Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment

Session 5

Wednesday – August 14, 2024

10 am – 12:30 pm

U.S. DEPARTMENT OF ENERGY

Welcome

- Welcome to the 5th Chilled Water Systems Virtual INPLT training series
- Eight, 2-1/2 hour webinars, focused on Industrial Process Cooling (Chilled Water) Systems Energy Assessment and Optimization
- These webinars will help you gain a significant understanding of your industrial process cooling system, undertake an energy assessment using a systems approach, evaluate and quantify energy and cost-saving opportunities using CWSAT and other US DOE tools and resources
- Thank you for your interest!

Process Cooling (Chilled Water Systems) Virtual INPLT Facilitator

Riyaz Papar, PE, CEM, Fellow – ASME, ASHRAE

Industrial Energy Efficiency & Decarbonization Advisor
Oak Ridge National Laboratory

paparra@ornl.gov
(346) 610 8787

Process Cooling Virtual INPLT Agenda (2024)

- Session 1 (July 17) – Industrial Chilled Water Systems Fundamentals
- Session 2 (July 18) – Review of Chilled Water System Scoping Tool; Efficiency Metrics & Calculations
- Session 3 (July 31) – Introduction to Chilled Water System Assessment Tool (CWSAT)
- Session 4 (August 1) – Using CWSAT to Quantify Energy Efficiency Opportunities – Part 1
- **Session 5 (August 14) – Using CWSAT to Quantify Energy Efficiency Opportunities – Part 2**
- **Session 6 (August 15) – US DOE MEASUR, 3EPlus, etc.; Undertaking a VINPLT Assessment & Reporting**
- **Session 7 (August 28) – Case Studies; Refrigerants – Past, Present & Future; Reclamation and O&M**
- **Session 8 (August 29) – Industrial Process Cooling (Chilled water) System VINPLT Wrap-up Presentations**

Agenda – Session 5

- Welcome and Introductions
- Safety and Housekeeping
- Today's Content:
  - Review of Sessions 3 and 4; Homework Discussion
  - Energy Efficiency Opportunities in chilled water systems
  - Quantifying Opportunities using CWSAT
- Kahoot Quiz Game
- Q&A

Better Buildings is an initiative of the U.S. Department of Energy

Safety and Housekeeping

- Safety Moment
  - As you trace chilled water supply and return headers to end-uses, watch for hazards along the way – follow human traffic pathways as much as possible
  - Wear hard hats to protect your head from bumping against headers
- You are welcome to ask questions at any time during the webinar

- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

Quick Review – Sessions 3 & 4

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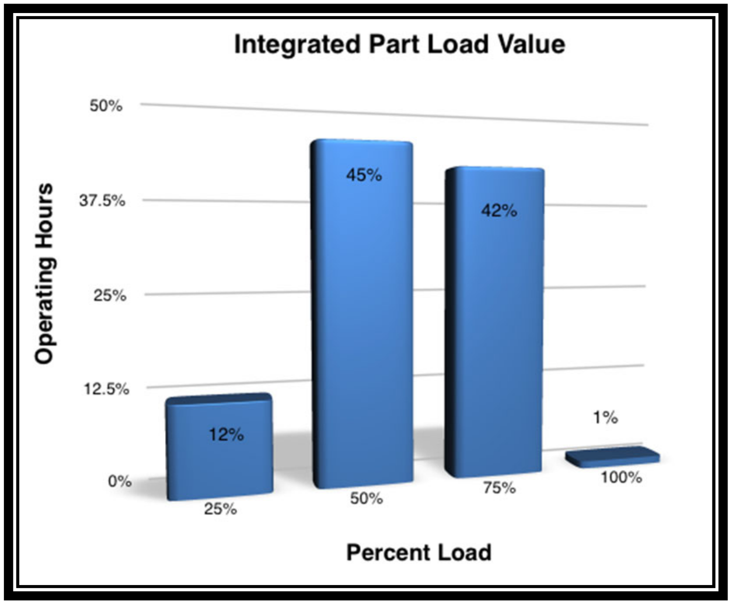
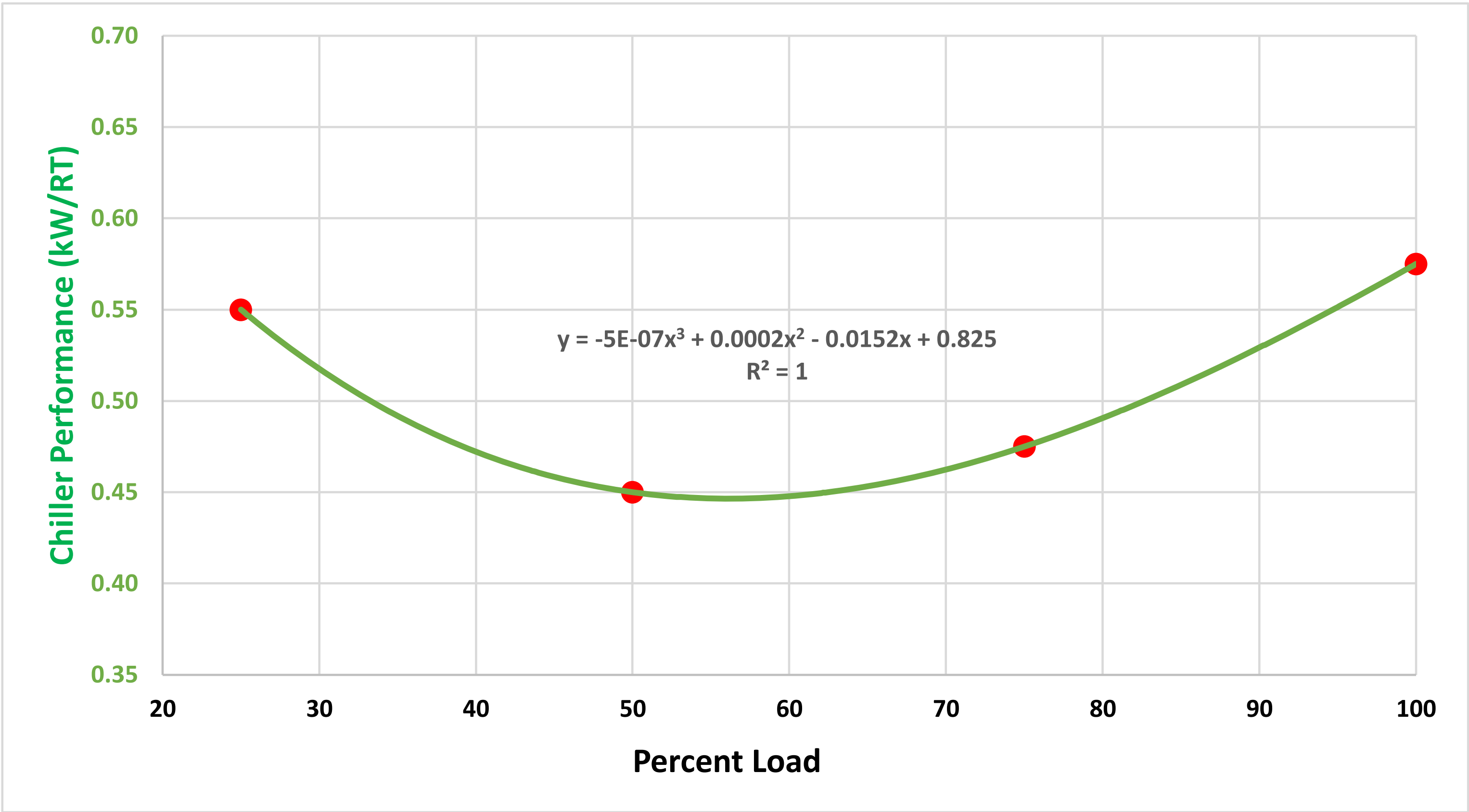
Integrated Part Load Value

- Generally, a chiller operates at full load design conditions for 1% of the total operating hours **ONLY**

- Hence, no decisions should be based on the design efficiency but instead they should be used as a guide to reach optimal solutions

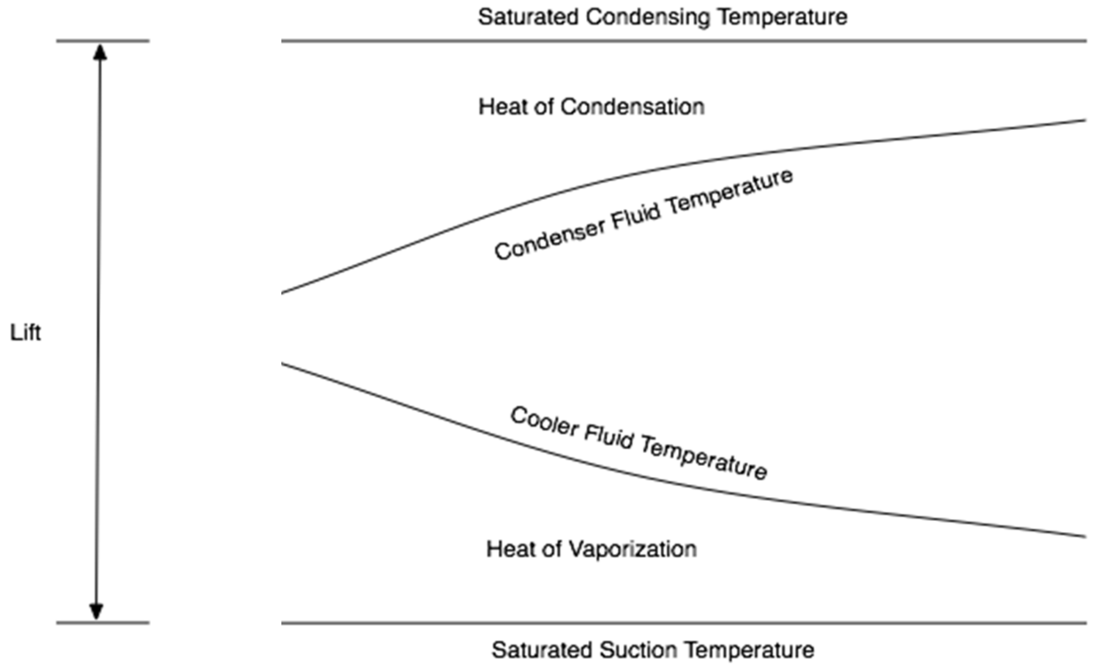


Overall Chiller (Plant) Performance

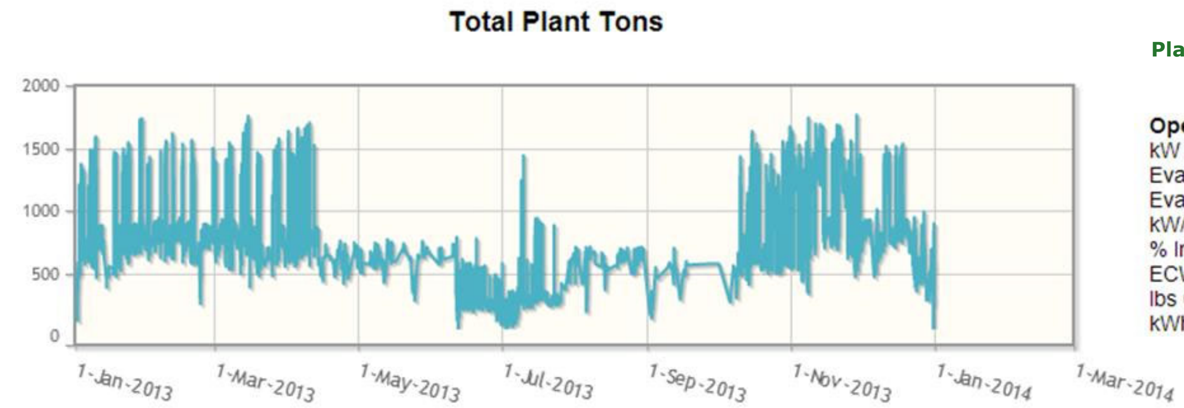


Chiller Lift

- Difference between Saturated Condensing Temperature and the Saturated Suction (Evaporating) Temperature

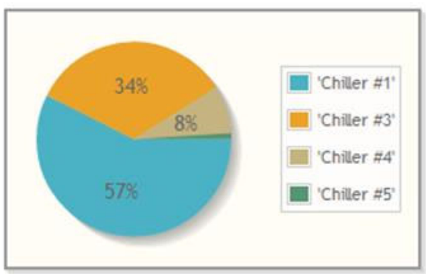


Food Manufacturing Plant Seasonal Operation

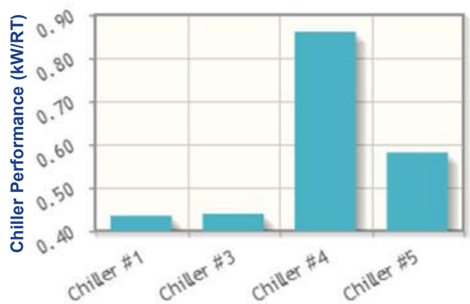


Plant Cooling Capacity - 3,500 RT

Operating Averages
kW = 273.83
Evaporator tons = 584
Evaporator Δ °F = 9.35
kW/ton = 0.515
% Input Power = 66.27
ECWT °F = 75.53
lbs CO2 Eq. produced = 375.14
kWh Cost = 13.69 per Hour



Cooling Load Hours (Tonhours) Contribution of Operating Chillers



Planning for Measurement & Data Collection

- Use a template
- Characterize the measurement
  - Local sensor
  - Data Acquisition
  - Historian
- **Instrumentation GAP Analysis Worksheet**
- Tick mark the appropriate boxes
- Complete for the chiller system
- Define final plan

	Chiller #1		
Chiller Capacity (RT)			
Refrigerant			
Chiller Manufacturer			
Chiller Model Number			
	Local Sensor	Data Acquisition	Historian
Condenser			
Saturation Temperature (°F)			
Condenser Pressure (psig)			
Inlet Water Temperature (°F)			
Outlet Water Temperature (°F)			
Water Flow rate (gpm)			
SubCooler			
Refrigerant Outlet Temperature (°F)			
Water Inlet Temperature (°F)			
Water Outlet Temperature (°F)			
Water Flow rate (gpm)			
Economizer			
Economizer Pressure (psig)			
Evaporator			
Saturation Temperature (°F)			
Evaporator Pressure (psig)			
Inlet CHW Temperature (°F)			
Outlet CHW Temperature (°F)			
CHW Flow rate (gpm)			
Compressor			
Suction Temperature (°F)			
Suction Pressure (psig)			
Discharge Temperature (°F)			
Discharge Pressure (psig)			

Better Plants Diagnostic Equipment Program (DEP)

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Diagnostic Equipment Program (DEP)

The Better Plants **Diagnostic Equipment Program (DEP)** allows partners to borrow over 22 different kinds of tools to collect energy data and improve equipment performance in their facilities.

Through this program, partners have the opportunity to test tools firsthand before deciding to purchase a piece of equipment on their own. This not only allows for the improved testing and collection of energy data, but also helps to demonstrate the value of certain tools in different applications throughout a facility.

FULL SUITE OF DIAGNOSTIC TOOLS

- Anemometer
- Combustion Analyzer
- Conductivity Meter
- Current Transformer
- Digital Manometer
- Digital Thermometer
- Infrared Camera
- Infrared Thermometer
- Laser Distance Meter
- Light Meter
- Pitot Tube
- Power Logger
- Pressure Transducer
- Pyrometer
- Sonic Imager
- Strobe Tachometer
- Temp/RH logger
- Thermocouple
- Thermocouple Logger
- Time of Use Logger
- Ultrasonic Flow Meter
- Ultrasonic Leak Detector

EXPLORE SOME OF THE TOOLS THAT YOU CAN BORROW THROUGH BETTER PLANTS:

POWER LOGGER

This device helps you directly measure energy consumption, which can be converted into costs. It also logs data to provide electric consumption trends.

CURRENT TRANSFORMER

Use this device with a data logger to quantify the electric current flowing to a component or system and identify wasted energy.

COMBUSTION ANALYZER

This analyzer quantifies excess oxygen in boilers and combustion process exhausts, helping you save fuel and heat energy.

LEAK DETECTOR

This device helps you identify leaks in compressed air or steam systems using high frequencies that are undetectable to the human ear.

betterbuildingssolutioncenter.energy.gov/better-plants/diagnostic-tools | @BetterPlantsDOE | linkedin.com/showcase/better-plants

EXPLORE THE FULL SUITE OF DIAGNOSTIC EQUIPMENT AND SUBMIT AN APPLICATION:

Scan the QR Code above, or click here to download the DEP rental application.

Send this completed form to the Better Plants Diagnostic Equipment Program Manager, Daryl Cox at coxdf@ornl.gov.

HAVE QUESTIONS ABOUT BORROWING EQUIPMENT?

Scan the QR code above, or click here to email Daryl Cox, DEP Program Manager.

Daryl Cox has over 20 years of experience managing industrial technology and equipment and can help you find the right tool for your energy needs.

Introducing CWSAT 3.0.1

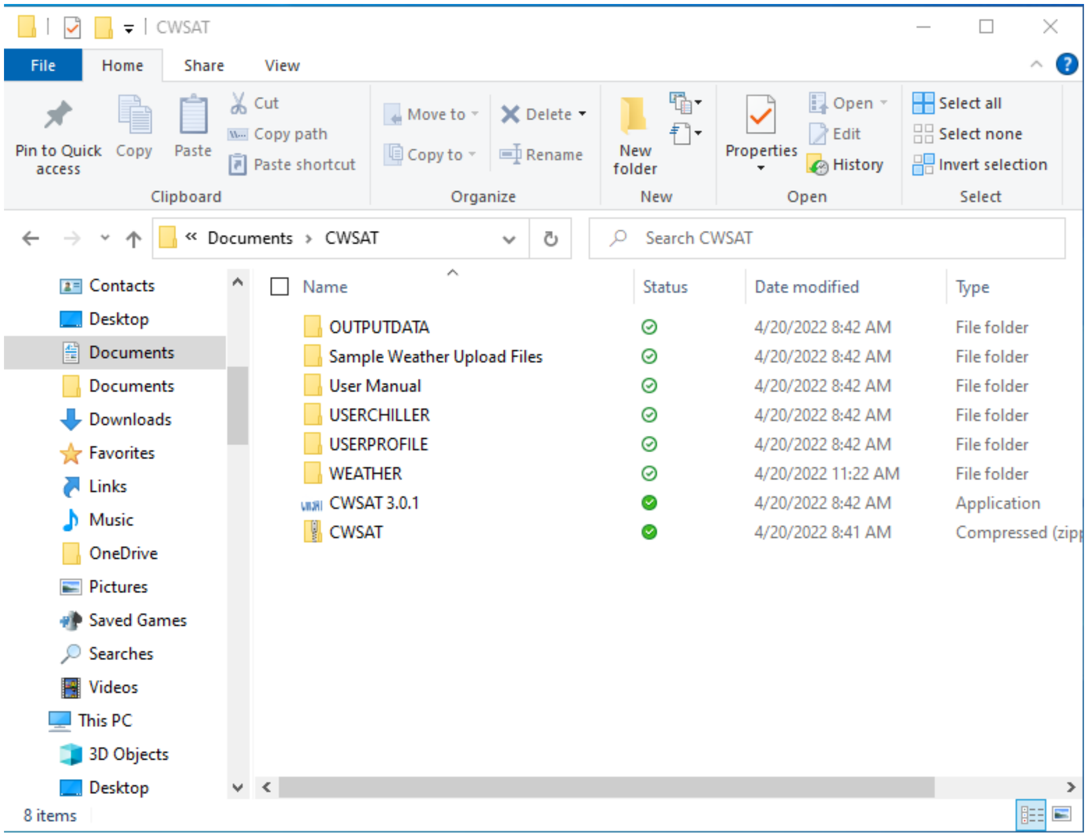
Chilled Water System Analysis Tool

Version 3.0.1

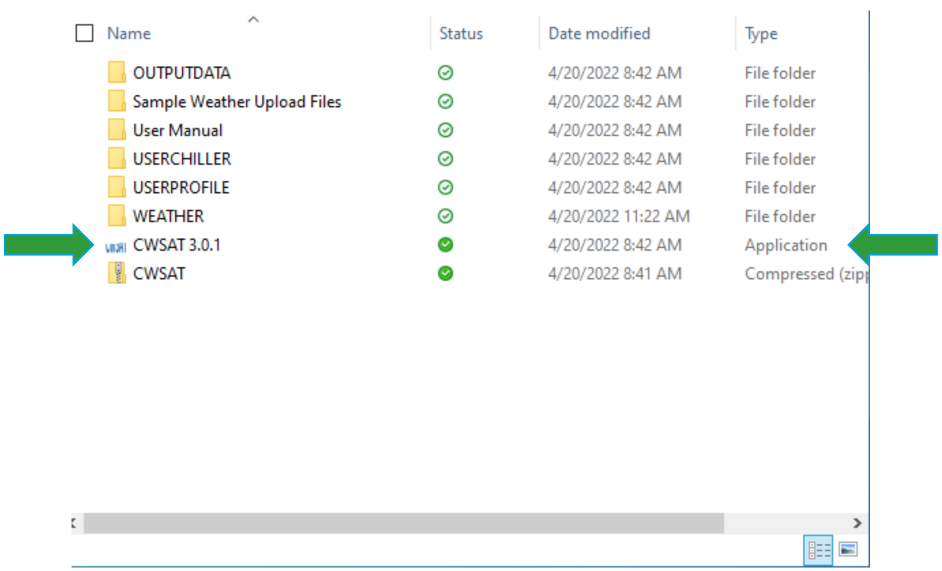
Description: This program calculates the annual energy requirements of various chilled water systems. It also evaluates the energy and cost savings that result when a variety of changes are made to the chilled water system.

