Optimizing Central Chilled Water Systems

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Learning Objectives

1. Gain a better understanding of the operational dynamics of various load and equipment components in chilled water systems
2. Understand opportunities to provide both functional and energy efficient operation of chilled water systems
3. Develop a logical approach to the performance optimization of chilled water systems
Presentation Outline

- Foundation of CHW Plant Operation
- Hydronic System Design
- Chiller Fundamentals
- Optimizing Plant Performance
- Building Interfaces
Sustainability Opportunities

- Optimize energy use
- Protect and conserve water
- Effective use of natural resources
Foundation of Operation

Deliver CHW to all loads under various load conditions as efficiently as possible

- Why look “outside the plant”?  
  - Understand how distribution system will operate  
  - Understand how CHW $\Delta T$ will be effected by dynamics of the systems connected
Understanding Loads & Their Impact on Design

- Overall plant capacity is determined by peak design load
- Cooling load profile describes how the load varies over time is needed to design the plant to stage efficiently
- Cooling load “diversity”
Chilled Water Plant Efficiency

- Operating kW/ton achievable in today’s plants (includes chillers, cooling towers and pumps)
  - 0.4 - 0.7  Excellent
  - 0.7 - 0.85  Good
  - >1.0  Needs Improvement
- We should design plants to measure and provide performance metrics
Discussion on Hydronics
Purpose of Pumping Systems

Move enough water through the piping system at the minimum differential pressure that will satisfy all connected loads.
Understanding Hydronics

• The pumping system will be required to operate under various load conditions

• Variable flow system differential pressures throughout the system will be dynamic

• Hydronic systems should be hydraulically modeled to design or troubleshoot complex systems
Caution

- Excessive pump head can cause systems to not function as designed and waste considerable energy
- Pump Selection
System & Pump Curves

- System Curve
- Combined Pump Curve

![Graph showing System & Pump Curves](image_url)
Hydronic Fundamentals

Variable Flow System Dynamics

- PUMP
- CLOSE LOAD
- REMOTE LOAD

Pressure (PSIG):

- Pump: 45 PSID
- Close Load: 38 PSID
- Remote Load: 12 PSID

Load Dynamics:

0 10 20 30 40 50 60 70

VFD

100 GPM 5 PSID

Load 5 PSID

DP 2 PSID

5 PSID

28 PSID
Hydronic Fundamentals

 Variable Flow System Dynamics

- VFD
- DP
- 100 GPM
- 0 GPM
- 5 PSID
- 38 PSID
- 0 PSID
- BAD SENSOR LOCATION

OPTIMIZING CENTRAL CHILLED WATER SYSTEMS
Hydronic Fundamentals

Variable Flow System Dynamics

- PUMP
  - 100 GPM
  - 5 PSID
  - 19 PSID

- CLOSE LOAD
  - 12 PSID

- REMOTE LOAD
  - 12 PSID
  - 0 GPM
  - 0 PSID

- VFD
  - Load
  - 5 PSID
  - 2 PSID

- DP
  - 12 PSID
## Hydronic Fundamentals

### Variable Flow System Dynamics

<table>
<thead>
<tr>
<th>CONTROL VALVE ΔP AT VARIOUS LOAD CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
</tr>
<tr>
<td>Full Flow</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Branch Flow (gpm)</td>
</tr>
<tr>
<td>Branch ΔP</td>
</tr>
<tr>
<td>Coil ΔP</td>
</tr>
<tr>
<td>Balancing Valve ΔP</td>
</tr>
<tr>
<td>Control Valve ΔP</td>
</tr>
</tbody>
</table>
Hydronic Fundamentals
Variable Flow System Dynamics

Control Valve Characteristics

Impact of Balancing Valve

Control Valve $\Delta P = 3.0$ psig
Coil $\Delta P = 5.0$ psig
Excess $\Delta P = 7.4$ psig

Size BV for Excess $\Delta P$
Balancing Considerations
Variable Flow Systems

• Too large a balancing valve pressure drop affects the performance and flow characteristic of the control valve. Too small a pressure drop affects its flow measurement accuracy as it is closed to balance the system.

