



Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment

Session 6

Thursday – July 7, 2022

10 am – 12:30 pm

Welcome

- Welcome to the 6th 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; Assessment Presentation**
- Week 7 (July 14) – MEASUR, 3EPlus; Case Studies; Refrigerants; Reclamation and O&M
- Week 8 (July 21) – Industrial Process Cooling (Chilled water) System VINPLT Wrap-up Presentations

Agenda – Session 6

- Welcome and Introductions
- Safety and Housekeeping
- Today's Content:
 - Review of Session 5 & Homework
 - Quantifying Opportunities using CWSAT
 - Preparing for the VINPLT Assessment Presentation
- Kahoot Quiz Game
- Q&A



Safety and Housekeeping

- Safety Moment

- Be mindful of electrical wiring and any other instrumentation conduits, etc while doing a plant walk-through - They can be tripping hazards putting you in immediate danger with electrical and rotating equipment

- 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 5

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



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?

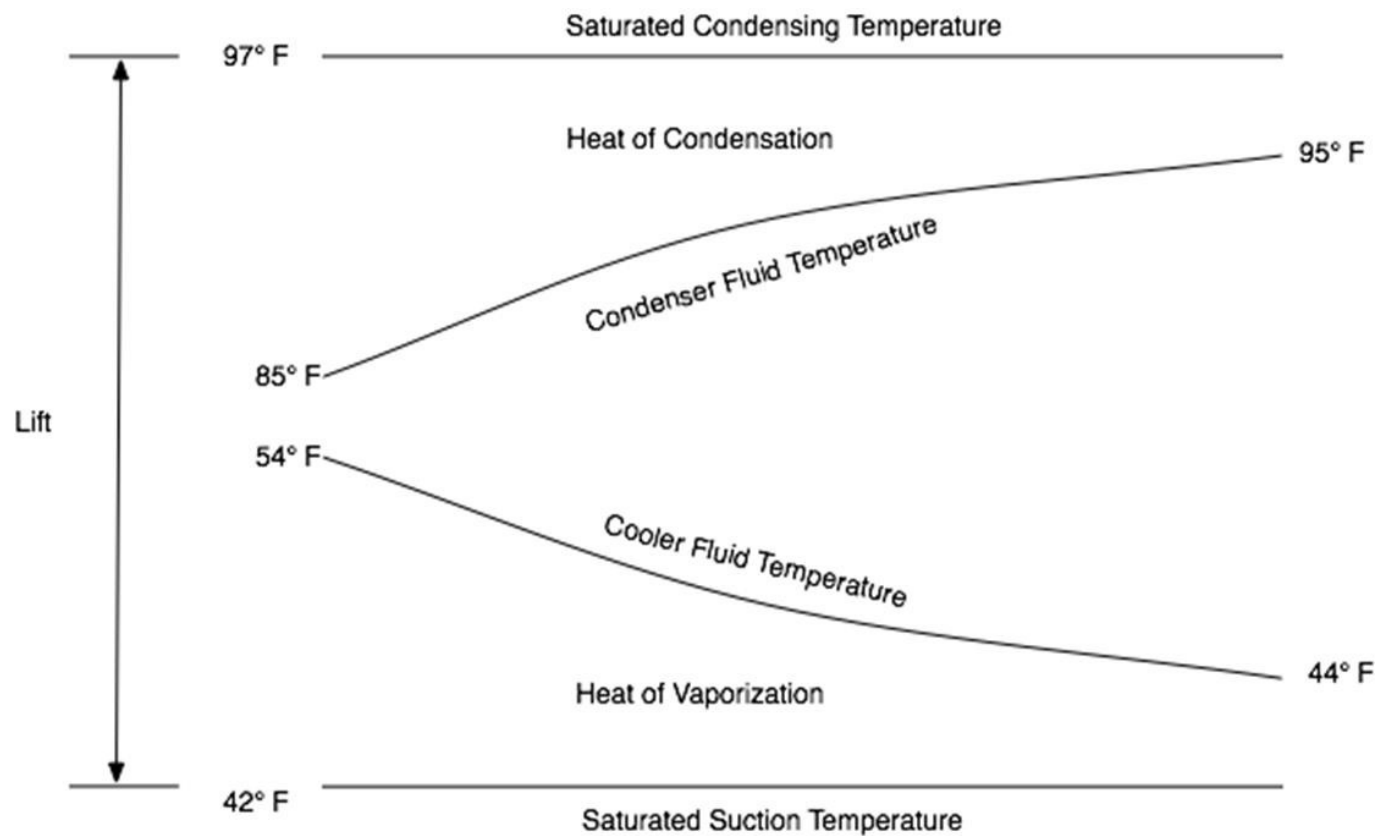
Use Free Cooling when Possible
Implement free cooling?

Replace Chiller Refrigerant
Change Refrigerants?

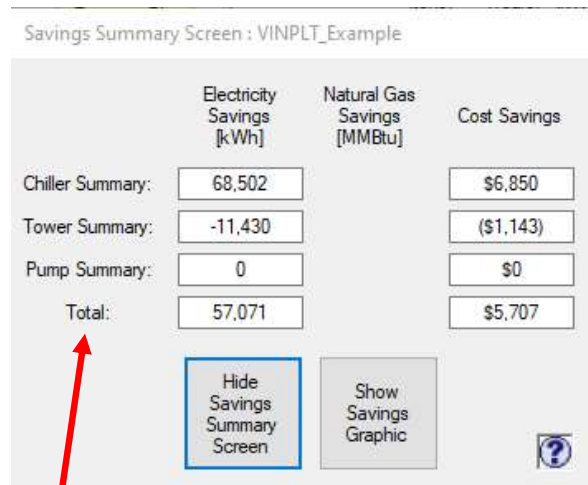
Install a VSD on each Centrifugal Compressor Motor
Number of centrifugal chillers: Install VSDs?

Remember Lift!

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



Student Exercise (Reduce Entering Condenser Water Temperature)



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



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



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

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

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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?

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:

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Replace Chiller(s)
Replace Chiller(s)?

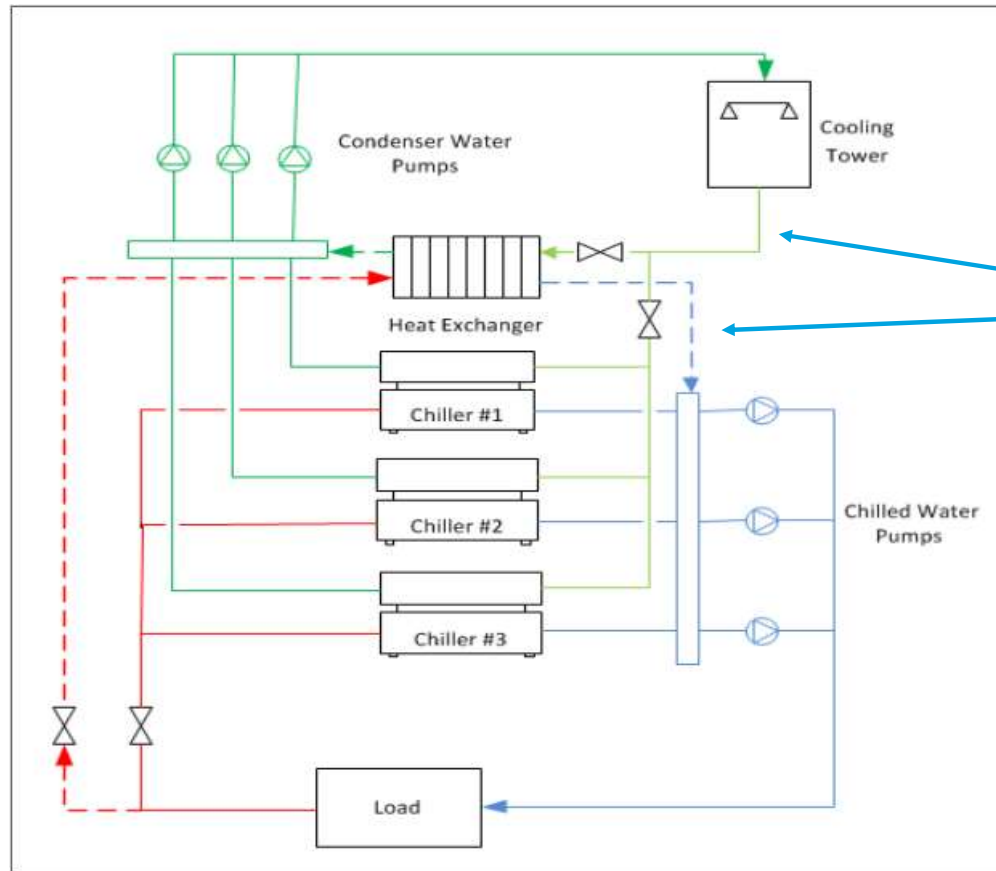
Upgrade Cooling Tower Fan Speed Control
Upgrade Fan Control? Current Control Proposed Control?

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?

Student Exercise (Using Free Cooling)



Approach of HX
Temperature
difference between
these 2 streams

Eliminate Inappropriate Uses of Chilled Water / Reduce Cooling Load

Reduction of Cooling Load

- Difficult to understand & implement
- Extreme caution required since a thorough understanding of the process will be required
- Very large energy and cost savings can be achieved by implementing a cooling load reduction strategy
- Several opportunities exist for reducing overall cooling load (RT)
- Start by asking two simple questions
 - Why is cooling needed for this end-use?
 - If cooling is required, what is the cooling load / temperature profile?

