Chilled Water System Design Decisions

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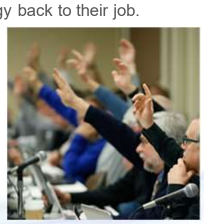

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Course Description

This presentation covers many common chilled water system decisions, benefits and adverse effects of those decisions, and reasons a design team may want to choose a particular option. The chapter will get to pick approximately 7-8 topics from the following list in this fast-paced presentation.

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Valves: Balancing or triple duty
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings
- Controlling chillers in series
- One or two pump misperception

Recommended audience: Students, consulting engineers, contractors, and facilities managers.

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Chilled Water System Design Decisions

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General CE hours

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Learning Objectives

- More fully understand reasons for design decisions
- Appreciate advantages and disadvantages
- Be able to explain decisions made to non-technical clients
- Keep your clients out of trouble!

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Today's "Pick-Six" Menu

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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BONUS!!!

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Today's "Pick-Six" Menu - BP

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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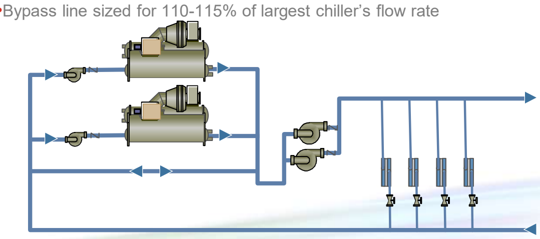
Primary/Secondary Operation

Turn chiller off when chiller(s) remaining on can satisfy load and flow
•Excess bypass flow ≥ 1.10 x chiller flow rate
•Bypass line sized for 110-115% of largest chiller's flow rate



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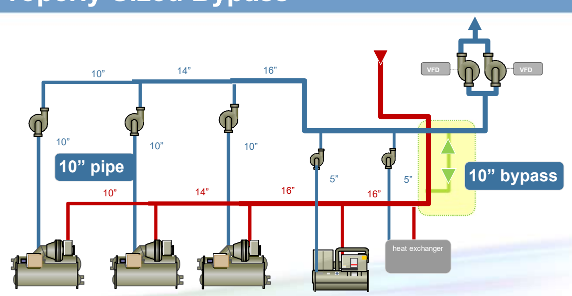
Primary/Secondary
Properly Sized Bypass



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Primary/Secondary
Example: Oversized Bypass

- University chilled-water plant
  - 5000 tons
  - 10,000 gpm (12ºF ΔT)
  - Manifold pipe size: 24"
- Five 1000 ton chillers
  - 2000 gpm
  - Pipe size: 10"
- Bypass
  - Size: 24" (same as manifolds)
  - Length: 8' (very little pressure drop)

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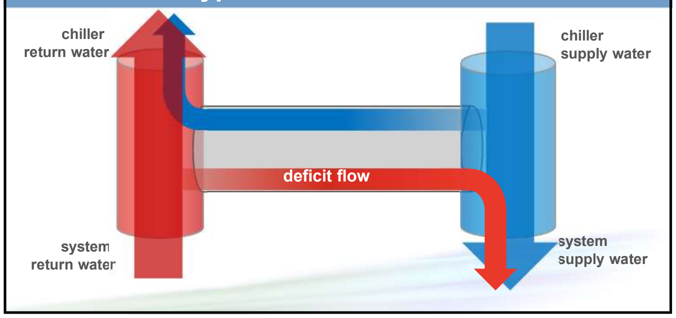
Primary/Secondary
Oversized Bypass



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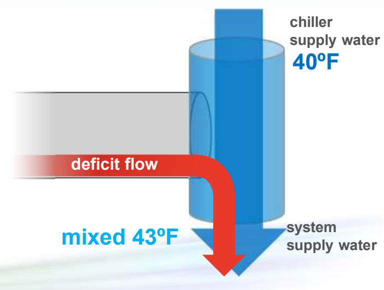
Primary/Secondary
Oversized Bypass Symptom 1

- Can't maintain system supply water temperature



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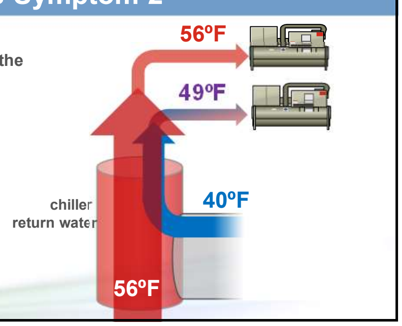
Primary/Secondary
Oversized Bypass Symptom 2

- Can't load chiller closest to the bypass



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Primary/Secondary
Oversized Bypass Mitigation

Impose a small pressure drop
- Some people put a valve in the bypass line
  - It's a big, expensive valve
  - Somebody will close it, somebody else will open it
  - Bypass should allow free flow
- Put an orifice plate with a hole about the size of the pipe going into the largest chiller
  - Still need to drain the system

Best to ensure the bypass pipe is sized properly

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Primary/Secondary
Short Bypass Line

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Pop Quiz
How should the bypass line be sized in a VPF System?

1. Same as primary secondary
2. Smaller than primary secondary
3. There is no need for a bypass line
4. Select the valve first, then the line size

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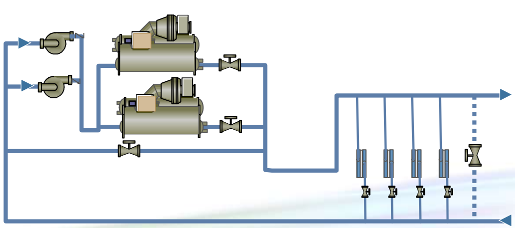
Variable Primary Flow (VPF) Bypass Line

- Sized for the largest minimum flow rate
- Smaller than the pipe going into the largest chiller.



