal to the minimum.

Static Pressure Reset

- Please note that this is the *total* static pressure across the fan, not external static pressure.

Supply Air Temperature Reset

- Supply air temperature will interpolate linearly between the values shown in the 'supply air temp' cells, as the OAT moves between the values in the OAT cells.
- If supply air temperature is constant, set the maximum temperature equal to the minimum

Temperature and Fan Setback

- Fan speed will interpolate between the max and min as OAT moves between the values in the respective heating and cooling ranges. Heating and cooling temperature ranges cannot overlap here.
- Advanced VAV controls can be implemented by adjusting the heating and cooling max and min airflows.

VAV Flow Adjustment

- Discharge air temperature interpolates linearly between the values shown, as OAT moves between the corresponding OA temperatures.
- Reheat flow% is the percentage of cooling airflow, and it interpolates linearly between the max and min values, as OAT moves between the corresponding OAT temperatures.
- Air side system calculates all savings related to air side measures, and for any high efficiency rooftop units and system changes

2.2.5 Details about Chilled Water System Measures

High-Efficiency Chiller

- Chiller efficiency is part load efficiency (kW/ton) of the respective chiller at the specified design conditions.

High Efficiency Cooling Tower

- A high efficiency cooling tower is simulated by describing a cooling tower with a lower approach temperature. This value is set and adjusted in the Water Side Economizer Optimization section.

Chilled Water Temperature Reset

- Chilled water supply temperature interpolates linearly between the entered values as OAT moves between the respective temperatures.
- To model constant supply temperature, set the max temperature equal to the minimum

Chilled Water Differential Pressure Reset

- Differential pressure, in PSI, interpolates linearly between the entered values as OAT moves between the respective temperatures

Chiller Staging Sequence Optimization

- Chillers are designated as 'on' if they run during the given stage; a blank indicates off. Capacity of the stages indicates the maximum tonnage of that stage, the minimum tonnage of each stage is the capacity of the previous stage. *These must be entered in ascending order.*

Chiller Plant Lockout Control

- This is the temperature below which the chiller is turned off

Condenser Water Temperature Reset

- Condenser water set point temperature interpolates linearly between the entered values as OAT moves between the respective temperatures

Cooling Tower Staging Control

- Cooling towers are designated as 'on' if they run during the given stage; a blank indicates off. Capacity of the stages indicates the maximum tonnage of that stage, the minimum tonnage of each stage is the capacity of the previous stage. *These must be entered in ascending order.*

Chilled Water Pump VFD and Speed Control

- Chilled water pump operation can either be set to VFD control or constant speed

Condenser Water Pump VFD and Speed Control

- Condenser water pump operation can either be set to VFD control or constant speed

Water Side Economizer Sequence Optimization

- If Chiller Replacement measure is enabled, two sets of savings will be created: one with the existing chillers characteristics and a second one with Title 24 baseline requirements for new chillers
- The waterside economizer is assumed to meet the full load whenever the OAT is below the Enable temperature.

2.2.6 Details about Hot Water System Measures

Hot Water Temperature Reset

- Hot water set point temperature interpolates linearly between the entered values as OAT moves between the respective temperatures

Hot Water Differential Pressure Reset

- Differential pressure, in PSI, interpolates linearly between the entered values as OAT moves between the respective temperatures

Boiler Staging Sequence

- Boilers are designated as 'on' if they run during the given stage; a blank indicates off. Capacity of the stages, entered higher up on the tool, indicates the maximum capacity of that stage, the minimum tonnage of each stage is the capacity of the previous stage. These must be entered in ascending order.

Hot Water Plant Lockout Control

- The user can modify the temperature above which the boiler turns off.

Hot Water Pump VFD and Speed Control

- Hot water pump operation can either be set to VFD control or constant speed

3 Refrigeration Calculation Tool

3.1 How to Use the Tool

The following section provides detailed instructions on how to use the Refrigeration Calculation Tool.

3.1.1 Facility Information

To begin, input customer information and consumption data in the launched tab

Customer Information

Name		Phone	
Contact		Email	

Building Information

Address				Type	Convention Center
City				SQFT	
Zip	00054	Zone	1	Year Built	

Enter Customer Information and all available Building Information.