Cooling Load

- Amount of cooling (RT) required by the process / plant
- All chiller systems are designed to be Load Followers (dependent)
 - Analogous to a boiler generating steam – a boiler doesn't know how much steam is needed – it continues to produce steam until it meets the setpoint pressure
 - A chiller plant continues to produce the cooling effect until it meets the setpoint chilled water outlet (supply) temperature
- Load profile is very important for every plant
- Cooling load can vary significantly based on
 - Production rate and schedules of operation
 - Seasonality due to weather and production cycles
 - Occurrence of certain losses – distribution system loss
 - Inappropriate uses of chilled water

Inappropriate Uses of Chilled Water

- Inappropriate chilled water uses include, but not limited to:
 - Processes where cooling tower water would be adequate to remove the heat
 - Areas where cooling is not needed – scheduled-based; seasonal; decommissioned processes / plant areas
 - Applications where no pre-cooling is done
 - Temperature pinch analysis
 - Systems where a fluid or product is cooled and then immediately heated again to bring it to ambient temperature
 - Take care to make sure that this is NOT a time-temperature process requirement
 - Processes where excessive cooling is demanded (most times is reflected in the chilled water set-point temperature)

Student Exercise

- The industrial plant engineer recently completed a chilled water system audit and identified some areas of inappropriate chilled water usage
- One identified area is the use of ~100 gpm of chilled water in the packaging area
- As per the manufacturer's recommendations, this system can use cooling tower water for cooling
- Use the CWSAT model to determine how much system energy could be saved if the plant shifted to cooling tower water for this process
- Discuss concerns and issues with the chosen option and what steps can be taken to mitigate them

Student Exercise

- How do we calculate cooling load of 100 gpm chilled water?
- $Q_{load} = m \cdot C_p \cdot \Delta T$
- $Q_{load} = 100 \frac{gal}{min} * 500 \frac{lb/hr}{gpm} * 1.0 \frac{Btu}{lb-F} * \Delta T$
- $\Delta T = \text{Chilled water return} - \text{Chilled water supply} = 55 - 44 = 11.0^\circ F$
- $Q_{load} = 100 \frac{gal}{min} * 500 \frac{lb/hr}{gpm} * 1.0 \frac{Btu}{lb-F} * 11.0^\circ F$
- $Q_{load} = 550,000 \text{ Btu/hr} = 46 \text{ RT}$

Student Exercise

- What are the modeling strategies to be used in CWSAT to model this cooling demand savings opportunity?
 - 46 RT
- Simple approach (1st method) – Proportionate energy and cost reduction
 - Not accurate but gets in the ballpark for detailed analysis further
 - Not representative of actual field operations but a great starting point
- Recall “base model” information and define “average cooling load”

Chilled Water System Baseline Model

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

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?: Yes

Constant CWT Setpoint: 85

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
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Tower Energy:

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

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

8,523,463	kWh	\$852,346
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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

- Overall operating energy cost of the chilled water system = \$852,346
- Can we determine specific cooling operating cost - \$/RT
- A difficult exercise but can be obtained with significant data analysis

Chiller Operating Details Screen (Baseline)

Current Chiller Details Screen : VINPLT_Example

	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	

Method 1 – Simple Approach

- Determine Annual Average Operating Cooling Load (RT)
- Each chiller's annual average operating cooling load (RT) can be calculated mathematically by a weighted sum operating load and operating hours
- The annual energy consumption and energy operating cost can be divided by this average operating load to define specific (unit) cooling cost (\$/RT)

Chiller Load, Ton-hours & Average Load Calculations

Chiller #1	1000	RT	
% Load	Actual Load (RT)	Hours	Ton-Hours
-	-	444	-
10	100	-	-
20	200	-	-
30	300	-	-
40	400	873	349,200
50	500	1,754	877,000
60	600	1,753	1,051,800
70	700	1,746	1,222,200
80	800	1,317	1,053,600
90	900	873	785,700
100	1,000	-	-
	Total	8,760	5,339,500
Average	610	RT	

Chiller #3	350	RT	
% Load	Actual Load (RT)	Hours	Ton-Hours
-	-	2,634	-
10	35	-	-
20	70	-	-
30	105	2,627	275,835
40	140	-	-
50	175	2,626	459,550
60	210	-	-
70	245	-	-
80	280	-	-
90	315	-	-
100	350	873	305,550
	Total	8,760	1,040,935
Average	119	RT	

Method 1 (Simple Approach)

■ Average Load

- $Q_{\text{average}} = (610) + (610) + (119) = 1,339 \text{ RT}$

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

- Unit cost of cooling

- $\text{Energy}_{\text{average}} = \frac{8,523,463}{1,339} = \sim 6,366 \frac{\text{kWh}}{\text{RT-y}}$

- $\text{Cost}_{\text{average}} = \frac{852,346}{1,339} = \sim 636 \frac{\$}{\text{RT-yr}}$

- Cost savings for 46 RT cooling load

- Savings = $636 * 46 = \$ 29,250$ annually

Method 2 – Impact Level Analysis

- This would be very representative of actual field operations
- Understand the control methodology of the chiller plant and how the chiller plant responds to a marginal change in the load
- Once the impact chiller(s) is/are identified and the representative chiller load reduction on each individual chiller is identified, then develop a NEW load profile of the impact chillers
- Run the CWSAT model with this NEW load profile and compare the energy (cost) usage to determine the energy savings
- This would be the most accurate analysis

Are the Savings Achievable?

- Be very careful and conduct a high-level of due diligence before implementing this opportunity
- Process **MUST** be understood
- Do not rob Peter to pay Paul!
- Was this chilled water **NOT** required for this end-use?
- If the process doesn't need to be cooled at all – then these savings are achievable
- If process needs cooling tower water cooling - then an incremental fan power will be required and may offset some savings

Replacing Chiller(s)

Replacing Chiller(s)

- A very common question for almost every chiller plant energy assessment
- Several categories
 - Replace like for like with higher energy efficiency chillers – especially, when one or more chillers are at their end-of-life with repeated failures, high maintenance costs, etc.
 - Replace with optimized rating higher energy efficiency chillers
 - Retrofit certain chillers to improve their energy efficiency – adding VFD
 - Change heat rejection methodology – air-cooled to water-cooled or vice versa
- CWSAT can be used to model all the categories of opportunities

Replacing (Adding) with Higher Energy Efficiency Chillers

Replacing Chillers

Operating Cost Reduction Opportunities Screen

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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)? *New chillers may be selected on the New Input Screen.*

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?

Replacing Chillers

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? 85 °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
Variable Flow? No
Flow Rate [gpm/ton]: 2.4
Motor Size [hp]: 20
Pump Efficiency [%]: 75
Motor Efficiency [%]: 85

Proposed Chiller Data
Same Chiller Selections
New Chiller Selections
User Chiller ? (Y/N)

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
Variable Flow? No
Flow Rate [gpm/ton]: 2.4
Motor Size [hp]: 20
Pump Efficiency [%]: 75
Motor Efficiency [%]: 85

Proposed Chiller Data
User Chiller ? (Y/N)
Compressor Type
Chiller Capacity [tons]
FLE Value [kW/ton]
Number of Chillers: 1, 2, 3, 4, 5
Return to Output Screen, Restart Screen, Exit Program

Provides the option to add, remove or keep the same number of chillers

Replacing Chillers

Proposed Chiller Data

Number of Chillers: 3

User Chiller ? (Y/N)	Compressor Type	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

OK

Presents the chillers as in the base model and then users can change the type, efficiency, capacity, age – as needed

New Operating Schedule Screen : VINPLT_Example

Weekly Operating Schedule

The typical weekly hours of operation are assumed to remain the same.

Monthly Operating Schedule

The typical weekly hours of operation are assumed to remain the same.

Loading Data

Does the chilled water system load vary according to the ARI 550/590 schedule? No

