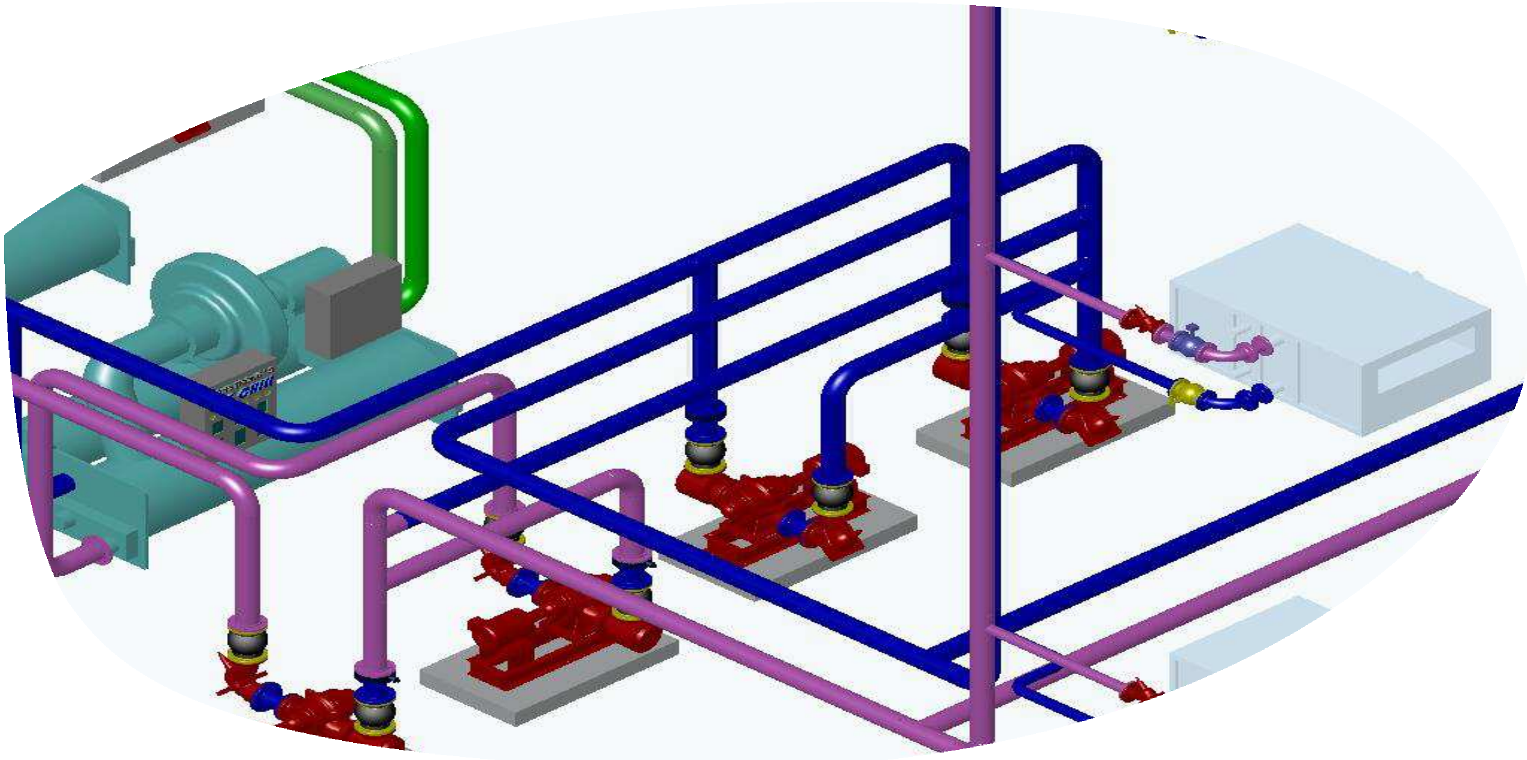
Chilled Water Piping Configurations



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

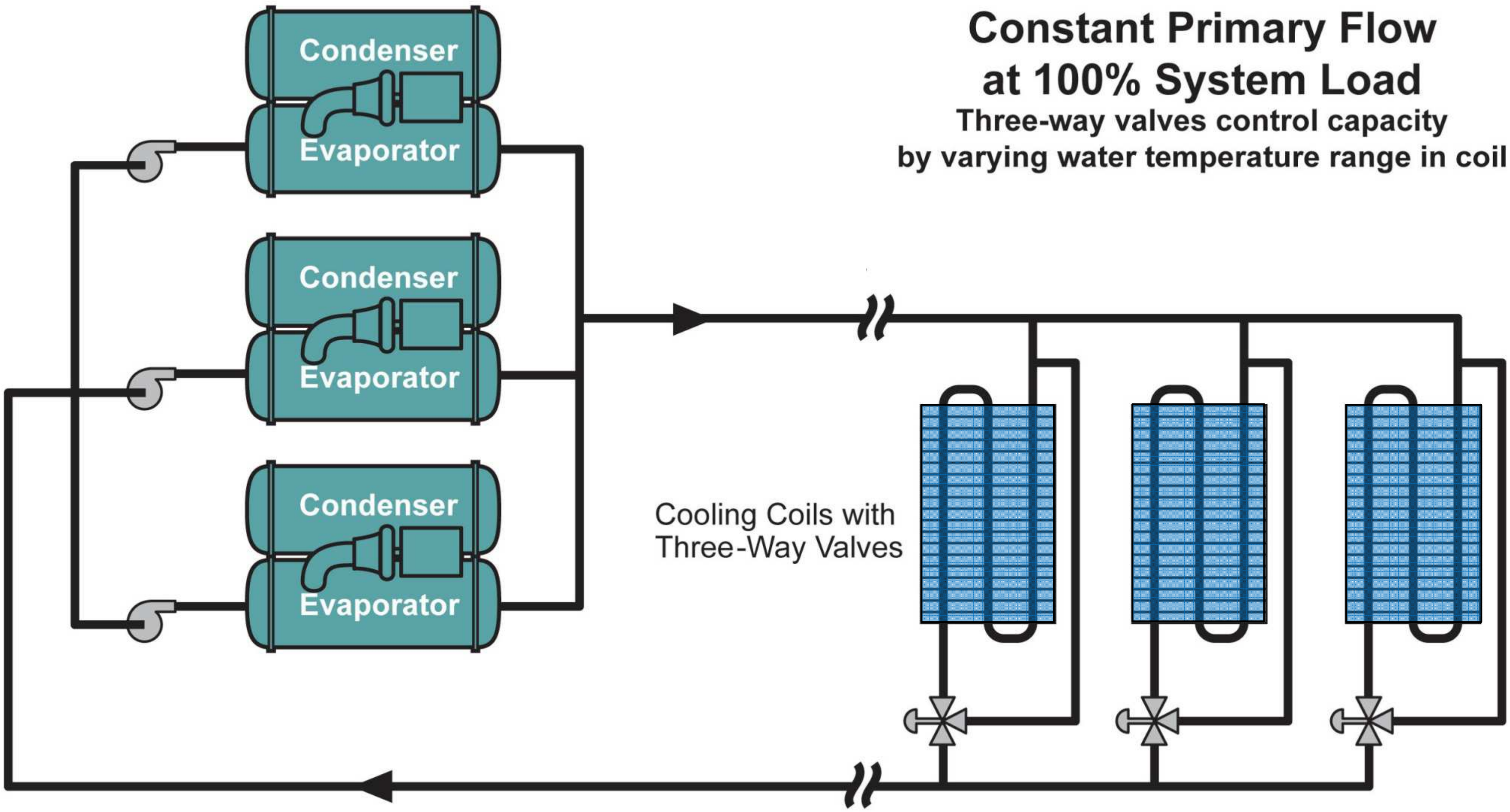
Load = Flow X DeltaT

Constant Primary Flow (CPF)

Constant Primary Flow (CPF)

Dedicated Pumping

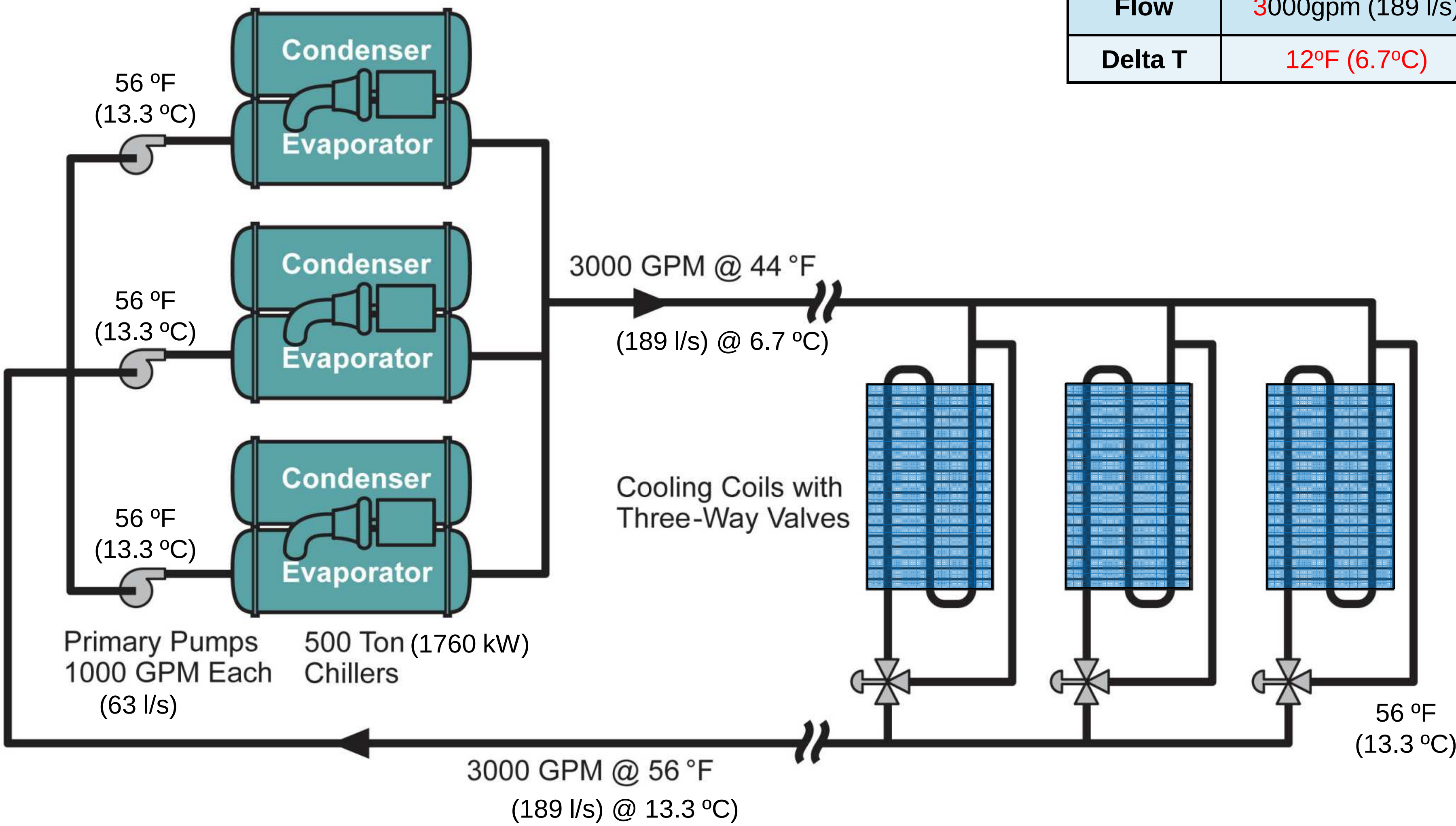
Load = Flow X DeltaT



Constant Primary Flow at Design

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

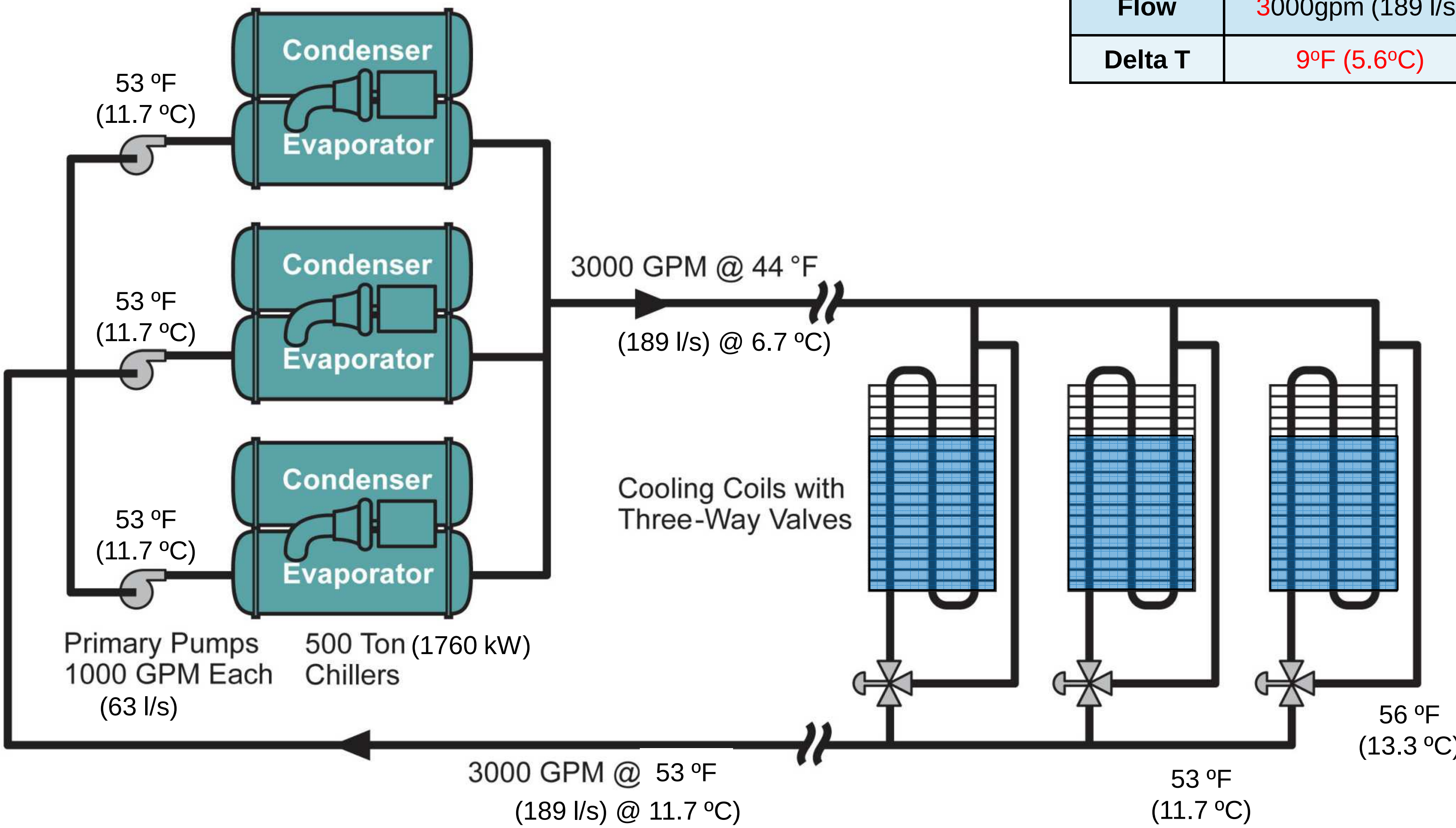
	Primary
Flow	3000gpm (189 l/s)
Delta T	12°F (6.7°C)



Constant Primary Flow at 75% Load

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

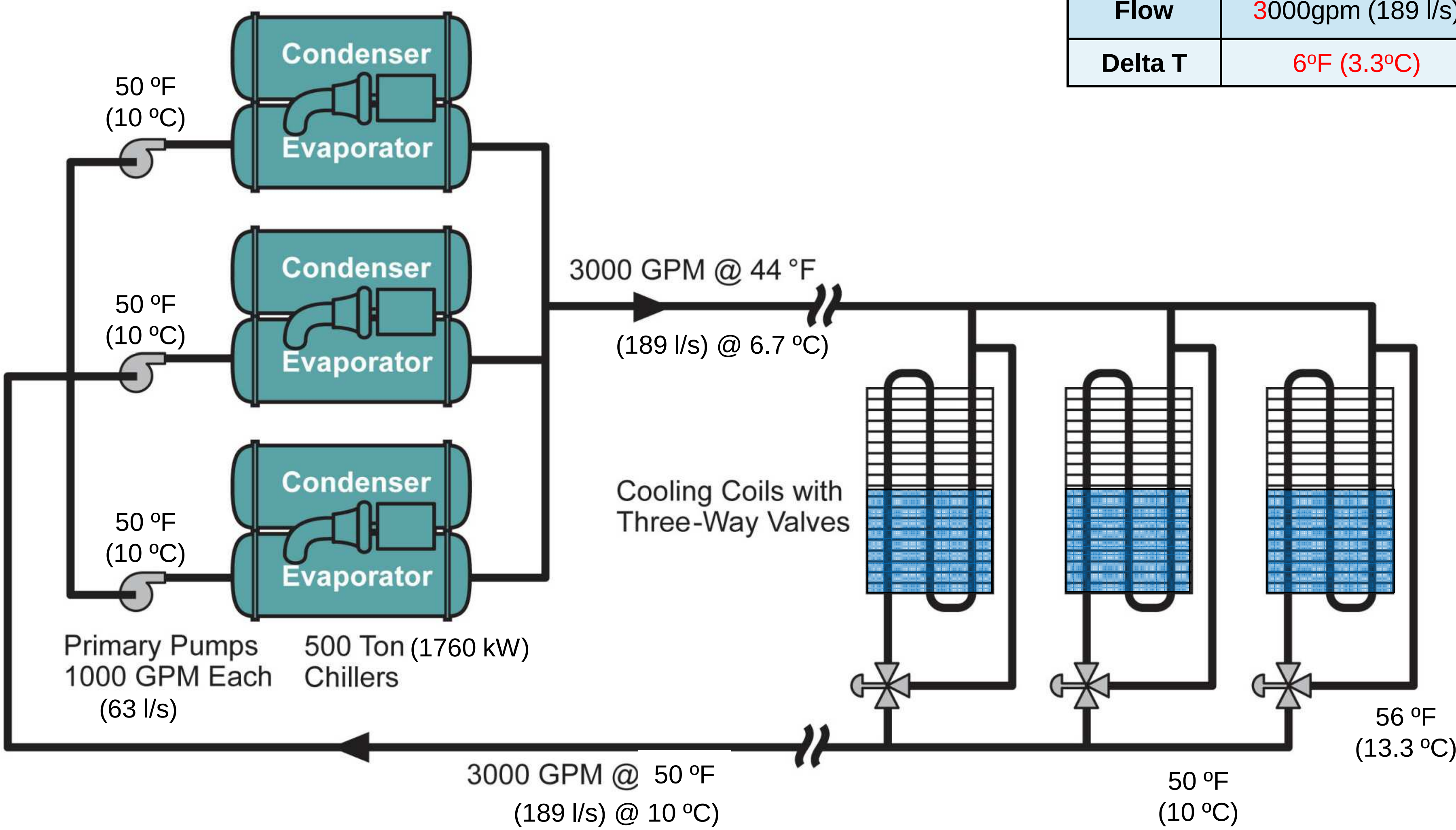
	Primary
Flow	3000gpm (189 l/s)
Delta T	9ºF (5.6ºC)



Constant Primary Flow at 50% Load

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

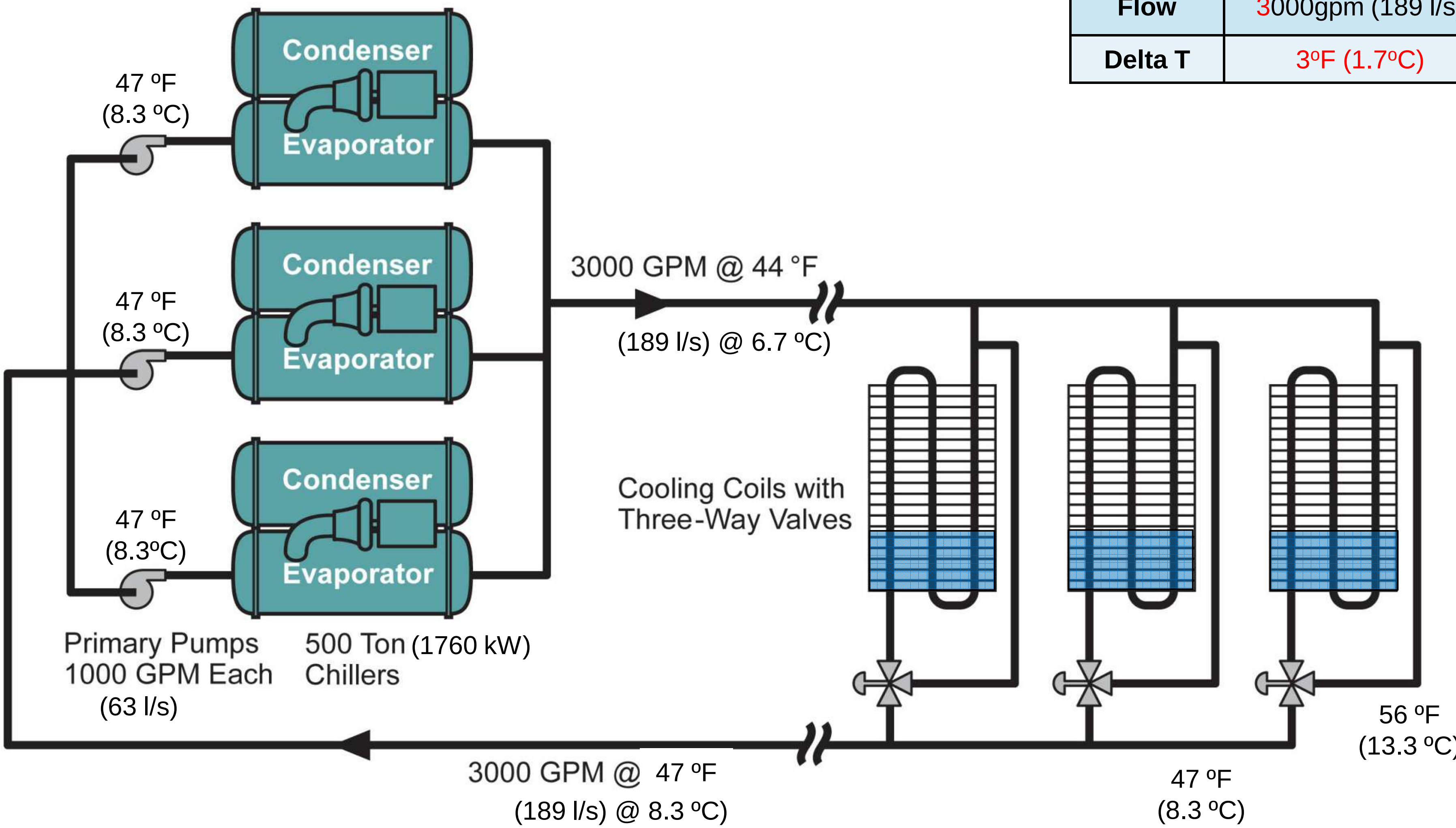
	Primary
Flow	3000gpm (189 l/s)
Delta T	6ºF (3.3ºC)



Constant Primary Flow at 25% Load

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

	Primary
Flow	3000gpm (189 l/s)
Delta T	3ºF (1.7ºC)