Consumption

	Peak kW	kWh	Therms	Electric Cost	Therm Cost		
Jan	1,197	577,999	25,587	$70,173	$17,206		
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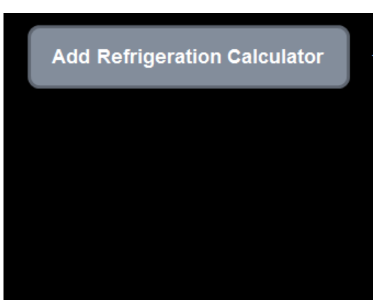
Oct	1,250	647,780	25,156	$95,430	$21,295		
Nov	1,107	557,830	36,992	$70,065	$31,817		
Dec	1,033	588,953	36,726	$70,988	$30,956	$/kWh	$/Therm
Annual	1,311	7,372,429	329,308	$1,081,177	$210,724	$0.15	$0.64

Include Total Cost for customers that receive bundled service. If the customer is direct access and the commodity cost is available, it should be included. Otherwise the Total Cost can be omitted.

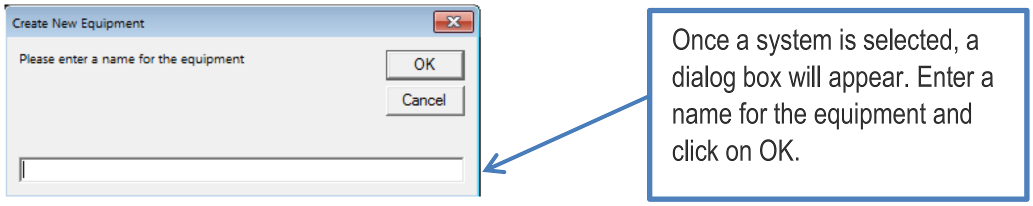
Enter Consumption data using building energy billing statements or manually enter $/kw and/or $/therm.

3.1.2 Measure Information

To begin, select the type of system you would like to implement on the main tab. For the Refrigeration tool there will be only one option



