How to optimize campus chilled water system

Diagnostics and treatment to make your cooling & heating system fit and sustainable.

Presentation to
Healthcare Facilities Management Society of New Jersey
And
US Green Building Council of New Jersey

by
Hemant Mehta, PE

April 18 2013
Introduction

- U.S. buildings consume \textit{400\% more energy} than European buildings

- One Btu of \textit{cooling costs 2.5 times} as much as a Btu of heating

- Chilled water cost is typically 35\% to 40\% of annual fuel and power costs
Causes of System Inefficiency

- Master Planning by young inexperienced engineers
- Poor and/or Signature Design
- Lack of Peer Review
- Fear
- Lack of Training
Let’s discuss how to optimize

- **Process for a project**
  - Master Plan
  - Detail design
  - Construction and Commissioning
  - Operators training
Definition of Master Plan

- master plan *n* (1929): “a plan giving overall guidance”
Master Plan periods

Master plan leading to optimum solution for:

- Near Term (1 - 2 years)
- Short Term (2 - 5 years)
- Long Term (5 - 20+ years)
<table>
<thead>
<tr>
<th>Utilities</th>
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<tbody>
<tr>
<td>High voltage electrical</td>
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<td>Low voltage electrical</td>
<td>Fire water</td>
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<td>Steam/hot water</td>
<td>Domestic water</td>
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<td>Domestic hot water</td>
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<td>Condenser water</td>
<td>Nitrogen</td>
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<td>Fuel oil</td>
<td>Communication &amp; life safety</td>
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<td>Natural gas</td>
<td>Laboratory waste</td>
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<td>Storm water</td>
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</table>
Approach to Master Planning

- On-site team
- Existing systems assessment
- Benchmarking
- Development of load projections
- Infrastructure alternatives
- Optimization modeling
- Life cycle cost analysis
- Near-term, short-term & long-term solutions
- Prioritization of projects
Deviating from normal approach can harvest big savings with

- One of the major tasks of the master plan is the site survey

- Engineers collect data of the existing system for the remaining life of the equipment, utility load etc.
What our experience brings us

• While performing site survey, if the engineering team includes well-experienced team members, they can identify many improvements for your immediate benefit during the survey with *Immediate payback*

• Let’s review some of the case histories
Chiller Review – Excessive Approach Identified

- Inefficient evaporator

Evaporator approach: 47 – 34 = 13°F. (>>2°F)

Chilled Water Delta T: 49 – 47 = 2°F.
Chiller Review – Excessive Approach
Resolved

Sent: Wednesday, June 30, 2010 2:58 PM
To: Barber, Ernest (ehb5d); Martin, Edward (esm3e)
Cc: Hemant Mehta
Subject: UVA Chiller Plant Performance

Ernie/Scott,
Per the attached Plant Graphic snap shot from 6-23-10, we calculated the kW/ton of the chiller to be over 30% greater than the rated energy use. This may be due to:
- low refrigerant charge
- fouled condenser water tubes
- excess oil in the evaporator
- low condenser water flow

Please have Trane take a look at the machine to determine the cause.....

Andre Pearson, PE, LEED AP, CEM
Senior Associate
WM Group Engineers, P.C.
370 Seventh Avenue, Suite 701
New York, NY 10001

From: Martin, Edward (esm3e) [mailto:esm3e@eservices.virginia.edu]
Sent: Friday, October 22, 2010 11:23 AM
To: Andre Pearson; Barber, Ernest (ehb5d)
Cc: Hemant Mehta; Gomez, Cheryl (clg9y)
Subject: RE: UVA Chiller Plant Performance

All,

Additional work on this issue revealed:
- Chiller #1 was 400lbs low on refrigerant charge and;
- Chiller #2 was 100lbs low on refrigerant charge

Bill Kirby informs me that the approach on both machines is now what we should expect.
• While performing site survey we noticed that the last building on the distribution system Amtrak building was imposing additional pressure drop of 23 feet on the whole system of 46,000 gpm

• We could eliminate this pressure drop by simply opening a valve
Chilled water pressure being utilized improperly at buildings…

Valve OPEN

Valve CLOSED

Both Pumps remain shut down
Building connections: Chilled water pressure being utilized improperly at buildings.

