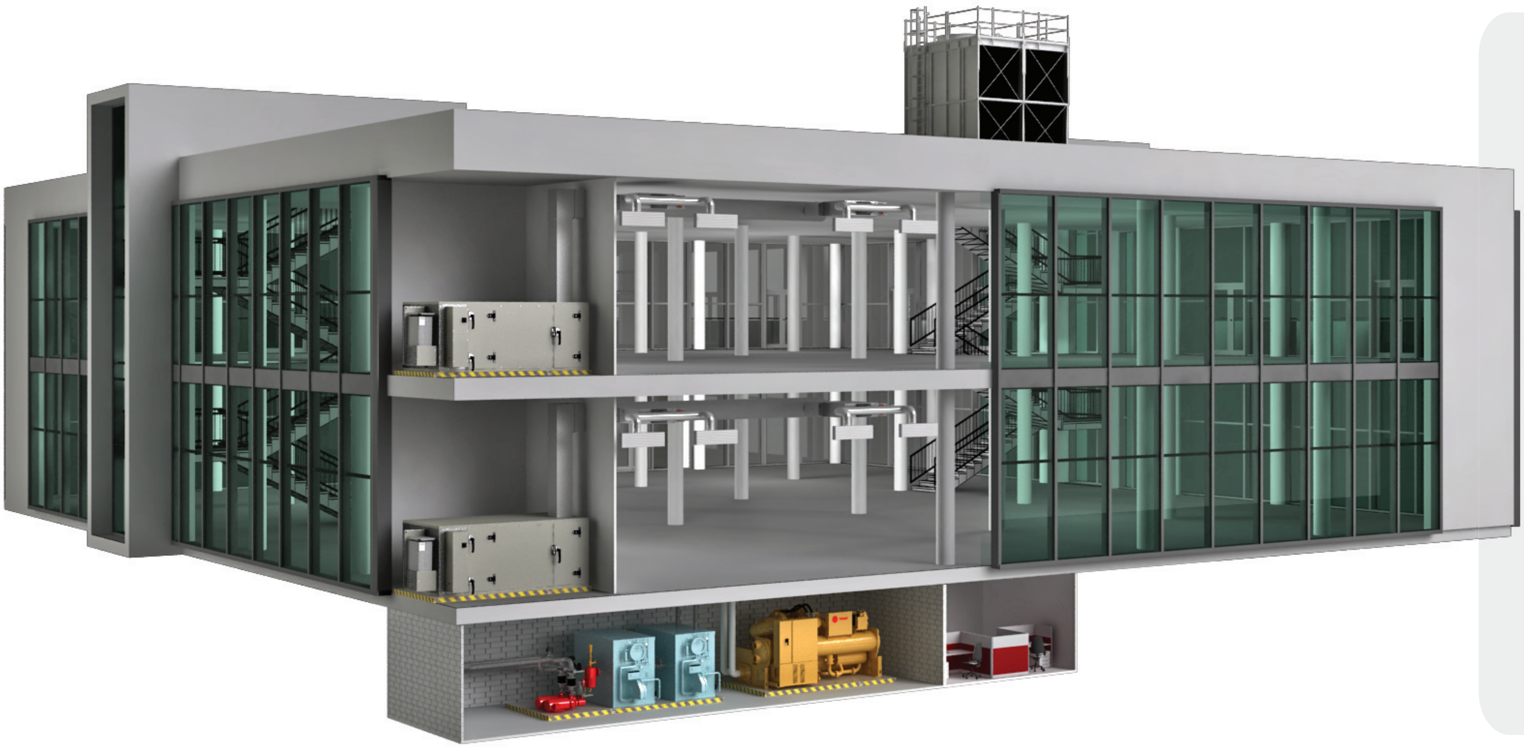
Trane Engineers Newsletter Live

Chilled-Water System Decisions

with Trane Engineers Dustin Meredith, Mick Schwedler, Justin Wieman and Jeanne Harshaw (host)



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Agenda

Trane *Engineers Newsletter Live* Series

Chilled-Water System Decisions

Abstract

Many chilled-water system decisions are made during the course of the design process. Those design decisions and the specific application lead to other system decisions – such as bypass line sizing and length, pump location, use of pressure independent valves, buffer tank size, etc. This ENL covers the reasons for many system decisions. Viewers will leave with practical guidance that should simplify the decision-making process for future design of chilled-water systems.

Presenters: Trane engineers Dustin Meredith, Mick Schwedler and Justin Wieman

After viewing attendees will be able to:

1. Summarize various control strategies for chillers in series
2. Understand how to properly size bypass lines in a chilled-water system
3. Determine whether to apply triple duty or balancing valves at the pump discharge
4. Summarize the importance of staying within the minimum and maximum flow limits
5. Identify the differences between manifolded or dedicated pumps
6. Determine whether to use existing coils for higher delta Ts

Agenda

Common Considerations

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils

Component Considerations

- Minimum and maximum flow limits
- Valves: Balancing or triple duty
- Pumps: Manifolded or dedicated
- Pressure independent valves
- Buffer tank size

AdvancedConsiderations

- Variable condenser-water flow
- Series counterflow savings
- Controlling chillers in series
- One or two pump misperception

Ingersoll Rand

Presenter biographies

Chilled-Water System Decisions

Dustin Meredith | systems engineer | Trane

Dustin joined Trane in 2000 as a marketing engineer and has spent most of his career in applications engineering. In his current role as a systems engineer, he develops and optimizes next-generation systems. His expertise includes fans, acoustics, air system design and overall system optimization. Dustin holds multiple patents and has been instrumental in advancing cutting-edge fan and motor applications to industry. He has authored a variety of technical engineering bulletins, white papers, Trane Engineers Newsletter articles and Trane Engineers Newsletter LIVE programs.

Dustin is a registered professional engineer and earned his mechanical engineering and computer science degrees from the University of Kentucky. He continued his education with an MBA from the Gatton College of Business and Economics at the University of Kentucky. Dustin is an ASHRAE Section Head and serves on the "Fans" and "Sound and Vibration" technical committees, including as past Chair of the latter. He is Trane's voting member for Air Movement and Control Association International, Inc. (AMCA) and serves on a number of AMCA committees.

Mick Schwedler | applications engineer | Trane

Mick has been involved in the development, training, and support of mechanical systems for Trane since 1982. With expertise in system optimization and control (in which he holds patents), and in chilled-water system design, Mick's primary responsibility is to help designers properly apply Trane products and systems. Mick provides one-on-one support, writes technical publications, and presents seminars.

Mick is an ASHRAE Fellow and Vice President on the Board of Directors. He is a recipient of ASHRAE's Exceptional Service, Distinguished Service and Standards Achievement Awards. He is past Chair of SSPC 90.1 and contributed to the ASHRAE GreenGuide. He is also active with the U.S. Green Building Council, having served on technical and education committees and is currently the LEED Technical Committee Chair. Mick earned his BSME degree from Northwestern University and his MSME from the University of Wisconsin Solar Energy Lab.

Justin Wieman | applications engineer | Trane

Justin Wieman partners with customers providing them system design and product knowledge to develop and deliver efficient, innovative, and sustainable designs.

Justin has been with Trane since 2001, and has held a variety of key roles within Trane including technical marketing, engineering, as well as project and product support management. Along with his HVAC chiller technology experience, Justin has also led efforts to develop and deploy Trane's suite of Design and Analysis tools that enable engineers to effectively design HVAC systems and develop the corresponding life cycle cost analyses, which includes managing the TRACE® 700 software. Justin earned his bachelor's degree in Chemical Engineering from the South Dakota School of Mines and Technology.

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Engineers Newsletter LIVE Series

Chilled-Water System Decisions

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What You'll Learn Today…

- A few control strategies for chillers in series
- How to properly size bypass lines in a chilled-water system
- Applying triple duty or balancing valves at the pump discharge
- The importance of staying within the minimum and maximum flow limits
- Differences between manifolded or dedicated pumps
- Whether you can use existing coils for higher delta Ts

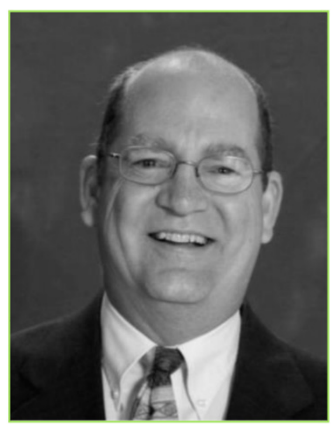
Today's Agenda

- 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

Today's Experts…

DUSTIN MEREDITH
systems engineer

JUSTIN WIEMAN
applications engineer



MICK SCHWEDLER
applications engineer

Today's Agenda

- **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
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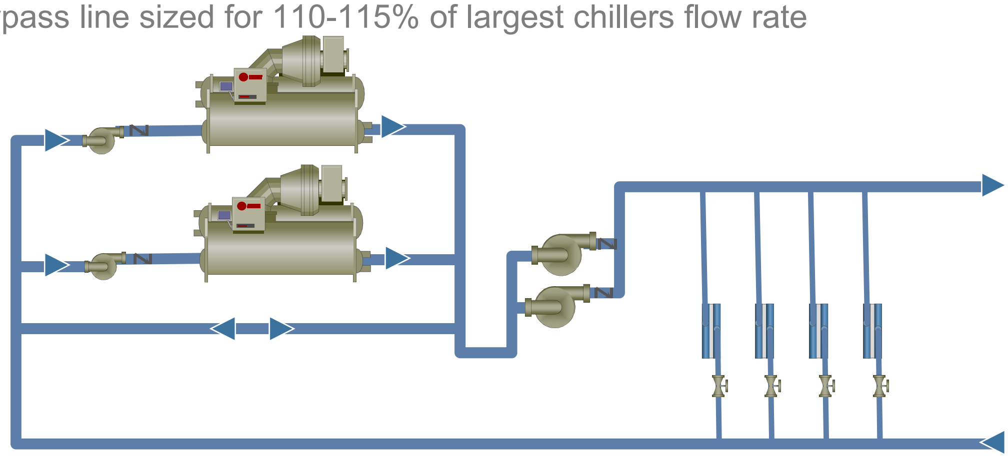
- One or two pump misperception

Primary/Secondary Operation

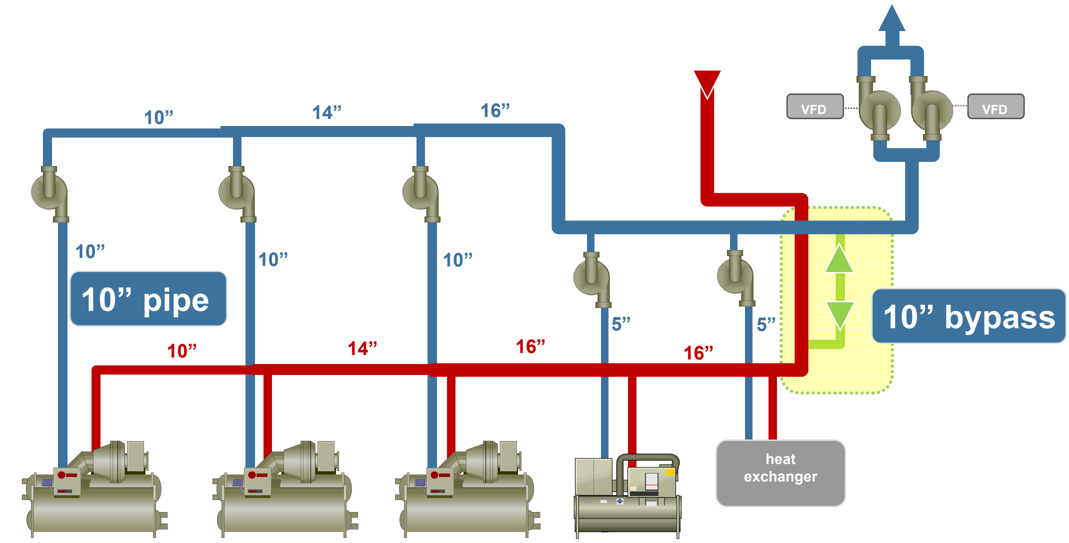
Turn chiller off when chiller(s) remaining on can satisfy load and flow

- Excess bypass flow ≥ 1.10 x chiller flow rate
- Bypass line sized for 110-115% of largest chillers flow rate



Primary/Secondary

Properly Sized Bypass

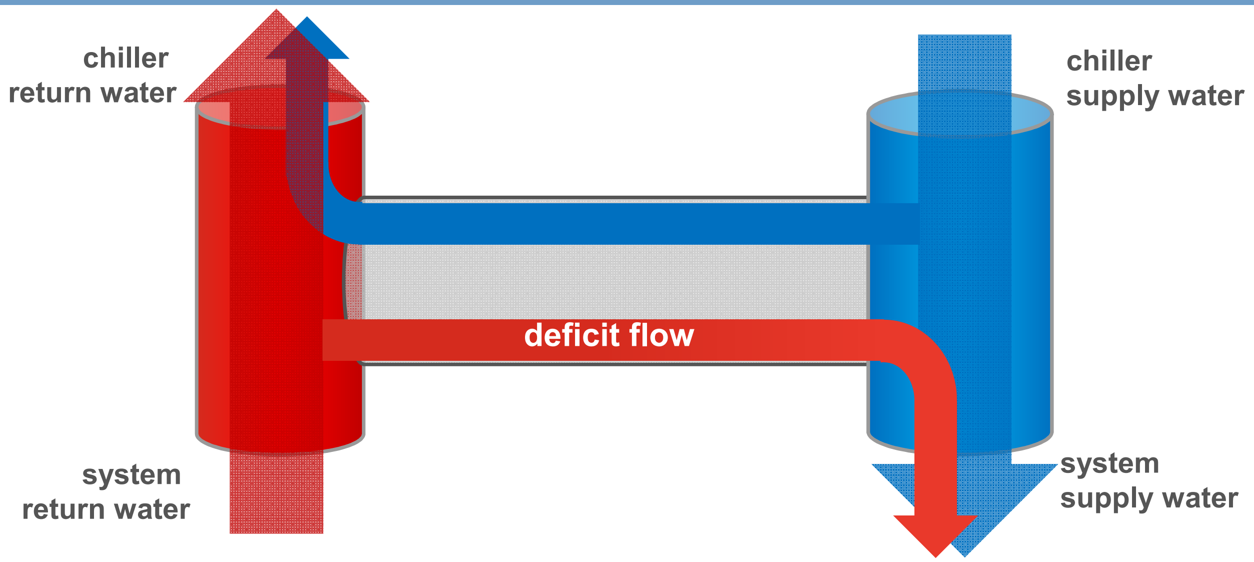


Primary/Secondary

Example: Oversized Bypass

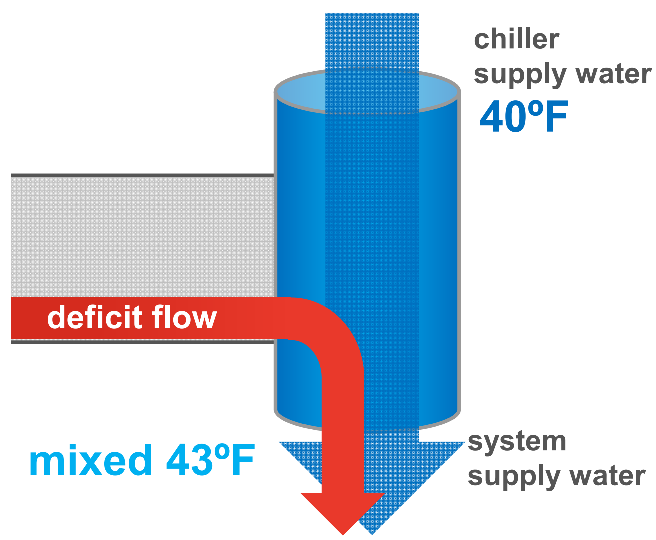
- University chilled-water plant
  - 5000 tons
  - 10,000 gpm (12ºF ∆T)
  - Manifold pipe size: 24”
- Five 1000 ton chillers
  - 2000 gpm
  - Pipe size: 10”
- Bypass
  - Size: 24” (same as manifolds)
  - Length: 8’ (very little pressure drop)

