



Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment

Session 5

Thursday – June 30, 2022

10 am – 12:30 pm

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!



Acknowledgments

- US Department of Energy, Advanced Manufacturing Office
 - Oak Ridge National Laboratory
- United Nations Industrial Development Organization
 - National Cleaner Production Center – South Africa
- Hudson Technologies Company
- Dr. Beka Kosanovic – University of Massachusetts, Amherst, MA
- Several industrial clients – both in the US and internationally

Process Cooling Virtual INPLT Agenda (2022)

- **Week 1 (June 2) – Industrial Chilled Water Systems Fundamentals**
- **Week 2 (June 9) – Review of Chilled Water System Scoping Tool; Efficiency Metrics & Calculations**
- **Week 3 (June 16) – IPLV; Additional Energy Efficiency Metrics; Instrumentation Gap Analysis; CWSAT**
- **Week 4 (June 23) – Using CWSAT to Build a Chilled Water Plant System Model**
- **Week 5 (June 30) – Using CWSAT to Quantify Energy Efficiency Opportunities**
- **Week 6 (July 7) – Using CWSAT to Quantify EEOs (contd); US DOE MEASUR, 3EPlus, etc.**
- **Week 7 (July 14) – Case Studies; Refrigerants – Past, Present & Future; Reclamation and O&M**
- **Week 8 (July 21) – Industrial Process Cooling (Chilled water) System VINPLT Wrap-up Presentations**

Agenda – Session 5

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



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 – Session 4

Start CWSAT 3.0.1

<input type="checkbox"/>	Name	Status	Date modified	Type
<input type="checkbox"/>	OUTPUTDATA	✓	4/20/2022 8:42 AM	File folder
<input type="checkbox"/>	Sample Weather Upload Files	✓	4/20/2022 8:42 AM	File folder
<input type="checkbox"/>	User Manual	✓	4/20/2022 8:42 AM	File folder
<input type="checkbox"/>	USERCHILLER	✓	4/20/2022 8:42 AM	File folder
<input type="checkbox"/>	USERPROFILE	✓	4/20/2022 8:42 AM	File folder
<input type="checkbox"/>	WEATHER	✓	4/20/2022 11:22 AM	File folder
<input checked="" type="checkbox"/>	CWSAT 3.0.1	✓	4/20/2022 8:42 AM	Application
<input type="checkbox"/>	CWSAT	✓	4/20/2022 8:41 AM	Compressed (zip)

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.

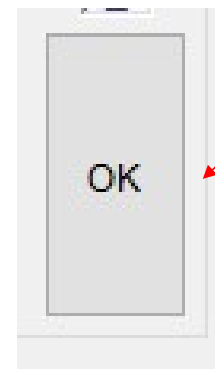


Copyright by The University of Massachusetts Amherst 2013 All Rights Reserved

Continue

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


Input Screen


File Tools

Basic System Data


Geographic Location: MO Saint Loui 


Number of Chillers: 3 


Chilled Water Supply Temperature: 44 °F 

Condenser Cooling Method: Water-Cooled 


Water-Cooled Data


CWT = Condenser Cooling Water Supply Temperature 


Is the CWT constant? Yes 


What is the CWT? 85 °F 


Tower Data

System with Free Cooling? ☐ Yes ☒ No 

Tower Type: 2-Cell With 1-Speed Motors 


Num of Towers: 1 

Size Tower by: Tons 2000 tons/tower 

Axial Fan Type 


Pump Data

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



Current Chiller Data

User Chiller ? (Y/N)	Compressor/Chiller Type	Full Load Eff Known?	Chiller Capacity [tons]	Age [Years]
Chiller 1				
<input type="radio"/> Y <input checked="" type="radio"/> N				
Chiller 2				
<input type="radio"/> Y <input checked="" type="radio"/> N				
Chiller 3				
<input type="radio"/> Y <input checked="" type="radio"/> N				



Chiller Specification Methodology – Method 3

Define Chillers

Please Input ARI Rating Data: ?

Compressor Type : Centrifugal

Chiller Capacity (Tons) : 1000

kW/Ton at % Loading

25%	0.63	50%	0.48	75%	0.51	100%	0.65
-----	------	-----	------	-----	------	------	------

Graph Chiller Performance % Power Equation $1.066666(X^3) + -0.8615372(X^2) + 0.687179(X) + 0.$

Chiller Name : INPLT_Test

Save to Database

Available Chillers in Database :

- CentrifugalWaterCooled
- GVG
- GVGCENTRI
- GVGTrial
- INPLT_Test
- Mike_200ton_Centrifug.
- R1
- R2
- UserChiller

Delete Selected Chiller

Chiller Performance Chart

kW / Ton vs. % Load

% Load	kW / Ton
25	0.63
50	0.48
75	0.51
100	0.65

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

System Information

Input Screen

File Tools

Basic System Data

Geographic Location: MO Saint Loui

Number of Chillers: 3

Chilled Water Supply Temperature: 44 °F

Condenser Cooling Method: Water-Cooled

Water-Cooled Data

CWT = Condenser Cooling Water Supply Temperature

Is the CWT constant? Yes

What is the CWT? 85 °F

Tower Data

System with Free Cooling? ☐ Yes ☒ No

Tower Type: 2-Cell With 1-Speed Motors

Num of Towers: 1

Size Tower by: Tons 2000 tons/tower

CHW CW

Pump Data

Variable Flow? No No

Flow Rate [gpm/ton]: 2.4 3

Motor Size [hp]: Unknown Unknown

Pump Efficiency [%]: 75 75

Motor Efficiency [%]: 85 85

Current Chiller Data

User Chiller ? (Y/N)	Compressor/Chiller Type	Full Load Eff Known?	Chiller Capacity [tons]	FLE Value [kW/ton]	Age [Years]
Chiller 1 <input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 2 <input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 3 <input type="radio"/> Y <input checked="" type="radio"/> N	Helical Rotary	Yes	350	0.75	10

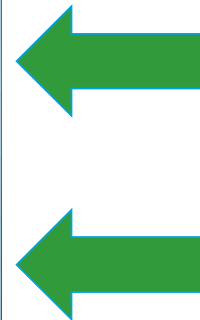
Energy Cost Data

Electricity Cost: 0.10 [\$/kWh]

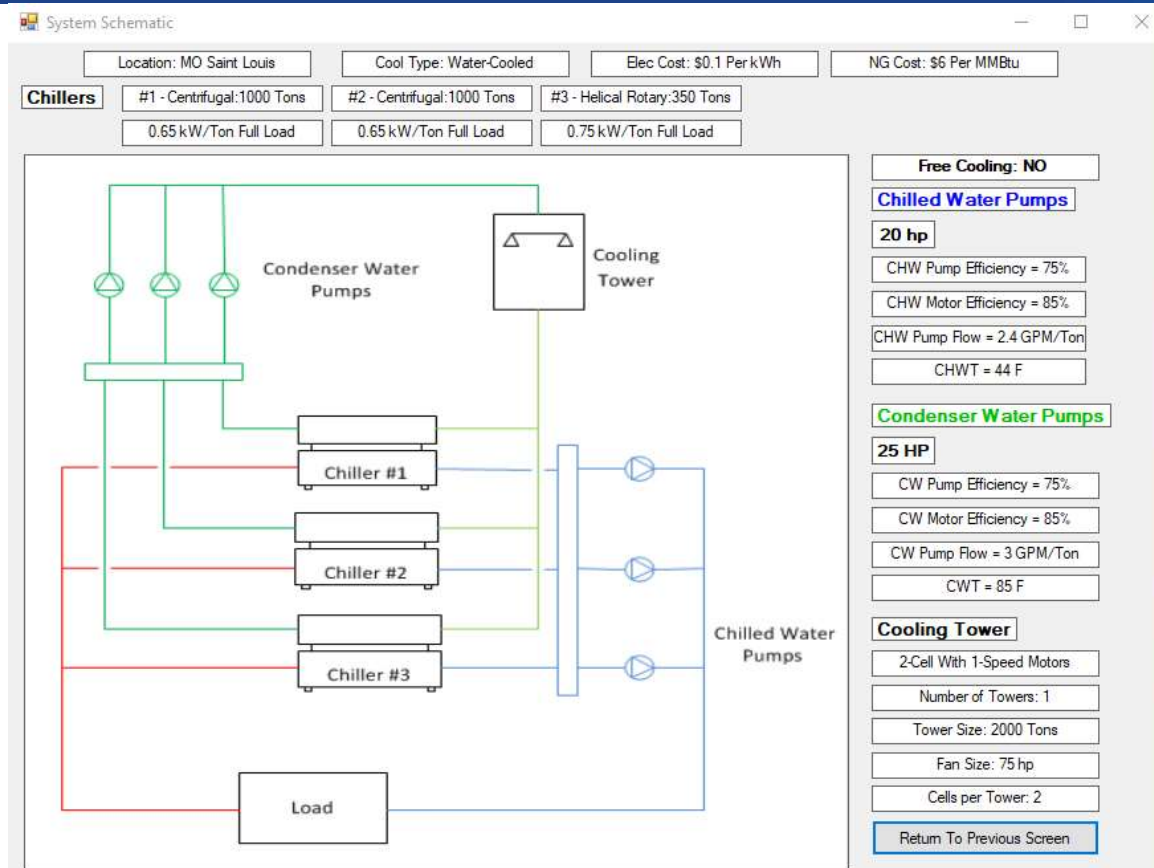
Natural Gas Cost: 6.00 [\$/MMBtu]

OK

- 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

Loading Schedule Screen : VINPLT_Example

Provide the loading schedule for the chiller(s). 

	Chiller #	Compressor Type	Capacity [tons]	Age [yrs]
Current Chiller	1	Centrifugal	1000	10

Loading Schedule

Time at:

0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total % Load
5	0	0	0	10	20	20	20	15	10	0	100

All Months

Copy Paste



Output Screen (Baseline)

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

Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers:

CHWT Setpoint:

Geographic Location:

Condenser Cooling Method:

Water-Cooled Summary

Constant CWT?:

Constant CWT Setpoint:

Tower Summary

Type:

#Towers: Sizing:

Fan Motor HP: Tons:

Number of Cells per Tower:

Pump Summary

	CHW	CW
Variable Flow?:	<input type="text" value="No"/>	<input type="text" value="No"/>
Flow Rate [gpm/ton]:	<input type="text" value="2.4"/>	<input type="text" value="3"/>
Motor Size (hp):	<input type="text" value="20"/>	<input type="text" value="25"/>
Pump Efficiency [%]:	<input type="text" value="75"/>	<input type="text" value="75"/>
Motor Efficiency [%]:	<input type="text" value="85"/>	<input type="text" value="85"/>

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]	
Chiller 1	<input type="text" value="Centrifugal"/>	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 2	<input type="text" value="Centrifugal"/>	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 3	<input type="text" value="Helical Rotary"/>	<input type="text" value="350"/>	<input type="text" value="10"/>	<input type="text" value="0.750"/>

Energy Summary

Chiller Energy: kWh

Tower Energy: kWh

Pump Energy: kWh

Total Energy: kWh

Go To Operating Cost Reduction Screen

Go To Current Chiller Details Screen

Go To Current Tower Details Screen

Go To Current Pump Details Screen

Return to Input Screen

Export to File

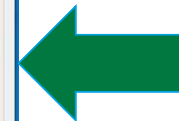
Show System Graphic

Show Energy/Cost Graphic

Exit Program

Comments Outtemp

Detail Screens



Chiller Operating Details Screen (Baseline)

