Today’s Topics

- **Fundamentals**
  - Chiller–tower interaction
  - Cooling-tower terminology, operation

- **Design conditions**
- **Cooling-tower control options**
- **System optimization**
- **Answers to your questions**
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A refrigeration cycle involving a two-stage compressor, evaporator, condenser, and economizer is illustrated. The cycle includes expansion devices and is shown in a pressure–enthalpy (p-h) chart, which tracks the state of the refrigerant from subcooled liquid at point A with 15.5 Btu/lb enthalpy to superheated vapor at point B with 92.4 Btu/lb enthalpy, both at 5 psia. 

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chiller–tower interaction
Heat Rejection

• Tower determines return condenser water temperature
• Chiller determines required heat rejection rate of tower
  ◆ Evaporator load
  ◆ Compressor energy

Hermetic motor:
100% of electrical input
Open motor:
electrical input × motor efficiency

chiller–tower interaction
Heat Rejection, Q

\[ Q = \text{evaporator load} + \text{input energy} \]

or

\[ Q = \text{evaporator load} \times (1 + 1/\text{COP}) \]
**electric chiller**

**Heat Rejection Example**

For 1 ton of evaporator load:

\[ Q = 12,000 \text{ Btu/h} \times (1 + 1/6.10) \]
\[ = 12,000 \text{ Btu/h} \times (1 + 0.16) \]
\[ = 13,967 \text{ Btu/h} \]

\[ \Delta T = \frac{Q (\text{Btu/h})}{(500 \times \text{gpm})} \]

For 1 ton of evaporator load, condenser water temperature rises ...

... 9.3°F at 3 gpm/ton

\[ \Delta T = \frac{13,967}{(500 \times 3)} = 9.3°F \]

... 14.0°F at 2 gpm/ton

\[ \Delta T = \frac{14,000}{(500 \times 2)} = 14.0°F \]
chiller–tower interaction
Heat Rejection

- Condenser water warms in proportion to heat rejection and condenser water flow rate
- Condenser pressure rises with condenser temperature
- Compressor work increases as condenser pressure rises

Cooling Tower

“Heat transfer device, often tower-like, in which atmospheric air cools warm water, generally by direct contact (evaporation).”

ASHRAE Terminology of HVAC&R
cooling tower Components

Ambient wet-bulb temperature drives tower design and selection

- 0.4% value is most conservative ... exceeded ~35 hours/year
cooling tower Performance Factors

- hot water temperature
- range
- cold water temperature
- approach
- ambient wet bulb

cooling tower certification CTI Performance Limits

- hot water \(< 125°F\)
- range \(> 4°F\)
- cold water temperature
- approach \(> 5°F\)
- ambient 60°F–90°F WB
example at standard rating conditions
Tower Performance

**Base condition**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
</tr>
<tr>
<td>Design WB, °F</td>
<td>78</td>
</tr>
<tr>
<td>Approach, °F</td>
<td>7</td>
</tr>
<tr>
<td>Hot water, °F</td>
<td>94.3</td>
</tr>
<tr>
<td>Cold water, °F</td>
<td>85</td>
</tr>
<tr>
<td>Fan power, hp</td>
<td>40</td>
</tr>
</tbody>
</table>

example at standard rating conditions
Same Tower, Lower Flow

- 96°F hot water
- 82°F cold water
- Range = 14°F
- Approach = 4°F
- 78°F WB design ambient
- 2 gpm/ton
example at standard rating conditions

**Tower Performance**

<table>
<thead>
<tr>
<th></th>
<th>Base condition</th>
<th>Same tower, lower flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
<td><strong>1000</strong></td>
</tr>
<tr>
<td>Design WB, °F</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Approach, °F</td>
<td>7</td>
<td><strong>4</strong></td>
</tr>
<tr>
<td>Hot water, °F</td>
<td>94.3</td>
<td><strong>96</strong></td>
</tr>
<tr>
<td>Cold water, °F</td>
<td>85</td>
<td><strong>82</strong></td>
</tr>
<tr>
<td>Fan power, hp</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

