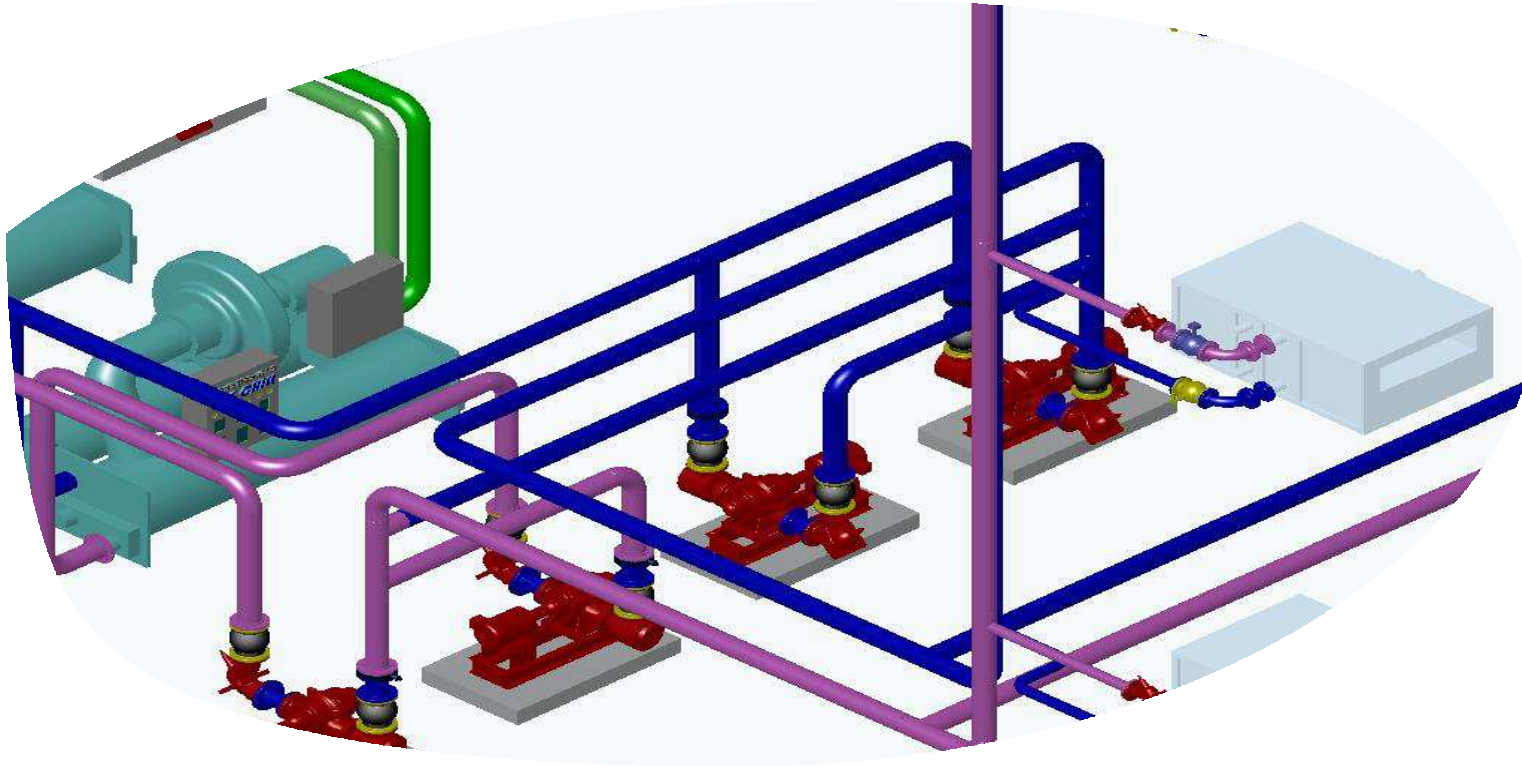


Chilled Water Piping Configurations



Roy Hubbard

Agenda

- ❑ **Understanding the three basic piping systems**
 - ❑ Design and Off-design operation
 - ❑ Advantages and Disadvantages
- ❑ **Low DeltaT Syndrome – causes, effects, and solutions**
- ❑ **Design & Control Considerations (VPF)**
 - ❑ Chillers
 - ❑ CHW Pumps
 - ❑ Bypass Valve



Chilled Water Piping System Types (typical)

Configuration	Load Valves	Installed Cost	Pumping Cost
Constant Primary Flow	3-way	Lowest	Highest
Primary / Secondary	2-way	Highest	Medium
Variable Primary Flow	2-way	Medium	Lowest

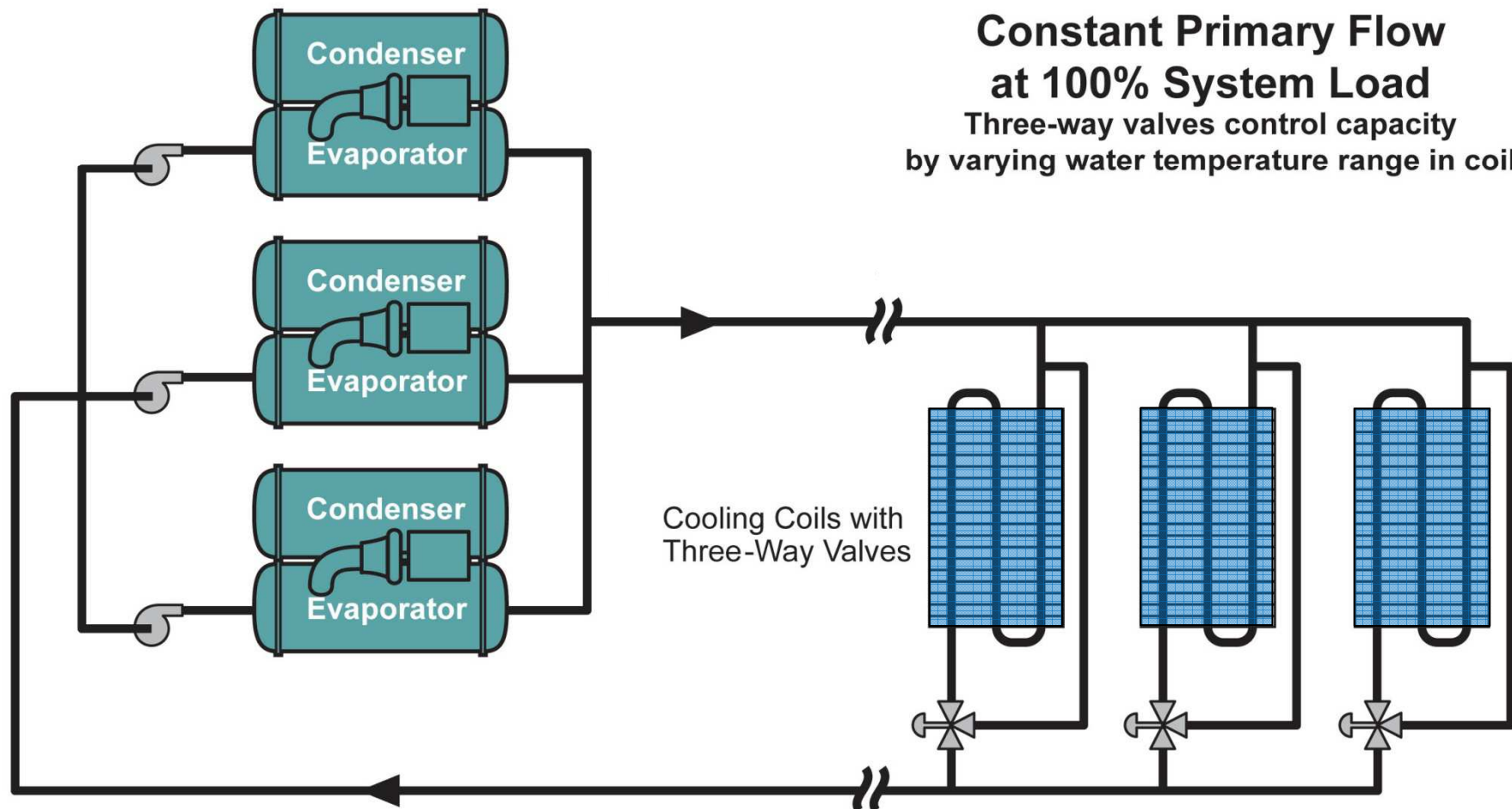
Load Equation

$$\text{Load} = \text{Flow} \times \text{DeltaT}$$

Constant Primary Flow (CPF)

Constant Primary Flow (CPF) *Dedicated Pumping*

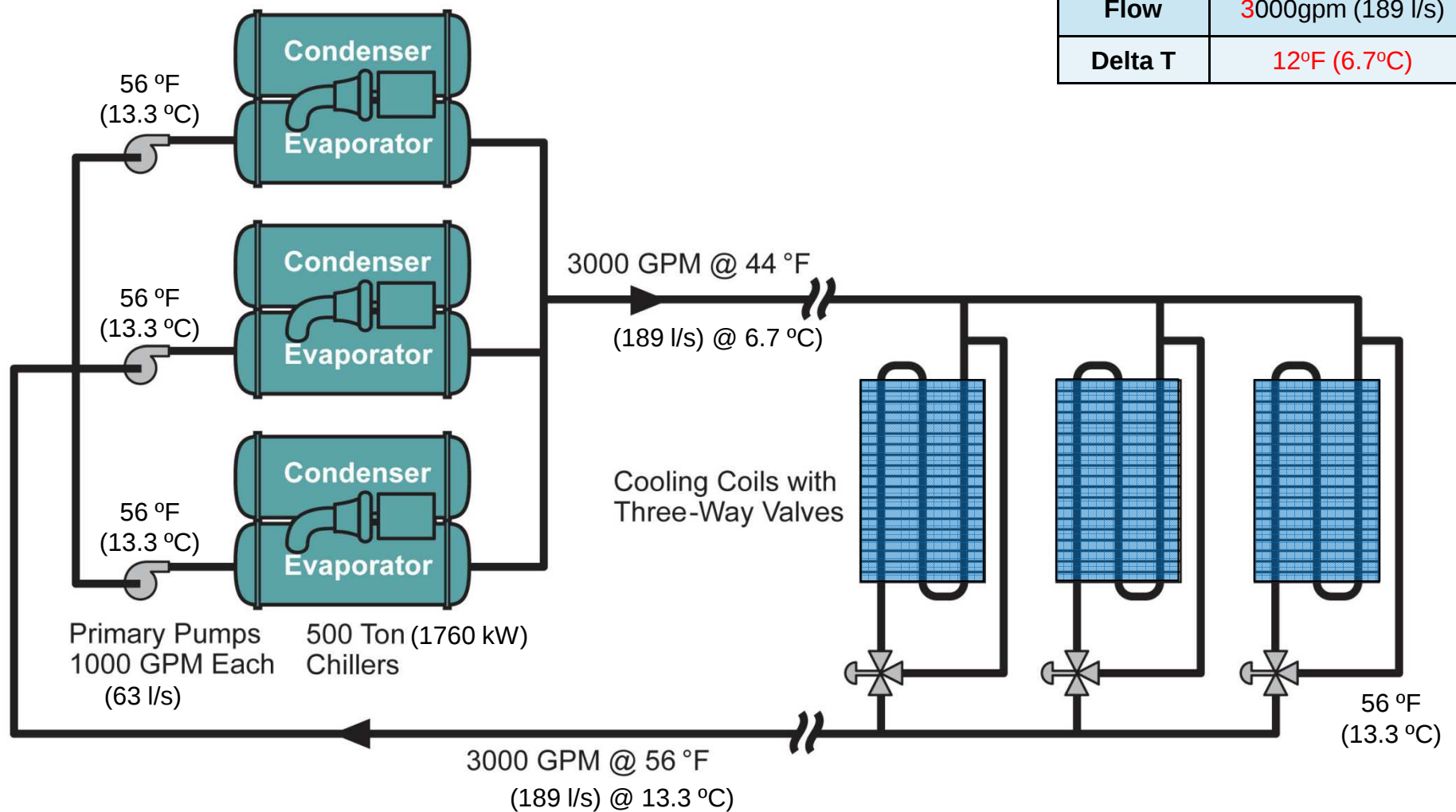
$$\text{Load} = \text{Flow} \times \Delta T$$



Constant Primary Flow at Design

	Per Chiller	System
Load	500 Tons (1760kW)	1500 Tons (5280kW)

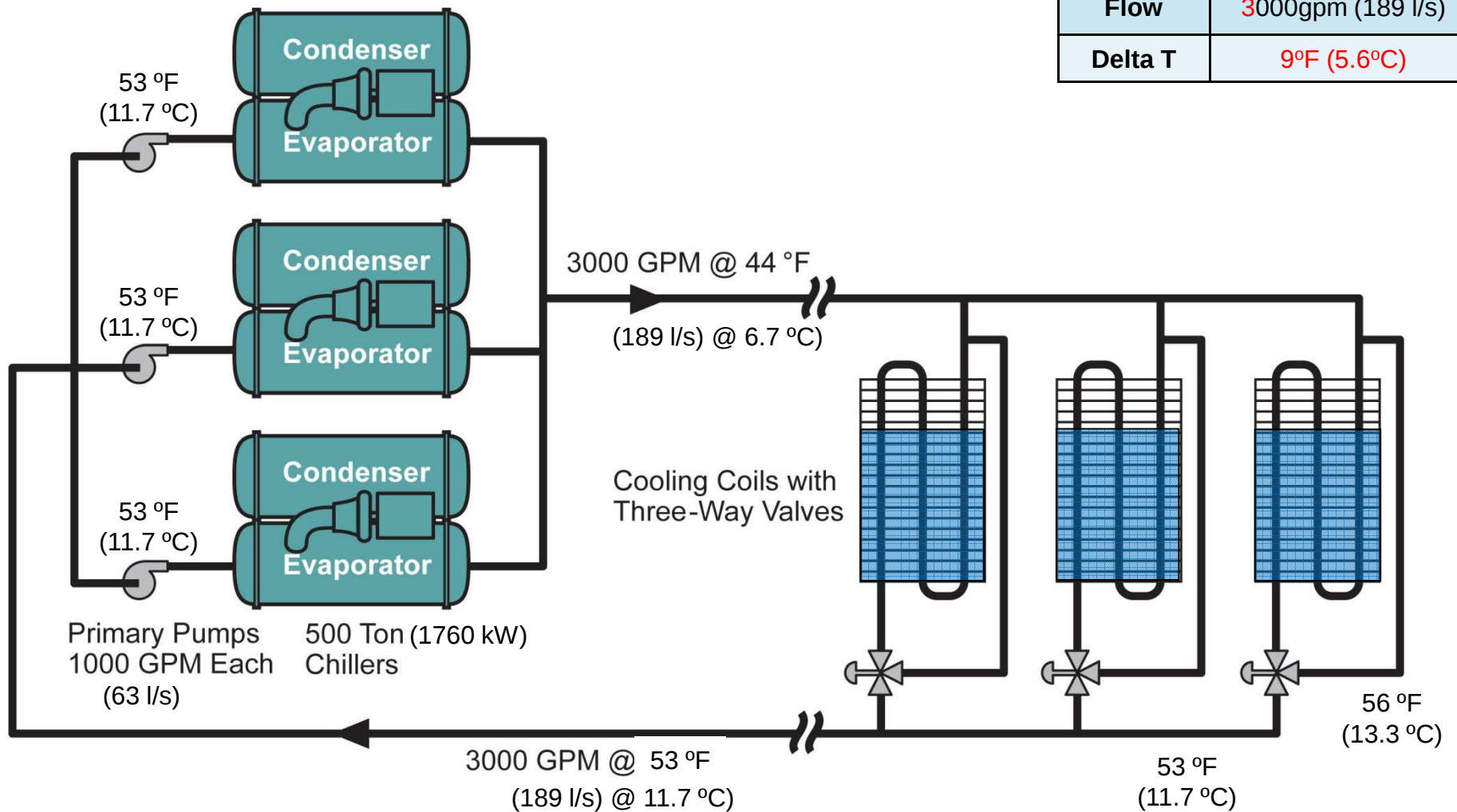
	Primary
Flow	3000gpm (189 l/s)
Delta T	12°F (6.7°C)



Constant Primary Flow at 75% Load

	Per Chiller	System
Load	375 Tons (1320kW)	1125 Tons (3960kW)

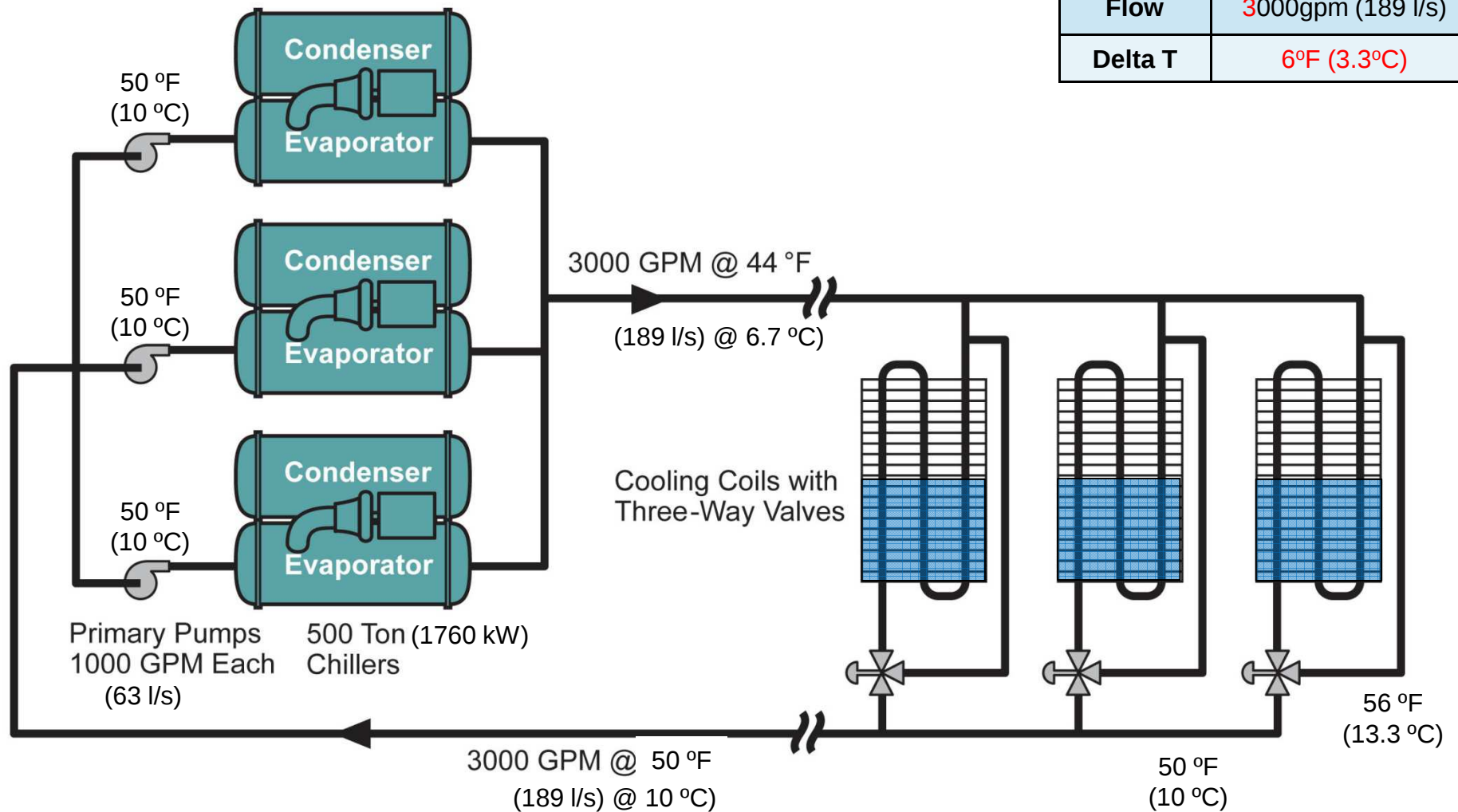
	Primary
Flow	3000gpm (189 l/s)
Delta T	9°F (5.6°C)



Constant Primary Flow at 50% Load

	Per Chiller	System
Load	250 Tons (880kW)	750 Tons (2640kW)

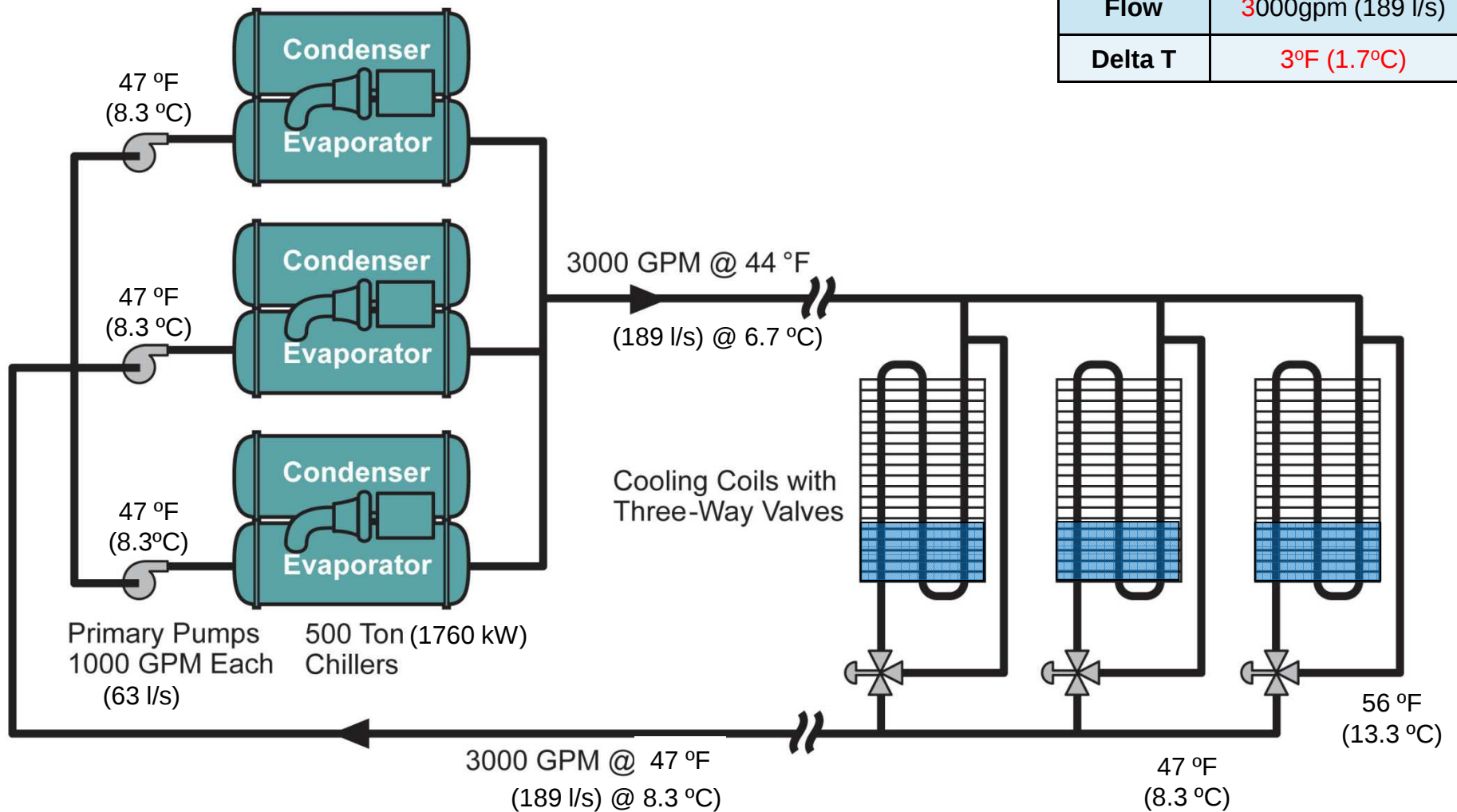
	Primary
Flow	3000gpm (189 l/s)
Delta T	6°F (3.3°C)



Constant Primary Flow at 25% Load

	Per Chiller	System
Load	125 Tons (440kW)	375Tons (1320kW)

	Primary
Flow	3000gpm (189 l/s)
Delta T	3°F (1.7°C)