Current Chiller Details Screen : VINPLT_Example.txt

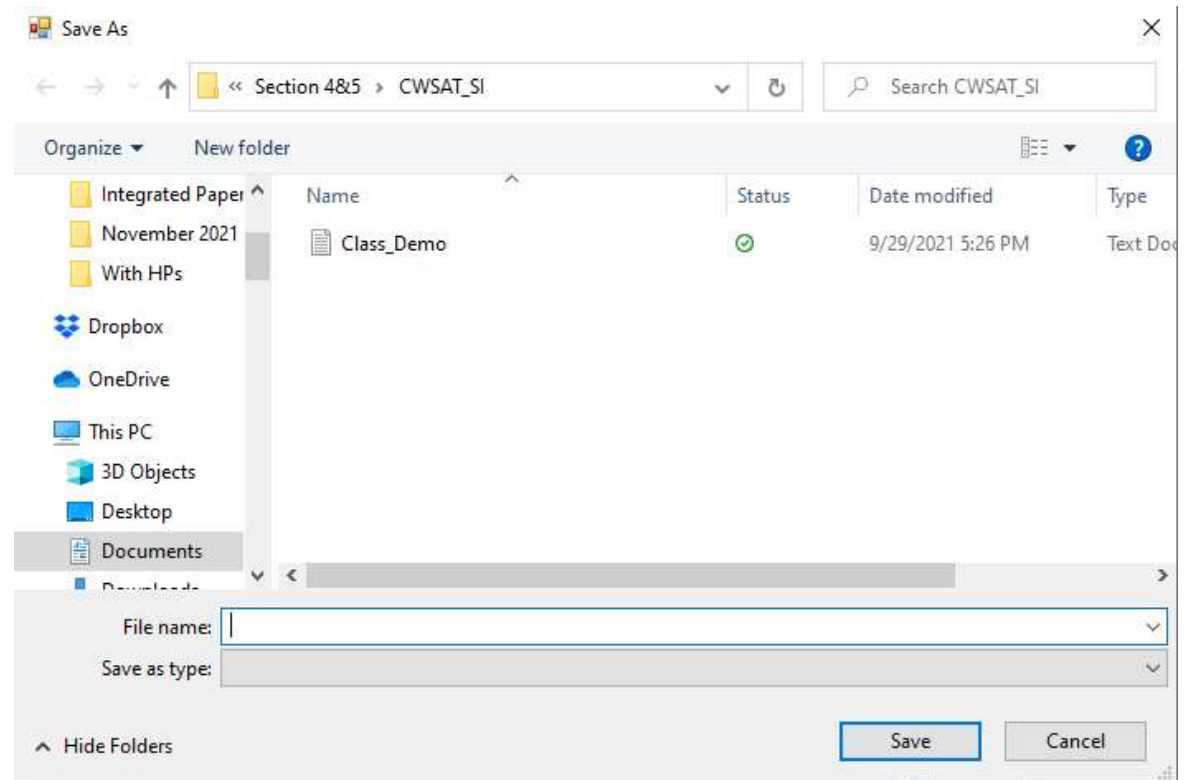
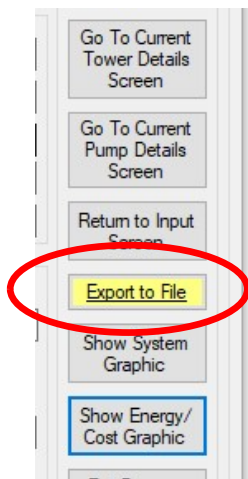
	0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total	?
Chiller 1: Centrifugal (Rated Capacity: 1000 tons)													
[kW/ton]:	0.000	0.000	0.000	0.000	0.608	0.591	0.592	0.609	0.638	0.675	0.000		
Hours:	444	0	0	0	873	1,754	1,753	1,746	1,317	873	0	8,760	
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)													
[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)													
[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

Chiller System Optimization Objectives

- **Reducing Operating Costs**
 - Improving energy efficiency of the system
 - Improving overall system reliability
 - Implementing operational and maintenance Best Practices
 - 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

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

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature
Decrease CWT?

Use Sliding Condenser Water Temperature
Use Sliding Temperature?

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)
Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)
Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control?

Use Free Cooling when Possible
Implement free cooling?

Replace Chiller Refrigerant
Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

“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

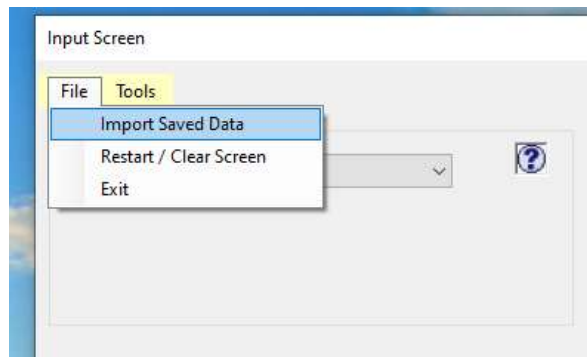
New Input Screen : Class_Demo.txt

Basic System Data		Water-Cooled Data			
Geographic Location:	ZA Johannesburg	CWT = Condenser Cooling Water Supply Temperature			
Chilled Water Supply Temperature:	6.5 °C	Is the CWT constant?	Yes		
Condenser Cooling Method:	Water-Cooled	What is the CWT?	25 °C		
Tower Data		Pump Data			
Tower Type:	2-Cell With 1-Speed Motors	Variable Flow?	CHW: No CW: No		
Num of Towers:	1	Flow Rate (l/s/kW):	CHW: 0.0431 CW: 0.0538		
Size Tower by:	Tower k1 5.276 kW/tower	Motor Size (kW):	CHW: 11.19 CW: 14.92		
	Axial Fan Type	Pump Efficiency [%]:	CHW: 75 CW: 75		
		Motor Efficiency [%]:	CHW: 85 CW: 85		
Proposed Chiller Data					
User Chiller ? (Y/N)	Compressor Type	Full Load Eff Known?	Chiller Capacity [kW]	FLE Value [COP]	Age [Years]
Chiller 1					
<input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	2640	0.65009	10
Chiller 2					
<input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	2640	0.65009	10
Chiller 3					
<input type="radio"/> Y <input checked="" type="radio"/> N	Helical Rotary	Yes	705	0.74989	10
Energy Cost Data					
Electricity Cost: 1.000 [\$/kWh]					
<div>Go To New Output Screen Return to Output Screen Restart Screen Exit Program</div>					

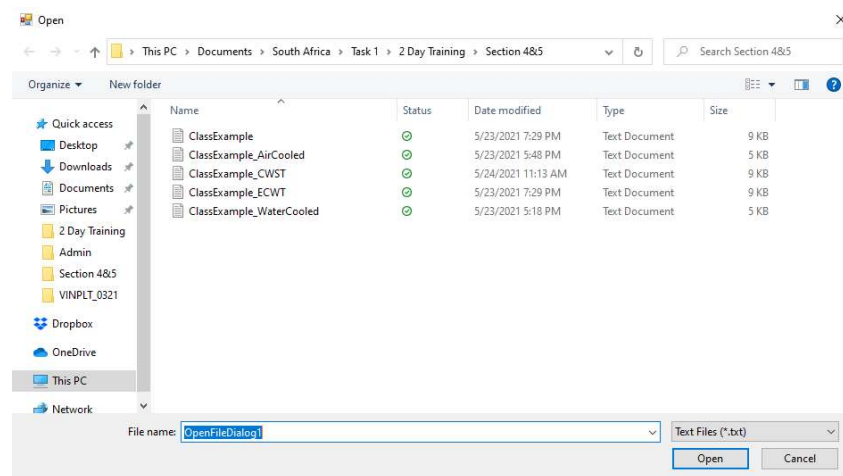
New Equipment Specification

- 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 Liters per second / kW
 - 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

Output Screen : VINPLT_Example

Current Chiller System			
Basic System Summary			
Number of Chillers:	3		
CHWT Setpoint:	44		
Geographic Location:	MO Saint Louis		
Condenser Cooling Method:	Water-Cooled		

Water-Cooled Summary			
Constant CWT?:	Yes		
Constant CWT Setpoint:	85		

Tower Summary			
Type:	2-Cell With 1-Speed Motors		
#Towers:	1	Sizing:	Tons
Fan Motor HP:	75	Tons:	2000
Number of Cells per Tower:	2		

Current Chiller Summary			
Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	1000	10	0.650
Chiller 2			
Centrifugal	1000	10	0.650
Chiller 3			
Helical Rotary	350	10	0.750

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

Energy Summary			
Chiller Energy:	7,485,839	kWh	\$748,584
Tower Energy:	138,817	kWh	\$13,882
Pump Energy:	898,807	kWh	\$89,881
Total Energy:	8,523,463	kWh	\$852,346

[Go To Operating Cost Reduction Screen](#)
[Go To Current Chiller Details Screen](#)
[Go To Current Tower Details Screen](#)
[Go To Current Pump Details Screen](#)
[Return to Input Screen](#)
[Export to File](#)
[Show System Graphic](#)
[Show Energy / Cost Graphic](#)
[Exit Program](#)
[?](#)
[Comments Outtemp](#)

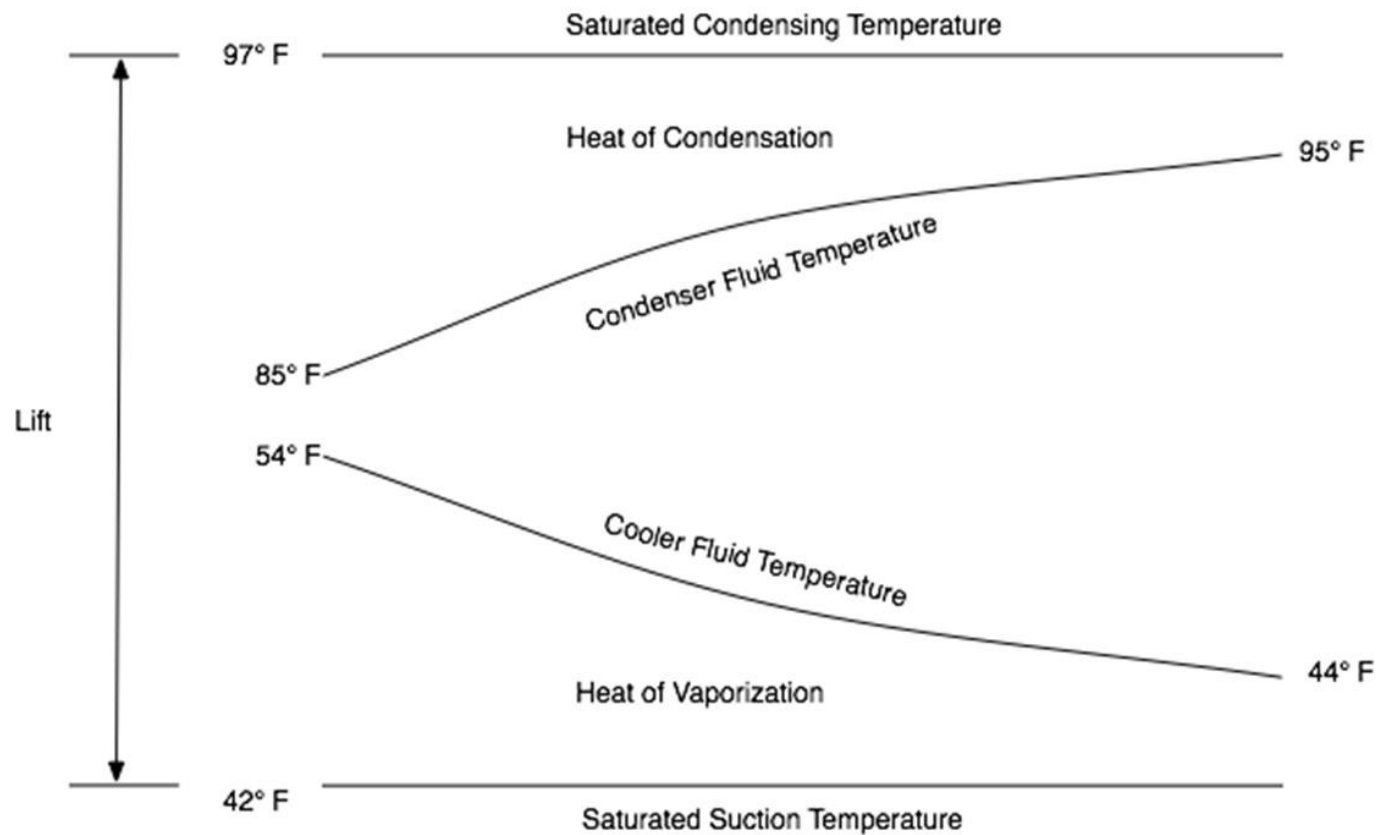
Entering Condenser Water Temperature (ECWT) Management