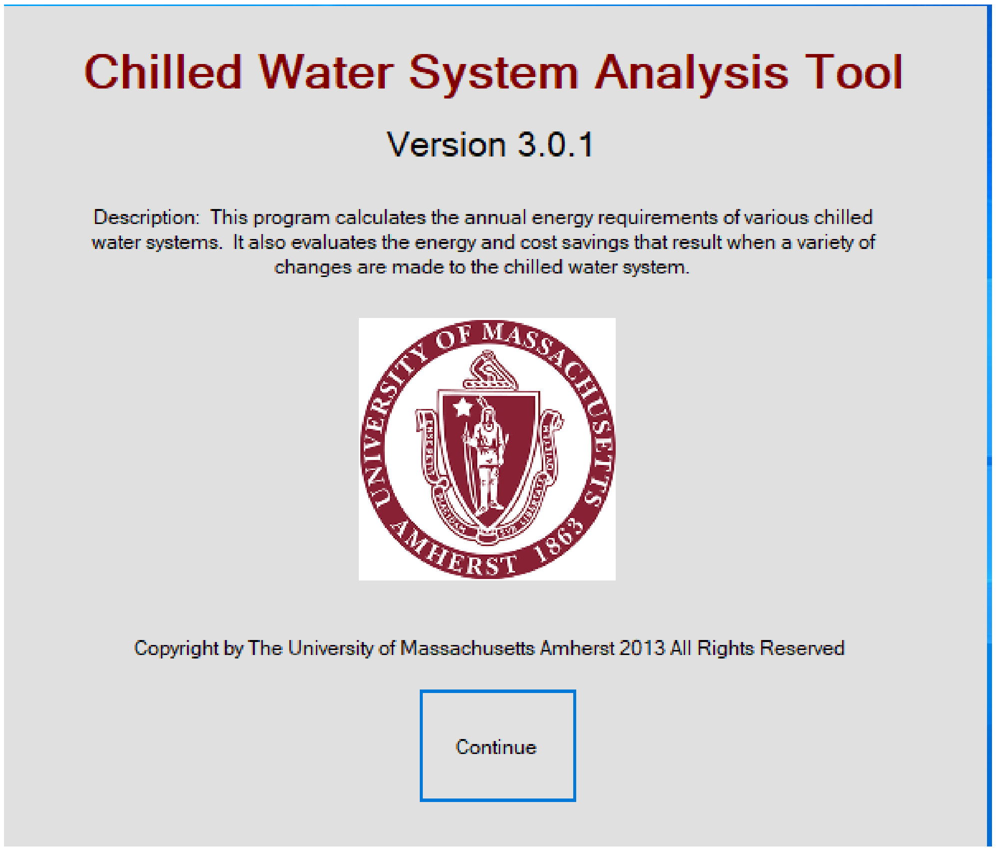
Continue

CWSAT Folder & Files



Start CWSAT 3.0.1



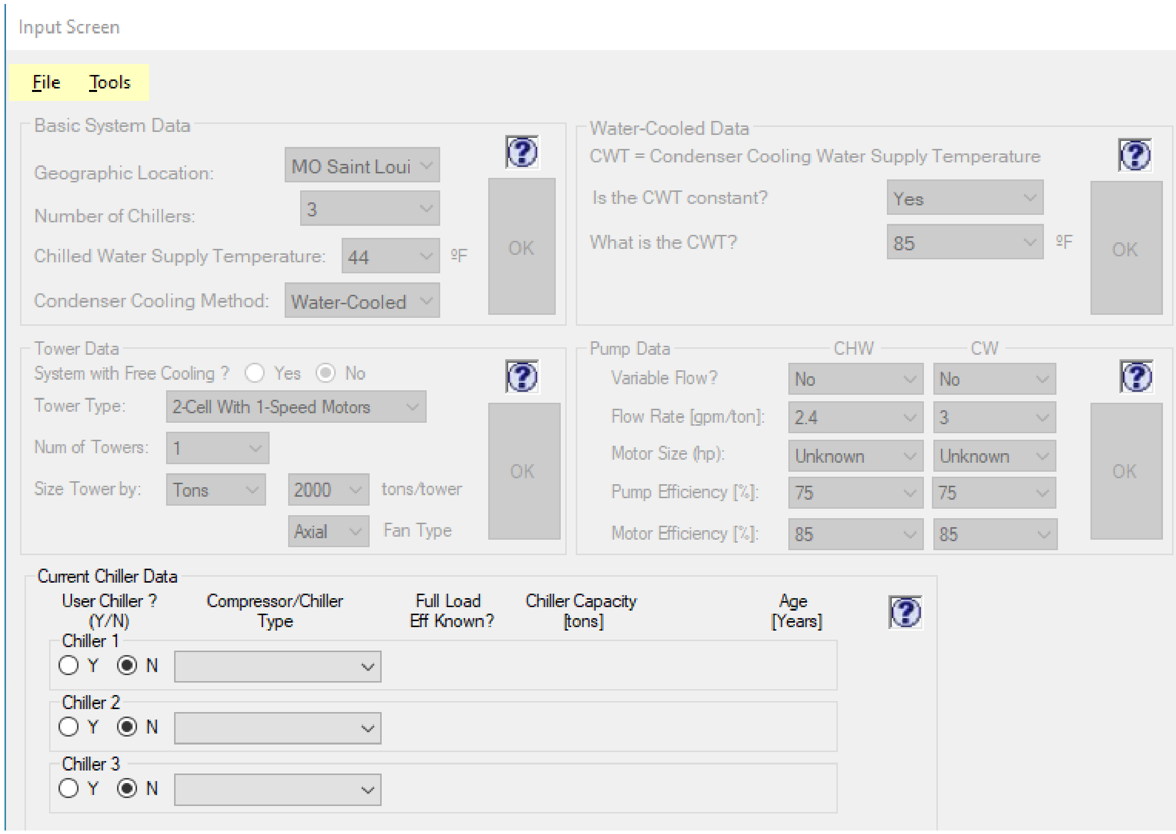


CWSAT INPUT Screenshots

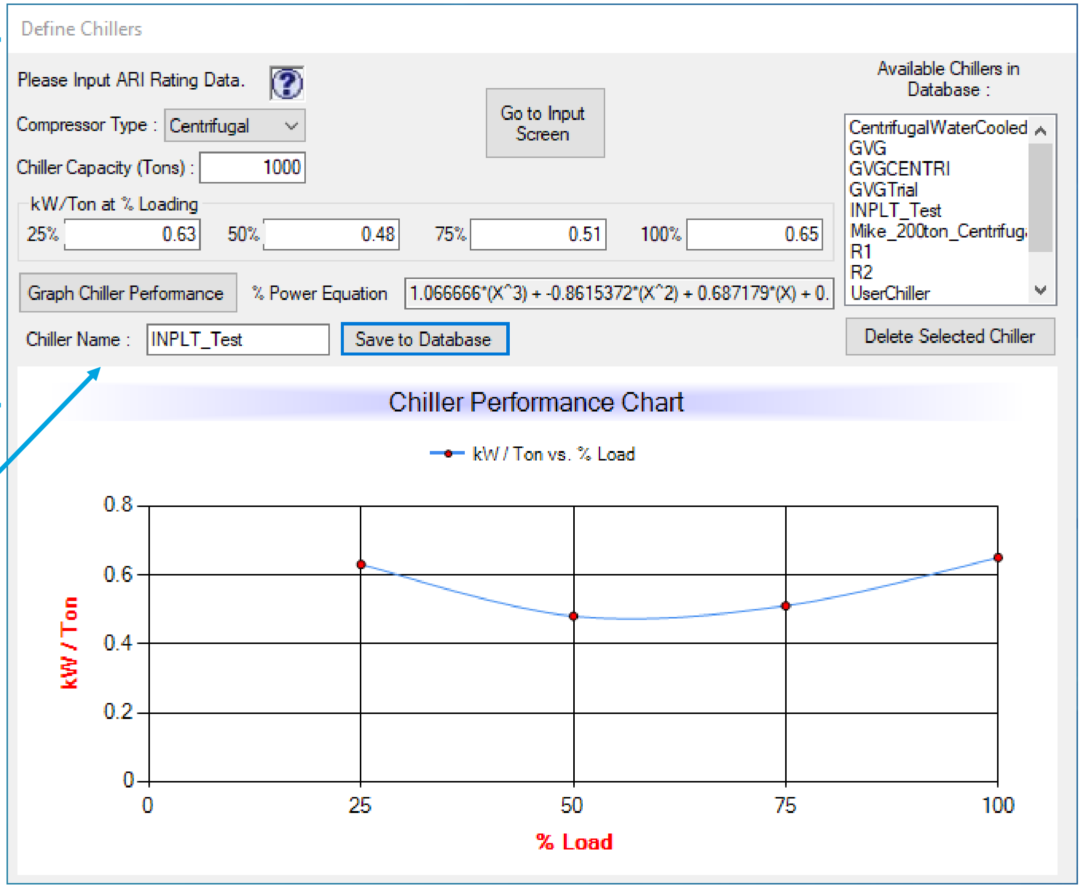
- Geographic location
- System description
- Heat rejection setup
- Pump setups
  - Chilled water
  - Condenser water (if applicable)
- Chiller setup
  - Default
  - Custom
- Utility Cost
- Operation Schedule & Load Profile

Click the "OK" Button to proceed to the next Input Sub-block

Sub-System Information

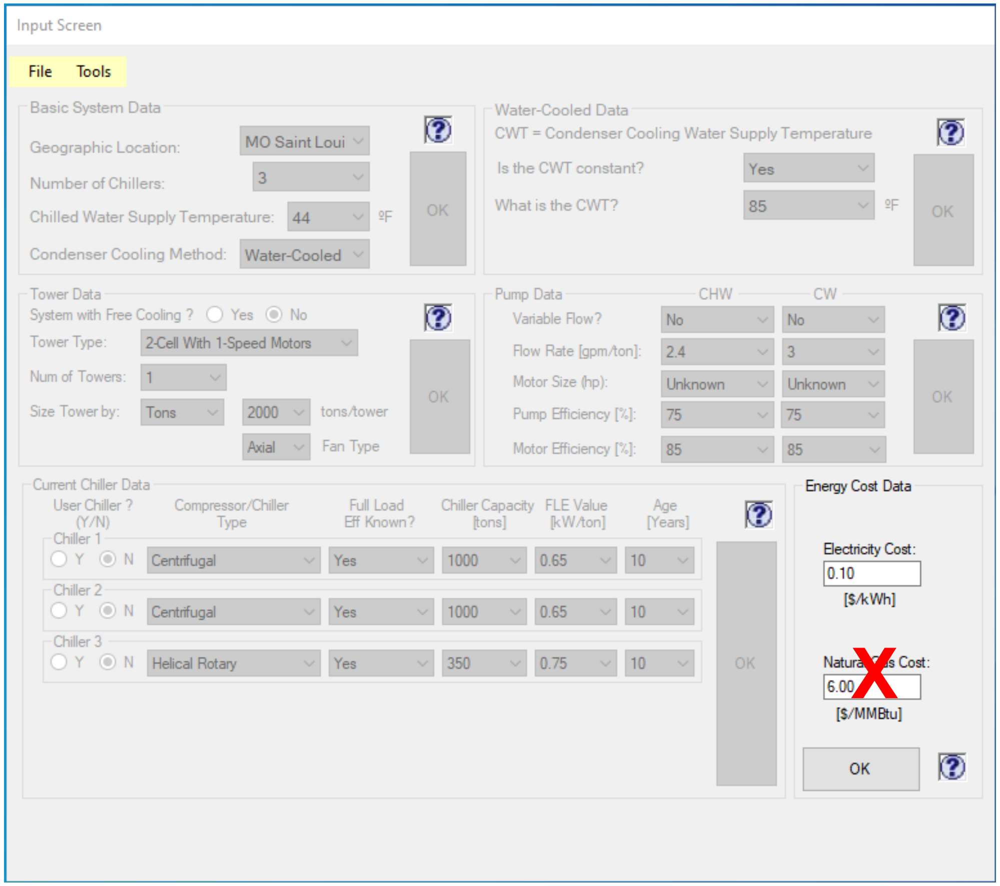


Chiller Specification Methodology – Method 3



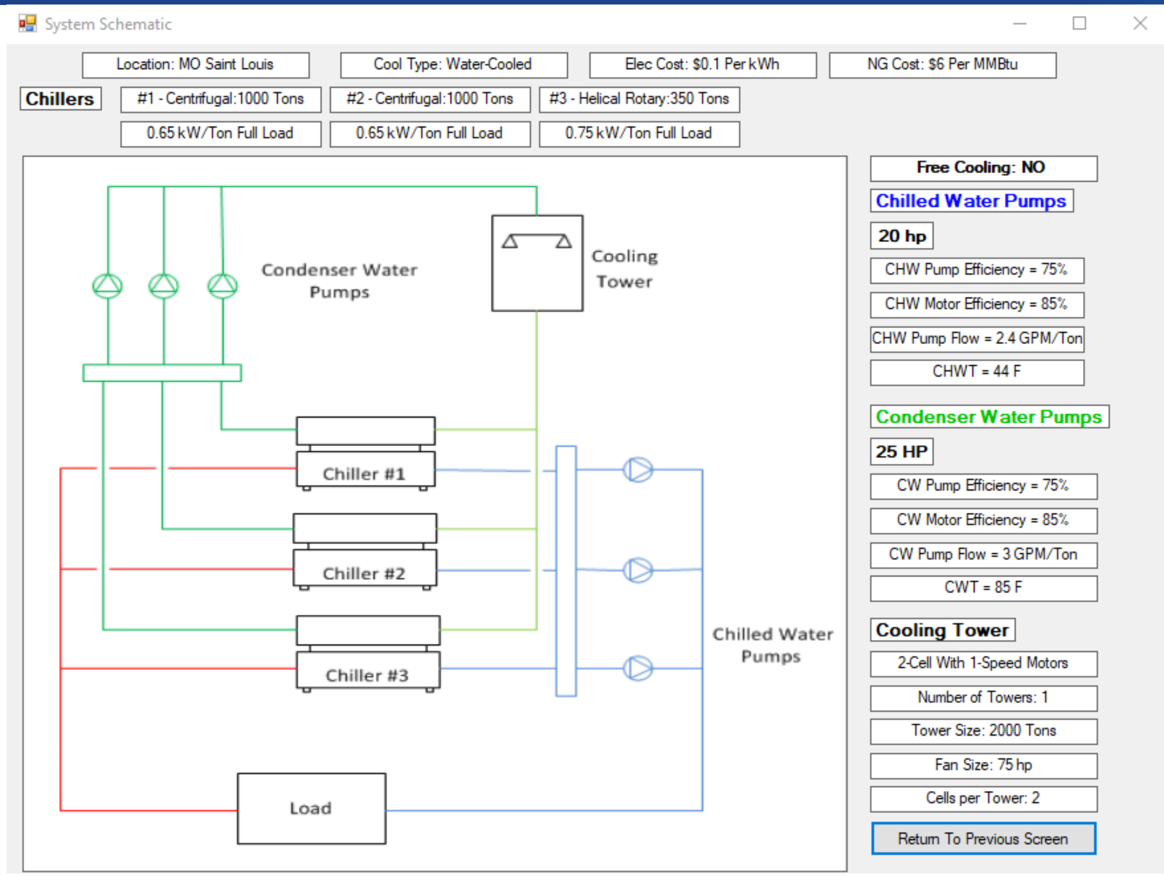
- Provide Chiller Name and it will now show up in the database

System Information



- The electricity utility rate is a very important number
- For CWSAT – a bundled cost (annual average) should be used
- For more detailed analysis, multiple bin models can be developed
- Natural gas cost can be ignored

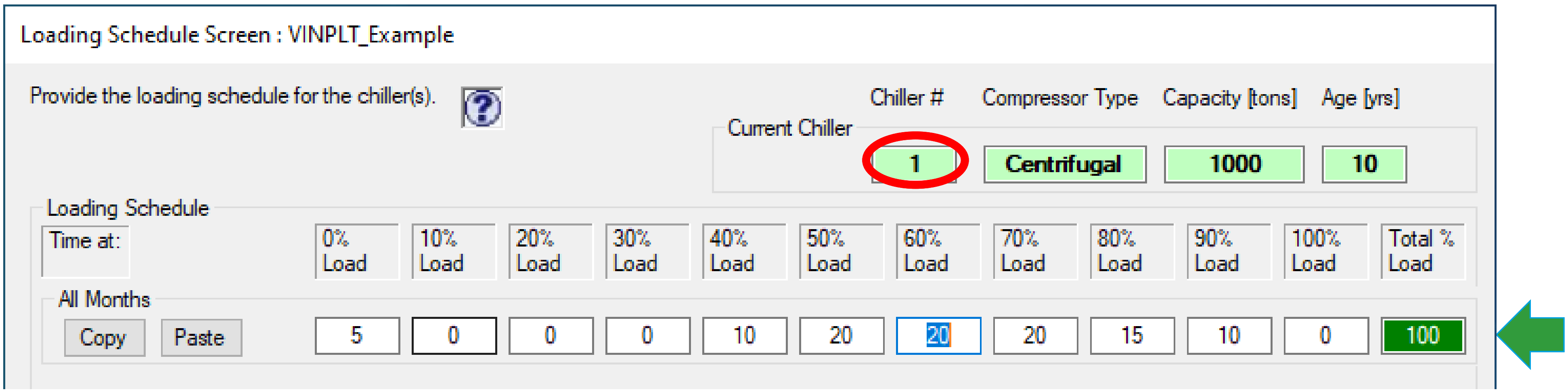
System Schematic



Review

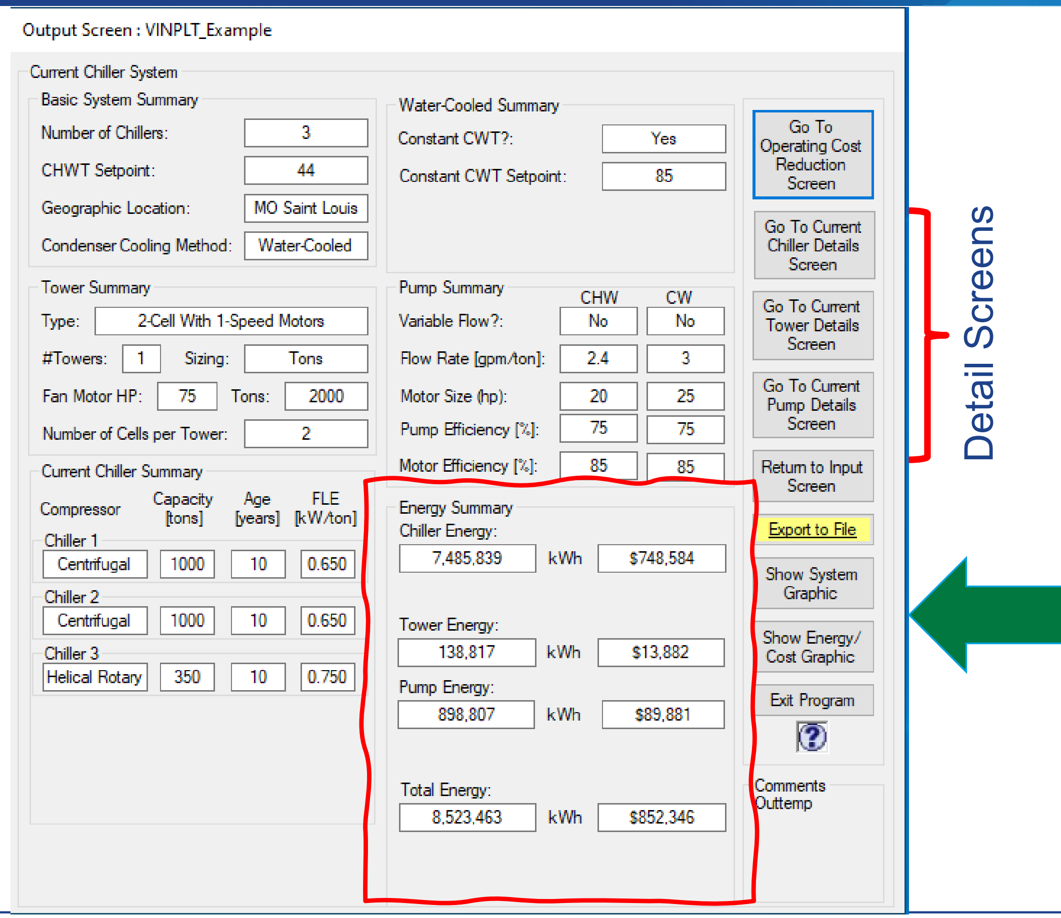
Centrifugal Chillers Load Profile

- There are 2 centrifugal chillers that are operated in a manner such that they are at similar load conditions all the time unless there is maintenance activity on one of them



Output Screen (Baseline)

- All the major inputs are shown here
- Annual energy consumption (kWh)
- Annual operating cost ($)
- System graphic
- Energy / Cost graphic



Chiller Operating Details Screen (Baseline)

Current Chiller Details Screen : VINPLT_Example.txt

Chiller 1: Centrifugal (Rated Capacity: 1000 tons)

	0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total
[kW/ton]:	0.000	0.000	0.000	0.000	0.608	0.591	0.592	0.609	0.638	0.675	0.000	
Hours:	444	0	0	0	873	1,754	1,753	1,746	1,317	873	0	8,760
Power [kW]:	0.0	0.0	0.0	0.0	243.1	295.6	355.2	426.4	510.1	607.3	0.0	
Energy [kWh]:	0	0	0	0	212,211	518,474	622,681	744,485	671,859	530,216	0	3,299,925

