Better Plants
U.S. DEPARTMENT OF ENERGY

Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment



Session 7

Wednesday – August 26, 2026

2:00 pm – 4:30 pm ET

U.S. DEPARTMENT OF ENERGY

Welcome

- Welcome to the 7th 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 MEASUR and other US DOE tools and resources
- Thank you for your interest!



Process Cooling (Chilled Water Systems) Virtual INPLT Facilitators



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Process Cooling Virtual INPLT Agenda (2026)

- Session 1 (July 16) – Industrial Chilled Water Systems Fundamentals
- Session 2 (July 23) – Review of Chilled Water System Scoping Tool; Efficiency Metrics & Calculations
- Session 3 (July 30) – Introduction to Process Cooling Assessment (using MEASUR)
- Session 4 (August 6) – Using MEASUR to Quantify Energy Efficiency Opportunities – Part 1
- Session 5 (August 13) – Using MEASUR to Quantify Energy Efficiency Opportunities – Part 2
- Session 6 (August 20) – Using MEASUR to Quantify EEO – Part 3; Other topics; Assessment & Reporting
- **Session 7 (August 26) – Other Modules & Calculators; Reclamation and O&M; Refrigerants – past, present and future**
- **Session 8 (September 3) – Industrial Process Cooling System VINPLT Wrap-up Presentations**

Agenda – Session 7

- Welcome and Introductions
- Safety and Housekeeping
- Today's Content:
  - Review of Session 5 & 6
  - Using other available tools – US DOE MEASUR – Other modules & Calculators; 3EPlus
  - Fluid Management – O&M BestPractices
  - Refrigerants – Past, Present & Future
  - Preparing for the VINPLT Assessment Presentation
- Kahoot Quiz Game
- Q&A

Safety and Housekeeping

- Safety Moment
  - Ensure refrigerant detection monitors are working properly, especially, in indoor and below grade mechanical rooms
  - The next generation of refrigerants are going to be mildly flammable and will require safer operating locations indoors or outdoors
- 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 & 6

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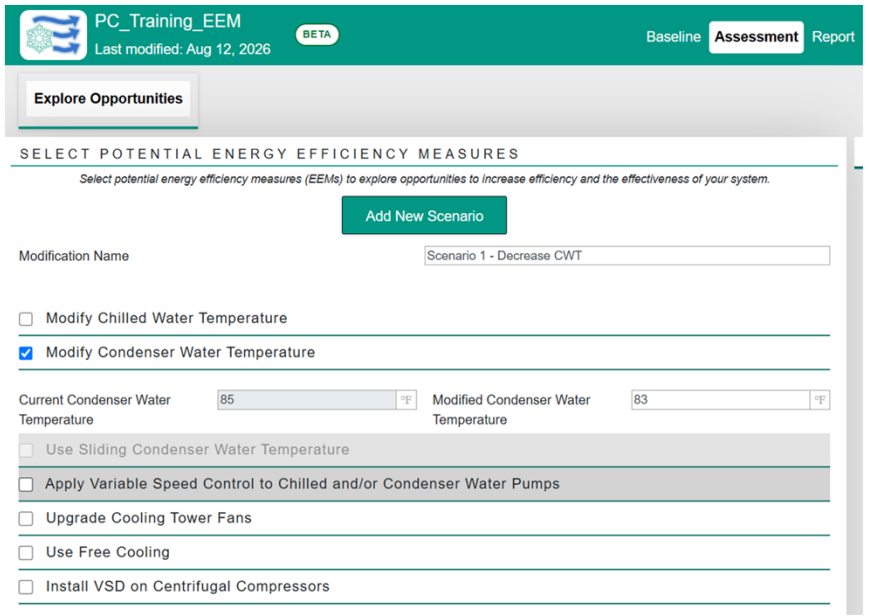
Chiller System Optimization Objectives

- **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



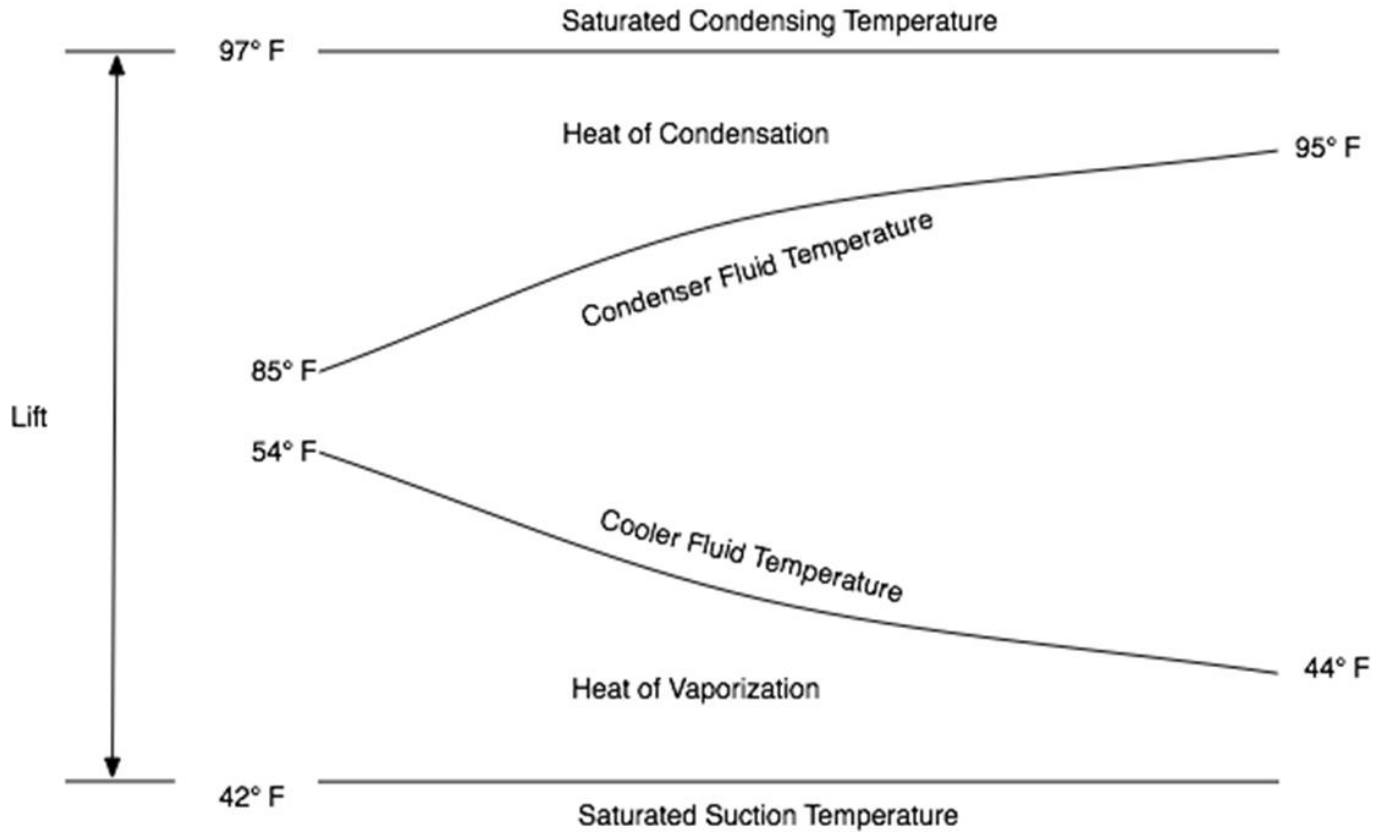
Operating Cost Reduction Scenarios

- 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)

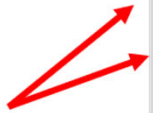
Note: Part of the chiller savings get offset by extra cooling tower operating costs

RESULTS | HELP

	Baseline	Scenario 1 - Decrease CWT
Percent Savings (%)	— —	0.3%
Chiller Energy (kWh)	7,485,479	7,415,498
Chiller Energy Cost ($)	$748,548	$741,550
Tower Energy (kWh)	125,435	172,998
Tower Energy Cost ($)	$12,544	$17,300
Chilled Water Pumping Energy (kWh)	399,470	399,470
Chilled Water Pumping Energy Cost ($)	$39,947	$39,947
Condenser Water Pumping Energy (kWh)	499,337	499,337
Condenser Water Pumping Energy Cost ($)	$49,934	$49,934
Total Pump Energy (kWh)	898,807	898,807
Total Pump Energy Cost ($)	$89,881	$89,881
Total Energy (kWh)	**8,509,721**	**8,487,303**
Energy Savings (kWh)	**— —**	**22,419**
Total Cost ($)	**$850,972**	**$848,730**
Cost Savings ($)	**— —**	**$2,242**
Energy Efficiency Measures Used	— —	Modify Condenser Water Temperature

Student Exercise (Increase Chilled Water Supply Temperature)

Savings on both – Chiller & Tower



RESULTS | HELP

	Baseline	Scenario 3 - Increase CHWT
Percent Savings (%)	——	1.0%
Chiller Energy (kWh)	7,485,479	7,403,626
Chiller Energy Cost ($)	$748,548	$740,363
Tower Energy (kWh)	125,435	125,333
Tower Energy Cost ($)	$12,544	$12,533
Chilled Water Pumping Energy (kWh)	399,470	399,470
Chilled Water Pumping Energy Cost ($)	$39,947	$39,947
Condenser Water Pumping Energy (kWh)	499,337	499,337
Condenser Water Pumping Energy Cost ($)	$49,934	$49,934
Total Pump Energy (kWh)	898,807	898,807
Total Pump Energy Cost ($)	$89,881	$89,881
Total Energy (kWh)	**8,509,721**	**8,427,766**
Energy Savings (kWh)	**——**	**81,955**
Total Cost ($)	**$850,972**	**$842,777**
Cost Savings ($)	**——**	**$8,196**
Energy Efficiency Measures Used	——	Modify Chilled Water Temperature

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 MEASUR

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

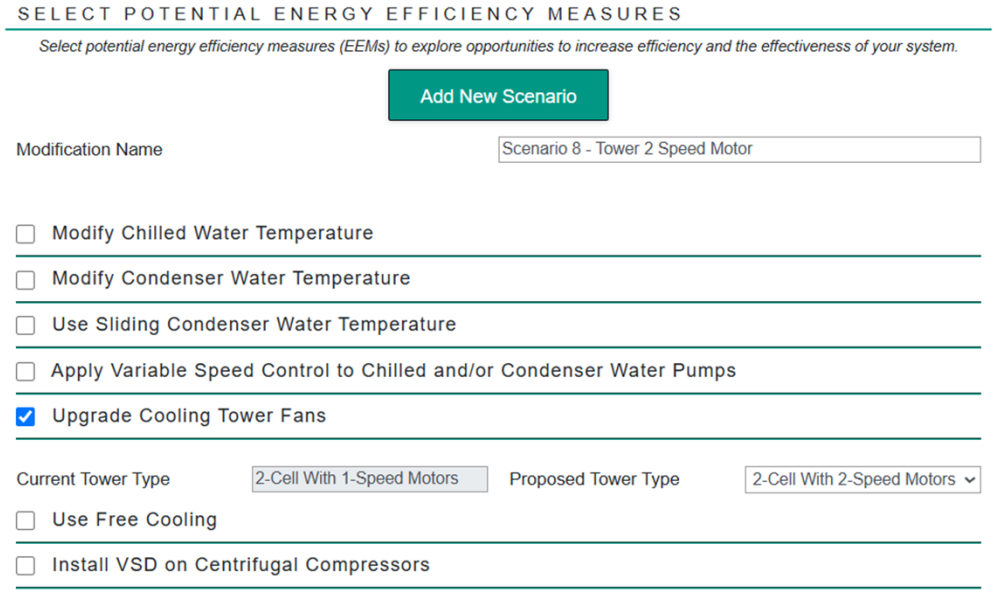
RESULTS | HELP

	Baseline	Scenario 6 - VFD to CHWP
Percent Savings (%)	— —	2.5%
Chiller Energy (kWh)	7,485,479	7,485,479
Chiller Energy Cost ($)	$748,548	$748,548
Tower Energy (kWh)	125,435	125,435
Tower Energy Cost ($)	$12,544	$12,544
Chilled Water Pumping Energy (kWh)	399,470	185,247
Chilled Water Pumping Energy Cost ($)	$39,947	$18,525
Condenser Water Pumping Energy (kWh)	499,337	499,337
Condenser Water Pumping Energy Cost ($)	$49,934	$49,934
Total Pump Energy (kWh)	898,807	684,585
Total Pump Energy Cost ($)	$89,881	$68,458
Total Energy (kWh)	**8,509,721**	**8,295,499**
Energy Savings (kWh)	**— —**	**214,223**
Total Cost ($)	**$850,972**	**$829,550**
Cost Savings ($)	**— —**	**$21,422**
Energy Efficiency Measures Used	— —	Apply Variable Speed Controls

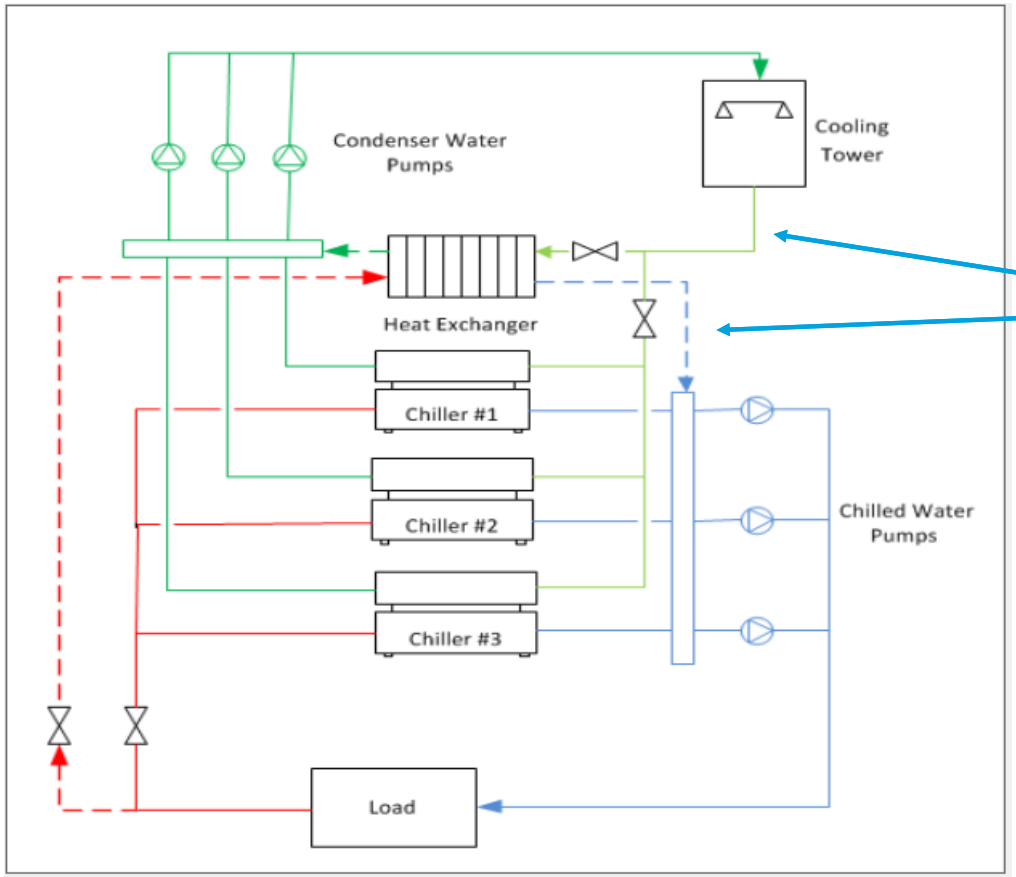
Application of Cooling Tower Fan Speed Control

- MEASUR 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

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)

Method 1 (Simple Approach)

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

	Baseline
Percent Savings (%)	— —
Chiller Energy (kWh)	7,485,479
Chiller Energy Cost ($)	$748,548
Tower Energy (kWh)	138,817
Tower Energy Cost ($)	$13,882
Chilled Water Pumping Energy (kWh)	399,470
Chilled Water Pumping Energy Cost ($)	$39,947
Condenser Water Pumping Energy (kWh)	499,337
Condenser Water Pumping Energy Cost ($)	$49,934
Total Pump Energy (kWh)	898,807
Total Pump Energy Cost ($)	$89,881
Total Energy (kWh)	**8,523,103**
Energy Savings (kWh)	— —
Total Cost ($)	**$852,310**
Cost Savings ($)	— —
Energy Efficiency Measures Used	— —

- Unit cost of cooling
  - $Energy_{average} = \frac{8{,}523{,}103}{1{,}339} = \sim 6{,}365 \ \frac{kWh}{RT-yr}$
  - $Cost_{average} = \frac{852{,}310}{1{,}339} = \sim 636 \ \frac{\$}{RT-yr}$
- Cost savings for 46 RT cooling load
  - Savings = $636 * 46$ = $ 29,250 annually

Replacing Chiller(s)