Does chiller loading vary from month to month? No

Does chiller loading vary from chiller to chiller? Yes

OK

Restart Screen

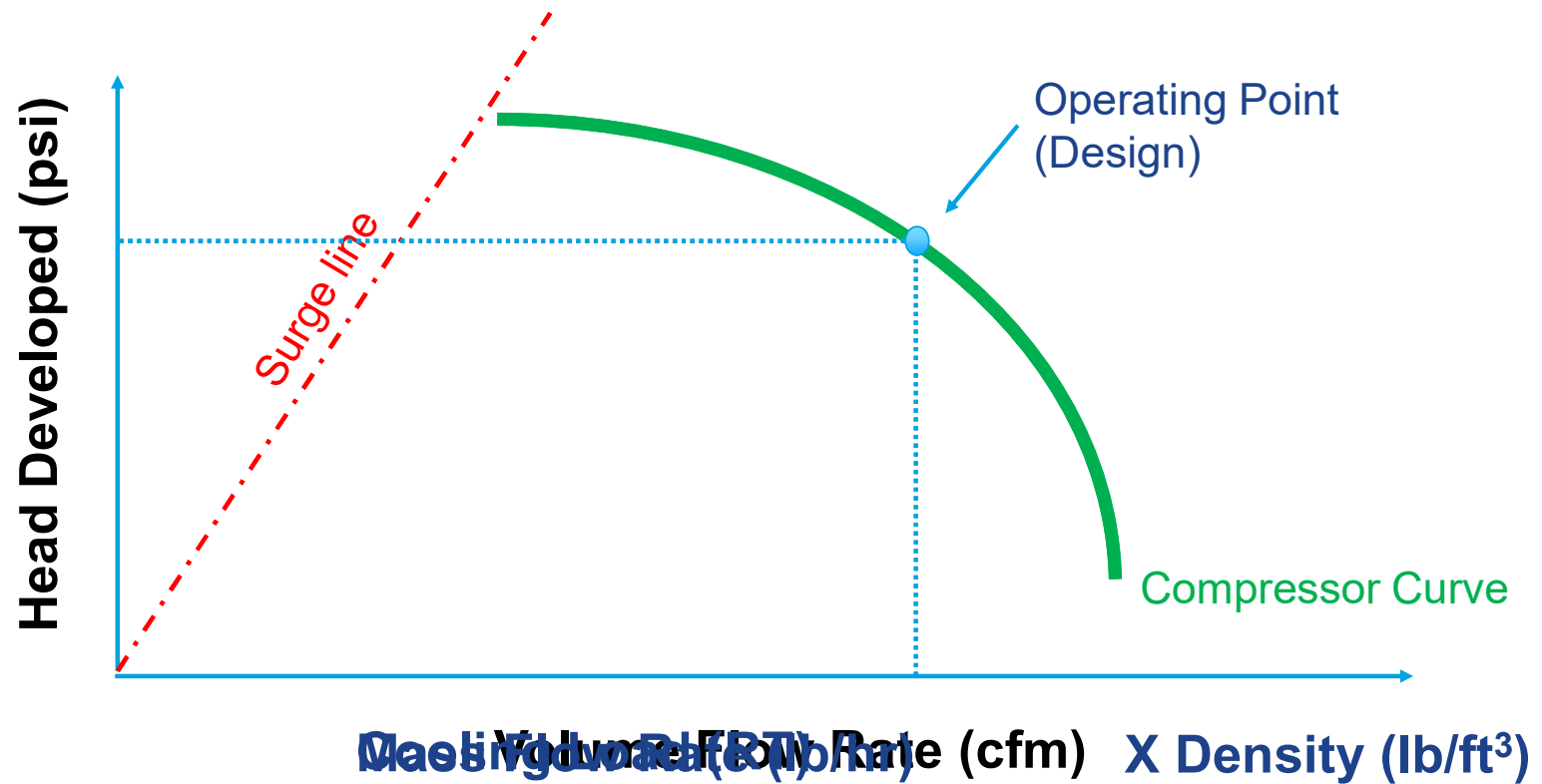
Exit Program

Application of Variable Frequency Drives

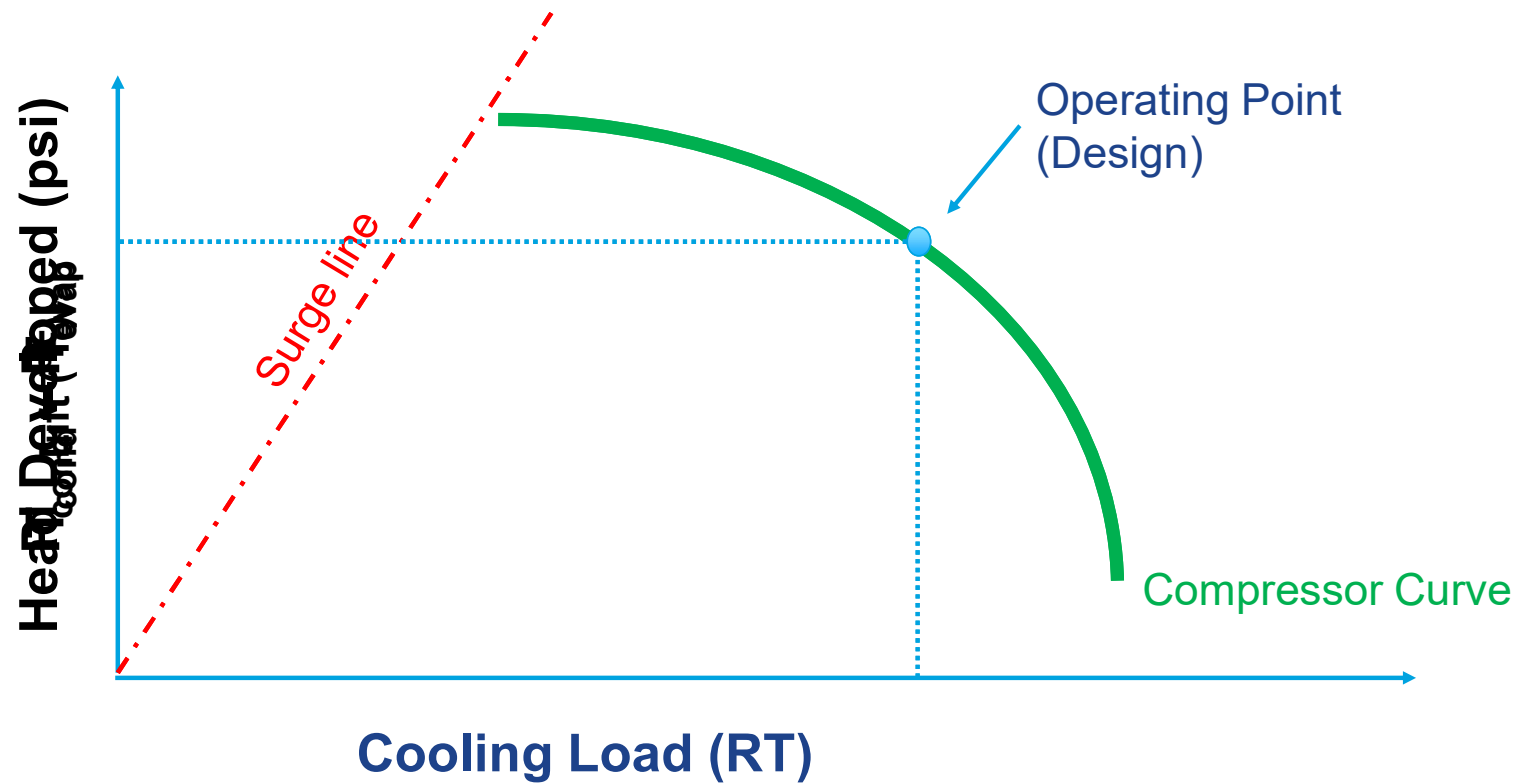
Implement Variable Frequency Driven Chillers

- This maybe a capital-intensive Energy Efficiency Opportunity but deserves a lot of merit
- Overall chiller plant efficiency can be improved by replacing old chillers with newer energy efficient systems – most new packaged chillers will come with a VFD option
- VFD chillers take advantage of lower ambient temperatures (lower lift) and correspondingly lower cooling loads (lower refrigerant flow rates) at those conditions
- The centrifugal compressor follows the cube law
 - $\text{Flow} \propto \text{Speed}$
 - $\text{Power} \propto \text{Speed}^3$

Understanding VFD Application on a Centrifugal Chiller

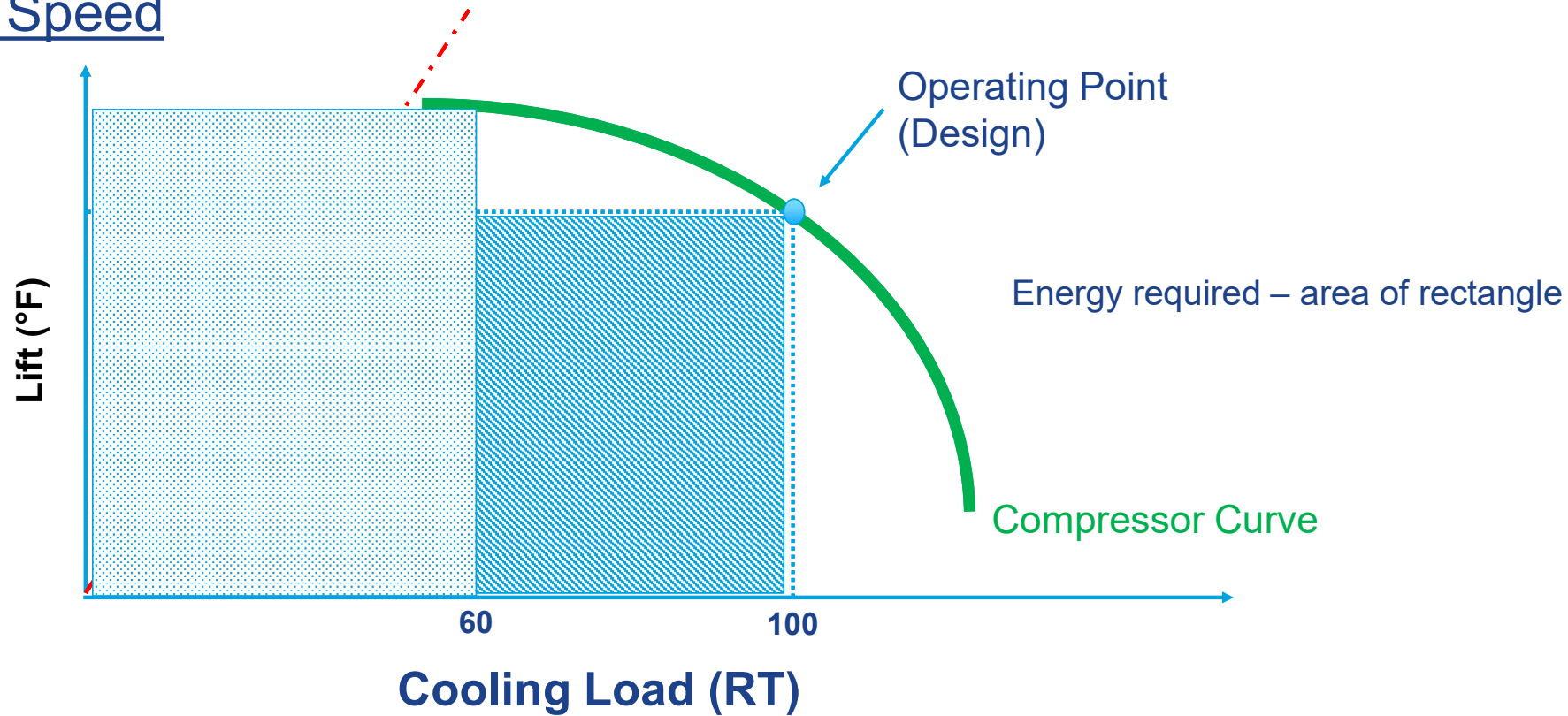


Understanding VFD Application on a Centrifugal Chiller



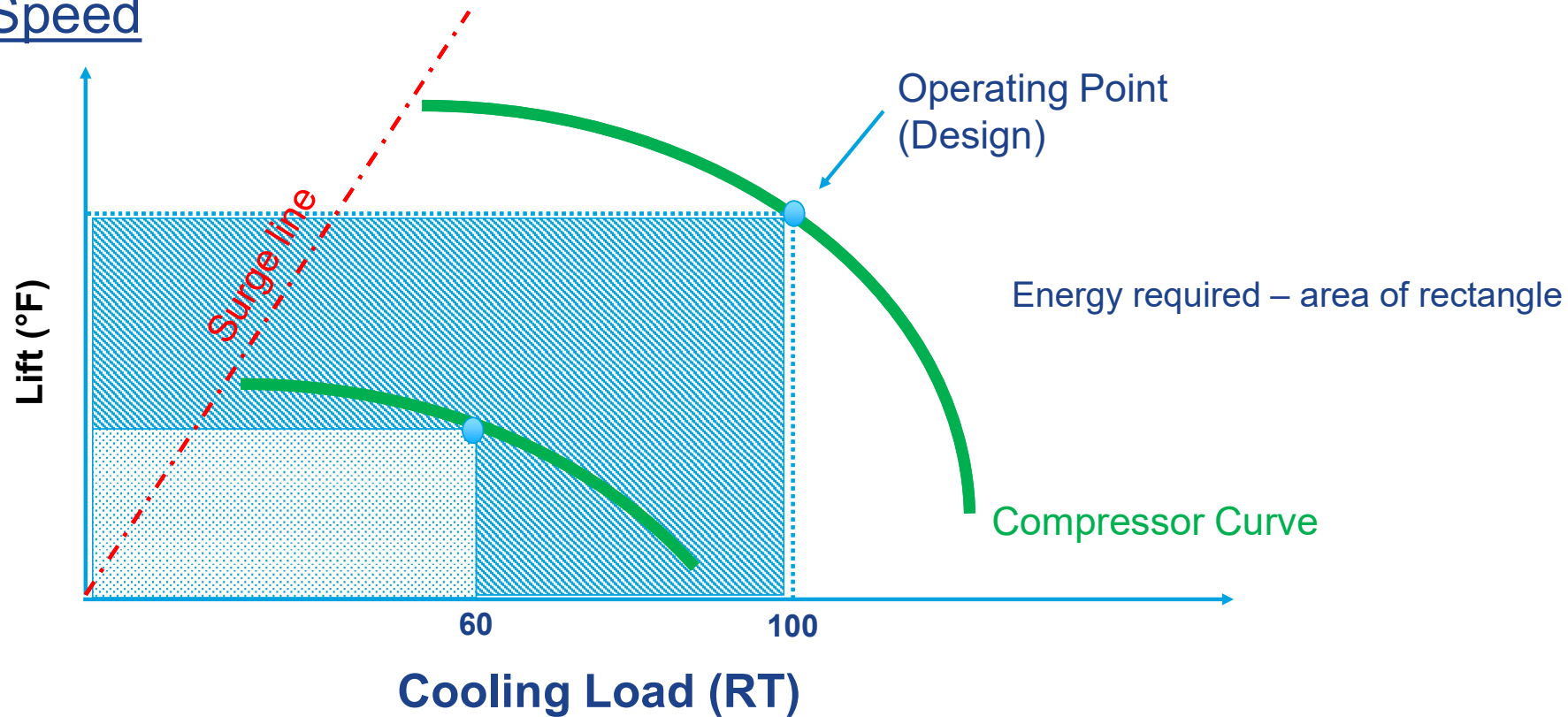
Understanding VFD Application on a Centrifugal Chiller

Constant Speed



Understanding VFD Application on a Centrifugal Chiller

Variable Speed



Understanding VFD Application on a Centrifugal Chiller

- New chiller packages now have the option of Variable Frequency Drives (VFD) for compressors
- VFD efficiency is extremely high (99%) and more importantly, it offers a benefit on the drive side by providing
 - Soft start capability
 - Power factor correction
- Reducing compressor speed reduces flow (tonnage) **proportionately** but reduces power by the **third power** – Centrifugal Law

Modeling Impact of VFD Chillers in CWSAT

- There are several ways to model implementation of VFD retrofit to chillers, new VFD chillers, etc.
- Method 1 – Use the CWSAT algorithm to simulate the new performance curve for the VFD chiller
- Method 2 – Use the part-load VFD chiller curve from the manufacturer and define a NEW chiller in CWSAT database
- Method 3 – Use a bin analysis methodology including lift variation

Student Exercise (Retrofitting with VFDs)

- Method 1
 - Quick – Use the menu driven option provided in CWSAT
- Method 2
 - More Accurate - Define a new User Chiller with the performance characteristics of the retrofitted VFD chiller
- This opportunity requires significant system due diligence to reap the full benefits of VFDs

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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?

