ASHRAE Illinois Spring Conference

Enhanced Chilled Water System Design and Optimization

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ASHRAE
Illinois Chapter

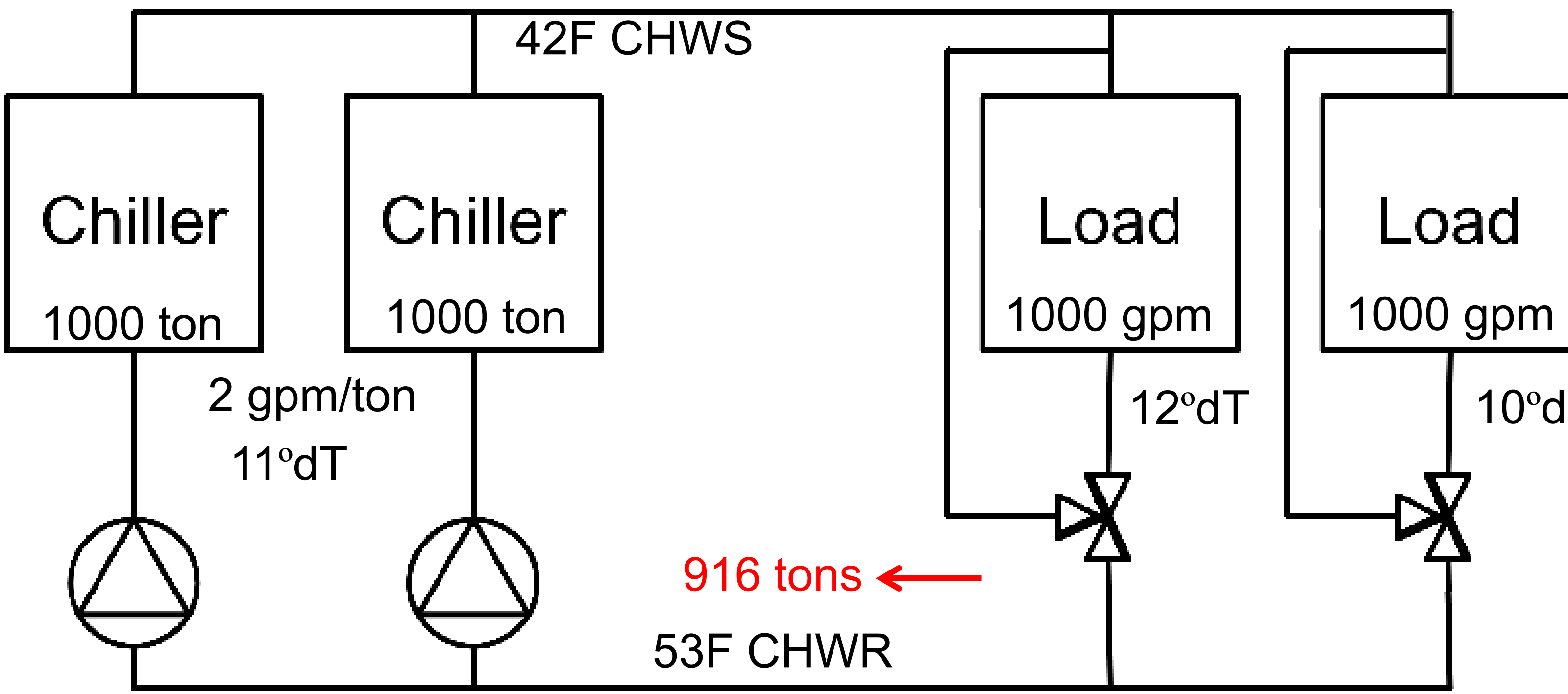
Learning Objectives

1. Common chilled water system configurations
2. Troubleshooting and optimization of Primary/Secondary CHW systems
3. Variable Primary Flow (VPF) chilled water system configuration
4. Design and controls considerations for proper operation of VPF chilled water systems
5. Additional CHW optimization measures

Chilled Water System History

Constant Primary Flow

- Constant Primary Flow was used before primary/secondary
- Advent of low delta T problem



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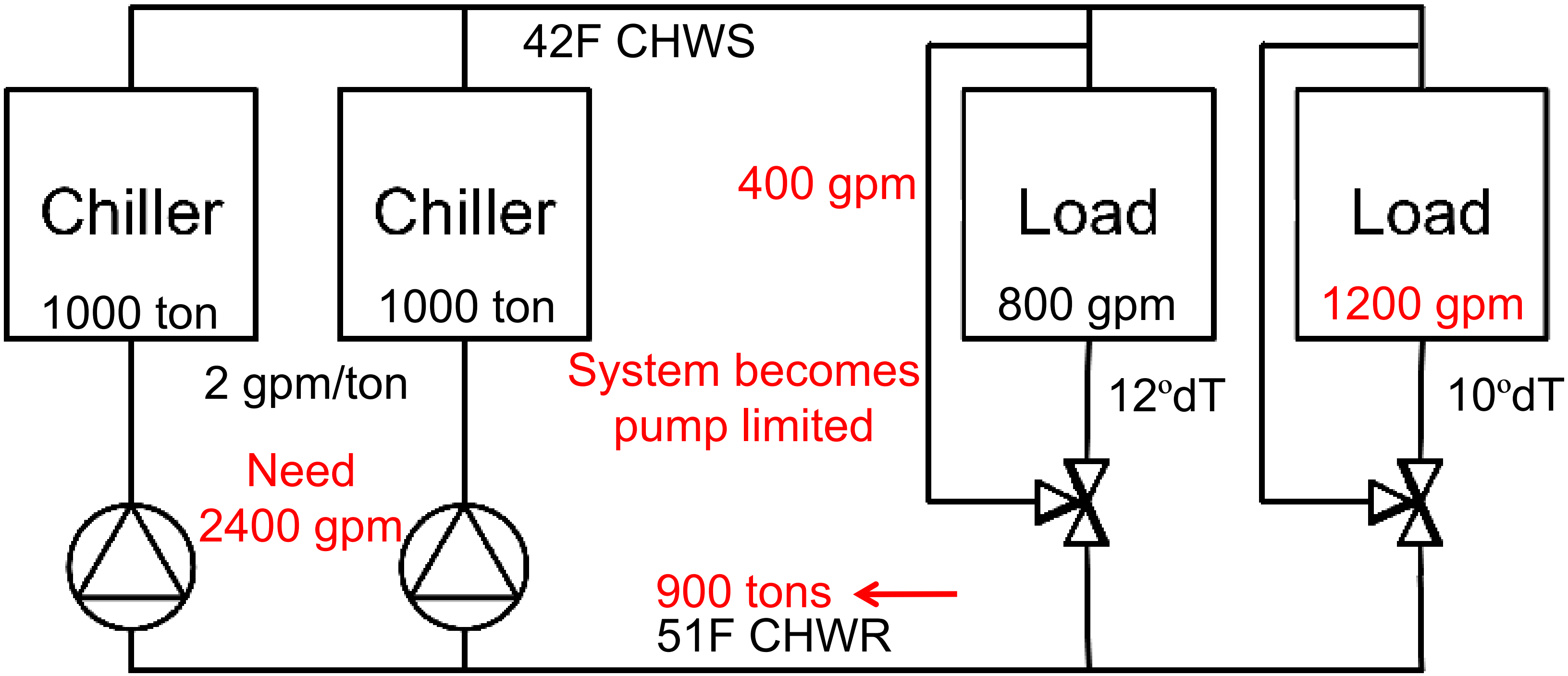
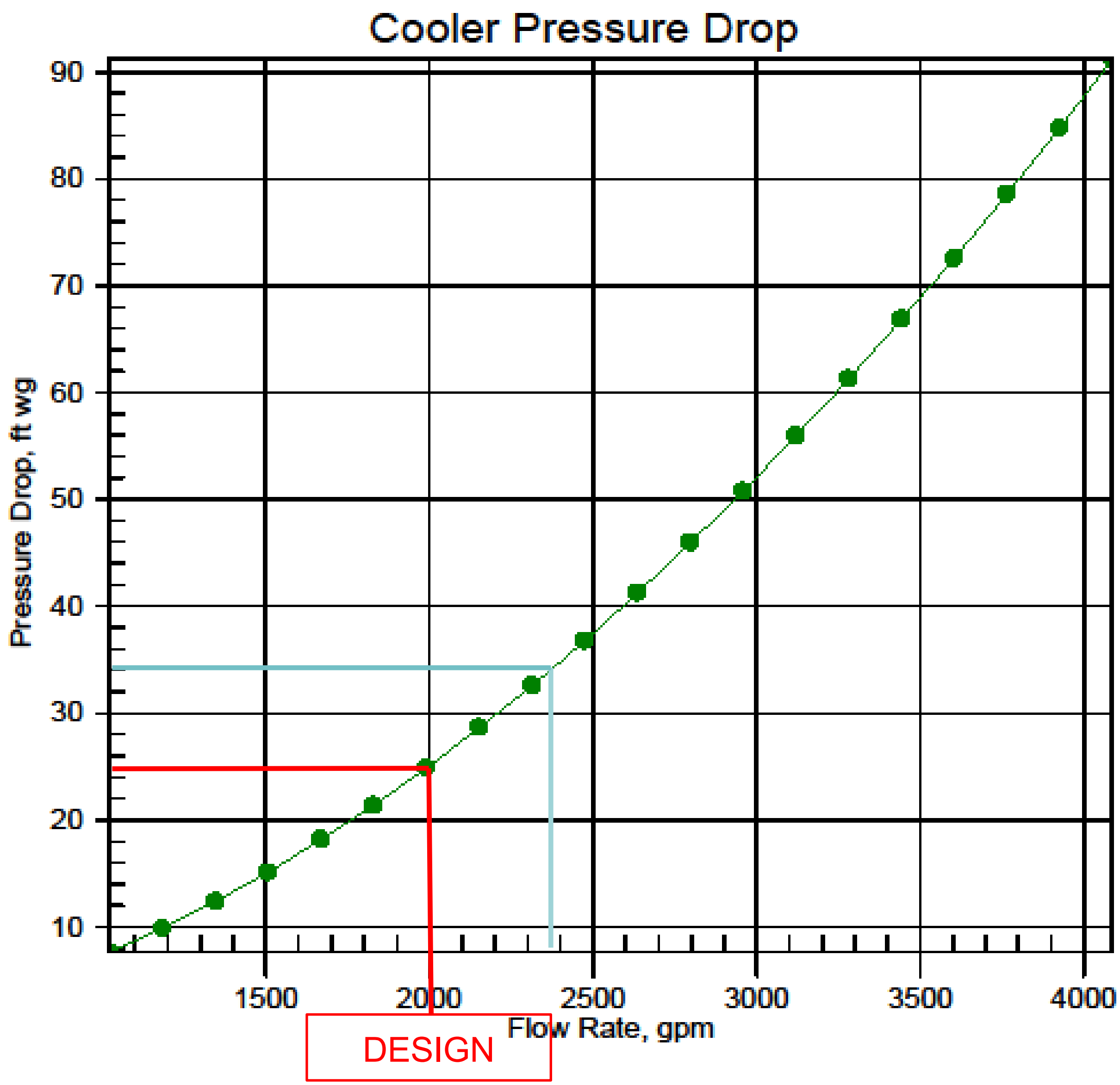