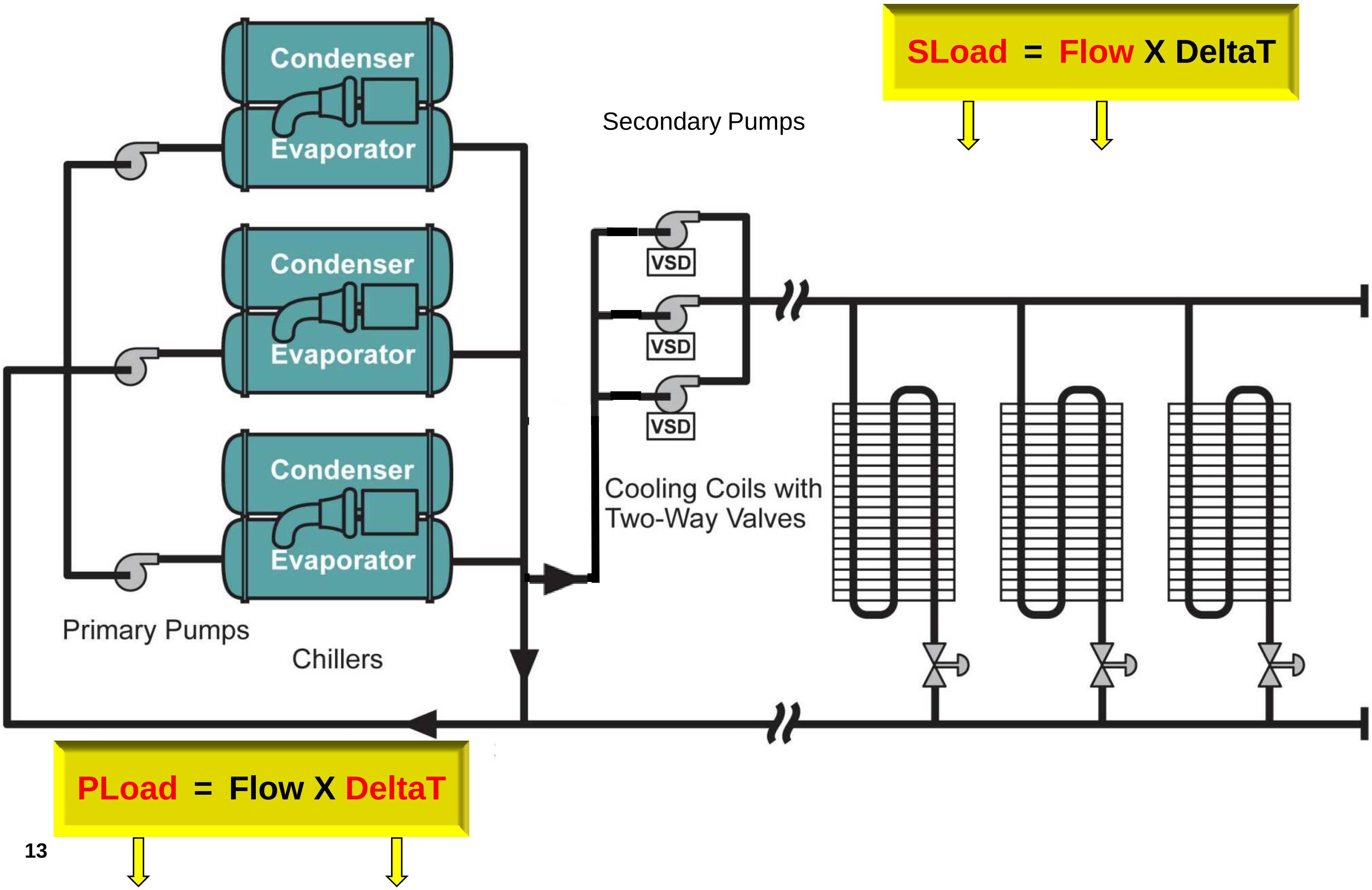


Constant Flow Primary

- **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)

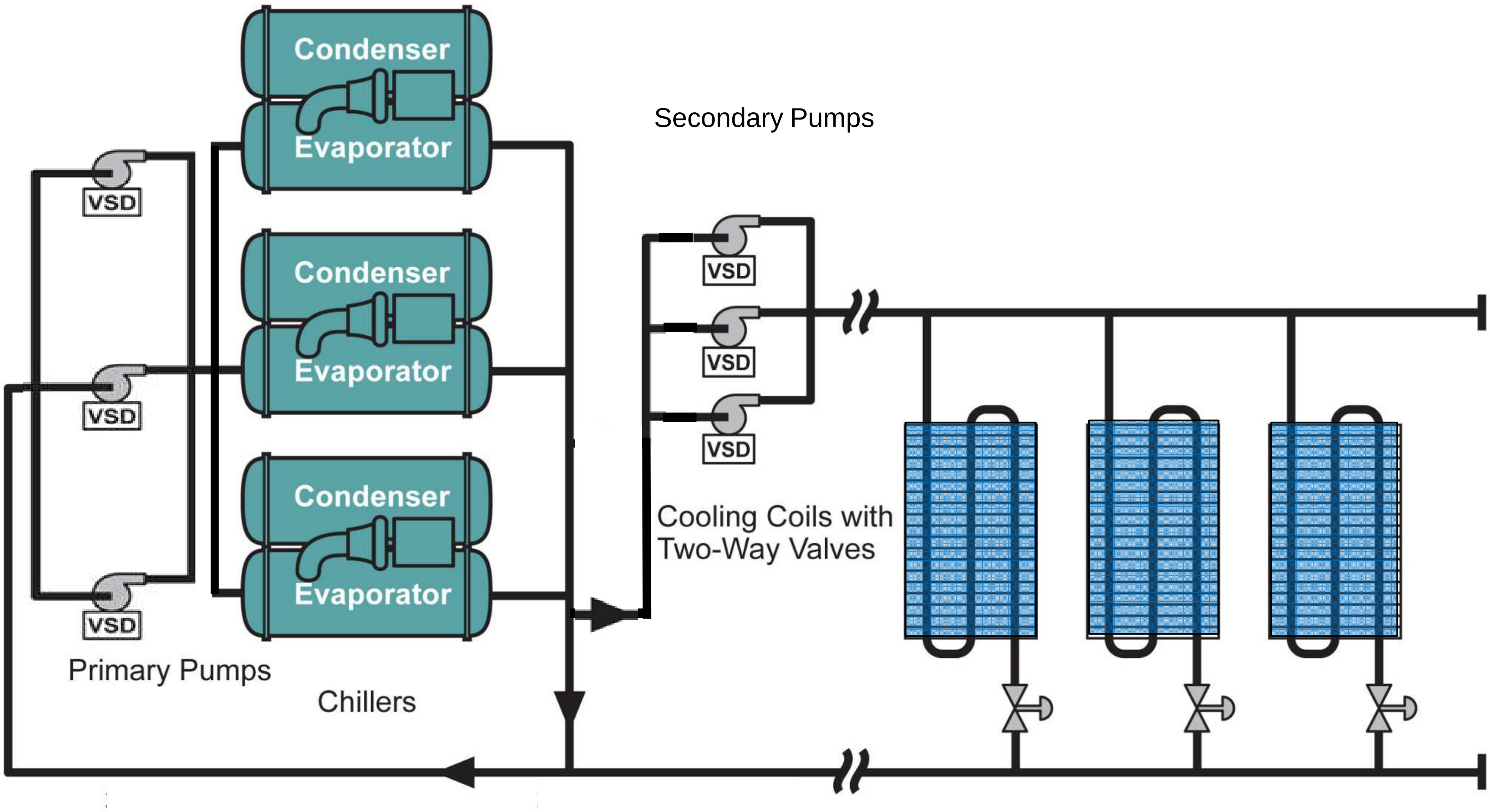
Primary (Constant) / Secondary (Variable)

Primary (Constant) / Secondary (Variable)



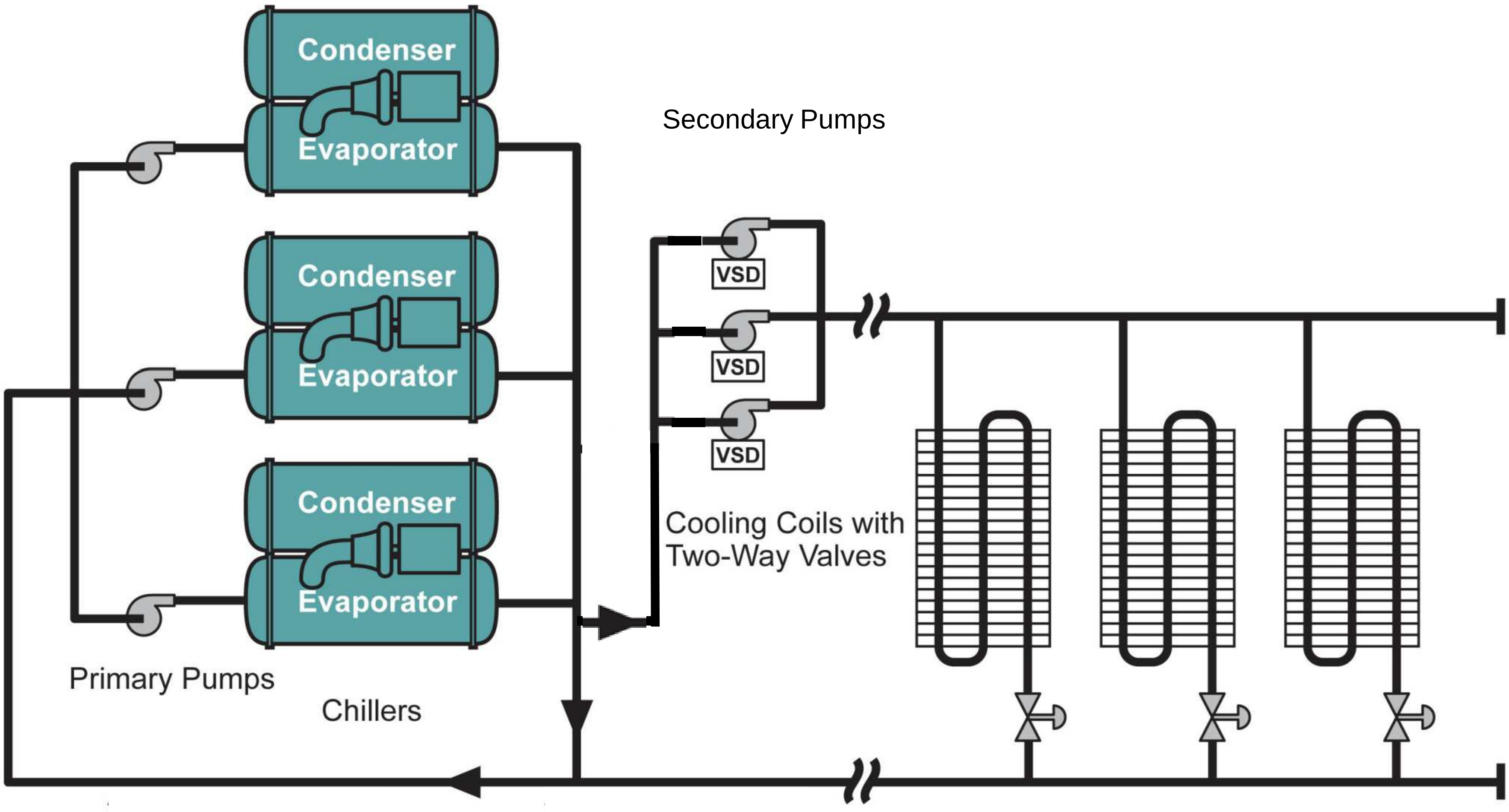
Primary (Constant) / Secondary (Variable)

Headered Pumping



Primary (Constant) / Secondary (Variable)

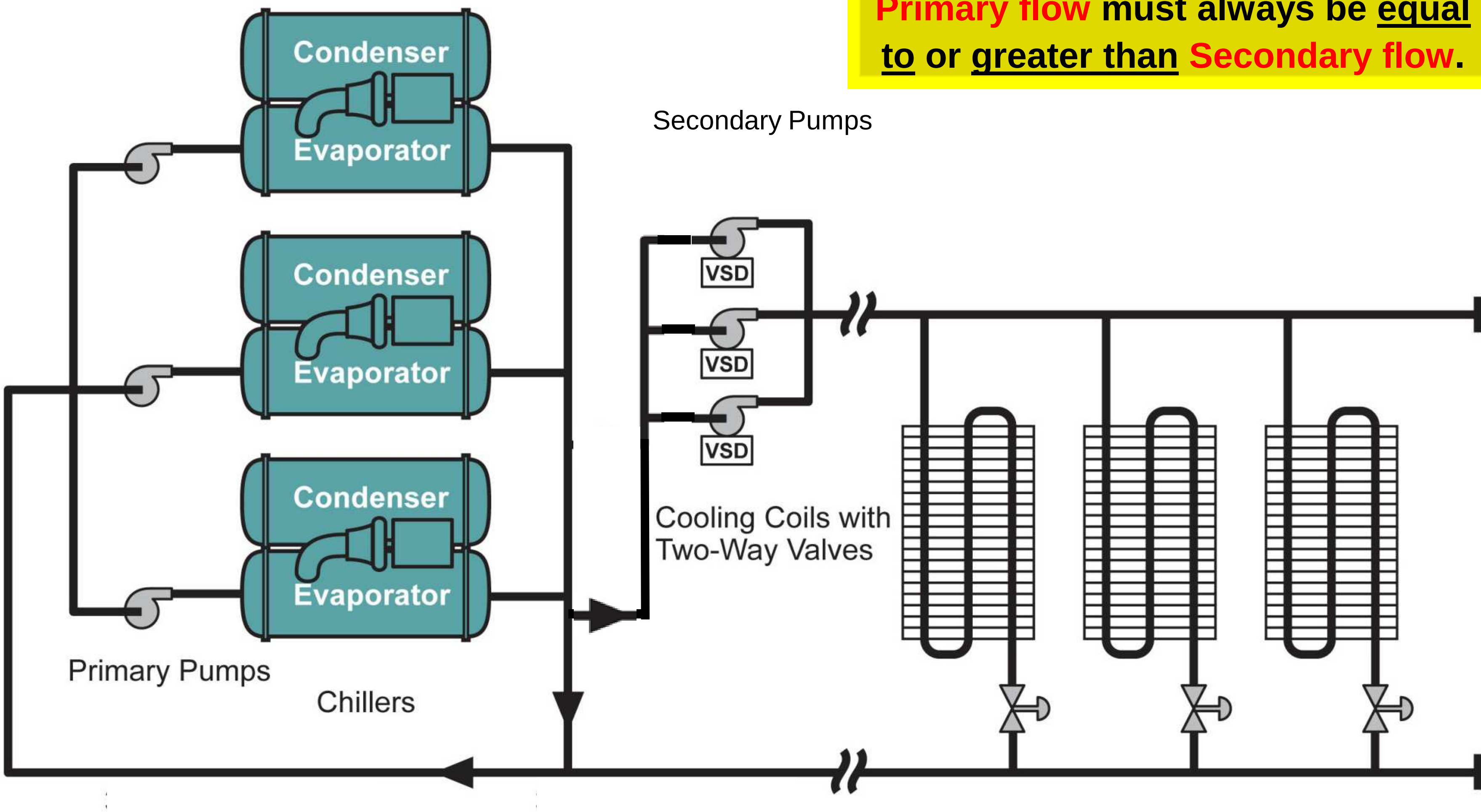
Dedicated Pumping



Primary (Constant) / Secondary (Variable)

Rule of Flow

Primary flow must always be <u>equal to</u> or <u>greater than</u> Secondary flow.

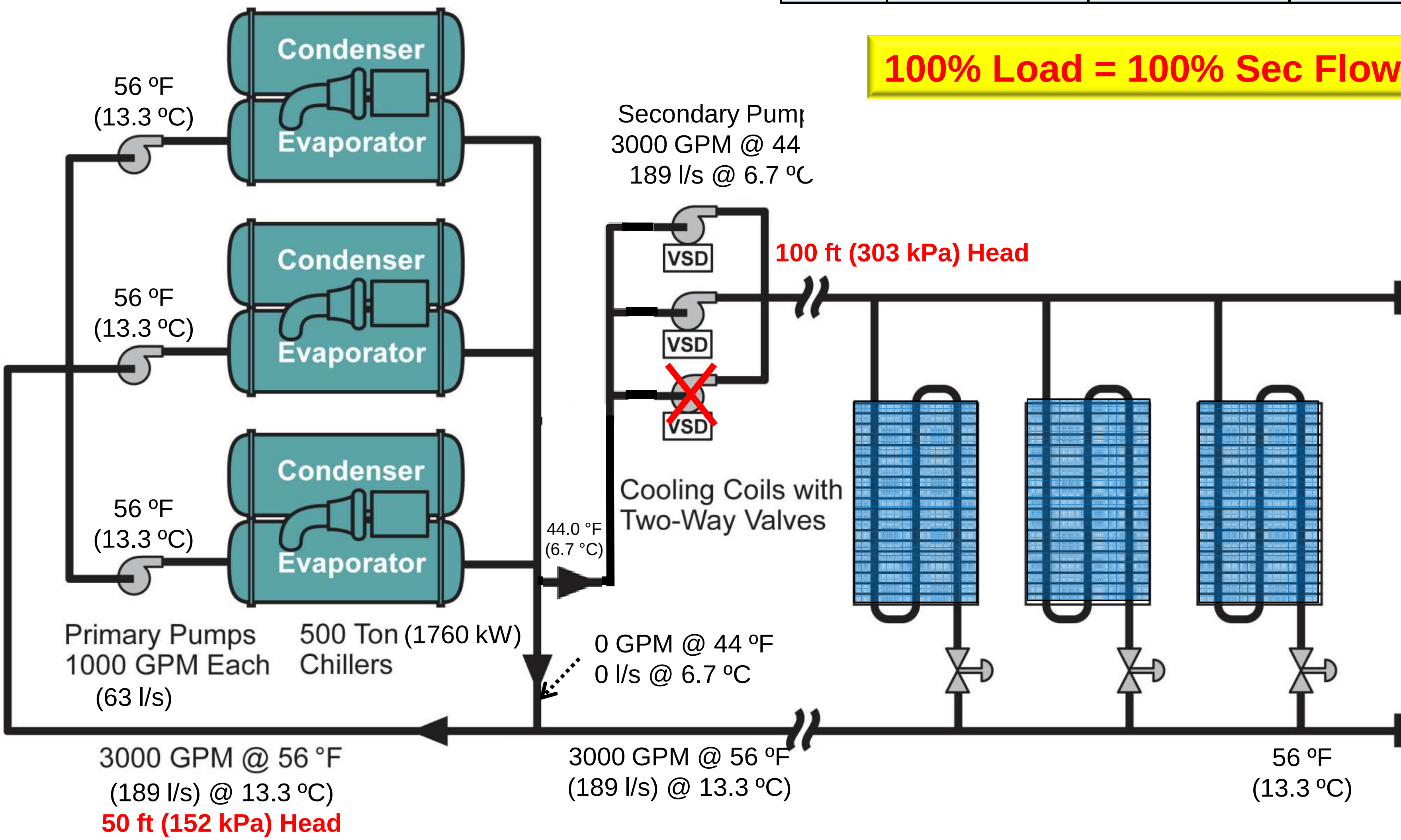


Primary/Secondary at Design

	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	12ºF (6.7ºC)	12ºF (6.7ºC)	----

100% Load = 100% Sec Flow

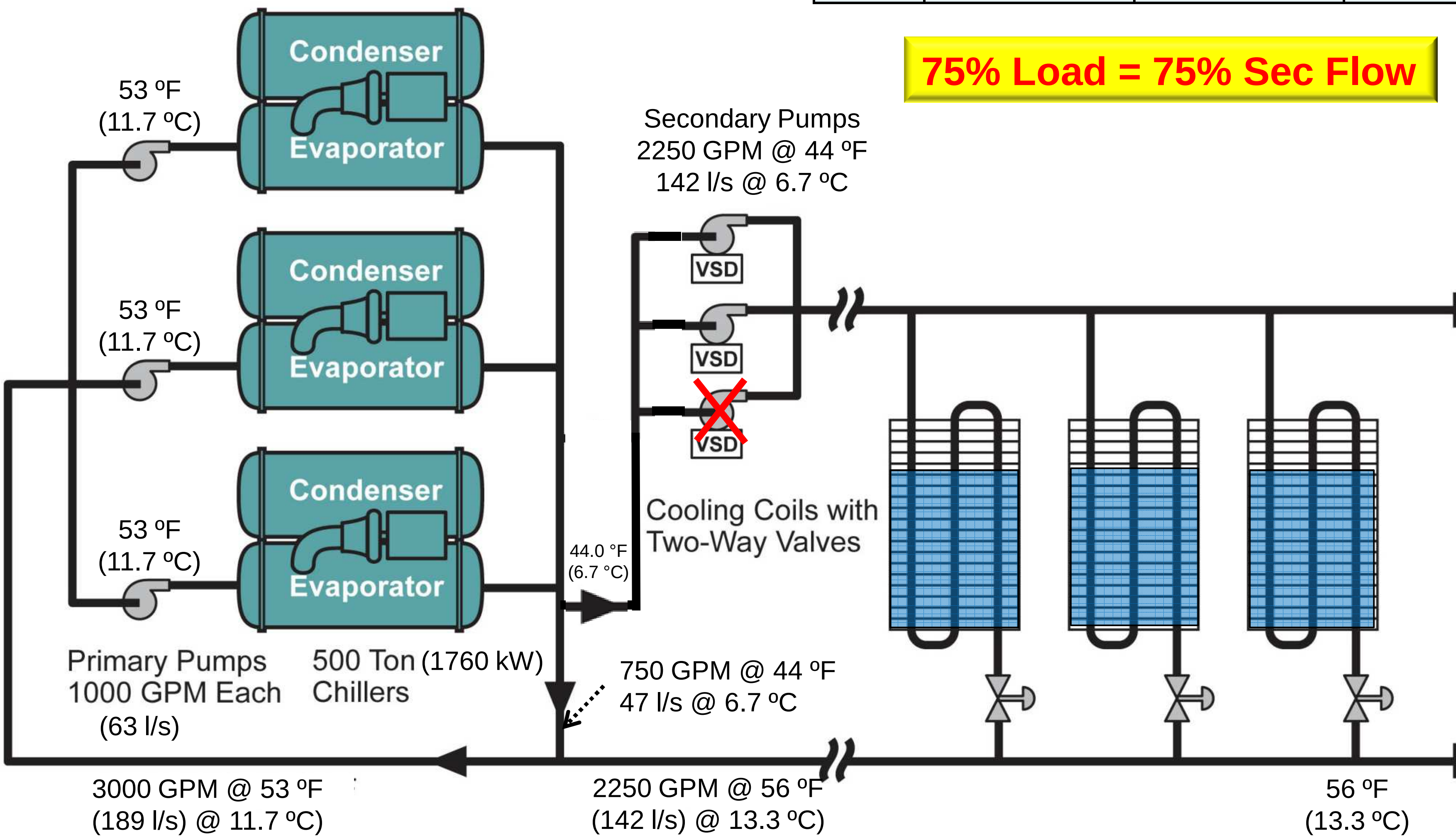


Primary/Secondary at 75% Load

	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	9ºF (5ºC)	12ºF (6.7ºC)	----

