U S Department of Energy
Recommendations
and
Industrial Chiller Plant Optimization

Presented by:
David Pleasants

2016
U S Department of Energy Recommendations and
Industrial Chiller Plant Optimization

I. DOE Recommendations & Better Plants Program
II. Chilled Water Plant Optimization
III. Impact of Traditional CHW Plant Design
IV. Methods to Optimize Plant kW/ton
V. Optimization Example: Integrated Primary/Secondary
VI. Questions & Answers
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Delivered energy consumption in the industrial sector totaled 24.5 quadrillion Btu in 2013, representing approximately 34% of total U.S. delivered energy consumption.  

Industry spends almost $230 billion on energy each year, but a significant portion of these costs could be avoided through improved energy efficiency.  

2. Better Plants Progress Update 2015, U S Department of Energy
Money saved through energy efficiency/effectiveness can be redirected toward:

- new technologies.
- upgraded equipment.
- additional employees.
- other investments that can help businesses stay competitive.
The industrial sector also accounts for the 

**largest share of the Nation’s greenhouse gas 
emissions by end use sector**—about 34%, 
ahead of the transportation sector at 28%.7

By lowering energy consumption, energy 
efficiency is a key tool for manufacturers to 
reduce their carbon footprint and help meet 
corporate sustainability goals.
Department of Energy is addressing this segment thru a program titled Better Plants.

The U.S. Department of Energy’s (DOE) Better Buildings, Better Plants Program and Challenge (Better Plants) is working with leading manufacturers to improve energy efficiency in the industrial sector.
Today, 157 industrial organizations representing 11.4% of the total U.S. manufacturing energy footprint are Better Plants Partners, a combined energy footprint greater than the state of Tennessee.

Partners have reported estimated cumulative energy savings of roughly 457 trillion British thermal units and $2.4 billion in energy costs.  

3. Better Plants Progress Update 2015, U S Department of Energy
BETTER PLANTS PARTNERS DISTRIBUTION
THERE’S MUCH MORE TO GO!
Industrial Manufacturing Plants Energy Inputs typically follow this sequence:

1. Primary energy input.
2. Central Generation = Central Energy Plant
3. Distribution.
4. Energy conversion, consisting of motors, fans, pumps and heat exchangers.
5. Processes, in which converted energy transforms raw materials and intermediates into final products.
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Presentation today on specific part of Central Energy Plant –

OPTIMIZATION OF

CHILLED WATER PRODUCTION
OPTIMIZATION OF

CHILLED WATER PRODUCTION

• MANY VENDORS TODAY
What is / is NOT CHW System Optimization?

- Optimization is NOT the same as minimizing load (kW.)
  - NOT just raising temperatures.
  - NOT replacing chillers.

Optimization (noun)

- Optimization is holistic operation: maximizing total plant efficiency (kW/ton.)
  - Chillers, chilled water & condenser pumps, cooling towers.
- Design practices, control techniques and operating methods to
  - Continuously minimize energy input while maximizing cooling output.
  - Maximize use of existing infrastructure investment/budget.
Chilled Water System Optimization:
Components/Opportunities

• Hydronic Design
  • Piping
  • Pumping
  • Valves

• Control System
  • Strategy
  • Algorithms
  • Instrumentation

• Operating Methods
  • Operator influence
  • Maintenance problems
  • System specific issues/requirements
Added Benefits of Optimization:

• Improved efficiency / effectiveness → *increases usable % of plant capacity.*

• More tonnage per chiller → **less chillers needed.**

• Less chillers needed → **less pumps, cooling towers needed.**

• Less chillers, pumps, cooling towers needed → **redundancy.**

• Less chillers, pumps, cooling towers needed → **less maintenance.**
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IV. Hydronic Design Impact on Efficiency
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Your Chiller Plant may be Wasting Money

Impact of Traditional Chilled Water System Design, Operation and Energy Efficiency, Effectiveness
Traditional Design Approach: Impact on Efficiency and Effectiveness

- 90% of plants operate at .95 kW per ton or higher!!

<table>
<thead>
<tr>
<th>kW / ton</th>
<th>0.5</th>
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<th>1.5</th>
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</thead>
</table>

- Up to 90% of plants can be improved, but . . .