Primary/Secondary
Oversized Bypass



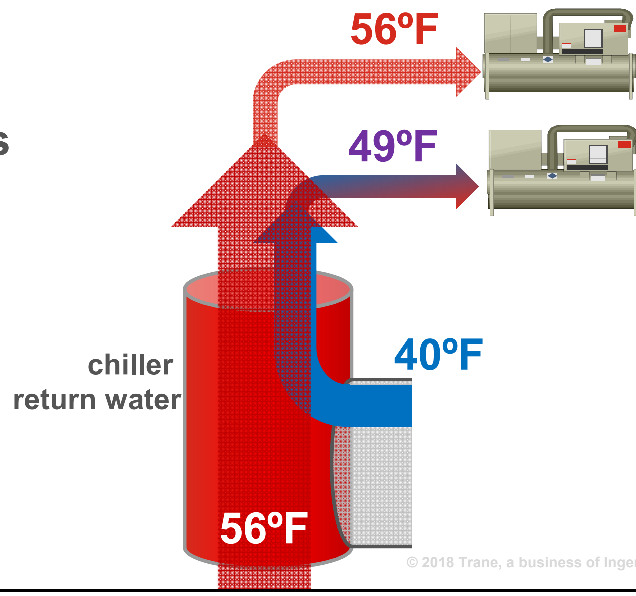
Primary/Secondary
Oversized Bypass Symptom 1

- Can't maintain system supply water temperature



Primary/Secondary
Oversized Bypass Symptom 2

- Can't load chiller closest to the bypass



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

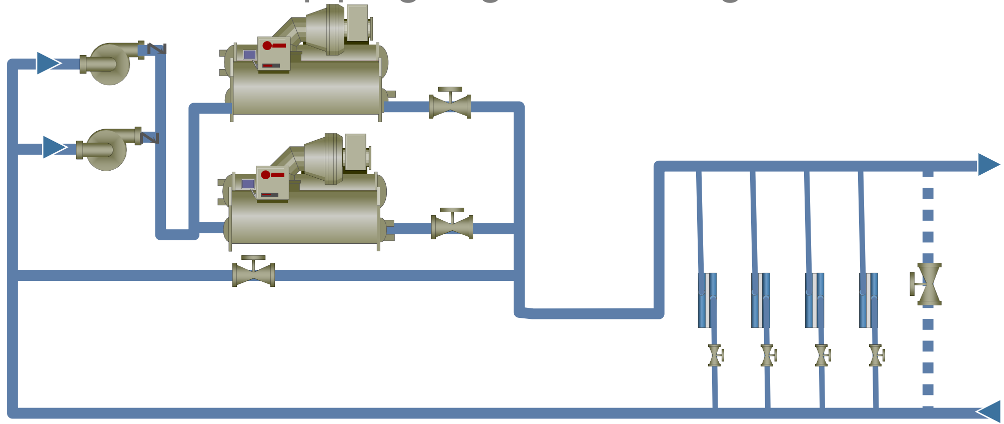
Best to ensure the bypass pipe is sized properly

Primary/Secondary

Short Bypass Line

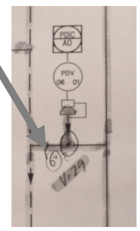
Variable Primary Flow (VPF) Bypass Line

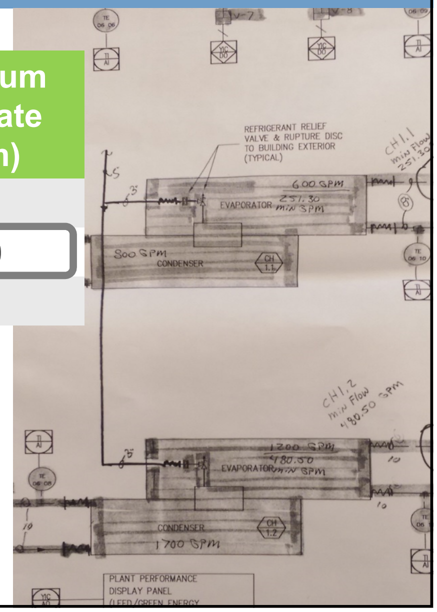
- Sized for the largest minimum flow rate
- Smaller than the pipe going into the largest chiller.



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	





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

Today's Agenda

- 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
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- Controlling chillers in series
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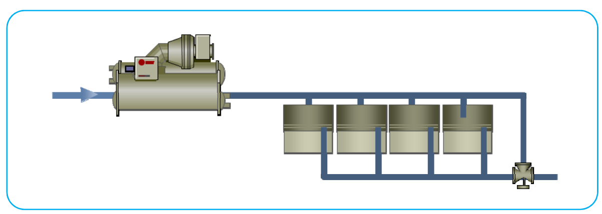
Ice and Chillers in Series

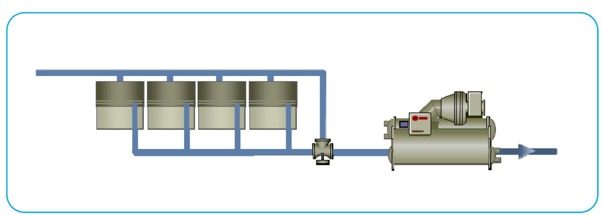
Chiller in upstream position:

- 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

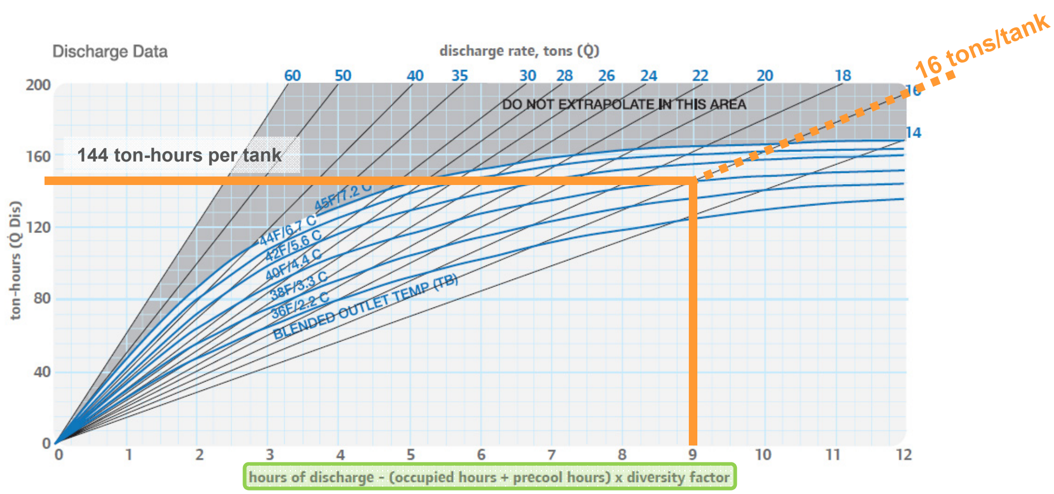


ice tanks in series with chiller

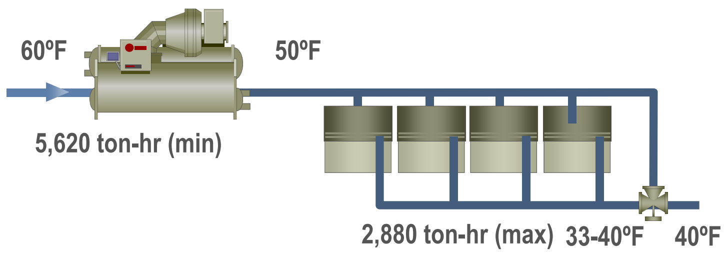
Downstream or Upstream?

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

Discharge Data 1190 – 50ºF inlet

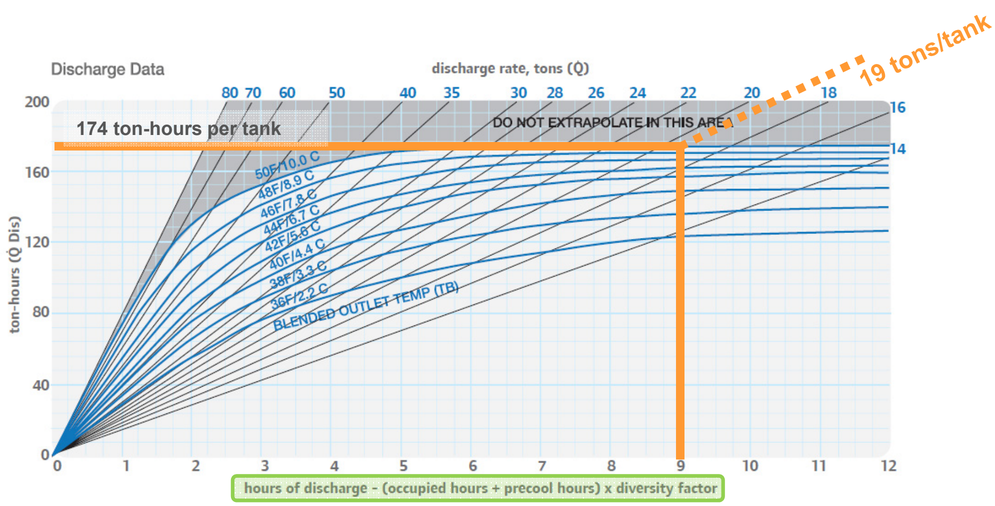


Ice Tanks *Downstream* of Chiller

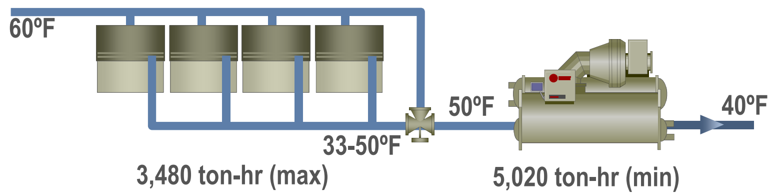


Total cooling required	=	8,500 ton-hours over 12 hours @ 75% diversity
Cooling by ice tanks	=	2,880 ton-hr (144 x 20)
Cooling by chiller	=	5,620 ton-hr
Ice peak discharge rate	=	320 tons (20 x 16)
On-peak chiller load	=	621 tons (941– 320 tons)
On-peak chiller efficiency (VSD)	=	**0.4575 kW/ton**
On-peak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

Discharge Data 1190 – 60ºF inlet



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**

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

Today's Agenda

- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- **Use of existing coils**
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Retrofit Applications

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

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

$$kW \propto gpm^3$$

ASHRAE 90.1-2016

15ºF or higher temperature difference…

6.5.4.7 Chilled-Water Coil Selection

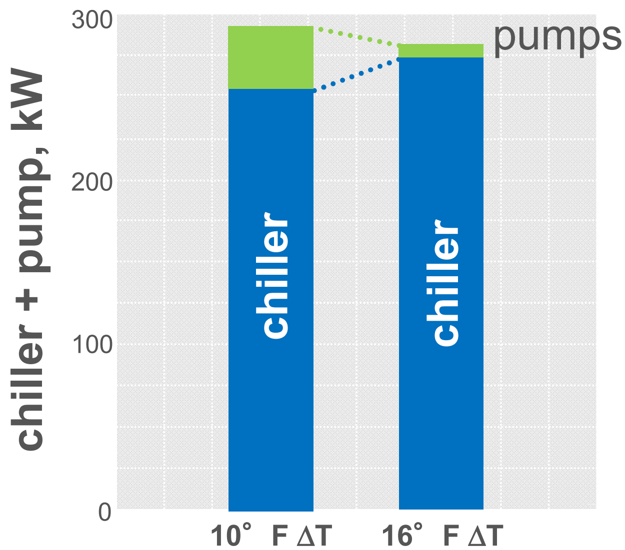
Chilled-water cooling coils shall be selected to provide a 15°F or higher temperature difference between leaving and entering water temperatures and a minimum of 57°F leaving water temperature at *design conditions*.

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)

Low-Flow Chiller Plants



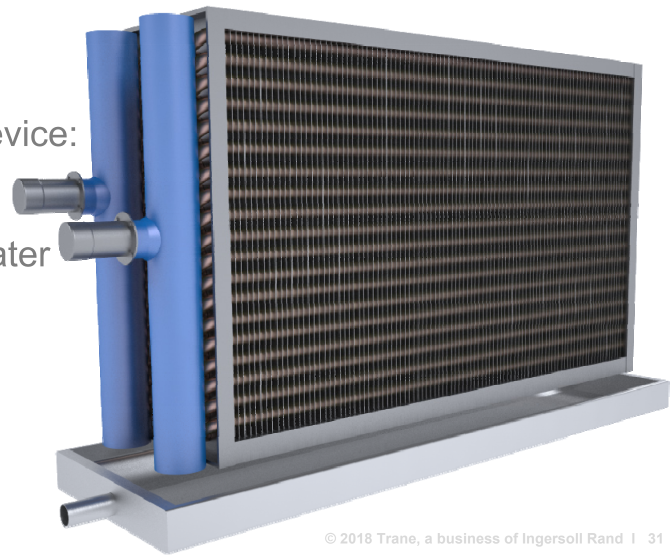
Retrofit Applications

Coil heat transfer:

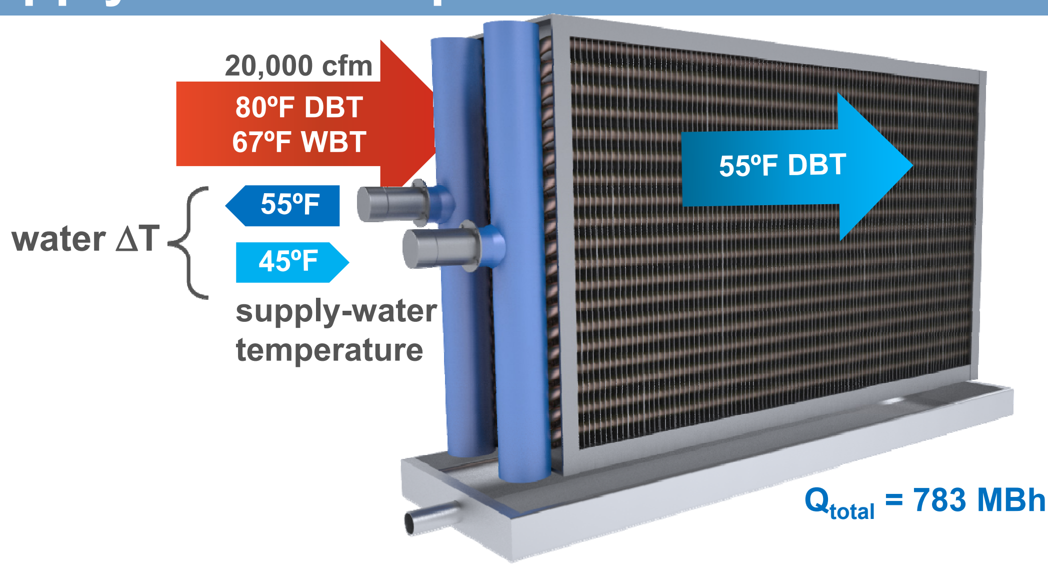
- It's a simple heat transfer device:

  $Q = U \times A \times LMTD$

- Reacts to colder entering water by returning it warmer



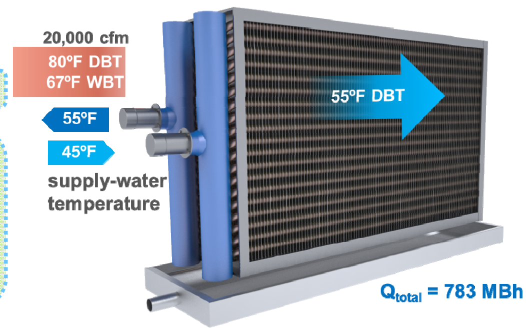
Supply-Water Temperature and ΔT



Q_{total} = 783 MBh

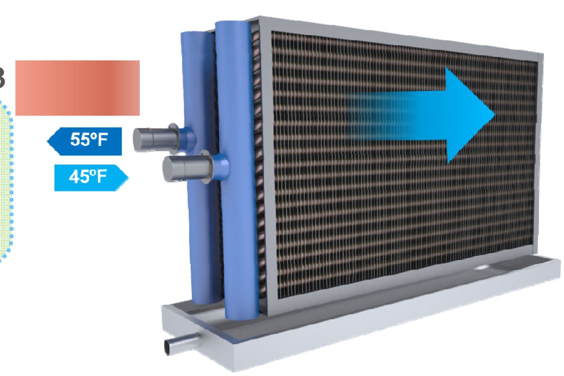
Example: Large CSAHU

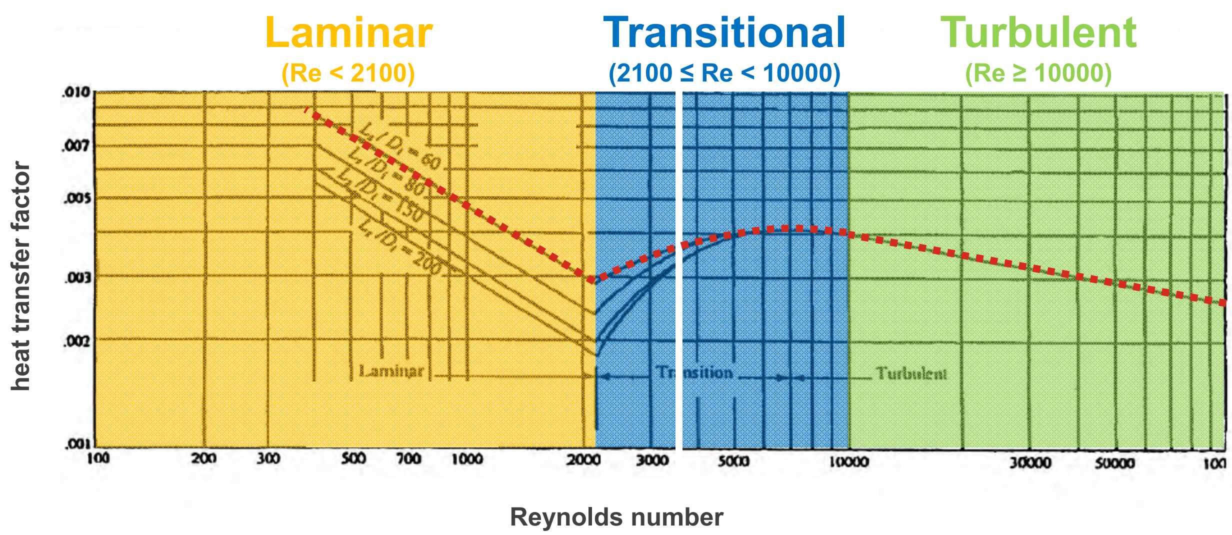
coil face area, ft^2	40	40
coil rows	6	6
enhanced?	no	no
capacity, mbh	783	783
supply water temperature, ºF	45	41
return water temperature, ºF	55	56.68
water ΔT, ºF	10	15.68
water flow rate, gpm	156.01	99.46
water velocity, ft/sec	4.66	2.97
water pressure drop, ft H_2O	16.48	7.2



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, ºF	45	38
return water temperature, ºF	55	53.19
water ΔT, ºF	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

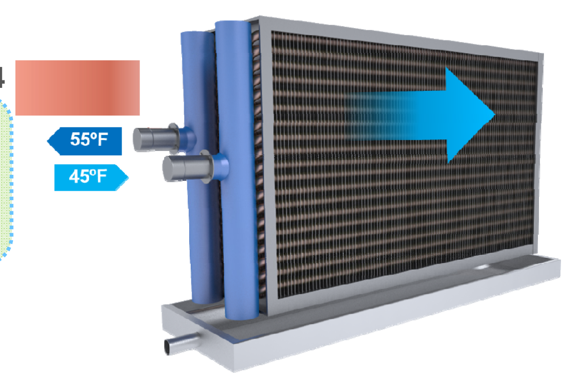




AHRI Standard 410-2001 (Figure 16)

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, ºF	45	41
return water temperature, ºF	55	56.78
water ΔT, ºF	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



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*

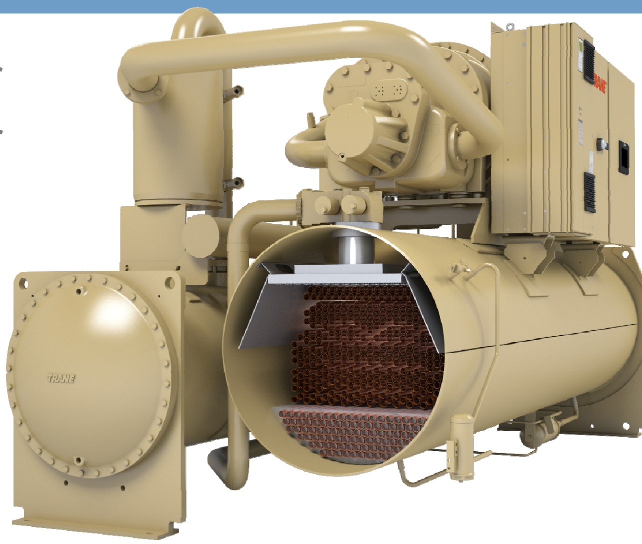
Today's Agenda

- 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

Why do chillers have a maximum and minimum flow?

Chiller Performance

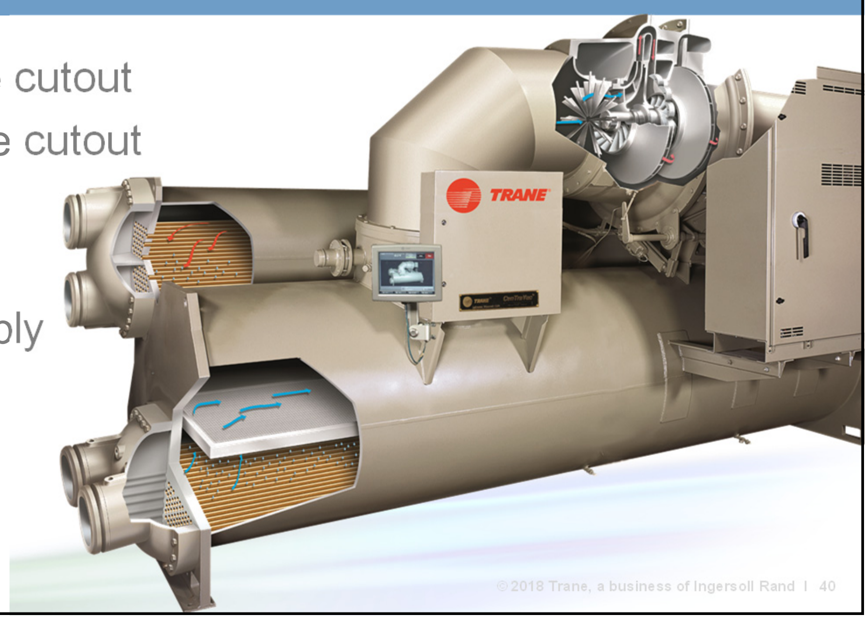
- Evaporator heat transfer
- Condenser heat transfer
- Fouling



Why do Chillers Have a Maximum and Minimum Flow?

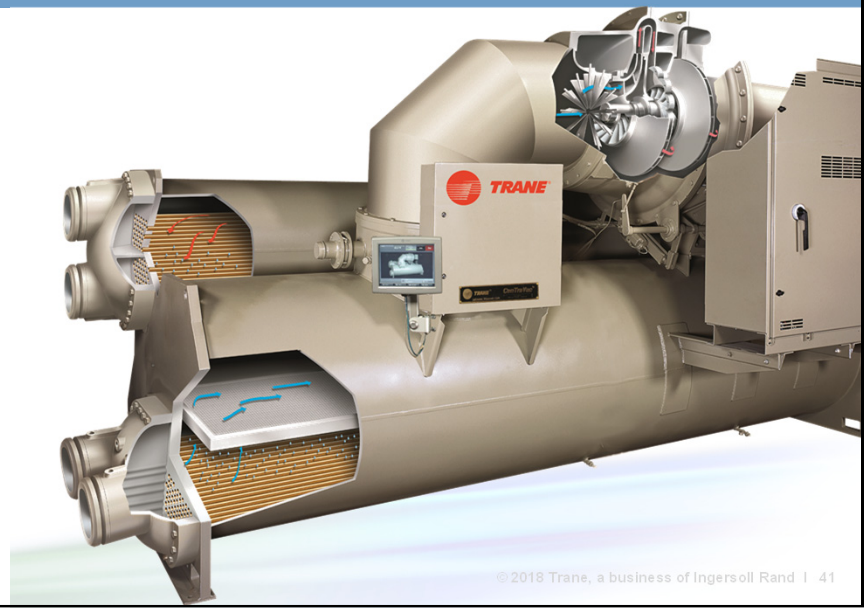
Chiller Stability

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

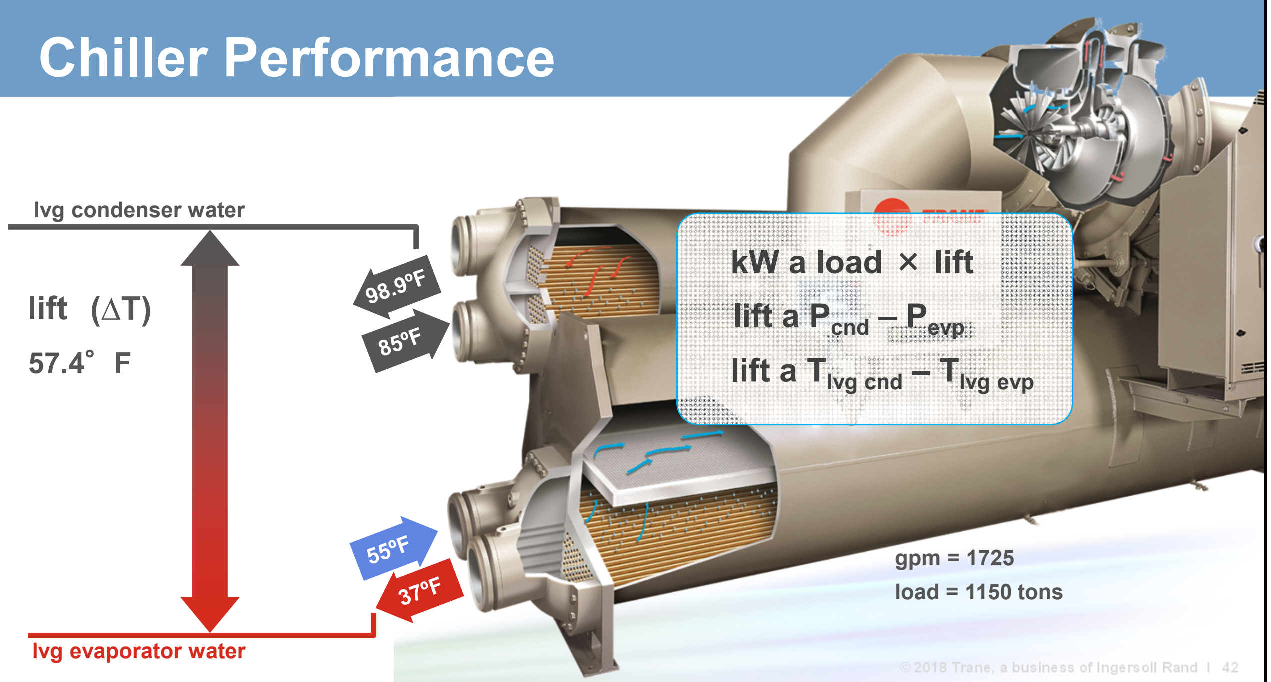


Why do chillers have a maximum and minimum flow?
Reliability

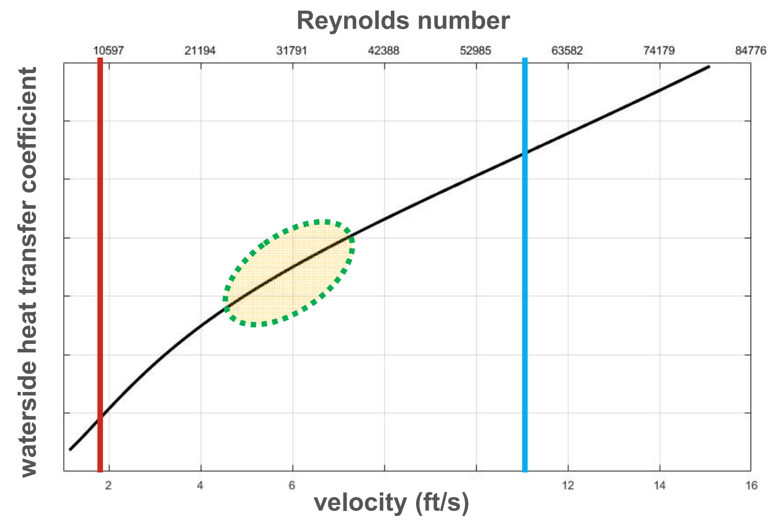
- Tube longevity



Chiller Performance



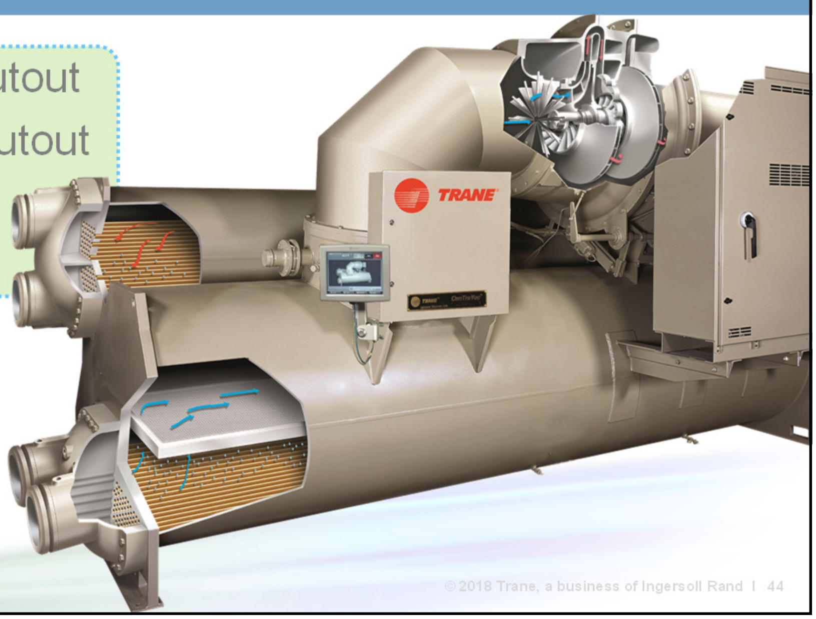
Tube Performance



Why do chillers have a maximum and minimum flow?

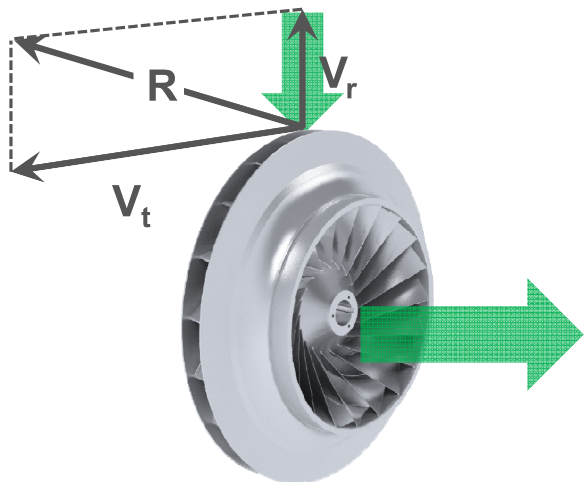
Chiller Stability

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



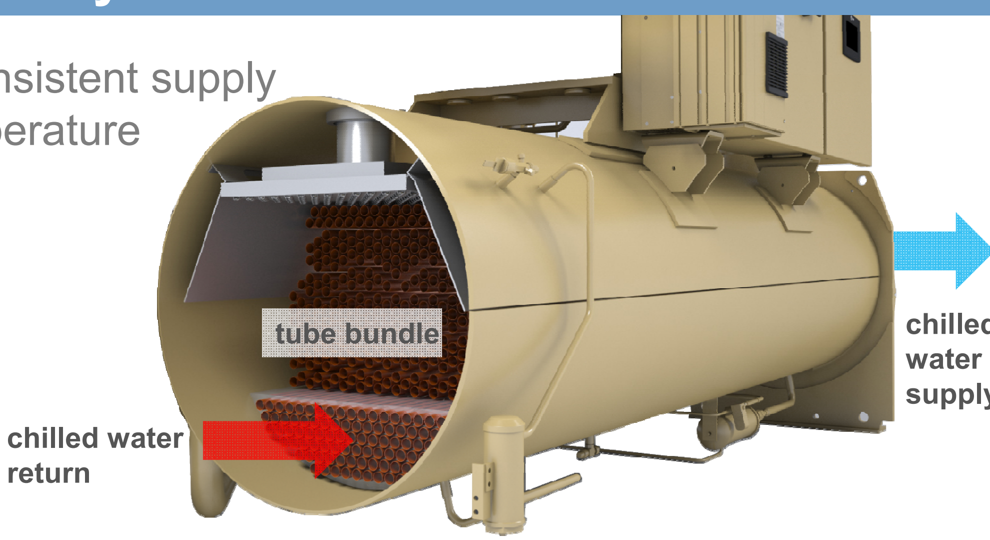
Surge

V_r < static pressure



Reliability

- Inconsistent supply temperature



Why do chillers have a maximum and minimum flow?