Chilled water flowing through non-operating pump.
Pressure drop: 10 psi
Head Loss: 23 ft.

At peak load flow of 46,000 GPM, additional power required for Pumps at Chiller Plant is

\[
46000 \times 23 / (3960 \times 0.8) = 335 \text{ HP or 250.2 kW}
\]

With equivalent 4000 full load hours, annual energy loss is 1,000,883 kWh
At $0.0912/kWh, annual loss is **$91,281**
Uneven Water Flow in Tower

Supply flow was below the allowable range, and there was also clogging in tower fill.

After observations, operators ran towers at higher flow and replaced the fill to fix problems.
Story of Six Different Consultants 2012

World Trade Center

- Central CHW Plant & River Water Systems Design
  - 12,500-ton central chiller plant and distribution system serving multiple buildings
  - River cooling water system and river water pump house restoration

- Six different consultants design interconnections to buildings in different ways…

- Memorial Building consultant installs secondary pumps one story below machine room!
  - We will get paid to correct this and remove the unnecessary pumps!
Return HTHW temp is 270 F. Flue gas after heat recovery should be less than 300 F, but because of mixing of return water and possible issues with heat exchanger, flue gas leaving temperature is 400 F, i.e. 100 degrees of heating is thrown away. Contributes to significant additional fuel costs.
Chillers are running on 30 degree day. Free cooling heat exchangers are not being used. Likely simultaneous heating and cooling in the spaces, as well as lost efficiency by running multiple chillers.
Review of the winter electrical demand indicates heavy winter cooling load.
Cooling tower supply temperature setpoint is not reset from the design temperature, adding 20% to chiller energy use. Estimated energy cost of at least $150,000.
How does delta T and condensing temperature affect Power?

• Compressor Energy (Ce):
  \[ Ce = \dot{m} \Delta P \]

• Refrigerant mass flow:
  \[ \dot{m} = \frac{200}{RE} \]

• RE: Refrigerant effect increases as \( \Delta T \) increases.
• Mass flow rate decreases with increase in \( \Delta T \).
• Hence compressor power decreases with increase in \( \Delta T \).
• Low \( \Delta T \) reduces chiller capacity and more chillers need to be operated.
Rutgers Newark HTHW System—Consequence of master plan performed by an inexperienced engineer

- Rutgers sent RFP to expand the boiler plant for cost of $5 million, based on master plan
- **Master plan must have been prepared by a smart but young engineer with no supervision**
- review of logs revealed operating temperatures were 360°F supply and 300°F return, while system design was 400°F supply and 250°F return temps.
- The poor delta T reduced the operating capacity by 60/150 = 40%
- Conclusion: No new boiler was required.
- Saved over 5 million dollars in investment.
Amgen California Consequence of master plan performed by an inexperienced engineer

- Site had two chillers plants interconnected but operated independently
- Recommended new (third) chilled water plant
- A quick two hours review indicated that there was no need for the third plant
- Savings of over Ten million dollars
System Optimization

Amgen, Inc.
Thousand Oaks, CA

Chilled Water Hydraulic Study and Plant Interconnection

- Creation of computerized hydraulic model of existing chilled water plant and distribution system.
- Identification of bottlenecks in system flow, evaluation of existing capacity for present and future loads.
- Two plants interconnected: Single plant operation for most of the year, second plant used for peaking.