Excess Flow causes increased PD



Chilled Water System History

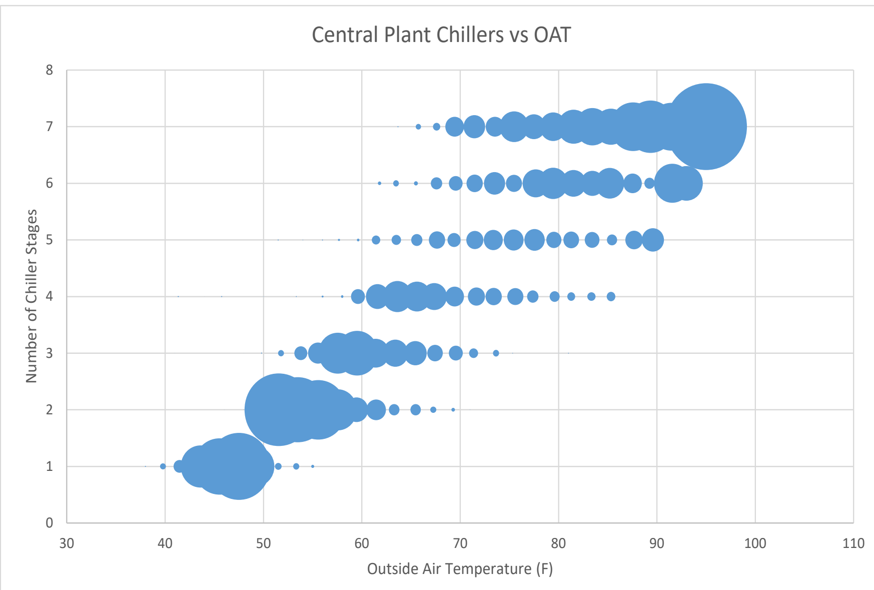
Constant Primary Flow

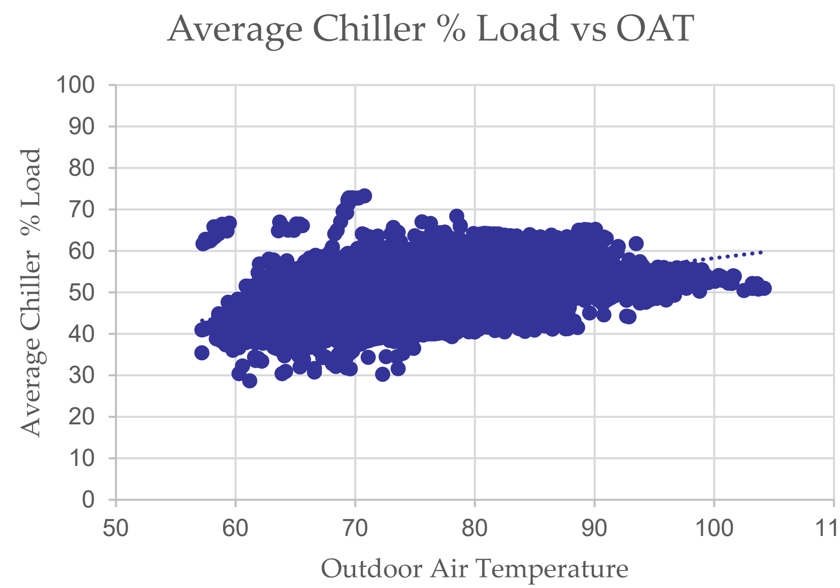
Serves Building:	Estimated Load From 2017 Trends (tons)	Peak Load ΔT from 2017 Data	Load/ΔT Priority
Bridge #1	780	4.60	1
Bridge #2	800	5.79	2
Bridge #3	1100	9.14	3
Bridge #4	1100	9.52	4
Bridge #5	550	6.73	5
Bridge #6	500	6.24	6
Bridge #7	400	5.90	7
Bridge #8	500	7.54	8
Bridge #9	400	6.85	9
Bridge #10	330	6.89	10
Bridge #11	350	7.65	11
Bridge #12	150	2.70	12
Bridge #13	140	4.42	13
Bridge #14	400	10.18	14
Bridge #15	400	11.32	15
Bridge #16	110	8.06	16
Bridge #17	250	12.07	17
Bridge #18	575	13.17	18
Bridge #19	600	N/A *	19

Chiller plant design dT = 14F!

Chilled Water System History

Constant Primary Flow



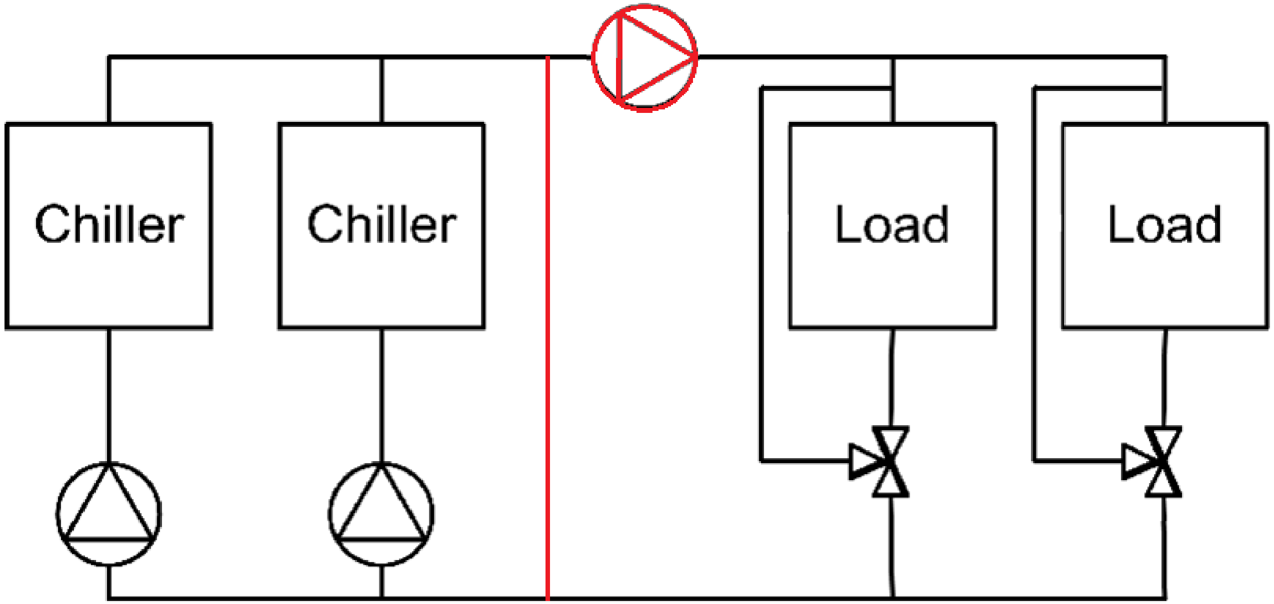


Chiller plant had to revise sequence from staging on CHWS to dT.
Stage up setpoint to satisfy flow demand was 9.5F
Plant limited to 68% of design capacity

Chilled Water System History

Constant Primary Flow (evolved)

- Decoupler and secondary pump installed
- Hydraulically separated loops
- Still low delta T problems



Converting Primary/Secondary

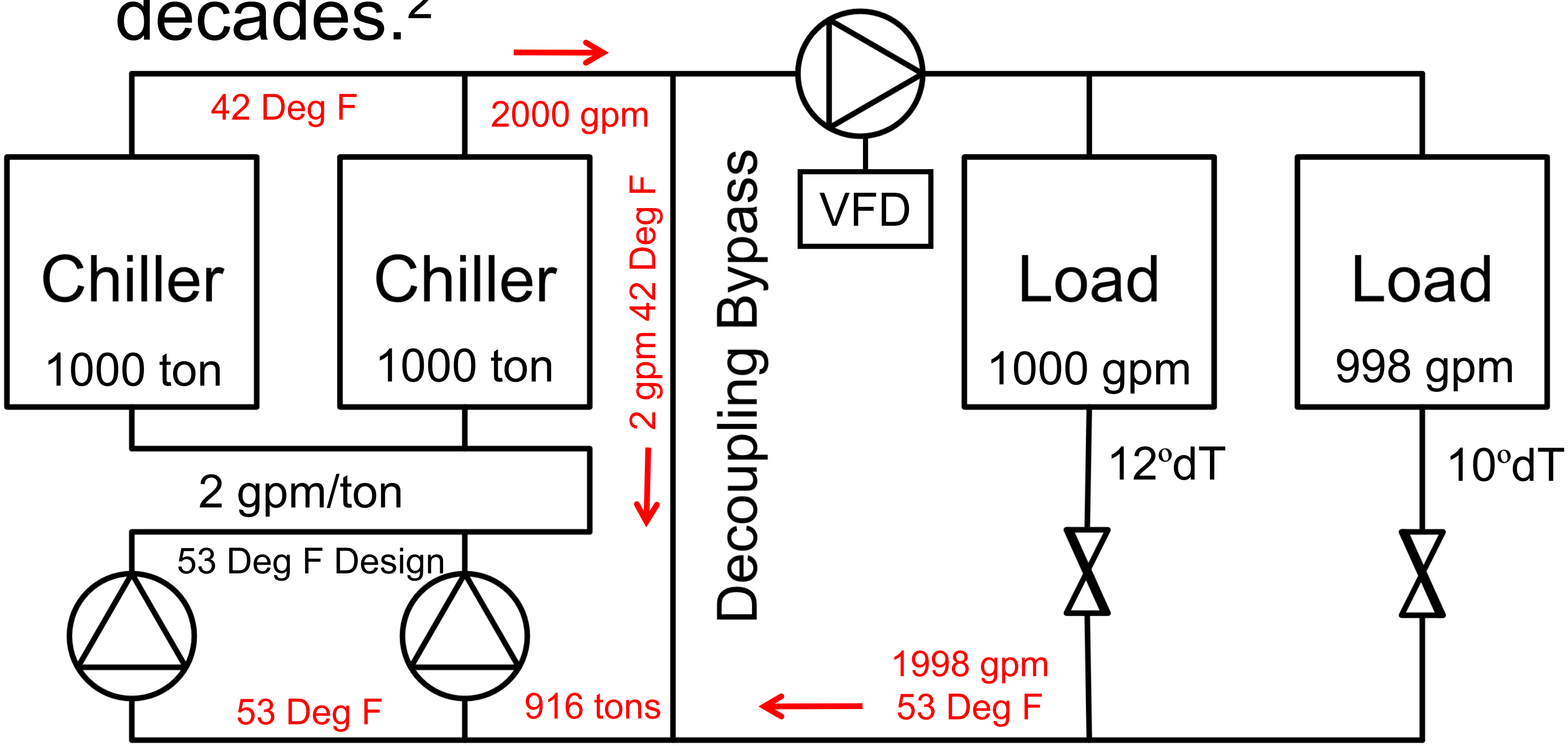
Converting to a variable secondary system:

- Adding VFDs to SCHWP
  - Flow meters in primary and secondary loops
  - At least (1) dP sensor in secondary loop, recommend multiple
  - Changing AHU valves
    - 3-way vs 2-way valves
  - Ensure temperature sensors in all locations across the decoupler
- Troubleshooting – not out of the woods yet!