**Example at standard rating conditions**

**Same Approach, Lower Flow**

- **99°F** hot water
- **range = 14°F**
- **85°F** cold water
- **approach = 7°F**
- **78°F** WB design ambient

**2 gpm/ton**
example at standard rating conditions

Tower Performance

<table>
<thead>
<tr>
<th></th>
<th>Base condition</th>
<th>Same tower, lower flow</th>
<th>Smaller tower, lower flow</th>
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</thead>
<tbody>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Design WB, °F</td>
<td>78</td>
<td>78</td>
<td>78</td>
</tr>
<tr>
<td>Approach, °F</td>
<td>7</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Hot water, °F</td>
<td>94.3</td>
<td>96</td>
<td>99</td>
</tr>
<tr>
<td>Cold water, °F</td>
<td>85</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
<td>Fan power, hp</td>
<td>40</td>
<td>40</td>
<td>25</td>
</tr>
</tbody>
</table>

cooling tower performance factors

Approach and Range

- Approach = 7
- 100% load
- Approach = 4
- 50% load

ambient wet bulb, °F

50 60 70 80

10.0
8.0
6.0
4.0
2.0
0.0

12.0
16.0

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Cooling Towers and Condenser Water Systems
Design and Operation

Design conditions

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a design issue
Flow Rates

♦ Past rule of thumb: 3 gpm/ton
  ♦ 10° F ΔT for older, less efficient chillers
  ♦ ~9°F ΔT for currently produced chillers

♦ Today’s design advice
  ♦ Reduce flow rates
  ♦ Increase temperature differences
Increase $\Delta T$, reduce flow rate
Condenser Water

<table>
<thead>
<tr>
<th>Industry advisor</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Gas and Electric CoolTools™</td>
<td>10°–15°F $\Delta T$ single stage</td>
</tr>
<tr>
<td></td>
<td>12°–18°F $\Delta T$ multistage or positive displacement</td>
</tr>
<tr>
<td>Kelly and Chan</td>
<td>14.2°F $\Delta T$ for 3.6–8.3% energy savings in various climates</td>
</tr>
<tr>
<td>ASHRAE Green Guide</td>
<td>12°–18°F $\Delta T$</td>
</tr>
</tbody>
</table>

A history of Chiller Performance

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

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Chilled water plant design
Condensing Components

- Chiller
- Condenser water pump
- Cooling tower

Chilled water plant design
Chiller Selection

Certified selections help assure expected chiller performance

- Full-load and part-load conditions
- Air-Conditioning & Refrigeration Institute (ARI)
chilled water plant design

Cooling Tower Selection

Cooling Technology Institute (CTI)
rates tower performance

chilled water plant design

Pump Selection

\[ hp = \frac{gpm \times \Delta P}{3960 \times \text{pump efficiency}} \]

\[ kW = \frac{0.746 \times hp}{\text{motor efficiency}} \]
**chilled water plant design**

**Pressure Drops**

... in the condenser water loop:
- Condenser bundle
- Pipes, valves, fittings
- Tower static head

**chilled water plant design**

**Base Design: 500 Tons**

Assumptions for our example ...
- 0.1% design ambient  78°F WB
- Entering condenser water temperature (ECWT)  85°F
- Condenser flow rate  3 gpm/ton, 1500 gpm
- Loop pressure drop  30 ft
- Pump efficiency  75%
- Pump motor efficiency  93%
### Chiller Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser flow rate, gpm/ton:</td>
<td>3.0</td>
</tr>
<tr>
<td>Power used, kW</td>
<td>286.0</td>
</tr>
<tr>
<td></td>
<td>0.572/ton</td>
</tr>
<tr>
<td>Condenser $\Delta P$, ft</td>
<td>25.7</td>
</tr>
</tbody>
</table>