Chiller 2: Centrifugal (Rated Capacity: 1000 tons)

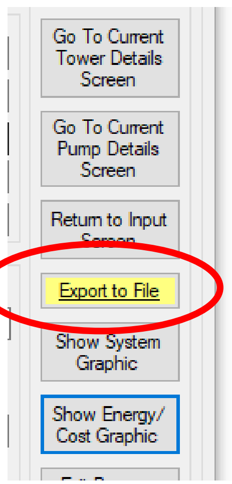
	0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total
[kW/ton]:	0.000	0.000	0.000	0.000	0.608	0.591	0.592	0.609	0.638	0.675	0.000	
Hours:	444	0	0	0	873	1,754	1,753	1,746	1,317	873	0	8,760
Power [kW]:	0.0	0.0	0.0	0.0	243.1	295.6	355.2	426.4	510.1	607.3	0.0	
Energy [kWh]:	0	0	0	0	212,211	518,474	622,681	744,485	671,859	530,216	0	3,299,925

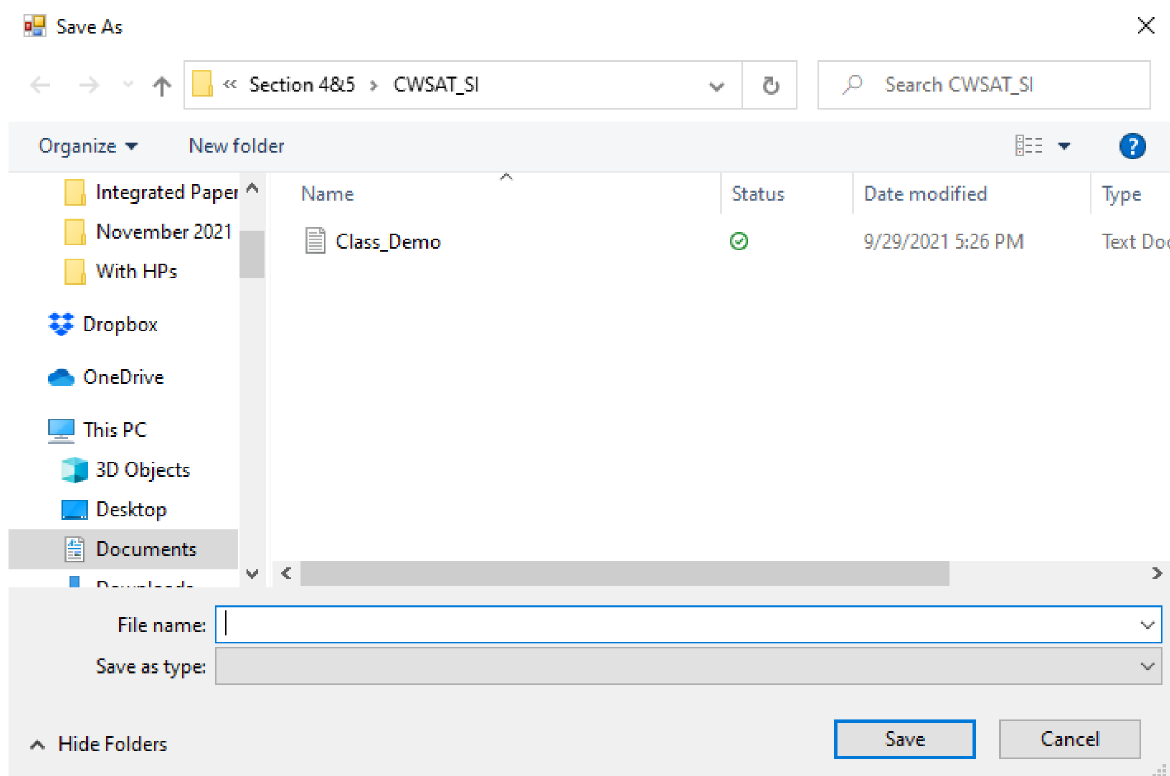
Chiller 3: Helical Rotary (Rated Capacity: 350 tons)

	0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total
[kW/ton]:	0.000	0.000	0.000	0.932	0.000	0.820	0.000	0.000	0.000	0.000	0.826	
Hours:	2,634	0	0	2,627	0	2,626	0	0	0	0	873	8,760
Power [kW]:	0.0	0.0	0.0	97.8	0.0	143.4	0.0	0.0	0.0	0.0	289.0	
Energy [kWh]:	0	0	0	257,036	0	376,682	0	0	0	0	252,271	885,988

Saving the Baseline Model file – MOST IMPORTANT!

- Output Screen





Energy Efficiency Opportunities in Chilled Water Systems

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Chiller System Optimization Objectives

- **Reducing Operating Costs**
- Improving energy efficiency of the system
- Improving overall system reliability
- Implementing operational and maintenance BestPractices
- Retrofitting with state-of-the-art controls
- Avoiding costly and unplanned shutdowns
- Enhancing product quality
- Reducing electricity- related GHG emissions

Typical Chiller Energy Management

- The current standard practice is to provide enough cooling capacity to meet the needs of the facility while minimizing ton hours
- This is achieved manually by operators or by a Building Automation System (BAS) / Energy Management System (EMS) with operator oversight

This Does Not Address the Enormous Potential Savings Opportunity of Maximizing Chiller Efficiency!

Typical Chiller Energy Management

- Modern Energy Management Systems can easily do the following:
  - Collect chiller operating data
  - Perform calculation blocks (such as kW/Ton)
  - Sequence multiple chillers with auto on and off capability
  - Control chiller and cooling tower set-points
  - Notify plant personnel when limit alarms are exceeded
  - Provide simple trending (e.g., chilled water temps, loads, etc.)
  - Basic Fault Detection and Diagnostics (FD&D)

3 Methods of Maximizing Chiller Plant Efficiency

- Preventive
  - Identify problems before they become expensive (cost avoidance)
  - Maintain optimum chiller plant efficiency
- Restorative
  - Identify heat transfer problems (i.e. off-design water flow, fouling or scaling, etc.)
  - Remove non-condensable gases
  - Maintain proper refrigerant levels
- Opportunity
  - Identify optimal chilled water set points
  - Proper chiller sequencing and load balancing
  - Proper tower basin water management
  - Peak demand management
  - Condition-based maintenance versus scheduled preventive maintenance

EXAMPLES

Examples of Energy Efficiency Opportunities (EEOs)

- Implement Entering Condenser Water Temperature (ECWT) management
- Optimize settings for Chilled Water Set-Point Temperature (ChWST)
- Eliminate refrigerant leaks
- Maintain design water flow rates in evaporator / condenser
- Remove non-condensable gases and moisture
- Reclaim refrigerant
- Insulate chilled water lines, tanks and end-users

No Cost / Low Cost EEOs

Examples of Energy Efficiency Opportunities (EEOs)

- Clean fouled and scaled evaporators
- Clean fouled and scaled condensers
- Sequence multiple chillers to optimize efficiency
- Maintain compressor isentropic efficiency
- Investigate application of VFDs to pumps and fans
- Minimize compressor surging
- Improve drive efficiency
- Eliminate inappropriate uses of chilled water

Medium Cost EEOs

Examples of Energy Efficiency Opportunities (EEOs)

- Apply VFDs to chillers
- Investigate implementation of high-efficiency chillers
  - Retrofit from air-cooled to water-cooled
- Undertake peak load management strategy
  - Thermal Energy Storage
- Install water-side economizers (free cooling)
- Evaluate process heat recovery & integration
- Implement a smart real-time chilled water plant optimizer
  - Artificial intelligence / Machine Learning based
  - Continuous commissioning

Higher Cost EEOs

Quantifying EEOs using CWSAT Software

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Chilled Water System – CWSAT

- Open CWSAT
- Load the system model file
- Review the Baseline
  - Schematic
  - Overall system energy and costs including sub-systems
- Data Validation
  - Can be done if actual energy numbers are available for the whole system and/or sub-systems
  - Aim to be within 10% of actual energy usage and costs

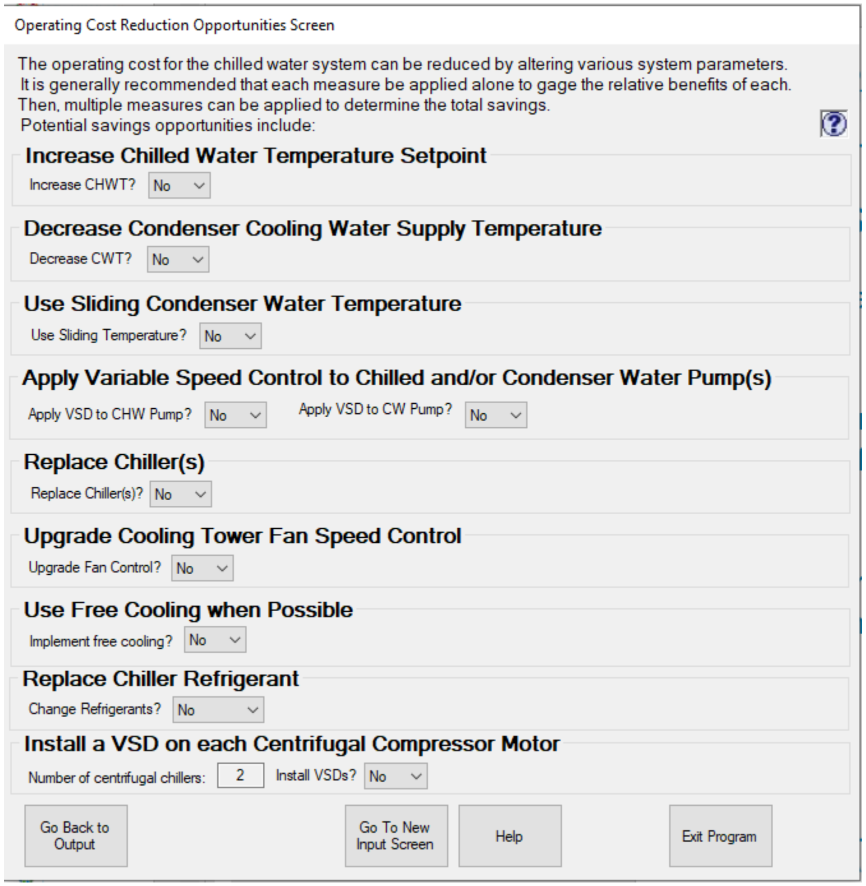
Next Steps with CWSAT Baseline Model

- Several system optimization opportunities can be modeled using a parametric “what-if” scenario configuration

- CWSAT allows for the following (“Adjusted Model” or “New Input”):
  - New Equipment Specification
    - Chillers, Towers, Pumps
  - Variable Speed Drive Installation
    - Centrifugal Chillers, Tower Fans, & Pumps
  - Various Chilled and Condenser Water Strategies
  - Air-cooled to Water-cooled system conversion
  - Using Free Cooling, when possible
  - Sequencing chillers

Operating Cost Reduction Screen

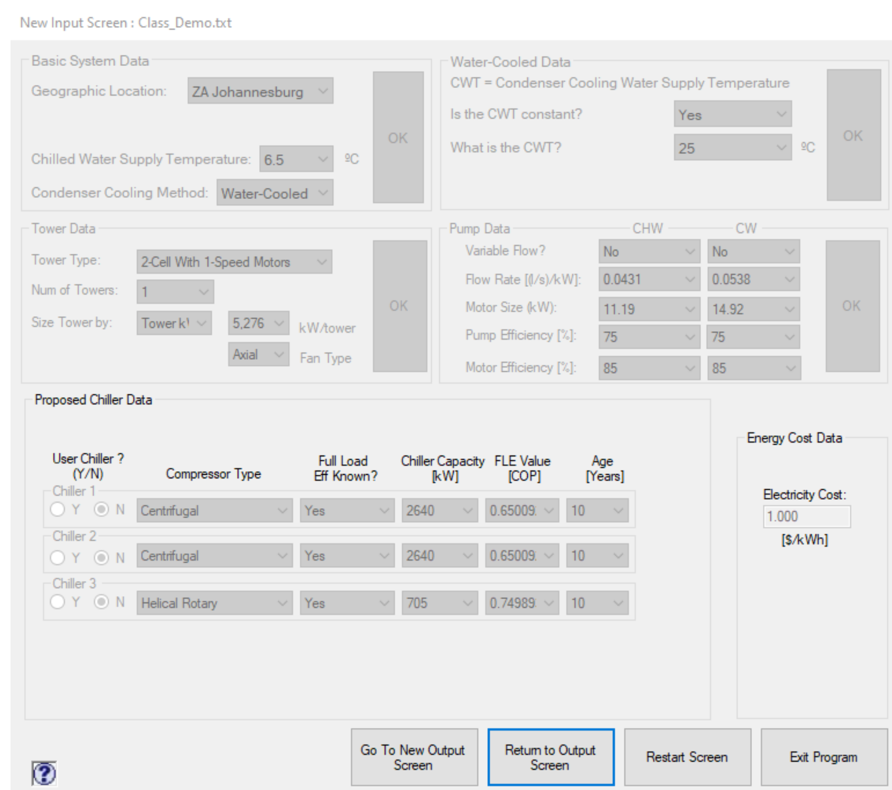
- Asks basic questions to allow the user to understand gaps
- Analyze energy conservation options simply by modifying one or more of the system inputs
- This feature allows combinatorial “What-If?” analyses



“Adjusted Model” or “New Input” Screen

- This allows the user to make very specific and targeted modifications so that the exact quantification of the energy conservation opportunities can be done

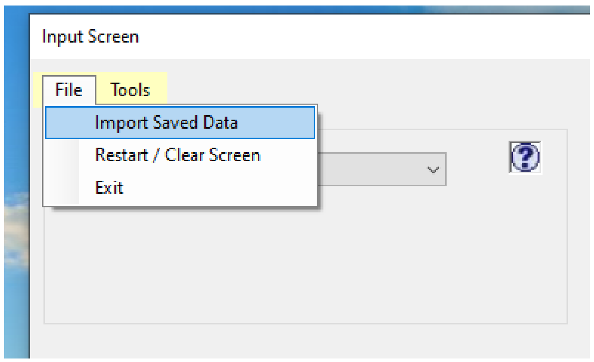
- Multiple inputs and “What-If?” scenarios can be modeled



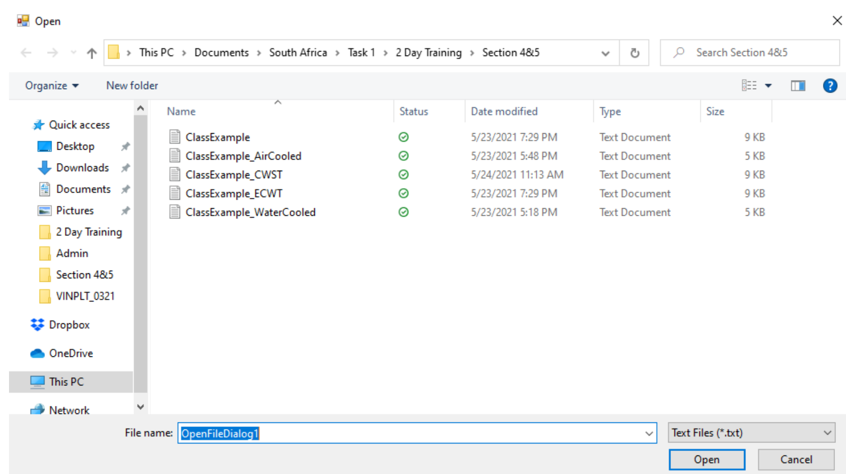
New Equipment Specification

- Within the Adjusted Model “NEW INPUT” Screen
  - Specify New Chillers
    - Optimize sizing
    - Optimize efficiency
    - Raise chilled water supply temperature
  - Specify New Cooling Tower(s)
    - Specify larger unit(s)
    - Install two-speed fans or variable speed drive-controlled fan motor(s)
    - Specify new condenser water control strategies
  - Specify New Pumps
    - Lower kW
    - Lower gpm/ton
    - Variable speed drives

Opening a SAVED file in CWSAT

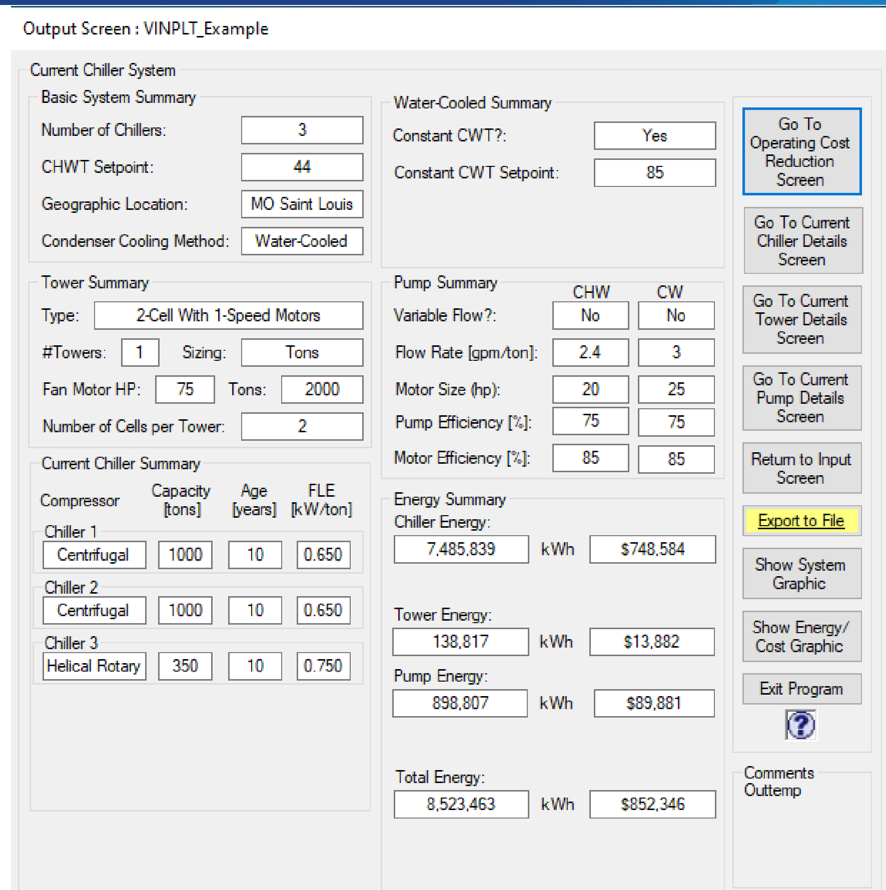


Go to the Folder, where the Example Chiller Plant file is saved and select the Text File to be opened



Output Screen (Baseline)

- All the major inputs are shown here
- Annual energy consumption (kWh)
- Annual operating cost ($)
- System graphic
- Energy / Cost graphic



Entering Condenser Water Temperature (ECWT) Management

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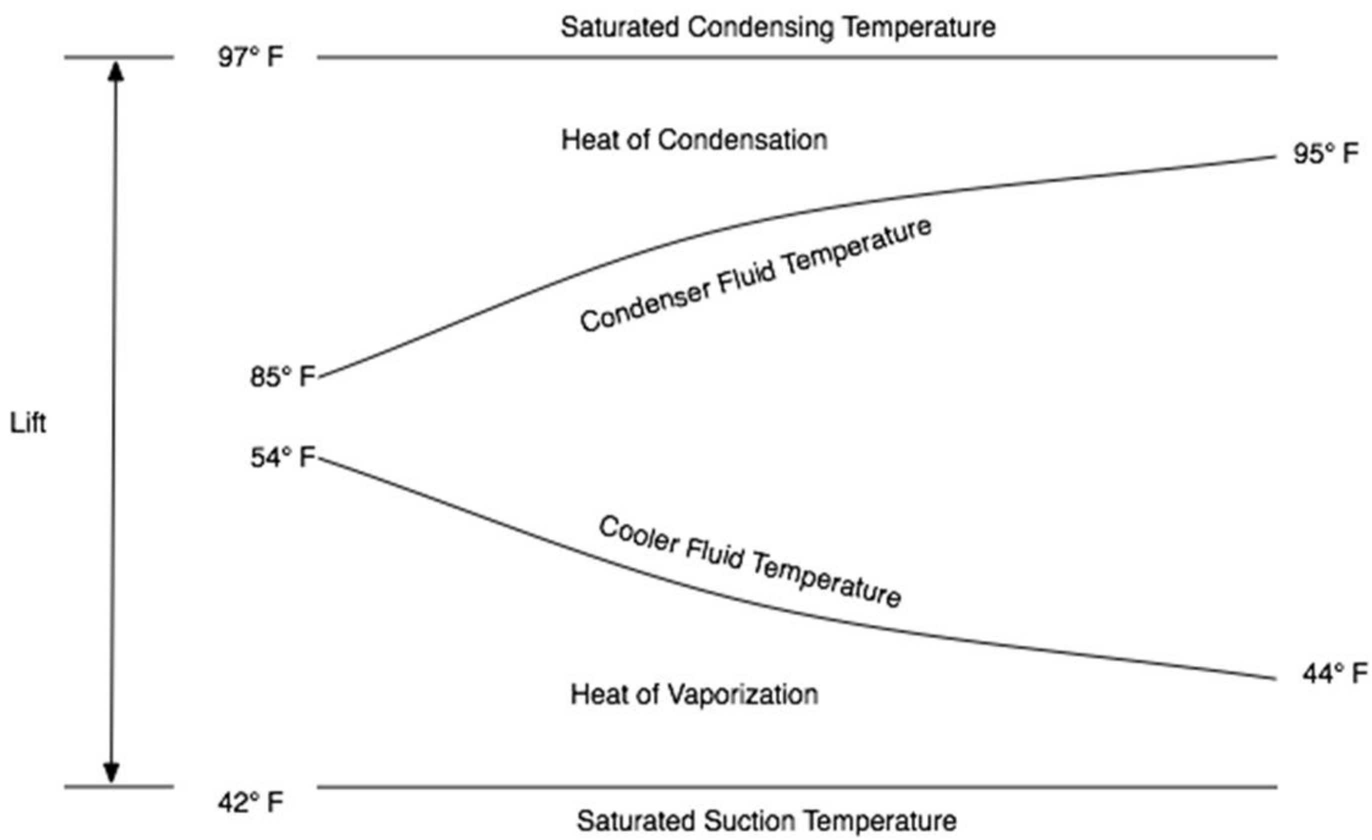
Implement ECWT Management

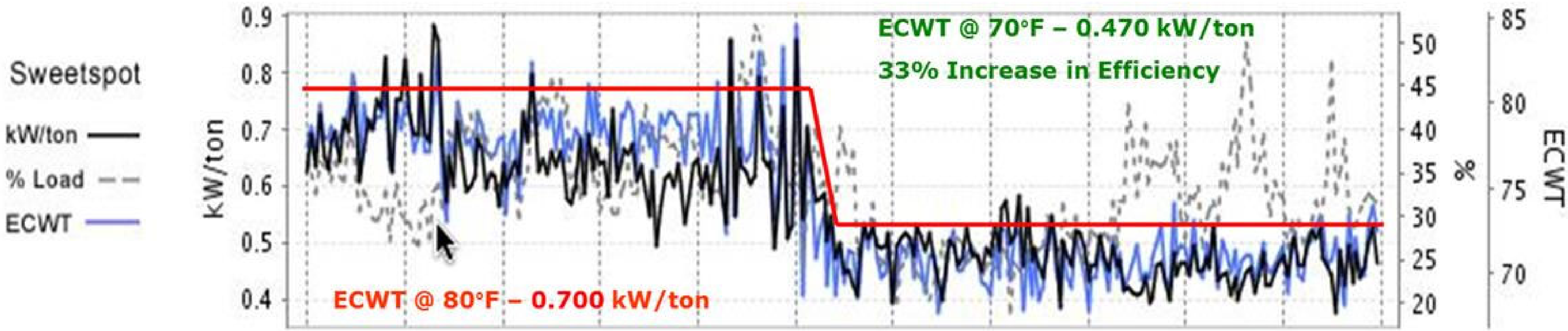
- ECWT – **E**ntering **C**ondenser **W**ater **T**emperature
- Cooling Tower Approach
  - The approach is the difference in temperature between the cooled-water temperature and the air "wet bulb temperature"
- Wet Bulb
  - Wet bulb temperature is the lowest temperature that can be reached by the evaporation of water only
  - It is determined by the atmospheric pressure, ambient temperature and relative humidity

Remember Lift!