Annual Energy Cost Savings: $500,000
<table>
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<th>Location</th>
<th>HP</th>
<th>Voltage</th>
<th>Kw</th>
<th>Description</th>
<th>Hours per Year</th>
<th>KwH per Year</th>
<th>Price per KwH</th>
<th>Power Factor</th>
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<td>$1,109,488</td>
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</table>

**Experience**

**AMGEN - from Client**

1,325 kW

**Total Annual Savings:** $1,109,488
Identification of Bottlenecks

- Two close valves created the blocked area which increases the increased in pump head.
- Identification and elimination of bottlenecks reduced thousands of dollars in operating cost.
CHW Pump Size Disparity

EE Building Plant Chilled Water Pumps:

140 ft. and 1200 gpm
And
100 ft. and 1200 gpm
The disparate pressures lead to fighting pumps and incorrect supply flows.
Uneven Water Flow in Tower

Weir dams in towers intended to distribute flow over fill. However, dams were installed sideways, making flow more uneven. Contributed to $25,000 of additional chiller energy use costs due to ineffective heat rejection at towers.

RECOMMENDED DISTRIBUTION
MIT site Survey

High System Pressure (no dP reset)

- Excess water pressure gets eaten up by control valves, which throttle down the flow

Supplied vs Real Required Pressure

Measured data for a system with four 1,500 HP pumps
Chiller have balancing valves half closed, eating up pressure drop so that VFD’s are 100% on to try to meet demand pressure. Estimated energy cost of $26,000
Pumps themselves have triple duty balancing valves half closed, eating up pressure drop so that VFD’s have to run at higher pressure to meet demand. Estimated energy cost of $20,000
Pennsylvania State Capitol Building Complex
Harrisburg, PA

**Chilled Water Systems Upgrade**
- Optimization of the system pumping
- Improvement of chilled water system temperature differential
- Conversion of the existing chilled water system from a primary/secondary/tertiary pumping system to an all-primary, variable volume system.

**Annual Projected Energy Savings:** $320,000 per year
**Estimated Implementation Cost:** $825,000
**Simple Payback:** 2.6 years
Our Solution for Immediate Implementation

REMOVE 150 PSIG PRVS (NORTH & SOUTH OFFICE BLOCS)

EXPANSION TANK

PRIMARY PUMPS "RUN-AROUND PUMPS"

CHILLERS

268 FT @ 3333 GPM
350 HP

SECONDARY PUMPS

NC

TEST PUMP (BOOST PUMP)

REMOVE OR REPLACE BUILDING CONTROL VALVE

CHWS

CHWR

WM Group Engineers
Smart solutions that work.
New Pressure Distribution Diagram
Prior to improvements, the chilled water $\Delta T$ was between 6°F and 7°F.
Poor and/or Signature Design:

- Many Engineering firms have one design concept they feel comfortable with.
- So regardless of what is best for the particular project they imposed the so called signature design.
- Many times I can just walk into the plant and name design consultant.
- With no peer review requirements in our industry client pays penalty.
Poor and/or Signature Design:

- Deviation from the normal Master Planning approach with experienced engineers on site survey team provides immediate benefit from improvements that could have been overlooked.
- Almost on all master plan projects we worked on we were able to save more than our engineering fees after the completion of site survey task.
- Discussing improvements with plant operators provides the training and empowers them as well.
Consequence of Signature Design

“Cut and Paste”

• Incompatible additions…

Primary/Secondary Variable

Primary-Constant Speed
**Consequence of signature design**

“Cut and Paste”

- *Oversized pumps* causing valves to throttle at ~60%
- Flow above 4,000 GPM routed through decoupler
Benefit of Peer Review

Duke University Project

- Plant #1 built in 2000
- Final bid docs for Plant #2 were being prepared for construction
- Our client from Yale asked that we review the Duke project
- Our peer review reduced cost by over $2 million
- As money was already funded, used to redesign Plant #1…

Dark blue pipes replaced old primary pumps
Benefit of Peer Review
IBM – Burlington, Vermont
Existing System

Boiler & Chiller Plant

B963

Chiller Plant

B971E

Chiller Plant

B971W
Task

- New Fabrication building
- Substantial growth of the heating and cooling load
- No room for expansion in the existing plants
- Proposed solution: Build a new $42 million plant
Proposed System

