PHASED APPROACH TO CAMPUS CHILLED WATER SYSTEM OPTIMIZATION

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PHASED APPROACH

Campus Optimization Timeline

- 2008: Hinson Plant Completed
- 2010: Long Term Improvement Planning
- 2012: East Plant Upgrades
- 2014: Optimization Phase 1
- 2016: Hinson Plant Upgrades & Optimization Phase 2
- 2018: 4th Campus Plant Completed & Optimization Phase 3
Clemson University

- Founded 1889
- Student Body
  - 19,669 Undergraduate
  - 5,282 Graduate
- 1,400 acres
- 75 Buildings
- 5.2 million Sq-Ft
SYSTEM DESCRIPTION

2008 – Hinson Plant Completed

- Two (2) existing central chiller plants
  - Central Energy Facility
  - East Plant

- Previous campus CHW delta T improvements achieved
  - Building decouplers
  - Flow limiting controls at buildings
  - Variable speed distribution pumping at central plants & buildings

- Completed construction of 3rd campus chiller plant
  - South Hinson Plant
Campus Chilled Water System – 2008

- Three (3) interconnected central chilled water plants totaling 11,400 tons of capacity

- Central Energy Facility
  - Built 1999
  - 5,400 tons

- South Hinson Plant
  - Built 2008
  - 3,600 tons

- East Plant
  - Built 1985
  - 2,400 tons
## SYSTEM DESCRIPTION

### 2008 – Campus Chiller Plant Summary

<table>
<thead>
<tr>
<th></th>
<th>Central Energy Facility</th>
<th>South Hinson Plant</th>
<th>East Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chillers</strong></td>
<td>3x 1,800-ton</td>
<td>3x 1,200-ton</td>
<td>2x 1,200-ton</td>
</tr>
<tr>
<td></td>
<td>Constant Speed</td>
<td>Constant Speed</td>
<td>Constant Speed</td>
</tr>
<tr>
<td><strong>Primary CHW Pumps</strong></td>
<td>3x 60 HP</td>
<td>3x 40 HP</td>
<td>2x 75 HP</td>
</tr>
<tr>
<td></td>
<td>Constant Speed</td>
<td>Constant Speed</td>
<td>Constant Speed</td>
</tr>
<tr>
<td><strong>Secondary CHW Pumps</strong></td>
<td>2x 100 HP; 2x 60 HP</td>
<td>2x 200 HP</td>
<td>2x 125 HP</td>
</tr>
<tr>
<td></td>
<td>Variable Speed</td>
<td>Variable Speed</td>
<td>Variable Speed</td>
</tr>
<tr>
<td><strong>Condenser Water Pumps</strong></td>
<td>2x 250HP</td>
<td>3x 100 HP</td>
<td>2x 100 HP</td>
</tr>
<tr>
<td></td>
<td>Constant Speed</td>
<td>Constant Speed</td>
<td>Variable Speed</td>
</tr>
<tr>
<td><strong>Cooling Towers</strong></td>
<td>Lake Hartwell</td>
<td>3x 50 HP</td>
<td>2x 50 HP</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>Variable Speed</td>
<td>1 Variable / 1 2-speed</td>
</tr>
<tr>
<td><strong>Free Cooling HX</strong></td>
<td>No</td>
<td>Yes / 40 °F</td>
<td>Yes / 40 °F</td>
</tr>
<tr>
<td><strong>CHW Supply Temp</strong></td>
<td>40 °F</td>
<td>40 °F</td>
<td>40 °F</td>
</tr>
<tr>
<td><strong>Condenser Supply Temp</strong></td>
<td>80 °F</td>
<td>85 °F</td>
<td>85 °F</td>
</tr>
<tr>
<td><strong>Distribution System</strong></td>
<td>Decoupled Tertiary Building Pumping</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BAS</strong></td>
<td>Johnson Controls Metasys</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
</tr>
<tr>
<td>2010</td>
</tr>
<tr>
<td>2012</td>
</tr>
<tr>
<td>2014</td>
</tr>
<tr>
<td>2016</td>
</tr>
<tr>
<td>2018</td>
</tr>
</tbody>
</table>
2010 – Defining the Issues & Challenges

- Struggled with best control strategy to achieve BOTH:
  - Peak efficiency
  - System demand and condition requirements

- Chiller & pump sequencing of all 3 plants proved challenging
  - Stage next chiller, pump, tower at 90-95% load
  - Avoid degradation of CHW supply & return temps

- Plant Staging Order – 1) Hinson → 2) CEF → 3) East

- CHW return bottlenecks during low loads
  - Return water reversed direction
  - Required excessive pumping to get water back to Hinson plant
• Read article about new approaches for cooling system efficiency

• Detailed field assessment and analysis performed by Optimum Energy determined significant opportunity for energy savings

• Substantial scope necessary to maximize benefits

• Multi-year phased approach put in place for capital project and operational budgeting
2012 – East Plant Upgrades

- East Chiller Plant Upgrades & Replacements

New chillers with VFDs (2x 1,400T)

Removed Primary CHW Pumps
Optimum Energy / Johnson Controls team awarded RFP for campus wide chilled water optimization project

East Plant chosen as initial optimization project

All-variable speed configuration

Quickest path to achieving savings
2014 – Existing Campus Chilled Water System Efficiency

Average annual chilled water plant efficiency in kW/ton. Input includes: chillers, tower fans, condenser pumps, and chilled water pumping.

