Chilled Water Piping Configurations

Roy Hubbard
Agenda

At the end of this session, you will understand:

- The three basic piping systems
- Low DeltaT Syndrome – causes, effects, and solutions
- Design & Control Considerations (VPF)
Chilled Water Piping System Types (typical)

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Load Valves</th>
<th>Installed Cost</th>
<th>Pumping Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Primary Flow</td>
<td>3-way</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>Primary / Secondary</td>
<td>2-way</td>
<td>Highest</td>
<td>Medium</td>
</tr>
<tr>
<td>Variable Primary Flow</td>
<td>2-way</td>
<td>Medium</td>
<td>Lowest</td>
</tr>
</tbody>
</table>
Waterside Load Equation

Load = Flow X DeltaT
Constant Primary Flow (CPF)
Constant Primary Flow (CPF)

Dedicated Pumping

Load = Flow \times \text{DeltaT}

Constant Primary Flow at 100% System Load
Three-way valves control capacity by varying water temperature range in coil

Cooling Coils with Three-Way Valves
Constant Primary Flow at **Design**

### Table: Per Chiller vs System

<table>
<thead>
<tr>
<th>Load</th>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Tons (1760kW)</td>
<td>1500 Tons (5280kW)</td>
<td></td>
</tr>
</tbody>
</table>

### Primary Flow

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

---

**Diagram Description**

1. **Condenser** and **Evaporator** temperatures are 56°F (13.3°C).
2. **Primary Pumps**: 1000 GPM Each (63 l/s).
3. **500 Ton (1760 kW) Chillers**.
4. **3000 GPM @ 56°F (189 l/s @ 13.3°C)**.
5. **Cooling Coils with Three-Way Valves**.
6. **44°F (6.7°C)**.
Constant Primary Flow at **75% Load**

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>375 Tons</td>
<td>1125 Tons</td>
</tr>
<tr>
<td>(1320 kW)</td>
<td>(3960 kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
</tr>
<tr>
<td>3000gpm (189 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
</tr>
<tr>
<td>9°F (5.6°C)</td>
</tr>
</tbody>
</table>

Primary Pumps
1000 GPM Each
(63 l/s)

500 Ton (1760 kW)
Chillers

53 °F
(11.7 °C)

53 °F
(11.7 °C)

53 °F
(11.7 °C)

3000 GPM @ 44 °F
(189 l/s) @ 6.7 °C

Cooling Coils with Three-Way Valves

53 °F
(11.7 °C)

56 °F
(13.3 °C)

44 °F
(6.7 °C)
Constant Primary Flow at **50% Load**
All Pumps & Chillers On

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>250 Tons</td>
<td>750 Tons</td>
</tr>
<tr>
<td>(880kW)</td>
<td>(2640kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
</tr>
<tr>
<td>Delta T</td>
</tr>
</tbody>
</table>

**Diagram Details:**
- **Condenser** and **Evaporator** units are shown.
- **Primary Pumps**: 1000 GPM Each (63 l/s)
- **Chillers**: 500 Ton (1760 kW)
- **Cooling Coils with Three-Way Valves**
- **Flow** at **50°F** (10 °C)
  - (189 l/s) @ 6.7 °C
Constant Primary Flow at **50% Load**
All pumps on, 2 chillers on

**Primary**

<table>
<thead>
<tr>
<th>Flow</th>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>375 Tons (1320 kW)</td>
<td>750 Tons (2640 kW)</td>
</tr>
<tr>
<td>Delta T</td>
<td>6°F (3.3°C)</td>
<td></td>
</tr>
</tbody>
</table>

**Diagram**

- **Condenser**
  - 53°F (11.7°C)
  - 53°F (11.7°C)
  - 53°F (11.7°C)

- **Evaporator**
  - 44°F (6.7°C)

- **Primary Pumps**
  - 1000 GPM Each (63 l/s)

- **Chillers**
  - 500 Ton (1760 kW)

