Chilled Water System Presentation
Constant Volume Distribution
Air-conditioning System Components
Constant Volume System Components
Typical 3-way Valve Zone
Full Load Condition

100 GPM @ 20 Ft
Load

0 GPM @ 0 Ft

Valve P.D. = 10 Ft
3 Way Valve

Balancing Valve

100 GPM at 45°F

100 GPM at 55°F
### Fully Loaded Coil

- Supply water temperature: 45°F
- Design return water temp: 55°F
- Coil design flow: 100 GPM
- Coil design pressure drop: 20 FT
- Load \( \text{(flow} \times 10^\circ\text{F} \Delta \times 500) \): 500,000 Btuh
- Coil \( \Delta P @ \text{design flow} \): 20 FT
- Bypass flow: 0 GPM
- Bypass \( \Delta P \): 3-way valve closed
- 3-way valve pressure drop: 10 FT
- Pump flow and head: 100 GPM @ 30 FT
- Actual return water temp: 55 °F
Unloaded Condition

0 GPM @ 0 Ft
Load

100 GPM @ 20 Ft

Valve P.D. = 10 Ft
3 Way Valve

Balancing Valve

100 GPM @ 45°F
Pump Provides 30 Ft D.P.
Across Supply & Return

100 GPM

A

B
Unloaded Coil

- Supply water temperature: 45°F
- Design return water temp.: 55°F
- Coil design flow: 0 GPM
- Coil design pressure drop: 3-way valve closed
- Load (flow x 10°FΔ x 500): 0.0 Btuh
- Coil ΔP @ design flow: 0 FT
- Bypass flow: 100 GPM
- Bypass ΔP: 20 FT
- 3-way valve pressure drop: 10 FT
- Pump flow and head: 100 GPM @ 30 FT
- Actual return water temp: 45 °F
• When the load on the coil is zero, the valve is returning “unused” chilled water at essentially supply temperature.
• Cold return water “unloads” the chillers, causing them to operate inefficiently.
Part Load Condition

50 GPM @ 5 Ft Load

? GPM @ ? Ft

Valve P.D. = 10 Ft
3 Way Valve

Balancing Valve

?? GPM at ??°F

Pump Provides 30 Ft differential

?? GPM at ??°F ??
Partially Loaded Coil

- Supply water temperature: 45°F
- Design return water temp: 55°F
- Coil design flow: 50 GPM
- Coil design pressure drop: 20 FT
- Load (flow x 10°FΔ x 500): 250,000 Btuh
- Coil ΔP @ design flow: 5 FT
- Bypass flow: ??? GPM
- Bypass ΔP: 3-way partially closed
- 3-way valve pressure drop: 10 FT
- Pump flow and head: ??? GPM @ 30 FT
- Actual return water temp: ?? °F
3-way Valve Characteristic

- 1/2 Through Coil
- 1/2 Through Bypass

% Valve Stroke vs. % Flow

- Full Flow Through Coil
- Full Flow Through Bypass
What’s Really Happening?

62.5 GPM @ ? Ft
Load

Valve P.D. = 10 Ft
3 Way Valve

Balancing Valve

62.5 GPM @ ? Ft

125 GPM at 45°F

Secondary Pump Creates 30 Ft D.P.
Across Supply & Return

?? GPM at ??°F

?? GPM at ??°F
Coil with 3-way Valve at Mid-position

- Supply water temperature: 45 °F
- Design return water temp: 55 °F
- Load (flow x 10°FΔ x 500): 250,000 Btuh
- Coil design pressure drop: 20 FT
- Coil flow: 62.5 GPM
- Coil ΔP @ 62.5% flow: 7.8 FT
- Coil leaving water temp: 53 °F
- Bypass flow: 62.5 GPM
- Bypass ΔP: 7.8 FT
- 3-way valve pressure drop: 10 FT
- Pump flow and head: 125 GPM @ 30 FT
- Actual return water temp: 49 °F (62.5 GPM @ 53 °F + 62.5 GPM @ 45 °F)
Head₂ = Head₁(Flow₂/ Flow₁)²

Head₂ = 20(.625/1)²

Head₂ = 20(.3906)

