End to End Chilled Water Optimization
Merck West Point, PA Site

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Site Background

- 500 Acre Mixed Use Manufacturing, Research, and Administration Site
  - 60+ buildings ranging in age from 1950s to 2000s
  - 6.1MM sq ft under roof
- Over 62,000 tons of installed chilled water capacity
  - 7 Plants – 43 chillers – 209 pieces of equipment
  - ~ 50/50 steam turbine and electric chillers
  - > 25 miles of distribution piping
- Unique cooling demands as a result of research and manufacturing
  - Significant variations in cooling demand from summer to winter
Systemic Chilled Water Challenges

Supply
- No Centralized Supply
- Control Schemes
- Cogen Constraints
- Zero Downtime

People
- Lack of understanding
- Disconnect between supply and demand

Demand
- Low dT / high dP
- Complex distribution
- Bypasses
- Simultaneous heating and cooling
- Load variations
End to End Optimization Goals

- Focused “end to end” optimization of chilled water to maximize the existing plant assets and improve building performance
  - Ensure reliable supply and efficient operation
  - Utilize our existing assets smarter = eliminate waste
  - Drive down utility cost and the need for additional capital assets
  - More Available Assets = Master plan flexibility
- Establish a process as a template for the next zone of the chilled water network optimization
End to End Optimization Scope

B8 – 12,000 tons
B8 – 12,000 tons

B45 – 6,500 tons

Remaining Site – 43,500 tons
End to End Optimization - Approach

Supply
- Focus on B8 plant that serves a pilot plant, multiple research and administration buildings
- 12,000 tons – 1 electric, 5 steam turbine chillers

People
- Focus on training and awareness of chilled water system

Demand
- Focus on resolving issues in the piping system and within the user buildings by a variety of methods
End to End Optimization – Key Activities

Supply
- B8 Chiller Plant Optimization Capital Project
- Termis Solution

People
- Pilot Plant Utility Alliance
- Training of Building Managers and Mechanics
- Education for Design Engineers

Demand
- Metering HMI
- BAS Interrogation
- Brute Force Walkdowns
Supply – Optimizing CHW Generation

- Plants use four fuel sources
  - Cogen Electric
  - Cogen Steam
  - Grid Electric
  - Boiler Steam

- Systems with multiple fuel sources but be optimized on common energy units or more preferably $.
  - All upstream system efficiencies and pricing must be understood
Supply – Optimizing CHW Generation

- All optimization is non-proprietary.
- Multivariable equations with adjustable coefficients
  - Number of Pumps
    - Equation Constants
      - A: 3.60746000000
      - B: 0.00014121000
      - C: -0.00856000000
      - D: -0.000000000297
      - E: 0.00002655000
      - F: -0.000000007695
  - CWST
    - Equation Constants
      - A: 15
      - B: 4.5
      - C: 0.78

- Data from PI is run through machine learning and constants can be updated as frequently as desired
Distribution Optimization with Termis

- Macro Distribution Decisions and Planning
- Potential Elimination of Chiller Plant B52
- Interconnection of all plants
- Plant Dispatch
Demand – Optimizing Customer Usage

• Policing our utility customers
  – Equipment overrun caused by low delta T
    • High flow + Low load = Poor COP
    • Isolate unloaded CHW flow
      – 3-way valves, bypasses, OOS equipment

• Big data at our disposal
  – 450 CHW instruments
  – >4,000 calculated tags
    • Tonnage, dT, dP, totalization, cost
  – Need a filter to help locate problems only

• Creation of a new HMI
Demand – Data Driven Investigations

- **Processbook HMI**
  - Holistic view of entire CHW network
  - Visually focused on problems
    - $dT$, $dP$, failed devices, unusual loading
- **Building Automation System (BAS)**
  - CHW control systems within a building
  - Focused on HVAC and process operation
- **Brute Force Walkdowns**
  - “Health” of a building’s CHW system
    - Leaking pneumatics, manual bypasses, clogged strainers
Case Study: B14 Low dT Investigation

900 GPM
1.5 years
Case Study: B14 Low dT Investigation

- **Chilled Water ΔT**
  - ΔT is the temperature difference between supply and return water flowing through a building
    - This temperature is a very good indicator for malfunctioning valves that are not maintaining adequate flow
  - Typically this temperature is ~10°F by design throughout the year
  - B14’s average ΔT was about 4°F!