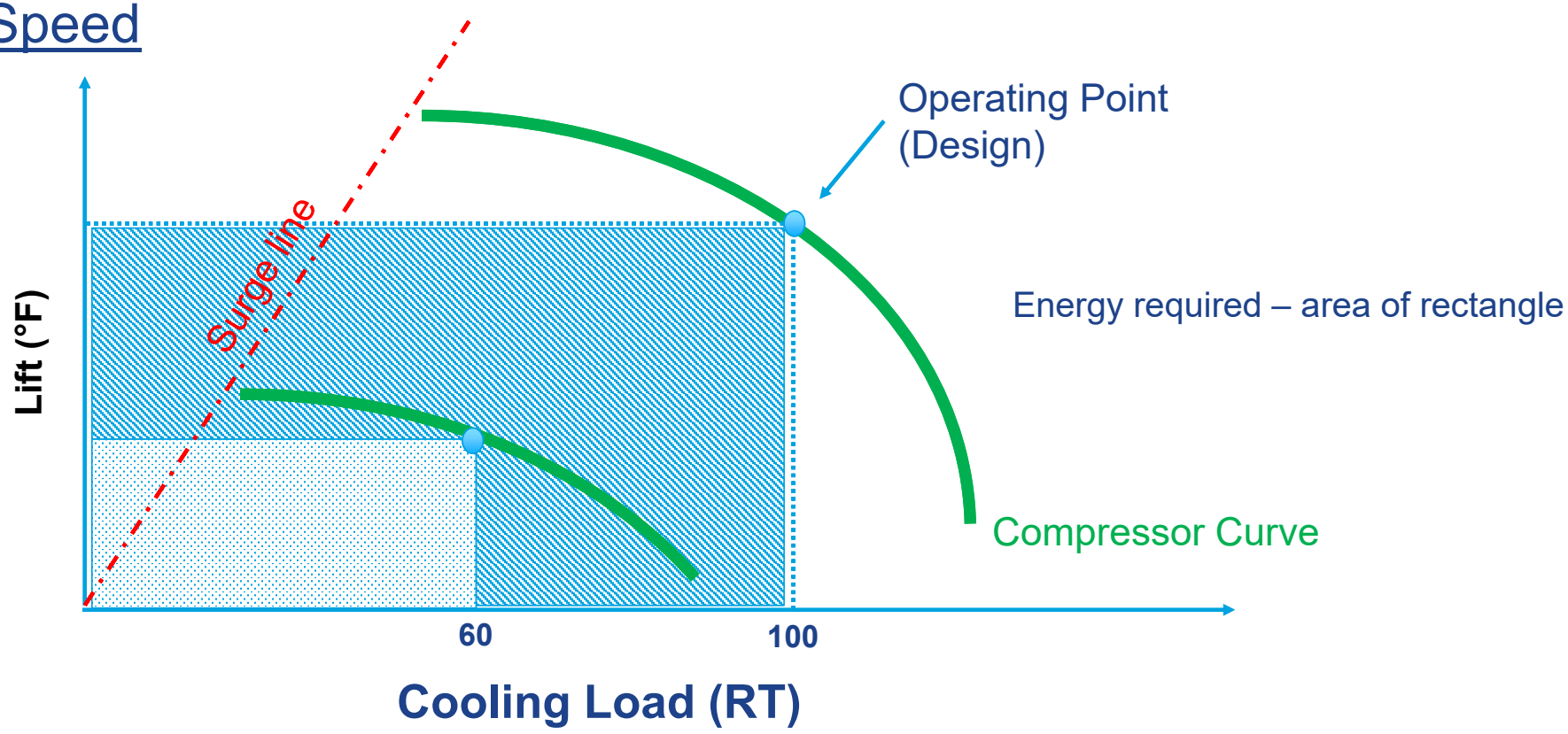
- A very common question for almost every chiller plant energy assessment

- 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

- MEASUR can be used to model all the categories of opportunities

Understanding VFD Application on a Centrifugal Chiller

Variable Speed



Modeling Impact of VFD Chillers in MEASUR

- There are several ways to model implementation of VFD retrofit to chillers, new VFD chillers, etc.
- Method 1 – Use the MEASUR 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 MEASUR database
- Method 3 – Use a bin analysis methodology including lift variation

Comparing Water-Cooled vs Air-Cooled

- System Savings using Water-Cooled Screw Chiller
  = 39,001 kWh ($3,900 annually)

Air-Cooled

RESULTS | HELP

	Baseline
Percent Savings (%)	— —
Chiller Energy (kWh)	1,014,160
Chiller Energy Cost ($)	$101,416
Tower Energy (kWh)	0
Tower Energy Cost ($)	— —
Chilled Water Pumping Energy (kWh)	53,765
Chilled Water Pumping Energy Cost ($)	$5,376
Condenser Water Pumping Energy (kWh)	0
Condenser Water Pumping Energy Cost ($)	— —
Total Pump Energy (kWh)	53,765
Total Pump Energy Cost ($)	— —
Total Energy (kWh)	**1,067,925**
Energy Savings (kWh)	**— —**
Total Cost ($)	**$106,792**
Cost Savings ($)	**— —**
Energy Efficiency Measures Used	— —

Copy Table

RESULTS | HELP

	Baseline
Percent Savings (%)	— —
Chiller Energy (kWh)	885,790
Chiller Energy Cost ($)	$88,579
Tower Energy (kWh)	8,722
Tower Energy Cost ($)	$872
Chilled Water Pumping Energy (kWh)	53,765
Chilled Water Pumping Energy Cost ($)	$5,376
Condenser Water Pumping Energy (kWh)	80,647
Condenser Water Pumping Energy Cost ($)	$8,065
Total Pump Energy (kWh)	134,412
Total Pump Energy Cost ($)	$13,441
Total Energy (kWh)	**1,028,924**
Energy Savings (kWh)	**— —**
Total Cost ($)	**$102,892**
Cost Savings ($)	**— —**
Energy Efficiency Measures Used	— —

Copy Table

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)

US DOE MEASUR – Other Modules & Calculators

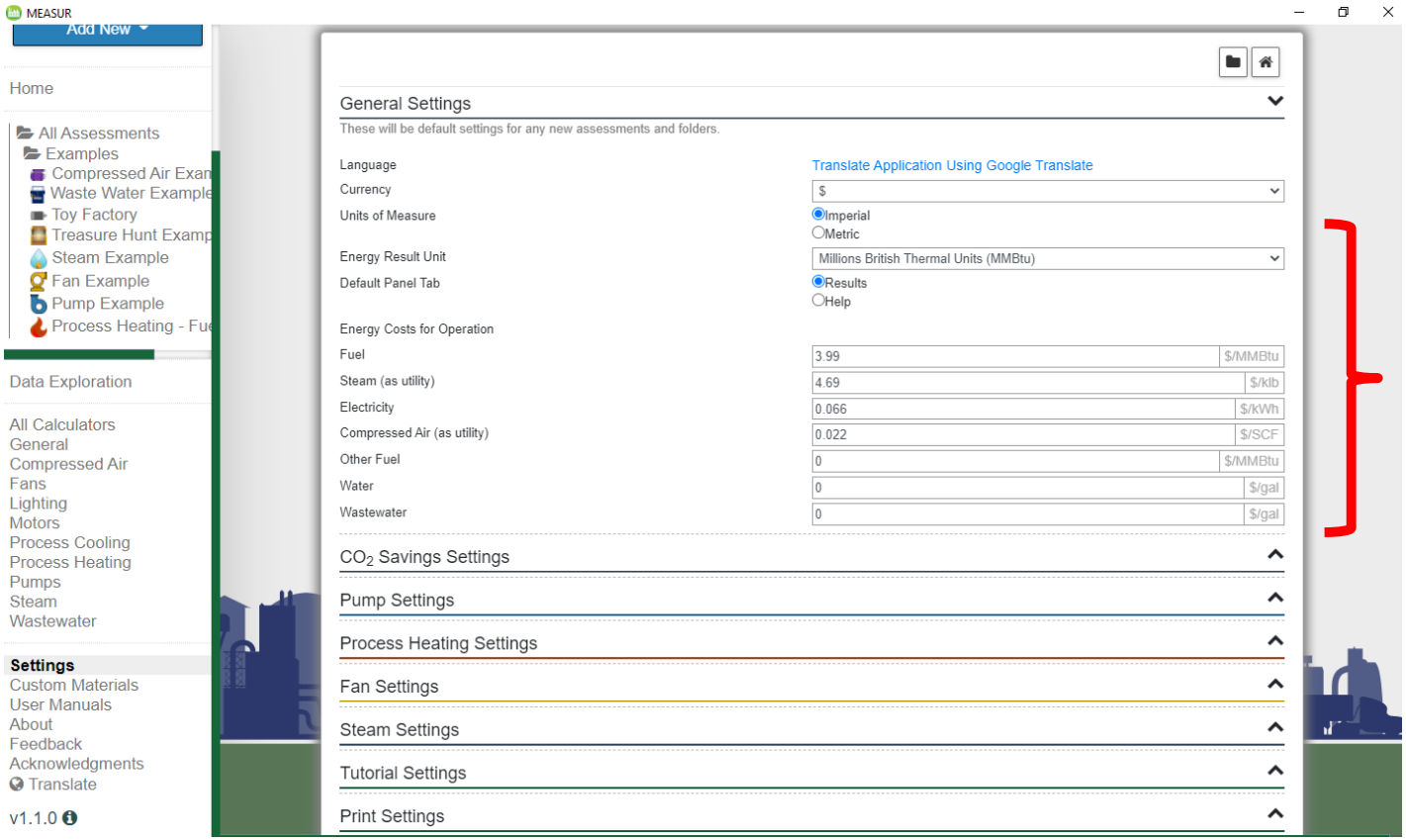
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US DOE MEASUR Tool



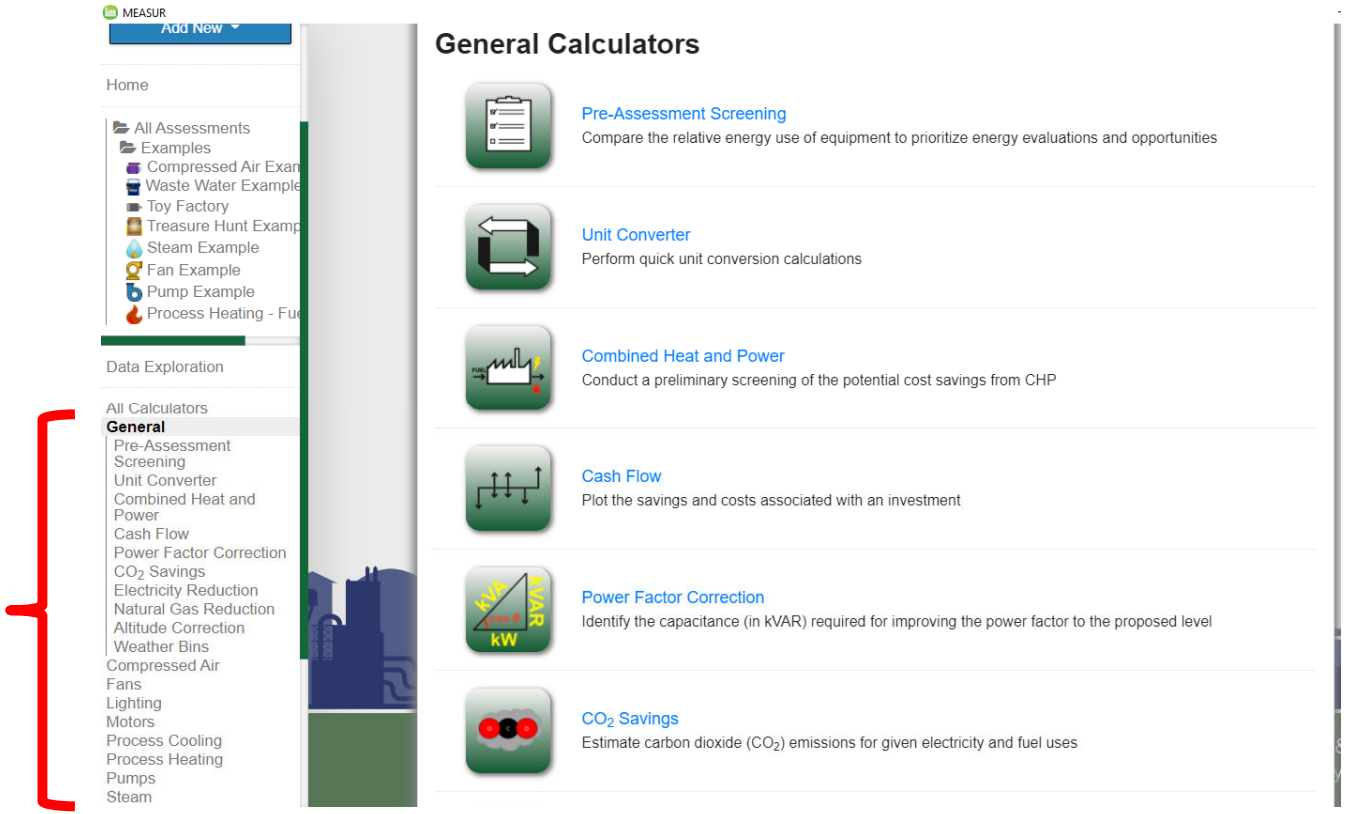
Settings

- The first place to be visited
- Sets all the unit defaults, costs, if information is available

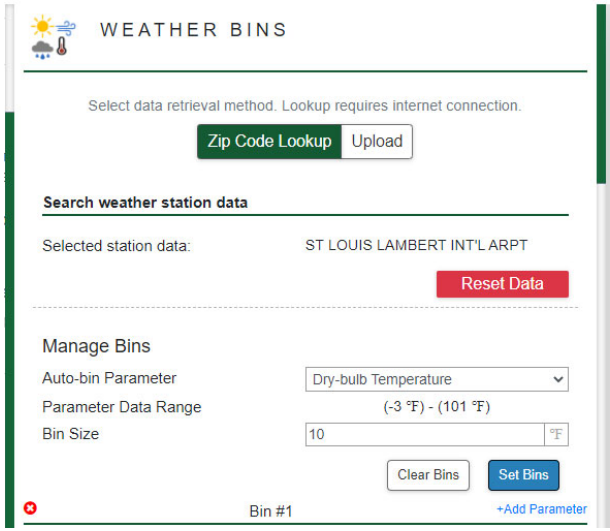


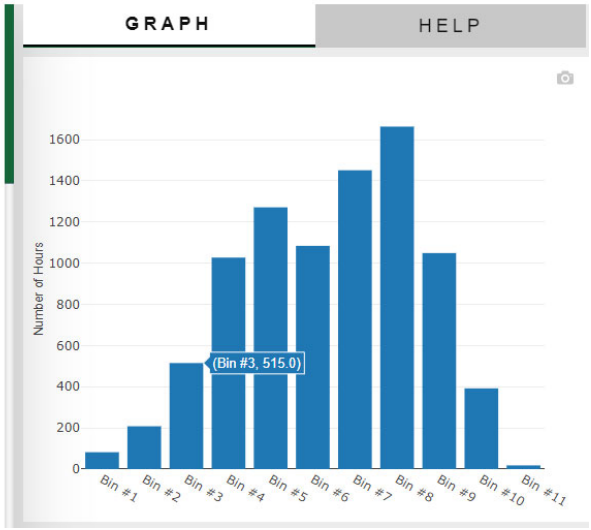
All Calculators

- MEASUR has several calculators
- General calculators are cross-cutting and NOT system specific



General Calculators – Weather Bins

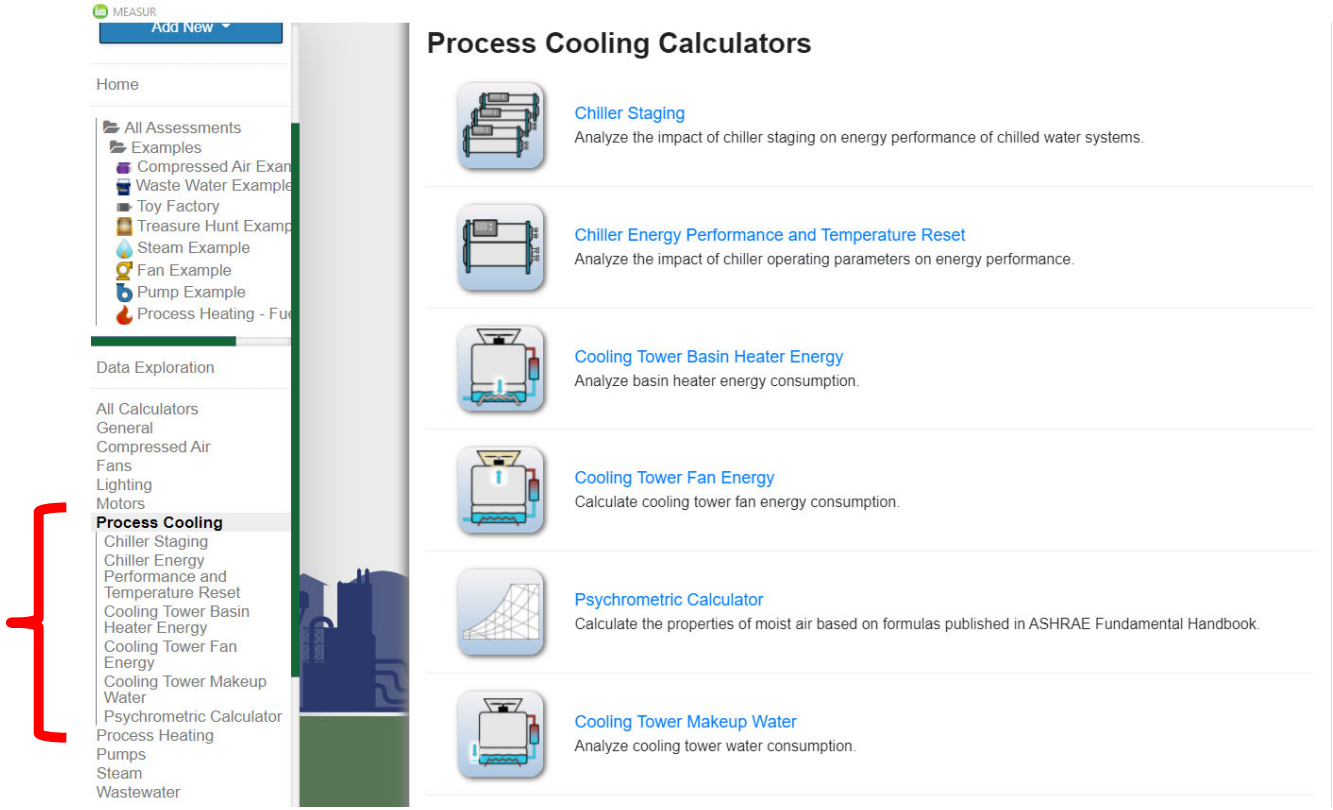




Bin #	Lower Bound (°F)	Upper Bound (°F)	Hours
Bin #1	-3	7	82
Bin #2	7	17	208
Bin #3	17	27	515
Bin #4	27	37	1027
Bin #5	37	47	1271
Bin #6	47	57	1084
Bin #7	57	67	1451
Bin #8	67	77	1663
Bin #9	77	87	1049
Bin #10	87	97	392
Bin #11	97	107	18