Head₂ = 7.8
\[ \Delta T = \frac{\text{Load}}{\text{Flow}} \times 500 \]

\[ \Delta T = \frac{250,000}{62.5} \times 500 \]

\[ \Delta T = 8 \]

Therefore, \( \text{LWT}_{\text{coil}} = 45 + 8 = 53 \)
RWT = (Flow₁ X EWT + Flow₂ X LWT)/ Flow₁ + 2

RWT = (62.5 X 45 + 62.5 X 53)/125

RWT = 49
3-way Valve in Mid Position

62.5 GPM @ 53°F
Load

62.5 GPM @ 45°F

Valve P.D. = 10 Ft
3 Way Valve

Balancing Valve

125 GPM at 45°F

125 GPM at 49°F

Secondary Pump Creates 30 Ft D.P.
Across Supply & Return

A
B
1. Low return water temperatures.
2. Robs chilled water from other coils at part load conditions.
3. Increases flow in primary piping.
4. Adds additional chillers on line.
5. Chiller performance is reduced.
Chiller Performance Curve

KW per Ton vs Percent Load

- KW per Ton decreases as Percent Load increases.
- The curve shows a significant drop in KW per Ton from 1.1 at 10% load to approximately 0.6 at 80% load.
- Beyond 80% load, the change in KW per Ton is minimal.

This graph illustrates the efficiency of chiller performance under varying load conditions.
Pump Sizing

- Select for full chiller flow
- Head must be adequate for:
  - Chiller evaporator
  - Longest circuit
  - Coil
  - Three way valve
  - Air separator
System Configuration

- Chiller Pump: 2 @ 625 Tons
- Constant Speed: 1500 GPM
- 75 Hp Each
- Balancing Valve
- Load
- 3 Way Valve
- Air-Separator

FLOW THINKING
Any Questions?
Variable Volume Constant Speed
Primary – Secondary System

**Primary** – Includes Chillers & Primary Pump. Constant water flow through the chiller is maintained and chilled water is produced.

**Secondary** – Chilled water is circulated to the demand area (load) by using Secondary pumps.
PRIMARY - SECONDARY

Primary Circuit | Secondary Circuit
Other Famous Names of Primary-Secondary

Primary – Production Loop

Secondary – Distribution Loop
Fundamental Idea

Load

A

B

Negligible Pressure Drop
No Secondary Flow

100 GPM @ 45°F

Secondary Pump: Off
Primary = Secondary

Load

100 GPM @ 45°F

Pump On

100 GPM @ 45°F

A
0 GPM

B

100 GPM @ 55°F
50 GPM @ 45°F
Pump On
100 GPM @ 45°F

Load

50 GPM @ 55°F
Mixing at Tee B

100 GPM @ 50°F
Primary < Secondary

Load

200 GPM @ 50°F

Pump On

200 GPM @ 55°F

100 GPM @ 45°F

Mixing at Tee A

100 GPM @ 55°F

100 GPM @ 55°F

A

B

100 GPM @ 55°F
Control Valve in Secondary

Load

Two-way Valve
Common Pipe Design Criteria

- Use the flow of the largest chiller
  - Chiller staging at half of this flow is common
- Head loss in common <1 1/2 ft
  - Distribution pipe size is often used where reductions would be inconvenient
- Three pipe diameters between tees
  - Excessive length increases total head loss
- Low velocities in system piping
Control Valve in Secondary

Variable flow through coil
Constant flow through system

Three Way Valve

Variable flow through coil
Variable flow through system

Two Way Valve
PRIMARY – SECONDARY CIRCUIT

- Chillers
- Primary Pumps
- Secondary Pumps
- Load
- Balancing Valve
- Air-Separator
- 2 Way Valve
Control Valves Change the Secondary System Curve
Head Absorbed by 2-way Valves

- TDH of pump
- Varying differential pressure absorbed by control valve
- System resistance

% Flow
Pump Horsepower Comparison

- **Constant Flow Primary Pumps, only**
- **Secondary Pumps**
- **Primary Pumps = V/V**