75% Load = 75% Sec Flow

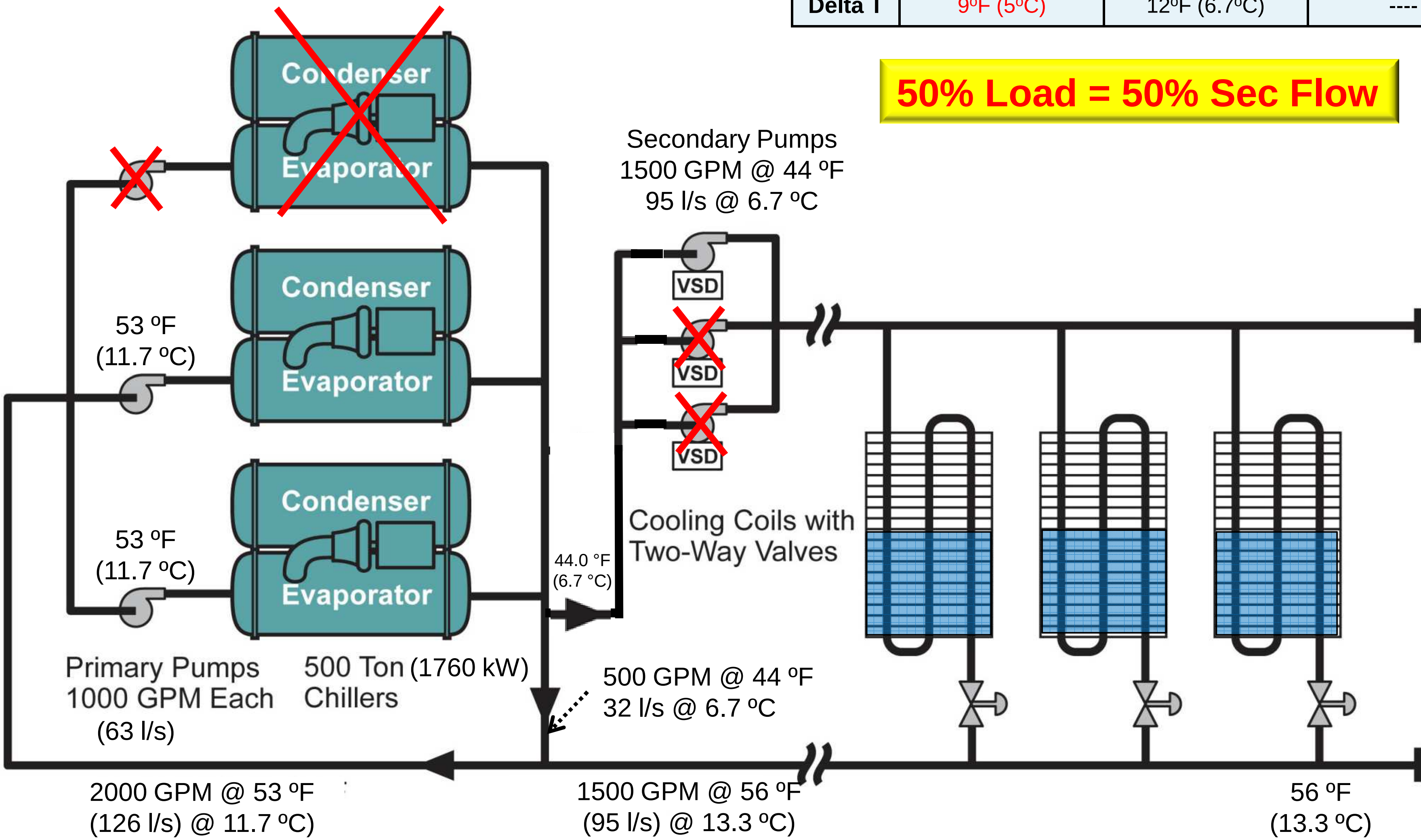


Primary/Secondary at 50% Load

	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	9ºF (5ºC)	12ºF (6.7ºC)	----

50% Load = 50% Sec Flow

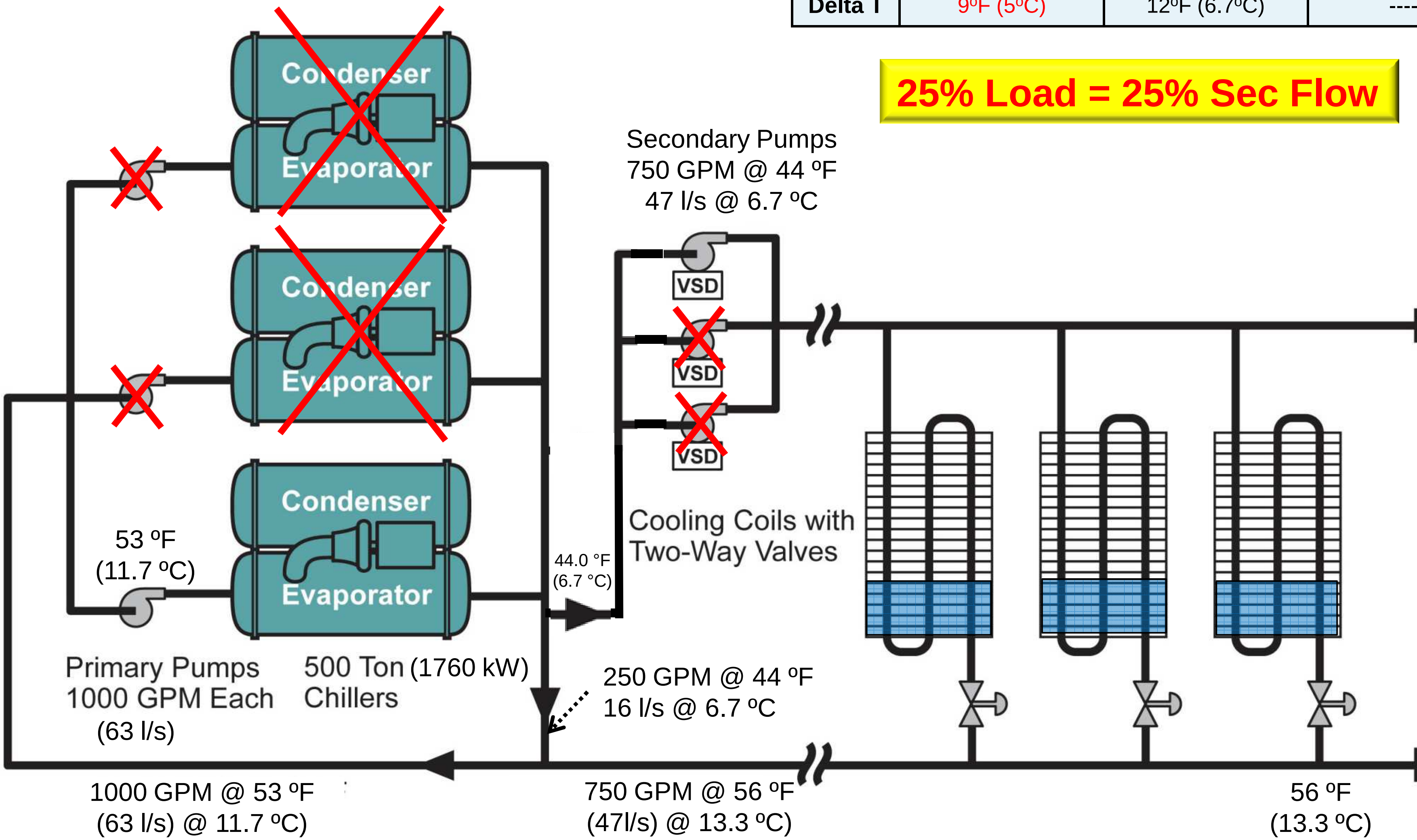


Primary/Secondary at 25% Load

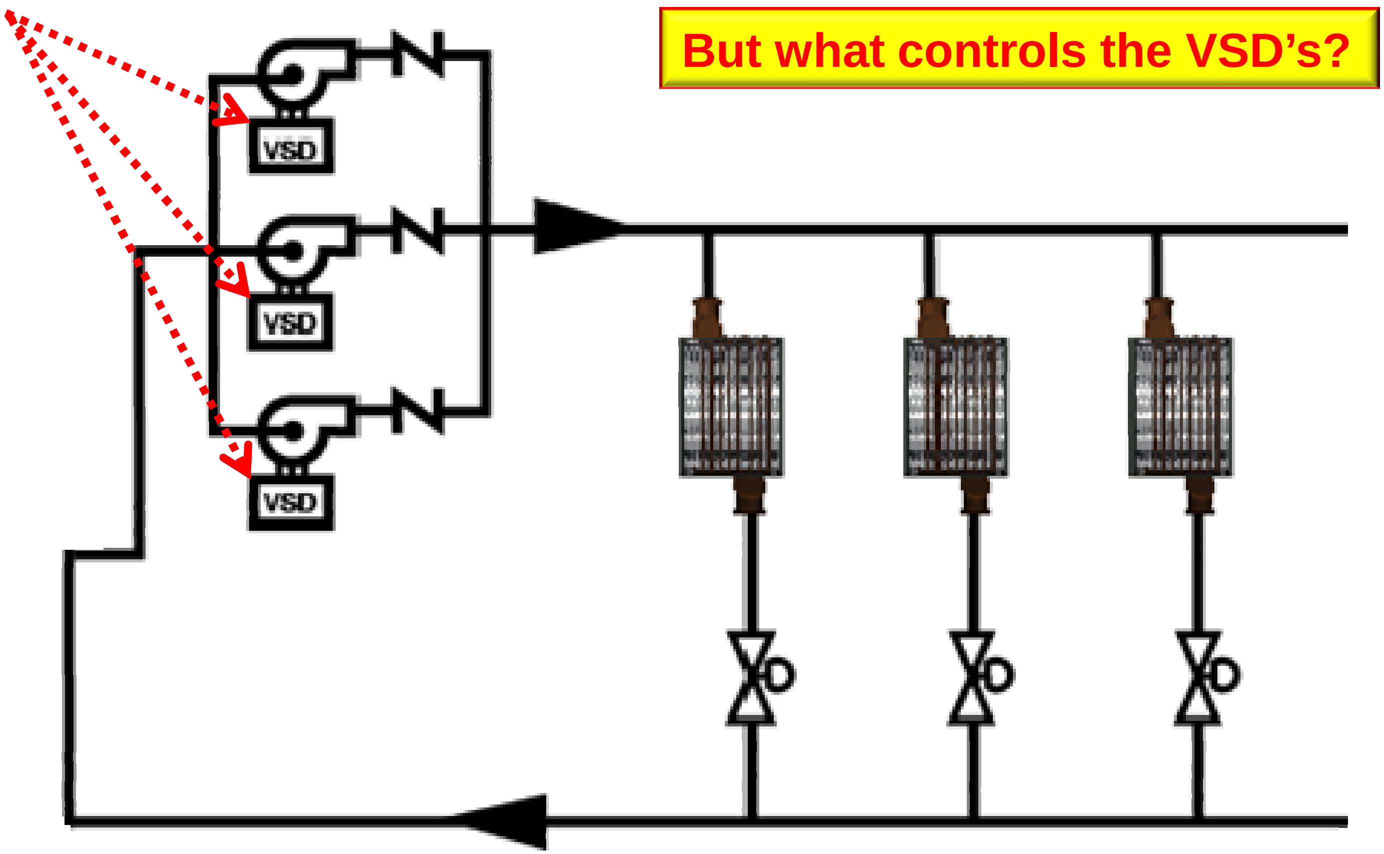
	Per Chiller	System
Load	375 Tons (1320kW)	375 Tons (1320kW)

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

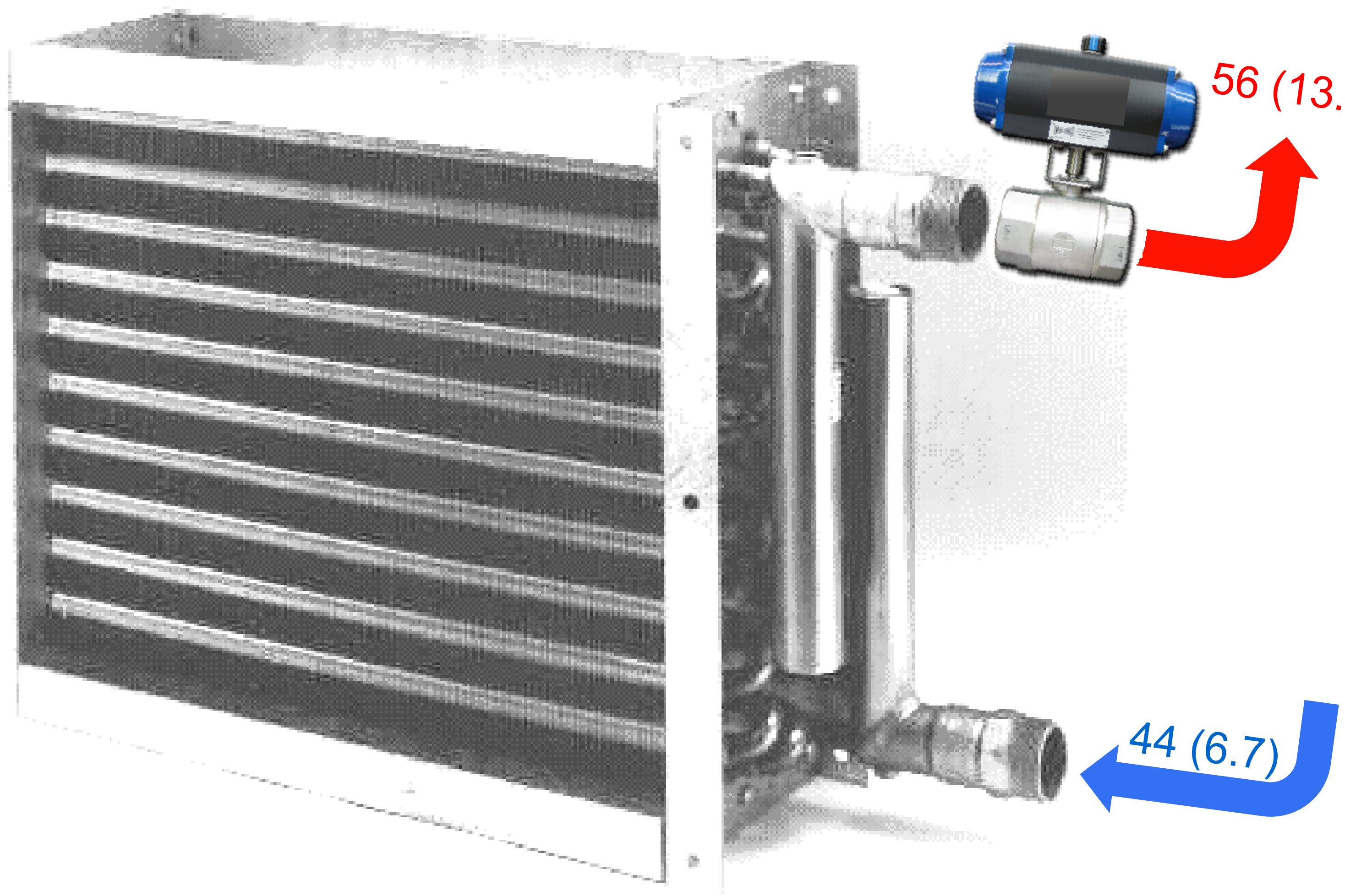
25% Load = 25% Sec Flow



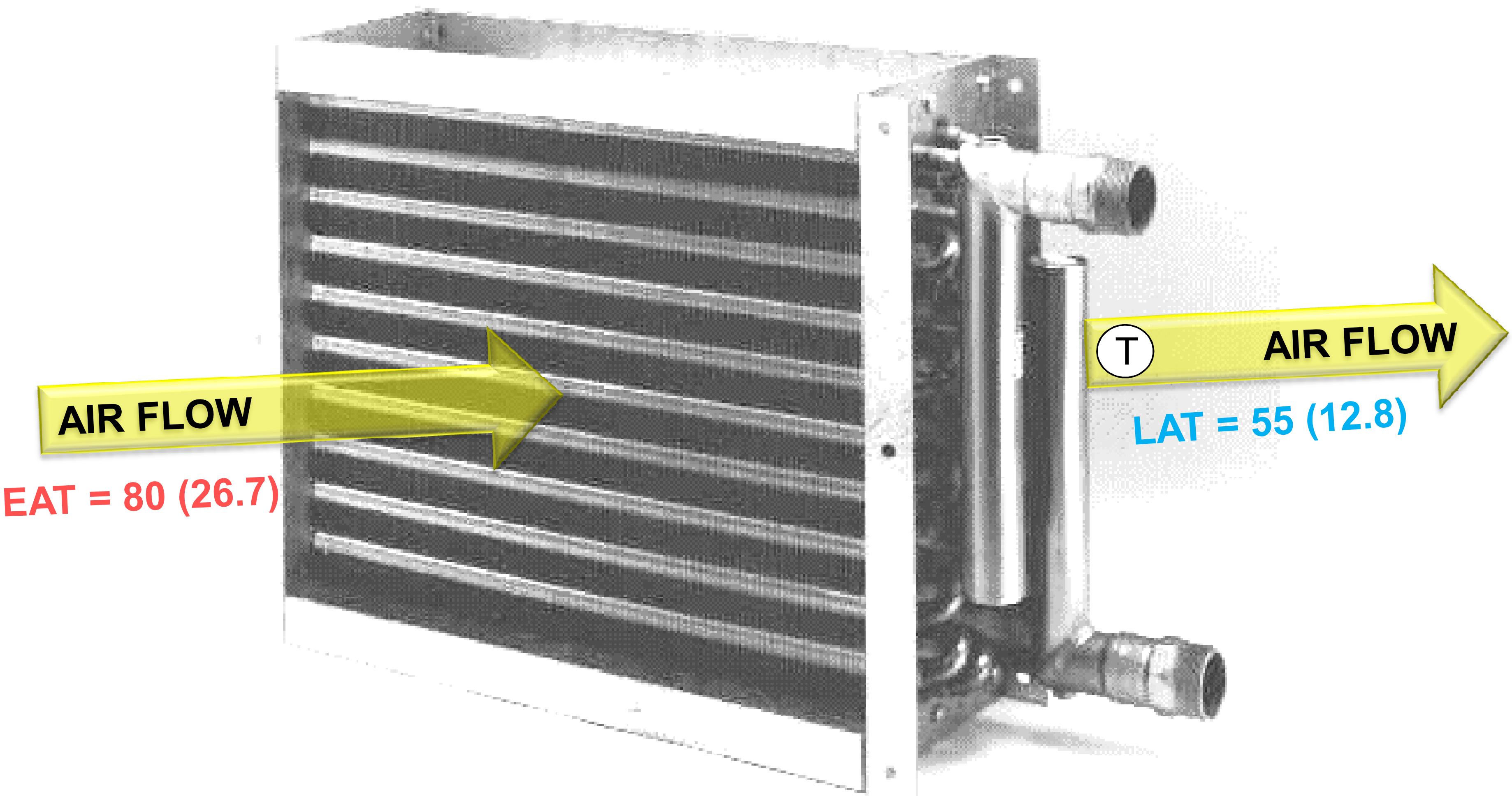
What Controls the Flow of the Secondary Loop?



Valve Controls Leaving Air Temperature (LAT)



Valve Controls Leaving Air Temperature (LAT)
Set Point = 55º (12.8º) LAT



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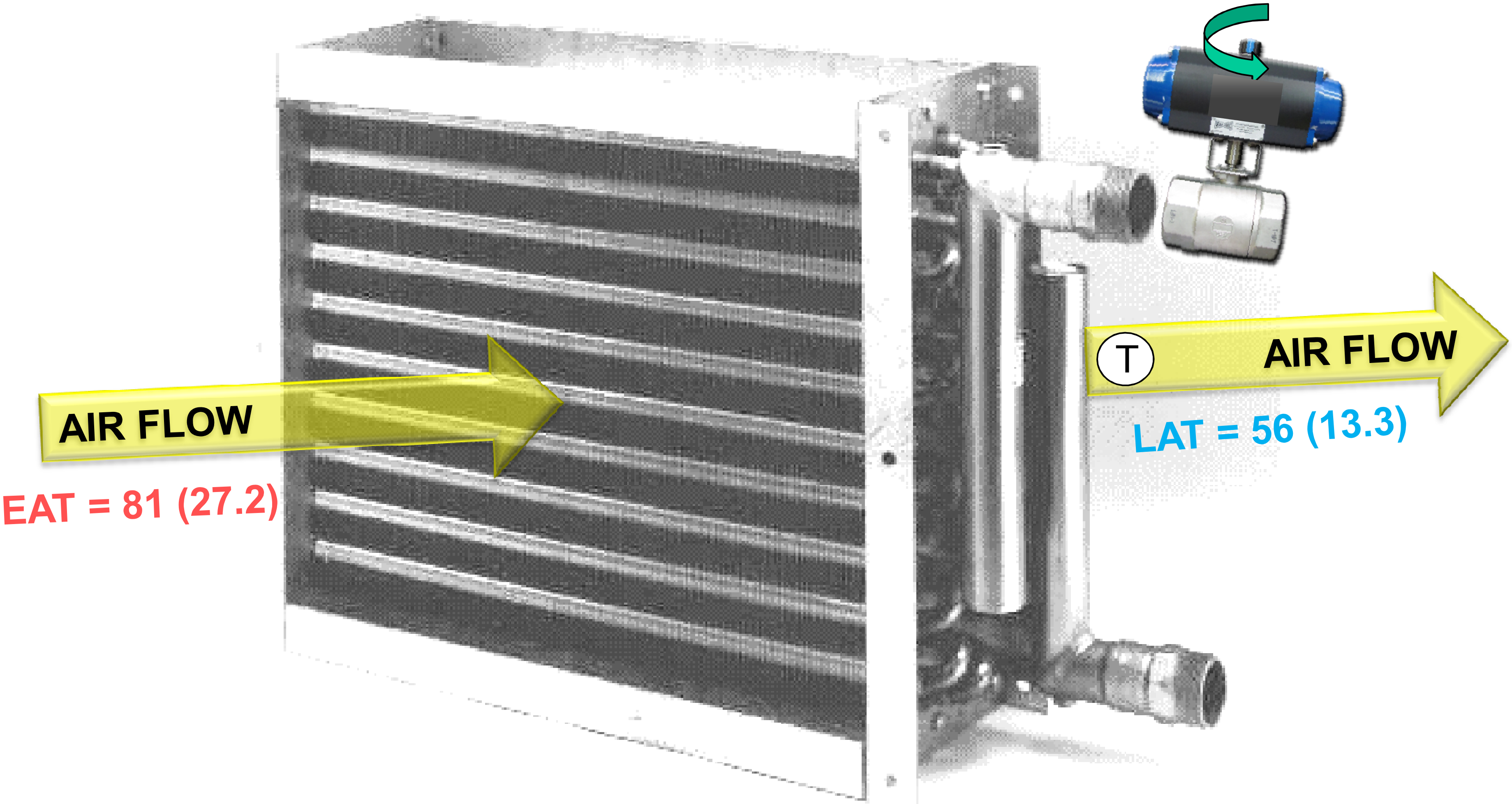

