



Applying Pressure Independent Control Valves in H.V.A.C. Systems

**A Presentation to:
Orange Empire ASHRAE
Santa Ana
Nov. 17, 2009**

Introduction

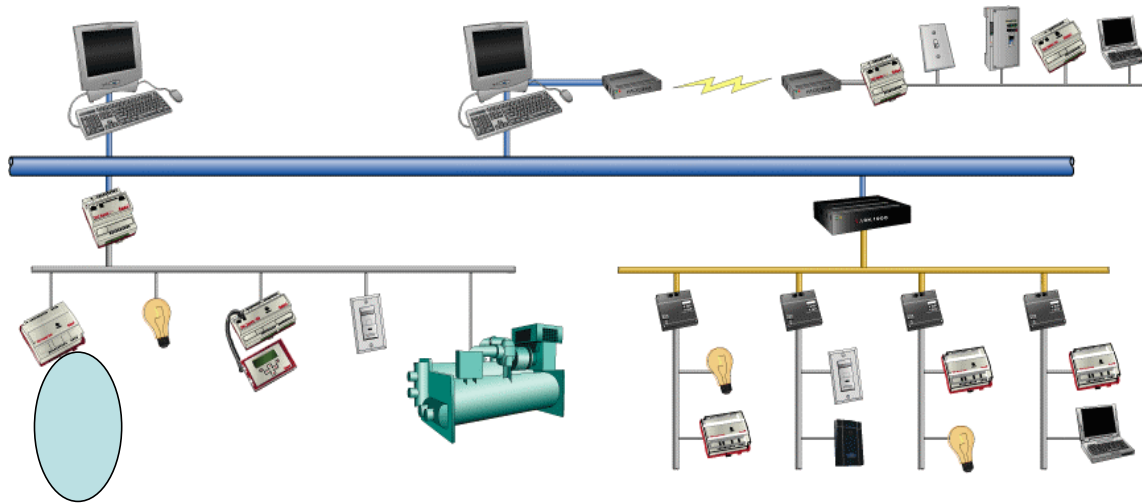


By: Steven Linn

Subject: Pres. Ind. Control Valves

I know, as building design consultants, so much of your effort is focused on overall design issues, architectural issues, sustainable design, LEED certification, etc. As we strive for highly efficient buildings, engineering all critical components become a priority.

Introduction



By: Steven Linn

Subject: Pres. Ind. Control Valves

Dealing with building owners backbone requirements, building automation, IT, security, energy management system integration, mechanical systems etc. absorb considerable design and coordination time. Somewhere in there, there are control valves.

Hydronic System Design Challenges



- **Designing for Maximum Design Conditions – and – maximizing partial load efficiencies**
- **Testing & Commissioning System to meet design criteria and intent**
- **Designing for long term system efficiency and maintenance**

By: Steven Linn

Subject: Pres. Ind. Control Valves

Some of these concerns are side effect resulting from the challenges of engineering energy efficient systems. In part we are faced with basic realities of design.

Pressure Independent Control Valves



New valve technology - Why Bother?

By: Steven Linn

Subject: Pres. Ind. Control Valves

Pres. Independent Control Valves



- **Track Record on Chilled Water Systems**

By: Steven Linn

Subject: Pres. Ind. Control Valves

Initially, this presentation will focus on chilled water systems, as there have been proven successes and track records of performance. Additionally, Chilled water system efficiencies reflect significant operating costs of a building or a campus.

BEST PRACTICES 2008



Award Category
HVAC Retrofit

System Features
Increases temperature rise in campus chilled

University of California, San Diego Chilled Water Valve Upgrades



UC San Diego upgraded the air handling units of 17 buildings with pressure-independent control valves to better regulate the flow of chilled water through the cooling coils. The retrofit greatly improves the efficiency of the campus chilled water loop during part-load conditions, saving 7,375,000 kWh annually.

Like many large universities, UC San Diego uses a centralized chilled water loop to provide its facilities with space conditioning. The campus increased the efficiency of this system by installing pressure-independent control valves on the air handling coils of seventeen buildings. The valves bring the temperature rise in the loop closer to design conditions, enabling the campus to fully load chillers during part-load conditions.

Nearly all chilled water distribution systems have difficulty maintaining design temperature rise at part load, a problem known as "low delta-T syndrome." Delta-T refers to the temperature difference between supply water

the ability of the pressure-independent valves to optimize heat transfer by precisely regulating the flow rate of chilled water through the cooling coil.

The flow of chilled water in a centralized distribution loop is constantly changing as buildings experience different loads throughout the day. Control valves respond to shifting load demands by adjusting the amount of chilled supply water entering the air handling coils to cool supply air. When flow changes, so does the heat transfer rate in the cooling coil. As flow increases it becomes more difficult for the cooling coil to exchange enough heat between outside air and water, which results

http://greenbuildings.berkeley.edu/pdfs/bp2008_ucsd_retrofit.pdf

By: Steven Linn

Subject: Pres. Ind. Control Valves

One example of a retro-fit project with significant payback.

Pres. Independent Control Valves



- Track Record on Chilled Water Systems
- **Benefits for Hot Water Systems**

By: Steven Linn

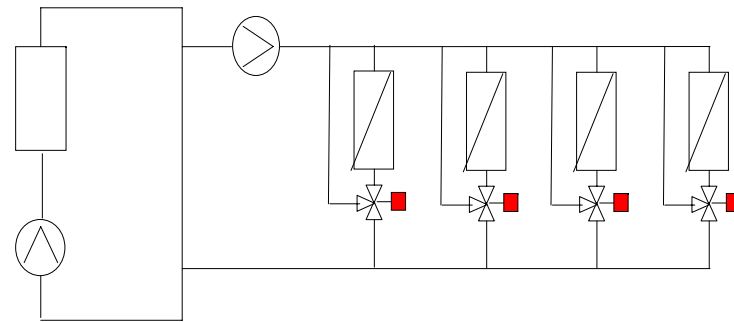
Subject: Pres. Ind. Control Valves

This can be more debatable and worthy of discussion.

Hydronic Design Development



Constant Flow System



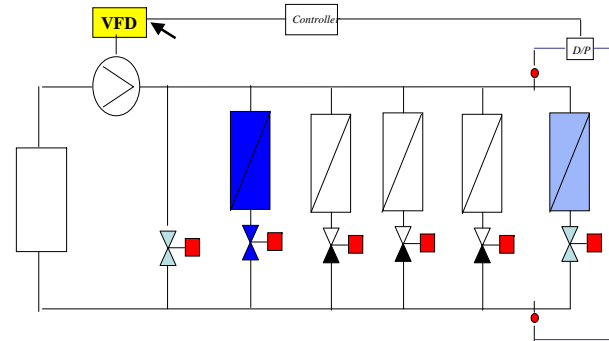
By: Steven Linn

Subject: Pres. Ind. Control Valves

Initially, valve engineering, and valve selection “rules” were based on constant flow systems. The operation of the valve is relevant only to the coil is controlling. Clearly, we have evolved greatly from these types of systems.

Hydronic Design Development

Variable Flow System



By: Steven Linn

Subject: Pres. Ind. Control Valves

Hence, we have seen development of variable flow systems which match flow to meet demand. Of course the major advantage of this system is energy savings from reduced pump power; and the reduction of flow that should maintain, or even improve delta T.

Actual System Performance

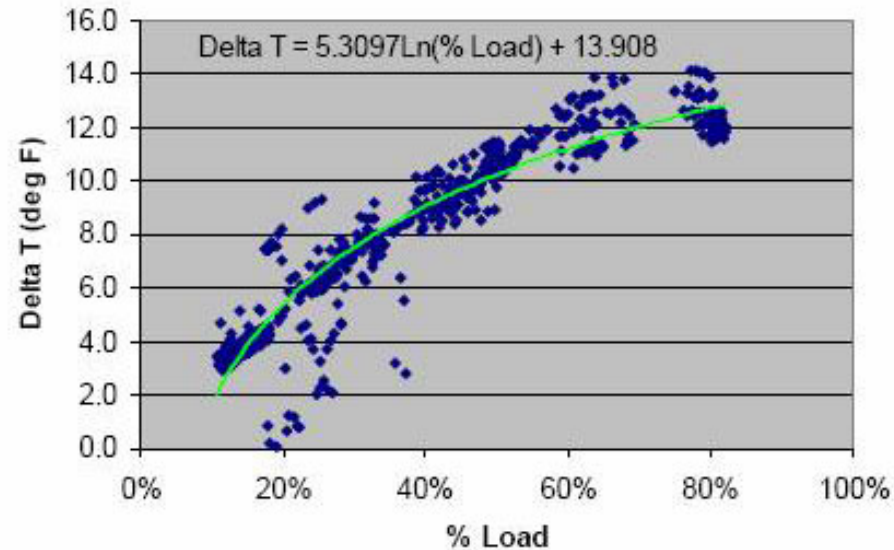


Figure 2: Systemwide Delta T Degradation in 14°F System

By: Steven Linn

Flow Control Industries Inc – Article dd. 9-16-04
Subject: Pres. Ind. Control Valves

However, practical observation of many installed systems show a degradation of efficiency at lower loads, of which low delta T across the system is a major symptom.