% Design Flow vs. HP
Constant vs Variable Volume

- **Base Design HP %**
- **% Full Load (Design) HP**

Graph showing the comparison between Constant Flow, C/S Pump (3 Way Valve) and Variable Flow, C/S Pump (2 Way Valve) in terms of HP and Flow. The graph illustrates the efficiency and performance differences between constant and variable volume systems.
Any Questions?
Step Function of Chillers
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FLOW THINKING

Distribution > Production

CHWS Temp 47.5°F

Secondary Pumps

Mixing (1500 @ 45) + (500 @ 55)

Common -- 500

ECW Temp 55°F

CHWR Temp 55°F

Chiller 2 OFF

Chiller 1 ON

0 1500

2000

2000

BE THINK INNOVATE
P/S Chiller Bridge - Front Loaded Common

(Flow in GPM)

Chiller 2
ON

Chiller 1
ON

1500

1500

3000

2100

Common – 900

Mixing (2100 @ 55) + (900 @ 45)

ECW Temp
52°F

CHWS Temp
45°F

Secondary Pumps

CHWR Temp
55°F

BE THINK INNOVATE
A chiller is a heat transfer device. Like most equipment, it is most efficient at full load.

To “load” a chiller means:
  – Supply it with its rated flow of water
  – Insure that water is warm enough to permit removal of rated Btu without freezing the water
Chiller Performance Curve

KW per Ton vs Percent Load

- KW per Ton: 0.5 to 1.1
- Percent Load: 10 to 100
Check Valve in Common?

- Chiller 2 OFF
- Chiller 1 ON

Supply: >1500 GPM @ 47.5°F

Return: >1500 GPM @ 55°F

Common: 0 GPM

Wrong!
What can we do?
• Lower chiller set point when mixing occurs to maintain a constant temperature to the system.
• Expect increases in cost of chiller operation at lower set point: 1-3% per degree of reset.
• Delays start of the next chiller.
• Coils that are selected at higher supply temperatures will not be impaired by small changes.
• Loads that require fixed temperatures may use a small chiller to reverse the effects of mixing.
Multiple Chillers

- Chiller 1
- Chiller 2

<table>
<thead>
<tr>
<th>% Time</th>
<th>% Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>75</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
</tr>
</tbody>
</table>

Chiller 2: 60%
Chiller 1: 40%
60/40 Chiller Split to Help Minimize Low Part Load Operation
Typical Load Profile

![Graph showing typical load profile with % Time on the y-axis and % Load on the x-axis. The bars represent load percentages ranging from 0-10, 30-40, 60-70, and 90-100. The highest percentage is in the 60-70 range.]

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FLOW THINKING
Three Unequally Sized Chillers
Approaching Flow = Load

% Load

Time
Any Questions?
Two Pipe Direct Return
Two Pipe Reverse Return
Primary-Secondary Pumping.

- Simplest to install.
- Simplest to operate.
- Flexible in design for present and future.
- Efficient to operate.

- May over-pressurize near zones.
Primary-Secondary-Tertiary
Primary-Secondary-Tertiary Pumping.

- Best piping flexibility.
- Best expansion flexibility.
- Provides hydraulic decoupling.
- Efficient to operate.

- May require added horsepower.
- Requires additional pumps and piping.
- Increased controls complexity.
Primary-Secondary-Tertiary Hybrid
Primary-Secondary-Tertiary Hybrid Pumping.

- Low present horsepower.
- Low future horsepower.
- Good piping flexibility.
- Good expansion flexibility.
- Provides hydraulic decoupling.

- May require added horsepower
- Requires additional pumps and piping.
- Increased controls complexity.
Primary-Secondary Zone Pumping
Primary-Secondary Zone Pumping.

- Low ‘built out’ horsepower.
- Low system head.

- Increased control complexity.
- Present horsepower total higher due to future needs.
- Present pumps sized for future requirements.
- Difficult to apply in retrofits projects.
Any Questions?
Variable Volume Variable Speed
Why Do We Need Variable Speed Secondary Pumps ???

• For Energy Saving....

• For better & optimise operation....
How Do We Achieve This Reduction In Power Consumption ??