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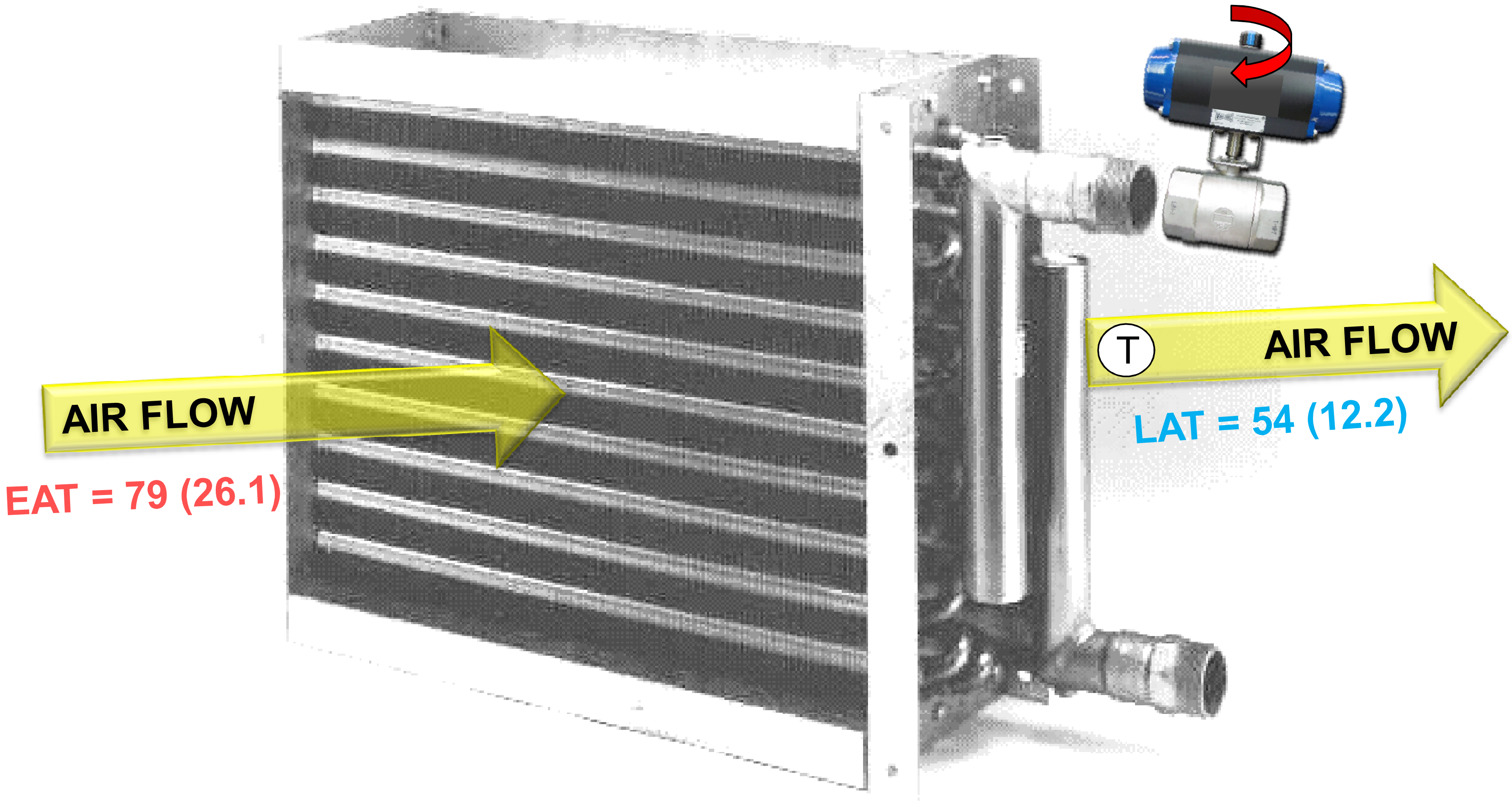
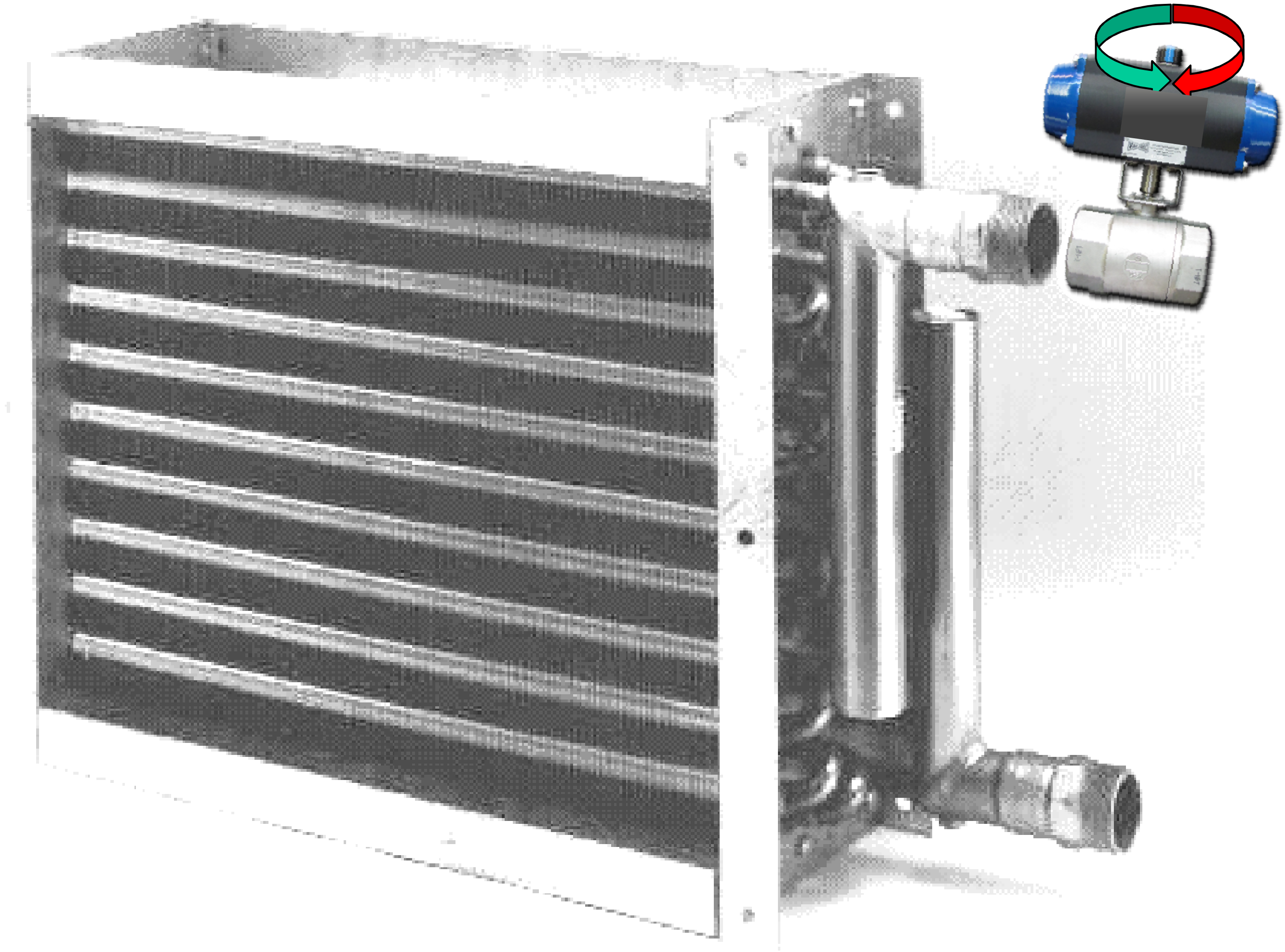


As Valve Opens, Pressure in loop lowers

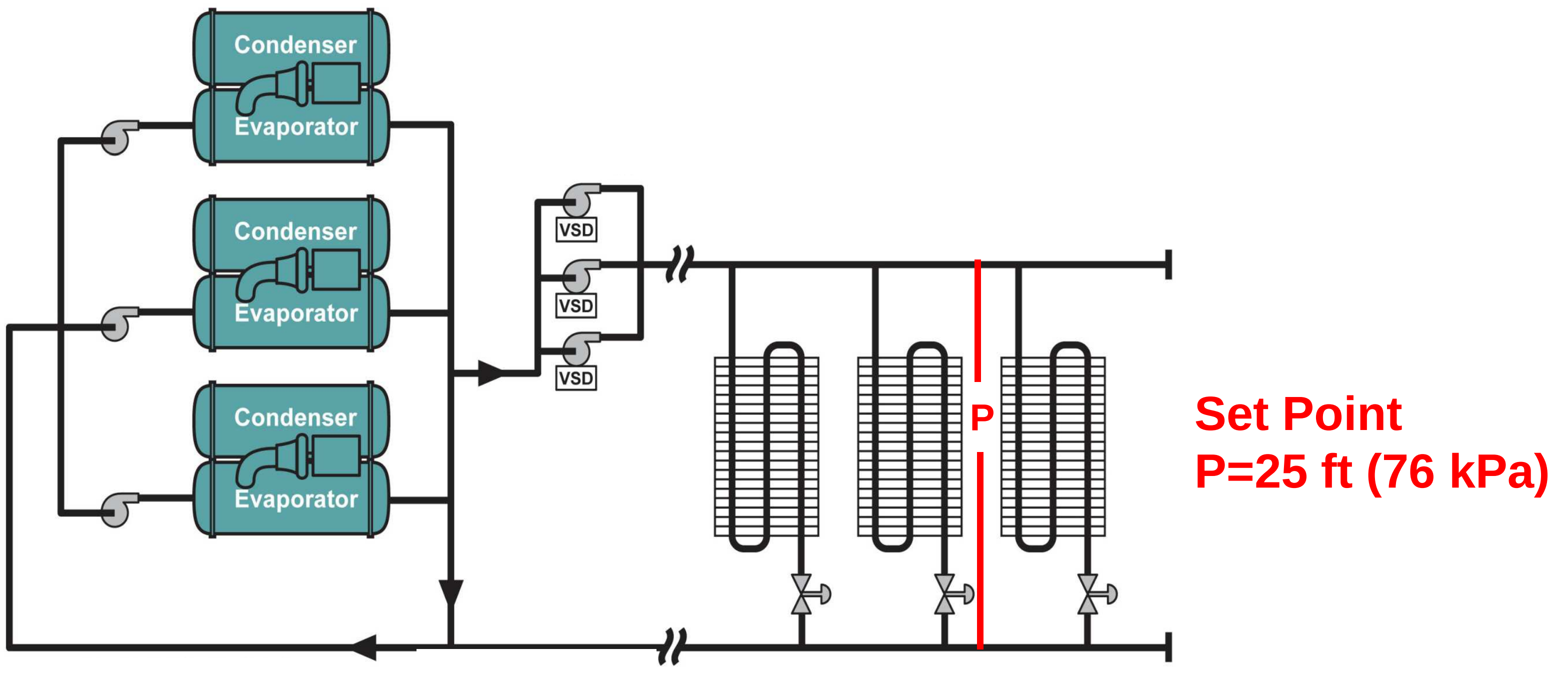
As Valve Closes, Pressure in loop rises



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

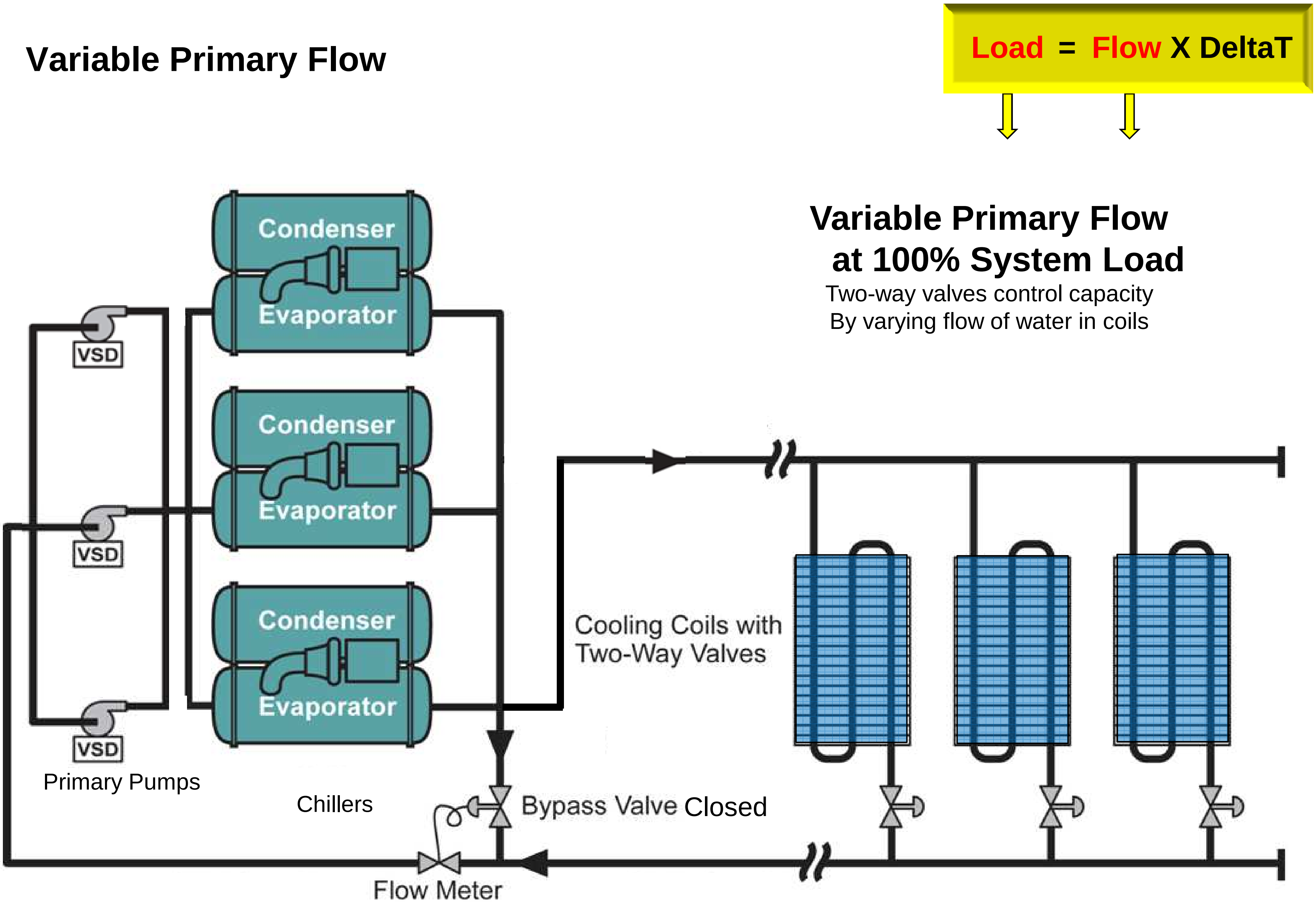
- Easy to Control
- Easy to Commission
- Loop separation
  - Easier trouble-shooting
  - Separating isolated loads/buildings for lower total pump energy
  - Lower Plant Energy (can sequence chillers and ancillary equipment)
- Versatile – multi-circuit capability

Disadvantages

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

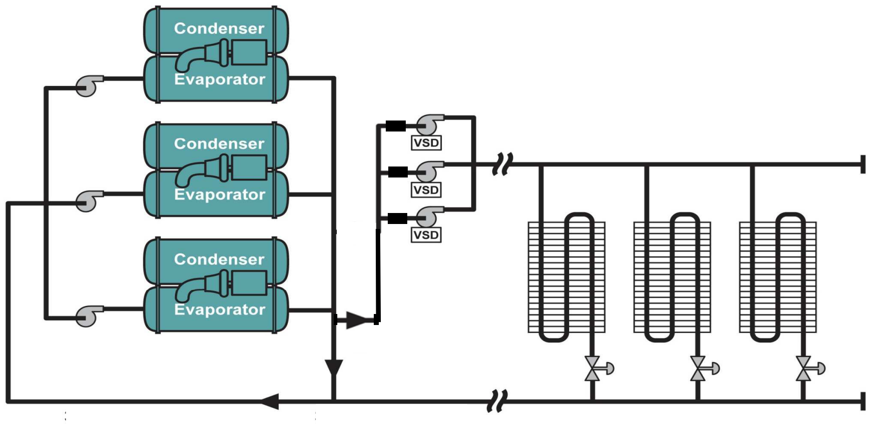
Variable Primary Flow

Variable Primary Flow

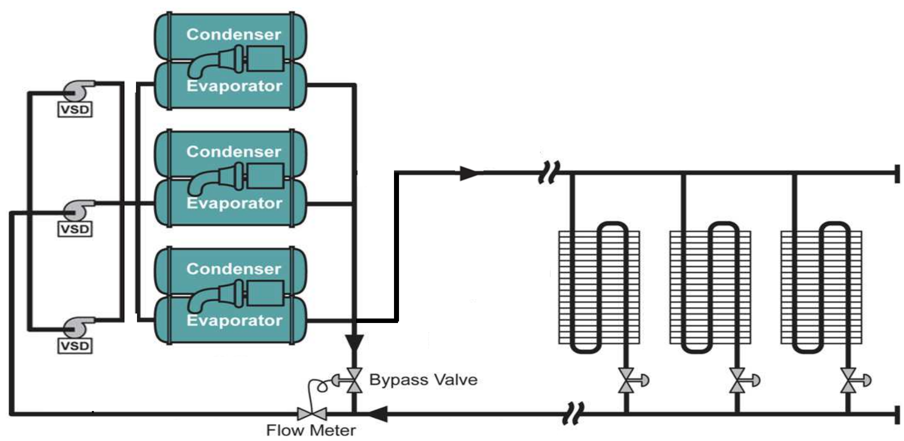


Primary/Secondary System

Three Differences?