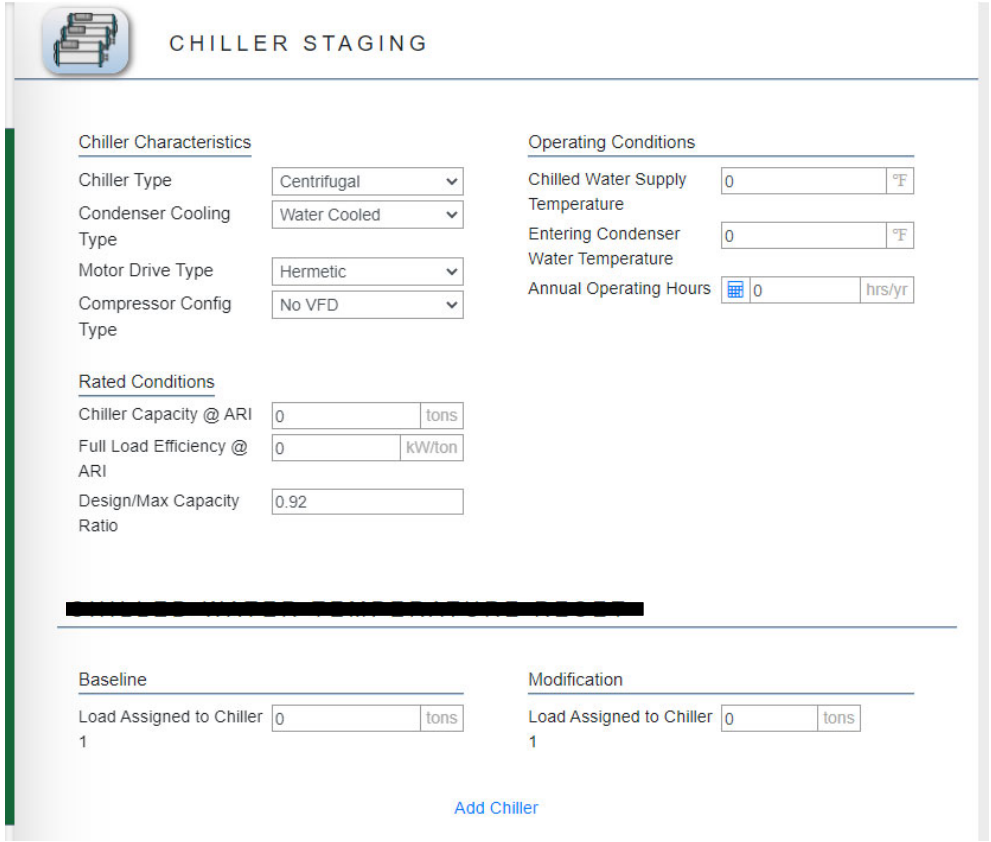
Process Cooling Calculators

- Several Process Cooling calculators are available
  - Chilled water system
  - Cooling tower ONLY



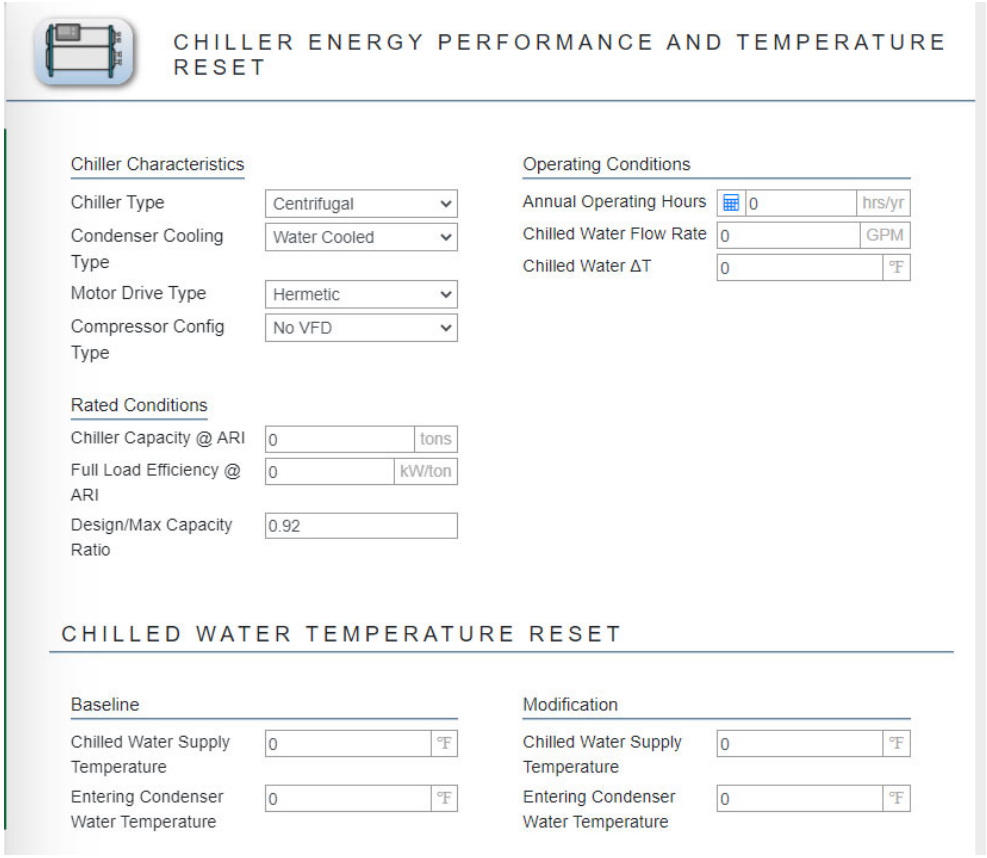
Chiller Staging Calculator

- Allows the user to stage multiple identical chillers for an optimum load configuration to minimize energy usage
- Uses Lift and chiller curves to determine performance (kW/ton) at different load conditions



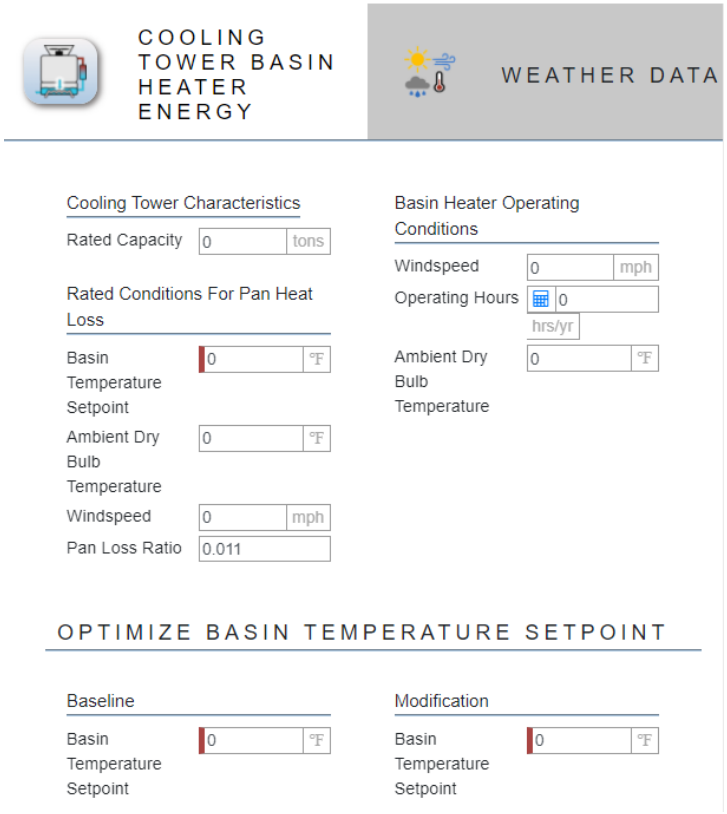
Chiller ECWT and ChWST Reset Calculator

- Allows the user to see the benefit of resetting ECWT, ChWST or both
- Modification of Lift and using chiller curves to determine performance (kW/ton) at similar load conditions



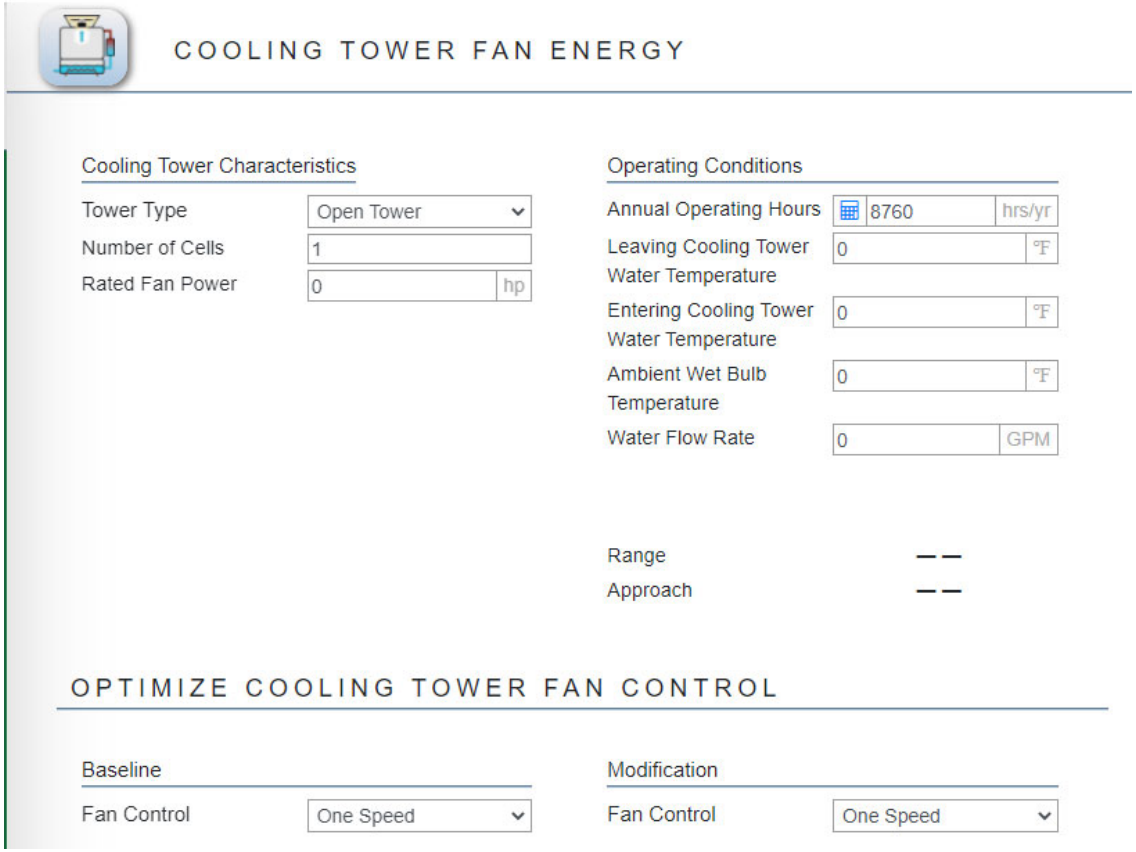
Cooling Tower Basin Heater Energy Calculator

- Allows the user to set an optimum basin temperature setpoint during the colder months when the basin heater would keep the basin water above a certain temperature



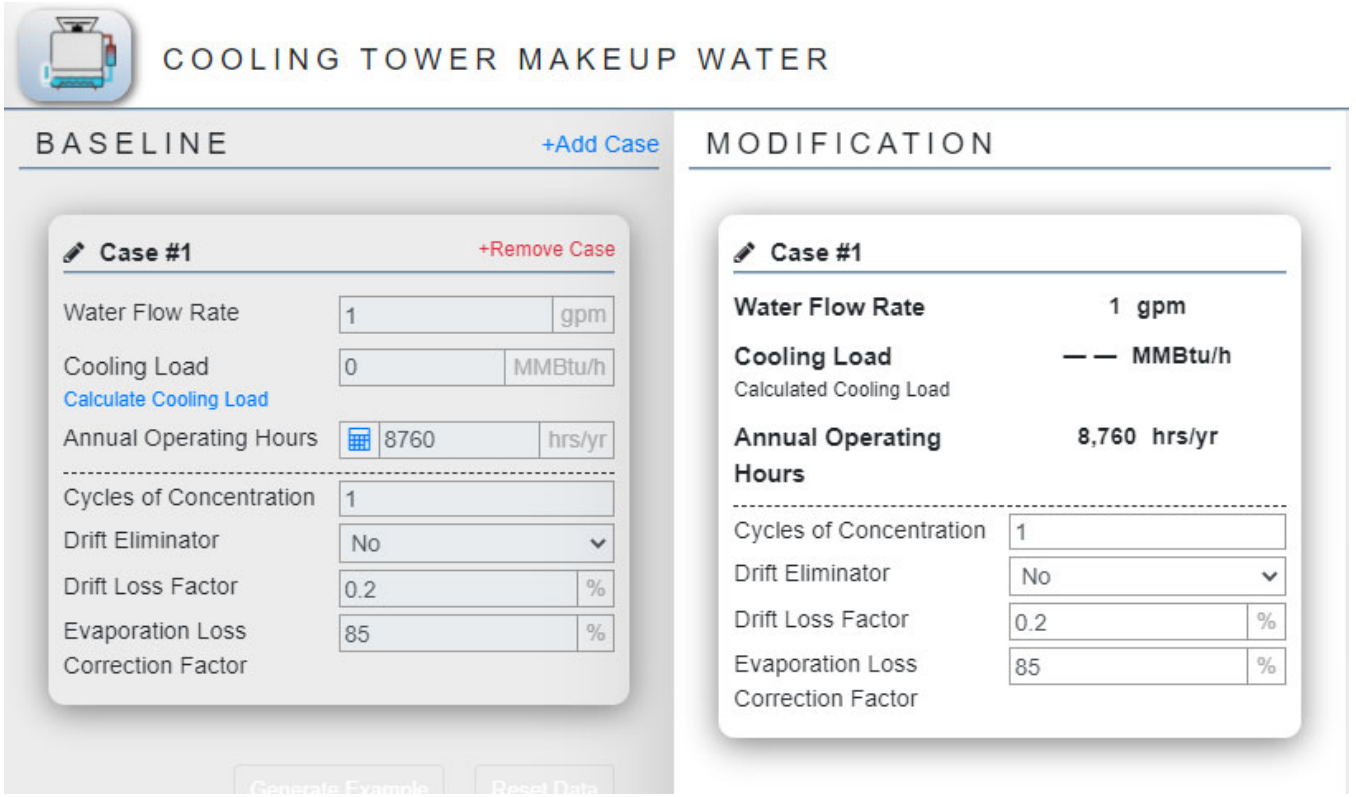
Cooling Tower Fan Energy Calculator

- Allows the user to determine the amount of cooling tower fan energy consumption
- Allows the user to define an optimum fan control strategy
  - One-speed
  - Two-speed
  - Variable speed



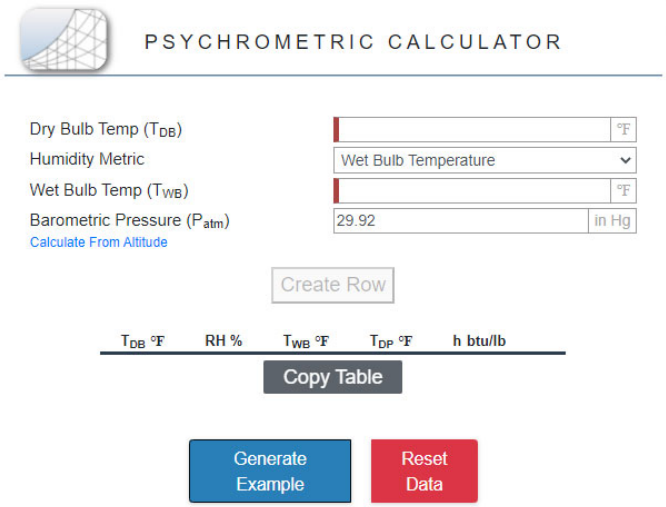
Cooling Tower Makeup Water Usage Calculator