- ASHRAE 2011 Applications Handbook, page 38.8
Hydronic Pumping Conclusions

- Coil heat transfer is easier to control in low head (< 50 ft) branches
- Remote, high head loads can be served more efficiently with variable speed series booster pumping
What You Must Know About CHW ΔT
CHW Temperature Differential

- Poor CHW ΔT is the largest contributor to poor CHW plant performance

- To predict ΔT, you must know:
  - Characteristics of connected loads
  - Control valve requirements and limitations
  - Control valve control algorithms and set points
  - Heat exchanger characteristics
### Chilled Water Coil Characteristics

Assumes Constant Load on a Given Coil

<table>
<thead>
<tr>
<th>CHWS Temperature °F</th>
<th>CHW ΔT °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>42</td>
<td>20</td>
</tr>
<tr>
<td>44</td>
<td>15</td>
</tr>
<tr>
<td>46</td>
<td>10</td>
</tr>
<tr>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>
Factors that Degrade $\Delta T$
Assuming Coils are Selected for Desired $\Delta T$

- Higher CHWS temperature
- Lower entering air temperature (economizer)
- Control valve issues
  - 3-way control valves
  - 2-position valves on fan coil units
  - Valves exposed to high $\Delta P$ and can’t shutoff
- Controls not controlling
  - Setpoint cannot be achieved
  - Valves not interlocked to close if unit turns off
\( \Delta T \) Conclusions

- Design, construction and operation errors that cause low \( \Delta T \) can be avoided
- Other causes for low \( \Delta T \) can never be eliminated
- Therefore, system design must accommodate the level of degradation anticipated
Chiller Fundamentals
Understanding Compressor Lift

- Temperature Lift = SCT - SST
  - Saturated Condensing Temperature (SCT) is dependent upon LEAVING condenser water temperature
  - Saturated Suction Temperature (SST) is based off of LEAVING chilled water temperature
Centrifugal Chiller without VFD
1200T Low Pressure

Percent Loaded

KW/ton

25 50 75 100

65 ECWT  75 ECWT  85 ECWT

0.2 0.4 0.6 0.8 1.0
Centrifugal Chiller with VFD
1200T Low Pressure

KW/ton

Percent Loaded

65 ECWT  75 ECWT  85 ECWT
Centrifugal Chiller without VFD

1200T High Pressure

- 65 ECWT
- 75 ECWT
- 85 ECWT

KW/ton vs. Percent Loaded

Optimizing Central Chilled Water Systems
Centrifugal Chiller with VFD

1200T High Pressure

![Graph showing KW/ton vs Percent Loaded for different ECWT configurations: 65 ECWT, 75 ECWT, 85 ECWT.](graph.png)
Centrifugal Chiller Comparison

- 65 ECWT
- 75 ECWT
- 85 ECWT

Constant Speed
Variable Speed

KW/ton

Percent Loaded

High Pressure
Low Pressure
Centrifugal Chiller with VFD
1000T High Pressure, Multiple Oil-Free Compressors

![Graph showing KW/ton vs Percent Loaded for different ECWT settings.](image-url)
Optimizing Plant Performance
Primary-Secondary vs Variable Primary Flow

- Variable primary flow plants can provide advantages over traditional primary-secondary configurations
- Less plant space required for VPF
- VPF is not conducive to CHW Thermal Energy Storage
Primary-Secondary Variable Flow
Part Load Operation - 4500 Ton Plant

1500 tons

1500 tons

OFF

54°F

1500 GPM

6000 GPM

58°F

4500 GPM

42°F

VFD

Load

Load

Load

Load

Load

3.000 Ton Load

1500 tons

58°F

42°F

42°F

42°F

VFD

ΔP

Optimizing Central Chilled Water Systems
Primary-Secondary Variable Flow

Effect of Low CHWR Temperature
Low $\Delta T$ Syndrome

Additional chiller will need to be started to maintain the secondary CHWS temperature setpoint if load increases.