Student Exercise (Retrofitting with VFDs)

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

Go To Operating Cost Reduction Screen

Go To Current Chiller Details Screen

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

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

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
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Tower Energy:

138,817	kWh	\$13,882
---------	-----	----------

Pump Energy:

898,807	kWh	\$89,881
---------	-----	----------

Total Energy:

8,523,463	kWh	\$852,346
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Comments Outtemp

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: 85

Return to New Input Screen

Go To Proposed Chiller Details Screen

Go To Proposed Tower Details Screen

Go To Proposed Pump Details Screen

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

Go To Proposed Tower Details Screen

Go To Proposed Pump Details Screen

Show System Graphic

Show Energy/Cost Graphic

Show Savings Summary Screen

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:

6,013,686	kWh	\$601,369
-----------	-----	-----------

Tower Energy:

106,912	kWh	\$10,691
---------	-----	----------

Pump Energy:

898,807	kWh	\$89,881
---------	-----	----------

Total Energy:

7,019,405	kWh	\$701,941
-----------	-----	-----------

Student Exercise (Retrofitting with VFDs)

Savings Summary Screen ; VINPLT_Example

	Electricity Savings [kWh]	Natural Gas Savings [MMBtu]	Cost Savings
Chiller Summary:	1,472,153		\$147,215
Tower Summary:	31,905		\$3,190
Pump Summary:	0		\$0
Total:	1,504,058		\$150,406

Savings on
both Chillers &
Cooling Tower



Student Exercise (Retrofitting with VFDs)

Current Chiller Details Screen : VINPLT_Example

	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	



Proposed Chiller Details Screen : VINPLT_Example

	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	0.330	0.337	0.411	0.498	0.576	0.642	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	131.9	168.5	246.5	348.8	461.2	578.2	0.0		
Energy [kWh]:	0	0	0	0	115,131	295,531	432,131	608,991	607,365	504,761	0	2,563,909	



VFD Issues – Work with Chiller Manufacturer/Expert

- Harmonics
 - Overheating of transformers, cables, motors, generators and capacitors connected to the same power supply
 - Electronic displays and lighting may flicker, circuit breakers can trip, computers may fail
 - Metering can give false readings
- Insulation damage for non-inverter rated motors
- Voltage spikes
 - Overshoot
 - Reflected voltage
 - Ringing
- Resonant frequency
- Bearing currents / damage

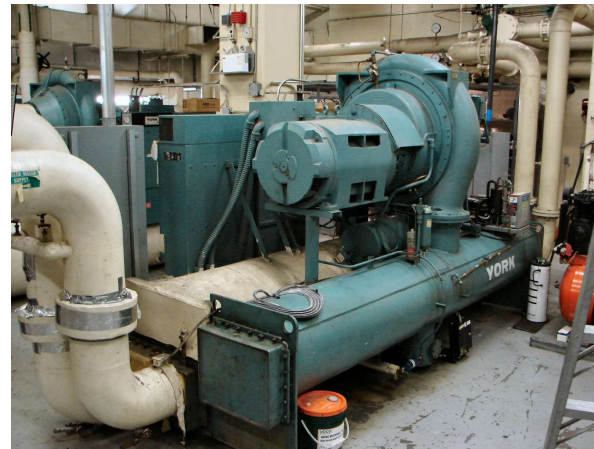
Reference: Chapter 45 – Motors, Motor Controls & Variable Frequency Drives; ASHRAE HVAC Systems & Equipment Handbook, 2020

Air-Cooled versus Water-Cooled

Air-Cooled versus Water-Cooled Systems



Air-Cooled



Water-Cooled

Impact of Chiller Lift

- Crux of chiller plant system optimization
- Significant impact on efficiency, capacity and reliability of system
- Several optimization concepts primarily revolve around reducing chiller plant lift
- But there are operating limits
 - Manufacturer's recommendations
 - System design
- Geography / Climate plays a strong role
 - Humid versus Dry ambient conditions