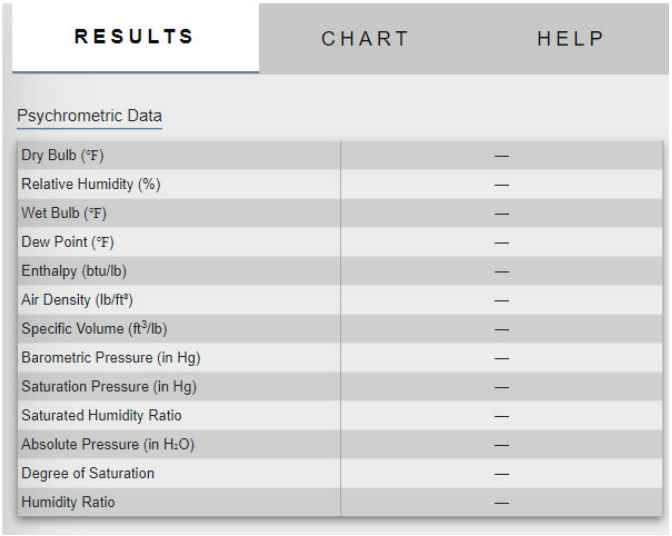
- Cooling tower water is expensive
- Additionally, there are treatment costs and sewer costs



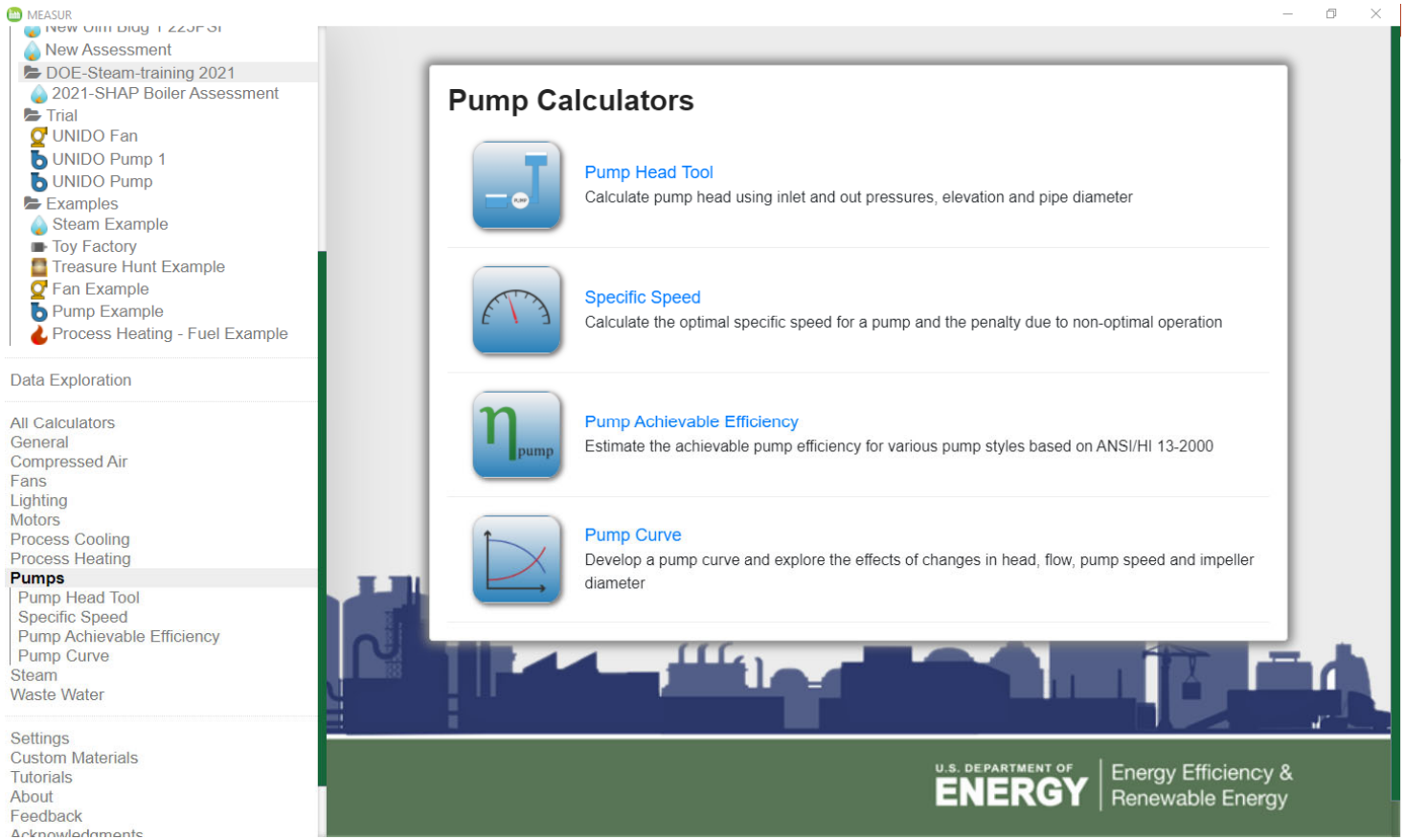
Psychrometric Calculator

- Allows the user to calculate the properties of ambient air using Dry-bulb and one of the following
  - Wet bulb temperature
  - Dew point
  - Relative Humidity



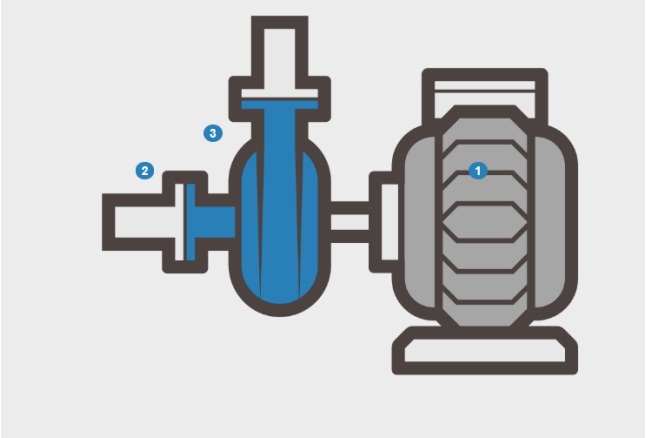


Pumping System Calculators

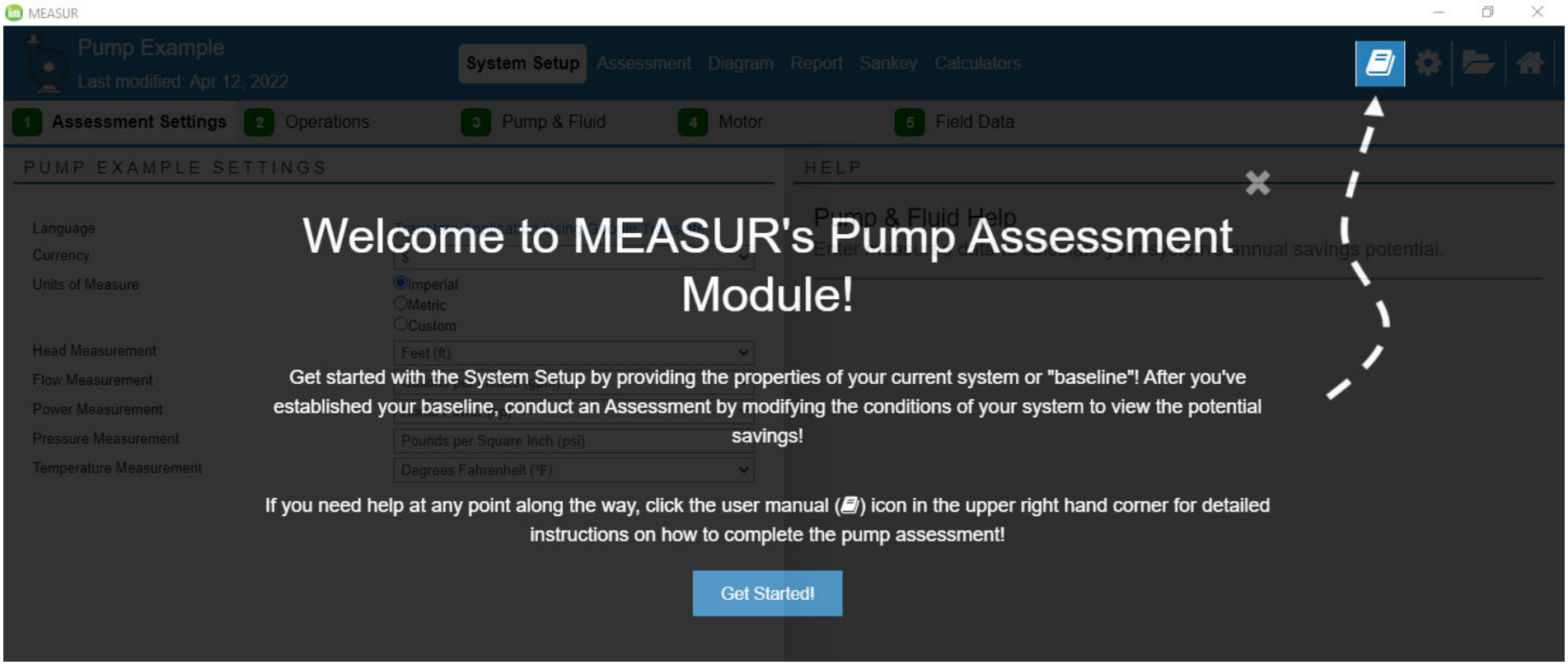


The MEASUR Tool for Pump Systems

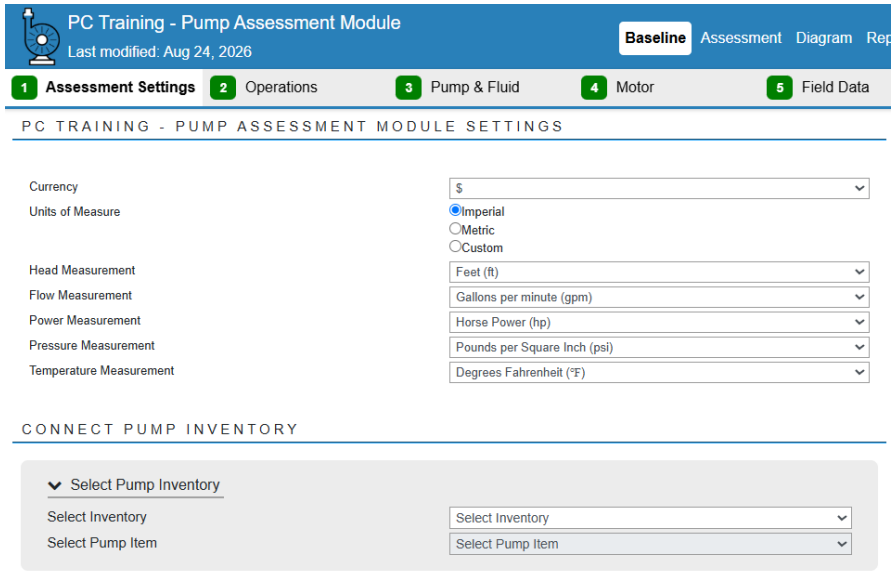
- Significance of Pumping Systems
  - Process Cooling systems can be spread across the plant and can require significant distribution
  - There are several different pumps required in a process cooling system
    - Primary, Secondary chilled water
    - Cooling tower water
    - Other process specific
  - Pumping system energy can be a significant fraction of the process cooling system energy usage

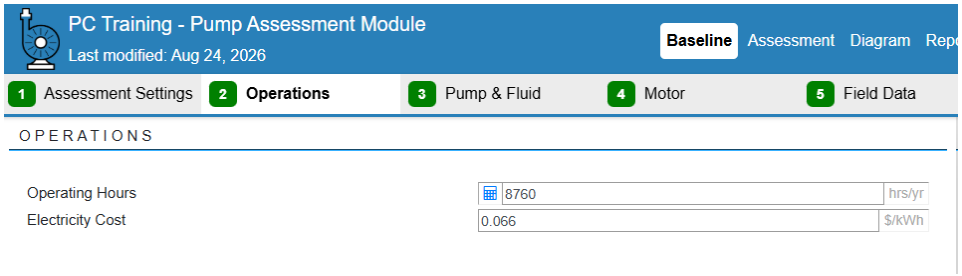


MEASUR's Pump Assessment Module

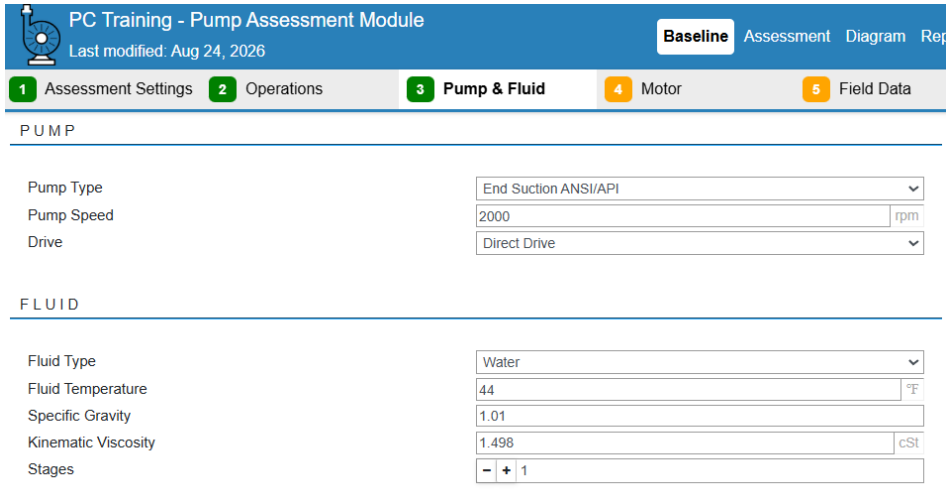


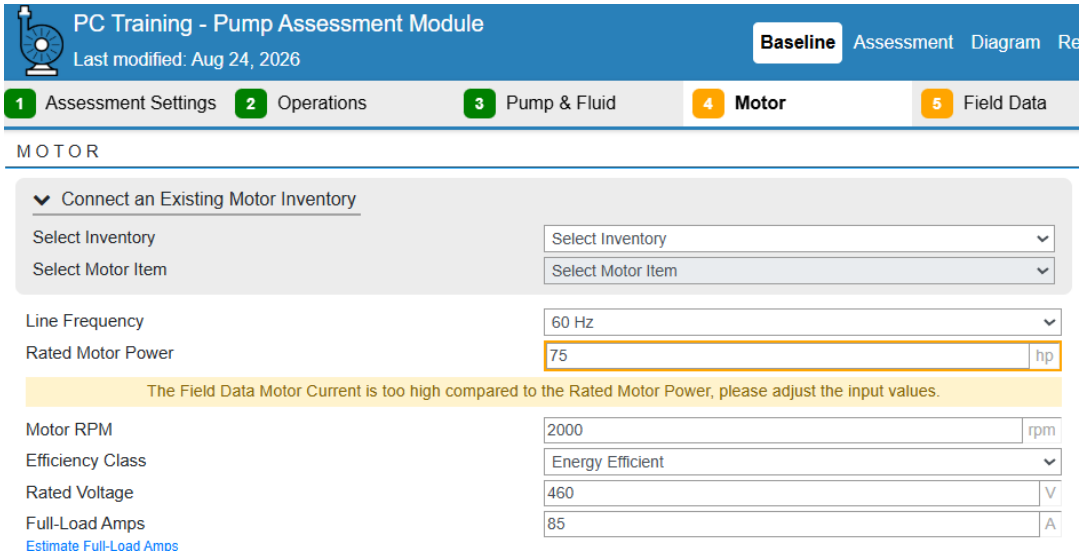
Input Sections – Assessment Settings / Operations