Chilled Water System History

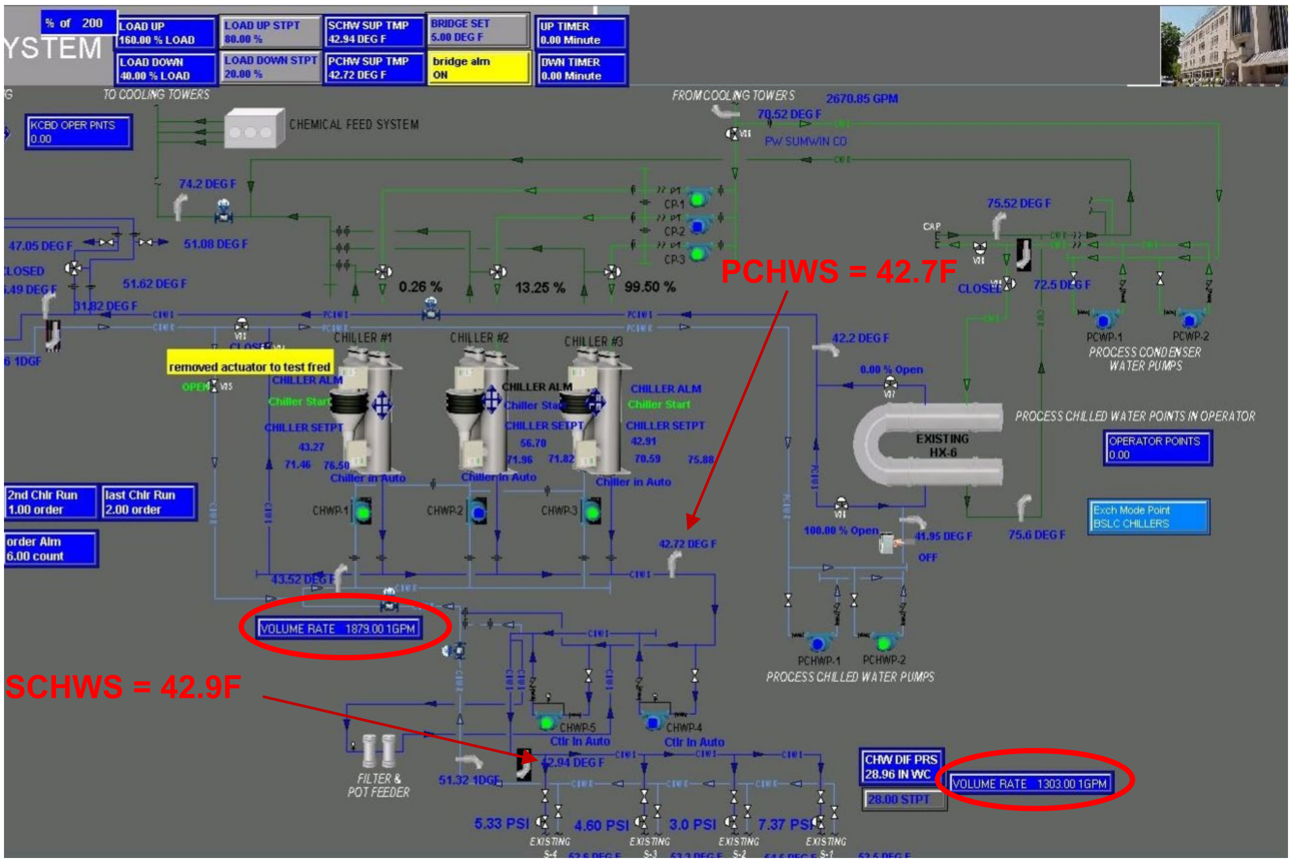
Primary/Secondary (Balanced)

- Constant Primary Flow / Variable Secondary Flow has been the industry standard for decades.[2]



Chilled Water System History

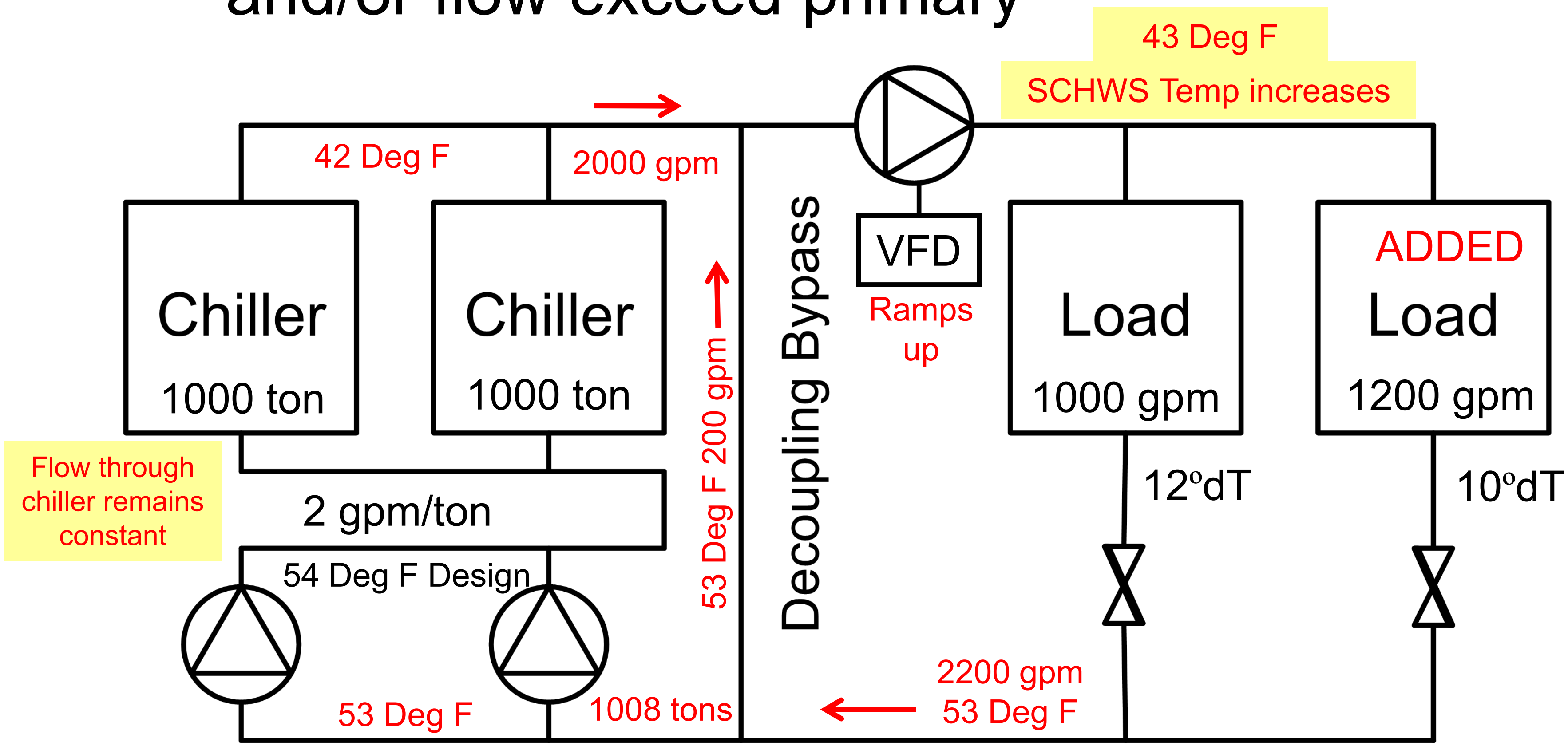
Primary/Secondary (Balanced)



Chilled Water System History

Primary/Secondary (Imbalanced)

- Problems propagate when secondary load and/or flow exceed primary



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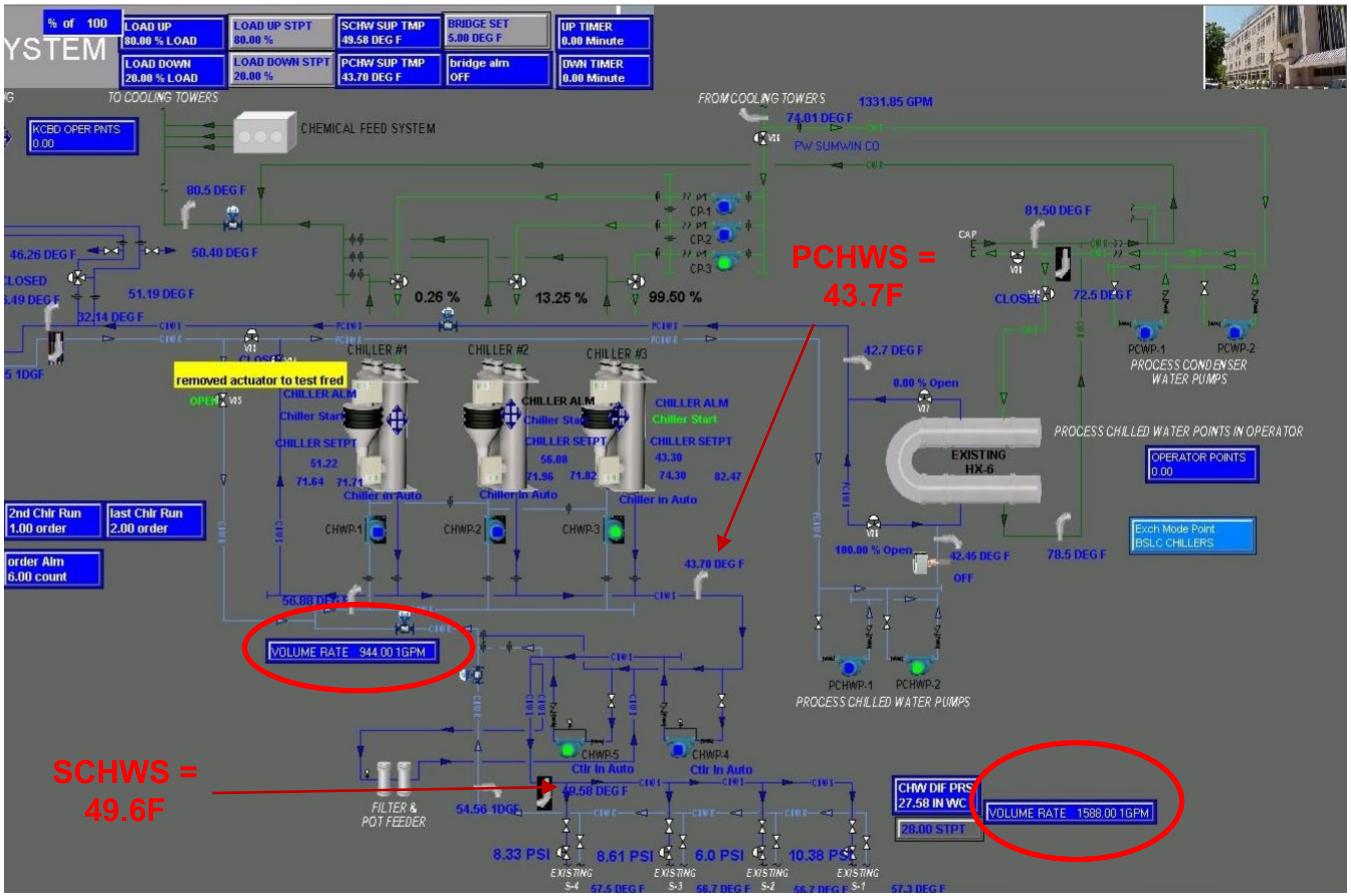
Primary/Secondary (Imbalanced)