Constant Flow Primary

☐ **Advantages**

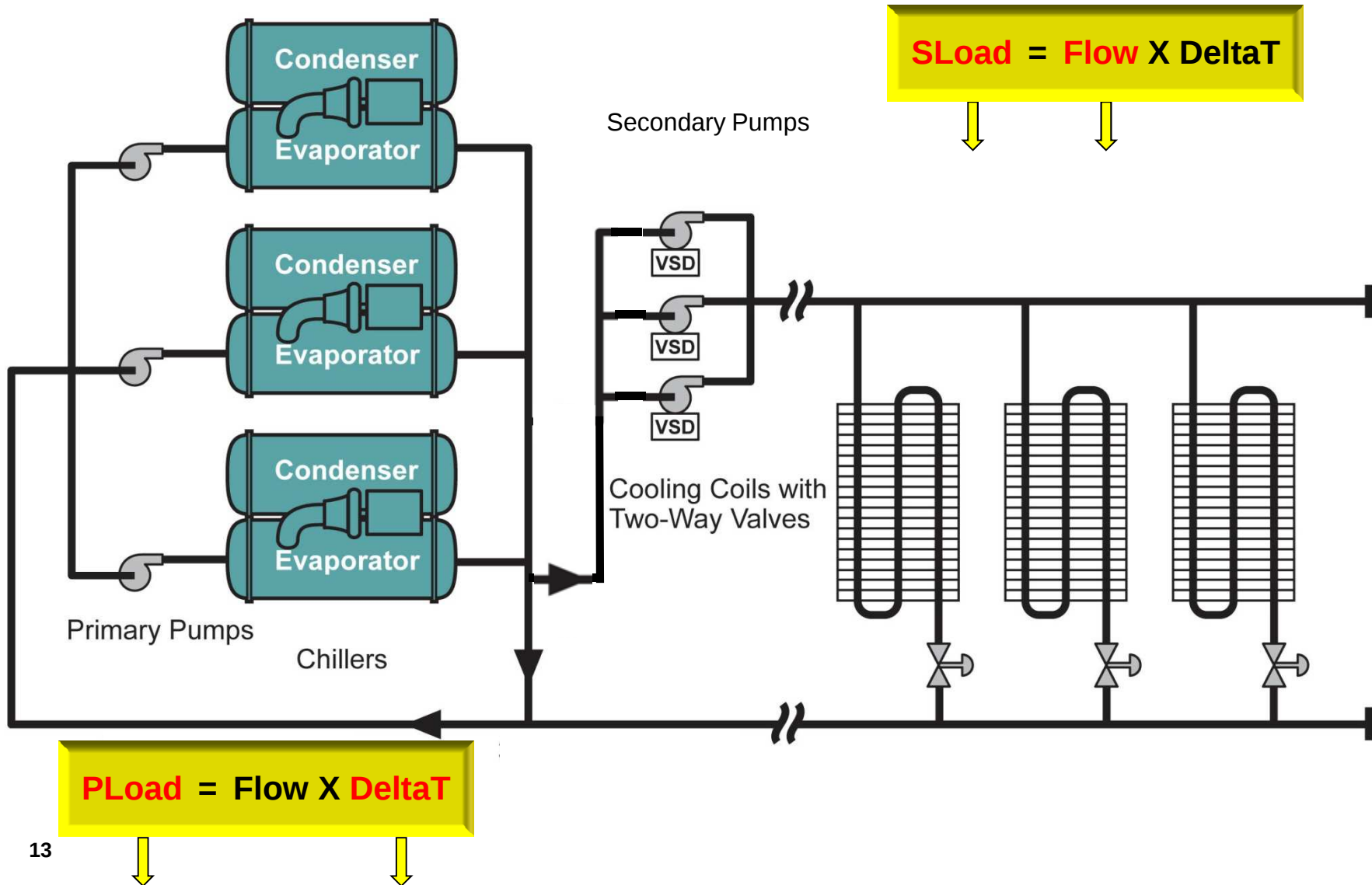
- ☐ Lowest installed cost
- ☐ Less plant space than P/S
- ☐ Easy to Control & Operate
- ☐ Easy to Commission

☐ **Disadvantages**

- ☐ Highest Plant Energy Cost (must run all, even at low loads)

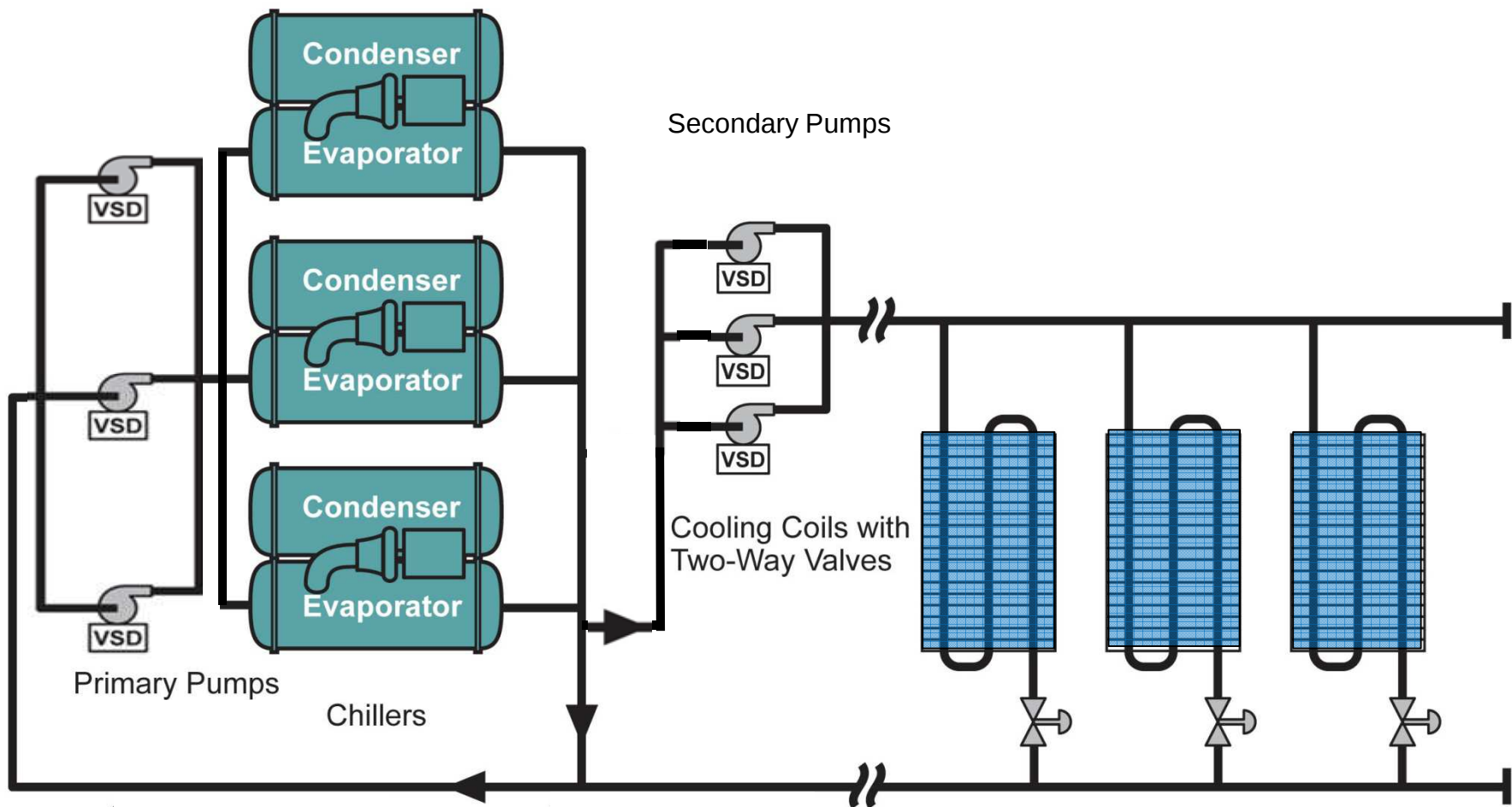
Primary (Constant) / Secondary (Variable)

Primary (Constant) / Secondary (Variable)



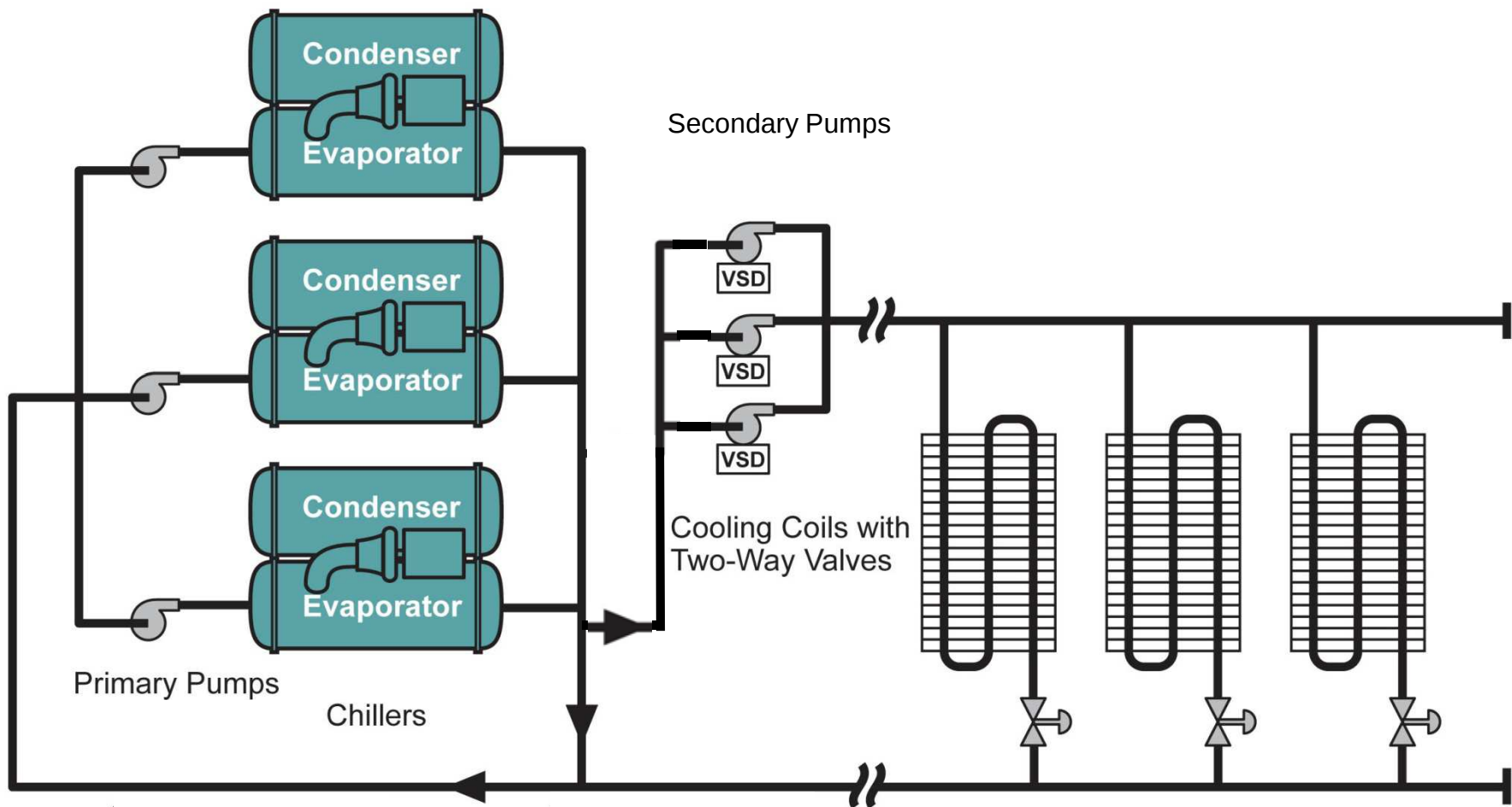
Primary (Constant) / Secondary (Variable)

Headered Pumping



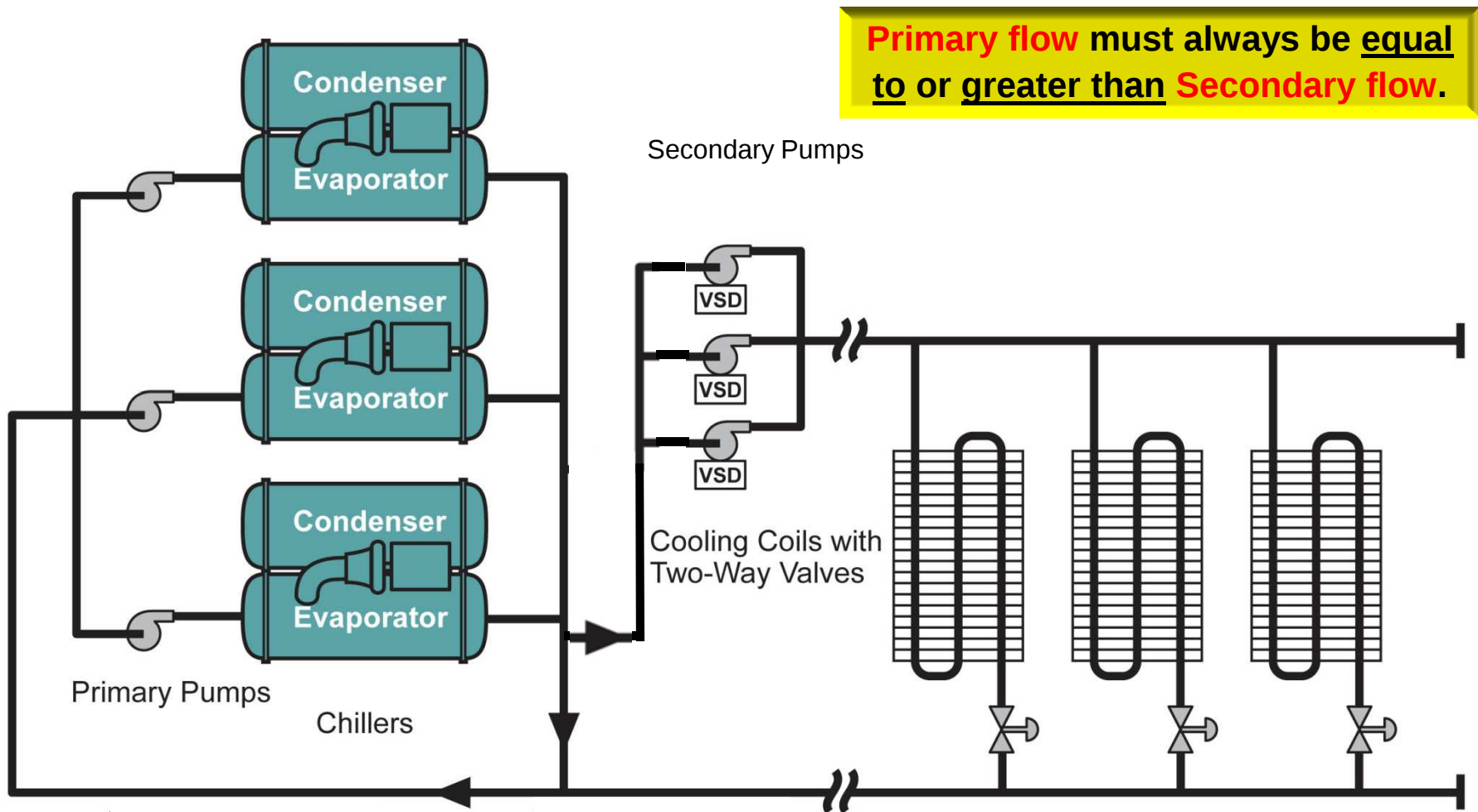
Primary (Constant) / Secondary (Variable)

Dedicated Pumping



Primary (Constant) / Secondary (Variable)

Rule of Flow

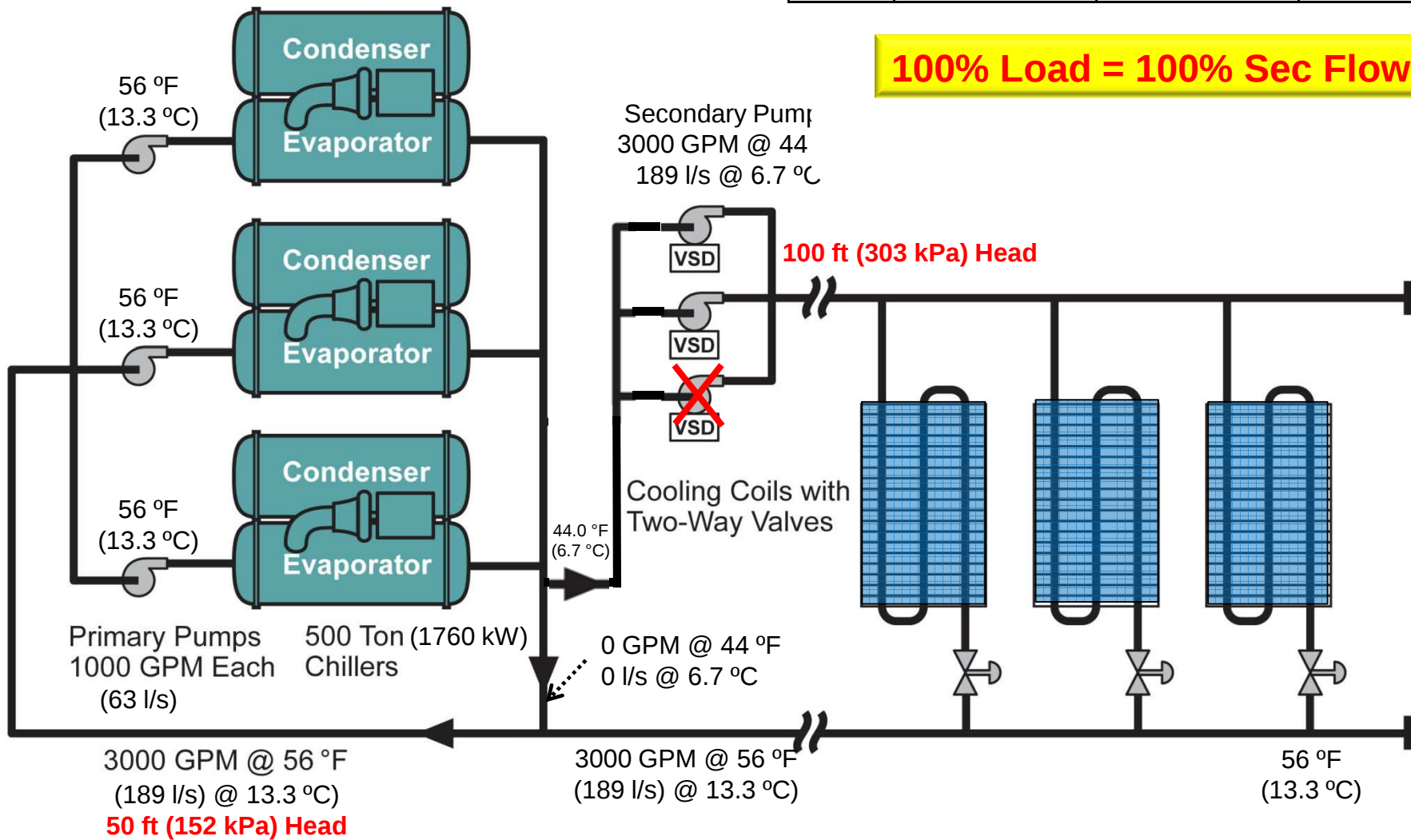


Primary/Secondary at **Design**

	Per Chiller	System
Load	500 Tons (1760kW)	1500 Tons (5280kW)

	Primary	Secondary	Bypass
Flow	3000gpm (189 l/s)	3000gpm (189 l/s)	0gpm (0 l/s)
Delta T	12°F (6.7°C)	12°F (6.7°C)	----

100% Load = 100% Sec Flow

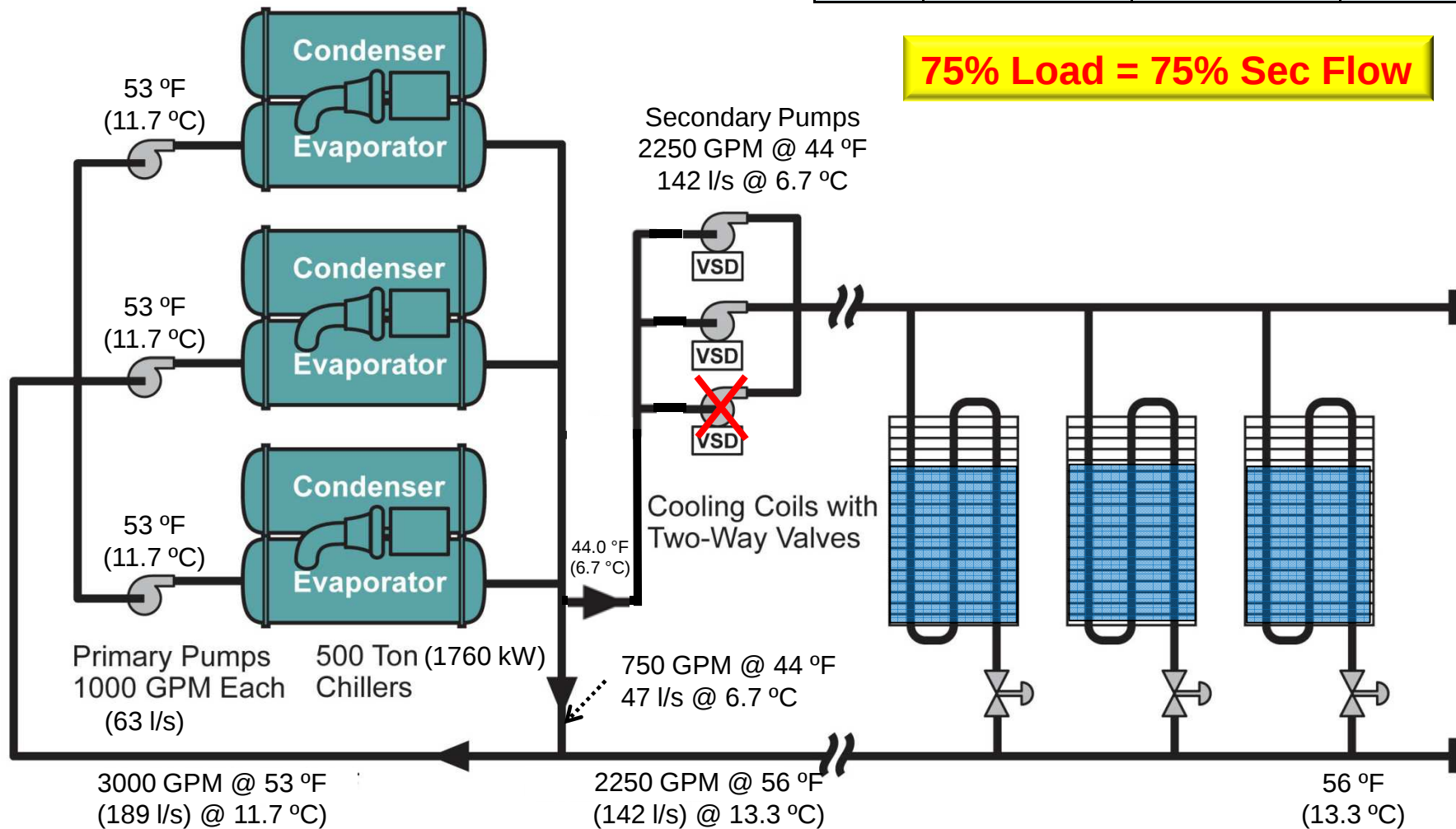


Primary/Secondary at 75% Load

	Per Chiller	System
Load	375 Tons (1320kW)	1125 Tons (3960kW)

	Primary	Secondary	Bypass
Flow	3000gpm (189 l/s)	2250gpm (142 l/s)	750gpm (47 l/s)
Delta T	9°F (5°C)	12°F (6.7°C)	----