**Base design**

### Cooling Tower Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
</tr>
<tr>
<td>Power rating, bhp, kW</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>31.2</td>
</tr>
<tr>
<td>Static head, ft</td>
<td>13</td>
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</table>

**Base design**
### Pump Selection

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Condenser flow rate, gpm/ton:</td>
<td>3.0</td>
</tr>
<tr>
<td>System head, ft</td>
<td>30</td>
</tr>
<tr>
<td>Bundle head, ft</td>
<td>25.7</td>
</tr>
<tr>
<td>Tower static, ft</td>
<td>13</td>
</tr>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
</tr>
<tr>
<td>Pump power, hp</td>
<td>34.7</td>
</tr>
<tr>
<td>kW</td>
<td>27.8</td>
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**Base design**

### System Energy Use

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<td>27.8</td>
</tr>
<tr>
<td>Cooling tower</td>
<td>32.1</td>
</tr>
<tr>
<td>Total kW</td>
<td>345.9</td>
</tr>
</tbody>
</table>

**Base design**

---

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chilled water plant design: example
Reduce Flow Rate

- Assumptions that won’t change ... 
  - Pipes  
    (Head varies with square of flow)  
  - Chiller cost
- What we’ll alter ... 
  - Condenser flow  
  - Cooling tower size, as appropriate

chilled water plant design: example
Chiller Selection

<table>
<thead>
<tr>
<th>Condenser flow rate, gpm/ton:</th>
<th>3.0</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power used, kW</td>
<td>286.0</td>
<td>307.0</td>
</tr>
<tr>
<td></td>
<td>0.572/ton</td>
<td>0.614/ton</td>
</tr>
<tr>
<td>Condenser ΔP, ft</td>
<td>25.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Base design</td>
<td>Reduced flow</td>
<td></td>
</tr>
</tbody>
</table>
### Cooling Tower Selection

<table>
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**Base design**

**Reduced flow**

**Costs 10% less than base**

### Pump Selection

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<th>Condenser flow rate, gpm/ton:</th>
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<td>13.3</td>
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<tr>
<td>Bundle head, ft</td>
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<td>17.7</td>
</tr>
<tr>
<td>Tower static, ft</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
<td>1000</td>
</tr>
<tr>
<td>Pump power, hp/kW</td>
<td>34.7</td>
<td>27.8</td>
</tr>
<tr>
<td></td>
<td>27.8</td>
<td>10.7</td>
</tr>
</tbody>
</table>

**Base design**

**Reduced flow**

- Prior to application, all flow rates were corrected to a common pressure.
- Flow rates and pump power were calculated.

- Costs 10% less than base

- Condenser flow rate, gpm/ton: 3.0
- System head, ft: 30
- Bundle head, ft: 25.7
- Tower static, ft: 13
- Flow rate, gpm: 1500
- Pump power, hp/kW: 34.7

- Condenser flow rate, gpm/ton: 2.0
- System head, ft: 13.3
- Bundle head, ft: 17.7
- Tower static, ft: 13
- Flow rate, gpm: 1000
- Pump power, hp/kW: 27.8

**Footnotes**

- Prior to application, all flow rates were corrected to a common pressure.
- Flow rates and pump power were calculated.

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chilled water plant design: example
System Energy Use

<table>
<thead>
<tr>
<th></th>
<th>Condenser flow rate, gpm/ton:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td>2.0</td>
</tr>
<tr>
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<td></td>
<td>10.7</td>
</tr>
<tr>
<td>Cooling tower</td>
<td>32.1</td>
</tr>
<tr>
<td></td>
<td>20.1</td>
</tr>
<tr>
<td>Total kW</td>
<td>345.9</td>
</tr>
<tr>
<td></td>
<td>337.7</td>
</tr>
<tr>
<td>Base design</td>
<td>Reduced flow</td>
</tr>
</tbody>
</table>

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chilled water plant design
Options

• Downsize pumps and tower to take full energy cost savings

OR

• Reduce pipe size to cut installed cost
  ◆ Reduces structural costs (tower, pipes, water in pipes)
  ◆ Can reinvest part of savings in more efficient chiller
  ◆ Reduces pump savings

Is reduced flow only for long piping runs?