Actual System Performance



**Delta T degradation is the result of
lower than expected return chilled
water temperature**

By: Steven Linn

Subject: Pres. Ind. Control Valves

Actual System Performance

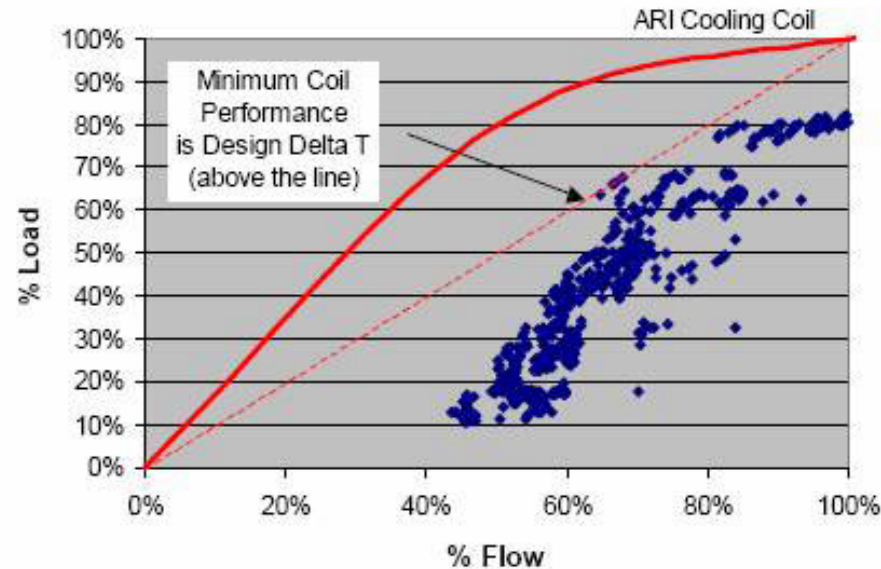


Figure 1: Typical Cooling System and Coil Performance with Low Delta T

By: Steven Linn

Flow Control Industries Inc – Article dd. 9-16-04
Subject: Pres. Ind. Control Valves

The loss of system Delta T can be traced to the loss of Delta T at the individual coils within the system – and the key contributor of this loss of coil performance is the main device controlling the coil – the control valve. Provided that the airhandler or terminal unit has the proper airflow, then loss of Delta T can only be attributed to overflow of liquid media in relationship to the heat transfer required.

Actual System Performance

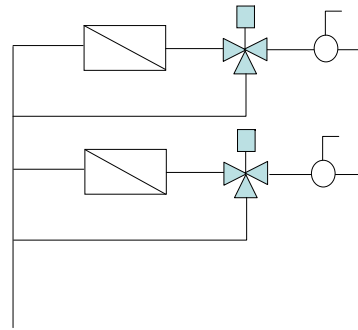


**One of
The Prime
Suspects:**

By: Steven Linn

Subject: Pres. Ind. Control Valves

Traditional Valve Selection Process



- ΔP Relative to Coil
- R.O.T. 3 – 5 psi

Worked OK for
constant flow
systems

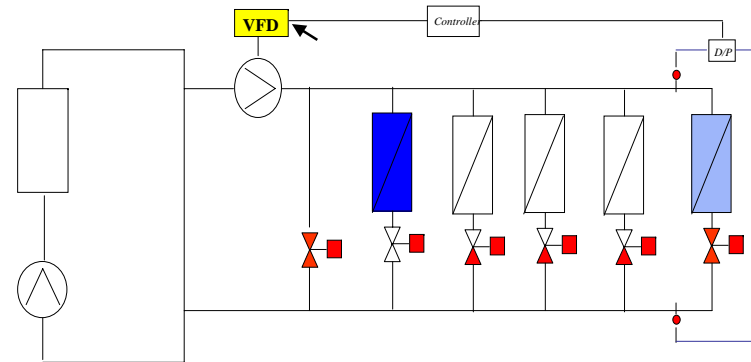
By: Steven Linn

Subject: Pres. Ind. Control Valves

So, standard valve sizing rules were developed, either with a pressure drop relative to the coil, or perhaps a standard rule of thumb. Additionally, valve sizes were developed that were line with pipe sizing.

Hydronic Design Development

Variable Flow System



By: Steven Linn

Subject: Pres. Ind. Control Valves

In the case of a system primarily using 2-way valves, each valve is not only active with the coil it is controlling, but each valve is interactive with the entire system. As valves open and close, they effect the control of the pump. As pump speed and flow modulates, the pressure across the system changes, affecting flow through each circuit.

Valve Authority



$$A = \frac{\Delta P \text{ valve @ max. flow}}{\Delta P \text{ valve @ min. flow}}$$

Chapter 42.8 ASHRAE Handbook – HVAC Systems and Equipment

By: Steven Linn

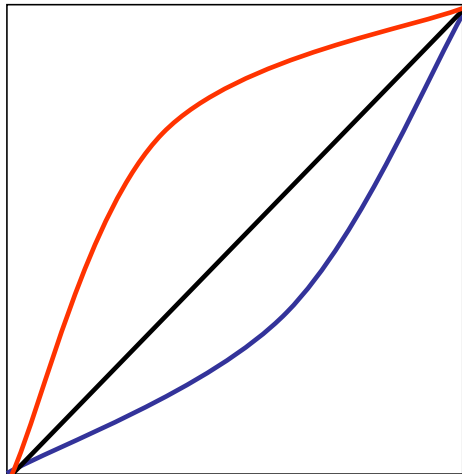
Subject: Pres. Ind. Control Valves

Because of this, we need to take into account valve authority when selecting control valves. Boiled down to its most simple terms, valve authority is defined by the above formula.

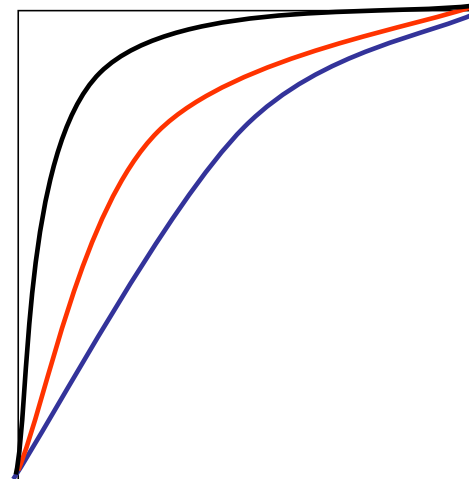
Effect of Valve Authority



Coil Control w/ Good Valve Authority .4 or greater.



