Industrial Process Cooling (Chilled Water) Systems

Virtual INPLT Training & Assessment

Session 8

Thursday – July 21, 2022

10 am – 12:30 pm

Welcome

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

Agenda – Session 8

- Welcome and Introductions
- Safety and Housekeeping
- Today's Content:
    - Review of Session 7
    - VINPLT Assessment Presentations
    - Case Studies & Success Stories
    - Specific requested topics
- Q&A

Safety and Housekeeping

- Safety Moment
  - Industrial energy systems pose several safety hazards and risk – electricity; chemicals; rotating equipment; hard and heavy material components
  - Be on full alert when working around industrial equipment – do not be distracted by anything – especially cell phones!
- 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 7

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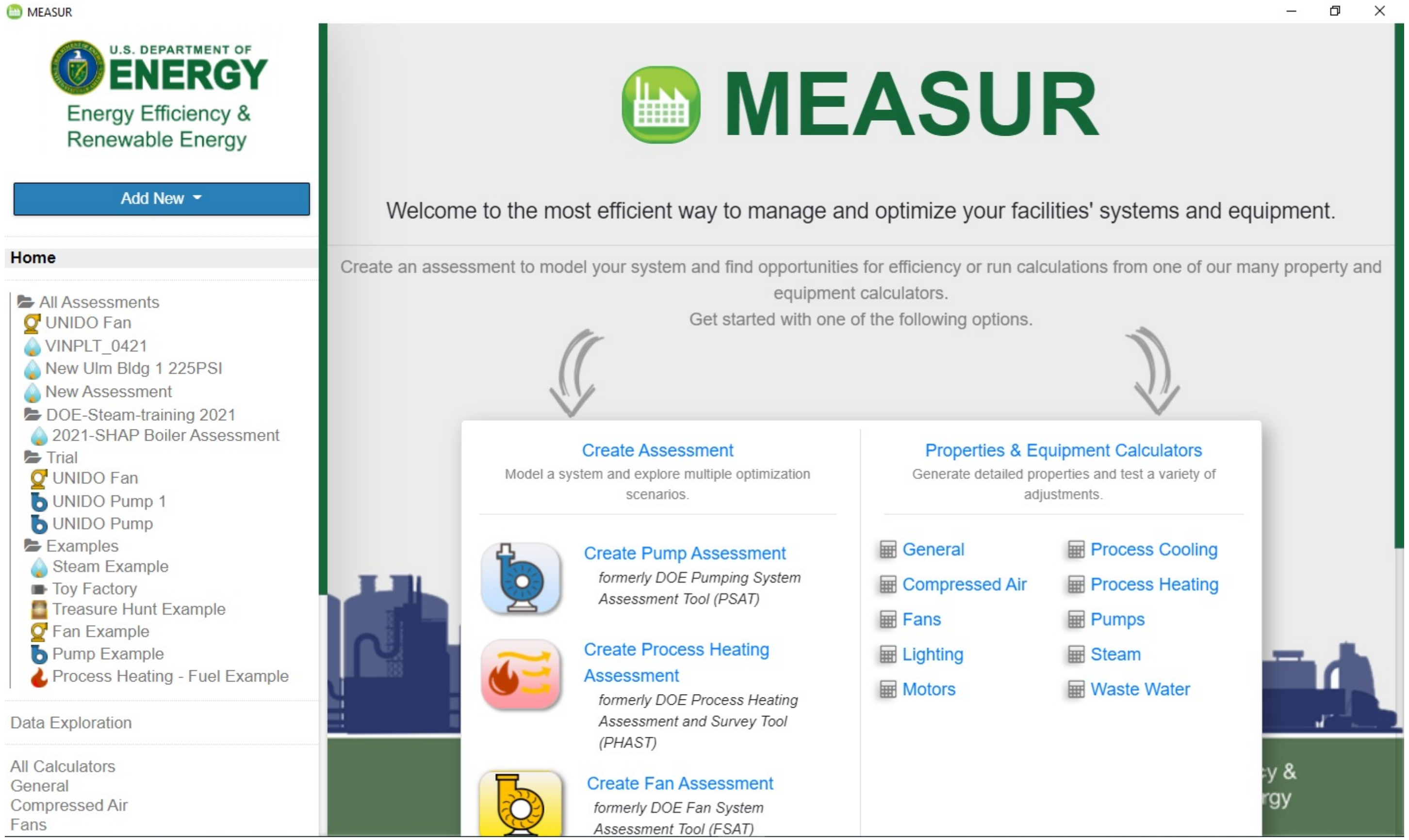
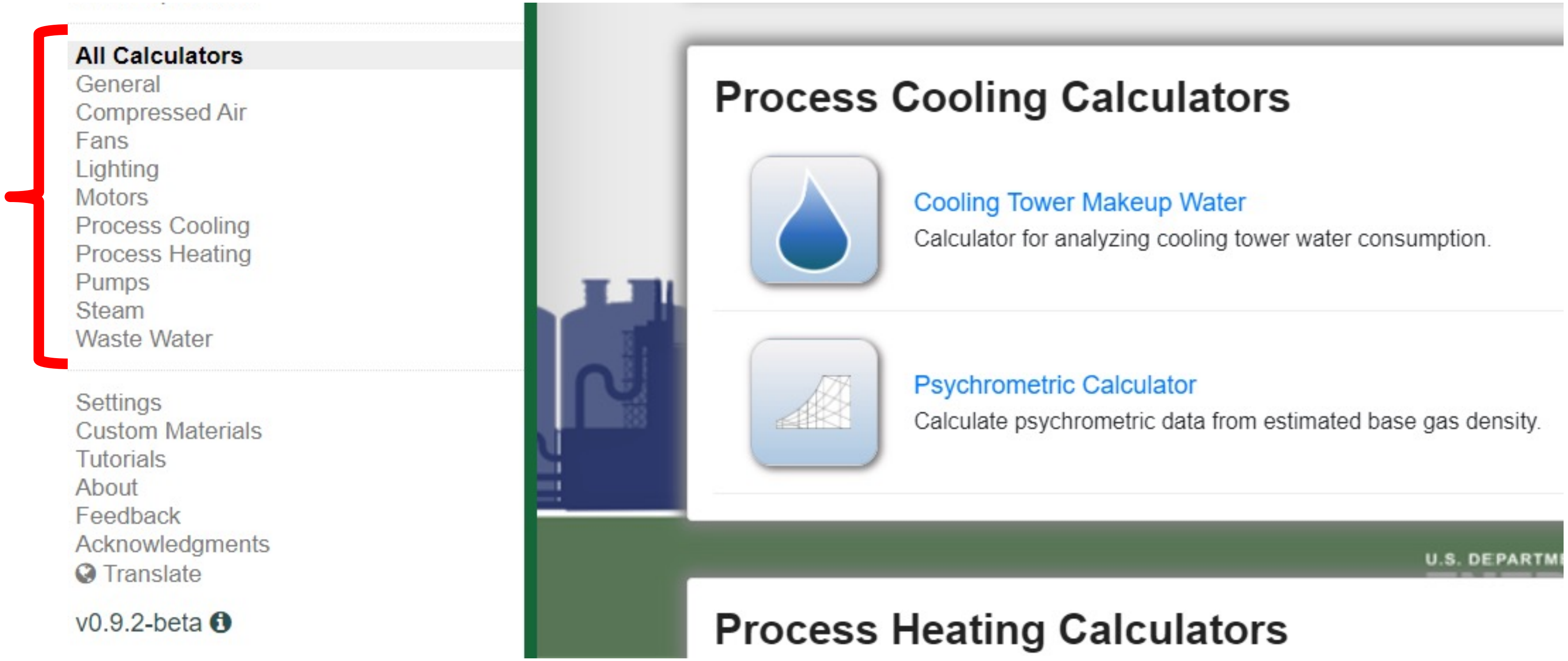
US DOE MEASUR Tool

- To be downloaded from the US DOE AMO website
  - Search for MEASUR tool
- Its platform independent
- Installation may require Admin privileges
- Future updates

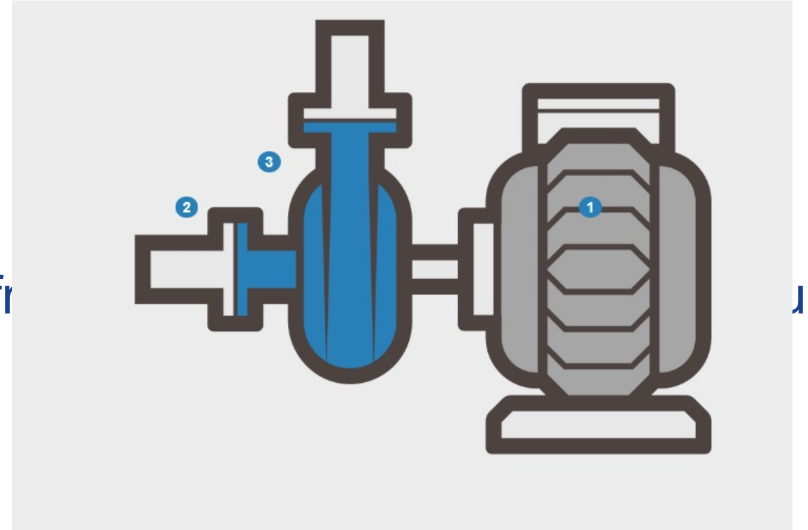


All Calculators



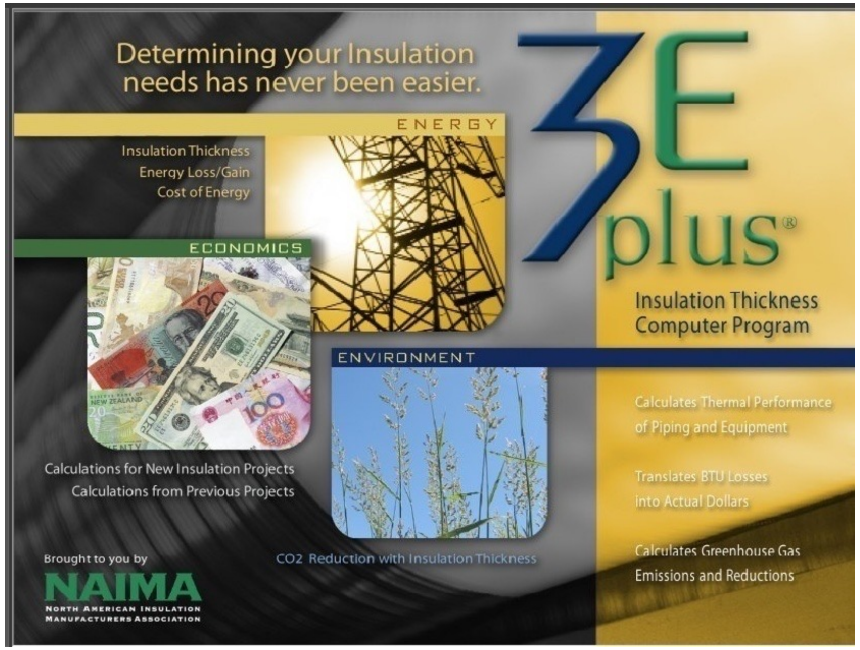
The MEASUR Tool for Pump Systems

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



3EPlus Insulation Evaluation Software

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



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

Refrigerant Testing / Analysis Criteria

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


AHRI Standard 700

2019 Standard for

Specifications for Refrigerants

AHRI
AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE

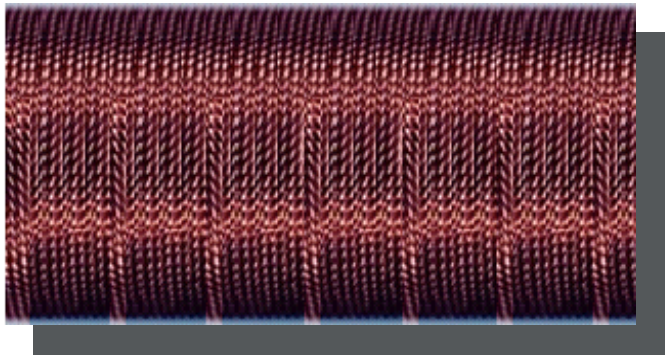
2311 Wilson Boulevard, Suite 400
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

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

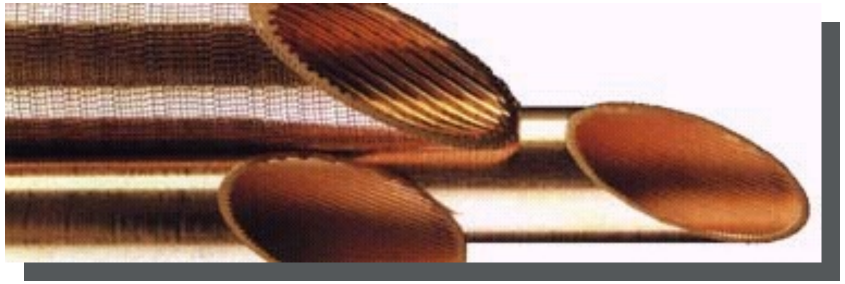
Oil Impact on Heat Transfer Surfaces

- Enhanced tube surfaces
  - Excellent heat transfer characteristics
  - Compact designs



- Oil fouls evaporator tube surfaces
  - Common problem
  - Significant research has been done to evaluate impact of oil on chilled water systems (ASHRAE TR-601, etc)

- Reduces heat transfer effectiveness
  - Reduces cooling capacity
  - Wastes energy



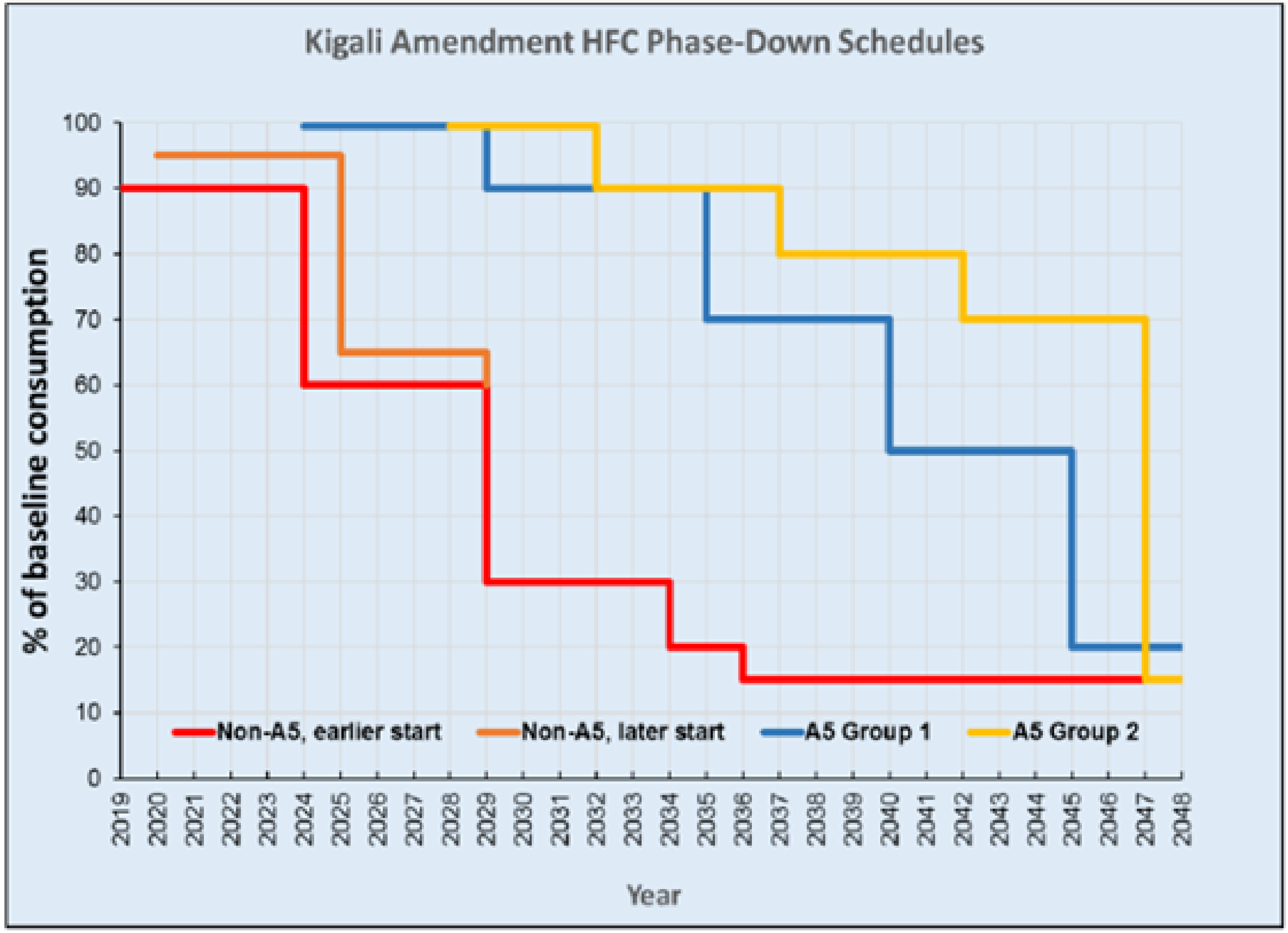
Frequency of Testing

- 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

The Kigali Amendment



- United States
  - Baseline – 2010-2013
  - Current – 95%
  - 2025 – 65%
  - 2029 – 30%
  - 2034 – 20%
  - 2036 – 15%
- Schedules may change

Refrigerants Past, Present & Future Trends

Past Refrigerants R11, R12 etc..

CFC's

- High ODP
- High GWP

Past / Current Refrigerants R123, R22 etc..