75% Load = 75% Sec Flow

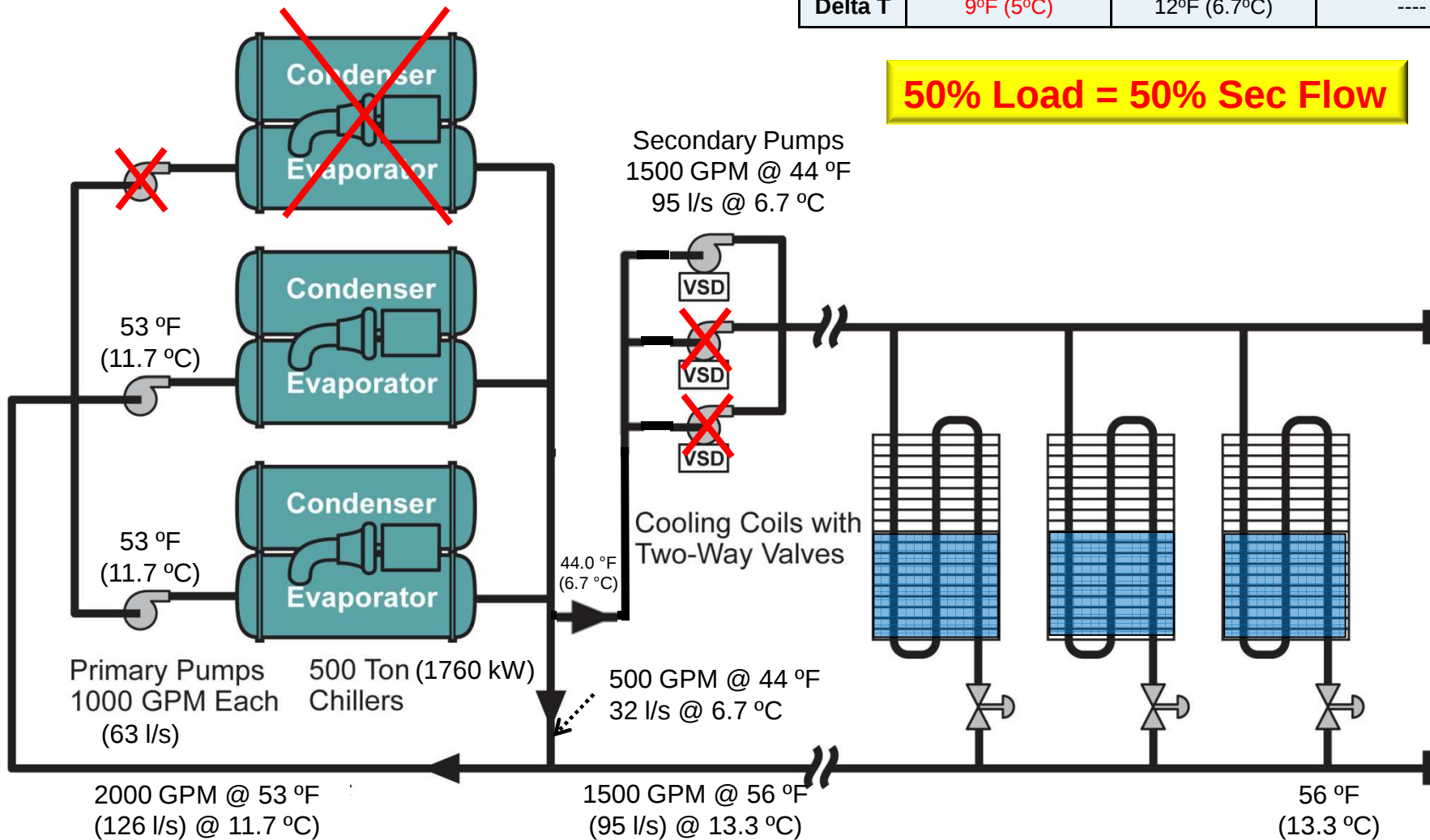


Primary/Secondary at 50% Load

	Per Chiller	System
Load	375 Tons (1320kW)	750 Tons (2640kW)

	Primary	Secondary	Bypass
Flow	2000gpm (126 l/s)	1500gpm (95 l/s)	500gpm (32 l/s)
Delta T	9°F (5°C)	12°F (6.7°C)	----

50% Load = 50% Sec Flow

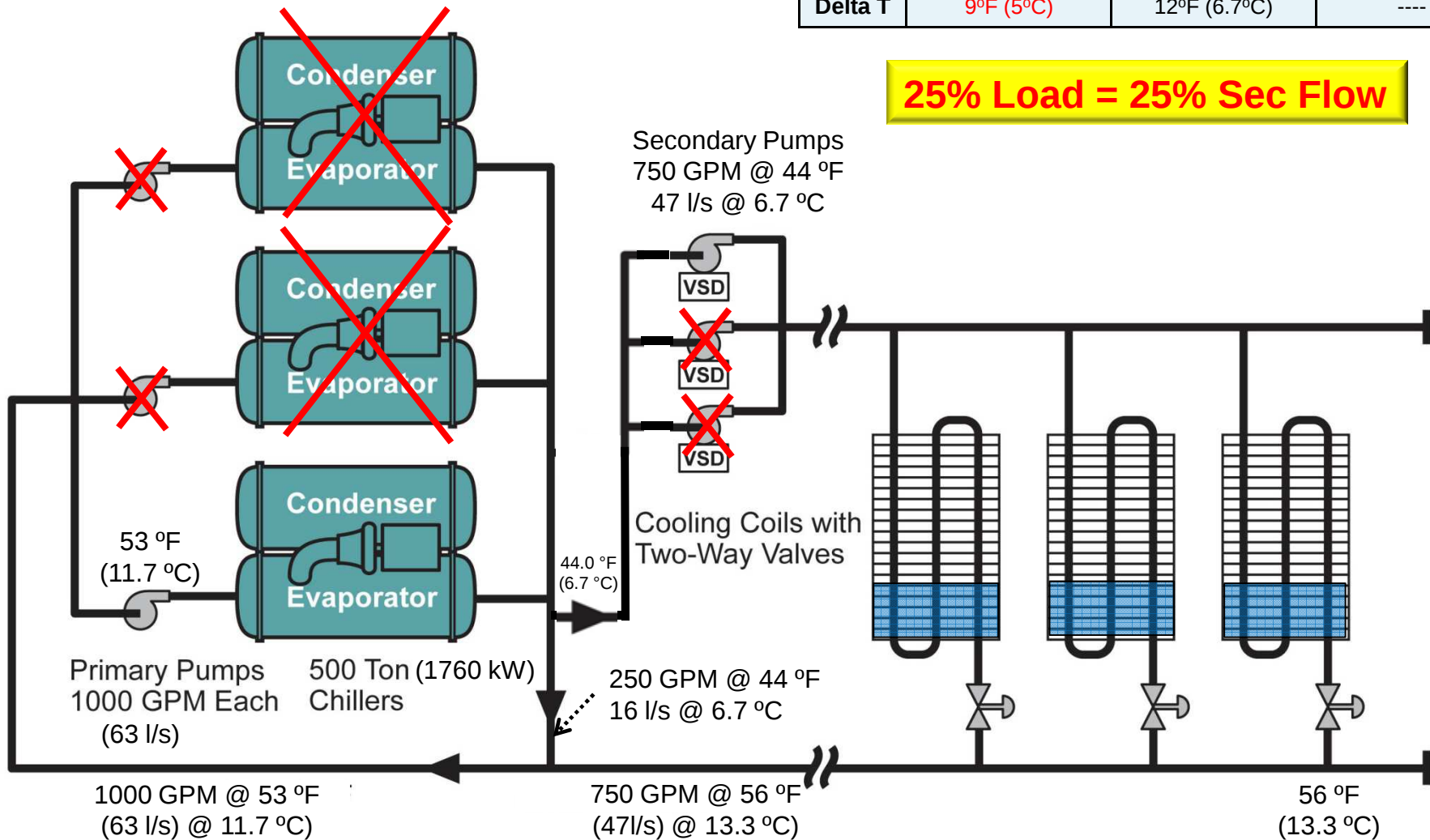


Primary/Secondary at 25% Load

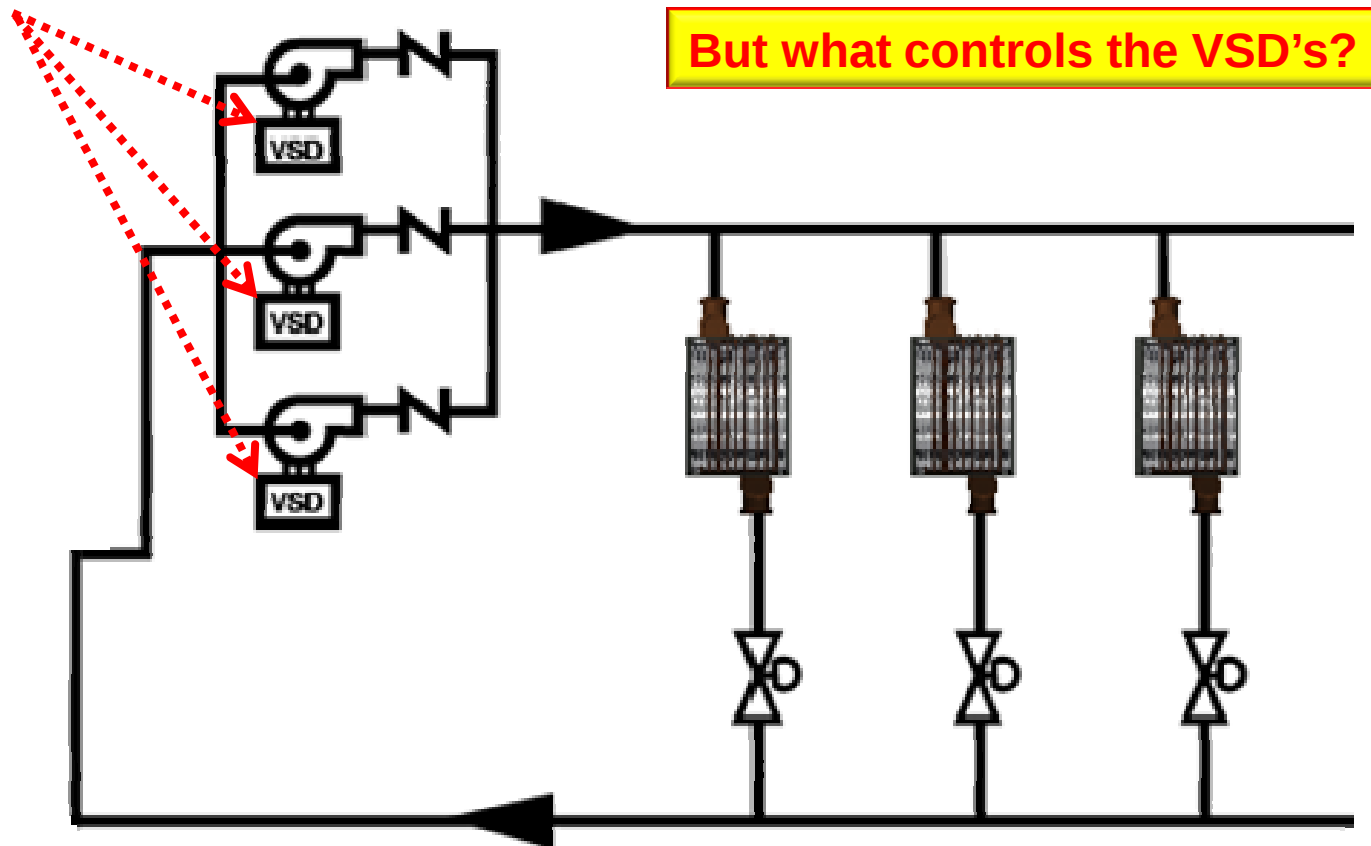
	Per Chiller	System
Load	375 Tons (1320kW)	375 Tons (1320kW)

	Primary	Secondary	Bypass
Flow	1000gpm (126 l/s)	750gpm (47 l/s)	250gpm (16 l/s)
Delta T	9°F (5°C)	12°F (6.7°C)	----

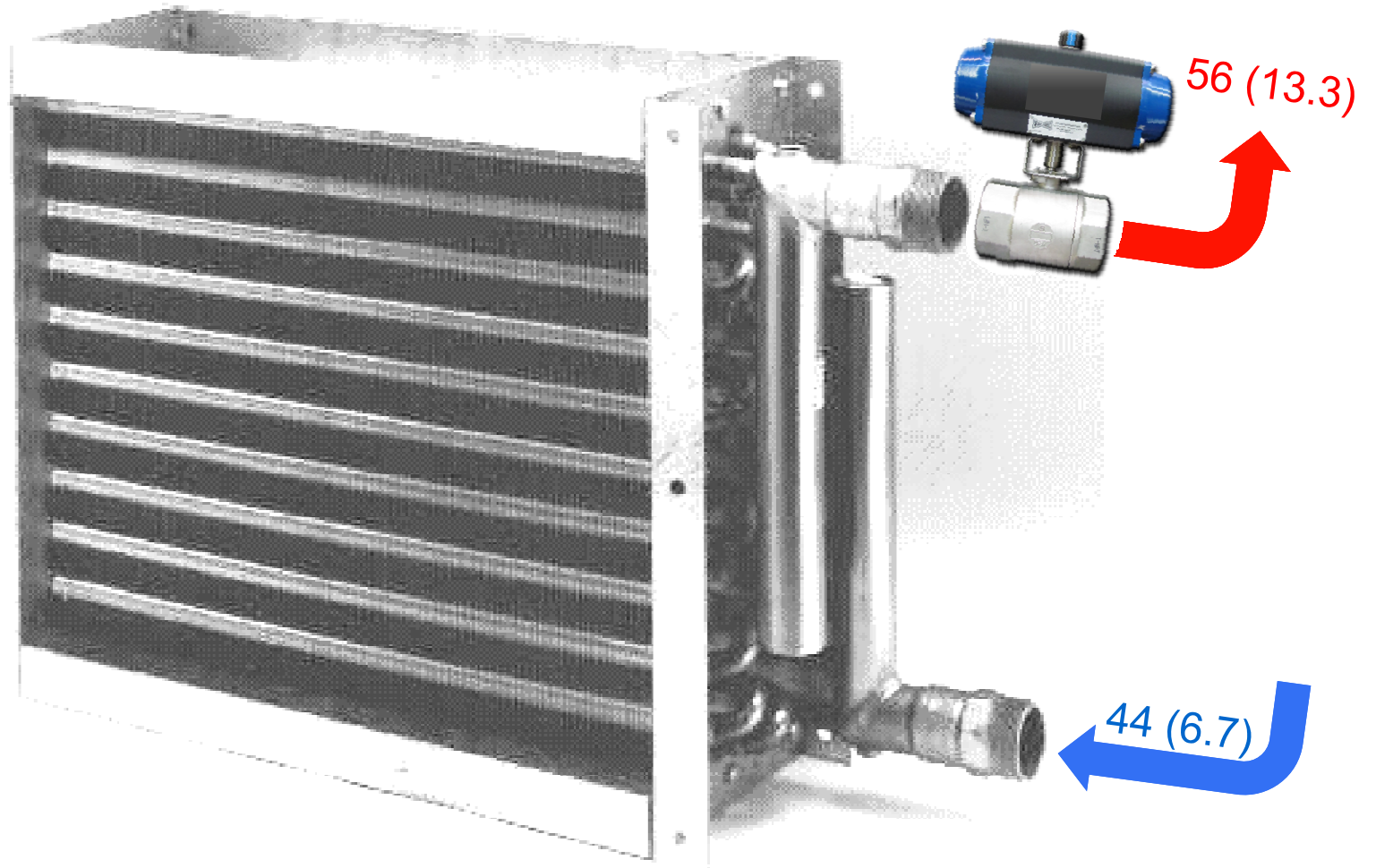
25% Load = 25% Sec Flow



What Controls the Flow of the Secondary Loop?

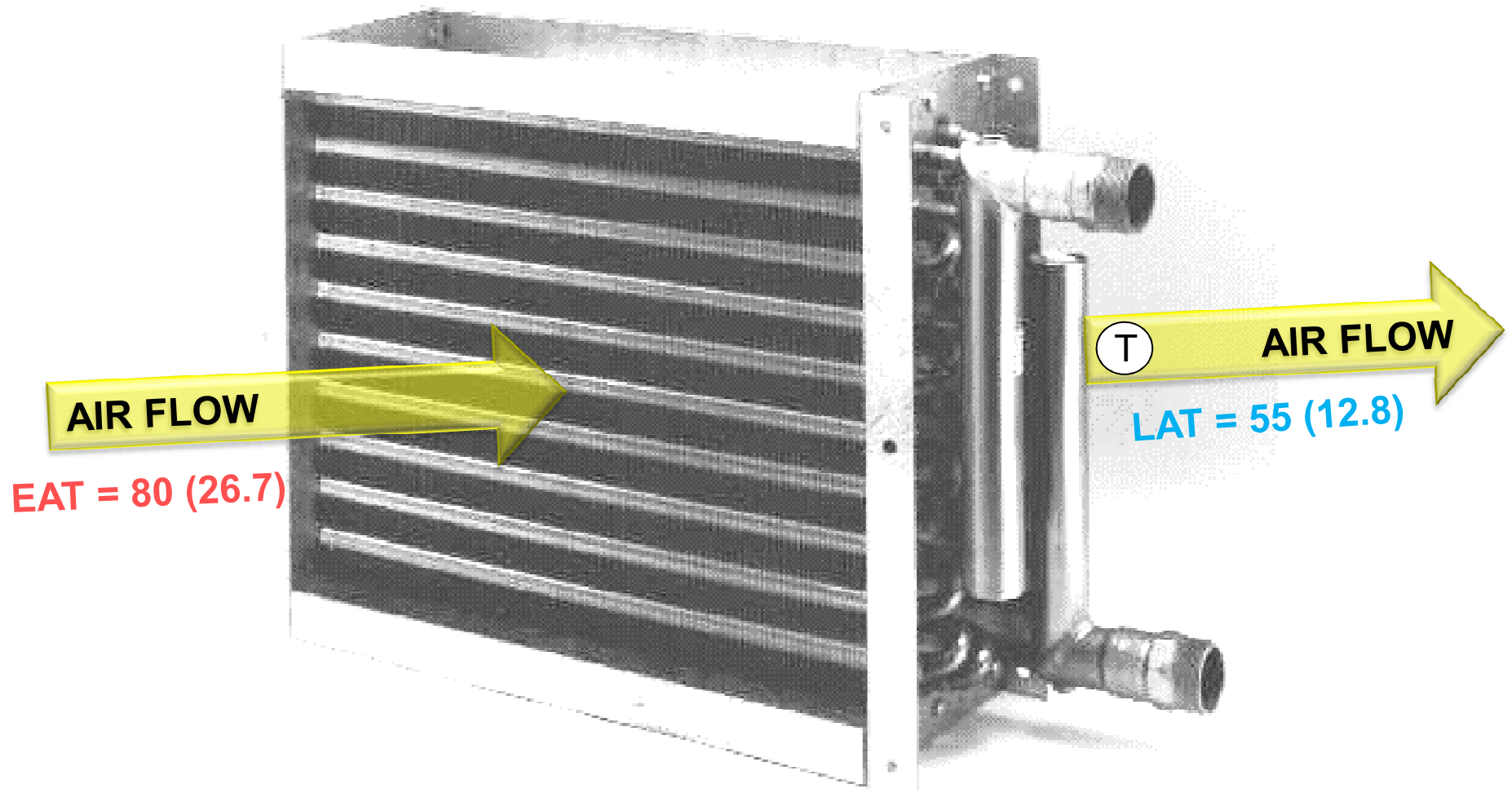


Valve Controls Leaving Air Temperature (LAT)



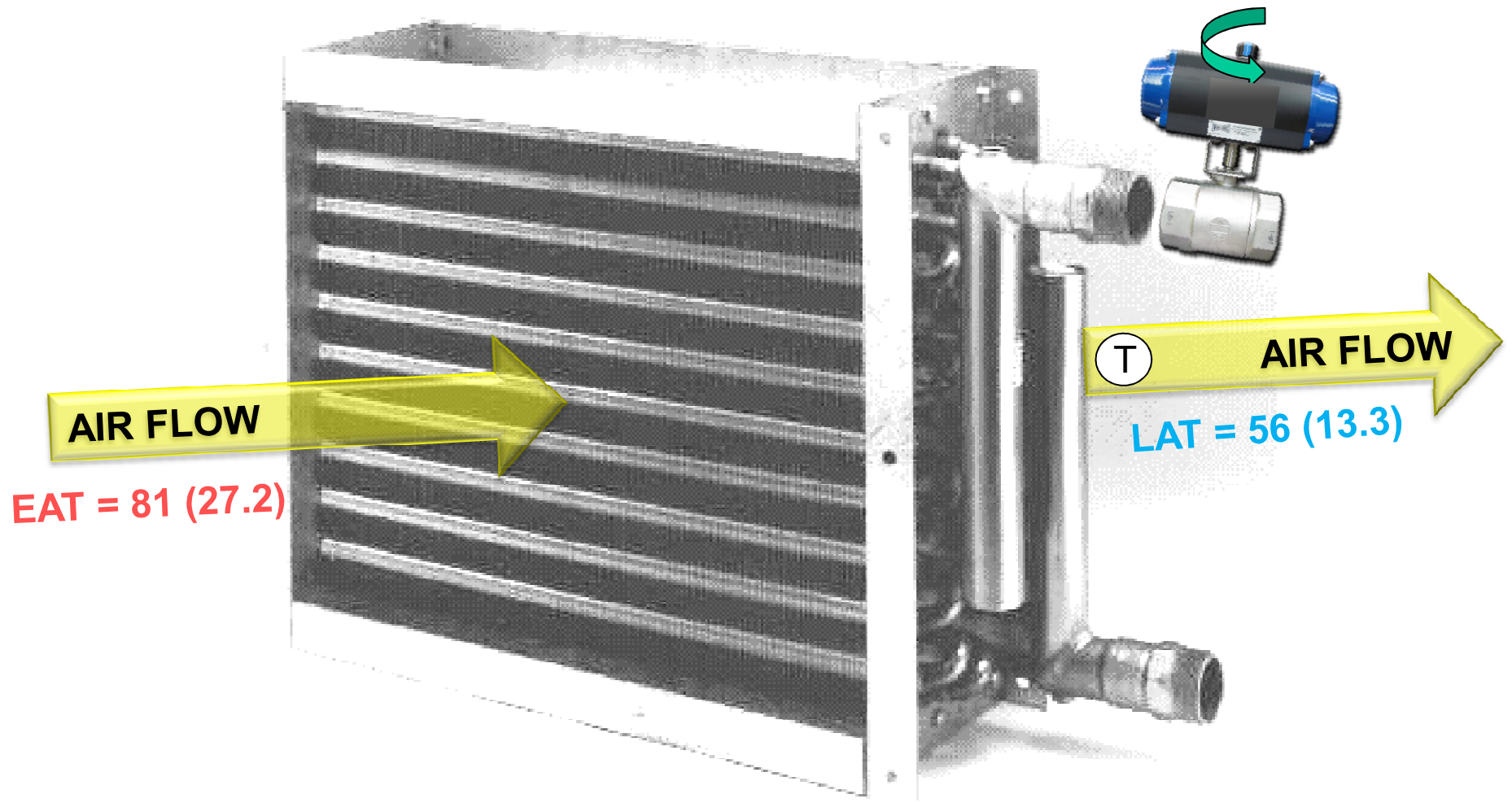
Valve Controls Leaving Air Temperature (LAT)

Set Point = 55° (12.8°) LAT



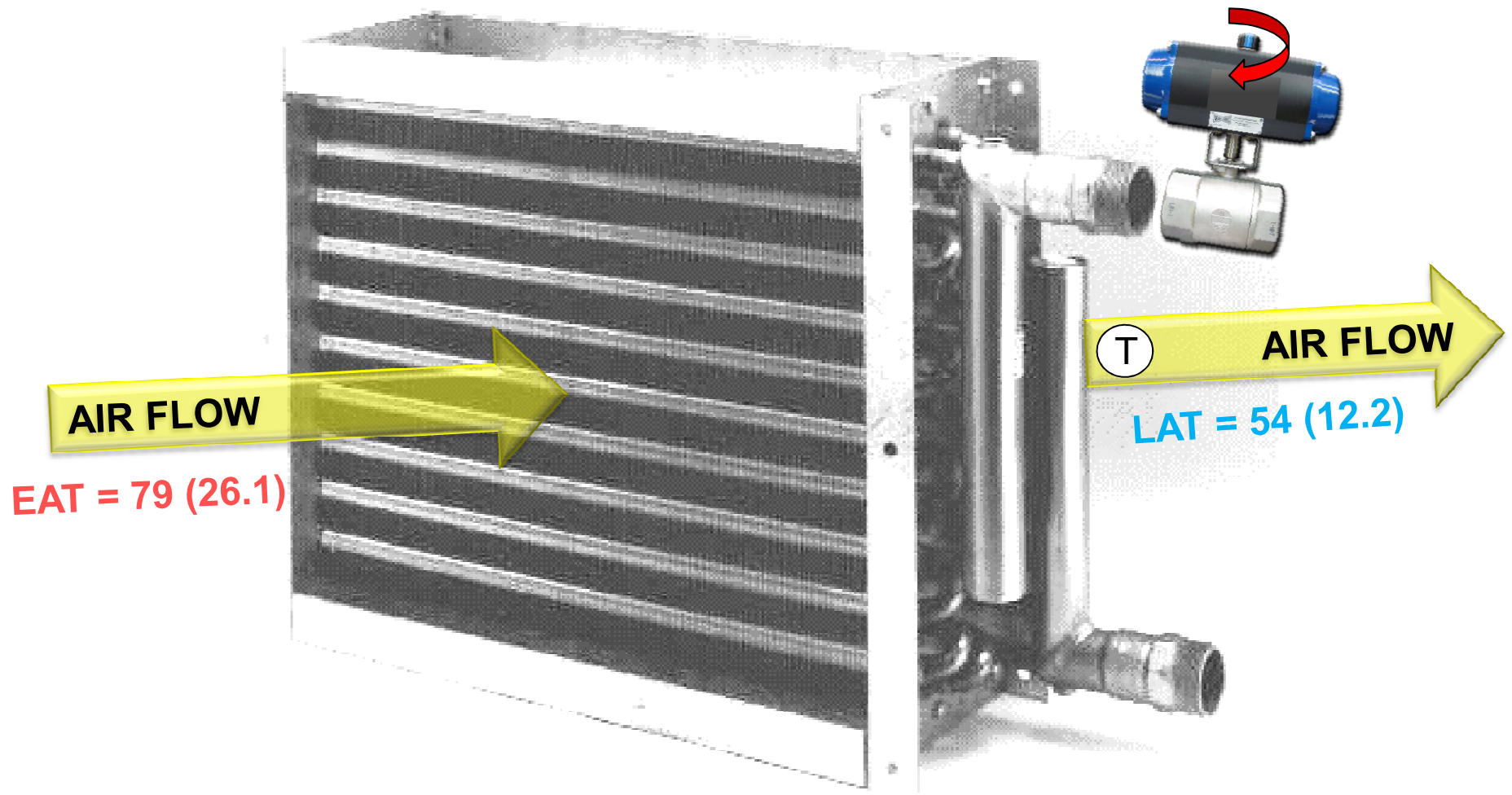
Valve Controls Leaving Air Temperature (LAT)