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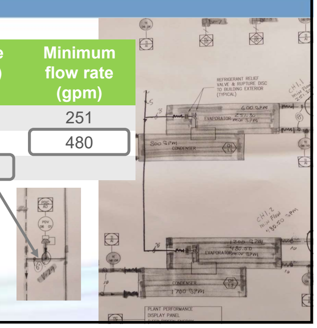
VPF Bypass Line Size

Component	Design flow rate (gpm)	Pipe size (inches)	Minimum flow rate (gpm)
Chiller 1	600	8	251
Chiller 2	1200	10	480
Bypass line	480	6	



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Bypass Line Size Summary

Primary/Secondary

- 110-115% of the largest chiller's flow rate
- Same size as pipe going into largest chiller
- 10 pipe diameters long
- Use piping "U-bend" if supply and return manifolds are close

VPF

- Largest minimum flow rate
- Length not critical

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Today's "Pick-Six" Menu - Ice

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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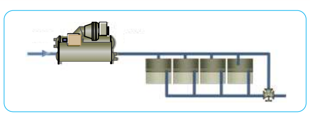
Ice and Chillers in Series

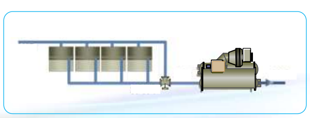
Chiller in upstream position:

- Increases chiller efficiency
- Increases chiller capacity
- Decreases ice capacity
- Simplifies system layout



Chiller in downstream position:

- Decreases chiller efficiency
- Decreases chiller capacity
- Increases ice capacity (reduced number of tanks?)
- Tank capacity benefit is substantial



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ice tanks in series with chiller
Downstream or Upstream?

Example	
On peak cooling required	8,500 ton-hr, 75% diversity (peak/average load)
Length of on peak period	12 hours
System flow rate	1,200 gpm
Cooling coil ∆T	20ºF
Fluid	25% ethylene glycol
Total Peak Tons	1200*20/25.5 = 941 tons
Available space	20 ice storage tanks

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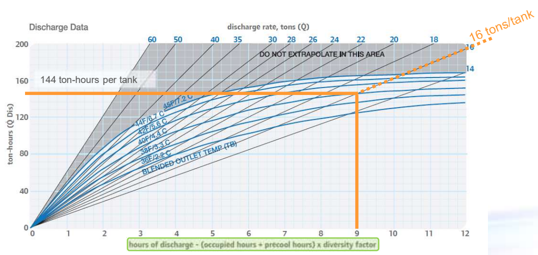
Discharge Data 1190 – 50ºF inlet



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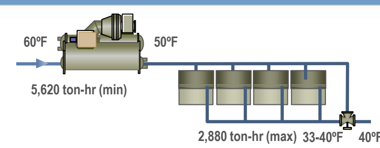
Ice Tanks *Downstream* of Chiller



Total cooling required	=	8,500 ton-hours over 12 hours @ 75% diversity
Cooling by ice tanks	=	2,880 ton-hr (144 x 20)
Cooling by chiller	=	5,620 ton-hr
Ice peak discharge rate	=	320 tons (20 x 16)
On-peak chiller load	=	621 tons (941– 320 tons)
On-peak chiller efficiency (VSD)	=	0.4575 kW/ton
On-peak power draw	=	284 kW

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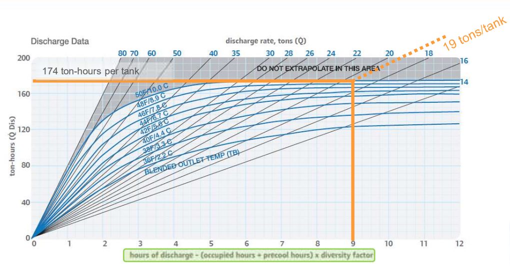
Discharge Data 1190 – 60ºF inlet



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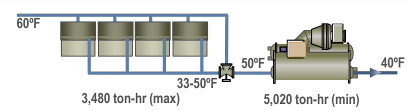
Ice Tanks *Upstream* of Chiller



Total cooling required	=	8,500 ton-hours over 12 hours @ 75% diversity
Max by ice tanks	=	3,480 ton-hr (174 x 20)
Cooling by chiller	=	5,020 ton-hr
Ice peak discharge rate	=	380 tons (20 x 19)
On-peak chiller load	=	561 tons (941– 380 tons)
On-peak chiller efficiency (VSD)	=	0.5932 kW/ton
On-peak power draw	=	333 kW

*Assumes 1200 is max gpm and 50ºF is max entering temp

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ice tanks in series with chiller

Downstream or Upstream
maximize tanks, minimize demand

tank location	downstream of chiller	upstream of chiller
max ice tank capacity 20 tank space constrained	2,880 ton-hr	3,480 ton-hr
on-peak power draw	284 kW	333 kW

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Today's "Pick-Six" Menu - Coils

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
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- One or two pump misperception

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Retrofit Applications

- Same coil: ↑ $\boldsymbol{\Delta T}$ results in ↓ $\boldsymbol{gpm}$
  - $\frac{\Delta T_1}{\Delta T_2} = \frac{GPM_2}{GPM_1}$ with $\Delta T_1 = 10$ and $\Delta T_2 = 15$
- Energy reduction:

0.3

$$gpm \propto \frac{1}{\Delta T}$$

$$kW \propto gpm^3$$

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ASHRAE 90.1-2016

15ºF or higher temperature difference…

6.5.4.7 Chilled-Water Coil Selection

Chilled-water cooling coils shall be selected to provide a 15°F or higher temperature difference between leaving and entering water temperatures and a minimum of 57°F leaving water temperature at *design conditions*.

Exceptions to 6.5.4.7

1. Chilled-water cooling coils that have an air-side pressure drop exceeding 0.70 in. of water when rated at 500 fpm face velocity and dry conditions (no condensation).
2. Individual fan-cooling units with a design supply airflow rate 5000 cfm and less.
3. Constant-air-volume *systems*.
4. Coils selected at the maximum temperature difference allowed by the chiller.
5. Passive coils (no mechanically supplied airflow).
6. Coils with design entering chilled-water temperatures of 50°F and higher.
7. Coils with design entering air dry-bulb temperatures of 65°F and lower.

100 ANSI/ASHRAE/IES Standard 90.1-2016 (I-P)

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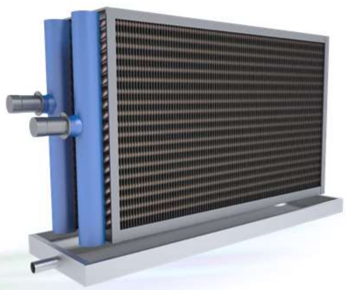
Retrofit Applications

Coil heat transfer:

- It's a simple heat transfer device

$$Q = U \times A \times LMTD$$

- Reacts to colder entering water by returning it warmer



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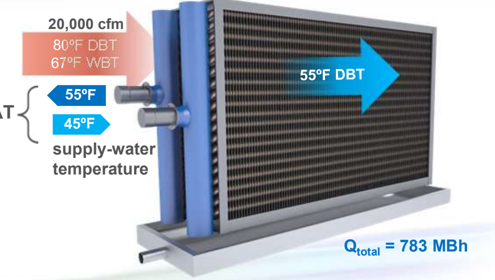
Supply-Water Temperature and ΔT

water ΔT



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Example: Large CSAHU

coil face area, ft^2	40	40
coil rows	6	6
enhanced?	no	no
capacity, mbh	783	783
supply water temperature, °F	45	41
return water temperature, °F	55	56.68
water ΔT, °F	10	15.68
water flow rate, gpm	156.01	99.46
water velocity, ft/sec	4.66	2.97
water pressure drop, ft H_2O	16.48	7.2