HCFC's

- Low ODP
- High GWP

Current Refrigerants R404a, R407C, R410A etc..

HFC's

- Zero ODP
- High GWP

Future Refrigerants R1234yf, R32, R4XX, R5XX, HFO Blends, HC, Natural Refrigerants

HFO's, Others

- Zero ODP
- Very Low GWP

ODP – Ozone Depletion Potential
GWP – Global Warming Potential

Case Study – Del Monte Foods, Modesto, CA

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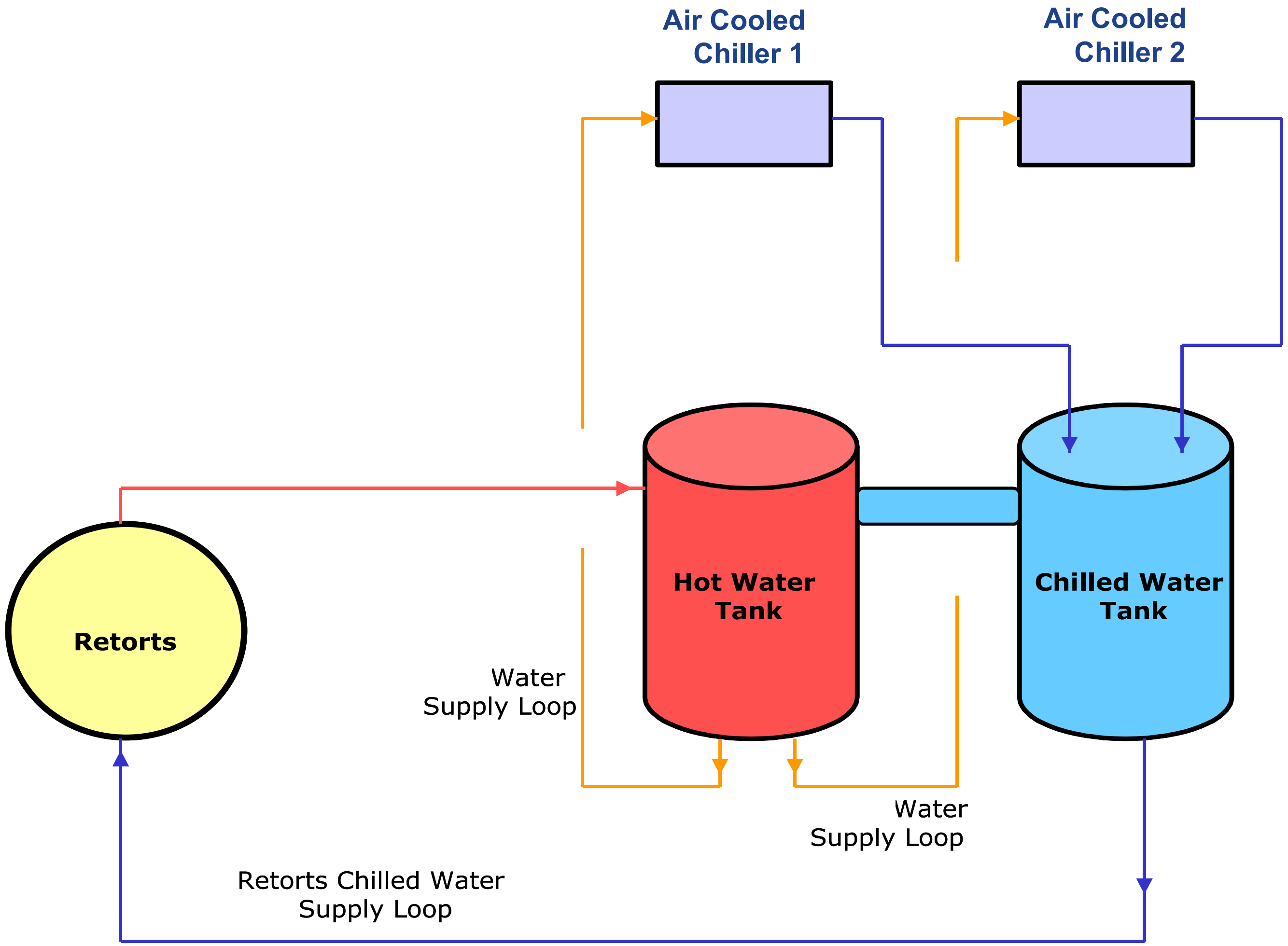
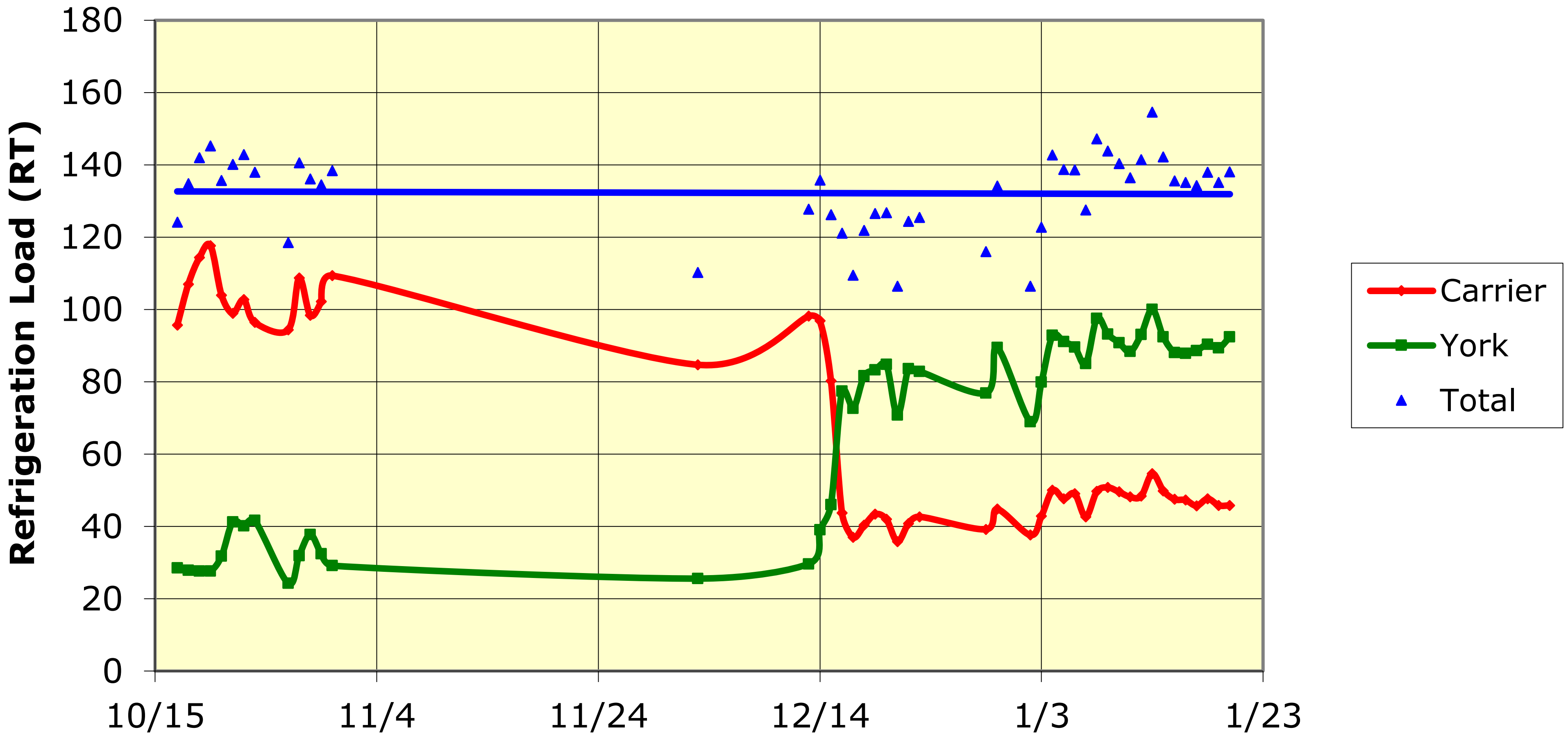
Del Monte Foods – Fruit To Go & Gel Cups

- System uses 4 Barriquand retorts and circulates 1,500 gpm of water
- Each retort cycle consists of:
  - Controlled heating
  - Sterilization
  - Controlled cooling
- Steam produced at 150 psig – used in retorts at 45 psig
- Cooling is done by two air-cooled chillers (150 RT and 110 RT)
- One cooling tower for process cooling