Coil Control w/ Poor Valve Authority .2 or less



Red = Typical Coil Heat Response Curve (x = media flow, y = BTUH capacity)

Blue = Valve Flow Response Curve (x = control output, y = media flow)

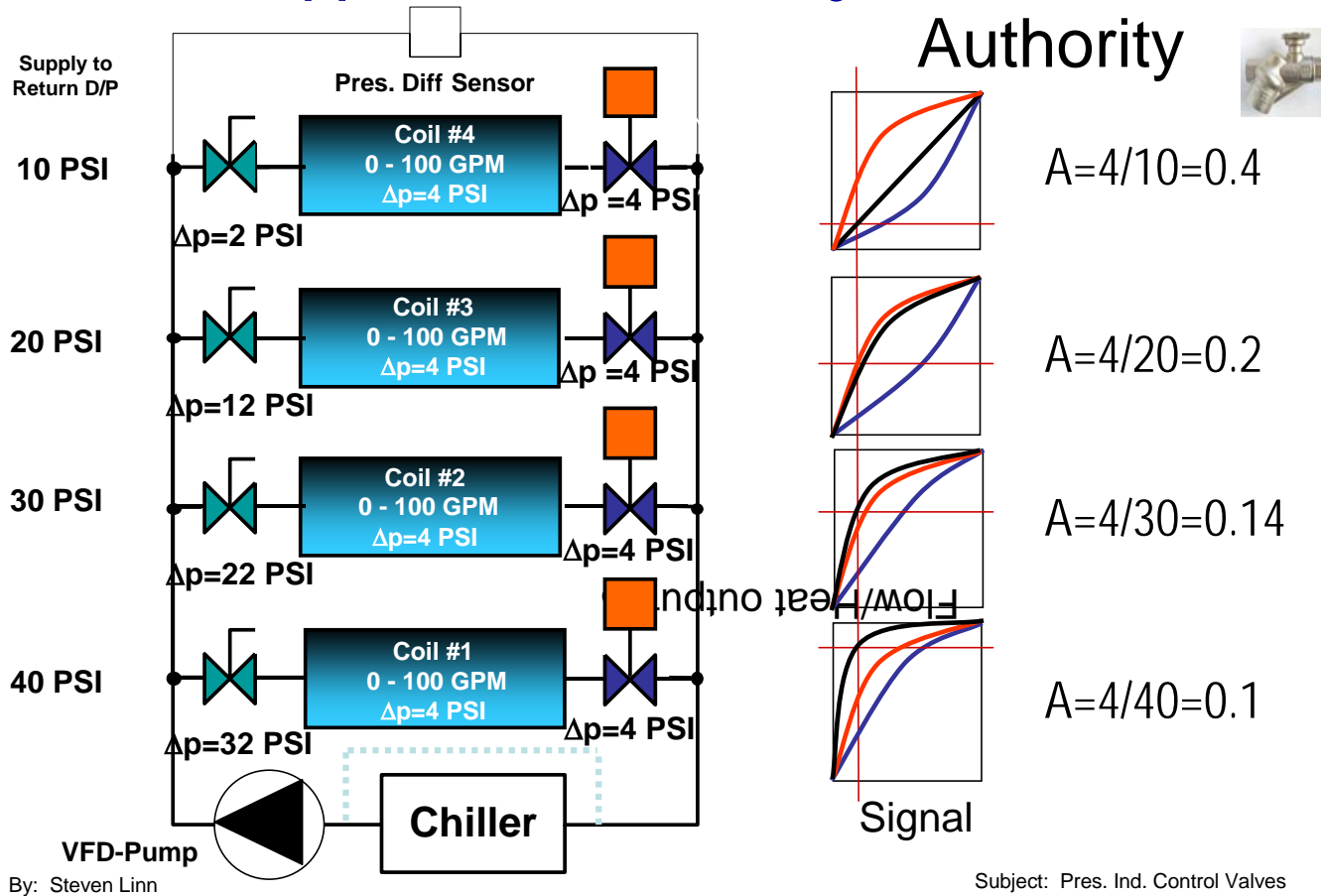
By: Ste

Black = Controller Output to Heat Response (x = control output, y = BTUH)

s

We need to account for another aspect of system design; the heat response of modulated flow coils, which is non-linear. Valves should be select to counter-act this non-linear response, and valve authority plays a major part in how a valve performs in a system.

Standard Application with 2-way Valves

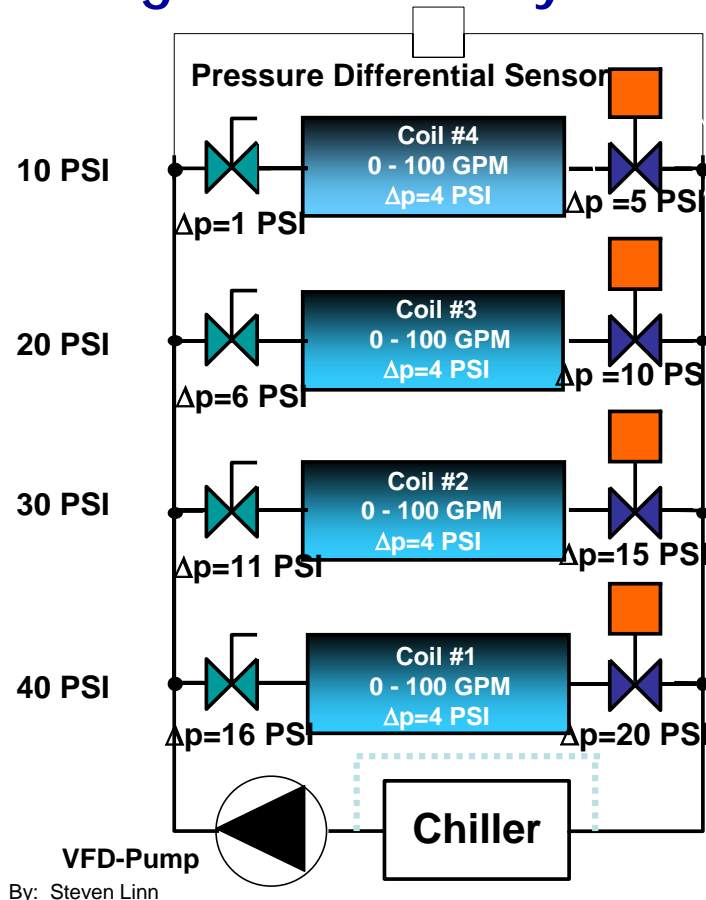


One common sizing technique is using a 4 PSI drop across the valve regardless of its location in the system.

Depicted here is a basic system that includes a chiller, pump, balancing valves before the coil, control valves after the coils, and a pressure differential sensor to control the pump. This simple system will be the basis for the remainder of the discussions involving sizing and systems.

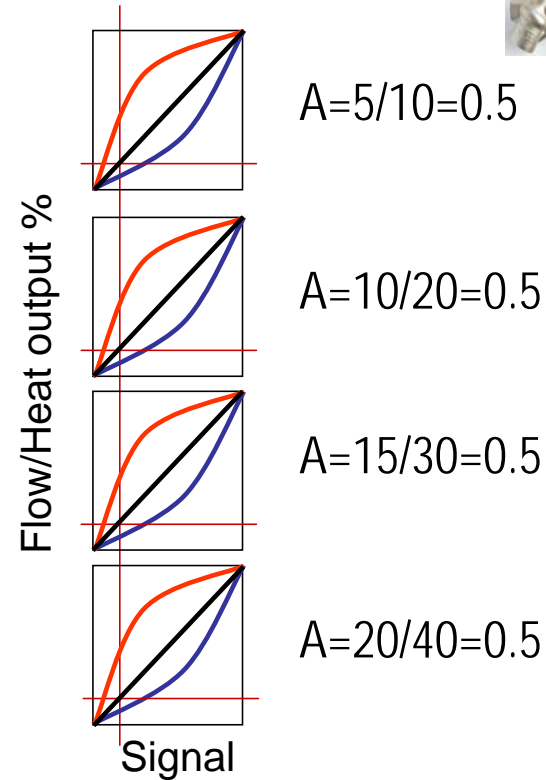
By using 4 PSI as a pressure drop for each valve, the result is unacceptable authorities in terminals close to the pump. These valves are controlling almost on-off or open just 0 to 20% in order to control 0 to 80% of the heat output.

Sizing with Authority Method



By: Steven Linn

Authority



Subject: Pres. Ind. Control Valves

The valve authority method takes into account the location of the valve. This method results in excellent controllability. As noted in the diagram, each control valve is sized with a different pressure drop. This ensures that each valve will have the recommended authority between 0.4 and 0.5.

However, there are some issues with this method. For example, the high pressure difference over valve could result in cavitation. Also, an authority of 0.4 to 0.5 is always required. When working with a linear coil, a much oversized equal percentage valve may be required.

Finally, this process requires a time intensive sizing and selection procedure.