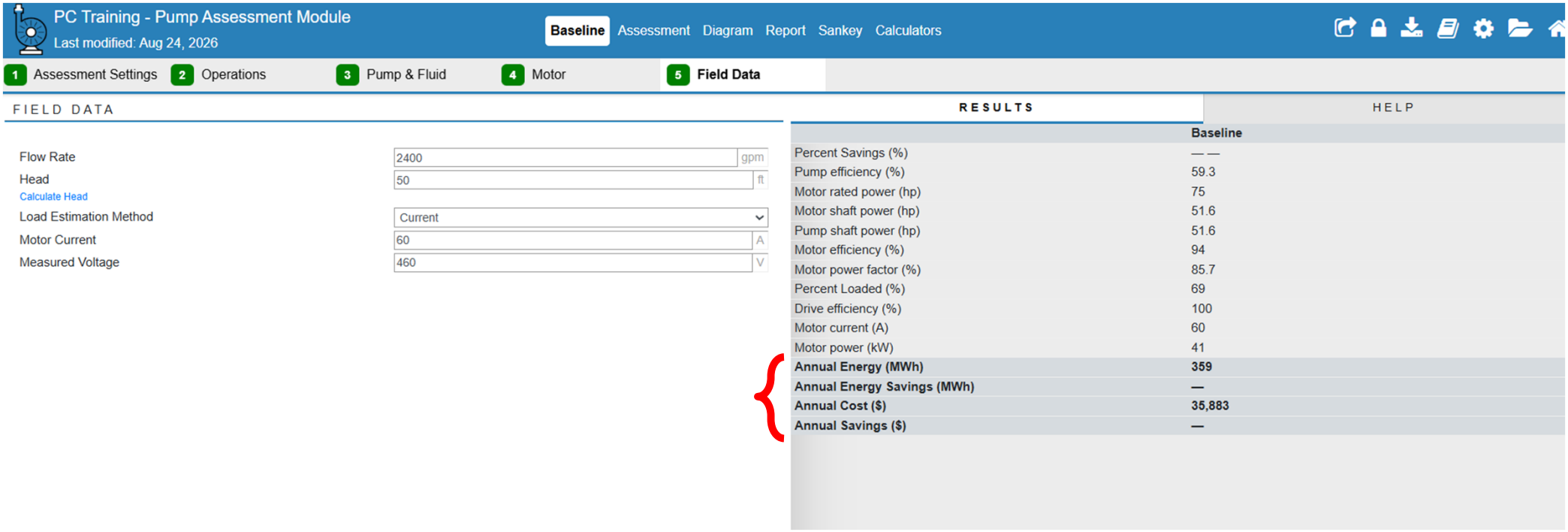


Input Sections – Pump & Fluid / Motor

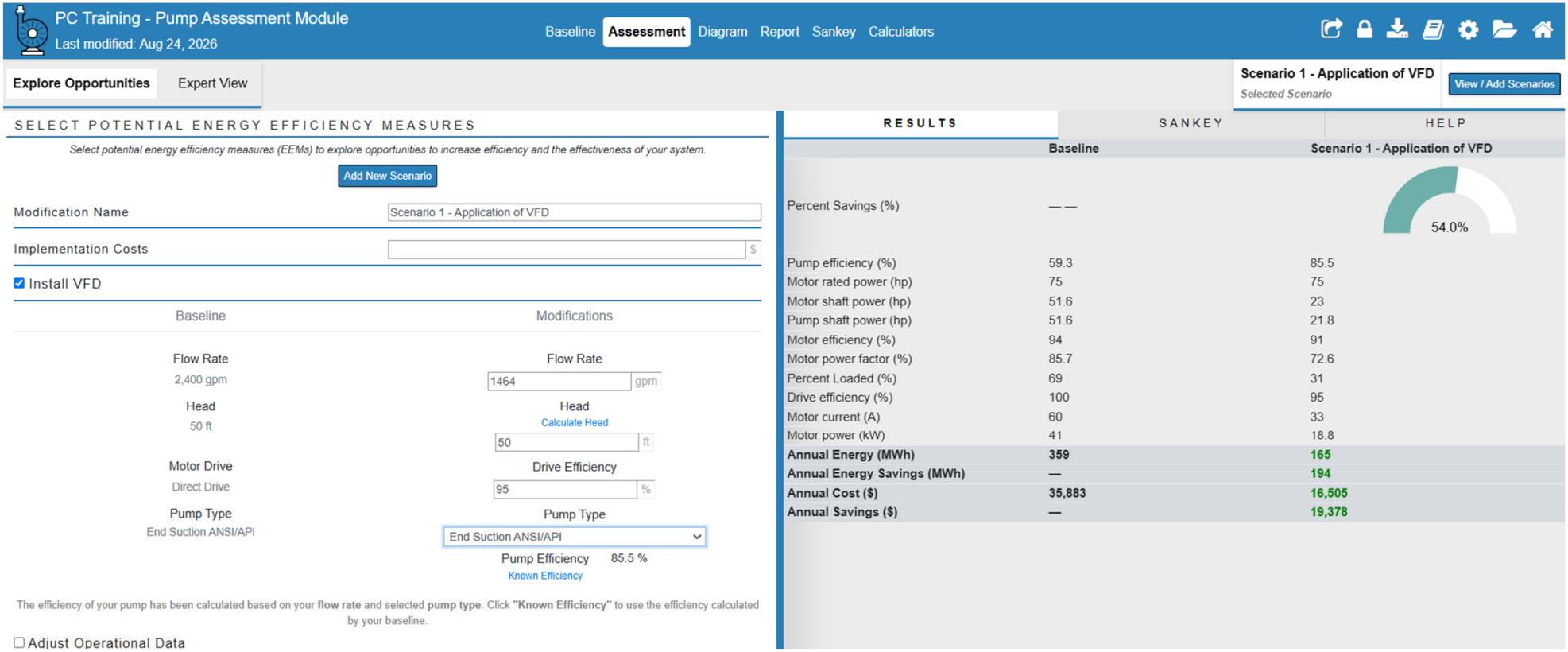




Input Sections – Field Data

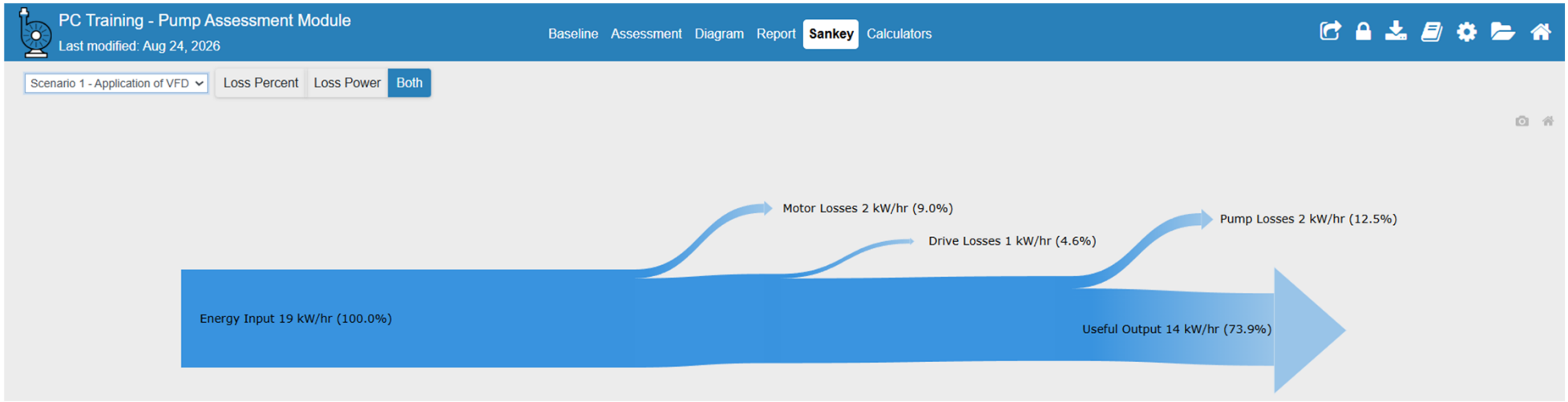


Assessment Page



Sankey Plot, Reporting Page

Modification (VFD/pump)



3EPlus Insulation Evaluation Software

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Chilled Water System Insulation

- Why is insulation necessary on Chilled Water systems?
  - Minimize energy gain and reduce system cooling load
  - Protection from ambient conditions
  - Preserve system integrity
  - Avoid condensation on equipment, pipes, etc.

- Typical areas of insulation improvement opportunities
  - Distribution headers
  - Compressor suction
  - Evaporators
  - Inspection man-ways
  - Valves
  - End-use equipment
  - Storage tanks, vessels, etc.
  - Building envelope



Chilled Water System Insulation

- There are several reasons for damaged or missing insulation and hence, energy savings opportunities in the insulation area
  - Missing insulation due to maintenance activities
  - Missing / damaged insulation due to abuse
  - Damaged insulation due to accidents
  - Normal wear and tear of insulation due to ambient conditions
  - Damaged insulation due to condensation
  - Valves and other components not insulated



Chilled Water System Insulation

- Some basic instruments, software and basic data required to quantify the economic impact of insulation
  - Process (chilled loop temperature)
    - Infra-red thermography camera
    - Infra-red temperature gun
  - Pipe diameter
  - Length (or Area) of uninsulated section
    - Measuring tape
  - 3E Plus insulation evaluation software
  - Operating information
    - Hours per year
  - Ambient conditions
    - Temperature
    - Wind





Chilled Water System Insulation Evaluation

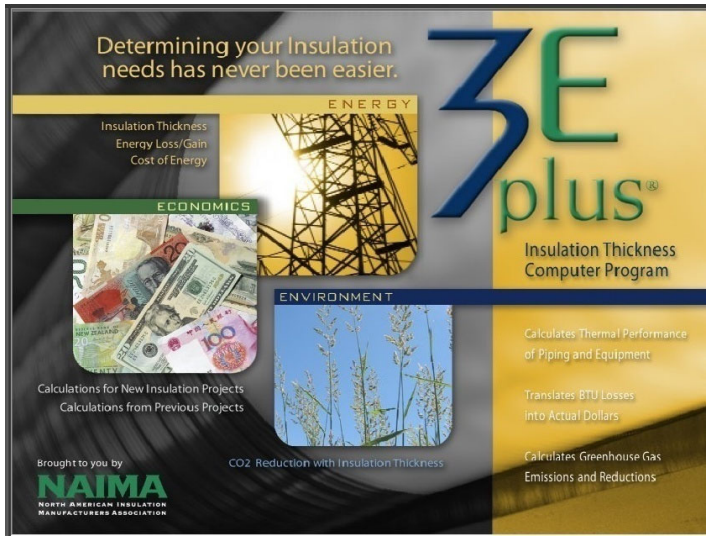
- Major challenges
  - Unlike hot surfaces, cold surfaces have condensation and so getting an accurate surface temperature is difficult!
  - Mode of heat transfer changes
    - Hot surfaces – convection and radiation with air as medium of heat transfer
    - Cold surfaces – condensation and convection with air and water as possible mediums of heat transfer
  - Accurate modeling cannot be done by the tools and resources that we may have available

Chilled Water System Insulation Evaluation

- But there are solutions available
  - 3EPlus insulation evaluation software can still be used very effectively
  - Conservative estimates for heat gain can be made assuming that convection with air as medium of heat transfer
    - Additional heat gain from condensation and convection with water will only increase the heat gain and project economics will be better than the conservative estimate
  - Accurate information on degradation of insulation can be derived based on modeling results in 3EPlus and actual observations in the field

3EPlus Insulation Evaluation Software

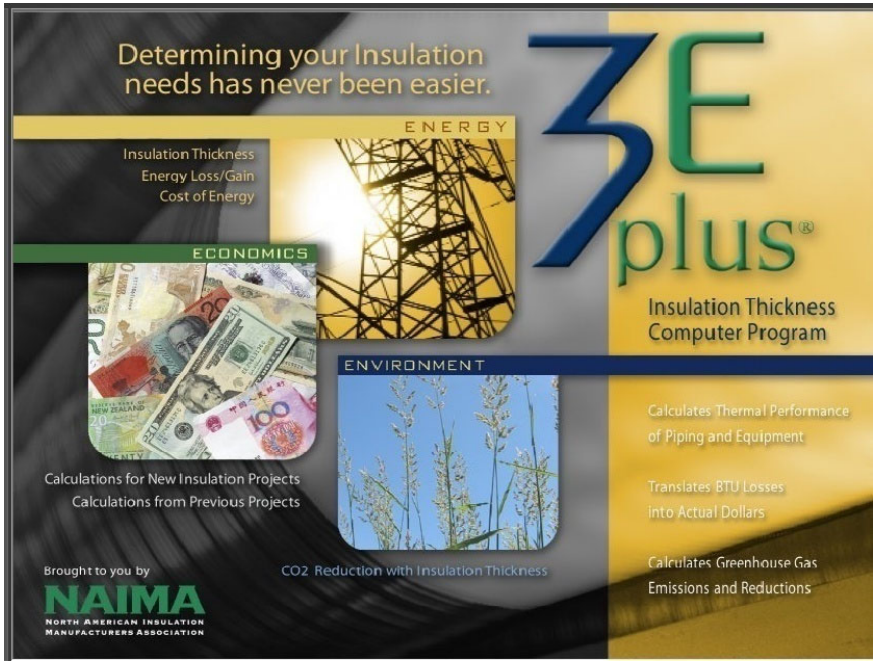
- Purpose
  - Evaluation of Heat Gain
  - Condensation Issues
- Heat Transfer Model
- Download free from website
- Customizable for Insulation materials
- Online version – 3eplus.org
- [Pipe Insulation | Calculate Thickness | 3E Plus Software (insulationinstitute.org)]



Insulation Evaluation Software

- Free Program available from NAIMA
- **E**nergy
  - Heat Gain
  - Cost Impact
- **E**nvironment
- **E**conomic Insulation Thickness
  - Life Cycle Cost Analysis

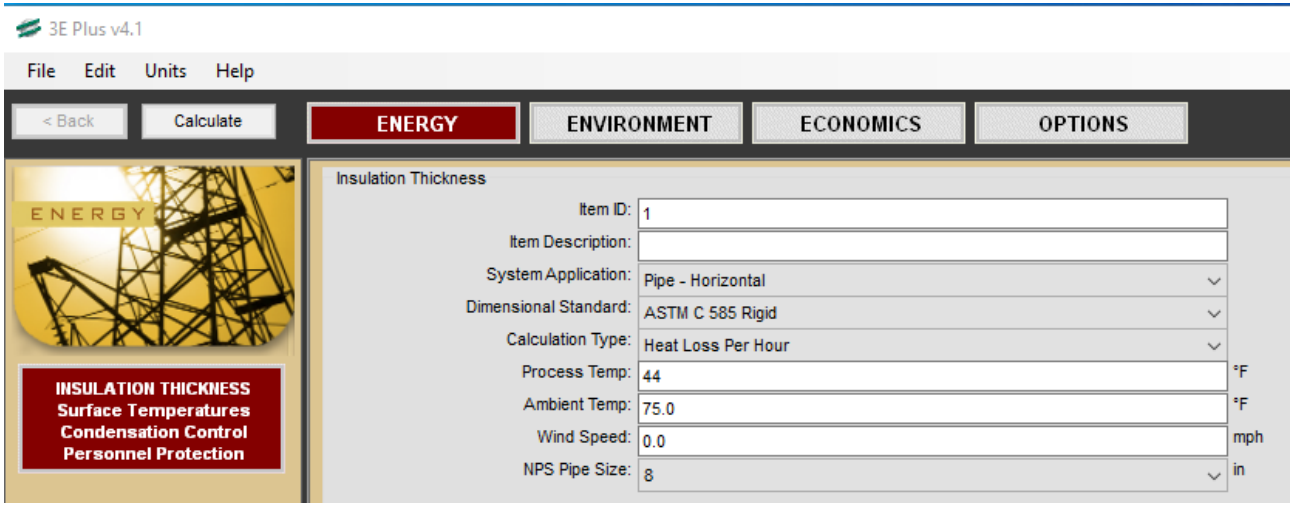
- Also available online
  - 3E Plus
  - https://www.3Eplus.org

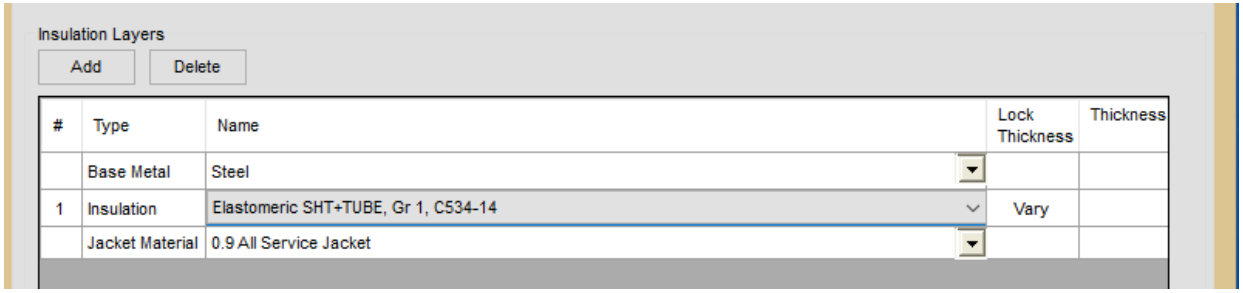


Example Chilled Water System - Missing Insulation on header

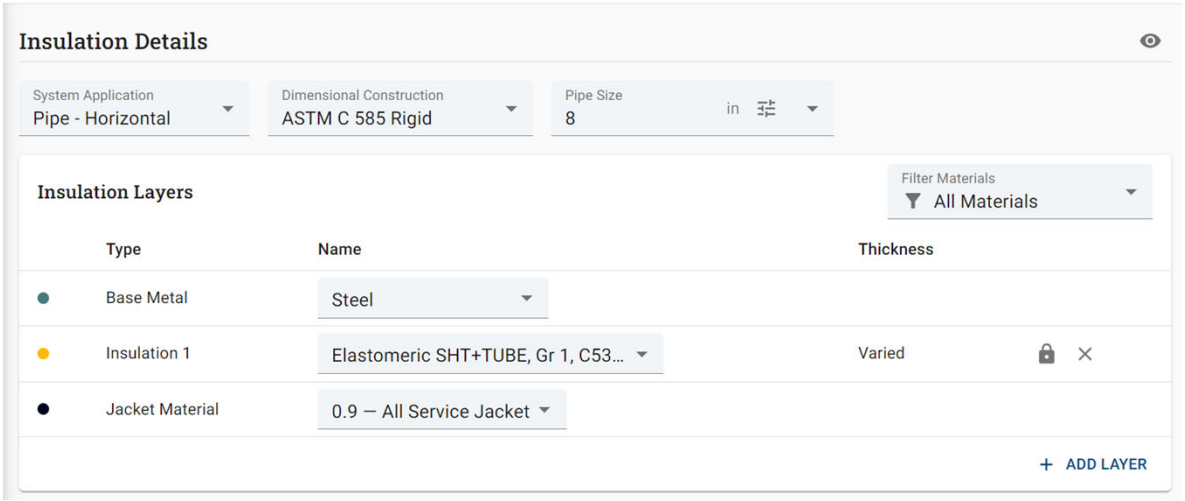
- During the walk through of a chilled water plant, it was found that there were several sections of the chilled water supply header (44°F) that were missing insulation. These areas also had condensation and were sweating.
- The plant engineer has provided basic information for the system as follows:
  - 8-inch nominal diameter
  - 300 ft total length of pipe which is uninsulated / damaged insulation
  - Insulation to be selected as follows:
    - Elastomeric (closed foam black) pipe insulation
    - 1-inch thick insulation
    - All service jacket
- Estimate the heat gain and the economic impact on system operations
  - Chiller plant performance = 0.75 kW/ton (based on plant simulation)
  - Unit cost of electricity = 0.10 $/kWh

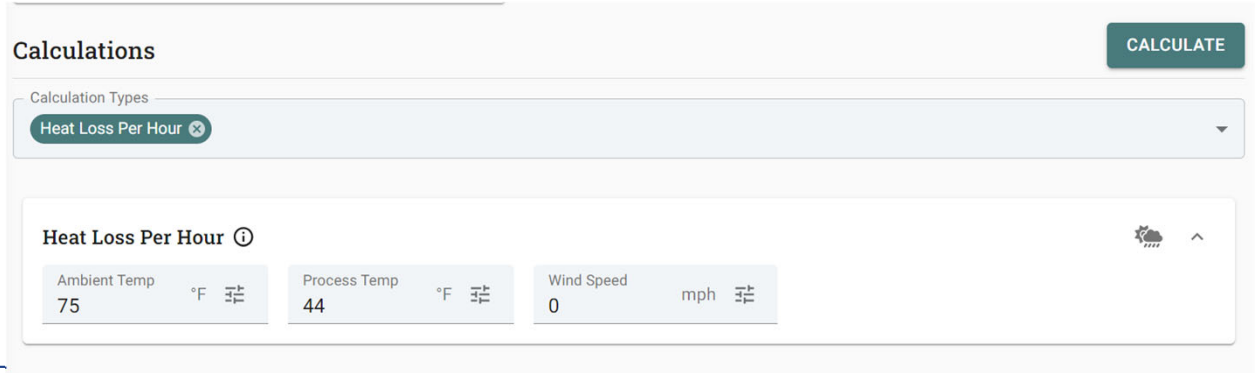
Insulation Evaluation





Insulation Evaluation (3E Plus Online Version)





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Insulation Evaluation

Variable Insulation Thickness	Surface Temp (°F)	Heat Gain (BTU/hr/ft)	Efficiency (%)
Bare	44.0	103.50	
0.5	66.1	31.57	69.50
1.0	70.2	17.87	82.73
1.5	71.6	13.28	87.17
2.0	72.4	10.75	89.62
2.5	73.0	8.82	91.48
3.0	73.4	7.79	92.47
3.5	73.6	7.02	93.22
4.0	73.8	6.43	93.79
4.5	73.9	5.95	94.25
5.0	74.0	5.56	94.63
5.5	74.1	5.23	94.95

Represents savings of heat gain versus the Bare pipe.

