Chilled Water System Commissioning: Variable Primary Flow

John D. Villani, P.E.
Associate
Grumman/Butkus Associates

AIA Quality Assurance

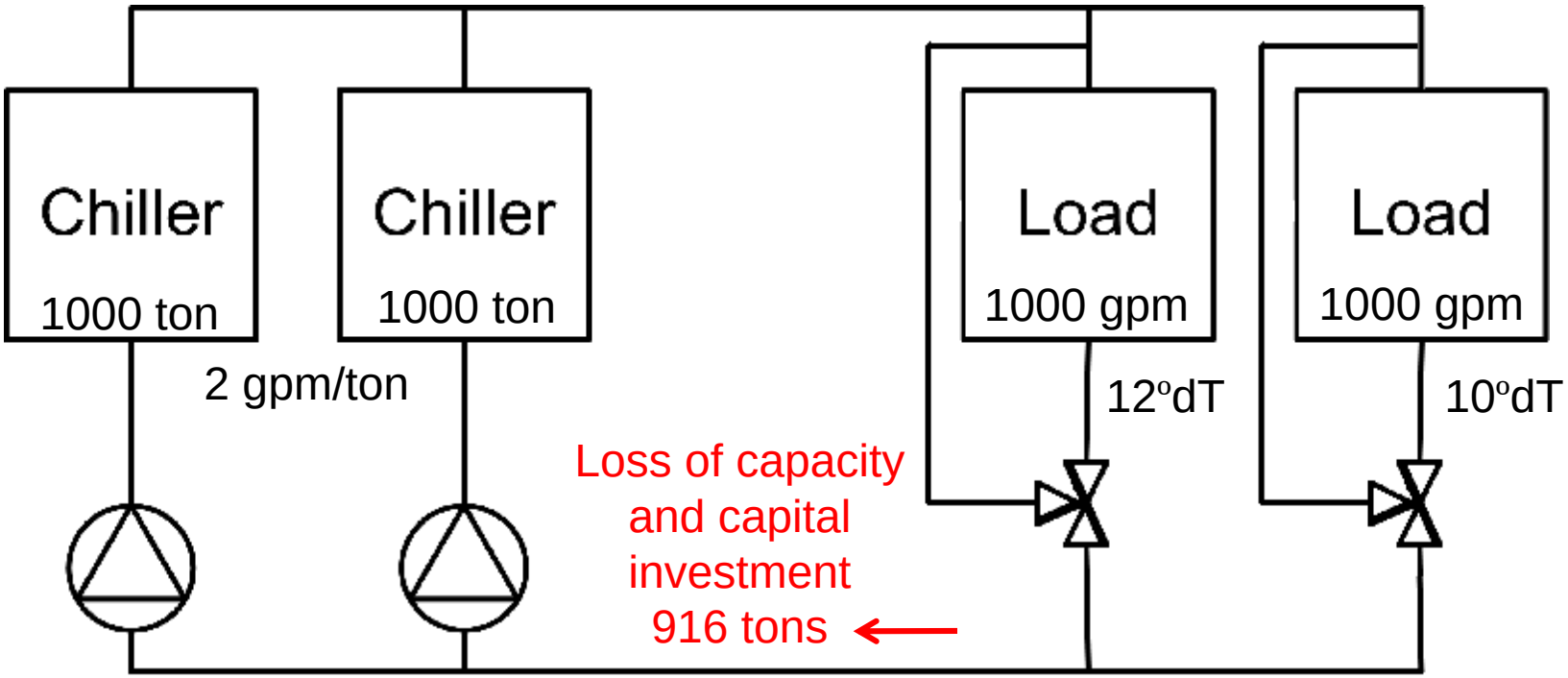
Learning Objectives

1. History of chilled water system configurations
2. Variable Primary Flow (VPF) chilled water system configuration
3. Design and Controls Considerations for proper operation of VPF chilled water systems
4. Things to look for when commissioning VPF chilled water systems

Chilled Water System History

Constant Primary Flow[1]

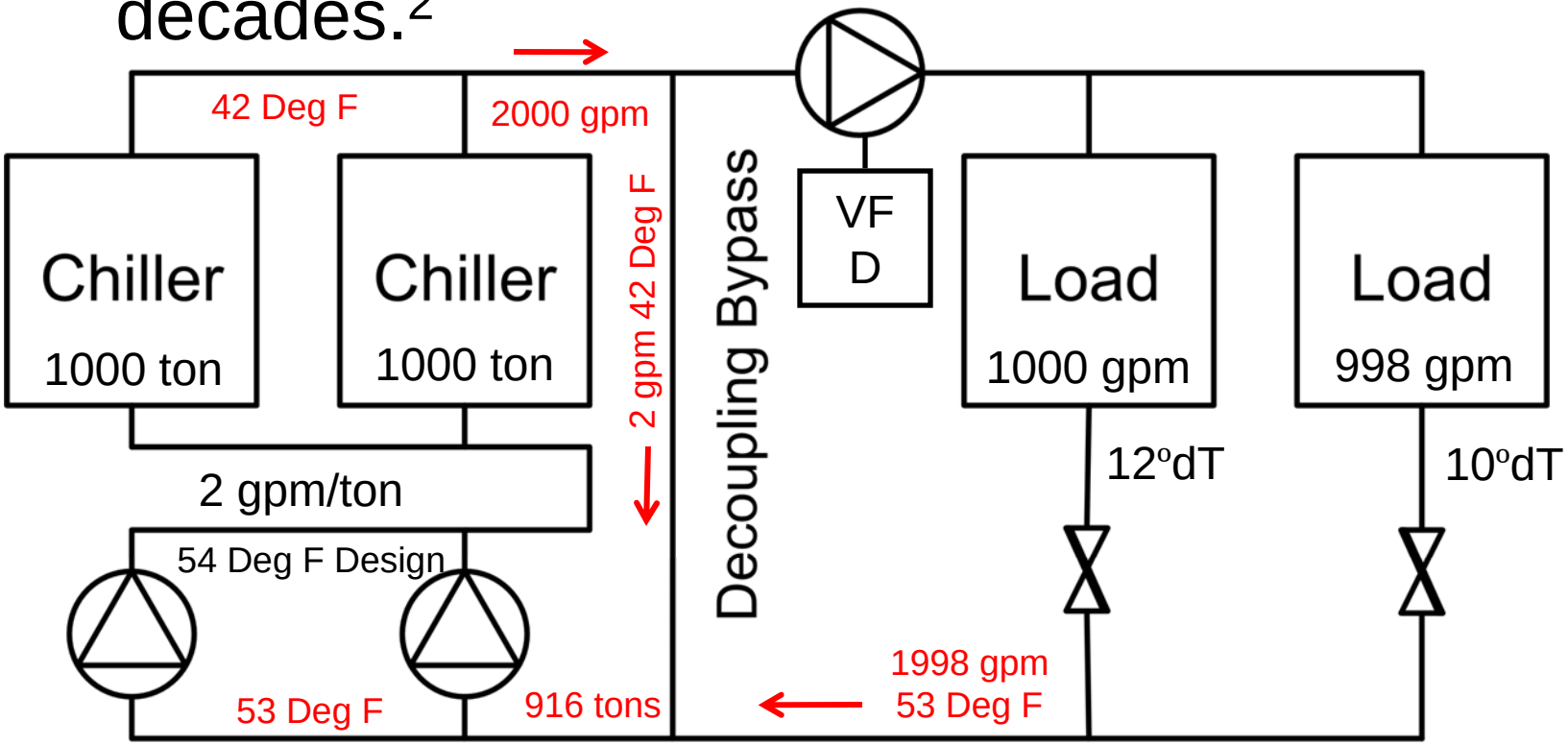
- Constant Primary Flow was used before primary/secondary
- Advent of low delta T problem



Chilled Water System History

Primary/Secondary (Balanced) [1]

