Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment

Session 6

Thursday – July 7, 2022

10 am – 12:30 pm

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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

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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

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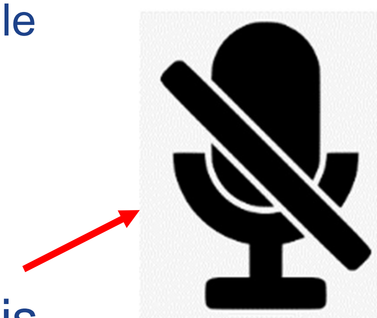
Safety and Housekeeping

- 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

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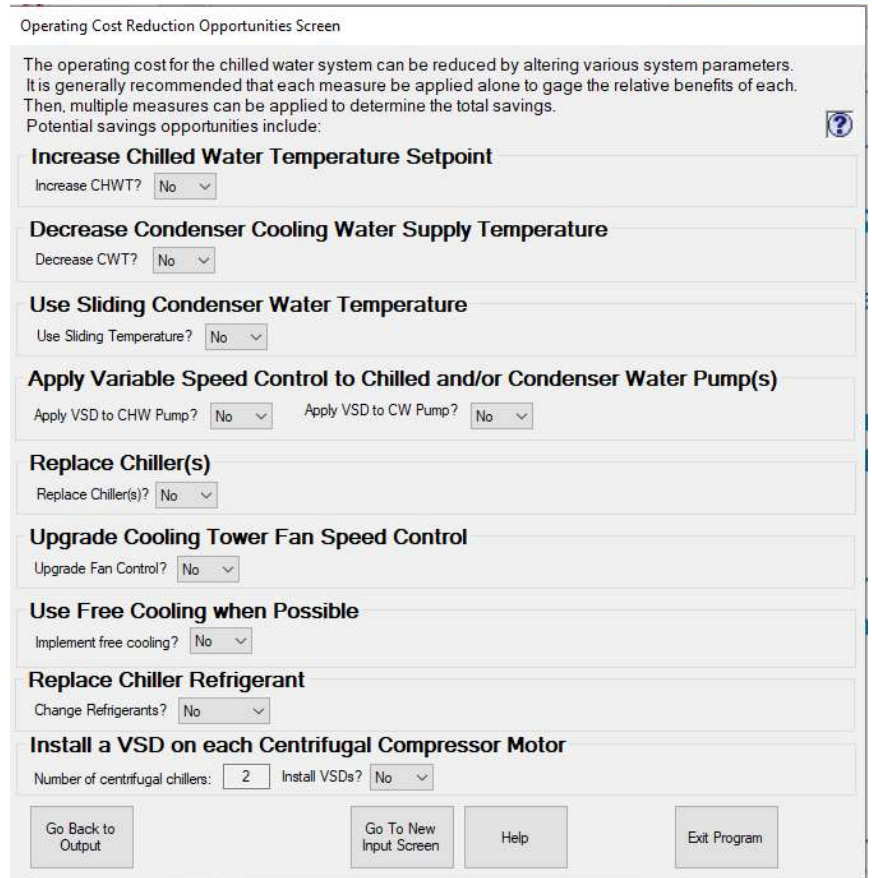
Chiller System Optimization Objectives

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

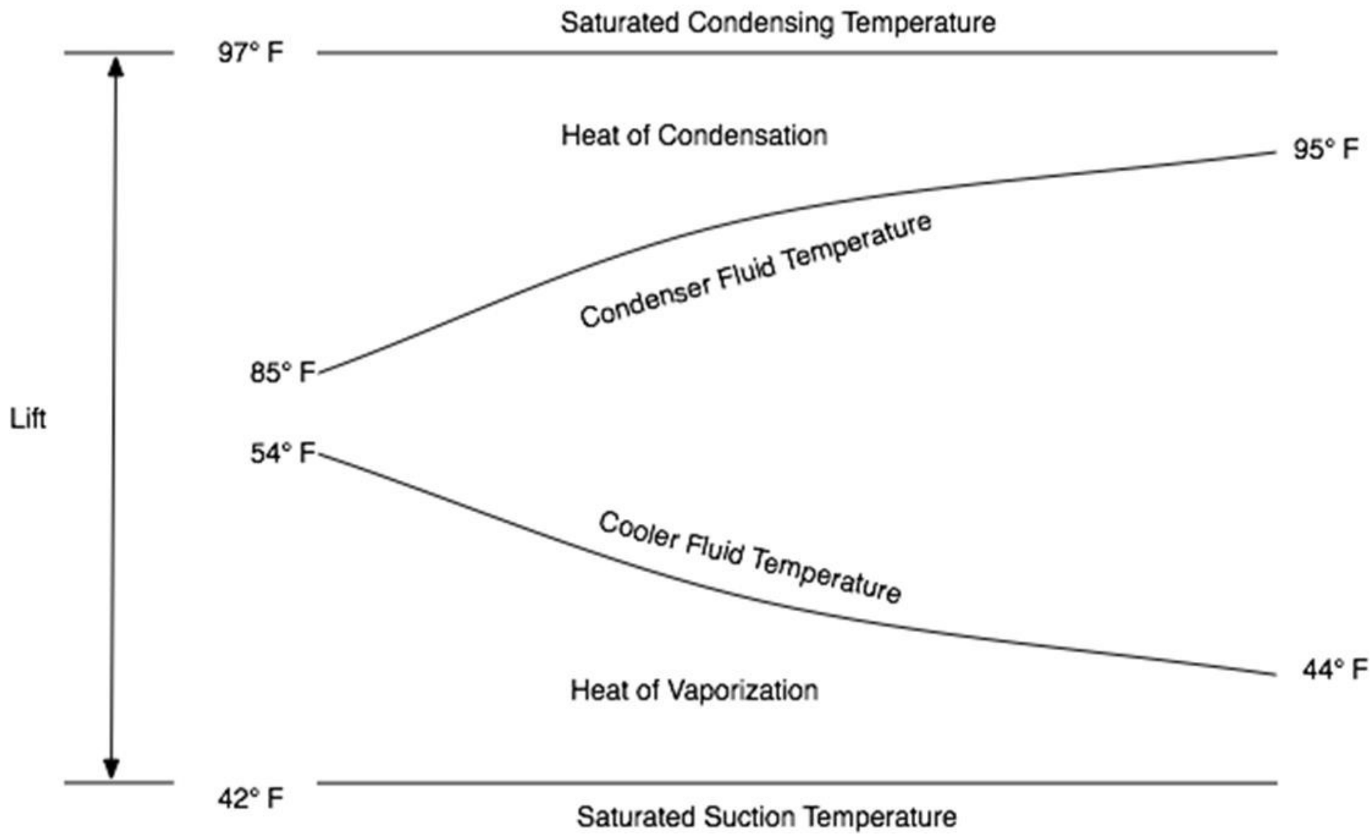
Operating Cost Reduction Screen

- 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

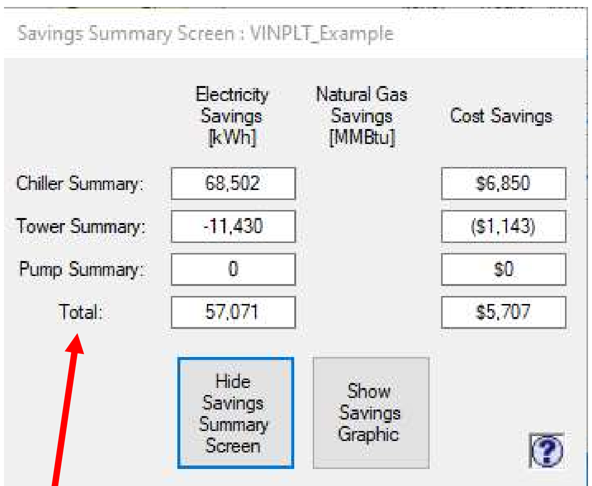


Remember Lift!

Lift = 97 – 42 = 55°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

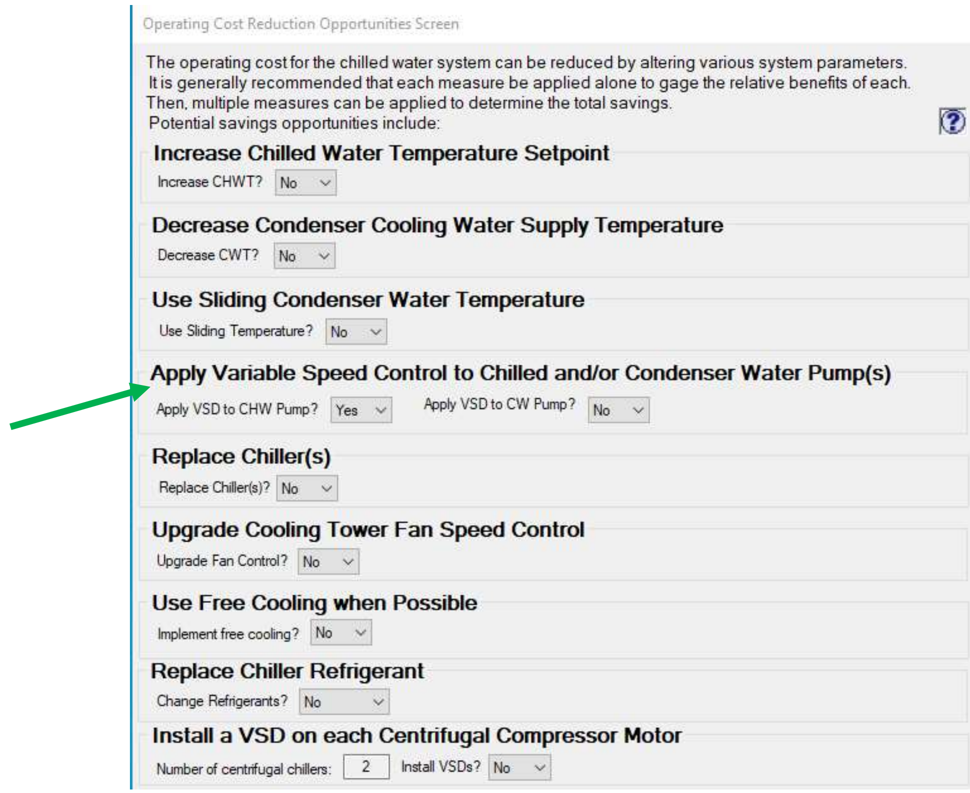
Savings on both – Chiller & Tower

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

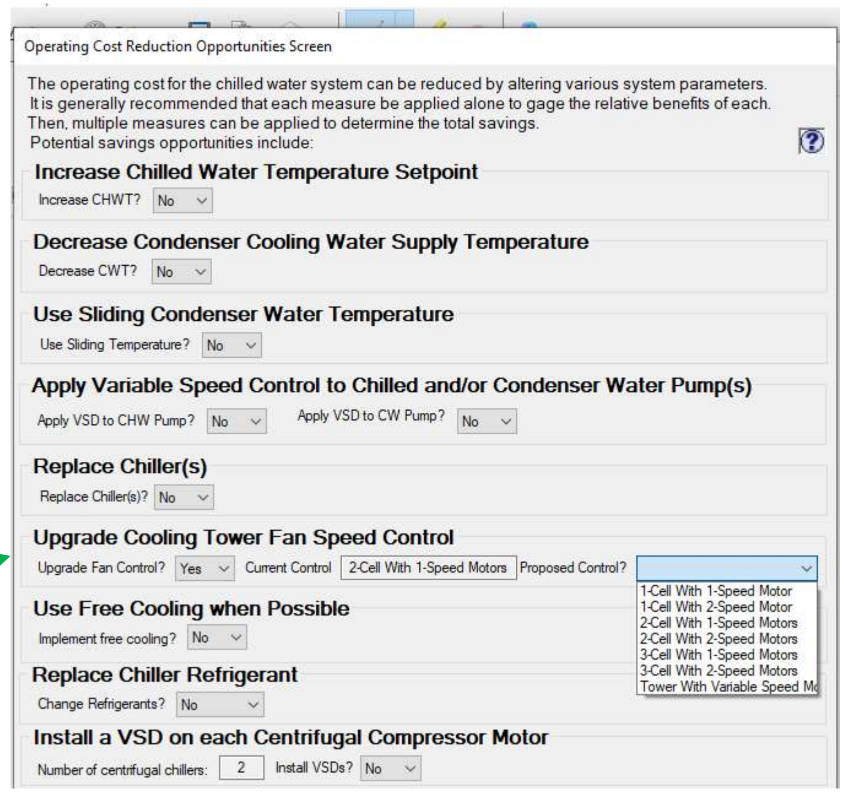
Modeling Application of VFDs to Pumps in CWSAT

- Remember – CWSAT models primary chilled water loop ONLY
- Model the pumps VFD application individually
  - Chilled water
  - Condenser water