Condenser water pump must overcome pressure drops
  ◆ Condenser bundle
  ◆ Tower static lift
  ◆ Pipes, valves, fittings

What if it was 0 ft of head?
Reduced flow works for short runs, too!

Does reduced flow work for all chillers?

- **Logan Airport, Boston**
  Cost savings: $426,000 construction
  7.3% operation

- **DuPont, Greenville**
  Cost savings: $45,000 excavation, concrete
  6.5% operation

- **Hewlett Packard, San Francisco**
  Cost savings: Piping
  2% operation (existing tower)
Proven savings for all manufacturers

- **Logan Airport, Boston**
  Cost savings: $426,000 construction
  7.3% operation

- **DuPont, Greenville**
  Cost savings: $45,000 excavation, concrete
  6.5% operation

- **Hewlett Packard, San Francisco**
  Cost savings: Piping
  2% operation (existing tower)

Does reduced flow work for retrofits?

**Opportunity:**
- Chiller must be replaced
- Cooling needs increased by 50%
- Cooling tower was replaced two years ago
- Condenser pump and pipes in good shape
Reduced flow can aid retrofit budgets

<table>
<thead>
<tr>
<th>Condenser-side opportunity:</th>
<th>Existing</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity, tons</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>Flow rate, gpm</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Condenser water:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>entering, °F</td>
<td>85</td>
<td>88</td>
</tr>
<tr>
<td>leaving, °F</td>
<td>95</td>
<td>102.4</td>
</tr>
<tr>
<td>Design wet bulb, °F</td>
<td>78</td>
<td>78</td>
</tr>
</tbody>
</table>

chilled water plant design
Analysis Tools

- System Analyzer™
- Chiller Plant Analyzer
- TRACE™ 700
- DOE 2.1
- HAP

OADB does not correlate directly to load!
chilled water plant design

Guidance

- Reduced flow saves installed and operating costs
- No “magic” flow rate ... Start at 2 gpm/ton and adjust
- Reinvest part of first-cost savings in more efficient chillers

always, always, ALWAYS

Remember ...

The meter is on the BUILDING
a win-win-win situation
Saving Energy–And More

“In addition to the electric energy savings, this chiller plant will have prevented the emissions of 1.1 million lb of CO₂ per year, 8,800 lb of SO₂ per year, and 3,100 lb of NOₓ per year. This is an overall win-win-win situation where the first cost is reduced, operating cost is minimized, plus significant environmental benefits are realized as an additional benefit.”

from “A Chiller Challenge” by T. Chan

Cooling Towers and Condenser Water Systems
Design and Operation

Cooling-tower control options

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chiller–tower optimization
Control

- **Capacity**
  - Design requirements
  - Tower control options
  - Sequence to conserve energy

- **System protection**
  - Chiller requirements
  - Tower requirements

cooling tower design requirements
ASHRAE 90.1–2001

Maximum allowable fan power ...

- Centrifugal fan < 20.0 gpm/hp
- Propeller or axial fan < 38.2 gpm/hp

... at 95°F EWT/85°F LWT/75°F WB
cooling tower design requirements
ASHRAE 90.1- 2001

Fan speed control required for motors 7.5 hp or larger ... reduce fan speed to 2/3 or less (VFD, two-speed or pony motor)

- Multiple-fan systems: 1/3 of fans may be on/off
- Fans that serve multiple refrigeration circuits
- Climates with >7,200 cooling-degree days (e.g., Phoenix, Miami, Taipei, Riyadh)

EXCEPTIONS

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cooling tower Capacity Control