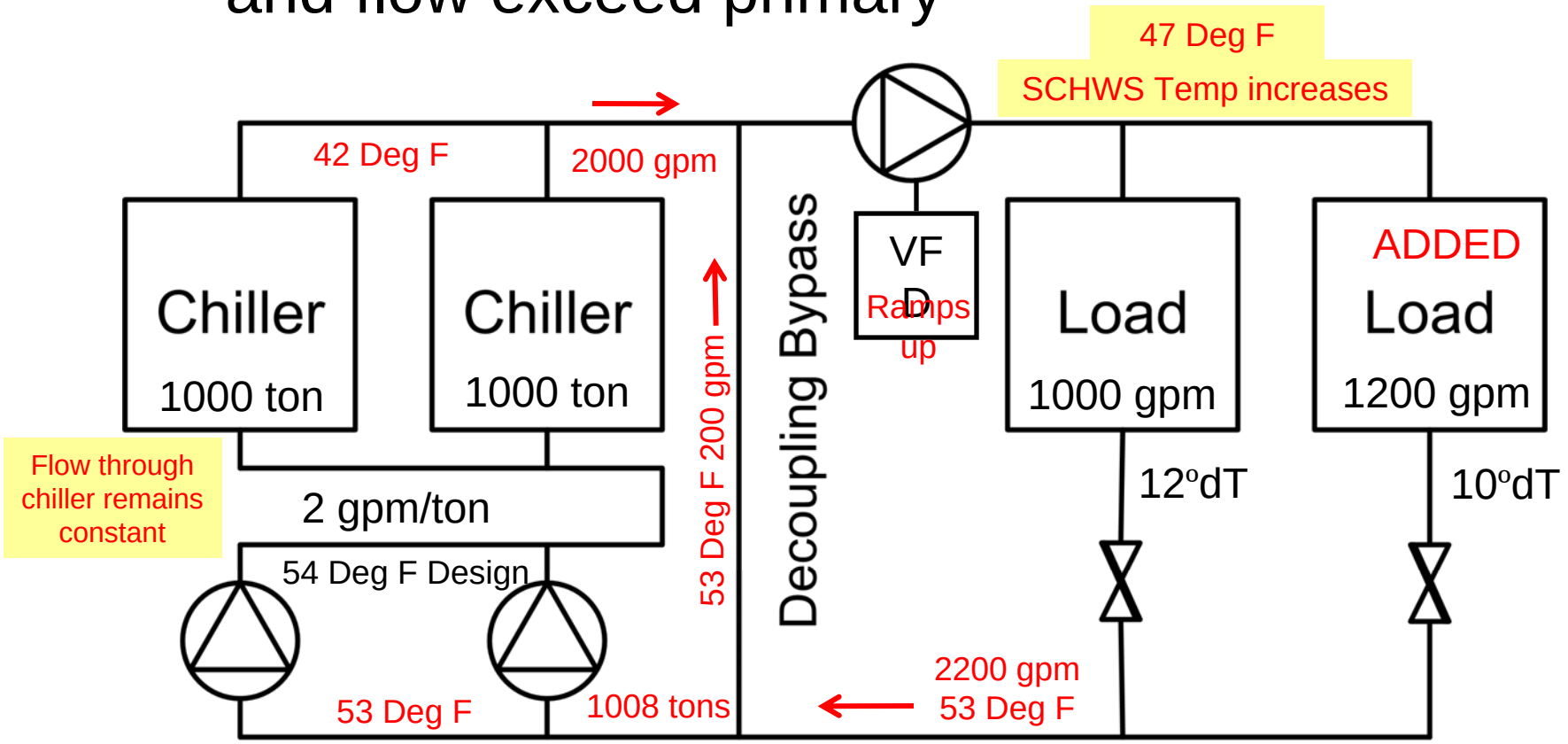
- Constant Primary Flow / Variable Secondary Flow has been the industry standard for decades.[2]



Chilled Water System History

Primary/Secondary (Imbalanced) [1]

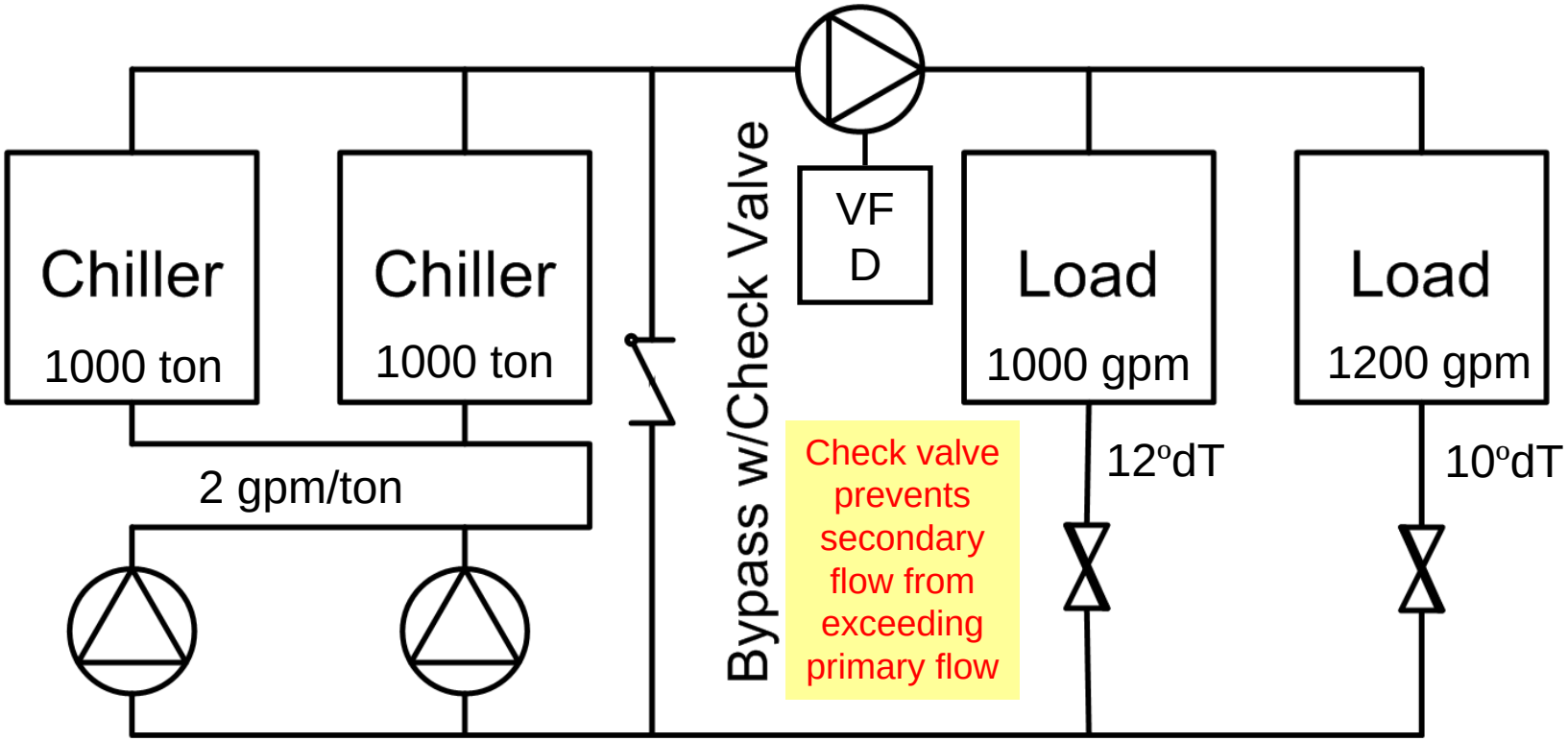
- Problems propagate when secondary load and flow exceed primary



Chilled Water System History

Primary/Secondary[1]