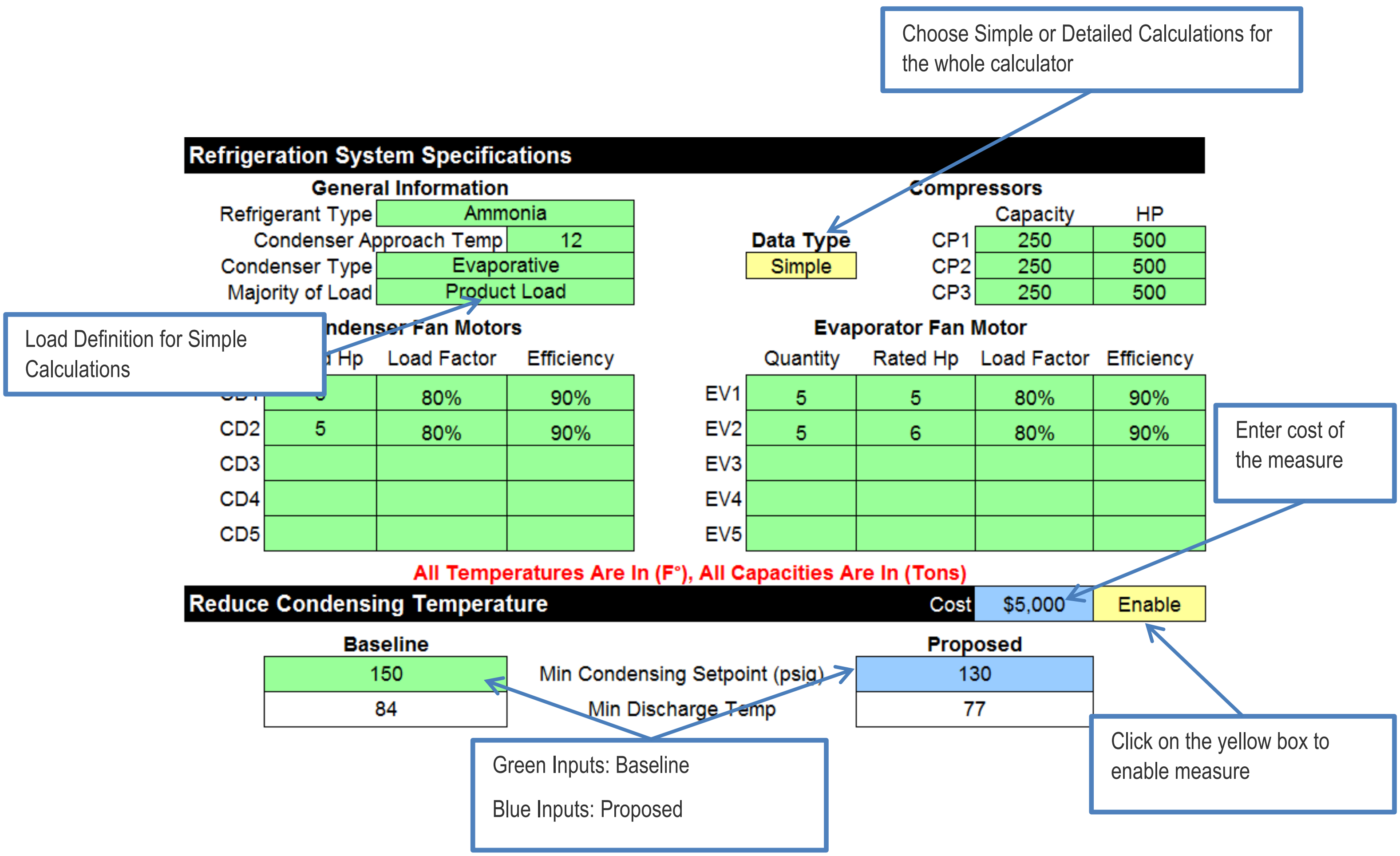
Select System



Once the equipment has been named, three new tabs will appear in the calculator: the calculations tab, the compressor performance curve tab for detailed calculations (ignore for simple calculations) and the engineering report tab.

To continue, complete the following information for all measures for that system, please note that an asterisk will appear by categories where the baseline and proposed parameters are different.

Since the refrigeration tool is a 8760 hourly analysis, please do not add more than one system for each excel file.



For users who choose to use the trend data option, enter for each compressor the hourly kW and Saturated Suction Temperature trend data into the table under the Calculation Engine (see below). This data will be used to calculate the Refrigeration Load for each of the 8760 hours.

Calculation Engine				Enter Detail Data Here					
8760 Hour	Hour	WBT	DBT	Baseline kW CP1	Baseline kW CP2	Baseline kW CP3	Baseline SST CP1	Baseline SST CP2	Baseline SST CP3
1	1	42	43	0	162	0	-40	-40	-40
2	2	41	42	0	150	0	-40	-40	-40
3	3	39	40	0	149	0	-40	-40	-40
4	4	39	39	0	152	0	-40	-40	-40
5	5	38	40	0	146	0	-40	-40	-40
6	6	40	42	0	170	0	-40	-40	-40
7	7	41	44	0	146	0	-40	-40	-40
8	8	41	45	0	170	0	-40	-40	-40

For detailed calculations, the user has to define the compressor performance curves under the Compressor Curve Input tab.

CP1 - Inputs by User				
SV Pos CP1	SCT (F) CP1	kW CP1	Cap CP1	SST CP1
100%	90	295	128.8	-40
98%	90	278.9	115.9	-40
96%	90	263	103.1	-40
94%	90	246.8	90.2	-40

Once all information is entered, click on the Calculate Measures button at the top of the sheet to complete the energy efficiency savings calculations.

Calculate Measures

The macros use the inputs under the Processing section to run the calculations. Basically, the calculations under the Calculation Engine section are updated with the inputs under the Processing section. These inputs are updated based on measures being enabled and the inputs provided by the user.

The macros will change these switches from Baseline to Proposed.

If the measure is enabled, the measure inputs will change values when the measure switch is updated from baseline to proposed.