Lift = 97 – 42 = 55°F



ECWT Management

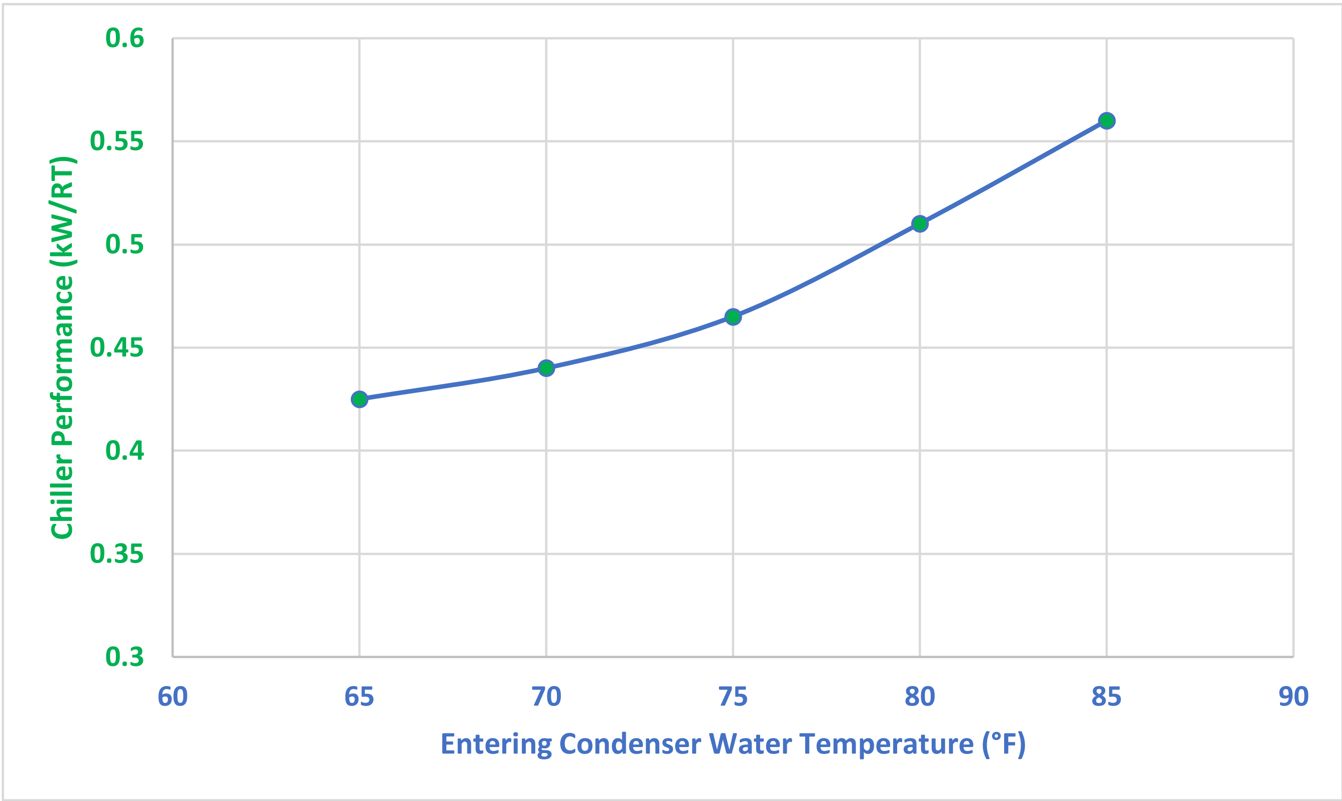


80°F ECWT drops to 70°F ECWT

kW/ton drops from 0.7 to 0.47 (33% improvement)

Questions: Can it be achieved? At what cost?

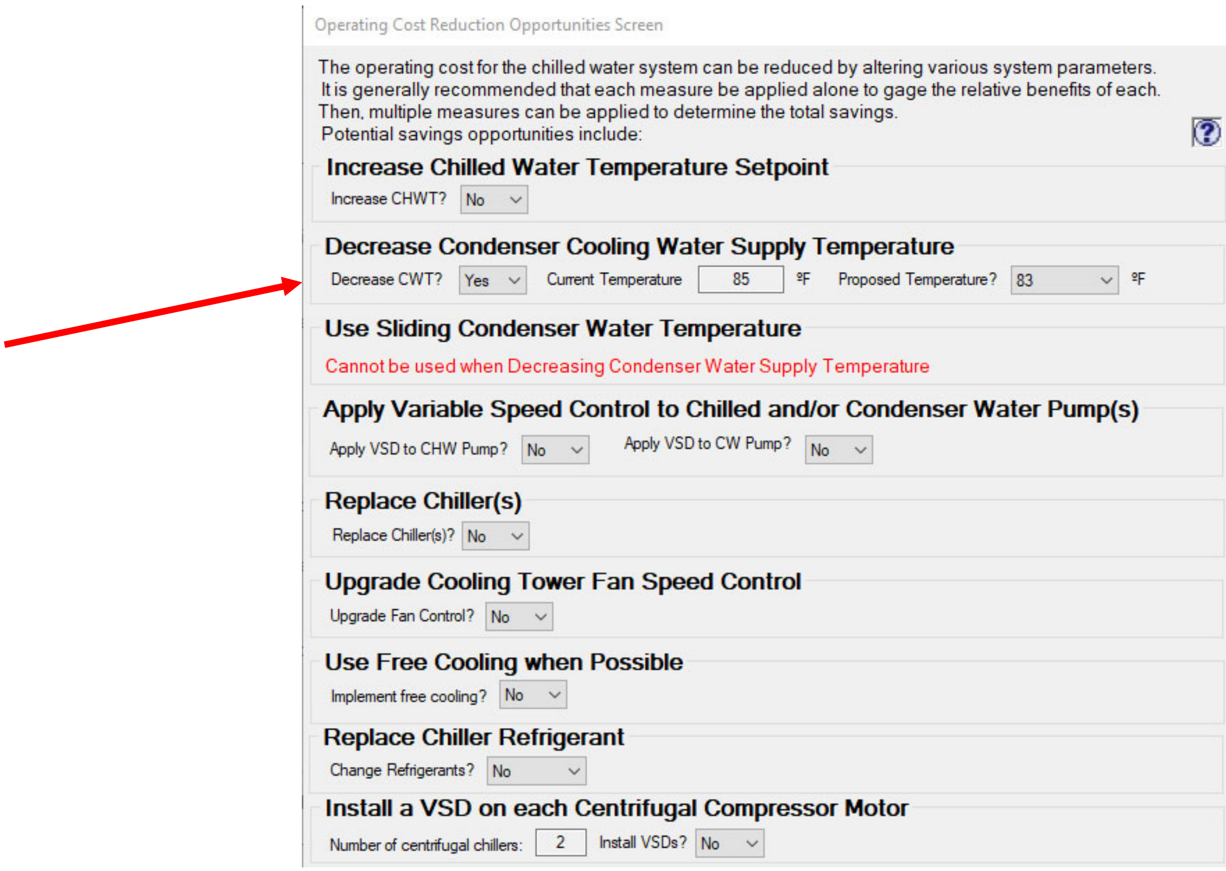
Implement ECWT Management



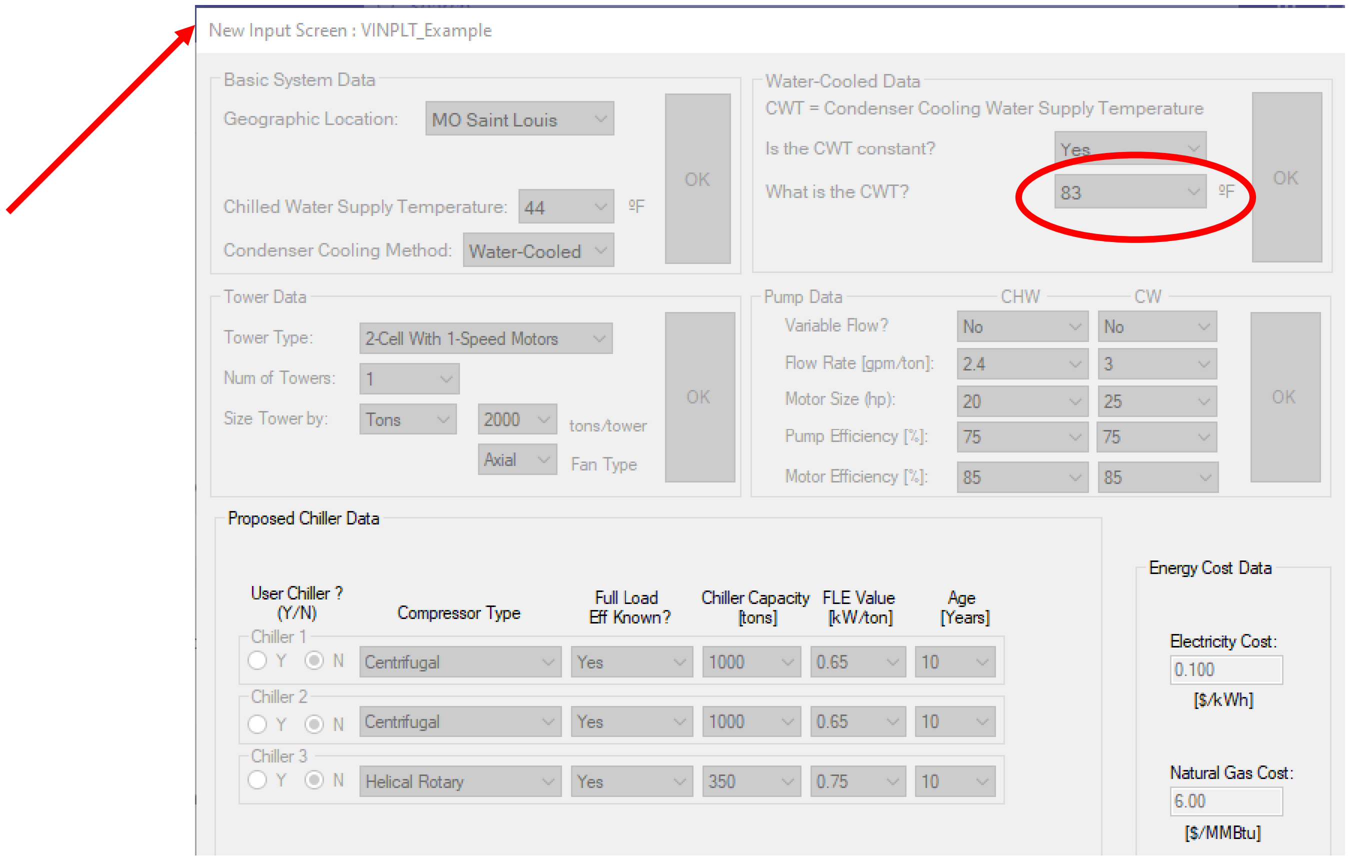
Student Exercise

- The industrial plant engineer recently completed a chilled water system audit and found that the cooling tower water supply temperature was fixed at 85°F.
- They wanted to determine if there would be a benefit to let the cooling tower water supply temperature be reduced by 2°F.
- Use the CWSAT model to determine how much system energy could be saved if the plant was able to reduce the cooling tower supply temperature by 2°F.
- Additionally, determine the energy and cost savings if the cooling tower water be allowed to float automatically based on the ambient conditions
- Discuss concerns and issues with the chosen option and what steps can be taken to mitigate them

Student Exercise (Reduce Entering Condenser Water Temperature)



Student Exercise (Reduce Entering Condenser Water Temperature)



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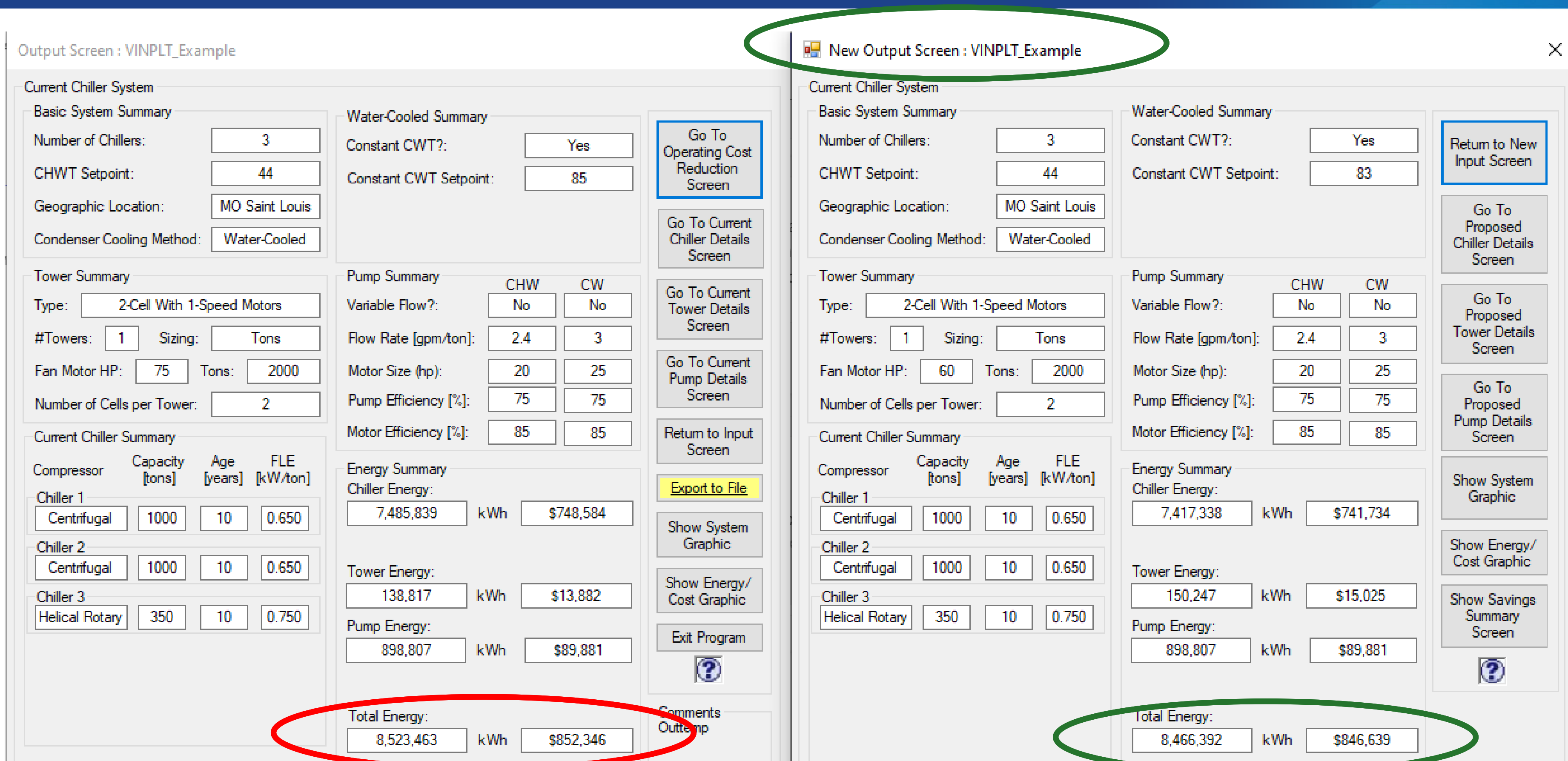
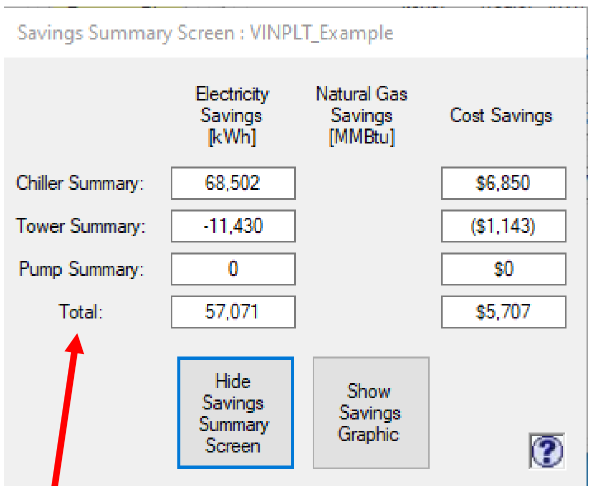


Student Exercise (Reduce Entering Condenser Water Temperature)

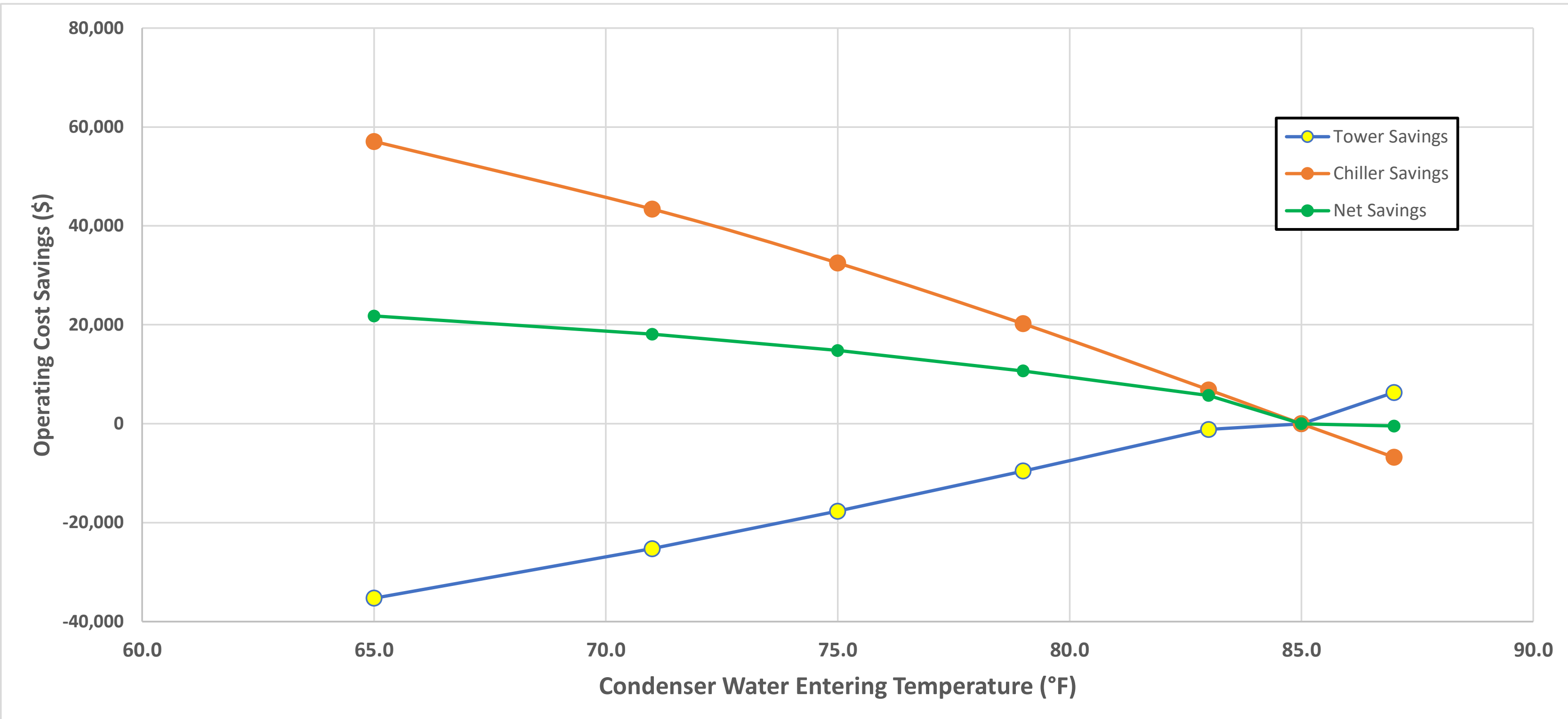


Note: Part of the chiller savings get offset by extra cooling tower operating costs