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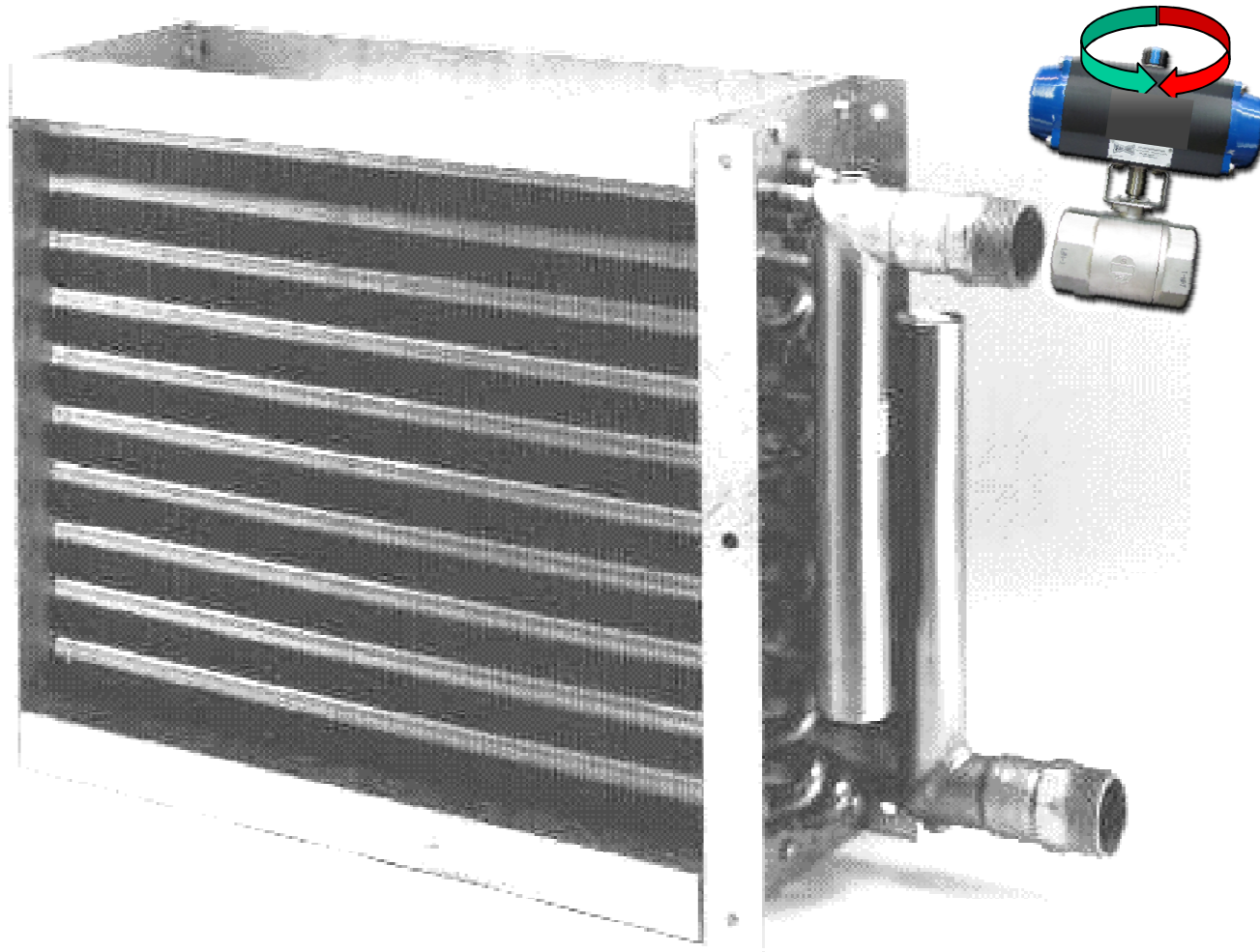


Valve Controls Leaving Air Temperature (LAT)

Set Point = 55° (12.8°) LAT



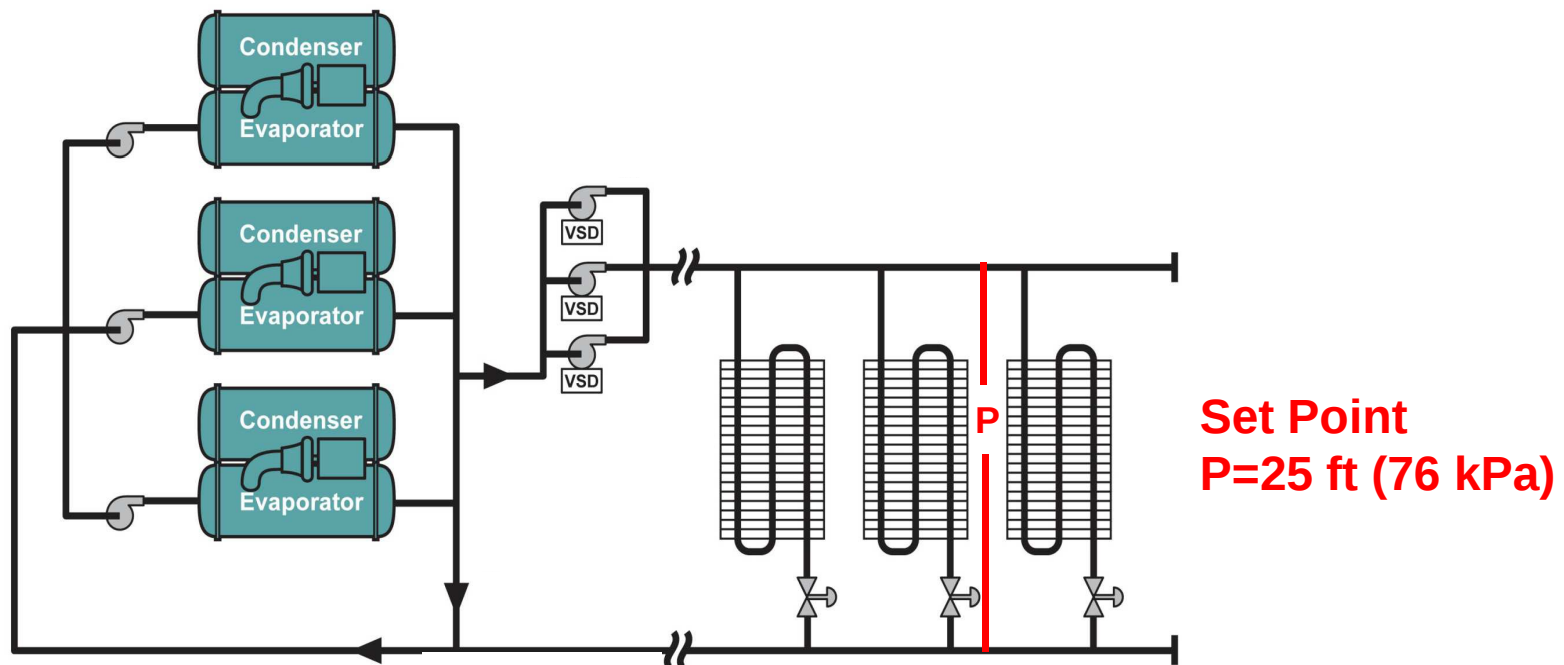
As Valve Opens, Pressure in loop lowers
As Valve Closes, Pressure in loop rises



Pressure Differential Sensor Controls Secondary Pump Speed

Differential Pressure sensor on last coil

- controls speed
- to Set Point (coil WPD+Valve PD+Piping PD+Safety)
- located at end of Index Circuit for best efficiency



Primary (Constant) / Secondary (Variable)

Advantages

- Easy to Control
- Easy to Commission
- Loop separation
 - Easier trouble-shooting
 - Separating isolated loads/buildings for lower total pump energy
 - Lower Plant Energy (can sequence chillers and ancillary equipment)
- Versatile – multi-circuit capability

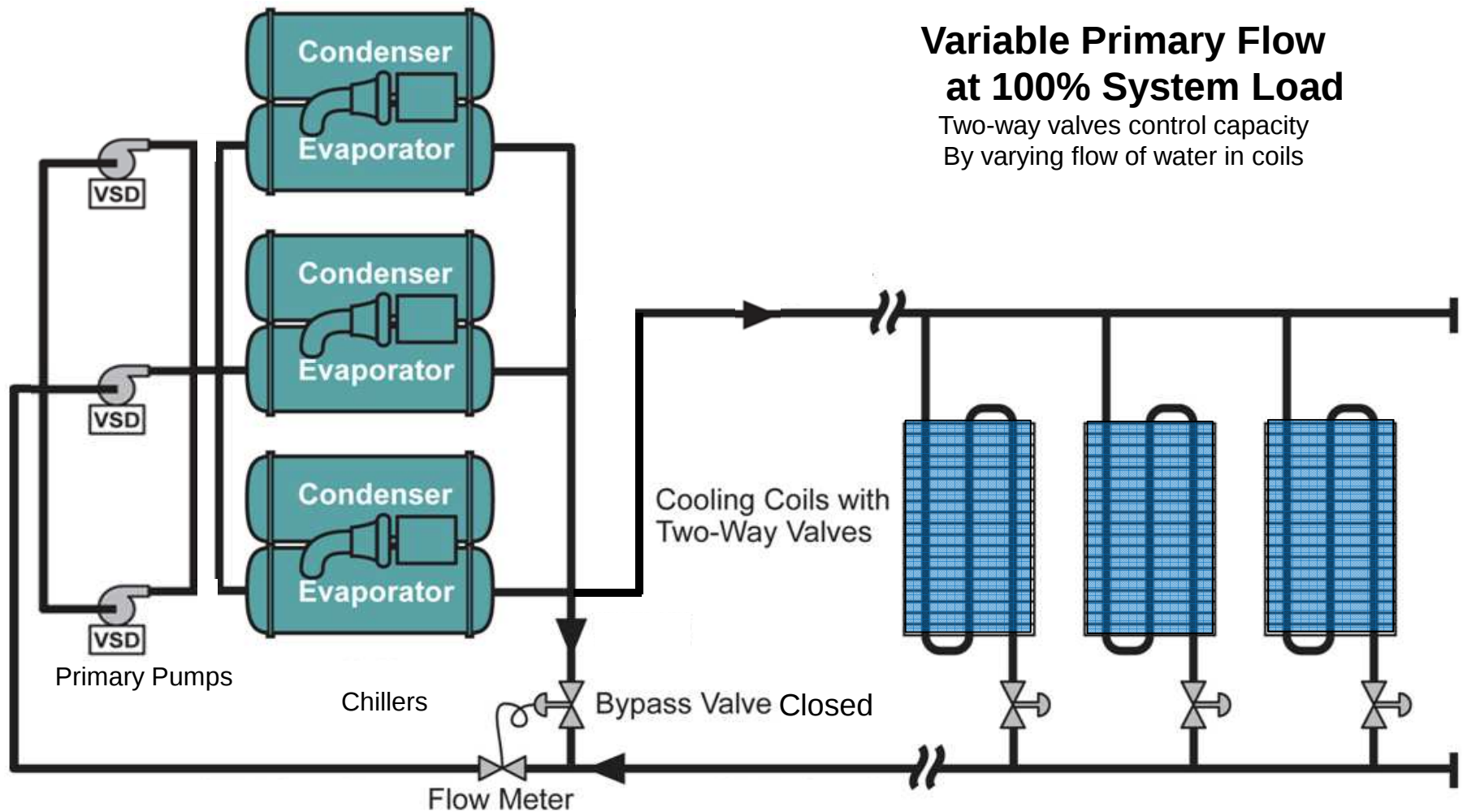
Disadvantages

- Medium Pump Energy Cost
- Highest Installed Cost (Sec Pumps, Piping, etc.)
- Potential for higher plant energy loss because of Low Delta T syndrome

Variable Primary Flow

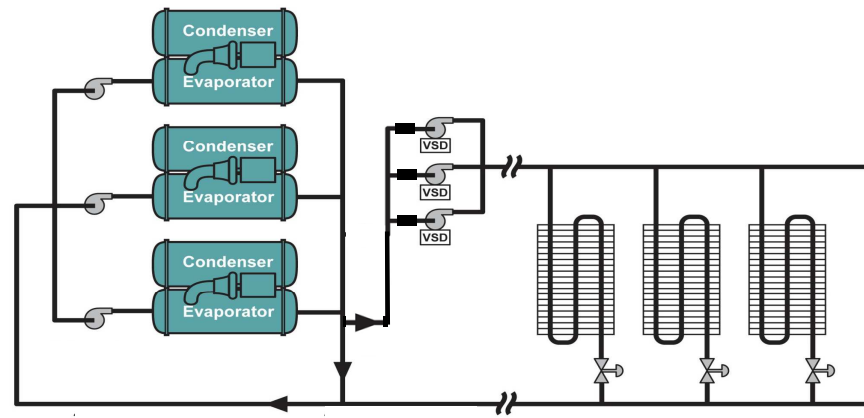
Variable Primary Flow

$$\text{Load} = \text{Flow} \times \Delta T$$

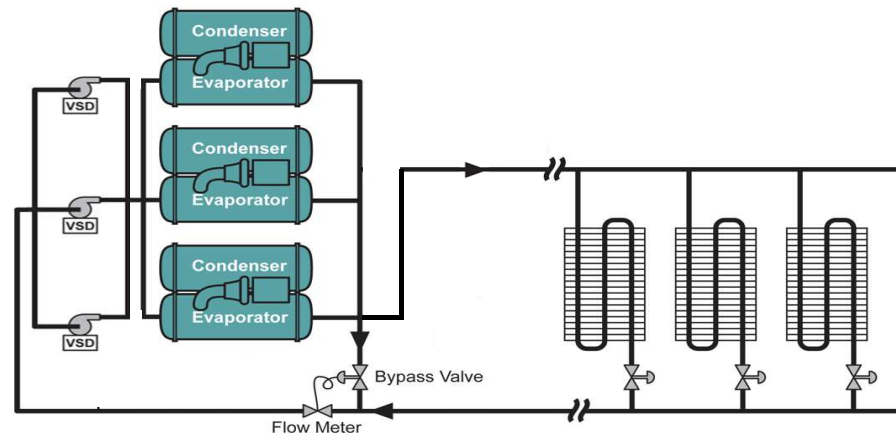


Primary/Secondary System

Three Differences?



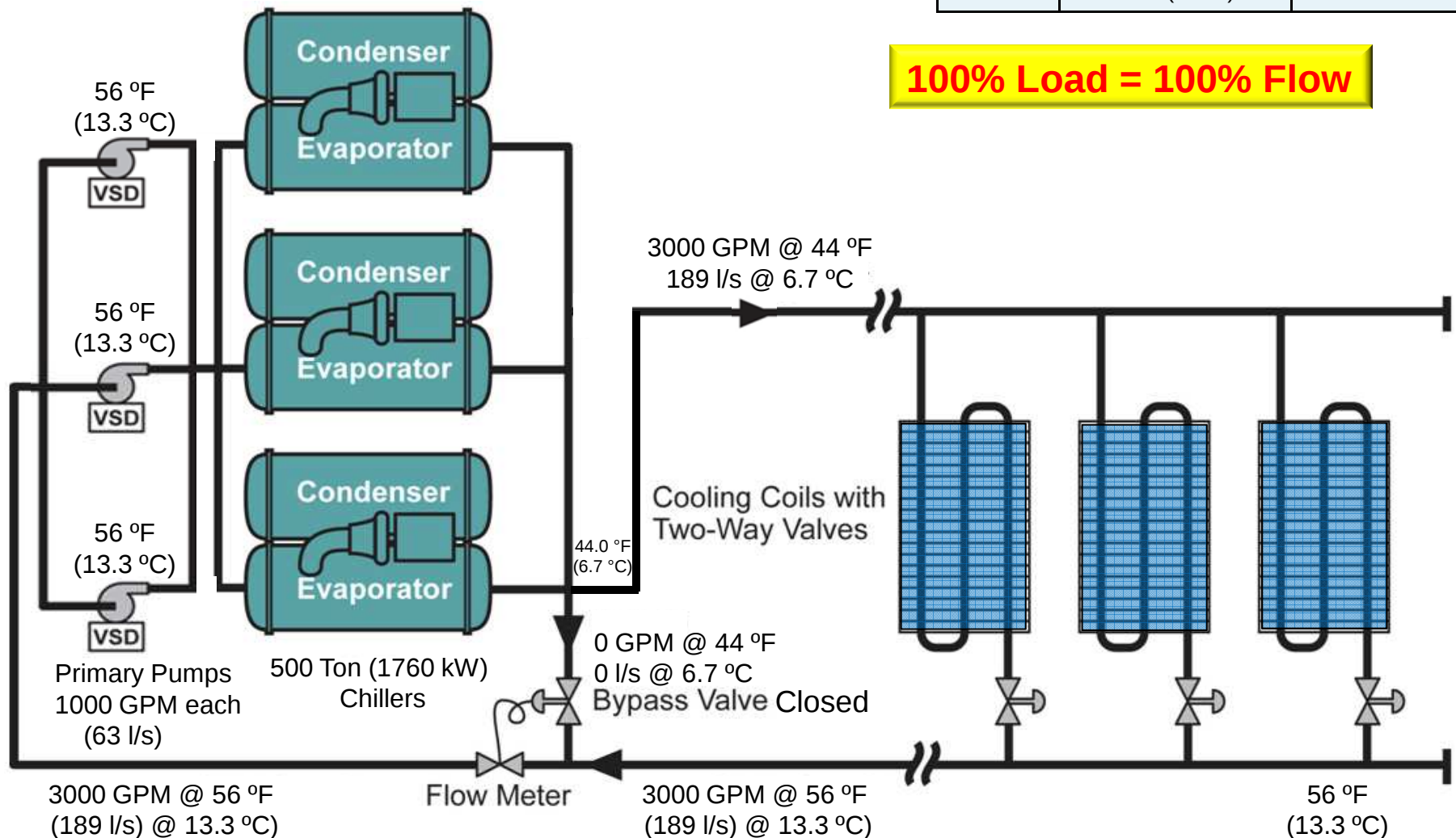
Variable Primary System



Variable Primary Flow **at Design**

	Per Chiller	System
Load	500 Tons (1760kW)	1500 Tons (5280kW)
	Primary	Bypass
Flow	3000gpm (189 l/s)	0gpm (0 l/s)
Delta T	12°F (6.7°C)	----

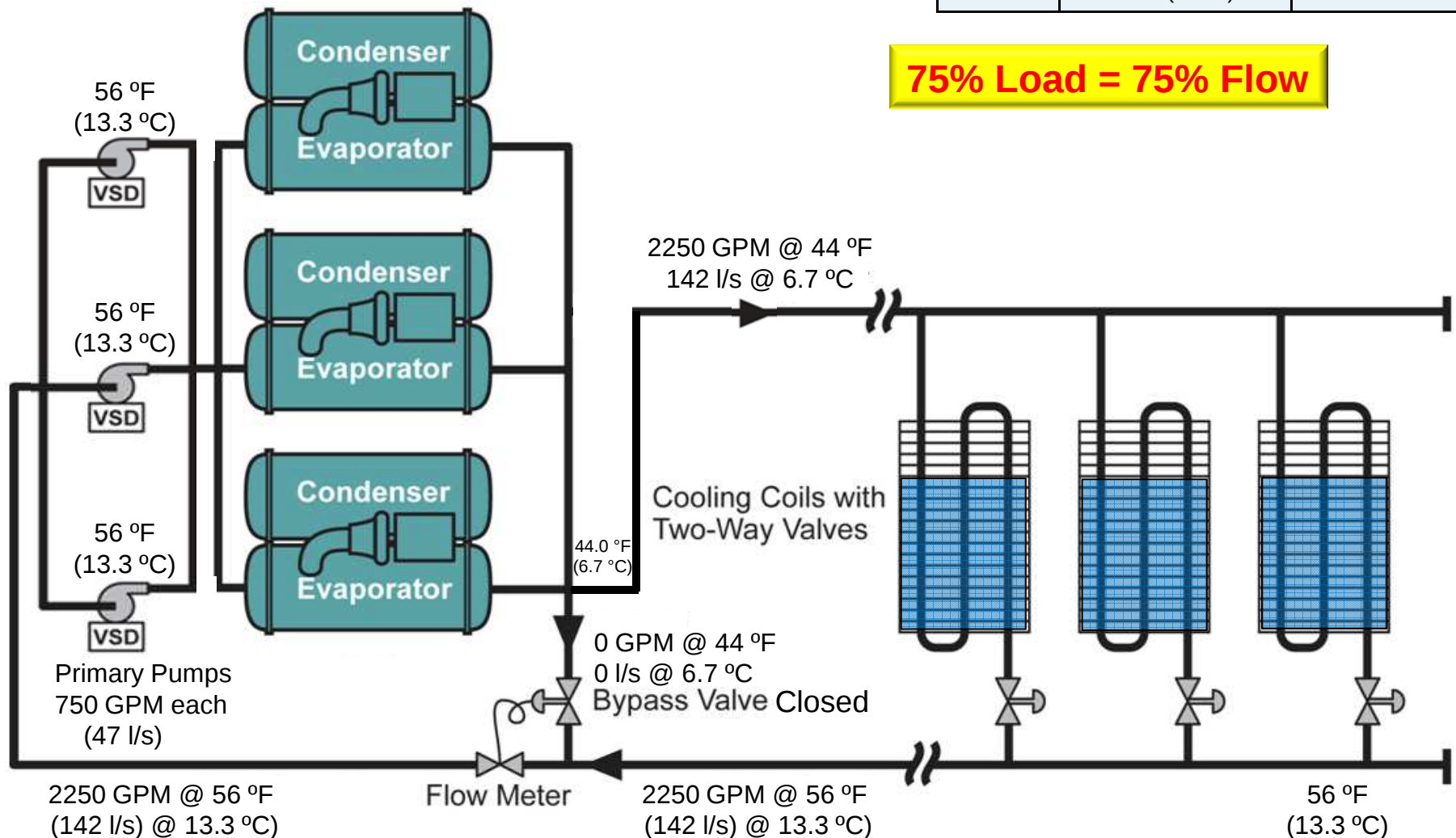
100% Load = 100% Flow



Variable Primary Flow at 75% Load

	Per Chiller	System
Load	375 Tons (1320kW)	1125 Tons (3960 kW)
	Primary	Bypass
Flow	2250 gpm (189 l/s)	0 gpm (0 l/s)
Delta T	12°F (6.7°C)	----