Processing

Switches	
Propose	Reduce Condensing Temp
Propose	Condenser Fan Control
Propose	Head Pressure
Propose	Suction Set Point (psig)
Propose	Staging Optimization
Propose	Compressor VFD
Propose	Evaporator VFD
Discharge Setpoint Reset	
130	Discharge Setpoint (psig)
Condenser Fan Control	
On-Off	Control
Head Pressure	
Floating	Head pressı 110
Suction Set Point Reset	
50	Suction Set Point (psig)
Peak kW First Line	4512
Last Line	4536

Calculated Variables	
28	Lookup Suction Temp Col
0.52	bhp/ton (by general equation)
8	Lookup Min Discharge Temp Col
33.8	Current Suction Temperature Set Point (°F)
46	Lookup Min Discharge Temp Row
68.1	Minimum Discharge Temperature
6.63	Condenser Power (kW)
36.5	Evaporator Power (kW)
Assumptions	
97%	VFD Efficiency
0.3%	Capacity Increase per degree decrease in SCT
1.3%	kW/ton Decreases per degree decrease in SCT
80%	Compressor Load Factor
95%	Compresser Motor Eff
90%	Refrigeration Peak Load Factor
80%	Product Load Factor
50%	Weather Load Factor

The calculations are reviewable by the user under the Calculation Engine Section. If the user wants to review a specific measure they need to disable all the other measures and enable the measure that they want to review and click on Calculate Measures. If the user wants to review the baseline calculations, then disabling all the measures and clicking on Calculate Measures will show the baseline hourly calculations.

The consumption and energy savings for each measure can be reviewed on the top right corner of the calculator.

Savings	CP kW	CP kWh	CD kW	CD kWh	EV kW	EV kWh	Total kW	Total kWh	Cost	Incentives
Reduce Condensing Temp	0	111,063	-1	-8,346	0	0	-1	102,717	$5,000	$8,217.38
Condenser VFD	0	0	0	0	0	0	0	0	$5,000	
Floating Head Pressure	0	116,579	-2	-14,000	0	0	-2	102,579	$5,000	$8,206.36
Increase Suction Pressure	0	0	0	0	0	0	0	0	$5,000	
Staging Optimization	0	0	0	0	0	0	0	0	$5,000	
Compressor VFD	0	0	0	0	0	0	0	0	$5,000	
Evaporator VFD	0	0	0	0	0	0	0	0	$5,000	
Total	**0**	**227,643**	**-3**	**-22,346**	**0**	**0**	**-3**	**205,297**	**$35,000**	**$16,423.74**

Consumption	CP kW	CP kWh	CD kW	CD kWh	EV kW	EV kWh	Total kW	Total kWh
Baseline	0	1,264,163	3	23,138	0	27,731	3	1,315,032
Reduce Condensing Temp	0	1,153,099	4	31,484	0	27,731	4	1,212,315
Condenser VFD	0	1,153,099	4	31,484	0	27,731	4	1,212,315
Floating Head Pressure	0	1,036,520	6	45,484	0	27,731	6	1,109,735
Increase Suction Pressure	0	1,036,520	6	45,484	0	27,731	6	1,109,735
Staging Optimization	0	1,036,520	6	45,484	0	27,731	6	1,109,735
Compressor VFD	0	1,036,520	6	45,484	0	27,731	6	1,109,735
Evaporator VFD	0	1,036,520	6	45,484	0	27,731	6	1,109,735
Proposed	0	1,036,520	6	45,484	0	27,731	6	1,109,735

3.2 System Calculations and Assumptions

3.2.1 System Calculations

Compressor Power (kW)

Refrigeration compressor power is primarily a function of saturated suction temperature, saturated condensing temperature and refrigeration load. At a minimum, the user should have the following information to use the refrigeration tool:

- Nameplate data for all refrigeration compressors
- Baseline Minimum Condensing Temperature (MCT)
- Baseline Saturated Suction Pressure (SST)
- Baseline Condenser Approach Temperature (CAT)
- Baseline Total condenser fan hp
- The detailed tool also requires detailed compressor operating curves shown in 'Compressor Curve Input' tabs.
- The simplified tool uses a generic formula to estimate bhp/ton (discussed later)

Based on the information provided by the user, the tool calculates the following key parameters:

- **Saturated Suction Temperature** (SST) is a user defined input value and is directly used in the compressor (kW) algorithm mentioned later.
- **Saturated Condensing Temperature** (SCT) is determined based on MCT and Ambient conditions:

$$SCT = GREATER\ VALUE\ OF: (MCT)\ OR\ (Ambient\ Air\ Temperature + CAT) \quad \text{Eq. 13}$$

Where,

SCT = Saturated Condensing Temperature

MCT = Minimum Condensing Temperature

CAT = Condenser Approach Temperature

Ambient Air Temperature = DBT for Air cooled condenser / WBT for Evaporative Cooled Condenser

- **Refrigeration load** is calculated differently in simplified and detailed version of the tool:

  The *simplified* tool calculates the refrigeration load depending on the user input of whether majority of load is 'Product Load' or 'Weather Sensitive Load'. Depending on user selection, the peak and average refrigeration load value is estimated as a percentage of total refrigeration capacity of all compressors combined. The annual refrigeration load profile is estimated by linearly scaling peak and average load to outside air temperature.

