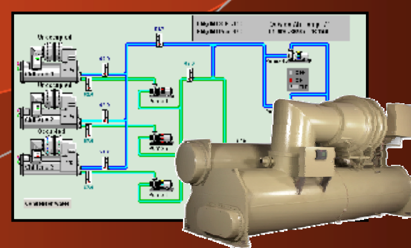
Chiller Optimization



Lee Cline PE
Systems Engineer

What is Chiller Optimization?

It's about the *SYSTEM !*

It's about the *SYSTEM* !

because…
The meter is on the *building!*

Chiller Optimization

Agenda

- What Affects Chiller System Energy Use?
- Distribution efficiency
- Chiller Maintenance
- Equipment sequencing
- Equipment efficiency

Chiller Optimization

What Affects Chiller System Energy Use?

1. Cooling load
2. Cooling load
3. Cooling load
4. Distribution efficiency
5. Chiller Maintenance
6. Equipment sequencing
7. Equipment efficiency

You can't have an efficient system without efficient equipment.

BUT…

You can have very poor system efficiency even with efficient equipment!

Chiller Optimization

Agenda

- What Affects Chiller System Energy Use?
- **Distribution efficiency**
- Chiller Maintenance
- Equipment sequencing
- Equipment efficiency

Chiller Optimization
Distribution efficiency

- **Low Flow systems**
  - **Chiller COP = 6 to 7**
  - **Pump COP = 0.6**

The ASHRAE *GreenGuide* recommends:

- 12-20°F chilled water ΔT (1.2 - 2. 0 gpm/ton flow rate)
- 12-18°F condenser water ΔT (1.6 – 2.35 gpm/ton flow rate)

7 | Chiller Plant Control

Chiller Optimization
Distribution efficiency

- Low Flow systems
  - Chiller COP = 6 to 7
  - Pump COP = 0.6
- **Constant Flow**

ASHRAE 90.1 requires variable flow systems:

- >10 hp total pump power (~150 tons)

AND

- More than 3 control valves

And individual variable flow pumps if:

- 100 feet of head and 50 hp motor - maximum
- 30% of design Watts maximum at 50% flow

8 | Chiller Plant Control

Chiller Optimization

Distribution efficiency

- Low Flow systems
  - Chiller COP = 6 to 7
  - Pump COP = 0.6
- Constant Flow
- **Chilled Water Low Delta T**
  - **Is an Air Side Problem!**

Causes of Low Delta T

- Improper AHU setpoints
- Dirty filters or coils
- Control calibration
- Three-way valves
- Coils piped backwards
- Uncontrolled loads
- Poor valve control
- Incorrect control valves
- Incorrectly selected coils
- Improperly applied CHW reset

9 | Chiller Plant Control

Chiller Optimization

Distribution efficiency

Improperly applied CHW reset

Warm Supply Water Temperature causes Low Delta T / High Flow -

8000 cfm Cooling Coil

Total Capacity (MBh)	Entering Water Temp (°F)	Leaving Water Temp (°F)	Delta T (°F)	Flow (gpm)
315	40.0	56.0	**16**	39.36
315	44.0	54.05	**10.05**	62.53

10 | Chiller Plant Control

Chiller Optimization

Distribution efficiency

Improperly applied CHW reset

Warm Supply Water Temperature causes Low Delta T / High Flow -

Use Chilled Water Reset
on Constant Flow Systems

DO NOT Use Chilled Water Reset
on Variable Flow Systems

Chiller Optimization

Agenda

- What Affects Chiller System Energy Use?
- Distribution efficiency
- **Chiller Maintenance**
- Equipment sequencing
- Equipment efficiency

Chiller Optimization

Compressor Work Principles

- $W_{Comp} \propto$ Load (tons)
  - Tons = (gpm x Δ T) / 24

    Double the tons = double the work
- $W_{comp} = f\,[\Delta\ Pres_{ref}]$
  - Cond Pressure = f [cond LEAVING water temp]
  - Evap Pressure = f [evap LEAVING water temp]
  - $\Delta\ Pres_{ref} = f$ [LEAVING water temps]

    Increasing the LEAVING water temperature differential 1°F increases the work by 1 to 3 percent.