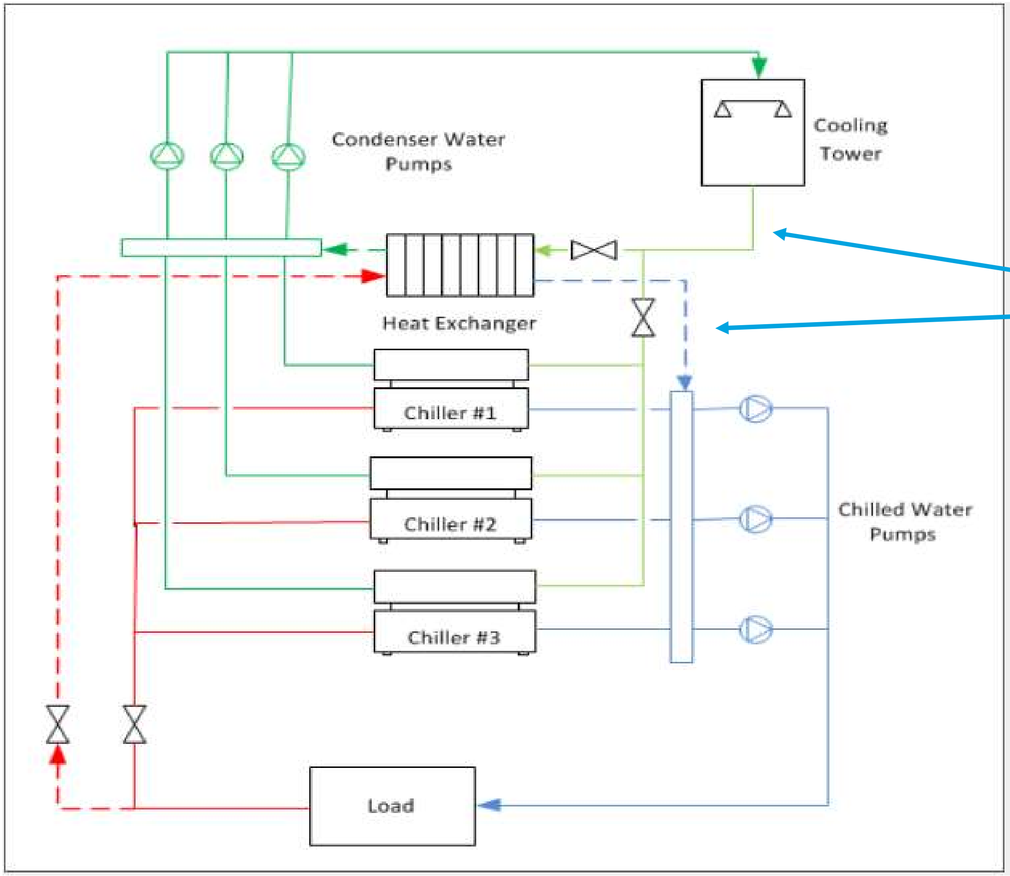


Application of Cooling Tower Fan Speed Control

- 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



Student Exercise (Using Free Cooling)



Approach of HX
Temperature difference between these 2 streams

Eliminate Inappropriate Uses of Chilled Water / Reduce Cooling Load

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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*Cp*ΔT
- $Q_{load} = 100\,\frac{gal}{min}$ *500 $\frac{lb/hr}{gpm}$ *1.0 $\frac{Btu}{lb-F}$ $*\Delta$T
- ΔT = Chilled water return – Chilled water supply = 55 – 44 = 11.0°F
- $Q_{load} = 100\,\frac{gal}{min}$ *500 $\frac{lb/hr}{gpm}$ *1.0 $\frac{Btu}{lb-F}$ $*$ 11.0°F
- $Q_{load} =$ 550,000 Btu/hr = 46 RT

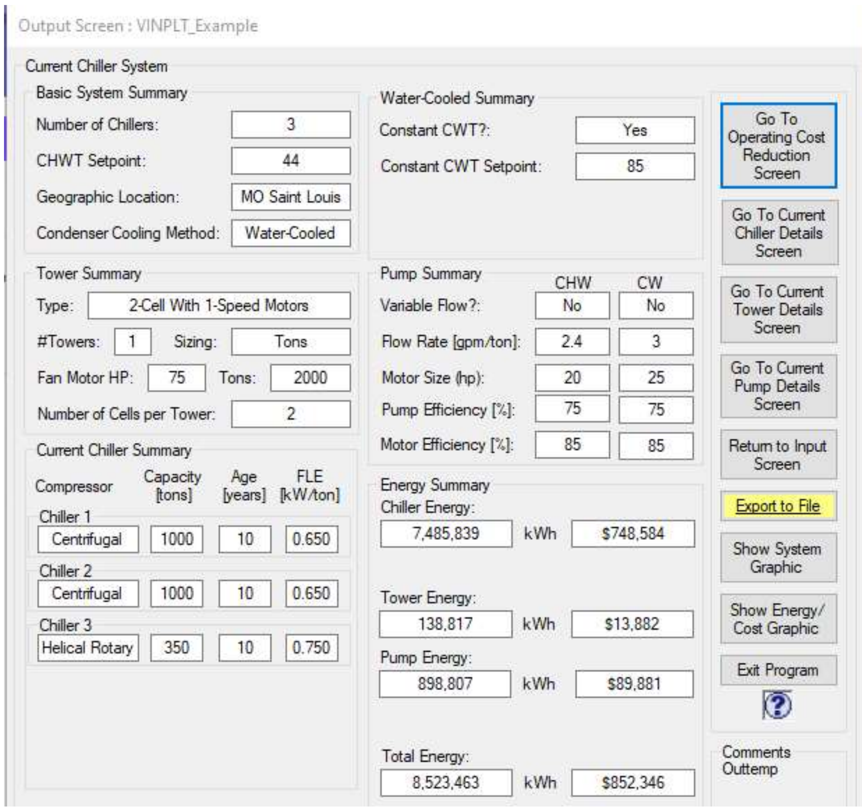
Student Exercise

- 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



- 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

Chiller 1: Centrifugal (Rated Capacity: 1000 tons)

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

Chiller 2: Centrifugal (Rated Capacity: 1000 tons)

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

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

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

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
  - $Q_{average}$ = (610) + (610) + (119) = 1,339 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
  - $Energy_{average} = \frac{8{,}523{,}463}{1{,}339} = \sim 6{,}366\ \frac{kWh}{RT-y}$
  - $Cost_{average} = \frac{852{,}346}{1{,}339} = \sim 636\ \frac{\$}{RT-yr}$
- 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)

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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

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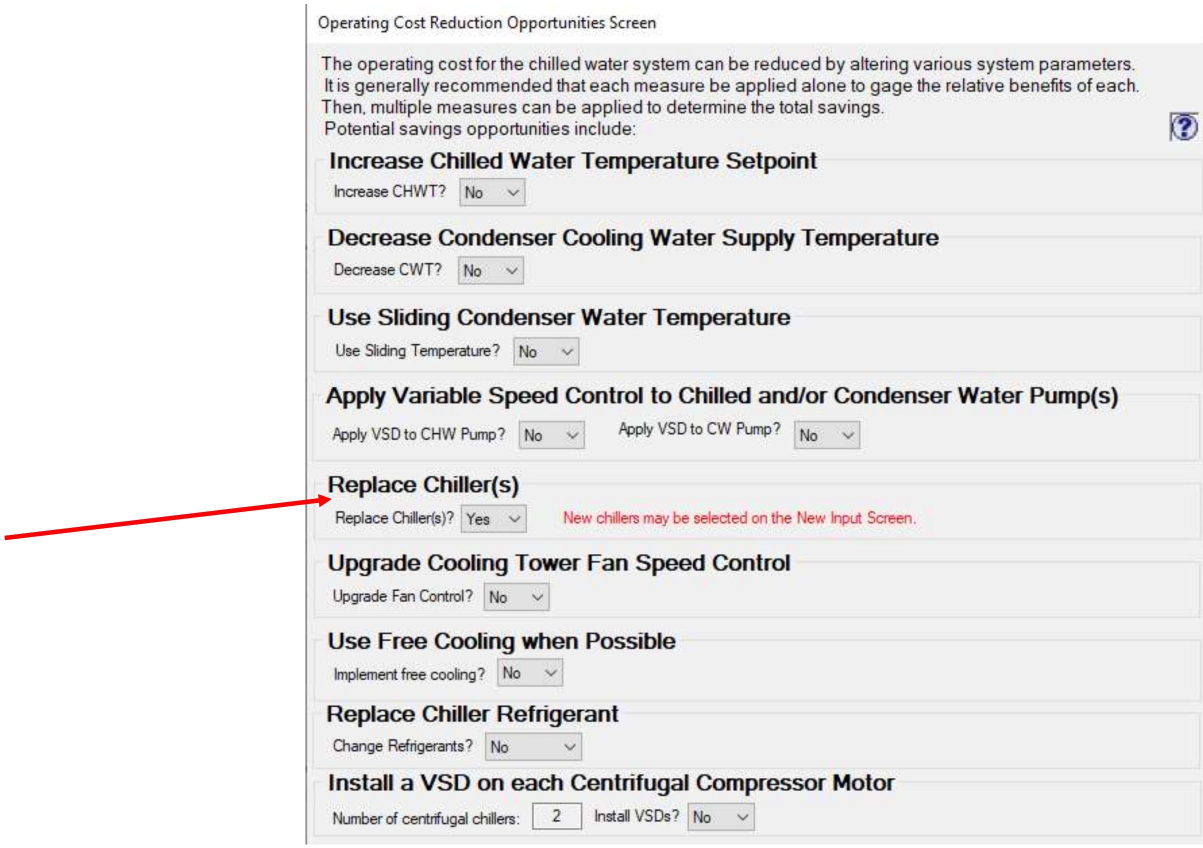
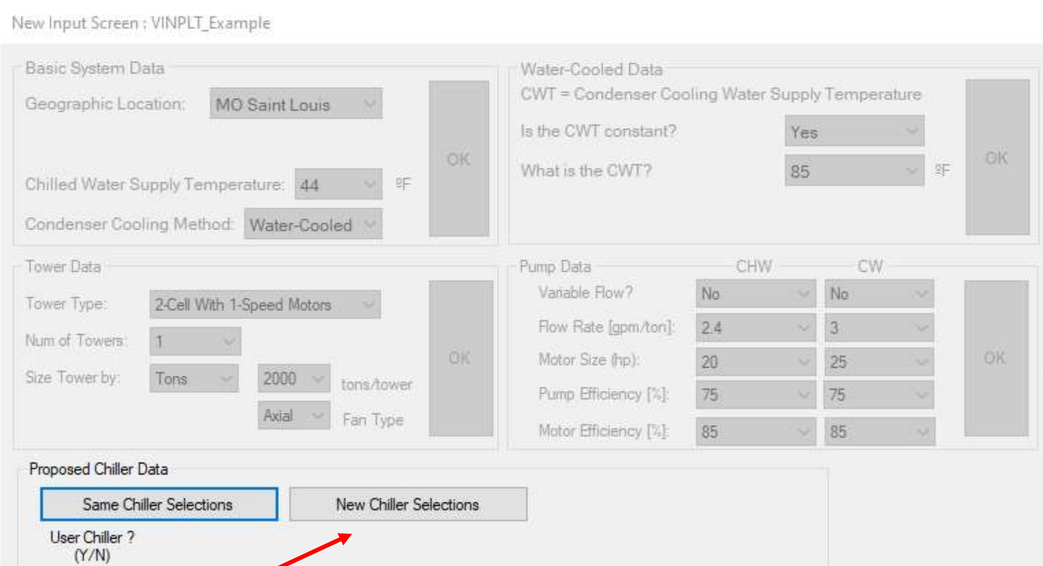
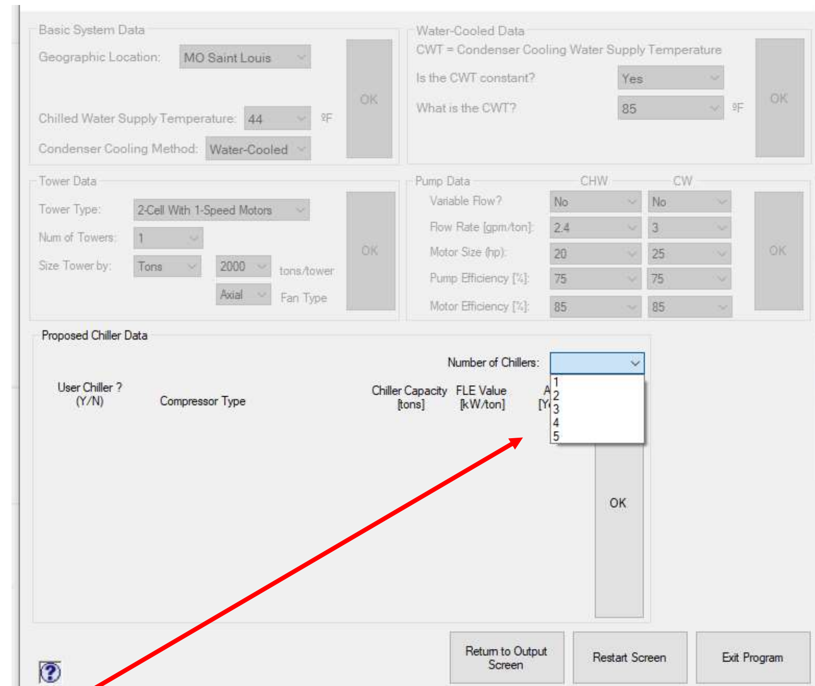
Replacing Chillers