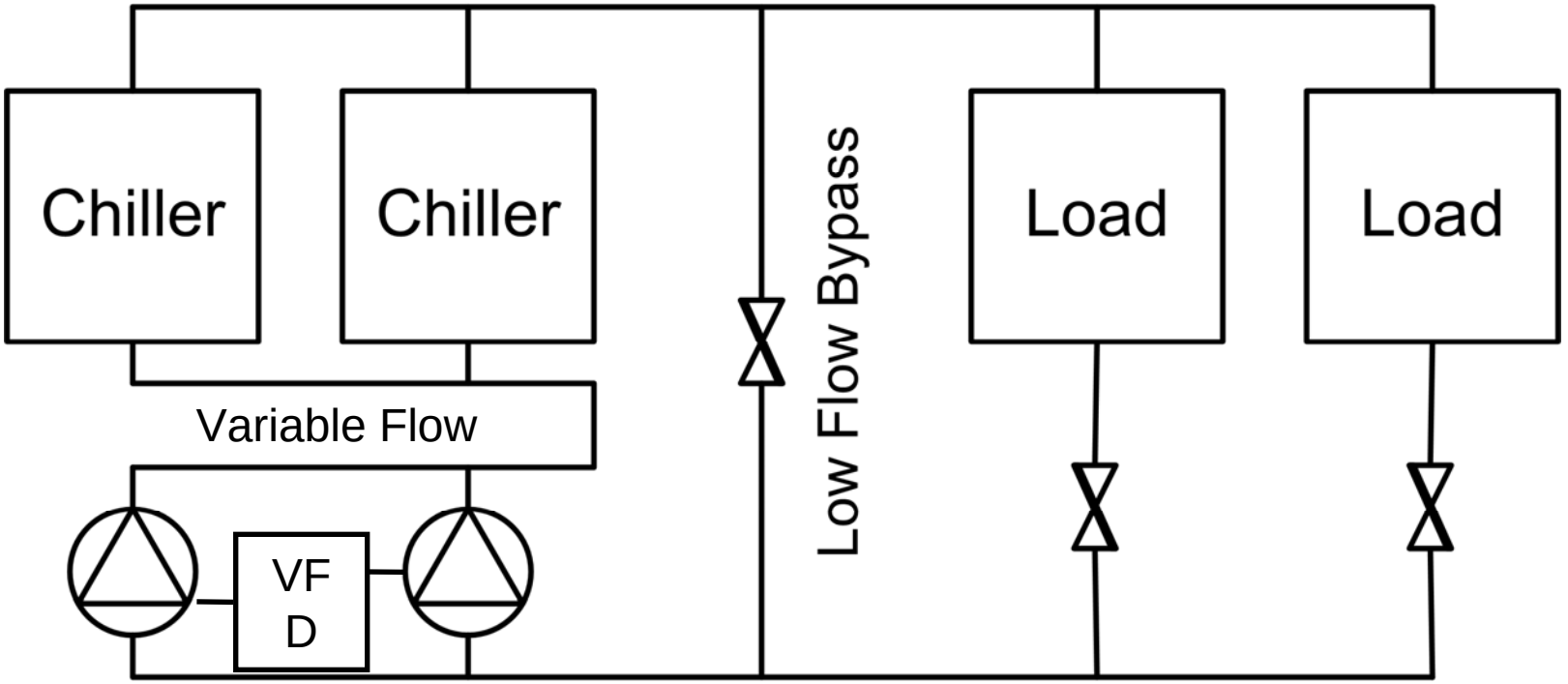
- Constant Primary Flow / Variable Secondary Flow with check valve, one of many options



Chilled Water System History

Variable Primary[1]

- Variable Primary Flow with Low Flow Bypass



Chilled Water System History

Why is Variable Primary Flow (VPF) New?

(According to survey of chiller manufacturers[1])

- 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 Issues

- 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

- Typical 3 – 12 ft/s tube velocity range
  $\therefore$ maximum turn down to ~25%