Chiller Optimization

Chiller Operation & Maintenance

	Condition	Energy Penalty
in the chiller…		
• Cond approach	2 ºF High	3.0 %
• Cond pressure	2 psi High	6.0 %
• Evap approach	1 ºF High	1.5 %
around the chiller…		
• Condenser water	1 ºF High	1.5 %
• Condenser Δ T	1 ºF High	1.5 %
• Evap setpoint	1 ºF Low	1.5 %
----------------		--------
• Total losses		15 %

Chiller Optimization

Chiller Operation & Maintenance

For a 500 ton chiller plant a 15% inefficiency results in increased annual utility costs in the range of $8,000 to $12,000.

15 | Chiller Plant Control

Chiller Optimization

Agenda

- What Affects Chiller System Energy Use?
- Distribution efficiency
- Chiller Maintenance
- **Equipment sequencing**
- Equipment efficiency

16 | Chiller Plant Control

Chiller Optimization

Equipment Sequencing

- **Chillers**
- Cooling Towers

Equipment Sequencing

Chillers

- What is the optimal sequencing for chillers?
  - Should I run one chiller at 100%
    OR
    two chillers at 80%?

What's wrong with this question?

80% + 80% ≠ 100%

Equipment Sequencing

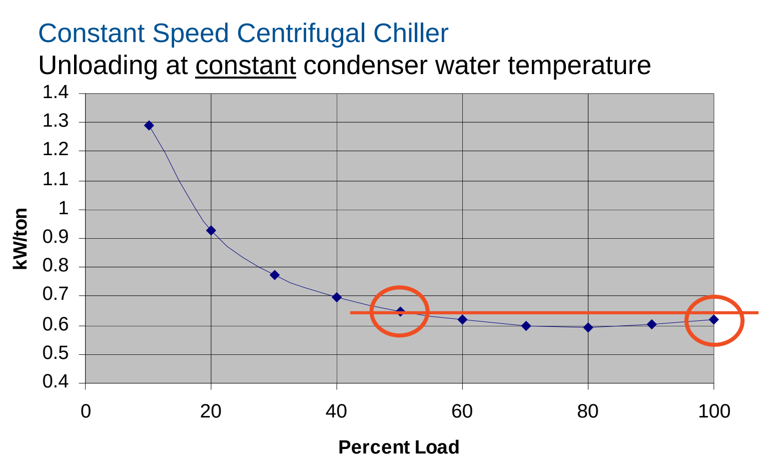
Chillers

- What is the optimal sequencing for chillers?
  - Should I run one chiller at 100%
    OR
    two chillers at 50%?
- The *givens*…
  - whether you run one chiller or two…
    - The building load does not change
    - The outside wet bulb temperature does not change
  - When you run two chillers…
    - You *may* double the number of pumps
    - You *may* double the number of tower cells

19 | Chiller Plant Control

Equipment Sequencing

One chiller at 100%? OR… Two chillers at 50%?



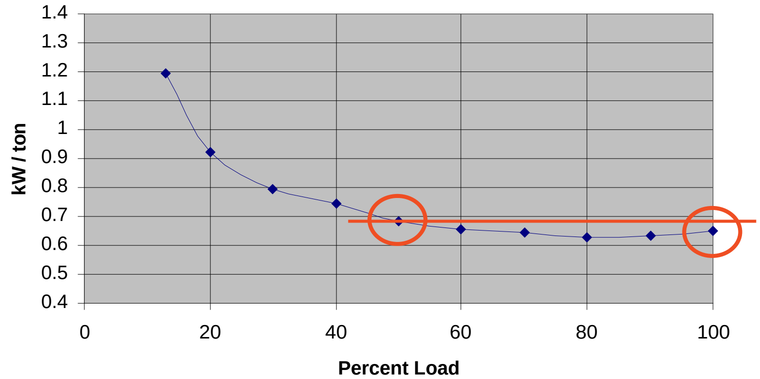
20 | Chiller Plant Control

Equipment Sequencing

One chiller at 100%? OR… Two chillers at 50%?

Variable Speed Centrifugal Chiller

Unloading at constant condenser water temperature



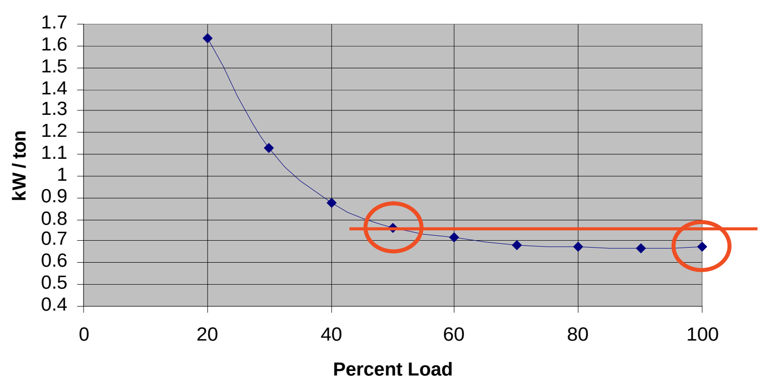
21 | Chiller Plant Control

Equipment Sequencing

One chiller at 100%? OR… Two chillers at 50%?