Implement ECWT Management

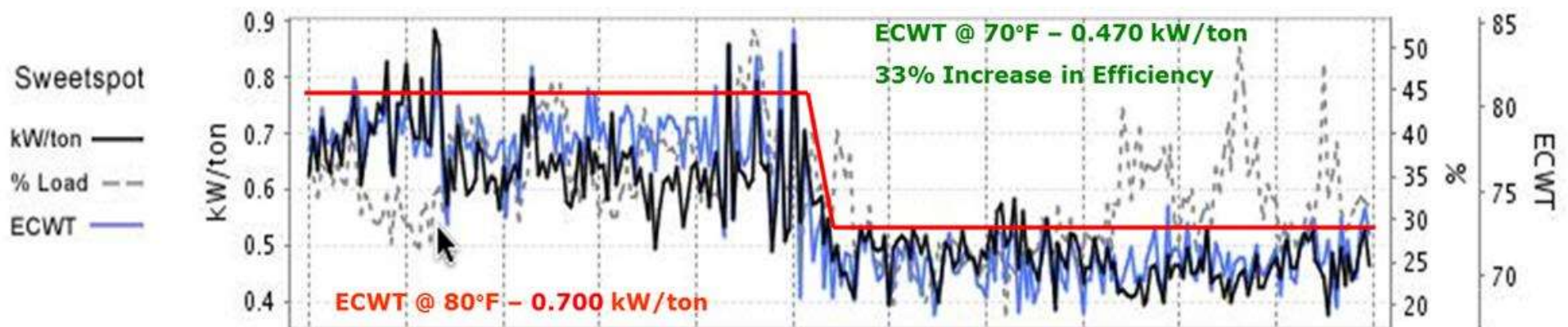
- ECWT – **E**ntering **C**ondenser **W**ater **T**emperature
- Cooling Tower Approach
 - The approach is the difference in temperature between the cooled-water temperature and the air “wet bulb temperature”
- Wet Bulb
 - Wet bulb temperature is the lowest temperature that can be reached by the evaporation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

Remember Lift!

$$\text{Lift} = 97 - 42 = 55^\circ\text{F}$$



ECWT Management

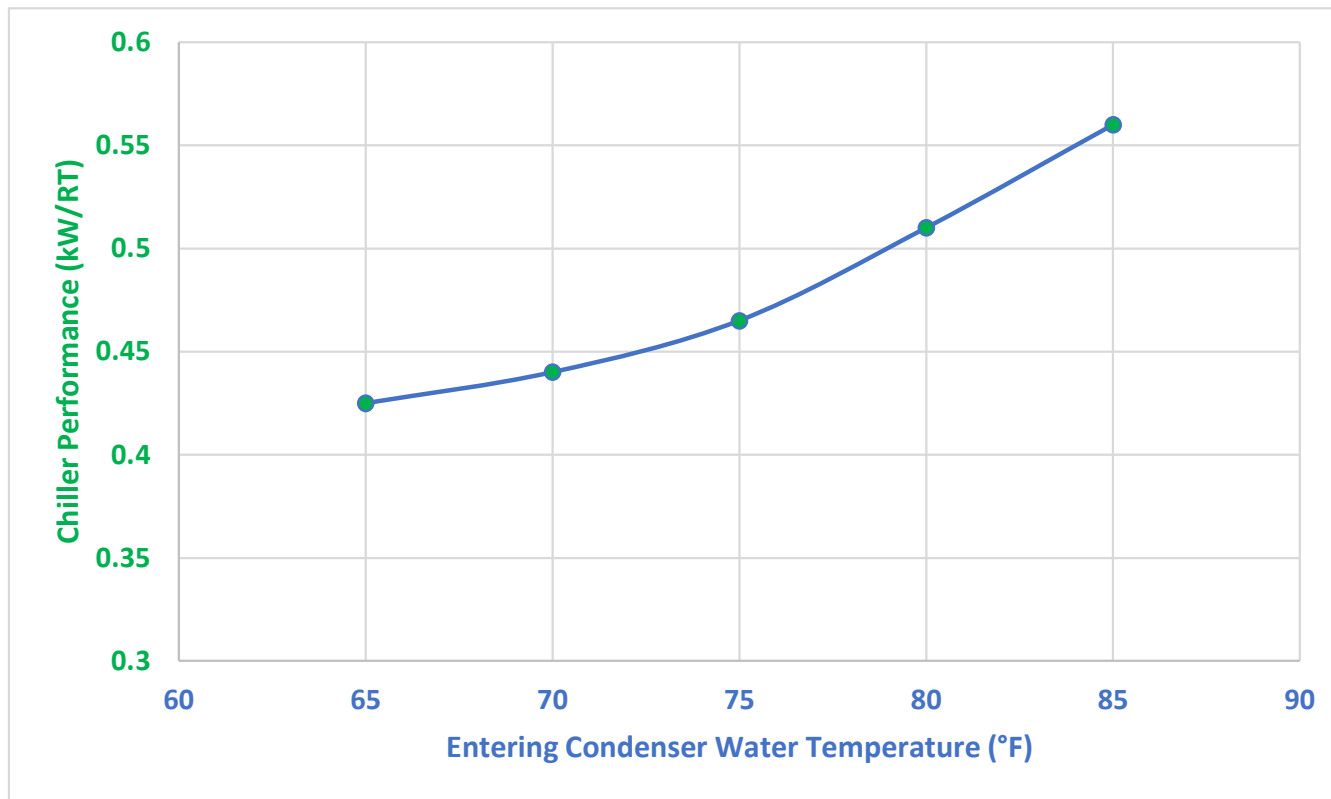


80°F ECWT drops to 70°F ECWT

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)

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature

Decrease CWT? Current Temperature °F Proposed Temperature? °F

Use Sliding Condenser Water Temperature

Cannot be used when Decreasing Condenser Water Supply Temperature

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

Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)

Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control

Upgrade Fan Control?

Use Free Cooling when Possible

Implement free cooling?

Replace Chiller Refrigerant

Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor

Number of centrifugal chillers: Install VSDs?

Student Exercise (Reduce Entering Condenser Water Temperature)

New Input Screen : VINPLT_Example

Basic System Data

Geographic Location: MO Saint Louis

Chilled Water Supply Temperature: 44 °F

Condenser Cooling Method: Water-Cooled

Water-Cooled Data

CWT = Condenser Cooling Water Supply Temperature

Is the CWT constant? Yes

What is the CWT? 83 °F

Tower Data

Tower Type: 2-Cell With 1-Speed Motors

Num of Towers: 1

Size Tower by: Tons 2000 tons/tower

Axial Fan Type

Pump Data

CHW CW

Variable Flow? No No

Flow Rate [gpm/ton]: 2.4 3

Motor Size (hp): 20 25

Pump Efficiency [%]: 75 75

Motor Efficiency [%]: 85 85

Proposed Chiller Data

User Chiller ? (Y/N)	Compressor Type	Full Load Eff Known?	Chiller Capacity [tons]	FLE Value [kW/ton]	Age [Years]
Chiller 1					
<input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 2					
<input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 3					
<input type="radio"/> Y <input checked="" type="radio"/> N	Helical Rotary	Yes	350	0.75	10

Energy Cost Data

Electricity Cost: 0.100 \$/kWh

Natural Gas Cost: 6.00 \$/MMBtu

Student Exercise (Reduce Entering Condenser Water Temperature)

Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers: 3

CHWT Setpoint: 44

Geographic Location: MO Saint Louis

Condenser Cooling Method: Water-Cooled

Water-Cooled Summary

Constant CWT?: Yes

Constant CWT Setpoint: 85

Tower Summary

Type: 2-Cell With 1-Speed Motors

#Towers: 1 Sizing: Tons

Fan Motor HP: 75 Tons: 2000

Number of Cells per Tower: 2

Pump Summary

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

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	1000	10	0.650
Chiller 2			
Centrifugal	1000	10	0.650
Chiller 3			
Helical Rotary	350	10	0.750

Energy Summary

Chiller Energy: 7,485,839 kWh \$748,584

Tower Energy: 138,817 kWh \$13,882

Pump Energy: 898,807 kWh \$89,881

Total Energy: 8,523,463 kWh \$852,346

Go To Operating Cost Reduction Screen

Go To Current Chiller Details Screen

Go To Current Tower Details Screen

Go To Current Pump Details Screen

Return to Input Screen

Export to File

Show System Graphic

Show Energy/Cost Graphic

Exit Program

Comments Output

New Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers: 3

CHWT Setpoint: 44

Geographic Location: MO Saint Louis

Condenser Cooling Method: Water-Cooled

Water-Cooled Summary

Constant CWT?: Yes

Constant CWT Setpoint: 83

Tower Summary

Type: 2-Cell With 1-Speed Motors

#Towers: 1 Sizing: Tons

Fan Motor HP: 60 Tons: 2000

Number of Cells per Tower: 2

Pump Summary

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

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	1000	10	0.650
Chiller 2			
Centrifugal	1000	10	0.650
Chiller 3			
Helical Rotary	350	10	0.750

Energy Summary

Chiller Energy: 7,417,338 kWh \$741,734

Tower Energy: 150,247 kWh \$15,025

Pump Energy: 898,807 kWh \$89,881

Total Energy: 8,466,392 kWh \$846,639

Return to New Input Screen

Go To Proposed Chiller Details Screen

Go To Proposed Tower Details Screen

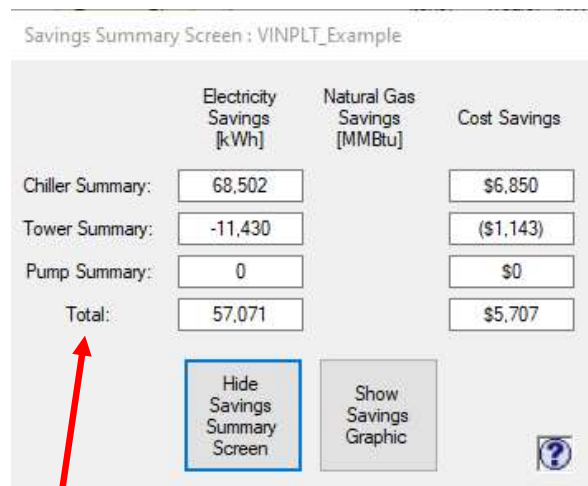
Go To Proposed Pump Details Screen

Show System Graphic

Show Energy/Cost Graphic

Show Savings Summary Screen

Student Exercise (Reduce Entering Condenser Water Temperature)