Chilled Water System History

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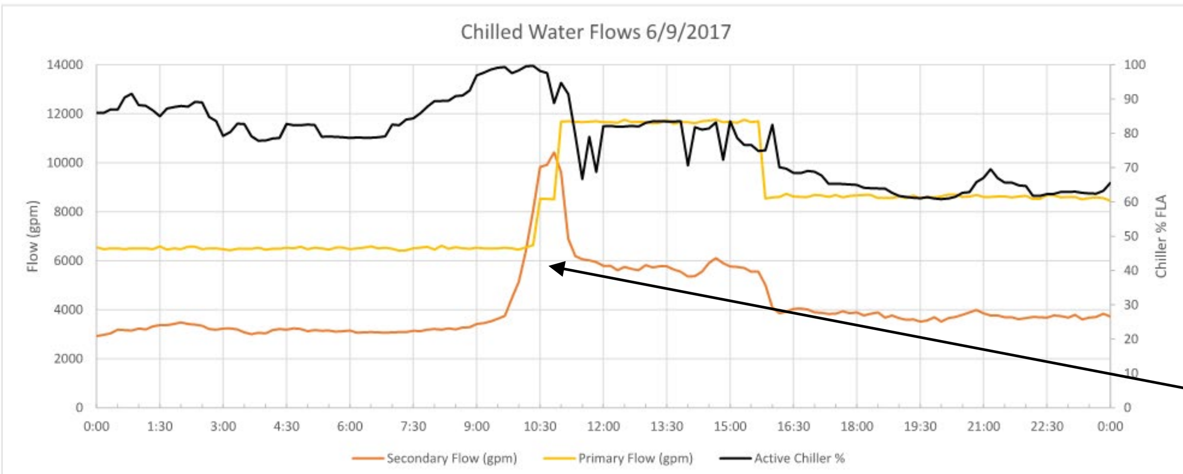
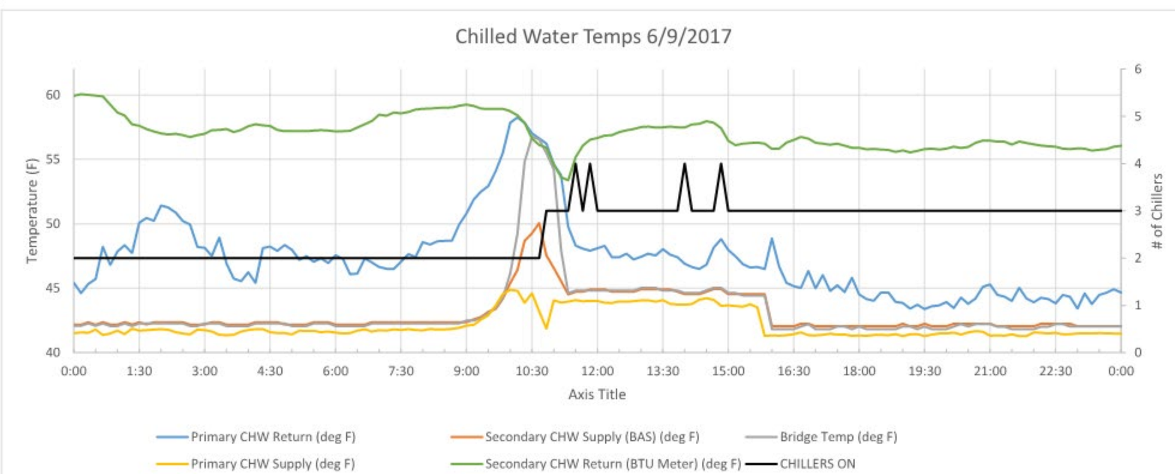


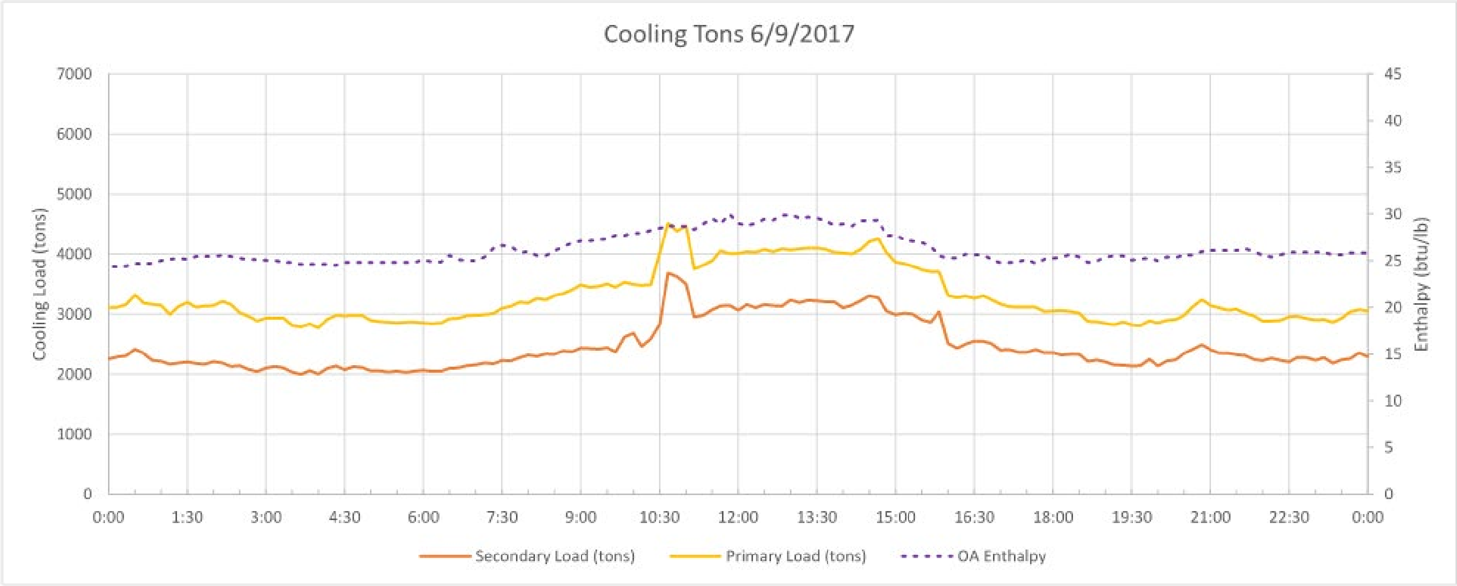


SCHW flow increases above Primary flow. Little actual load increase on plant.

SCHW deltaT drops to 6F, from approximately 15F.

Chilled Water System History

Primary/Secondary (Imbalanced)



Chilled Water System History

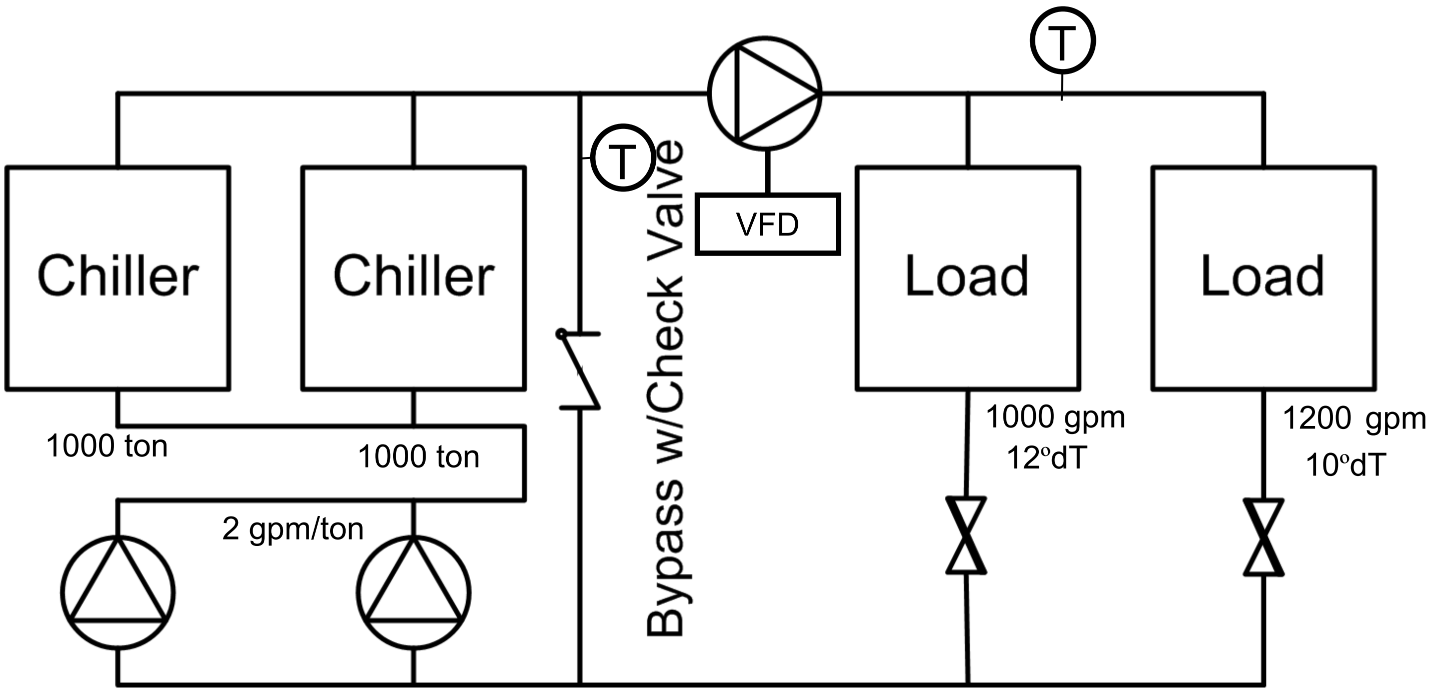
Primary/Secondary (Imbalanced)

Why show frozen towers?

Chilled Water System History

Primary/Secondary "Improvements"

- Constant Primary Flow / Variable Secondary Flow improvements, many options



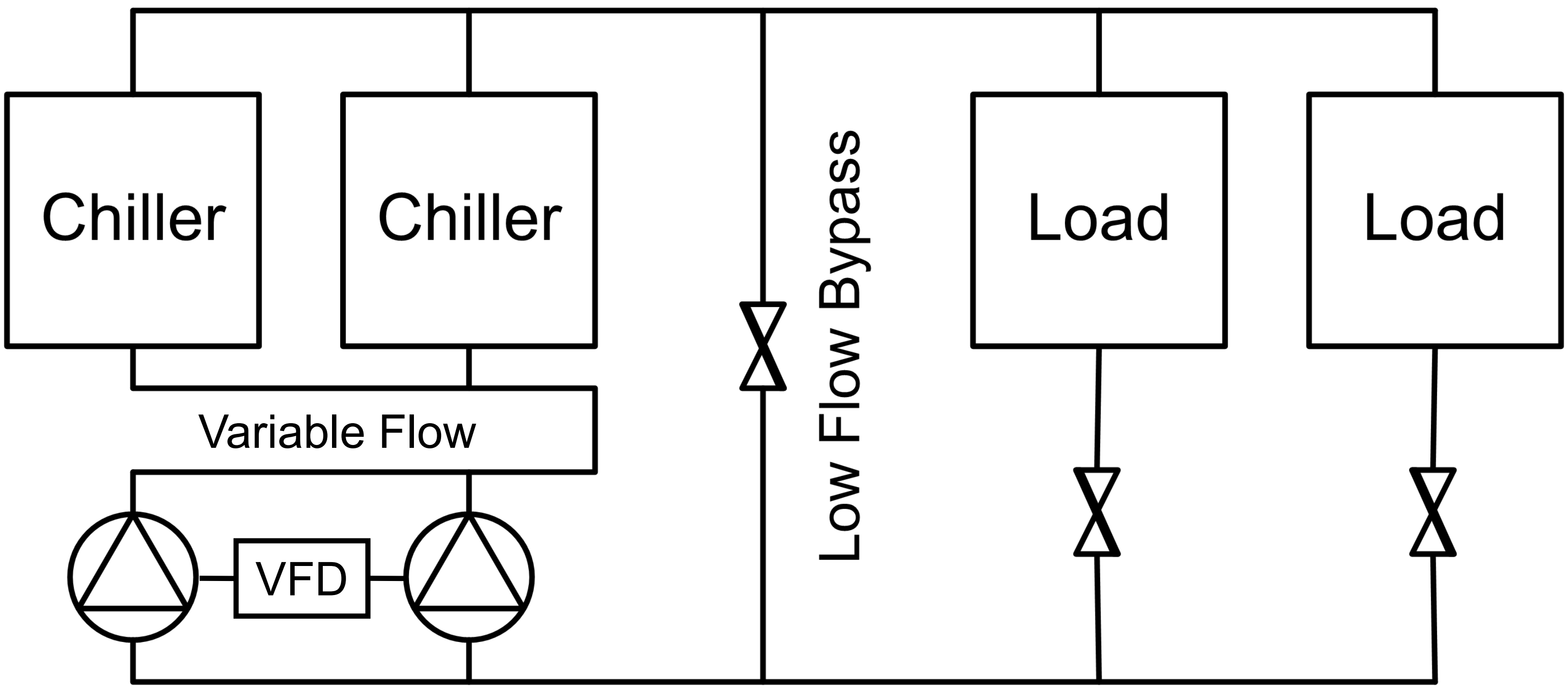
Typical "band-aids":

- Install check valve in decoupler
- Stage chillers on secondary supply temperature
- Stage chillers on decoupler temperature?