Loss of CHWS temp control

52°F

1500 tons

OFF

1500 tons

42°F

44°F

3000 GPM

6000 GPM

3.000 Ton Load

VFD

9000 GPM

Load

Load

Load

Load

52°F
Variable Primary Flow
Part Load Operation - 4500 Ton Plant

Bypass is not needed if minimum flow through chiller is guaranteed.
Variable Primary Flow
Effect of Low CHWR Temperature

1500 tons
54°F

1500 tons
42°F

OFF

6000 GPM

VFD

CLOSED

Load

Load

Load

Load

3,000 Ton Load

ΔP

Load

Load

Load

Load

FM
Series Arrangement

- In applications with high lift, a series evaporator arrangement can improve overall plant performance
Series versus Parallel
With High Lift Requirement

Parallel-Parallel Arrangement
Series versus Parallel
With High Lift Requirement

30 feet head increase on condenser water would result in 230 KW increase in pump power

Series-Counterflow Arrangement

7% KW Reduction on Chillers
or
220

450 KW Reduction on 10,000 ton Plant
Series versus Parallel
With High Lift Requirement

Series-Parallel Arrangement

7% KW Reduction
or
450 KW Reduction on 10,000 ton Plant
Optimize Heat Rejection

- Oversized cooling towers can decrease approach to lower chiller lift requirements and improve plant KW/ton
- Approximately 1.5% chiller KW reduction per °F lift reduction

*Lowering CWS by from 95°F to 93°F  
  3% Chiller KW Reduction  
  or  
  180 KW Reduction on 10,000 ton Plant*
### CHW ΔT

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHWS Temp</td>
<td>40°F</td>
<td>38°F</td>
</tr>
<tr>
<td>CHWR Temp</td>
<td>56°F</td>
<td>58°F</td>
</tr>
<tr>
<td>CHW ΔT</td>
<td>16°F</td>
<td>20°F</td>
</tr>
<tr>
<td>Plant Size</td>
<td>10,000 tons</td>
<td>10,000 tons</td>
</tr>
<tr>
<td>CHW Flow</td>
<td>15,000 gpm</td>
<td>12,000 gpm</td>
</tr>
<tr>
<td>Head</td>
<td>200 feet head</td>
<td>146 feet head</td>
</tr>
<tr>
<td>Pump KW</td>
<td>667</td>
<td>413</td>
</tr>
</tbody>
</table>

**Increased chiller lift would result in 167 KW increase in chiller power**

38% Pump KW Reduction

87

254 KW Reduction on 10,000 ton Plant
Thermal Energy Storage

- Chilled water thermal storage is a viable means of reducing peak electrical demand and increasing plant efficiency
- Less chiller and cooling tower capacity required
- You may qualify for a Permanent Load Shift incentive
- Keep it simple!
Building Interface Considerations
Building Interface Considerations

Energy Transfer Stations Using Heat Exchangers

- Heat exchangers designed with lower approaches will typically yield higher CHW $\Delta T$
- Always focus on supplying load with proper CHWS temperature
Building Interface Considerations
without Heat Exchangers

• Avoid chilled water tertiary loops
  - Remember cooling coil fundamentals
• A variable speed booster pump should be used to boost differential pressure when needed
Building Interface Considerations
without Heat Exchangers

Building Load
VFD
Boosted Secondary

Tertiary Loop
A Case for Metering

- Most efficiently designed systems are horribly inefficient after several years of operation
- How can we improve operation if we don’t evaluate the efficiency?
- Calibrate regularly
A Case for Commissioning

- Commissioning is a systematic process of assuring that systems perform in accordance with the design intent and owner’s operational needs
- Retro-commissioning
Control Design Issues

• Control strategies should consider impact on complete system
• Aim to continually optimize energy efficiency for entire system
  - Demand control
  - Relational control
• Aim for reliability and “simplicity”
Summary

• Understand parameters that affect chiller plant and overall system performance
• Optimize operation through equipment selection and control sequences to deliver CHW to all loads as efficiently as possible throughout the year
• Commission and monitor plant performance
If you are not prepared to be wrong, you won’t come up with anything original
For More Information

- ASHRAE Self Directed Learning Course “Fundamentals of Water System Design”
- ASHRAE Journal series “Optimizing Chilled Water Plants”
- Hydronic System Design & Operation by E.G. Hansen
Thank You