  The *detailed* tool requires user to input hourly average baseline compressor demand (kW) and SST trend data. Refrigeration load is calculated for each compressor using a biquadratic regression model built using the user input compressor operating curves and compressor kW trend data.

$$Load\ (tons) = b + (m_1 \times SCT) + (m_2 \times SCT^2) + (m_3 \times SST) + (m_4 \times SST^2) + (m_5 \times CP - kW) + (m_6 \times CP - kW^2) \quad \text{Eq.14}$$

Where,

b = regression intercept value

m_1, m_2, m_3, m_4, m_5, m_6 = regression model coefficients

CP-kW = Compressor demand (trend data)

The three parameters (SST, SCT and load) required to calculate compressor power have been established. Compressor power is calculated as discussed below:

Simplified Tool:

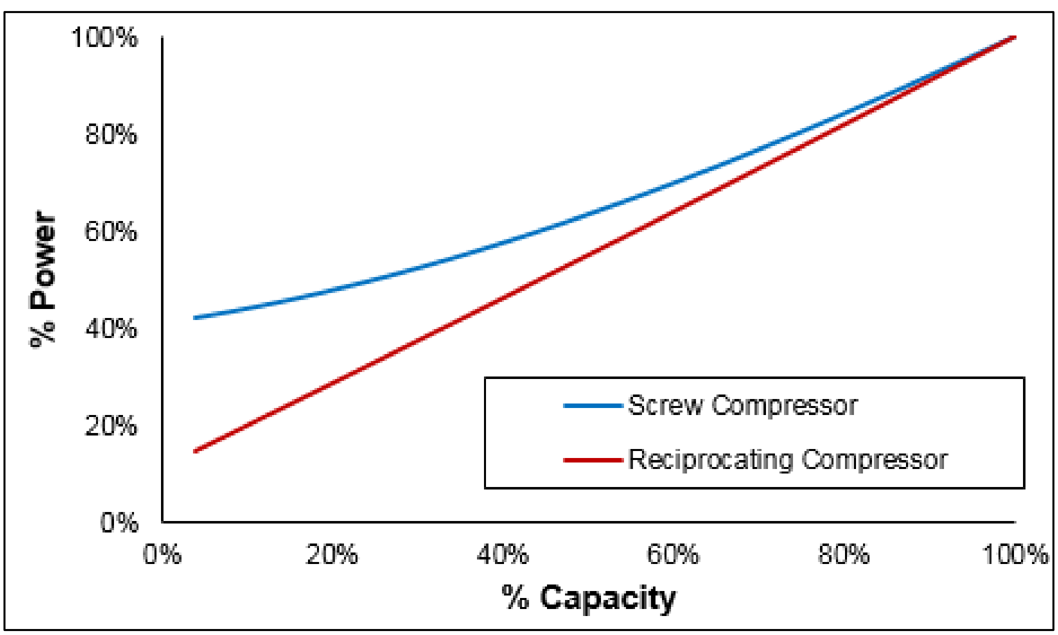
The simplified tool should be used to get a general idea of compressor performance in absence of detailed compressor manufacturer provided operating curves. The "*IRC Industrial Refrigeration Energy Efficiency Guidebook, 2004; page 6-162*" provides an algorithm to estimate compressor performance **- *bhp/ton***:

$$\frac{bhp}{ton} = 0.339 - (6.92E - 03 \times SST) + (1.28E - 04 \times SST^2) + (5.61E - 03 \times SCT) + (9.17E - 05 \times SCT^2) - (2.35E - 04 \times SST \times SCT) \quad \text{Eq.15}$$

By using compressor bhp/ton and refrigeration load, the tool can calculate compressor power (kW).

