Case Studies on Chiller Plant System
Energy-saving Control Strategies
Analysis – Shanghai IFC

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Carrier

turn to the experts

City University of Hong Kong
Energy Pareto

Global

- Transportation 28%
- Industry 32%
- Buildings 40%

Buildings (USA)

- HVAC 40%
- Lightings 16%
- Water heating 10%
- Electronics 9%
- Other 25%

Chiller Plant

- Chillers 70%
- Pumps 24%
- CT & etc 6%

Importance of Part Load Operation

Life Cycle Cost = 

- Power consumption
- Water consumption
- Equipment maintenance (etc.)
- Initial investment
- Residual Values
- Utility Rebate
- Taxes
- Non-monetary costs & benefits

Operating Cost

First cost

Operating Cost Saving

Part Load operation is 95%~99% of whole system operating hours

Gross Margin Increasing
Maintenance & Retrofit

With the System Solution, the system efficiency could be maintained and even increased. The energy consumption could be saved for life cycle.
Location Map - Shanghai ifc
## Shanghai ifc - Section Plan

### Total Area
- Total Area: 399,400 m²

### Total C/P space:
- Total C/P space: 1,900 nos

### Floor Plans

<table>
<thead>
<tr>
<th>Floor Type</th>
<th>Location</th>
<th>Storeys</th>
<th>Area (m²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OFFICE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 storeys</td>
<td>Office Tower</td>
<td>30</td>
<td>82,600</td>
<td></td>
</tr>
<tr>
<td>45 storeys</td>
<td>Office Tower</td>
<td>45</td>
<td>123,000</td>
<td></td>
</tr>
<tr>
<td><strong>RETAIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 storeys</td>
<td>Retail Tower</td>
<td>6</td>
<td>98,500</td>
<td></td>
</tr>
<tr>
<td>23 storeys</td>
<td>Retail Tower</td>
<td>23</td>
<td>47,900</td>
<td></td>
</tr>
<tr>
<td><strong>RITZ CARLTON</strong></td>
<td>Hotel Tower</td>
<td>15</td>
<td>47,400</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HSBC Building</strong></td>
<td>(One ifc)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Two ifc</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Podium &amp; Basement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Services apartments</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
International Retail Mall

- Most prestigious shopping destination in Shanghai
Apple
MTR Tunnel
Grade A Office

• over 2.2 million sq.ft office area
Luxury Hotels

Ritz-Carlton Hotel
• totaling 300 luxury guestrooms
## Equipment List of Chiller Plant

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Type</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chillers</td>
<td>1000 Tons (centrifugal)</td>
<td>3+6</td>
</tr>
<tr>
<td></td>
<td>2850 Tons (centrifugal)</td>
<td></td>
</tr>
<tr>
<td>Primary chilled water pumps</td>
<td>37 KW, 132 KW</td>
<td>3+7</td>
</tr>
<tr>
<td>Secondary chilled water pumps</td>
<td>132 KW, 220 KW (VFD)</td>
<td>7+4</td>
</tr>
<tr>
<td>Condensing water pumps</td>
<td>110 KW, 315 KW</td>
<td>3+7</td>
</tr>
<tr>
<td>Cooling tower fans</td>
<td>55 KW</td>
<td>14 * 3</td>
</tr>
</tbody>
</table>
Plant Configuration

- Cooling towers
- Secondary chilled water pumps
- Primary chilled water pumps
- Condensing water pumps
- Chillers

低座酒店
裙楼及地库
南塔楼低座
南塔楼中座及高座
北塔楼低座
北塔楼中座及高座
### Health Analysis of Chiller Plant System before System Optimizing Retrofit

#### Warning Board of Fault Equipments

Note: fault equipments marked in yellow,

#### Breakdown of Plant Power Consumption

Note: power meter data of a typical summer day.