- **3000 GPM**
  - 48°F
  - (189 l/s) @ 8.8°C

- **Cooling Coils with Three-Way Valves**
- **56°F (13.3°C)**
- **53°F (11.7°C)**

- **System**
  - 3000gpm (189 l/s)
  - 6°F (3.3°C)
Constant Primary Flow at **50% Load**
All pumps on, 2 chillers on with CHW reset

<table>
<thead>
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<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
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<td>750 Tons</td>
</tr>
<tr>
<td>1320kW</td>
<td>(2640kW)</td>
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</tbody>
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<table>
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<tbody>
<tr>
<td>Flow</td>
</tr>
<tr>
<td>3000gpm</td>
</tr>
<tr>
<td>Delta T</td>
</tr>
</tbody>
</table>

Need an automation System
Constant Primary Flow at **25% Load**

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>125 Tons (440kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
</tr>
<tr>
<td>Delta T</td>
</tr>
</tbody>
</table>

- **47 ºF (8.3 ºC)**
- **25% Load**
- **125 Tons (440kW)**
- **375Tons (1320kW)**

- **Primary Pumps**
  - 1000 GPM Each (63 l/s)
- **500 Ton (1760 kW)**
- **Chillers**

- **3000 GPM @ 44 ºF**
  - (189 l/s) @ 6.7 ºC

- **Cooling Coils with Three-Way Valves**
- **56 ºF (13.3 ºC)**
- **44 ºF (6.7 ºC)**

- **47 ºF (8.3 ºC)**
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 (all pumps on always, possibly chillers as well)
Primary (Constant) / Secondary (Variable)
Primary (Constant) / Secondary (Variable)

SLoad = Flow X DeltaT

PLoad = Flow X DeltaT
Primary (Constant) / Secondary (Variable)

Headered Pumping

[Diagram of a HVAC system showing primary pumps, condensers, evaporators, secondary pumps, cooling coils, and two-way valves.]
Primary (Constant) / Secondary (Variable)

Dedicated Pumping
Primary (Constant) / Secondary (Variable)

Rule of Flow

Primary flow must always be equal to or greater than Secondary flow.
Primary/Secondary at Design

<table>
<thead>
<tr>
<th>Load</th>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Tons</td>
<td>500 Tons (1760 kW)</td>
<td>1500 Tons (5280 kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow</th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 gpm (189 l/s)</td>
<td>3000 gpm (189 l/s)</td>
<td>0 gpm (0 l/s)</td>
<td></td>
</tr>
<tr>
<td>Delta T</td>
<td>12°F (6.7°C)</td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

100% Load = 100% Sec Flow

100 ft (303 kPa) Head

Cooling Coils with Two-Way Valves

56 °F (13.3 °C)
Primary/Secondary at 75% Load

<table>
<thead>
<tr>
<th>Flow</th>
<th>Per Chiller</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000gpm (189 l/s)</td>
<td>375 Tons (1320kW)</td>
<td>2250gpm (142 l/s)</td>
<td>750gpm (47 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td>9°F (5°C)</td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

75% Load = 75% Sec Flow
Primary/Secondary at 50% Load

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>375 Tons</td>
<td>750 Tons</td>
</tr>
<tr>
<td>1320kW</td>
<td>2640kW</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Flow</td>
<td>Flow</td>
</tr>
<tr>
<td>2000gpm</td>
<td>1500gpm</td>
<td>500gpm</td>
</tr>
<tr>
<td>(126 l/s)</td>
<td>(95 l/s)</td>
<td>(32 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9°F (5°C)</td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

50% Load = 50% Sec Flow

Primary Pumps
1000 GPM Each
(63 l/s)

500 Ton (1760 kW)
Chillers

Secondary Pumps
1500 GPM @ 44 °F
95 l/s @ 6.7 °C

Cooling Coils with Two-Way Valves

2000 GPM @ 53 °F
(126 l/s) @ 11.7 °C

1500 GPM @ 56 °F
(95 l/s) @ 13.3 °C

56 °F
(13.3 °C)
Primary/Secondary at 25% Load

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
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<tbody>
<tr>
<td>Load</td>
<td>375 Tons (1320 kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow</th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>1000gpm (126 l/s)</td>
<td>750gpm (47 l/s)</td>
<td>250gpm (16 l/s)</td>
</tr>
<tr>
<td>Secondary</td>
<td>9°F (5°C)</td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