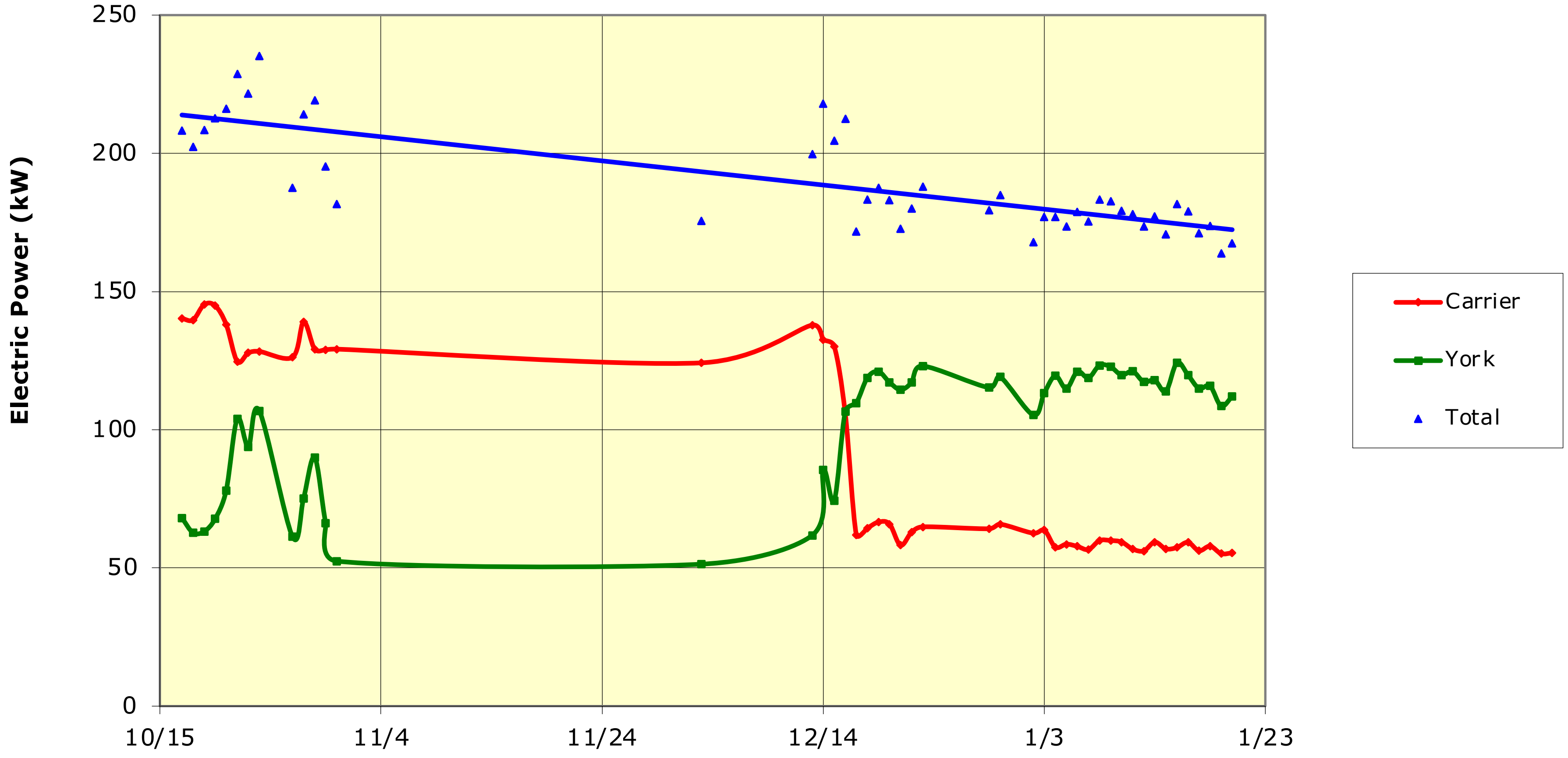
Circulating Chilled Water System



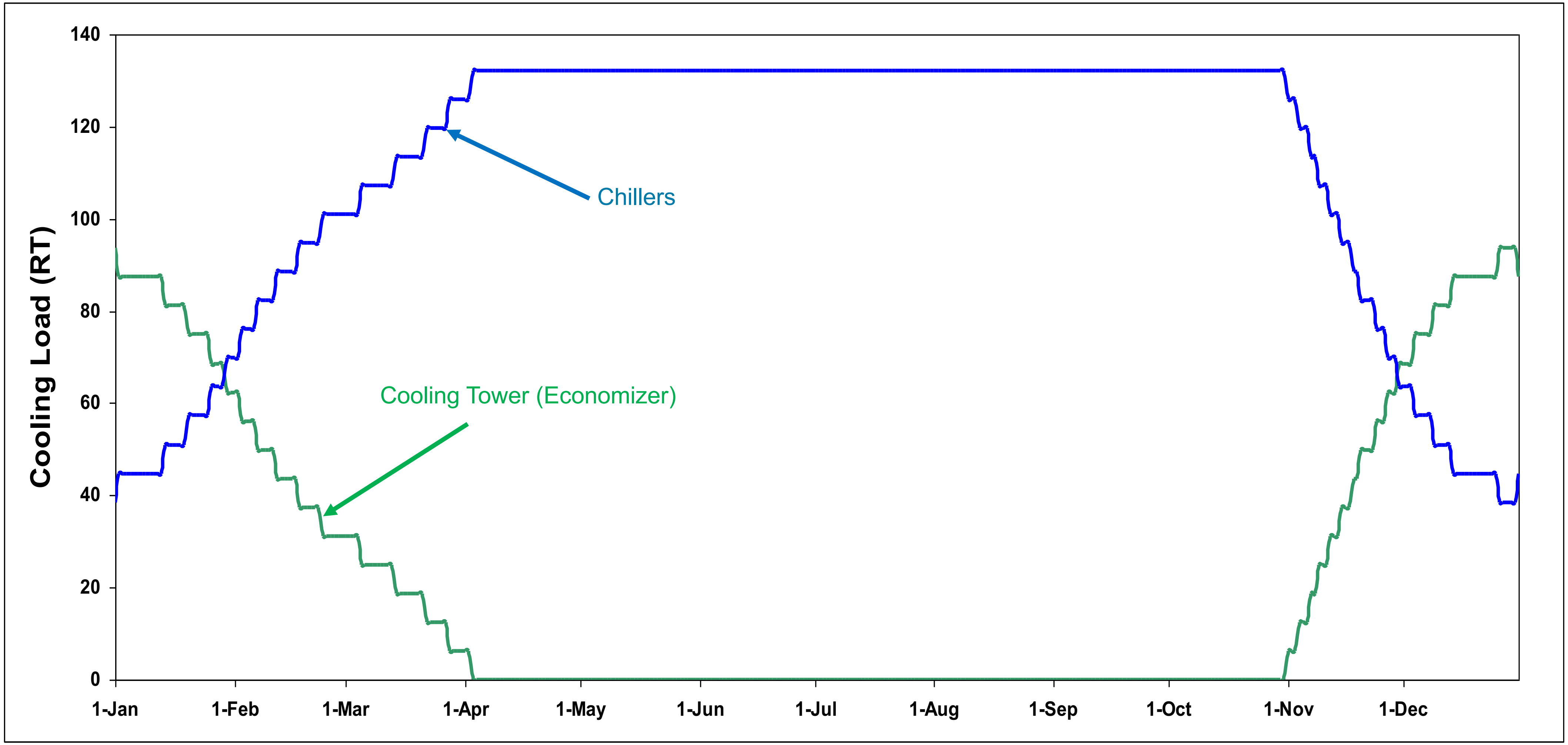
Load Profiles



Load Profiles



Cooling Tower (Economizer) Load Sharing



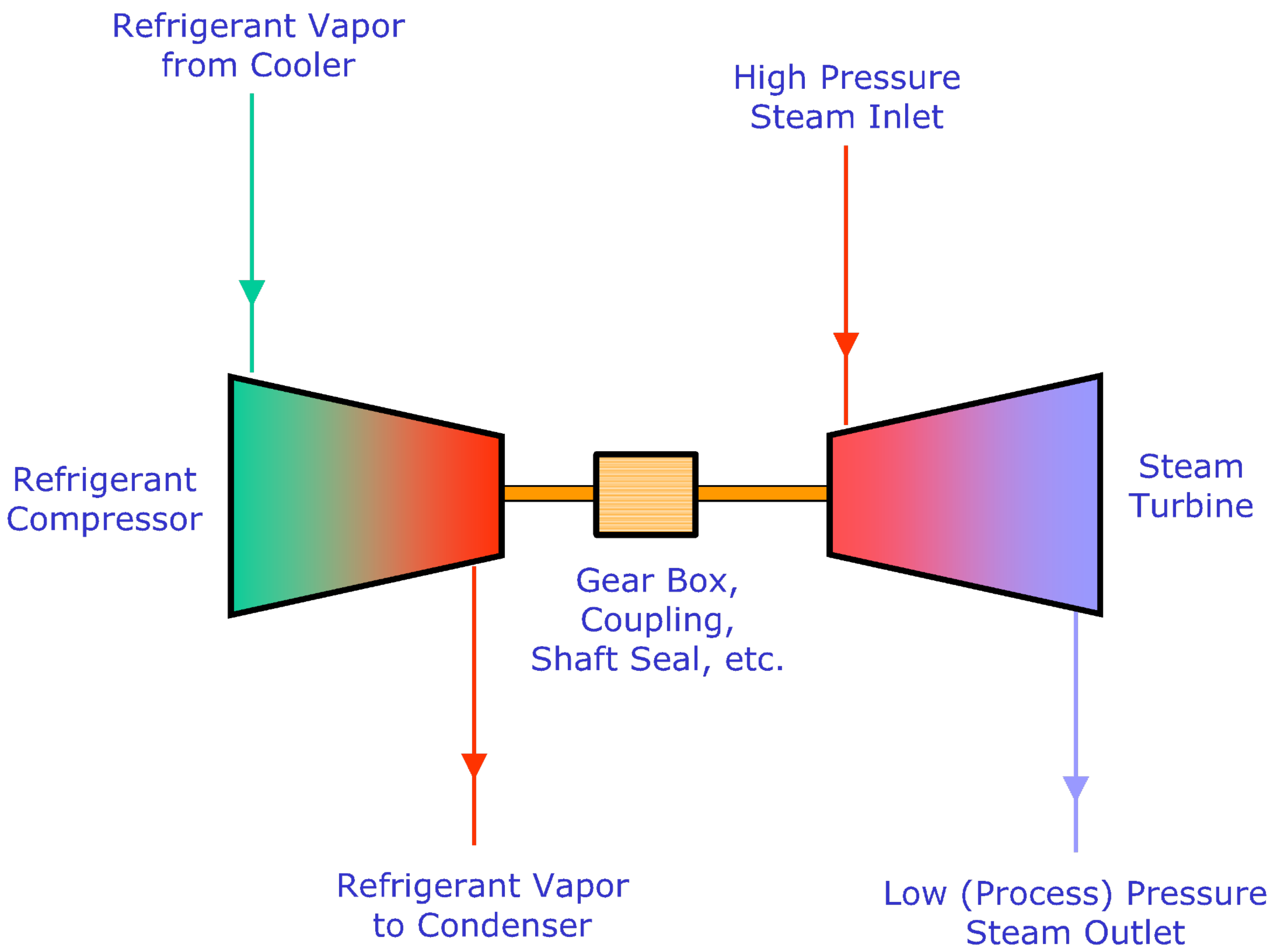
Energy Optimization Options Analysis

- Cooling Tower Only
  - Supplemental cooling load by air-cooled chiller
- Cooling Tower + Water Cooled Chiller
  - Supplemental cooling load by air-cooled chiller
- Cooling Tower + Steam-Turbine driven Water Cooled Chiller
  - Supplemental cooling load by air-cooled chiller
  - Large reduction in electrical energy costs
  - Partly offset by increase in fuel cost of Natural gas

Energy Optimization Quantitative Analysis

- Current Baseline
  - Energy – 1,833,192 kWh; Peak Demand – 227 kW
- Cooling Tower Only
  - Energy – 1,790,937 kWh; Peak Demand – 214.3 kW
- Cooling Tower + Water Cooled Chiller
  - Energy – 1,371,415 kWh; Peak Demand –145.2 kW
- Cooling Tower + Steam-Turbine driven Water Cooled Chiller
  - Electrical Energy – 910,995 kWh; Peak Demand – 84.6 kW;
  - Fuel Energy – 2,900 MMBtu

Energy Optimized Solution



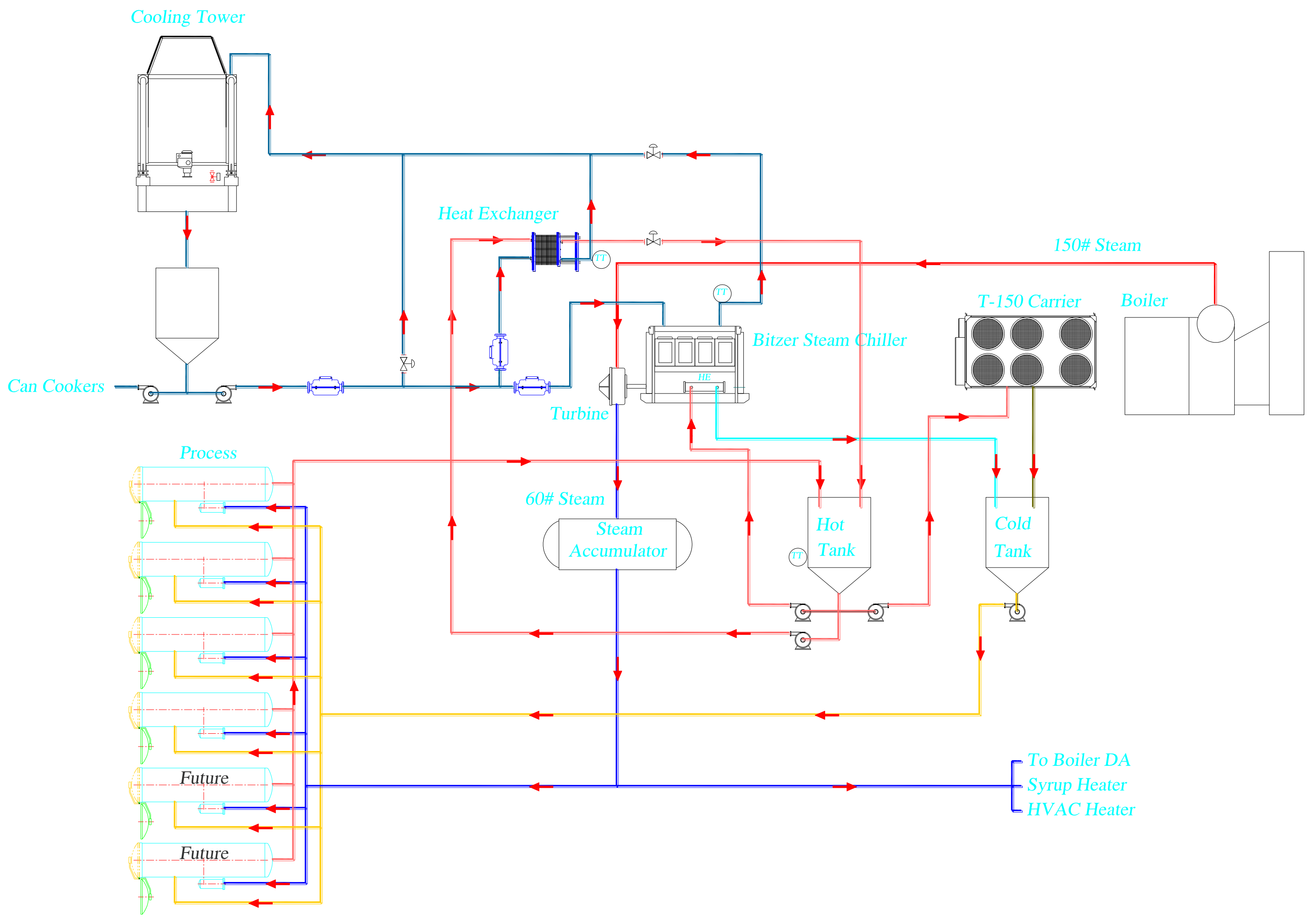
Energy Optimized Solution

Topping Cycle (TC) Definition: In a steam turbine topping cycle system, boiler-generated steam will operate a steam turbine application such as a chiller, The exhaust steam from the turbine is used for low pressure steam applications such as process heating requirements.

Del Monte Foods-Modesto Topping Cycle Application

1. A steam turbine (Elliott: 87 hp; 4000 RPM; 11 klb/hr) is directly coupled to a screw chiller (Bitzer 85 RT cooling capacity).
2. Plant boiler (150 psig) will provide steam to turbine with the low pressure exhaust (45 psig) providing steam to operations and retorts.

Energy Optimized Solution



Actual Project Cost-Benefits Summary

Cost Summary

Steam turbine and controls: $30,000

Bitzer Chiller and Controls: $56,000

Savings Summary

Steam chiller vs electric unit: 104 kW and 540,000 kWh (in-season)

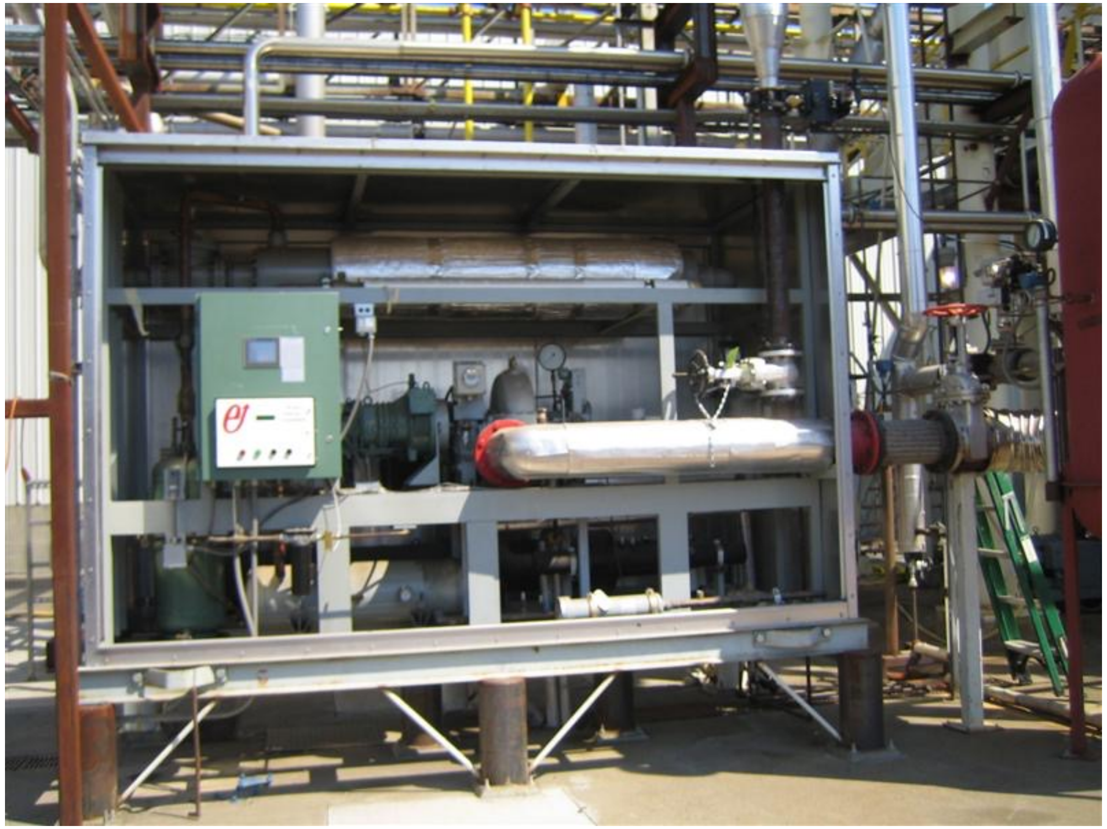
Natural gas net increase of 1,900 MMBtu due to an increase in steam generation to offset the steam enthalpy change across the steam turbine.

Net annual savings: $45,000

Simple payback: 1.9 years

Case Study – Del Monte Foods

- Utilities Integration
  - Cooling & Heating
  - Cogeneration (Topping cycle)
  - Free Cooling (Water-side Economizer)
- High Repeatability
- Minimal Risk



- Acknowledgments – Del Monte Foods, California Energy Commission, Lawrence Berkeley National Laboratory

Case Study – DOW Chemical Company, SCO, LA

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Objectives

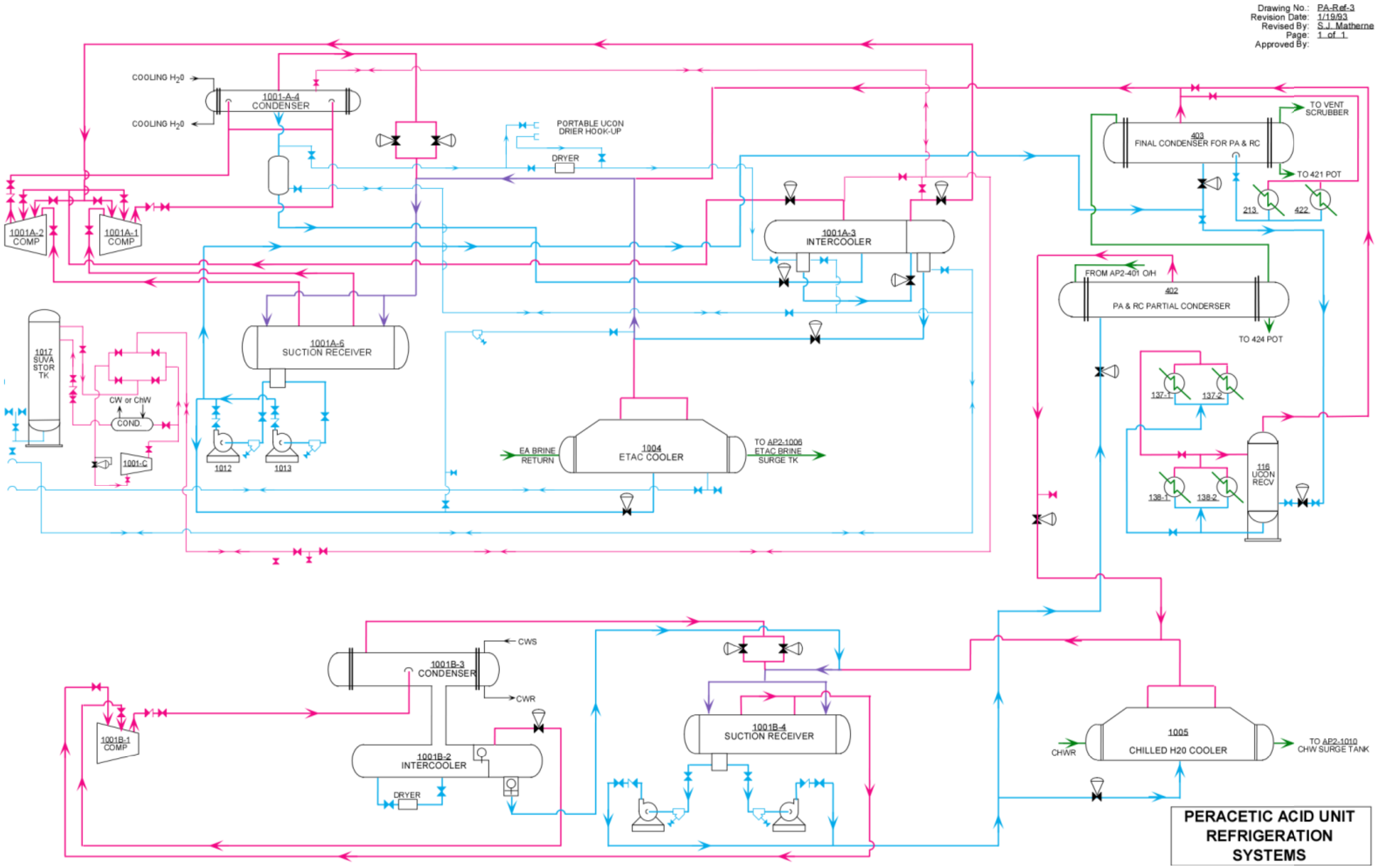
- Conduct a chilled water (process cooling/refrigeration) system Energy Savings Assessment (ESA) using a Systems Approach at the Peracetic Acid Plant
- Identify (and quantify) process cooling/refrigeration energy savings opportunities
- Assist plant personnel to gain familiarity with certain bestpractices and to continue to identify energy efficiency improvement opportunities at the site

Process Cooling/Refrigeration System

- Steam-turbine driven system
- Steam supply ~ 600 psig, 675°F
- Uses R134a ~ 225,000 lbs
- Total plant capacity ~ 6,500 RT
- Consists of two independent sub-systems
  - System A
    - Two 3-stage centrifugal compressors
    - Steam discharge pressure – 75 psig
    - Provides 0°F refrigeration capacity
  - System B
    - One 2-stage centrifugal compressor
    - Steam discharge pressure – 200 psig
    - Provides 44°F cooling capacity