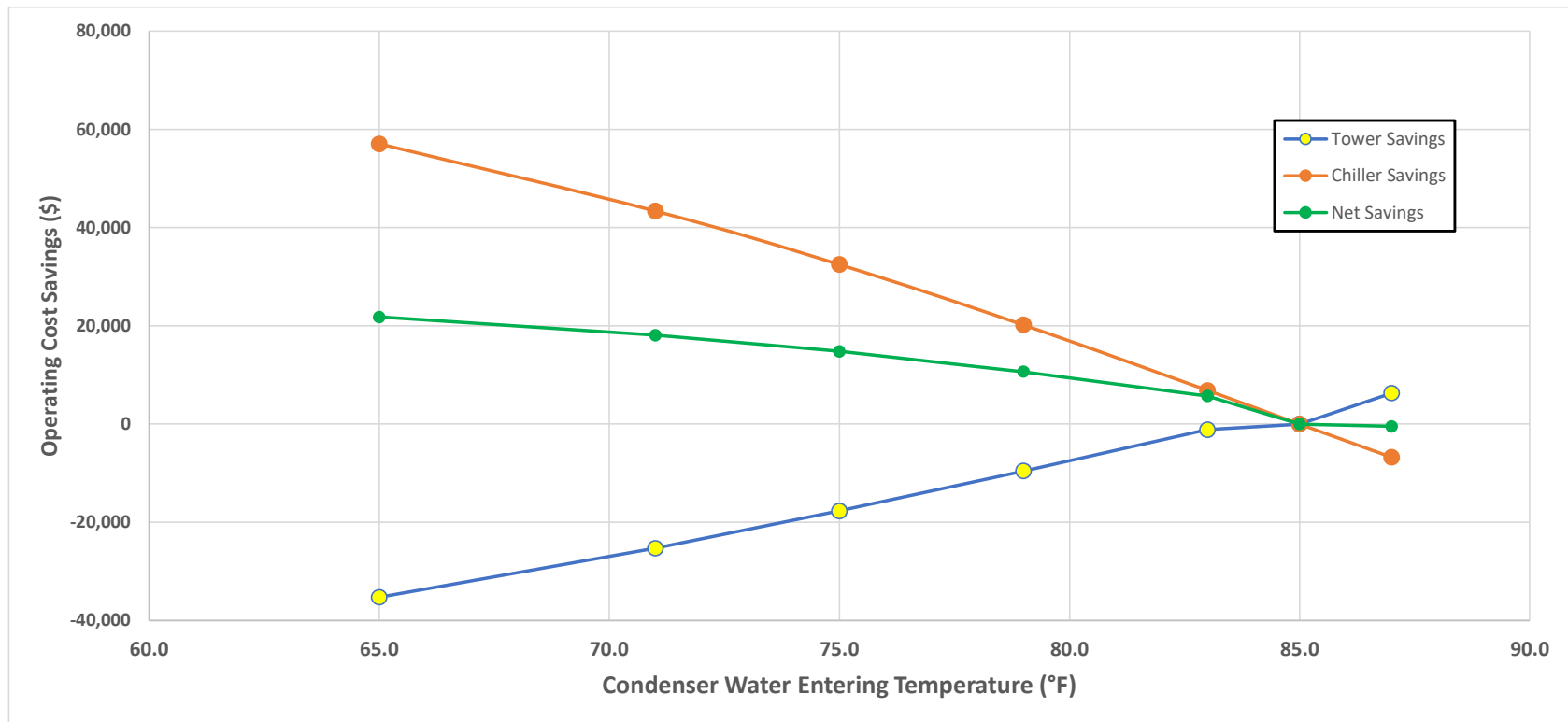
Note: Part of the chiller savings get offset by extra cooling tower operating costs



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

Output Screen : VINPLT_Example_FloatECWT

Current Chiller System			
Basic System Summary			
Number of Chillers:	3		
CHWT Setpoint:	44		
Geographic Location:	MO Saint Louis		
Condenser Cooling Method:	Water-Cooled		
Water-Cooled Summary			
Constant CWT?:	No		
Following Difference:	3		
Tower Summary			
Type:	2-Cell With 1-Speed Motors		
#Towers:	1	Sizing:	Tons
Fan Motor HP:	75	Tons:	2000
Number of Cells per Tower:	2		
Current Chiller Summary			
Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	1000	10	0.650
Chiller 2			
Centrifugal	1000	10	0.650
Chiller 3			
Helical Rotary	350	10	0.750
Pump Summary			
Variable Flow?:	CHW	CW	
	No	No	
Flow Rate [gpm/ton]:	2.4	3	
Motor Size (hp):	20	25	
Pump Efficiency [%]:	75	75	
Motor Efficiency [%]:	85	85	
Energy Summary			
Chiller Energy:	6,826,647	kWh	\$682,665
Tower Energy:	706,381	kWh	\$70,638
Pump Energy:	898,807	kWh	\$89,881
Total Energy:	8,431,834	kWh	\$843,183

Go To Operating Cost Reduction Screen

Go To Current Chiller Details Screen

Go To Current Tower Details Screen

Go To Current Pump Details Screen

Return to Input Screen

Export to File

Show System Graphic

Show Energy/Cost Graphic

Exit Program

Comments Outtemp

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

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature
Cannot be used with Sliding Condenser Water Temperature

Use Sliding Condenser Water Temperature
Use Sliding Temperature? CWT follows ambient wet-bulb plus °F °F

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)
Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)
Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control?

Use Free Cooling when Possible
Implement free cooling?

Replace Chiller Refrigerant
Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

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



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

Output Screen : VINPLT_Example_FloatECWT

The screenshot displays the VINPLT software interface with the following sections:

- Current Chiller System**
 - Basic System Summary
 - Number of Chillers: 3
 - CHWT Setpoint: 44
 - Geographic Location: MO Saint Louis
 - Condenser Cooling Method: Water-Cooled
 - Tower Summary
 - Type: 2-Cell With 1-Speed Motors
 - #Towers: 1 Sizing: Tons
 - Fan Motor HP: 75 Tons: 2000
 - Number of Cells per Tower: 2
 - Current Chiller Summary
 - Compressor Capacity [tons] Age [years] FLE [kW/ton]
 - Chiller 1: Centrifugal 1000 10 0.650
 - Chiller 2: Centrifugal 1000 10 0.650
 - Chiller 3: Helical Rotary 350 10 0.750
- Water-Cooled Summary**
 - Constant CWT?: No
 - Following Difference: 6
- Pump Summary**

	CHW	CW
Variable Flow?:	No	No
Flow Rate [gpm/ton]:	2.4	3
Motor Size [hp]:	20	25
Pump Efficiency [%]:	75	75
Motor Efficiency [%]:	85	85
- Energy Summary**

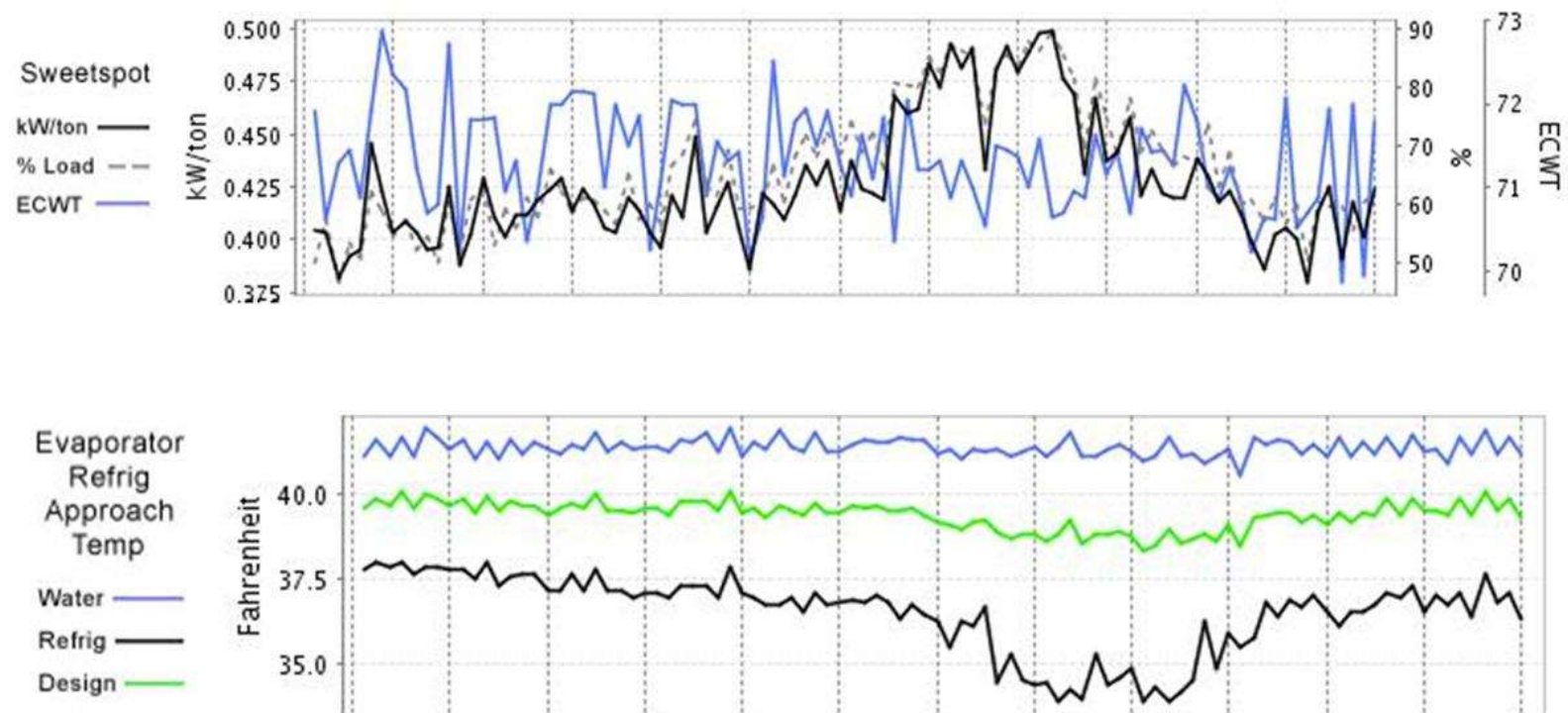
	kWh	\$
Chiller Energy:	6,829,160	\$682,916
Tower Energy:	694,625	\$69,463
Pump Energy:	898,807	\$89,881
Total Energy:	8,422,592	\$842,259

Navigation buttons on the right side include: Go To Operating Cost Reduction Screen, Go To Current Chiller Details Screen, Go To Current Tower Details Screen, Go To Current Pump Details Screen, Return to Input Screen, Export to File, Show System Graphic, Show Energy/Cost Graphic, Exit Program, and Comments Outtemp.

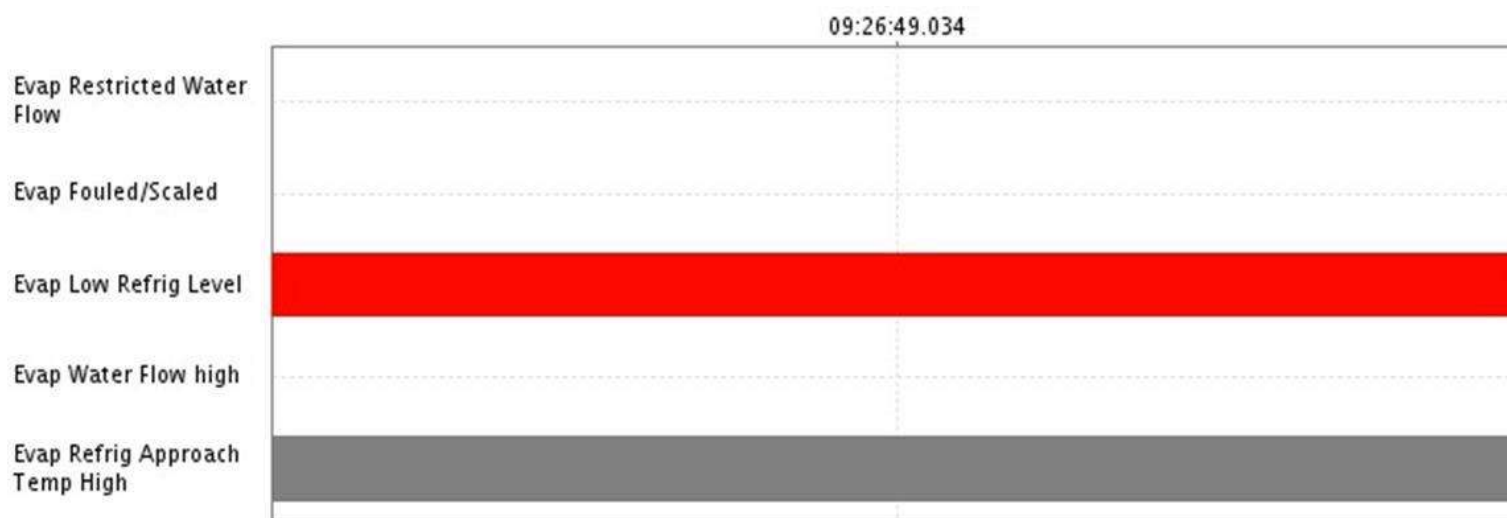
Eliminate Refrigerant Stacking

- 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

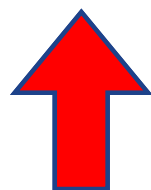
Refrigerant Stacking



Refrigerant Stacking



How do you eliminate stacking?