25% Load = 25% Sec Flow

Primary Pumps
1000 GPM Each
(63 l/s)

Cooling Coils with Two-Way Valves
250 GPM @ 44°F
16 l/s @ 6.7°C

Secondary Pumps
750 GPM @ 44°F
47 l/s @ 6.7°C

Chillers
500 Ton (1760 kW)

**Delta T**

- 9°F (5°C)
- 12°F (6.7°C)
- ----

**25% Load at 25% Sec Flow**
What Controls the Flow of the Secondary Loop?

But what controls the VSD’s?
Valve Controls Leaving Air Temperature (LAT)
Valve Controls Leaving Air Temperature (LAT)
Set Point = 55° (12.8°) LAT

EAT = 80 (26.7)

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

AIR FLOW
EAT = 79 (26.1)

LAT = 54 (12.2)
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

Set Point
P=25 ft (76 kPa)
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
- Lower pump energy cost than CPF

Disadvantages
- Higher Pump Energy Cost vs VPF
- 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

Load = Flow \times \Delta T

Variable Primary Flow at 100% System Load
Two-way valves control capacity
By varying flow of water in coils

Primary Pumps

Condenser
Evaporator

Condenser
Evaporator

Condenser
Evaporator

Chillers

Flow Meter

Bypass Valve Closed

Cooling Coils with Two-Way Valves
Primary/Secondary System

Four Differences?

Variable Primary System
Variable Primary Flow at Design

<table>
<thead>
<tr>
<th>Primary</th>
<th>Bypass</th>
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<tbody>
<tr>
<td>Flow</td>
<td>3000gpm (189 l/s)</td>
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</table>

100% Load = 100% Flow
Variable Primary Flow at 75% Load

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
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<tbody>
<tr>
<td>Load</td>
<td>375 Tons (1320kW)</td>
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</tbody>
</table>

Primary Bypass

<table>
<thead>
<tr>
<th>Flow</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2250 gpm (189 l/s)</td>
<td>0 gpm (0 l/s)</td>
</tr>
</tbody>
</table>

Delta T

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12°F (6.7°C)</td>
</tr>
</tbody>
</table>

75% Load = 75% Flow

Primary Pumps
750 GPM each
(47 l/s)

2250 GPM @ 56 °F
(142 l/s) @ 13.3 °C

Cooling Coils with Two-Way Valves

Flow Meter

56 °F
(13.3 °C)
Variable Primary Flow at 50% Load

Primary Pumps
750 GPM each
(47 l/s)

1500 GPM @ 56 °F
(95 l/s) @ 13.3 °C)

Cooling Coils with Two-Way Valves

0 GPM @ 44 °F
0 l/s @ 6.7 °C
Bypass Valve Closed

1500 GPM @ 56 °F
(95 l/s) @ 13.3 °C)

56 °F
(13.3 °C)

Flow Meter

1500 GPM @ 56 °F
(95 l/s) @ 13.3 °C)

56 °F
(13.3 °C)

<table>
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<tr>
<td>(1320 kW)</td>
<td>(2640 kW)</td>
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<th>Bypass</th>
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<tbody>
<tr>
<td>Flow</td>
<td></td>
</tr>
<tr>
<td>1500 gpm</td>
<td>0 gpm</td>
</tr>
<tr>
<td>(95 l/s)</td>
<td>(0 l/s)</td>
</tr>
<tr>
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</tr>
<tr>
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<td>----</td>
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</tbody>
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50% Load = 50% Flow
Variable Primary Flow at 25% Load

<table>
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<th></th>
<th>Per Chiller</th>
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<td>Load</td>
<td>375 Tons (1320kW)</td>
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</tr>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>750 gpm (95 l/s)</td>
<td>0 gpm (0 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