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

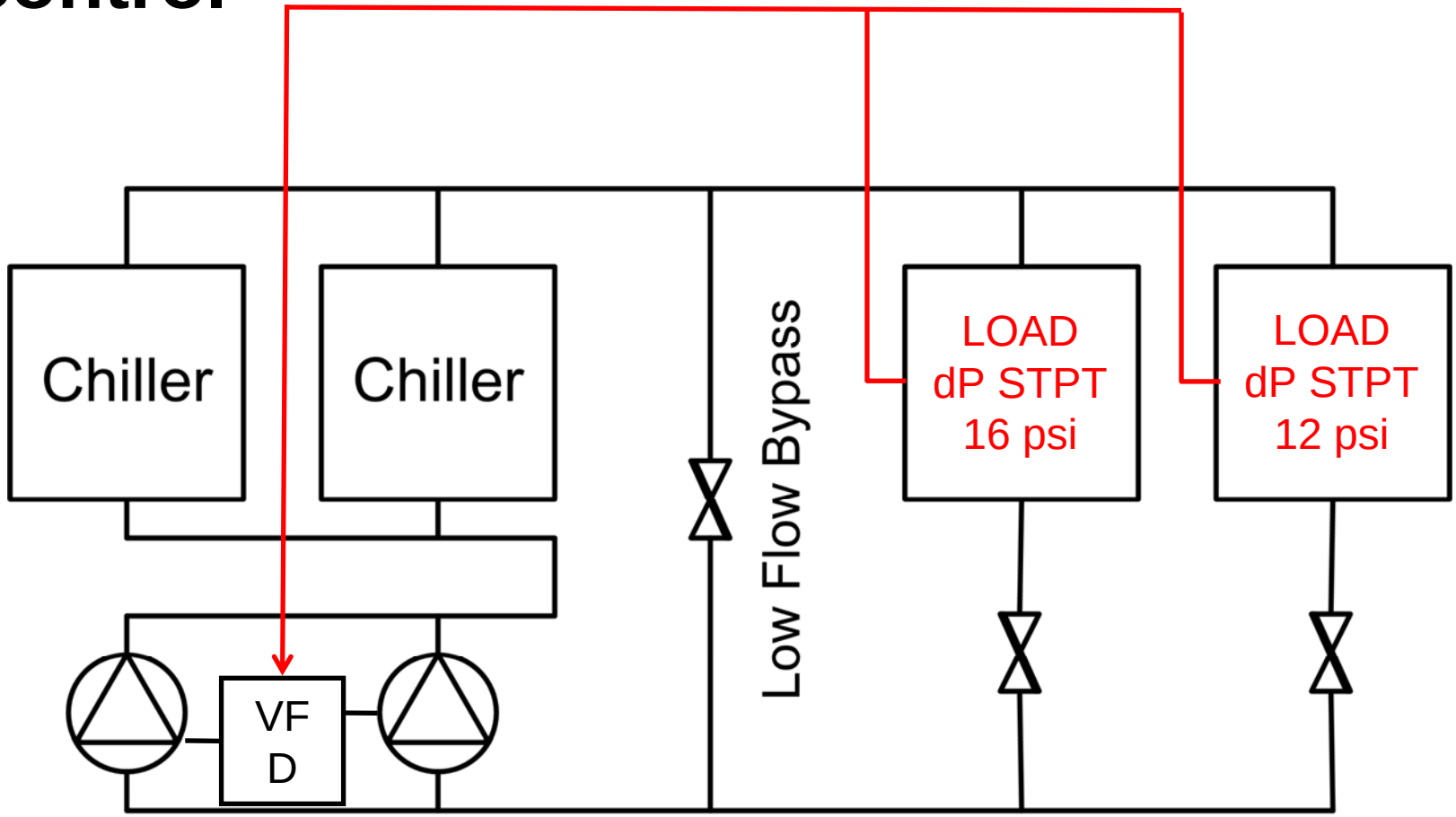
VPF Controls Considerations

Differential Pressure (dP) pumping control

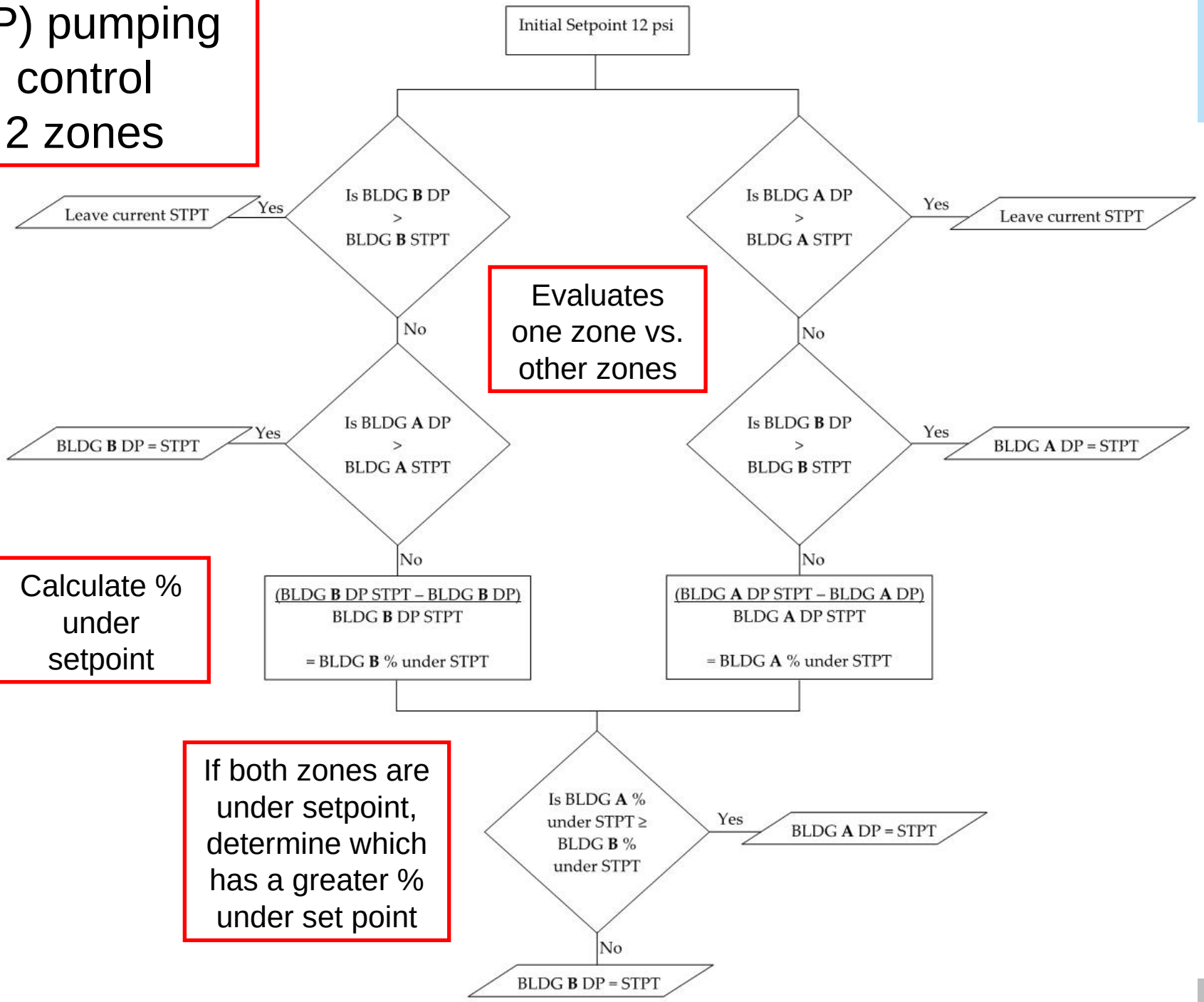
- Need a sequence to stage pumps
- Pumps can be staged to keep several pumps running at a lower speed
- Don’t let pump speed go below ≈40% or 24Hz, pump will not flow water, look at the pump curve
- Stage up/down at 80%, 60%, 53%
- Put in a dP dead band so pumps don’t hunt!!

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

Low Flow Bypass controls

- Valve type and actuator must be fast acting
- Bypass control proportional, integral, derivative (PID) loop must be fast acting
- Bypass control loop must be able to handle changes in system operation such as a failure of a load (air handler) which suddenly shuts the CHW control valve

Case Study – Results

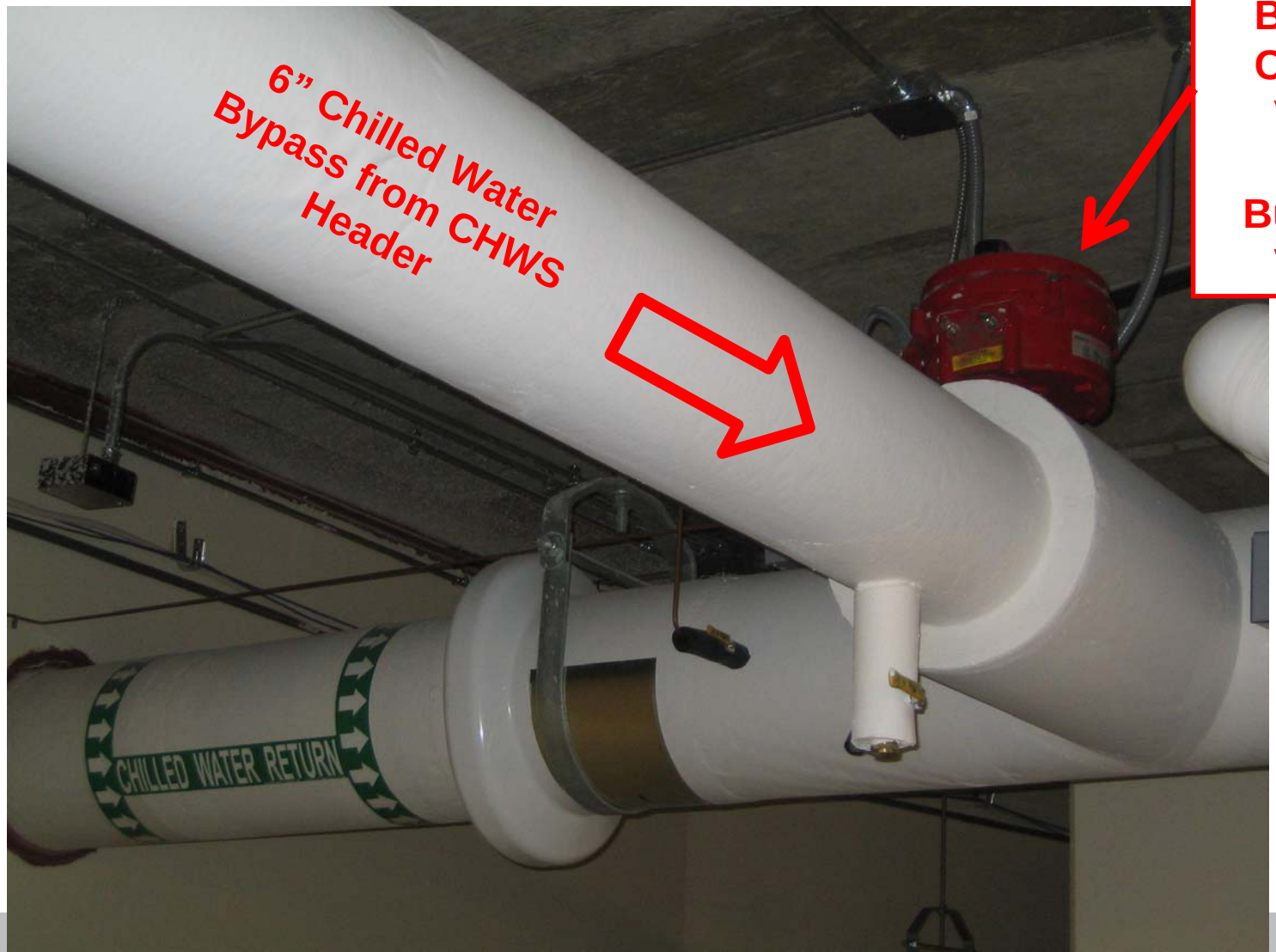
Case Study - Low Flow Bypass

- (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

Case Study – Results

Case Study - Low Flow Bypass



VPF Controls Considerations

Chiller Staging

- Pumps are controlled by system dP's
- Chillers are staged based on leaving chilled water supply water temperature