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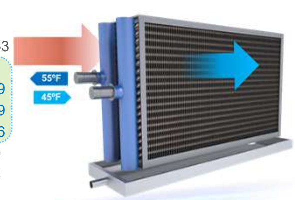
Example: Small CSAHU

coil face area, ft^2	6	6
coil rows	8	8
enhanced?	no	no
capacity, mbh	109.53	109.53
supply water temperature, °F	45	38
return water temperature, °F	55	53.19
water ΔT, °F	10	15.19
water flow rate, gpm	21.83	14.36
water velocity, ft/sec	1.51	0.99
water pressure drop, ft H_2O	1.02	0.48



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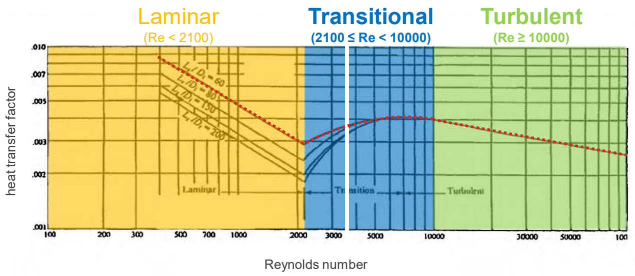

AHRI Standard 410-2001 (Figure 16)

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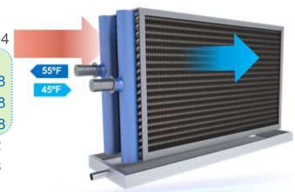
Example: Enhanced Coil Tubes

coil face area, ft^2	6	6
coil rows	8	8
enhanced?	yes	yes
capacity, mbh	117.04	117.04
supply water temperature, °F	45	41
return water temperature, °F	55	56.78
water ΔT, °F	10	15.78
water flow rate, gpm	23.33	14.78
water velocity, ft/sec	1.61	1.02
water pressure drop, ft H_2O	2.72	1.38



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Coil Retrofit Applications

- Works great for coils that have higher fluid velocities
  - Coils with higher Reynolds numbers in particular
- Enhanced tubes enable higher delta Ts with small coils
- Higher delta Ts reduce pressure drop penalty of enhanced tubes
- Rule of thumb: for every 2 degree reduction in EWT, expect about a 1 degree increase in LWT*

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Today's "Pick-Six" Menu – Min/Max Flow

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
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- One or two pump misperception

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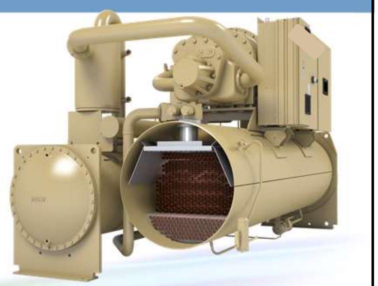
Why do chillers have a maximum and minimum flow?

Chiller Performance

- Evaporator heat transfer
- Condenser heat transfer
- Fouling



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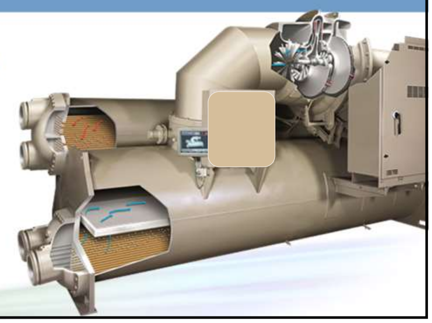
Why do Chillers Have a Minimum Flow?

Chiller Stability

- Low temperature cutout
- High temperature cutout
- Surge
- Lost capacity
- Inconsistent supply temperature



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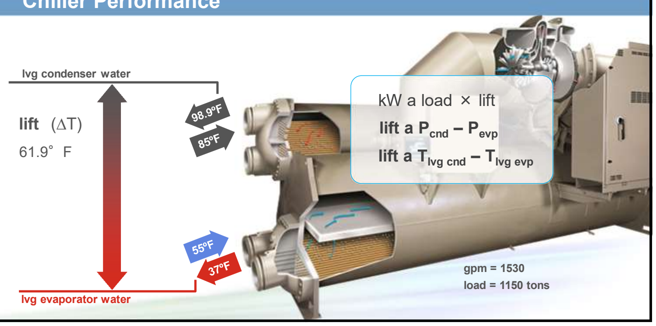
Chiller Performance



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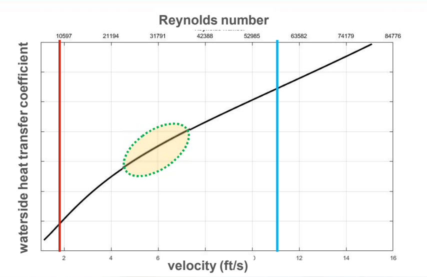
Tube Performance



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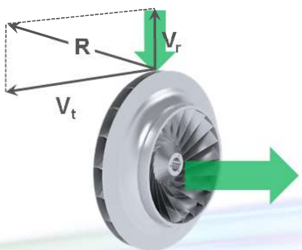
Surge

V_r < static pressure



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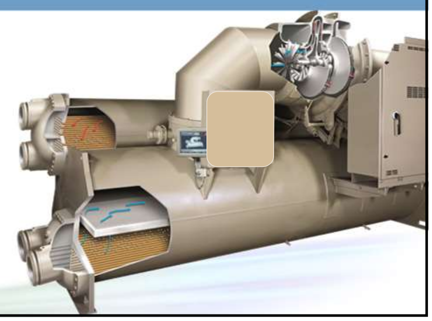
Why do chillers have a maximum flow?

Reliability

- Tube longevity



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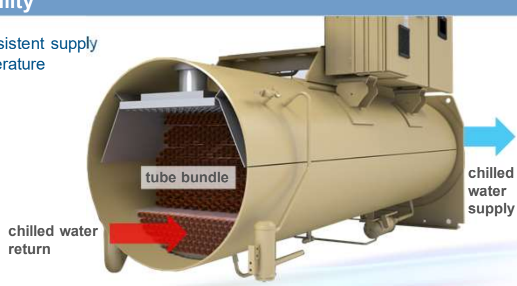
Reliability

- Inconsistent supply temperature



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Why do chillers have a maximum and minimum flow?