25% Load = 25% Flow

Primary Pumps
750 GPM (47 l/s)

750 GPM @ 44 °F
47 l/s @ 6.7 °C

Cooling Coils with Two-Way Valves

Flow Meter
0 GPM @ 44 °F
0 l/s @ 6.7 °C
Bypass Valve Closed

750 GPM @ 56 °F
(47 l/s) @ 13.3 °C

56 °F (13.3 °C)
Variable Primary Flow in **Bypass Mode**

System flow below chiller min flow (250 gpm)

<table>
<thead>
<tr>
<th></th>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load</strong></td>
<td>50 Tons (176kW)</td>
<td>50Tons (176 kW)</td>
</tr>
<tr>
<td><strong>Primary</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flow</strong></td>
<td>250 gpm (95 l/s)</td>
<td>150 gpm (9.5 l/s)</td>
</tr>
<tr>
<td><strong>Delta T</strong></td>
<td>12°F (6.7°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

**Primary Pumps**
- 250 GPM @ 48.8 °F (15.8 l/s) @ 9.3 °C

**Cooling Coils with Two-Way Valves**
- 150 GPM @ 44 °F 9.5 l/s @ 6.7 °C
- Open

**Flow**
- 250 GPM @ 48.8 °F (15.8 l/s) @ 9.3 °C
- 100 GPM @ 56 °F (6.3 l/s) @ 13.3 °C
- 56 °F (13.3 °C)
Varying Flow Through Chillers - Issues

- **Issue 1 - 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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  - 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 2 - Adding Chillers**
  - Add chiller to sequence…operating chillers experience nuisance trips off-line (annoying)
Variable Primary System – Staging on chillers & changes in flow rate

Current Situation – 1 chiller running

<table>
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<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>500 Tons (1760kW)</td>
<td>500 Tons (1934kW)</td>
</tr>
</tbody>
</table>

Primary Pumps
500 GPM each
(32 l/s)

1000 GPM @ 56 °F
(63 l/s @ 13.3 °C)

44.0 °F
(6.7 °C)

Cooling Coils with
Two-Way Valves

Bypass Valve Closed

Flow Meter

1000 GPM @ 44 °F
63 l/s @ 6.7 °C
Variable Primary System – Staging on chillers & changes in flow rate

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

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>275 Tons (967kW)</td>
</tr>
</tbody>
</table>

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

Primary Pumps
550 GPM each (35 l/s)

1100 GPM @ 57 ºF
(69 l/s @ 13.9 ºC)

Flow Meter

Bypass Valve Closed

Condenser

Evaporator

Condenser

Evaporator

Condenser

Evaporator

1100 GPM @ 45 ºF
69 l/s @ 7.2 ºC

Cooling Coils with Two-Way Valves

57 ºF
(13.9 ºC)
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 (Total Head is 50 + 100 = 150 ft)
Variable Primary Flow \( (\text{Total Head is } 50 + 100 - 10 = 140) \)

- 140 ft \((424 \text{ kPa})\) Head
- 500 Ton \((1760 \text{ kW})\) Chillers
- 1000 GPM each \((63 \text{ l/s})\) Primary Pumps
- 0 GPM @ 44 °F, 0 l/s @ 6.7 °C Bypass Valve Closed
- 0 GPM @ 44 °F, 189 l/s @ 6.7 °C
- 3000 GPM @ 44 °F, 189 l/s @ 6.7 °C
- 3000 GPM @ 56 °F, 189 l/s @ 13.3 °C
- 189 l/s @ 6.7 °C
- 3000 GPM @ 56 °F, 189 l/s @ 13.3 °C
- 3000 GPM @ 56 °F, 189 l/s @ 13.3 °C

13.3 °C}
Pump Energy (water as fluid)

\[ \text{BHP} = \frac{\text{GPM} \times \text{Head}}{3960 \times \text{Pump}_{\text{Eff}}} \]
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
  - **Higher Pump Efficiency**
Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
Pump Curves - Pump Efficiency

