

Use of Balance Valves In Chilled Water Systems

Editor's note: This article is followed by an article by Richard Hegberg with a different viewpoint.

By James B. (Burt) Rishel, P.E.

Fellow ASHRAE, Life Member

There has been widespread disagreement on the use of balance valves on cooling coils in chilled water systems. Traditionally, balance valves are used on all heating and cooling coils when three-way coil control valves are used. The advent of variable volume systems with two-way control valves on these coils creates new considerations for the use of balance valves.

One of the great concerns for determining the correct use of balance valves is the energy consumption of these valves. Every pump brake horsepower consumed by balance valves results in a loss of 2,544 Btu/hr (0.746 kW) and adds approximately one-fifth of a ton of cooling to the chiller load. Recently, an analysis was made at Wichita State University where an analysis of pressure losses revealed a pressure drop of 50 to 56 psi (344.8 to 379.2 kPa) across balance valves installed on the discharge of the secondary pumps. This resulted in an energy loss of over 900,000 KWH per year.

This information was received from Michael Walker, P.E., of Mid-Kansas Engineering Consultants in Wichita. This is why it is imperative that balance valves are used properly on chilled water systems.

There have been field tests that demonstrate that energy can be saved on variable volume systems by eliminating the effect of balance valves. This is typified in tests at a high school that showed significant energy can be saved by fully opening existing balance valves.

The data in *Table 1* represents the test results at this high school. Not only was energy conserved, but additional cooling capacity was made available for a proposed addition. The increase in load with the balance valves opened was due to a load change on the chilled water system.

Does this mean that balance valves should be banned from all chilled water systems? Of course not. It does mean that certain types of chilled water systems should use balance valves while others do not require them. How do we discern the difference between these different systems? The pressure gradient diagram demonstrates easily which chilled water systems should use balance valves.

This diagram is constructed by plotting the pump head vertically in feet of head. There is no horizontal scale. The hori-

Item	Balance Valves Set Traditionally	Balance Valves Opened Completely	Percent Change
Flow, GPM	700	750	+7%
Cooling Load, Tons	215.8	278.1	+29
Supply Temp., F	45.0	45.4	-
Return Temp., F	52.4	54.3	+4
Diff. Temp., F	7.4	8.9	+20
Secondary Pump	67	58	-13
Dis. Pr., PSIG			
Pump Speed, RPM	1232	1032	-16
Pump Power, KW	18	16	-11
Pump KW/Ton	0.083	0.058	-30

Source: From Ben. L. Kincaid and Andrew Spradley, *Removing Manual Balancing in a High School*, 1995.

Table 1: Energy data for an existing high school.

zontal dimension is used to separate the various elements of the system to clarify the use of pump head in that system. Pressure losses in various components of a water system in feet of head are plotted vertically downward or diagonally. Typical pressure gradient diagrams are shown in *Figures 3, 4, 5, 7, and 9* for the systems and flow conditions discussed herein. This diagram is very useful in the evaluation of the use of various balance valves on particular types of chilled water systems. The actual loss for each valve is shown clearly. There should be no question as to the effect of control or balance valves on each system that is being considered.

The pressure gradient diagram demonstrates the use of pump head and the control of pressures in chilled water systems under different load conditions. The nodes, A through F and M through R, in the included gradient diagrams are used to identify various points in the system drawings and those diagrams.

For example, in *Figure 3*, the pump head is 100 ft* (plotted vertically), the loss in the pumping system is 5 ft (Nodes A to B), the loss in the supply header from the pumping system to coil 1

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* Multiply feet by 0.3048 to obtain meters.

is 3 ft (Nodes B and C), the loss in the supply header between coils 1 and 100 is 31 ft (Nodes C and D), the loss in the return header between coils 100 and 2 is 31 ft (Nodes E and F), and the loss in the return header from Coil 1 to the pumping system is 5 ft (Nodes F and A). Under design load, the loss through a coil is 12.5 ft, and the loss across the control valve is also 12.5 ft as shown for Coil 100.