Summary

- Chiller performance
- Chiller stability
- Reliability

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Today's "Pick-Six" Menu - Pumps

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
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- One or two pump misperception

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Pop Quiz Answer in Chat
Which design choice do you normally make?

1. Dedicated pumps (one-to-one with chillers)
2. Manifolded pumps

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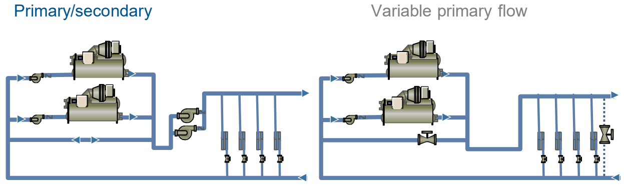
Dedicated Pumps

Primary/secondary

Variable primary flow



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Dedicated Pumps

Advantages
- Simple
  - Pumps and chillers are paired
- Pumps can be selected for different flow rates and pressure drops

Disadvantages
- Lack of redundancy

Mitigation
- Double the number of pumps
- Pipe a "swing pump"

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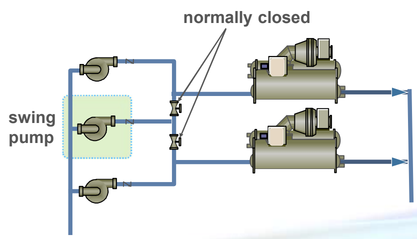
Dedicated Pumps – N+1



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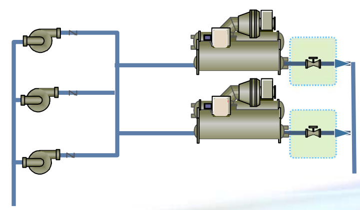
Manifolded Pumps



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Manifolded Pumps

Advantages

- Redundancy, any pump can work with any chiller
- Can optimize pumping separately from cooling (VPF)
- "Overpumping" of chillers in systems with "low ΔT"

Disadvantages with different chillers

- Hard to balance chillers with different flow rates or pressure drops
- Overlap between design and minimum flow rates in a VPF system

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Different Chillers: Evap Pressure Drop

	Capacity (tons)	Selection Flow (gpm)	Selection ΔP (ft H2O)	Actual Flow (gpm)	Actual ΔP (ft H2O)	Flow Change %
Chiller 1	500	750	12	819	14.3	+9.2
Chiller 2	300	450	20	381	14.3	-15.3

- Select evaporator pressure drops as close as possible to one another, OR
- Put balancing valve in series with lower pressure drop chiller(s)

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Manifolded Pumps

Advantages

- Redundancy, any pump can work with any chiller
- Can optimize pumping separately from cooling (VPF)
- "Overpumping" of chillers in systems with "low ΔT"

Disadvantages

- Hard to balance chillers with different flow rates or pressure drops

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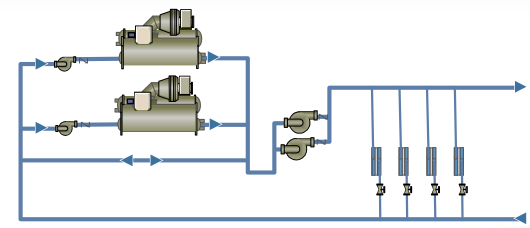
Primary-Secondary System and Low ΔT



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Primary-Secondary Systems and Low ΔT

Mode	Flow rate (gpm)	Inlet Temp (°F)	Outlet Temp (°F)	Capacity (tons)
Design	750	56	40	500

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Primary-Secondary Systems and Low ΔT

Mode	Flow rate (gpm)	Inlet Temp (°F)	Outlet Temp (°F)	Capacity (tons)	
Design	750	56	40	500	
Load conditions	1000	50	40	417	
• Chiller 1	750	46.7	40	208.5	40% each
• Chiller 2	750	46.7	40	208.5	

- Additional pump and chiller operate to satisfy flow (not load) requirements
- Chillers cannot fully load and system may operate inefficiently
- Additional chilled and condenser water pumps must operate

Result: Inefficient system operation

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VPF systems and Low ΔT
"Overpumping" Chillers

Mode	Flow rate (gpm)	Inlet Temp (°F)	Outlet Temp (°F)	Capacity (tons)
Design	750	56	40	500
Actual	1000	50	40	417

- Tons = gpm ΔT / 24
- Chiller is fully loaded by pumping more than design flow through it
- Chilled water system responds more efficiently to Low ΔT but…
- Low Δ must be fixed at the cause – the airside system

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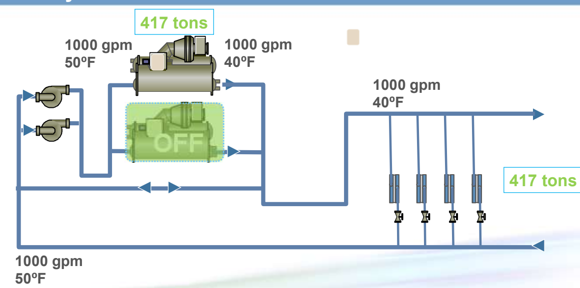
VPF Systems and Low ΔT



62

"Overpumping" and Low ΔT

- "Overpumping" doesn't fix Low ΔT
- The problem is at the coils
- For mitigation techniques:
  - Transactions: AC-02-6-1 -- Degrading Chilled Water Plant Delta-T: Causes and Mitigation

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Pumps Dedicated or Manifolded?

Dedicated
- Different chiller pressure drops (maybe)
- Different chiller capacities

Manifolded
- Redundancy
- Flexibility
- Respond to "low ΔT"

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Today's "Pick-Six" Menu - PICV

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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Pressure Independent (PI) Control Valves

$$C_v = Q \times \sqrt{\frac{SG}{\Delta P}} \qquad Q = C_v \times \sqrt{\frac{\Delta P}{SG}}$$

Where:

- C_v is the flow coefficient of the valve
- Q is the flow rate (gpm)
- SG is the specific gravity of the fluid (water = 1.0)
- ΔP is the pressure drop for the valve (psi)

66

Pressure Independent (PI) Control Valves

Promoted advantages of PI valves:

- More stable
- More accurate
- Easy to select
- Easy to install

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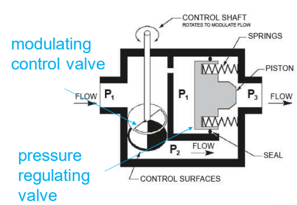
Types of PI Valves

mechanical PI valve



electronic PI valve

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Mechanical PI Valves

Advantages:
- More compact
- Will accept any rotary actuator
- Easier to select
- No additional power, programming, or sensor installation