<table>
<thead>
<tr>
<th>Cooling Tower at CTI Conditions</th>
<th>Marley UPDATE Version 3.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-Jun-03 1:34:43 PM</td>
<td>NC Class: NC8305JR</td>
</tr>
<tr>
<td></td>
<td>Flow Rate: 1500 GPM</td>
</tr>
<tr>
<td></td>
<td>Motor Output: 40.0 HP</td>
</tr>
<tr>
<td></td>
<td>Motor RPM: 1600</td>
</tr>
<tr>
<td></td>
<td>Fan RPM: 473</td>
</tr>
<tr>
<td></td>
<td>(Full Speed)</td>
</tr>
<tr>
<td></td>
<td>Number of Cells: 1</td>
</tr>
</tbody>
</table>

Design Conditions:
- Flow Rate: 1500 GPM
- Hot Water: 95.00 °F
- Cold Water: 80.00 °F
- Wet-Bulb: 70.00 °F

- 12.00 °F Range
- 10.00 °F Range
- 5.00 °F Range
- Design Point

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**cooling tower**

**Capacity vs. Airflow**

![Graph showing cooling tower capacity vs. airflow]

- **Fan control**
  - Cycling single-speed fan
  - Two-speed fan
  - Variable-speed drive

- **Modulating dampers**
  - Centrifugal two-speed fan
one tower fan
Perfect Capacity Control

capacity, %

airflow AND full-load power, %

0 20 40 60 80 100

capacity, %

Perfect Capacity Control

variable-speed drive

capacity vs. airflow

airflow vs. fan power

one tower fan
Capacity Control

variable-speed drive

single-speed fan

two-speed fan: 100% and 50%

two-speed fan: 100% and 67%

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**cooling tower**

**Rules for Capacity Control**

- ASHARE 90.1 requirements make sense
- Invest in VFDs on all tower fans
- Operating multiple fans at part speed saves energy
  - Consumes less power than one fan at full speed and the other off

**cooling tower capacity control**

**Sequence of Operation**

1. When a chiller is operating and the cooling tower basin temperature rises to two (2) degrees F above the current tower leaving water setpoint, the lead cooling tower fan shall be turned on at minimum speed and the DDC control loop enabled.
   
   a. When the operating fan(s) are operating at 50 percent speed, an additional fan shall be enabled and controlled at the same speed as the operating fans until all active cooling tower cell fans are enabled.
   
   b. When operating fans are running at minimum speed and the tower supply water temperature is five (5) degrees below the current tower leaving water setpoint, the most lag tower fan shall be turned off.
   
   c. Cooling tower fans shall have five (5) minute minimum on and off time delays.
chiller–tower optimization

Control

- Capacity
  - Design requirements
  - Tower control options
  - Sequence to conserve energy
- System protection
  - Chiller requirements
  - Tower requirements

system protection

Chiller Head Pressure

Condenser pressure set by leaving-condenser water temperature

Evaporator pressure set by leaving-evaporator water temperature

Cooling load
system protection
Chiller Requirements

Achieve and maintain sufficient “head” pressure

Pressure and time required varies by chiller type …

- Oil return
- Refrigerant flow (through expansion devices)
- Motor cooling
- Oil supply

system protection
Chiller Head Pressure

Condenser pressure set by leaving-condenser water temperature

41.8°F

Evaporator pressure set by leaving-evaporator water temperature

44°F

Cooling load

46°F

Water-cooled chiller

40°F

Cooling tower

44°F

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system protection

Chiller Head Pressure

Measure evaporator–condenser \( \Delta P \) or condenser pressure or water temperatures ...

then:

- Control entering water temperature
  - Fan control
  - Reduce water flow over tower—e.g., 3-way bypass into sump (not preferred)
- Reduce flow through condenser
  - 2-way valve
  - VFD on condenser pump
  - condenser bypass with 3-way valve

---

system protection

Diverting Valve at Tower

- Tower bypass with 3-way or 2-way valves
- Constant flow through chiller

**NOT PREFERRED**

Longer lag time makes control difficult
Throttling Valve

- Throttling valve modulates based on refrigerant $\Delta P$
- Low-cost alternative
- Short periods with low flow over tower