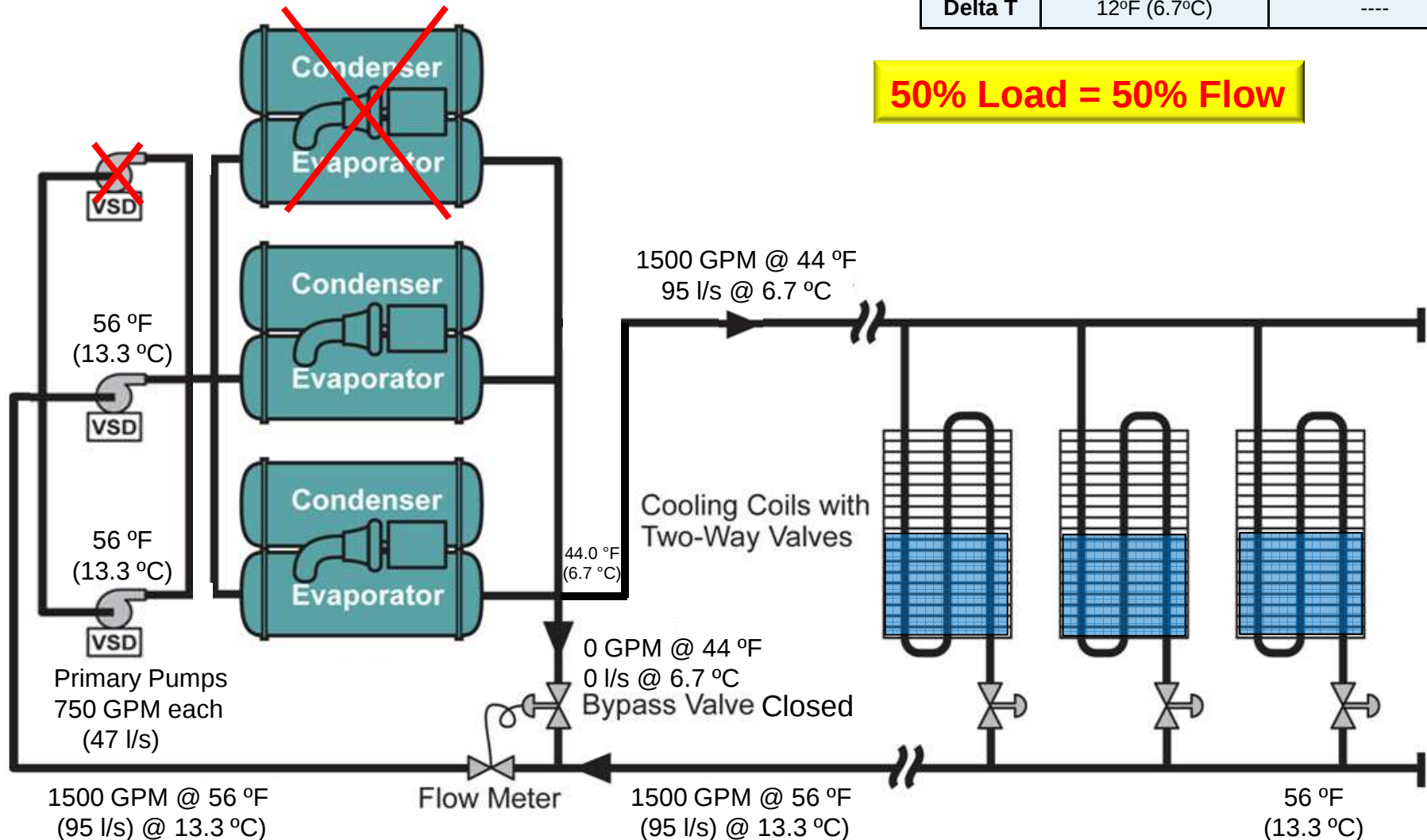
75% Load = 75% Flow



Variable Primary Flow at **50% Load**

	Per Chiller	System
Load	375 Tons (1320kW)	750 Tons (2640 kW)
	Primary	Bypass
Flow	1500 gpm (95 l/s)	0 gpm (0 l/s)
Delta T	12°F (6.7°C)	----

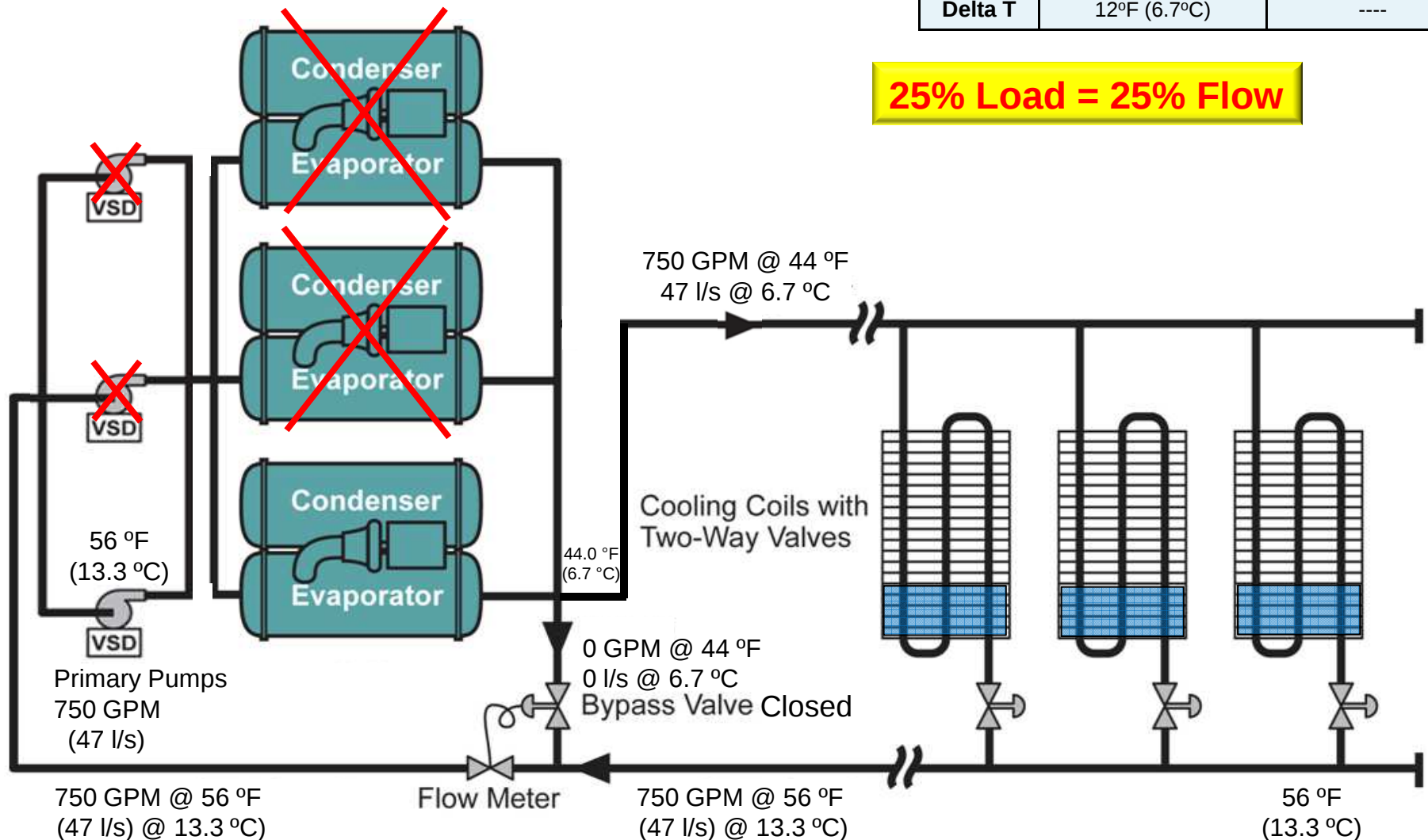
50% Load = 50% Flow



Variable Primary Flow at **25% Load**

	Per Chiller	System
Load	375 Tons (1320kW)	375 Tons (1320 kW)
	Primary	Bypass
Flow	750 gpm (95 l/s)	0 gpm (0 l/s)
Delta T	12°F (6.7°C)	----

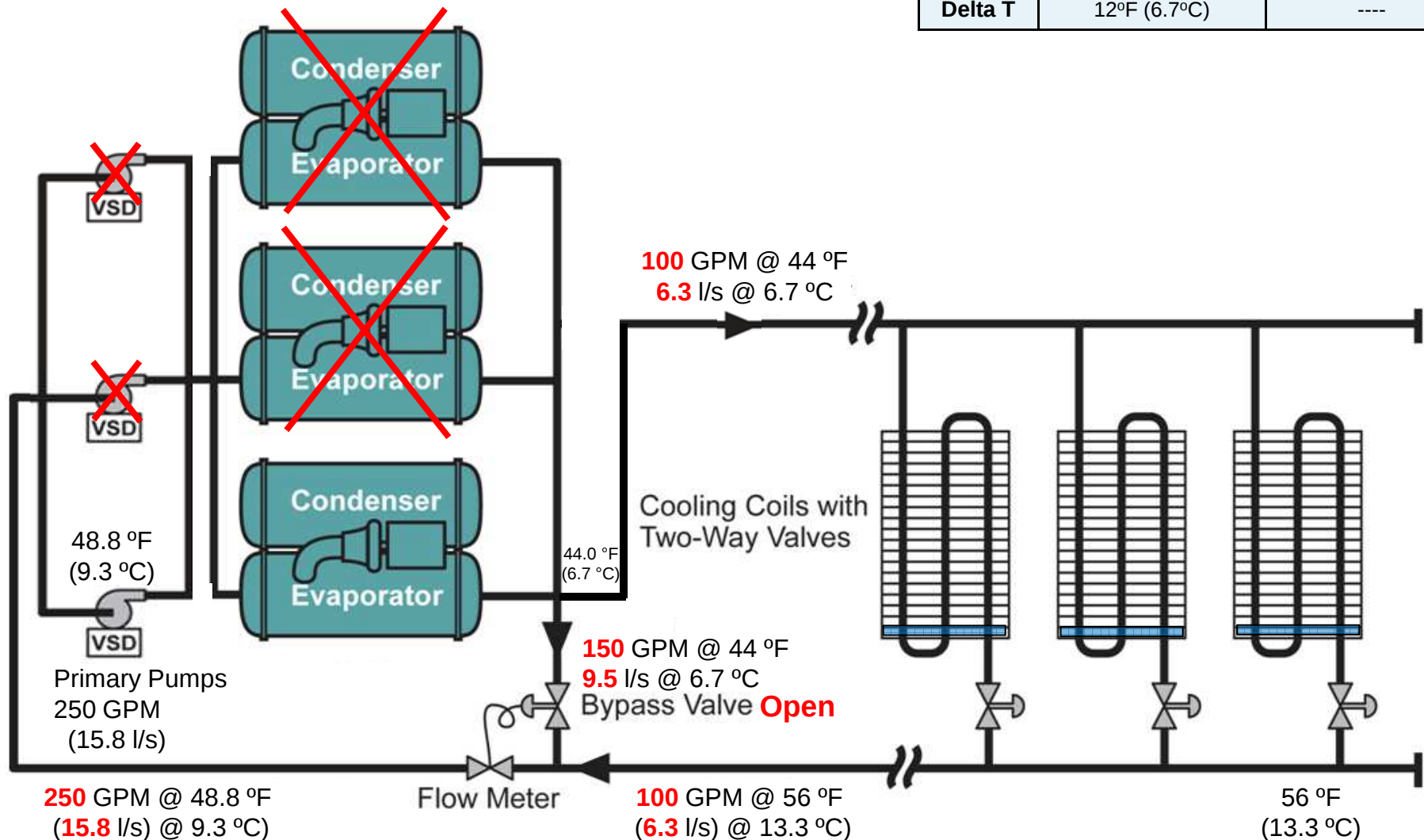
25% Load = 25% Flow



Variable Primary Flow in **Bypass Mode**

System flow below chiller min flow (**250 gpm**)

	Per Chiller	System
Load	50 Tons (176kW)	50Tons (176 kW)
	Primary	Bypass
Flow	250 gpm (95 l/s)	150 gpm (9.5 l/s)
Delta T	12°F (6.7°C)	----



Varying Flow Through Chillers - Issues

☐ Issue During Normal Operation

- ☐ Chiller Type (centrifugal fast, absorbers slow)
- ☐ Chiller Load (min load - no variance, full load - max variance)
- ☐ System Water Volume (more water, more thermal capacitance, faster variance allowed)
- ☐ Active Loads (near or far from plant)
- ☐ Typical VSD pump ramp rate setting of 10%/minute (accel/decel rates set to 600 seconds)

Varying Flow Through Chillers - Issues

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- ☐ Active Loads (near or far from plant)
- ☐ Typical VSD pump ramp rate setting of 10%/minute (accel/decel rates set to 600 seconds)

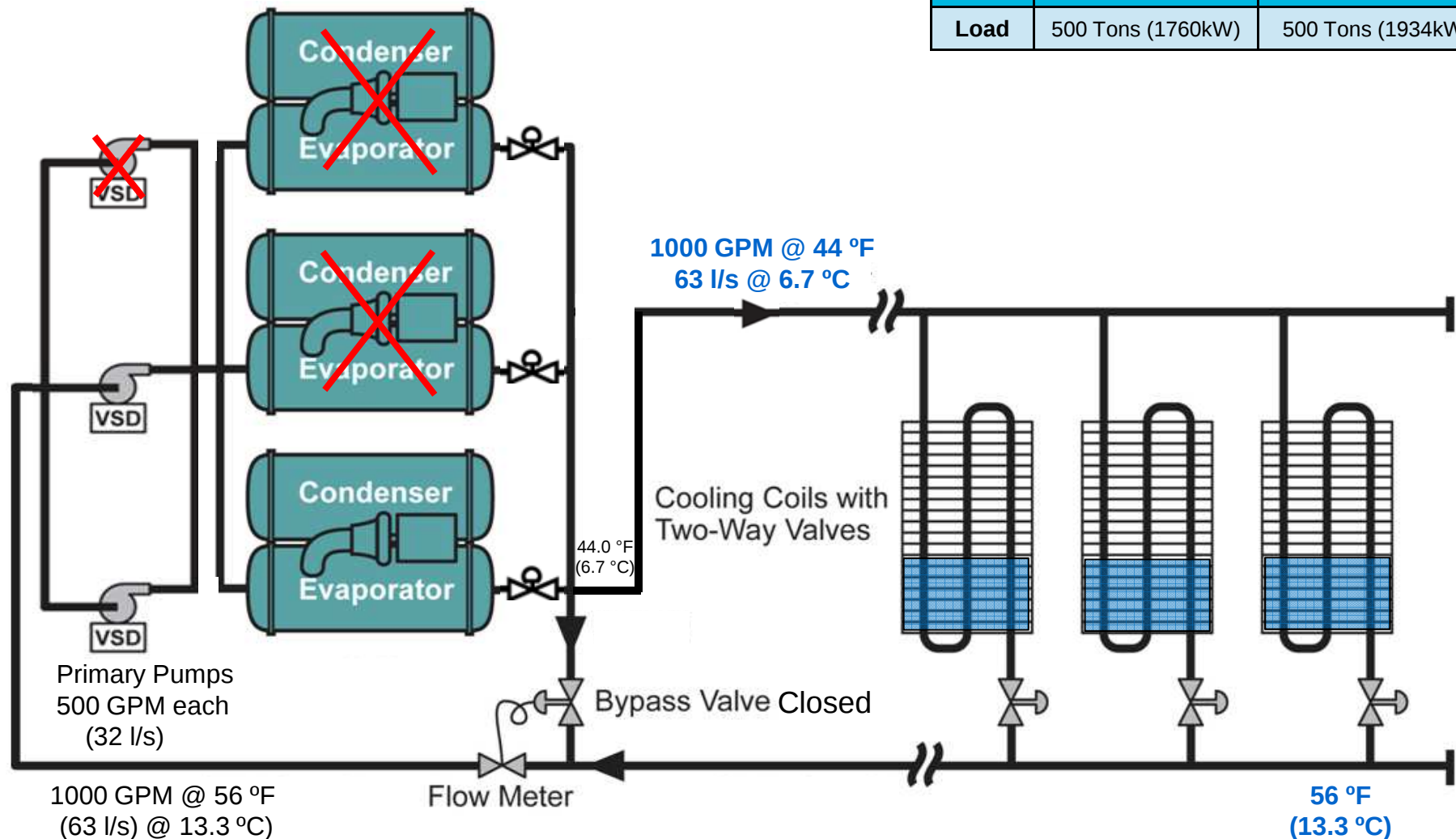
☐ Issue Adding Chillers

- ☐ Modulating isolation valves on chillers

Variable Primary System – Staging on chillers & changes in flow rate

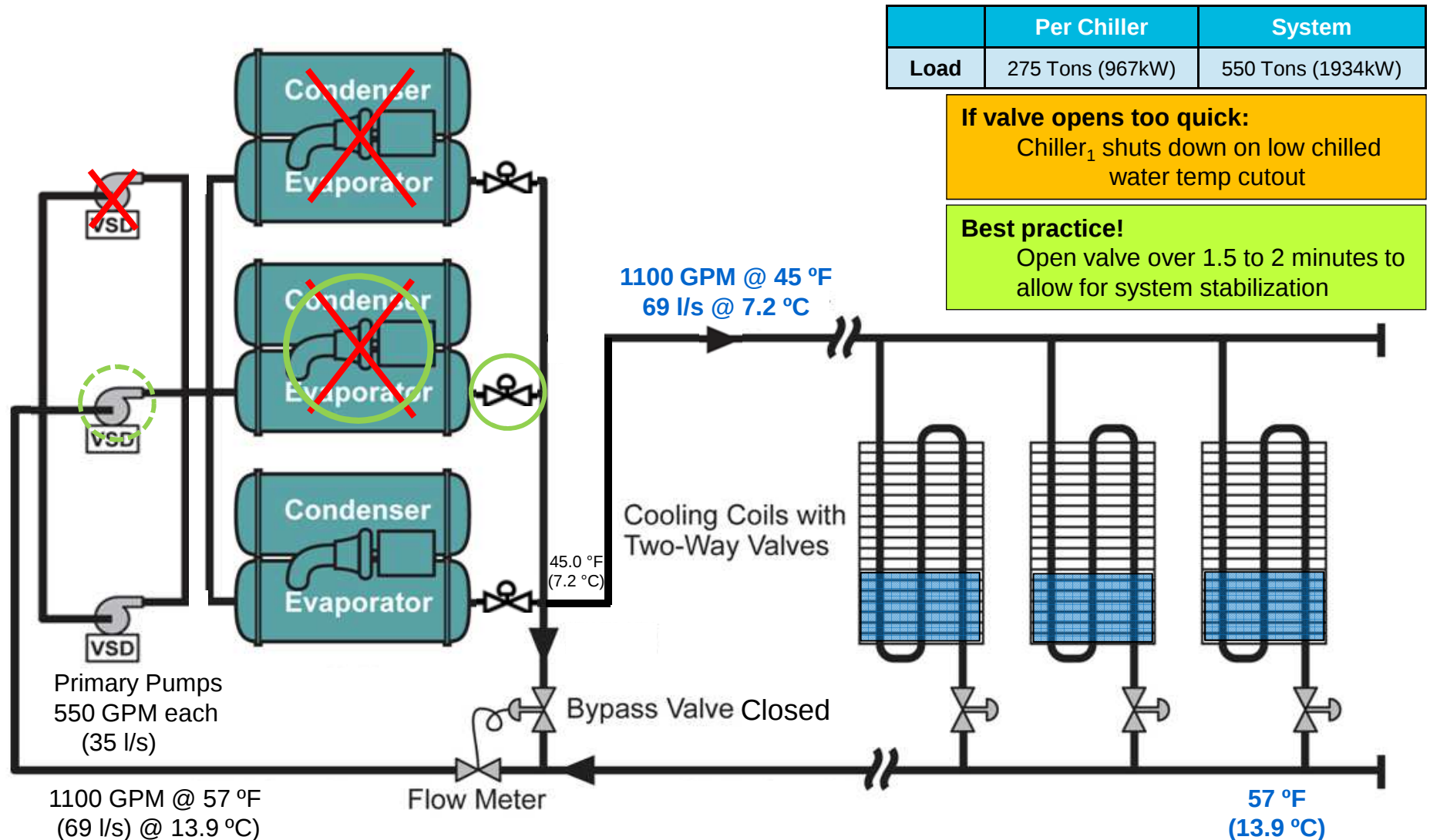
Current Situation – 1 chiller running

	Per Chiller	System
Load	500 Tons (1760kW)	500 Tons (1934kW)



Variable Primary System – Staging on chillers & changes in flow rate

Current Situation –building load increases, valve opens, second chiller starts

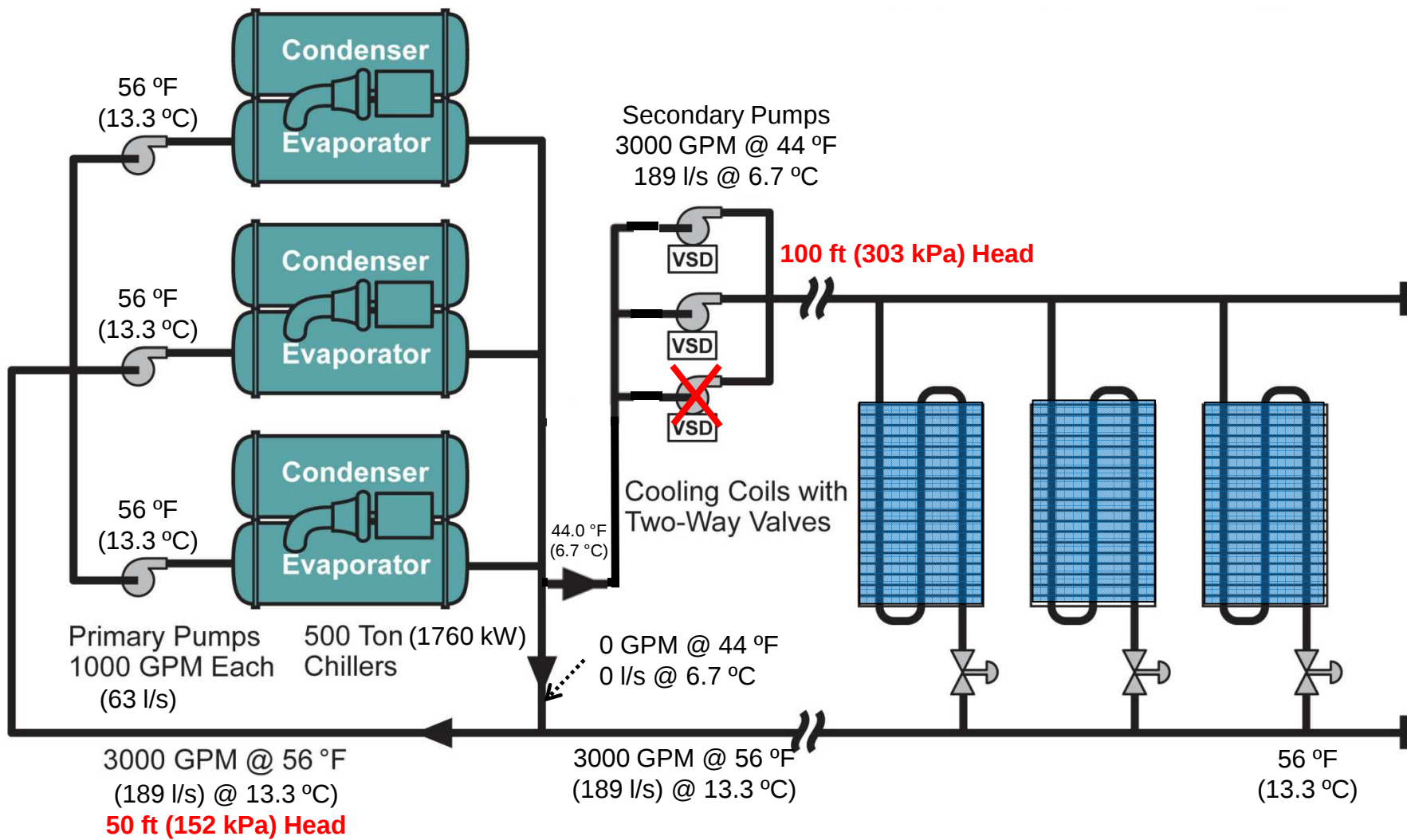


Variable Primary Flow (VPF) System Arrangement

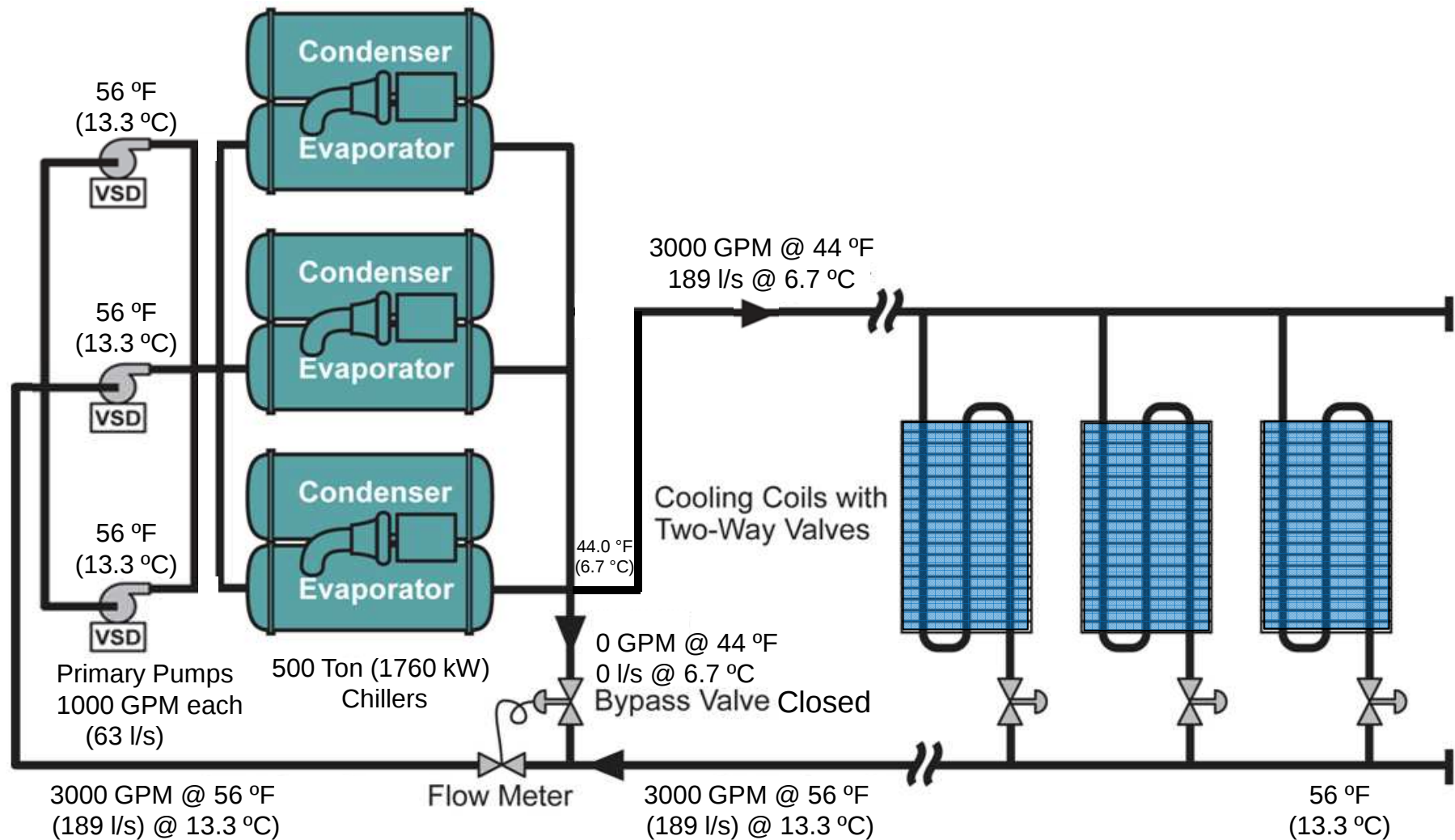
☐ Advantages

- ☐ Lower Installed Cost (approx. 5% compared P/S)
 - ☐ No secondary Pumps or piping, valves, electrical, installation, etc.
 - ☐ Offset somewhat by added 2W Bypass Valve and more complex controls
- ☐ Less Plant Space Needed
- ☐ Best Chilled Water Pump Energy Consumption **(most optimeady configuration)**
 - ☐ VSD energy savings
 - ☐ Lower Pump Design Head