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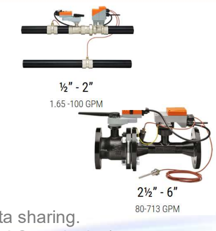
Electronic PI Valves

Advantages:
- Potential for lower hardware costs
- Provides load measurement
- Programmable for various operation methods:
  - Flow limiting
  - ΔT limiting
  - Energy limiting
- BACnet™ Communication to BAS system for data sharing. (requires licensing and commissioning another BACnet device)



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Case Study

- Demonstrated some AHU control problems
- Two floors:
  - 3rd floor AHU retrofitted with a PI valve
  - 4th floor AHU kept existing conventional valve

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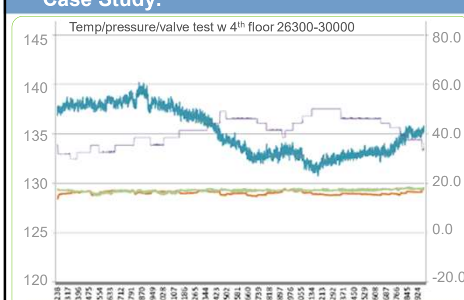
Case Study:



3rd floor (conventional)
4th floor (PI valve)

3rd floor CHW Delta T
4th floor CHW Delta T

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PI Valves—Conclusions

Advantages:
- More stable and accurate
  - Increased delta T
- Easier to select
- Easier to install
- May be cost neutral

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Today's "Pick-Six" Menu – Buffer Tank

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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Buffer Tanks

- Why use them?
- When to use them?
- How big should they be?
- Where should the tank be installed?

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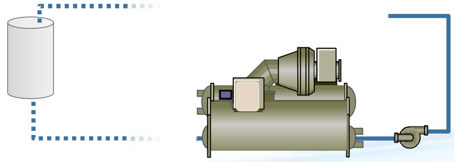
Buffer Tanks: Why Use Them?

- Chiller stability
  - "Loop time" is chiller specific
- Temperature control



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Buffer Tanks: When To Use Them

- Short water loop
- Low loop time

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Buffer Tanks: How Big?

- Required volume =
  Flow rate (gpm) x Loop time (min)
- System volume =
  the amount of fluid in the coil, pipes, evaporator barrel, storage tank, etc., (gallons)
- Methods to attempt to avoid buffer tank
  - Larger pipes
  - Higher Delta T (lower flow rate)

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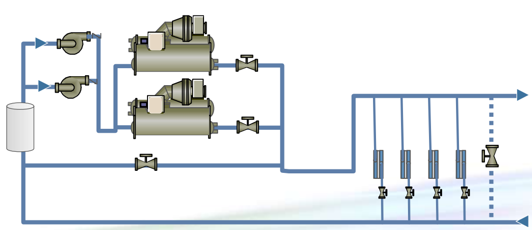
Buffer Tanks: Installed where?

- Return piping, on chiller side of bypass line
- If installed on supply line, cold water bypass when bypass valve opens



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Buffer Tanks: Summary

- Why use them?
  - Stable control
- When do you use them?
  - Loop time too short
- How big should they be?
  - Required volume – system volume
- Where should it be installed?
  - Return piping, on chiller side of bypass line

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Today's "Pick-Six" Menu – Variable CW

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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Pop Quiz – Answer in Chat
What is your opinion about variable condenser water flow?

1. Do it every time
2. Not a chance that it can work
3. Depends on the operators and controls
4. The juice isn't worth the squeeze

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Variable Condenser Water Flow

- Determine minimum condenser-water flow rate… highest of:
  - Cooling tower minimum flow rate
  - Chiller condenser minimum flow rate
  - Minimum pump speed to "lift" water from basin to top of cooling tower
- Determine optimal tower fan and condenser water pump speeds
  - At all combinations of load and wet-bulb temperature experienced during the year
- Ensure controls don't cause the chiller to surge
- Document the system sequence of operation
- Help commission the system

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Base System

- Variable-speed drives on chillers
- Variable-speed drives on cooling tower fans
- Condenser design flow rate: 3 gpm/ton
- Constant flow condenser water pump
- Near-optimal tower control
  (minimize sum of chiller + tower kW at each operating point during the year)

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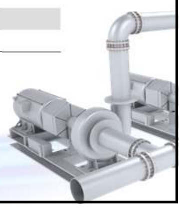
VSD on Condenser Water Pump?

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Plant Annualized kW/ton
VS	VS	3	CF	Opt	0.5462



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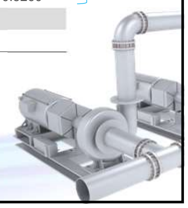
VSD on Condenser Water Pump?

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Plant Annualized kW/ton
VS	VS	3	CF	Opt	0.5462
VS	VS	3	VF	Opt	0.5260

3.7%



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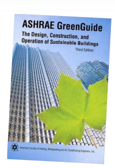
Industry Recommendations for Condenser Water Design

Source	Condenser Water ΔT °F
ASHRAE GreenGuide	12 - 18
50% AEDGs • Small/Med office	(air-cooled)
• K-12 Schools	Not addressed
• Hospitals	≥14
Taylor (ASHRAE Journal)	15
ASHRAE Learning Institute ChW Course	Begin with 15



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VSD on Condenser Water Pump?

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Plant Annualized kW/ton
VS	VS	3	CF	Opt	0.5462
VS	VS	3	VF	Opt	0.5260
VS	VS	2	CF	Opt	0.5255

3.8%

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VSD on Condenser Water Pump?

Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Plant Annualized kW/ton
VS	VS	3	CF	Opt	0.5462
VS	VS	3	VF	Opt	0.5260
VS	VS	2	CF	Opt	0.5255
VS	VS	**2**	**VF**	Opt	0.5252

3.8%

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VSD on Condenser Water Pump?