With VPF you will need larger impellers compared to P/S, but they will be operating at a more efficient point, yielding energy savings.
Pump Energy (water as fluid)

\[ \text{BHP} \downarrow = \frac{\text{GPM} \times \text{Head}}{3960 \times \text{Pump}^{\text{Eff}}} \]
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

- **Advantages**
  - Medium Installed Cost (approx. 5% compared P/S)
    - No secondary Pumps or piping, valves, electrical, installation, etc.
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  - Less Plant Space Needed (vs P/S)
  - Best Chilled Water Pump Energy Consumption (most optimally 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
  - Can be limited on flexible expandability of the plant
  - 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

Design Delta T = 12°F

Primary Pumps

Condenser
Evaporator
Condenser
Evaporator
Condenser
Evaporator

Secondary Pumps

Cooling Coils with Two-Way Valves

Chillers

VSD

44°F

56°F
Major Causes of Low Delta T

- Dirty Coils
Chilled Water Coil
Chilled Water Coil

Load = Flow X Delta T

56 (13.3)

44 (6.7)
Chilled Water Coil

Load = Flow \times \Delta T
Major Causes of Low Delta T

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

AIR FLOW

56 (13.3)

44 (6.7)
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

Condenser
Evaporator
Condenser
Evaporator
Condenser
Evaporator

Primary Pumps
Chillers

Secondary Pumps

Cooling Coils with Two-Way Valves

VSD

44°F

56°F
Primary/Secondary at Design

Ideal Operation

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>500 Tons (1760kW)</td>
<td>1500 Tons (5280kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>3000gpm (189 l/s)</td>
<td>3000gpm (189 l/s)</td>
<td>0 gpm (0 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td>12ºF (6.7ºC)</td>
<td>12ºF (6.7ºC)</td>
<td>----</td>
</tr>
</tbody>
</table>

100% Load = 100% Sec Flow

12ºF (6.7ºC)
Primary/Secondary at 67% Load

Ideal Operation

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>500 Tons</td>
<td>1000 Tons</td>
</tr>
<tr>
<td>1760 kW</td>
<td>3518 kW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow</th>
<th>Flow</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000gpm (126 l/s)</td>
<td>2000gpm (126 l/s)</td>
<td>0 gpm (0 l/s)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Delta T</th>
<th>Per Chiller</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>12ºF (4.4ºC)</td>
<td>12ºF (6.7ºC)</td>
<td>----</td>
<td></td>
</tr>
</tbody>
</table>

Primary/Secondary

- Condenser
- Evaporator

56 ºF (13.3 ºC)

Primary Pumps
1000 GPM Each
(63 l/s)

2000 GPM @ 56 ºF
(126 l/s) @ 13.3 ºC)

Secondary Pumps
2000 GPM @ 44 ºF
126 l/s @ 6.7 ºC

Cooling Coils with Two-Way Valves

44 ºF (6.7 ºC)

67% Load = 67% Sec Flow

12ºF (6.7ºC)
Primary/Secondary at 67% Load

Low DeltaT

### System Load

<table>
<thead>
<tr>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>500 Tons (1760kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow</th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000gpm (126 l/s)</td>
<td>2280gpm (144 l/s)</td>
<td>280 gpm (0 l/s)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Delta T</th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°F (5.6°C)</td>
<td>10°F (5.6°C)</td>
<td>----</td>
<td></td>
</tr>
</tbody>
</table>

### Flow and Delta T

- **Primary Pumps**: 1000 GPM Each (63 l/s)
- **Secondary Pumps**: 2280 GPM @ 44°F (144 l/s @ 6.7°C)
- **Bypass Flow**: 280 GPM @ 54°F (12.2°C)