The chilled water systems under consideration are:

Figure 1: Variable volume system with direct return and modulating type coil control valves. It is assumed that this is a large system with 100 equal cooling coils. This enables us to eliminate any effect of one coil on the system header losses. The differential pressure transmitter located near coil 100 controls the speed of the secondary pump. *Figure 2* describes the coil connections with and without a balance valve

The pressure gradient for this system is shown under three conditions:

Figure 3: Full load with all coils at design flow.

Figure 4: Full load on all coils excepting Coil 1 which has no load.

Figure 5: No load on any coil but Coil 1 which is fully loaded.

Figure 6: Same chilled water system as Figure 1 except the coils are small and equipped with two position, on-off, control valves and automatic balancing valves. The pressure gradient for this system is shown in *Figure 7* with full load on all coils.

Figure 8: Reverse return system with two position, on-off, control valves and balance valves. The pressure gradient for this system is shown in *Figure 9* with full load on all coils.

What follows here is a discussion of these three principal systems.

I. Variable Volume, Direct Return Chilled Water Systems

A. Modulating Type Coil Control Valves (Figures 1 through 5): The development of the two-way control valve on cooling coils brought the use of direct return, variable volume chilled water systems as described in *Figure 1*. This figure includes only the distribution part of a primary/secondary chilled water system. For clarity, the expansion tank and its pressure are not included in this diagram or the pressure gradient dia-

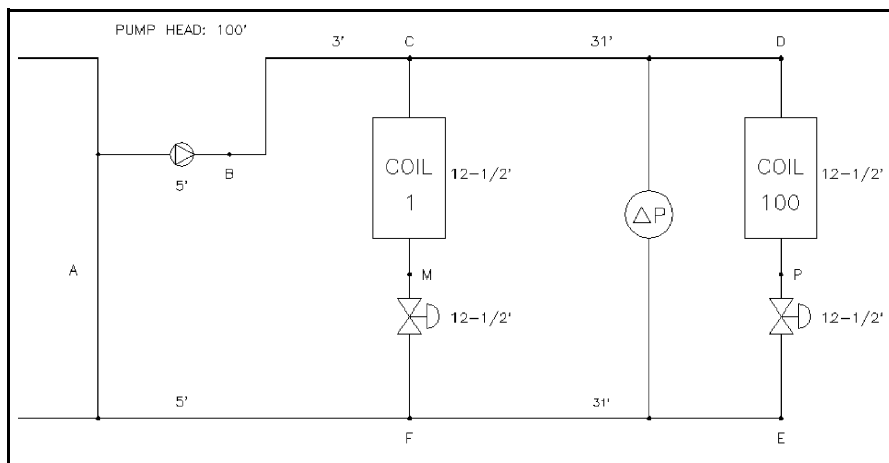


Figure 1: A variable volume system with direct return chilled water system with modulating type coil control valves.