Chilled water loop

Process Cooling / Refrigeration System PFD



Chilled water loop

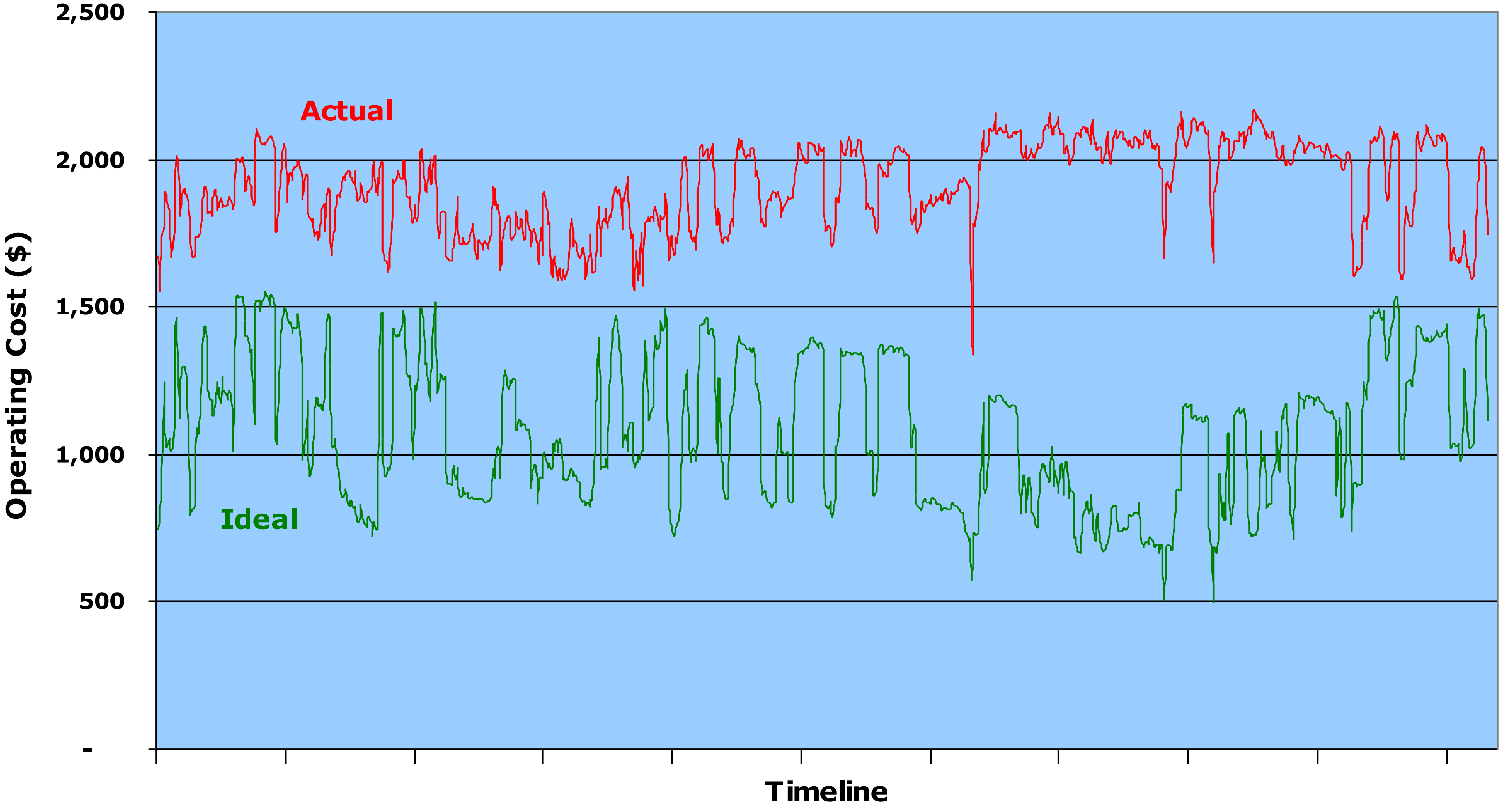
Data Collection

- Tiered structure
  - Preliminary stage
    - P&ID's, PFDs
    - Refrigeration Unit Walk-throughs
  - Intermediate stage
    - Design information
    - Previous engineering reports
  - Final stage
    - Identification of instrumentation
    - Annual 6-hour interval averages
    - Total data for ~6,200 hrs of operation

Global Systems Approach

- Actual Operation
  - System Hardware is fixed & has to respond to different loads
  - Operational inefficiencies
  - Cost savings (energy) and/or increase in production rates possible
- Ideal Operation
  - No operational losses
  - High equipment & component efficiencies (as per design)
  - Target (best efficiency point) level

Opportunity Cost Delta (Gap) Analysis



System Level Opportunities

- Following opportunities were implemented
  - Increase & maintain condenser cooling water flow
  - Eliminate non-condensables
  - Monitor contaminants & decontaminate refrigerant charge
  - Reduce surge and excessive hot gas bypass
  - Improve steam turbine performance
- Defined a metric to measure and improve performance for each opportunity
- Isolated the effect of each individual opportunity in terms of energy savings …. wherever possible

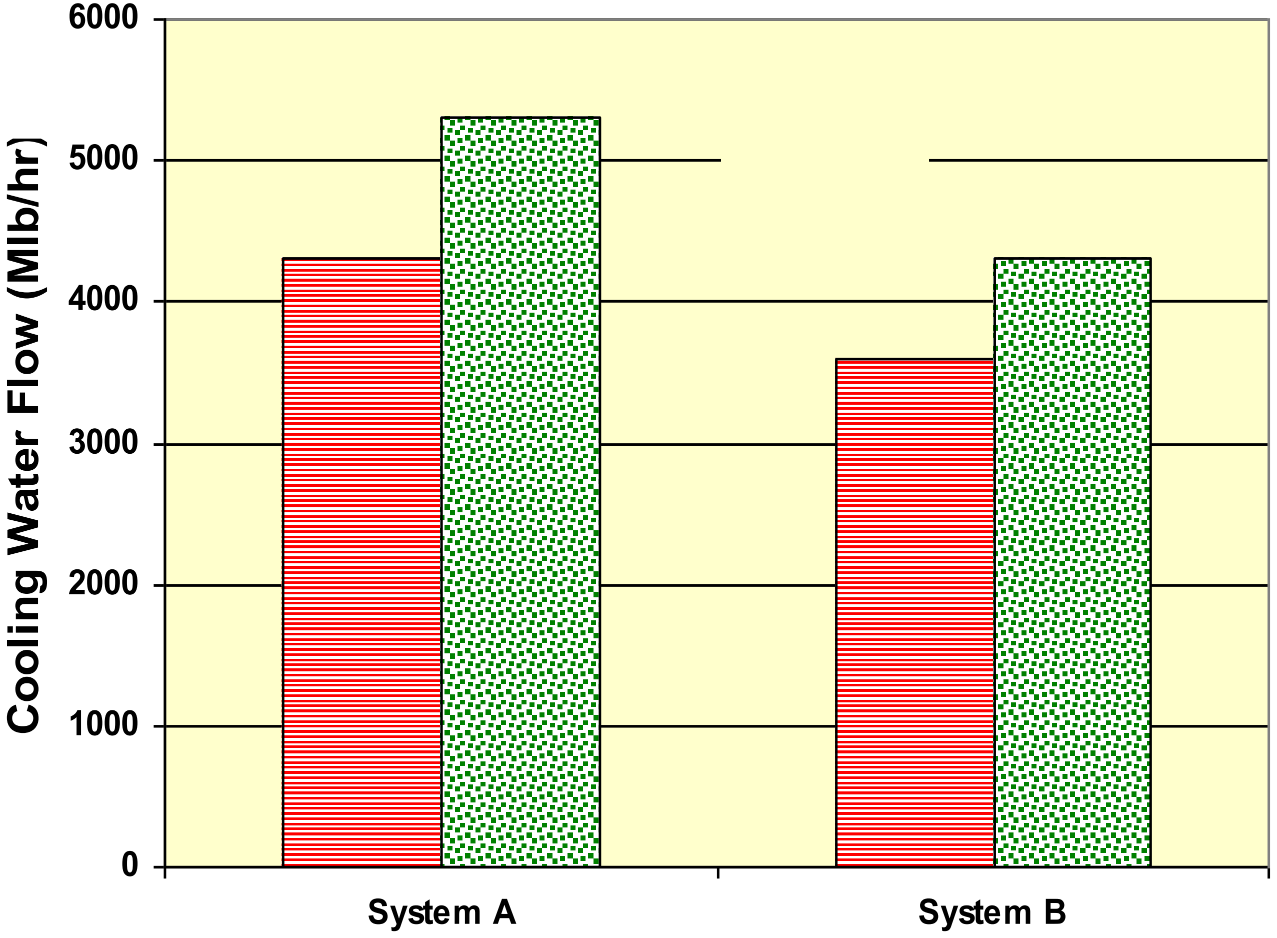
Increase & Maintain Condenser Cooling Water Flow

- Mississippi river water is used
- Heavy fouling potential – silt & debris
- System A & B flow lower than normal
- Flow restriction orifice downstream

- Implementations
  - Annual cleaning of condensers before peak
  - Back-flushing regularly
  - Removal of flow restriction orifice

- Results
  - 24% increase in flow in System A
  - 18% increase in flow in System B

Increased Condenser Cooling Water Flow



Eliminate Non-Condensables

- No clear procedure for evacuation and purging prior to refrigerant charging
- System A had ~ 10% non-condensables
- System B had ~ 1% non-condensables
- Increased head pressure, loss of efficiency and loss of capacity

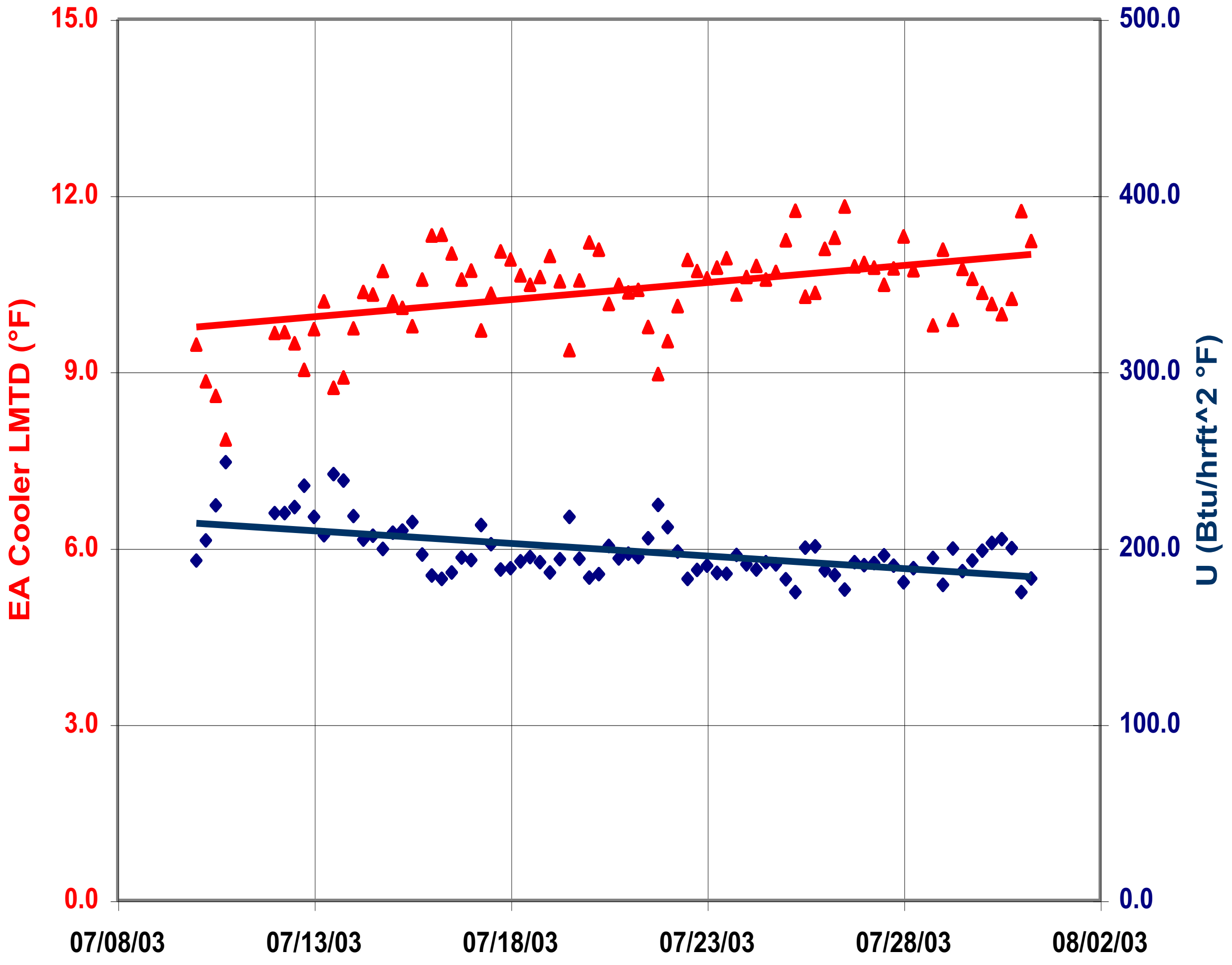
- Implementations
  - Periodic monitoring of non-condensables and purging as necessary
  - Documented proper procedure for evacuation

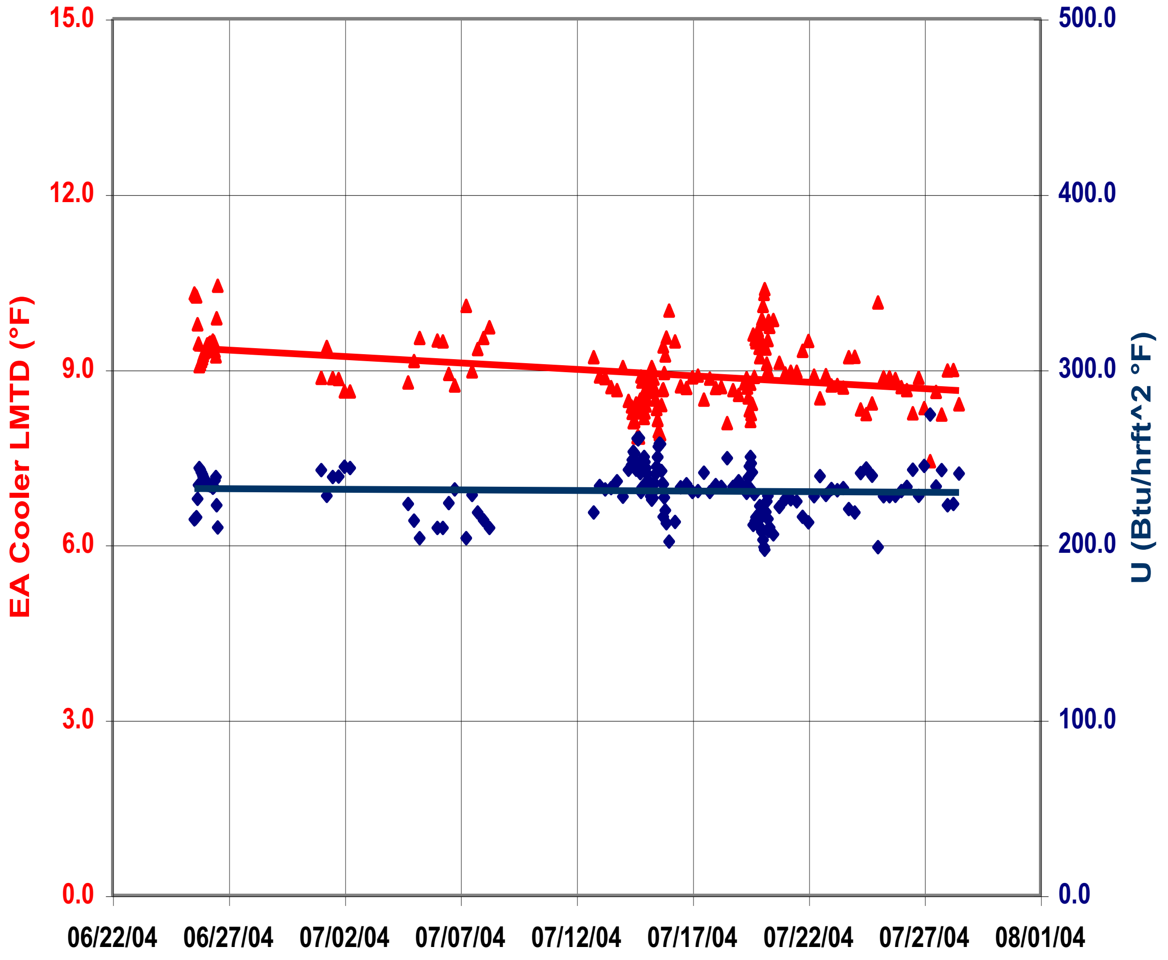
- Results
  - 7.5% gain in efficiency in System A
  - 1% gain in efficiency in System B

Monitor Contaminants & De-Contaminate Refrigerant

- System has history of refrigerant contamination by process fluids
- Contamination affects the system in one or more of the following ways:
  - Reduces system efficiency
  - Reduces evaporator capacity
  - Process fluid breakdown leading to acid formation (corrosion) and non-condensables
  - Fouling of heat exchangers
  - Reaction with oil
- Implementations
  - Reclamation of R134a and decontamination of the inventory
  - Periodic sampling to monitor refrigerant contaminant levels
- Results
  - 16% gain in heat transfer coefficient of Ethyl Acetate cooler

Monitor Contaminants & De-Contaminate Refrigerant





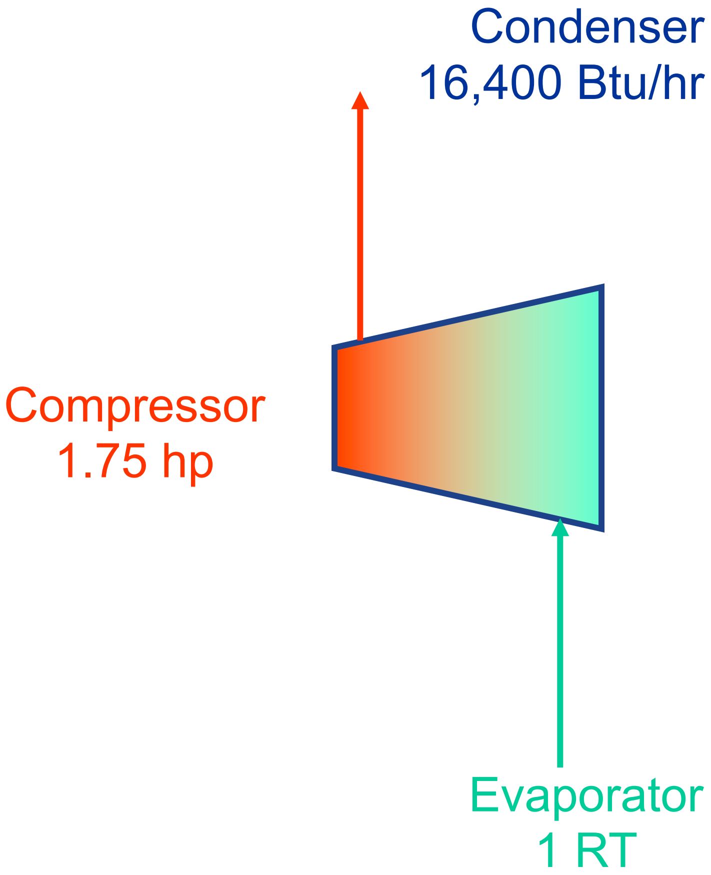
Reduce Surge & Excessive Hot Gas Bypass

- The main causes of surge and operation with hot gas bypass are:
  - Low load conditions
  - High head due to non-condensables
  - Inadequate cooling water flow
  - High cooling water temperature
  - Low turbine speed (hp)
  - Heat exchanger fouling