Summary

- Chiller performance
- Chiller stability
- Reliability

Today's Agenda

- 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
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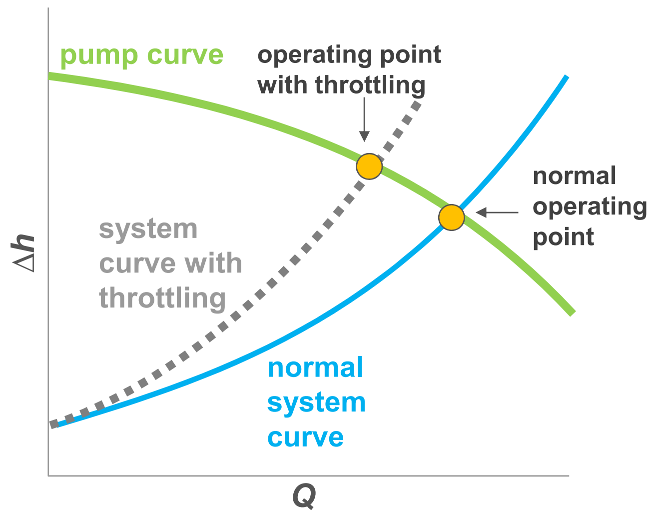
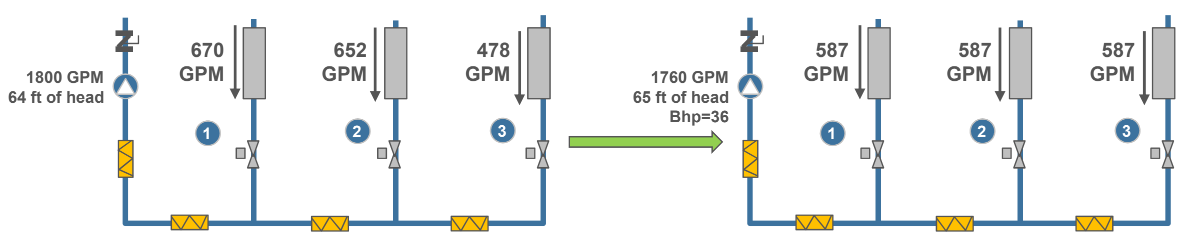
Balancing Valves
(a.k.a. pump throttling valves)

- Why are they needed?
  - Pumps are often oversized



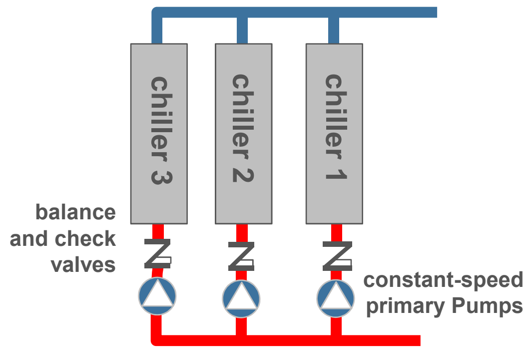
Balancing Valves
(a.k.a. pump throttling valves)

- Why are they needed?
  - Pumps are often oversized
  - Adjust pump flow after balancing the loads



Balancing Valves

- How to adjust pump flow:
  - Throttle the pump with a balancing valve

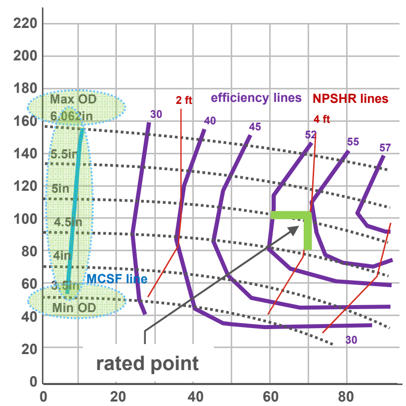


Triple Duty Valves

- Triple duty valves combine:
  - A balancing valve
  - A check valve
  - An isolation valve

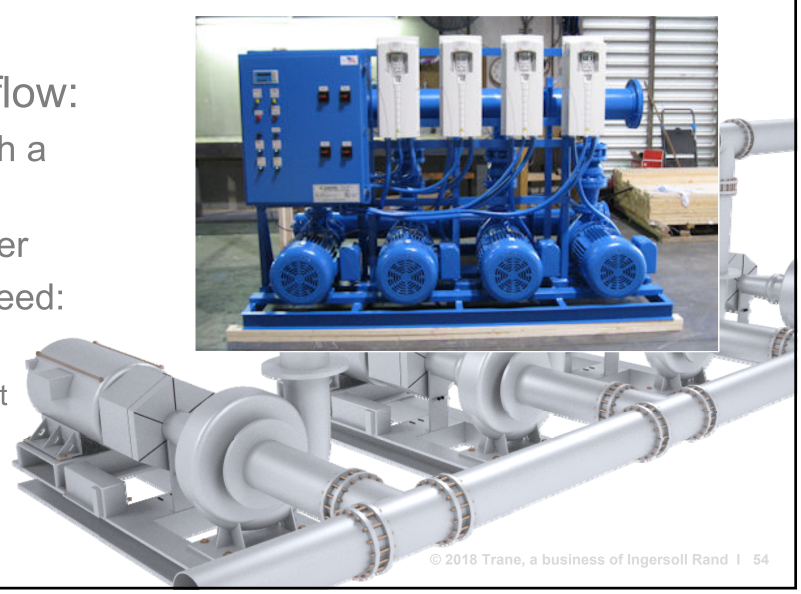
Balancing Valves

- How to adjust pump flow:
  - Throttle the pump with a balancing valve
  - Trim the pump impeller



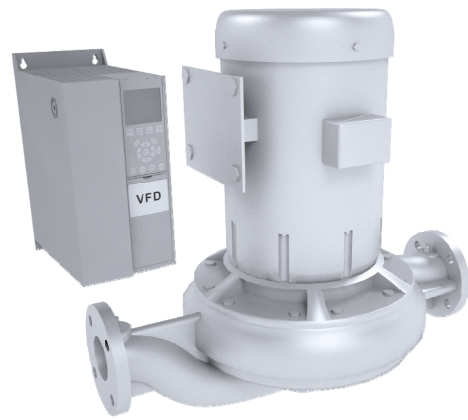
Balancing Valves

- How to adjust pump flow:
  - Throttle the pump with a balancing valve
  - Trim the pump impeller
  - Change the pump speed:
  - Use a VSD
    - Reliable, reasonable cost
    - Motor-drive compatibility



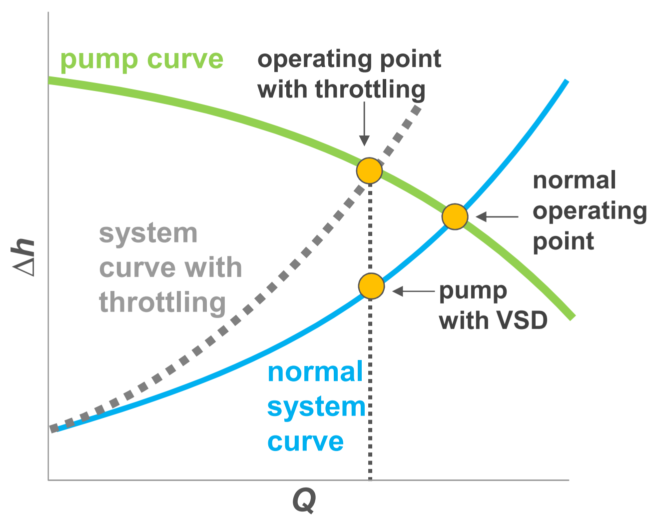
Balancing Valves

- How about variable flow systems?
  - Just use the VSD
- Balancing valves aren't needed
  - Neither are triple-duty valves



Adjusting Pump Flow

- Which of the following is more efficient?
  - Trim the impeller
  - Change the speed
- Things to consider:
  - Time and effort
  - Hydraulic efficiency
  - Limits

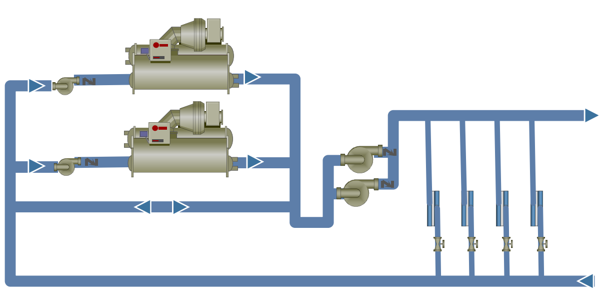


Today's Agenda

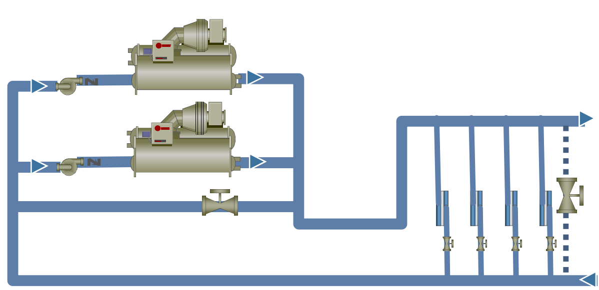
- Bypass line sizing
- Ice tanks upstream or downstream of chillers
- Use of existing coils
- Minimum and maximum flow limits
- Valves: Balancing or triple duty
- **Pumps: Manifolded or dedicated**
- Pressure independent valves
- Buffer tank size
- Variable condenser-water flow
- Series counterflow savings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

Dedicated Pumps

Primary/secondary



Variable primary flow



Dedicated Pumps

Advantages

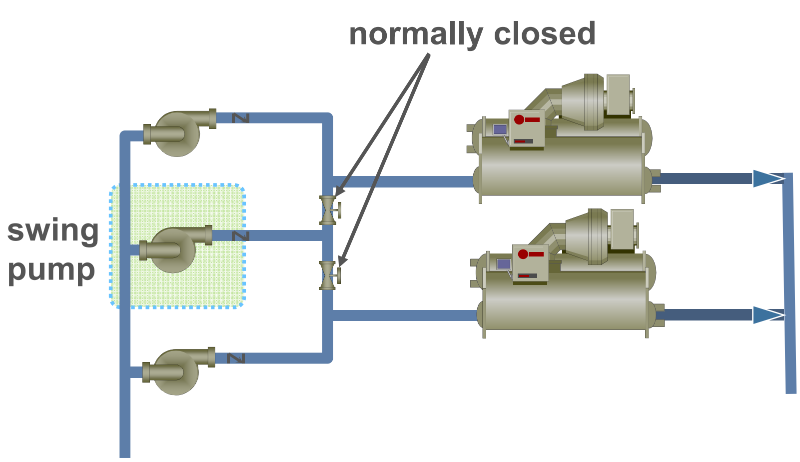
- Simple
  - Pumps and chillers are paired
- Pumps can be selected for different flow rates and pressure drops

Disadvantages

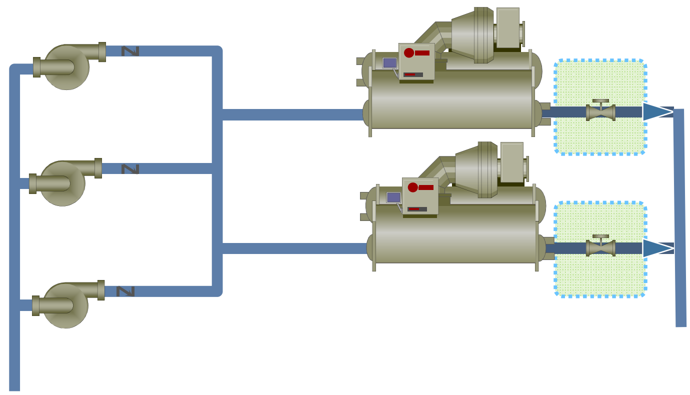
- Lack of redundancy

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

Dedicated Pumps – N+1



Manifolded Pumps



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

Different Chillers: Evap Pressure Drop

	Capacity	Selection		Actual		Flow Change
	(tons)	Flow (gpm)	ΔP (ft H2O)	Flow (gpm)	ΔP (ft H2O)	%
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)

Manifolded Pumps

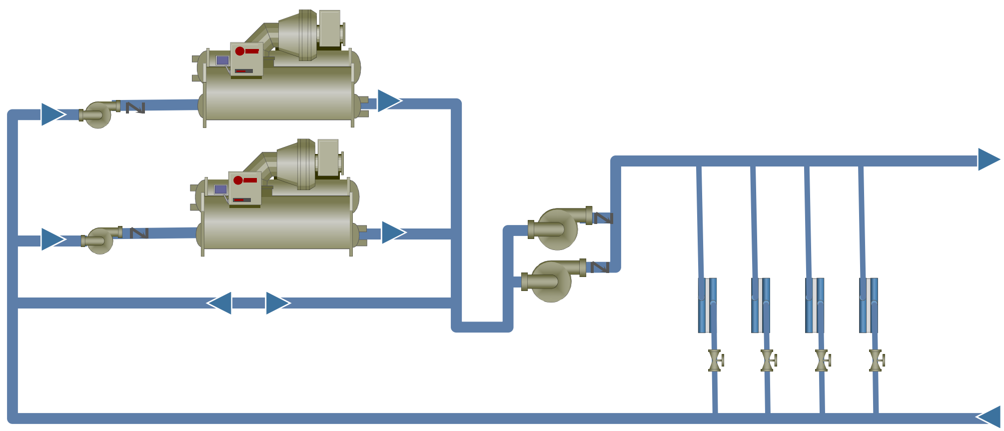
Advantages

- 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

Primary-Secondary System and Low ΔT



Primary-Secondary Systems and Low ΔT

Mode	Flow rate (gpm)	Inlet Temp (⁰F)	Outlet Temp (⁰F)	Capacity (tons)
Design	750	56	40	500

Primary-Secondary Systems and Low ΔT

Mode	Flow rate (gpm)	Inlet Temp (^{0}F)	Outlet Temp (^{0}F)	Capacity (tons)
Design	750	56	40	500
Load conditions	1000	50	40	417
• Chiller 1	750	46.7	40	208.5
• Chiller 2	750	46.7	40	208.5

40% each

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

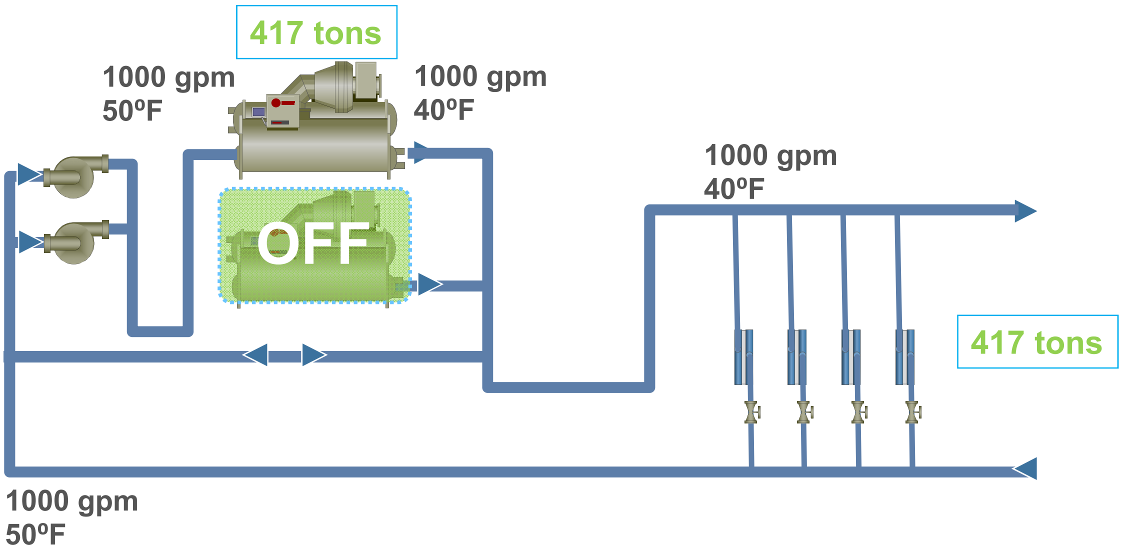
Result: Inefficient system operation

VPF systems and Low ΔT
"Overpumping" Chillers

Mode	Flow rate (gpm)	Inlet Temp (^{0}F)	Outlet Temp (^{0}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

VPF Systems and Low ΔT



“Overpumping” and Low ΔT

- “Overpumping” doesn’t fix Low ΔT
- The problem is at the coils
- For mitigation techniques:
  - 2017 Myths and Realities ENL
  - AC-02-6-1 -- Degrading Chilled Water Plant Delta-T: Causes and Mitigation http://www.taylor-engineering.com/Websites/taylorengineering/articles/ASHRAE_Symposium_AC-02-6-1_Degrading_Delta-T.pdf

Pumps Dedicated or Manifolded?