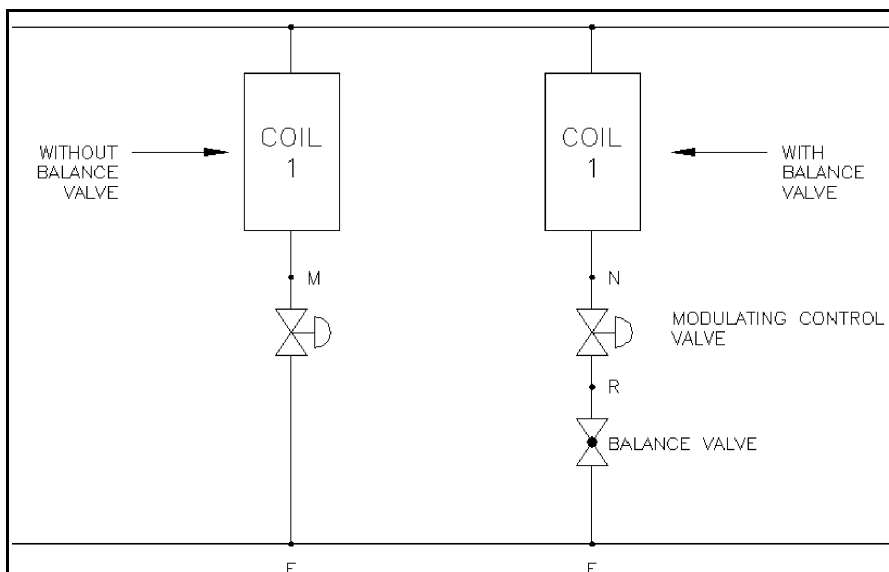


Figure 2: Control valve arrangement for Coil No. 1.

grams. The losses between the various nodes are shown in feet of head.

Figure 2 describes the nodes for Coil 1, with and without a manual balance valve, while *Figure 3* provides the pressure gradient diagram at full load on the chilled water system. The segment for Coil 1 in *Figure 3* shows both the pressure gradient with and without the balance valve. If the balance valve were used, it would be set to overcome the excess pressure not required for full flow through the coil or the control valve. In this case, the loss through the balance valve would be 62 ft.

Gil Avery, ASHRAE Fellow, Life Member, demonstrated in his July 1993 *ASHRAE Journal* article that control valves can be selected to overcome differential pressures such as the 74½ feet

encountered in this diagram. Obviously, the pressure drop across the control valve and the balance valve can be apportioned differently, but there is no need for a balance valve for this type of chilled water system with a properly selected control valve.

Figure 4 shows this chilled water system with the system fully loaded excepting Coil 1 which has no load and no flow in the coil. All of the differential pressure, 87 ft, is now imposed upon the control valve, as there is no loss in either the coil or the manual balance valve. The control valve must be designed to withstand this differential pressure whether or not there is a balance valve in series with the control valve.

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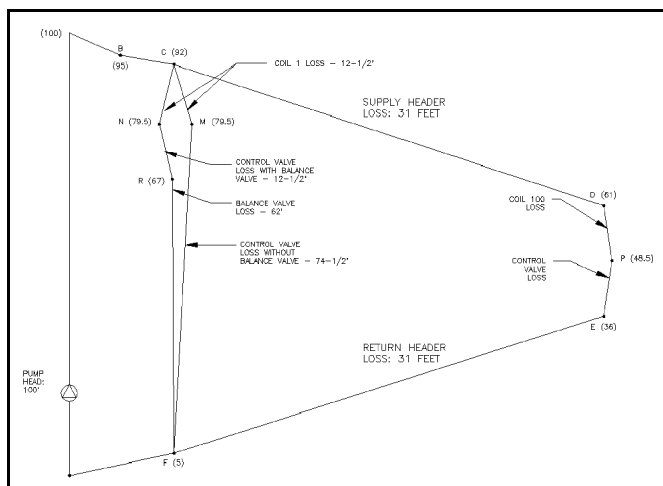


Figure 3: Pressure gradient for variable volume, direct return chilled water system at full load.

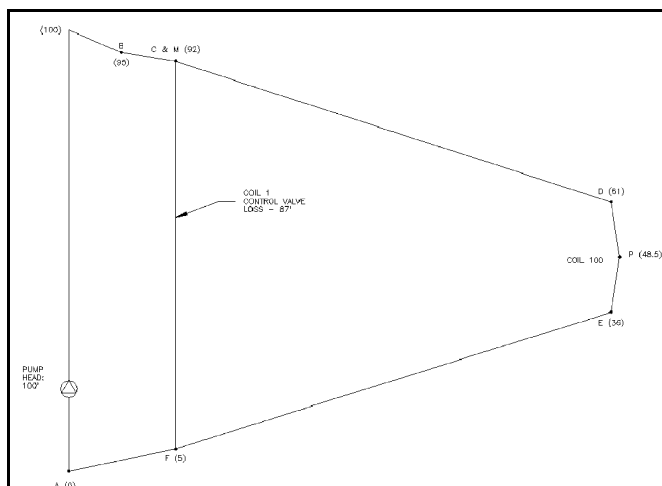


Figure 4: The pressure gradient for the system (shown in Figure 1) with a full load on all coils, except Coil No. 1.