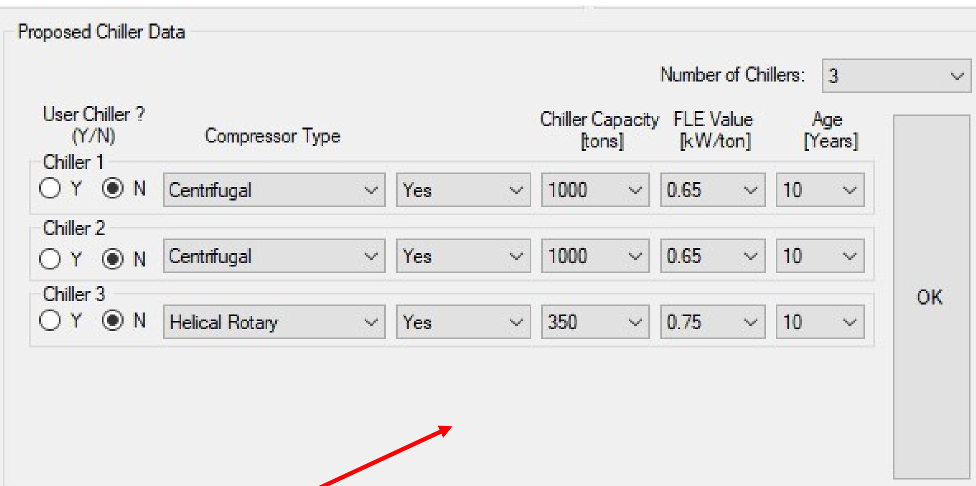
Replacing Chillers

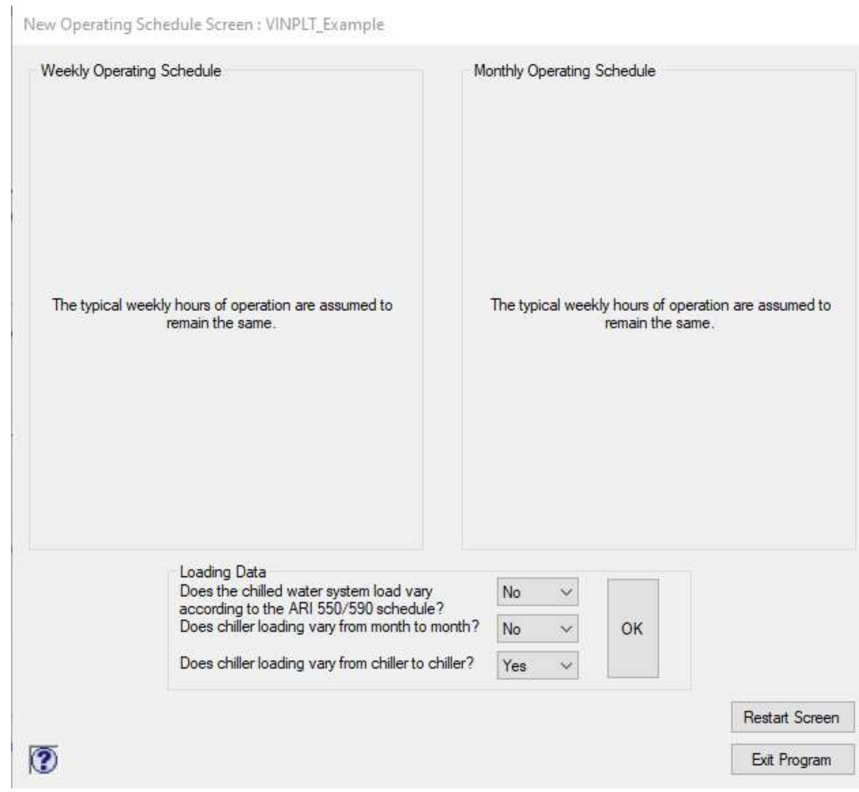




Provides the option to add, remove or keep the same number of chillers

Replacing Chillers





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

Application of Variable Frequency Drives

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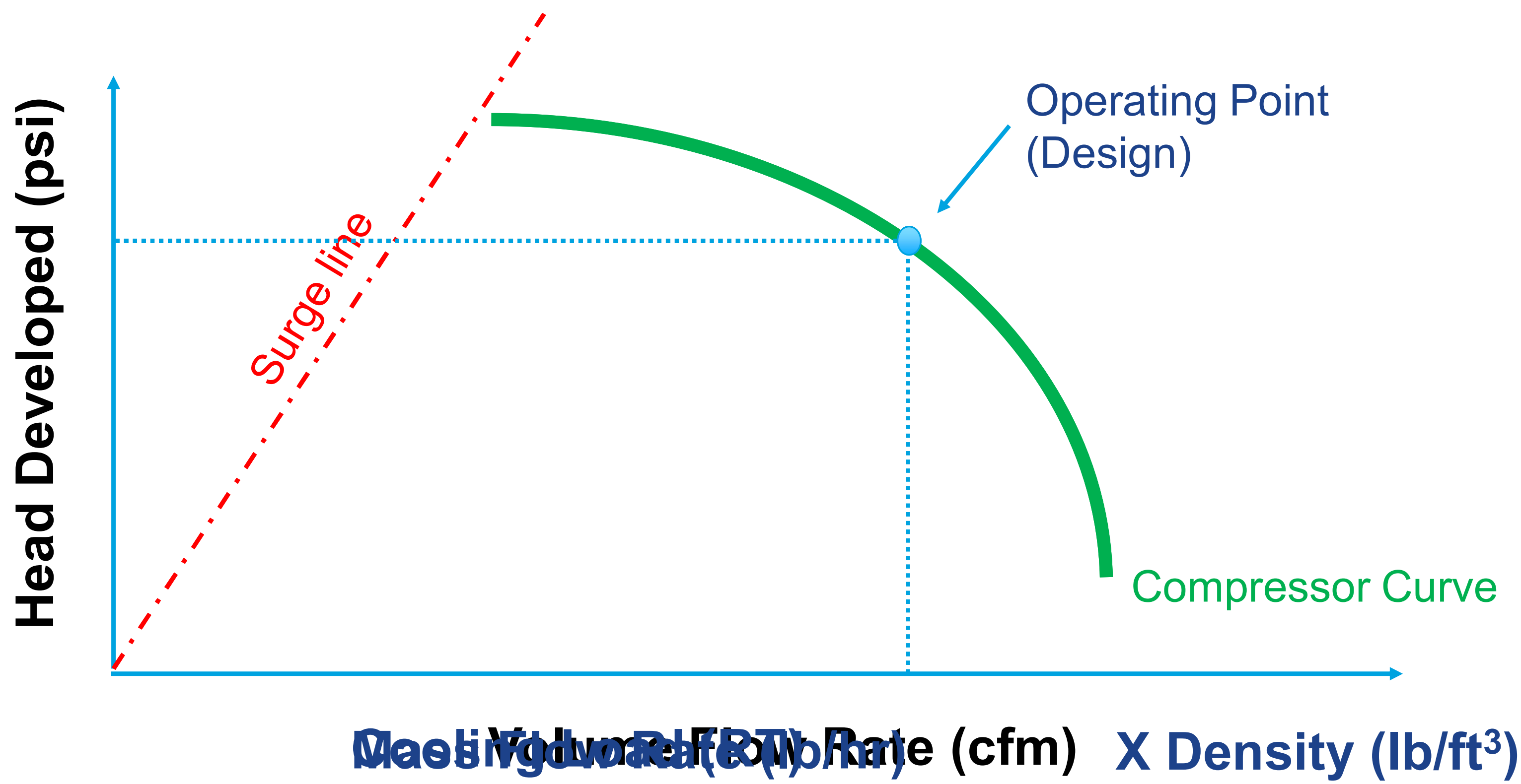
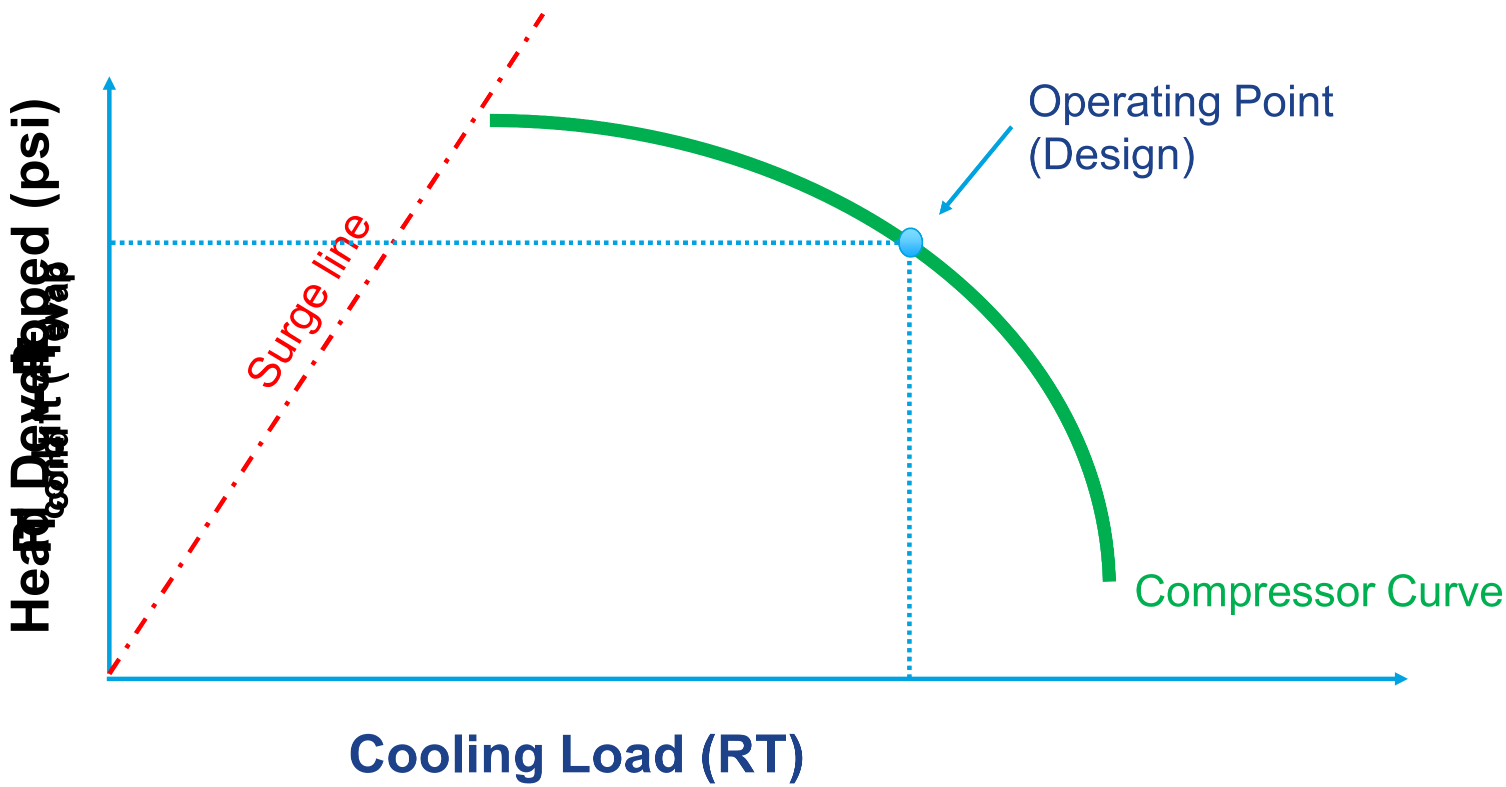
Implement Variable Frequency Driven Chillers

- 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
  - Flow $\propto$ Speed
  - Power $\propto$ Speed^3