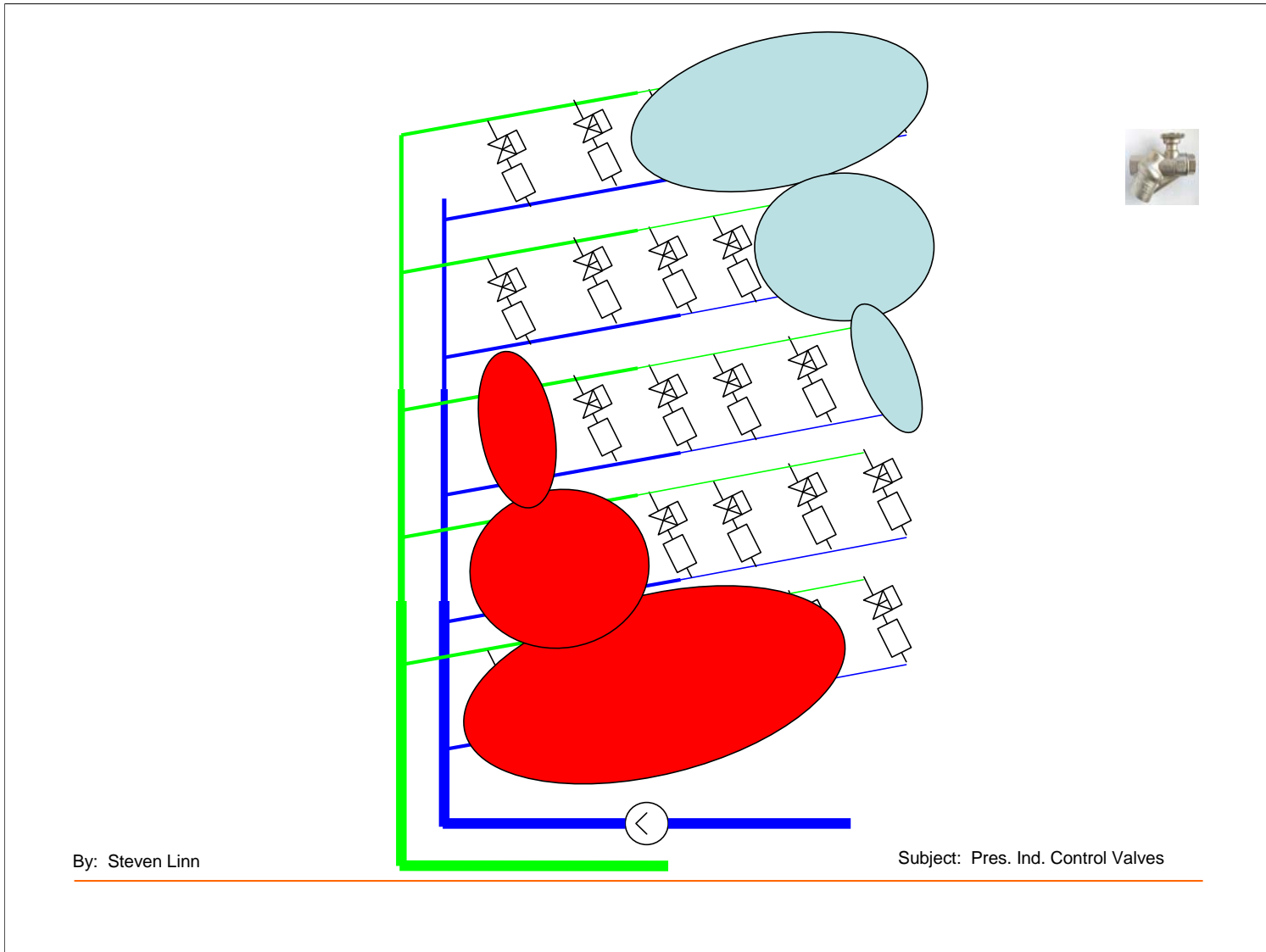
Design Solutions



- **Complete Valve Authority Analysis**
- **“Zoned” Pressure Drop Assignment**

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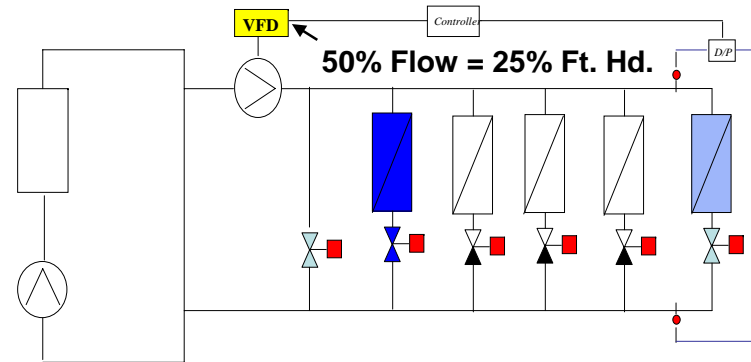


Blue is area of low pressure drops across circuits – stable area of system pressure drop

Red is area of high pressure drops across circuits – greatest area of system pressure changes due to system flow changes

Hydronic Design Development

Variable Flow System



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Subject: Pres. Ind. Control Valves

This would be an example of an uneven nature of load. In this case, zone 1 is requiring a full load, zones 2 thru 4 are unoccupied, and zone 5 is at partial load.. The system would still require a sufficient pressure drop across circuit one to satisfy the full flow of circuit. Because most of the valves are closed down, the pump would be turned down with a significant reduction in available head pressure, which might not create sufficient pressure drop across circuit 1 to produce the rated flow. The control system would have to compensate by increasing the speed of the pump.

Design Solutions

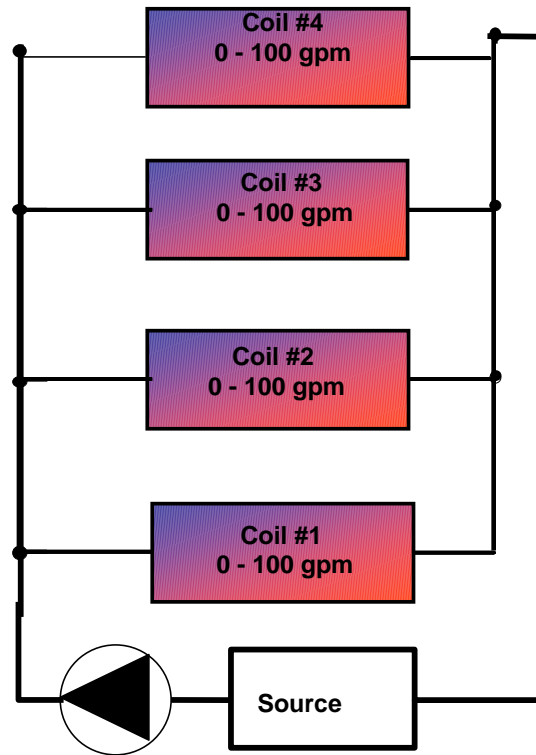


- Complete Valve Authority Analysis
- “Zoned” Pressure Drop Assignment
- **Reverse Return Piping**
- **Increasing Pipe Sizes of Mains and Risers**

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Subject: Pres. Ind. Control Valves

Piping - Reverse Return Piping



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Subject: Pres. Ind. Control Valves

A reverse return system equalizes the pressure drops amongst the coils located on the loop. The first coil on the supply side is the last coil on the return side, and the last coil on the supply side is the first on the return side. Control valves can be sized with the same pressure drops. However, there may be extensive additional piping required, and additional pump energy required to overcome the resistance of the additional piping.

Pressure Independent Valves Make Cost Effective Alternative to Reverse Return System for US Census Bureau



Photo credit: U.S. Census Bureau.

It was right there in black and white.

Paraphrased, the guideline stated that pump and piping systems shall be arranged in a reverse return configuration.

The standard is part of the GSA's (US General Service Administration) design guide, known as the PBS-P100, and serves as the guideline for all US governmental buildings. However to all rules, there are at least one or two exceptions. Such was the case with the new US Census Bureau headquar-

systems: Belimo Pressure Independent Characterized Control Valves (PICCV).

How It Works

The PICCV is a two-way valve that supplies a specific flow through each coil, regardless of system pressure fluctuations. The pressure independent valve provides consistent flow over its entire operating range, from 0.5 to 80 GPM. The PICCV maintains consistent flow even during extremely low system flows, so that facilities are better able to capitalize on the benefits of variable

Self-balancing Even At Low Flow

Self-balancing is not the only advantage of the PICCV, says Steve Taylor. Other balancing devices such as automatic flow limiting valves can also provide self-balancing at design conditions. However, they have no

By: Steven Linn

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This design build project in Washington D.C. demonstrated the value of the PICCV by eliminating the need for expensive reverse return piping. The geometry of the building did not lend itself to economical reverse return piping. In order to deal with significant differences in pressure drops across the various coil circuits, PICCV's were selected.

