Optimized System for Your Bottom Line

Trane Training Class
1 Dec, 2017
Total Cost of Ownership
Setting your system for great payback

Where is money spent over a 30 year lifetime?

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Cost</td>
<td>4.9%</td>
</tr>
<tr>
<td>Service</td>
<td>6.6%</td>
</tr>
<tr>
<td>Power</td>
<td>88.5%</td>
</tr>
</tbody>
</table>

A Balanced Approach, with a Focus on Efficiency
### Chiller Plant Efficiency

**Note:** Based on electrically driven centrifugal chiller plants in comfort conditioning application with 5.6°C nominal chilled water supply temperature and open cooling towers sized for 29.4°C maximum entering condenser water temperature and 20% excess capacity.

<table>
<thead>
<tr>
<th>Category</th>
<th>COP</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Technology All-Variable Speed Chiller Plants</td>
<td>7.0</td>
<td>EXCELLENT</td>
</tr>
<tr>
<td>High-efficiency Optimized Chiller Plants</td>
<td>5.9</td>
<td>GOOD</td>
</tr>
<tr>
<td>Conventional Code Based Chiller Plants</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Older Chiller Plants</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Chiller Plants with Correctable Design or Operational Problems</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

**Average Annual Chiller Plant Efficiency in kW/ton (C.O.P.)**

*Input energy includes chillers, condenser pumps, tower fans and chilled water pumping.*

<table>
<thead>
<tr>
<th>kW/ton</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
</tr>
</thead>
</table>
Chiller Plant Efficiency

Optimal Plant Efficiency = Guaranteed chiller performance + System application & control strategy
Chiller Plant Efficiency

- Major Equipment for water-cooled chiller plant
  - Chiller
  - Pump
  - Cooling Tower
Chiller Performance

History of Chiller Efficiency

ASHRAE Standard 90.1

Chiller efficiency, COP


Centrifugal >600 tons
Screw 150-300 tons
Scroll <100 tons
Reciprocating <150 tons

“best” available
### Chiller Performance

**BEEO Requirement (2015)**

#### Table 6.12b: Minimum Coefficient of Performance for Chiller at Full Load

<table>
<thead>
<tr>
<th>Type of compressor</th>
<th>Reciprocating</th>
<th>Scroll</th>
<th>Screw</th>
<th>VSD Screw</th>
<th>Centrifugal</th>
<th>VSD Centrifugal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air-cooled</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity Range (kW)</td>
<td>Below 400 kW</td>
<td>Below 400 kW &amp; above</td>
<td>Below 500 kW &amp; above</td>
<td>Below 500 kW</td>
<td>500 kW &amp; above</td>
<td>All Ratings</td>
</tr>
<tr>
<td>Minimum COP at cooling (free air flow$^{(a)}$)</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8 (3.6)$^{(a)}$</td>
<td>2.9 (3.7)$^{(a)}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.9 (3.7)$^{(a)}$</td>
<td>3.1 (4.0)$^{(a)}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of compressor</th>
<th>Reciprocating / Scroll</th>
<th>Screw</th>
<th>VSD Screw</th>
<th>Centrifugal</th>
<th>1000 kW to 3000 kW</th>
<th>Above 3000 kW</th>
<th>1000 kW to 3000 kW</th>
<th>Above 3000 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water-cooled</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity Range (kW)</td>
<td>Below 500 kW</td>
<td>500 to 1000 kW</td>
<td>Above 1000 kW</td>
<td>Below 500 kW</td>
<td>500 to 1000 kW</td>
<td>Above 1000 kW</td>
<td>Below 1000 kW</td>
<td>1000 kW to 3000 kW</td>
</tr>
<tr>
<td>Minimum COP (Cooling)</td>
<td>4.2</td>
<td>4.7</td>
<td>5.3</td>
<td>4.8</td>
<td>5.0</td>
<td>5.5</td>
<td>4.7 (6.1)$^{(a)}$</td>
<td>4.9 (6.3)$^{(a)}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.2 (6.7)$^{(a)}$</td>
<td>5.6$^{(a)}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Comprehensive review to be conducted in 2018, 2021 and 2024 respectively.
### Chiller Performance