Lowering heat rejection temperature



Lowers head pressure

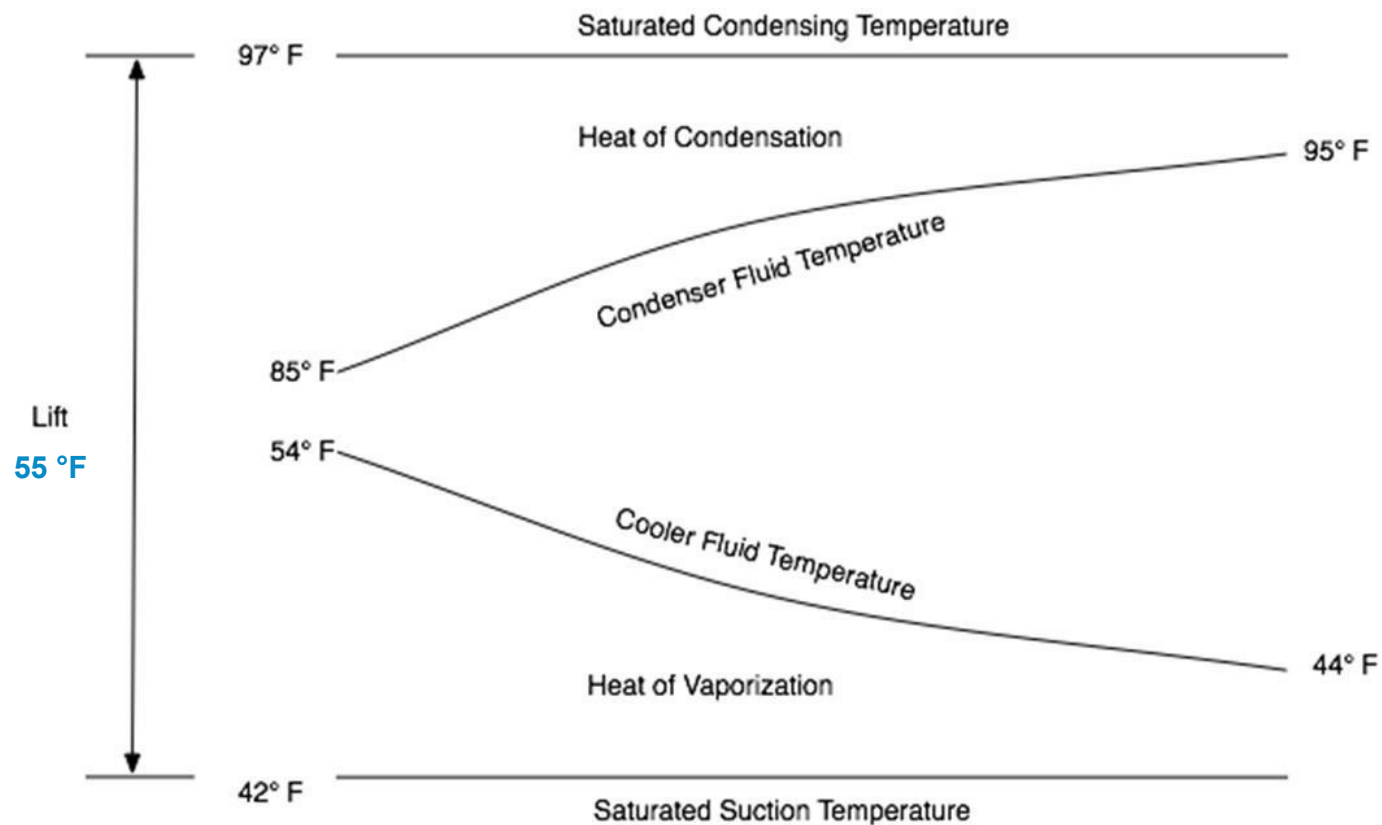


Reduces compressor work

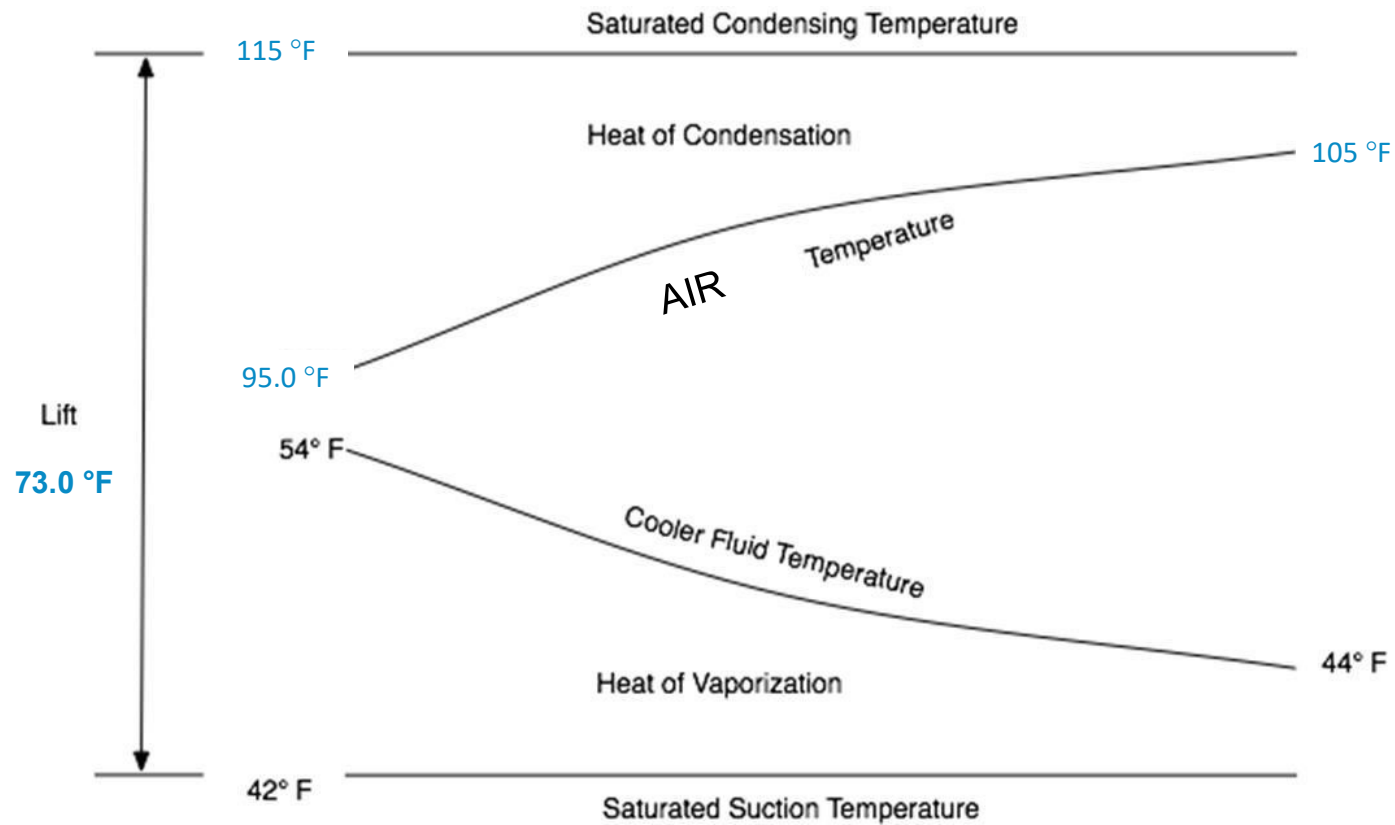


Reduces energy consumption

Chiller Lift – Water-Cooled Chiller



Chiller Lift – Air-Cooled Chiller



Student Exercise

- The Screw chiller at the industrial plant has to be replaced and the plant engineer is evaluating two replacement options
 - Option 1: Air-Cooled chiller with identical capacity
 - Option 2: Identical Water-Cooled chiller
- Use a CWSAT model to determine which option would be beneficial if operating energy and costs have to be minimized
- Discuss concerns and issues with the chosen option and what steps can be taken to mitigate them

Student Exercise

- This may sound like a simple problem but gets complicated for evaluation
 - Facility has 3 chillers and ONLY 1 chiller is being evaluated for replacement
 - CWSAT supports ONLY 1 cooling method for the whole plant
- What options exist for such an evaluation?
 - Model the whole system as air-cooled and then do a proportionality analysis
 - Not representative of the actual system per se
 - Make a new CWSAT model with ONLY the Screw chiller as the operating unit with the same schedule and then build another “air-cooled” model to compare
 - Significant more effort but more realistic and representative of actual field operations

Modeling ONLY Screw Chiller (Water-Cooled)

- One chiller system
- Screw Chiller
- Capacity – 350 RT
- Cooling tower sizing based on 350 RT
- FLE – 0.75 kW/RT
- Use the Base Model and modify inputs

Input Screen : VINPLT_Example

File Tools

Basic System Data

Geographic Location: MO Saint Louis ?

Number of Chillers: 1

Chilled Water Supply Temperature: °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 350 tons/tower

Axial Fan Type

Pump Data

Variable Flow? CHW No CW No

Flow Rate [gpm/ton]: CHW 2.4 CW 3

Motor Size [hp]: CHW 20 CW 25

Pump Efficiency [%]: CHW 75 CW 75

Motor Efficiency [%]: CHW 85 CW 85

Current Chiller Data

User Chiller? (Y/N) ☐ Y ☒ N

Compressor/Chiller Type: Helical Rotary

Full Load Eff Known? Yes

Chiller Capacity [tons]: 350

FLE Value [kW/ton]: 0.75

Age [Years]: 10

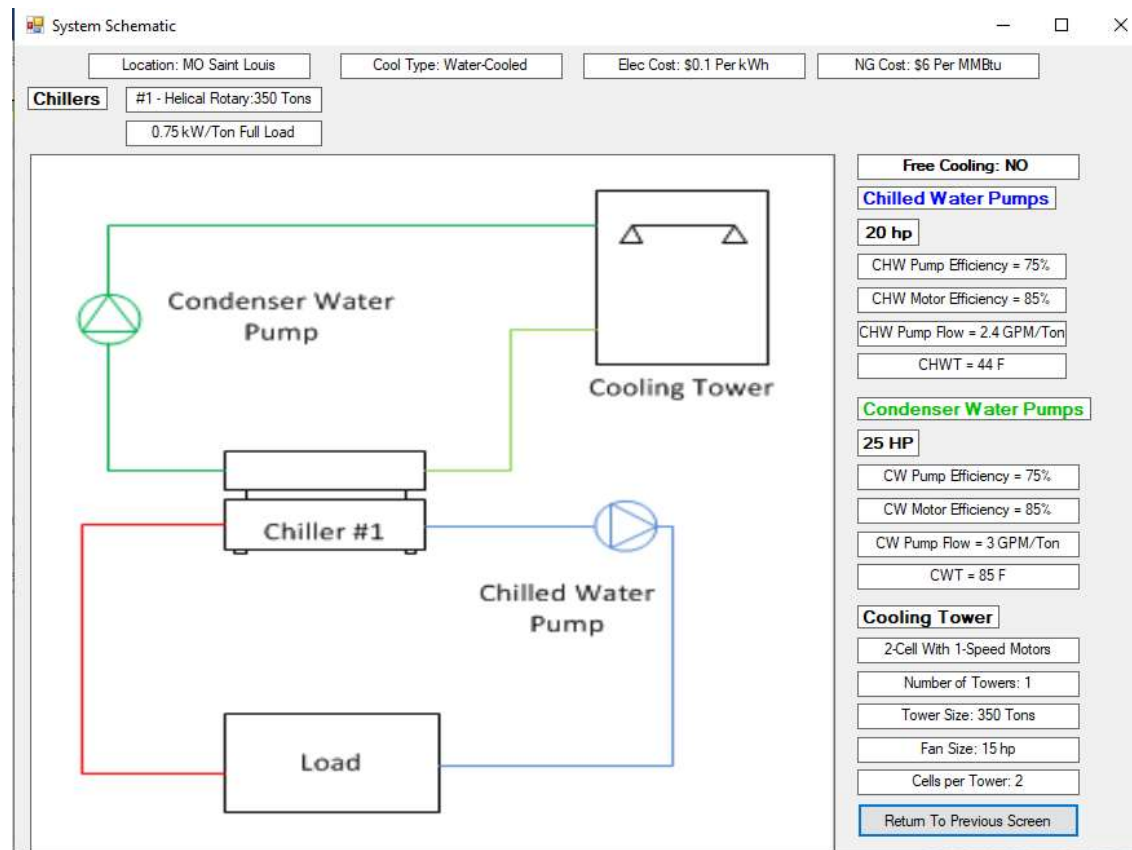
Energy Cost Data

Electricity Cost: 0.1 [\$/kWh]

Natural Gas Cost: 6 [\$/MMBtu]

OK

Modeling ONLY Screw Chiller (Water-Cooled)



Modeling ONLY Screw Chiller (Water-Cooled)

Operating Schedule Screen

Weekly Operating Schedule

Please input the typical weekly operating hours for the chiller. This information is used to exclude weather data for non-operating hours.
If system is ON all day, start: 0000; finish: 2400
If system is OFF all day, set values equal.

Sunday	0000	To	2400
Monday	0000	To	2400
Tuesday	0000	To	2400
Wednesday	0000	To	2400
Thursday	0000	To	2400
Friday	0000	To	2400
Saturday	0000	To	2400

Monthly Operating Schedule

Please input the typical monthly operating hours for the system. The allowable input values are in increments of 24 hours. This information is used to calculate the annual operating hours of the chilled water system...

January	744	hours	July	744	hours
February	672	hours	August	744	hours
March	744	hours	September	720	hours
April	720	hours	October	744	hours
May	744	hours	November	720	hours
June	720	hours	December	744	hours

Weekly: M-F, 8-5 only

Weekly: Copy Mon to Tue-Fri

Input: 8,760 Hours

Loading Data

Does the chilled water system load vary according to the ARI 550/590 schedule? No

Does chiller loading vary from month to month? No

OK

Monthly: Maximum hours


Restart Screen

Exit Program

Modeling ONLY Screw Chiller (Water-Cooled)

- Input the screw chiller load profile

Loading Schedule Screen : VINPLT_Example

Provide the loading schedule for the chiller(s). 

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
All Months	30	0	0	30	0	30	0	0	0	0	10	100

Copy Paste

Modeling ONLY Screw Chiller (Water-Cooled)

Output Screen : VINPLT_Example

Current Chiller System

Basic System Summary

Number of Chillers: 1

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: 15 Tons: 350

Number of Cells per Tower: 2

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Helical Rotary	350	10	0.750

Water-Cooled Summary

Constant CWT?: Yes

Constant CWT Setpoint: 85

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: 885,879 kWh \$88,588

Tower Energy: 11,270 kWh \$1,127

Pump Energy: 241,941 kWh \$24,194

Total Energy: 1,139,090 kWh \$113,909

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

- Check for all the input information
- Once satisfied with the model, **SAVE** it as a new file

Modeling ONLY Screw Chiller (Air-Cooled)

- Build a whole new CWSAT model with Air-Cooled as the method of heat rejection
- FLE – 1.25 kW/RT
- NOTE: Fewer inputs
- Can model both indoor and outdoor installations

Input Screen

File Tools

Basic System Data

Geographic Location: MO Saint Louis

Number of Chillers: 1

Chilled Water Supply Temperature: 44 °F

Condenser Cooling Method: Air-Cooled

OK

Air-Cooled Data

Outdoor Air Design Temperature: 95 °F

Cooling Air Source: Outside

CT follows ambient dry-bulb plus: 20 °F

OK

Pump Data

CHW

Variable Flow?: No

Flow Rate [gpm/ton]: 2.4

Motor Size [hp]: 20

Pump Efficiency [%]: 75

Motor Efficiency [%]: 85

OK

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	Helical Rotary	Yes	350	1.25	0