AND

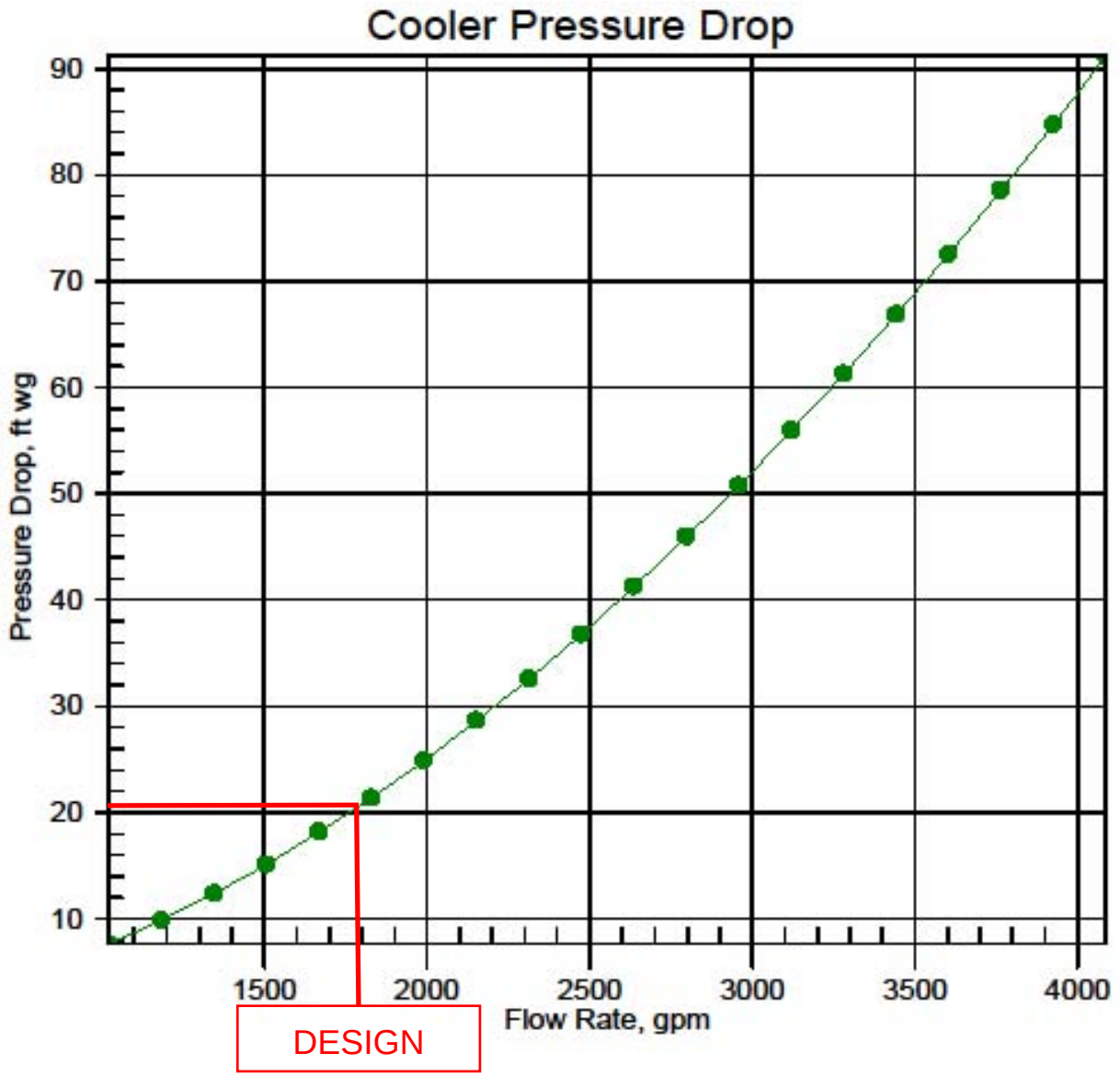
- Chiller chilled water flow rates or differential pressure across evaporator

VPF Controls Considerations

Chiller Staging Problems

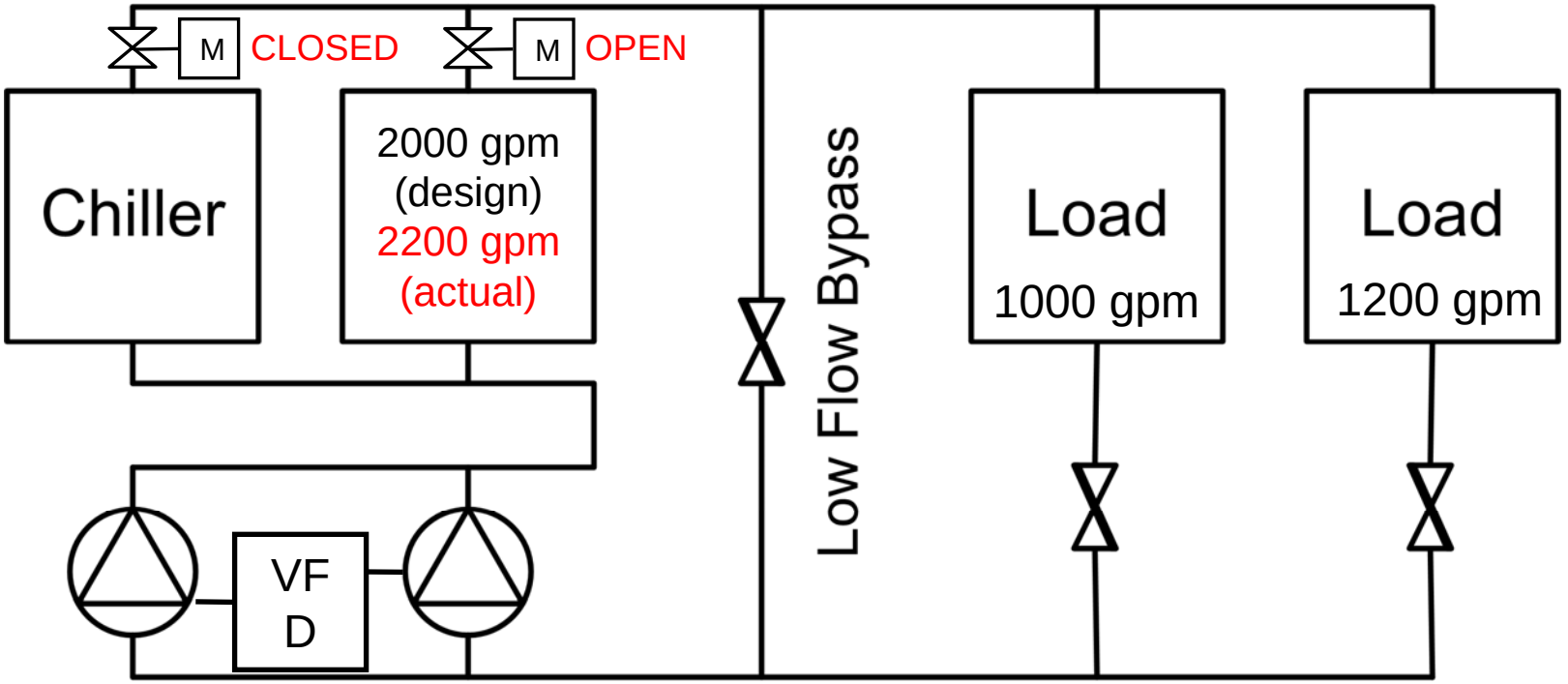
- Due to decoupled pumps and chillers
- Load can increase demanding more pumping
- Chillers may be able to still meet the leaving CHW setpoint
- Flow through chiller may exceed the system “allowable” pressure drop and cause loss of pressure in the field