#### Centrifugal Chiller

<table>
<thead>
<tr>
<th>Type of Refrigerant</th>
<th>R-123</th>
<th>R-134a</th>
<th>R-134a</th>
<th>R-134a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Refrigerant Efficiency</td>
<td>0.433 kW/ton (8.1 COP)</td>
<td>0.460 kW/ton (7.6 COP)</td>
<td>0.460 kW/ton (7.6 COP)</td>
<td>0.460 kW/ton (7.6 COP)</td>
</tr>
<tr>
<td>Centrifugal Chiller Cycle Efficiency</td>
<td>0.388 kW/ton (9.1 COP)</td>
<td>0.415 kW/ton (8.5 COP)</td>
<td>0.415 kW/ton (8.5 COP)</td>
<td>0.415 kW/ton (8.5 COP)</td>
</tr>
<tr>
<td>Drive Train Efficiency</td>
<td>100%</td>
<td>98.1%</td>
<td>97.9%</td>
<td>100%</td>
</tr>
<tr>
<td>Compressor Efficiency</td>
<td>83.3%</td>
<td>80.4%</td>
<td>81.8%</td>
<td>78.8%</td>
</tr>
<tr>
<td>Motor Efficiency</td>
<td>95.5%</td>
<td>95.0%</td>
<td>95.0%</td>
<td>97.0%</td>
</tr>
<tr>
<td>Chiller Efficiency</td>
<td>0.487 kW/ton (7.2 COP)</td>
<td>0.554 kW/ton (6.3 COP)</td>
<td>0.545 kW/ton (6.4 COP)</td>
<td>0.543 kW/ton (6.5 COP)</td>
</tr>
</tbody>
</table>
AHRI Definition of Integrated Part Load Value (IPLV/NPLV)

\[
\text{IPLV} = \frac{1\%}{A} + \frac{42\%}{B} + \frac{45\%}{C} + \frac{12\%}{D}
\]

Temperatures: Expected Entering Tower Water
AHRI Conditions: Chilled Water: 54°/44°F (12.2°/6.6°C)
Condenser Water: 3 GPM/Ton (0.054 L/S/kW)

- **A** = kW/Ton @ 29.4°C (85°F) @ 100% Load
- **B** = kW/Ton @ 23.9°C (75°F) @ 75% Load
- **C** = kW/Ton @ 18.3°C (65°F) @ 50% Load
- **D** = kW/Ton @ 18.3°C (65°F) @ 25% Load

Real World Chillers Operate at Real World Conditions
Chiller Performance
Efficiency Comparison – Index Rating vs. Real-World

Hong Kong (Two Chiller Plant)
Custom Analysis versus Generic NPLV Estimates

Where Do The Chillers in Your Plant Run?
Always, Always Remember … The Meter is On The BUILDING
Compliant calculation methodologies

Chiller Plant Efficiency

Pump Performance

• Hydraulic Power $P_{h(kW)} = q \rho \ g \ h / (3.6 \times 10^6)$
  - $q$ = flow capacity (m$^3$/h)
  - $\rho$ = density of fluid (kg/m$^3$)
  - $g$ = gravity (9.81 m/s$^2$)
  - $h$ = pump head (m)

• Pump Head is the total resistance that a pump must overcome
  - Static Head
  - Friction Head
  - Pressure Head
  - Velocity Head
Pump Performance

Pump Head Calculation

- Never oversize pump
- Select pump duty point for best efficiency
Pump Performance
Reduce Friction Loss
BEC 2015 Chapter 6 Energy Efficiency Requirements for Air-conditioning Installation

6.9 Frictional Loss of Water Piping System

6.9.1 Water piping with diameter 50 mm or below should be sized for water flow velocity not exceeding 1.2 m/s.

6.9.2 Water piping with diameter larger than 50 mm should be sized for frictional loss not exceeding 400 Pa/m and –
   (a) water flow velocity not exceeding 2.5 m/s for system that operates under non-variable flow condition; or
   (b) water flow velocity not exceeding 3.0 m/s for system that operates under variable flow condition.