Primary/Secondary



Variable Primary Flow



140 ft (424 kPa) Head

Pump Energy

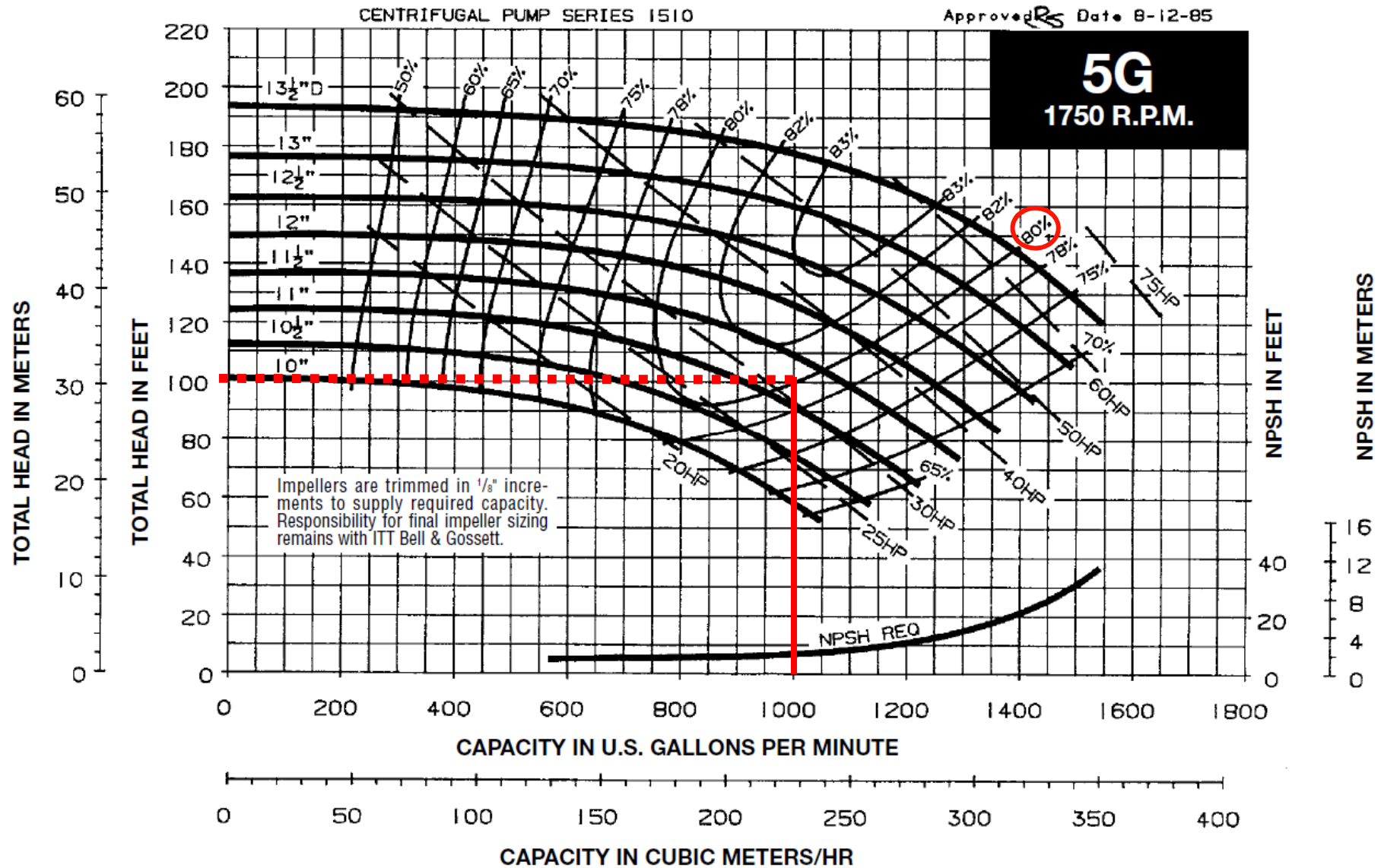
$$\text{BHP} = \frac{\text{GPM} \times \text{Head}}{3960 \times \text{Pump}_{\text{Eff}}}$$

Variable Primary Flow (VPF) System Arrangement

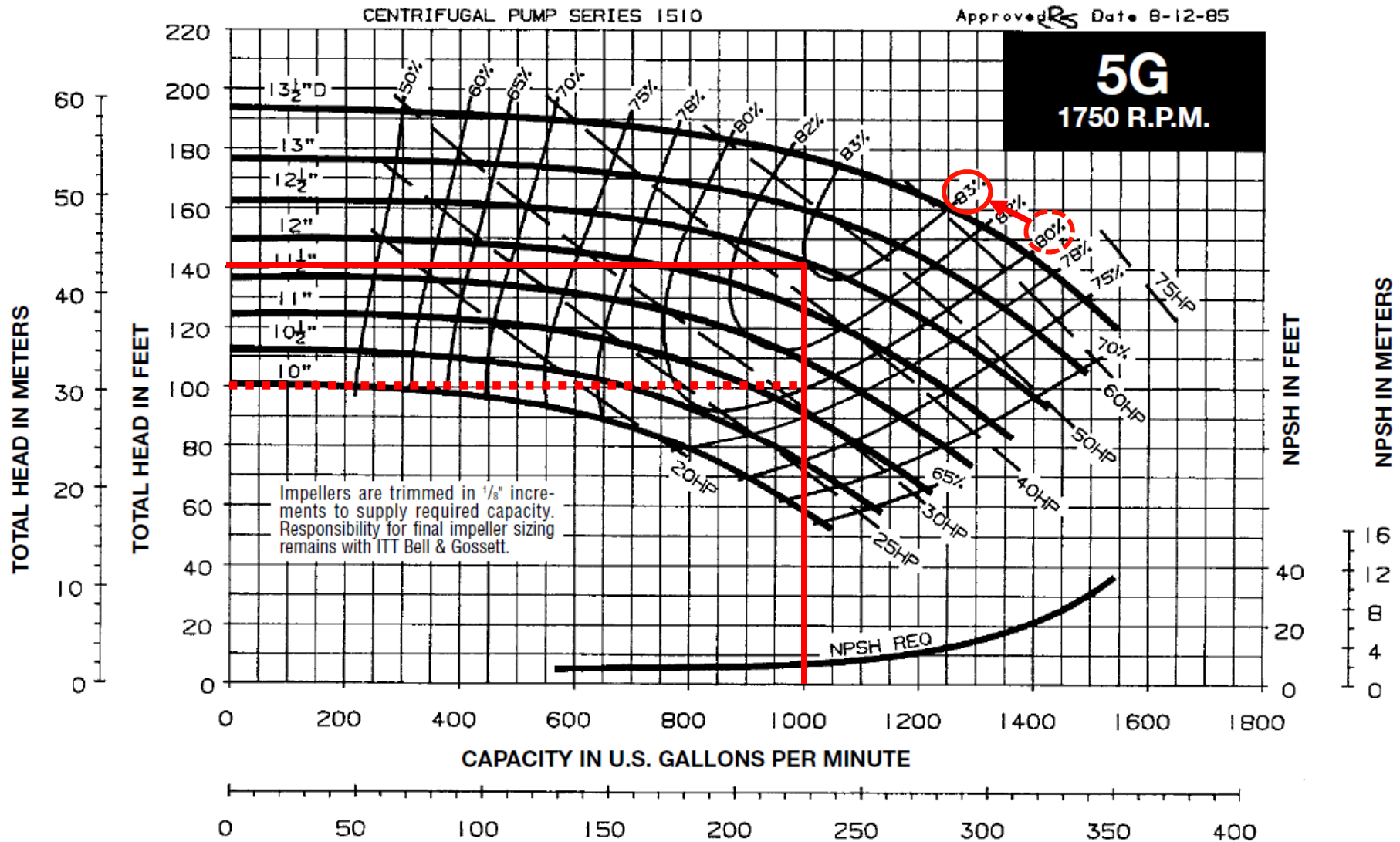
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- ☐ Less Plant Space Needed
- ☐ Best Chilled Water Pump Energy Consumption (most optimeady configuration)
 - ☐ VSD energy savings
 - ☐ Lower Pump Design Head
 - ☐ **Higher Pump Efficiency**

Pump Curves - Pump Efficiency



Pump Curves - Pump Efficiency



With VPF you will need larger pumps compared to P/S, but they will be operating at a more efficient point, yielding energy savings

Pump Energy

$$\text{BHP} = \frac{\text{GPM X Head}}{3960 \times \text{Pump}_{\text{Eff}}}$$

Variable Primary Flow (VPF) System Arrangement

☐ Advantages

- ☐ Medium Installed Cost (approx. 5% compared P/S)
 - ☐ No secondary Pumps or piping, valves, electrical, installation, etc.
 - ☐ Offset somewhat by added 2W Bypass Valve and more complex controls
- ☐ Less Plant Space Needed (vs P/S)
- ☐ Best Chilled Water Pump Energy Consumption (**most optimeady configuration**)
 - ☐ VSD energy savings
 - ☐ Lower Pump Design Head
 - ☐ Higher Pump Efficiency
- ☐ Lower potential impact from Low Delta T (can over pump chillers if needed)

Variable Primary Flow (VPF) System Arrangement

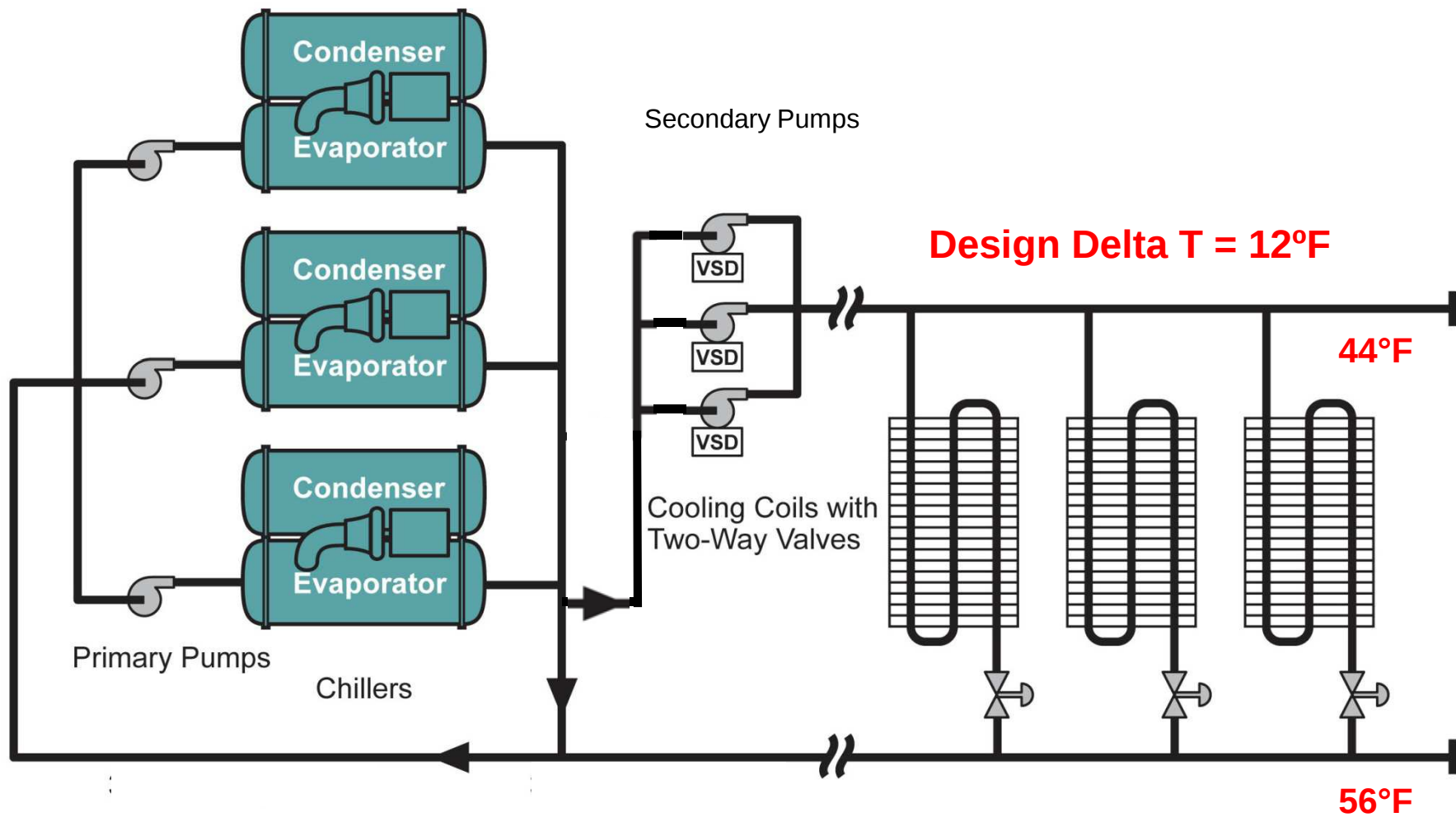
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- ☐ Less Plant Space Needed (vs P/S)
- ☐ Best Chilled Water Pump Energy Consumption (most optimeady configuration)
 - ☐ VSD energy savings
 - ☐ Lower Pump Design Head
 - ☐ Higher Pump Efficiency
- ☐ Lower potential impact from Low Delta T (can over pump chillers if needed)

☐ Disadvantages

- ☐ Requires more robust (complex and properly calibrated) control system
- ☐ Requires coordinated control of chillers, isolation valves, and pumps
- ☐ Potentially longer commissioning times to tune the system
- ☐ Need experienced facility manager to operate/maintain properly