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Figure 5 describes this same chilled water system with a minimum load on all of the coils except Coil 1 which is now fully loaded. It is assumed that the flow in Coil 1 is a small part of the total system flow, so there is no need for changes in the pressure in the system headers. With the balance valve set to withstand all of the overpressure in Figure 3, namely 64 ft, when that overpressure disappears as is the case in Figure 5, inadequate flow exists in the cooling coil. The actual flow would be 25/89 or 53% of design flow in the coil. It will now be necessary to reopen the manual balance valve to achieve design flow in the coil.

This demonstrates that it is impossible to adjust manual balance valves on variable volume, direct return, chilled water systems with modulating type coil control valves. When do you set the balance valve? At minimum load or maximum load? Figures 4 and 5 prove that manual balance valves should not be used on variable volume, direct return chilled water systems.

Automatic balance valves would be of no use either on this system, as they would be fully open under the conditions shown in Figure 4 where there is no load on Coil No. 1. Again, the control valve would be required to sustain all of the pressure differential shown in this figure, so why impose the extra pressure drop of an automatic balance valve. The pressure loss for automatic balancing valves varies usually from two to 6 psi (41.37 kPa) or over 4 ft to 14 ft of head at design flow in the coil.

B. On-off (Two position) Type Coil Control valves (Figures 6 and 7): Many

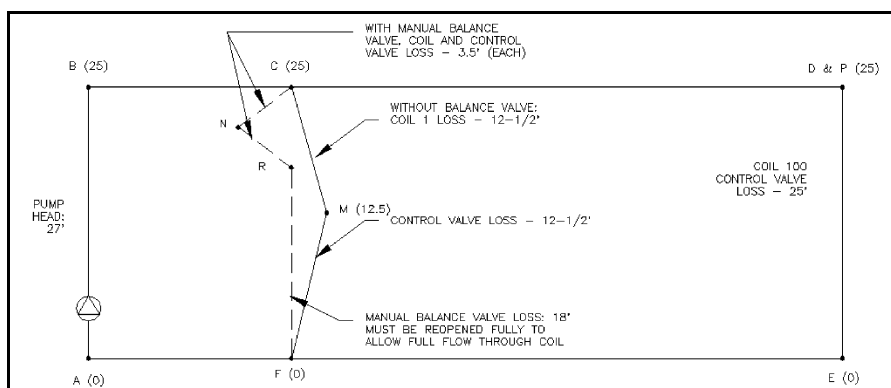


Figure 5: The system (shown in Figure 1) with a minimum load on all coils except Coil No. 1 which is fully loaded.