Dedicated

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

Manifolded

- Redundancy
- Flexibility
- Respond to “low ∆T”

Today’s Agenda

- Bypass line sizing
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- **Pressure independent valves**
- Buffer tank size
- Variable condenser-water flow
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- Controlling chillers in series
- One or two pump misperception

Pressure Independent (PI) Control Valves

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

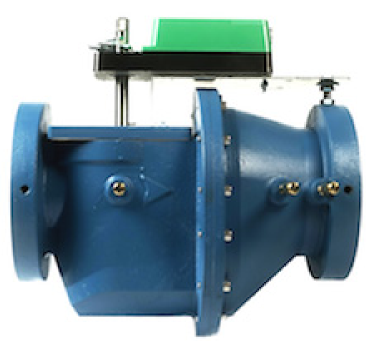
Where:

- 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)

Pressure Independent (PI) Control Valves

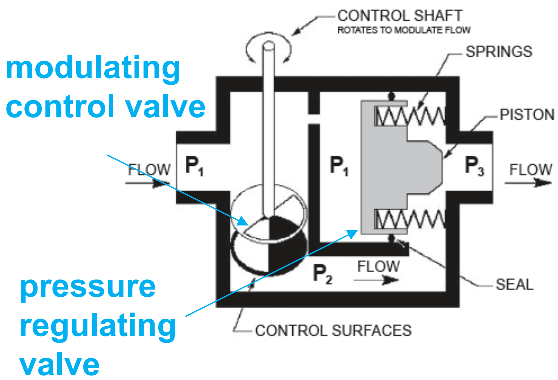
Promoted advantages of PI valves:

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



Types of PI Valves

mechanical PI valve

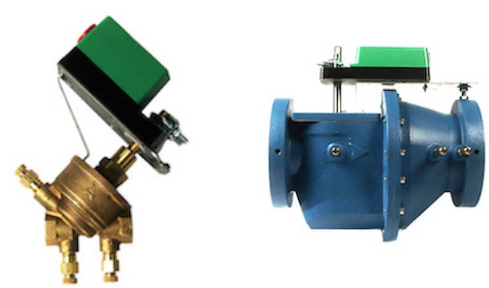


electronic PI valve

Mechanical PI Valves

Advantages:

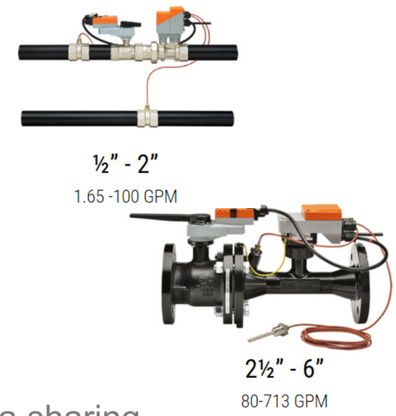
- More compact
- Will accept any rotary actuator
- Easier to select
- No additional power, programming, or sensor installation



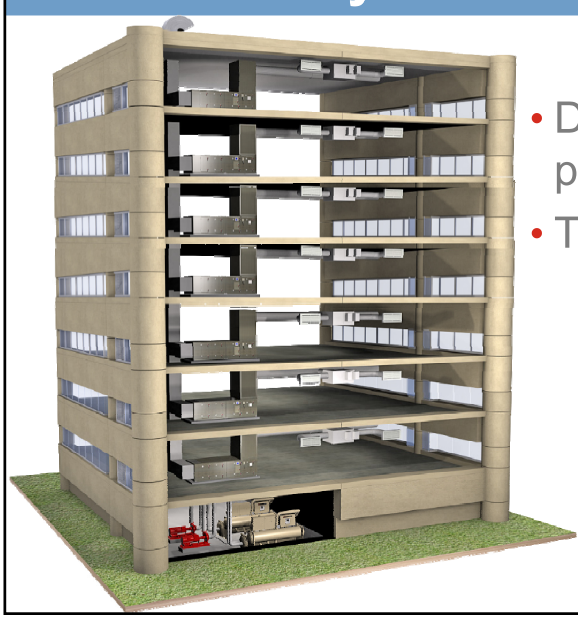
Electronic PI Valves

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)

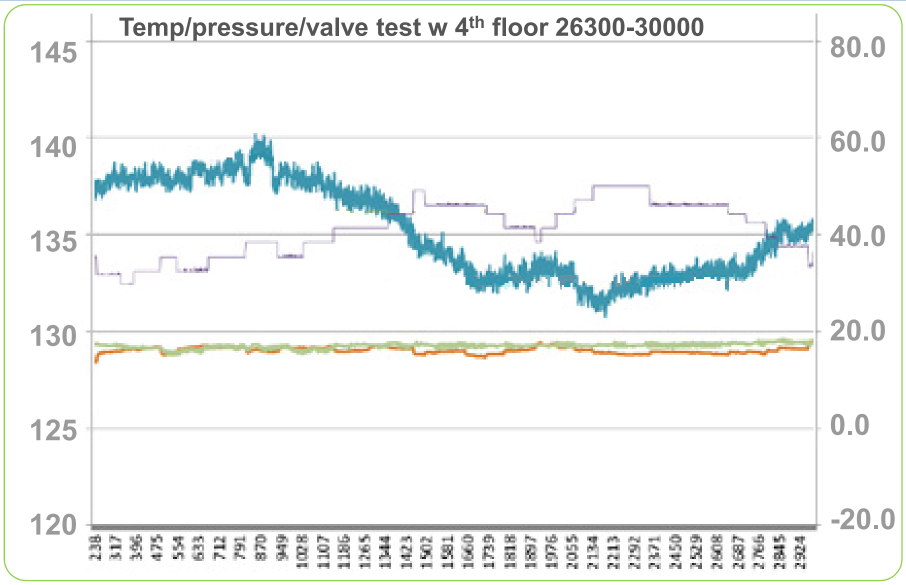


Case Study



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

Case Study:



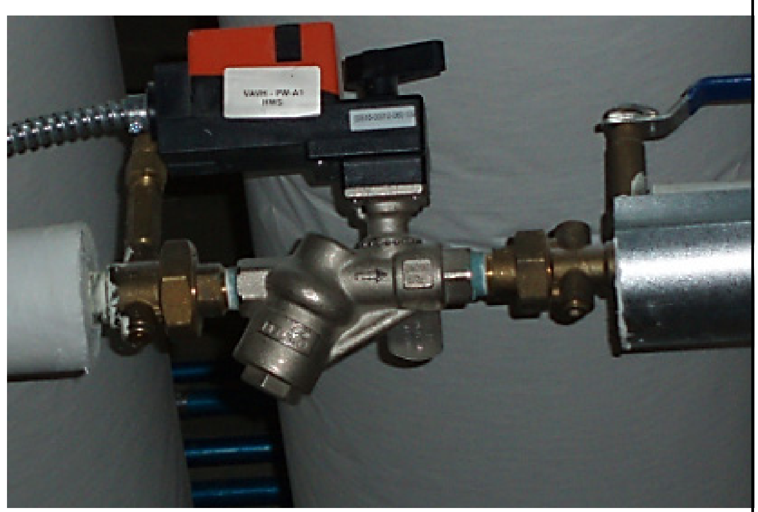
3rd floor (conventional)
4th floor (PI valve)

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

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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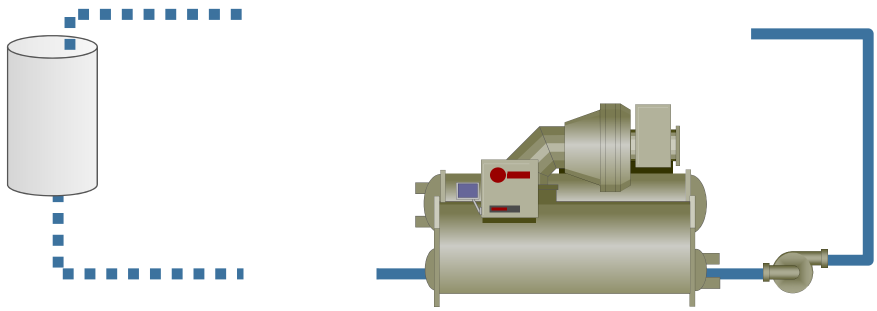
Buffer Tanks

- Why use them?
- When to use them?
- How big should they be?

Buffer Tanks: Why Use Them?

- Chiller stability
- Temperature control



Buffer Tanks: When To Use Them

- Short water loop
- Low loop time

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)
- Elimination or size reduction
  - Larger pipes
  - Higher Delta T

Buffer Tanks: Summary

- Why use them?
  - Stable control
- When do you use them?
  - Loop time to short
- How big should they be?
  - Required volume – system volume

Today's Agenda

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- Controlling chillers in series
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Variable Condenser Water Flow?

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Variable Condenser Water Flow

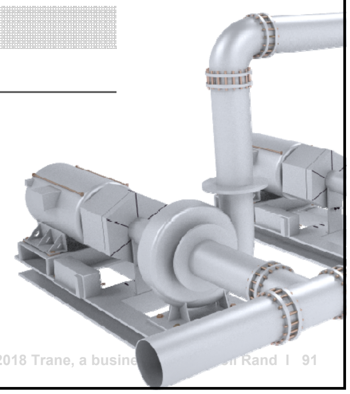
- Determine minimum condenser-water flow rate… highest of:
  - Cooling tower minimum flow rate
  - Chiller condenser minimum flow rate
  - Minimum pump speed to "lift" water from basin to top of cooling tower
- Determine optimal tower fan and condenser water pump speeds
  - At all combinations of load 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

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)

VSD on Condenser Water Pump?

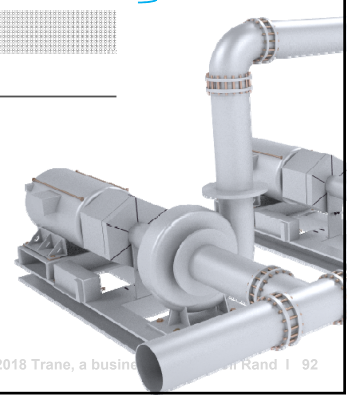
Chiller Type	Cooling Tower Fan	Cond Water Flow Rate (gpm/ton)	Cond Water Flow Type	Tower Control Method	Plant Annualized kW/ton
VS	VS	3	CF	Opt	0.5462



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%



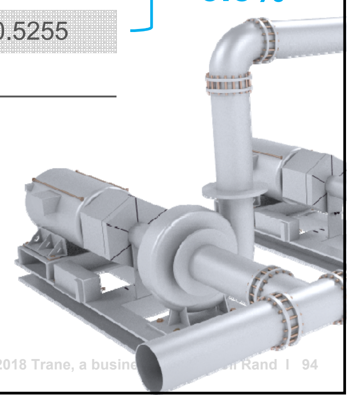
Industry Recommendations for Condenser Water Design

Source	∆T (ºF)	Flow rate(s) (gpm/ton
Historical Practice	9.4	3.0
Today's industry recommendations		
ASHRAE GreenGuide	12 - 18	2.3 – 1.7
Kelly and Chan	14	2.0
Taylor	15	1.9

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

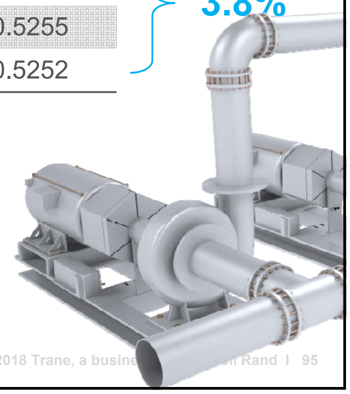
3.8%



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%



2013 ENL: VSD on Condenser Water Pump?

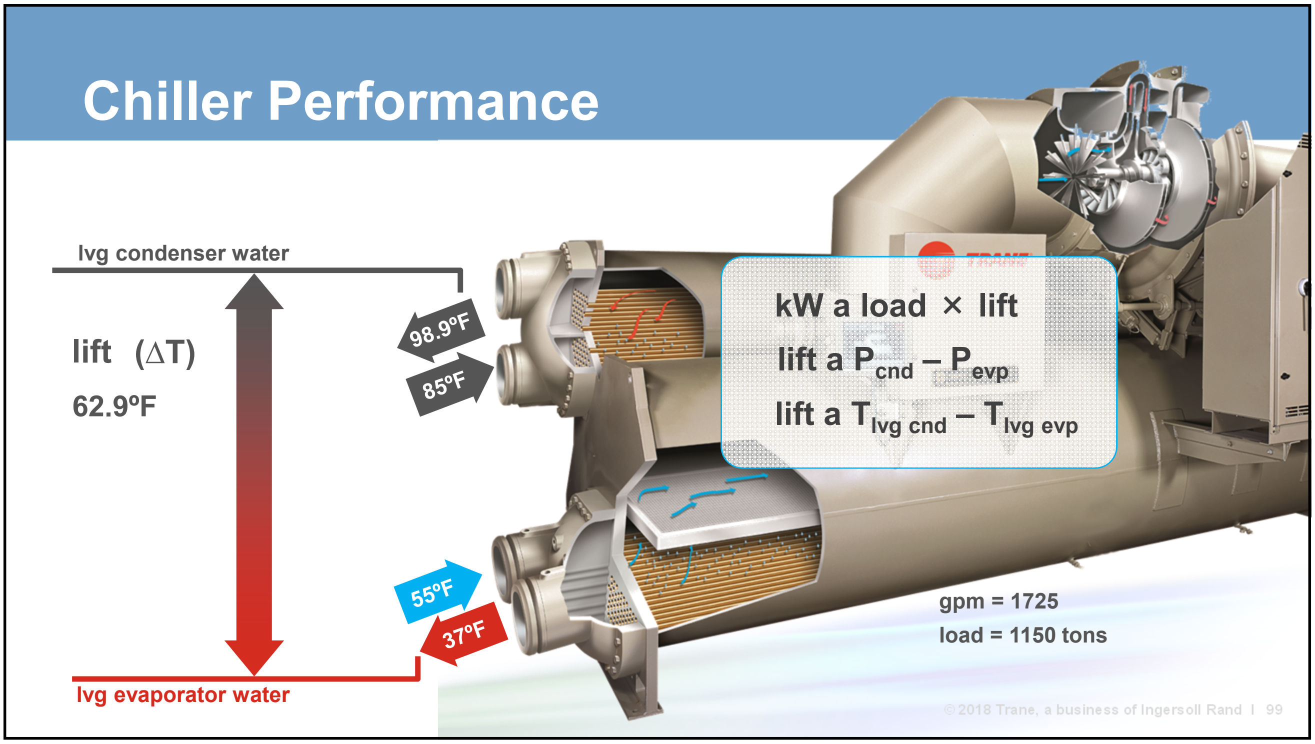
- Similar savings trends
  - In Chicago, Memphis, Albuquerque and Miami
  - Office buildings and hospitals
  - Two choices (Higher design flow – VF, Lower design flow CF)
    - Performance almost the same in all cases
- Exception in Miami
  - Virtually no savings for variable speed drive on condenser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