Raise
ECWT

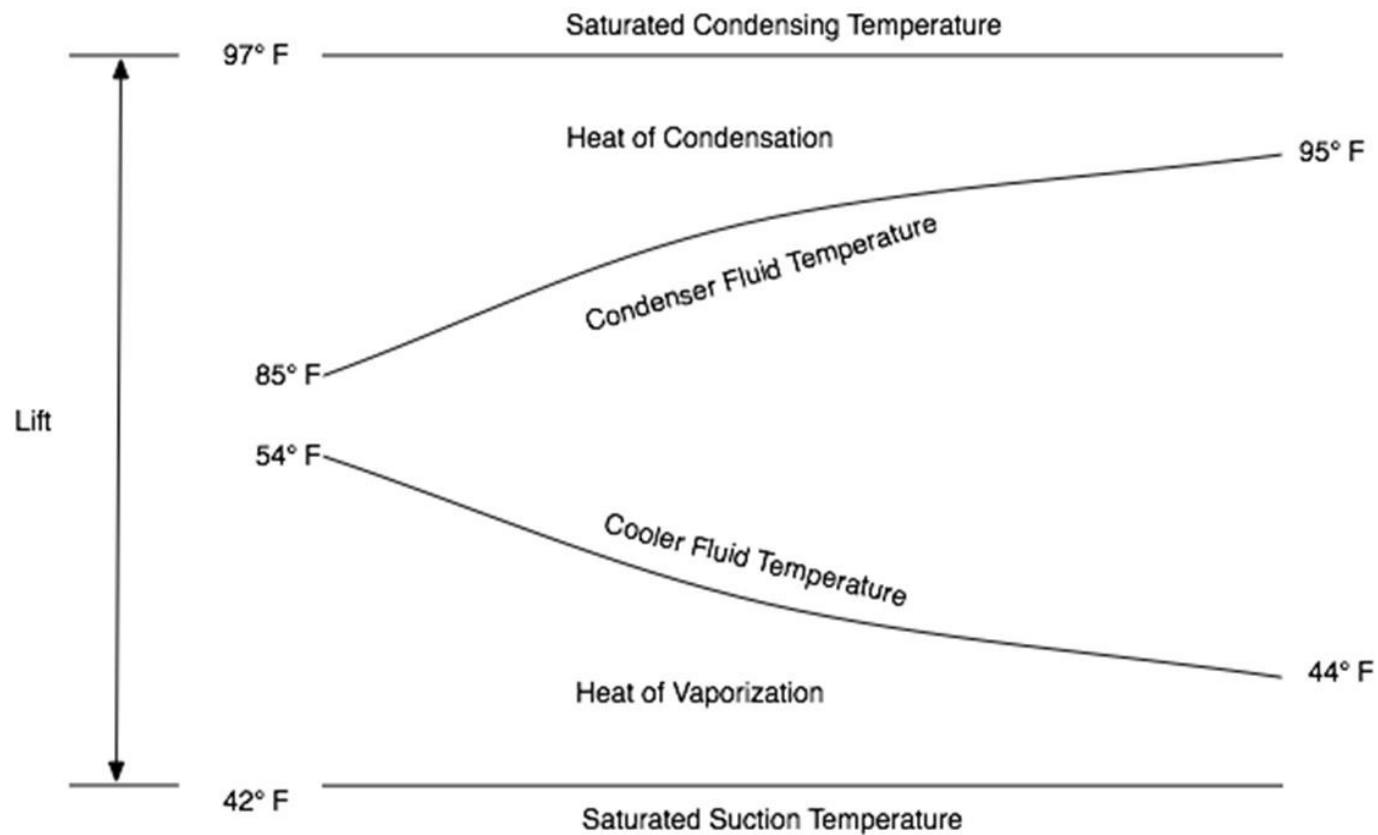
Optimizing Chilled Water Set-Point (ChWST)

Optimize Settings for ChWST

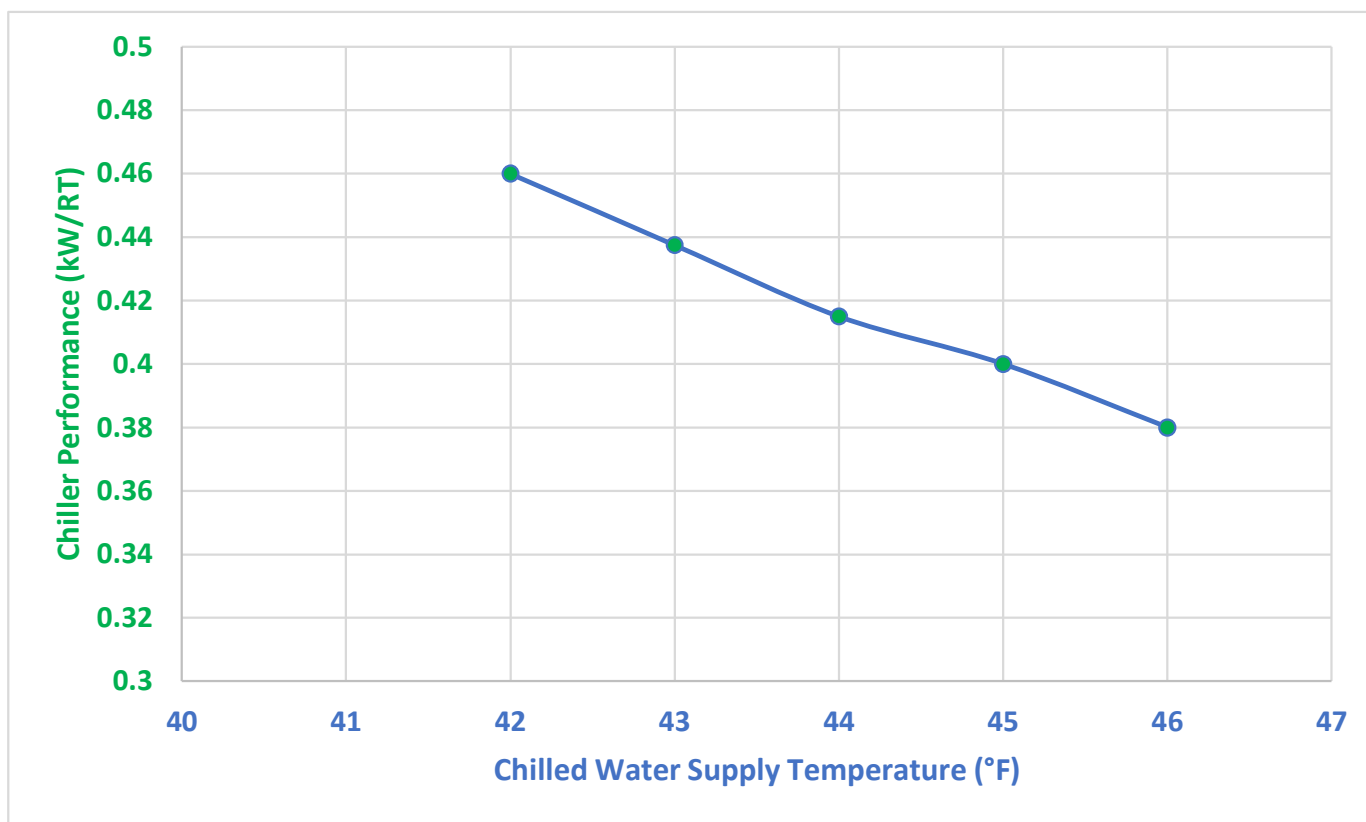
- **ChWST – Chilled Water Supply Temperature**
- **Approach**
 - The Refrigerant Approach Temperature is the difference in temperature between the chilled-water supply temperature and the refrigerant saturated temperature in the evaporator
 - It provides the driving force to transfer the heat from the 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
- **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!

$$\text{Lift} = 97 - 42 = 55^\circ\text{F}$$



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 gauge 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? Current Temperature °F Proposed Temperature? °F

Decrease Condenser Cooling Water Supply Temperature

Decrease CWT?

Use Sliding Condenser Water Temperature

Use Sliding Temperature?

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

Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)

Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control

Upgrade Fan Control?

Use Free Cooling when Possible

Implement free cooling?

Replace Chiller Refrigerant

Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor

Number of centrifugal chillers: Install VSDs?

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

Student Exercise (Increase Chilled Water Supply Temperature)

New Input Screen : VINPLT_Example

Basic System Data

Geographic Location: MO Saint Louis

Chilled Water Supply Temperature: 45 °F

Condenser Cooling Method: Water-Cooled

OK

Water-Cooled Data

CWT = Condenser Cooling Water Supply Temperature

Is the CWT constant? Yes

What is the CWT? 85 °F

OK

Tower Data

Tower Type: 2-Cell With 1-Speed Motors

Num of Towers: 1

Size Tower by: Tons 2000 tons/tower

Axial Fan Type

OK

Pump Data

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

OK

Proposed Chiller Data

User Chiller ? (Y/N)	Compressor Type	Full Load Eff Known?	Chiller Capacity [tons]	FLE Value [kW/ton]	Age [Years]
Chiller 1 <input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 2 <input type="radio"/> Y <input checked="" type="radio"/> N	Centrifugal	Yes	1000	0.65	10
Chiller 3 <input type="radio"/> Y <input checked="" type="radio"/> N	Helical Rotary	Yes	350	0.75	10

Energy Cost Data

Electricity Cost:
0.100
[\$/kWh]

Natural Gas Cost:
6.00
[\$/MMBtu]

Student Exercise (Increase Chilled Water Supply Temperature)

Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers:

CHWT Setpoint:

Geographic Location:

Condenser Cooling Method:

Water-Cooled Summary

Constant CWT?:

Constant CWT Setpoint:

Tower Summary

Type:

#Towers: Sizing:

Fan Motor HP: Tons:

Number of Cells per Tower:

Pump Summary

	CHW	CW
Variable Flow?:	<input type="text" value="No"/>	<input type="text" value="No"/>
Flow Rate [gpm/ton]:	<input type="text" value="2.4"/>	<input type="text" value="3"/>
Motor Size (hp):	<input type="text" value="20"/>	<input type="text" value="25"/>
Pump Efficiency [%]:	<input type="text" value="75"/>	<input type="text" value="75"/>
Motor Efficiency [%]:	<input type="text" value="85"/>	<input type="text" value="85"/>

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 2			
Centrifugal	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 3			
Helical Rotary	<input type="text" value="350"/>	<input type="text" value="10"/>	<input type="text" value="0.750"/>

Energy Summary

Chiller Energy: kWh

Tower Energy: kWh

Pump Energy: kWh

Total Energy: kWh

Buttons:

- Go To Operating Cost Reduction Screen
- Go To Current Chiller Details Screen
- Go To Current Tower Details Screen
- Go To Current Pump Details Screen
- Return to Input Screen
- Export to File
- Show System Graphic
- Show Energy/Cost Graphic
- Exit Program
- Comments Outtemp

New Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers:

CHWT Setpoint:

Geographic Location:

Condenser Cooling Method:

Water-Cooled Summary

Constant CWT?:

Constant CWT Setpoint:

Tower Summary

Type:

#Towers: Sizing:

Fan Motor HP: Tons:

Number of Cells per Tower:

Pump Summary

	CHW	CW
Variable Flow?:	<input type="text" value="No"/>	<input type="text" value="No"/>
Flow Rate [gpm/ton]:	<input type="text" value="2.4"/>	<input type="text" value="3"/>
Motor Size (hp):	<input type="text" value="20"/>	<input type="text" value="25"/>
Pump Efficiency [%]:	<input type="text" value="75"/>	<input type="text" value="75"/>
Motor Efficiency [%]:	<input type="text" value="85"/>	<input type="text" value="85"/>

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Centrifugal	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 2			
Centrifugal	<input type="text" value="1000"/>	<input type="text" value="10"/>	<input type="text" value="0.650"/>
Chiller 3			
Helical Rotary	<input type="text" value="350"/>	<input type="text" value="10"/>	<input type="text" value="0.750"/>

Energy Summary

Chiller Energy: kWh

Tower Energy: kWh

Pump Energy: kWh

Total Energy: kWh

Buttons:

- Return to New Input Screen
- Go To Proposed Chiller Details Screen
- Go To Proposed Tower Details Screen
- Go To Proposed Pump Details Screen
- Show System Graphic
- Show Energy/Cost Graphic
- Show Savings Summary Screen

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

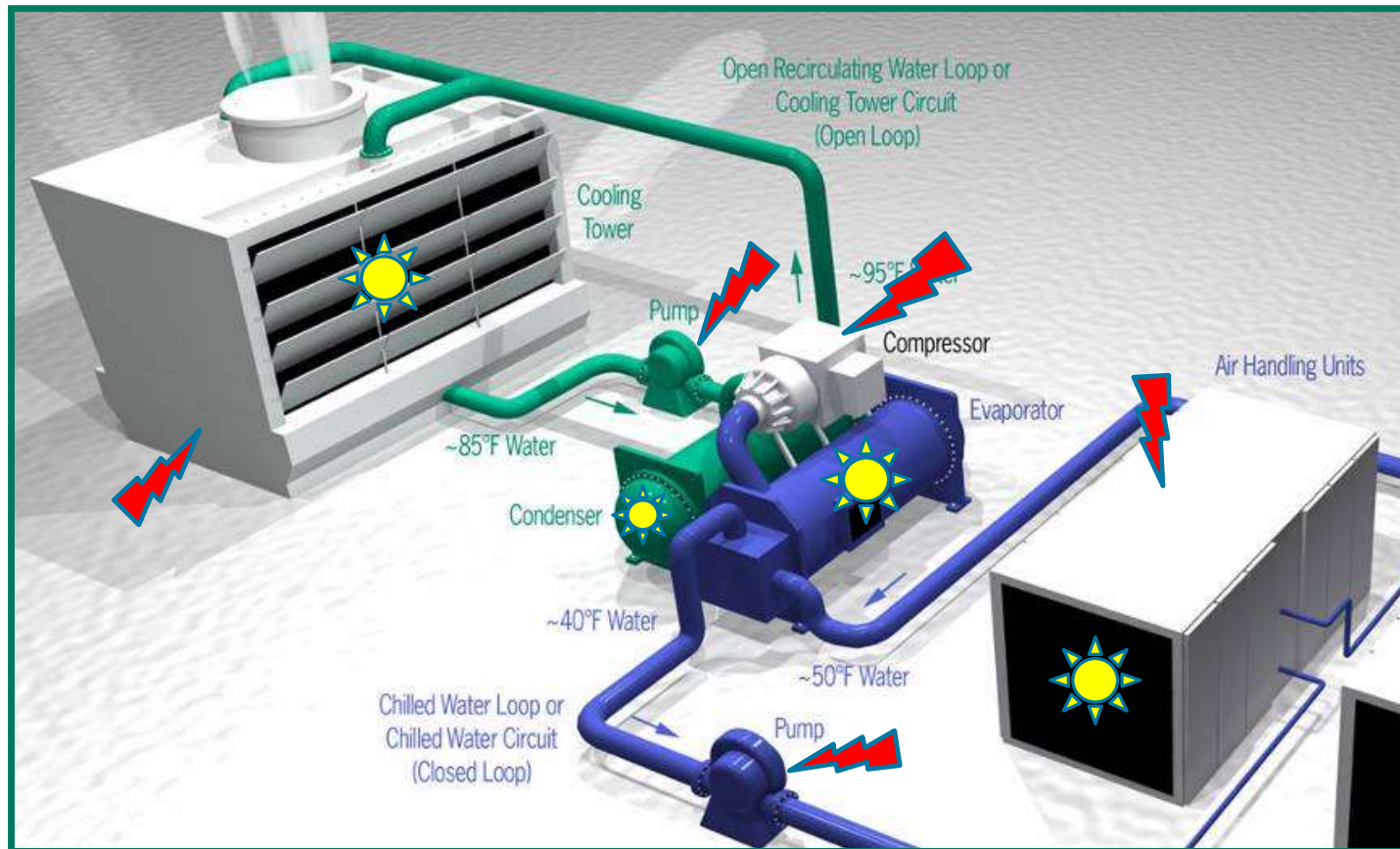
- As the chilled water supply temperature setpoint is increased
 - The Lift reduces
 - This reduces the work done by the compressor implying a lower kW/RT
 - This results in direct chiller savings
 - The heat rejected by the condenser is the sum of the evaporator load (which is the same) and the compressor 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 – if the chilled water flow remains constant

A Simple Chilled Water System

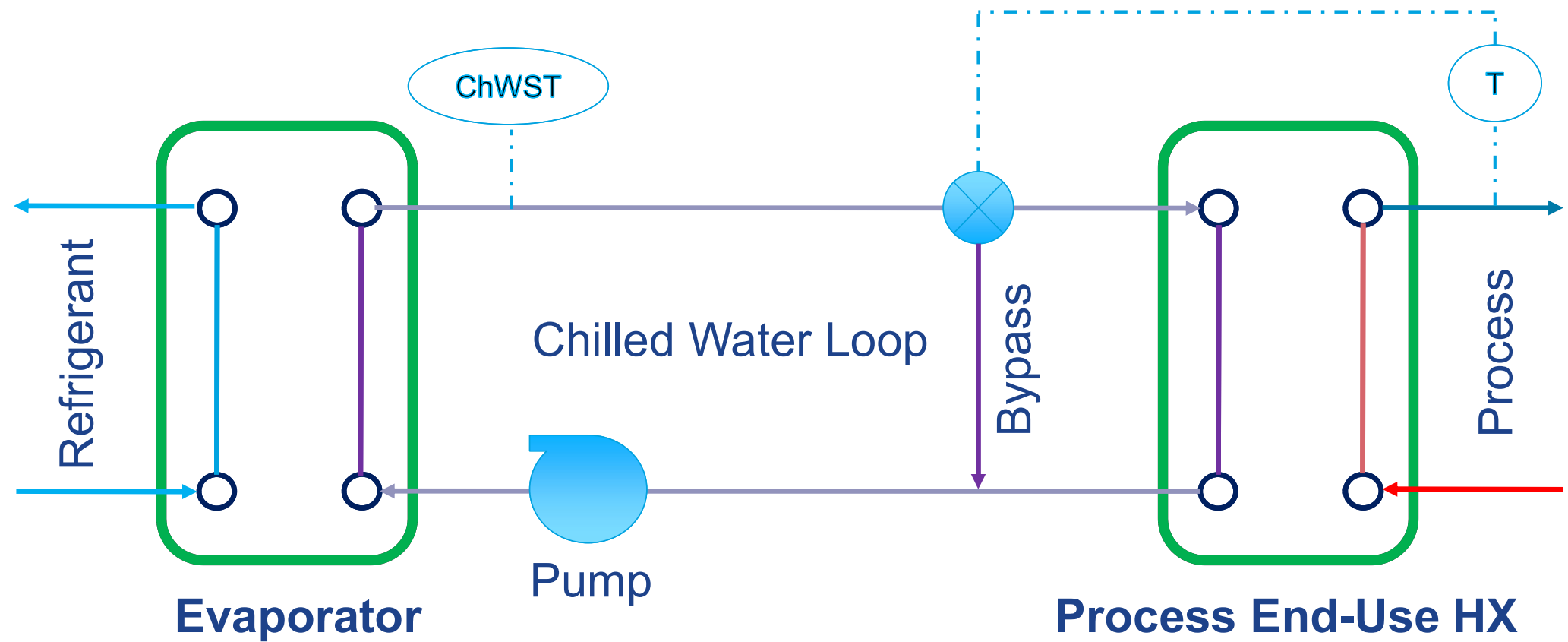

Electrical

Nexus

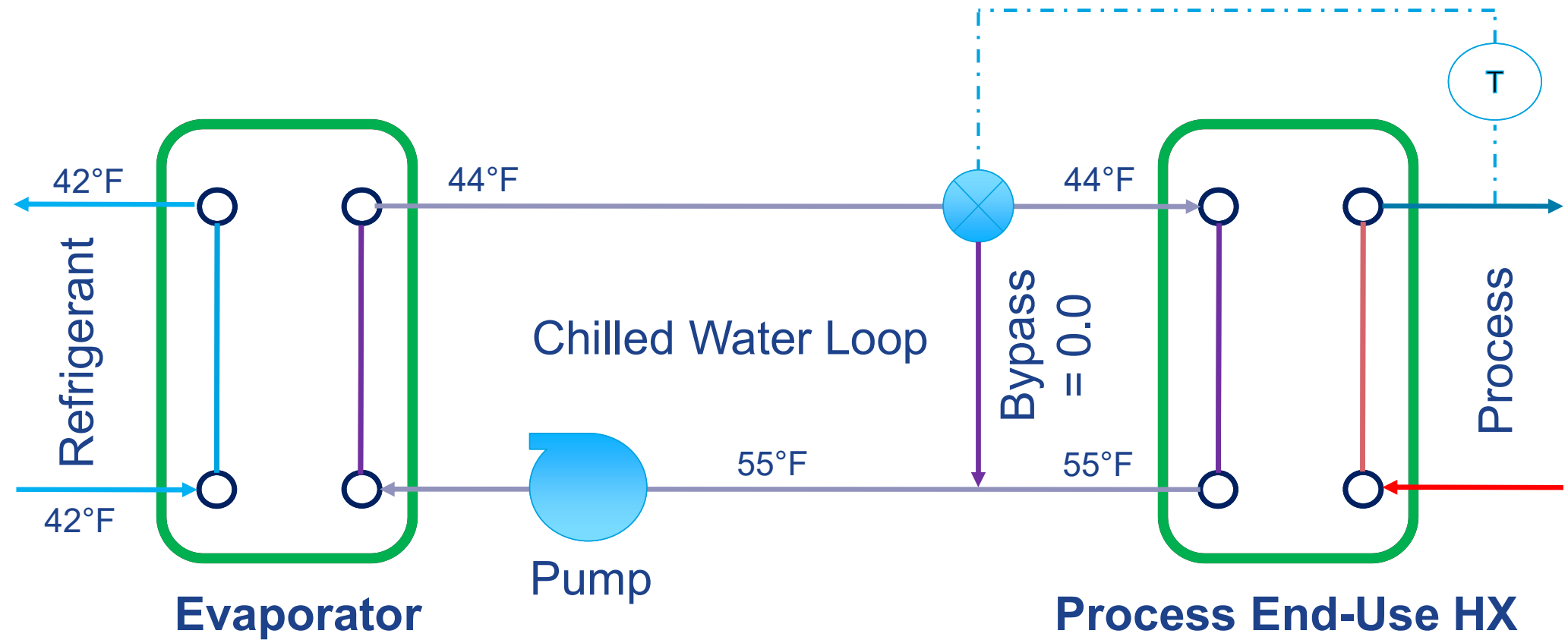

Thermal



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
- $Q_{\text{evap}} = UA * \text{LMTD}$
- $UA_{\text{evap}} = 17.01 \text{ RT/°F}$

$$\text{LMTD} = \frac{(T_{\text{out}} - T_{\text{sat}}) - (T_{\text{in}} - T_{\text{sat}})}{\ln \frac{(T_{\text{out}} - T_{\text{sat}})}{(T_{\text{in}} - T_{\text{sat}})}}$$