Understanding VFD Application on a Centrifugal Chiller

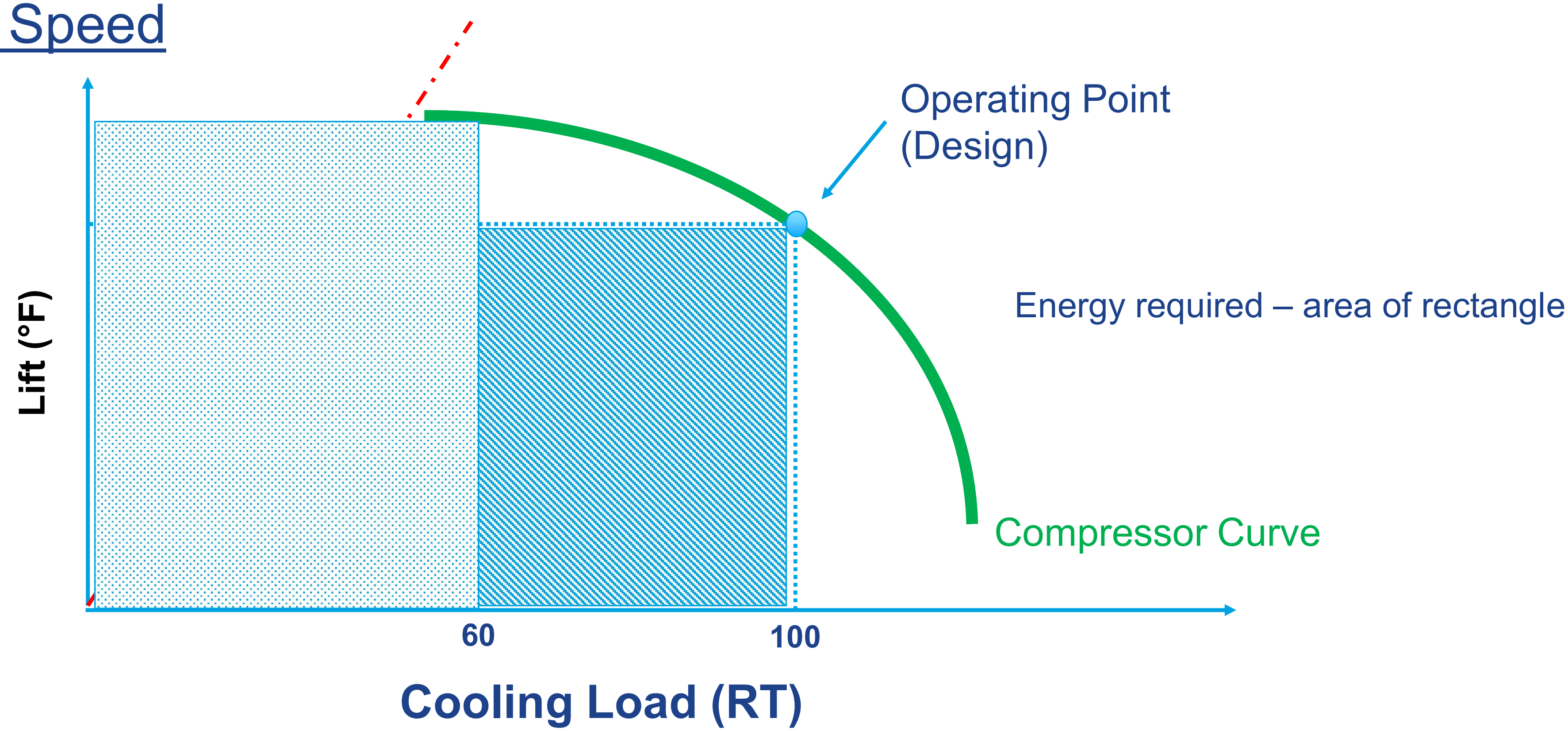


Understanding VFD Application on a Centrifugal Chiller



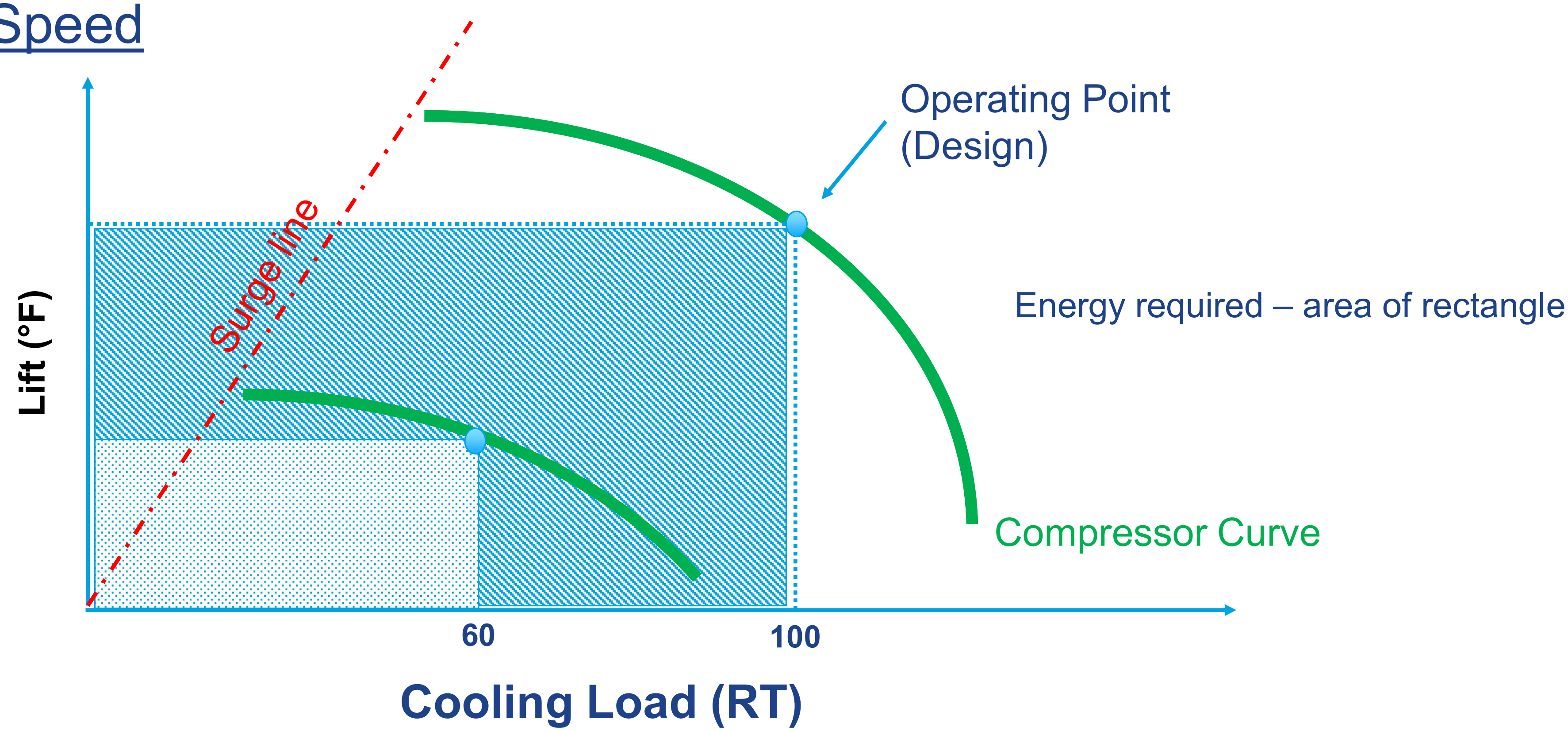
Understanding VFD Application on a Centrifugal Chiller

Constant Speed



Understanding VFD Application on a Centrifugal Chiller

Variable Speed



Understanding VFD Application on a Centrifugal Chiller

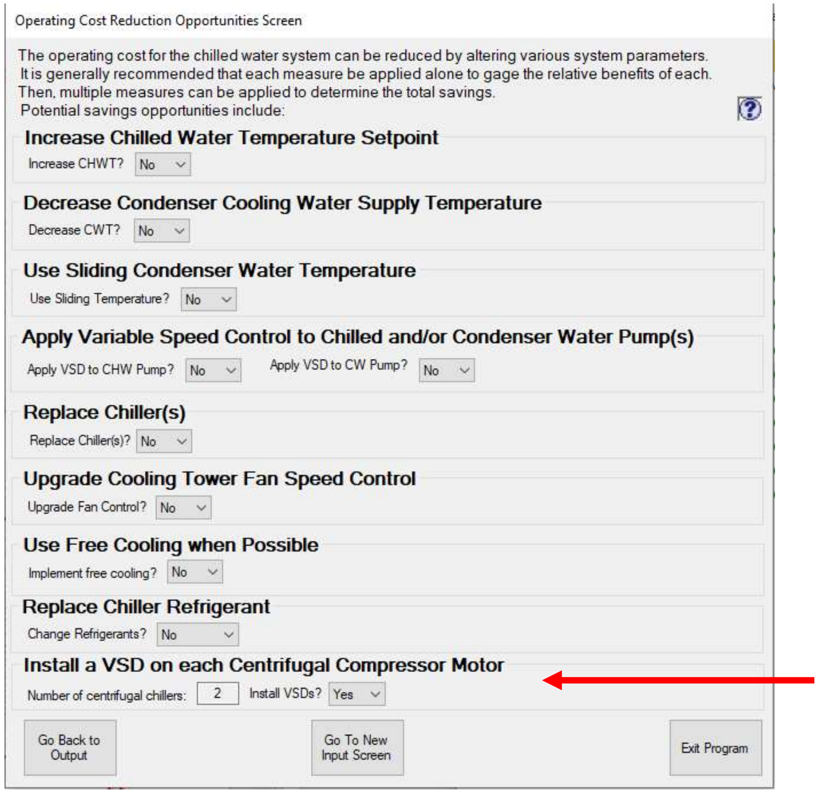
- New chiller packages now have the option of Variable Frequency Drives (VFD) for compressors
- VFD efficiency is extremely high (99%) and more importantly, it offers a benefit on the drive side by providing
  - Soft start capability
  - Power factor correction
- Reducing compressor speed reduces flow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

Modeling Impact of VFD Chillers in CWSAT

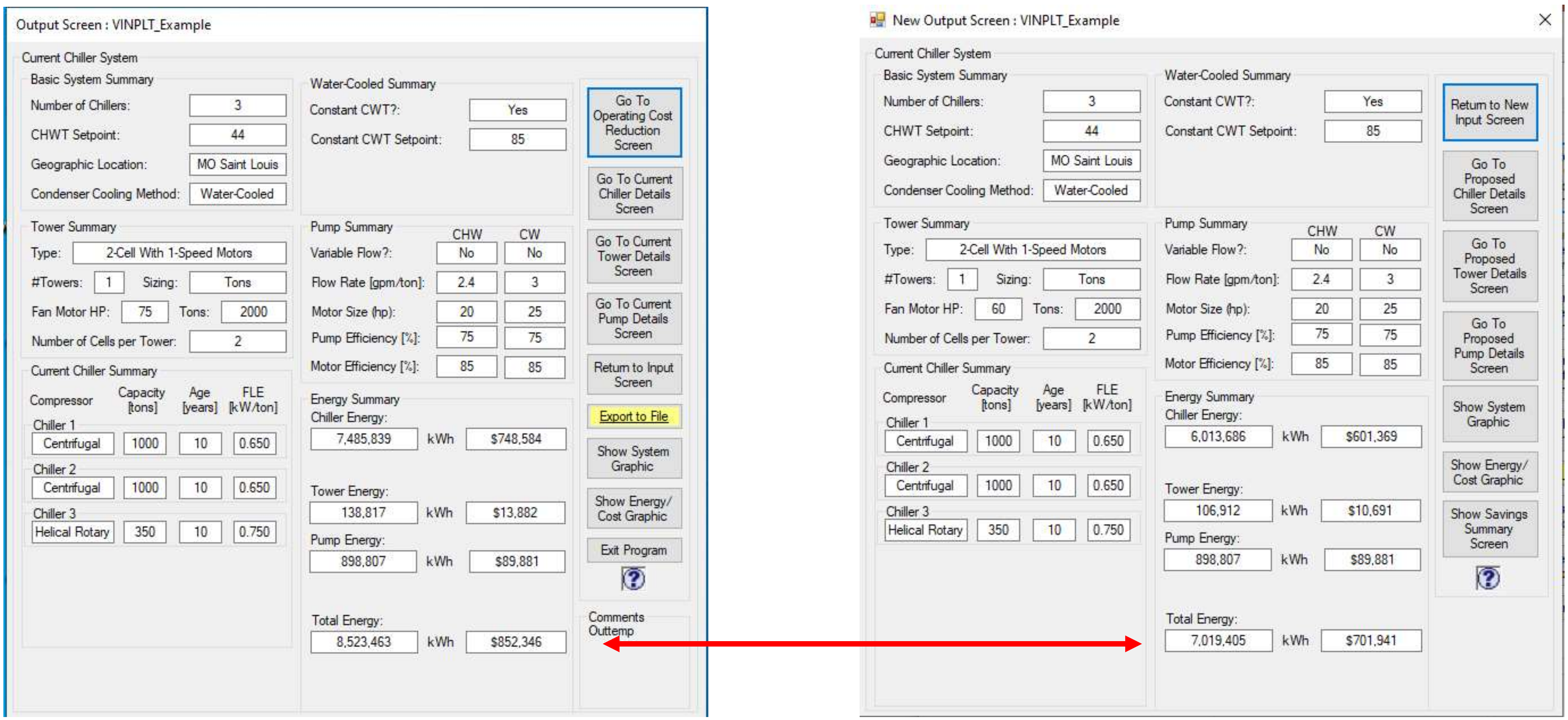
- There are several ways to model implementation of VFD retrofit to chillers, new VFD chillers, etc.
- Method 1 – Use the CWSAT algorithm to simulate the new performance curve for the VFD chiller
- Method 2 – Use the part-load VFD chiller curve from the manufacturer and define a NEW chiller in CWSAT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



Student Exercise (Retrofitting with VFDs)



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

Chiller 1: Centrifugal (Rated Capacity: 1000 tons)

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

Proposed Chiller Details Screen : VINPLT_Example

Chiller 1: Centrifugal (Rated Capacity: 1000 tons)

	0% Load	10% Load	20% Load	30% Load	40% Load	50% Load	60% Load	70% Load	80% Load	90% Load	100% Load	Total
[kW/ton]:	0.000	0.000	0.000	0.000	0.330	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

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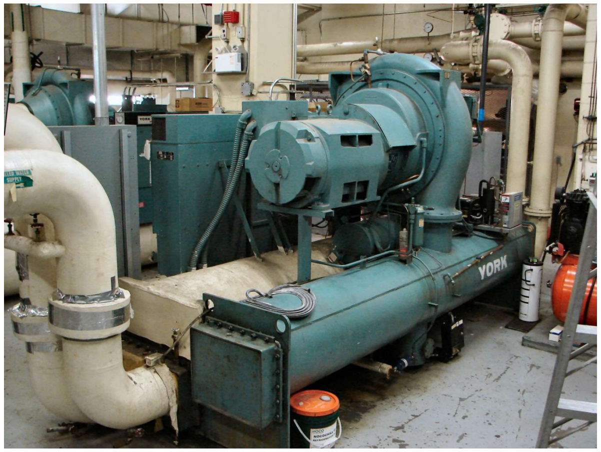
Air-Cooled versus Water-Cooled Systems