- Elimination of surge / hot gas bypass results in:
  - Increased compressor efficiency
  - Lower process temperatures
  - Increased capacity
  - Less wear and tear on the compressor
  - Reduced refrigerant pumping power

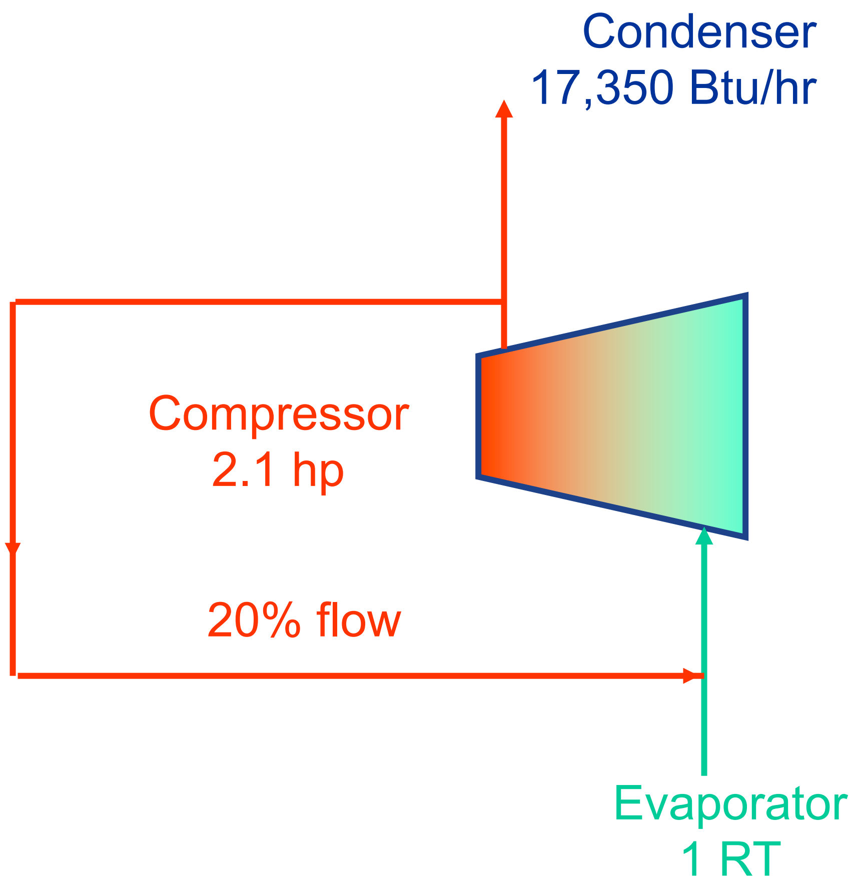
Compressor Surge

- Normal Operation
  - 1.75 hp/ton
- Rotating Stall



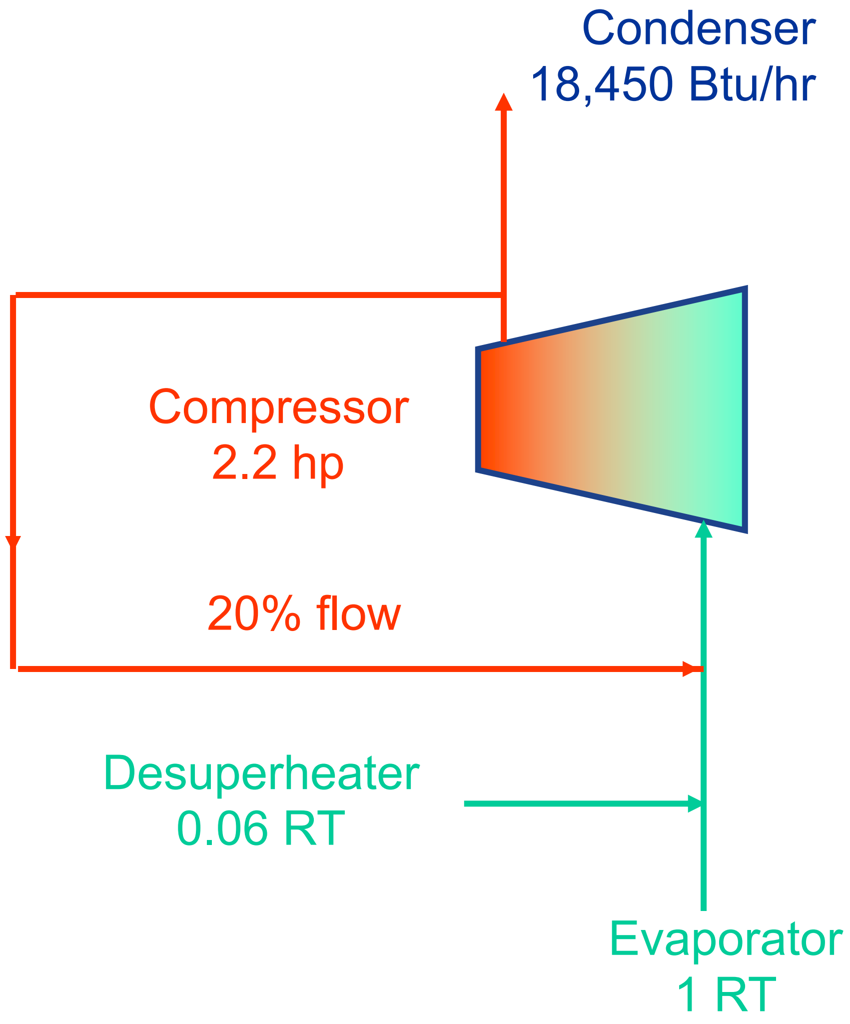
Compressor Surge

- Normal Operation
  - 1.75 hp/ton
- Surge initiation
  - Controller reacts
  - Opens HGBP
  - 2.1 hp/ton



Compressor Surge

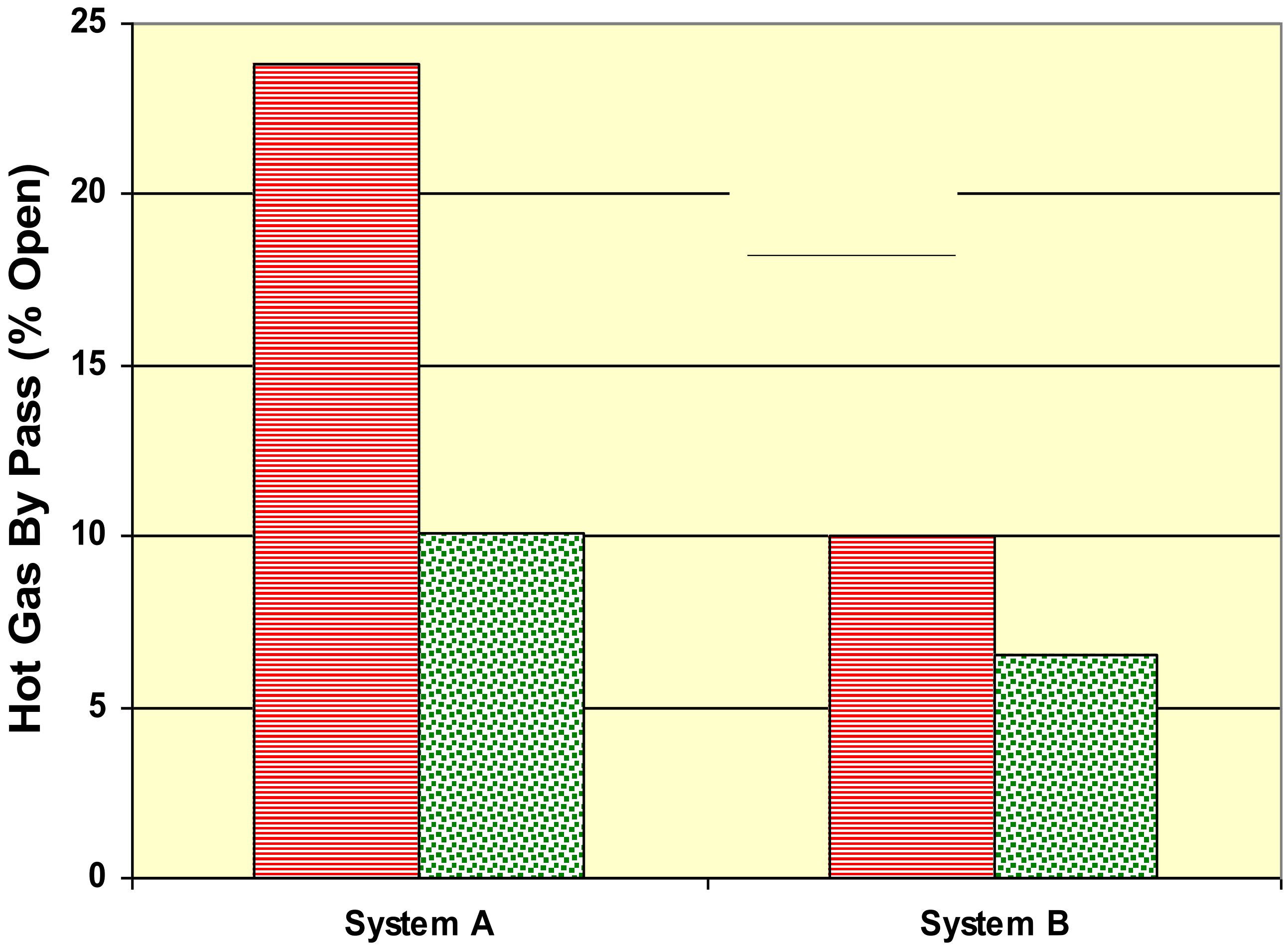
- Normal Operation
  - 1.75 hp/ton
- Surge initiation
  - Controller reacts
  - Opens HGBP
  - 2.1 hp/ton
- But also adds superheat!
  - Desuperheat with refrigerant liquid
  - Double whammy!
  - 2.2 hp/ton
- 25.7% increase in energy
- 12.5% increase in condenser load



Reduce Surge & Excessive Hot Gas Bypass

- Implementations
  - Improvements to reduce high discharge pressures
  - Surge protection factors were tightened to prevent hunting and instability
  - Production planned to operate at design conditions
  - Monitor any changes to surge curve and initiate compressor overhauls
  - Better controls for IGV to limit hot gas bypass operation
- Results
  - Significant drop in the hot gas bypass flow (direct indication by the “% open” valve position)

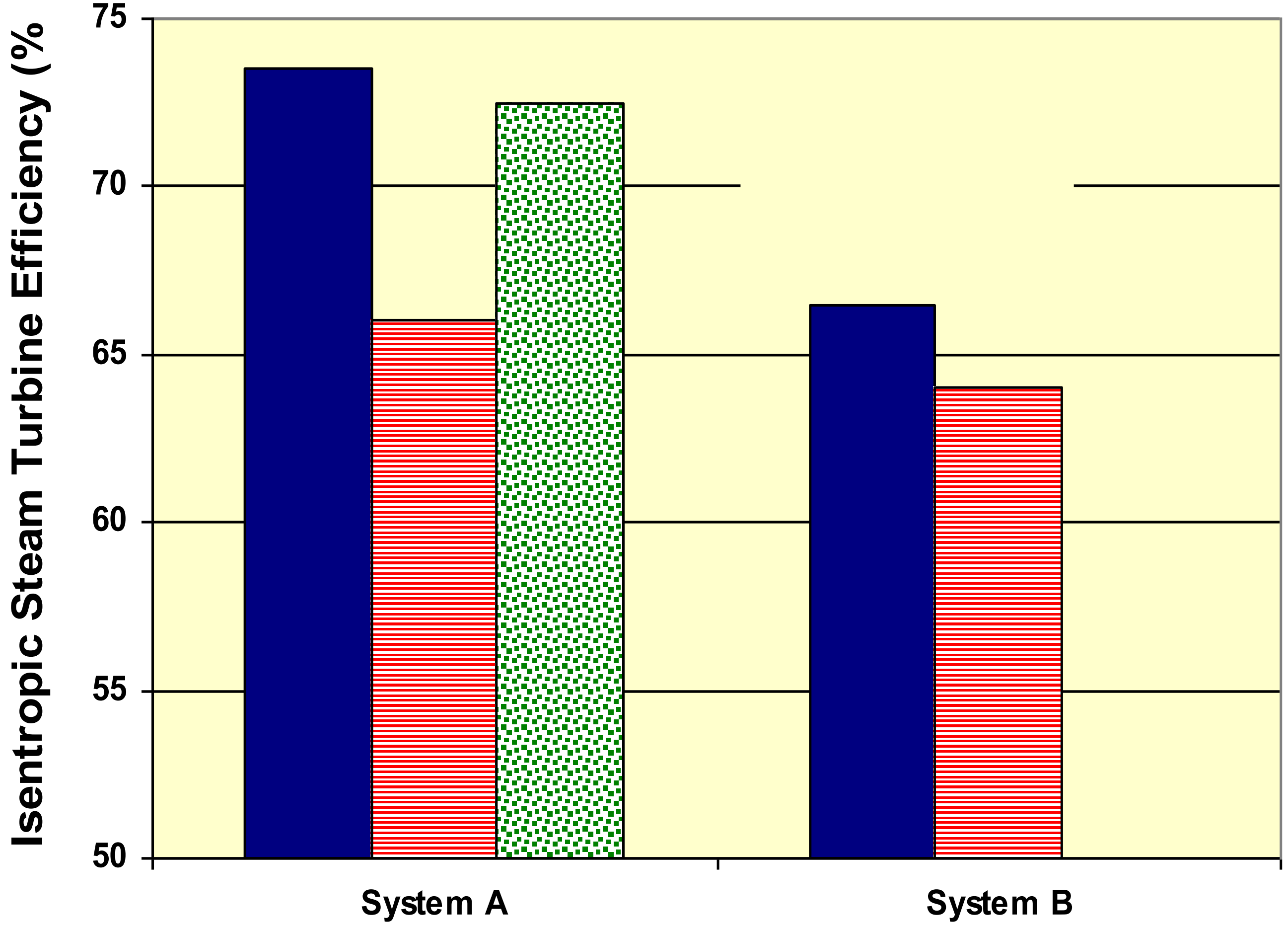
Reduce Surge & Excessive Hot Gas Bypass



Improve Steam Turbine Performance

- No historical turbine efficiency data
- Steam turbine efficiency almost 7 points lower than manufacturers' data
- System bottleneck due to horsepower limitations
- Implementations
  - Rebuild System A steam turbine
  - System B steam turbine rebuild scheduled for future
  - Better steam cost negotiation – price to reflect enthalpy (amount of superheat)
- Results
  - Steam turbine efficiency close to manufacturers design information

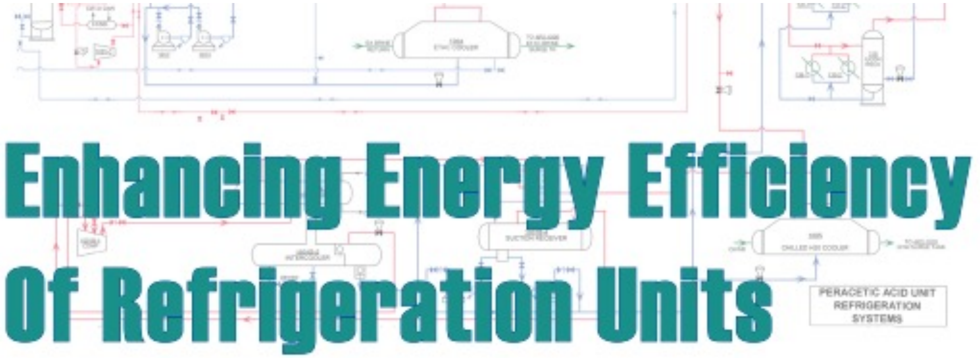
Improve Steam Turbine Performance



System Optimization Results

- 11% improvement in System A for the metrics used in six sigma methodology
- System B showed 9% improvement
- Overall energy savings are estimated to be ~$400,000 annually
- Total cost for improvements
  - Turbine rebuild - $100,000 (once in 5 years)
  - Refrigerant decontamination - $175,000
  - Hydro-blasting condensers - $40,000

System Optimization Results



Enhancing Energy Efficiency Of Refrigeration Units

By **Riyaz Papar, P.E.,** Member ASHRAE; **Kevin Zugibe, P.E.,** Member ASHRAE; and **Jeffrey Heitler, P.E.**

This article focuses on the systems approach and the results of energy-efficiency enhancement of two steam-turbine driven refrigeration units in the PXC plant at The Dow Chemical Company (St. Charles Operations, Hahnville, La.).

The plant manufactures specialty chemicals and is spread over an area of about 40 acres. Similar to other Dow chemical plant sites, this site operates a cogeneration facility that is managed by Dow Chemical Energy Services Group.