Boiler & Chiller Plant

Chiller Plant

Chiller Plant

New

HTHW & Chiller Plant
1. Remove Chillers from Plant B963.
2. Install additional HTHW Boilers for the increased load in Plant B963.
3. Relocate Chillers from Plant B963 and install new Chillers in new Central Chiller Plant to meet increased load.
Out-of-the-Box Solution – Cont’d

4. Results:
   • Central Boiler Plant
   • Central Chiller Plant
   • $12 Million construction cost
   • $30 Million Savings over original concept
   • Over 20% energy cost reduction
Virtual Central Plant Regains 3600 tons of Additional Capacity

NYU Medical Center (2007)

- Plant survey and hydraulic model indicated unnecessary pumps
- 1,300 horsepower of pumps are being removed, including 11 pumps in two brand new chiller plants
- $300,000 implementation cost
- $460,000 annual energy savings
Teach operator to run a system not machines

New York Presbyterian Hospital

- Uptown and Downtown Facilities
- Chilled water system optimization
- ~650 kW peak demand savings
- Saved over $500,000 per year

*Now peak cooling demand is met by 4 chillers rather than 6 chillers prior to modification*
Remove Operators Fear by educating

Constant Chilled Water and Condenser Water Temperatures...

- VFD-equipped chillers can achieve exceptional part-load efficiency if they take advantage of condenser water temperature relief/reset.

![Electric Centrifugal VFD Chiller Efficiency Curves](chart.png)
Remove Operators Fear by educating

Constant Chilled Water and Condenser Water Temperatures...

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<thead>
<tr>
<th>Month</th>
<th>Total ton-hr</th>
<th>Chiller Energy (kWh)</th>
<th>Cooling Tower Energy (kWh)</th>
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<td>Feb</td>
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<tr>
<td>Mar</td>
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<tr>
<td>May</td>
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Remove Managers Fear by educating

Pfizer

• “…changes had always been viewed as too risky… During winter months, one 2,000-ton chiller was supporting only about 300 tons of a very critical manufacturing process load.”

• A hydraulic analysis showed, however, that this plant could safely be shut down, with the load transferred to another plant. The site has operated in this manner for two years now, saving significant amounts of energy.

• “Had WM Group not instilled the confidence in our operators to overcome the fear of failure, the savings would never have been realized.”
  – Bill Geiling, CEM, Manager of Plant Engineering and Maintenance, Chiller Plant Operations.
Results of Lack of Training

OAT: 45

Temp Set: 56
Actual Temp: 58

Mixed Air Temp: 54
Valve leak, Pre heat temp: 59
Overheating of air

Cooling Valve: 42% open to cool air to set temp.
Lack of Training

Training Session Feedback...

I found his whole strategy for operating the west plant and expansion was the most useful because it was laid out sort of like a guide on how to successfully operate our refrigeration plant and it would be nice to have everyone on the same page.

Mr. Hemant delivered quite a bit of technical information in a way that kept our attention through the whole session. It was well prepared and illustrated with his drawings on the whiteboard.

The information that he compiled on both plants was very good. Also knowing that he had an active part in the planning of phase 1 plant added to the knowledge base.
Optimum Design Concepts
Virtual Variable Primary System. Educate client to make the bold move

19,000 tons CHW production capacity interconnected
32 pumps bypassed
23 pumps demolished
$1 million in projected annual energy savings
$662,000 NYSERDA funding
Summary:
How To Keep Your System in Shape

1. Keep **operating logs**; have logs reviewed by an expert
2. Don’t be afraid of change; use **state-of-the-art technology**
3. *Educate managers to remove their fear*
4. Provide **system training** to operators
5. Interchange operating personal between plant and buildings, or “**cross training**”
6. Convert HVAC controls to **process controls**
Summary:
Believe in our education

- We are engineers with power to make our planet Green
- Please stop and think before you jump into design
- Yes, “cut and Paste” design will make little extra money in short term but it is a loss in long term
Thank You

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