Note exponential decay of increase in efficiency numbers

Insulation Evaluation

$$Q_{saved} = (103.5 - 17.9) \times 300 = 25{,}680\ Btu/hr = 2.14\ RT$$

$$Electricity_{saved} = Q_{saved} * kW/RT$$

$$Electricity_{saved} = 2.14\ RT \times 8{,}760 \frac{hr}{yr} \times 0.75 \frac{kW}{RT} = 14{,}060\ kWh/yr$$

$$Cost\ Savings = 14{,}060 \frac{kWh}{yr} \times 0.10 \frac{\$}{kWh} = 1{,}400 \frac{\$}{yr}$$

Actual savings will be higher than predicted due to condensation

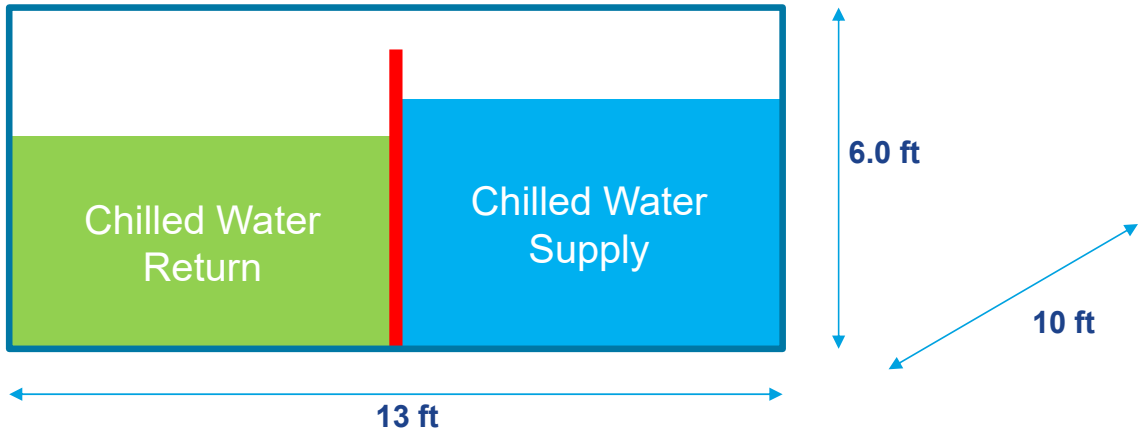
Chilled Water Storage Tanks (Primary / Secondary)

- In several industrial plants, chilled water supply and return storage tanks are commonly used to allow for load fluctuations, thermal energy storage and for providing enough NPSH for primary and secondary chilled water pumps. These tanks can also be used for storage during chilled water plant shutdowns. Should these tanks be insulated?



Example – Chilled Water Storage Tank

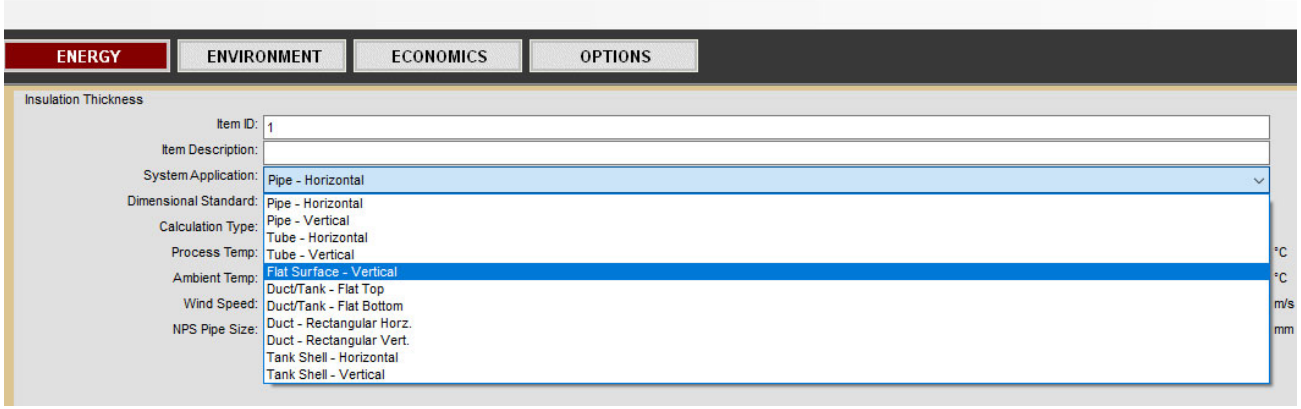
- In the chilled water system, a tank held chilled water and secondary pumps provided chilled water supply to the end-uses. This tank was internally divided into two compartments and the other compartment served as the return tank. The primary pumps used water from this side of the tank to supply to the chillers. The internal divider allowed overflow between the tanks to accommodate loads.



Example – Chilled Water Storage Tank

- Chilled water supply temperature was 44°F and chilled water return was 55°F.
- The plant engineer has assumed average temperature to be 50°F and year-round average ambient temperature to be 75°F
- Insulation to be selected as follows:
  - Elastomeric (closed foam black) sheet insulation
- Estimate the heat gain and the economic impact on system operations
  - Chiller plant performance = 0.75 kW/RT (based on plant simulation)
  - Unit cost of electricity = 0.10 $/kWh

Insulation Evaluation



#	Type	Name	Lock Thickness	Thickness
	Base Metal	Steel		
1	Insulation	Elastomeric SHT+TUBE, Gr 1, C534-14	Vary	
	Jacket Material	0.9 All Service Jacket		

Insulation Evaluation

Variable Insulation Thickness	Surface Temp (°F)	Heat Gain (BTU/hr/ft^2)	Efficiency (%)
Bare	50.0	34.29	
0.5	67.6	9.74	71.59
1.0	70.5	5.69	83.42
1.5	71.8	4.02	88.27
2.0	72.4	3.11	90.92
2.5	72.9	2.54	92.59
3.0	73.2	2.15	93.74
3.5	73.4	1.86	94.58
4.0	73.6	1.64	95.22
4.5	73.7	1.47	95.73
5.0	73.9	1.33	96.14
5.5	74.0	1.21	96.47

Represents amount of heat gain versus the Bare pipe.

Note exponential decay of increase in efficiency numbers

Insulation Evaluation

*Surface Area = 2 * (13 * 6) + 2 * (10 * 6) + (13 * 10) = 406 ft²*

$$Q_{saved} = (34.3 - 5.7) \times 406 = 11{,}600\ Btu/hr = 0.97\ RT$$

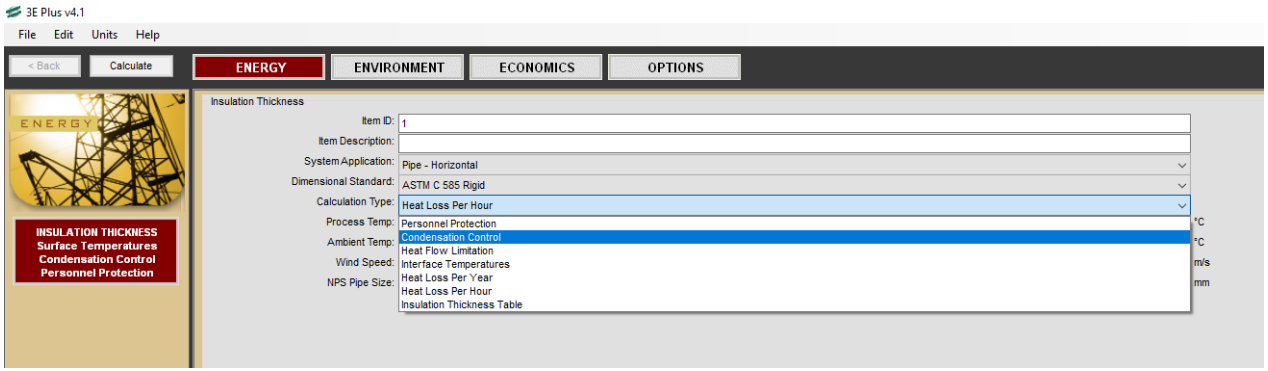
$$Electricity_{saved} = Q_{saved} * kW/RT$$

$$Electricity_{saved} = 0.97\ RT \times 8{,}760 \frac{hr}{yr} \times 0.75 \frac{kW}{RT} = 6{,}357\ kWh/yr$$

$$Cost\ Savings = 6{,}357 \frac{kWh}{yr} \times 0.10 \frac{\$}{kWh} = 636 \frac{\$}{yr}$$

Condensation Control

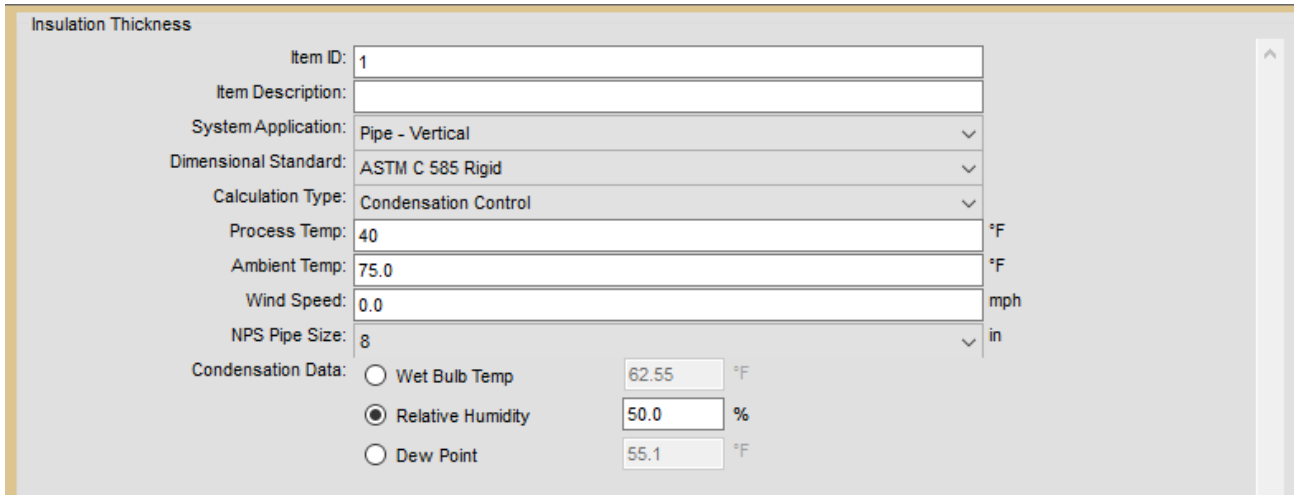
- Chilled water systems operate below dew-point temperature of ambient air
- This results in moisture condensing on bare and on insulated surfaces
- Depending on the surface temperature, the surface can have
  - Moist or Sweating
  - Dripping water

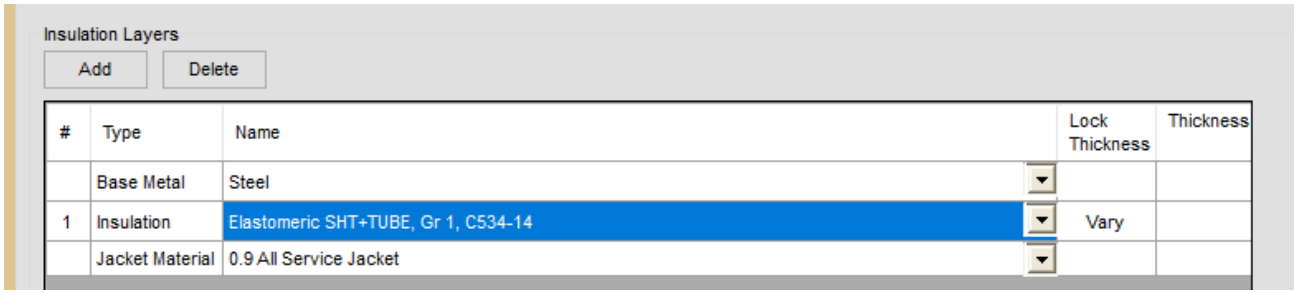


Example – Condensation Control

- A 3 ft section of 40°F suction of the compressor is observed to be un-insulated
  - 8-inch nominal diameter
  - Existing insulation on the remainder of the compressor is as follows:
    - 1-inch thick insulation
    - Elastomeric insulation
    - All service jacket
- Estimate the minimum insulation thickness required to eliminate condensation issues on this suction pipe to the compressor.

Condensation Control





Condensation Control

Variable Insulation Thickness	Surface Temp (°F)	Heat Gain (BTU/hr/ft)	Efficiency (%)
Bare	40.0	112.30	
0.5	64.7	35.23	68.62
1.0	69.5	20.04	82.15
1.5	71.1	14.92	86.71
2.0	72.1	12.08	89.24
2.5	72.8	9.92	91.16
3.0	73.1	8.76	92.19
3.5	73.4	7.90	92.96
4.0	73.6	7.23	93.56
4.5	73.8	6.70	94.04
5.0	73.9	6.26	94.43
5.5	74.0	5.89	94.75

Indicates the minimum insulation thickness that needs to be provided to ensure that the surface temperature is above the dew-point

This will eliminate any sweating and condensation on the external surface of the insulation

Predictive & Preventative O&M BestPractices

Acknowledgments: Hudson Technologies Company

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First Things First - Fluid Management

- Understanding “Cause” and “Effect” is very important for Root Cause Analysis
- This enhances chilled water system reliability and reduces unplanned shutdowns
- Significant savings in maintenance costs
- Most maintenance BestPractices are testing-based
  - Refrigerant, oil and water testing
  - Rotating equipment monitoring
    - Vibration analysis
  - Eddy-current testing
- In chilled water systems, contaminants affect efficiency and capacity
  - Chemistry-based solutions

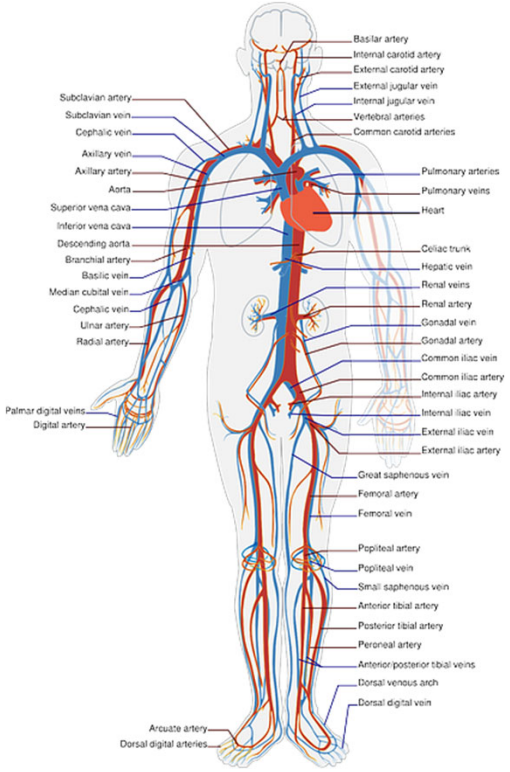
System Fluids & Chemistry



- Chilled Water Systems contain several fluids
  - Refrigerant(s)
  - Water
  - Oil
  - Glycol
  - Brine
  - Air
- Understanding the properties of these fluids and their interactive chemistry is very important
- Every fluid in the system has to meet specific standards