- Similar savings trends
  - In Chicago, Memphis, Albuquerque and Miami
  - Office buildings and hospitals
  - Two choices (Higher design flow – VF, Lower design flow CF)
    - Performance almost the same in all cases
- Exception in Miami
  - Virtually no savings for variable speed drive on condenser water pump – regardless of design flow rate

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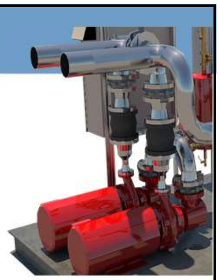
Condenser Water Guidance



- Existing systems designed at 3 gpm/ton
  Consider variable CW flow
  - Savings available
  - **Not** climates that are always humid
  - Determine if the complexity is worth the savings.
- Design new systems for 1.7 – 2.3 gpm/ton
  - Constant speed performance is very close to 3 gpm/ton and variable speed.
  - Keeps the system simple
  - Optimizing the design flow rate and varying condenser water pump speed saves very little additional energy

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Today's "Pick-Six" Menu - SCF

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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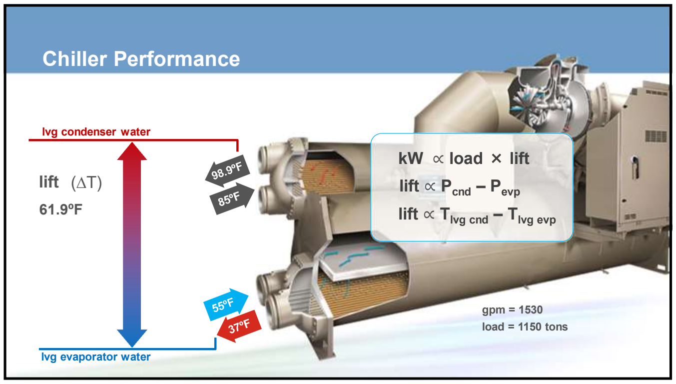
Chiller Performance
lvg condenser water
lift (ΔT)
61.9ºF
98.9ºF
85ºF
55ºF
37ºF
lvg evaporator water
kW ∝ load × lift
lift ∝ P cnd − P evp
lift ∝ T lvg cnd − T lvg evp
gpm = 1530
load = 1150 tons

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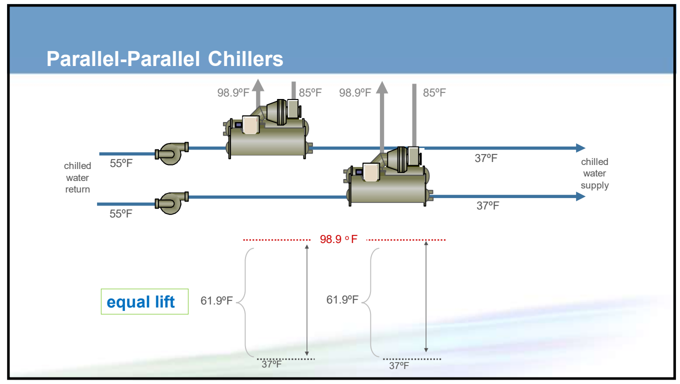
Parallel-Parallel Chillers
98.9ºF
85ºF
98.9ºF
85ºF
chilled water return
55ºF
55ºF
37ºF
37ºF
chilled water supply
98.9 ºF
equal lift
61.9ºF
61.9ºF
37ºF
37ºF

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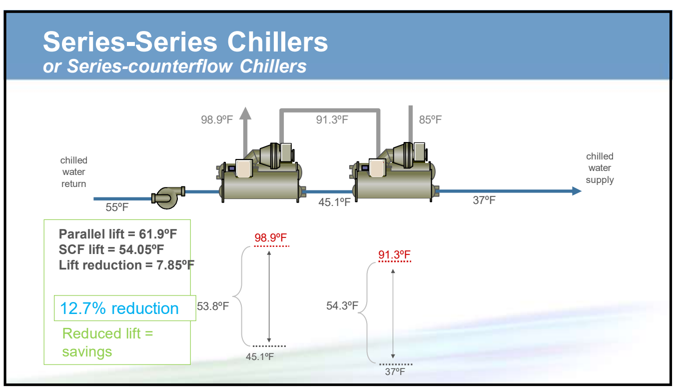
Series-Series Chillers
or Series-counterflow Chillers
98.9ºF
91.3ºF
85ºF
chilled water return
chilled water supply
55ºF
45.1ºF
37ºF
Parallel lift = 61.9ºF
SCF lift = 54.05ºF
Lift reduction = 7.85ºF
12.7% reduction
Reduced lift = savings
98.9ºF
91.3ºF
53.8ºF
54.3ºF
45.1ºF
37ºF

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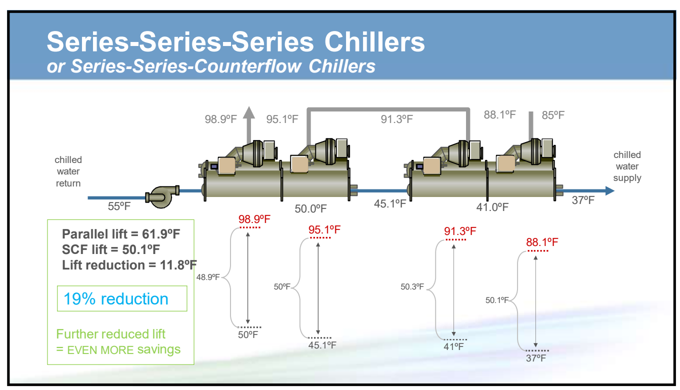
Series-Series-Series Chillers
or Series-Series-Counterflow Chillers
98.9ºF
95.1ºF
91.3ºF
88.1ºF
85ºF
chilled water return
chilled water supply
55ºF
50.0ºF
45.1ºF
41.0ºF
37ºF
Parallel lift = 61.9ºF
SCF lift = 50.1ºF
Lift reduction = 11.8ºF
19% reduction
Further reduced lift = EVEN MORE savings
98.9ºF
95.1ºF
91.3ºF
88.1ºF
50ºF
45.1ºF
41ºF
37ºF

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Summary

- kW α load × lift

Configuration	Lift	% reduction
Parallel	61.9ºF	baseline
Series counterflow	54.05ºF	12.7%
Series duplex	50.1ºF	19%

"Series-Series Counterflow for Central Chilled Water Plants,"
ASHRAE Journal, June 2002.