(COP) 0.815 kW/ton

<table>
<thead>
<tr>
<th>C.O.P</th>
<th>kW/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2.9)</td>
<td>1.2</td>
</tr>
<tr>
<td>(3.2)</td>
<td>1.1</td>
</tr>
<tr>
<td>(3.5)</td>
<td>1.0</td>
</tr>
<tr>
<td>(3.9)</td>
<td>0.9</td>
</tr>
<tr>
<td>(4.4)</td>
<td>0.8</td>
</tr>
<tr>
<td>(5.0)</td>
<td>0.7</td>
</tr>
<tr>
<td>(5.9)</td>
<td>0.6</td>
</tr>
<tr>
<td>(7.0)</td>
<td>0.5</td>
</tr>
<tr>
<td>(8.8)</td>
<td>0.4</td>
</tr>
<tr>
<td>(11.7)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Baseline

Campus Load Distribution (Pre-Optimization)

- East: 12,962,405
- Hinson: 9,390,342
- CEF: 9,994,838

CEF 31%, East 40%, Hinson 29%
Control

2014 – Optimization System Architecture

Machine Learning Layer
- Predictive Free Cooling
- Dynamic Sequencing
- Chiller Diagnostics

Cloud Layer

Optimization Layer

Real-Time Dynamic Commissioning

Optimization Modules
- OptimumLOOP
- OptimumEDGE
- OptimumAIR
- OptimumHEAT

Sensor & Intelligence Layer

Device Layer
- VFDs
- Chiller Plant
- Boiler Plant
- Pumps & Valves
- Tower Fans
- AHUs
- VAVs / CAVs

2008  2010  2012  2014  2016  2018
2014 – Relational Based Control Optimization (East Plant)

Control System Schematic

- Cooling Tower Fan Speed
- Condenser Pump Speed
- Chiller Vane & Speed
- Chilled Water Pump Speed
- Air Handler Fan Speed

VFD’s

<table>
<thead>
<tr>
<th>Fixed temp</th>
<th>Fixed flow</th>
<th>Fixed Temp Full Load Staging</th>
<th>Variable Flow Fixed Plant DP</th>
<th>Original Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Temp Relational Control</td>
<td>Variable Flow Relational Control</td>
<td>Variable Temp Natural Curve</td>
<td>Variable Flow Variable Remote DP</td>
<td>Optimum Control</td>
</tr>
</tbody>
</table>

Total System Schematic

2008 2010 2012 2014 2016 2018
2016 – Hinson Plant Upgrades & Optimization Phase 2

- South Hinson Chiller Plant Upgrades

- New CDWP VFDs
- Chillers configured for variable flow
- Removed Primary CHW Pumps
Multiple Plants Add Complexity

- Plant Staging
- Chilled Water Pump Control
Control 2016 – Campus Control

CEF Plant
- Backup Plant Only

Hinson Plant
- 2nd Plant
- CHWP Controls to Flow Set Point

East Plant
- Lead Plant
- CHWP Controls to Remote DP
2018 – 4th Campus Plant Completed & Optimization Phase 3

- West Plant Completed & Optimized – 3,000 ton All-Variable Speed
Campus Chilled Water System – 2018
- Four (4) interconnected central chilled water plants totaling 14,800 tons of capacity
  - South Hinson Plant
    - Upgraded 2016
    - 3,600 tons
  - Central Energy Facility
    - Built 1999
    - 5,400 tons
  - East Plant
    - Upgraded 2012
    - 2,800 tons
  - West Plant
    - Built 2018
    - 3,000 tons
2018 – Chiller Plant Optimization Results

Average annual chilled water plant efficiency in kW/ton.
Input includes: chillers, tower fans, condenser pumps, and chilled water pumping.

- **Baseline:**
  - COP: (4.31 COP)
  - kW/ton: 0.815

- **Optimized:**
  - COP: (5.71 COP)
  - kW/ton: 0.616

24% Improvement

Campus Load Distribution (Post-Optimization)

- **East:**
  - 2008: 14,752,714
  - 2018: 17,003,360

- **Hinson:**
  - 2008: 14,752,714
  - 2018: 5,740,198

CEF, 5,740,198
2018 – Chiller Plant Optimization Results

Optimization Savings (2014 Baseline)

- 8,406,000 kWh
- 15,520,000 lbs of CO₂
- 2,593,000 gallons H₂O
- USD $475,000
CONCLUSIONS


- Optimization does not have to be an “All-or-Nothing” approach
- When splitting into short term phases, always remain focused on the long term goals
- Partner with experienced experts that can help guide your path
- Ongoing maintenance & support is critical for long term success

QUESTIONS?