ECWT Management

- Can the plant continue to reduce the entering condenser water temperature further?
- Is there is an OPTIMUM cooling tower water temperature?
- What is the optimum temperature dependent on?
- CWSAT can be used iteratively to determine if such an optimum does exist and where

Optimal Entering Condenser Water Temperature Setpoint



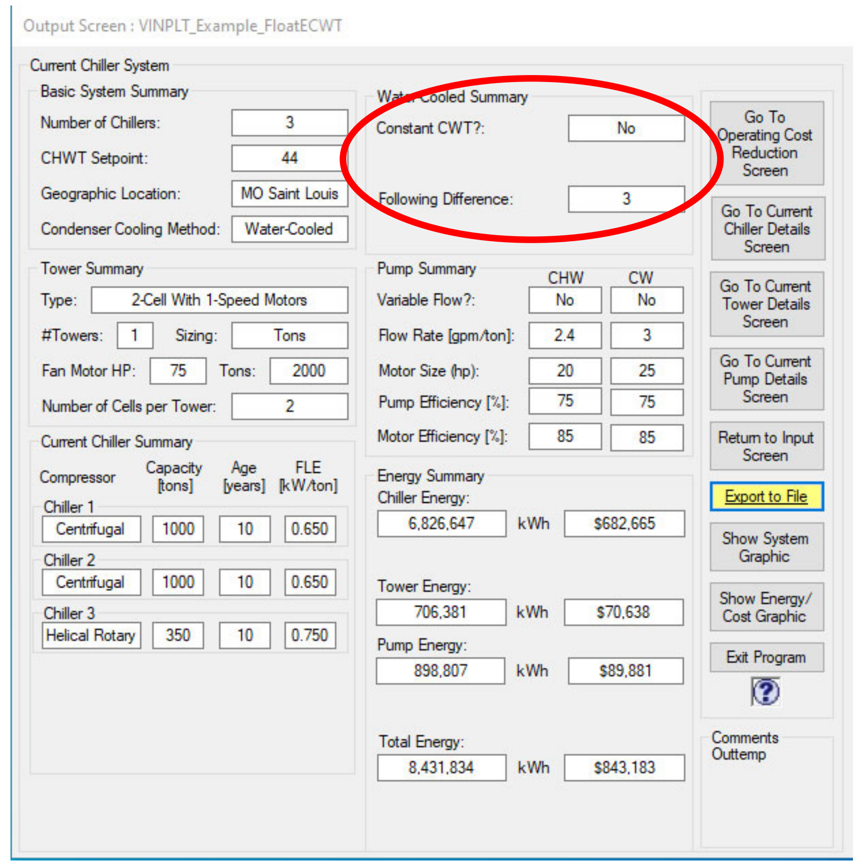
Constant Condenser Water Flow Rate; Same Load/Load Profile

ECWT Management

- Another control strategy for controlling ECWT is by managing (fixing / floating) approach to wet-bulb
  - This will automatically float the ECWT based on the ambient conditions
- Is there is an OPTIMUM approach to wet-bulb temperature?
- What factors determine this optimum approach temperature?
- CWSAT can be used iteratively to determine if such an optimum does exist and where

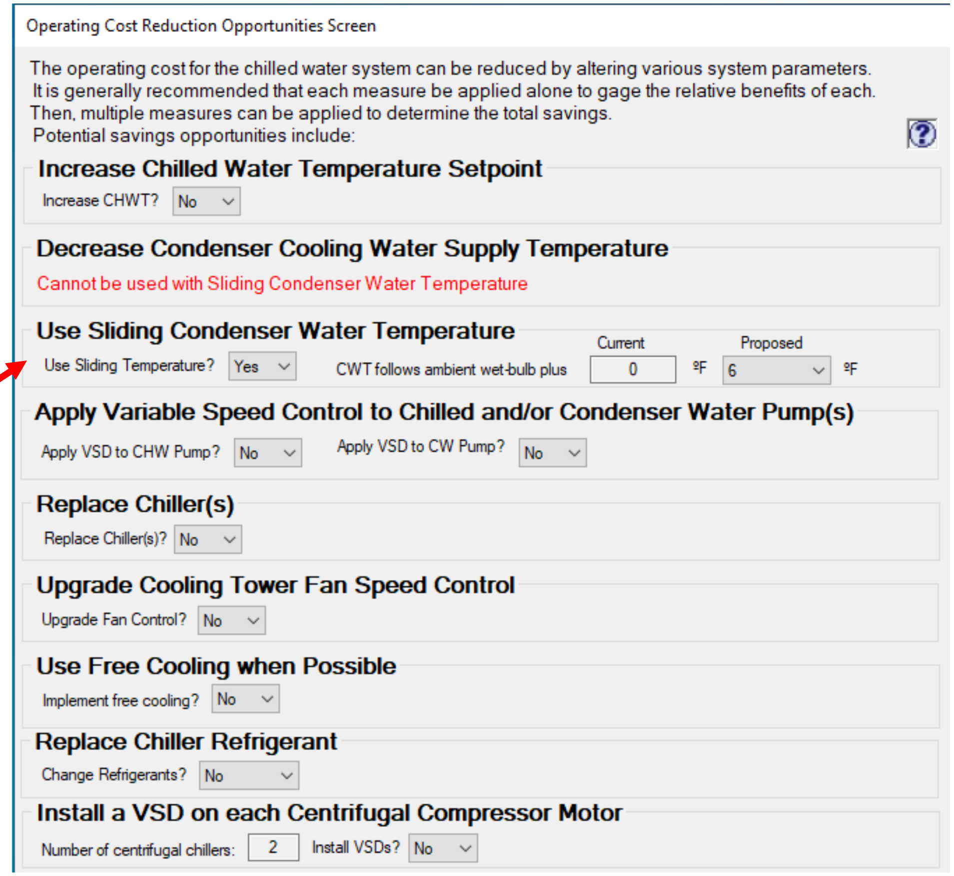
Student Exercise (Floating Entering Condenser Water Temperature)

- There are 2 separate analysis that will be required to determine the optimum
- 1st Step – comparison of fixed ECWT with varying ECWT (but with a fixed wet-bulb approach)
- 2nd Step – vary the wet-bulb approach temperature to determine optimum



Student Exercise (Floating Entering Condenser Water Temperature)

- 1st Step – comparison of fixed ECWT with varying ECWT (but with a fixed wet-bulb approach)
- Use Base Model
- Turn on "Use Sliding Condenser Water Temperature"
- Set Approach to 6°F



Student Exercise (Floating Entering Condenser Water Temperature)

Savings Summary Screen : VINPLT_Example

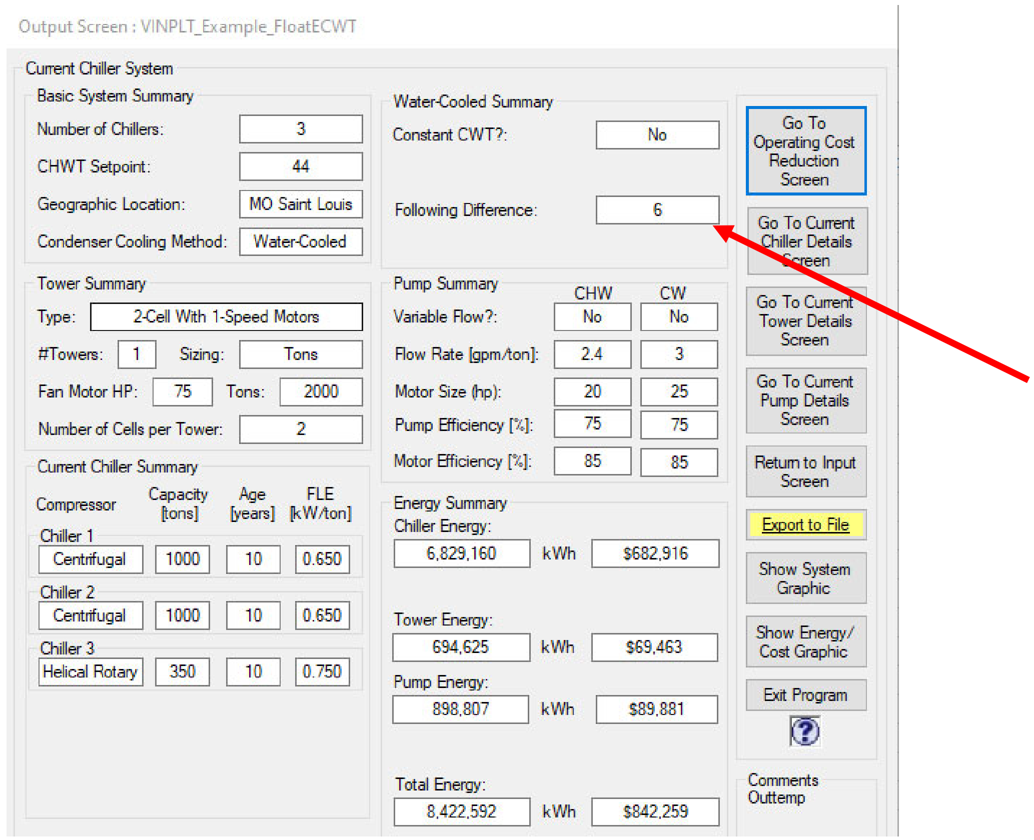
	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	656,680		$65,668
Tower Summary:	-416,882		($41,688)
Pump Summary:	0		$0
Total:	239,797		$23,980

Hide Savings Summary Screen

Show Savings Graphic

Student Exercise (Floating Condenser Water Temperature Setpoint)

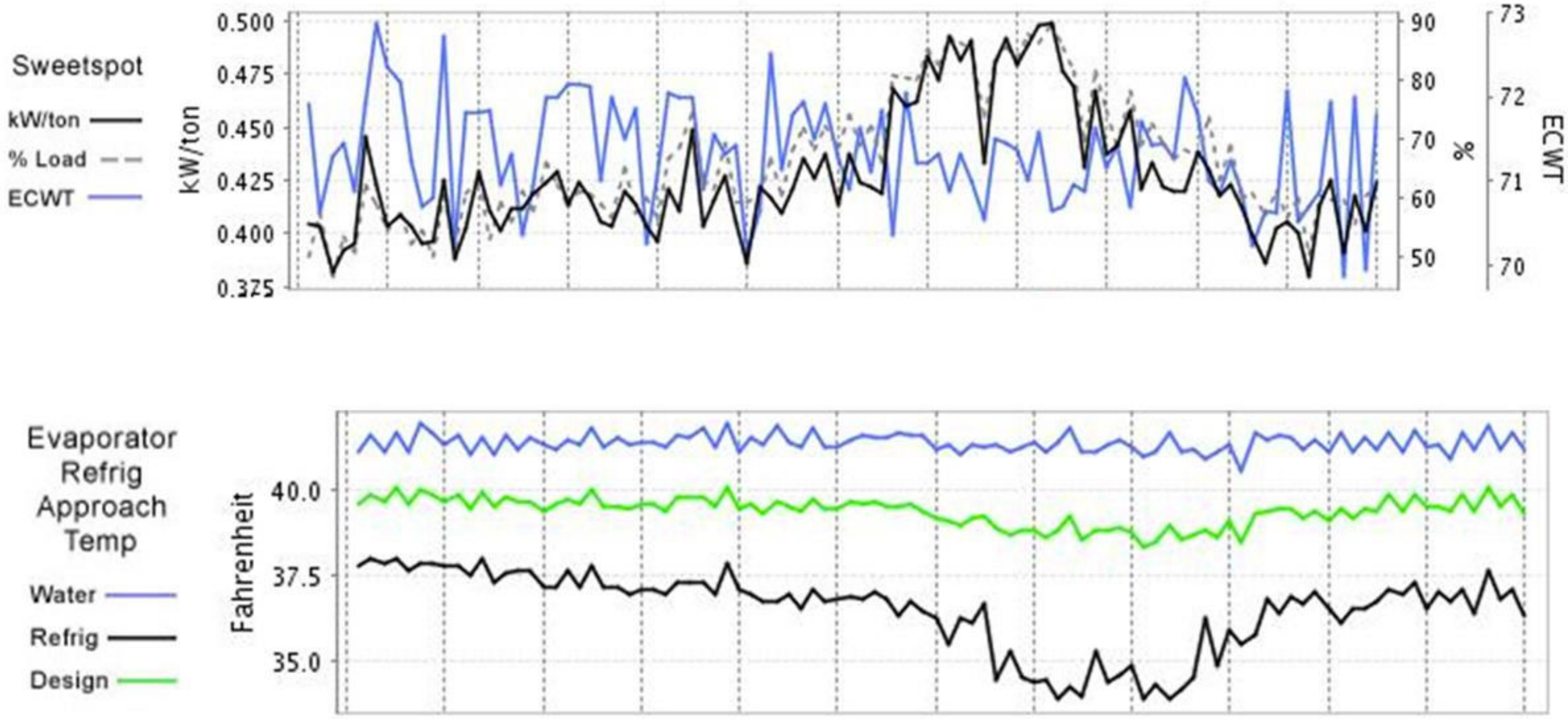
- Create a new base model with ECWT following 6°F approach to wet-bulb
- Do a parametric analysis by changing the approach to wet-bulb in the energy efficiency opportunity



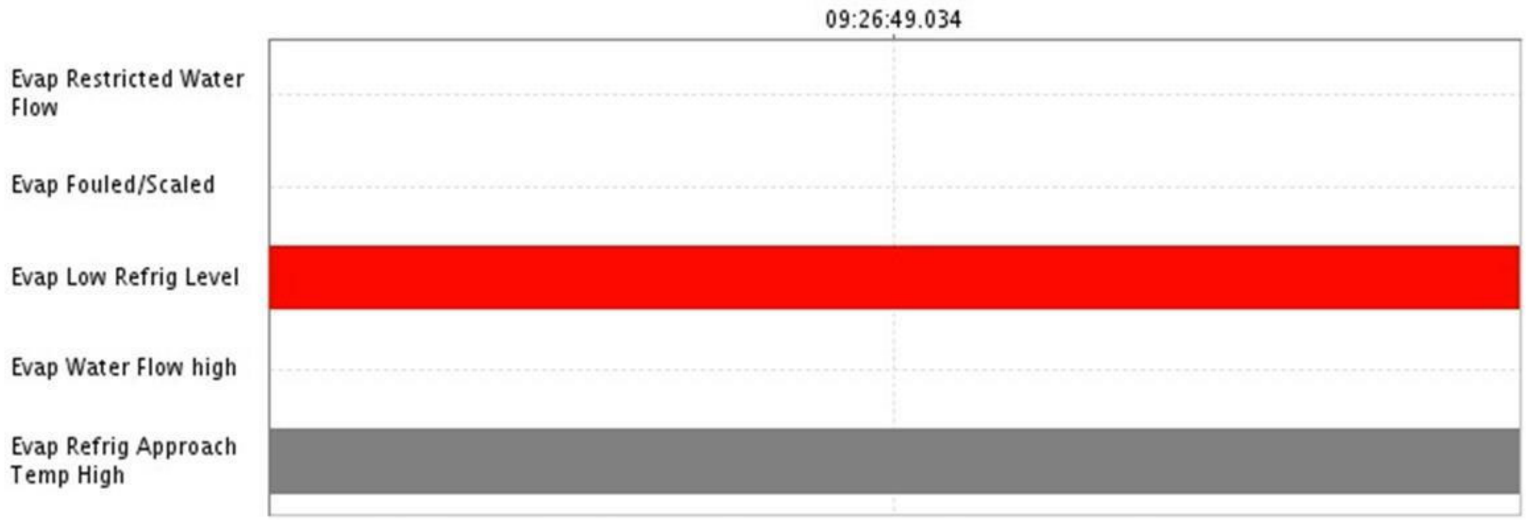
Eliminate Refrigerant Stacking

- Refrigerant stacking is an abnormal accumulation of refrigerant in the condenser
- Common causes
  - Decrease in the differential pressure or “lift” between the condenser and the evaporator
  - Reduced pressure drop prevents the refrigerant from flowing back to the evaporator to complete the refrigerant cycle
  - Too low ECWT for the part load of the chiller
- Refrigerant stacking impacts heat transfer efficiency in both the evaporator and condenser
  - Higher kW/Ton and energy costs
- Leads to reduced compressor capacity
- May Cause:
  - Chiller surging or stalling
  - Shut down on low refrigerant temperature/pressure

Refrigerant Stacking



Refrigerant Stacking



How do you eliminate stacking?

Raise ECWT

Optimizing Chilled Water Set-Point (ChWST)

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Optimize Settings for ChWST

- **ChWST** – **Ch**illed **W**ater **S**upply **T**emperature

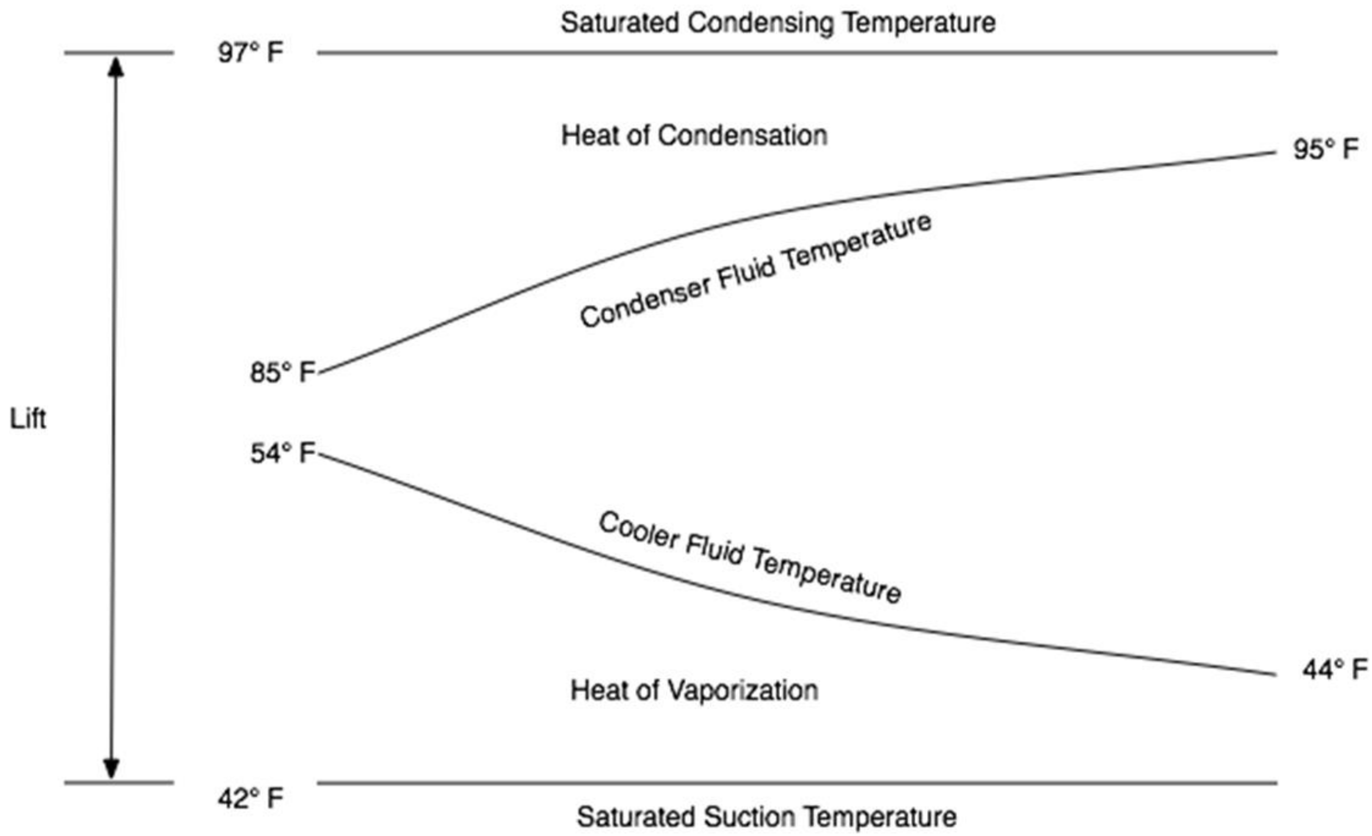
- Approach
  - The Refrigerant Approach Temperature is the difference in temperature between the chilled-water supply temperature and the refrigerant saturated temperature in the evaporator
  - It provides the driving force to transfer the heat from the water to the refrigerant

- Tell-tale signs for sub-optimal operations in chiller plants
  - Lower chilled water return temperature than design
  - High chilled water bypass flows
  - Chilled water flow control valves throttled at end-users