Variable Primary System

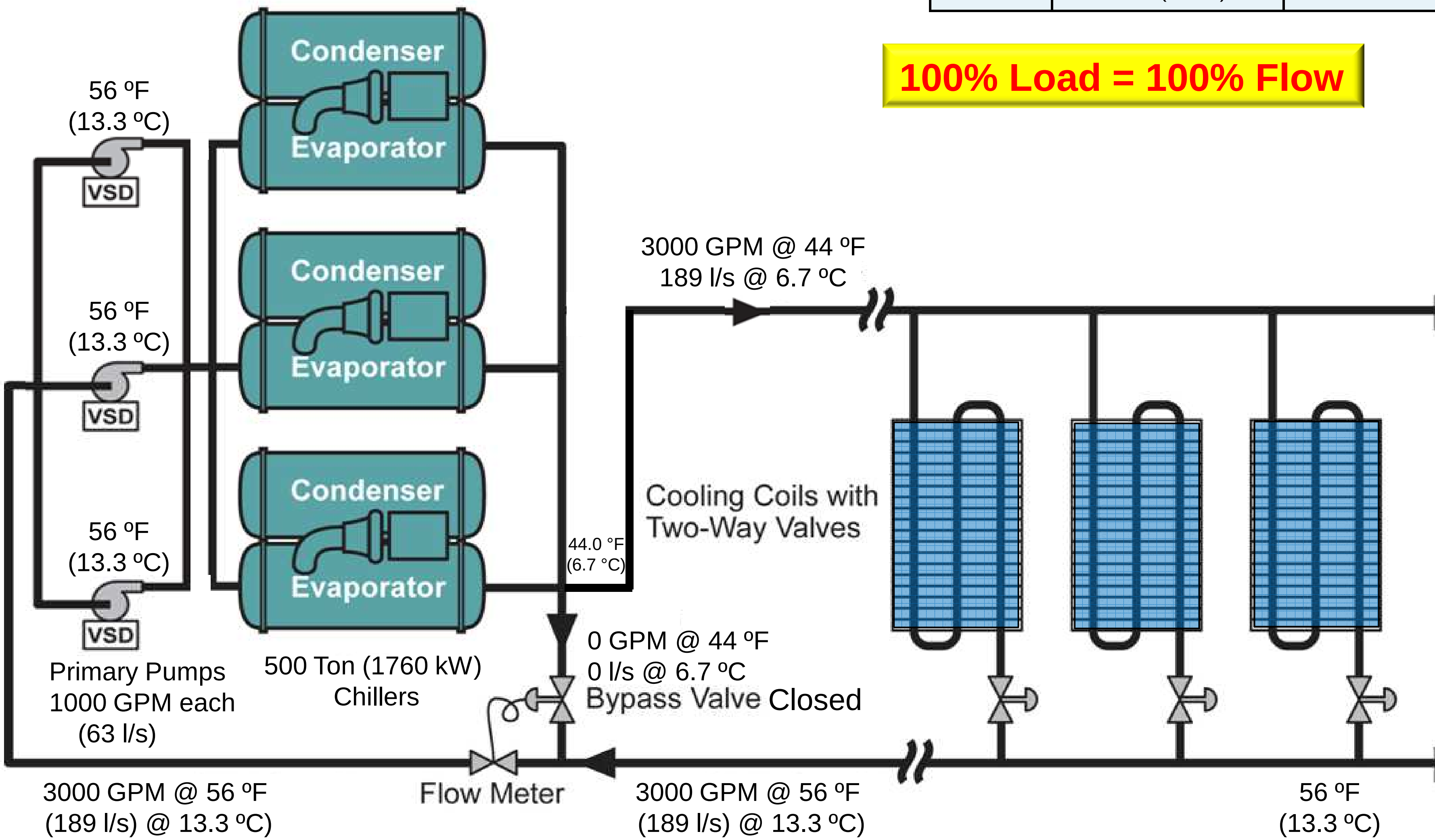


Variable Primary Flow at Design

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

	Primary	Bypass
Flow	3000gpm (189 l/s)	0gpm (0 l/s)
Delta T	12ºF (6.7ºC)	----

100% Load = 100% Flow

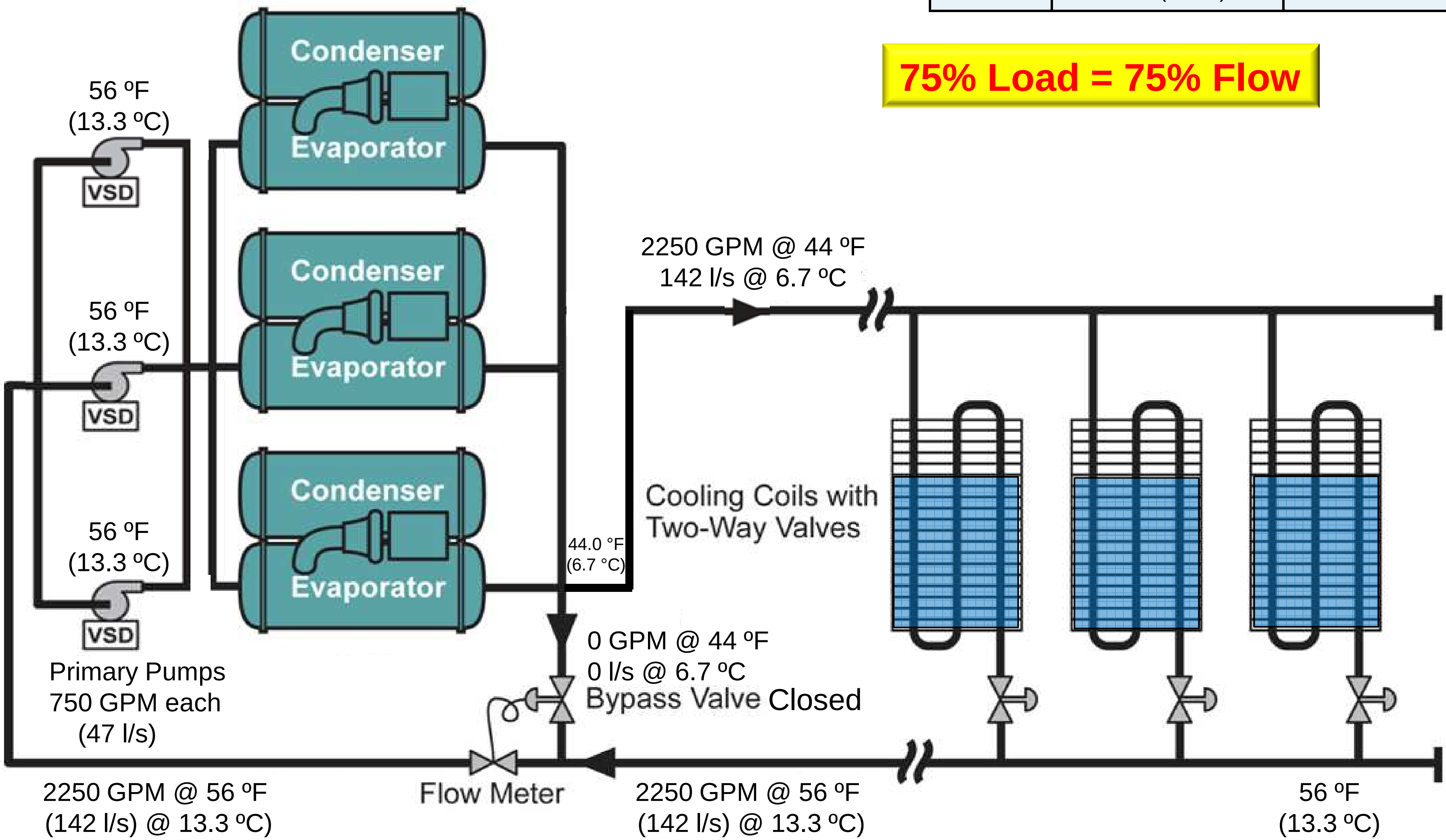


Variable Primary Flow at 75% Load

	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	12ºF (6.7ºC)	----

75% Load = 75% Flow

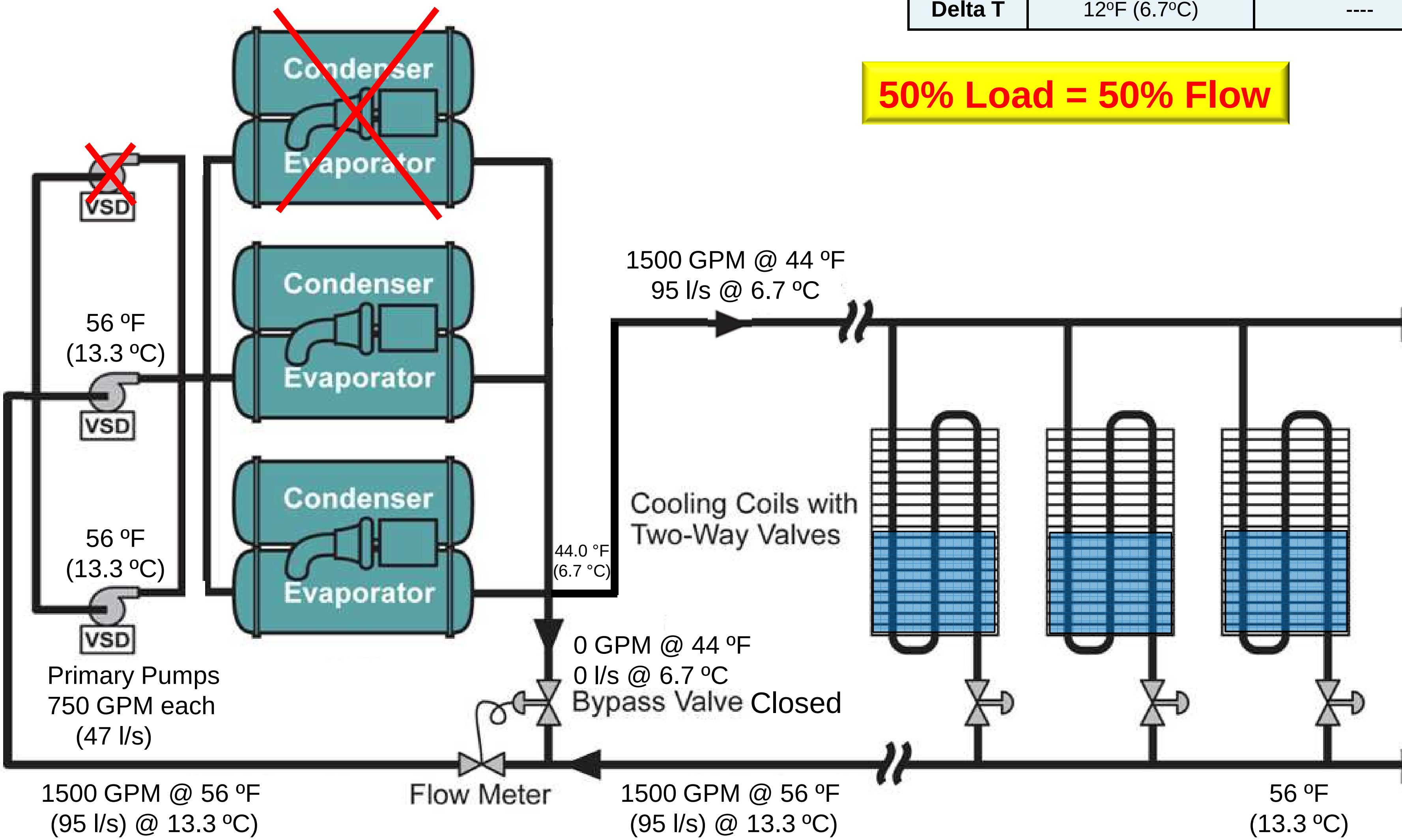


Variable Primary Flow at 50% Load

	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	12ºF (6.7ºC)	----

50% Load = 50% Flow

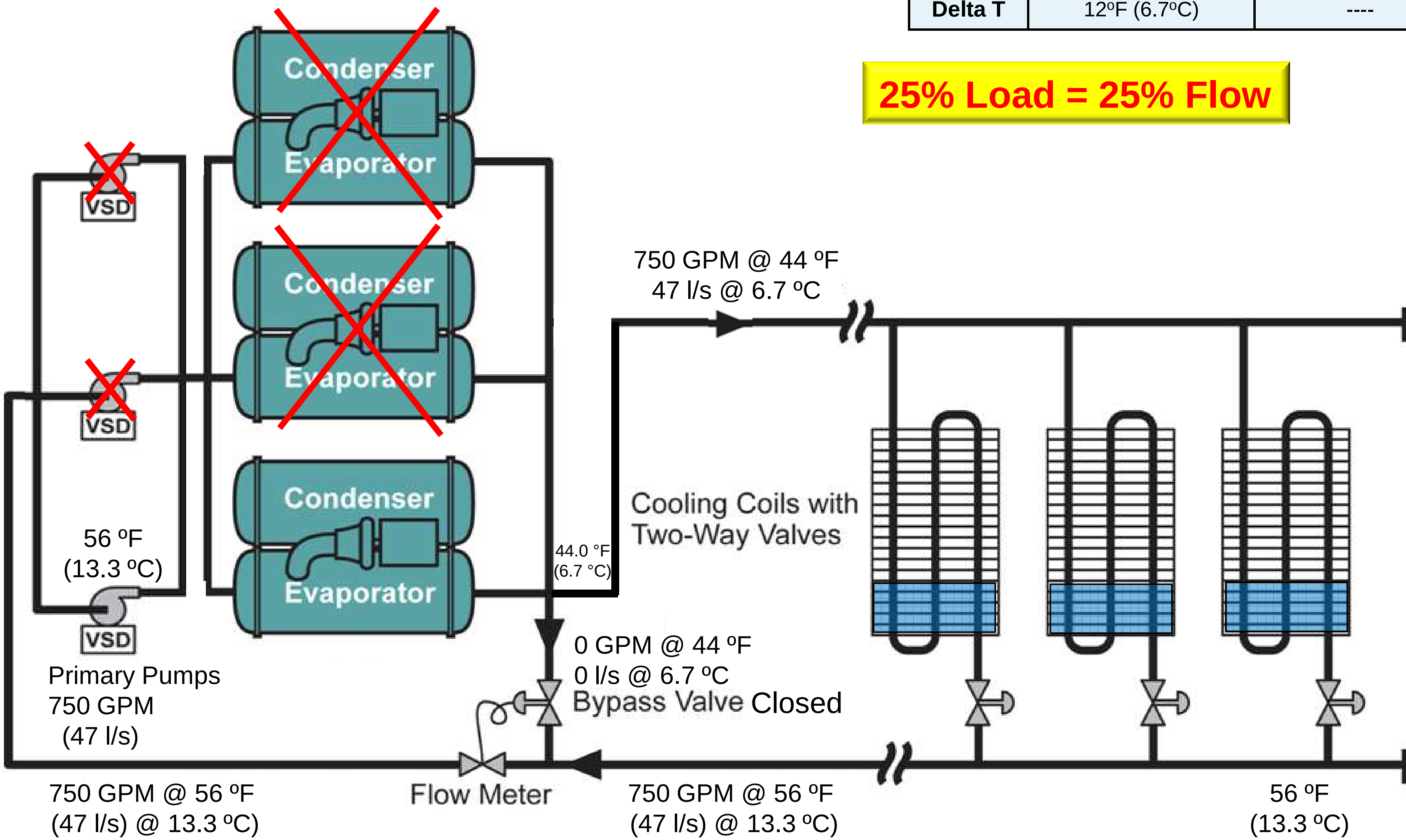


Variable Primary Flow at 25% Load

	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	12ºF (6.7ºC)	----

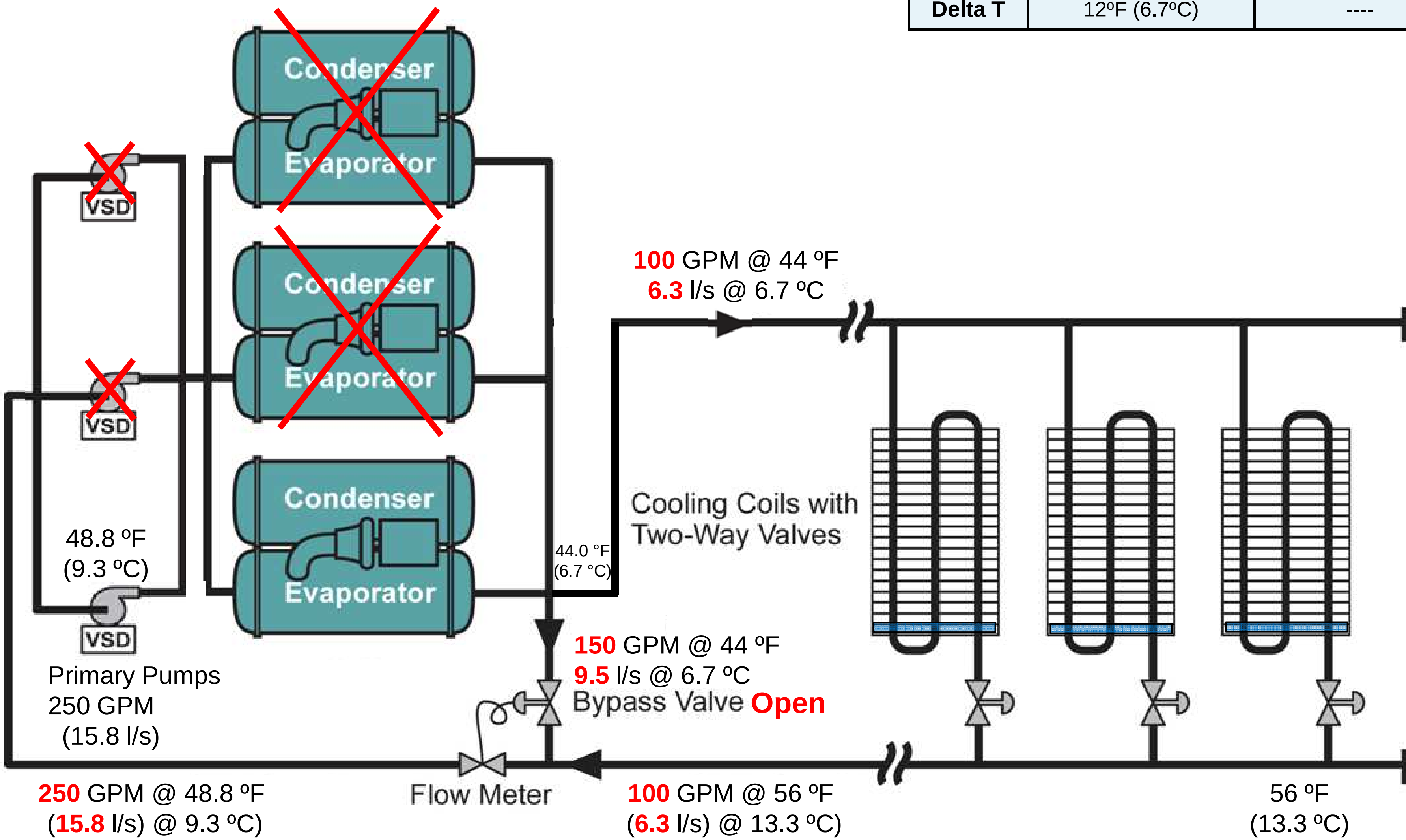
25% Load = 25% Flow



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	12ºF (6.7ºC)	----



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)

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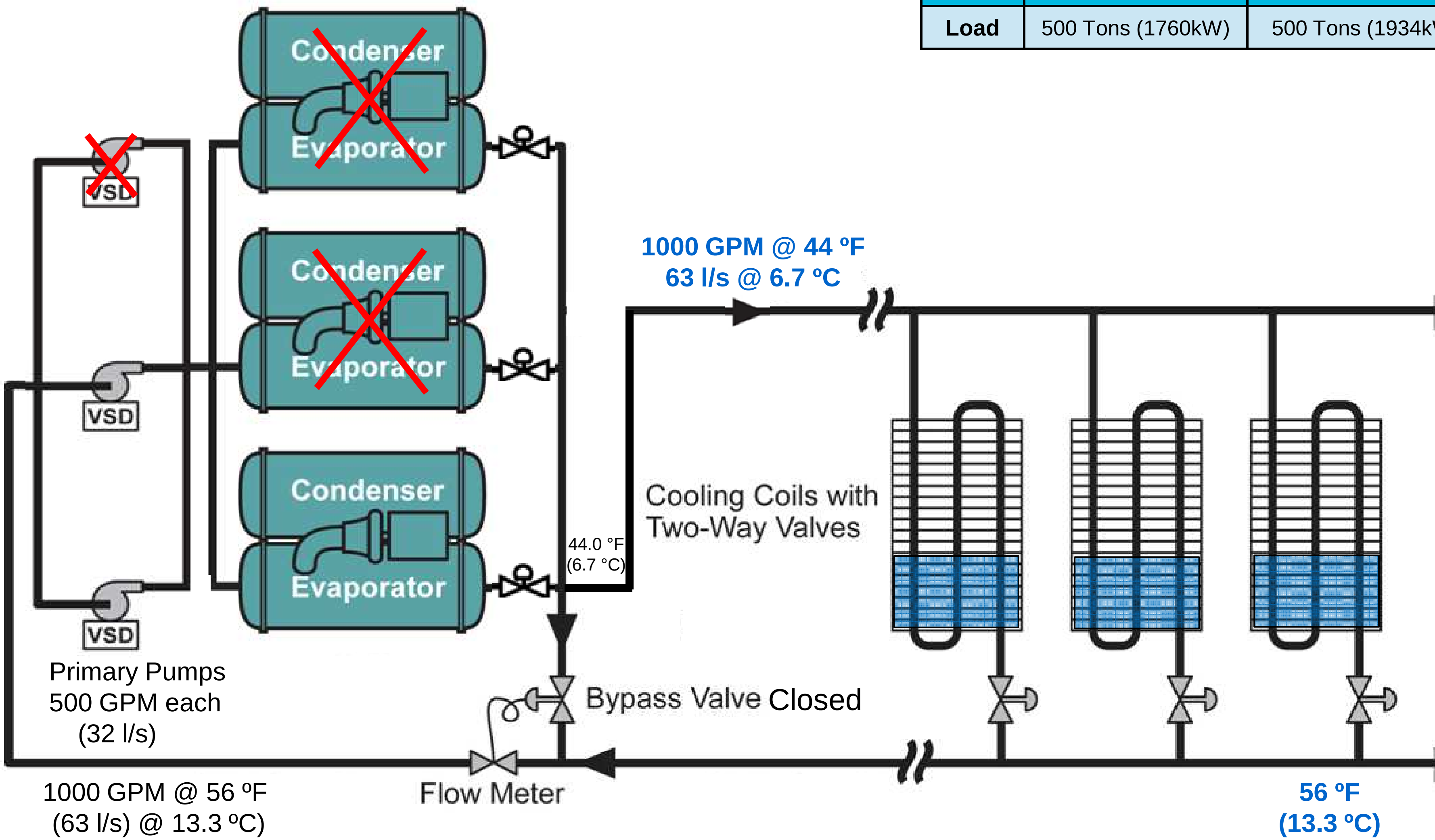
  - System Water Volume (more water, more thermal capacitance, faster variance allowed)
  - Active Loads (near or far from plant)
  - Typical VSD pump ramp rate setting of 10%/minute (accel/decel rates set to 600 seconds)
- **Issue Adding Chillers**
  - Modulating isolation valves on chillers

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)



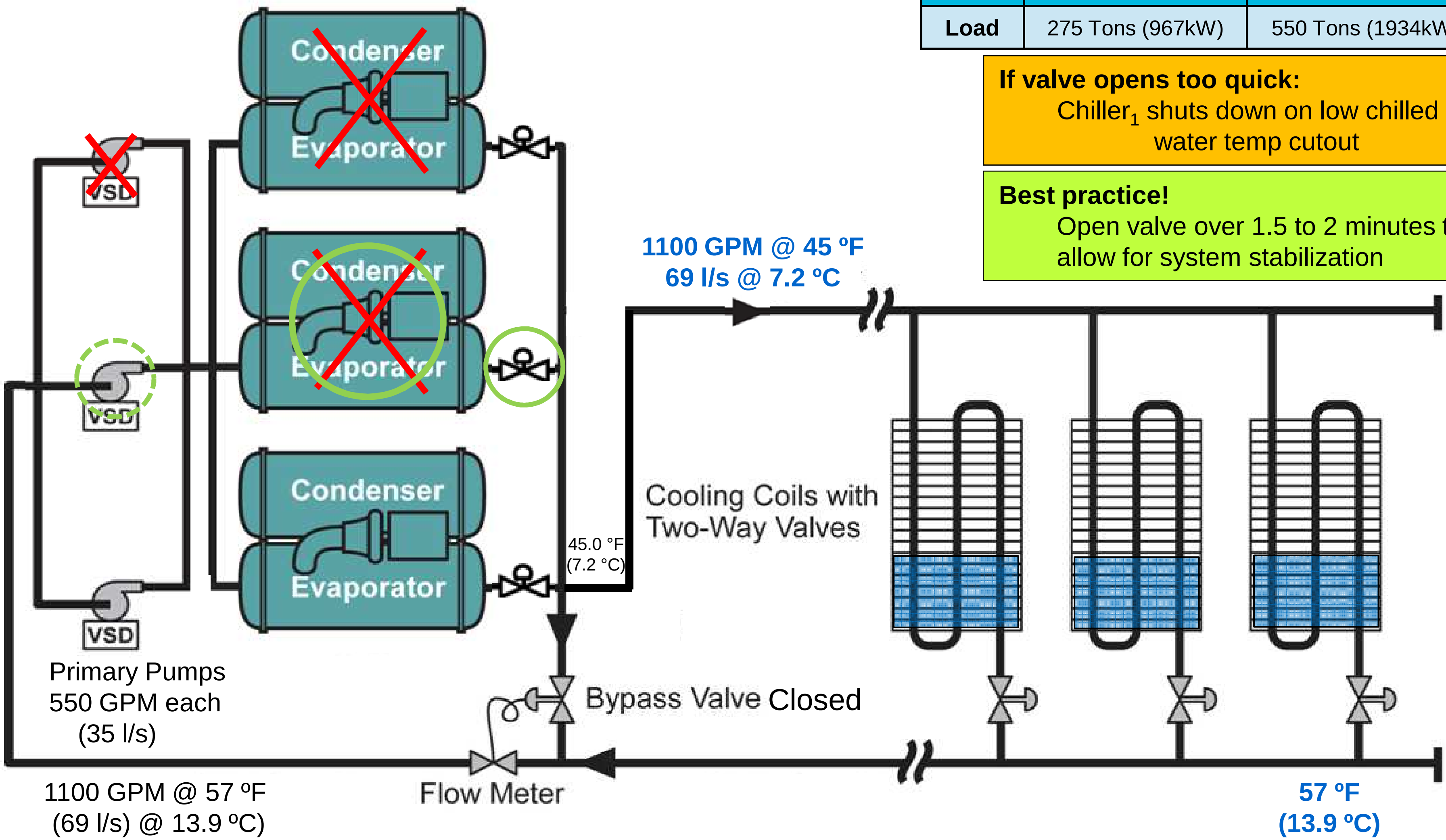
Variable Primary System – Staging on chillers & changes in flow rate

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

	Per Chiller	System
Load	275 Tons (967kW)	550 Tons (1934kW)

If valve opens too quick:
Chiller$_1$ shuts down on low chilled water temp cutout

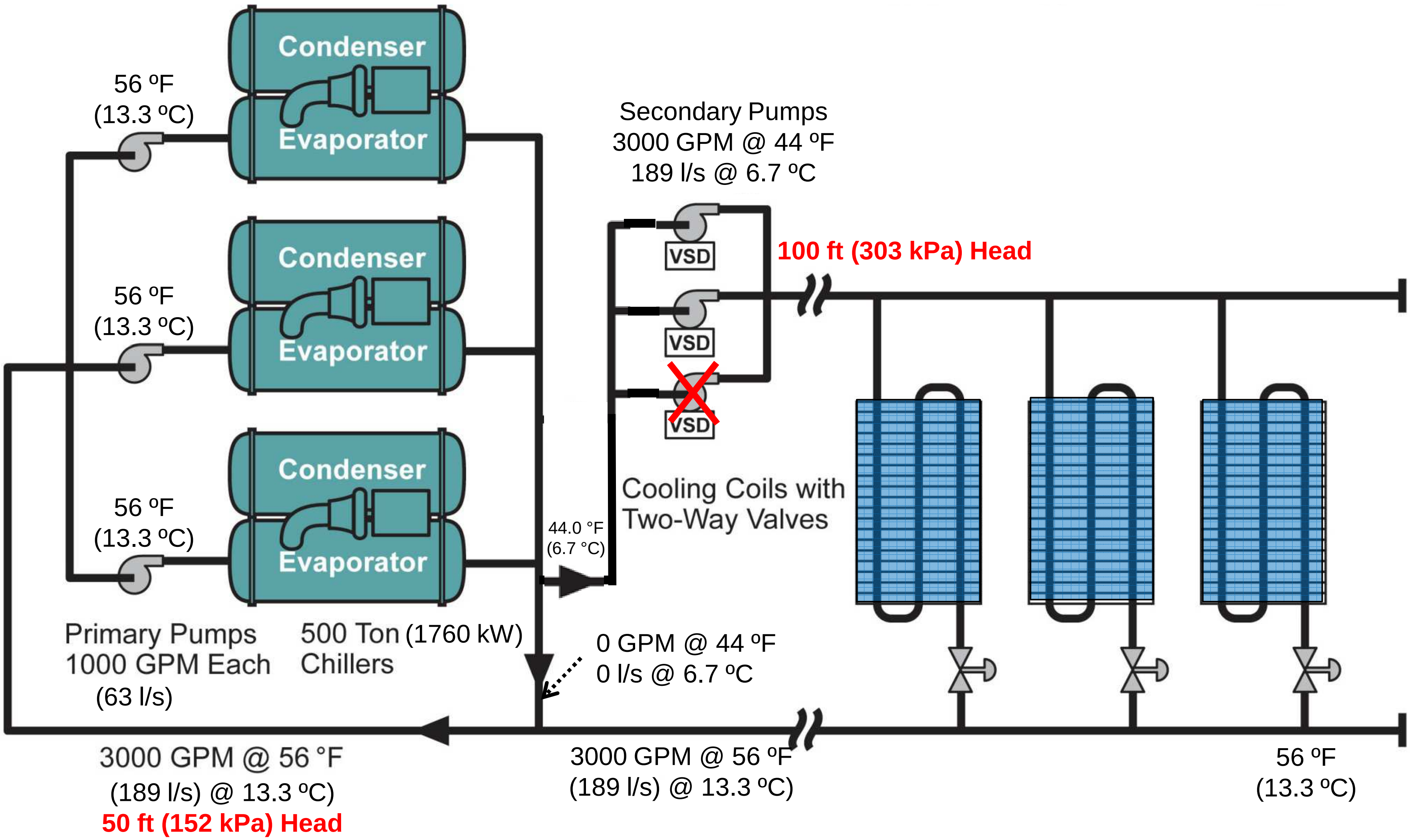
Best practice!
Open valve over 1.5 to 2 minutes to allow for system stabilization