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

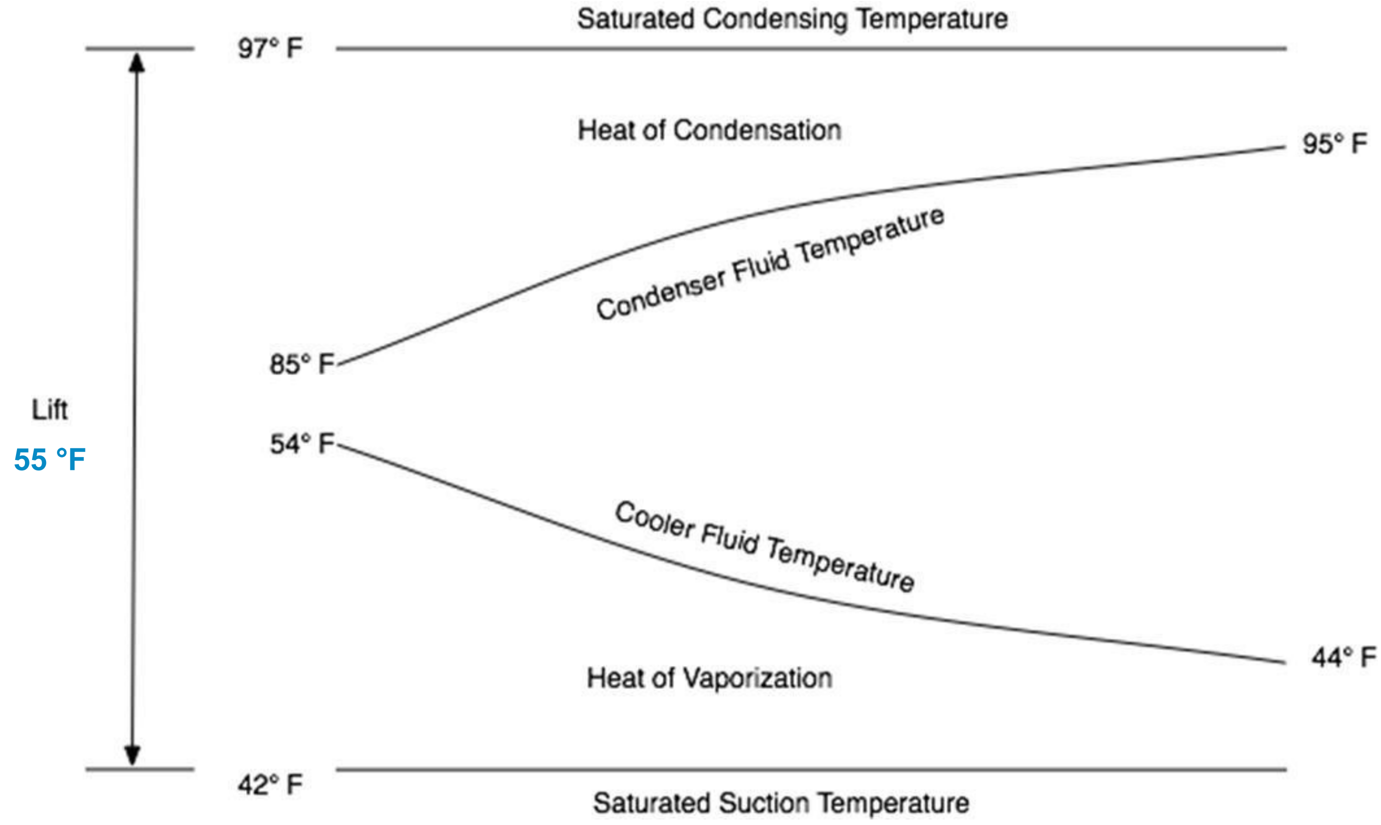
↓

Reduces compressor work

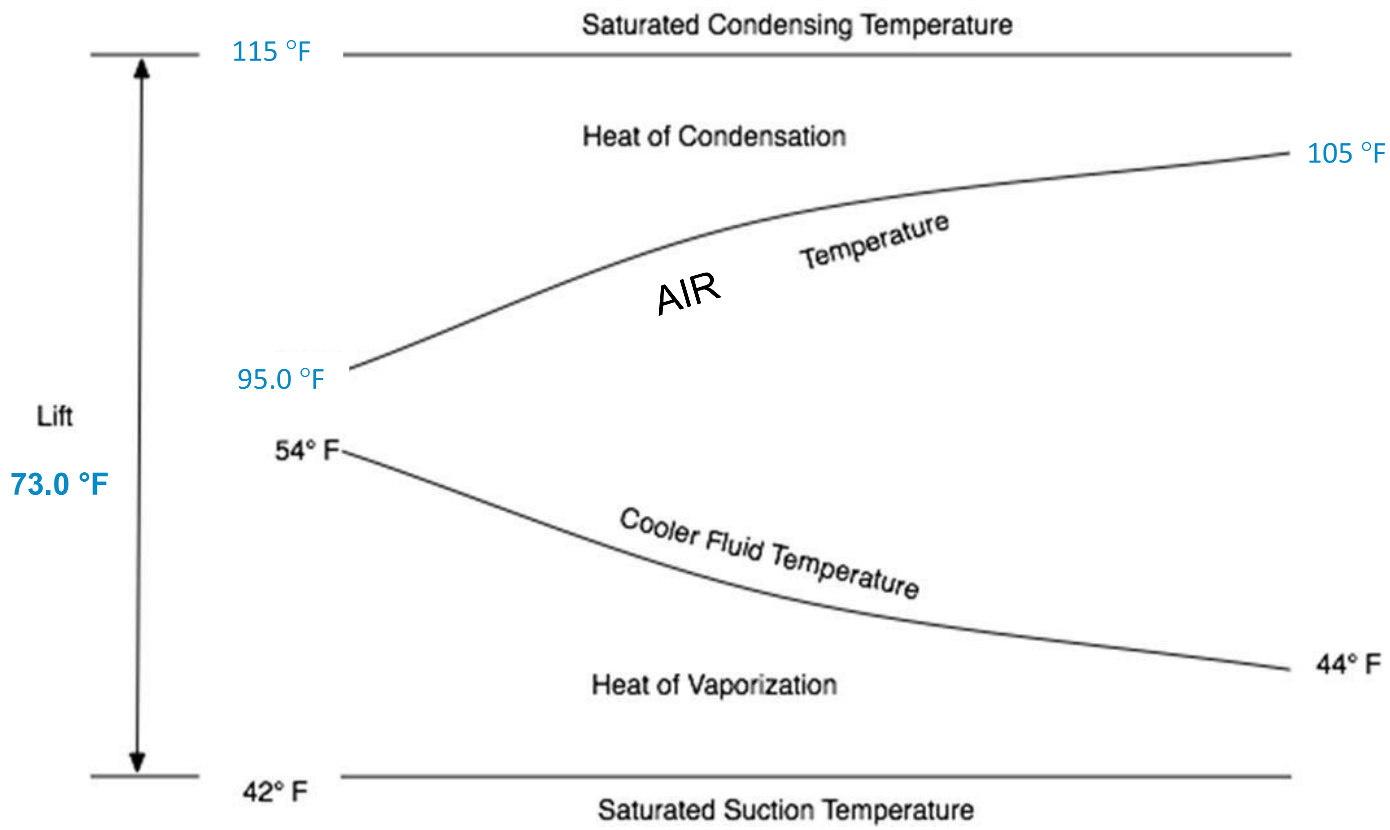
↓

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

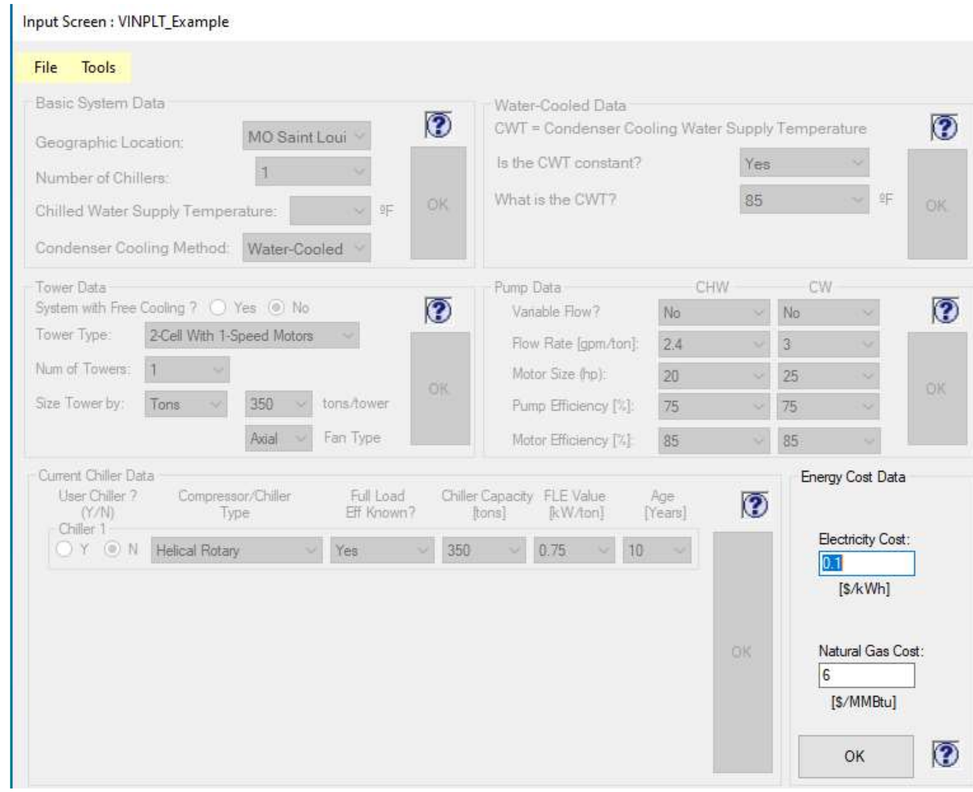
- This may sound like a simple problem but gets complicated for evaluation
  - Facility has 3 chillers and ONLY 1 chiller is being evaluated for replacement
  - CWSAT supports ONLY 1 cooling method for the whole plant

- 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

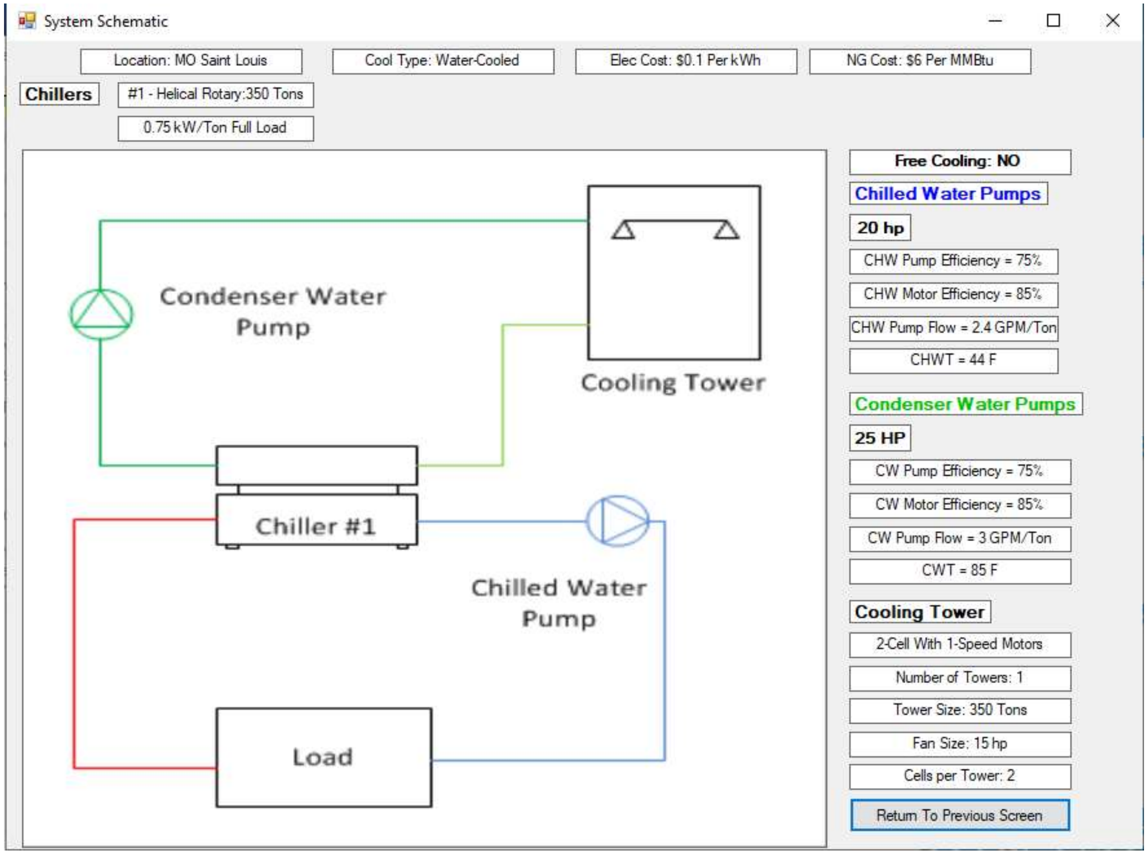
Modeling ONLY Screw Chiller (Water-Cooled)

- One chiller system
- Screw Chiller
- Capacity – 350 RT
- Cooling tower sizing based on 350 RT
- FLE – 0.75 kW/RT

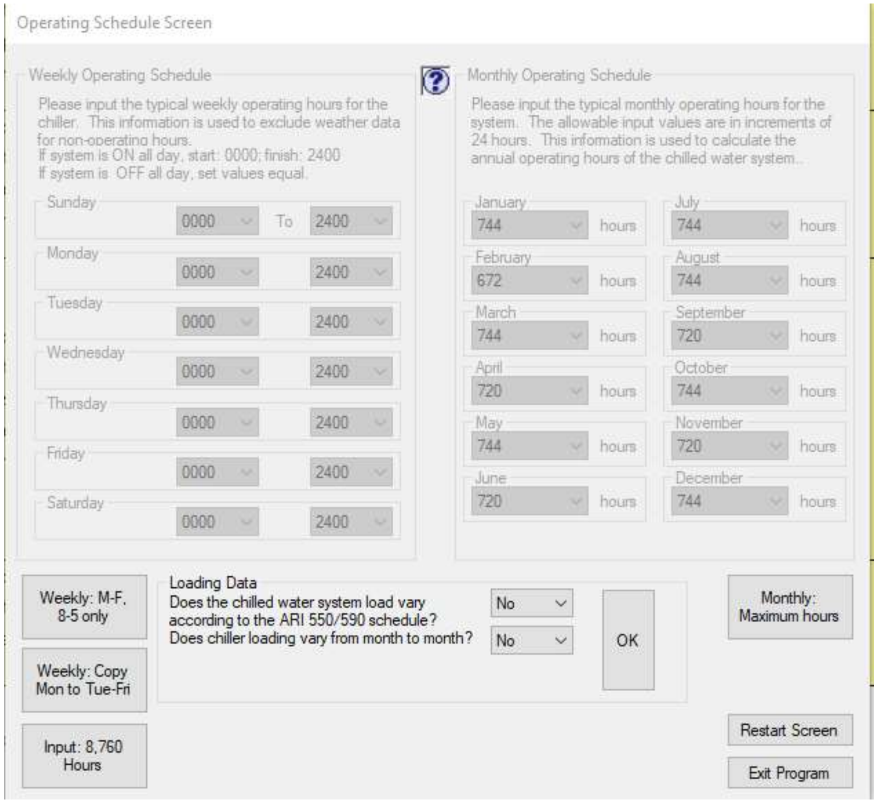
- Use the Base Model and modify inputs



Modeling ONLY Screw Chiller (Water-Cooled)