Chilled Water System History

Variable Primary

- Variable Primary Flow with low flow bypass



Chilled Water System History

Why is Variable Primary Flow (VPF) New?

(According to survey of chiller manufacturers)

- Was always *technically* feasible
- Practical application limited by on-board controls in use prior to mid-1990s
    - Capacity modulation
    - Freeze protection
    - Flow detection
- Improvements in all areas have increased manufacturer support for variable primary flow

VPF Design Considerations

Design Concerns

- Pumps are controlled by load differential pressure (dP), not staged with chillers
- Low Flow Bypass is critical to maintain minimum chilled water flow through the chillers

Flow Rate Range Limits (min. flow)

- Typical 3 – 12 ft/s tube velocity range
  ∴ maximum turn down to ~25% (from max)

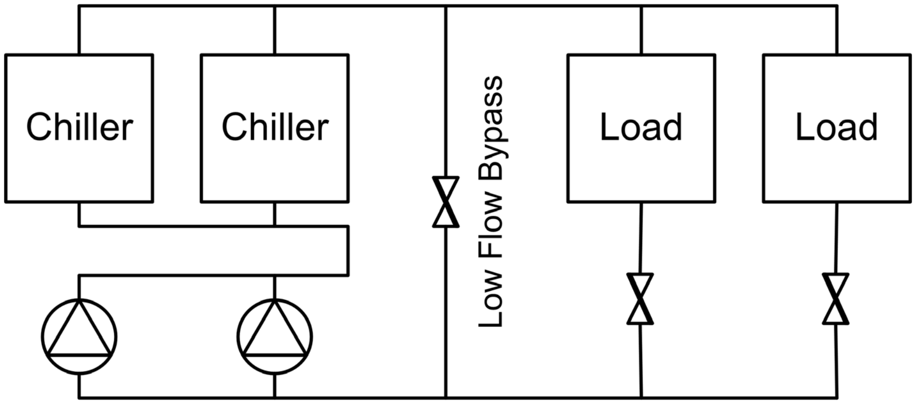
Rate of change of flow

- Do not exceed rate of change greater than 30% of design flow per minute[3]
- Older constant speed chillers, do not exceed 10%[3]

VPF Controls Considerations

Controls Complications with VPF

- Differential Pressure (dP) pumping control
- Low Flow Bypass controls
- Chiller staging effect on flow through chillers
- Chiller modulating flow control valves to balance flow through multiple chillers in operation



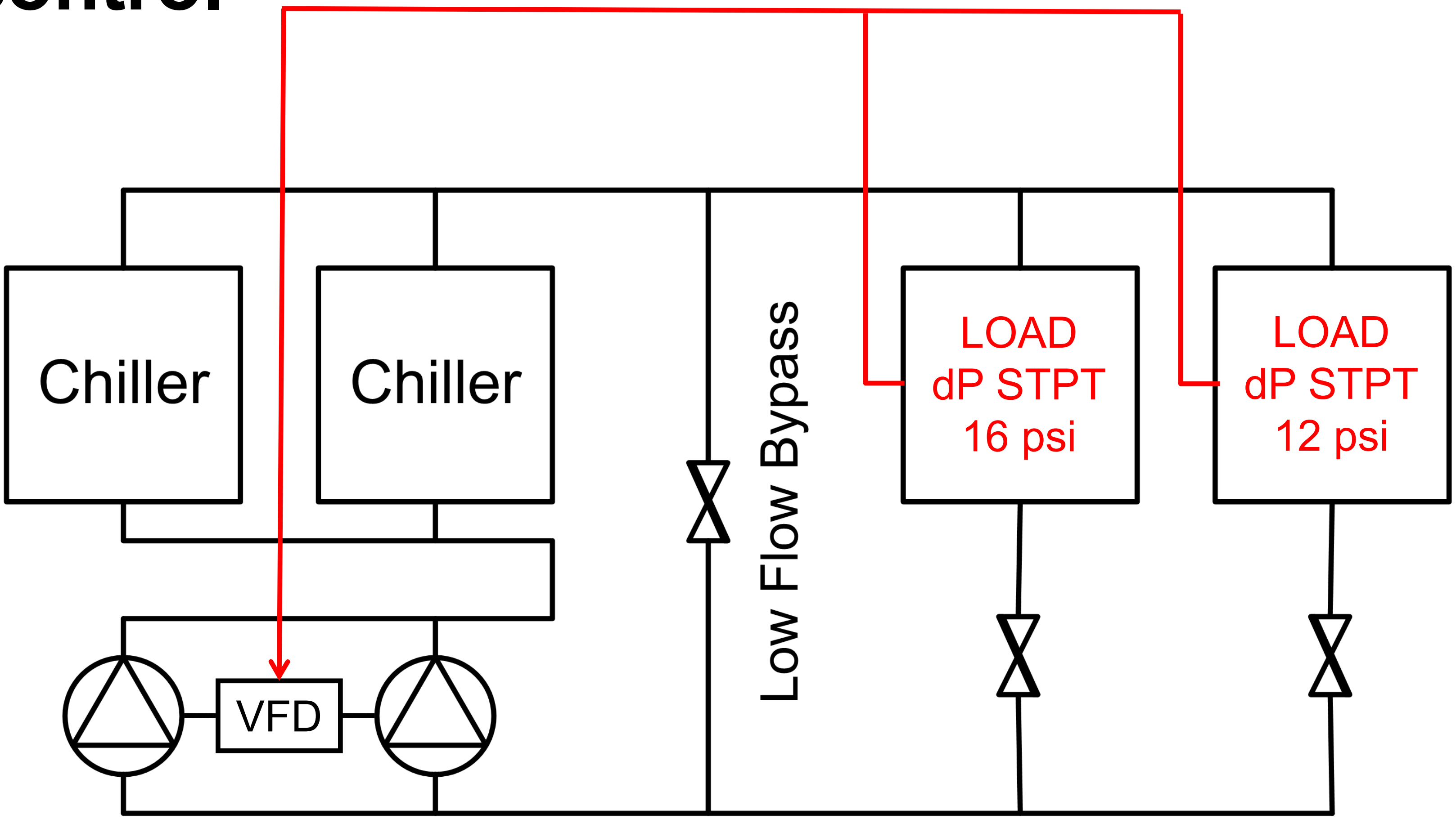
VPF Controls Considerations

Differential Pressure (dP) pumping control

- Common chilled water systems feed multiple loads, air handlers and buildings
- System configurations typically have multiple risers and/or buildings
- Resulting in varying dP requirements throughout the system
- VPF pumps need to satisfy the hydraulically most critical zone, which is the zone furthest below set point