The Human Body

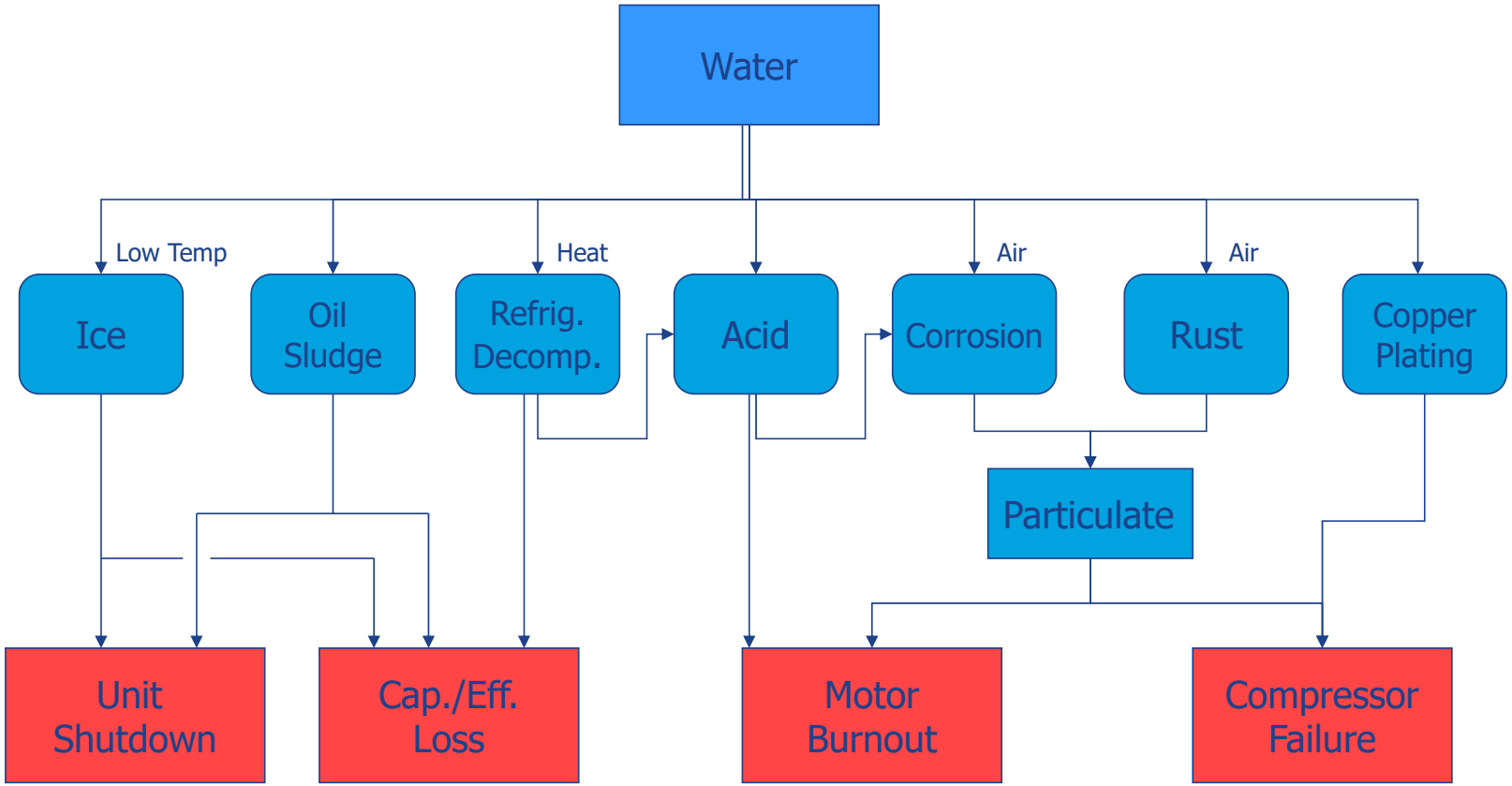
- Best analogy to a chilled water system
- The human body also has fluids circulating – blood, water, air
- There is a significant information carried by the circulating fluids in a human body
- The human body's temperature, heart rate, low and high pressure are the operating parameters
- The Heart is analogous to the compressor in a chilled water system
- All the fluids meet specific standards for the human body to function normally



Why Test Fluids?

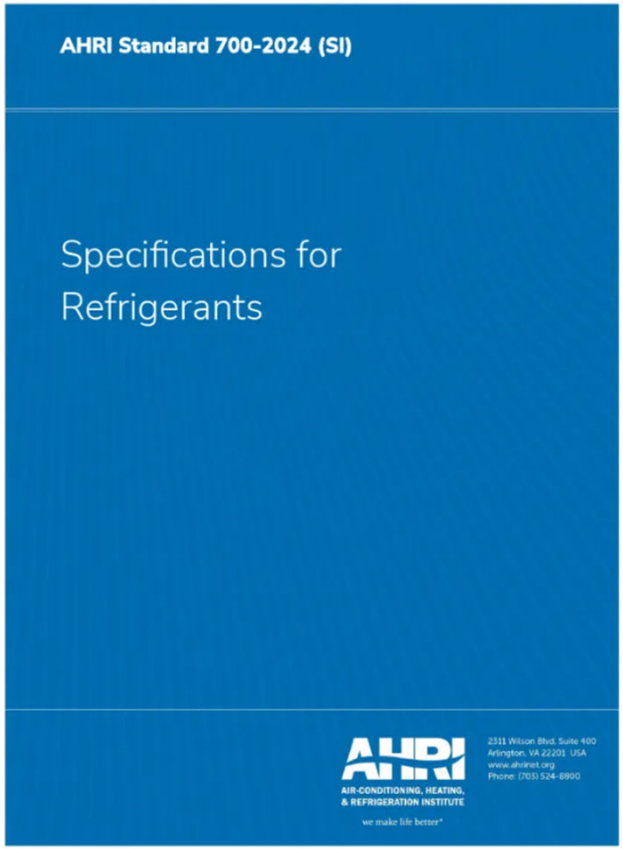
- Fluids that circulate in a chilled water system carry important information that can be used to detect and diagnose current issues or anticipate potential problems
- Whether examining a human body or chiller, fluids are an essential diagnostic tool
- Potential problems can be identified, monitored and corrected by periodically testing and trending of refrigerant, oil and water chemistry analysis

Effects of Water Contamination with Refrigerant



Refrigerant Testing / Analysis Criteria

- Moisture
- Oil
- Particulate
- Chlorides
- Acid
- Purity
- Non-Condensables
- Other Contaminants



A Sample Refrigerant Test Report

- The key to refrigerant testing is trending the impurities
- Compare w/Standard
- Identify what changes are occurring over a period of time

AHRI MEMBER

REFRIGERANT ANALYSIS

No. Samples: 1

Refrigerant Type: R123 / 2,2-dichloro-1,1,1-trifluoroethane

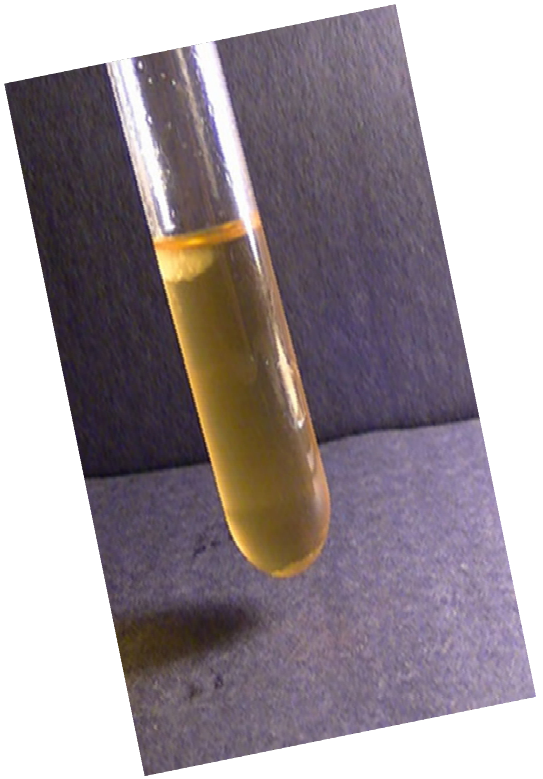
Sample Source: Evaporator
Refrigerant Temperature: 75 F
Make: Trane
Model: CVHE450

TEST	MEASUREMENT	AHRI-700 STANDARD	8/22/17 SAMPLE ONE	12/5/19 SAMPLE TWO	1/8/21 SAMPLE THREE
Moisture	PPM by weight	20	14	8	10
Chloride	no turbidity to pass	Pass	Pass	Fail (2)	Fail (2)
Acidity	PPM as HCL	<1.0 PPM	<1.0	<1.0	<1.0
High Boiling Residue	% by weight	<0.01%	0.03	1.12 (3)	2.29 (3)
Other Refrigerants	% by weight	0.50%	0.08 (1)	0.06 (4)	0.06 (5)
Non-condensable Gases	% by volume	N/A	N/A	N/A	N/A
Particulate	Pass / Fail	Pass	Pass	Pass	Fail (6)

COMMENTS: (1) The refrigerant contained R-123 breakdown components, 285 PPM of R-133a. (2) The sample failed the qualitative test for the presence of chloride. This is most likely a false-positive due to the elevated oil content. (3) The sample is rated marginal due to the elevated oil content. (4) The refrigerant contained R-123 breakdown components, 121 PPM of R-133a. (5) The refrigerant contains R-123 breakdown components, 123 PPM of R-133a. (6) A minimal amount of fine particulate is present in the sample.

Used Oil Analysis Testing

- Viscosity
- FTIR Spectroscopy (Infrared)
- TAN/TBN Titration
- Visual Observation/Crackle Testing
- Particle Counters
- Direct Reading Ferrography (DR III)
- Rotary Disc Electrode (RDE)
- Analytical Ferrography
- Karl Fisher



Oil Testing Sample Report

CONDITION REPORT

ACTION REQUIRED

Change Oil — Ref Sample Needed

NAME: CVHF1470 / L01H10170
LUBRICANT: Trane Centrifugal Oil 00022
RESERV CAP: 6-10 Gallons
LUBE TIME: Not Provided **MACH HRS:** Not Provided
SPID #: 178913

SAMPLE DATE: 11/18/2020
TEST SUITE: H002
CNTL#: 5351348
ASSET: Compressor - General

Data of Concern

- The particle count and silicon levels are high. This indicates a contaminated lubricant.
- Q174526 / 21126993

AREAS OF CONCERN

particle — silicon

Actions Needed

- An oil change is recommended.
- An unused portion of this lubricant is required to establish baseline values. This sample should be taken from an opened drum of this lubricant if possible.

Consequences of Inaction

- Contamination will generate wear particles over time and can result in component failure.

REPORT RATINGS:

									LIMITS			
Sample Date	08/20/2015	08/03/2017	11/19/2019	11/18/2020								
Ratings	Normal	Normal	Normal	Serious	Reference Transfer	Reference Storage	Reference Arrival	Upper Alert	Upper Alarm	Lower Alert	Lower Alarm

VISCOSITY (ASTM D445)

Viscosity 40C	54.43	57.61	58.06	59.37		**58.00**			69.600		46.400

PHYSICAL/CHEMICAL PROPERTIES:

Acid Number (ASTM D664)											
TAN (mg KOH)	0.115	0.016	0.067	0.071							
FT-IR (ASTM E2412)											
Oxidation (abs)			4	1							
Nitration (abs)			2	1							
Sulfur (abs)			40	11							
Hydroxide (abs)			6	5							
Glycol (FTIR) (abs)			0	0							
Anti-Wear (abs)			12	10							
Karl Fischer (ASTM D6304)											
Karl Fischer (ppm)	25.5	15.4	13.3	12							
Karl Fischer % (%)	0.003	0.002	0.001	0.001							
Visual/Crackle											
Crackle Water (Y/N)	N	N	N	N							
Refrigerant (Y/N)	Y	Y	Y	Y							
Visual Glycol (Y/N)	N	N	N	N							
Visible Water (Y/N)	N	N	N	N							
Ammonia (Y/N)	N	N	N	N							

REC'D DATE: 12/11/2020 **REPORT DATE:** 12/17/2020 **ANALYST:** Snelling Page: 1

(**) - Test performed by a Trico Corporation contracted ISO 17025 Accredited Laboratory

Particles (Y/N)	N	N	N	N

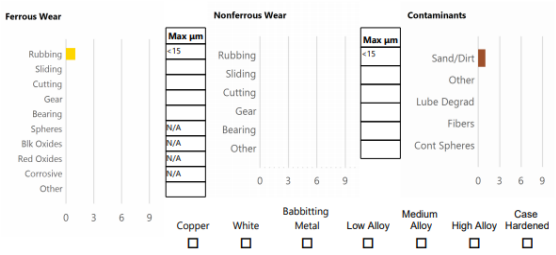
PARTICULATES:

Direct Read				
DL			1.0	2.6
DS			0.8	1.8
WPC			1.8	4.4
FT-IR (ASTM E2412)				
Soot			0	3
Particle Count (ISO 4406)				
>4um			2387	55408
>6um			769	24227
>14um			44	2567
>21um			7	257
>38um			1	18
>70um			0	1
ISO PC			18/17/13	23/22/19

TRACE ELEMENTS by ICP (ASTM 5185)

Equipment	Iron (ppm)	1	2	5	1
	Chromium (ppm)	0	0	0	0
	Aluminum (ppm)	0	0	0	0
	Copper (ppm)	0	0	2	0
	Lead (ppm)	0	0	0	0
	Tin (ppm)	1	1	0	0
	Silver (ppm)	0	0	0	0
	Nickel (ppm)	0	0	0	0
Contaminants/Additives	Silicon (ppm)	0	0	0	25
	Sodium (ppm)	0	0	0	1
	Potassium (ppm)	3	0	0	1
	Boron (ppm)	0	0	3	0
	Molybdenum (ppm)	0	0	0	0
	Magnesium (ppm)	0	0	0	0
	Calcium (ppm)	1	0	0	0
	Barium (ppm)	0	0	0	0
	Phosphorus (ppm)	0	0	1	0
	Zinc (ppm)	34	71	77	9
Other	Vanadium (ppm)	0	0	0	0
	Titanium (ppm)	0	0	0	0

WEAR PARTICLE ANALYSIS



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Water Testing and Analysis

- Cooling tower water testing and analysis
  - Open loop – evaporation of water
  - Control of corrosion, scale and biological activity
  - Material of construction plays a very important role
  - Testing conducted for pH, TDS, conductivity, hardness, alkalinity, chlorides, silica, bacteria, etc.
- Chilled Water testing and analysis
  - Closed loop – generally less issues
  - Lower temperatures
- Work with a water chemist/treatment company
  - Periodic testing program

Water Testing Sample Report

Purpose and Recommendations

Purpose:
Check all feed systems, chemical inventories, and troubleshoot any issues with cooling towers to improve overall water treatment program. Verify the status of the treatment program that began last week at the interstate location.

Recommendations:
Treated towers:

- Results are within acceptable limits for all target cooling water parameters except free Chlorine residual.
- The results from the interstate tower look great. The blowdown of the tower has greatly decreased the conductivity and brought it within acceptable levels. The blowdown rate can be decreased and cycles increased when a permanent blowdown solution is determined and a needle valve installed. Great job here!
- Trasar levels are similar to the values obtained in Nalco's program simulation meaning that adequate chemical is being fed for scale and corrosion inhibition.
- The cycles of concentration in the North East tower can be increased from what they are currently. I suggest decreasing the blowdown of the tower by around 20%. This will help with water savings.
- Free Chlorine is below set target which can result in microbio growth in systems. We suggest a microbio program to prevent growth in system.
- Please refill the 15 drum of 3DT230 feeding to the North West tower.
- I talked with our chemical division, and once 3DT230 chemical has been used, the 15 gallon drums can be cleaned and filled with the new 3DT465 for treatment.

Untreated towers:

- Samples will be taken during next visit on the untreated towers to evaluate future treatment options.

Water Testing Results

9/28/2017	Makeup		Nalco Treated			Untreated	
Current Test Date	City Water	Target	NW	NE	Interstate	SE	SW
Conductivity	350	1200	914	564	751		
pH	9.2		9.0	8.71	8.7		
Trasar	0		165.1	152.5	154.4		
Total Hardness	125	330	260	166	176		
M Alk	175	500	460	265	355		
Free Chlorine	0.5	0.5	0.01	0.02	0		
Iron	0	0.5	0	0.1	0.1		
Ca Hardness	50	165	84	145	68		

Cycles of Concentration

9/28/2017	Makeup	Nalco Treated			Untreated	
Test Date	City Water	NW	NE	Interstate	SE	SW
Cond. COC	1.00	2.61	1.61	2.15	0	0
T Hard COC	1.00	2.08	1.33	1.408	0	0
M-Alk COC	1.00	2.63	1.51	1.36	0	0

Inventory Data

	Current Reading	Previous Reading	Deliveries	Average Usage	Estimated days to empty
North East CT 3DT230	25 gal 9/27/2017 12:00 PM	30 gal 7/27/2017 12:00 PM	-	0.08 gal/Day	310
North West CT 3DT230-1	3 gal 9/27/2017 12:00 PM	10 gal 7/27/2017 12:00 PM	-	0.11 gal/Day	26.57
Interstate CT - 3DT465	13 gal 9/27/2017 12:00 PM	15 gal 9/21/2017 12:00 PM	-	0.33 gal/Day	39

Predictive and Preventive Measures

- Benefits of refrigerant, oil and water analysis
  - Maximizes predictive abilities
  - Provides opportunities for preventative services
  - Adds proactive maintenance/root cause analysis capability
- Benefits of correlating refrigerant, oil and water analysis
  - All are essential diagnostic & preventative tools
- Maximal benefit – correlation of results
  - Certificates of analysis
  - Chemist's interpretive report
  - Comprehensive engineering review
    - Compare & correlate
    - Specific service recommendations

Frequency of Testing

- Depends on criticality of system operations
  - Mission Critical (Large warehouses, Data Centers, Cleans rooms, Hospitals, etc.)
    - Once in 3 months
  - Industrial plants – Continuous operation, all year
    - Once in 3 or 6 months
  - Commercial – Space Cooling applications
    - Twice a year
    - Early during the season; Just before season ends
- Typical refrigerant, oil and water testing can be ~$500 per chiller
- Availability of certified laboratories

Reclamation of Refrigerants

- Used refrigerants cannot be vented to the environment
- Every unit mass of refrigerant has to be “RECOVERED”
- Refrigerants are mandated substances under the local/federal Environmental agencies, Air Quality / Pollution boards, etc.
- So can we reuse and recycle refrigerants?



