IDEA Presentation

SMALL CAMPUS CHILLED WATER PLANT OPTIMIZATION.
Pre-Project Details

• Hawaiian Community College Campus consisting of 16 individual buildings totaling 308,000 sq.ft of conditioned space.

• Prior to upgrade the central plant consisted of three 15yr to 20yr old chillers & constant primary pumping:
  – Carrier Constant Speed Centrifugal 400Ton
  – York Constant Speed Centrifugal 250Ton
  – Carrier Reciprocating Chiller 100Ton.
  – All cooling valves in the buildings 3-way.

• Extremely poor performance as a result of deferred maintenance and age of the equipment. Typical central plant performance in the range of 0.9 kW/Ton and 1.5 kW/Ton.

• College expansion taking place 2011~2012. Expansion requires additional pumping head to service newly attached buildings.
Load Profile – Equipment Selection Challenge

![Graph showing load profile and wet bulb temperature over different plant cooling capacities.](image_url)
Proposed Solution

• Complete central plant upgrade:
  – Two new variable speed chillers.
  – New cooling towers selected for low approach with variable speed drives.
  – Pumping system upgraded to a variable primary/variable secondary system with 175FT of capability.
  – Air handlers and fan coil units all upgraded to 2-way valves.
  – New campus wide automation system.
  – Central plant M&V equipment installed alongside a chiller plant optimization server.
## Proposed Plant Configurations

<table>
<thead>
<tr>
<th>Lowest Cost – Const Speed</th>
<th>Variable Speed Plant</th>
<th>Premium Optimized Plant</th>
</tr>
</thead>
</table>
| • Two equal sized constant speed centrifugal chillers.  
  Full load = 0.57 kW/Ton  
  NLPV = 0.49 kW/Ton | • Two equal sized variable speed centrifugal chillers.  
  Full load = 0.575 kW/Ton  
  NLPV = 0.37 kW/Ton | • Variable speed magnetic bearing & traditional VFD chiller.  
  Full load = 0.58 kW/Ton  
  NLPV = 0.32 kW/Ton |
| • Primary/ Secondary Chilled water pumping with variable speed secondary pumps. | • Primary/ Secondary Chilled water pumping with variable speed secondary pumps. | • Primary/ Secondary Chilled water pumping with variable speed secondary pumps. |
| • Constant speed condenser water pumps. | • Constant speed condenser water pumps. | • Variable speed condenser water pumps. |
| • Two equal sized cooling towers. Tower temperature control 10°F offset from wet bulb. | • Two equal sized cooling towers. Tower temperature control 10°F offset from wet bulb. | • Four cooling towers. Tower temperature control via optimization loop. |
| • Constant chilled water pump differential pressure set point. | • Constant chilled water pump differential pressure set point. | • Variable chilled water pump differential pressure set point based on AHU valve position. |
Performance Comparisons

Annual performance: 0.75 kW/Ton
Annual performance: 0.66 kW/Ton
Annual performance: 0.56 kW/Ton
# Proposed Plant Configurations

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<th>Lowest Cost – Const Speed</th>
<th>Variable Speed Plant</th>
<th>Premium Optimized Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual power consumption:</td>
<td>1,086,855 kWh</td>
<td>960,487 kWh</td>
<td>824,967 kWh</td>
</tr>
<tr>
<td>First cost differential:</td>
<td>$0</td>
<td>$112,500</td>
<td>$333,000</td>
</tr>
<tr>
<td>25yr estimated energy cost:</td>
<td>$12,680,293 USD</td>
<td>$11,205,974 USD</td>
<td>$9,624,865 USD</td>
</tr>
<tr>
<td>SIMPLE ROI:</td>
<td>4.2 YRS Vs Lowest Cost Plant</td>
<td>4.2 YRS Vs Lowest Cost Plant</td>
<td>4.8 YRS Vs Variable speed Plant</td>
</tr>
</tbody>
</table>
Chiller Plant Details

1x 400Ton Mag Bearing Oil Free Chiller

1x 400Ton York Chiller with VFD

4 x Low Approach Towers with large flow range

Variable speed primary, secondary & condenser pumps.

HVAC System optimization/ condition monitoring
Optimization - Strategies Applied

- Variable primary pumping control with reset based on weighted AHU & FCU valve position.

- Optimized cooling tower temperature control that utilizes chiller load data and actual cooling tower off design correlations (merkel equations).

- Optimized sequencing of chillers & pumps using 15min buffered data and actual equipment models.

- Variable speed condenser water control for part load optimization.

- Chilled water reset based on AHU fan power, discharge air set point and percentage cooling valve position.
Variable Primary Pumping $\Delta P$ Reset

- Looks at all the AHU & FCU valves in the system.
- Attempt to maintain valves between 80% and 90% open.
- Moves the system curve continuously!
- Resets must take place at a controlled rate and upper and lower limits need to be set.
- Error conditions such as a stuck open valve need to be detected and handled.
- Should be implemented along side an air side optimization program that includes AHU condition monitoring.
Variable Primary Pumping $\Delta P$ Reset

Maintain at 80% to 90% Via dp reset strategy.
Variable Primary Pumping $\Delta P$ Reset

Reduced head – moving system curve limits the system valve throttling and unnecessary pump work.
Optimized Tower Control

- Optimized approach accepts that tower approach at constant load varies with wet bulb temperature.
- Air's ability to take on heat decreases as wet bulb temperature decreases.
- Use of constant wet bulb offset results in non-optimal control in many instances.
- Wet bulb calculation relies on RH% & dry bulb temperature measurements.
- Commercial grade sensors (capacitive or resistive type) frequently lose calibration or delivered accuracy is less than acceptable error for low approach tower selections.
Optimized Tower Control

- Tower approach and optimal temperature control even more complex when tower water flow is varied.