OK

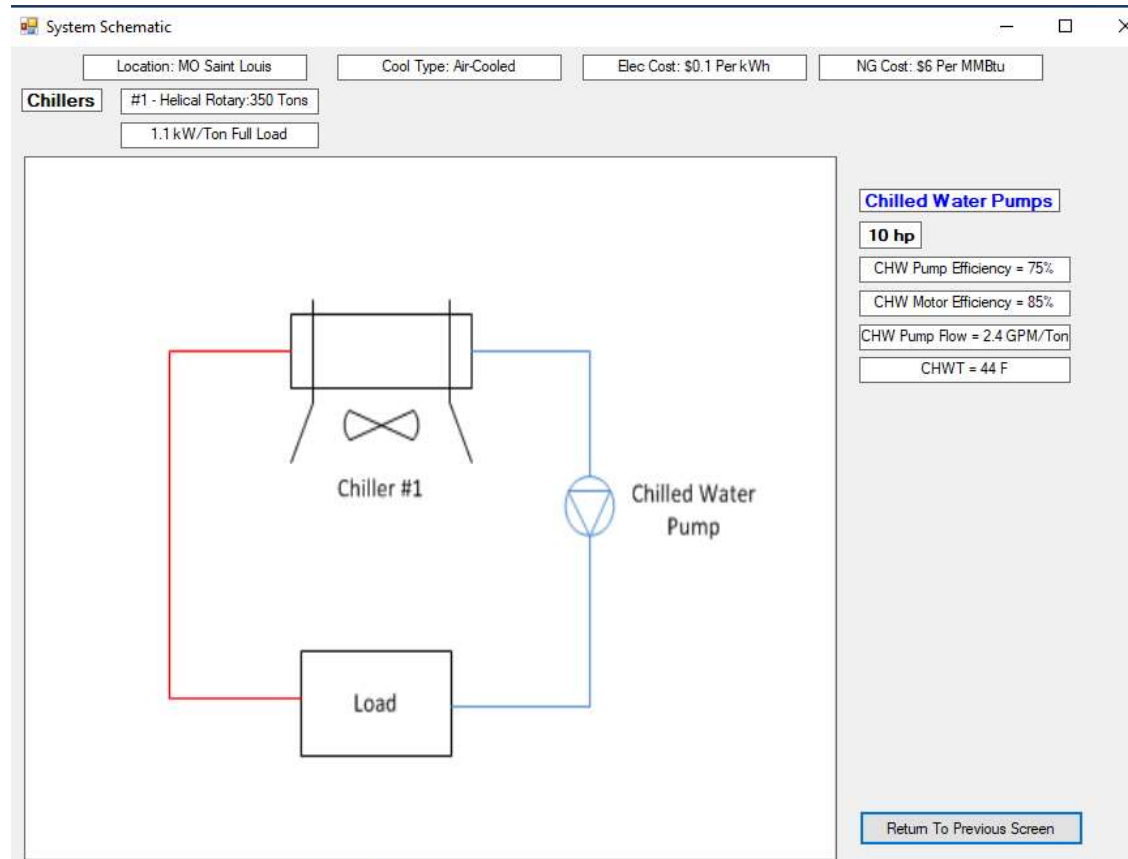
Energy Cost Data

Electricity Cost: 0.10 [\$/kWh]

Natural Gas Cost: 6.00 [\$/MMBtu]

OK

Modeling ONLY Screw Chiller (Air-Cooled)



Modeling ONLY Screw Chiller (Air-Cooled)

Operating Schedule Screen

Weekly Operating Schedule

Please input the typical weekly operating hours for the chiller. This information is used to exclude weather data for non-operating hours.
If system is ON all day, start: 0000; finish: 2400
If system is OFF all day, set values equal.

Sunday	0000	To	2400
Monday	0000	To	2400
Tuesday	0000	To	2400
Wednesday	0000	To	2400
Thursday	0000	To	2400
Friday	0000	To	2400
Saturday	0000	To	2400

Monthly Operating Schedule

Please input the typical monthly operating hours for the system. The allowable input values are in increments of 24 hours. This information is used to calculate the annual operating hours of the chilled water system.

January	744	hours	July	744	hours
February	672	hours	August	744	hours
March	744	hours	September	720	hours
April	720	hours	October	744	hours
May	744	hours	November	720	hours
June	720	hours	December	744	hours

Loading Data

Does the chilled water system load vary according to the ARI 550/590 schedule? No ☐

Does chiller loading vary from month to month? No ☐

Weekly: M-F, 8-5 only

Weekly: Copy Mon to Tue-Fri

Input: 8,760 Hours

Monthly: Maximum hours

OK

Restart Screen

Exit Program

Loading Schedule Screen : VINPLT_ScrewChiller

Provide the loading schedule for the chiller(s).

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
All Months	30	0	0	30	0	30	0	0	0	0	10	100

Modeling ONLY Screw Chiller (Air-Cooled)

Output Screen

Current Chiller System

Basic System Summary

Number of Chillers:

CHWT Setpoint:

Geographic Location:

Condenser Cooling Method:

Air-Cooled Summary

OADT:

Cooling Air Source:

Following Difference:

Pump Summary

CHW

Variable Flow?:

Flow Rate [gpm/ton]:

Motor Size (hp):

Pump Efficiency [%]:

Motor Efficiency [%]:

Current Chiller Summary

Compressor	Capacity [tons]	Age [years]	FLE [kW/ton]
Chiller 1			
Helical Rotary	<input type="text" value="350"/>	<input type="text" value="0"/>	<input type="text" value="1.250"/>

Energy Summary

Chiller Energy:

<input type="text" value="1,188,451"/>	kWh	<input type="text" value="\$118,845"/>
--	-----	--

Pump Energy:

<input type="text" value="107,529"/>	kWh	<input type="text" value="\$10,753"/>
--------------------------------------	-----	---------------------------------------

Total Energy:

<input type="text" value="1,295,980"/>	kWh	<input type="text" value="\$129,598"/>
--	-----	--

Go To Operating Cost Reduction Screen

Go To Current Chiller 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

Comparing Water-Cooled vs Air-Cooled

- System Savings using Water-Cooled Screw Chiller
= 156,890 kWh (\$15,700 annually)

Air-Cooled

Energy Summary		
Chiller Energy:		
1,188,451	kWh	\$118,845
Pump Energy:		
107,529	kWh	\$10,753
Total Energy:		
1,295,980	kWh	\$129,598

Water-Cooled

Energy Summary		
Chiller Energy:		
885,879	kWh	\$88,588
Tower Energy:		
11,270	kWh	\$1,127
Pump Energy:		
241,941	kWh	\$24,194
Total Energy:		
1,139,090	kWh	\$113,909

Comparing Water-Cooled vs Air-Cooled

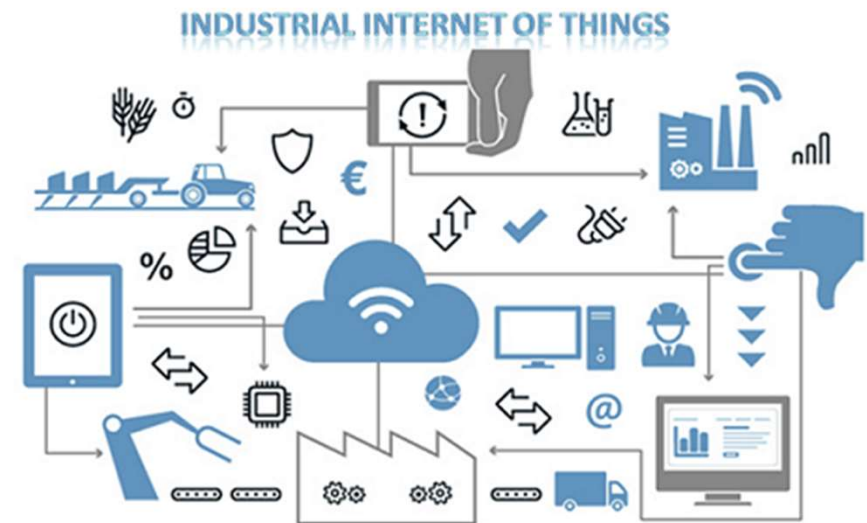
- What about water and chemical treatment costs?
- What about maintenance of extra pumps, fans, etc?
- What should be the Air-Cooled screw chiller performance curve and FLE value to offset the cost difference between the two screw chillers?
- NOTE: Strong dependence on Equipment size (Load); Operating hours and Load profile; Controls and Geographic location (Weather data)

Implementing an Intelligent Chilled Water System

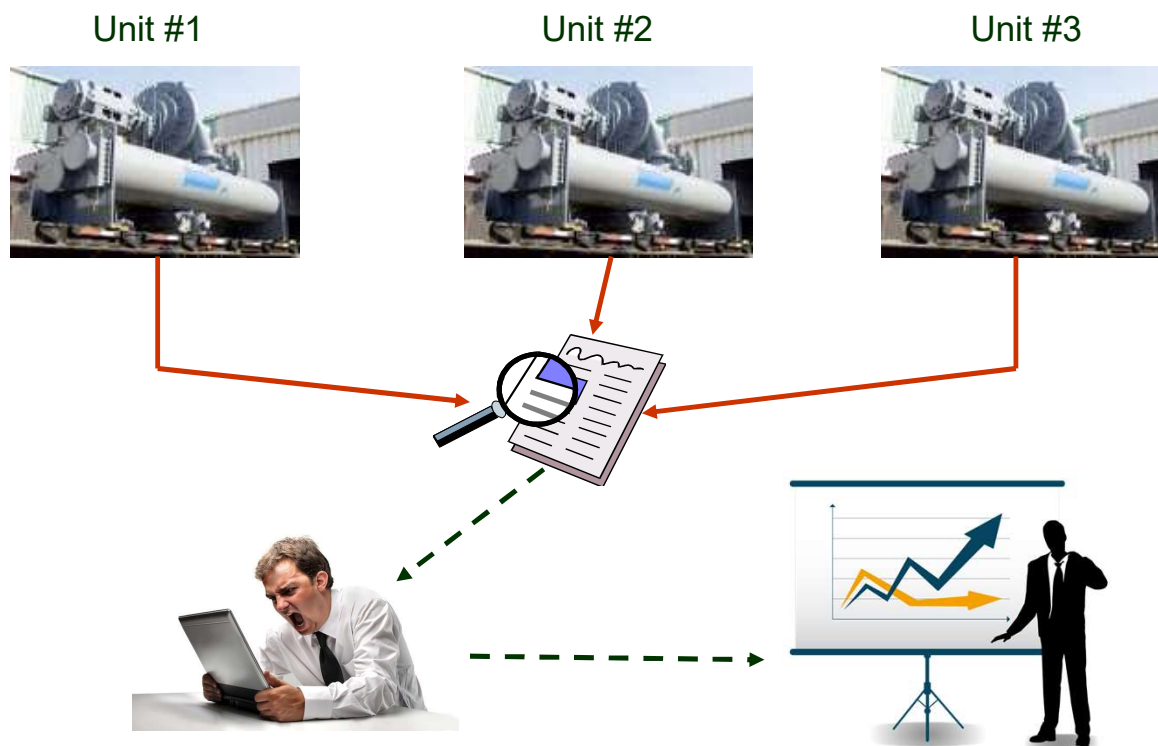
CANNOT BE MODELED in CWSAT

Intelligent Chilled Water Systems with FD&D

- Intelligent refers to the state-of-the-art Industrial Internet of Things (IIOT) managed intelligent systems
- Technology has advanced with Artificial Intelligence and Machine Learning
- Fault Detection & Diagnostics (FD&D) leads to Real-Time Optimization
- Continuous Commissioning



Where did we Start?