Modeling ONLY Screw Chiller (Water-Cooled)



Modeling ONLY Screw Chiller (Water-Cooled)

- Input the screw chiller load profile

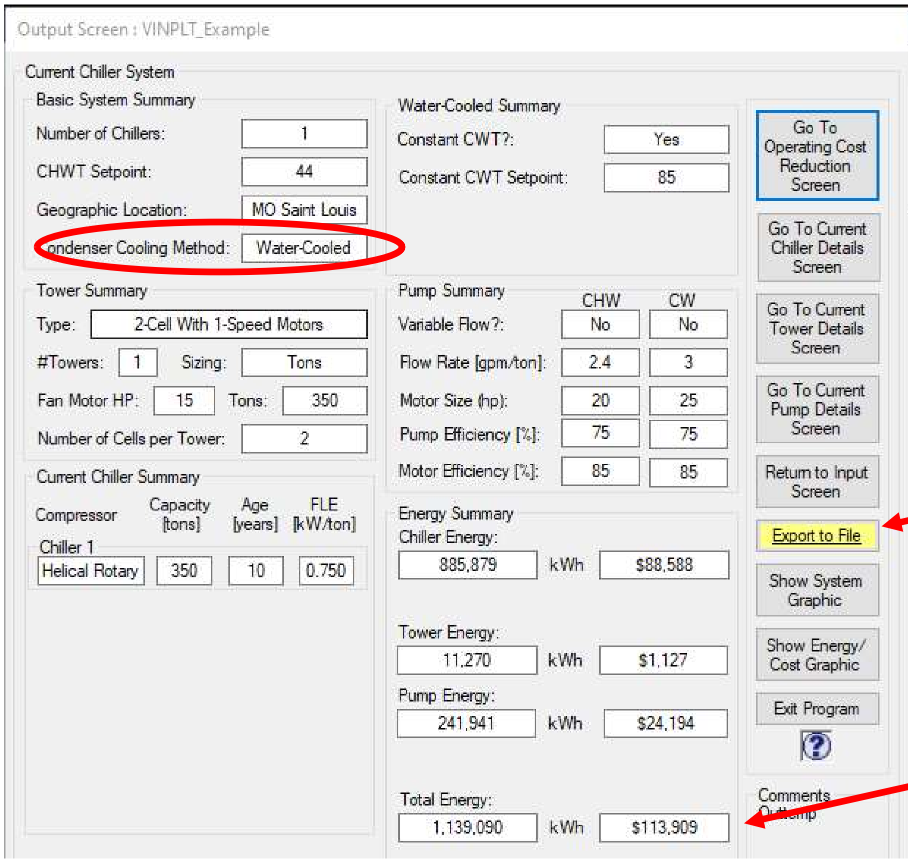
Loading Schedule Screen : VINPLT_Example

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 (Copy / Paste)	30	0	0	30	0	30	0	0	0	0	10	100

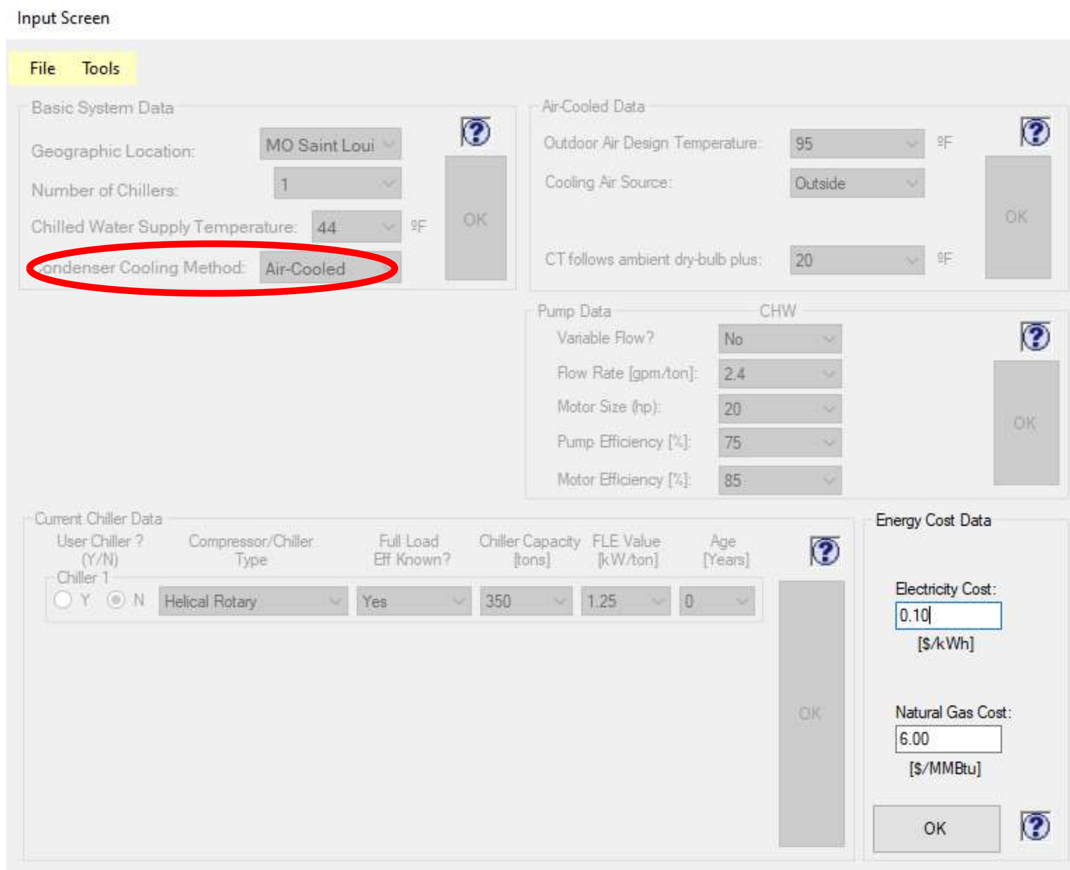
Modeling ONLY Screw Chiller (Water-Cooled)



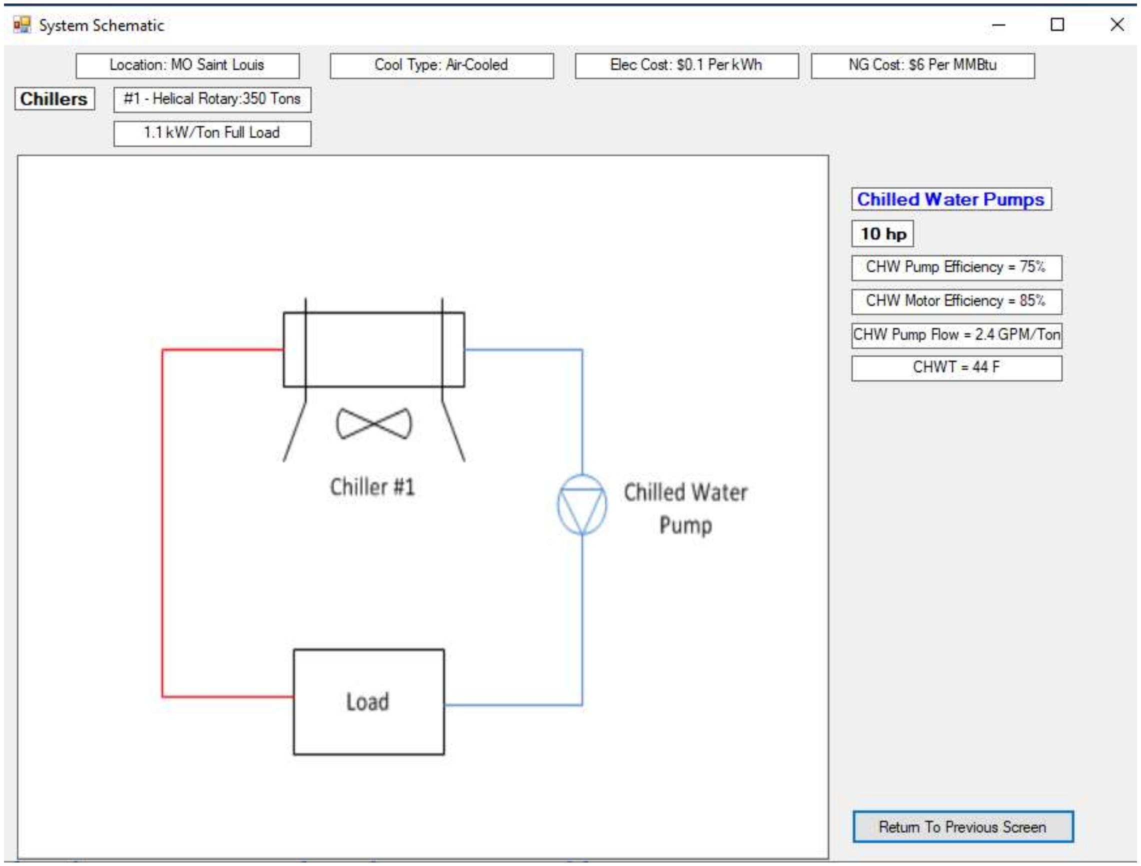
- Check for all the input information
- Once satisfied with the model, SAVE it as a new file

Modeling ONLY Screw Chiller (Air-Cooled)

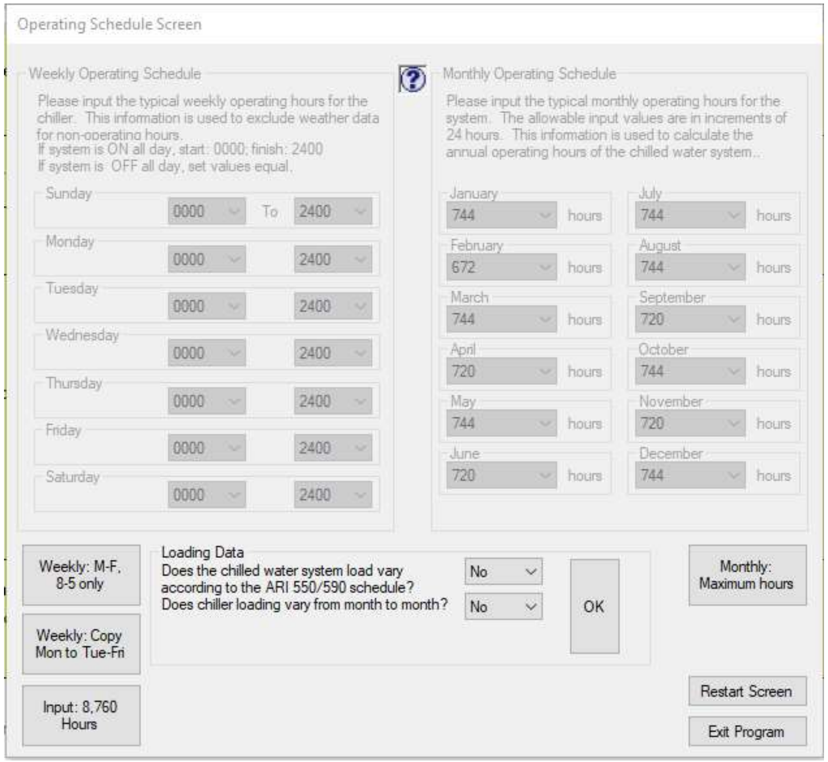
- Build a whole new CWSAT model with Air-Cooled as the method of heat rejection
- FLE – 1.25 kW/RT
- NOTE: Fewer inputs
- Can model both indoor and outdoor installations

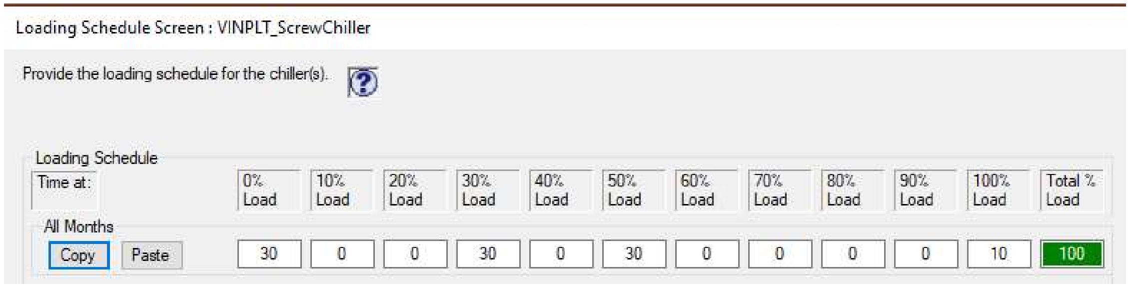


Modeling ONLY Screw Chiller (Air-Cooled)