Constant Speed Screw Chiller Unloading

Unloading at constant condenser water temperature



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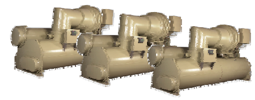
Equipment Sequencing

Chillers



- What is the optimal sequencing for chillers?
  - Should I run one chiller at 100%
    OR
    two chillers at 50%?
- For systems with 4 chillers or less:
  - Match plant capacity to building's load

  Said another way...
  - Run as few chillers as possible
    as hard as possible

23 | Chiller Plant Control

Chiller Optimization

Equipment Sequencing

- Chillers
- **Cooling Towers**

24 | Chiller Plant Control

Equipment Sequencing

Cooling Tower Work Principles

- $W_{fan} \propto$ **Load (tons)**
  - **Tons = (gpm x Δ T) / 24**

    Double the tons = double the work
- $W_{fan} = f$ **[difference between: leaving tower water temperature and outside wet bulb temperature]**

  The cooling tower fan consumes more energy.
  - ***For lower leaving water temperatures***
  - ***At higher outside wet bulb temperatures***

  It is NOT a linear function

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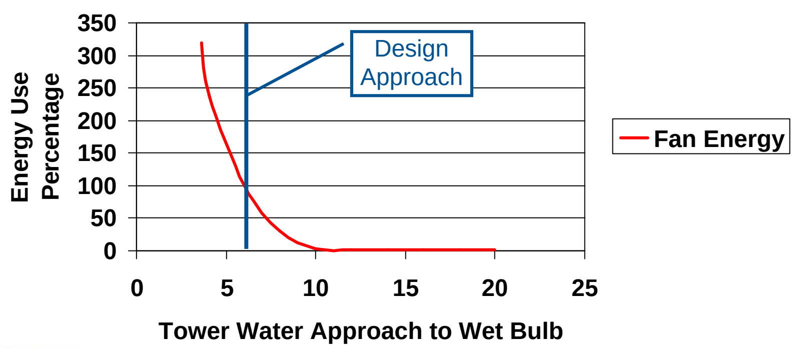
Equipment Sequencing

Cooling Tower Work Principles

Cooling Tower Approach VS Energy Consumption

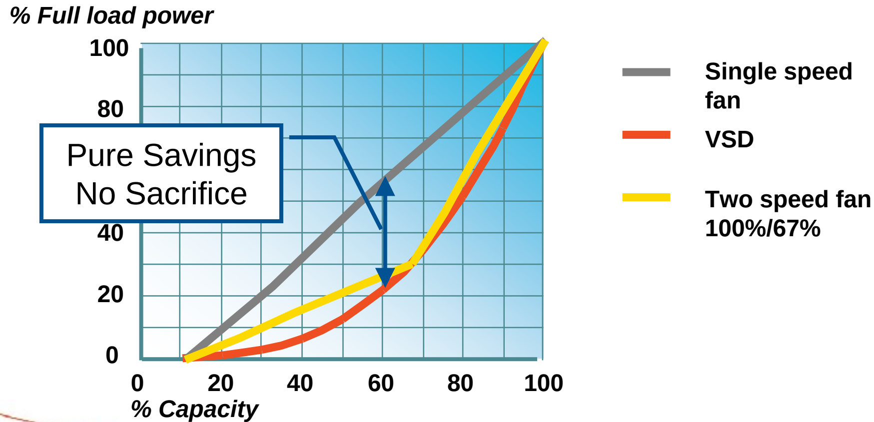


26 | Chiller Plant Control

Equipment Sequencing

Cooling Tower Work Principles

Cooling Tower Unloading



Equipment Sequencing

ASHRAE 90.1- 2001

Cooling Tower Design Requirements

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)**

EXCEPTIONS

- **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)**

Equipment Sequencing

Condenser Water System

- Optimal Condenser Water Setpoint
- Cooling Tower Sequence
- Cooling Tower Fan Sequence