- Pressure drop per unit length
  - 2.5m/s @ 200mm pipe
  - 240 Pa/m with 89.7kg/s

CIBSE Guide C4
Flow of Fluids in Pipes and Ducts
Pump Performance

Pump Head Calculation

- Friction Losses in Elbow (equiv. length)
  - 18 Feet (90° Elbow)
- Pressure drop
  \[
  \frac{18}{3.3} \times 240 \text{ Pa/m} = 1.309 \text{kPa}
  \]
- Pump Power Consumption
  \[
  1.309 \times 89.7 / 0.7 / 0.93 / 1,000 = 0.18 \text{ kW}
  \]
- Annual Operation Cost
  \[
  0.18 \times 12 \times 365 \times 1.2 = \text{HKD946}
  \]
Pump Performance
Pump Head Calculation

- Friction Losses in Elbow (equiv. length)
  - 10 Feet (45° Elbow)
  - 18 Feet (90° Elbow)
- Pressure drop difference
  \[
  \frac{(18 - 10)}{3.3} \times 240 \text{ Pa/m} \times 2 \\
  = 1,164 \text{ Pa} = 1.164 \text{ kPa}
  \]
- Pump Power Consumption
  \[
  1.164 \times 89.7 \div 0.7 \div 0.93 \div 1,000 \\
  = 0.16 \text{ kW}
  \]
- Annual Operation Cost
  \[
  0.16 \times 12 \times 365 \times 1.2 \\
  = \text{HKD841}
  \]
Pump Performance
Reduce Friction Loss
Pump Performance
Reduce Friction Loss
Pump Performance
Reduce Friction Loss
Pump Performance
Reduce Friction Loss
Pump Performance
Reduce Friction Loss

Optimal chiller plant layout and careful selection of low pressure drop devices reduces pressure losses
Pump Performance
Simplify Piping Layout

- Friction Loss in 100% open balancing valve
  - Nominal Size: 200mm
  - Flow Rate: 89.7 l/s
  - Pressure drop = 17.8 kPa

- Pump Power Consumption
  \[ 17.8 \times 89.7 / 0.7 / 0.93 / 1,000 \]
  \[ = 2.45 \text{ kW} \]

- Annual Operation Cost
  \[ 2.45 \times 12 \times 365 \times 1.2 \]
  \[ = \text{HKD12,877} \]
Pump Performance
Simplify Piping Layout

Water-cooled chiller

Condensing water pump

Chilled water pump

Cooling tower

Water tank
Pump Performance
Simplify Piping Layout

Apply low friction loss fitting
• Reduce overall pressure drop

Equal pipe length for self-balancing
• Eliminate balancing equipment
Pump Performance
Reduce Friction Loss

• Increase the pipe diameter of the system
• Minimize the length of the piping in the system
• Simplifying the layout as much as possible
• Minimize the number of elbows, tees, valves, fittings and other obstructions in the piping system
• Reduce the flow rate
Cool More or Pump More?

- Pump efficiency ≈ 70%
  COP ≈ 0.7
- Chiller COP ≈ 7.0
- Chiller COP ≈ 10x the pump COP

Conclusion: work your most efficient equipment harder
System Enhancement
Earthwise Application

- Low Flow
- Low Temperature
- High Efficiency Systems
System Enhancement
Earthwise Application

Supply temperature

Flow rates

Temperature differential

Fans
Ductwork
Pump
Piping
System Enhancement

Why Consider Variable Primary Flow (VPF) Now?