Most owners don’t acknowledge the problems or don’t know how to fix.
# Evolution of CHW System Design

<table>
<thead>
<tr>
<th>Time</th>
<th>Design</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to 1970</td>
<td>Constant Volume</td>
<td>Constant flow thru evaporator</td>
</tr>
<tr>
<td>Mid 70’s</td>
<td>Primary Secondary</td>
<td>Modulate flow, improve staging</td>
</tr>
<tr>
<td>Mid 90’s:</td>
<td>Variable Primary (VP)</td>
<td>Reduce first cost, more effective</td>
</tr>
<tr>
<td>Today</td>
<td>Convert existing systems to full variable flow</td>
<td>Lower kW / ton, improved flow</td>
</tr>
</tbody>
</table>
Typical CHW System Energy Issues

Primary/Secondary Production System

- Chilled water bypassed through decoupler line and blends with warm return water.

P/S Example
- Design ΔT: 12°
- Design ST: 44°
- Design RT: 56°
- 50% Load
Typical CHW System Energy Issues

Primary/Secondary Production System

- Chilled water bypassed through decoupler line and blends with warm return water.

P/S Example

- Design ΔT: 12°
- Design ST: 44°
- Design RT: 56°
- 50% Load

T_{RETURN}: 50 °F
T_{SUPPLY}: 44 °F
Actual ΔT: 6 °F

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Typical CHW System Energy Issues
Primary/Secondary System with Low ΔT

- Equipment/conditions prevent proper heat transfer.
  - Leaking / low quality control valves
  - Fouled coils (air & water.)
  - Undersized coils
  - Broken thermostats

**P/S Example**
- Design ΔT: 12°
- Design ST: 44°
- Design RT: 56°
- 50% Load

**Actual ΔT:** 4 °F

**T<sub>RETURN</sub>:** 48 °F
**T<sub>SUPPLY</sub>:** 44 °F

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Typical CHW System Energy Issues
Primary/Secondary System with Low $\Delta T$

- Equipment/conditions prevent proper heat transfer.
  - Leaking / low quality control valves
  - Fouled coils (air & water.)
  - Undersized coils
  - Broken thermostats

$\quad 2,000 \text{ gpm} @ 44 \degree F$

$\quad 1,000 \text{ gpm} @ 44 \degree F$

$\quad 1,000 \text{ gpm} @ 52 \degree F$

$\quad \text{T}_{\text{RETURN}} = 48 \degree F$

$\quad \text{T}_{\text{SUPPLY}} = 44 \degree F$

Actual $\Delta T = 4 \degree F$

So what?

P/S Example
- Design $\Delta T: 12\degree$
- Design ST: 44\degree
- Design RT: 56\degree
- 50% Load

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Primary/Secondary System with Low $\Delta T$

Effect of on CHW Pumping Energy

 ✓ CHW flow (gpm/ton) = $24/\Delta T$ (°F)
  - 12 °F Design $\Delta T \Rightarrow 2$ gpm/ton
  - 6 °F Actual $\Delta T \Rightarrow 4$ gpm/ton

 ✓ Pump affinity law: power cubed proportional to flow$^3$.
  - 12 °F Design $\Delta T \Rightarrow 2$ gpm/ton $\Rightarrow n$ kW
  - 6 °F Actual $\Delta T \Rightarrow 4$ gpm/ton $\Rightarrow 8n$ kW

 ✓ $\frac{1}{2} \Delta T \Rightarrow 8 \times$ pump power theoretical
Primary/Secondary System with Low $\Delta T$

Effect on Chiller Loading and Capacity

- Chiller tonnage variables = $\Delta T \times q$ (evaporator flow.)
- Design tonnage requires design $q$ (flow) and $\Delta T$ .... or increased $q$ (flow) to compensate for decreased $\Delta T$.
- Primary loop has constant flow $\Rightarrow$ no compensation.
- Example: actual $\Delta T = 6^\circ = 50\% = 500$ tons
  design $\Delta T = 12^\circ$
- Two chillers required for loads > 500 tons.
- Premature operation of CT fans/pumps.
- Chiller kW/ton increases probably.

P/S Example
- Design $\Delta T$: 12°
- 1,000 ton chiller
Primary/Secondary System with Low $\Delta T$

**Effect on Chiller Loading and Capacity**

<table>
<thead>
<tr>
<th>Load (tons)</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3000</th>
</tr>
</thead>
<tbody>
<tr>
<td># of chiller sets</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
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**Example**
- 3 x 1000 ton chillers
- 12° design / 6° actual

Chiller set includes
- Cooling tower
- CDW pump
- PCHW pump

- Maximum cooling production
  - @ $6^\circ \Delta T$
  - @ $12^\circ \Delta T$
Optimization Opportunity