29 | Chiller Plant Control

Equipment Sequencing

Optimal Chiller-Tower Control

- Design Setpoint?
  (85 F setpoint - minimizes tower energy use)
- As Cold As Possible?
  (55 F setpoint - minimizes chiller energy use)
- Real time optimization?
- **Protect the tower & chiller!**
  - **Low limit**

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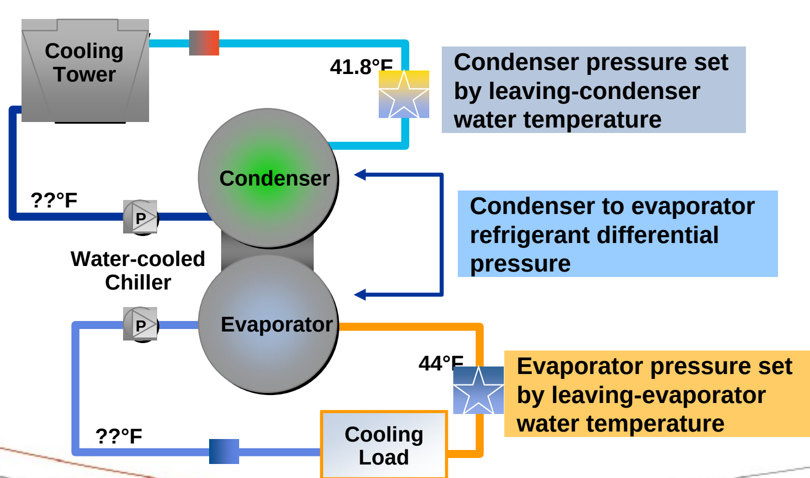
Equipment Sequencing

Chiller Refrigerant Head Pressure Control

- Achieve and maintain sufficient “head” pressure
- Pressure and time required varies by chiller type …
  - Oil return
  - Oil supply
  - Refrigerant flow (through expansion devices)
  - Motor cooling
  - NOT for system operational efficiency!

Equipment Sequencing

Chiller Refrigerant Head Pressure Control



Equipment Sequencing

Chiller Refrigerant Head Pressure Control

- Control is required when condenser water is much lower than design or optimal operating temperature
  - Start up phenomenon
  - Free Cooling
- Can be controlled with:
  - Fan control
  - Tower or chiller flow by-pass
  - Chiller flow reduction

33 | Chiller Plant Control

Equipment Sequencing

Chiller Refrigerant Head Pressure Control

If fan control is not sufficient

- Bypass chiller or tower flow with 3-way valve
- Throttle flow with 2-way valve or VFD pump control
  - Input variable must be hardwired from pressure transducer or chiller pressure output. (communicated signals may be to slow for control)
  - PID control

Design flow during normal operation

34 | Chiller Plant Control

Equipment Sequencing

Chiller Refrigerant Head Pressure Control

- Centrifugal Chillers
  - CVHE / CVHF / CVDF / AdaptiView Control Retrofit
    - Analog output for condenser pressure OR refrigerant differential pressure
    - CVT-PRB006-EN
- Screw Chillers
  - RTHB
    - Refrigerant differential pressure analog output
    - RLC-EB-4
  - RTHD / RTWD
    - Analog output to control condenser flow
    - RLC-PRB017-EN

35 | Chiller Plant Control

Equipment Sequencing

Optimal Chiller-Tower Control

- **Design Setpoint?**

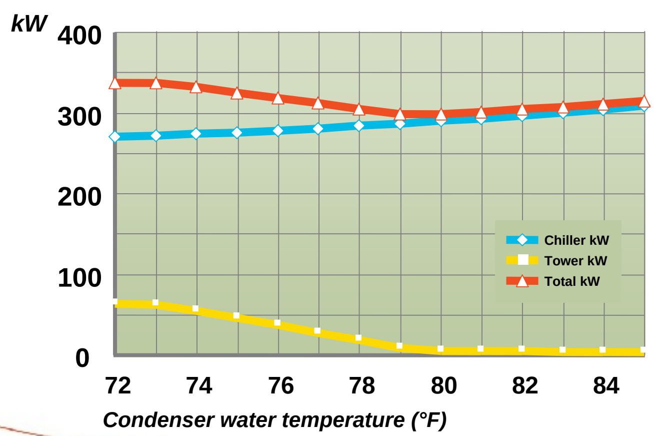
  (85 F setpoint - minimizes tower energy use)
- **As Cold As Possible?**

  (55 F setpoint - minimizes chiller energy use)
- **Real time optimization?**
- Protect the tower & chiller!
  - Low limit