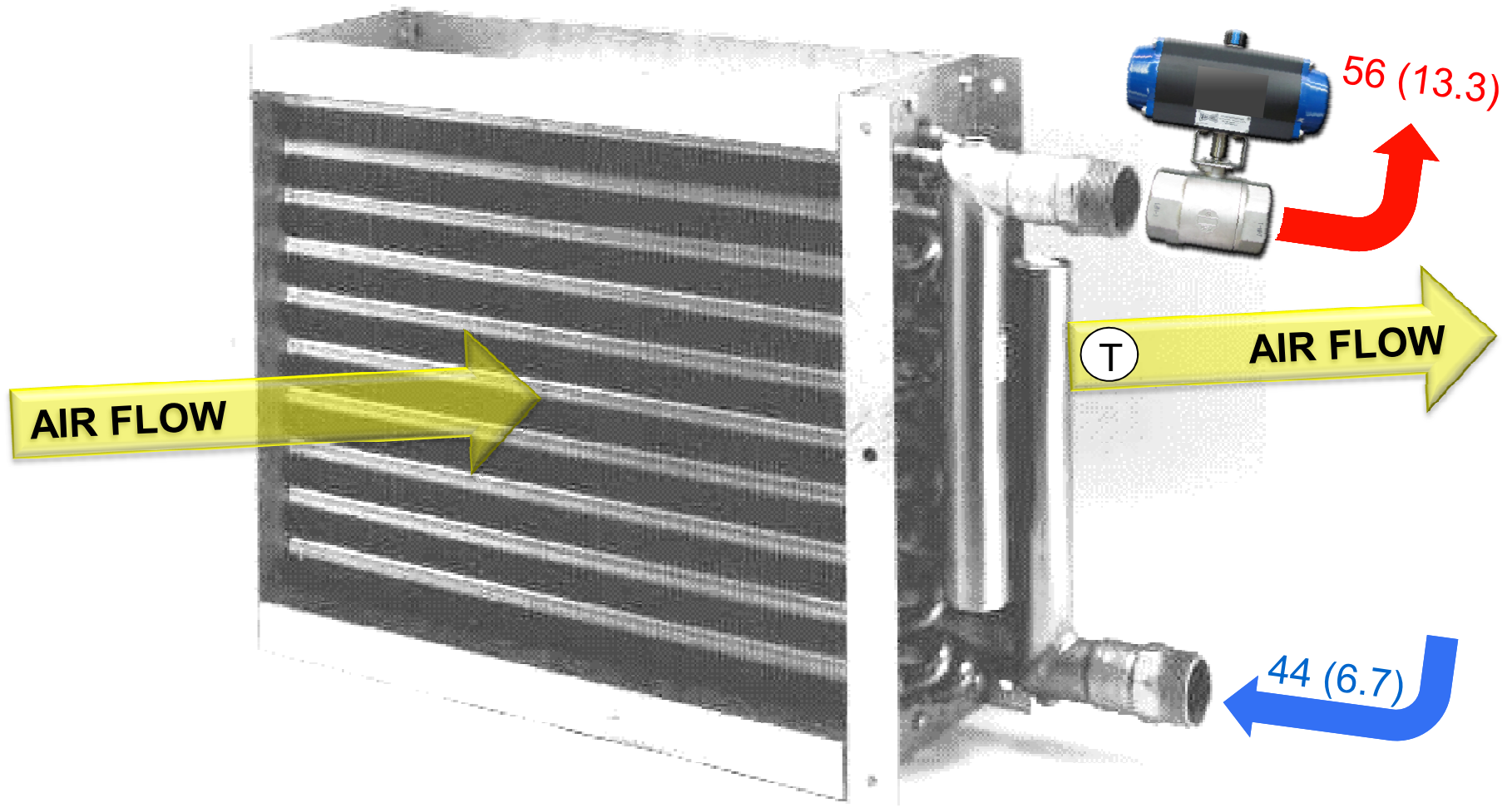
Low Delta T Syndrome



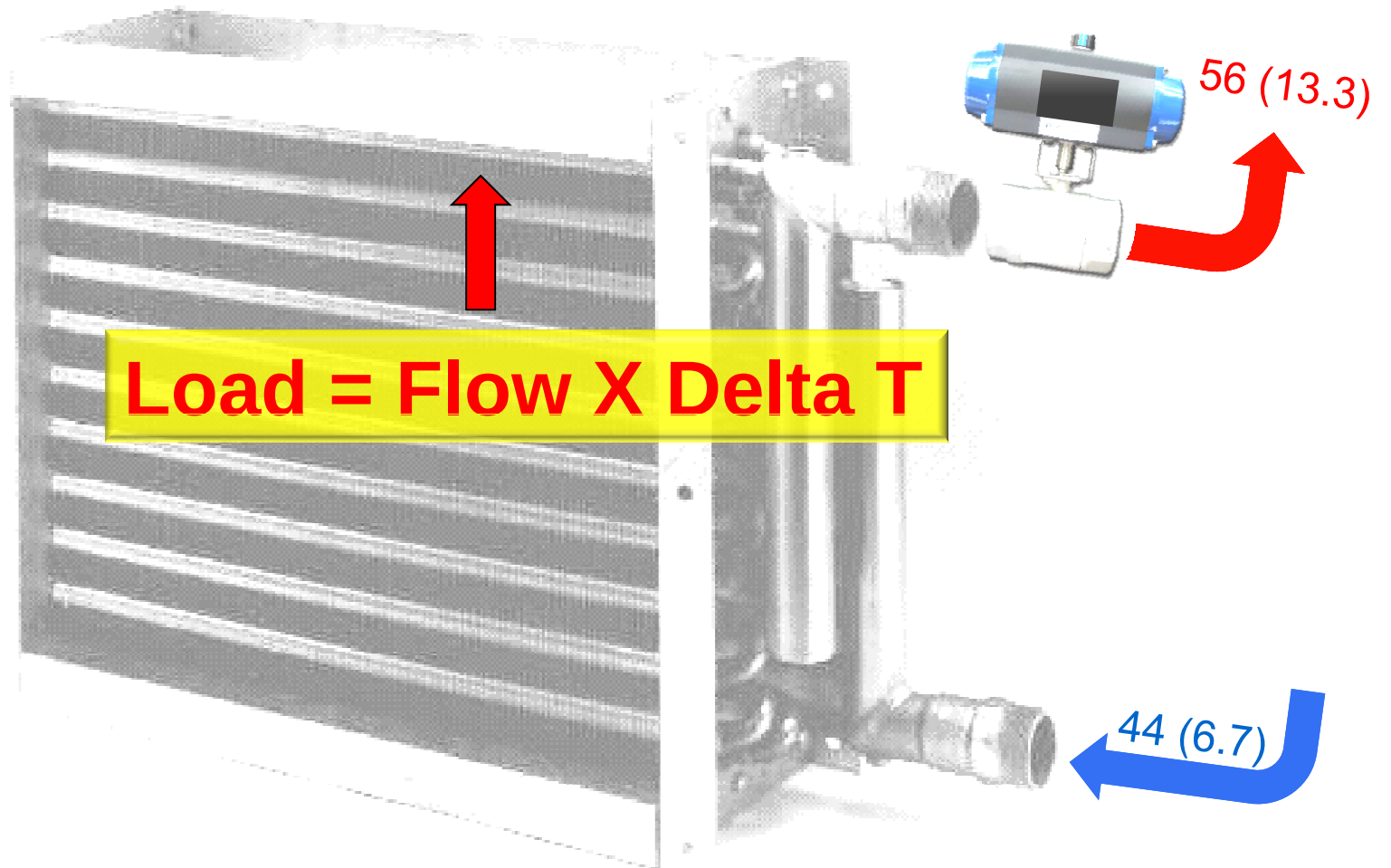
Major Causes of Low Delta T

- ❑ Dirty Coils

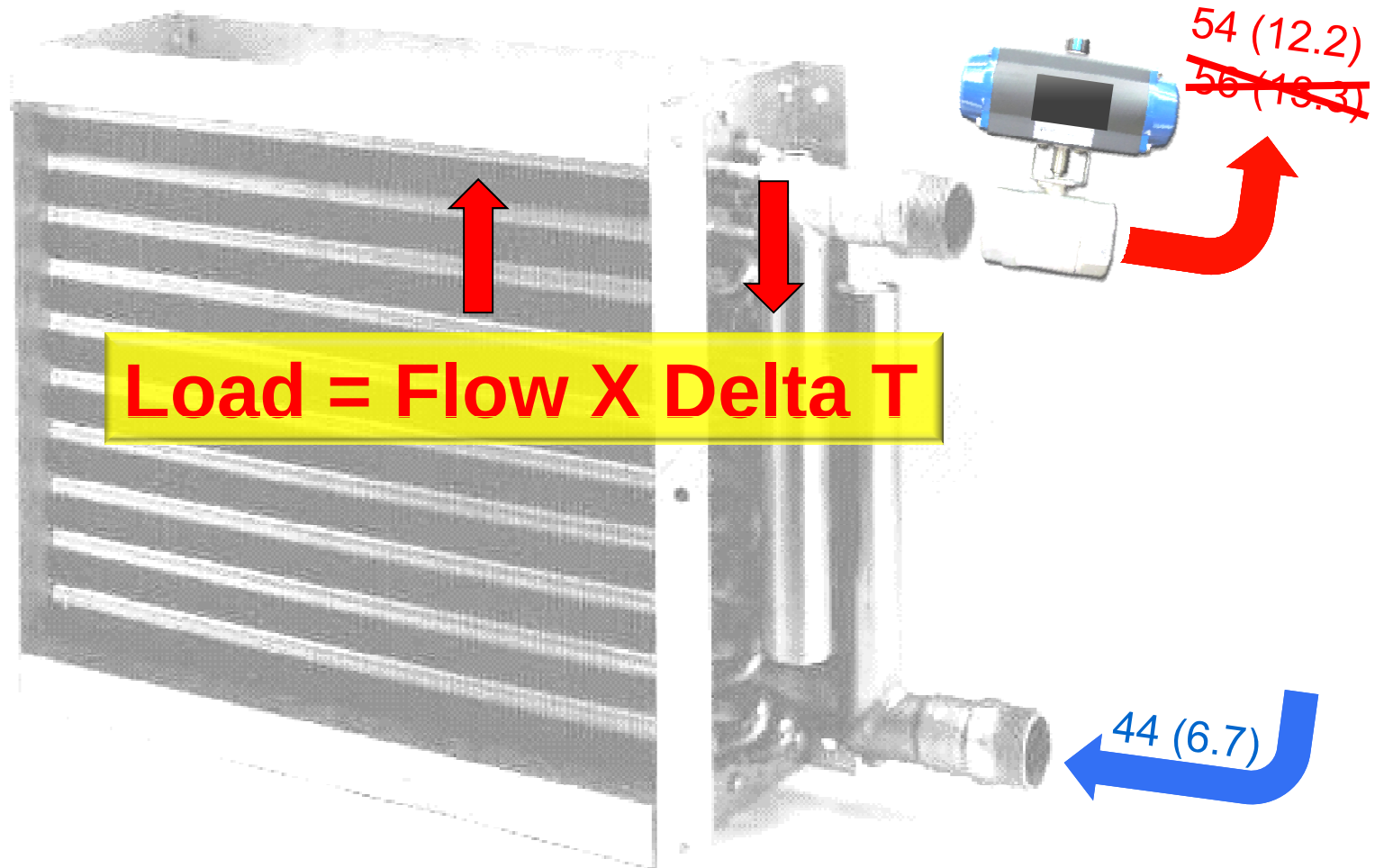
Chilled Water Coil



Chilled Water Coil



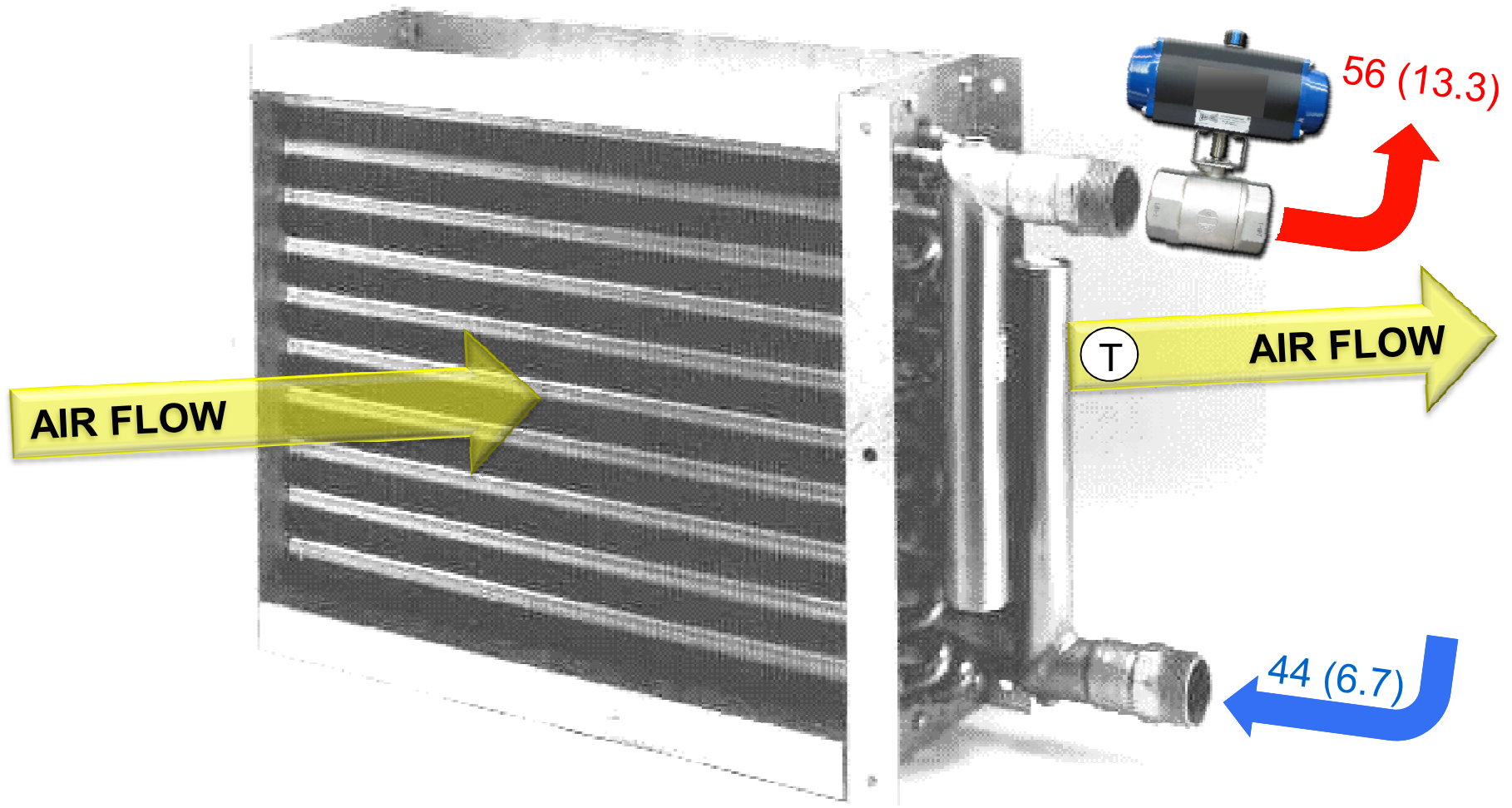
Chilled Water Coil



Major Causes of Low Delta T

- ☐ Dirty Coils
- ☐ Controls Calibration
- ☐ Leaky 2-Way Valves
- ☐ Coils Piped-Up Backwards

Chilled Water Coil

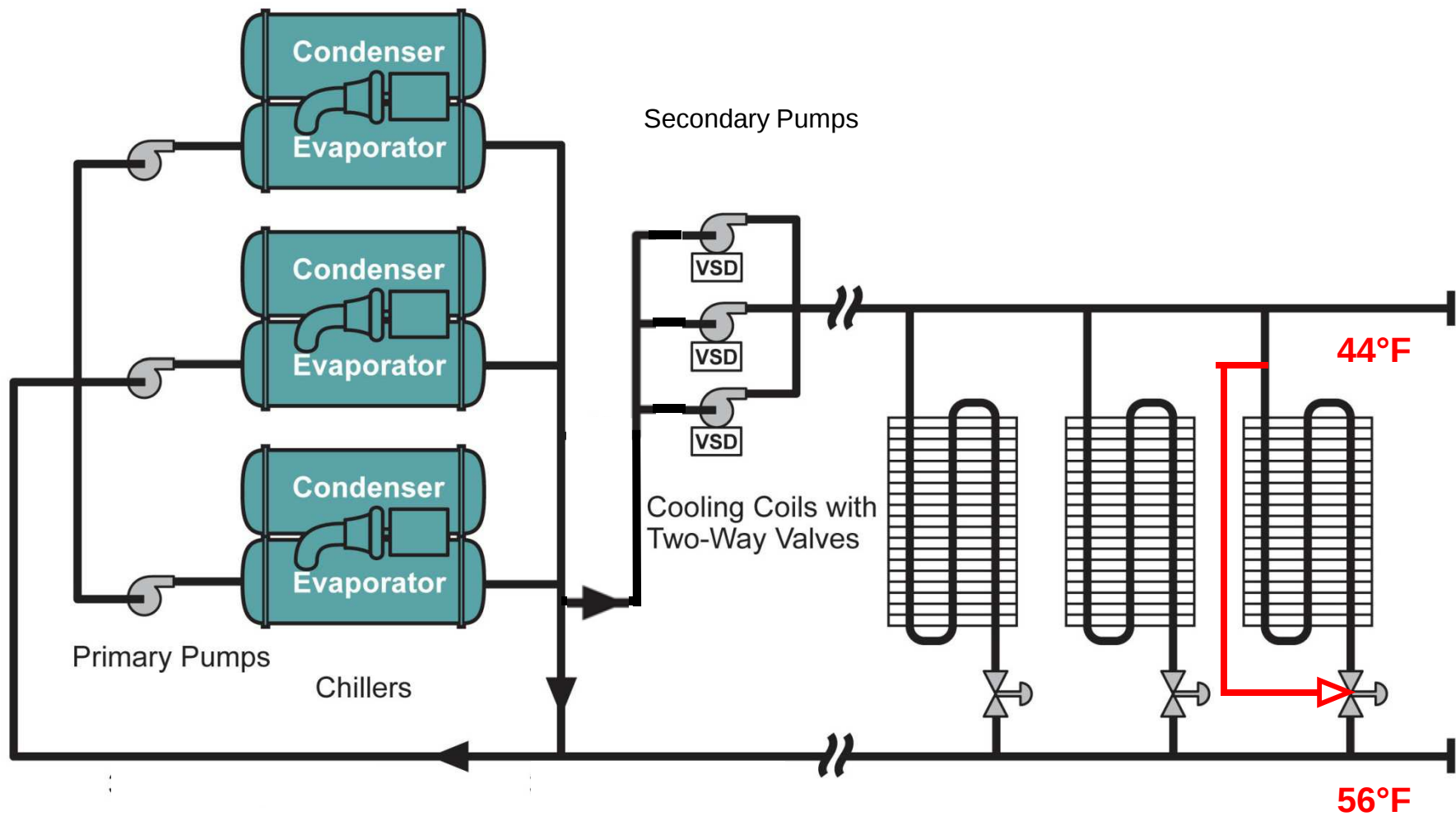


Major Causes of Low Delta T

- ☐ Dirty Coils
- ☐ Controls Calibration
- ☐ Leaky 2-Way Valves
- ☐ Coils Piped-Up Backwards
- ☐ Mixing 2-Way with 3-Way Valves in the same system

Low Delta T Syndrome

3 Way Valves Mixed with 2 Way



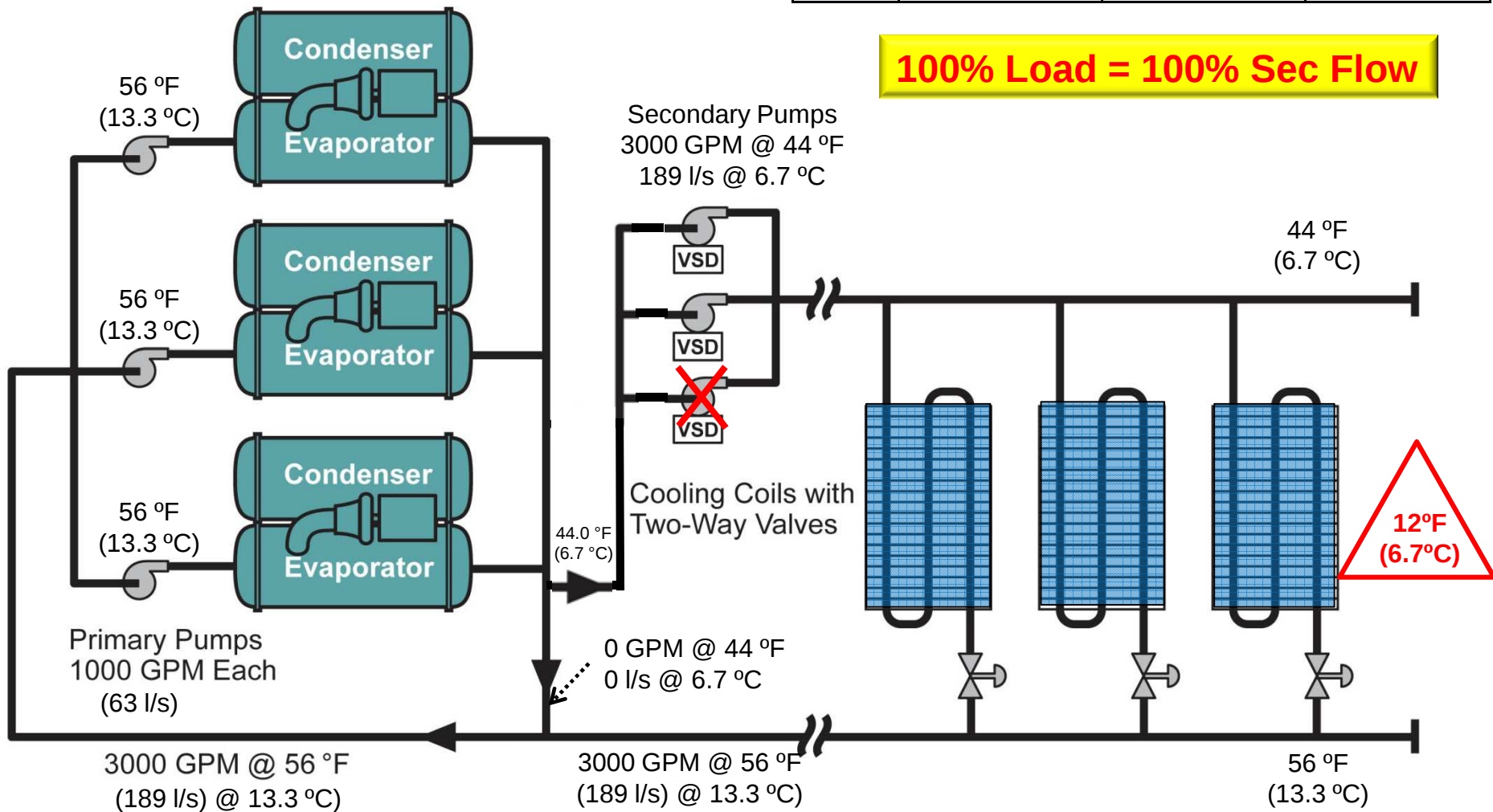
Primary/Secondary at Design

Ideal Operation

	Per Chiller	System
Load	500 Tons (1760kW)	1500 Tons (5280kW)

	Primary	Secondary	Bypass
Flow	3000gpm (189 l/s)	3000gpm (189 l/s)	0 gpm (0 l/s)
Delta T	12°F (6.7°C)	12°F (6.7°C)	----

100% Load = 100% Sec Flow

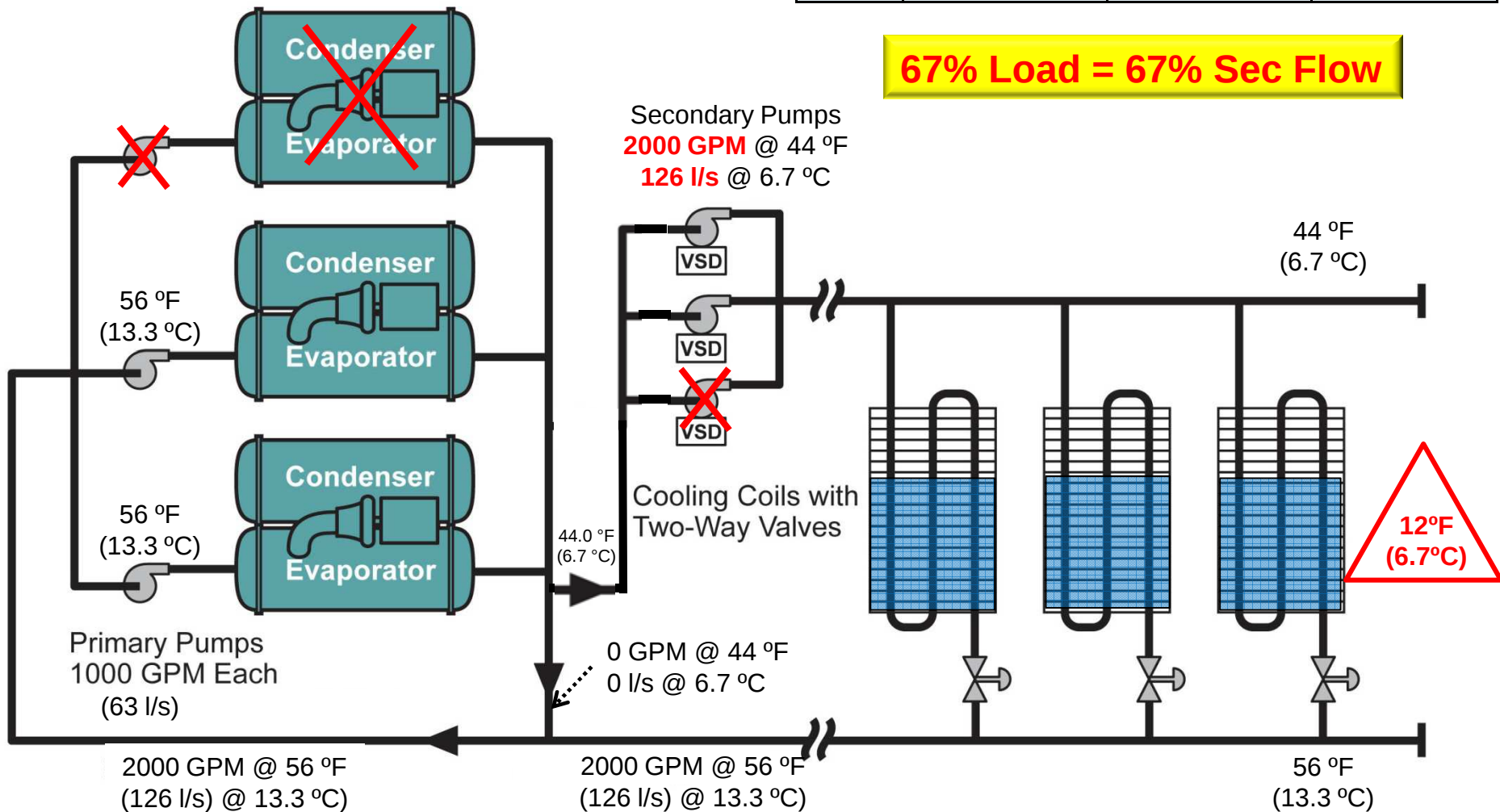


Primary/Secondary at 67% Load Ideal Operation

	Per Chiller	System
Load	500 Tons (1760kW)	1000 Tons (3518kW)

	Primary	Secondary	Bypass
Flow	2000gpm (126 l/s)	2000gpm (126 l/s)	0 gpm (0 l/s)
Delta T	12°F (4.4°C)	12°F (6.7°C)	----

67% Load = 67% Sec Flow



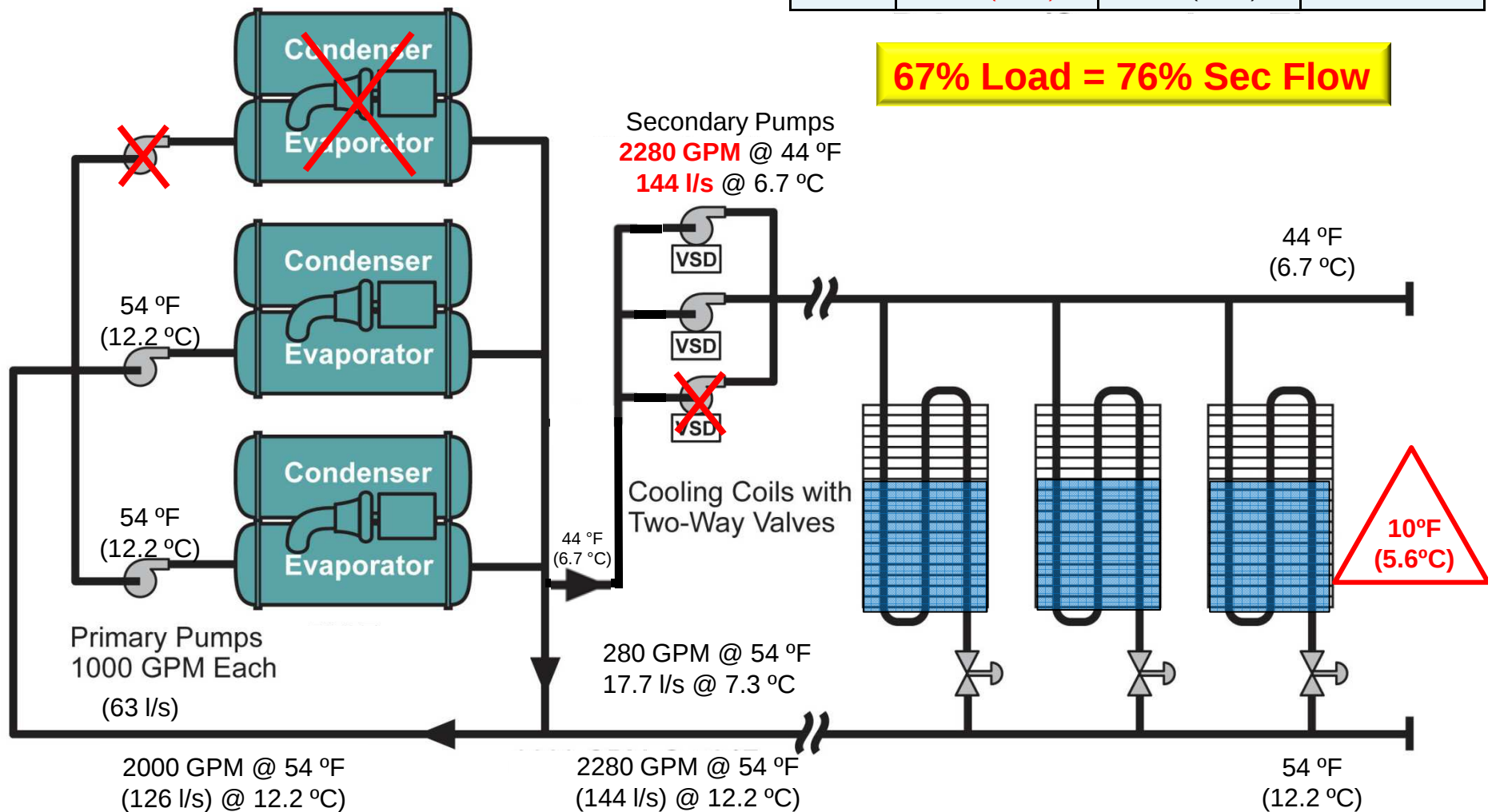
Primary/Secondary at 67% Load

Low DeltaT

	Per Chiller	System
Load	500 Tons (1760kW)	1000 Tons (3518kW)

	Primary	Secondary	Bypass
Flow	2000gpm (126 l/s)	2280gpm (144 l/s)	280 gpm (0 l/s)
Delta T	10°F (5.6°C)	10°F (5.6°C)	----