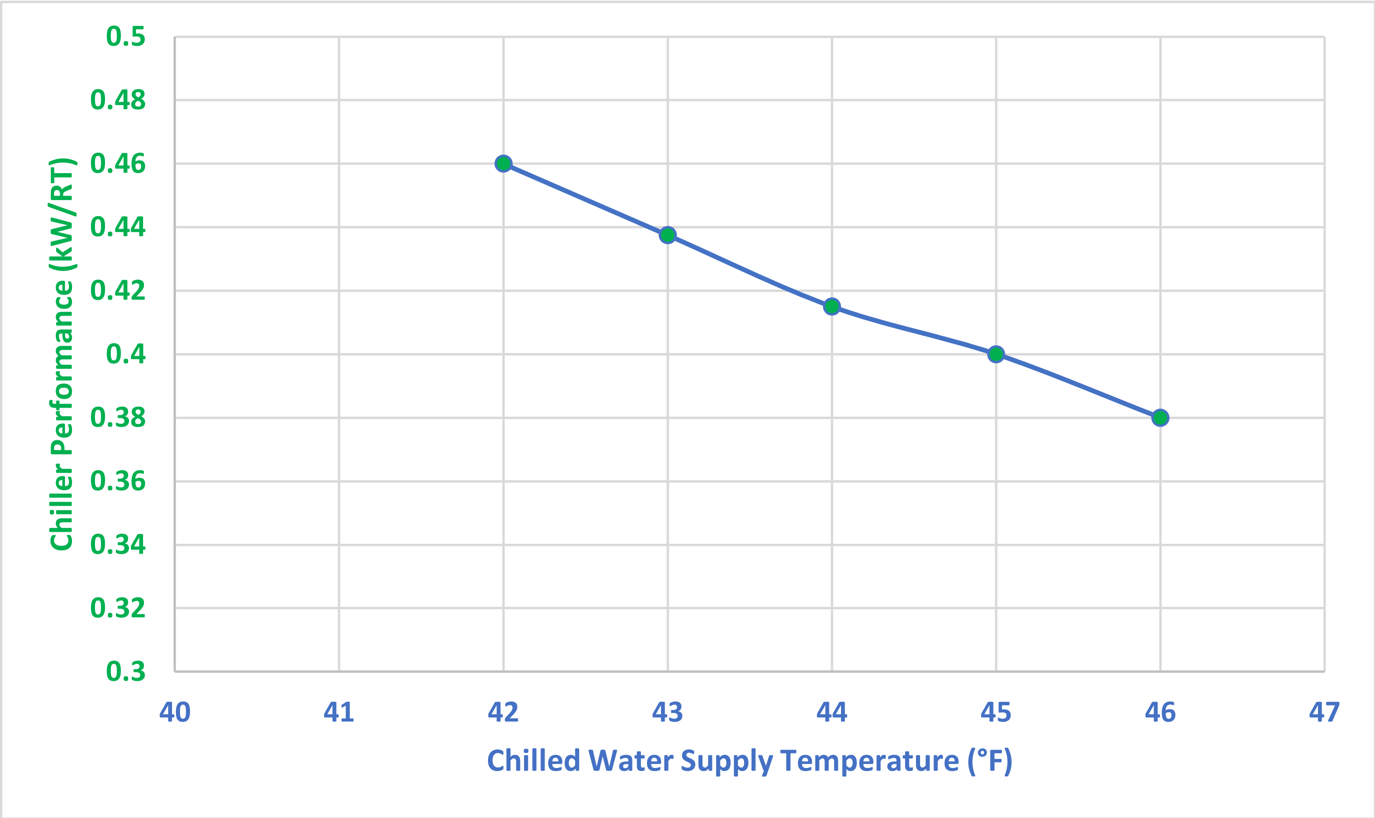
- Optimized ChWST will also allow for better load control and optimal number of chiller operation
  - Required cooling controlled by chilled water flow bypass
  - Alternate methodology – variable pumping

Remember Lift!

Lift = 97 – 42 = 55°F



Chiller Plant Efficiency and Chilled Water Set-Point



Student Exercise

- The industrial plant engineer recently completed a chilled water system audit and found that the chilled water supply temperature was fixed at 44°F.
- They wanted to determine if there would be a benefit to let the chilled water supply temperature be increased by 1°F.
- Use the CWSAT model to determine how much system energy could be saved if the plant was able to increase the chilled water supply temperature by 1°F.
- Discuss concerns and issues with the chosen option and what steps can be taken to mitigate them

Student Exercise (Increase Chilled Water Supply Temperature)

Operating Cost Reduction Opportunities Screen

The operating cost for the chilled water system can be reduced by altering various system parameters.
It is generally recommended that each measure be applied alone to gage the relative benefits of each.
Then, multiple measures can be applied to determine the total savings.
Potential savings opportunities include:

Increase Chilled Water Temperature Setpoint

Increase CHWT? Yes | Current Temperature 44 ºF | Proposed Temperature? 45 ºF

Decrease Condenser Cooling Water Supply Temperature

Decrease CWT? No

Use Sliding Condenser Water Temperature

Use Sliding Temperature? No

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)

Apply VSD to CHW Pump? No | Apply VSD to CW Pump? No

Replace Chiller(s)

Replace Chiller(s)? No

Upgrade Cooling Tower Fan Speed Control

Upgrade Fan Control? No

Use Free Cooling when Possible

Implement free cooling? No

Replace Chiller Refrigerant

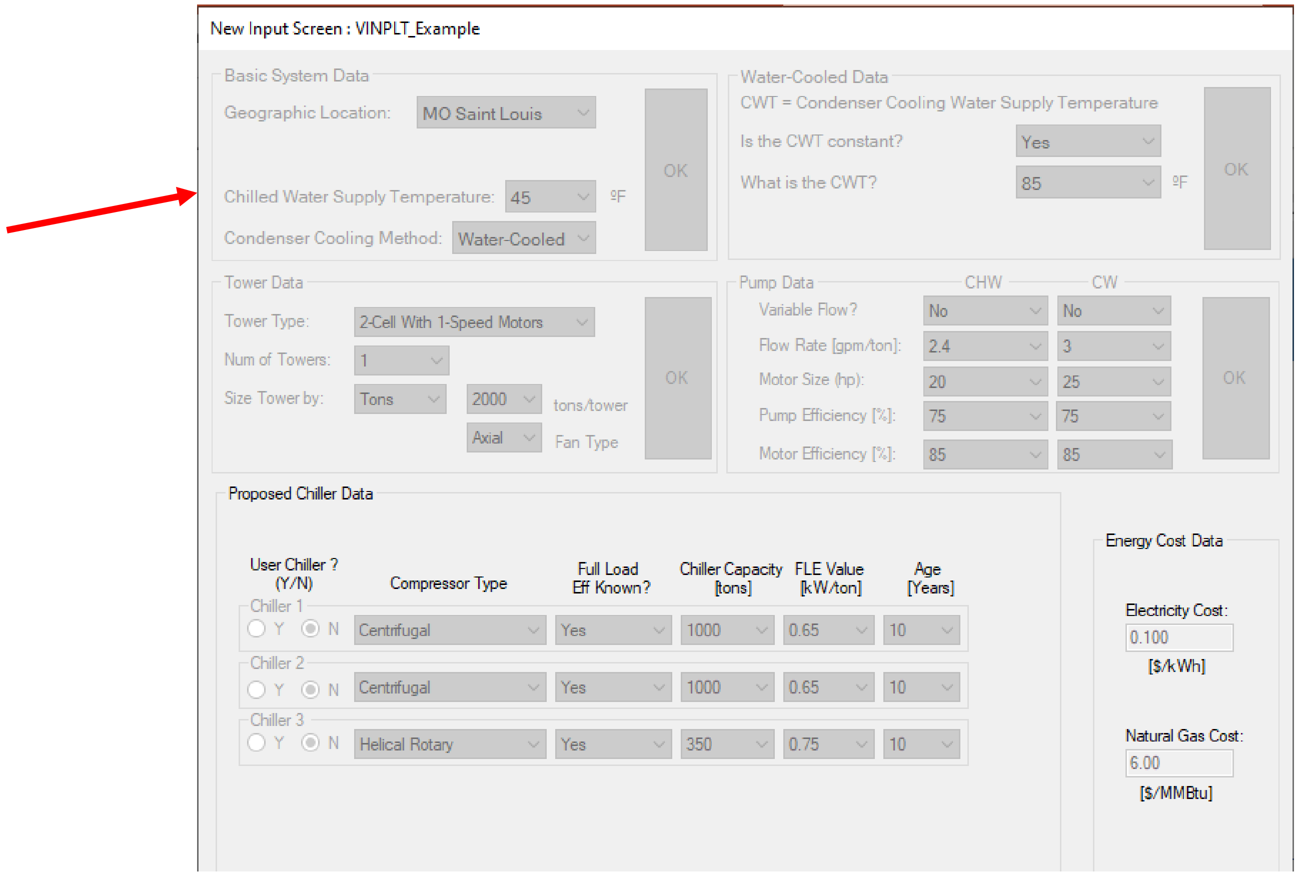
Change Refrigerants? No

Install a VSD on each Centrifugal Compressor Motor

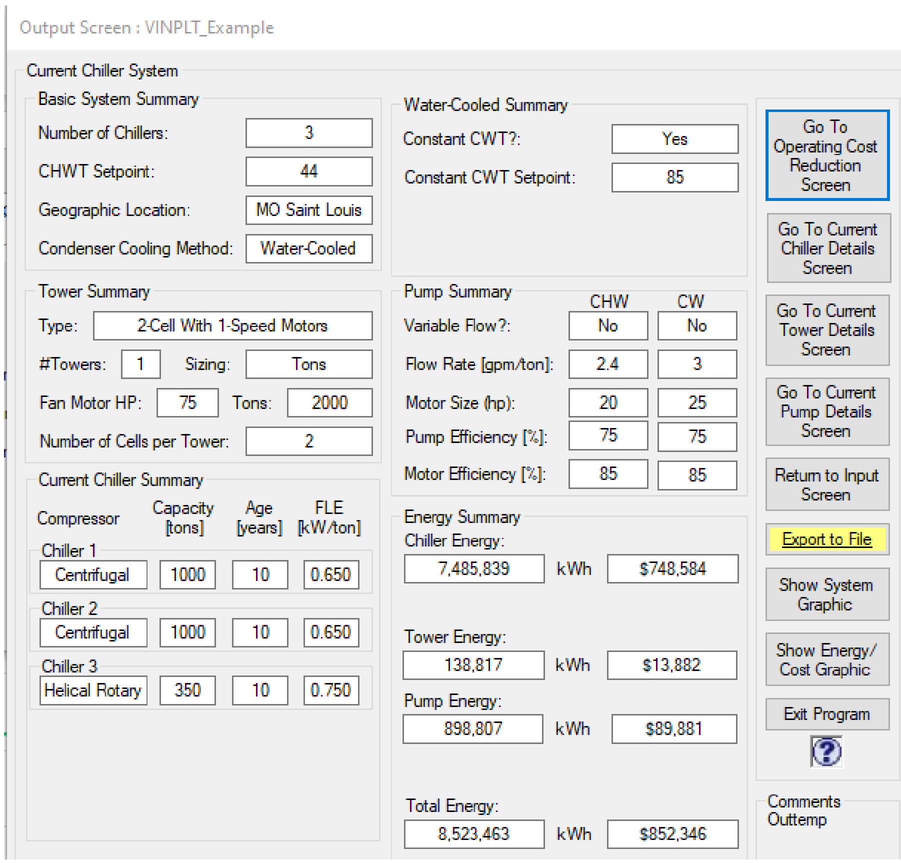
Number of centrifugal chillers: 2 | Install VSDs? No

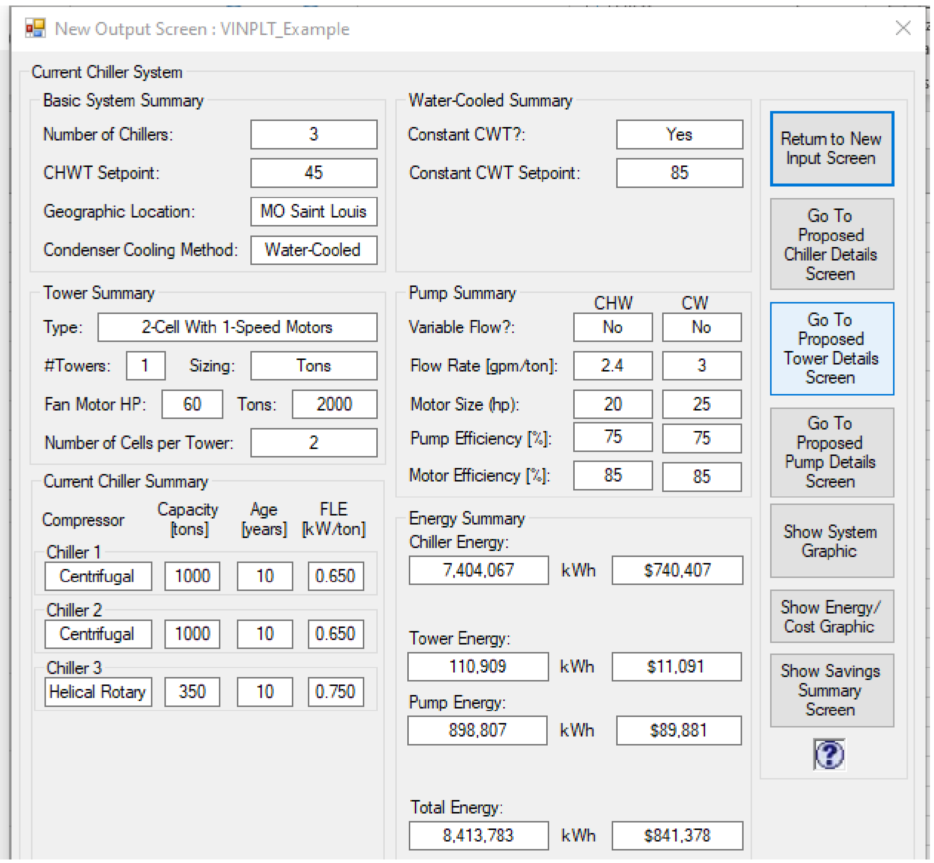
NOTE: This opportunity does not change the chilled water flow rate

Student Exercise (Increase Chilled Water Supply Temperature)



Student Exercise (Increase Chilled Water Supply Temperature)





Student Exercise (Increase Chilled Water Supply Temperature)

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	81,773		$8,177
Tower Summary:	27,907		$2,791
Pump Summary:	0		$0
Total:	109,680		$10,968

Savings on both – Chiller & Tower

Combinatorial Savings

- As the chilled water supply temperature setpoint is increased
  - The Lift reduces
  - This reduces the work done by the compressor implying a lower kW/RT
  - This results in direct chiller savings
  - The heat rejected by the condenser is the sum of the evaporator load (which is the same) and the compressor work (which has reduced)
  - So the heat rejected by the condenser reduces
  - This reduces the cooling tower fan energy

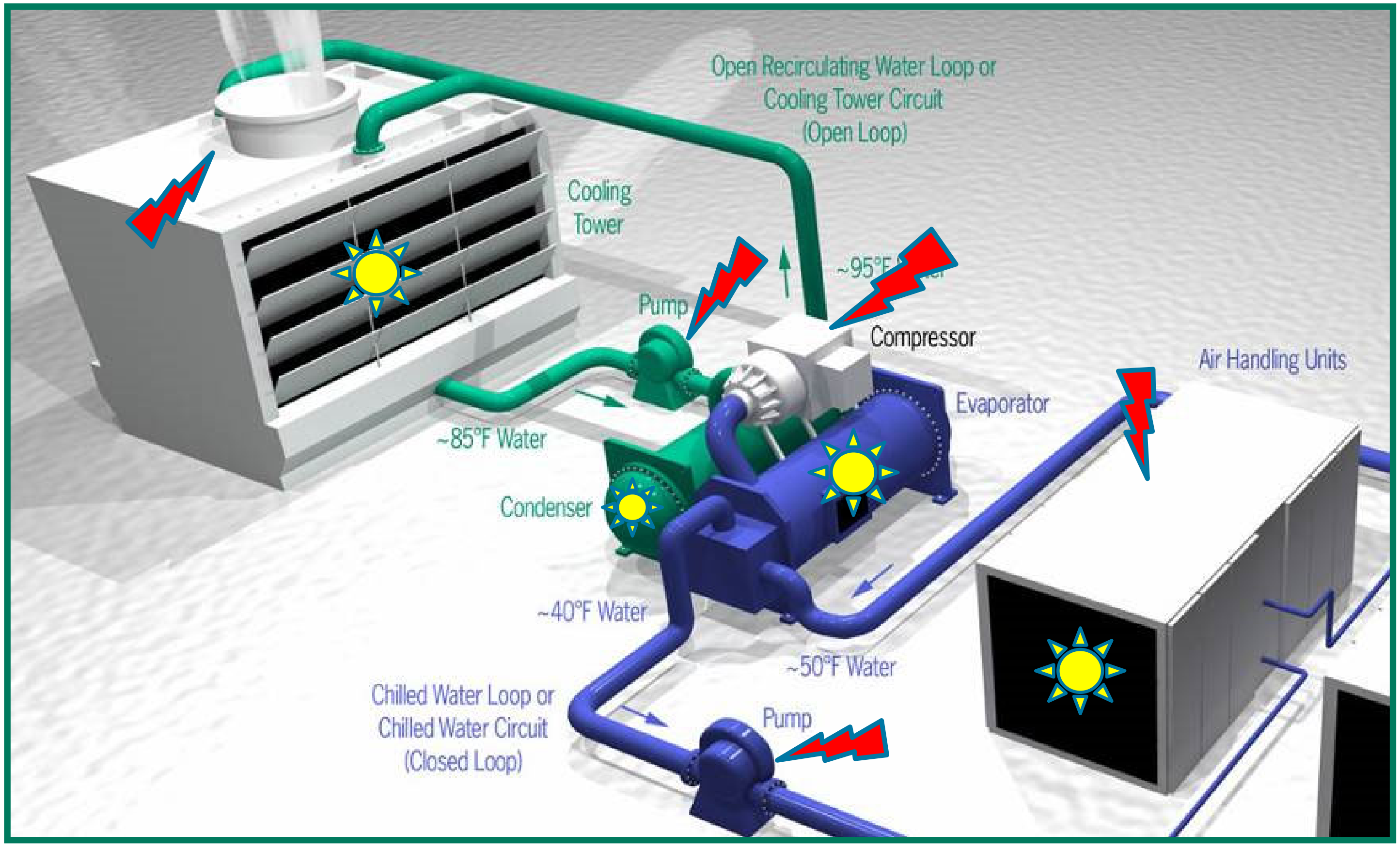
- Hence, the savings are combinatorial and higher the chilled water supply temperature, higher the savings – <u>if the chilled water flow remains constant</u>