VPF Controls Considerations

Differential Pressure (dP) pumping control

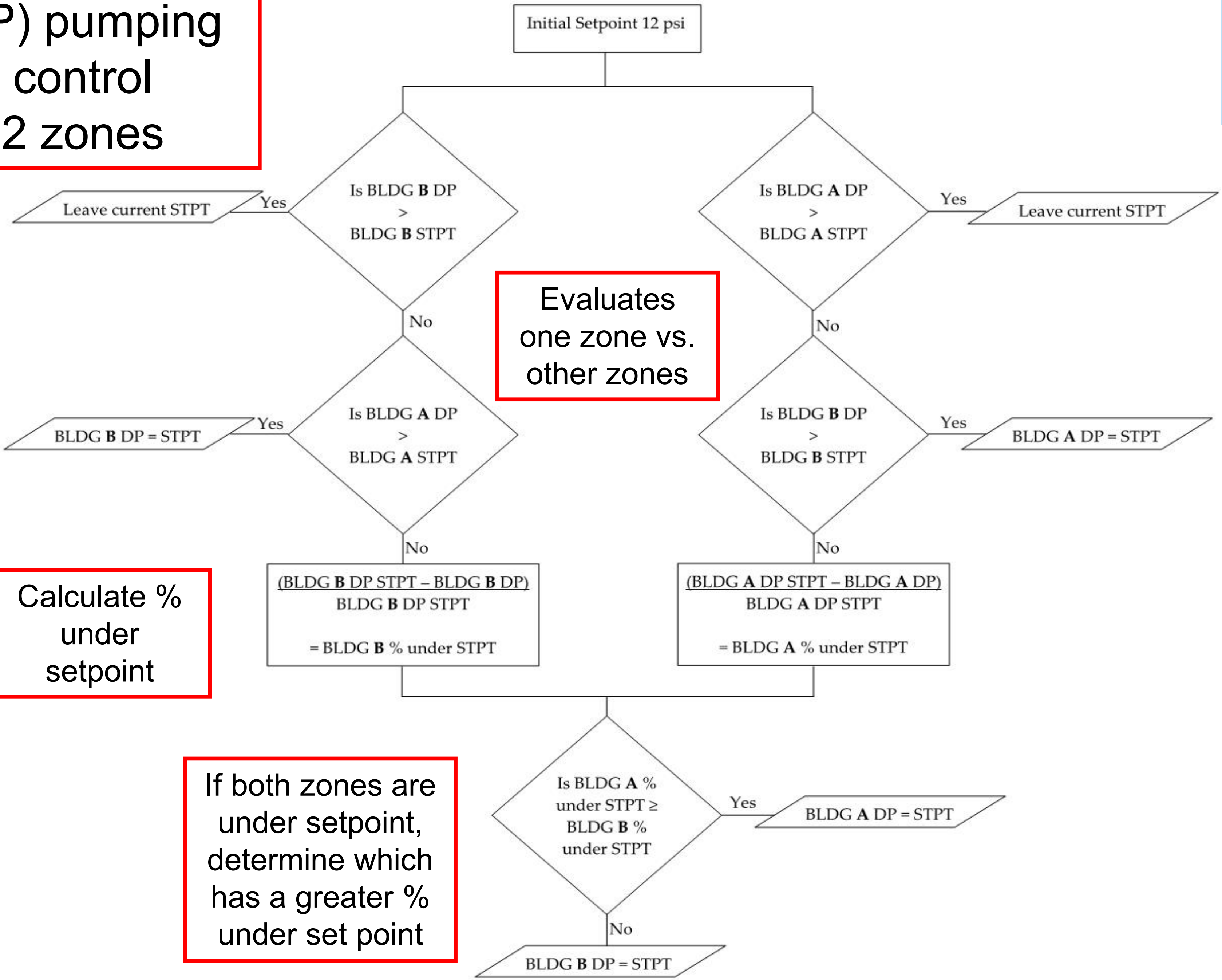


(dP) pumping control 2 zones

Evaluates one zone vs. other zones

Calculate % under setpoint

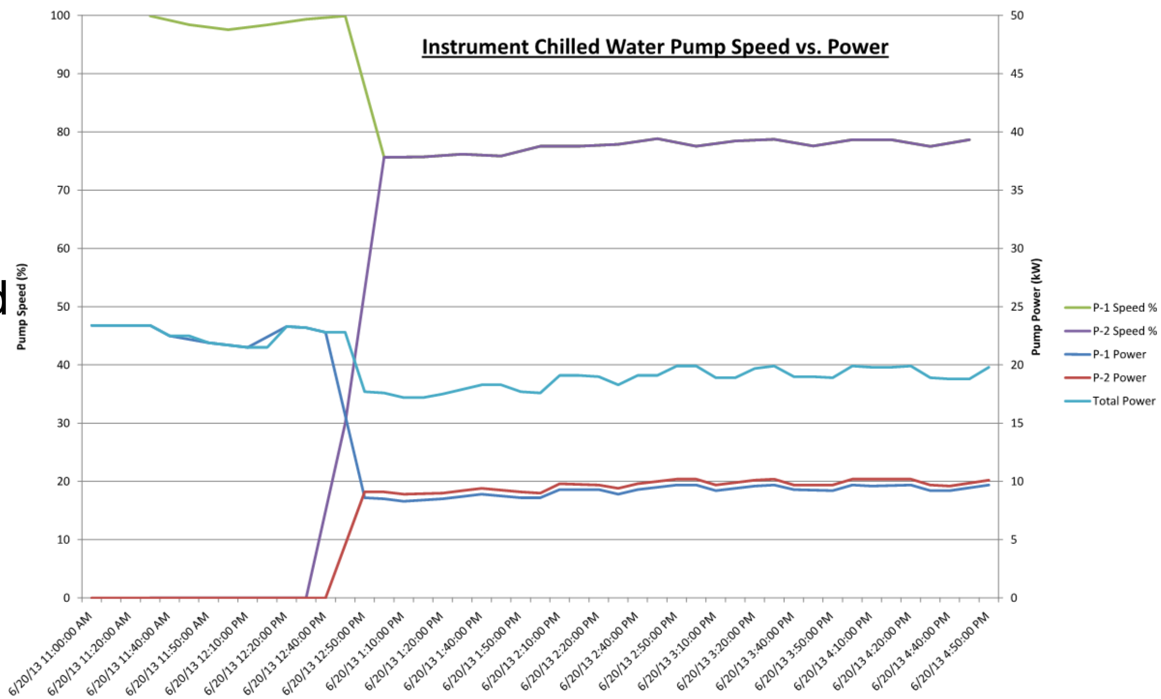
If both zones are under setpoint, determine which has a greater % under set point



VPF Controls Considerations

Differential Pressure (dP) pumping control

- Pumps are now staged to keep several pumps running at a lower speed
- Stage up/down at 80%, 60%, 53%
- Can leverage BAS data, and Cx, to optimize staging stpts



VPF Controls Considerations

Differential Pressure (dP) pumping control

- Need a sequence to stage pumps
  - Typically slow Lead pump down to an “arbitrary” speed and ramp up Lag pump until it meets it, then release.
  - With as little disturbance to system as possible to prevent system instability
  - Consider keeping Lead pump controlling to dP stpt. Enable Lag pump and use a BAS “ramp” to slowly increase speed. Lead pump slows to maintain dP, eventually pumps’ speed is equal.

Additional dP Optimization Opportunities

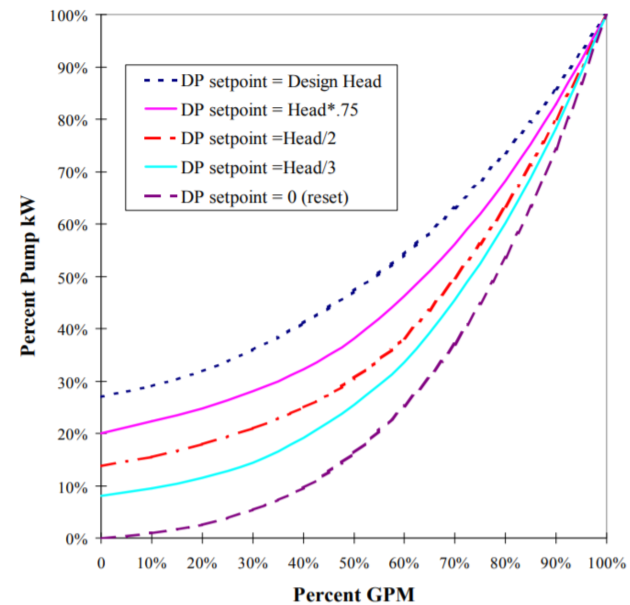
Pump dP Reset

Benefits:

- Reduce set-point when building load is less than design
- Monitor AHU chilled water valve positions as pumps slow.
- Reduce dP setpoint 0.1 in.w.c. every 15 minutes when CHW valves are less than 90% open.

Things to keep in mind:

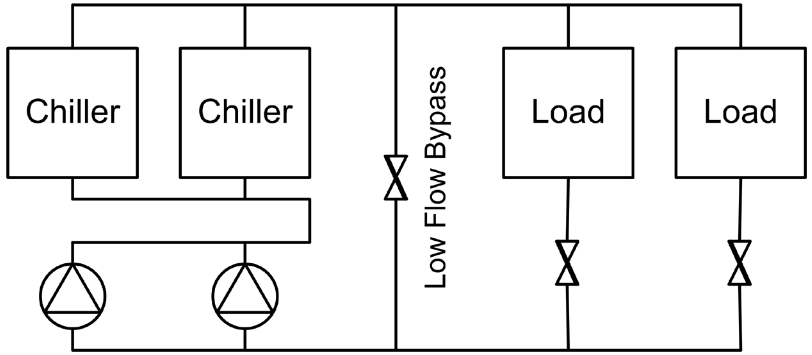
- What is current setpoint?
- Minimum pump speed should dictate min DP setpoint.



VPF Controls Considerations

Low Flow Bypass controls

- Recommend valve type and actuator be fast acting
- Bypass control proportional, integral, derivative (PID) loop may need to be fast acting
- Flow measuring device required for evaporator flow
  - Can we use factory chiller dP transmitter?
- Be aware of sequences that cause pump dP control and bypass valve control from fighting.
  - When minimum flow is reached, as measured by flow metering device, lock pumps' speed in place, and utilize dP setpoint to control bypass valve.



VPF Cx Considerations and Realities

Low Flow Bypass controls (testing)

- Hard to Cx without load on the building, will operate with bypass open and no load on chillers
- Maximum turn down to 25% is optimistic, too little water through the evaporator to keep the system stable
- Expect some surging at low flow conditions and Low Evaporator Temperature trips

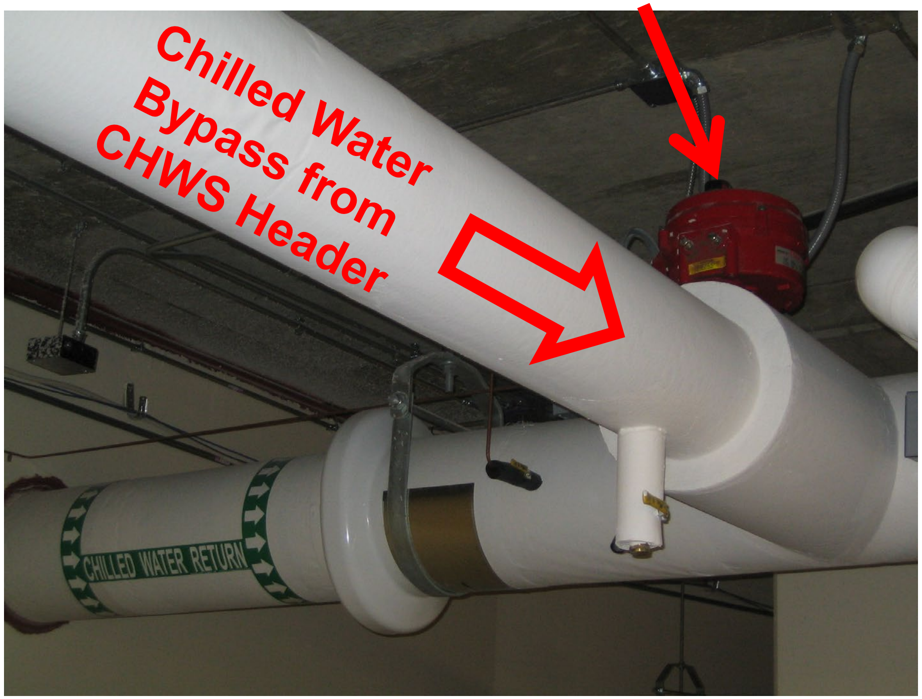
Case Study – Results

Case Study - Low Flow Bypass

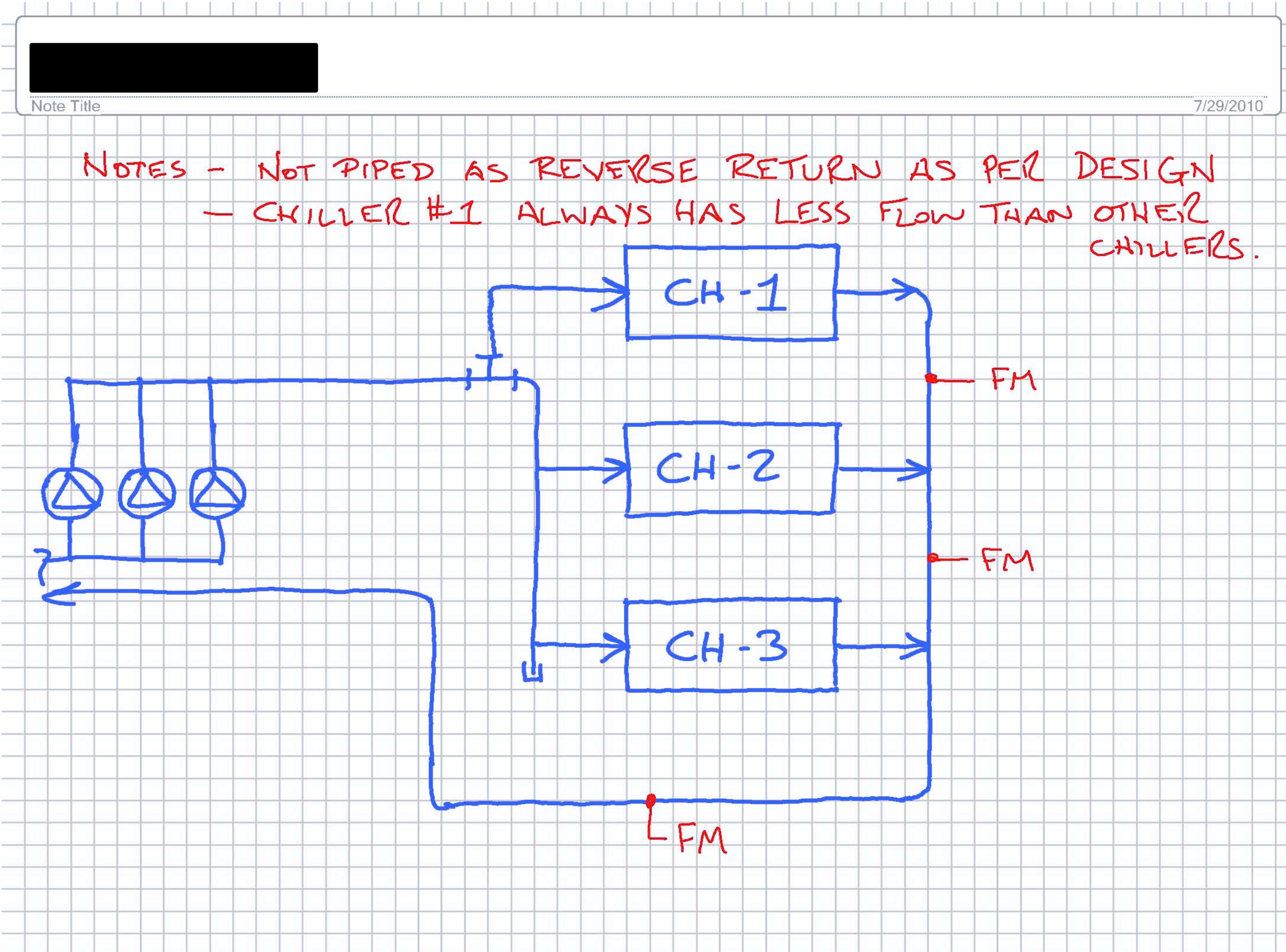
- (3) electric centrifugal 400 ton chillers
- 2 gpm chilled water design flow rate per ton
- 800 gpm per chiller
- Minimum Flow Rate = 210 gpm
- Chilled water header = 10"
- Low Flow Bypass Line Size = 6"