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

Today's Agenda

- 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


Chiller Performance
lvg condenser water
lift (ΔT)
62.9ºF
98.9ºF
85ºF
55ºF
37ºF
lvg evaporator water
kW α load × lift
lift α P cnd – P evp
lift α T lvg cnd – T lvg evp
gpm = 1725
load = 1150 tons
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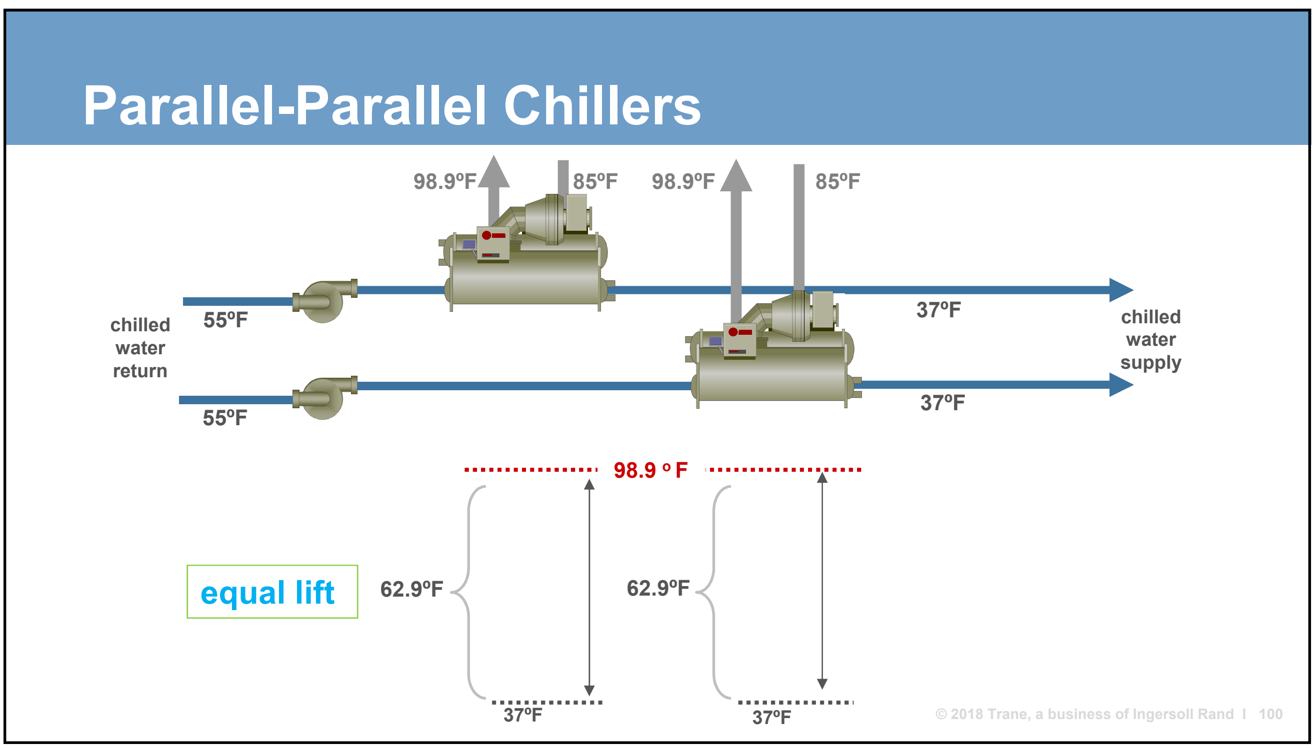
Parallel-Parallel Chillers
98.9ºF
85ºF
98.9ºF
85ºF
chilled water return
55ºF
55ºF
37ºF
37ºF
chilled water supply
98.9 º F
equal lift
62.9ºF
62.9ºF
37ºF
37ºF
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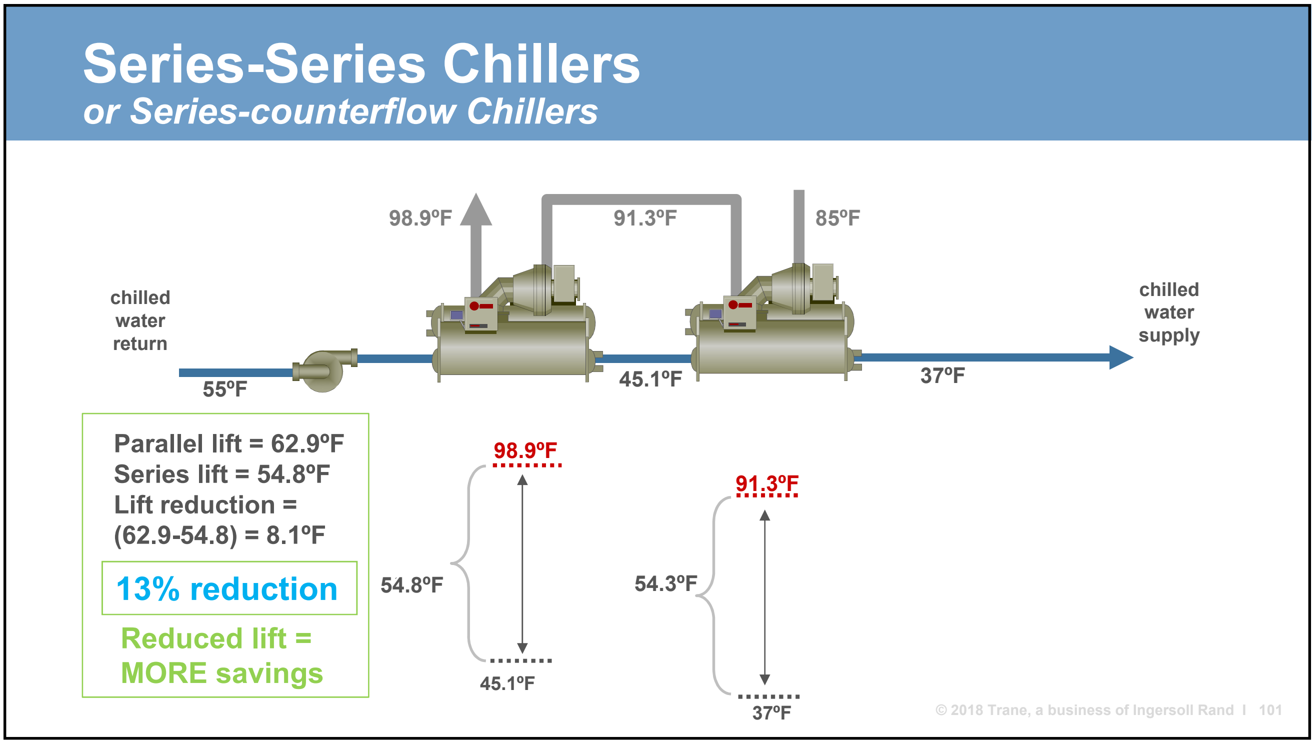
Series-Series Chillers
or Series-counterflow Chillers
98.9ºF
91.3ºF
85ºF
chilled water return
chilled water supply
55ºF
45.1ºF
37ºF
Parallel lift = 62.9ºF
Series lift = 54.8ºF
Lift reduction = (62.9-54.8) = 8.1ºF
13% reduction
Reduced lift = MORE savings
98.9ºF
54.8ºF
45.1ºF
91.3ºF
54.3ºF
37ºF
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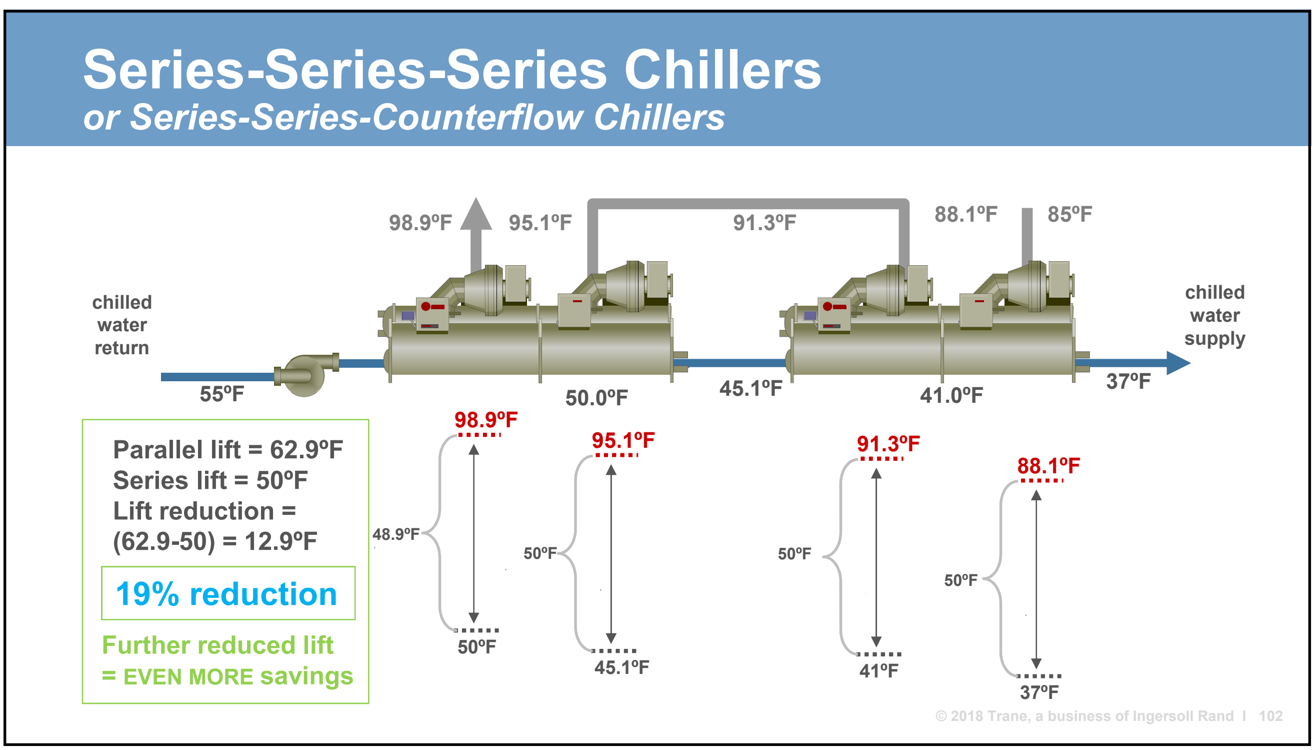
Series-Series-Series Chillers
or Series-Series-Counterflow Chillers
98.9ºF
95.1ºF
91.3ºF
88.1ºF
85ºF
chilled water return
chilled water supply
55ºF
50.0ºF
45.1ºF
41.0ºF
37ºF
Parallel lift = 62.9ºF
Series lift = 50ºF
Lift reduction = (62.9-50) = 12.9ºF
19% reduction
Further reduced lift = EVEN MORE savings
98.9ºF
48.9ºF
50ºF
95.1ºF
50ºF
45.1ºF
91.3ºF
50ºF
41ºF
88.1ºF
50ºF
37ºF
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Summary

- kW α load × lift

Configuration	Lift	% reduction
Parallel	62.9ºF	baseline
Series counterflow	54.5ºF	13%
Series duplex	50.0ºF	19%

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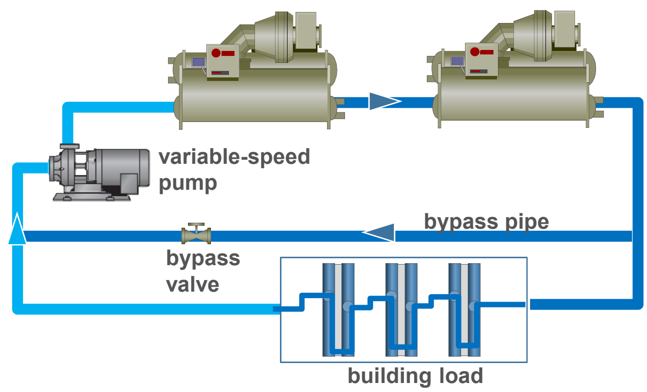
- One or two pump misperception

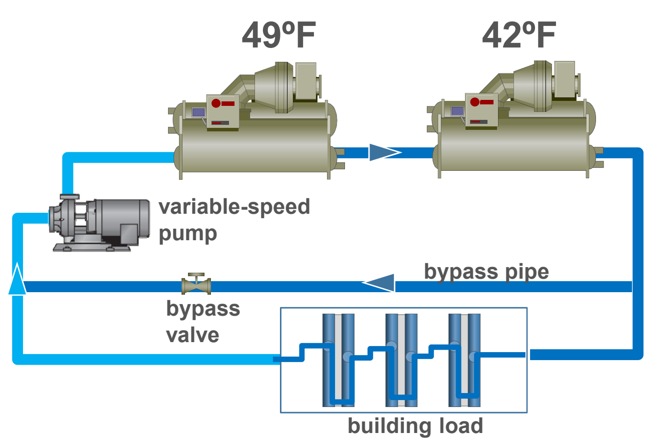
Series Chiller Control

- Chiller setpoints
- Sequencing
- Loading strategies



Temperature Control

- Setpoints
  - Equal
  - Staggered



Staggered Setpoints

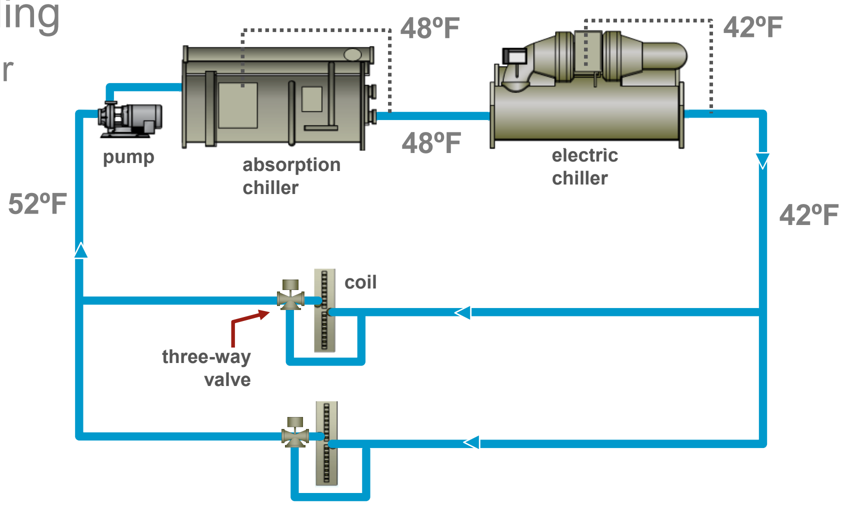
- Downstream setpoint:
  - System supply water temperature
- Upstream setpoint:
  - Dynamically reset to balance load