Excess Flow causes increased PD



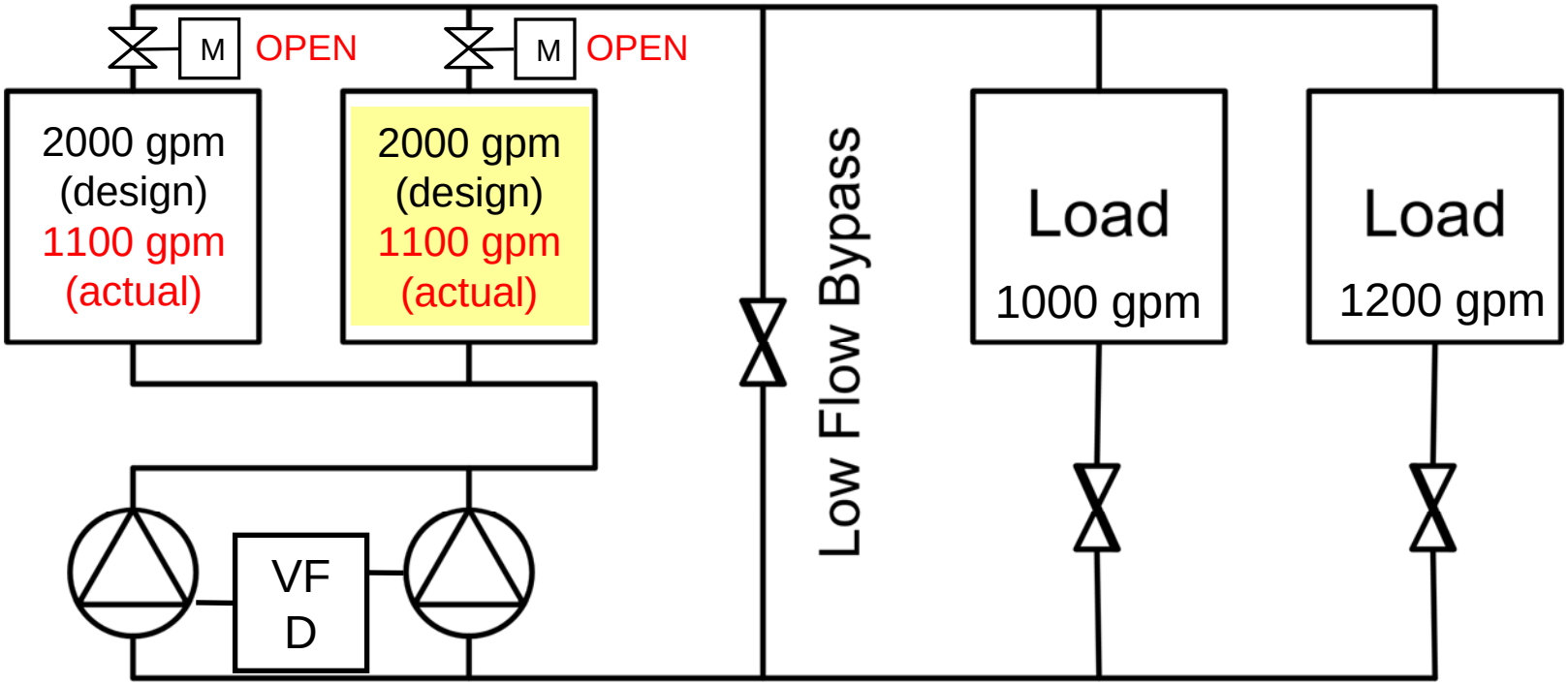
Chiller Staging Problems

- 1 Chiller operating near full load
- CHWS temperature setpoint may be low 42 F



Chiller Staging Problems

- Staging on the second chillers
- Valves must be modulating and slow acting



Chiller Staging Problems

Evergreen Chiller Cooler Pressure Drop

Project Name: Untitled
Sales Office: Temperature Equipment Corp.