One excellent solution ...



Pressure Independent Control Valves



By: Steven Linn

nd. Control Valves

One excellent solution ...

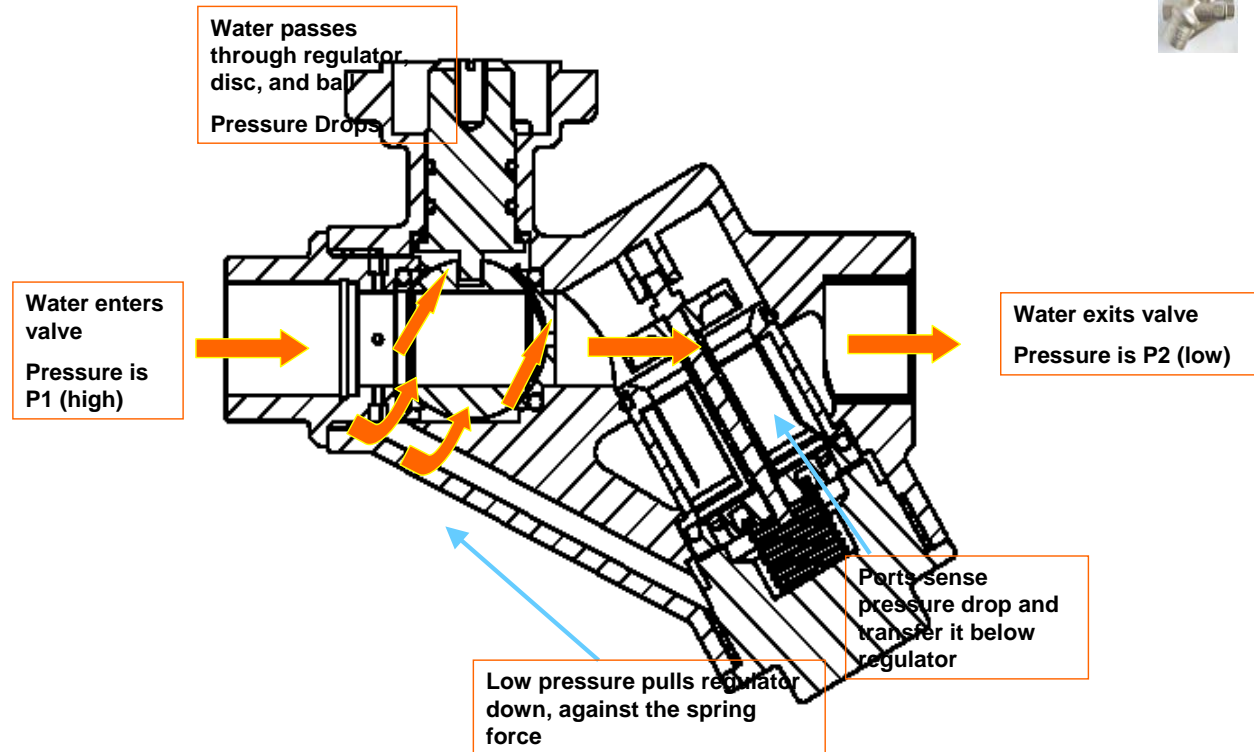


- **Pressure Independent Valves**
- **Designed to be flow constant at a wide range of pressure drops**
- **Respond instantaneously to system pressure changes**
- **Simplify Design – no longer need to factor Cv and pressure drop**

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Subject: Pres. Ind. Control Valves

Operational Theory

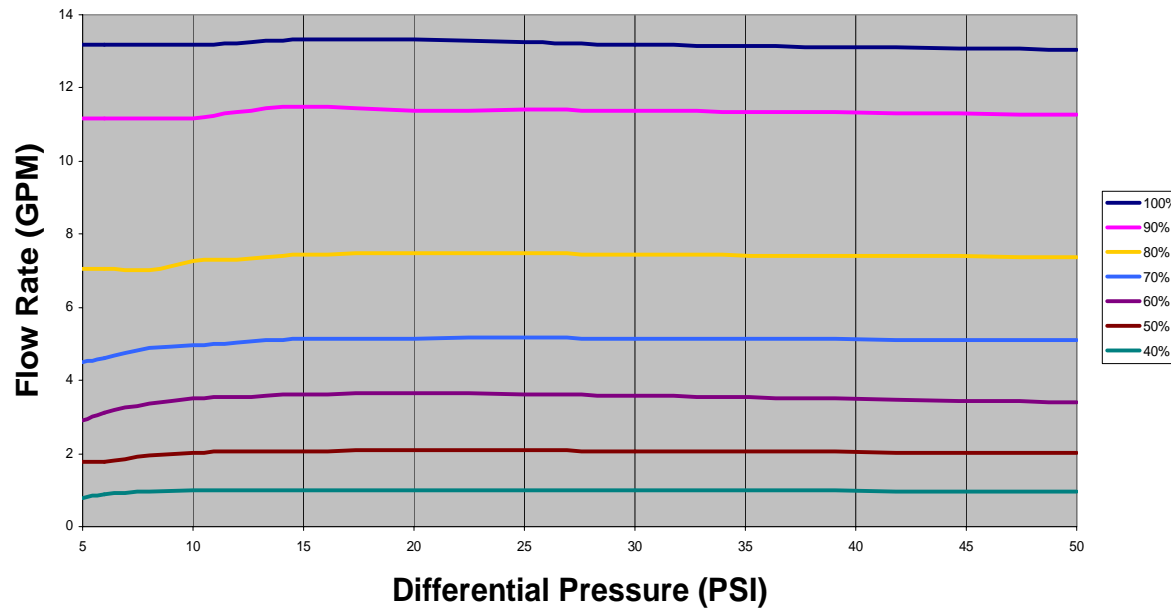


By: Steven Linn

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Description of the workings of a pressure independent control valve. This type of valve uses two chambers. A flow metering chamber, driven by an actuator, and controlled via the EMS. Valve is positioned to maintain a setpoint. The second chamber is a pressure compensation device, which constantly measures across the valve. The compensator adjusts in reaction to pressure changes occurring in the system. The compensator picks up or releases pressure drop, resulting in a constant pressure across the metering chamber, resulting in constant flow – regardless of pressure variations in the system.

Flow Characteristic of Pressure Independent Valve

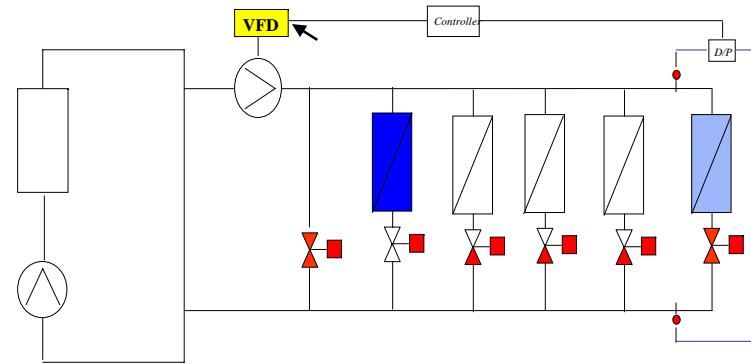


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Subject: Pres. Ind. Control Valves

These are the flow curves of a pressure independent control valve factory set for 13 GPM. Note that at any given position, the flow remains constant with a pressure drop of 5 to 50 psi. Also note the equal percentage flow characteristic of this valve. At 100% control signal, flow is 13 GPM. Incremental 10% reductions in control signal at the high end result in relatively high rates of change in flow, and at the low end, relatively low rates of change in flow. This characteristic offsets the natural BTU output of the coil relative to flow, and increases controllability in low demand conditions.

Each Valve is un-affected by system changes



By: Steven Linn

Subject: Pres. Ind. Control Valves

Changes in system pressures due to other valves opening or closing, or the VFD ramping up or down do not affect the control valve. Only the controller changes flow in response to heat load changes in individual zones

System Advantage



***What happens at setpoint –
Stays at setpoint!***



By: Steven Linn

Subject: Pres. Ind. Control Valves

Analysis of the Iowa Energy Center's Independent Testing of the PICCV

By Brian Allen and Tricia Bruenn
Beimo Aircontrols (USA), Inc.