All the plants on the Hahnville site receive their electrical power from the central cogeneration facility. The thermal needs of the plants are satisfied by steam supplied at different pressures from the cogeneration facility. The utility cost structure to individual plants on the site is interlaced with costs and credits for the supply and return steam to the plant headers.

As a first step towards a systems approach for enhancing the operating energy efficiency of the refrigeration units, The Dow Chemical Company initiated a feasibility study (gap analysis). This study required development of detailed system and individual equipment analysis models to understand bottlenecks and inefficiencies. The evaluation was done on a load profile basis from data collected over a year. The results of this study are presented here, and the projects that were done are described. Most of the study's findings have been implemented, resulting in significant improvement in system operation. The systems approach and analysis incorporated the supply and demand-sides and targeted all cost savings achievable for the overall refrigeration system. The supply-side included steam flow rate, superheat (temperature, pressure), cost of steam, etc. The demand-side included production rates, process loads, cooling water temperature, etc. After the projects were completed, operational data was

About the Authors
Riyaz Papar, P.E., is director at Hudson Technologies in The Woodlands, Texas. **Kevin Zugibe, P.E.,** is CEO of Hudson Technologies in Pearl River, N.Y. **Jeffrey Heitler, P.E.,** is an improvement engineer at the Union Carbide Corporation, A Subsidiary of The Dow Chemical Company, in Hahnville, La.

Other Energy Efficiency & BestPractices Success Stories

Acknowledgments: Hudson Technologies Company

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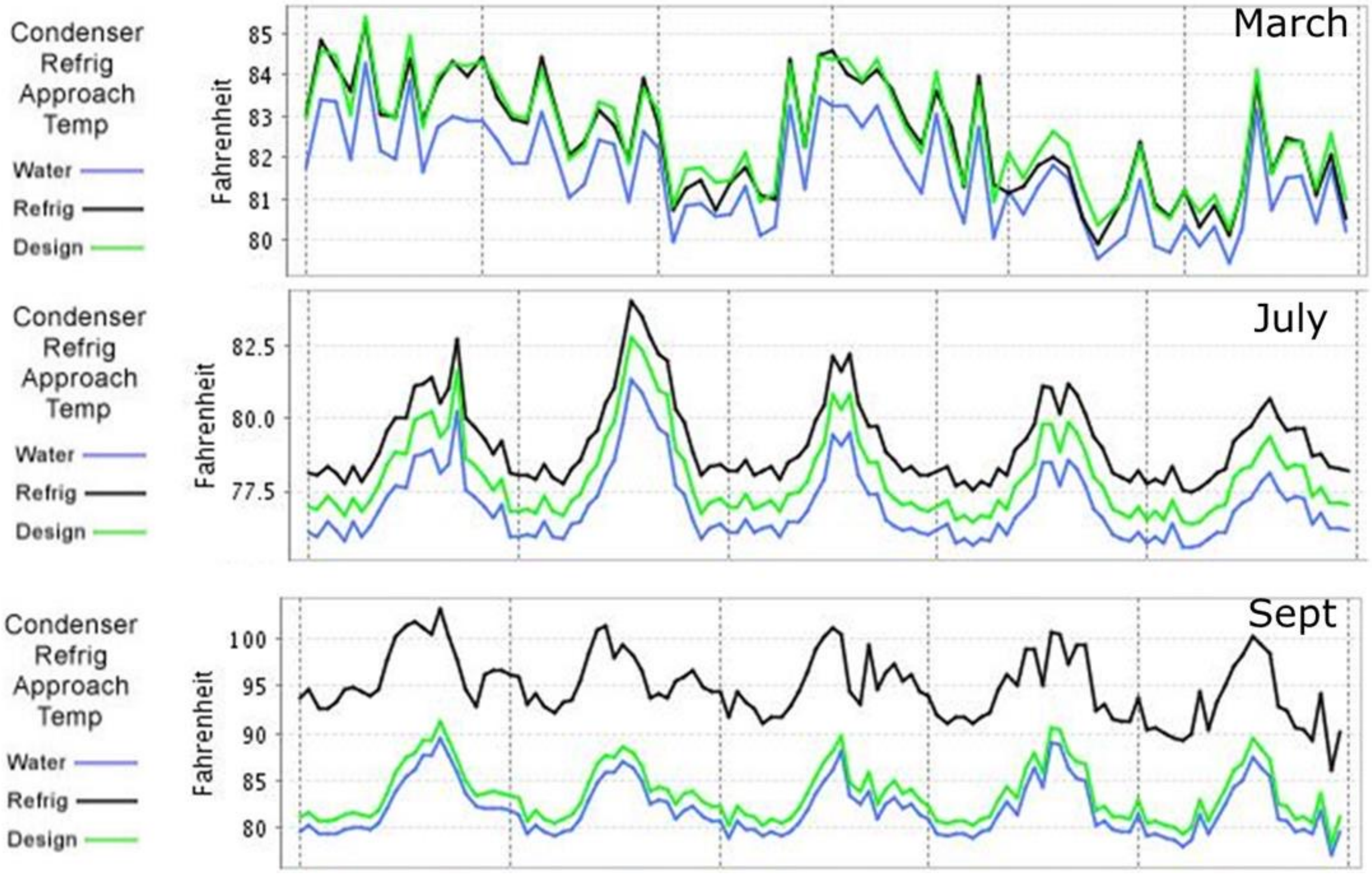
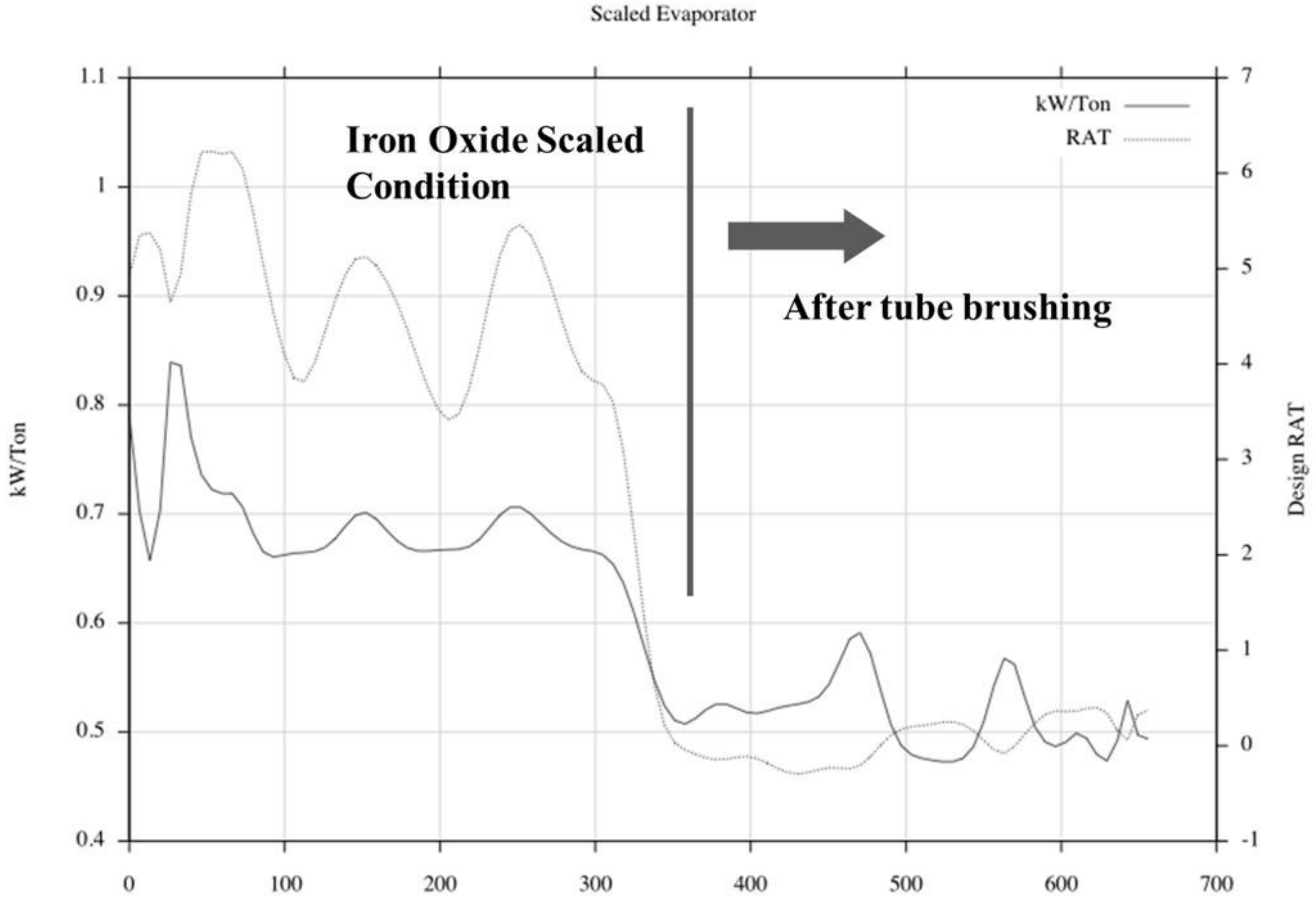
Clean Fouled & Scaled Condenser

- Fouling in the condenser primarily consists of microbiological growth and scaling
- Uncontrolled microbiological growth can form sticky slime deposits on the tube bundle of the chiller
- Fouling can also develop into a scale deposit consisting of microbes, carbonates and iron
- Scale may require costly and extensive manpower to remove and bring the heat exchanger back to design operations

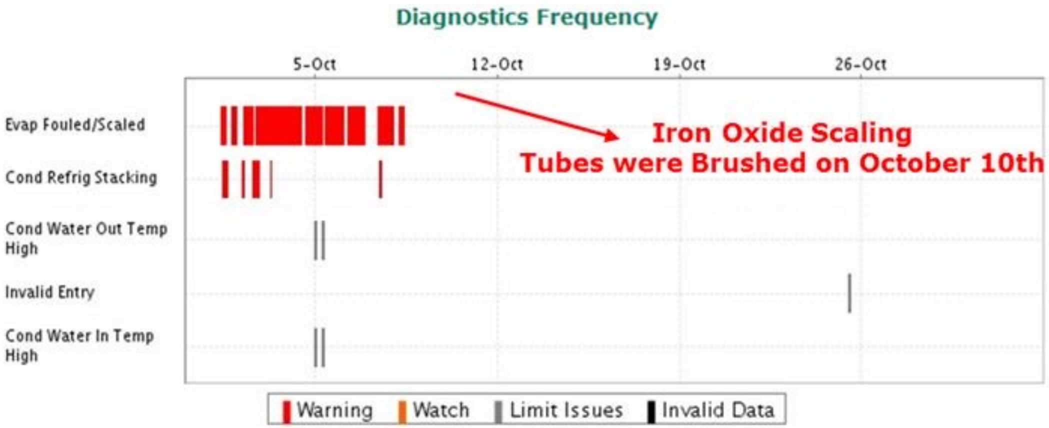
Clean Fouled & Scaled Condenser



Clean Scaled Evaporator



Clean Scaled Evaporator



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30	1 P: 0.686 T: 11831 C: $486.72	2 P: 0.699 T: 13248 C: $555.49	3 P: 0.730 T: 15780 C: $691.38	4 P: 0.727 T: 13838 C: $604.03	5 P: 0.728 T: 15857 C: $692.98	6 P: 0.680 T: 11947 C: $487.36
7 P: 0.688 T: 12312 C: $508.56	8 P: 0.669 T: 4377 C: $175.58	9	10	11	12	13
14	15	16 P: 0.514 T: 7177 C: $221.15	17 P: 0.523 T: 14201 C: $445.52	18 P: 0.496 T: 14948 C: $445.03	19 P: 0.502 T: 16193 C: $487.63	20 P: 0.497 T: 17974 C: $536.44
21 P: 0.535 T: 17404 C: $559.17	22 P: 0.540 T: 19894 C: $644.75	23 P: 0.541 T: 18487 C: $600.34	24 P: 0.539 T: 16894 C: $546.62	25 P: 0.495 T: 20175 C: $599.42	26 P: 0.460 T: 16929 C: $466.83	27 P: 0.466 T: 16479 C: $460.50
28 P: 0.455 T: 14740 C: $402.61	29 P: 0.452 T: 16236 C: $440.08	30 P: 0.449 T: 17855 C: $480.82	31 P: 0.450 T: 18969 C: $512.57	1	2	3

Legend: P = Performance Average kW/Ton | T = Tons | C = Costs kWh

Performance averaging 0.700 kW/ton

Performance averaging 0.500 kW/ton

28% increase in Efficiency

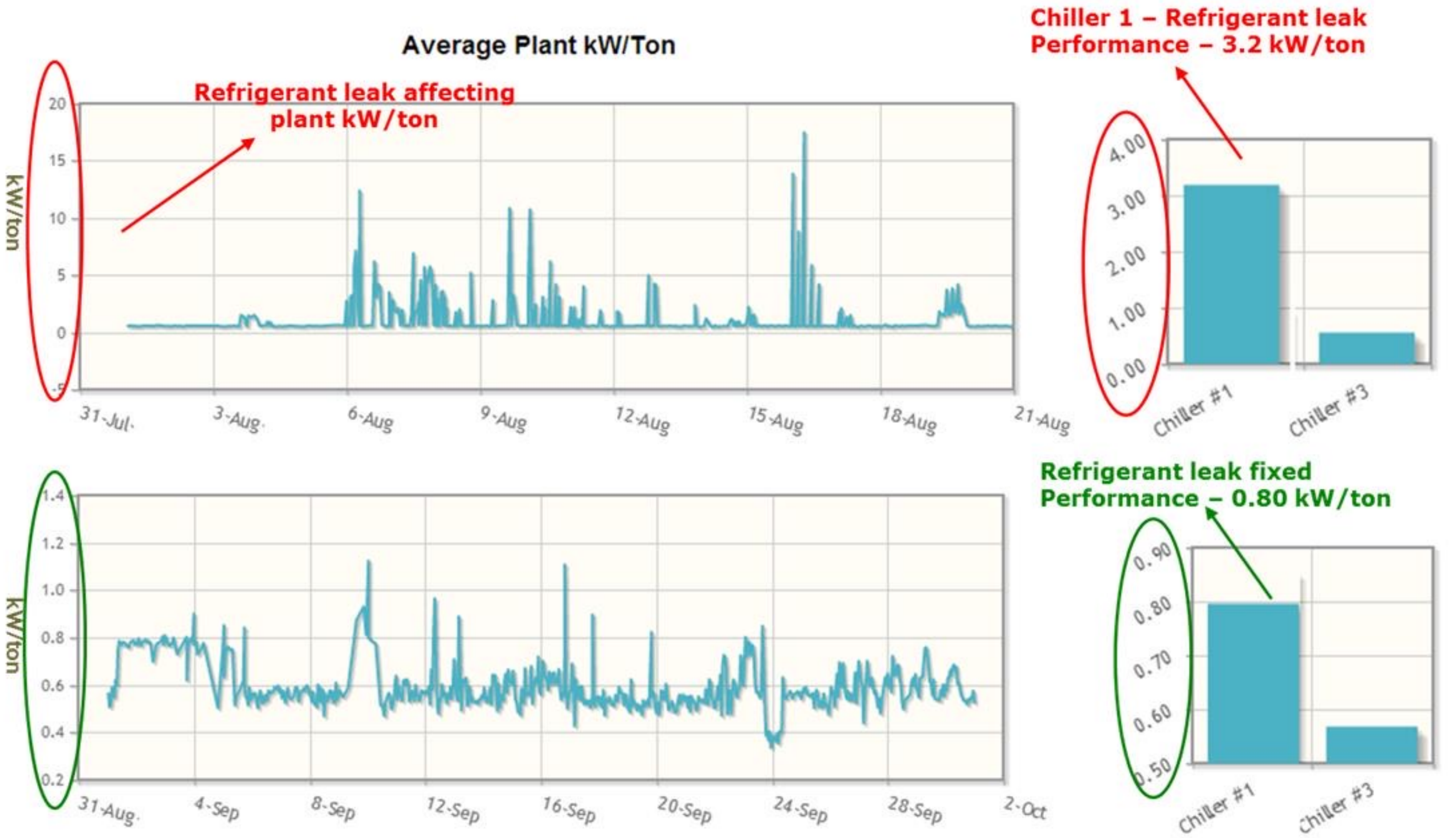
Clean Scaled Evaporator

- A university campus chiller plant unit – 600 RT chiller
  - Base case (Fouled and scaled evaporators) - 0.700 kW/ton
  - After tube brushing – 0.500 kW/ton
  - Efficiency Increase – 28%
- Annual Hours Chiller Operated – 5,000 hrs
- Energy & Cost Savings Analysis
  - Base Case (Fouled and scaled evaporator)
    - Energy Consumption – 2,100,000 kWh
    - Annual Operating Cost - $147,000
  - After tube brushing and cleaning
    - Energy Consumption – 1,500,000 kWh
    - Annual Operating Cost - $105,000
  - Energy Savings – 600,000 kWh
  - Cost Savings - $42,000

Eliminate ALL Refrigerant Leaks

- Every chiller needs a certain amount of refrigerant liquid inventory
  - Is dependent on load also
- If refrigerant charge is lost from the chiller, it can lead to evaporator tubes “not-wetted”
- This results in heat transfer area loss
- Additionally, refrigerant suction superheat increases leading to higher compressor power and reduced chiller capacity!