Detailed Tool:

The detailed tool uses % Power - % Capacity relationship and a regression model built using compressor manufacturer provided operating curves to calculate compressor power. The regression model uses SST, SCT and refrigeration load (calculated previously) as key inputs. It is important to note that part load performance of the compressor is modeled by using the following relationship between %Capacity (load) and %Power. The compressor power calculated using regression model is multiplied by %power.



Condenser Fan Power (kW)

The detailed and simplified tools use the same algorithm to calculate condenser fan power. The cycling rate determines energy usage of condenser fan at hourly interval. Cycling rate is calculated based on condensing temperature, ambient conditions and condenser approach temperature.

Evaporator Fan Power (kW)

The detailed and simplified tools use the same algorithm to calculate evaporator fan power. The cycling rate for the evaporator is determined based on refrigeration load and design evaporator capacity at the suction temperature setpoint for the system.

3.2.2 Difference between Simple and Detailed Calculations

For the refrigeration tool there are two different types of calculations: Simple and Detailed. That choice is made at the top of the calculator and it affects all measures. The main differences between the simple and detailed calculations are the following.

Simple Calculations

- Load is defined by Majority of Load: Product Load or Weather Load. The macro uses the Forecast formula to calculate the load for each hour depending on the outside air temperature (OAT). See below a summary of each of the options.

  For Product Load the forecast formula is created the following way

Known Variables	Peak Load	Average Load
Y – Cooling Tons	90% of Compressors Capacity	Peak Load *80%
X - OAT	OAT at Peak Demand (defined by DEER)	Median OAT for Climate Zone

  For Weather Load the forecast formula is created the following way

Known Variables	Peak Load	Average Load
Y – Cooling Tons	90% of Compressors Capacity	Peak Load * 50%
X - OAT	OAT at Peak Demand (defined by DEER)	Median OAT for Climate Zone

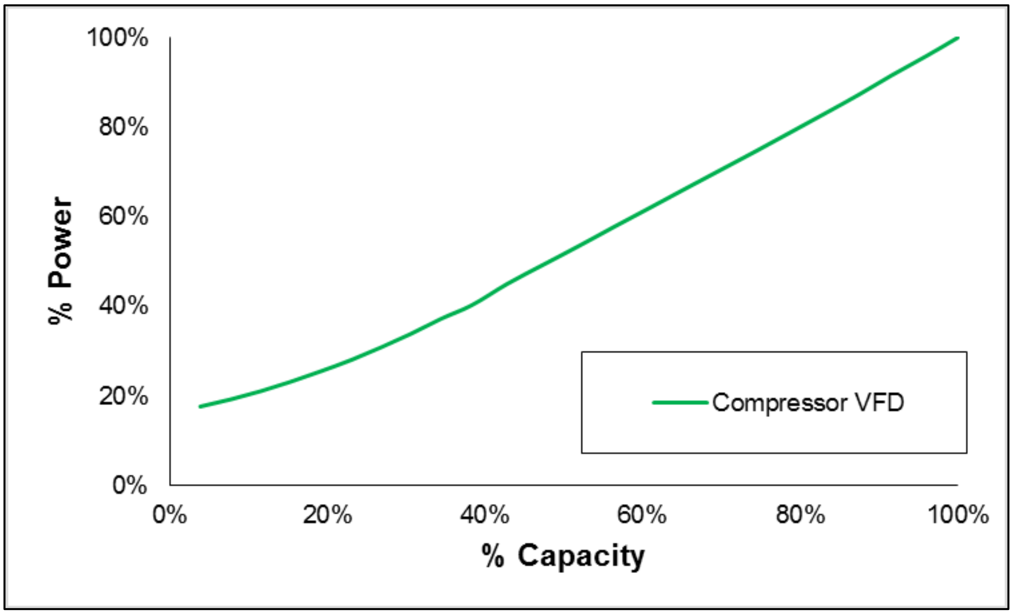
- The compressor performance curves are pre-defined by the tool

Detailed Calculations

- Load is defined by the hourly kW inputted by user
- User defines the compressor curves.