#### Summary of System Operating Status Analysis

<table>
<thead>
<tr>
<th>No</th>
<th>Existing Problems (before retrofit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The chillers load-unload control and the starting sequence are irrational, resulting in system operating with low efficiency</td>
</tr>
<tr>
<td>2</td>
<td>Fixed chilled water temperature set points, no considering changes of weather and load requirement</td>
</tr>
<tr>
<td>3</td>
<td>Irrational start and stop of cooling tower and fan control, cooling tower did not fully functioning, resulting in a waste of energy</td>
</tr>
<tr>
<td>4</td>
<td>Primary and secondary pump exist the reverse flow phenomena, resulting in inefficient system performance</td>
</tr>
<tr>
<td>5</td>
<td>Secondary chilled water pumps running at fixed speed, resulting in high power consumption even at low load conditions</td>
</tr>
<tr>
<td>6</td>
<td>No suitable energy consumption metrology device, resulting in the operators do not know the energy consumption of each equipments and which equipment has the high-energy consumption</td>
</tr>
</tbody>
</table>
# Optimization Strategies Recommendations

<table>
<thead>
<tr>
<th>No</th>
<th>Optimization Control Strategies (Phase I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling Tower Optimization Control</td>
</tr>
<tr>
<td>2</td>
<td>Chilled Water Supply Temperature Reset</td>
</tr>
<tr>
<td>3</td>
<td>Chiller Start/Stop Sequence control</td>
</tr>
<tr>
<td>4</td>
<td>Secondary Pump Start/Stop Control</td>
</tr>
<tr>
<td>5</td>
<td>Anti-reverse flow control for primary-secondary system</td>
</tr>
<tr>
<td>6</td>
<td>Standard Chiller Monitoring Interface</td>
</tr>
<tr>
<td>7</td>
<td>Energy Consumption Monitoring System</td>
</tr>
<tr>
<td>8</td>
<td>Sensors Failure Diagnose and Calibration Reminder</td>
</tr>
<tr>
<td>9</td>
<td>Data Report, operating logging</td>
</tr>
</tbody>
</table>
Chiller + Cooling Tower Optimization

Standard design
4C Approach

Optimization
3.3C Approach

- Low approach CT leads to lower ECWT
- Lower ECWT improves chiller efficiency
- Further optimize chiller selection for better efficiency

Chiller

- Low approach results lower ECWT
- Cost increase
- Balance BTW cost and performance

Cooling tower
Chiller + Cooling Tower Optimization

![Graph showing Chiller COP vs. Chiller Load (%) for different ECWT temperatures: ECWT=32°C, ECWT=28°C, ECWT=24°C, ECWT=18°C. The COP values decrease as the chiller load decreases for all ECWT temperatures.]
Chiller + Cooling Tower Optimization
Chilled Water Supply Temperature Reset

**Conventional Mode**

Set point at 7°C

1. Outdoor air dew point temp.
2. Building load
3. Dehumidification requirement

If we increase Chilled Water Supply Temperature at partial Load, Chiller performance can be improved.

**Energy-saving Mode**

Set point according to
1. Outdoor air dew point temp.
2. Building load
3. Dehumidification requirement

Less chiller power consumption

Chilled water temp.

<table>
<thead>
<tr>
<th>Chilled Water Temperature Reset Optimization Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Method Select:</td>
</tr>
<tr>
<td>Reset According to Outside Air Temperature</td>
</tr>
<tr>
<td>No Reset</td>
</tr>
<tr>
<td>Reset According to Outside Air Temperature</td>
</tr>
<tr>
<td>Reset According to Building Load</td>
</tr>
</tbody>
</table>
Chiller Control Challenges

Dynamic Changes of Building Loads

Variable Utility Rates

Characteristics of Building Heat Response

Conventional Control Methods

Chiller Performance at Different Conditions

Performance of Different Chillers

Constant settings
Schedules
Sensor feedbacks
Depends on people
(manual control)

No cost function
No degradation
Non-optimized
Non-predictive

……
Chiller Plant Controls
3D optimization

Save money?

Other Targets:
✓ Operation efficiency
✓ Energy efficiency
✓ Comfort
✓ Safety
✓ ……
Control System Structure

Advanced Chiller Plant Control System

- Model Libraries
- User Interface (UI)
- Database
- Interfaces
- Fault / Energy Diagnostics
- Optimization Engine

Real-time data (up), commands (down)

Data Checking

Real-time data (up), commands (down)

Building Automation System (BAS)

- Terminals
- Chillers
- Pumps
- Cooling Towers
- Boilers, etc
Enhancement of Secondary Pump Control

Reset the differential pressure setting of the most critical location with reference to the differential chilled water temperature.
Anti-reverse Flow Control

Primary-Secondary Water System

Phenomena: reverse flow in de-coupler when secondary side demand is greater than chiller load.