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

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

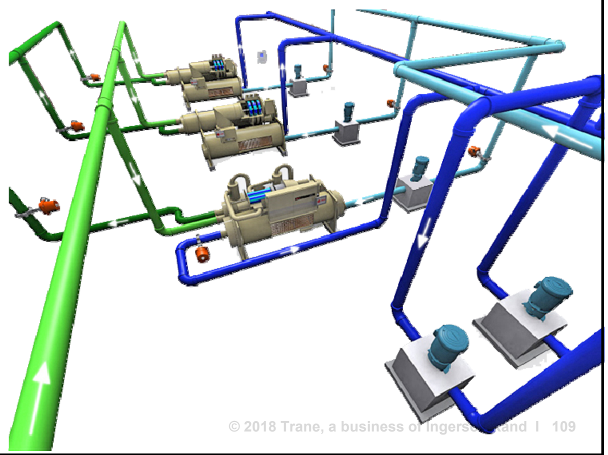
Loading Strategies

- Preferential loading
  - Upstream chiller
- Equal loading



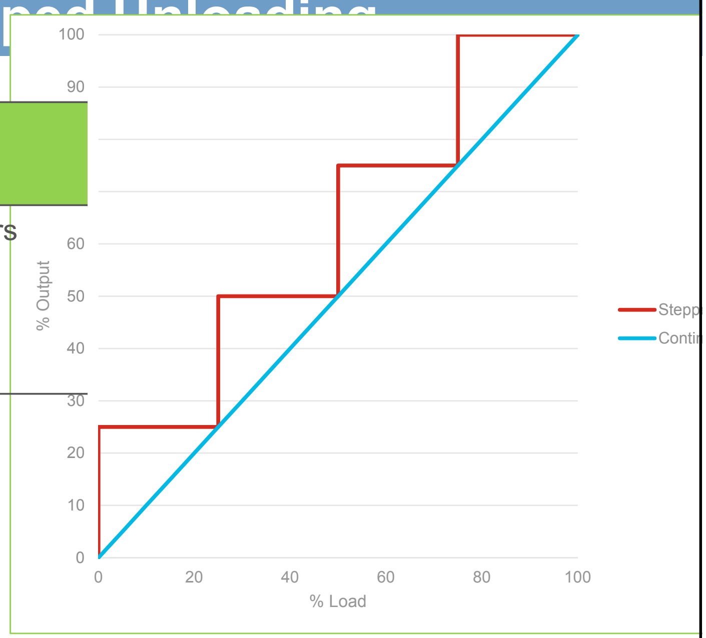
Chiller Sequencing

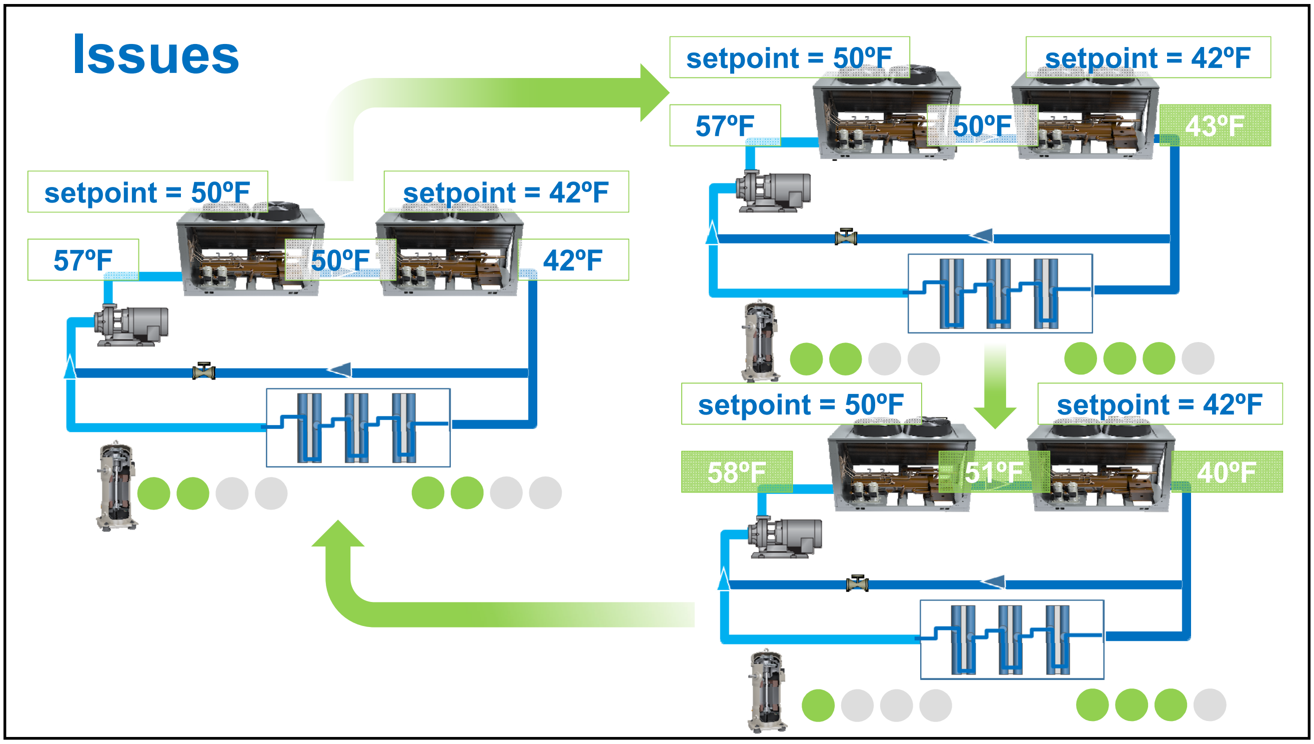
- Start one chiller
  - The more efficient one or the one with a VFD
- Start next chiller
- Start next chiller pair
- Start/stop chillers in pairs

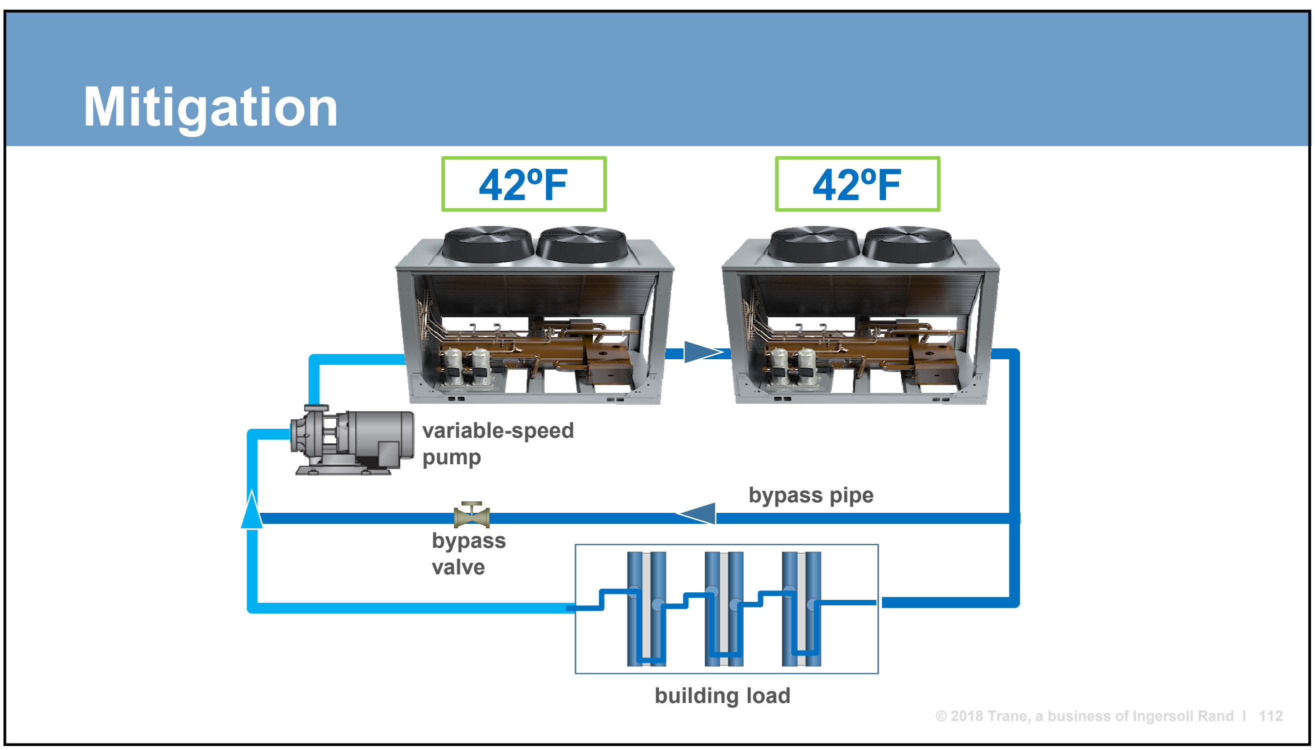


Continuous vs. Stepped Unloading

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




Issues
setpoint = 50°F
setpoint = 42°F
57°F
50°F
43°F
setpoint = 50°F
setpoint = 42°F
57°F
50°F
42°F
setpoint = 50°F
setpoint = 42°F
58°F
51°F
40°F


Mitigation
42°F
42°F
variable-speed pump
bypass pipe
bypass valve
building load
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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
  - Scroll compressors:
    - System supply water temperature
- Sequencing

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- 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**

Is It More Efficient to Operate More Pumps?

Pump laws

- Flow ∝ Speed
- ΔP ∝ Flow^2
- Power ∝ Flow^3

Thought process

- Operating more pumps decreases flow per pump
- Power ∝ Flow^3

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

Improper use of pump laws

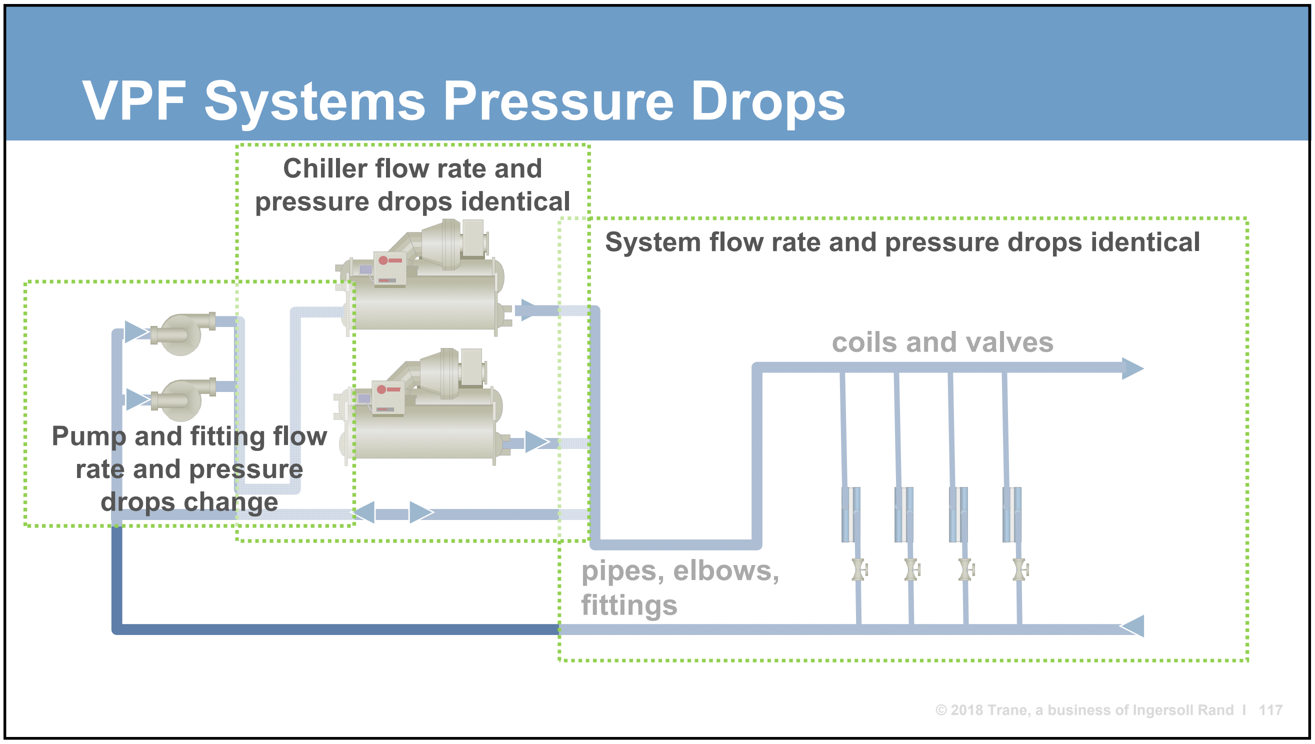
System flow rate and ΔP don't change for most components

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?


VPF Systems Pressure Drops
Chiller flow rate and pressure drops identical
System flow rate and pressure drops identical
coils and valves
Pump and fitting flow rate and pressure drops change
pipes, elbows, fittings
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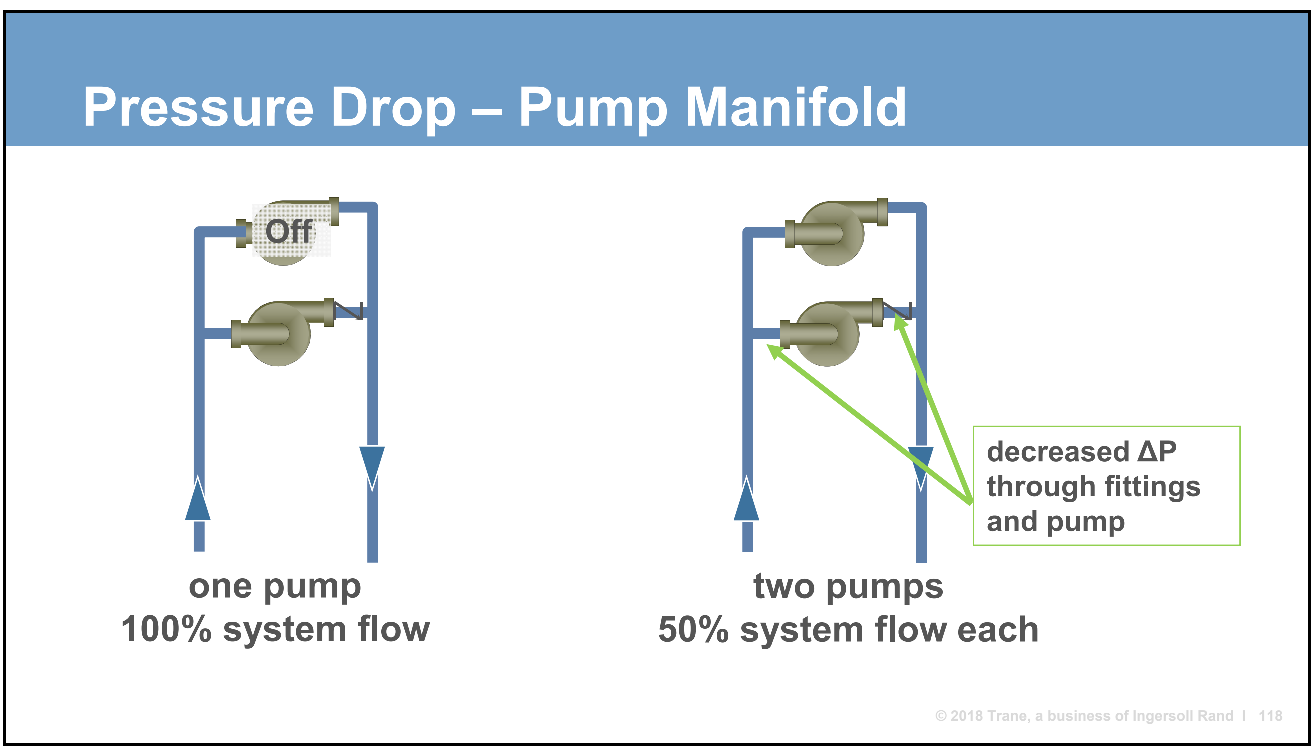
Pressure Drop – Pump Manifold
Off
decreased ΔP through fittings and pump
one pump
100% system flow
two pumps
50% system flow each
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Pump Power

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

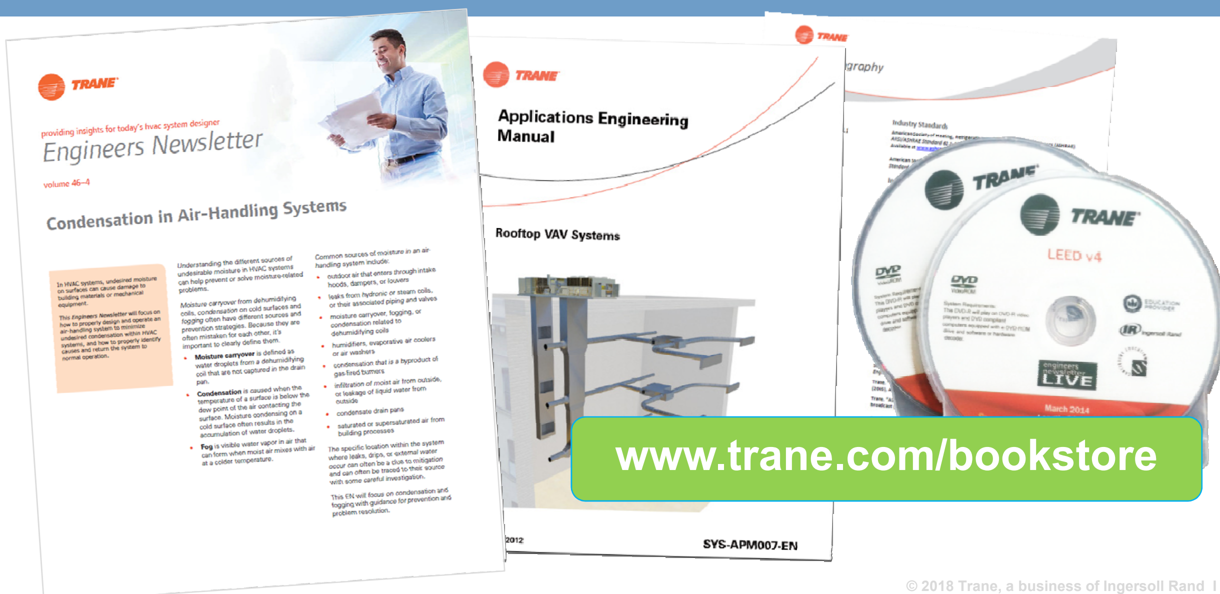
Operate an Additional Pump?