A Simple Chilled Water System

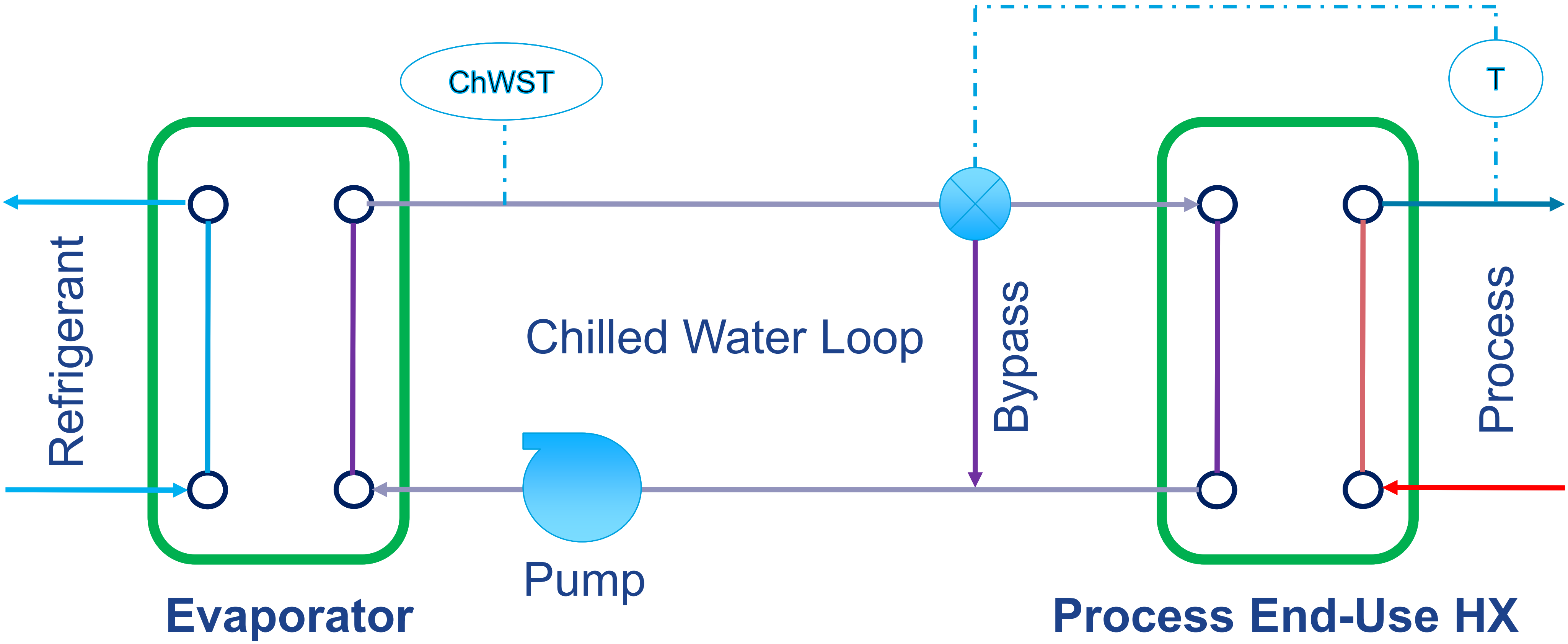
Electrical

Nexus

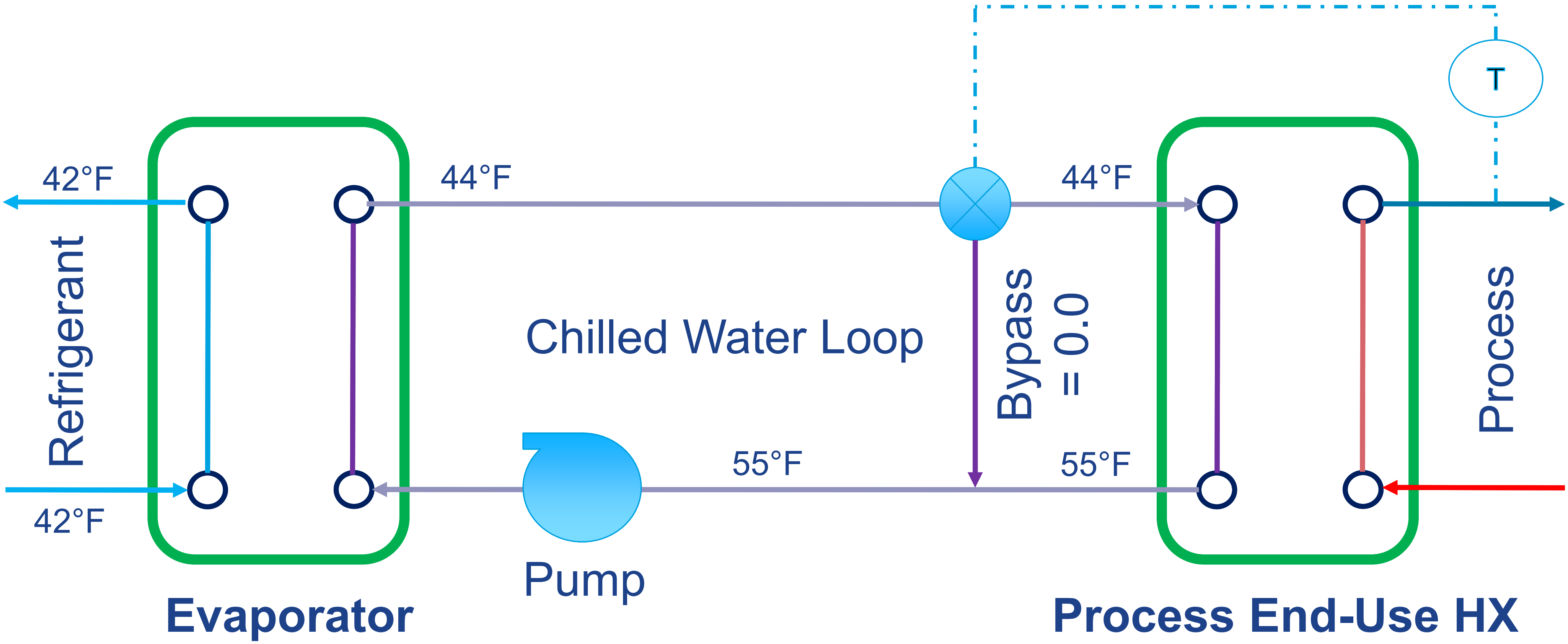
Thermal



Simplified Chilled Water Loop (Constant Speed Pump)



Simplified Chilled Water Loop (Constant Speed Pump)



Simplified Chilled Water Loop (Constant Speed Pump)

- Normal (Design) Operation
  - Bypass flow = 0
  - Process end use cooling demand = 100 RT
  - Chilled water flow through HX = 240 gpm
  - Chilled water supply temperature = 44°F
  - Chilled water return temperature = 55°F
  - Evaporator refrigerant saturation temperature = 42°F
  - LMTD on the evaporator = 5.88°F
  - Qevap = UA*LMTD
  - UAevap = Qevap / LMTD = 17.01 RT/°F

$$\text{LMTD} = \frac{(Tout - Tsat) - (Tin - Tsat)}{\ln\frac{(Tout - Tsat)}{(Tin - Tsat)}}$$

Easy Tell-tale Signs to Raise ChWST

- An inline valve – typically, at chilled water pump discharge – is throttled
  - Chilled water flow is being restricted
  - Pump may not be designed properly
  - The end-use HX may not be designed correctly for full design flow

- Opportunity to raise ChWST and increase flow in the loop

- Opportunity to use VFD on pump and also raise ChWST

Easy Tell-tale Signs to Raise ChWST

- The Bypass flow is significant (> 20%)
  - Flow to the process end-use HX is less than 80% of the chilled water supply flow
  - Pump may not be designed properly
  - The end-use HX may not be designed correctly for the full design flow
  - The end-use HX has significant more area than required for the process heat duty
  - Process end-use demand is LOWER than design
- Opportunity to raise ChWST and increase flow in the end-use HX
- Opportunity to raise ChWST and may be to use VFD on pump

Impact of Optimizing ECWT & ChWST

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Modeling Multiple EEOs in CWSAT

- CWSAT has the ability to model combinatorial impacts of multiple energy efficiency opportunities (EEOs)
  - Allows the user to NOT double-count
  - Avoids pitfalls where one EEO may negate or offset another EEO
- While doing an overall analysis model CWSAT with all the EEOs together
- For each specific project and to determine priority in EEOs based on budget constraints, schedules and return on investments – also model each opportunity in CWSAT individually

Individual EEO Results

- Reduce ECWT by 2°F

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	68,502		$6,850
Tower Summary:	-11,430		($1,143)
Pump Summary:	0		$0
Total:	57,071		$5,707

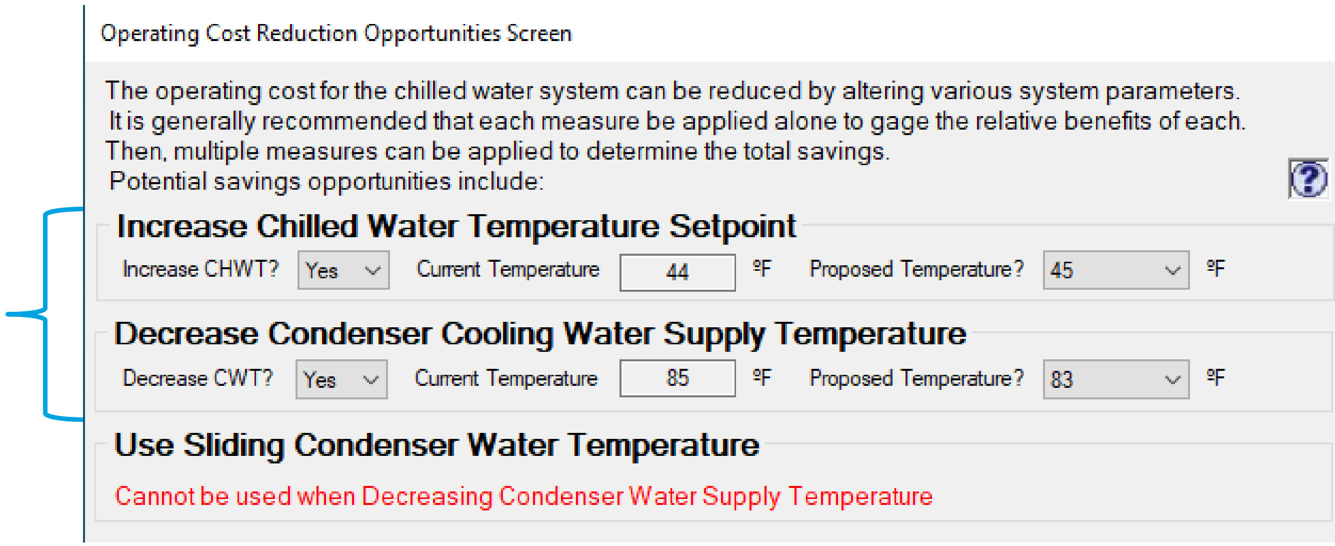
- Increase ChWST by 1°F

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	81,773		$8,177
Tower Summary:	27,907		$2,791
Pump Summary:	0		$0
Total:	109,680		$10,968

Total Savings: $16,675

Modeling both the EEOs together in CWSAT

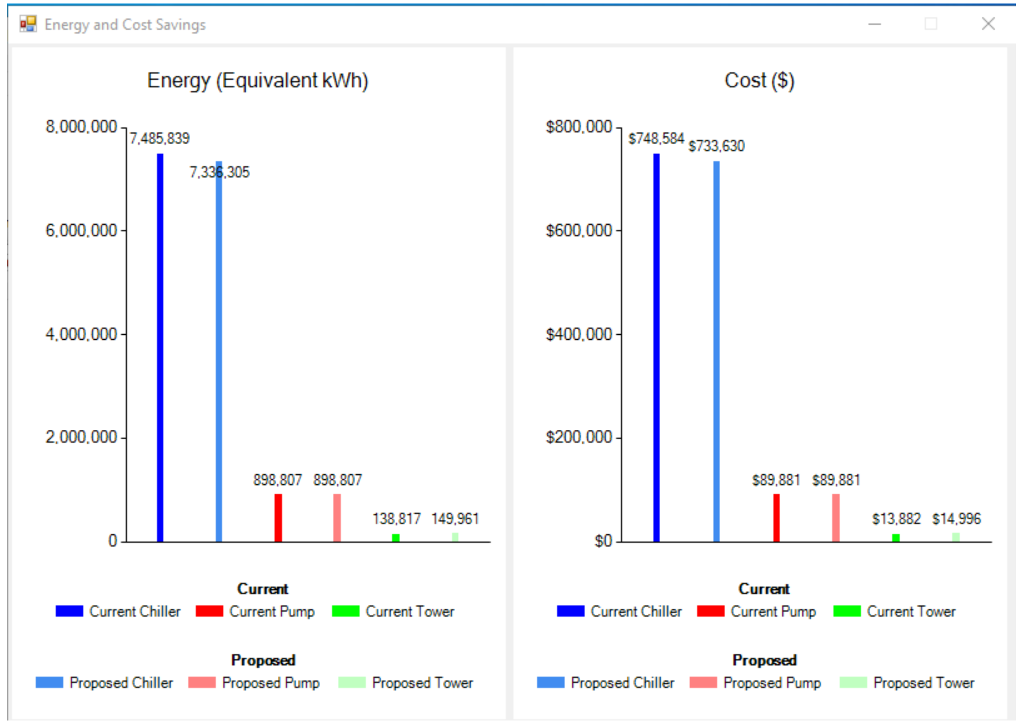


- One word of caution – It is always best to start CWSAT from the base model whenever modeling EEOs
  - It avoids leaving past evaluated projects ON in error

Modeling both the EEOs together in CWSAT

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	149,535		$14,953
Tower Summary:	-11,144		($1,114)
Pump Summary:	0		$0
Total:	138,390		$13,839



NOTE: Savings less than sum of individual EEOs

Why do the Savings NOT Match

- EEO savings may not be additive
  - Savings may not be linear when comparing them with Lift
- Chiller performance curves (kW/RT) are not linear when comparing them with changes in Lift
- The distribution of load, operation of cooling tower fan can all play a very significant role
- The higher the confidence level in the base model results, chiller performance curves – higher the fidelity of the CWSAT EEOs results

Applying VFDs to Pumps

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Application of Variable Frequency Drives to Pumps

- VFD pumps can play a very important role in reducing total system energy consumption

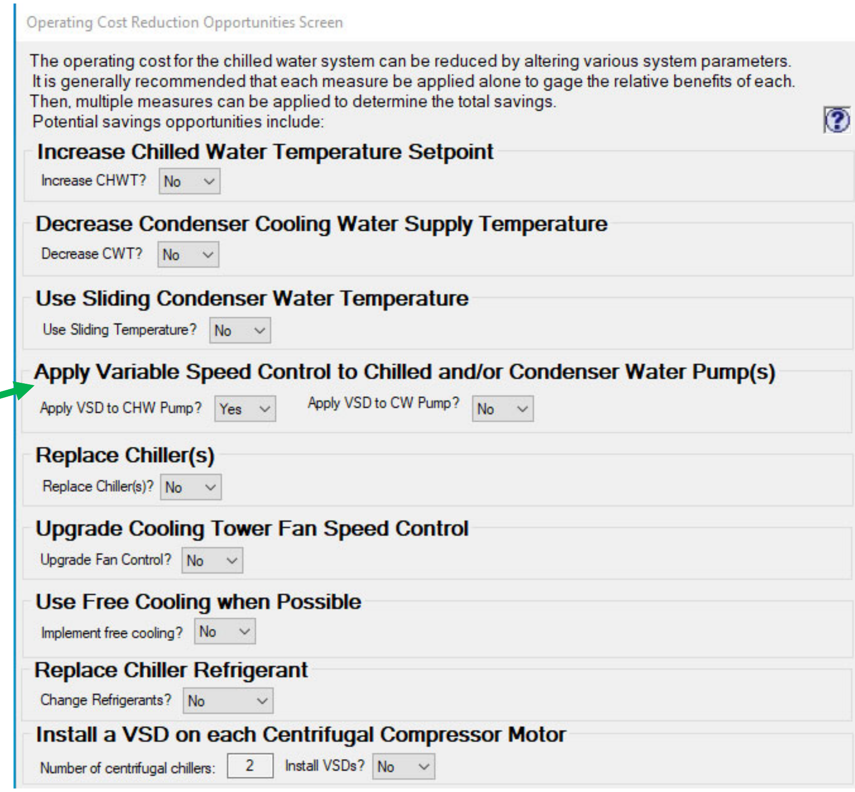
- The centrifugal pump follows the cube law
  - Flow $\propto$ Speed
  - Power $\propto$ Speed^3

- The example chilled water central plant facility
  - Primary chilled water pumps
  - Secondary chilled water pumps
  - Condenser water (cooling tower) pumps

Modeling Application of VFDs to Pumps in CWSAT

- Remember – CWSAT models primary chilled water loop ONLY

- Model the VFD pumps application individually
  - Chilled water
  - Condenser water



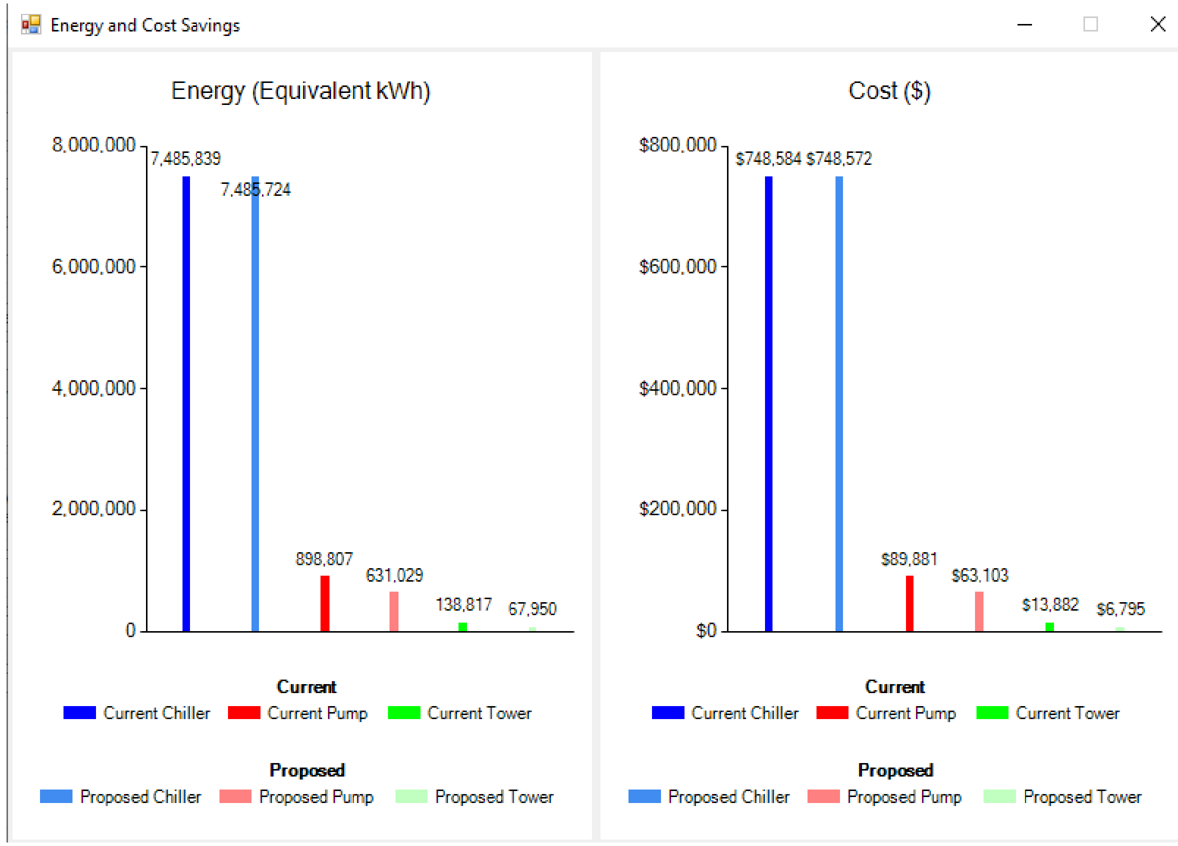
Modeling Application of VFDs to CW Pumps in CWSAT

Pump Summary

	CHW	CW
Variable Flow?:	No	Yes
Flow Rate [gpm/ton]:	2.4	3
Motor Size (hp):	20	25
Pump Efficiency [%]:	75	75
Motor Efficiency [%]:	85	85

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	115		$12
Tower Summary:	70,867		$7,087
Pump Summary:	267,778		$26,778
Total:	338,760		$33,876



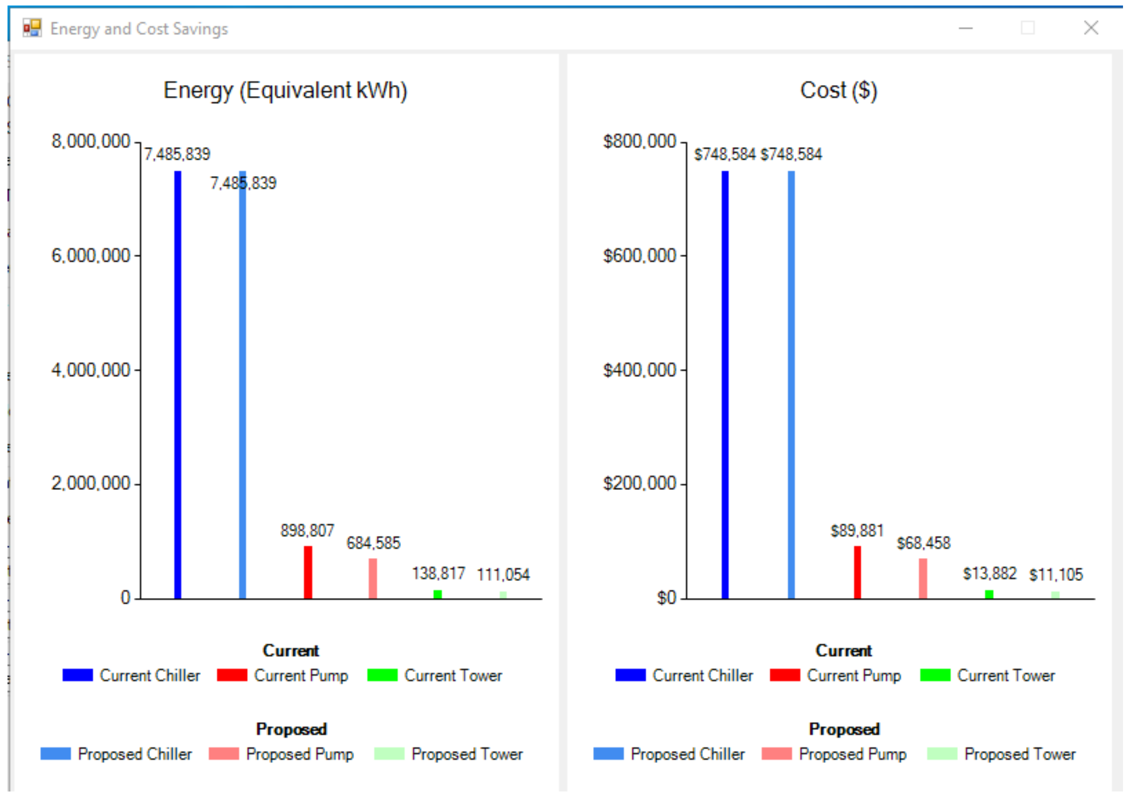
Modeling Application of VFDs to CHW Pumps in CWSAT

Pump Data	CHW	CW
Variable Flow?	Yes	No
Flow Rate [gpm/ton]:	2.4	3
Motor Size (hp):	20	25
Pump Efficiency [%]:	75	75
Motor Efficiency [%]:	85	85

OK

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	0		$0
Tower Summary:	27,763		$2,776
Pump Summary:	214,223		$21,422
Total:	241,986		$24,199