Objective:

The purpose of this report is to summarize the findings of the independent testing done by the Iowa Energy Center on Pressure Independent Characterized Control Valve (PICCV). The overall objective of the study was to evaluate the performance of the PICCV against conventional globe control valves for terminal reheat and chilled water cooling coil applications in a commercial office building. The facts are condensed into a user friendly format that will enable you to analyze and compare the performance of both valves on a heating and cooling system. All charts and findings come directly from the full report.

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- 1-3. Operation
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2.0 The Iowa Energy Center

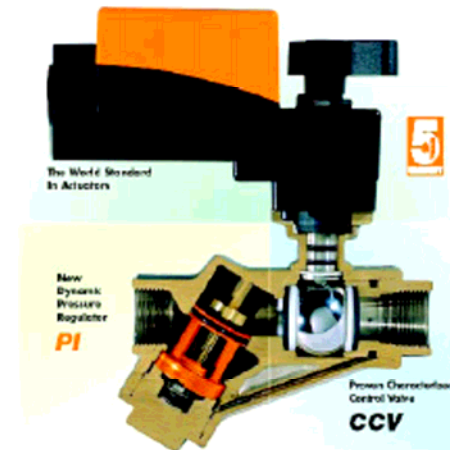
- 2-1. The Facility
- 2-2. Testing Procedures
- 2-3. Schematic of Heating Water Loop and Instrumentation
- 2-4. Schematic of Chilled Water Loop and Instrumentation

3.0 Terminal Reheat Open Loop Test

- 3-1. Results

1.0 Description of Pressure Independent Valve

1-1. Design



By: Steven Linn

This is an independent test study on the performance of pressure independent control valves done by the Iowa Energy Center.

I.E.C. Test

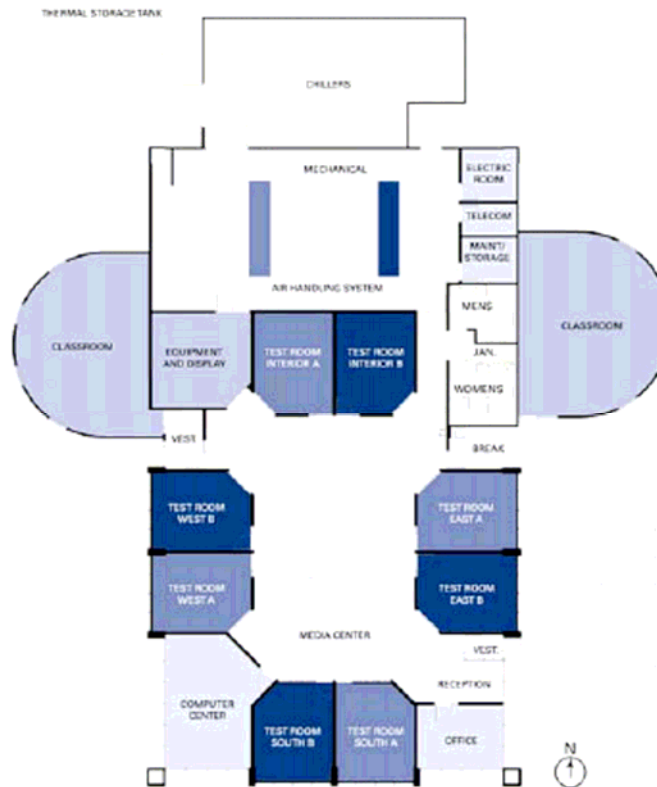


Figure 2-1: Schematic of the side-by-side test rooms of the Energy Resource Station.

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Twin heating and cooling systems were set up in side by side zones with common exposures in a building. One system uses standard pressure dependent control valves, and the other system uses pressure independent control valves. Each system was monitored for zone temperature control, valve response to control signal, water flow, temperature differential, discharge air, and pumping power.

Valve Hunting & Control

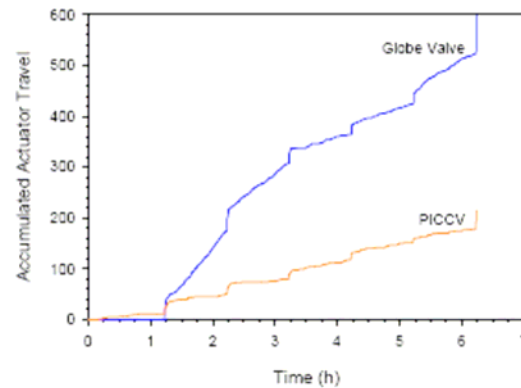


Figure 4-4: Accumulated actuator travel.

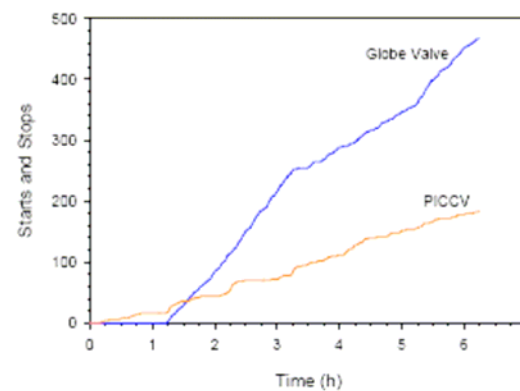


Figure 4-5: Accumulated starts and stops.

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Subject: Pres. Ind. Control Valves

A comparison of actuator travel while holding setpoint in equivalent zones. The blue line is a “traditional” pressure dependent valve, and the orange line is a pressure independent control valve. Graph starts from a higher demand to a lower demand.

Maximizing System Performance

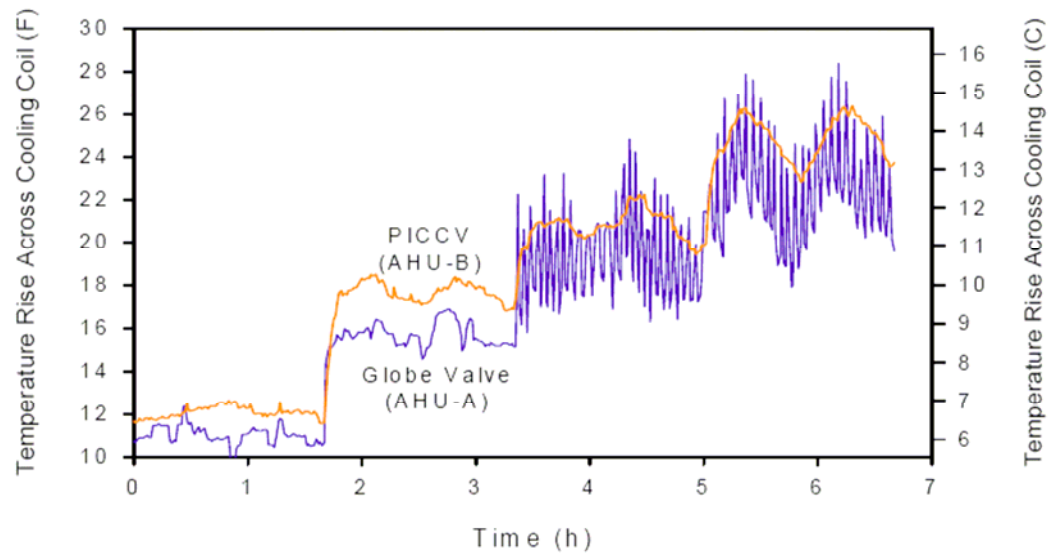


Figure 6-6: Temperature rise across the chilled water cooling coil

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Subject: Pres. Ind. Control Valves

Test results show how delta-T across the coil oscillates as the standard control valve tries to hold set-point at the lower modulated levels.