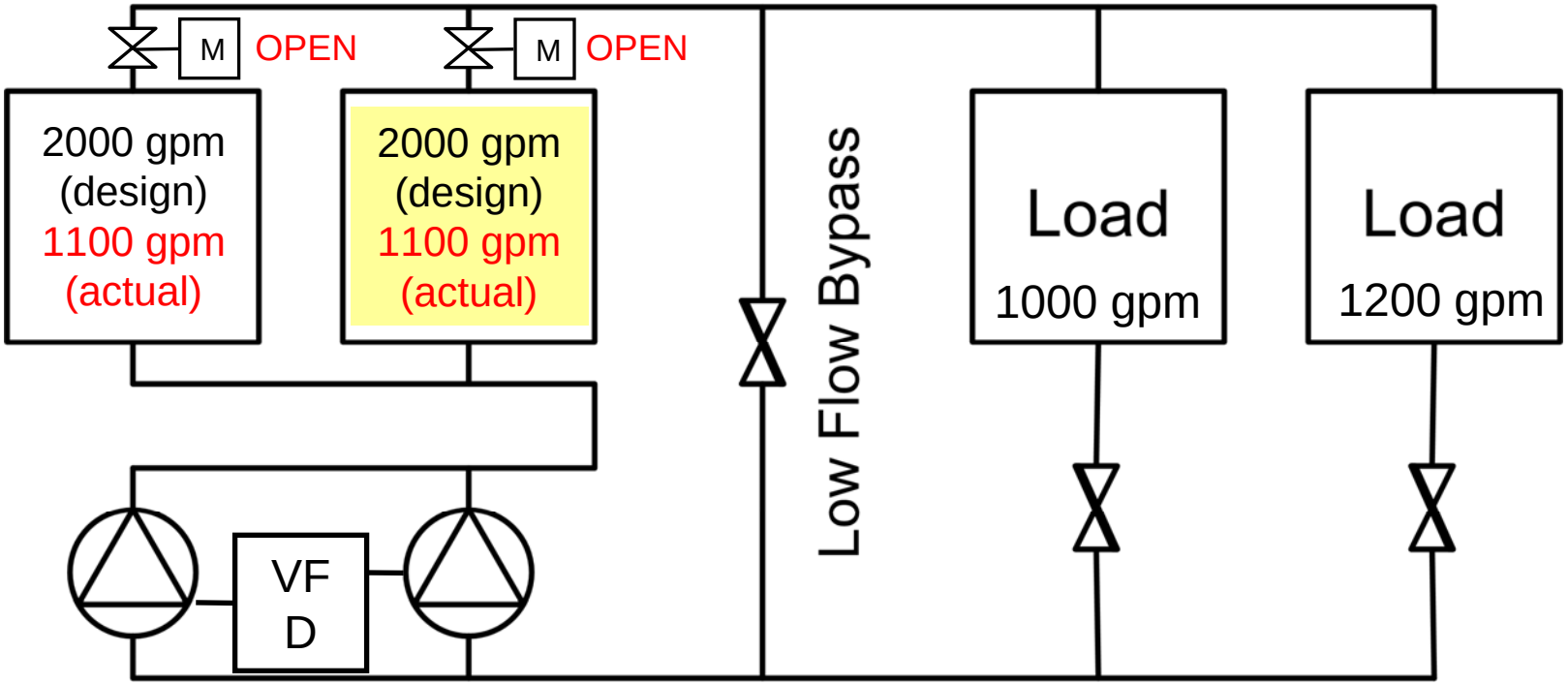
03/26/2010
11:39 AM

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

- 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

Chiller Staging Suggestions

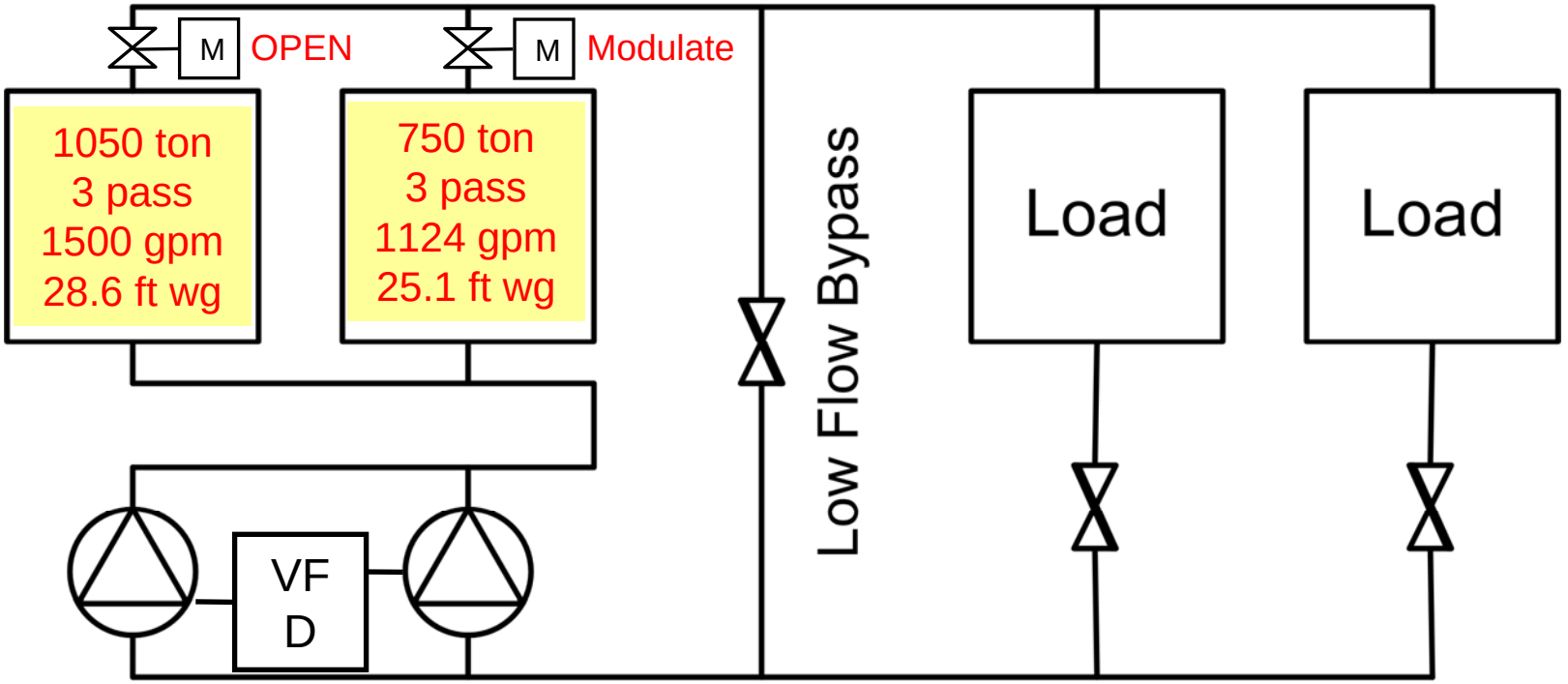
Chiller Staging Sequence Suggestions

- 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
- You don’t want to pump control sequence to start speeding up pumps due to a drop in system pressure as the second chiller stages on, this will cause faster flow through the chiller

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

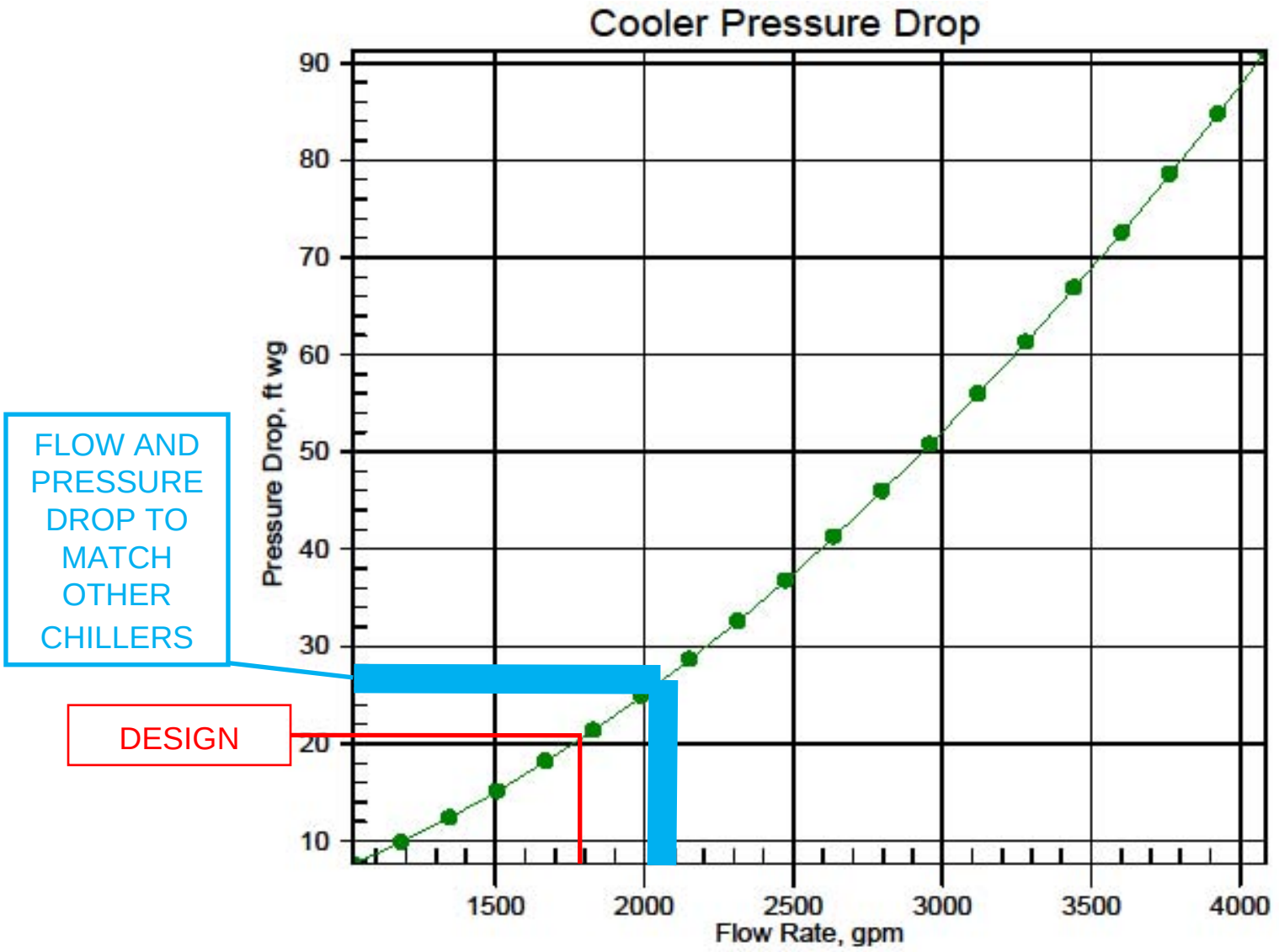


Staging & Hydraulically Most Remote Chiller

- 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?

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



Chiller Staging and Pressure Drop Problems

2009 12:00:03 PM

OA TEMP	77.51 DEG F	SUMMER ON	60.00 DEG F	OVERVIEW2	FANS	TOWERS	PLANT
OA HUMIDITY	69.06 PERCN	SUMMER OFF	50.00 DEG F				

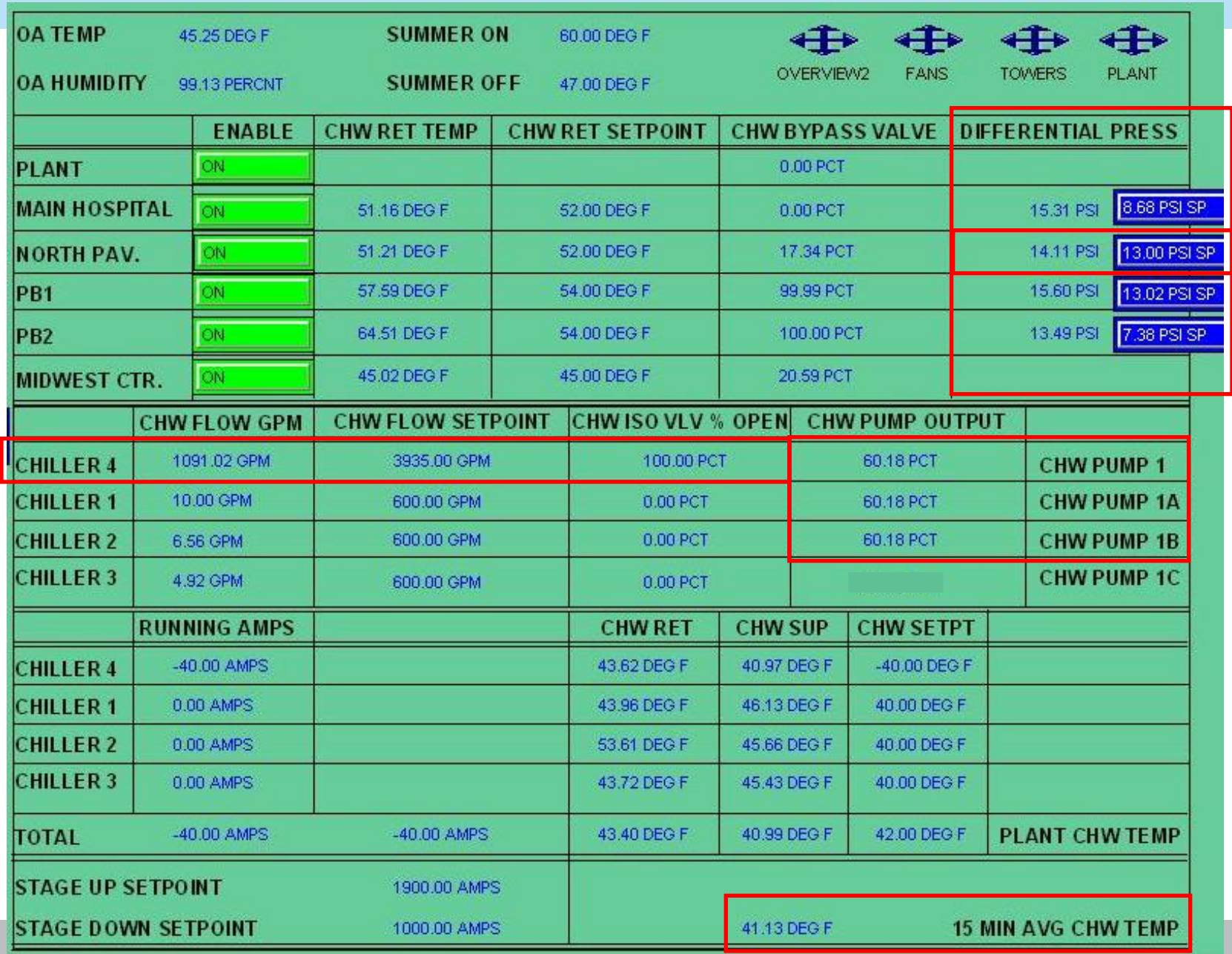
	ENABLE	CHW RET TEMP	CHW RET SETPOINT	CHW BYPASS VALVE	DIFFERENTIAL PRESS
PLANT	ON			1.18 PCT	
MAIN HOSPITAL	ON	52.23 DEG F	52.00 DEG F	100.00 PCT	0.98 PSI
NORTH PAV.	ON	55.32 DEG F	50.00 DEG F	100.00 PCT	1.48 PSI
PB1	ON	54.04 DEG F	54.00 DEG F	54.17 PCT	3.02 PSI
PB2	ON	57.13 DEG F	54.00 DEG F	100.00 PCT	1.75 PSI
MIDWEST CTR.	ON	46.90 DEG F	50.00 DEG F	100.00 PCT	