3.2.3 Assumptions

- California DEER climate zone data is used for weather
- The simplified tool assumes the peak refrigeration load factor is 90% of rated capacity of total refrigeration plant capacity.
- For product driven load, the average load is 80% of peak load
- For weather sensitive load, the average load is 50% of peak load
- Refrigeration compressor %power v/s %capacity is assumed to follow the curve shown above
- Refrigeration compressor with VFD follows %power v/s %capacity curve shown below:



The curve was determined based on outputs for multiple compressors from compressor manufacturer selection program: GEA RT Select

- The simplified tool assumes weather sensitive refrigeration load varies linearly with outside air temperature
- Condenser performance is modeled using simple fan cycling rate calculation. Refrigeration heat of rejection calculations are not used
- The detailed tool assumes compressors are only switched ON when refrigeration load is above 15% of compressor capacity. This is a reasonable assumption since it is a standard practice to control compressor sequencing to avoid such a scenario especially for slide valve controlled screw compressors as they have poor energy efficiency at low load conditions (for example: At Load<20% compressor capacity; power usage is 40%)

4 Engineering Report

To generate an Engineering Report utilizing the previously entered data, click on the Engineering Report tab.

Enter Assumptions here:

Assumptions

*Regression models are created based on outdoor dry bulb temperature.
*2013 DEER California Climate Zone weather file is used for savings calculation.

Enter Project Notes here:

Project Notes

Please write down any influence documentation or any other relevant project information.

To complete and generate the Engineering Report, click on the Create Report button.

Create Report

The macro will incorporate the system information:

Summary of Systems

Air Side Systems

Input	AHU-1
Equipment Vintage	2009
Supply Fan HP	65
Supply Fan CFM	60,000
Supply Fan Control	VFD
Return Fan HP	25
Return Fan CFM	60,000
Return Fan Control	VFD

Chilled Water System

Input	Main Chiller	Lag Chiller	Chiller
Capacity (tons)	400	600	500
Design kW/ton	0.8	0.8	0.9
Design CHWT	44	44	44

Cooling Tower System

Input	CT - 1	CT - 2	CT - 3
Capacity (tons)	375	750	375
Fan HP	40	50	40
Motor Efficiency (%)	0.93	0.95	0.93

Secondary Chilled Water Pump

Input	SCHWP
# on Pumps	2
Baseline Controls	VFD

Condenser Water Pumps

Input	CWP
# on Pumps	3
Baseline Controls	VFD

The macro will also summarize all the energy savings for all the measures:

Energy Savings

Equipment/System Name	Measure Name	Measure Type	Measure EUL	Savings with Existing Baseline			Savings with Title 24/Code Baseline		
				Total kW	Total kWh	Therms	Energy Usage (kWh)	Peak Demand (kW)	Energy Usage (Therms)
AHU-2	Supply Air Temperature Reset	BRO	3	34	131,163	27,528			
Hot Water System 2	HW Temp Reset	BRO	3	0	0	186			
Chilled Water System 2	Chiller Replacement (or Load Change)	BRO	3	105	253,995	0	32	76,199	0
Chilled Water System 2	Chilled Water Temperature Reset	BRO	3	40	95,746	0	40	95,746	0
Hot Water System	HW Lockout Control	BRO	3	0	15,896	18,721			
Chilled Water System	Chilled Water Plant Lockout Control	BRO	3	0	739,448	0			
AHU-1	Economizer Optimization	BRO	3	0	(2,370)	15,099			
AHU-1	Supply Air Temperature Reset	BRO	3	15	43,587	13,751			

And will create a simple financial analysis:

Financial Analysis

Incentive Rates	
Basic Non Lighting	$0.08
Target Non Lighting	$0.15
Peak Demand	$150.00
Natural Gas	$1.00
To Code/ISP Electric	$0.03
To Code/ISP Gas	$0.40