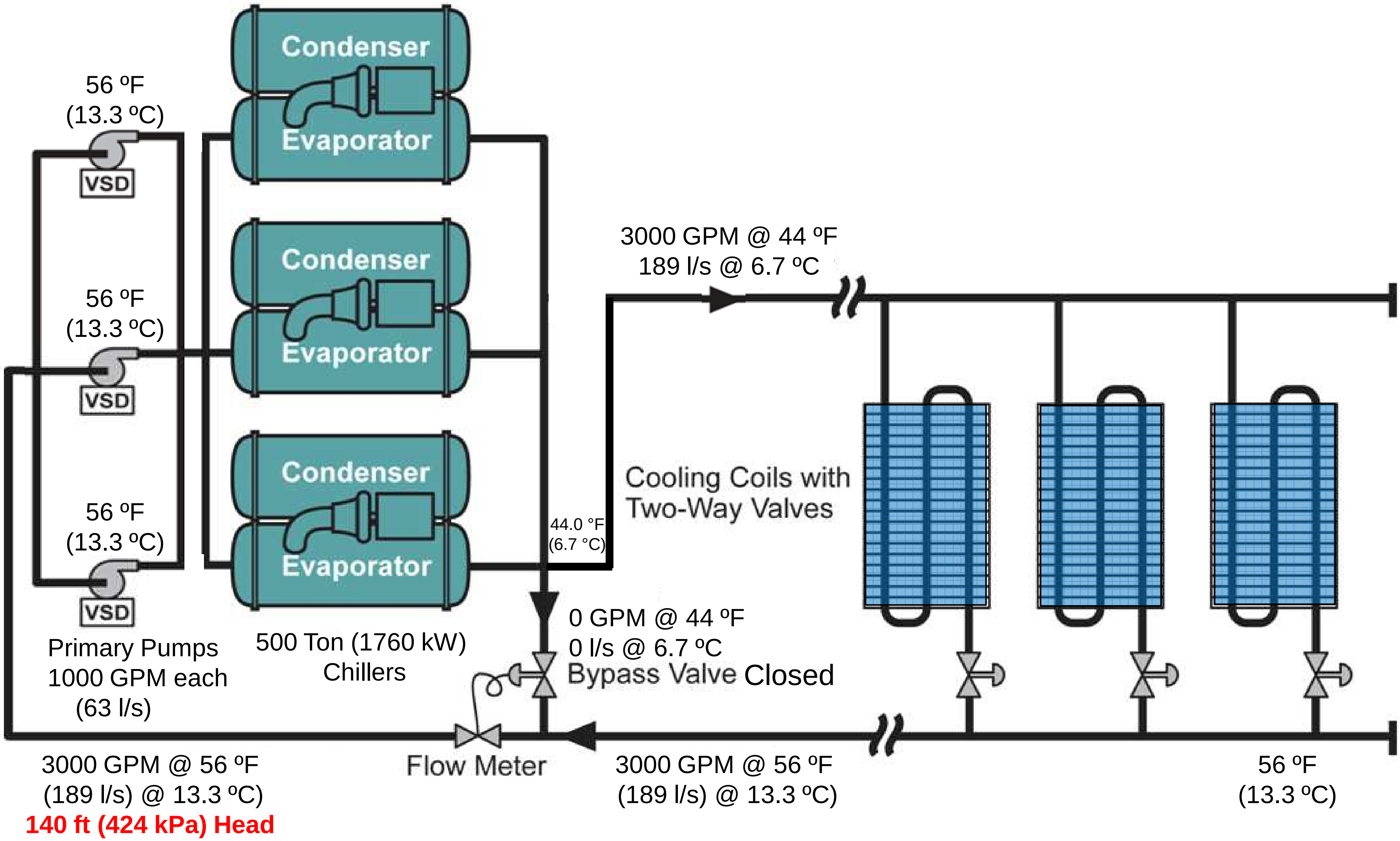
Variable Primary Flow (VPF) System Arrangement

- **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



Pump Energy

$$BHP = \frac{GPM \times Head}{3960 \times Pump_{Eff}}$$

Variable Primary Flow (VPF) System Arrangement

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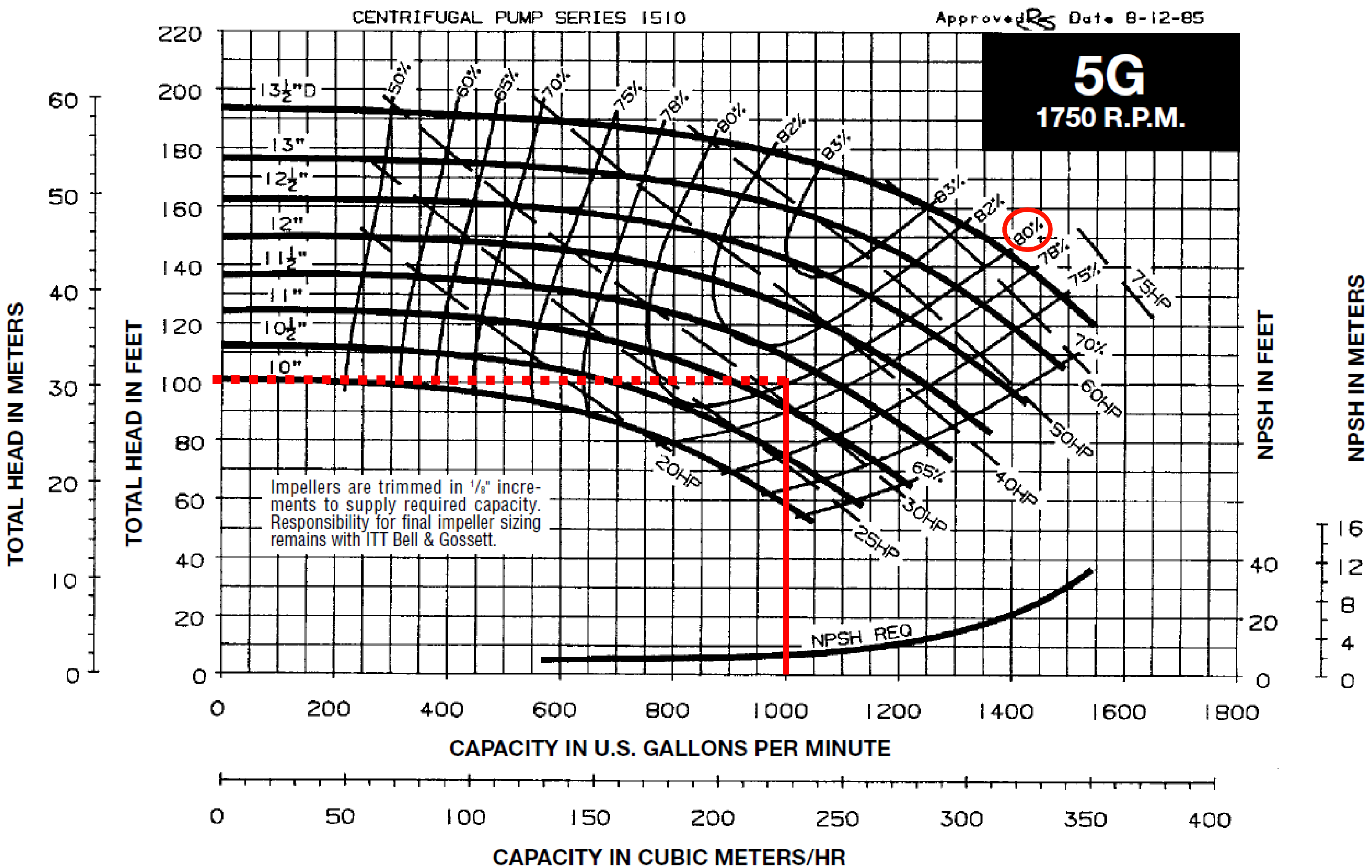
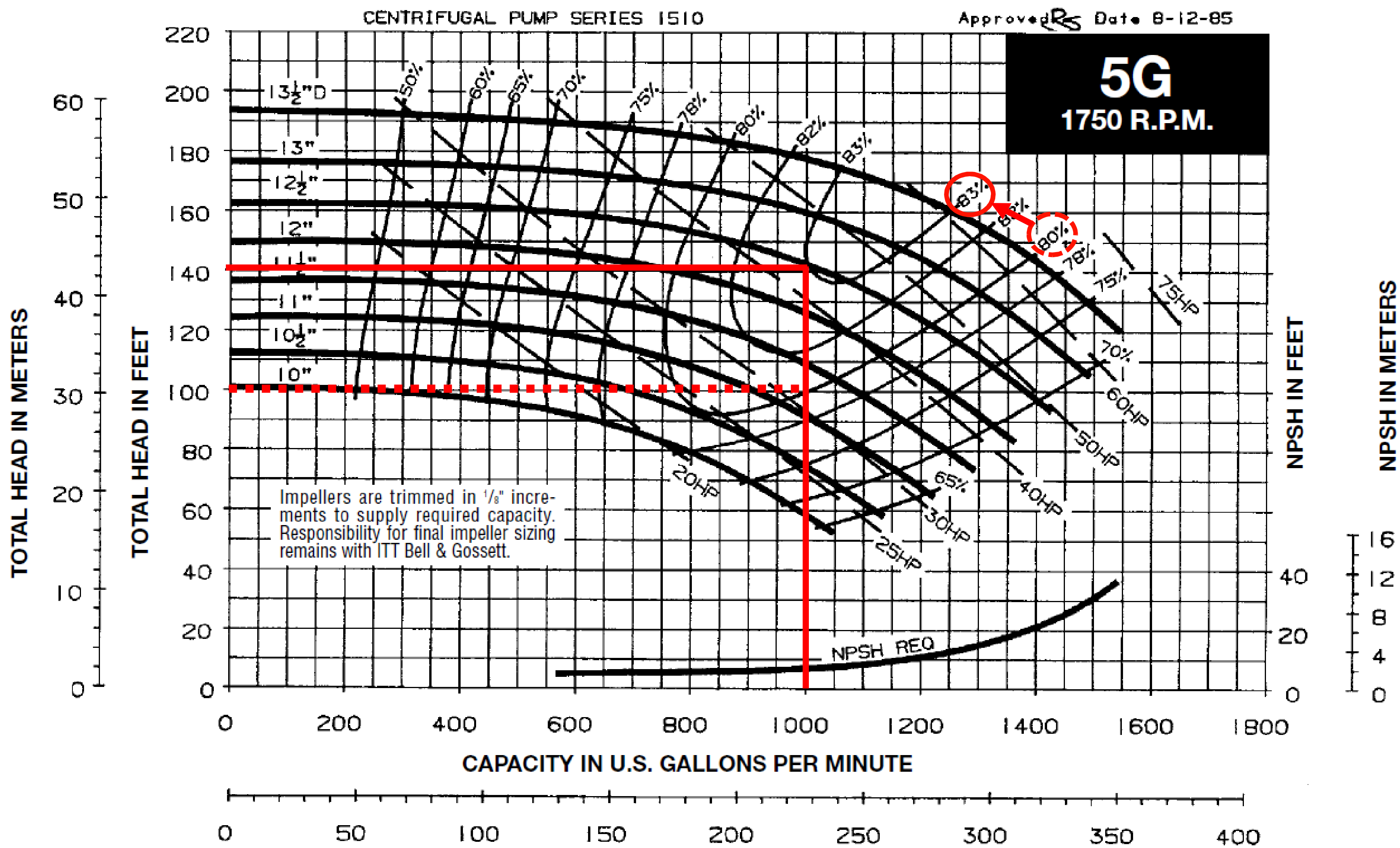
    - Lower Pump Design Head
    - **Higher Pump Efficiency**

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

$$BHP = \frac{GPM \times Head}{3960 \times Pump_{Eff}}$$

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)
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    - VSD energy savings
    - Lower Pump Design Head
    - Higher Pump Efficiency
  - Lower potential impact from Low Delta T (can over pump chillers if needed)

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  - Medium Installed Cost (approx. 5% compared P/S)
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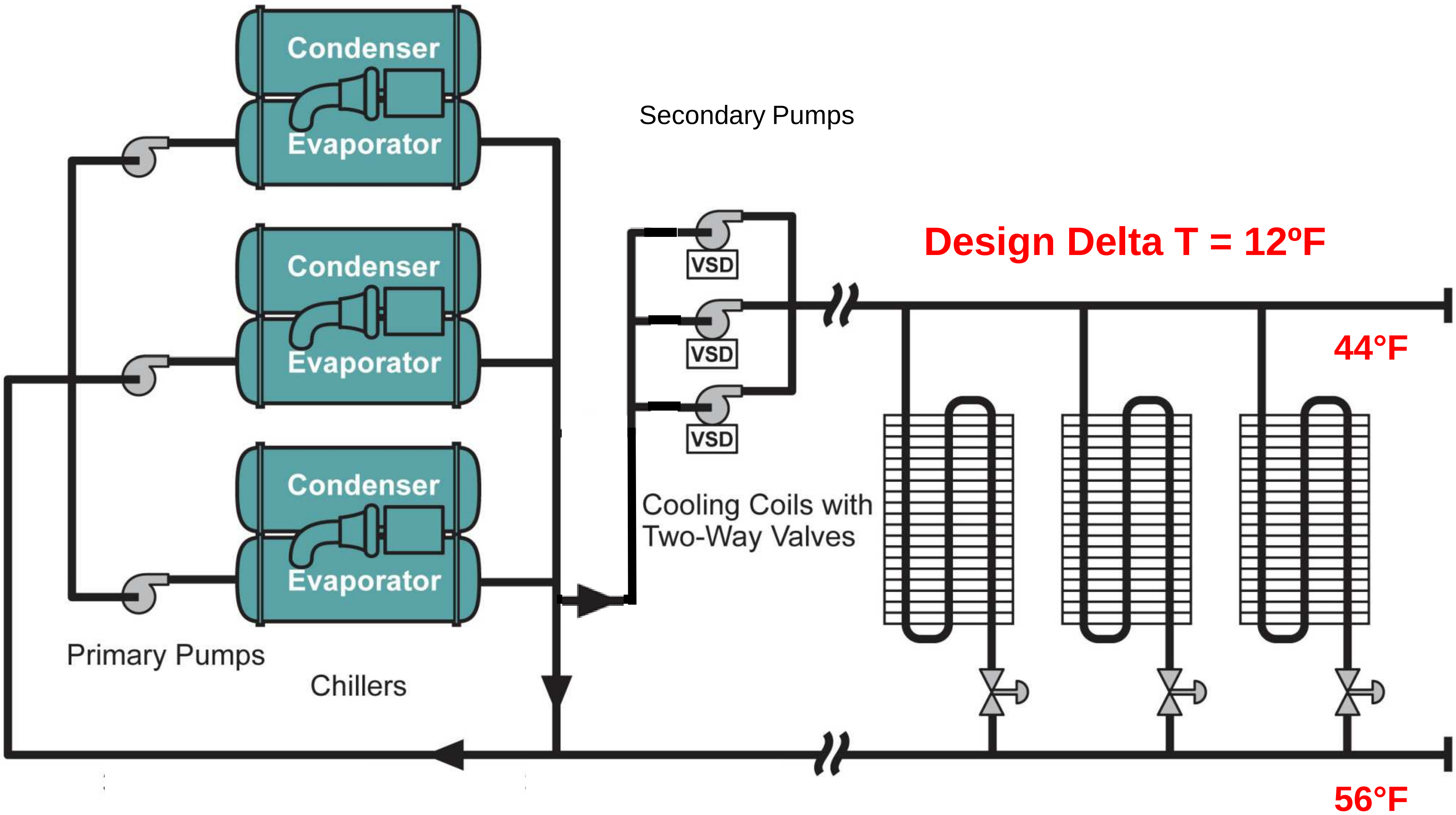
  - Less Plant Space Needed (vs P/S)
  - Best Chilled Water Pump Energy Consumption (most optimeady configuration)
    - VSD energy savings
    - Lower Pump Design Head
    - Higher Pump Efficiency
  - Lower potential impact from Low Delta T (can over pump chillers if needed)
- **Disadvantages**
  - Requires 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