Basic Ingredients of Intelligent Systems

- Continuous monitoring of key data
- Trending of performance metrics
- Cloud-based system analytics
- Performance gap quantification with part load simulation (digital twin)
- Fault Detection & Diagnostics
- Seamless integration with plant's DCS
- Closed loop feedback control for optimizing systems
- Ability to benchmark operations and verify energy savings
- Multiple chiller optimization
- Cyber-security

Fault Detection & Diagnostics 101

- Critical data provide the ability to run diagnostics on system operations
- Main objective is to ensure that faults, inefficiencies and issues can be identified as soon as they occur
- Saves significant money, time and effort
- Increases system reliability
- Ensures optimum performance
- Cornerstone for Predictive & Preventative Maintenance

Application of Real-time Optimizer-based Controls

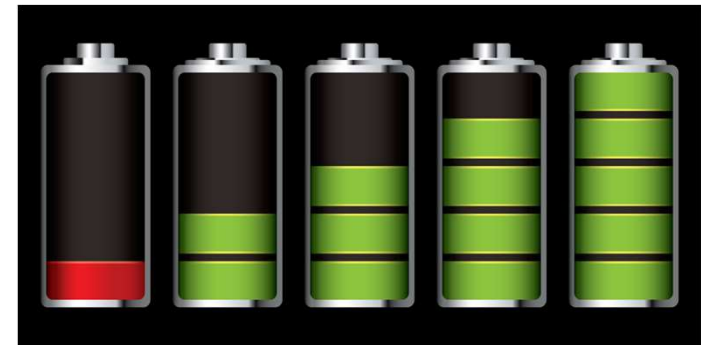
- Implementation of higher efficiency chiller systems
 - Using VFD chillers with real-time ECWT and ChWST setpoint controls
 - Using highly integrated and automated control strategies
- Full integration of pumping loops, cooling towers and end-users
- Trending and performance tracking using state-of-the-art technologies
- Continuous commissioning
- Implementing preventive and predictive maintenance BestPractices using Fault Detection and Diagnostics algorithms

Thermal Energy Storage

CANNOT BE MODELED in CWSAT

Chilled Water Systems with Thermal Energy Storage

- Thermal Energy Storage is NOT new and neither NEXT GENERATION
- Its application is what makes it unique
- Its impacts are system-wide – Peak Load Management Strategy
- Could have a strong influence on Decarbonization and reducing carbon footprint



What is Thermal Energy Storage (TES)?

- It is a battery which serves as a source or sink for energy
- Thermal storage
 - Cold – to be covered in this class
 - Hot – out of scope here
- Several different methods of thermal energy storage and can be used very effectively to
 - Minimize both operating and capital costs
 - Reduce electrical / thermal demand
 - Reduce overall energy consumption & increase system efficiency
 - Reduce greenhouse gas emissions (w/renewables mix)

Benefits of TES

- Energy cost savings
 - Reduce peak on-time electricity demand
 - Decouple time-of-use (load) and pricing
 - Higher system efficiency – constant set-point operations
- Decarbonization benefit
 - Use of renewables – solar and wind
 - Elimination of fast-acting electric grid and peaker plant response
- Reduced equipment size
 - Systems can be designed for average year-round load rather than peak loads which occur for less than 5% of the operating hours

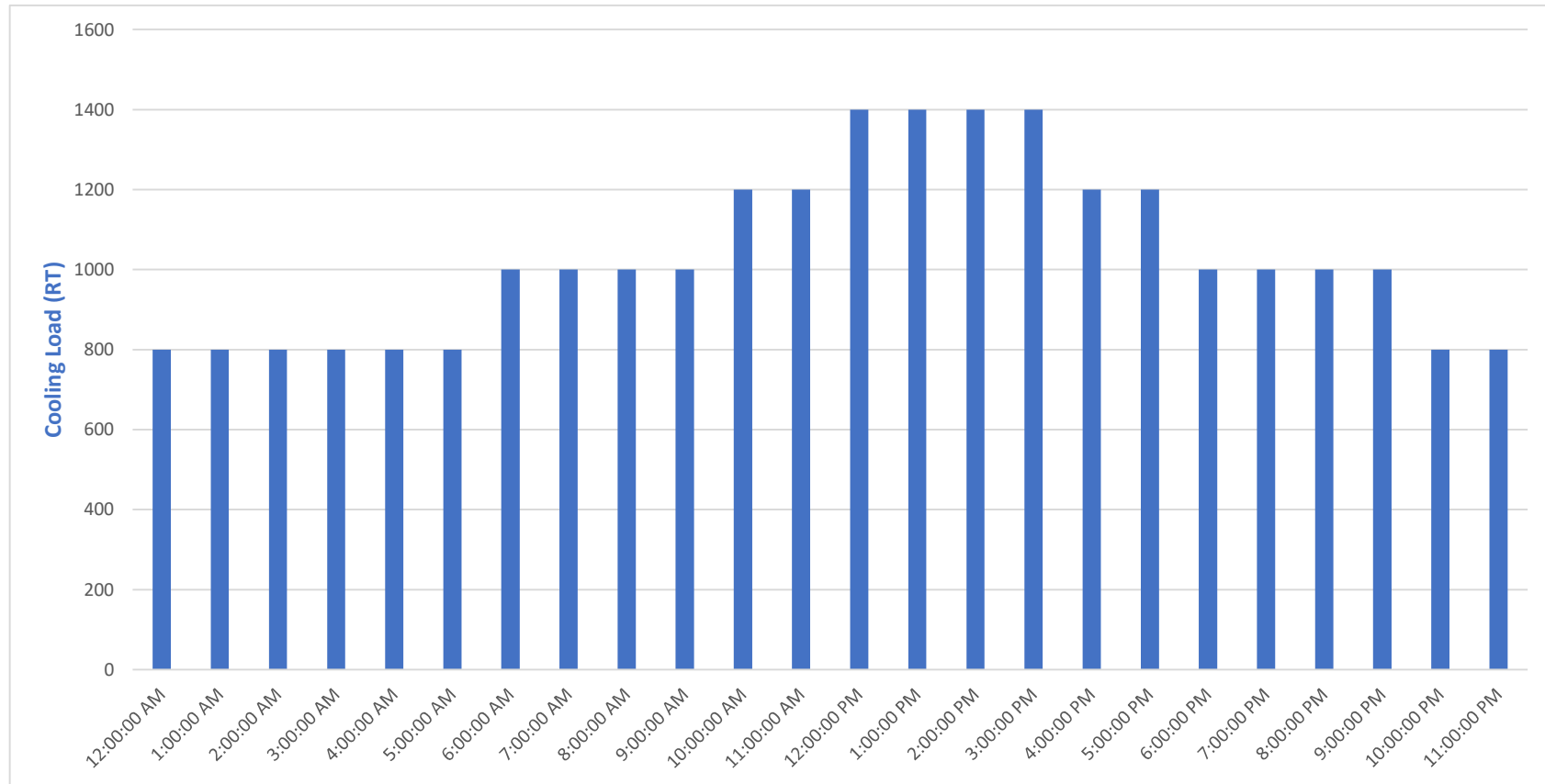
Benefits of TES

- Capital cost savings
 - Downsizing large chillers and cooling equipment at design-level
 - Smaller systems and equipment – pumps, fans, transformers, etc.
- System benefits
 - Optimization of system assets – eliminate part-load operations
 - Operate systems at favorable conditions allowing for higher system efficiency
- Increased reliability and redundancy
 - TES can provide additional capacity always and N+1 redundancy
 - Primary equipment operations are more stable enhancing reliability
 - Ability to do periodic and preventive maintenance to enhance reliability

Classification of TES

- Type of storage medium
 - Sensible heat
 - Latent heat
- Sensible thermal storage (types)
 - Horizontal tanks
 - Thermal stratification (vertical tanks)
 - Multiple compartments
 - Multiple tanks
 - Labyrinth tanks
 - Underground concrete structures
 - Aquifers
- Sensible thermal storage (materials used) – chilled water; aqueous (brines, glycols) and non-aqueous fluids; Low Temperature Fluids (LTFs)

Daily Load Profile (an example)

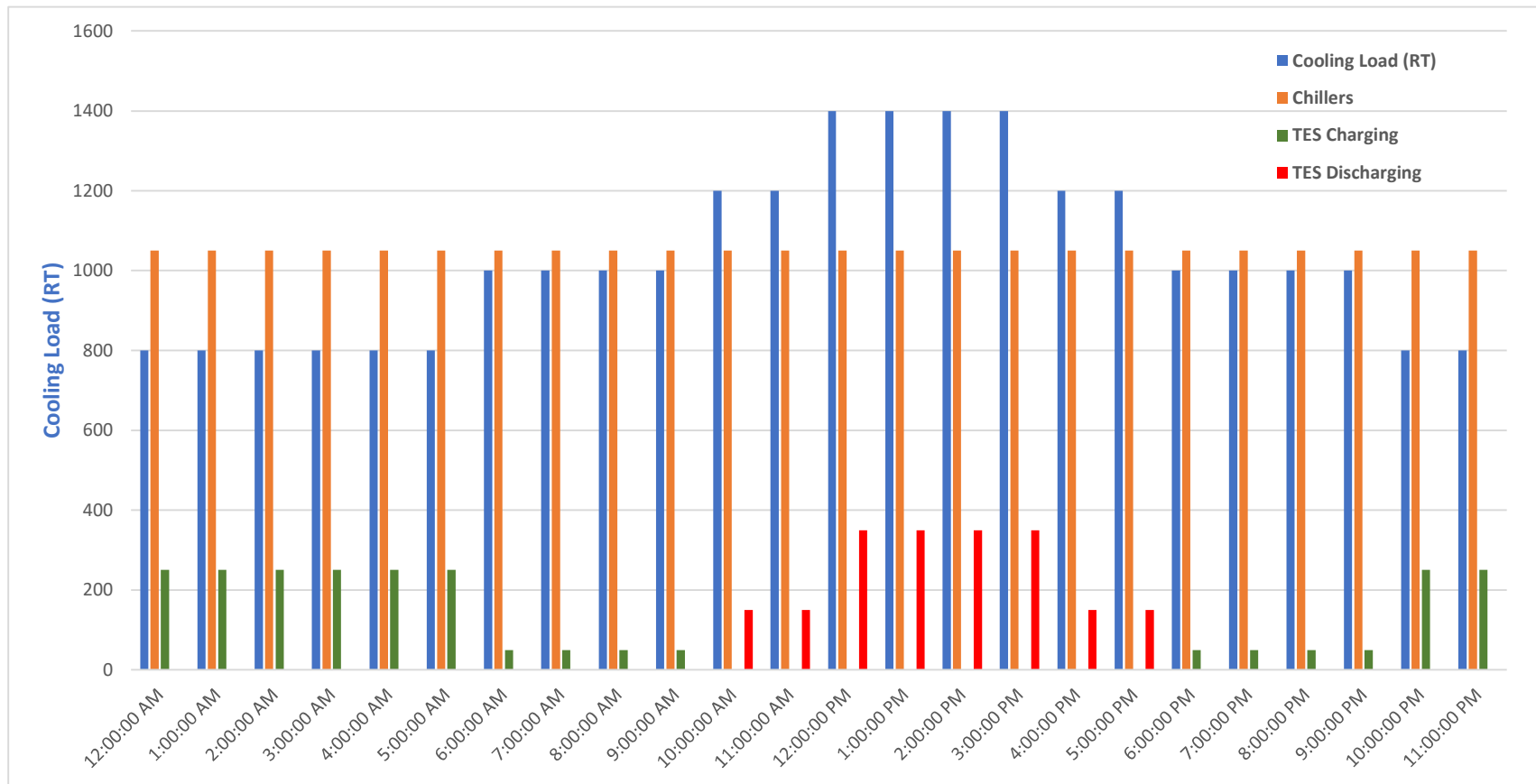


Daily Operations (an example)