Utility Cost	
$/kWh	$0.147
$/therm	$0.640

Equipment/System Name	Measure Name	Yearly Utility Cost Savings ($)	Estimated Incentives ($)	Implementation Cost		Payback		Measure Lifetime ROI	
				Measure Cost	w/ Incentives ($)	w/o Incentives (years)	w/ Incentives (years)	w/o Incentives (%)	w/ Incentives (%)
AHU-2	Supply Air Temperature Reset	$ 36,857	$ 1,500	$ 3,000	$ 1,500.00	0.08	0.04	3686%	7371%
Hot Water System 2	HW Temp Reset	$ 119	$ 186	$ 1,000	$ 814.00	8.41	6.85	36%	44%
Chilled Water System 2	Chiller Replacement (or Load Change)	$ 37,261	$ 38,099	$ 100,000	$ 61,900.70	2.68	1.66	112%	181%
Chilled Water System 2	Chilled Water Temperature Reset	$ 14,046	$ 9,000	$ 18,000	$ 9,000.00	1.28	0.64	234%	468%
Hot Water System	HW Lockout Control	$ 14,312	$ 1,000	$ 2,000	$ 1,000.00	0.14	0.07	2147%	4293%
Chilled Water System	Chilled Water Plant Lockout Control	$ 108,477	$ 4,000	$ 8,000	$ 4,000.00	0.07	0.04	4068%	8136%
AHU-1	Economizer Optimization	$ 9,314	$ 2,500	$ 5,000	$ 2,500.00	0.54	0.27	559%	1118%
AHU-1	Supply Air Temperature Reset	$ 15,194	$ 5,000	$ 10,000	$ 5,000.00	0.66	0.33	456%	912%

The Measure Lifetime ROI is calculated based on the energy efficiency measure Expected Useful Life (EUL). For example, for an RCx measure the EUL is 3 years. For a retrofit measure, DEER database has been used as a reference.

The engineering report will also recommend an M&V plan depending on the savings achieved by the measure. For those measures smaller than 75,000 kWh and 7,500 therms a streamlined M&V plan is recommended. These values are just for reference and can be updated based on the user's needs.

M&V Requirements

Equipment/System Name	Measure Name	M&V Type	Parameters
AHU-2	Supply Air Temperature Reset	Minimum Two Weeks Trend Data	OAT or RAT, Fan Speed, SP setpoint and SP
Hot Water System 2	HW Temp Reset	Spot Measurement/EMS Snapshot/Photo	HWST Min and Max Setpoints, HWST Reset Control Logic
Chilled Water System 2	Chiller Replacement (or Load Change)	Minimum Two Weeks Trend Data	Cooling load, chiller status, amps or kW, OAT db
Chilled Water System 2	Chilled Water Temperature Reset	Minimum Two Weeks Trend Data	OAT db, CHWST, CHWST Set Point, Cooling Load
Hot Water System	HW Lockout Control	Spot Measurement/EMS Snapshot/Photo	Lockout Outside Air Temperature
Chilled Water System	Chilled Water Plant Lockout Control	Minimum Two Weeks Trend Data	OAT db, chiller status (amps or kW), cooling load
AHU-1	Economizer Optimization	Spot Measurement/EMS Snapshot/Photo	AHU Diagram and Economizer Control Sequence
AHU-1	Supply Air Temperature Reset	Spot Measurement/EMS Snapshot/Photo	AHU Diagram and SP Reset Logic

5 Acronyms

B – Boiler

BHP – Brake Horsepower

BL – Base Load Compressor

CD – Condenser

CFM – Cubic Feet per Minute

CH – Chiller

CHWST – Chilled Water Supply Temperature

CP – Compressor

CT – Cooling Tower

CWP – Condenser Water Pump

CWST – Condenser Water Supply Temperature

DAT – Discharge Air Temperature

DBT – Dry Bulb Temperature

ECON – Economizer

EV - Evaporator

FT – Feet

GPM – Gallons per Minute

HP – Horsepower

HSPF - Heat Seasonal Performance Factor

HWST – Hot Water Supply Temperature

MAT – Mixed Air Temperature

OA – Outside Air

OAT – Outside Air Temperature

OCC – Occupied

PCHWP – Primary Chilled Water Pump

PHWP – Primary Hot Water Pumps

POS – Position

PSI - pounds per square inch

RF – Return Fan

RH – Reheat

SAT – Supply Air Temperature

SCHWP – Secondary Chilled Water Pump

SCT - Saturated Condensing Temperature

SF – Supply Fan

SHWP – Secondary Hot Water Pump

SQFT – Square foot

SST – Saturated Suction Temperature

SV – Slide Valve

T1 – Trim Compressor #1

T2 – Trim Compressor #2

UNOCC – Unoccupied

VAV – Variable Air Volume

VFD – Variable Frequency Drive

WBT – Wet Bulb Temperature

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