- **The Culprit: AHU 7**
  - February 2016 AHU 7 was found to be off with its CHW control valve wide open due to a design flaw
    - This valve was allowing roughly 800 GPM through the AHU for 1.5 years or about 600,000,000 gallons
Demand – The Metering Problem

- Building load regressions
  - How has the building behaved in the past?
    - Dependency on weather conditions

- Error detection equation
  \[ PI \ exp = \frac{(0.01681 \times WB^3 - 1.59587 \times WB^2 + 47.20835 \times WB - 451.85376) - (B14 \ tonnage)}{(0.003 \times WB^3 - 0.51214 \times WB^2 + 18.4556 \times WB - 291.935)} + 10 \]
  - Derived from PI historian data using PI Datalink
    - Custom built report automatically creates PI expressions
    - Detects unusual load conditions based on OA wet bulb temp

- Translation to HMI
  - Must be illustrated graphically to have use
  - Gives user clear indication of need to act
Demand – Creating Active Regressions

Building tonnage behavior (PI Datalink)

Tonnage vs. Wet Bulb

- Graph-Generated
- Poly. (UpStdDev)
- Poly. (DownStdDev)
- Regression Eq

Real-time HMI (PI Processbook)
Demand – Error Detection in Action

Differential Pressure flow meter: clogged low-side sensing line
People

• Pilot Plant Utility Alliance
  – Identified as the largest consumer of chilled water (among other utilities)
    • Cross functional team established with strong building leadership to improve efficiency

• Training of Demand Side Owners and Mechanics
  – Supply side driven effort to train the building managers and their mechanics as to the impact of inefficient use of chilled water

• Education For Design Engineers
  – Central utilities involved in early design decisions
    – Established a notification process for using CHW
## End to End Optimization – Results Summary

### B08 Optimization Results (Pre Machine Learning)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Optimization</th>
<th>Post Optimization</th>
<th>Savings</th>
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</thead>
<tbody>
<tr>
<td>Steam Chiller Average lb/Ton</td>
<td>11.10</td>
<td>9.40</td>
<td>lb/Ton</td>
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<tr>
<td>Elec Chiller Average kW/Ton</td>
<td>0.76</td>
<td>0.63</td>
<td>kW/Ton</td>
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<tr>
<td>CHW Pump Average kW/Ton</td>
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<td>0.057</td>
<td>kW/Ton</td>
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<tr>
<td>CW Pump Average kW/Ton</td>
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<td>0.128</td>
<td>kW/Ton</td>
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<tr>
<td>CT Fan Average kW/Ton</td>
<td>0.068</td>
<td>0.054</td>
<td>kW/Ton</td>
</tr>
</tbody>
</table>
Lessons Learned

• GENERAL
  – No silver bullet solution – customizable approach for each situation
    • Complex relationships between supply and demand exist

• SUPPLY
  – Chiller plant optimization without demand side optimization is short sighted
    • Machine learning and network distribution optimization is the current focus

• DEMAND
  – Metering is key!
    • Need to have eyes on the system at all time
    • Being able to quantify low delta T and converting it a meaningful metric
  – Fresh eyes are needed for field walkdowns

• PEOPLE
  – Training and re-training is key
    • Speak demand side language (criticality, risk, compliance)
Next Steps

• SUPPLY
  – Future Optimization
    • Optimizing the balance of the plant CHW systems over the next 3 years
  – Termis calibration and utilization for operational improvements and site master planning

• DEMAND
  – Metering
    • Significant investment in metering of buildings

• PEOPLE
  – Continuing to promote connection between chilled water optimization and overall system reliability
    • Speaking production and research language
Phase 1 - Complete

Phase 2 - Complete

Phase 3 - Underway
Thank You / Questions?