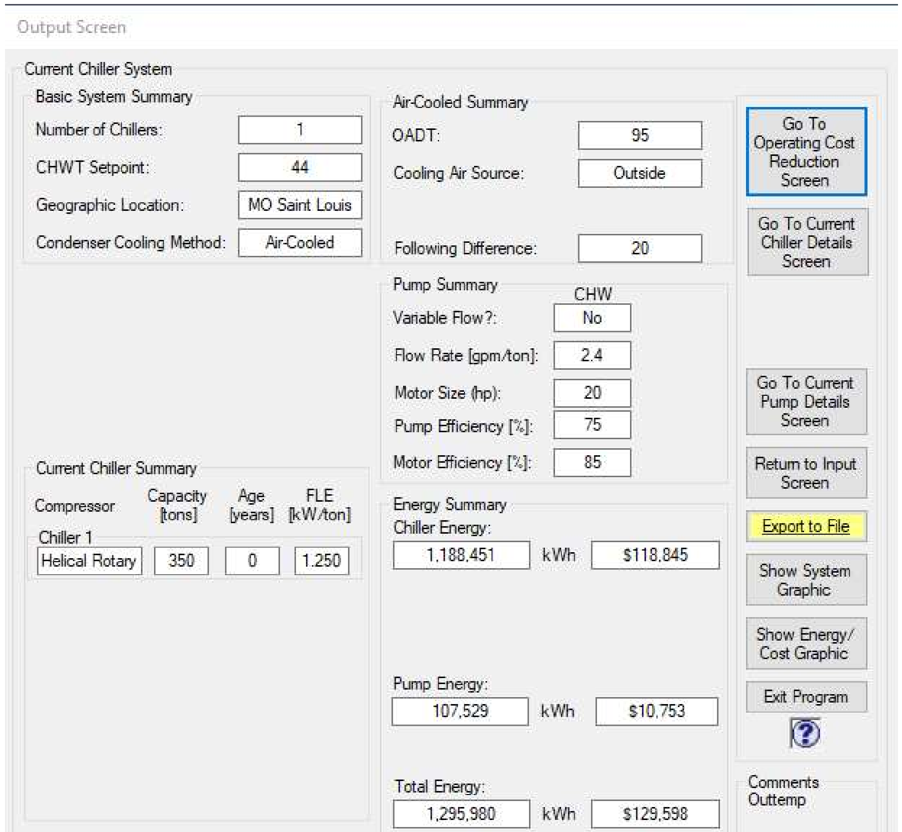


Modeling ONLY Screw Chiller (Air-Cooled)





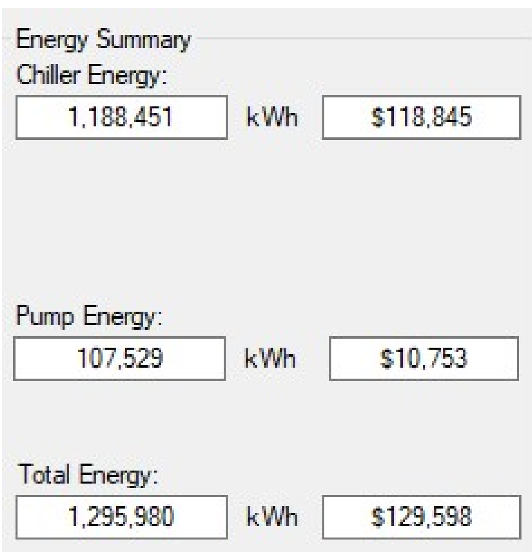
Modeling ONLY Screw Chiller (Air-Cooled)

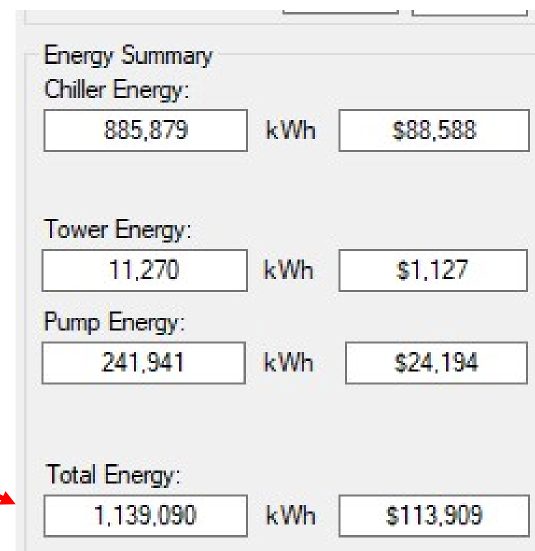


Comparing Water-Cooled vs Air-Cooled

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

Air-Cooled





Water-Cooled

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

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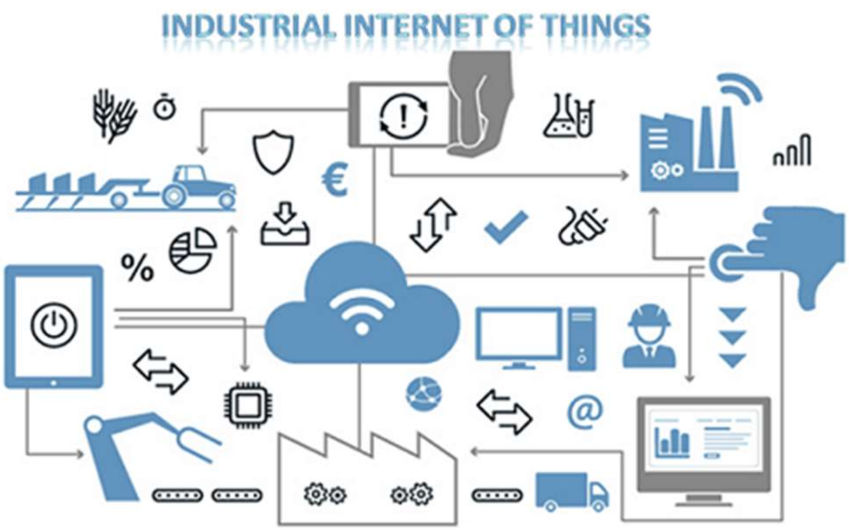
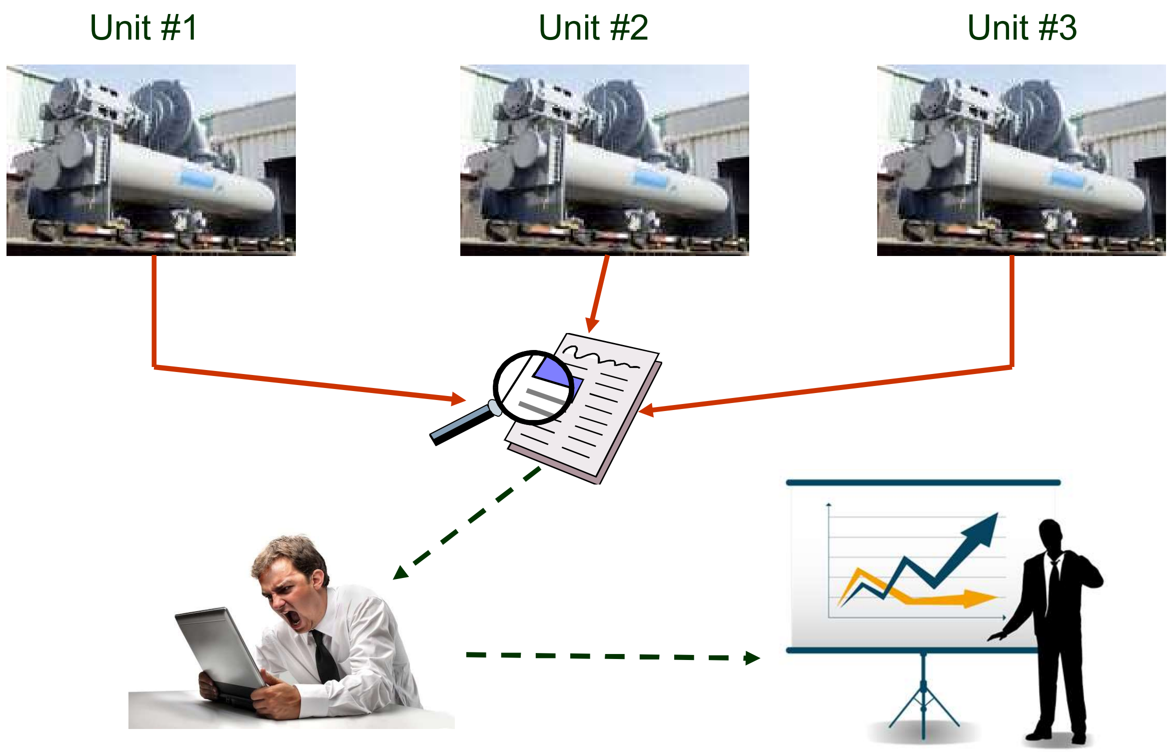
Intelligent Chilled Water Systems with FD&D

- 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

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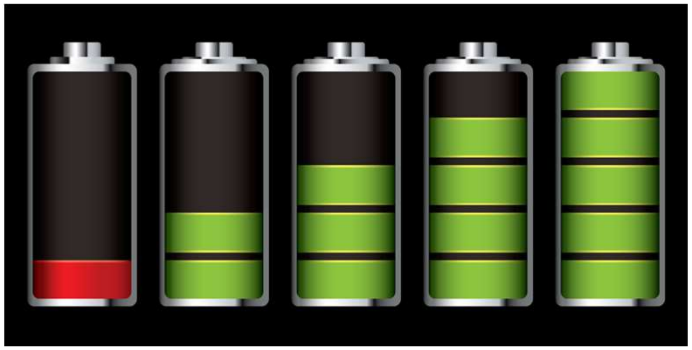
Chilled Water Systems with Thermal Energy Storage

- 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

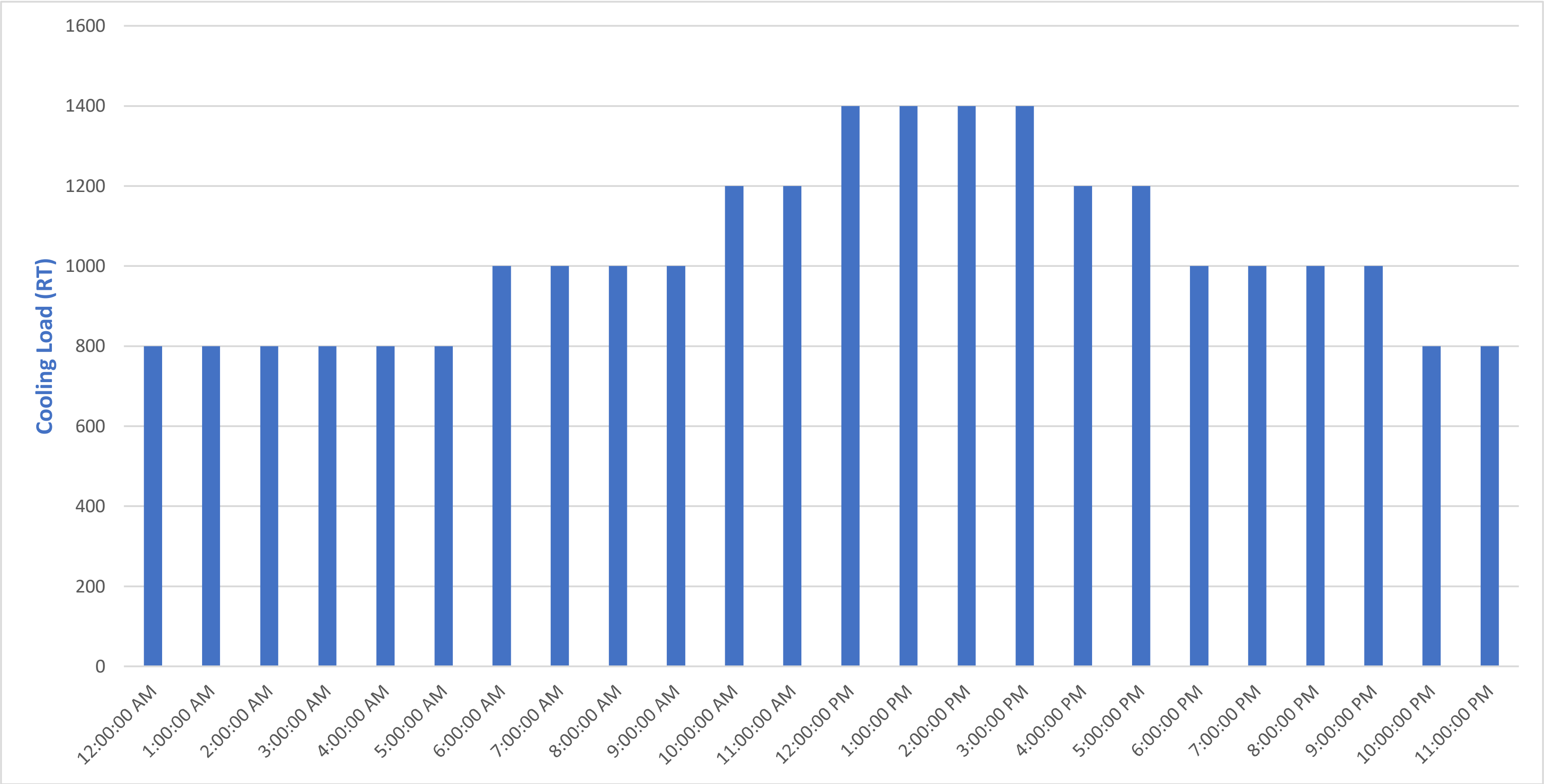
Benefits of TES

- 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)