Diverting Valve at Chiller

- Chiller bypass with 3-way or 2-way valves
- Constant flow over tower
- More precise control
... for chiller head pressure:

1. The BAS shall monitor the refrigerant pressure in each chiller’s evaporator and condenser. The BAS shall use PID-based DDC control of the \([\text{chiller-condenser-pump VFD}][\text{cooling-tower bypass valve}][\text{chiller-condenser bypass valve}]\) to maintain no less than the minimum pressure differential specified by the chiller manufacturer.
Trane literature
Condenser Water Control

CTV-PRB006-EN
Condenser Water Temperature Control for CenTraVac Centrifugal Chiller Systems

RLC-PRB017-EN
Water-Cooled Series R Chiller Models RTHB & RTHD Condenser Water Control

system protection
Flow Limits: An Example

<table>
<thead>
<tr>
<th>Flow</th>
<th>500-ton chiller</th>
<th>500-ton cooling tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>1000 gpm</td>
<td>1000 gpm</td>
</tr>
<tr>
<td>Maximum</td>
<td>2469 gpm</td>
<td>1290 gpm</td>
</tr>
<tr>
<td>Minimum</td>
<td>449 gpm</td>
<td>780 gpm</td>
</tr>
</tbody>
</table>

Tower flow range can be much narrower than that of chiller

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**System Protection**

**Tower Flow Limits**

<table>
<thead>
<tr>
<th>Flow violation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too low</td>
<td>• “Holes” in fill coverage</td>
</tr>
<tr>
<td></td>
<td>• Lost efficiency</td>
</tr>
<tr>
<td></td>
<td>• Mineral deposits</td>
</tr>
<tr>
<td>Too high</td>
<td>• “Over-flow” distribution</td>
</tr>
<tr>
<td></td>
<td>• Lost efficiency</td>
</tr>
<tr>
<td></td>
<td>• Lost water</td>
</tr>
<tr>
<td></td>
<td>• Lost treatment chemicals</td>
</tr>
</tbody>
</table>

Consult tower manufacturer ... Specify limits

Cooling Towers and Condenser Water Systems
Design and Operation

System optimization

© 2005 American Standard Inc.
simple case: constant water flow

Operating Dependencies

- Wet bulb
- Condenser water temperature
- Load
- Tower design

- Load
- Condenser water temperature
- Chiller design

condenser water control
"Normal" Setpoint

- Hot?
  e.g., 85°F, minimizes tower energy consumption

- Cold?
  e.g., 55°F, minimizes chiller energy consumption

- Optimized?
optimal condenser water control
Chiller–Tower Interaction

energy consumption, kW

condenser water temperature, °F

chiller–tower optimization
An Example ...

- 720,000 ft² hotel
- 2 chillers, 2 tower cells
- Control strategies
  - Make leaving-tower water cold as possible (55°F)
  - Optimize system operation
  - Entering-condenser setpoint equals design ...
    - 85°F for humid climates,
    - 80°F for dry climates
chiller–tower control strategies
North America

control strategy:
- 55°F lvg tower
- optimal control
- design ECWT

annual operating cost, $ USD

Mexico City | Orlando | San Diego | Toronto

chiller–tower control strategies
Global Locations

control strategy:
- 55°F lvg tower
- optimal control
- design ECWT

annual operating cost, $ USD

Dubai | Paris | Sao Paulo | Singapore

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chiller–tower optimization
Operating Cost Savings

<table>
<thead>
<tr>
<th>Location</th>
<th>Operating Cost Savings, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dubai</td>
<td>14</td>
</tr>
<tr>
<td>Paris</td>
<td>10</td>
</tr>
<tr>
<td>Sao Paulo</td>
<td>8</td>
</tr>
<tr>
<td>Singapore</td>
<td>6</td>
</tr>
<tr>
<td>Mexico City</td>
<td>4</td>
</tr>
<tr>
<td>Orlando</td>
<td>2</td>
</tr>
<tr>
<td>San Diego</td>
<td>0</td>
</tr>
<tr>
<td>Toronto</td>
<td>0</td>
</tr>
</tbody>
</table>

For centrifugal chillers ≥ 300 tons, ASHRAE 90.1 requires ...