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Today's "Pick-Six" Menu – Series Control

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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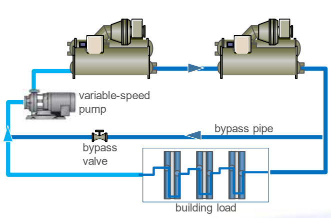
Series Chiller Control

- Chiller setpoints
- Sequencing
- Loading strategies



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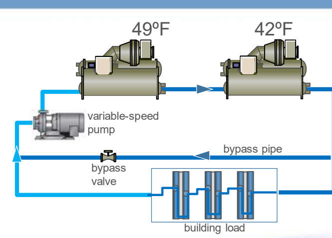
Temperature Control

- Setpoints
  - Equal
  - Staggered



100

Staggered Setpoints

- Downstream setpoint:
  - System supply water temperature
- Upstream setpoint:
  - Dynamically reset to balance load

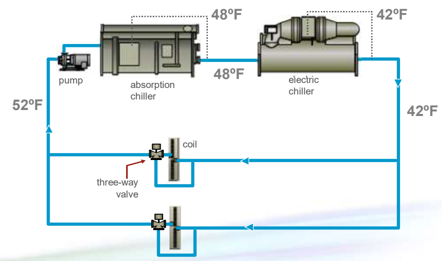
$$Setpoint_{upstream} = RWT - Fraction_{upstream} \times (RWT - SWT)$$

$$Setpoint_{upstream} = 50 - 0.5 \times (50 - 42) = 46$$

101

Loading Strategies

- Preferential loading
  - Upstream chiller
- Equal loading



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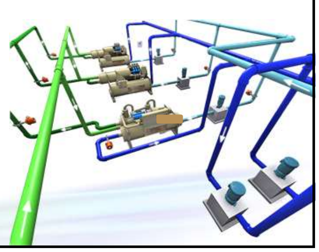
Chiller Sequencing

- Start one chiller
  - The more efficient one or the one with a VFD
- Start next chiller
- Start next chiller pair
- Start/stop chillers in pairs



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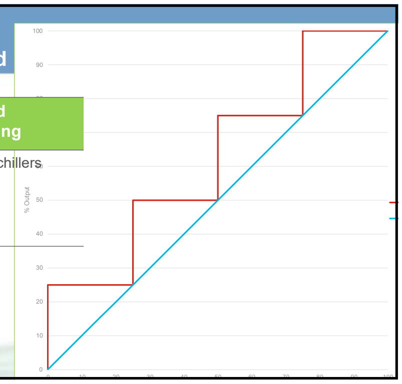
Continuous vs. Stepped

Continuous Unloading	Stepped Unloading
• Centrifugal chillers • Screw (helical-rotary) chillers	• Scroll chillers



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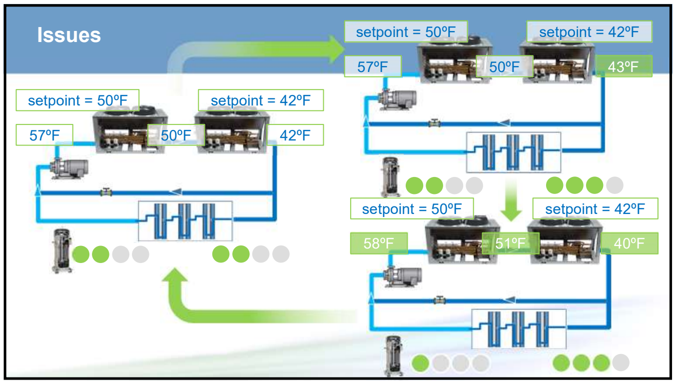
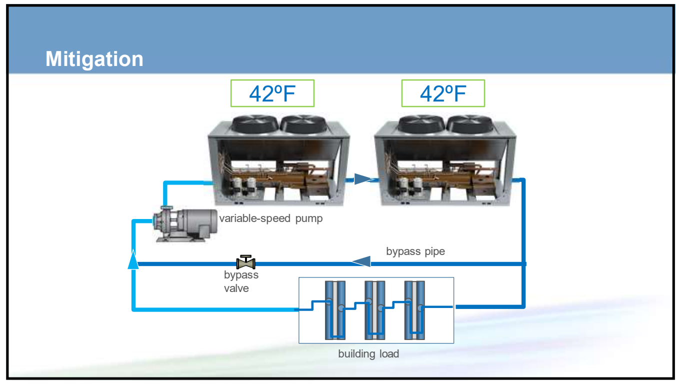


105



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Series Chiller Control

- Downstream setpoint:
  - System supply water temperature
- Upstream setpoint:
  - Centrifugal or helical-rotary compressors:
    - Dynamically reset to balance load
  - Constant speed scroll compressors:
    - System supply water temperature
- Sequencing

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Today's "Pick-Six" Menu – Pump Misperception

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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Is It More Efficient to Operate More Pumps?

Pump laws

- Flow ∝ Speed
- ΔP ∝ Flow²
- Power ∝ Flow³

Thought process

- Operating more pumps decreases flow per pump
- Power ∝ Flow³

2 x Design kW x (50% Flow)³ < Design kW?

0.25 x Design kW < Design kW?

Improper use of pump laws

System flow rate and ΔP don't change for most components

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Pump Power

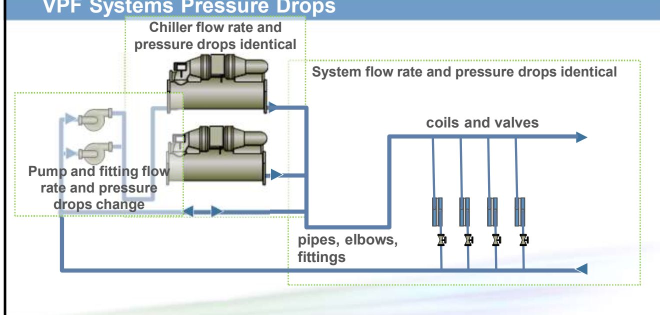
$$Pump\ kW = \frac{Flow \times \Delta P \times 0.746}{3960 \times Pump\ eff \times Motor\ eff \times Drive\ eff}$$

Turn on another pump

- System flow is the same
- Pump, motor and drive efficiency may get better or worse
- How does system ΔP change?

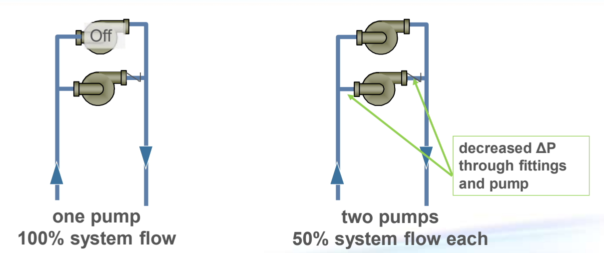
110

VPF Systems Pressure Drops



111

Pressure Drop – Pump Manifold



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Pump Power

$$Pump\ kW = \frac{Flow \times \Delta P \times 0.746}{3960 \times Pump\ eff \times Motor\ eff \times Drive\ eff}$$

113

Operate an Additional Pump?

$$Pump\ kW = \frac{Flow \times \Delta P \times 0.746}{3960 \times Pump\ eff \times Motor\ eff \times Drive\ eff}$$

- System flow: Identical
- Chiller, coil and piping pressure drop identical
- System pressure drop a little lower (pump and fittings)
- Are pump, motor and drive efficiencies similar? Better? Worse?
- At same efficiencies, pump power a little lower

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Savings are NOT proportional to the cube of the pump flow

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Today's "Pick-Six" Menu – Bonus!!!