By Using Variable Frequency Drive and Logic controller with the Secondary Pumps....
Power Comparison at Reduced Speed

![Graphs showing power comparison at reduced speed.](image)
Basic Law which helps in achieving this – Affinity law

1. \( \text{Flow}_2 = \text{Flow}_1 \left( \frac{\text{Speed}_2}{\text{Speed}_1} \right) \)
2. \( \text{Head}_2 = \text{Head}_1 \left( \frac{\text{Speed}_2}{\text{Speed}_1} \right)^2 \)
3. \( \text{BKW}_2 = \text{BKW}_1 \left( \frac{\text{Speed}_2}{\text{Speed}_1} \right)^3 \)

If Diameter of Impeller is to be trimmed then instead of speed the same can be used in above formulas.
Variable flow system

System Curve as two way valves close

Pump Curve

Head

Flow
Energy savings offset

- Pump Curve
- System Curve at part load
- System Curve at design flow
- Increased head loss

H vs Q graph
Pumps in parallel
Parallel pumping power savings

Horsepower %

Flow %

Single Large Pump

Two Parallel Pumps

Single Parallel Pump
Theoretical Savings

- Pump Curves
- 100% Speed
- 90%
- 80%
- 70%
- 60%
- 50%
- 40%
- 30%
- Design
- Head
- HP Draw
- BHP
- Flow

% Head vs. % Design Flow graph

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FLOW THINKING

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Establishing Efficiency Curves

% Speed Curves

Constant Efficiency Curve

Head, Feet

GPM
“No Valve” System Curve

25 FT Differential Head Maintained Across Load (Set Point)

Overall system curve

Distribution piping head loss curve

Flow

Head

Pump TDH

Set Point
Effect of Constant Set Point

- Control curve
- Overall system curve
- Distribution piping head loss curve

Flow vs. Head graph with
- Set point, 25 FT
- Pump TDH
Control curve

- Flow
- Head
- Control curve
- Variable head loss
- ΔP
- P1
- P2
- 100%
- 75%
- 50%
Large systems, long pipe runs

Annual Operating Cost
($1000/year @ $0.10/kwh)
Variable Head Loss Ratio

C/S, Constant Flow System
Pump Head Matched to System at Design Flow

Base

C/S, Variable Flow

Percent Design BHP

V/S, 0% Variable Hd Loss, 100% Constant ∆ Hd

V/S, 25% Variable Hd Loss, 75% Constant ∆ Hd

V/S, 50% Variable Hd Loss, 50% Constant ∆ Hd

V/S, 75% Variable Hd Loss, 25% Constant ∆ Hd

V/S, 100% Variable Hd Loss, 0% Constant ∆ Hd

% Flow
Variable Head Ratio w/ Overheading

- **Constant Flow, C/S Pump**
  - Pump O'Headed by 150%
  - (3 Way Valve)
- **C/S Pump**
  - (2 Way Valve)

- **Base Design HP %**
- **% Full Load (Design) HP**

*25/75 Means: 25 % Variable HD Loss
75 % Constant HD Loss*
Locations of Sensor

Where to install the Sensor?

What type of Sensor?
Single Point Pressure Sensor
Is Single Point Pressure Sensor Correct?
Wrong !!

Why?

-Pump is a differential pressure device.

-A single point is only influenced by pressure. This is good for booster only.

-In a closed loop system, system pressure rises due to thermal expansion, pumps will slow down.

-When static pressure decreases, pumps will speed up.

-This is self-defeating since now the pump speed is not influenced by the system load changes, but rather by system water pressure.

-Therefore, single pressure sensor are a misapplication in a closed loop HVAC system.
Single Point Differential Pressure Sensor

Primary - Secondary Circuit With Variable Speed
Secondary Pumps

- Primary Pumps
- Chillers
- Common
- Panel with PLC & VFD's
- Secondary Pumps
- Balancing Valve
- DPT
- 2-Way Valve
- Air - Separator
- Load
Opening/Closing of 2-Way Valve

- Signal from the sensor, installed at load regulates the valve opening & closing.
- This way differential across 2-way valve also changes & accordingly output signal is given to PLC.
Question:

Can we put the DPT across coil alone?
Question:

Across the pumps?
To Maximize energy system, we must maximize the variable head loss in the system. This is done by locating the sensor at the most remote zone (hydraulically) in the system.
System Control Curve

- Control curve
- Overall system curve
- Distribution piping head loss curve

Flow, gpm

Pump TDH

Set point, 25 FT
Variable vs Constant Head Loss

Variable Head Loss

Constant Head Loss

Chillers
Primary Pumps

Adjustable Frequency Drives

Supply

Return

DPT
The “Active Zone”

- Zone set points do not have to be the same.
- Pump controller scans all zones often, comparing process variable to set point in each case.
- Pumps are controlled to satisfy the worst case.
- What happens to the rest of the zones?
Basic Concept

PMU – Pump Management Unit

PFU – Pump Functional Unit

Set Value

From Field Sensor (DPT)

4 – 20 mA

Output To VFD/Pump

PFU – Pump Functional Unit

PMU – Pump Management Unit
Multi Point Differential Pressure Sensor

Different Sensor Signal To Common PFU Panel

- Chillers
- Secondary Pumps
- Balancing Valve
- Load
- DPT
- Common Panel with PLC & VFD's
POSSIBILITY OF MULTIPLE PROCESS SIGNALS FROM DIFFERENT ZONES

All zones can have different set values
POSSIBILITY OF MULTIPLE PROCESS SIGNALS FROM DIFFERENT ZONES

All zones can have different set values
HVAC Control System

DPT Signal Comparator
DPT Signal Comparator

- High and Low Signal Selections
- Signal Averaging
- High/Low Limit Control

The module has the addition following features:

1) LED status indications
2) Accepts voltage or milliamp input signal
3) DIP switch-selectable operating modes
4) Accepts 24 VAC/DC power
DPT Signal Comparator

**Benefits**

1) We are able to supply VFD systems with multiple inputs signals ranges to compete with our competitors.

2) We are able to use Grundfos PFU 2000 as the main processor to control the full system operations.

3) We will be minimising outsourcing or external controller in order to serve the HVAC market.

4) The MM allows us to integrate into the system multiple sensor control at a more cost effective price.
Other Types of Systems
Separate System for Each Zone

- Chillers
- Primary Pumps
- Secondary Pumps
- Air Separator
- Expansion Tank
- Balancing Valve
- DPT 2-Way Valve
- DPT
- Load
- Panel with PLC & VFD's
- Common
Systems In Multi - Zones

Two options:

1. Separate Systems can be used for different zones. So each zone will have its own sensor.

2. Signal from different zone sensors is given to the common PFU and most deviated signal, from the set point, is given as output.
Tertiary Pumping System

VFD pumps For Each Zone

Chillers

Primary Pumps

Secondary Pump

Balancing Valve

DPT

E-pumps

Load

2-Way Valve

Expansion Tank

Air Separator

Common
Reverse Return Pumping

Chillers

Primary Pumps

Balancing Valve

Secondary Pumps

Load

Panel with PLC & VFD`s

Air - Separator
Reverse Return Pumping

Benefits:

1) Equalize the pressure drops of each zone.
2) Selections of the sensor becomes easier.
3) If load are similar or symmetrical, 1 centrally located sensor is adequate.
4) As in direct return system, multiple sensor can still provide a benefit to the end user.
Type of VFD Systems
Possible Options of Variable Speed panels

Type ME - Multiple Pumps & Multiple VFDs.

Type MF - Common VFD for Multiple Pumps.
System with Multi Pumps & Multi VFDs

Signal from Field Sensor(s) (DPT)

Panel with PFU & PMU

VFD - 1

VFD - 2

Secondary Pumps
System with Common VFD for All Pumps

Signal from Field Sensor(s) (DPT)

Panel with PFU & PMU

VFD

Secondary Pumps
APPROVAL FROM INTERNATIONAL AGENCIES

Approval from – CE, U/L
Conforms to - Electromagnetic compatibility (89/336/EEC) to standard EN 50 081 – 1 and EN 50 082 – 2 and Electrical equipment design 73/23/EEC standard to EN 60 204-1.
Single PMU For Control of 8 Zones/Pumps
Single PMU For Control of 8 Zones/Pumps
The End