- Varying L/G ratio’s and the tower performance model is a little understood concept in the common HVAC engineering world.

- Specialized tools required to perform analysis, tower manufactures programs typically only support selections within +/- 20% of design flow.

Only known analysis tools specific to chiller plants:
- Kiltech Inc: 4years to assemble a field tested and validate tool.

- Taylor Engineering coolTools (inhouse program database).
Optimized Tower Control
Finding the Energy Sweet spot

Optimized condenser control effect on system power, 250Ton (880kW)
VFD centrifugal chiller operating at part load
VFD Speed Condenser Pump + VFD Tower

Condenser Water Temp deg. F

kW Input

- Fan
- Pump
- Chiller
Optimized Chiller Sequencing

• When applied to variable speed chillers algorithm needs to accept that chiller performance on a VFD centrifugal varies greatly with lift (CWRT – CHWST). Constantly changing sequence point!

• Compressor operation at higher lift have smaller operating envelopes (compressors run closer to the surge line).

• Optimized sequencing needs to look at load, condenser water flow rate and lift.
Optimized Chiller Sequencing

- CPECS uses a multivariate regression model to predict chiller performance based on:
  - CHWST
  - CWST
  - CWRT
  - Power Input
  - Evaporator and Condenser Approach temperatures.

\[
\text{CAPFT} = a + b \cdot \text{CHWS} + c \cdot \text{CHWS}^2 + d \cdot \text{CWRT} + e \cdot \text{CWRT}^2 + f \cdot \text{CHWS} \cdot \text{CWRT}
\]

\[
\text{EIRFT} = a + b \cdot \text{CHWS} + c \cdot \text{CHWS}^2 + d \cdot \text{CWRT} + e \cdot \text{CWRT}^2 + f \cdot \text{CHWS} \cdot \text{CWRT}
\]

\[
\text{EIRFPLR} = a + b \cdot \text{PLR} + c \cdot \text{PLR}^2 + d \cdot \text{dT} + e \cdot \text{dT}^2 + f \cdot \text{PLR} \cdot \text{dT}
\]
Typical Chiller Performance Model at fixed leaving chilled water temperature

![Graph showing YK VFD Chiller Curves - std conditions](chart.png)
Optimized Chiller Sequencing – Putting the chiller performance models to work

Chiller Sequencing Based on Optimized Set points
2x 255Ton Chillers used in example.

Up to 37% energy wasted by incorrectly staging chillers—this number increases as the number of installed chillers increases.
Optimized Chiller Sequencing

• How does it work?
  – 15min rolling averaged conditions are used in an iterative algorithm that seeks to select the right number of chillers that satisfy the cooling load at the lowest kW input.

• Minimum chiller flows must be taken into account.

• Additional loads such as dedicated primary pumps or condenser water pumps should be included.

• Predicted demand and time of day useful to avoid short cycling
Variable Speed Condenser Water Pumping

• Needs to be carefully analyzed against load profile prior to selection of strategy.
• 30% of surveyed applications should not adopt this.
• Needs to be made in conjunction with tower control optimization strategy.
• 15% error on flow can result in operation less efficient than constant speed pumping.
• Tower minimum flow (fill coverage) needs to be closely adhered to.
• Chiller minimum flow and fouling avoidance needs to be taken into account – know your condenser design tube velocity.
Variable Speed Condenser Water Pumping

- VFD chiller performance changes rapidly with lift!
- Lift is based on leaving condenser water temperature not entering – low condenser water temperature at low flow might get you the same result as full flow with a higher temperature (less fan power).
- Algorithm seeks to achieve lowest:
  \[
  \text{CHILLER KW + TOWER KW + COND PUMP KW}
  \]
Putting it all together

Effect of tower water flow and air flow on system power input (chiller at 60% load with 61°F Twb)

- 100% Flow
- 90% Flow
- 80% Flow
- 70% Flow
- 60% Flow
- 50% Flow
- 40% Flow

% Cond Flow
% Fan Speed

Total kW (chiller+pump+tower)
Optimization – How do we know it works?

• Continuous feedback.
• Displayed target values.
• Visual Real-time Comparison to baseline performance models.

• Reporting with traceable accuracies.

• Beware of the “green washers”
Comparison with actual results
eQuest Vs Actual
APRIL 2013

• Actual operating hours greater than original model.
• Peak load within 4% of model.
• Increase in Ton-hrs proportional to the increase in operating hours.
• Modeled performance Vs actual performance for month of April was 0.55kW/Ton Vs 0.53kW/Ton.
• Actual performance within 4.3% of initial analysis.