- Bypass line sizing
- Ice tanks upstream or downstrea... rs
- Use of existing coils
- Minimum and maxim...
- Pumps: Manifol...
- Pressure ...
- Bu...
- ... r flow
- ... savings (even for small systems)
- ... hillers in series
- C... r two pump misperception

BONUS!!!

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Bonus

- How did 10ºF ΔT originate?

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ASHRAE 90.1-2016 & 2019

15ºF or higher temperature difference… minimum 57ºF leaving water temperature

6.5.4.7 *Chilled-Water Coil Selection*

Chilled-water cooling coils shall be selected to provide a 15°F or higher temperature difference between leaving and entering water temperatures and a minimum of 57°F leaving water temperature at *design conditions*.

Exceptions to 6.5.4.7

1. Chilled-water cooling coils that have an air-side pressure drop exceeding 0.70 in. of water when rated at 500 fpm face velocity and dry conditions (no condensation).
2. Individual fan-cooling units with a design supply airflow rate 5000 cfm and less.
3. Constant-air-volume *systems*.
4. Coils selected at the maximum temperature difference allowed by the chiller.
5. Passive coils (no mechanically supplied airflow).
6. Coils with design entering chilled-water temperatures of 50°F and higher.
7. Coils with design entering air dry-bulb temperatures of 65°F and lower.

100 ANSI/ASHRAE/IES Standard 90.1-2016 (I-P)

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Industry Recommendations Temperature Differences

Source	Chilled Water ∆T ºF	Condenser Water ∆T ºF
ASHRAE® 90.1-2016	≥ 15	Not addressed
ASHRAE GreenGuide	12 – 20	12 - 18
50% AEDGs		
• Small/Med office	≥15	(air-cooled)
• K-12 Schools	12 – 20	Not addressed
• Hospitals	≥15	≥14
Taylor (ASHRAE Journal)	>12	15
ASHRAE Learning Institute ChW Course	Begin with 25!	Begin with 15

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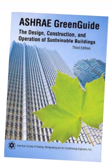
After 85 years it's time to listen to the industry… …and provide better system designs.

Source	Chilled Water ∆T (ºC)	Condenser Water ∆T (ºC)
ASHRAE® 90.1-2016	≥ 8.3	
ASHRAE GreenGuide	6.7 – 11	6.7 - 10
50% AEDGs		
• Small/Med office	≥8.3	
• K-12 Schools	16.7 – 11	
• Hospitals	≥18.3	≥7.8
Taylor (ASHRAE Journal)	>6.7	8.3
ASHRAE Learning Institute ChW Course	14	8.3



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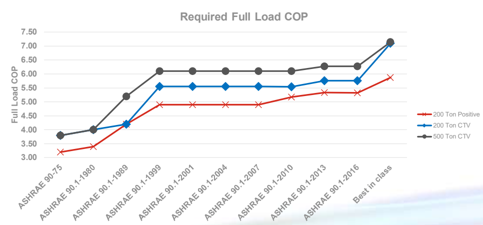
A History of Chiller Performance



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Q: Where did the old tradition of 10ºF [5.6ºC] ∆T originate?

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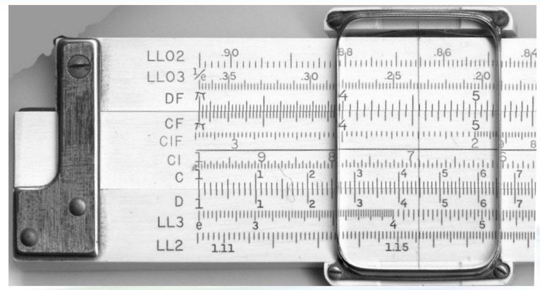
Theory 1: Slide Rules or Dividing by 10



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Theory 2: AHRI 550/590 "Standard" Rating Conditions

- Evaporator: 2.4 gpm/ton (yields 10ºF)
- Condenser 3.0 gpm/ton with COP of 4 yields 10ºF

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Theory 3: Willis Carrier

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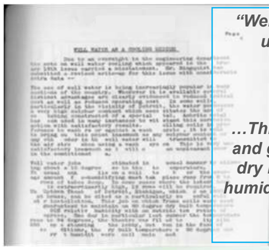
Theory 4:
10 degrees "started" with well water

- March 2, 1935



"Well water jobs can be estimated in the usual manner by allowing about a
10 degree (F) rise
in the well water temperature….

…This job on which (the) coils were used and guaranteed to maintain an 80 degree dry bulb temperature and a 50% relative humidity with an outside air temperature of 95 degrees."

125

After 87 years it's time to listen to the industry …and provide better system designs.

Source	Chilled Water ∆T °F	Condenser Water ∆T °F
ASHRAE® 90.1-2016	≥ 15	Not addressed
ASHRAE GreenGuide	12 – 20	12 - 18
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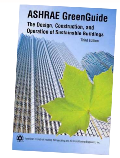
Taylor (ASHRAE Journal)	>12	15
ASHRAE Learning Institute ChW Course	Begin with 25!	Begin with 15



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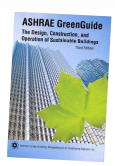
After 87 years it's time to listen to the industry… …and provide better system designs.

Source	Chilled Water ∆T (°C)	Condenser Water ∆T (°C)
ASHRAE® 90.1-2016	≥ 8.3	
ASHRAE GreenGuide	6.7 – 11	6.7 - 10
50% AEDGs • Small/Med office	≥8.3	
• K-12 Schools	16.7 – 11	
• Hospitals	≥18.3	≥7.8
Taylor (ASHRAE Journal)	>6.7	8.3
ASHRAE Learning Institute ChW Course	14	8.3



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Today's "Pick-Six" Menu

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings (even for small systems)
- Controlling chillers in series
- One or two pump misperception

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BONUS!!!

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ASHRAE 2019-2025 Strategic Plan

- Initiatives
  - Resilient Buildings and Communities
  - Indoor Environmental Quality
  - Organizational Streamlining
  - Improve Chapter Engagement, Capacity and Support

https://www.ashrae.org/about/strategic-plan

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Please fill out the DL Evaluation Form

Thanks for all the volunteering you do

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