Eliminate ALL Refrigerant Leaks



Maintain Design Water Flow Rates

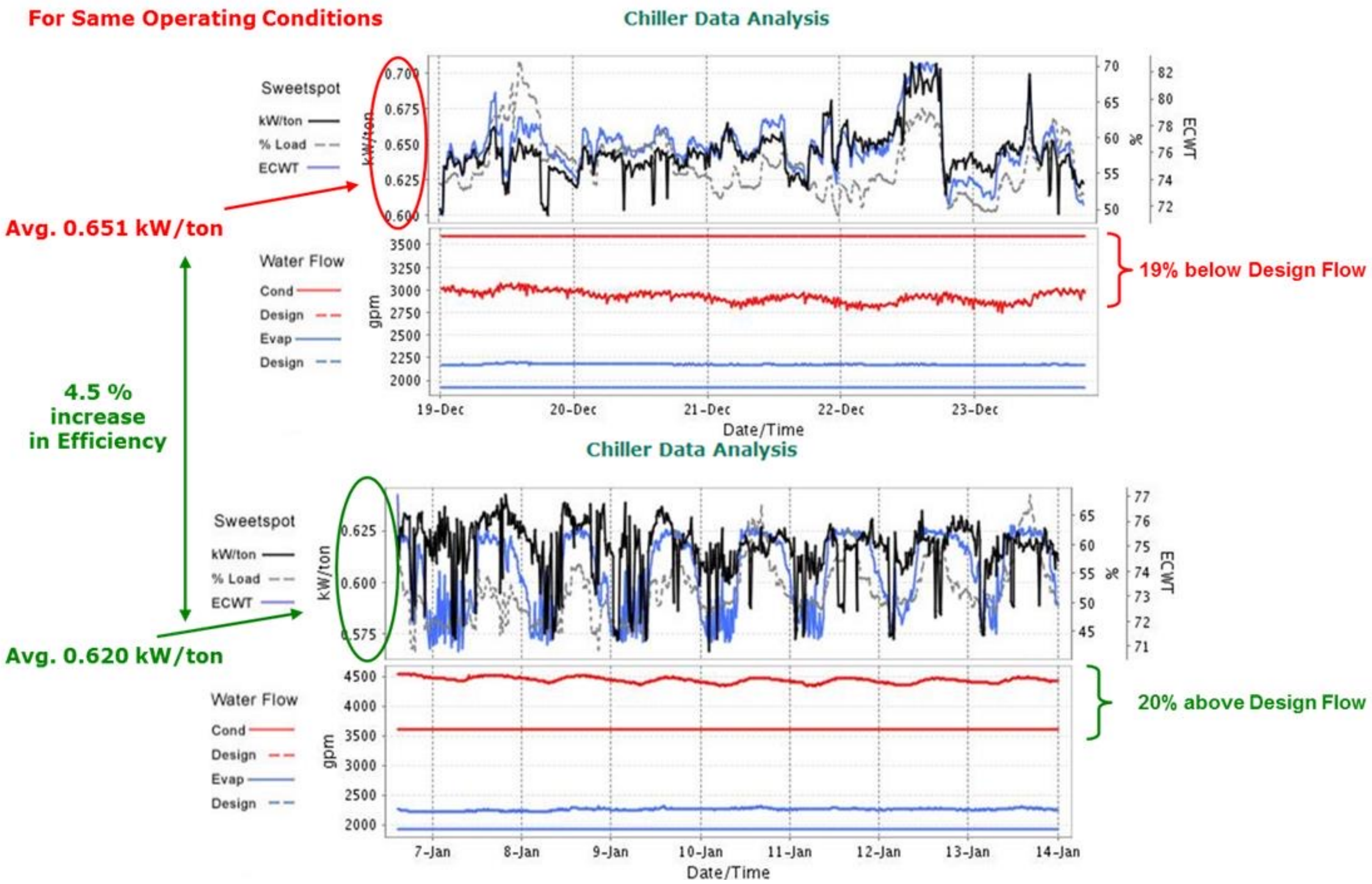
- When the flow is reduced or restricted, it can create undesirable laminar flow (<3 ft/s) through the chiller's heat exchangers, which can also cause a water treatment program to fail

- The tube-side heat transfer coefficient is a function of Reynolds' number (velocity)

- Above design flow (>12 ft/s) through the chiller's heat exchangers may cause vibration wear and erosion / corrosion of the tubes, reducing reliability and life

- Cracks and pitting holes can develop causing leaks in the tube bundle

Maintain Design Water Flow Rates



Remove Non-Condensable Gases and Moisture

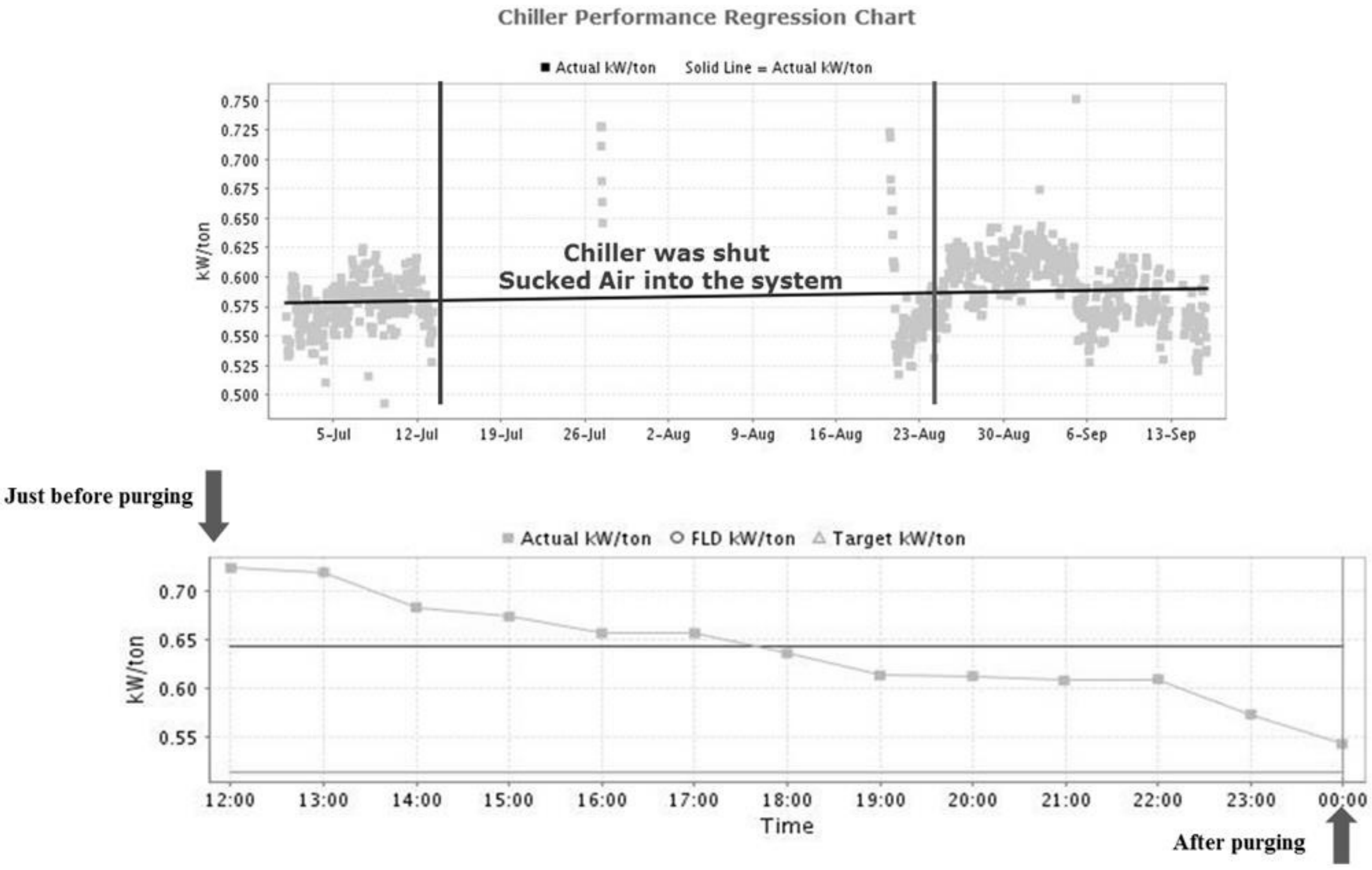
- A Non-Condensable Gas is a gas that isn’t condensed by cooling it
  - Nitrogen
  - Oxygen
  - Carbon dioxide

  AIR

- Leaks cause air and moisture to be pulled in through the evaporator or they are introduced during system charging

- To help minimize the affect of non-condensable gasses in low-pressure chillers, purge units and regular leak detection are required.

Remove Non-Condensable Gases and Moisture



Remove Non-Condensable Gases and Moisture

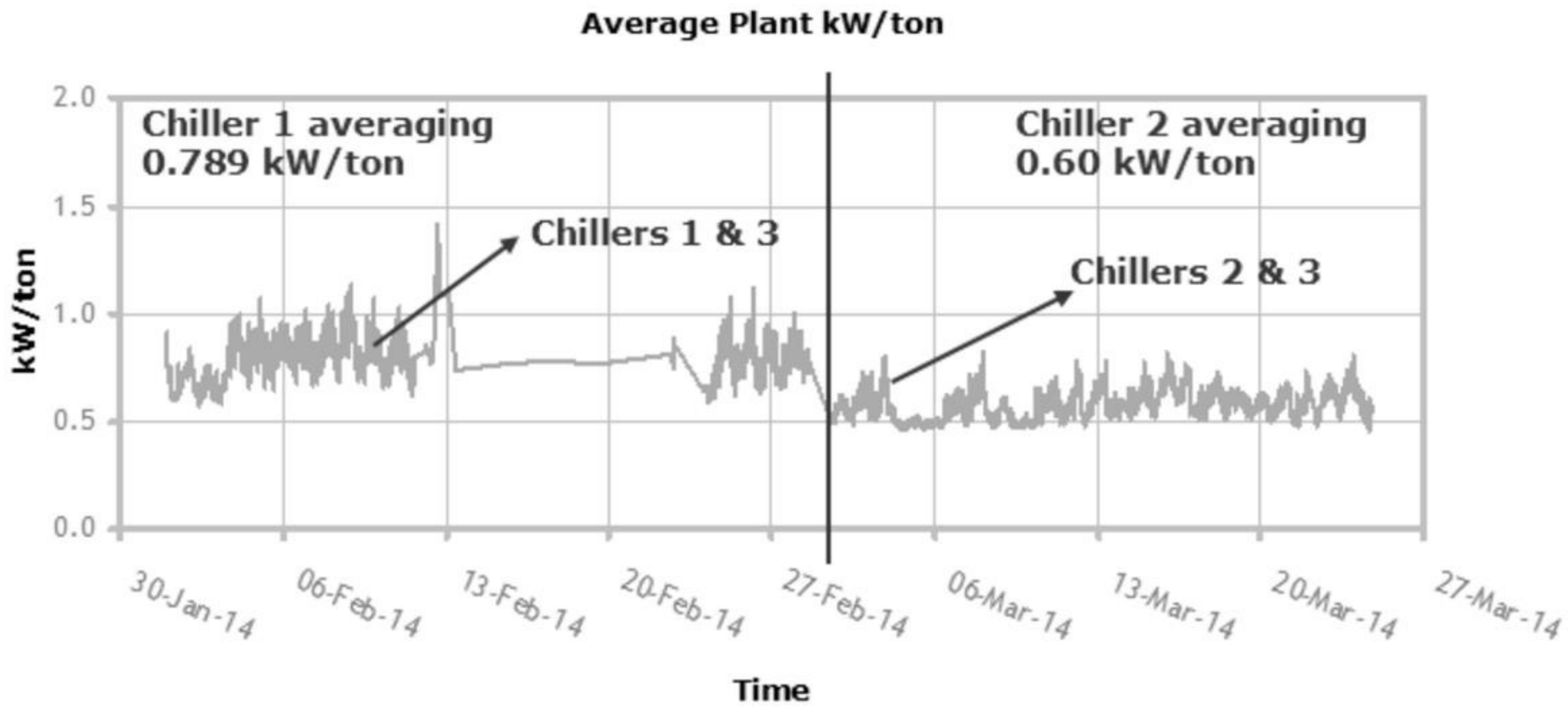
- A county government center building – 570 RT chiller
  - Base case (Without Purging Non-Condensables) - 0.725 kW/ton
  - After proper Purge Operation – 0.550 kW/ton
  - Efficiency Increase – 25%
- Annual Hours Chiller Operated – 4,000 hrs
- Energy & Cost Savings Analysis
  - Base Case (Without Purging NC’s)
    - Energy Consumption – 1,653,000 kWh
    - Annual Operating Cost - $115,710
  - After Purge operation and removal of NC’s
    - Energy Consumption – 1,254,000 kWh
    - Annual Operating Cost - $87,780
  - Energy Savings – 339,000 kWh
  - Cost Savings - $27,900

Sequence Multiple Chillers to Optimize Efficiency

- All chillers will have an optimal operating (best efficiency) point
- When multiple chillers are operating, the overall plant's composite operating curve maybe very different from the individual chiller's curve
- It is important to know how each of the chillers operate under different load conditions
- Pick the best chiller operating combination for the current operating conditions – Dynamic Optimization problem (NOT Easy)

Sequence Multiple Chillers to Optimize Efficiency

- Look for the most efficient chillers to run long hours
- Optimize overall plant performance

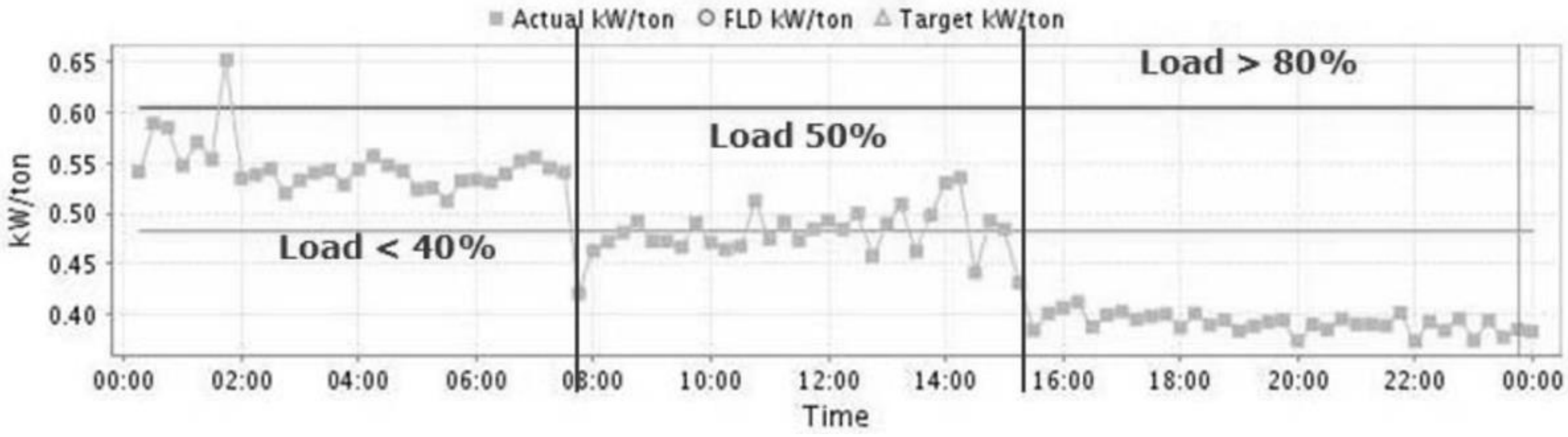


Sequence Multiple Chillers to Optimize Efficiency

- A manufacturing assembly plant – 4 chillers in system
- Operating load – 1,000 RT
  - Base case (Chillers #1 and #3) - 0.789 kW/ton
  - New operating case (Chillers #2 and #3) – 0.600 kW/ton
- Chilled water tons impacted – 320 RT
  - Chiller #1 and #2 are the same tonnage
- Efficiency Increase – 24%
- Annual Hours Chiller Operated – 4,380 hrs
- Energy & Cost Savings Analysis
  - Base Case (Chillers #1 and #3)
    - Energy Consumption – 1,106,000 kWh
    - Annual Operating Cost - $77,500
  - New Operating Case (Chillers #2 and #3)
    - Energy Consumption – 841,000 kWh
    - Annual Operating Cost - $59,900
  - Energy Savings – 265,000 kWh
  - Cost Savings - $18,600

Sequence Multiple Chillers to Optimize Efficiency

- Impact of different types of chillers in a plant
- Relationship between part-load and efficiency