	CHW FLOW GPM	CHW FLOW SETPOINT	CHW ISO VLV % OPEN	CHW PUMP OUTPUT	
CHILLER 4	2179.84 GPM	1800.00 GPM	74.40 PCT	99.98 PCT	CHW PUMP 1
CHILLER 1	1445.63 GPM	1500.00 GPM	78.09 PCT	99.98 PCT	CHW PUMP 1A
CHILLER 2	7.19 GPM	1500.00 GPM	0.00 PCT	0.00 PCT	CHW PUMP 1B
CHILLER 3	11.02 GPM	1125.00 GPM	0.00 PCT	100.00 PCT	CHW PUMP 1C

	RUNNING AMPS		CHW RET	CHW SUP	CHW SETPT	
CHILLER 4	0.00 AMPS		52.97 DEG F	40.76 DEG F	Cab Failed DE	
CHILLER 1	802.00 AMPS		52.86 DEG F	40.19 DEG F	40.00 DEG F	
CHILLER 2	0.00 AMPS		63.23 DEG F	50.24 DEG F	40.00 DEG F	
CHILLER 3	0.00 AMPS		61.61 DEG F	50.39 DEG F	40.00 DEG F	
TOTAL	792.00 AMPS	792.00 AMPS	52.63 DEG F	40.84 DEG F	42.00 DEG F	PLANT CHW TEMP

STAGE UP SETPOINT	1900.00 AMPS		
STAGE DOWN SETPOINT	1000.00 AMPS	40.81 DEG F	15 MIN AVG CHW TEMP

Chiller Staging and Pressure Drop Problems



OA TEMP	45.25 DEG F	SUMMER ON	60.00 DEG F
OA HUMIDITY	99.13 PERCNT	SUMMER OFF	47.00 DEG F

OVERVIEW2 FANS TOWERS PLANT

	ENABLE	CHW RET TEMP	CHW RET SETPOINT	CHW BYPASS VALVE	DIFFERENTIAL PRESS	
PLANT	ON			0.00 PCT		
MAIN HOSPITAL	ON	51.16 DEG F	52.00 DEG F	0.00 PCT	15.31 PSI	8.68 PSI SP
NORTH PAV.	ON	51.21 DEG F	52.00 DEG F	17.34 PCT	14.11 PSI	13.00 PSI SP
PB1	ON	57.59 DEG F	54.00 DEG F	99.99 PCT	15.60 PSI	13.02 PSI SP
PB2	ON	64.51 DEG F	54.00 DEG F	100.00 PCT	13.49 PSI	7.38 PSI SP
MIDWEST CTR.	ON	45.02 DEG F	45.00 DEG F	20.59 PCT		

	CHW FLOW GPM	CHW FLOW SETPOINT	CHW ISO VLV % OPEN	CHW PUMP OUTPUT	
CHILLER 4	1091.02 GPM	3935.00 GPM	100.00 PCT	60.18 PCT	CHW PUMP 1
CHILLER 1	10.00 GPM	600.00 GPM	0.00 PCT	60.18 PCT	CHW PUMP 1A
CHILLER 2	6.56 GPM	600.00 GPM	0.00 PCT	60.18 PCT	CHW PUMP 1B
CHILLER 3	4.92 GPM	600.00 GPM	0.00 PCT		CHW PUMP 1C

	RUNNING AMPS		CHW RET	CHW SUP	CHW SETPT	
CHILLER 4	-40.00 AMPS		43.62 DEG F	40.97 DEG F	-40.00 DEG F	
CHILLER 1	0.00 AMPS		43.96 DEG F	46.13 DEG F	40.00 DEG F	
CHILLER 2	0.00 AMPS		53.61 DEG F	45.66 DEG F	40.00 DEG F	
CHILLER 3	0.00 AMPS		43.72 DEG F	45.43 DEG F	40.00 DEG F	
TOTAL	-40.00 AMPS	-40.00 AMPS	43.40 DEG F	40.99 DEG F	42.00 DEG F	PLANT CHW TEMP

STAGE UP SETPOINT	1900.00 AMPS		
STAGE DOWN SETPOINT	1000.00 AMPS	41.13 DEG F	15 MIN AVG CHW TEMP

VPF Cx Considerations and Realities

Low Flow Bypass controls

- Review bypass valve size and actuator stroke time
- Hard to Cx without load on the building. Without load the system 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* alarm trips

VPF Cx Considerations and Realities

Sequence of Operations

- Request from the design team the chiller plant and pumping staging sequence
- Request a matrix on which chillers AND piping make the hydraulically most remote chillers and how to modulate the CHW flow control valves

VPF Cx Considerations and Realities

Chiller Performance Submittal

- Review chiller minimum and maximum flow rates
- Review chiller rated pressure drop
- Review chiller pressure drop curve
- This many not be provided in a standard chiller submittal and must be requested
- If all this information is not provided, there will be guess work in the field

VPF Cx Considerations and Realities

Controls

- Limit the speed at which the chilled water pump VFD's can speed up and down
- Limit the time span the chilled water flow control valve actuators can stroke from min to max
- Review the system dP's and how the pumps track to maintain the lowest from setpoint
- Put in a dead band so the pumps are not always hunting due to system size and complexity

VPF Cx Squeezing More Efficiency

Controls

- **TREND** air handler control valves and bypass valve
- RESET chilled water supply temperature setpoint based something, valve position
- This will provide chiller electrical savings at the expense of increased pumping
- Condenser water reset still works great!

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. [4]

References

1. William P. Bahnfleth, Eric B. Peyer, 2003, Variable Primary Flow: Potential Benefits and Application Issues
2. ASHRAE Handbook HVAC Systems and Equipment, 1996
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)
4. Johnson Controls Inc./York International Corporation – (Project and Chiller Specific, refer to your particular chiller manufacturers details)

AIA Quality Assurance

Portland Energy Conservation, Inc is a registered provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Questions AND thank you

John D. Villani, P.E., LEED AP, C.E.M., QCxP
Grumman/Butkus Associates

jdv@grummanbutkus.com

(847) 328-3555