Lesson Learned, size the bypass line appropriately and select a fast acting modulating actuator; controllability of the bypass can be extremely difficult

Chilled Water Bypass Control Valve Bray Butterfly Valve



Case Study – Results



VPF Controls Considerations

Chiller Staging

- Chillers are staged based on leaving chilled water supply temperature
- Due to independent pump and chiller control
  - Load and flow demand may rise while chillers can still meet setpoint
  - Flow through chiller may exceed the system “allowable” pressure drop and cause loss of pressure in the field
  - May need to have secondary logic that acts as chiller flow “high limit”
- Need for delays on stage up/down, and additional delays to prevent runaway staging. Let system “settle” between stages.

Chiller Staging Problems

[redacted]

Evergreen Chiller Cooler Pressure Drop

03/26/2010
11:59 AM

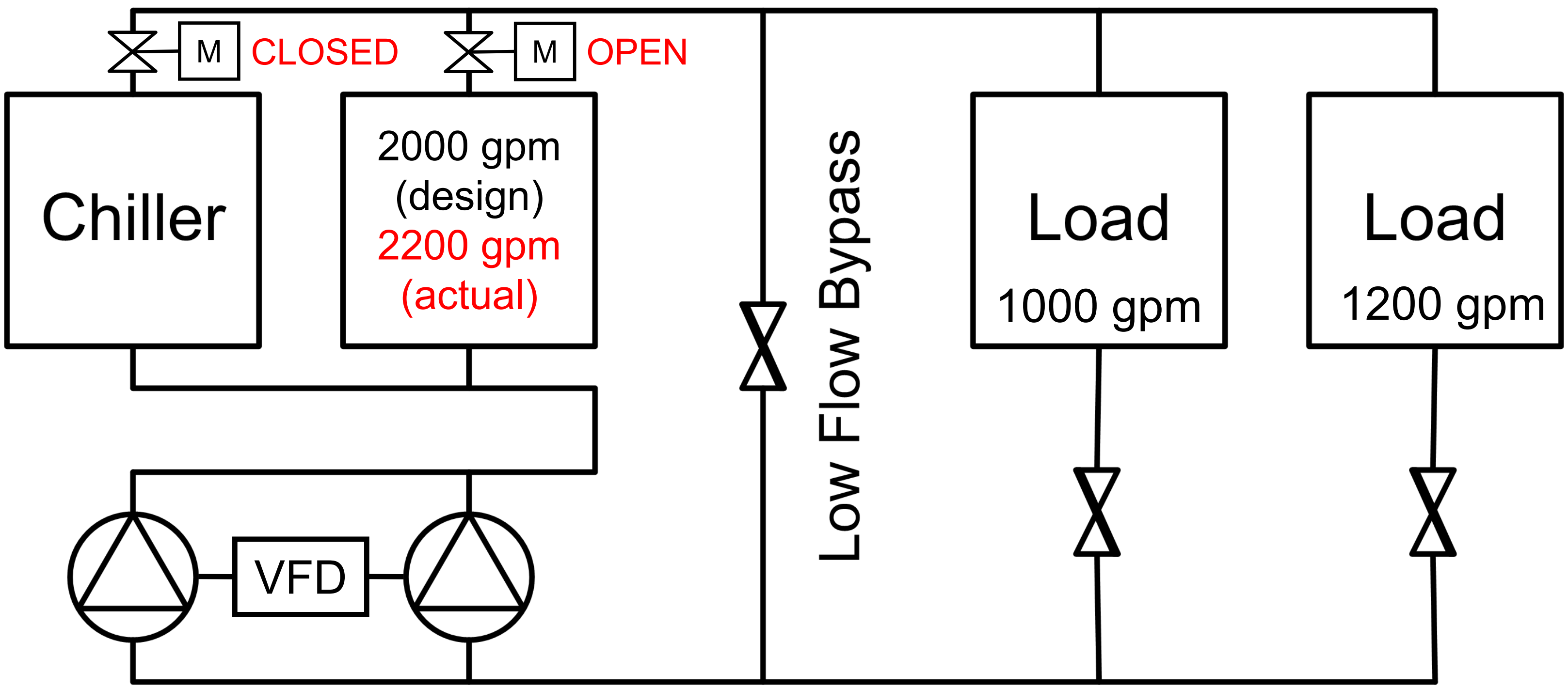
Tag Name	19XR	
Chiller Model	19XR-7577576MEH64	
Cooler Size	75	
Cooler Waterbox Type	Nozzle-in-Head, 150 psi	
Cooler Passes	2	
Cooler Tubing Type	Super E3 (SUPE3), .025 in, Copper	
Cooler Flow Rate	1783.5	gpm
Cooler Pressure Drop	20.5	ft wg
Cooler Fluid Type	Fresh Water	
Cooler Minimum Flow Rate	1021.6	gpm
Cooler Maximum Flow Rate	4086.3	gpm

Note: This does not imply that the chiller can be properly applied over the entire range of condenser water flow rates represented. The chart is to represent pressure drops only.

Chiller Staging Problems

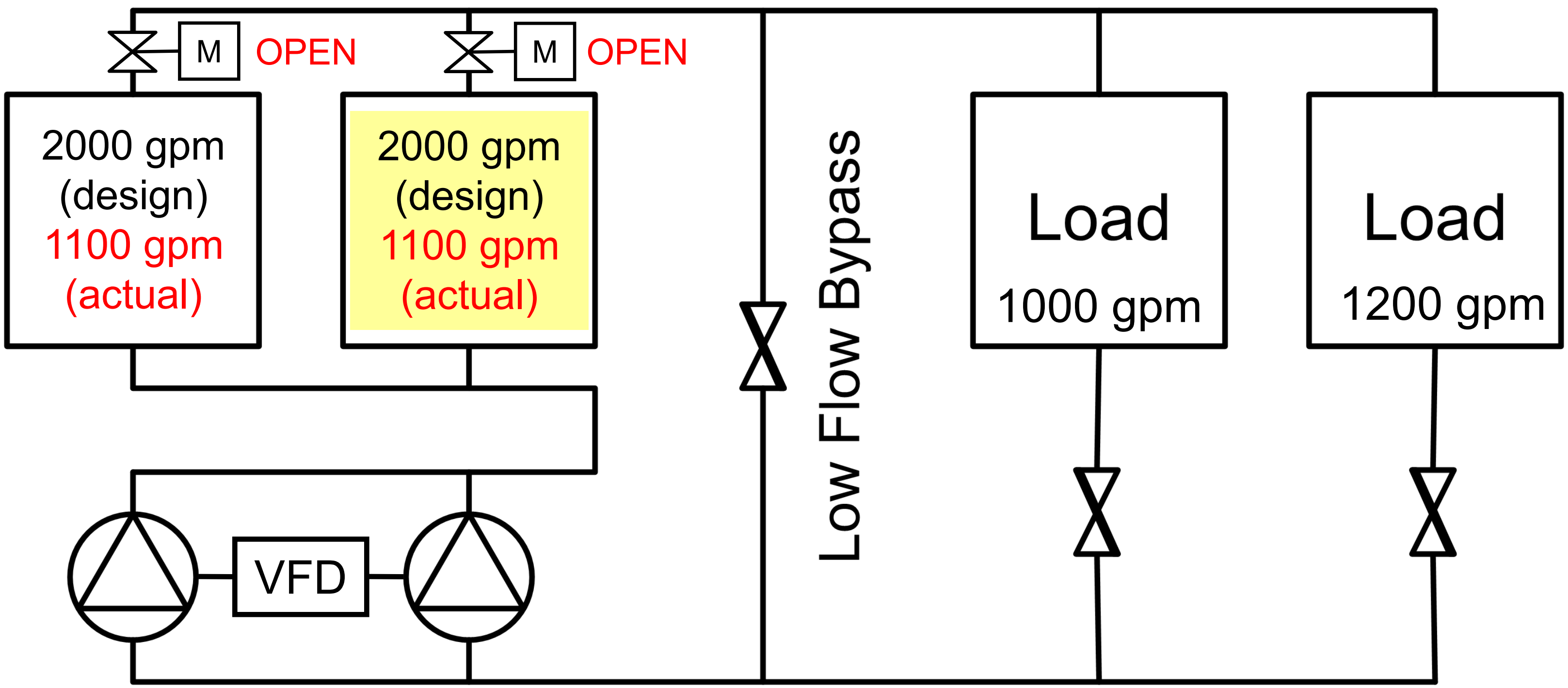
Chiller Staging Problems

- 1 Chiller operating near full load
- CHWS temperature may still be at setpoint



Chiller Staging Problems

- Staging on the second chillers
  - Valves should be modulating and slow acting
  - Rate of change limit 30%, 2000 gpm = 600 gpm
  - Flow drops 1100 gpm, need to take ≈ 2 minutes to open second chillers control valve