- 0.576 kW/ton at full load
- 0.549 kW/ton at IPLV

... under ARI standard rating conditions
chiller–tower optimization
Perspective on Savings

<table>
<thead>
<tr>
<th>Savings, %</th>
<th>Equivalent chiller efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.576</td>
</tr>
<tr>
<td>2.8</td>
<td>0.560</td>
</tr>
<tr>
<td>4.5</td>
<td>0.550</td>
</tr>
<tr>
<td>6.2</td>
<td>0.540</td>
</tr>
<tr>
<td>14.0</td>
<td>0.495</td>
</tr>
</tbody>
</table>

chiller–tower optimization
Documented Savings

- Braun, Diderrich: *ASHRAE Transactions* (1990)
- Crowther, Furlong: *ASHRAE Journal* (July 2004)
chiller–tower optimization
What’s the “Catch”?

The chiller works harder
  ◆ Takes advantage of chiller COP
  ◆ Tower fans consume less energy
Where’s the Meter?

On the
BUILDING

2004 award for
Best Sustainable Practice

presented to Trane for
“Near optimal chiller–tower operation”

by the Sustainable Buildings Industry Council (SBIC)
chiller–tower optimization
Finding “Near Optimal”

- **Tower design**
  (flow rate, range, approach)

- **Chiller design**
  - Refrigeration cycle
    (vapor compression vs. absorption)
  - Compressor type
  - Capacity control (variable-speed drive)

- **Changing conditions**
  (chiller load, ambient wet bulb)

chiller–tower optimization
Necessities

- System-level controls
- Variable-frequency drive on tower fans
- High-quality relative humidity sensor
chiller–tower optimization

Calculating the Savings

Available tools include
TRACE™ 700, Chiller Plant Analyzer,
System Analyzer™

<table>
<thead>
<tr>
<th>% Full load</th>
<th>Wet bulb (deg F)</th>
<th>Tower setpoint</th>
<th>Chiller + tower kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**chiller–tower optimization: dry climate**

**Specification Chart**

<table>
<thead>
<tr>
<th>% Full load</th>
<th>Wet bulb (deg F)</th>
<th>Tower setpoint</th>
<th>Chiller + tower kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Coldest condenser water is **not** better
- Optimal control saves money
  - Real, quantifiable savings
  - Proven control strategy that’s more than 10 years old
Variable-Speed Pump?

**Limiting factors:**
- Tower static lift
- Proper water distribution throughout tower fill (nozzles)
- Required flow through condenser

**Reduced speed/flow:**
- Increases chiller power (warmer water leaving condenser)
- Alters heat-transfer effectiveness of tower
Variable-Speed Pump?

No definitive answer ... yet

Control strategy varies with each installation based on chiller and tower selections
Summary

- **Tower fundamentals**
  - Larger range (lower flow rate) reduces tower size or approach
  - Approach increases as ambient wet bulb decreases

- **Reduce flow rates**
  - Lowers capital and operating costs
  - Benefits the environment

---

Summary

- **Cooling-tower control options**
  - Invest in VFDs on all tower fans
  - Head pressure control is critical to reliability

- **Chiller–tower optimization**
  - Minimize system energy consumption
  - Offers significant operating-cost savings
references for this broadcast
Where to Learn More

- 2000 ASHRAE Handbook–Systems & Equipment (Chapter 36)
- Marley Cooling Technologies web site
  http://www.marleyct.com/publications.asp
- Cooling Technology Institute’s CTI Standard STD-201-96
- Bibliography

Upcoming Broadcasts

- May 25 Energy analysis–LEED™ modeling
- Sep 21 ASHRAE Std 62.1-2004 ventilation requirements
- Nov 16 Demand-controlled ventilation based on CO₂