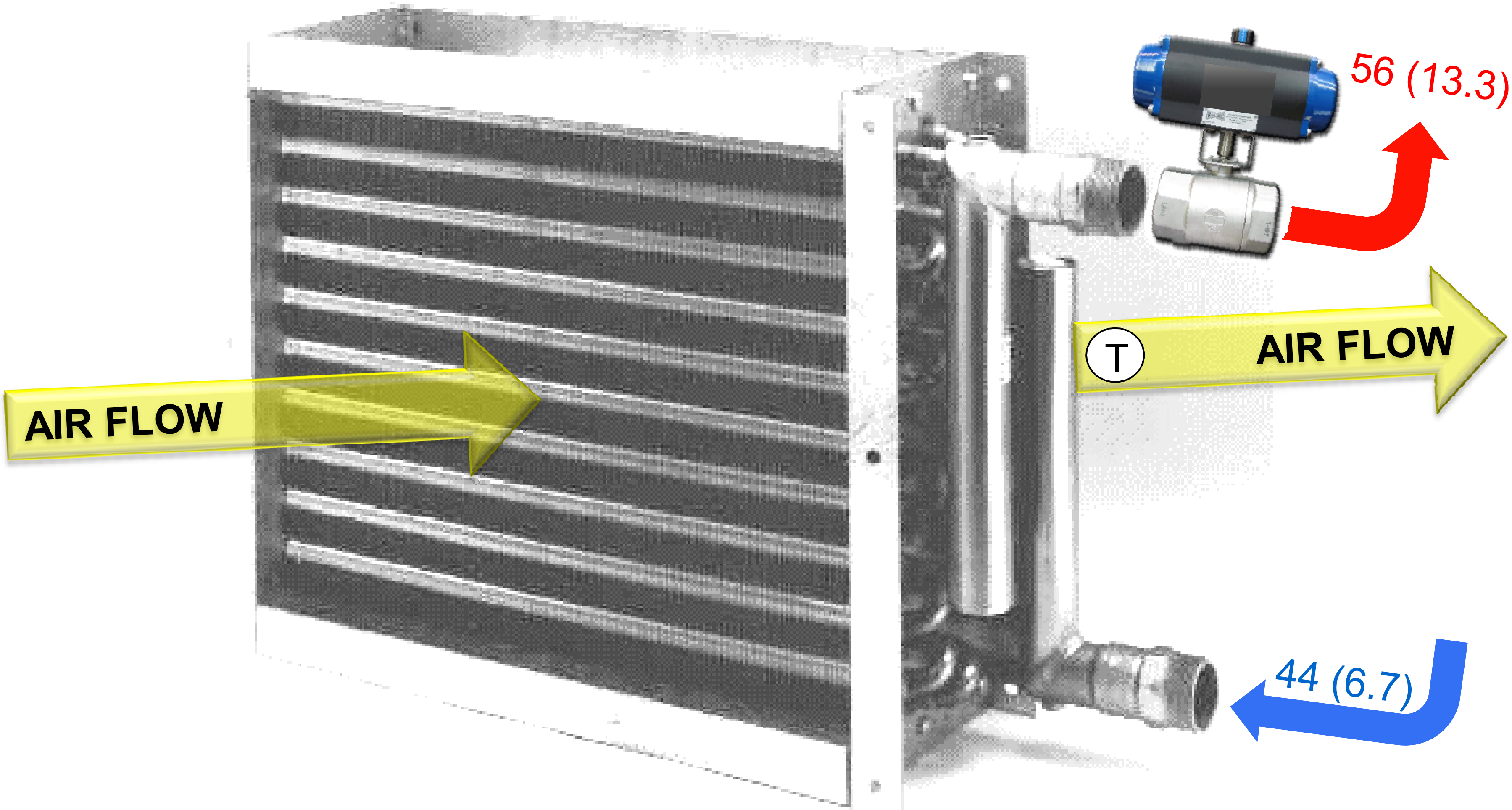
Low Delta T Syndrome



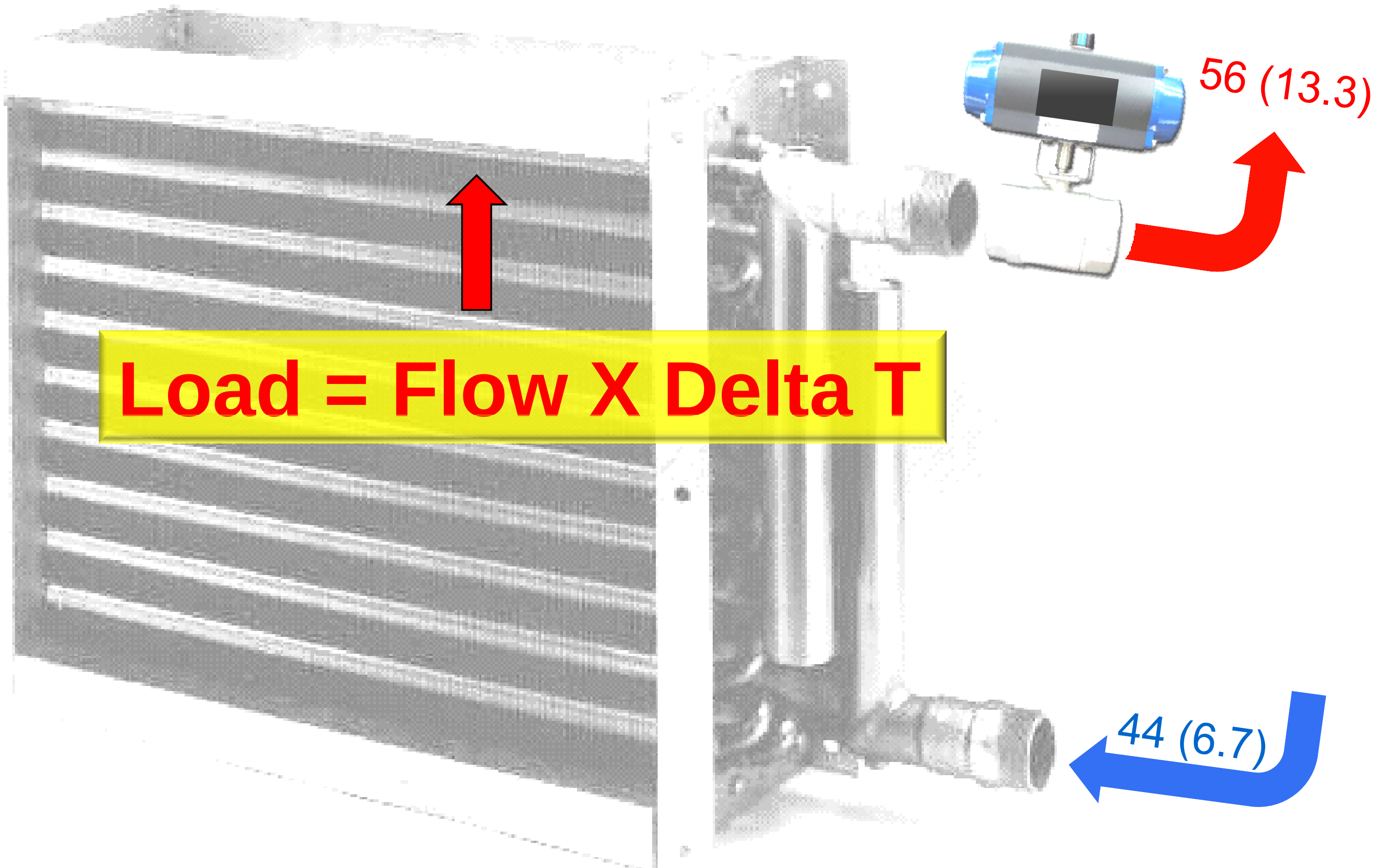
Major Causes of Low Delta T

- Dirty Coils

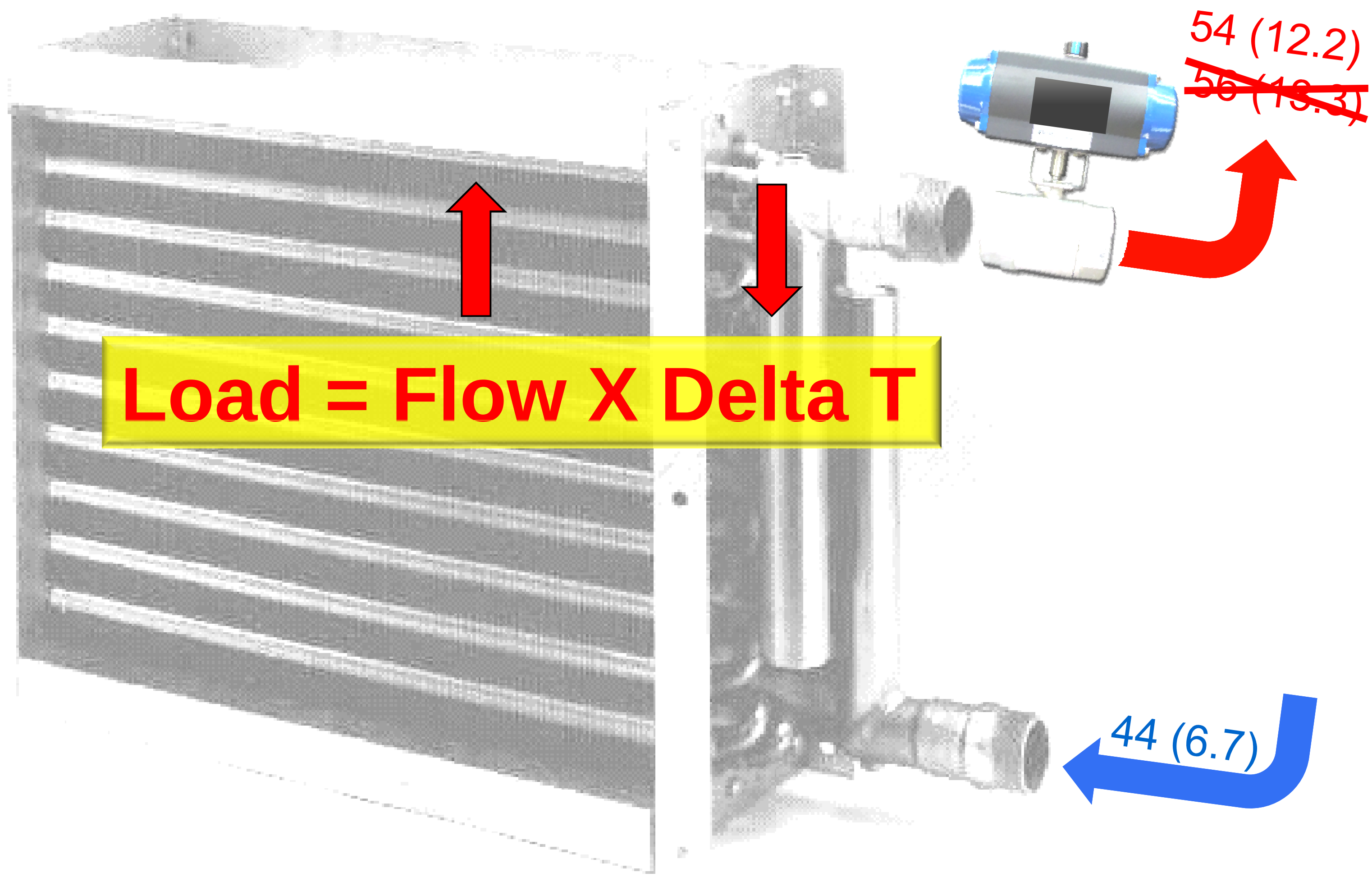
Chilled Water Coil



Chilled Water Coil



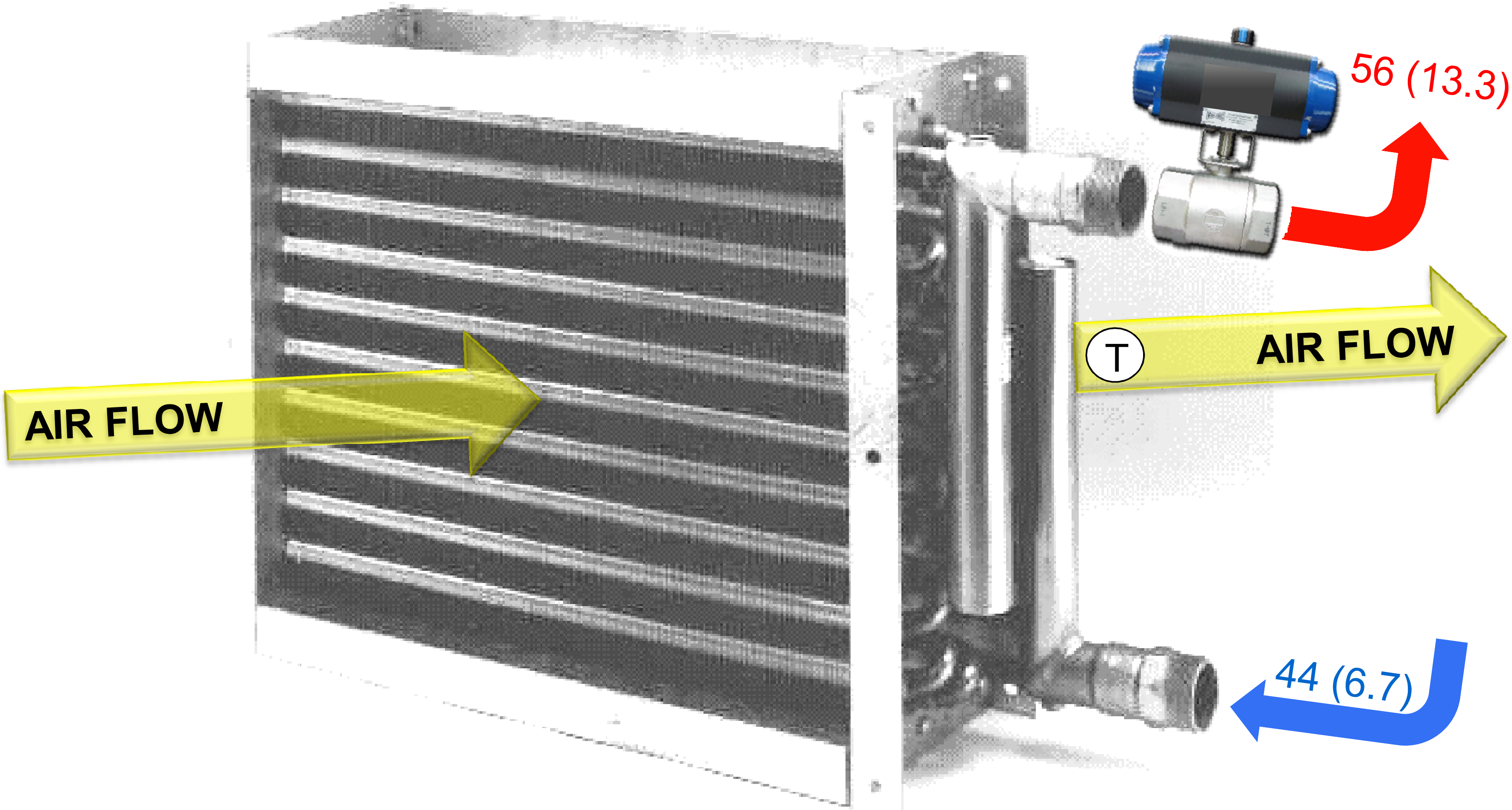
Chilled Water Coil



Major Causes of Low Delta T

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

Chilled Water Coil

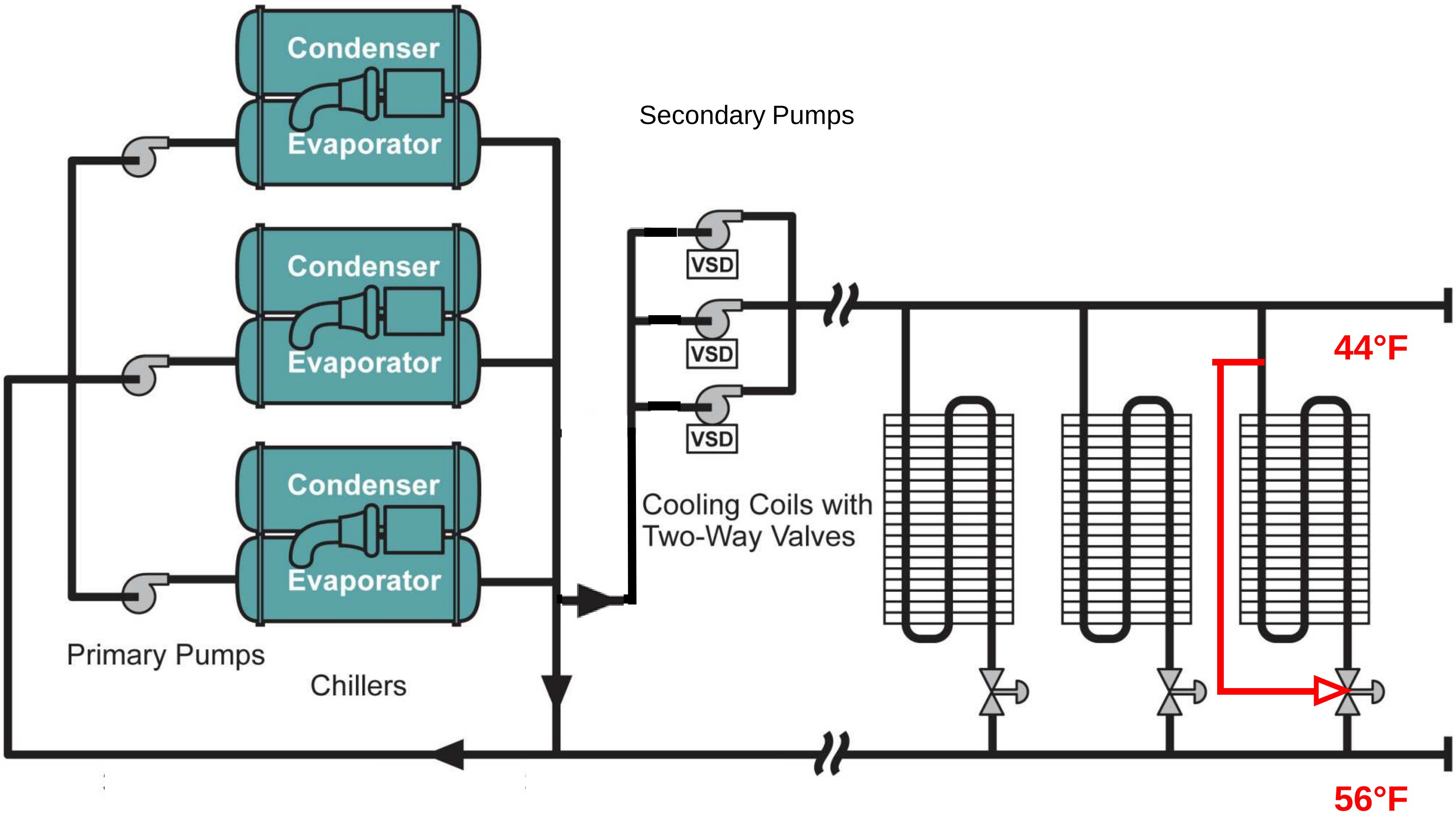


Major Causes of Low Delta T

- 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



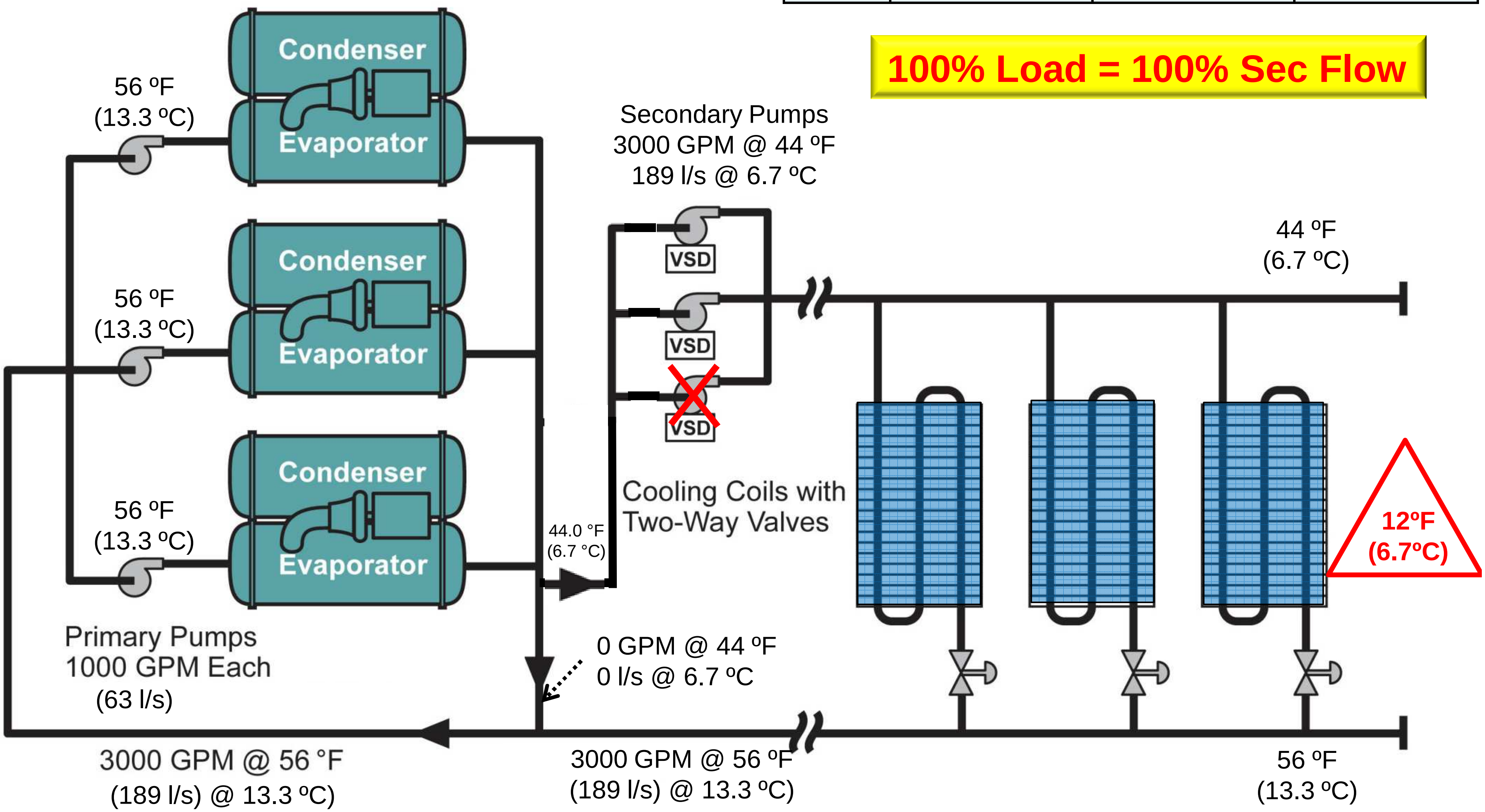
Primary/Secondary at Design

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	12ºF (6.7ºC)	12ºF (6.7ºC)	----

100% Load = 100% Sec Flow



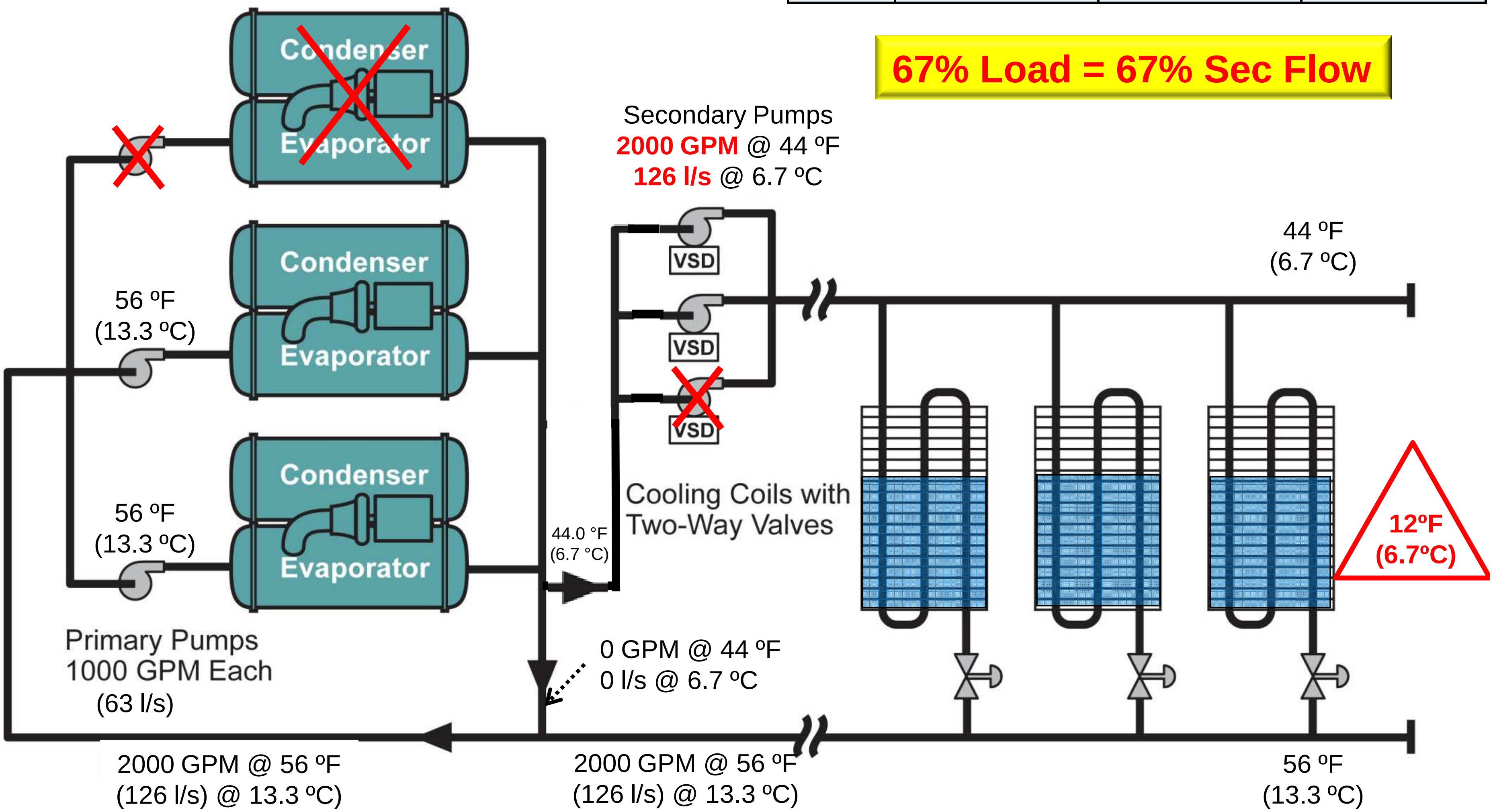
Primary/Secondary at 67% Load

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	12ºF (4.4ºC)	12ºF (6.7ºC)	----

67% Load = 67% Sec Flow



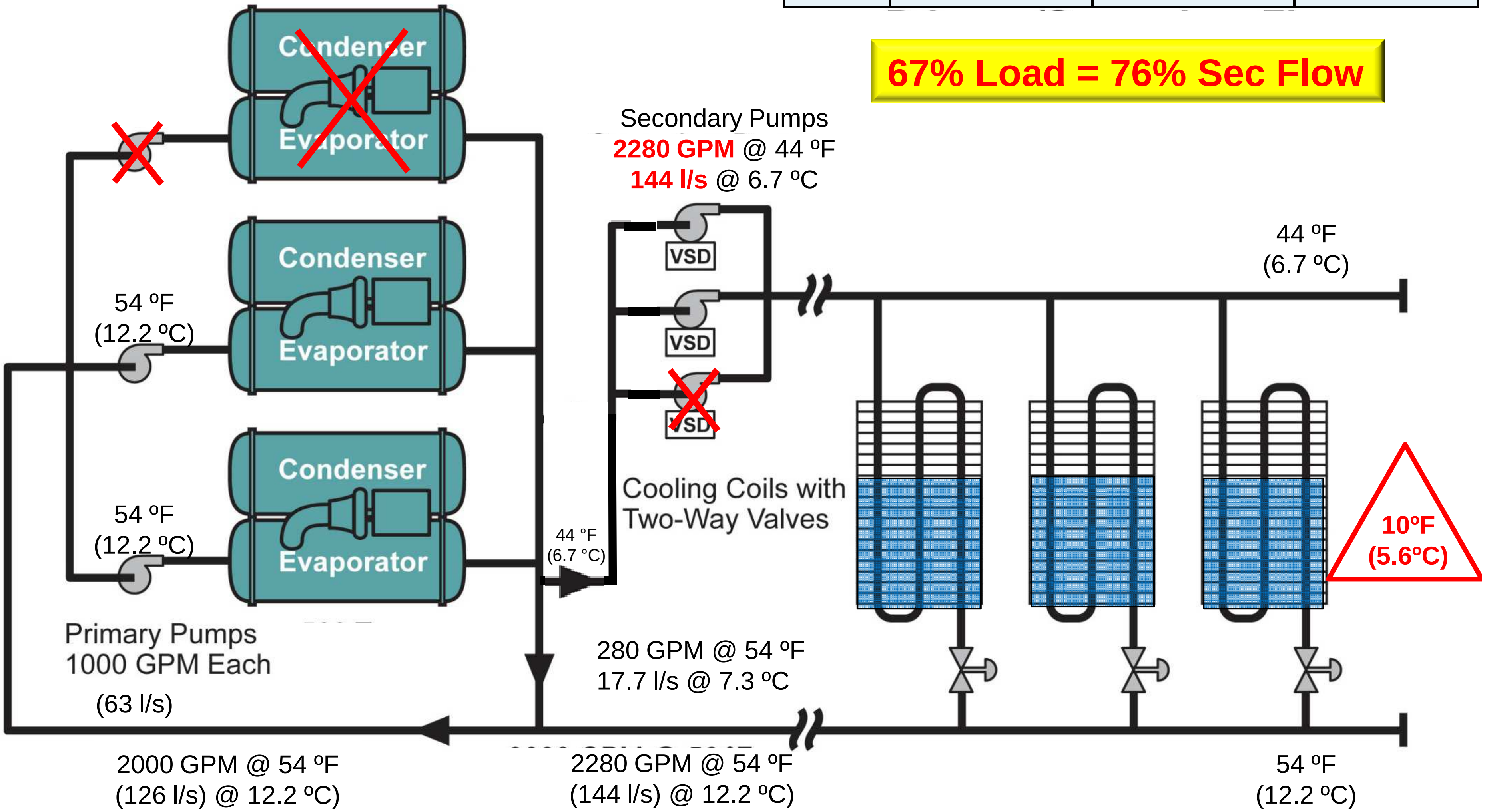
Primary/Secondary at 67% Load

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	10ºF (5.6ºC)	10ºF (5.6ºC)	----