**67% Load = 76% Sec Flow**
Primary/Secondary at 67% Load

Low DeltaT

<table>
<thead>
<tr>
<th></th>
<th>Per Chiller</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>417 Tons (1467kW)</td>
<td>934 Tons (3286kW)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>2000gpm (126 l/s)</td>
<td>2280gpm (144 l/s)</td>
<td>280 gpm (18l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td>10°F (5.6°C)</td>
<td>10°F (5.6°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

67% Load = 76% Sec Flow
Primary/Secondary at 67% Load

Low DeltaT

<table>
<thead>
<tr>
<th>System</th>
<th>Primary</th>
<th>Secondary</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>333 Tons (1172kW)</td>
<td>1000 Tons (3518kW)</td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>3000gpm (189 l/s)</td>
<td>2280gpm (144 l/s)</td>
<td>720 gpm (0 l/s)</td>
</tr>
<tr>
<td>Delta T</td>
<td>8°F (4.4°C)</td>
<td>10°F (5.6°C)</td>
<td>----</td>
</tr>
</tbody>
</table>

67% Load = 76% Sec Flow

- Condenser
- Evaporator
- Secondary Pumps
  - 2280 GPM @ 44 °F
  - 144 l/s @ 6.7 °C
- Cooling Coils with Two-Way Valves
- Primary Pumps
  - 1000 GPM Each
  - (63 l/s)
- 3000 GPM @ 52 °F
  - (189 l/s) @ 11.1 °C
- 2280 GPM @ 54 °F
  - (144 l/s) @ 12.2 °C
- 720 GPM @ 44 °F
  - 45 l/s @ 6.7 °C
- 44 °F
  - (6.7 °C)
- 54 °F
  - (12.2 °C)
Primary (Constant) / Secondary (Variable)

Rule of Flow

Primary flow must always be equal to or greater than 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

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<tbody>
<tr>
<td>Load</td>
<td></td>
</tr>
<tr>
<td>500 Tons</td>
<td>1000 Tons</td>
</tr>
<tr>
<td>(1760kW)</td>
<td>(3518kW)</td>
</tr>
</tbody>
</table>

Primary

<table>
<thead>
<tr>
<th>Flow</th>
<th>Bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000gpm</td>
<td>0gpm</td>
</tr>
<tr>
<td>(126l/s)</td>
<td>(0 l/s)</td>
</tr>
</tbody>
</table>

Delta T

| 12°F (6.7°C) | ---- |

67% Load = 67% Flow
Variable Primary Flow at 67% Load

Low ΔT (can over-pump chillers)

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<tbody>
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<td>Flow</td>
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<tr>
<td>2280gpm (144l/s)</td>
<td>0gpm (0 l/s)</td>
</tr>
<tr>
<td>ΔT</td>
<td></td>
</tr>
<tr>
<td>10°F (5.6°C)</td>
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</tbody>
</table>

67% Load = 76% 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
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
Review Chilled Water Piping Configurations

- Name the 3 basic piping configurations
- Finish Equation: Load = ? X ?
- What is the Rule of Flow in P/S configuration?
- What are the three negative impacts of Low DeltaT Syndrome
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 – Load-based sequencing…run chillers to max load (Supply Temp rise). Do not run more chillers than needed (water-cooled, single compressor assumed)
Energy-Based Sequencing of Chillers (CSD Example)
Max Cap Sequencing of Chillers (CSD Example)
VPF Systems Design/Control Considerations

- **Chillers**
  - Equal Sized Chillers preferred, but not required
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- **Sequence**
  - If CSD Chillers – Load-based sequencing…run chillers to max load (Supply Temp rise). Do not run more chillers than needed (water-cooled, single compressor assumed)
  - If VSD Chillers – Energy-based sequencing…run chillers between 30% and 70% load (depending on ECWT and actual off-design performance curves). Run more chillers than load requires.
Energy-Based Sequencing of Chillers (VSD Example)
VPF Systems Design/Control Considerations

- **Chillers**
  - Equal Sized Chillers preferred, but not required
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- **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 (but run an extra pump than # chillers for over-pumping in low delta T situations)
  - 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 Time) 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 (flow to time)
- 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)