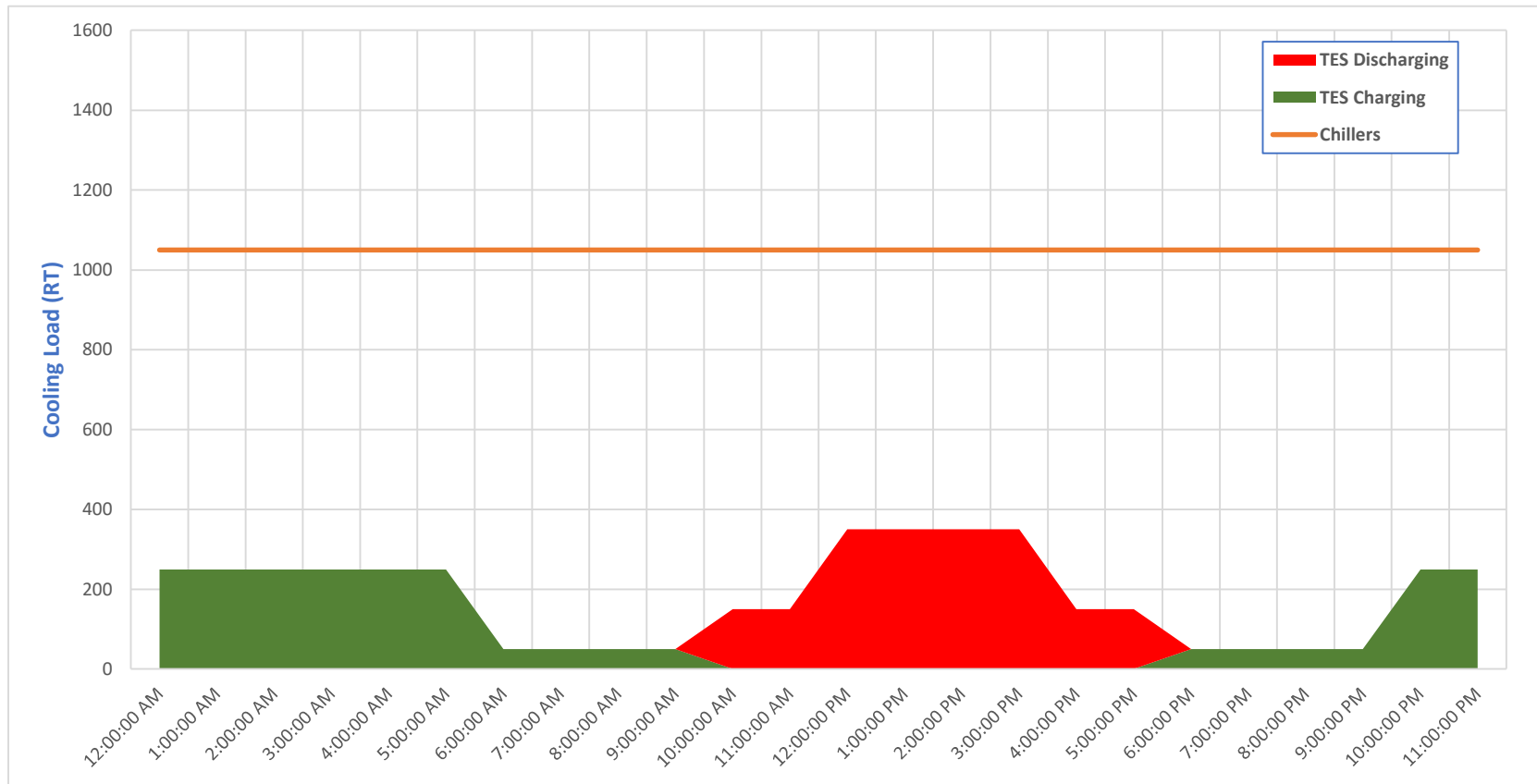
- Option 1
 - Chiller Plant Size – 1,400 RT
 - Daily cooling load – 24,800 Ton-hours

- Option 2
 - Daily cooling load – 24,800 Ton-hours + Circulating losses
 - Chiller Plant Size – 1,050 RT
 - TES size – 2,400 Ton-hours

Daily Load Profile w/TES (an example)



Daily Load Profile w/TES (an example)



Most Favorable Scenarios for TES

- High (or very high) chilling load of relatively short duration
 - Think of cooling demand having a compressed air system profile
- High electric power demand charges
- Low (or very low or negative) electrical energy during off-peak hours
- Expansion on a very limited budget
- Mission critical systems that still need to operate with minimal backup generation capability
- Industry looking to decarbonize and use higher amounts of renewables mix when available

Other Tools

US DOE MEASUR Tool

The screenshot displays the MEASUR tool interface. On the left is a sidebar with the U.S. Department of Energy logo and a list of links under 'Home', 'Data Exploration', and 'All Calculators'. The main content area features the MEASUR logo and a welcome message. It provides instructions on how to create an assessment or use calculators, with two main options: 'Create Assessment' and 'Properties & Equipment Calculators'. The 'Create Assessment' section includes links for 'Create Pump Assessment', 'Create Process Heating Assessment', and 'Create Fan Assessment'. The 'Properties & Equipment Calculators' section includes links for 'General', 'Compressed Air', 'Fans', 'Lighting', 'Motors', 'Process Cooling', 'Process Heating', 'Pumps', 'Steam', and 'Waste Water'.

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

MEASUR

Welcome to the most efficient way to manage and optimize your facilities' systems and equipment.

Create an assessment to model your system and find opportunities for efficiency or run calculations from one of our many property and equipment calculators.

Get started with one of the following options.

Create Assessment
Model a system and explore multiple optimization scenarios.

- Create Pump Assessment**
formerly DOE Pumping System Assessment Tool (PSAT)
- Create Process Heating Assessment**
formerly DOE Process Heating Assessment and Survey Tool (PHAST)
- Create Fan Assessment**
formerly DOE Fan System Assessment Tool (FSAT)

Properties & Equipment Calculators
Generate detailed properties and test a variety of adjustments.

- General
- Compressed Air
- Fans
- Lighting
- Motors
- Process Cooling
- Process Heating
- Pumps
- Steam
- Waste Water

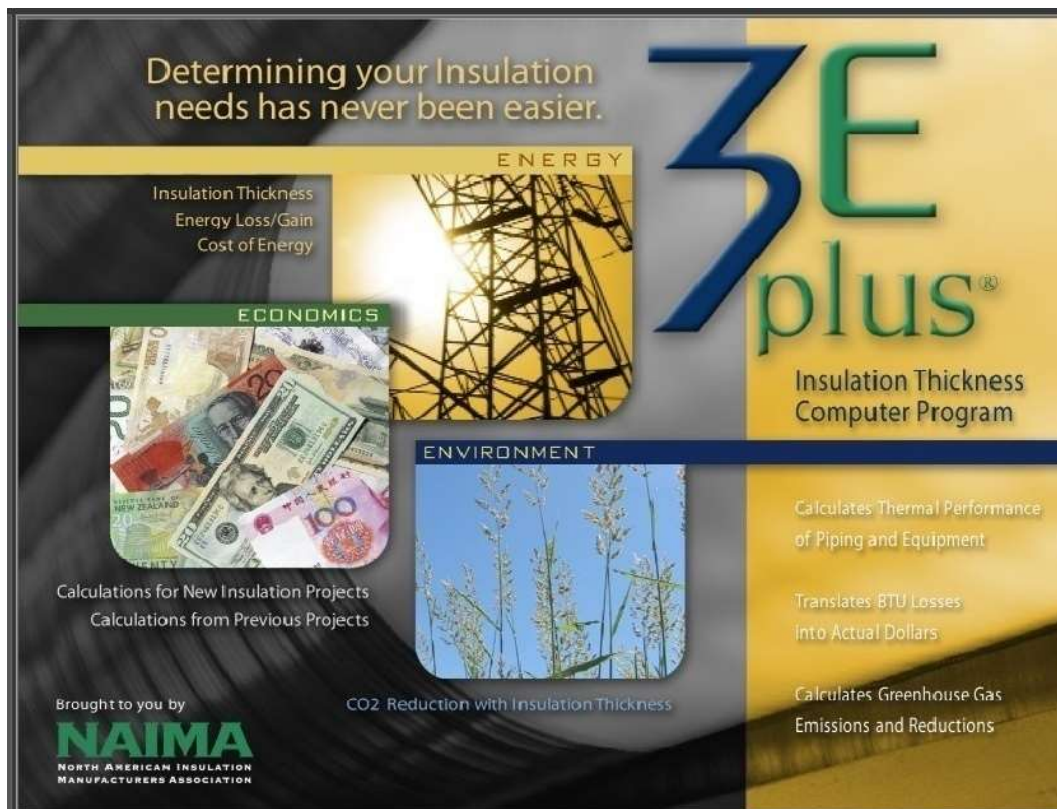
Home

- All Assessments
 - UNIDO Fan
 - VINPLT_0421
 - New Ulm Bldg 1 225PSI
 - New Assessment
 - DOE-Steam-training 2021
 - 2021-SHAP Boiler Assessment
- Trial
 - UNIDO Fan
 - UNIDO Pump 1
 - UNIDO Pump
- Examples
 - Steam Example
 - Toy Factory
 - Treasure Hunt Example
 - Fan Example
 - Pump Example
 - Process Heating - Fuel Example

Data Exploration

- All Calculators
 - General
 - Compressed Air
 - Fans

3E Plus Software Tool



Determining your Insulation needs has never been easier.

ENERGY

Insulation Thickness
Energy Loss/Gain
Cost of Energy

ECONOMICS

Calculations for New Insulation Projects
Calculations from Previous Projects

ENVIRONMENT

CO₂ Reduction with Insulation Thickness

3E plus[®]

Insulation Thickness
Computer Program

Calculates Thermal Performance
of Piping and Equipment

Translates BTU Losses
into Actual Dollars

Calculates Greenhouse Gas
Emissions and Reductions

Brought to you by
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Homework #6

- Finalize your plant's chilled water system model in CWSAT and quantification of energy efficiency opportunities
- Identify discrepancies and shortcomings, if any, in the CWSAT software
- Start compiling the information to be able to put together a presentation in Session 8 for your plant
- Install US DOE MEASUR and 3EPlus

Kahoot Quiz Time



Thank You all for attending today's webinar.

See you all on next Thursday – July 14, 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**