Potential Topics Identified – Low ΔT Syndrome

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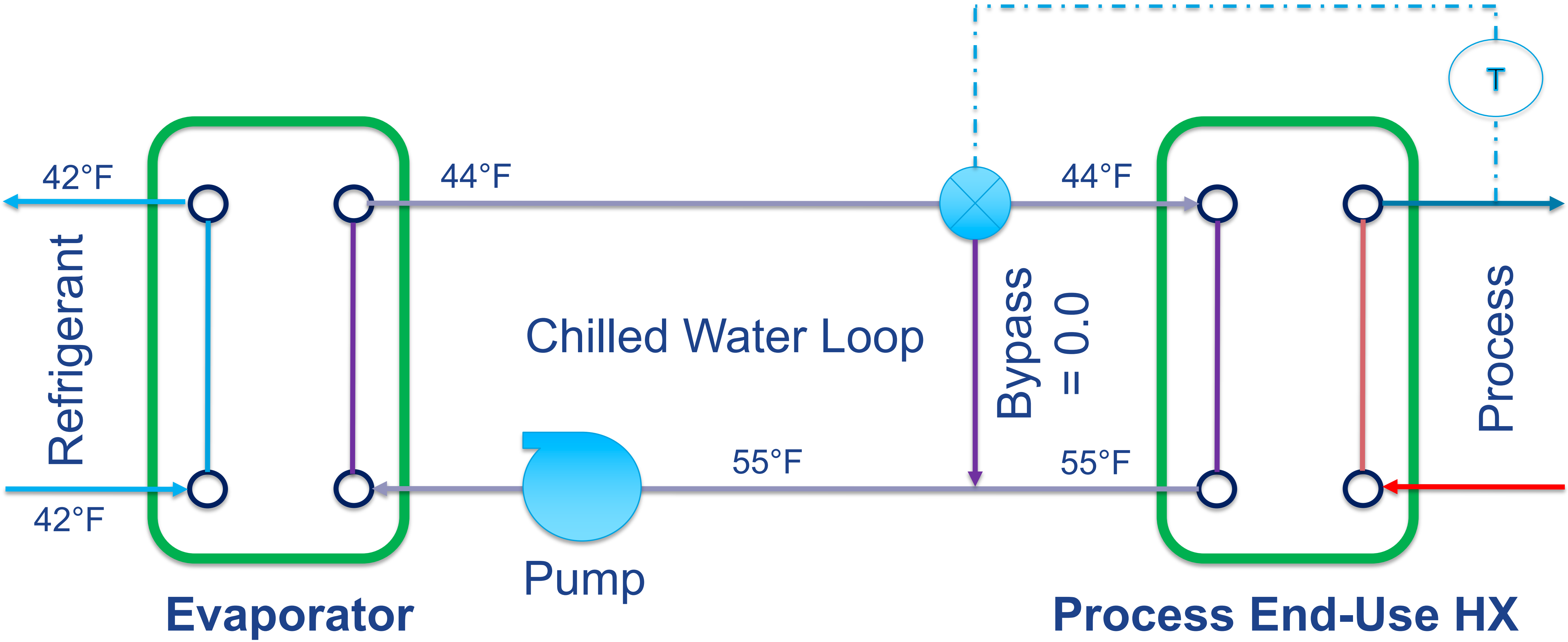
Low ΔT Syndrome

- ΔT is difference between chilled water return and supply temperatures
- It is generally observed in chilled water flow systems having one or more of the following attributes
  - Constant chilled water (primary) flow
  - Fixed chilled water setpoint temperature
  - Low load conditions
- There maybe other system specific conditions that present this scenario
- The main impact of Low ΔT Syndrome is poor overall plant operating efficiency and more chillers needed to meet the load compared to design configuration

Simplified Chilled Water Loop (Constant Speed Pump)

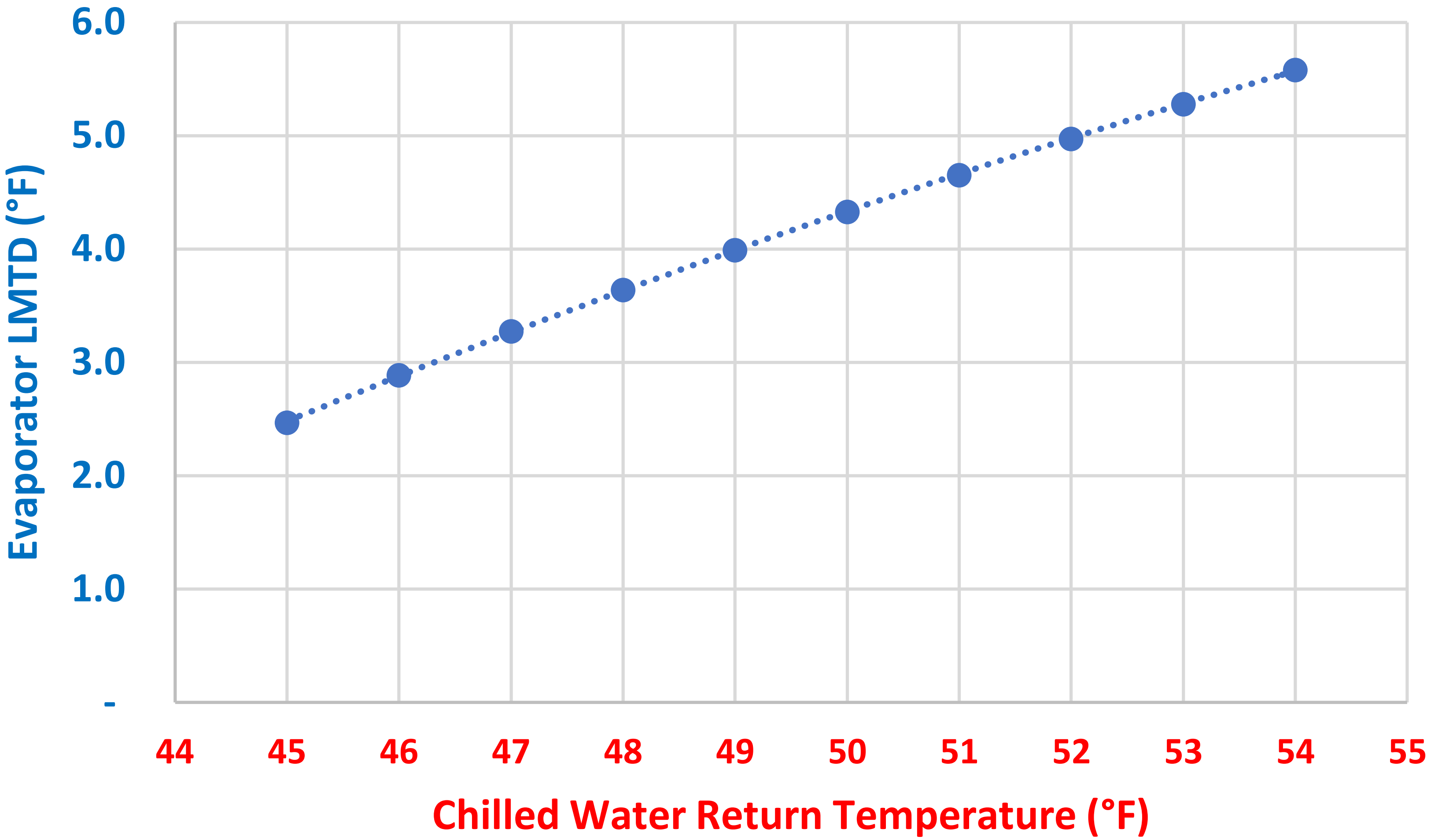


Simplified Chilled Water Loop (Constant Speed Pump)

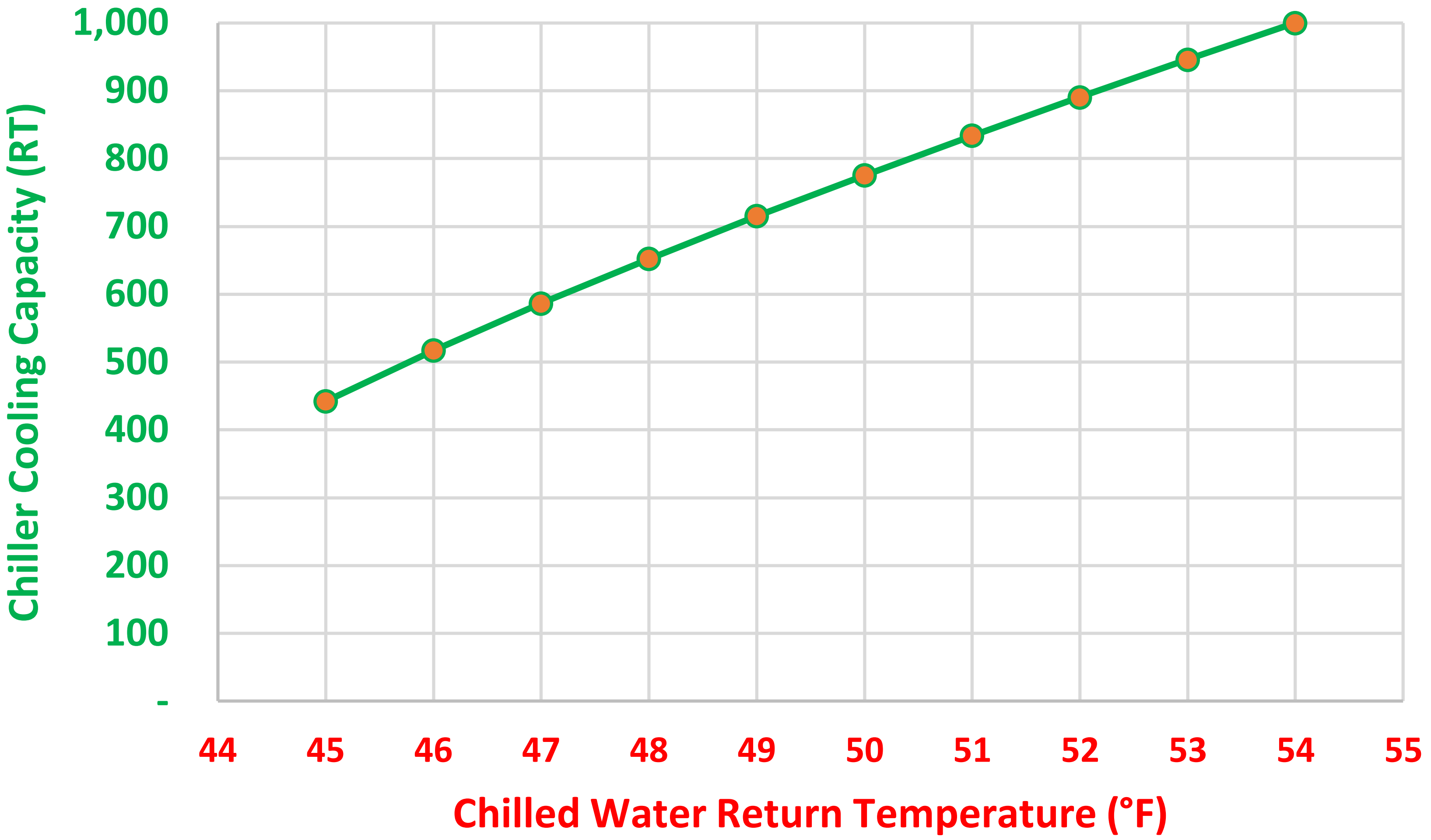
- Normal (Design) Operation
  - Bypass flow = 0
  - Process end use cooling demand = 1000 RT
  - Chilled water flow through HX = 2400 gpm
  - Chilled water supply temperature = 44°F
  - Chilled water return temperature = 54°F
  - Evaporator refrigerant saturation temperature = 42°F
  - LMTD on the evaporator = 5.58°F
  - Qevap = UA*LMTD
  - UAevap = Qevap / LMTD = 179 RT/°F

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

Low ΔT Syndrome



Low ΔT Syndrome



Low ΔT Syndrome – In Practical Situations

- Compressor isentropic efficiency varies with chiller load
- The chiller is unable to meet set-point temperature
  - Evaporator saturation pressure (suction) reduces thereby lowering evaporator Tsat
  - Increase in chiller lift
  - Increase in kW per RT
  - Reach chiller operating limits (low suction pressure or high amps)
  - Additional chiller(s) need to be turned ON
- All chillers operate at low load conditions leading to overall very inefficient operations
- Additional maintenance costs

How to Avoid Low ΔT Syndrome – Some BestPractices

- Increase chilled water setpoint temperature
- Allow for variable chilled water flow to end-user to ensure return temperature provides the LMTD design on the chiller evaporator
- Variable primary chilled water flow may help but limitations exist as regards pressure drop and velocity of chilled water
- Reduce or eliminate bypass flows
- Incorporating a master controller over all the chillers to appropriately stage the chillers for maximizing operating efficiency at varying load conditions

Potential Topics Identified – Heat Recovery Chillers

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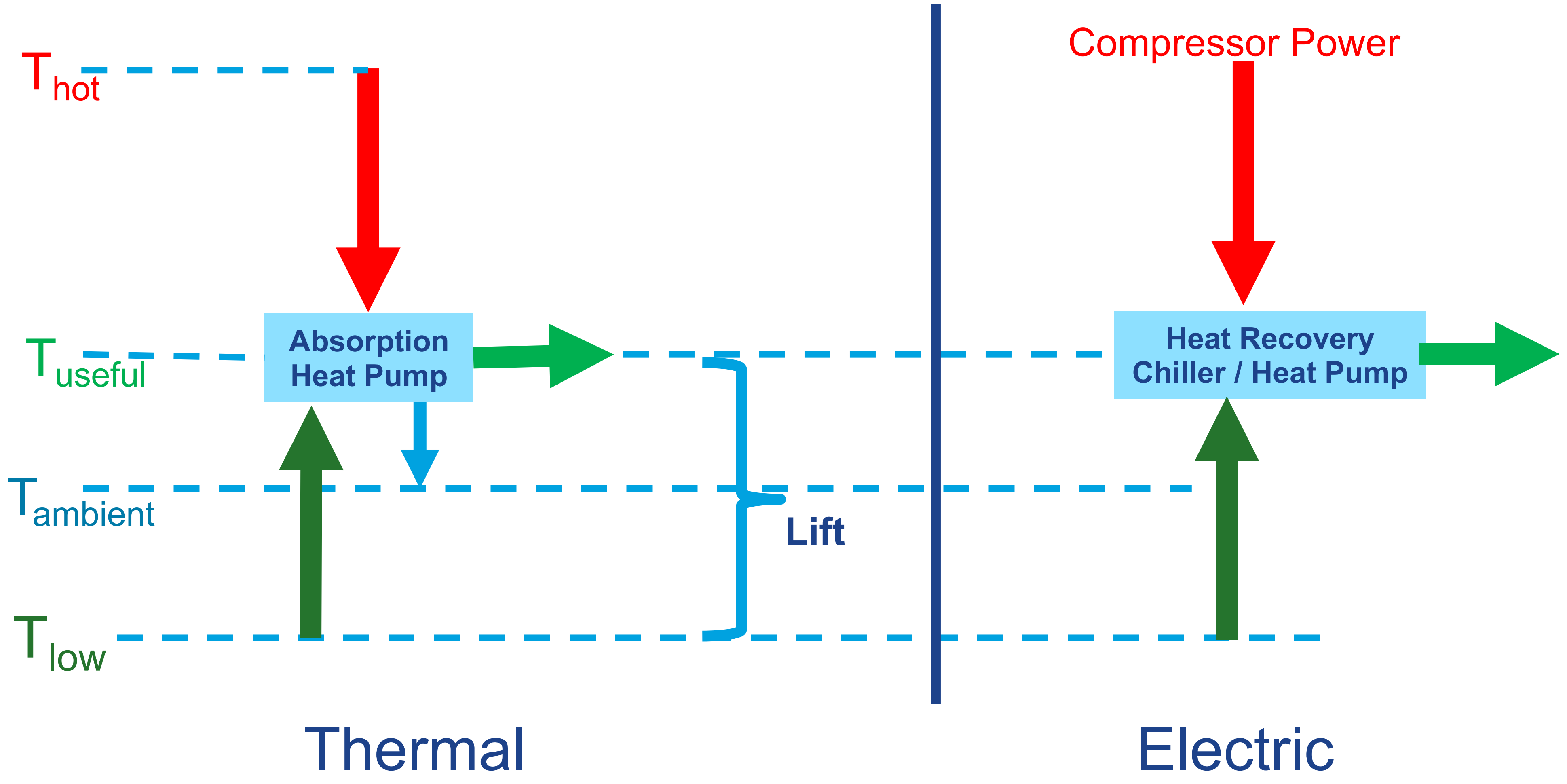
Heat Recovery Chillers (Heat Pump Systems)

- Energy (heat) always flows downhill – in the natural irreversible process
  - 2nd law of thermodynamics dictates the direction of heat flow
- There are systems which can reverse this downhill flow
  - Those systems are heat pumps!
- Heat pumps take energy at a lower temperature and transfer it to a higher temperature
  - Doesn't the chiller or refrigeration system do the same thing?
- On paper and thermodynamically, the cycles are the same – operating conditions are different, equipment may or may not be different and the "useful effect" determines the terminology

Industrial Heat Pumps



Heat Recovery Chillers

- Very common and function like regular chillers
- Main difference – heat rejection temperature and methodology
- Heat rejection temperature
  - Generally, to provide hot water to process or heating facility / domestic usage
  - Range – 120-140°F
  - Lift is significantly higher
- Heat rejection methodology
  - Condenser is water-cooled (closed heating loop)
  - NO cooling tower
- Heat recovery chiller performance is given by COP

Industrial Heat Pumps

- System integration using a PINCH ANALYSIS sheds light on heat sinks and heat sources in an industrial plant
- Process industries have several unit operations that can be overwhelming and it is advisable to breakdown the processes by temperature blocks
- Aligning amount of heat matching with an appropriate lift provides an optimal solution for an industrial heat pump application
- Industrial heat pumps when applied properly can
  - Increase the energy efficiency of the overall industrial operations
  - Reduce greenhouse gas emissions
  - Reduce primary energy use and hence, reduce operating energy costs
- First cost of heat pumps will be higher than conventional systems

Industrial Heat Pumps – Favorable Scenarios

- Continuous operations with relatively steady chilling demand and simultaneous need for low temperature heat in process/facility
- Close geographical proximity of heat source (Cold) and sink (Useful)
- Temperature lifts within equipment availability and material / fluids compatibility
- Large operating hours to allow for quicker paybacks
- Higher fuel and energy costs
- Corporate mandate to decarbonize and reduce carbon footprints

Thank You all for attending the US DOE VINPLT webinar series on Process Cooling (Chilled Water Systems)

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