Easy Tell-tale Signs to Raise ChWST

- An inline valve – typically, 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 throttled to less than 80%
 - 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

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

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? Current Temperature °F Proposed Temperature? °F

Decrease Condenser Cooling Water Supply Temperature

Decrease CWT? Current Temperature °F Proposed Temperature? °F

Use Sliding Condenser Water Temperature

Cannot be used when Decreasing Condenser Water Supply Temperature

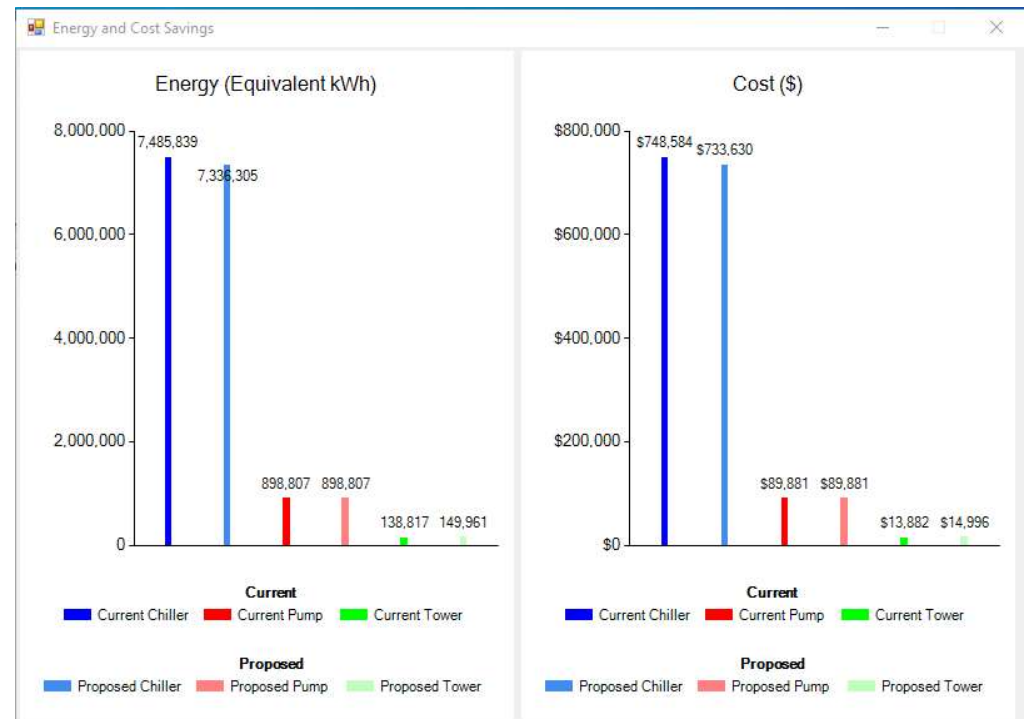
- One word of caution – It is always best to start CWSAT from the base model whenever modeling EEOs
 - It avoids leaving certain project ON in error

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

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 Speed³
- 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 pumps VFD application individually
 - Chilled water
 - Condenser water

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature
Decrease CWT?

Use Sliding Condenser Water Temperature
Use Sliding Temperature?

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)
Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)
Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control?

Use Free Cooling when Possible
Implement free cooling?

Replace Chiller Refrigerant
Change Refrigerants?

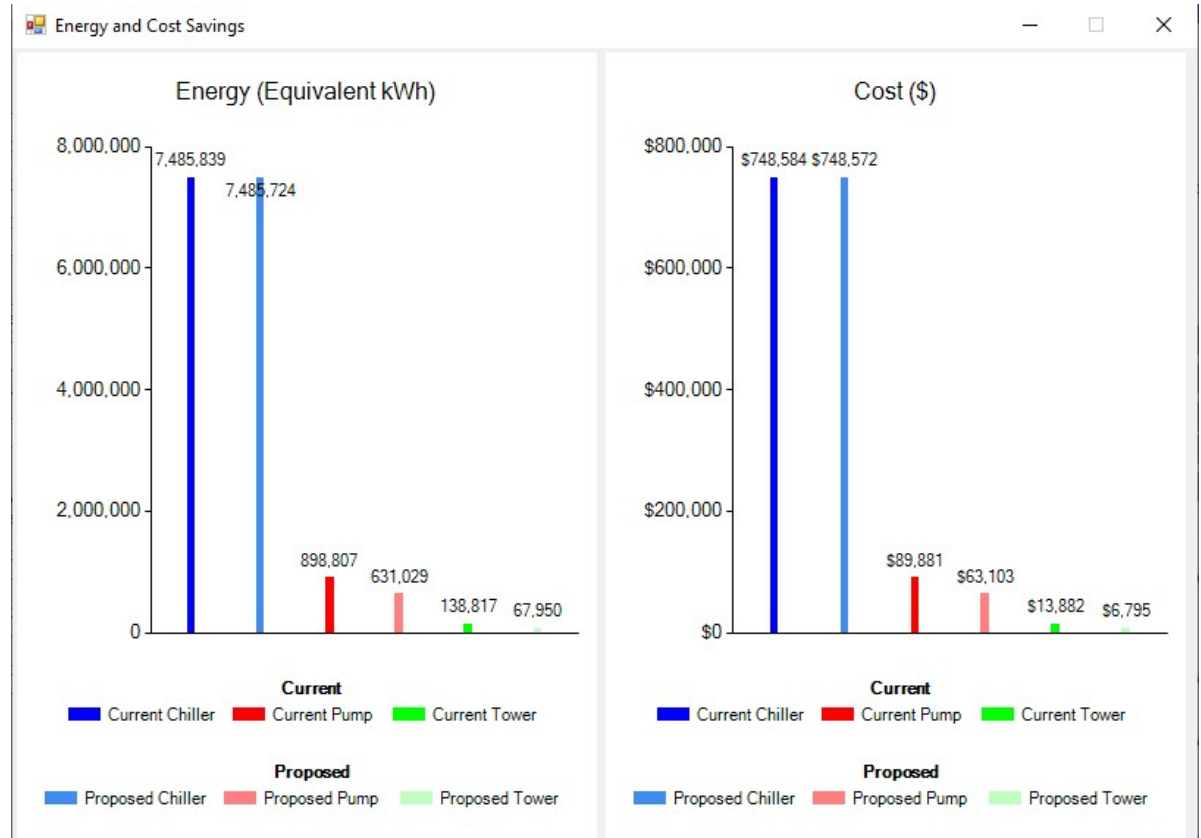
Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

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



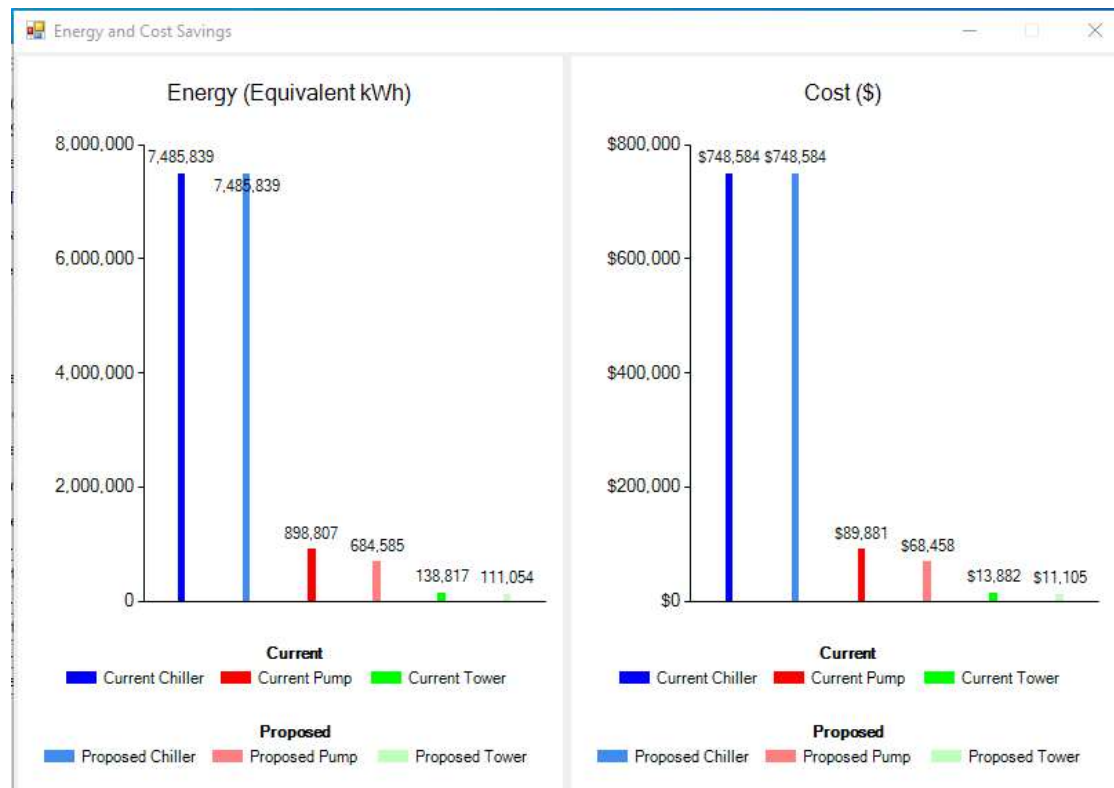
Modeling Application of VFDs to CHW Pumps in CWSAT

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



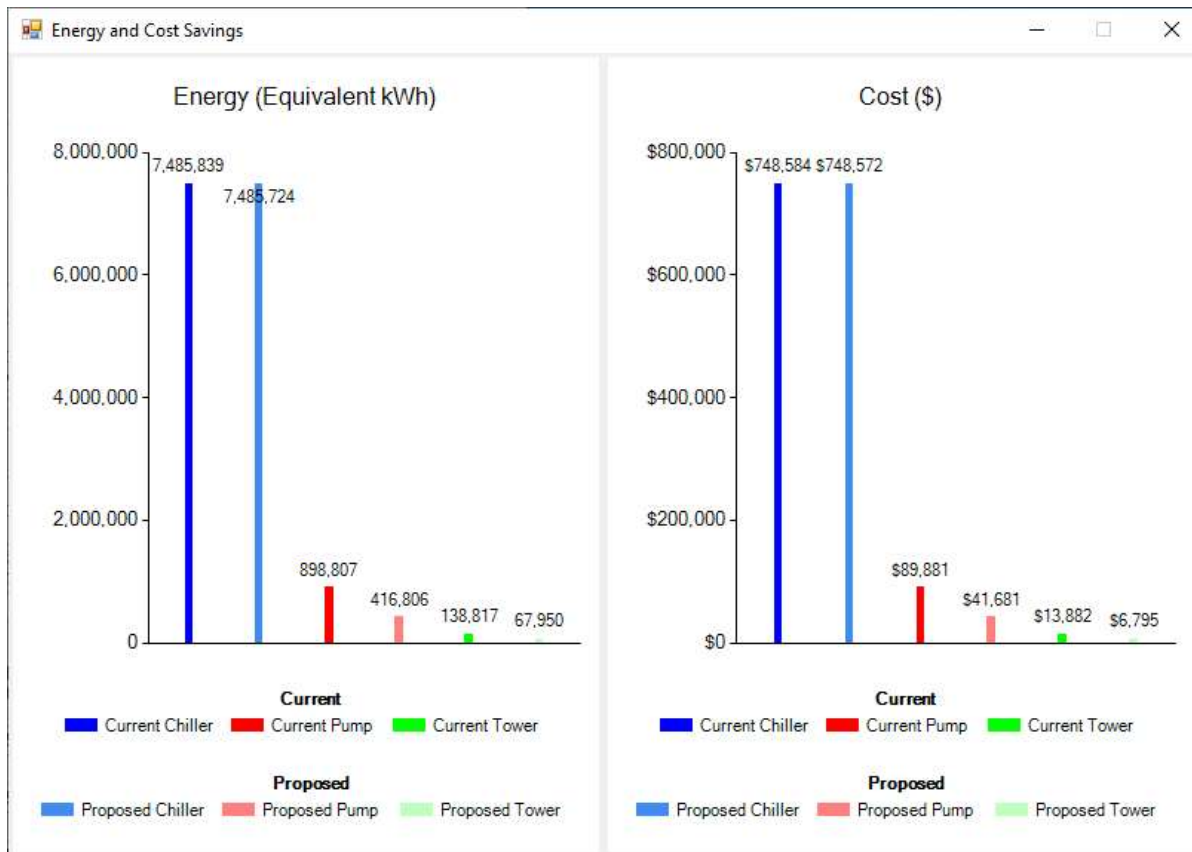
Modeling Application of VFDs to CHW & CW Pumps in CWSAT

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

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
 - $\text{Flow} \propto \text{Speed}$
 - $\text{Power} \propto \text{Speed}^3$
- 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

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature
Decrease CWT?