- Chiller control sophistication
- Operating cost savings
  - Pump energy
  - Response to low ΔT Syndrome
Variable Primary Flow (VPF)

**Advantages**

- Reduces capital investment
- Saves mechanical-room space
- Simplifies control
- Improves system reliability
- Improved chiller performance
Variable Primary Flow (VPF)

Improve chiller performance
Variable Primary Flow (VPF)
Improve chiller performance

CenTraVac Part Load Performance CTV-1
% Load vs. kW/ton -- using Constant Condenser Method

Variable Primary Flow (VPF)
Improve chiller performance
Variable Primary Flow (VPF)

Three Key Application Requirements

- Chillers must be able to accommodate a change of flow of at least 10% per minute; 30% or even 50% is even better
- Minimum and maximum flows must not be violated
- A bypass is required to maintain minimum flow
Chiller-Tower Optimization (CTO)
Optimal condenser water control

![Graph showing energy consumption vs. condenser water temperature]

- **Total** line
- **Chiller** line
- **Tower** line

Optimal control point
Chiller-Tower Optimization (CTO)

Dependent On?

• Chilled water plant
  - Tower design
  - Chiller design
    ▪ Centrifugal
    ▪ Helical rotary
    ▪ Variable speed drive
    ▪ Absorption
  - Changing conditions
    ▪ Chiller load
    ▪ Ambient wet bulb
System Enhancement

• EarthWise Application
  - Low flow, low temperature and large ΔT system
• Variable Primary Flow
• Chiller-tower Optimization
Energy Approach

Walk Through  
Customer Needs  
System Design  
Energy Analysis  
Turn Key Project

PERFORMANCE MANAGEMENT
Energy Approach
Baseline Energy Consumption
Energy Approach

Strategies for chiller upgrades & optimization

• Correctly Size the New Equipment
• Proper Chiller plant design
  - System Schematic
  - Layout
• Implement of Chiller Plant Control
Energy Approach
Correctly Size the New Equipment

- Determine actual building load
  - From BMS/operation log
  - Estimated from electric bill

Electricity Fee

Annual Electricity Fee – HKD 8,711,063 @ 2008

Electricity Fee for Chiller Plant = HKD 5,662,191 (65% of overall)
Energy Approach
Correctly Size the New Equipment

- Determine actual building load
  - From BMS/operation log
  - Estimated from electric bill
- Downsize Chiller if possible
  - Match with cooling load profile
  - Reduce initial cost and payback period
- Replace with higher efficiency chiller
  - Improve overall savings
Energy Approach

Correctly Size the New Equipment

- Energy Analysis
  - Employ TRACE 700 Chiller Plant Analyzer for plant configuration comparisons
  - Input existing energy profile for analysis
  - Calculate the energy and economic effects on different configuration
Energy Approach
Correctly Size the New Equipment
Energy Approach
Correctly Size the New Equipment

- Alternative 1
  - 2 no 600 TR water-cooled centrifugal chiller
  - 1 no 600 TR water-cooled centrifugal chiller c/w AFD

- Alternative 2
  - 2 no 750 TR water-cooled centrifugal chiller
  - 1 no 300 TR water-cooled screw chiller

Total 1,800TR cooling capacity will be provided
Energy Approach
Correctly Size the New Equipment

Alternative 1

Annual Saving: HKD 2,287,377 (40%)

Alternative 2

Annual Saving: HKD 2,084,079 (36.6%)
Energy Approach
Chiller Plant Design (Schematic)

- Review of Existing System Arrangement
- Consideration of System Change-over / Migration
- Select chilled / condensing water distribution system
- Decide equipment design condition
  (e.g. Chilled Water Temp, Cooling Tower Approach)
- Properly size pipe sizes
- Associated system design
  (e.g. Make-up / bleed off system, chemical treatment system)
Energy Approach
Chiller Plant Design (Schematic)
Energy Approach
Chiller Plant Design (Layout)

- Satisfy statutory requirement
- Sufficient space for maintenance and service
- Minimize water pressure drop
Energy Approach
Chiller Plant Design (Layout)
Energy Approach
Chiller Plant Control

Comprehensive control system with Cooling Tower Optimization
Energy Approach
Chiller Plant Control

- Fully Automation
- Trend log for major equipment
- Alarm Management
Energy Approach

Summary

• System analysis for plant configuration design
• Select high efficiency for better energy saving
• Consider pressure drop and future maintenance during pipework and layout design
• Reliable Chiller Plant Control System
• Monitor the system performance after installation