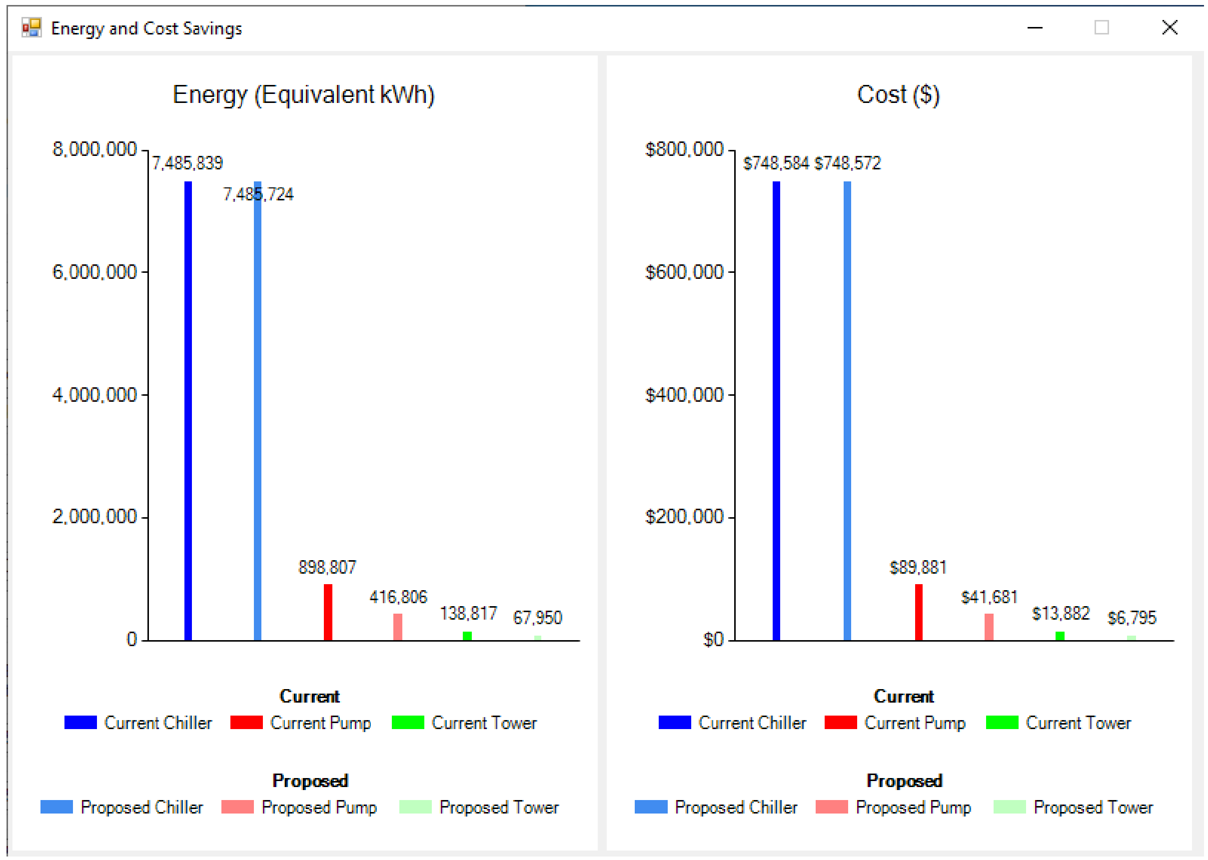
Modeling Application of VFDs to CHW & CW Pumps in CWSAT

Pump Summary

	CHW	CW
Variable Flow?:	Yes	Yes
Flow Rate [gpm/ton]:	2.4	3
Motor Size (hp):	20	25
Pump Efficiency [%]:	75	75
Motor Efficiency [%]:	85	85

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	115		$12
Tower Summary:	70,867		$7,087
Pump Summary:	482,001		$48,200
Total:	552,983		$55,298



Comments on Using CWSAT for VFD on Pumps

- Personal thought – CWSAT allows user to get a good idea of the potential energy and cost savings of VFDs on pumps
- Better tools exist – USDOE MEASUR – that can be used to more accurately quantify VFD savings on pumps
- CWSAT has a limited pump loop definition
- The specific pump curve at the plant may be very different compared to the generic pump curve in CWSAT

Cooling Tower Fan Speed Control

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Application of Cooling Tower Fan Speed Control

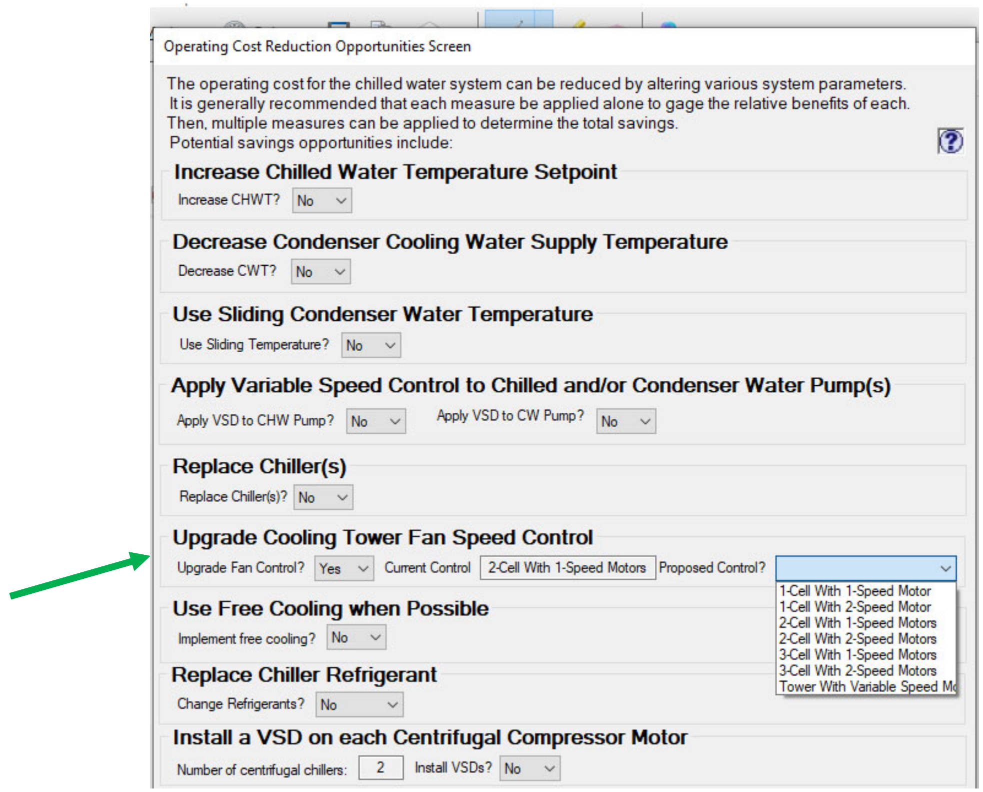
- There are different types of cooling tower fan controls
  - Constant speed – motor goes ON/OFF
  - 2-speed control – motor goes High speed, Low speed and Off
  - Variable speed control
  - Fan pitch control – in axial fans ONLY

- The centrifugal fan follows the cube law
  - Flow $\propto$ Speed
  - Power $\propto$ Speed^3

- CWSAT allows selection of fan and type of speed control

Application of Cooling Tower Fan Speed Control

- CWSAT cooling tower model uses the fundamental principles of psychrometrics, heat transfer, mass transfer and fluid flow
- Evaluate the cooling tower fan control
  - 2-speed
  - VFD



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Application of Cooling Tower Fan Speed Control

- CWSAT cooling tower model w/2-speed fan control

Tower Summary

Type:	2-Cell With 2-Speed Motors
#Towers:	1
Sizing:	Tons
Fan Motor HP:	60
Tons:	2000
Number of Cells per Tower:	2

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	0		$0
Tower Summary:	78,759		$7,876
Pump Summary:	0		$0
Total:	78,759		$7,876

Application of Cooling Tower Fan Speed Control

- CWSAT cooling tower model w/VFD fan control

Tower Summary

Type:	Tower With Variable Speed Motor(s)		
#Towers:	1	Sizing:	Tons
Fan Motor HP:	60	Tons:	2000
Number of Cells per Tower:	2		

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	-2		$0
Tower Summary:	79,151		$7,915
Pump Summary:	0		$0
Total:	79,150		$7,915

2-speed fan control (2 cells) & VFD control – provide very similar savings

Implement Free Cooling (Water side Economizer)

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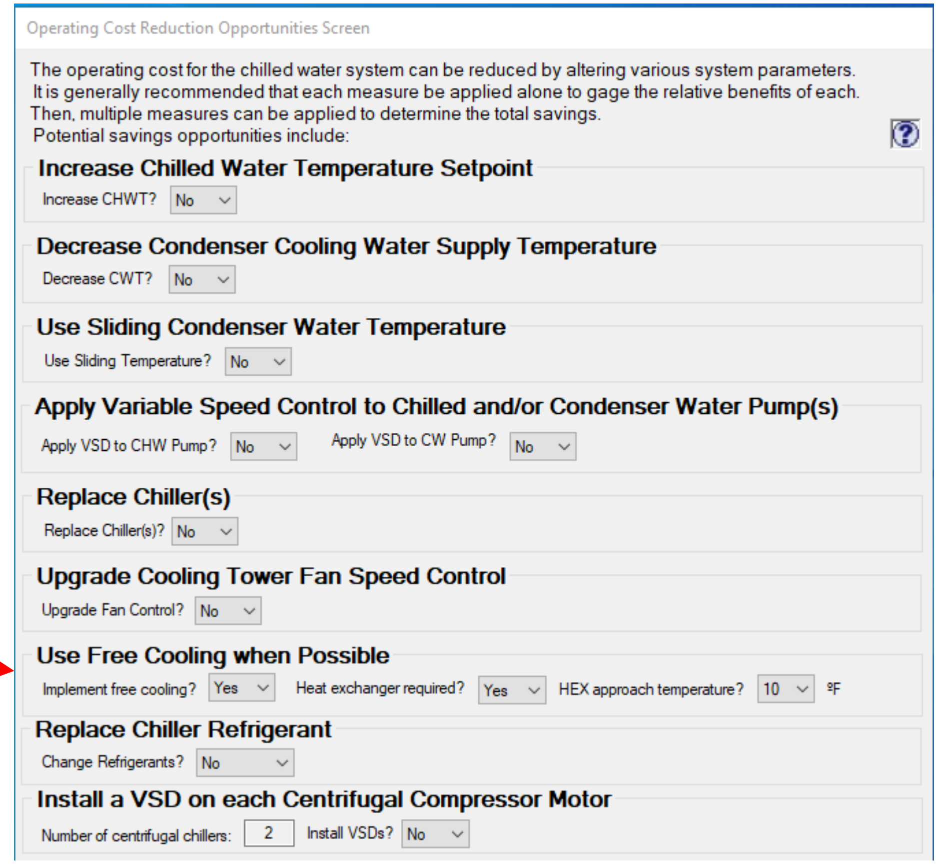
Install Water-side Economizers (Free Cooling)

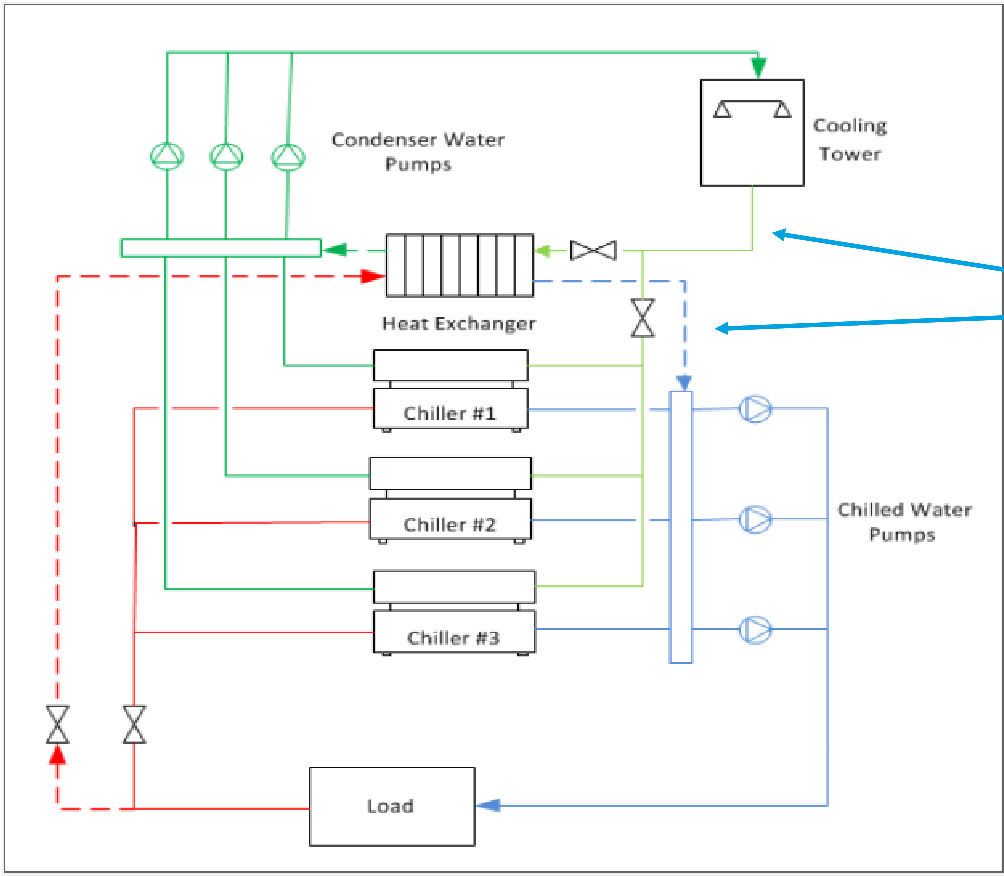
- This energy efficiency opportunity is applicable and cost-effective in certain geographical areas only but can have a huge impact on energy savings
- Installing a water-side economizer allows for “free cooling” during times of the year when the outdoor ambient conditions allow for very low wet-bulb temperatures
- The cooling tower water provides a portion or all of the chilled water load and reduces the chilled water plant’s operating time
- NOTE: Always evaluate if any portion of the chilled water end-use load can be offset by using cooling tower water!

Student Exercise (Using Free Cooling)

- Different configurations of free cooling are possible
- Direct (without HX) allows for maximum potential but may not be practical in chilled water loops
- Indirect (with HX) requires temperature approach as an input



Student Exercise (Using Free Cooling)



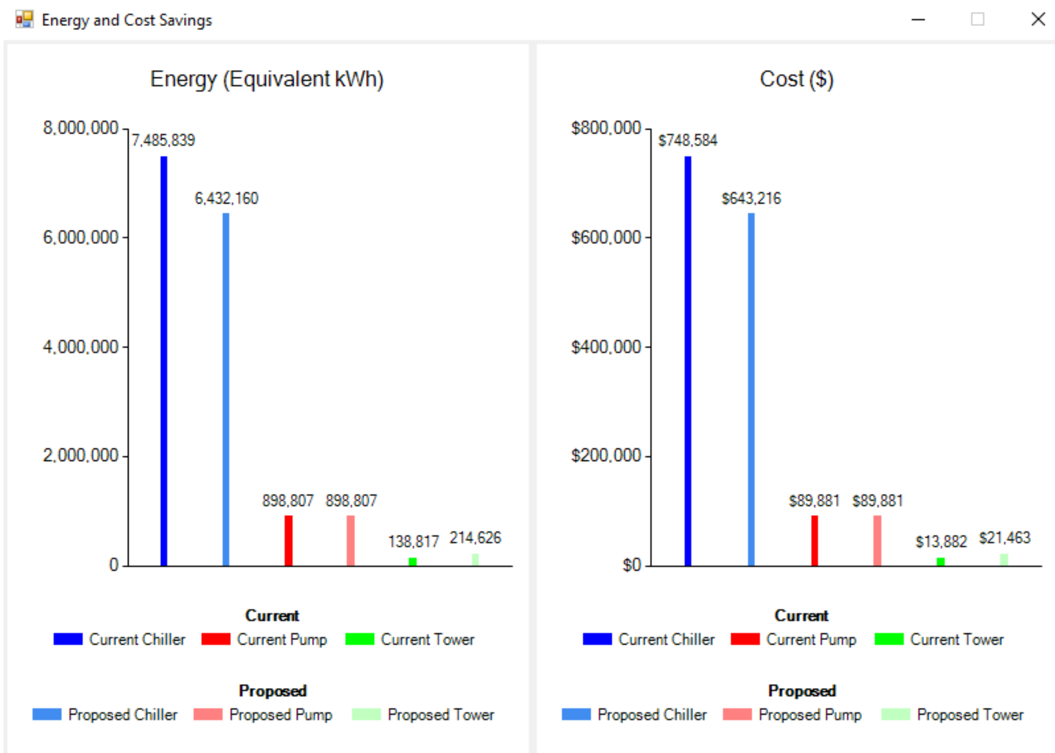
<u>Approach of HX</u>

Temperature difference between these 2 streams

Student Exercise (Using Free Cooling)

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	1,053,680		$105,368
Tower Summary:	-75,810		($7,581)
Pump Summary:	0		$0
Total:	977,870		$97,787



Implementing Free Cooling – Exercise Caution

- Be careful with this opportunity – a lot of misapplications occur

- Proper temperature and flow control loops have to be incorporated and retrofitting may make it a little more challenging if 3-way tie-ins on the chilled water loop and cooling tower loop are not easily available

- On several occasions, a separate cooling tower (separate basin) and water loop maybe needed

Implementing Free Cooling – Exercise Caution

- When cooling towers are sized by Tower Tons in CWSAT, the algorithm continues to optimize and evaluate the cooling tower fan power necessary - which does reduce as chiller load reduces
- Nevertheless, pay attention to proposed tower details screen to understand if it all makes sense – overall tower energy use has to increase with this opportunity!
- CWSAT is limited in some ways – there maybe increased pumping power depending on the loop and flow control configuration

Student Exercise (Using Free Cooling)

- If designed correctly, this is a great opportunity to offset partial chiller loads

Proposed Tower Details Screen : VINPLT_Example

Tower Summary

Tyoe of Tower:	2-Cell With 1-Speed Motors
Number of Towers:	1
Number of Cells per Tower:	2
Tower Sized by:	Tons
Tower Tons:	2000
Fan Motor Size (hp):	60
Fan CWT Setpoint Not Achieved:	1,000

Tower Energy Summary

WB Bin:	WB < 35 ºF	35 - 45 ºF	45 - 55 ºF	55 - 65 ºF	65 - 75 ºF	WB > 75 ºF	Total
Hours:	2,030	1,464	1,296	1,680	1,898	392	8,760
Energy [kWh]	103,573	0	0	11,172	72,838	27,043	214,626

Note: Tower calculations are made on an hourly basis. Bins are shown here for brevity

Replace Refrigerant

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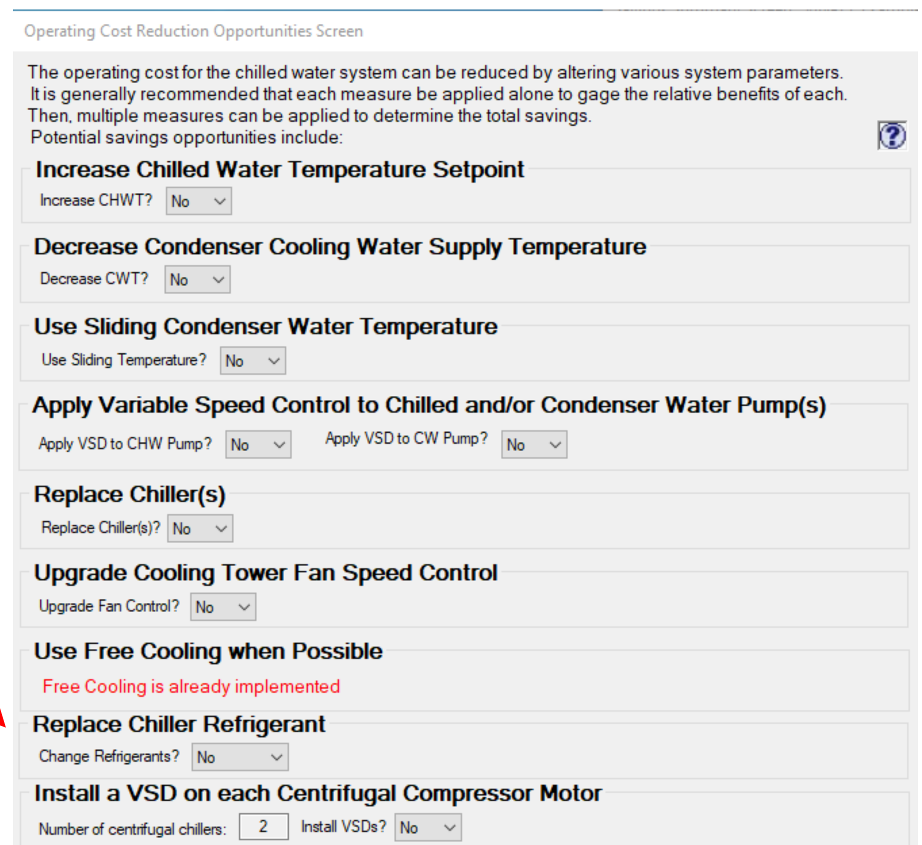
Replace Refrigerant

- **DO NOT USE**
- This was setup for drop-in replacements of R11 w/R123 and R12 w/R134a
- It may provide some ball-park information but there are better ways to model this EEO



Homework #5

- Finalize your plant's chilled water system model in CWSAT
- Build confidence in the total energy consumed and the cost of operation of your chilled water system
- From CWST exercises (HW#2), identify two or three opportunities that can be modeled in CWSAT as operating cost reduction strategies
- Use the CWSAT model to quantify these opportunities
- Identify discrepancies and shortcomings, if any, in the CWSAT software

Thank You all for attending today's webinar.

See you all tomorrow – August 15, 2024 – 10 am ET

If you have specific questions, please stay online and we will try and answer them.

Alternately, you can email questions to me at paparra@ornl.gov

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Kahoot Quiz Time