Chiller Staging Suggestions

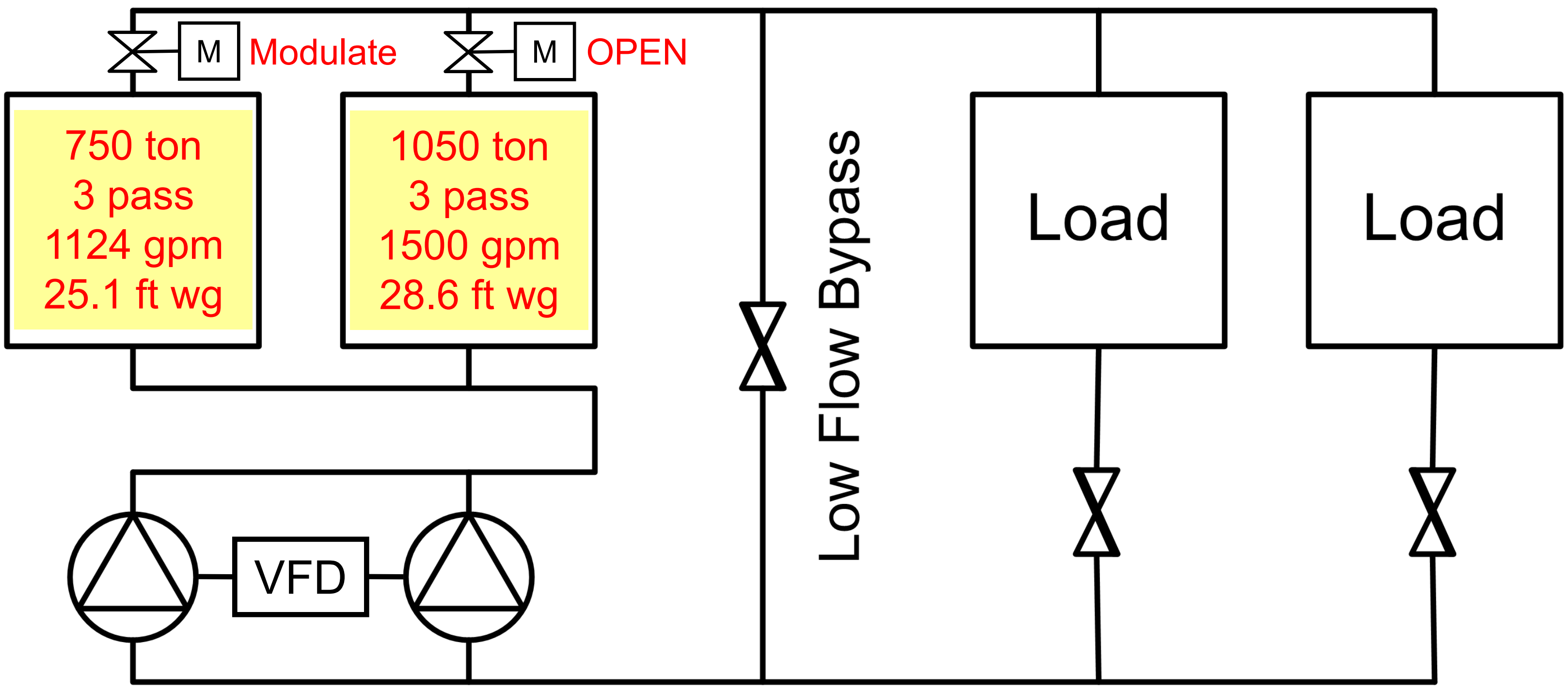
Chiller Staging Sequence Suggestions

- Before staging on next chiller, raise the operating chillers setpoint
  - This should be done a few minutes before opening the second chillers evaporator flow control valve
  - This will back off how hard the first chiller is working and help prepare it for the sudden drop in chilled water flow
  - After the second chiller is staged on for a period of several minutes, start resetting the CHWS temp setpoint back down
  - *LOCK THE PUMPS at their current speed while staging chillers on and off
  - *Drop in system dP will cause a sudden increase in pump energy into system, causing system dP to rise, resulting in pumps slowing down.

Staging & Hydraulically Most Remote Chiller

Chiller Staging Problems

- Plants consist of both variable speed chillers and constant speed chillers of different capacities
- Need to assess pressure drop across chillers & piping

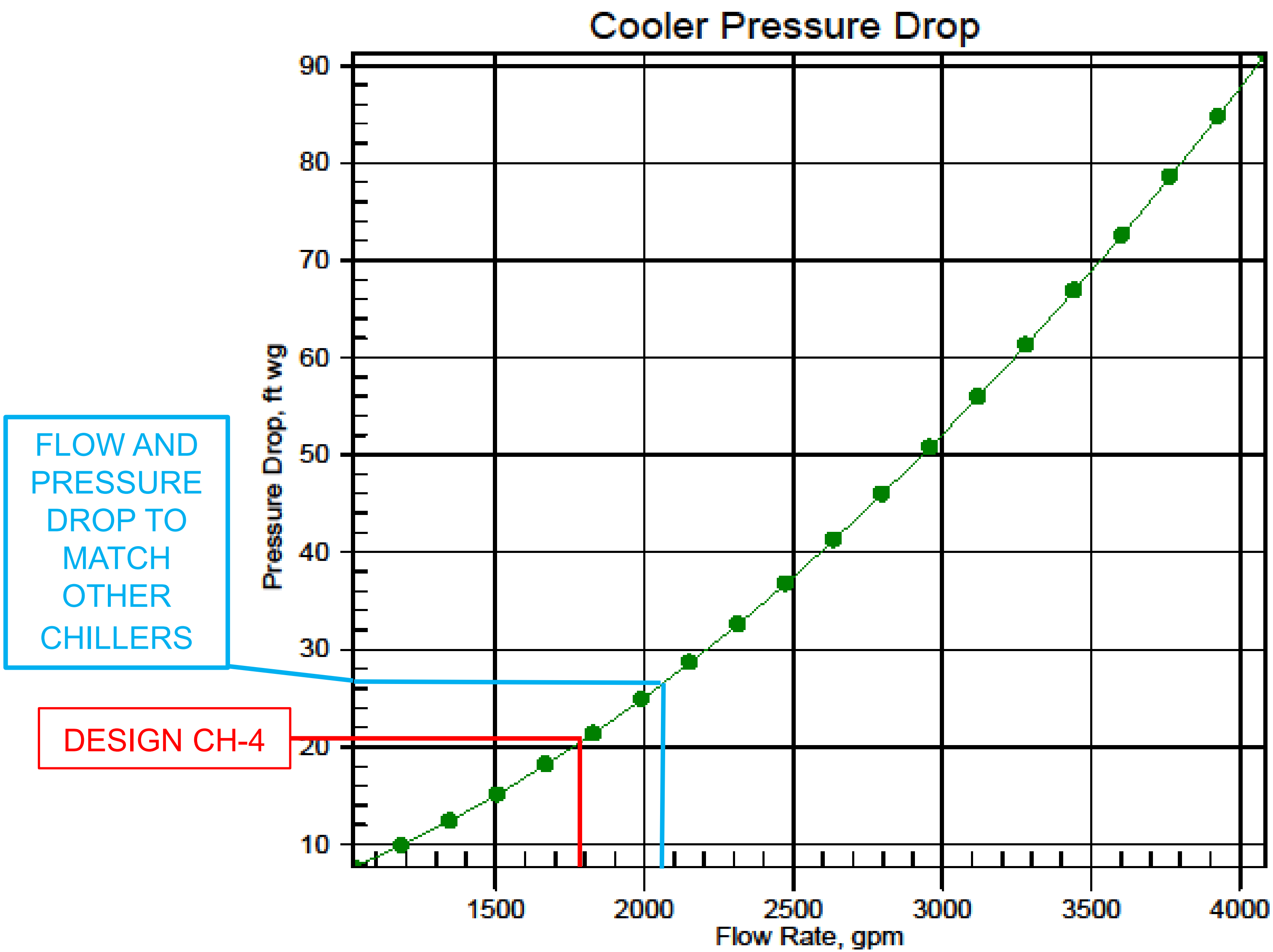


Staging & Hydraulically Most Remote Chiller

- Which chiller is hydraulically the most remote?
- Take piping into account when determining this
- How do you select which chiller valves are open and which modulate?
- Possibly modulate based on chiller capacity ratio.

Chiller Performance Characteristics				
Chiller #	1	2	3	4
rated tonnage	1050	1050	750	1190
# of Evap Passes	3	3	3	2
Evap gpm	1500	1500	1124	1783
Evap PD ft wg	28.6	28.6	25.1	20.5

Staging & Hydraulically Most Remote Chiller



Additional Optimization Opportunities

Potential Energy Conservation Measures

- Open triple duty valves
  - trim impeller or install VFDs
- Replace failed temperature or differential pressure sensors
- Chilled water temperature reset
- Condenser water temperature reset
- Chiller staging modifications
- Add free cooling heat exchanger
- Chiller VFDs or replacement

Additional Optimization Opportunities

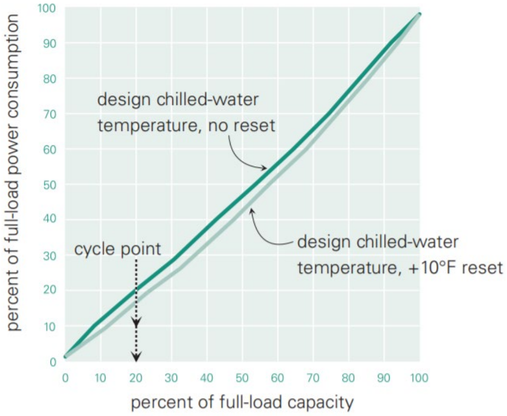
Chilled Water Temperature Reset

Benefits:

- Raise set-point when building load is less than design
- Warmer chilled water reduces burden on compressor resulting in energy savings
- “Rule of thumb” each 1°F increase in CHWST = 1-1.5% reduction of chiller energy

Things to keep in mind:

- Warmer CHWS may increase pump energy
- Warmer CHWS may reduce dehumidification
- Consider process loads



Additional Optimization Opportunities

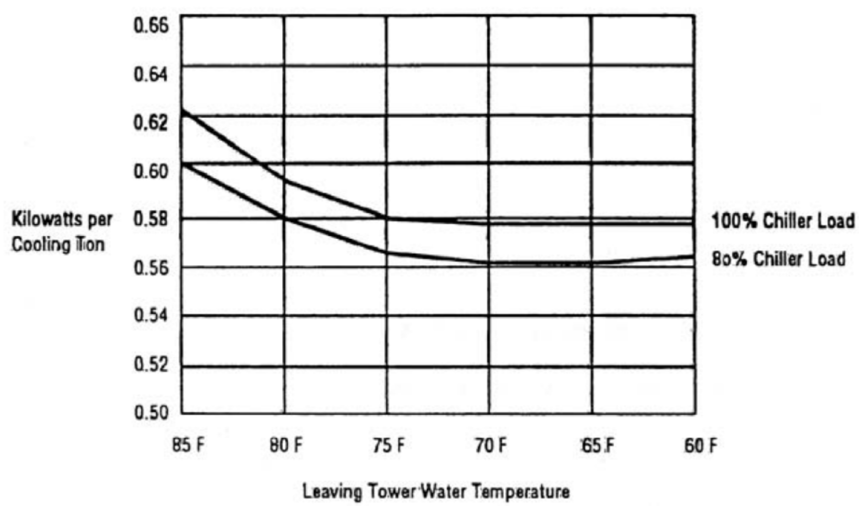
Condenser Water Temperature Reset

Benefits:

- Lower setpoint when building load is less than design
- Colder condenser water reduces burden on compressor resulting in energy savings
- CWST stpt = OA WB + 7F (typ.)
- Typical min CWST stpt = 65F

Things to keep in mind:

- How smooth is cooling staging.
- Are the chiller savings greater than the increased tower fan energy?
- Monitor min. pressure differential between condenser and evaporator



VPF Cx you can't make this stuff up!!

Controls

- Johnson Controls buys York, Aug 2005
- May 2010, York startup tech says chilled water reset is not a good idea and disallows JCI from doing chilled water reset
- After a Cx "discussion", the next days . . .
- York allows JCI access to do CHW reset
- Only to find out – that now you have to control the chillers demand limiting function as well?? Limit to 80% for the first 30 min.

References

References

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2. McQuiston, F., J. Parker and J. Spitler, 2000 Heating, ventilating and air conditioning – analysis and design, 5th edition
3. Carrier Corporation – (Project and Chiller Specific, refer to your particular chiller manufacturers details)
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6. TRACE 700 User's Manual
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Questions?

Thank you!

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