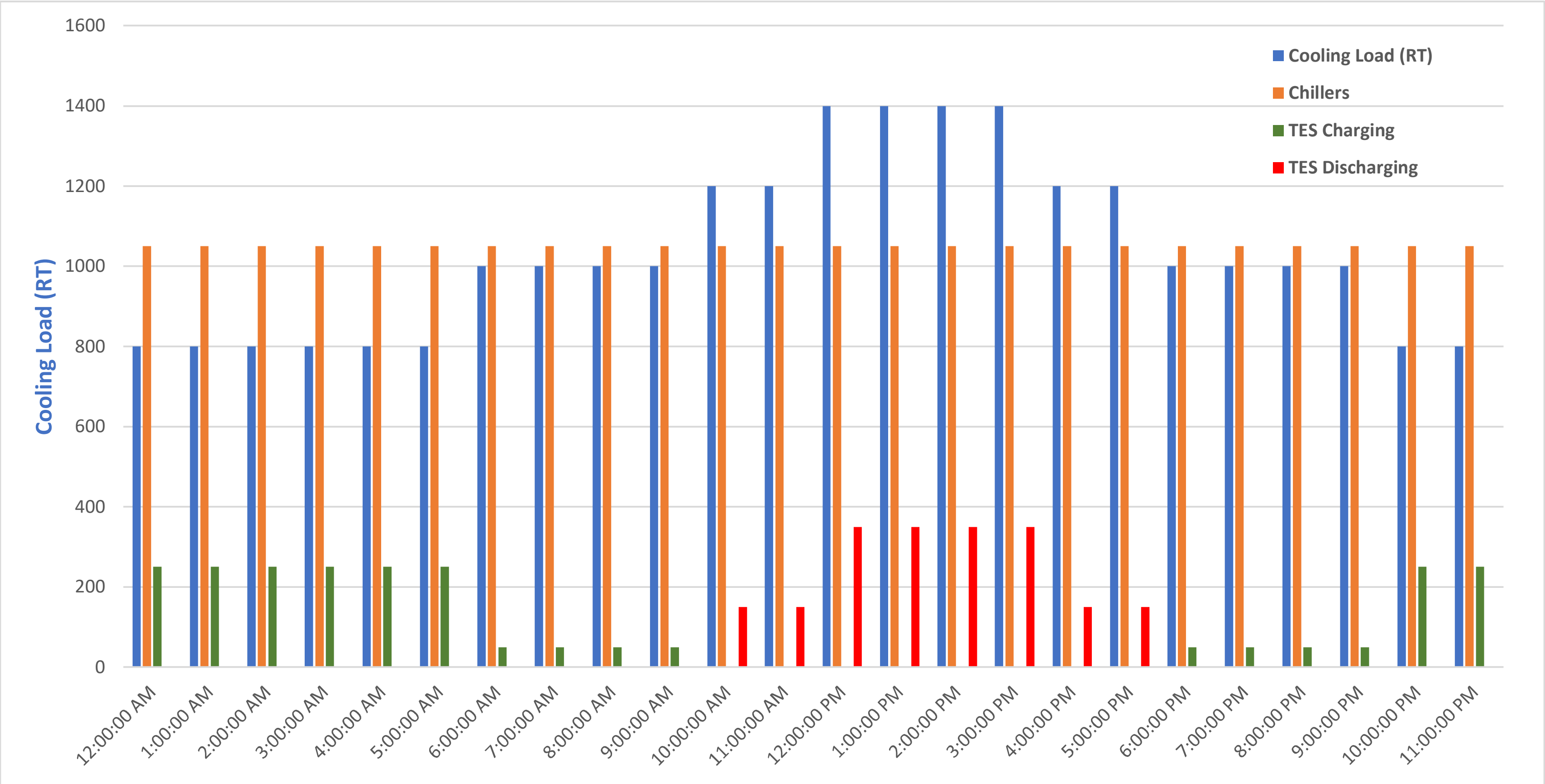


Daily Operations (an example)

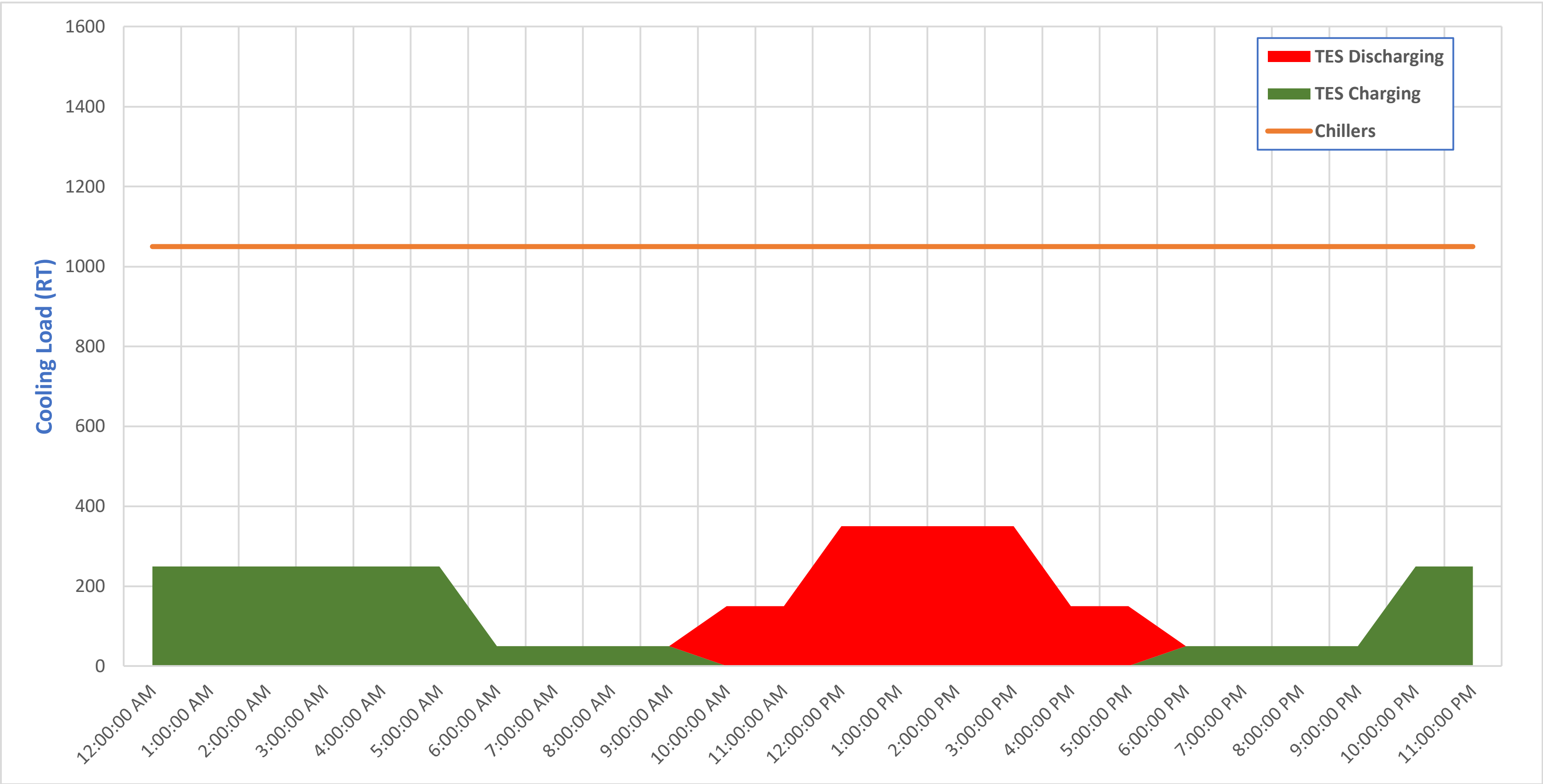
- Option 1
  - Chiller Plant Size – 1,400 RT
  - Daily cooling load – 24,800 Ton-hours

- 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

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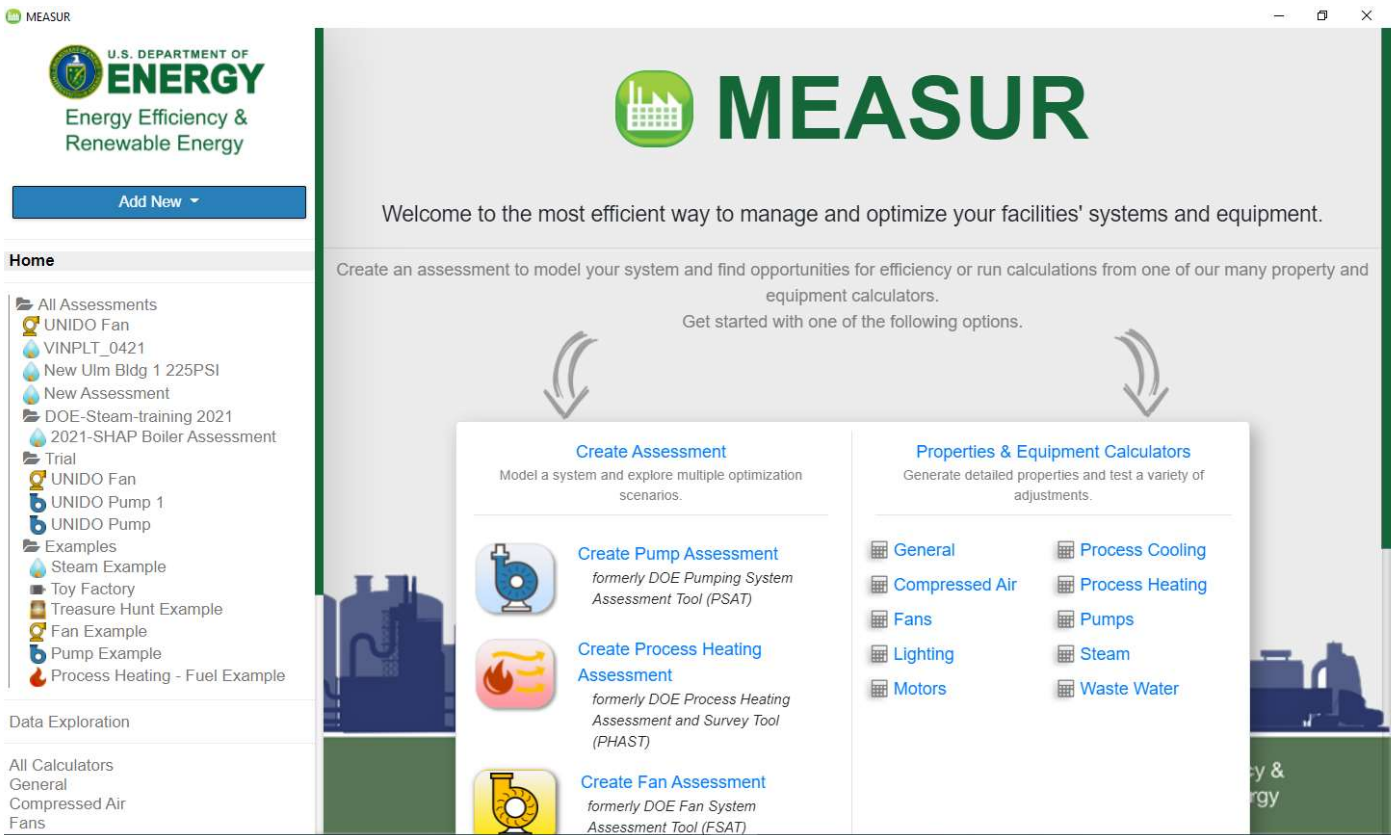
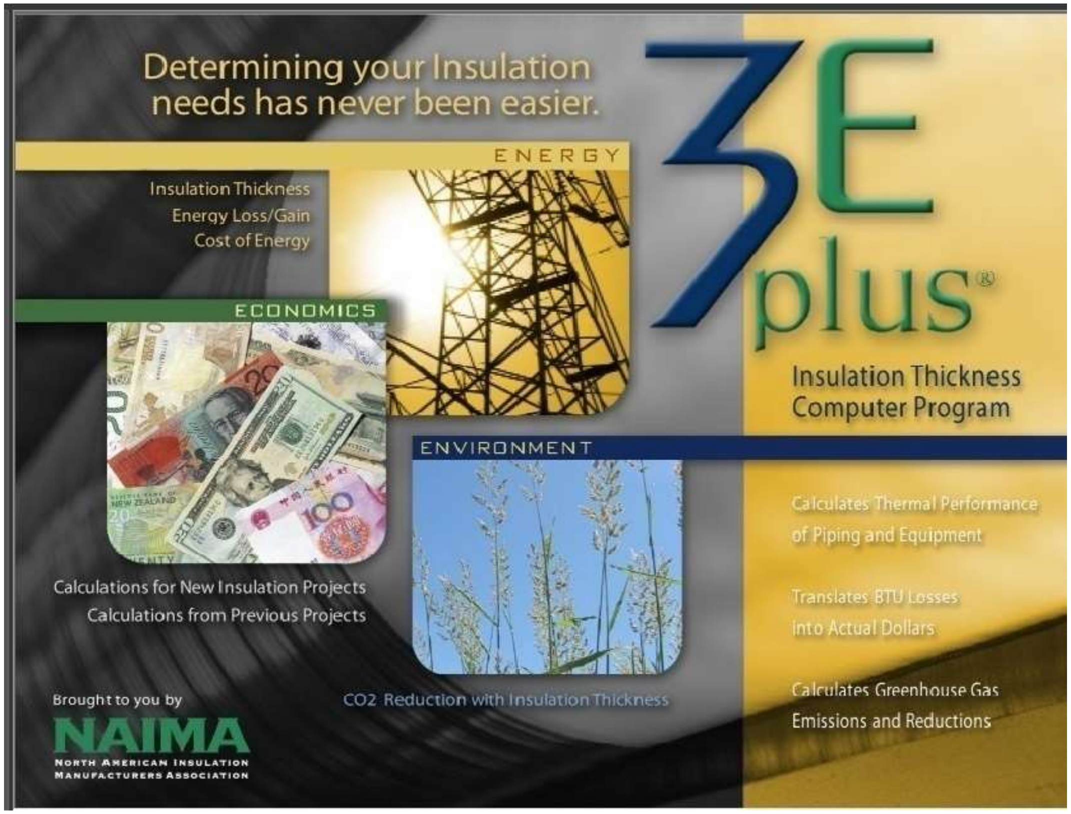
US DOE MEASUR Tool



3E Plus Software Tool



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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

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