67% Load = 76% Sec Flow



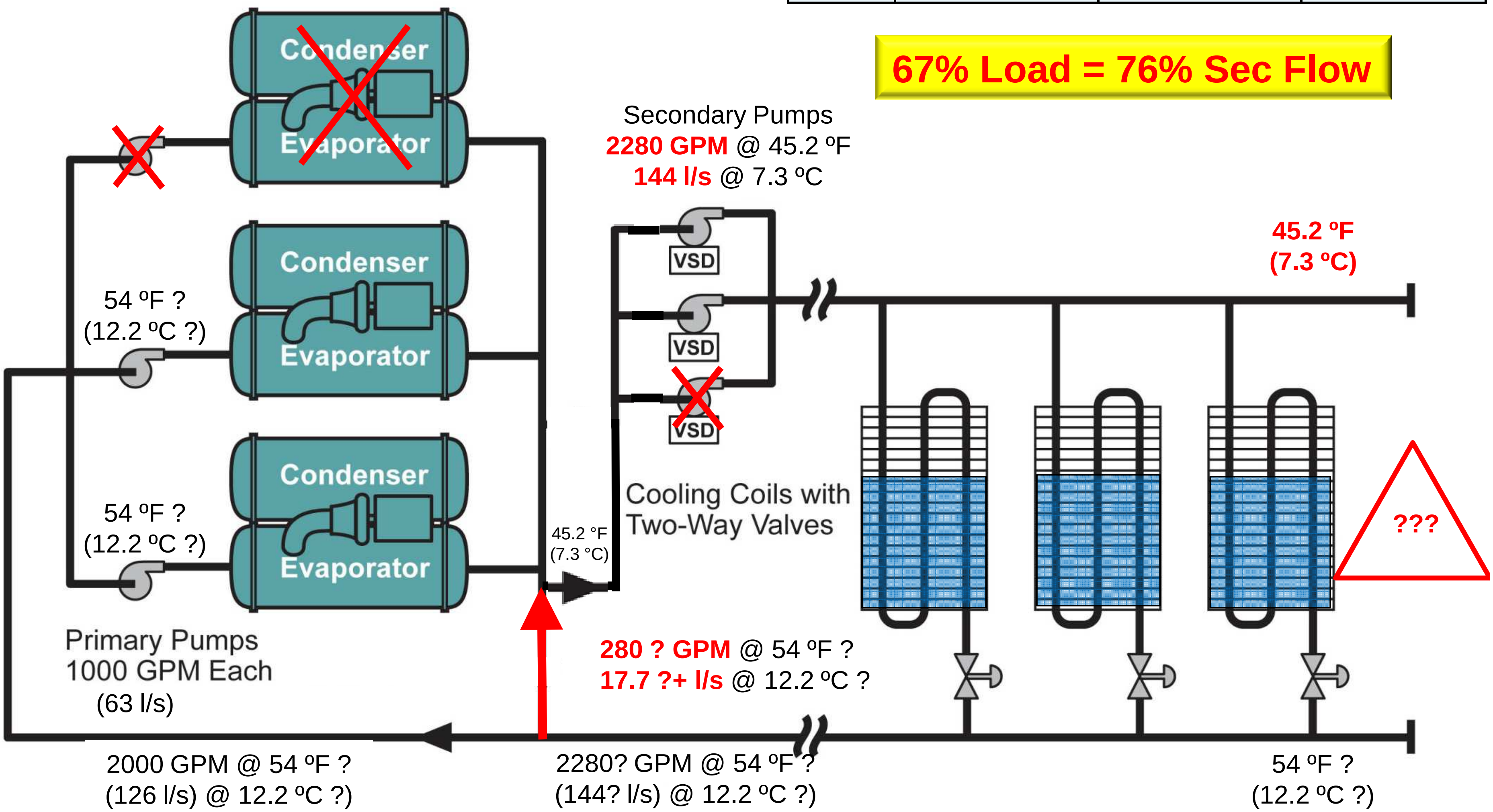
Primary/Secondary at 67% Load

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	10ºF (5.6ºC)	10ºF (5.6ºC)	----

67% Load = 76% Sec Flow



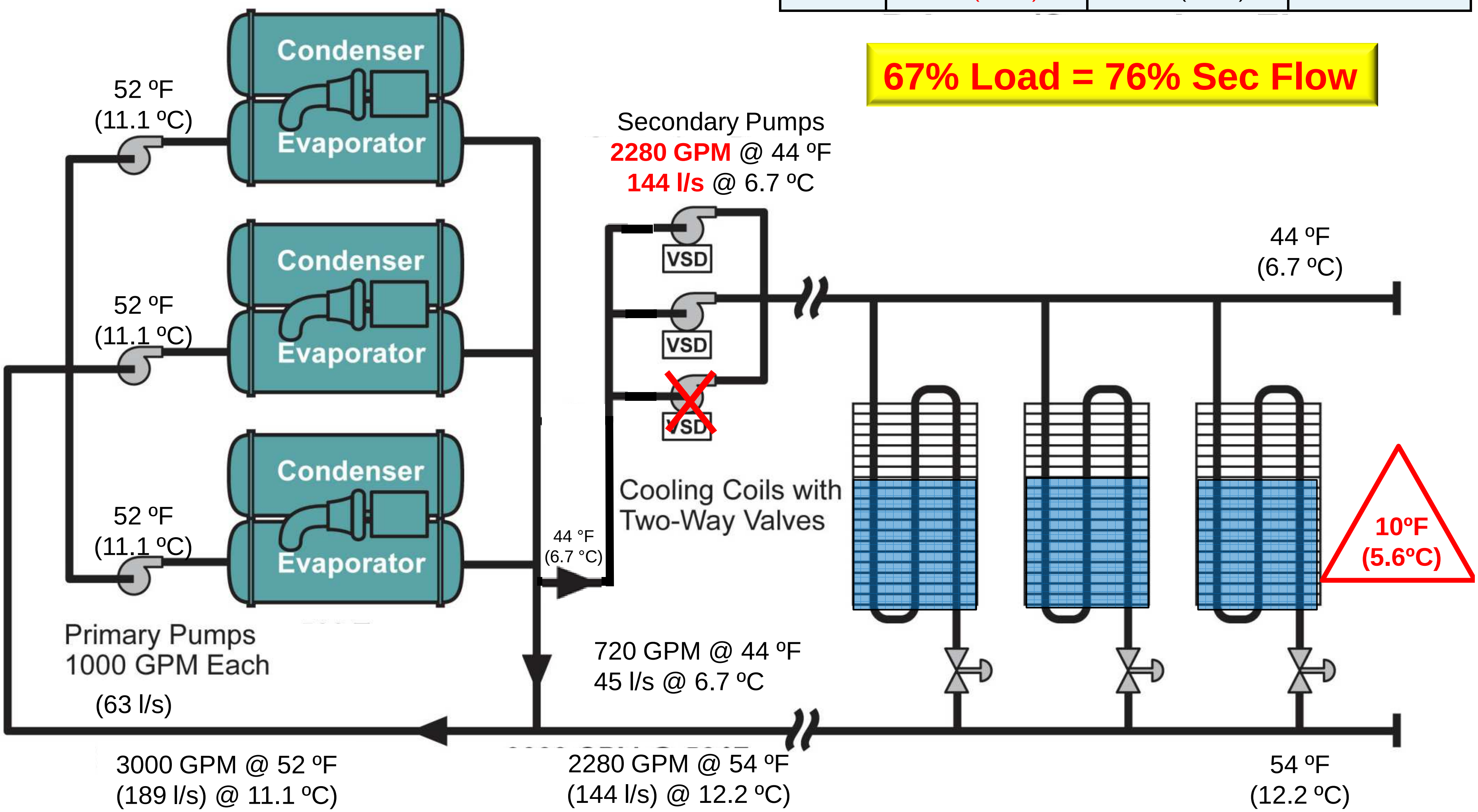
Primary/Secondary at 67% Load

Low DeltaT

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

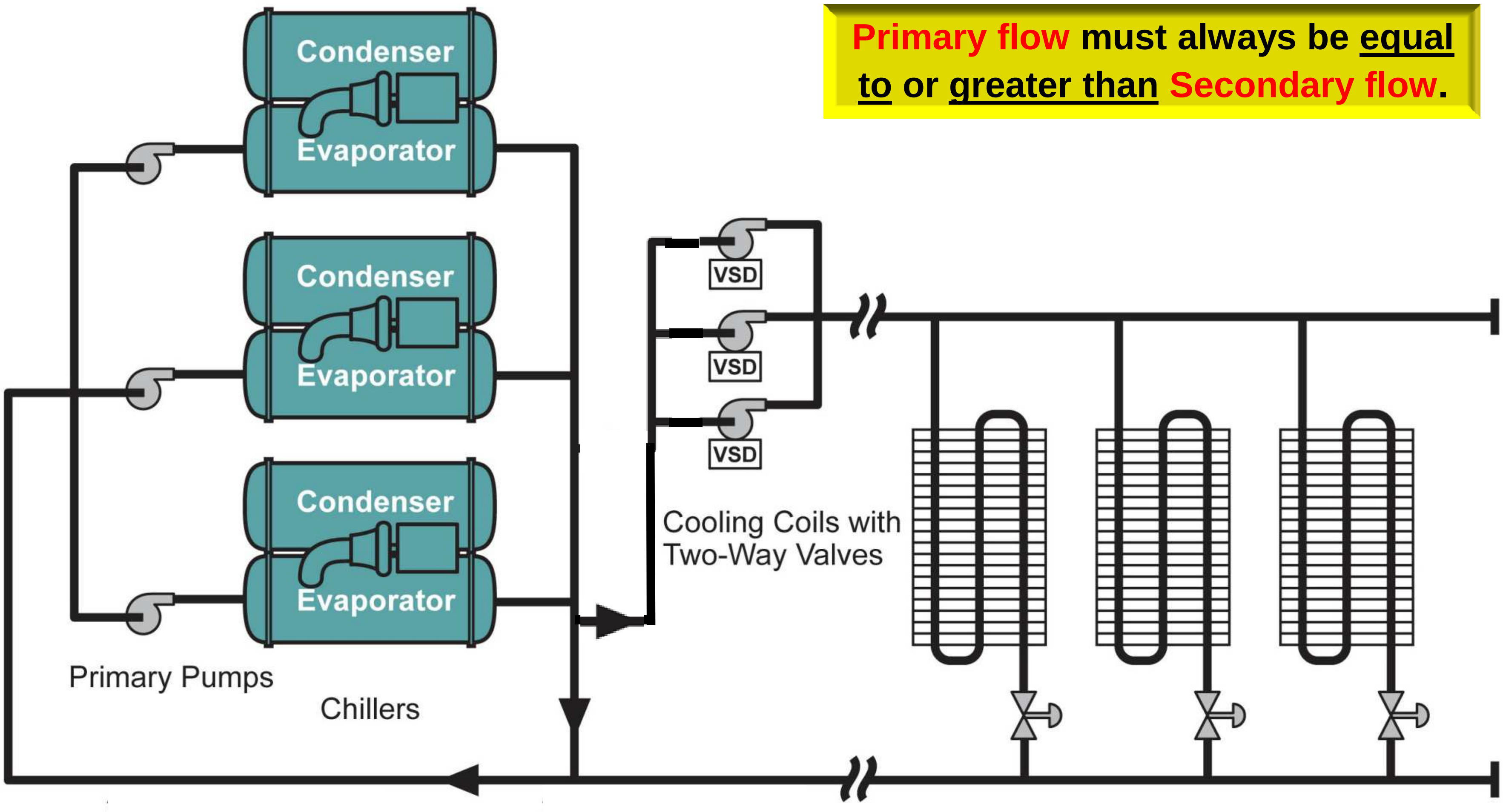
	Primary	Secondary	Bypass
Flow	3000gpm (189 l/s)	2280gpm (144 l/s)	720 gpm (0 l/s)
Delta T	8ºF (4.4ºC)	10ºF (5.6ºC)	----

67% Load = 76% Sec Flow



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

Primary flow must always be <u>equal to</u> or <u>greater than</u> Secondary 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

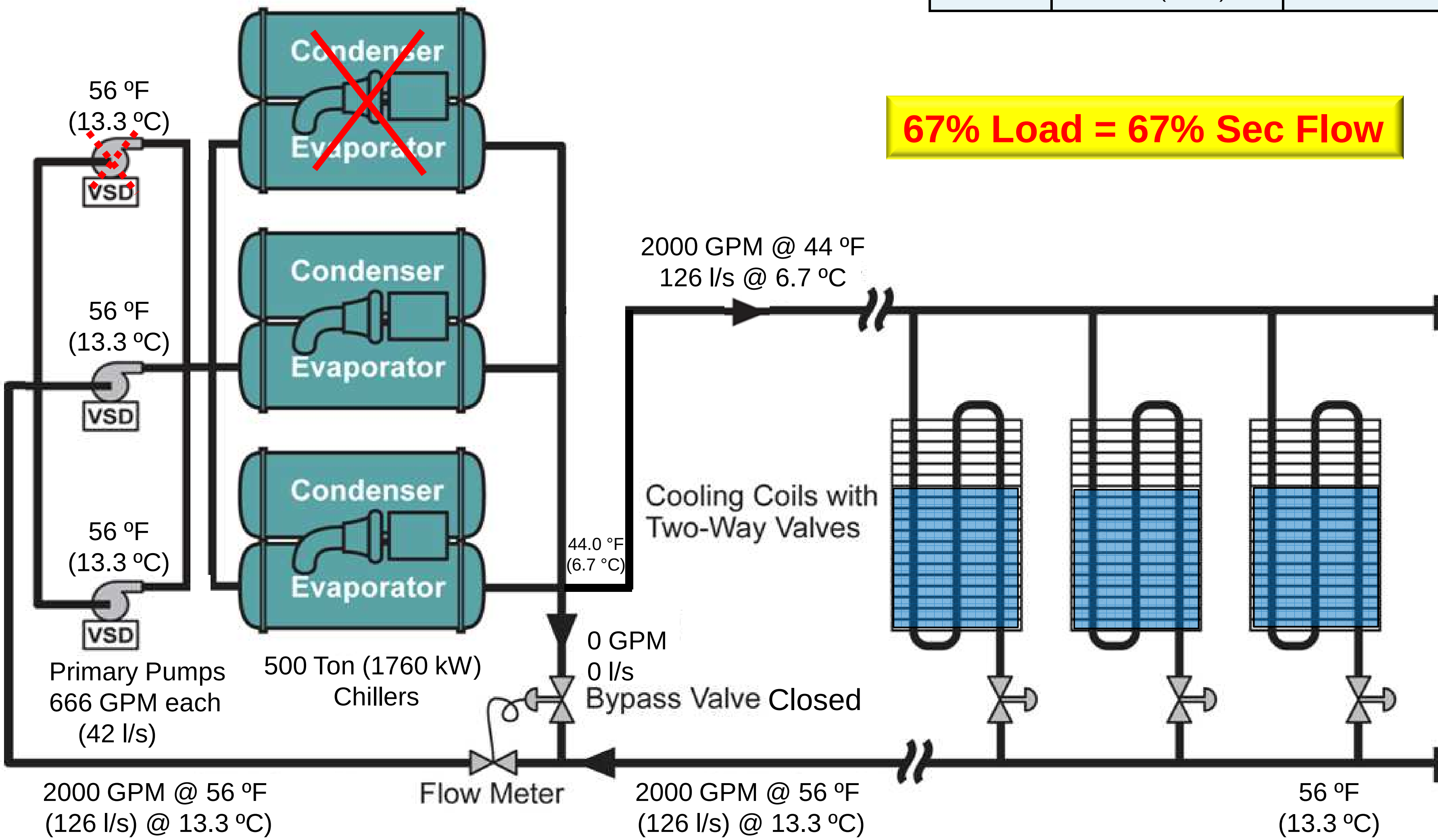
Variable Primary Flow at 67% Load

Ideal Operation

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

	Primary	Bypass
Flow	2000gpm (126l/s)	0gpm (0 l/s)
Delta T	12ºF (6.7ºC)	----

67% Load = 67% Sec Flow

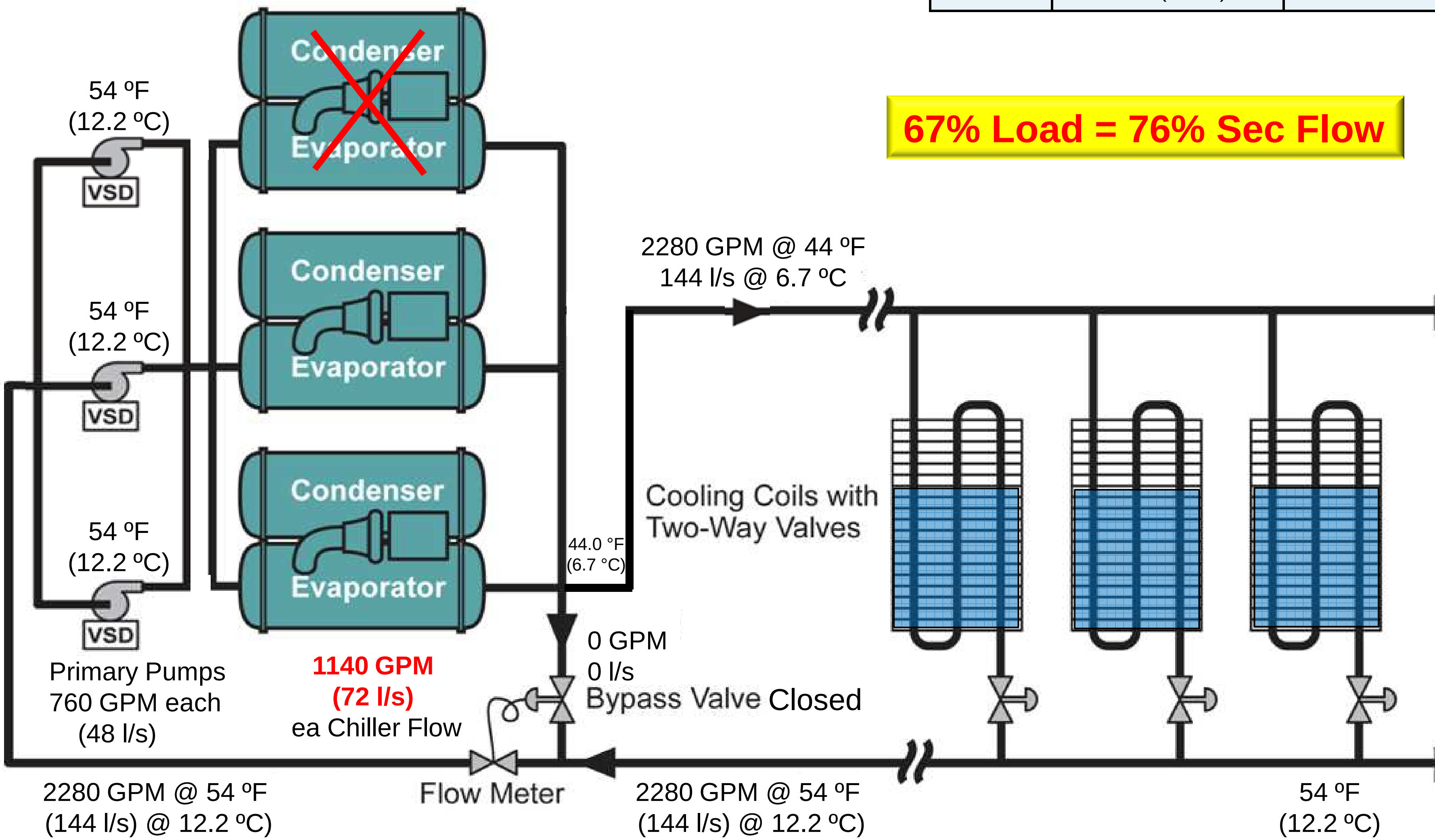


	Per Chiller	System
Load	500 Tons (1760kW)	1000 Tons (3518kW)

	Primary	Bypass
Flow	2280gpm (144l/s)	0gpm (0 l/s)
Delta T	10ºF (5.6ºC)	----

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

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)

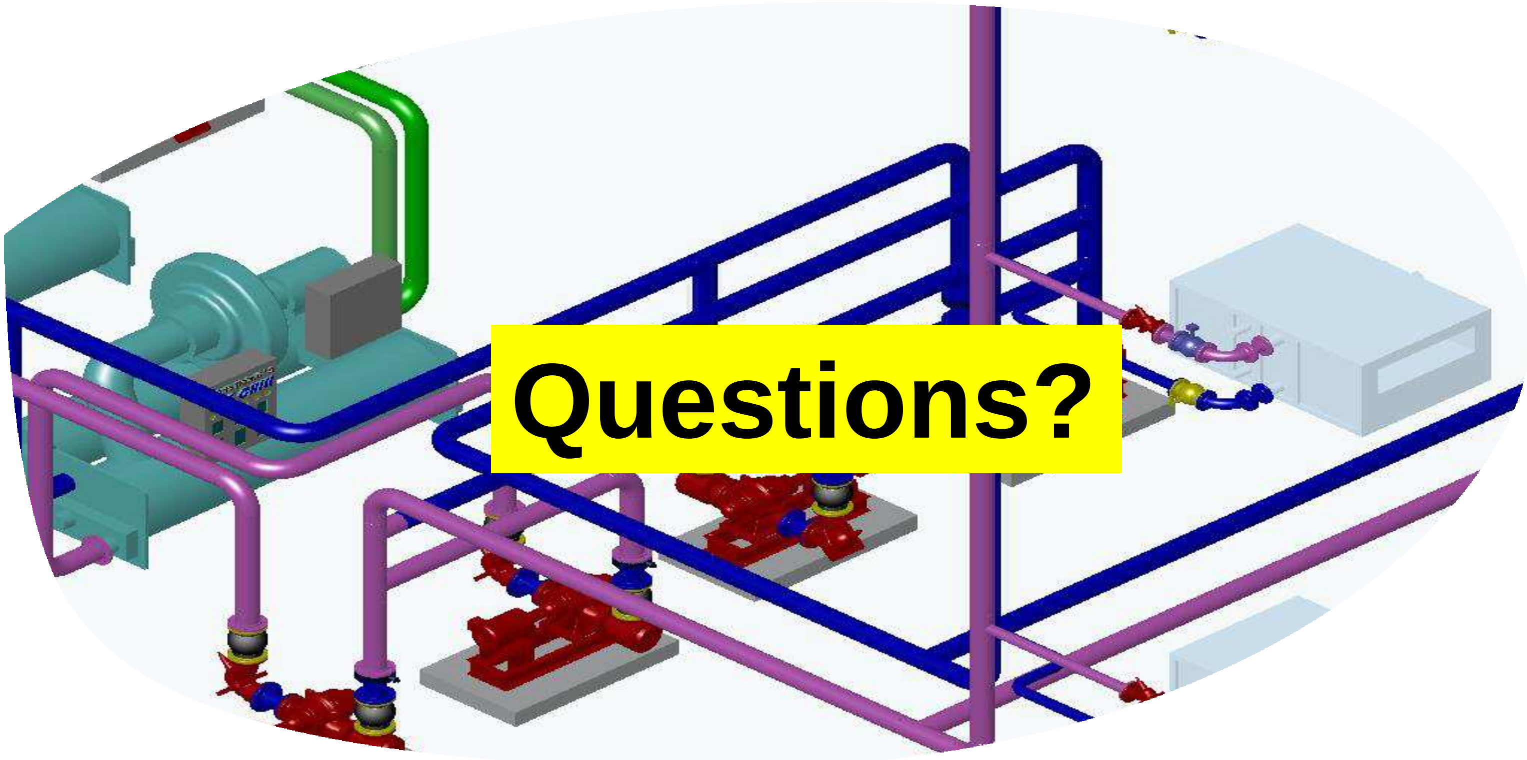
2 Way Valves

- 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



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