Maximizing System Performance

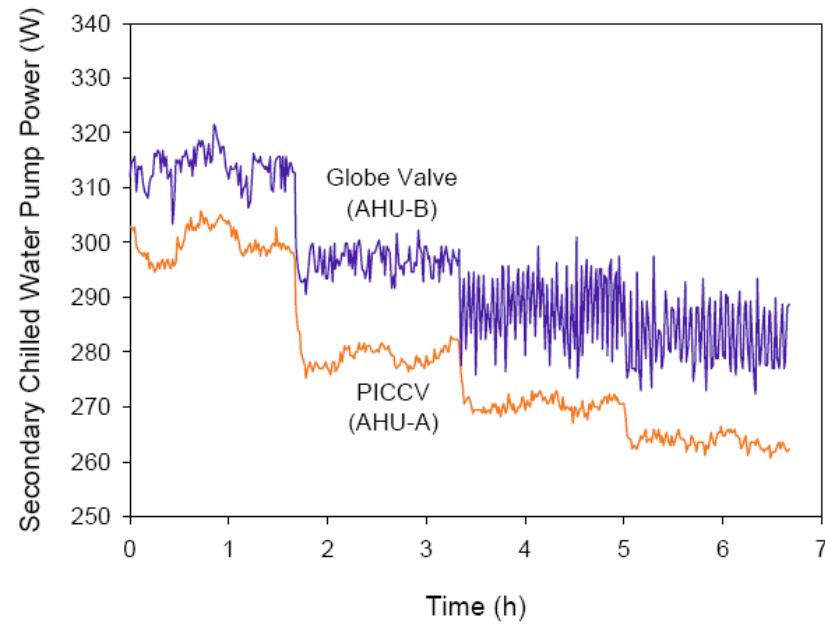


Figure 6-7: Secondary chilled water pump power

By: Steven Linn

Control Valves

Additionally, we can measure the energy consumption of the pump as the system modulates down. Although we see a drop in both cases, the PICCV provides a greater drop, and greater energy savings over the standard valve.

Pres. Independent Control Valves



Maximizing HW system efficiency

- Delta T is already High
- Total flow is not significant
- We don't vary system flow on HW
- You can't modulate less than 1 GPM
- You don't want to modulate less than 1 GPM
- HW re-heat valves are inexpensive

By: Steven Linn

Subject: Pres. Ind. Control Valves

Pres. Independent Control Valves

Maximizing HW system efficiency



- **Coil response curve is very steep**
- **We are focusing on every efficiency area we can**
- **We can vary flow on HW – VFDs are cost efficient**
- **Requirements of condensing boilers?**
- **DDC controllers want to modulate re-heat**
- **HW re-heat valves are inexpensive –**
service labor is not!

By: Stephen Jinn

Subject: Pres. Ind. Control Valves

Pressure Independent Control vs. Automatic Flow Limiting



- Pressure independent valves in addition to limiting the maximum flow, also guarantee a precise flow at each degree of opening, regardless of the system pressure fluctuations across the valve.
- Flow limiting devices (aka automatic balancing valves, auto-flow valves) limit the maximum flow through the valve. At modulated conditions, they function as pressure dependent devices.

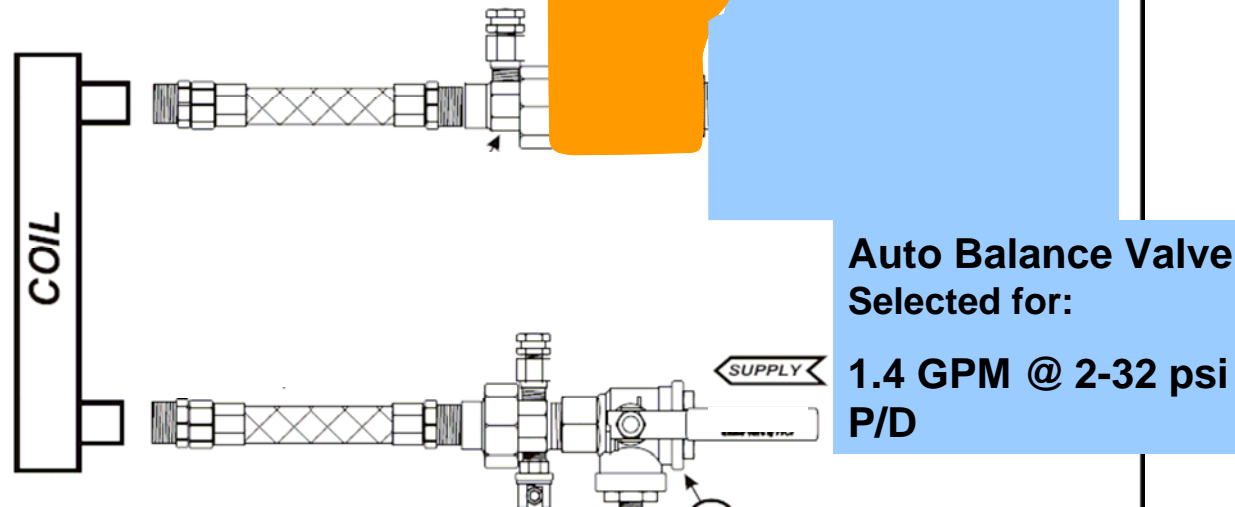
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Control Valve w/ Auto Balance Valve

0.8 Cv Electronic Control Valve

3.0 psi P/D @ 1.4 GPM



By: Steven Linn

Subject: Pres. Ind. Control Valves

A standard "pressure dependent" control valve of .8 Cv is selected for a 1.4 GPM coil. A 1.4 Auto Balance Valve is selected to balance the system. The Auto Balance (Flow Limiting) Device is active from 2 – 32 psi drop.

Test Results – November 2005



Measured Flow in GPM – Valve Modulation @ Total Circuit Pres. Drop.

% Open	5 PSI	5.5 PSI	7 PSI	10 PSI	15 PSI	20 PSI	25 PSI	30 PSI
99	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6
80	1.1	1.2	1.4	1.6	1.6	1.6	1.6	1.6
70	1.0	1.2	1.3	1.5	1.6	1.6	1.6	1.6
60	0.9	0.9	1.0	1.4	1.6	1.6	1.6	1.7
50	0.7	0.7	0.8	0.9	1.2	1.4	1.5	1.7
40	0.4	0.4	0.4	0.5	0.7	0.7	0.8	1.0

Acceptable Modulation Range

Valve Hunting Range

Target Flow 1.4 GPM

Control Valve: Belimo B209: 0.8 Cv - 3.0 psi p/d @ 1.4 GPM

Auto Balance Valve: FDI AC0050L: 1.4 GPM @ 2-32 psi p/d

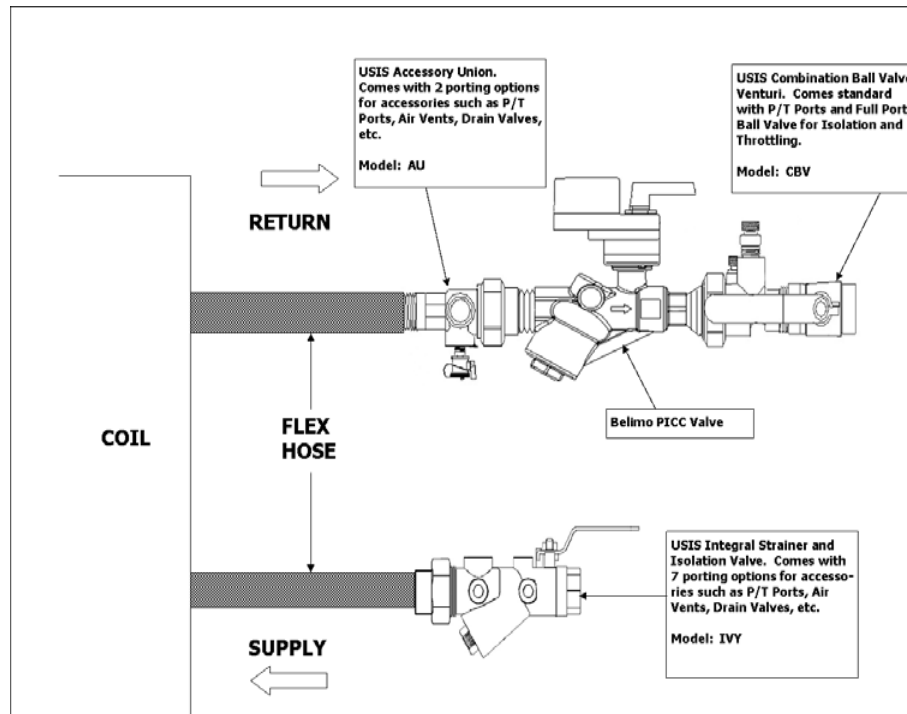
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Note how the automatic balancing valve fights the control valve on flow reduction when circuit pressure drops are higher. The auto balancing valve needs to unload before the control valve is able to reduce flow in the system. This situation can create a significant control hysteresis – particularly coming off high demand conditions.

This is an excellent example of valve authority. With the higher pressure drops across the circuit, the balancing device has much more influence on the circuit flow than the control valve.