$3^\circ \Delta T$ Increase Effect on Loading and Capacity

**Example**
- 3 x 1000 ton chillers
- 12° design / 6° actual

<table>
<thead>
<tr>
<th># of chiller sets</th>
<th>Load (tons)</th>
<th>6° $\Delta T$</th>
<th>9° $\Delta T$</th>
<th>12° $\Delta T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>1000</td>
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<td>3</td>
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<td></td>
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Maximum cooling production
@ 6°$\Delta T$
@ 9°$\Delta T$
@ 12°$\Delta T$

Available Capacity Increased

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CHW System Optimization Overview

- **Standard Goal**: make enough cold water on a design day.
- **Energy/Effectiveness Goal**: meet demand at the lowest kW per ton.
- Algorithms should utilize real-time values of variables that affect both operation *and* efficiency: flow, ΔT, DP, kW, etc.
- Automatic, real-time adjustments to optimize kW per ton.
CHW System Optimization Opportunity

Optimized Control of Variable Speed Pumps

- Pump speed regulated to meet demand.
- # of pumps based on minimum pump power.
- *Pump kW Sequence Model* – based on specific hydronic system and affinity laws.
- Adaptive algorithm could auto reset setpoint to minimize pump power.

- Model: xyz 6 x 8
- Head: 85 feet
- Flow: 1700 GPM

ON setpoint for 1st sequence operation using model
ON setpoint for next operation using adaptive algorithm

kW evaluated after each lag pump sequence operation

Pump kW Sequence Model

- Lead pump
- Lead + Lag pump
- ON setpoint for next operation using adaptive algorithm
- ON setpoint for 1st sequence operation using model
- Total kW

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CHW System Optimization Opportunity
Optimized Control vs. “Make-it-work”

From standard specification: “… sequence ON lag pump after lead pump operates at 90% of rated speed for 1 minute.”
Optimization Opportunity

Optimization Control of System DP Setpoint

- Meet load with least volume of water.
- Reset DP setpoint to maximize open coil valve position.
- Now required by ASHRAE 90.1

• Reduces pump speed & system head.
• Pump kW varies with the cube of the speed.
CHW System Optimization Opportunity

Optimized Control of CDW Temperature

- Control Strategy: balance CT fan speed vs. chiller lift.
- Minimizes total kW of chiller and tower.
Optimization Architecture Options:

- Central Plant Control
- Lighting AHU
- BAS Net
  - LON
  - BACnet
  - Modbus
- Workstations
  - Data Collection
  - Operator Interface
- Security
- AHU
- Lighting

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Optimization Architecture Options
Direct Control Engine (multiple vendors)

- PLC physically connected to equipment.
- Real-time adaptive control and optimization of plant.
- Control of the rest of facility and local service remain with control BAS contractor.
BAS writes values to PLC.
PLC performs optimization algorithms and writes status to BAS.
BAS physically controls outputs.
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Typical Optimization Opportunity
Integrated Primary/Secondary Conversion

- Convert system to variable flow.
- Unlock hidden tonnage of existing plant.
- Use existing equipment instead of buying more.
- Avoid major construction and logistical hassles.
- Lower total plant kW per ton.
Putting it All Together: Integrated Primary/Secondary System

• Goal: Minimize bypass flow, maximize efficiency.
• Standard solution: control valve to eliminate bypass flow.
• Valve installation may require shutdown.
• Alternate Solution if not possible:
  • Match primary & secondary loop flow to minimize bypass flow.
    ✓ VFDs on primary pumps.
    ✓ DPTs for evaporator flow (limited straight pipe)
    ✓ Control logic and optimization algorithms.
    ✓ Minimum chiller required flow thru bypass.

Reduce flow & blending, increase $\Delta T$
Central Plant Optimization Projects
Evaluating Opportunities & Expectations

Minimum Production: 2,000,000 ton-hrs (based 12¢/kWh.)
Target Improvement: .10 to .60 kW per ton (20 – 50%).

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- **IP/S or optimized VP with Adaptive Control**
- **VP design / standard control sequence**
- **Standard Primary/Secondary and BAS control sequence**
- **Inefficient Designs / Manual Control / Older Plants / Operational Problems**

-.10 kW/ton
-.10 -.20 kW/ton
-.20 -.40 kW/ton
-.40 -.60 kW/ton

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### Annual Mechanical Cooling Operation
8,760 hours

### Average Load
500 tons

### Annual Cooling Production
4,380,000 ton-hours

### Improvement Factor - based on:
0.2 kW per ton

### Current Hydronic Design:
Primary/Secondary

### Current Control Strategy:
BAS

### Other factors:
existing ΔT = 6-8°F

### Energy Savings
876,000 kWh

### Average Blended Electricity Cost
$0.11 / kWh

### Annual Savings
$96,360

### Required payback period
3 years

### Total Project budget up to
$289,080
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