Use Sliding Condenser Water Temperature
Use Sliding Temperature?

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)
Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)
Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control? Current Control Proposed Control?

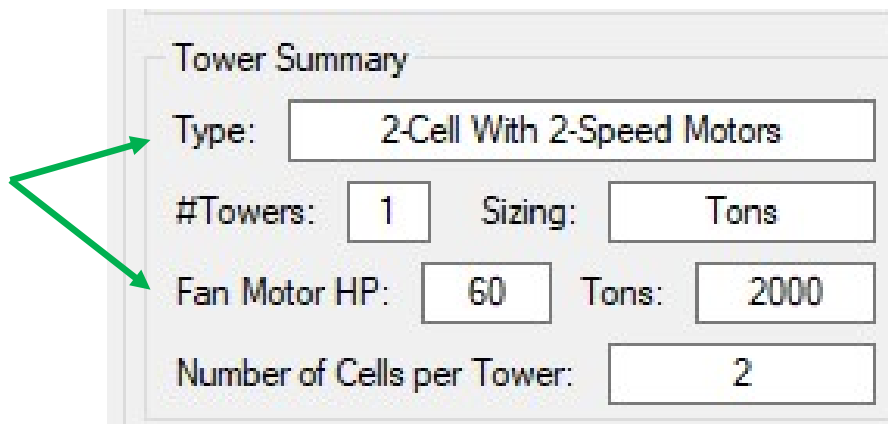
Use Free Cooling when Possible
Implement free cooling?

Replace Chiller Refrigerant
Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

Application of Cooling Tower Fan Speed Control

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



Tower Summary

Type:

#Towers: Sizing:

Fan Motor HP: Tons:

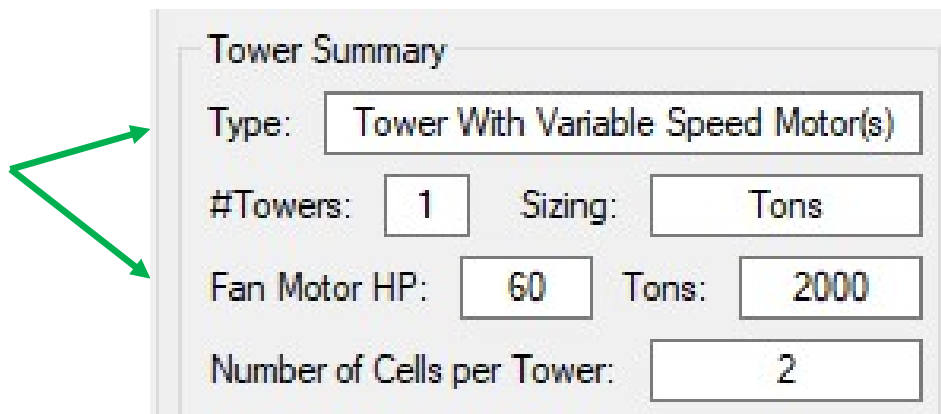
Number of Cells per Tower:

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	<input type="text" value="0"/>		<input type="text" value="\$0"/>
Tower Summary:	<input type="text" value="78,759"/>		<input type="text" value="\$7,876"/>
Pump Summary:	<input type="text" value="0"/>		<input type="text" value="\$0"/>
Total:	<input type="text" value="78,759"/>		<input type="text" value="\$7,876"/>

Application of Cooling Tower Fan Speed Control

- CWSAT cooling tower model w/VFD fan control



Tower Summary

Type:

#Towers: Sizing:

Fan Motor HP: Tons:

Number of Cells per Tower:

Savings Summary Screen : VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	<input type="text" value="-2"/>		<input type="text" value="\$0"/>
Tower Summary:	<input type="text" value="79,151"/>		<input type="text" value="\$7,915"/>
Pump Summary:	<input type="text" value="0"/>		<input type="text" value="\$0"/>
Total:	<input type="text" value="79,150"/>		<input type="text" value="\$7,915"/>

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

Implement Free Cooling (Water side Economizer)

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

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?

Decrease Condenser Cooling Water Supply Temperature
Decrease CWT?

Use Sliding Condenser Water Temperature
Use Sliding Temperature?

Apply Variable Speed Control to Chilled and/or Condenser Water Pump(s)
Apply VSD to CHW Pump? Apply VSD to CW Pump?

Replace Chiller(s)
Replace Chiller(s)?

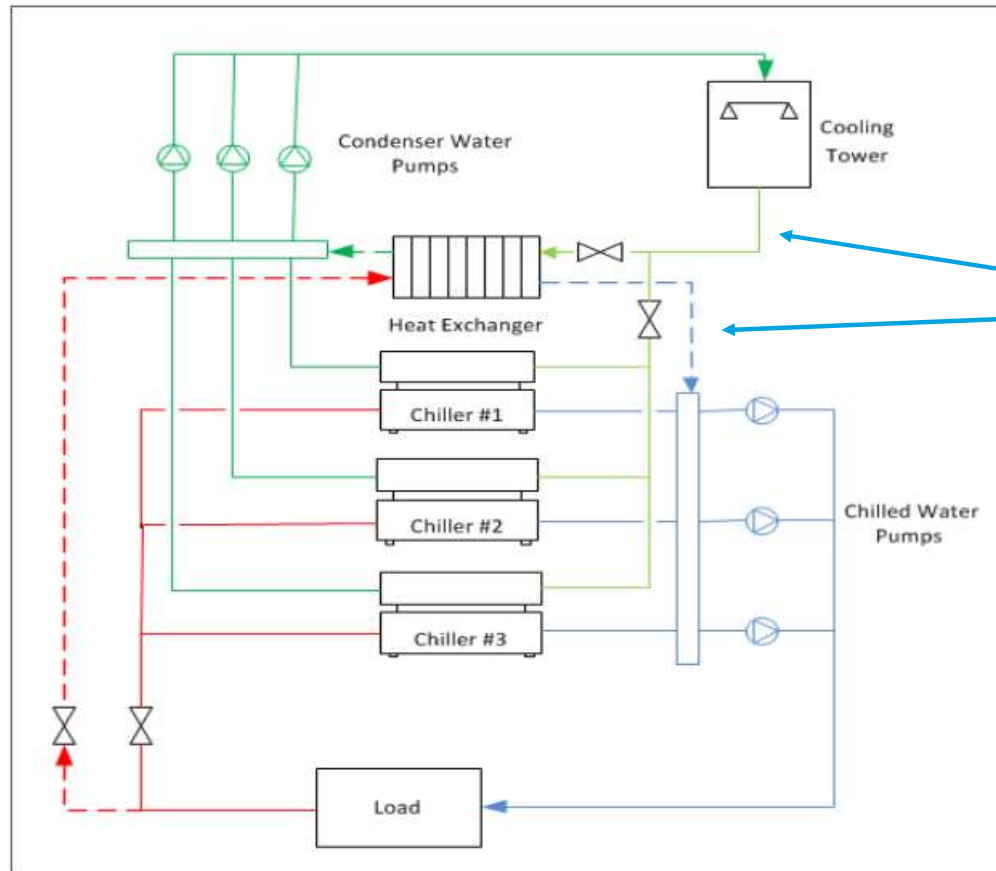
Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control?

Use Free Cooling when Possible
Implement free cooling? Heat exchanger required? HEX approach temperature? °F

Replace Chiller Refrigerant
Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

Student Exercise (Using Free Cooling)



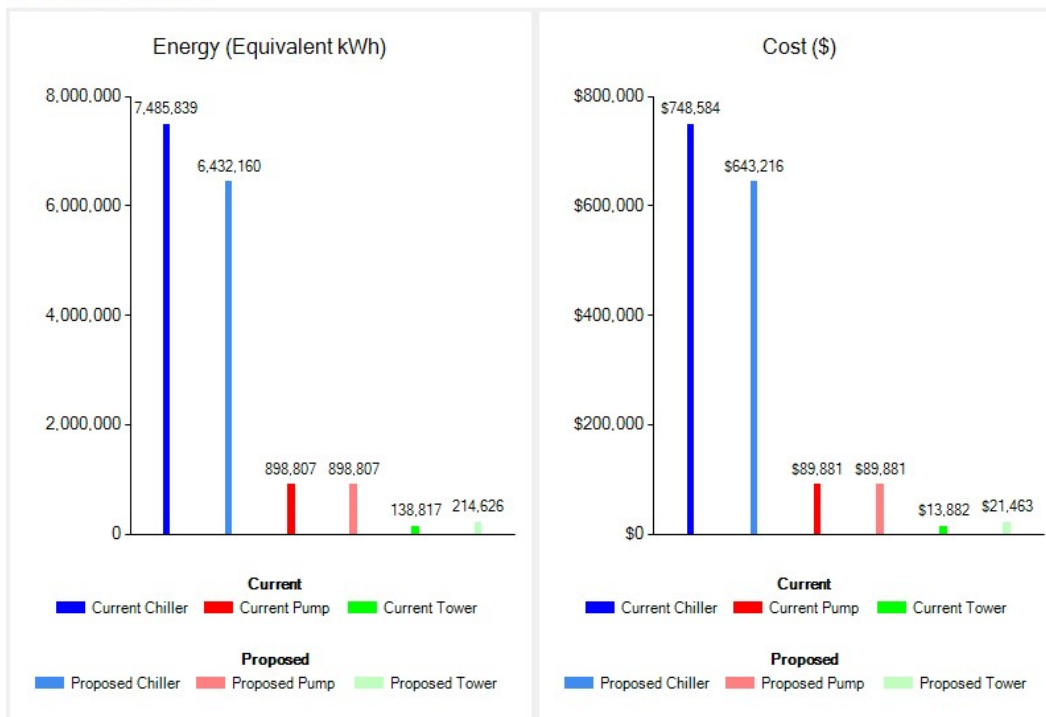
Approach of HX
Temperature
difference between
these 2 streams

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

Energy and Cost Savings



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

Type 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 °F	35 - 45 °F	45 - 55 °F	55 - 65 °F	65 - 75 °F	WB > 75 °F	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

Replace Refrigerant

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

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 gauge 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?

Decrease Condenser Cooling Water Supply Temperature

Decrease CWT?

Use Sliding Condenser Water Temperature

Use Sliding Temperature?

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

Apply VSD to CHW Pump?

Apply VSD to CW Pump?

Replace Chiller(s)

Replace Chiller(s)?

Upgrade Cooling Tower Fan Speed Control

Upgrade Fan Control?

Use Free Cooling when Possible

Free Cooling is already implemented

Replace Chiller Refrigerant

Change Refrigerants?

Install a VSD on each Centrifugal Compressor Motor

Number of centrifugal chillers:

Install VSDs?



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

Kahoot Quiz Time



Thank You all for attending today's webinar.

See you all on next Thursday – July 7, 2022 – 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
rapapar@c2asustainable.com**