67% Load = 76% Sec Flow



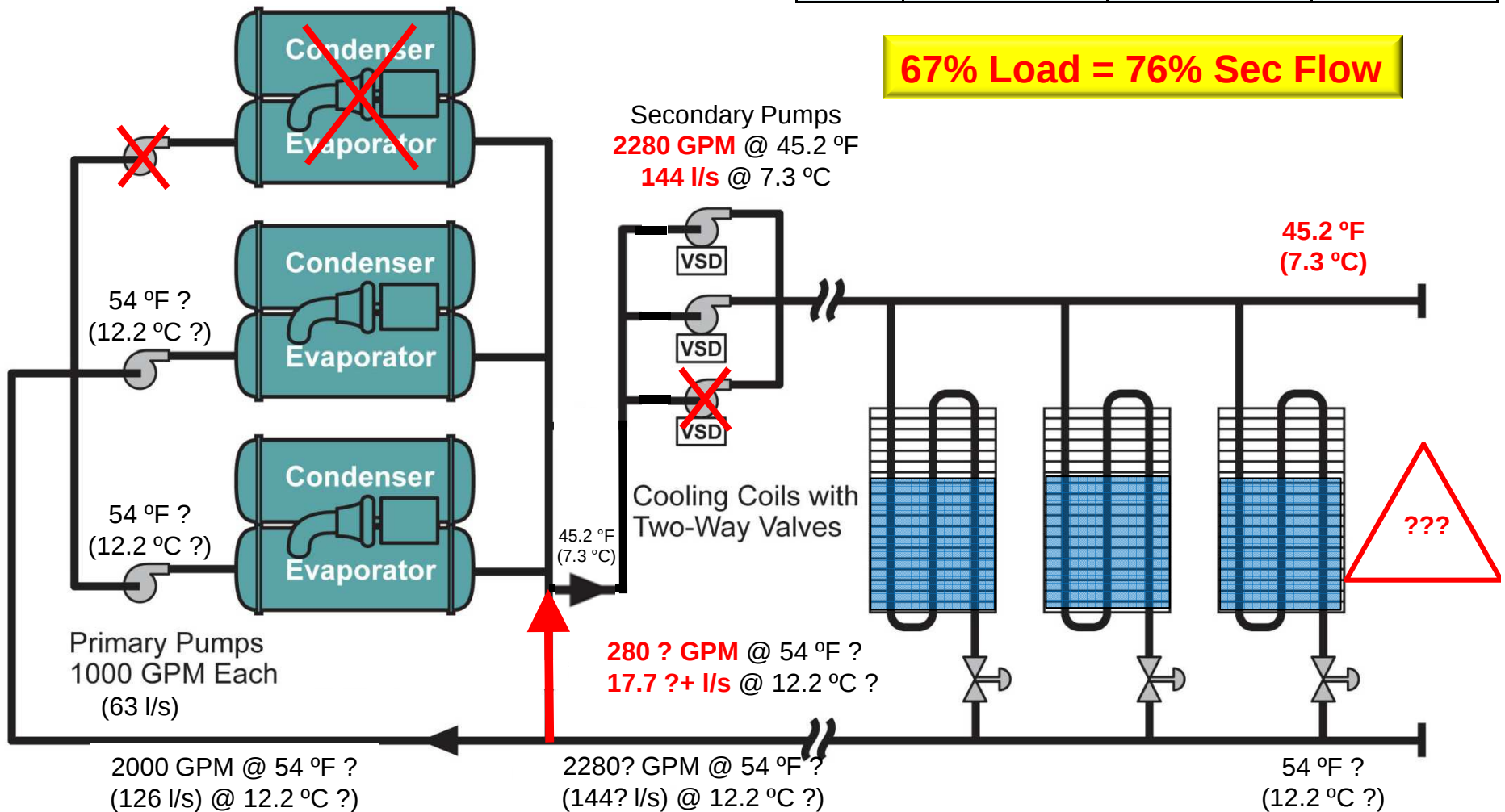
Primary/Secondary at 67% Load

Low DeltaT

	Per Chiller	System
Load	417 Tons (1467kW)	934 Tons (3286kW)

	Primary	Secondary	Bypass
Flow	2000gpm (126 l/s)	2280gpm (144 l/s)	280 gpm (18l/s)
Delta T	10°F (5.6°C)	10°F (5.6°C)	----

67% Load = 76% Sec Flow



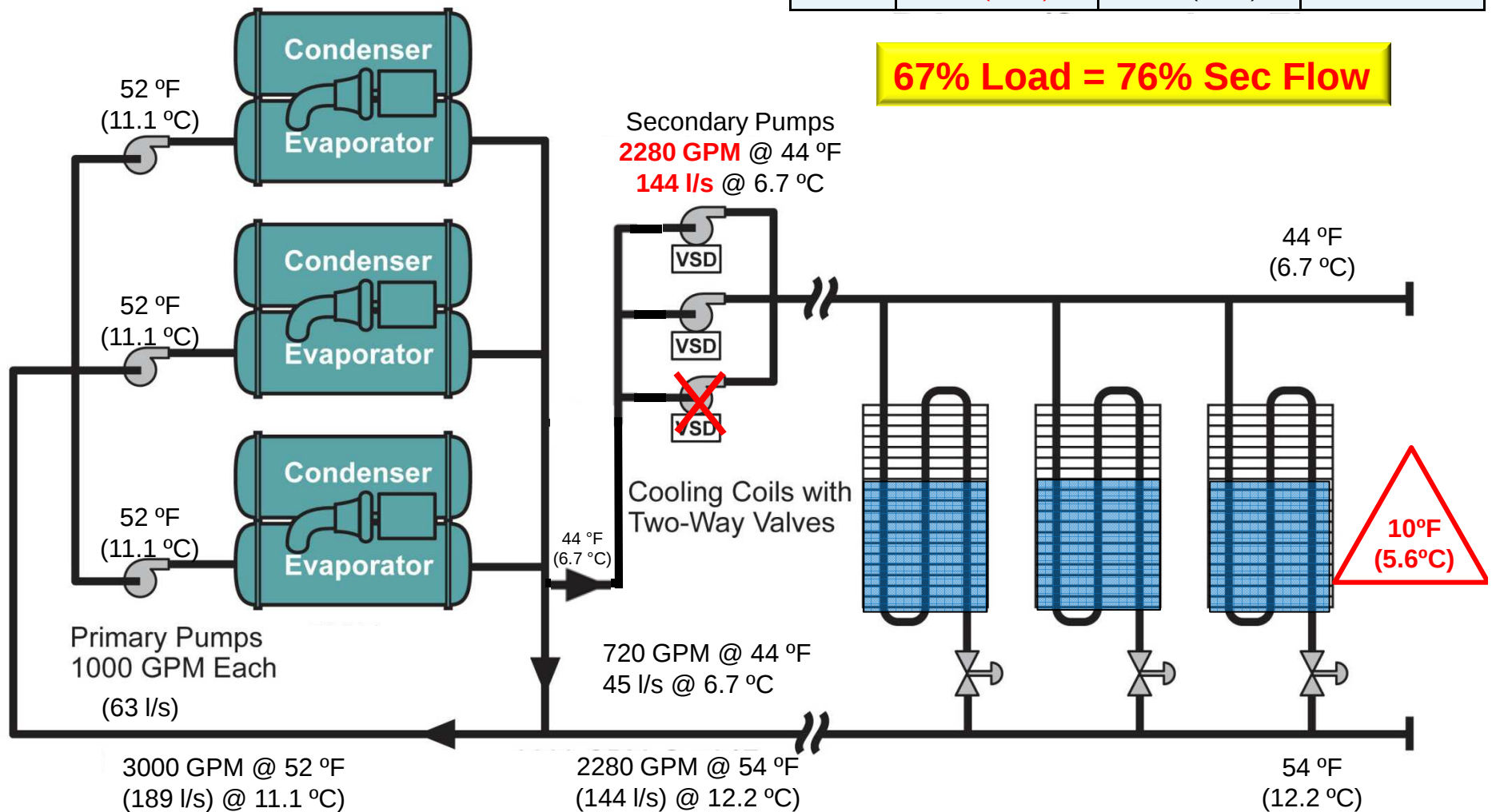
Primary/Secondary at 67% Load

Low DeltaT

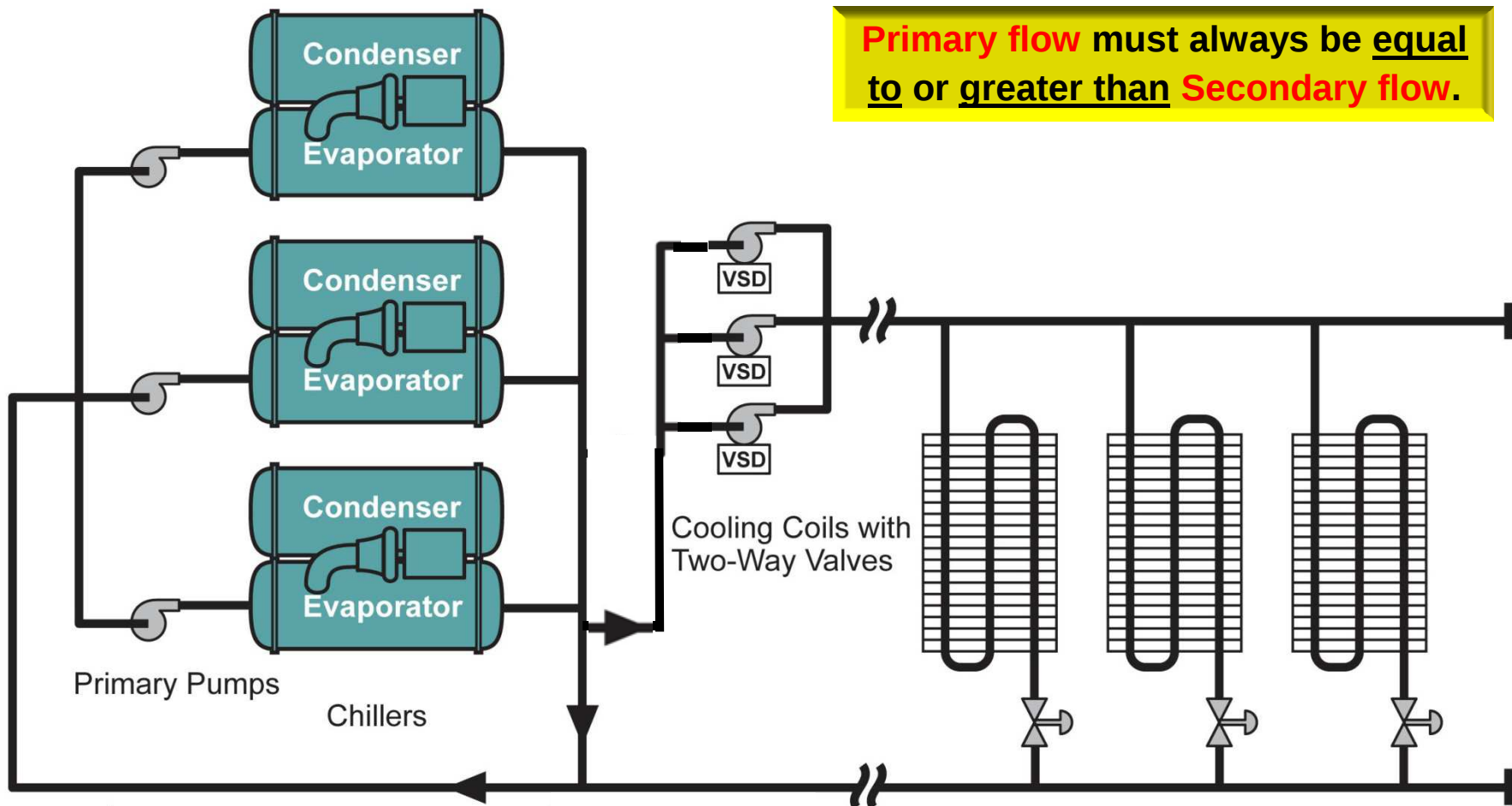
	Per Chiller	System
Load	333 Tons (1172kW)	1000 Tons (3518kW)

	Primary	Secondary	Bypass
Flow	3000gpm (189 l/s)	2280gpm (144 l/s)	720 gpm (0 l/s)
Delta T	8°F (4.4°C)	10°F (5.6°C)	----

67% Load = 76% Sec Flow



Primary (Constant) / Secondary (Variable) Rule of Flow



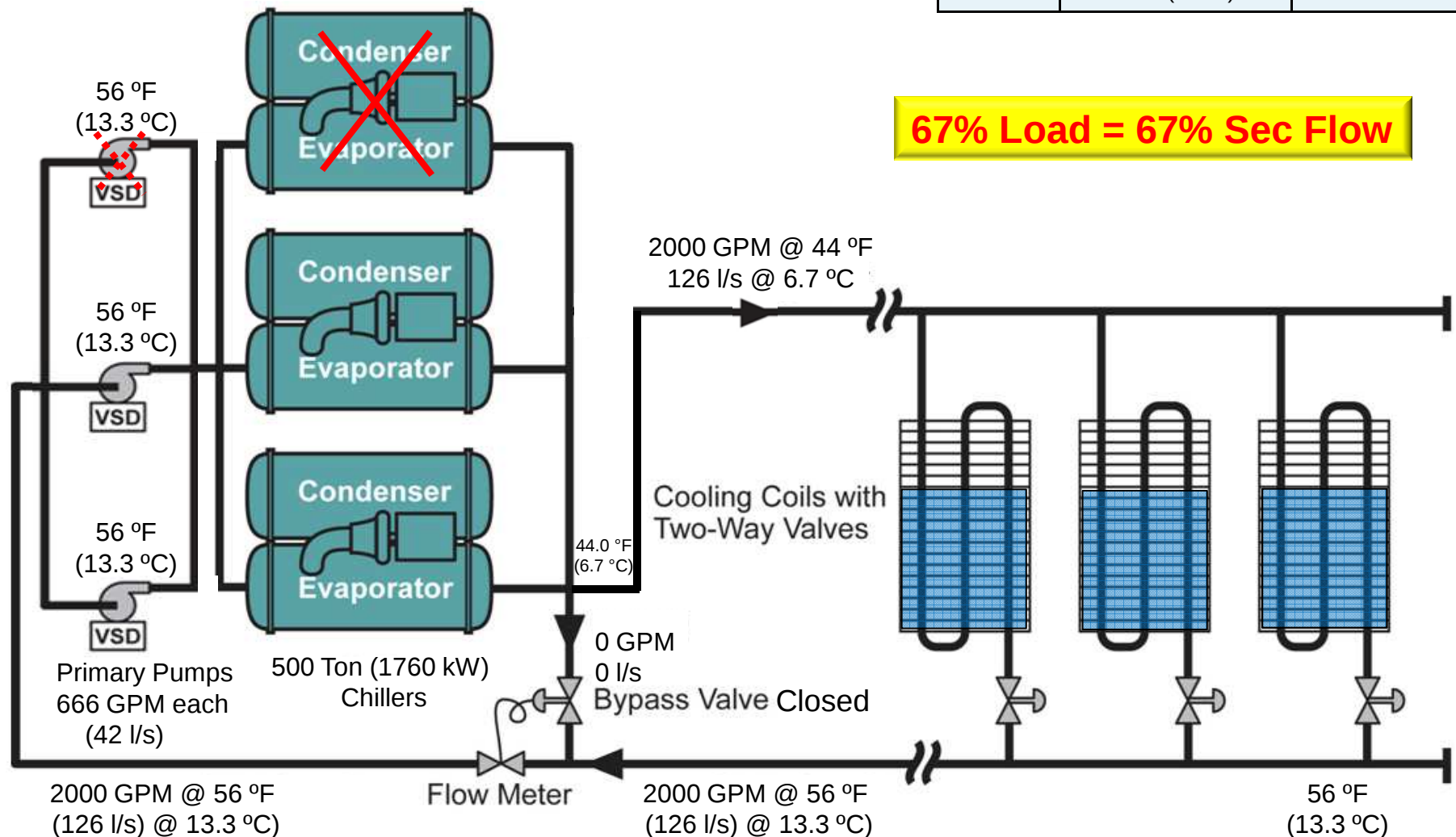
Negative Effects of Low Delta T in P/S Systems

Consequences:

- ☐ Higher secondary pump energy
 - ☐ pumps run faster
- ☐ Higher chilled water plant energy
 - ☐ Ancillary equipment
- ☐ Can't load up chillers
 - ☐ more than ratio Act DT / Des DT
 - ☐ $10/12 = 83\%$ or 417 tons

Variable Primary Flow at 67% Load *Ideal Operation*

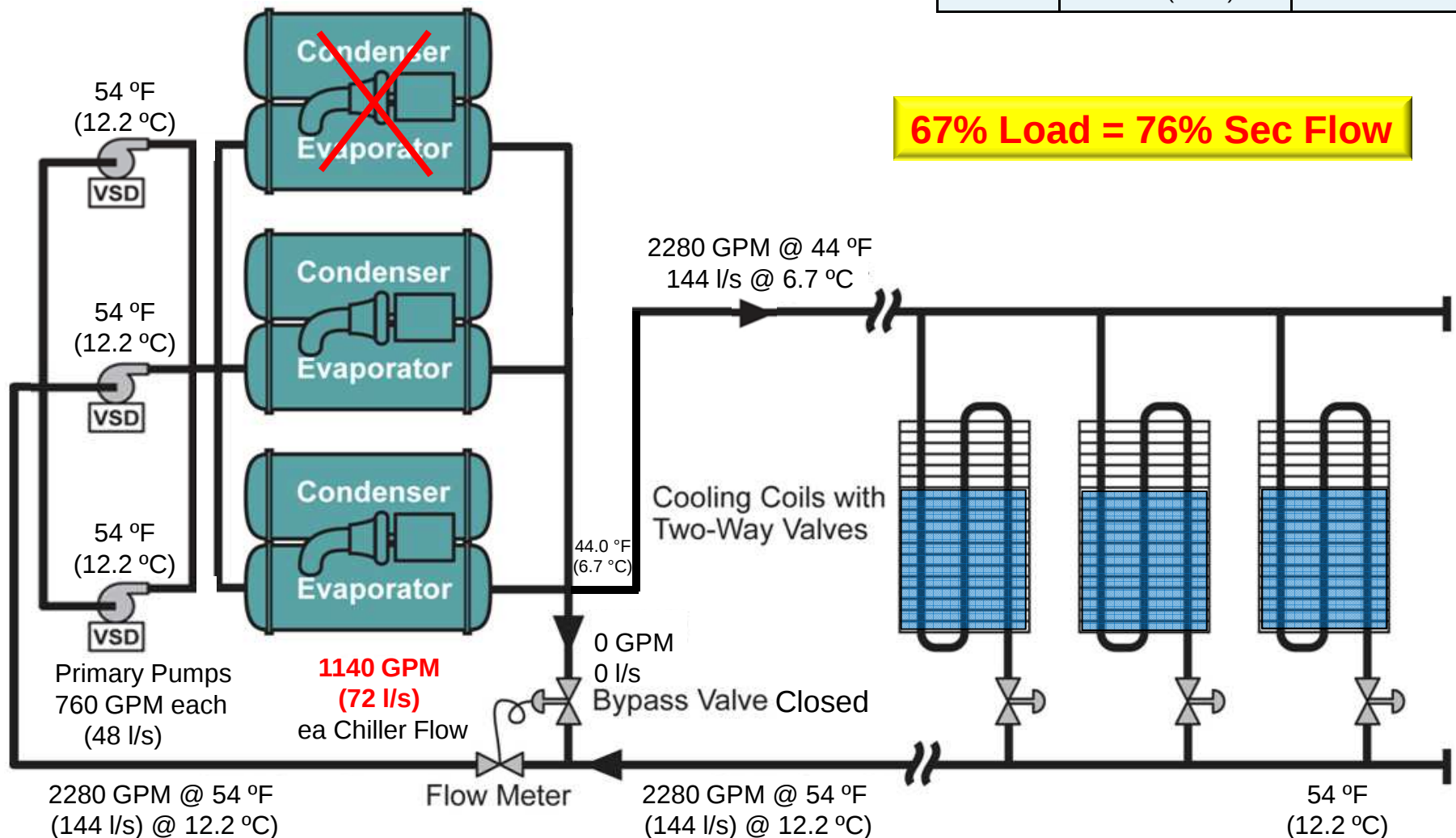
	Per Chiller	System
Load	500 Tons (1760kW)	1000 Tons (3518kW)
	Primary	Bypass
Flow	2000gpm (126l/s)	0gpm (0 l/s)
Delta T	12°F (6.7°C)	----



Variable Primary Flow at 67% Load Low DeltaT (can over-pump chillers)

	Per Chiller	System
Load	500 Tons (1760kW)	1000 Tons (3518kW)
	Primary	Bypass
Flow	2280gpm (144l/s)	0gpm (0 l/s)
Delta T	10°F (5.6°C)	----

67% Load = 76% Sec Flow



Negative Effects of Low Delta T in VPF Systems

Consequences:

- ☐ Higher secondary pump energy
 - ☐ pumps run faster
- ☐ Higher chilled water plant energy
 - ☐ Ancillary equipment
- ☐ Can't load up chillers
 - ☐ more than ratio Act DT / Des DT
 - ☐ $10/12 = 83\%$ or 417 tons

VPF Systems mitigate Low Delta T Impacts

But:

- ☐ No additional energy from running more chillers than required.
- ☐ Can fully load up chillers by over-pumping.
 - ☐ more than ratio Des DT / Act DT
 - ☐ $12/10 = 120\%$ or 1200 gpm (1000 des)
 - ☐ 20% increase in flow is 44% increase in WPD, so 15 ft would rise to 22 ft.
 - ☐ Max WPD for YKs 2P is 45 ft, 3P is 67 ft

Solution to (or reduce effects of) Low Delta T

- ☐ Address the causes
 - ☐ Clean Coils
 - ☐ Calibrate controls periodically
 - ☐ Select proper 2W valves (dynamic/close-off ratings) and maintain them
 - ☐ No 3W valves in design
 - ☐ Find and correct piping installation errors
- ☐ Over deltaT chillers by resetting supply water down (P/S)
- ☐ Over pump chillers at ratio of Design Delta T / Actual Delta T (VPF)
- ☐ Use VSD Chillers & Energy-based sequencing (from 30 to 80% Load)

**Solve at Load,
Mitigate at Plant**

VPF Systems Design/Control Considerations

☐ Chillers

- ☐ Equal Sized Chillers preferred, but not required
- ☐ Maintain Min flow rates with Bypass control (1.5 fps)
- ☐ Maintain Max flow rates (11.0 to 12.0 fps) and max WPDs (45' for 2P, 67' for 3P)
- ☐ Modulating Isolation Valves (or 2-position stroke-able) set to open in 1.5 to 2 min
- ☐ Don't vary flow too quickly through chillers (VSD pump Ramp rate – typical setting of 10%/min)
- ☐ Sequence
 - ☐ If CSD Chillers – run chillers to max load (Supply Temp rise). Do not run more chillers than needed (water-cooled, single compressor assumed)
 - ☐ If VSD Chillers – run chillers between 30% and 80% load (depending on ECWT and actual off-design performance curves). Run more chillers than load requires.
 - ☐ Add Chiller - CHW Supply Temp or Load (Flow X Delta T) or amps (if CSD)
 - ☐ Subtract Chiller - Load (Flow X Delta T) or Amps (if CSD)

VPF Systems Design/Control Considerations

- ☐ Pumps
 - ☐ Variable Speed Driven
 - ☐ Headered arrangement preferred
 - ☐ Sequence
 - ☐ with chillers (run more pumps than chillers for over-pumping capability)
 - ☐ Flow-based sequencing
 - ☐ Energy-based sequencing (most efficient combination of pumps)
 - ☐ Speed controlled by pressure sensors at end of index circuit (fast response important)
 - ☐ Direct wired
 - ☐ Piggyback control for large distances
 - ☐ **Optimized** - Reset pressure sensor by valve position of coils

VPF Systems Design/Control Considerations

- ☐ Bypass Valve
 - ☐ Maintain a minimum chilled water flow rate through the chillers
 - ☐ Differential pressure measurement across each chiller evaporator
 - ☐ Flow meter preferred
 - ☐ Modulates open to maintain the minimum flow through operating chiller(s).
 - ☐ Bypass valve is normally open, but closed unless Min flow breeched
 - ☐ Pipe and valve sized for Min flow of operating chillers
 - ☐ High Range-ability (100:1 or better preferred)
 - ☐ PSID Ratings for Static, Dynamic, And Close Off = Shut Off Head of Pumps
 - ☐ Linear Proportion (Flow to Valve Position) Characteristic preferred
 - ☐ Fast Acting Actuator
 - ☐ Locate in Plant around chillers/pumps (preferred)
 - ☐ Energy
 - ☐ Avoid Network traffic (response time is critical to protect chillers from potential freeze-up)

VPF Systems Design/Control Considerations

- ☐ Load Valves
 - ☐ High Range-ability (200:1 preferred)
 - ☐ PSID Ratings for Static, Dynamic, and Close Off = Shut-off Head of Pumps
 - ☐ Equal Percentage (Flow to Load) Characteristic
 - ☐ Slow Acting Actuator
- ☐ Staging Loads
 - ☐ Sequence AHUs On/Off in 10 to 15 min intervals

Summary on VPF Design (optimal design criteria)

Chillers

- ☐ Size equally with same WPDs (best)
- ☐ Respect Min/Max Flows (and max WPDs) through chillers
- ☐ Set Pump VSD Ramp function to about 10%/min (600 sec 0 to Max Speed)
- ☐ Use Modulating (preferred) or Stroke-able Valves (if linear flow to time) on chiller evapside, headered pumping
- ☐ Use 2 Position Valves on chiller evaps, dedicated pumping

Pumps

- ☐ VSD Controllers
- ☐ Headered Pumping Arrangement (preferred)
- ☐ Dedicated Pumping OK (over-size pumps)

2 Way Valves

- ☐ Select for Static, Dynamic, Close-off ratings (PSID) equal to pump SOH (plus fill pressure)
- ☐ Range-ability 100 to 200:1
- ☐ If Bypass – fast acting, linear proportion
- ☐ If Coils – slow acting, equal percentage, “On-Off” stagger air units (10-15 min intervals)

Controls

- ☐ Set-point far out in index circuit (lower the value, the better the pump energy)
- ☐ Set Ramp function in VSD Controller (10%/min average or decel rate of 600 sec from max speed to zero)
- ☐ Run 1 more pump than chillers (when headered)
- ☐ Chillers On by common Supply Temp, Load, Amps
- ☐ Chillers Off by Load, Amps
- ☐ Over-pump Chillers to combat Low Delta T and get Max Cap out of chillers
- ☐ Bypass controlled by flow meter (preferred) or evap WPD of largest chiller (best location in plant for best energy)

Chilled Water Piping Configurations