36 | Chiller Plant Control

Equipment Sequencing

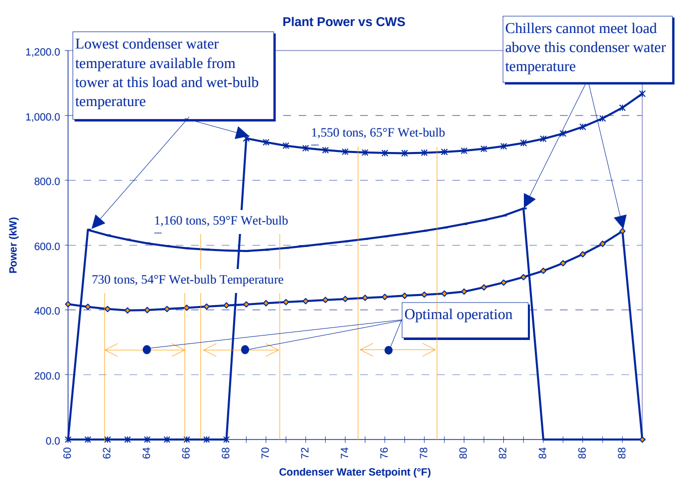
Optimal Chiller-Tower Control



37 | Chiller Plant Control

Equipment Sequencing

Optimal Chiller-Tower Control



Hydeman, et. al. Pacific Gas and Electric. Used with permission.

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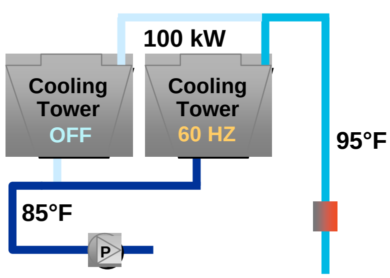
Equipment Sequencing

Condenser System Design and Control

- Condenser Water Setpoint
- **Cooling Tower Sequence**
- Cooling Tower Fan Sequence

Equipment Sequencing

Cooling Tower Sequence?

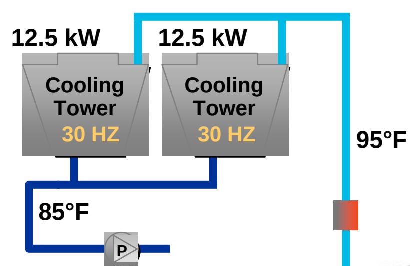


For Free Discharge Fans
W2 = W1 x $(S2 / S1)^3$

W2 = 100 kW x $(30 \text{ hz} / 60 \text{ hz})^3$

W2 = 12.5 kW

Total Fan kW = 25 kW



Equipment Sequencing

Cooling Tower Sequence?

Example chiller and tower flow limits

Flow	500-ton chiller	500-ton cooling tower
Design	1000 gpm	1000 gpm
Maximum	2469 gpm	1290 gpm
Minimum	449 gpm	780 gpm

Tower flow range *may be* much narrower than that of chiller

41 | Chiller Plant Control

Equipment Sequencing

Cooling Tower Sequence?

Tower flow limits

Flow violation	Result
Too low	• “Holes” in fill coverage • Lost efficiency • Mineral deposits
Too high	• “Over-flow” distribution • Lost efficiency • Lost water • Lost treatment chemicals

Consult tower manufacturer … Specify limits

42 | Chiller Plant Control

Equipment Sequencing

Cooling Tower Sequence?

- Tower cell sequencing
  - Run as many cells as possible - **while maintaining tower minimum flow**
- Tower fan sequencing
  - Run as many fans as possible
  - Run fans as slow as possible
  - Run fans at the same speed **to meet desired tower water setpoint**

Freezing Weather May Be An Exception

43 | Chiller Plant Control

Chiller Optimization

Agenda

- What Affects Chiller System Energy Use?
- Distribution efficiency
- Chiller Maintenance
- Equipment sequencing
- **Equipment efficiency**

44 | Chiller Plant Control

Chiller Optimization

Equipment efficiency

Buy the most efficient equipment you can afford

You're going to have it for a long time!

45 | Chiller Plant Control

Optimization

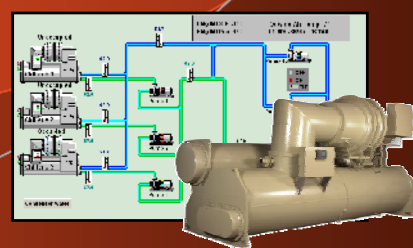
The meter is on the building!

46 | Chiller Plant Control

TRANE

Chiller Optimization

Questions?



Ingersoll Rand