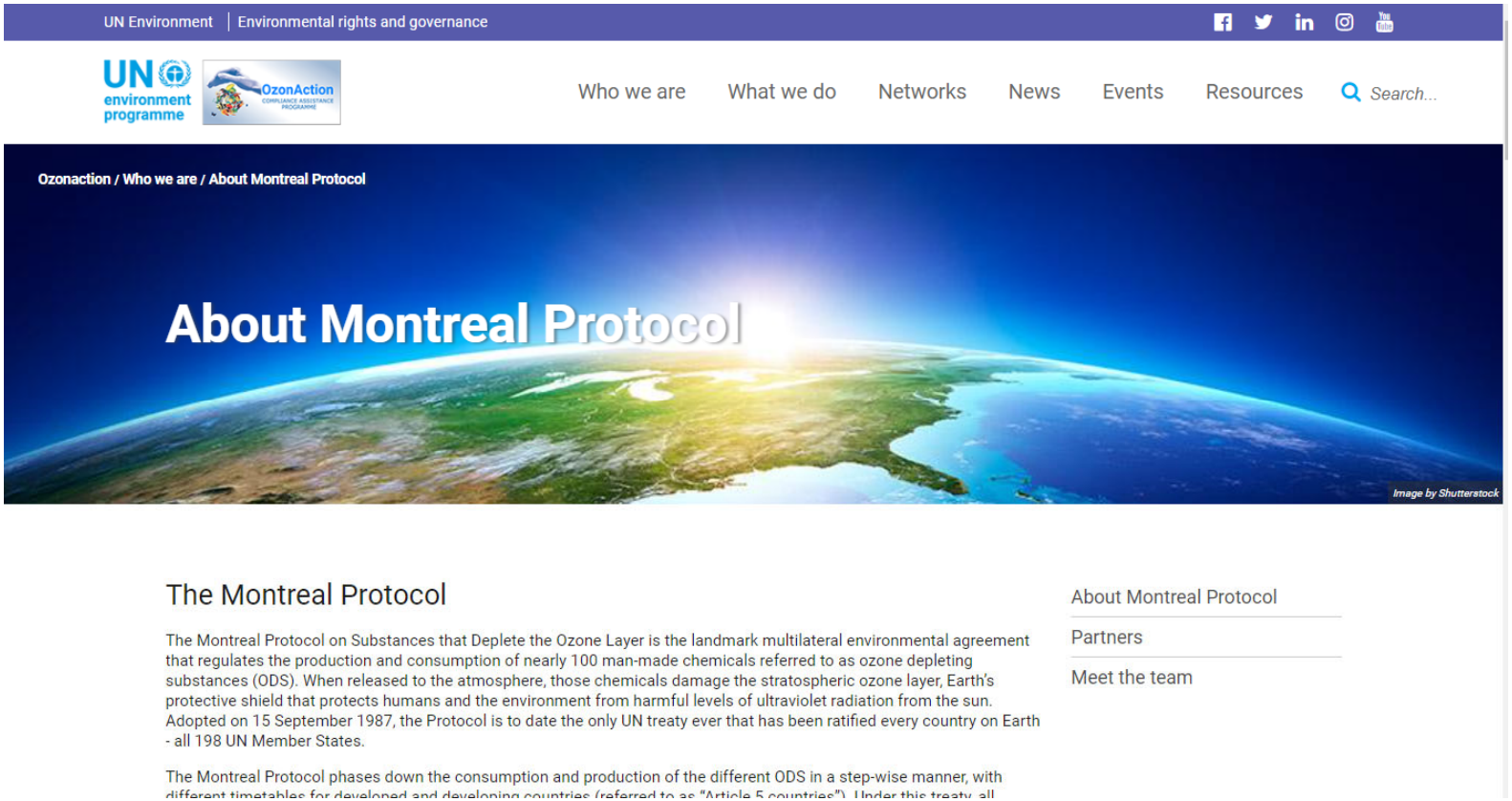
Reclaim Refrigerant

- Over time and continuous operations, the refrigerant in the chilled water system gets contaminated and results in
  - Fouling of heat exchangers
  - Reductions in heat transfer coefficients
- The process of recovering the refrigerant and bringing it back to AHRI-700 specifications is known as “Reclamation”
- Reclaiming a refrigerant improves overall operating performance and increases the chilled water system’s capacity & reliability
- Periodic sampling/testing of refrigerants is key to ensuring that the chiller chemistry is well-maintained
  - Analogous to maintaining water chemistry in boilers

Refrigerants – Past, Present & Future

U.S. DEPARTMENT OF ENERGY

The Montreal Protocol



The Montreal Protocol - General Information

- Adopted on 15th September 1987 – ratified by every country (198 UN member States)
- Regulates the production and consumption of nearly 100 man-made chemicals known as Ozone Depleting Substances (ODS)
- When released, chlorine from these substances damages the stratospheric ozone layer
- Phasedown of different ODS substances in a step-wise manner with different time-tables for developed and developing countries
- The protocol has articles (provisions) and Annexes (for different substances – CFCs, HCFCs)
- Treaty evolves over time based on new scientific, technical and economic developments
- Annual meetings – Governance Body & Open-ended Working Group

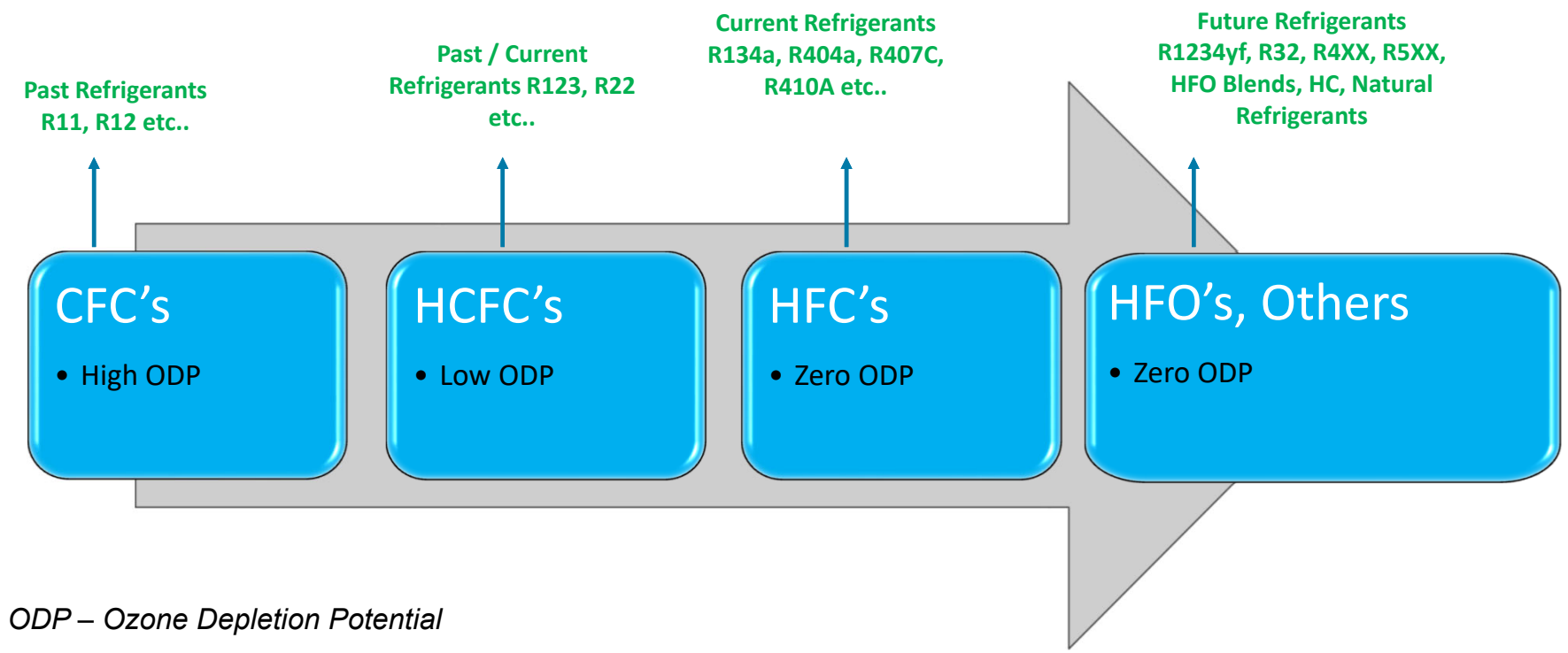
The Montreal Protocol – United States

- Production and importation of CFC's was banned completely in 1996
- In 2010, US regulations banned the production and importation of HCFC's – R22 and R142b for use in new equipment
- www.epa.gov/ozone-layer-protection

U.S. Action to Meet the Montreal Protocol Phaseout Schedule

Year to Be Implemented	Implementation of HCFC Phaseout through Clean Air Act Regulations	Year to Be Implemented	Percent Reduction in HCFC Consumption and Production from Baseline
2003	No production or import of HCFC-141b	2004	35.0%
2010	No production or import of HCFC-142b and HCFC-22, except for use in equipment manufactured before January 1, 2010	2010	75.0%
2015	No production or import of any other HCFCs, except as refrigerants in equipment manufactured before January 1, 2020	2015	90.0%
2020	No production or import of HCFC-142b and HCFC-22	2020	99.5%
2030	No production or import of any HCFCs	2030	100.0%

Refrigerants Past, Present & Future Trends



ODP – Ozone Depletion Potential

Properties of Refrigerants

- Safety
  - Toxicity
  - Flammability
- Thermophysical
  - Boiling point
  - Critical temperature, pressure
- Refrigerant performance in a system
  - Operating pressures; Compression ratios
  - Net refrigerant effect
  - Specific heat
  - Oil handling
- Amount of refrigerant charge needed (depends on system type)

Refrigerants – Flammability & Toxicity

- ASHRAE Refrigerant Classification System



A – Occupational Exposure Limit of >400 ppm
B – OEL < 400 ppm

1 – No Flame Propagation (Non-Flammable)
2 – Flame Propagation; Lower Flammability Limit > 0.0062 lb/ft^3
AND Heat of Combustion < 8,169 Btu/lb
2L – (Optional Class 2) – burning velocity < 3.9 in/s
(Mildly Flammable)
3 - Flame Propagation; Lower Flammability Limit < 0.0062 lb/ft^3
OR Heat of Combustion > 8,169 Btu/lb (Highly Flammable)

Refrigerants – Flammability & Toxicity

- ASHRAE Refrigerant Classification System

Examples of Refrigerants	Classification
R22, R134a, R404a, R407a, R410a, R1336mzz, R448, R449, R507a, R513a, R515a	A1
R32, R1234yf (& ze), R143a, R454b	A2L
R142b, R152a	A2
Methane (R50), Propane (R290), Butane (R600), IsoButane (R600a)	A3
R123, DiChloroFlouroMethane (R21), R245fa, R514a	B1
Ammonia (R717)	B2L
Methyl Chloride (R40), DiChloroMethane (R30)	B2
	B3

Next Generation Refrigerants

- Most focus and targets are looking at a systematic approach
  - Option 1 – a transition plan
    - Provides time for industry to adapt
  - Option 2 – immediate change
    - One-time change and be done with it
- Industry is looking at “No one shirt fits all” approach
  - Application specific
  - Availability of a drop-in replacement
  - Availability of reclaimed refrigerant
- Natural refrigerants are being looked at closely provided they are feasible based on the properties of refrigerants
  - System compatibility
  - Safety
  - Cost of new system

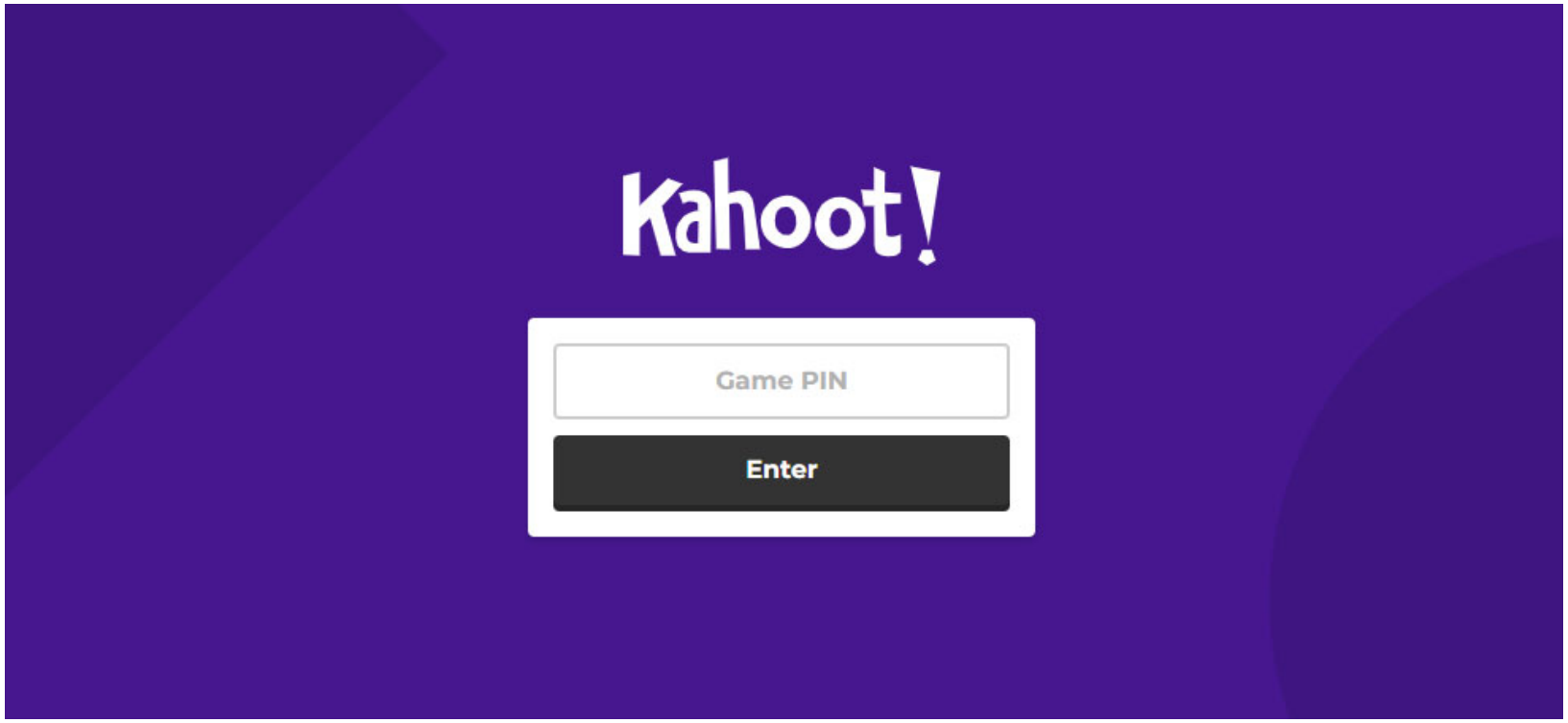
Significant New Alternatives Policy (SNAP)

- EPA website for acceptable and unacceptable substitute refrigerants
  - https://www.epa.gov/snap/unacceptable-and-acceptable-substitutes-tables#refrig
- Centrifugal Chillers
  - Capacities range from 60 to 6,000 RT
  - https://www.epa.gov/snap/substitutes-centrifugal-chillers
- Positive Displacement Machines
  - **Reciprocating compressors** range of 3 to 510 RT
  - **Screw compressors** range of 3 to 2,000 RT
  - **Scroll compressors** range of 3 to 510 RT
  - https://www.epa.gov/snap/substitutes-positive-displacement-chillers

Homework #7

- Finalize your CWST, MEASUR models for your chilled water plant system
- Identify all ongoing BestPractices in your chilled water system
- Identify all energy efficiency opportunities in your chilled water system
- Make an effort to quantify these opportunities and identify them as Low-cost / No-cost, Medium and High-cost (or based on Paybacks)
- Make a list of qualitative recommendations that were not evaluated in the current VINPLT assessment
- Complete your VINPLT presentation for Session 8

Kahoot Quiz Time



Thank You all for attending today's webinar.

See you all tomorrow - Thursday – September 3, 2026 – 2 pm ET

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

Alternately, you can email questions to paparra@ornl.gov or g@greensystemio.com

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