Results: mixed chiller water supply temperature is raised higher than chiller supply temperature, resulting in energy waste.

Coordination control of flow and temperature is a key problem to be resolved.
Performance Visualization & Energy Management

Chiller standard monitoring interface

Energy consumption monitoring system

Power meter monitoring interface

Optimization suggestion interface
Optimization suggestion interface
Sensors Failure Diagnose and Calibration Reminder

Functions:
✓ Diagnose all main sensors running status;
✓ Remind operators to calibration sensors according to each sensors calibration time.

Control sensor problems can increase energy waste

Possible problems:
• Un-calibrated sensor
• Incorrectly placed sensor
• Faulty sensor
• Mistakes in control setting

Examples of critical control sensors:
• Chilled water supply temperature sensor
• Return air temperature sensor
• Carbon dioxide sensor
Data Report and Operation Logging

Functions:
✓ Record history data which can be used for system energy analysis and chart plotting (Offline Data Analysis Tool);
✓ Record operators’ actions which can be used for cause checking and performance feedback.
Chiller Plant Efficiency

**Definition**

Chiller Plant Efficiency = \( \frac{\text{Input electricity (kW)}}{\text{Output Cooling (ton)}} \) = ikW/ton

Example:

\[ \frac{120 \text{ (kW)}}{100 \text{ (ton)}} = 1.20 \text{ ikW/ton} \]

Building Cooling Demands

Chiller Plant System

**Output**

Cooling in refrigeration ton (ton)

**Input**

Electricity supply (kW)

Our objective is to reduce this.
Chiller Plant Efficiency
Benchmarks (Source: ASHRAE Journal)

EXCELLENT  GOOD  FAIR  NEEDS IMPROVEMENT

kW/ton  0.5  0.6  0.7  0.8  0.9  1.0  1.1  1.2
C.O.P.  (7.0)  (5.9)  (5.0)  (4.4)  (3.9)  (3.5)  (3.2)  (2.9)

AVERAGE ANNUAL CHILLER PLANT EFFICIENCY IN KW/TON (C.O.P.)
(Input energy includes chillers, condenser pumps, tower fans and chilled water pumping)

Based on electrically driven centrifugal chiller plants in comfort conditioning applications with
42F (5.6C) nominal chilled water supply temperature and open cooling towers sized for 85F
(29.4C) maximum entering condenser water temperature and 20% excess capacity.
Local Climate adjustment for North American climates is +/- 0.05 kW/ton

Building Cooling Load Prediction

• Traditional modeling approach using predefined profiles of weather, occupancy, operating schedules, etc. to predict the building cooling load

• They are unable to respond directly to the current weather and building conditions

• Real time building cooling load is impossible by these approaches.
Real time Cooling Load Prediction

- Artificial neural network (ANN) model learns the nonlinear correlation between the weather and building conditions and the building cooling load through the historical data of the building systems.

- The prediction can be improved along with time when more and more data of the building systems is fed into the artificial neural network model.

Kwok SSK, Yuen RKK, Lee EWM (2011) An intelligent approach to assessing the effect of building occupancy on building cooling load prediction, Building and Environment 46(8), 1681-1690.
Ahead Prediction of Cooling Load

• Ahead prediction can be used for building energy saving (e.g. chiller sequencing, chiller on/off, etc.)

• The application of real-time cooling load prediction can be applied to system fault diagnosis.

• When the actual cooling load is largely deviated from the predicted cooling load, it may indicates the abnormality of the building systems.
General ANN Model

- Real time cooling load
- Temperature
- Relative Humidity
- Solar irradiance
- Occupancy Rate of Office Towers
- Occupancy Rate of Shopping Mall
- Landlord power consumption rate
- Tenants power consumption rate
Weather Stations

Pyranometer for measurement of solar irradiance
Measurement of Occupancy Rate

Turnstiles at Office Lift Lobbies

People Counting System at Shopping Mall
Network Configuration for Cooling Load Prediction
Ahead Prediction of Cooling Load

Date in March 2013

Cooling Load (Tons)
Key Factors for Energy Saving of HVAC

- Production
- Distribution
- Prediction
- Demand
- Maintenance
Conclusion

• Adaptive control in comparison with traditional fixed logic chiller plant control
• Advanced intelligent technique in predicting cooling load
• No modification on mechanical parts
• Easily applied for existing projects
THANK YOU!

Inspired