Pres. Ind. Control Valve Installation Example



By: Steven Linn

Subject: Pressure Independent Control Valves

Piping is very similar to tradition coil piping, except that balancing devices are eliminated. This particular set up includes a venturi measuring device combined with an isolation valve on the return piping. This is an economical way to verify flows through the circuit if necessary. This verification can also be accomplished through the coil. Option Pete's Plugs on the PICCV and take the place of a Pete's plug on the between the PICCV and isolation valve. I always recommend a Pete's Plug on the outlet of the coil.

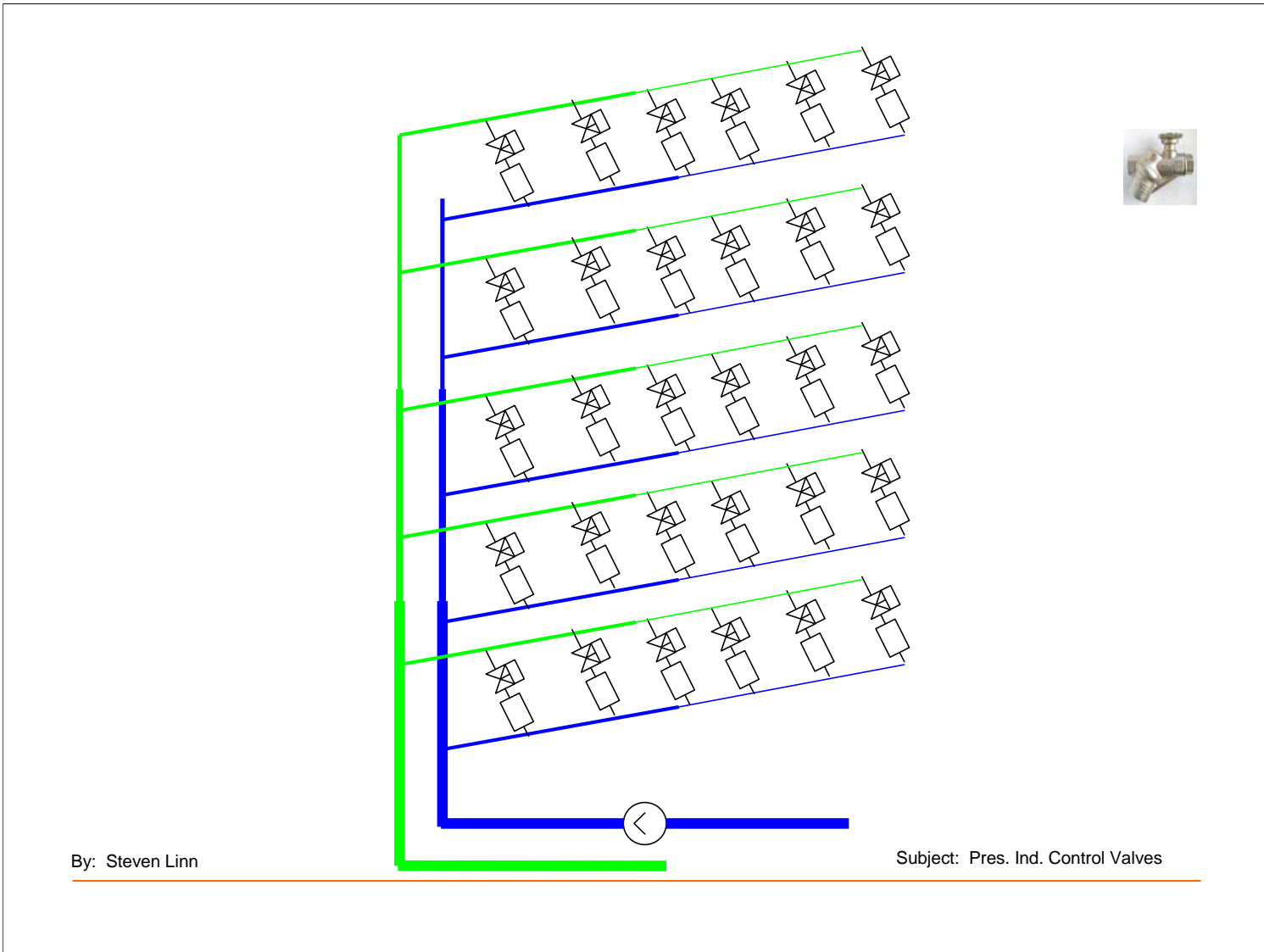
Pres. Ind. Control Valves



Balancing and Commissioning

By: Steven Linn

Subject: Pres. Ind. Control Valves



What is the goal of Balancing. It should be to make sure that circuit for the zone is sufficient, and that flow will go throughout the installation under all conditions.

Maximum Flow Setting



Max Flow Setter 3-Pt. Floating Models

- Factory Set w/ Model Number
- Field Adjustable

By: Steven Linn

Subject: Pres. Ind. Control Valves

Pressure Independent valves are also flow limiting up to their specified pressure drop range. They are ordered from the factory to be closely matched to the coil schedule. They should not need manual setting in the field. In some cases, the maximum flow will be set via a manual adjustment, and in some cases (as seen in the next slide), it will be an electronic adjustment within the actuator.

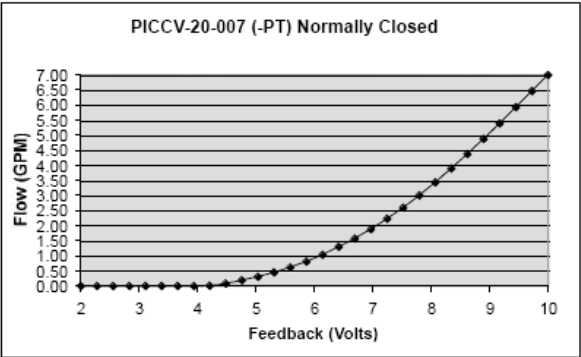
Maximum Flow Setting



MFT (Analog Signal) Actuated Valves

MFT Adjustment Table

Product Range	NC will open as voltage increases (no flow at 0-2V) - actuator switch on Y ₂					
	Default*		Flow Adjustable**		MFT angle of rotation max. setting	MFT angle of rotation min. setting
	Flow rate		Flow rate			
	GPM	l/s	GPM	l/s		
PICCV-20-006(-PT) + LRX24-MFT	6	0.38	6.5	0.41	74%	0%
PICCV-20-007(-PT) + LRX24-MFT	7	0.44	7.5	0.47	77%	0%
PICCV-20-008(-PT) + LRX24-MFT	8	0.50	8.5	0.54	80%	0%
PICCV-20-009(-PT) + LRX24-MFT	9	0.57	9.5	0.60	83%	0%
PICCV-20-010(-PT) + LRX24-MFT	10	0.63			90%	0%



By: Steven Linn

Subject: Pres. Ind. Control Valves

Pres. Independent Control Valves



- **Balancing Perspective:**
- **PI Control Valves either come set from the factory very close to the coil scheduled flow – they do not need to be re-set in the field**
- **If a verified flow is required, PI Valves are dynamic. A balancer can confirm Delta P across the valve to confirm that the Delta P is sufficient to “power” the valve**
- **An Independent measuring reference is needed to verify flow – e.g. coil P/D, venturi station, independent flow test meter**
- **Some valves are shipped as factory tested, however, there may still be differences between factory testing, and field measurements. The valve may need to be “tweaked.”**

By: Steven Linn

Subject: Pres. Ind. Control Valves

Pres. Independent Control Valves



- **Commissioning Perspective:**
- **Does the zone operate within specifications/intent**
- **The DDC system can usually trend and alarm**
- **IF NOT, how do I identify and fix.**
- **Is the overall system operating efficiently:**
 - Is system Delta-T at or near design criteria**
 - Are pumps running averaging the lowest power draw**

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Incorporating into LEED Design



What is the LEED value of an advanced hydronic system design?

- **Innovation?**
- **Plant Efficiency – maintaining design targets!**
- **Tying in Design to 3rd Party Commissioning**
- **PICCV and Delta P valves can be designated as key components to stabilizing coil control**

Facility Owners Buy-In – Basis of Design!

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Technological Advantages P.I.C.C.V.



Improved Operation of System

- **Greater Control of Individual Coils**
 - **No Hunting - Better coil efficiencies – stable return water temps – actually attain design delta T's**
 - **No Hunting – Valves and actuators last longer – lower lifetime cost and maintenance**
 - **Stable Steady States – Pump VFD's actually cycle down**
 - **Tighter Control – Better Comfort**

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Pressure Independent Control Valves



Questions?

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