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

- 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

Savings are NOT proportional to the cube of the pump flow

Where to Learn More



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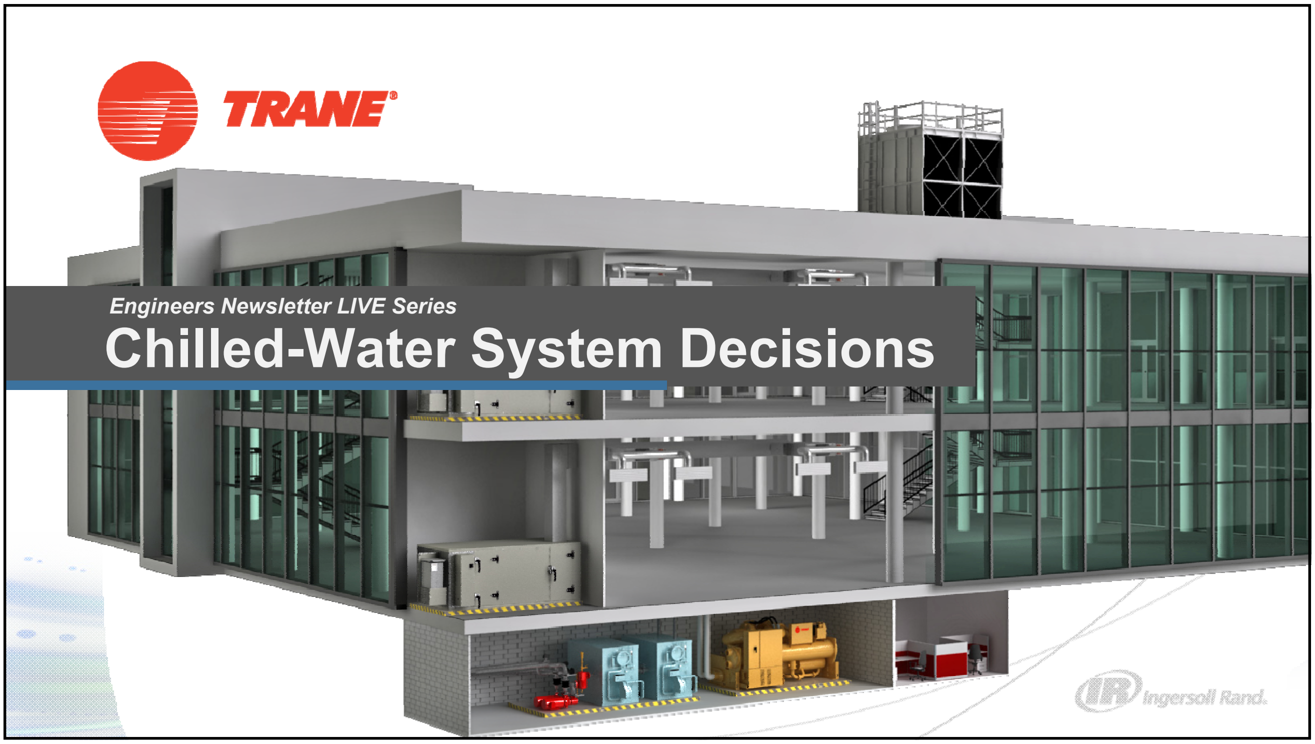
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Bonus track
Where did 10ºF ΔT come from?
Systems
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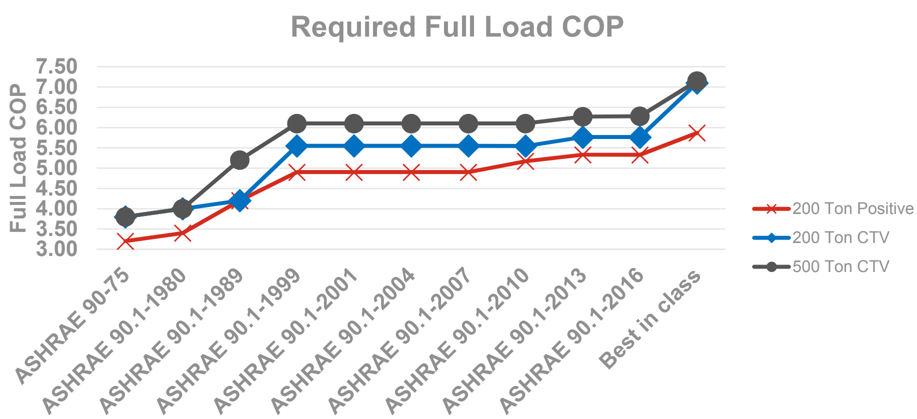
A History of Chiller Performance



ASHRAE 90.1-2016

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.

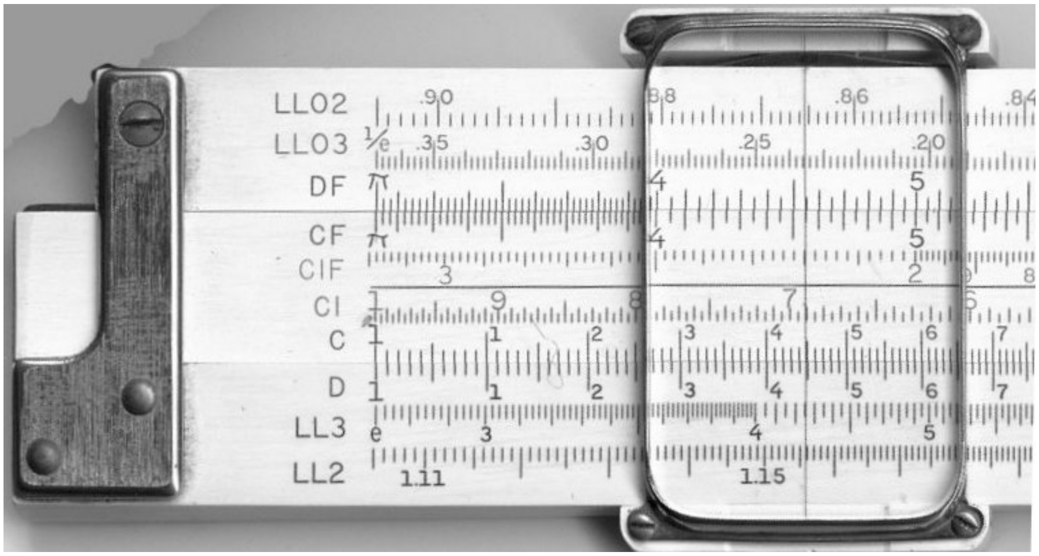
100 ANSI/ASHRAE/IES Standard 90.1-2016 (I-P)

Industry Recommendations Temperature Differences

Source	ΔT (ºF)	ΔT (ºF)
ASHRAE 90.1-2016	≥15	NA
ASHRAE GreenGuide	12 – 20	12 - 18
Kelly and Chan	18	14
Taylor	>12	15

Q: Where did the old tradition of 10ºF ΔT come from?

Theory 1: Slide Rules or Dividing by 10



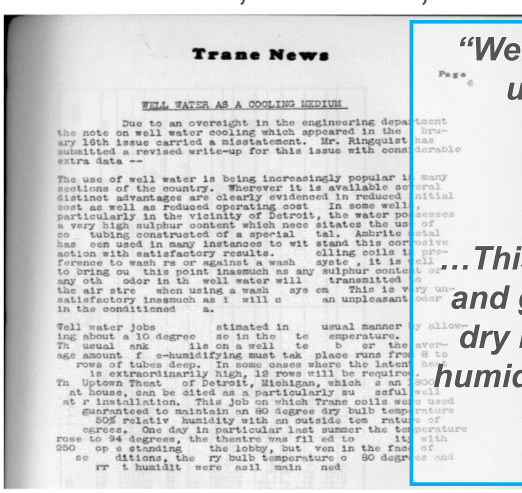
Theory 2:
AHRI 550/590 "Standard" Rating Conditions

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

Theory 3: Willis Carrier

Theory 4: 10 degrees "started" with well water

- Trane News, March 2, 1935



Trane News

Page 6

WELL WATER AS A COOLING MEDIUM

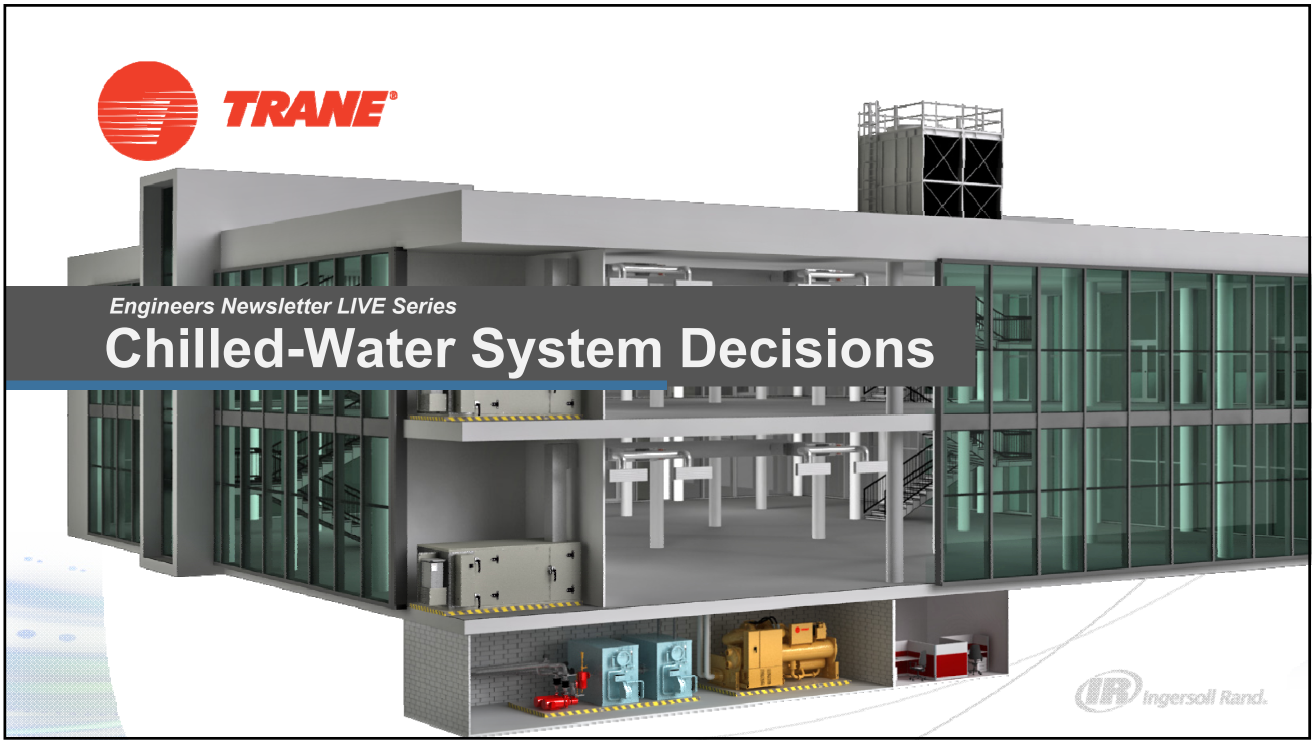
Due to an oversight in the engineering department the note on well water cooling which appeared in the bru-ary 16th issue carried a misstatement. Mr. Ringquist has submitted a revised write-up for this issue with considerable extra data --

The use of well water is being increasingly popular in many sections of the country. Wherever it is available several distinct advantages are clearly evidenced in reduced initial cost as well as reduced operating cost. In some wells, particularly in the vicinity of Detroit, the water possesses a very high sulphur content which nece sitates the use of co tubing constructed of a special tal. Ambrite metal has een used in many instances to wit stand this corrosive action with satisfactory results. elling coils in pre-ference to wash rs or against a wash syste , it is well to bring ou this point inasmuch as any sulphur content or any oth odor in th well water will transmitted to the air stre when using a wash sys em This is very un-satisfactory insmuch as i will c an unpleasant odor in the conditioned a.

Well water jobs stimated in usual manner by allow-ing about a 10 degree se in the te emperature. Th usual ank ils on a well te b er the aver-age amount f e-humidifying must tak place runs from 8 to rows of tubes deep. In some cases where the latent heat is extraordinarily high, 12 rows will be required. Th Uptown Theat of Detroit, Michigan, which s an 1800 at house, can be cited as a particularly su ssful well at r installation. This job on which Trane coils were used guaranteed to maintain an 80 degree dry bulb temperature 50% relativ humidity with an outside tem rature of egrees. One day in particular last summer the temperature rose to 94 degrees, the theatre was fil ed to ity with 250 op e standing the lobby, but ven in the face of se ditions, the ry bulb temperature o 80 degrees and rr t humidit were asil main ned.

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

…This job on which Trane 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."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Trane *Engineers Newsletter LIVE:* Chilled-Water System Decisions
APP-CMC065-EN QUIZ

1. Which of the following are symptoms of an oversized bypass line?
    a. Erratic condenser water temperatures
    b. Elevated chilled water system supply temperature
    c. All chillers are loaded to equal percentages
    d. The chiller closest to the bypass line cannot load fully
    e. Excessive flow noise from the bypass line
2. With respect to dynamically varying condenser water flow rate, which of the following guidance was NOT given in the program?
    a. Variable condenser water flow is simple, because it's done by keeping the condenser ΔT constant
    b. In existing systems designed at 3 gpm/ton savings are available
    c. Designing condenser flow rate of 1.8 – 2.3 gpm/ton results in similar performance to designing at 3 gpm/ton and dynamically varying condenser water flow rate
    d. Climates that are humid all the time receive almost no energy savings by dynamically varying the condenser flow rate
    e. Varying condenser water flow helps avoid chiller surge.

3. Reducing the lift on a chiller will make the chiller more efficient
    a. True
    b. False

4. Installing ice storage tanks downstream of the chiller will increase the amount of ton/hrs available from the tanks
    a. True
    b. False

Bibliography

March 2018

Chilled-Water System Decisions

Industry Resources (www.ashrae.org/bookstore)

ANSI/ASHRAE *Standard 90.1-2016: Energy Standard for Buildings Except Low-Rise Residential Buildings*.

ASHRAE GreenGuide (third edition), Atlanta, GA: ASHRAE, 2010.

2017 ASHRAE Handbook: Fundamentals; 2017, Atlanta, GA: ASHRAE.

Groenke, S. and M. Schwedler, " Series-Series Counterflow for Central Chilled-Water Plants," ASHRAE Journal, June 2002.

Taylor, S. "Optimizing Design & Control Of Chilled Water Plants." ASHRAE Journal (December 2011): 22-34. Available at www.ashrae.org

Trane Application Manuals

Order from <www.trane.com/bookstore>

Hanson, S., M. Schwedler, *Multiple Chiller System Design and Control*, application manual SYS-APM001-EN, 2012.

Trane *Engineers Newsletters*

Available to download from www.trane.com/engineersnewsletter (Waterside)

Sullivan, B., "**Chiller Selection Made Easier with myPLV**," 2015, volume 44-4.

Schwedler, M., "Condenser water system savings: Optimizing flow rates and control," 2012, volume 41-3.

Trane *Engineers Newsletters Live* Programs

Available from www.trane.com/ContinuingEducation

Cline, L., Eppelheimer, D.., and M. Schwedler, "VSDs and Their Effect on System Components," *Engineers Newsletter Live* program (2006) APP-CMC025-EN

Hanson, S., M. Schwedler, B. Spalding. "Upgrading Existing Chilled-Water Systems," *Engineers Newsletter Live* program (2011) APP-CMC041-EN.

Cline, L., S. Hanson, M. Schwedler. "All Variable-Speed Chilled-Water Plants," *Engineers Newsletter Live* program (2013) APP-CMC049-EN.

Hanson, S., M. Patterson. "Chilled-Water System Design Trends," *Engineers Newsletter Live* program (2015) APP-CMC056-EN.Cline, L., M. Schwedler, B. Sullivan. "Variable-Speed Compressors on Chiller." (2015) APP-CMC053-EN (DVD)

Murphy, J., B. Hafendorfer, T. Michael and J. Harshaw. "Coil Selection and Optimization," *Engineers Newsletter Live* program (2015) APP-CMC054-EN (DVD).

Trane *Air Conditioning Clinics*

Available to order from www.trane.com/bookstore

Chilled-Water Systems (2018) TRG-TRC016-EN.

Analysis Software (trial versions available for download)

Trane Air-Conditioning and Economics (TRACE™ 700). Available at www.trane.com/TRACE
Trane myPLV™ chiller performance evaluation tool available at www.trane.com/myplv
Trane Chiller Plant Analyzer evaluation tool available at www.traneCDS.com (see Analysis Tools)

Product Information

Optimus™ Chiller Model RTHD: Sales Brochure: RLC-SLB031-EN**,** Catalog: RLC-PRC020F-EN
Stealth™ Chiller Model RTAE: Sales Brochure: RLC-SLB026-EN**,** Catalog: RLC-PRC042D-EN
Sintesis™ Chiller Model RTAF: Sales Brochure: RLC-SLB036-EN**,** Catalog: RLC-PRC049-EN
EarthWise™ CenTraVac™ Chillers: Brochures: CTV-SLB026-EN, CTV-SLB041-EN, CTV-SLB042-EN, Catalog: CTV-PRC007L-EN (120-3950 ton, 50 and 60 Hz), AFDJ-PRC001-EN (AFD with Tracer™ AdaptiView™[SM1])

Engineers Newsletter Live - Audience Evaluation

Chilled-Water System Decisions

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Was the topic appropriate for the event? Yes No

Rate the content of the program. Excellent Good Needs Improvement

Rate the length of the program. Appropriate Too long Too short

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What was most interesting to you?

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