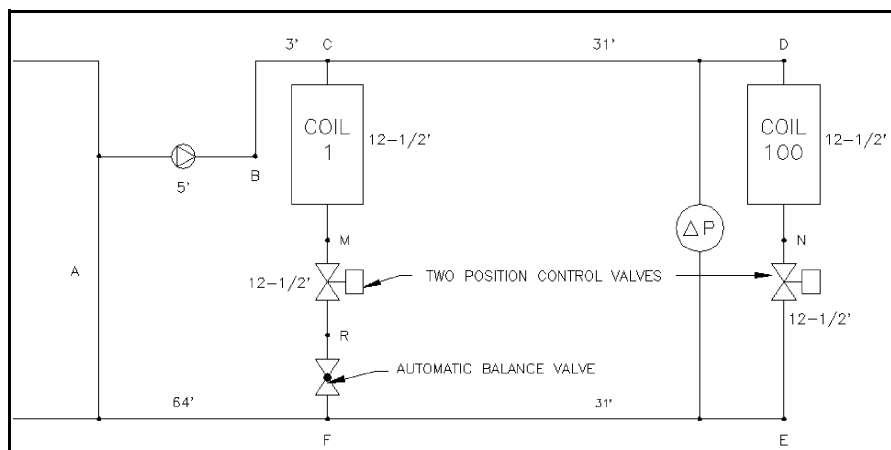


Figure 6: The variable volume, direct return chilled water system (shown in Figure 1) with on-off (two-position) coil control valves and automatic balancing valves.

small cooling loads are handled by fan-coil units that use two-position (on-off) control valves. This system is shown by Figure 6. Since the control valve is either fully open or closed, it cannot handle any excess branch flow. Therefore, a

balance valve must overcome the variation in differential pressures as the loads vary on the system. The manual balance valve cannot possibly work, since the differential pressure varies with these loads on the system. The automatic bal-

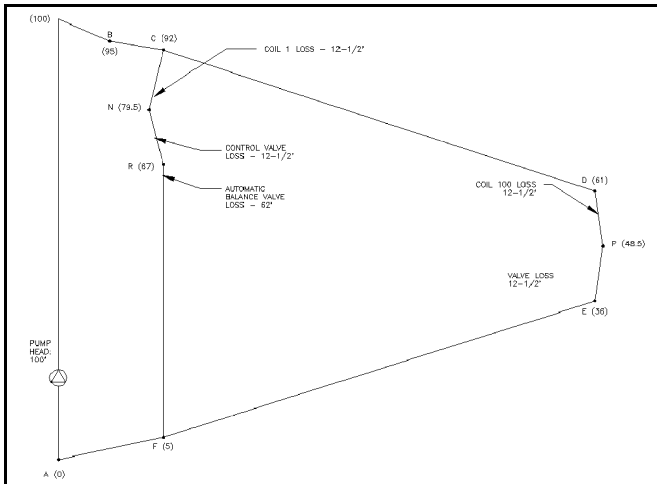


Figure 7: The pressure gradient for the system with a full load on all coils with two-position control valves and automatic balance valves.

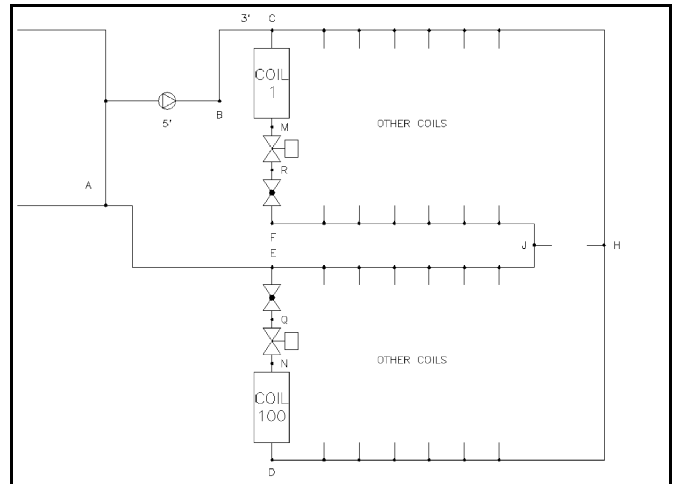


Figure 8: The reverse return system with two-position control valves on coils with balance valves.

ance valve does function properly, preventing any excess flow through the coil due to load variation in the system. This is shown in *Figure 7*.

Since the automatic balance valve is fully open when the two position control valve is closed, both valves may create noise as the control valve opens. All such valves should be installed in accordance with the valve manufacturers' recommendations. High quality, easily accessible strainers should be installed ahead of all automatic balance valves and coil control valves.

C. Mixtures of Coils with Modulating and On-Off Control Valves: When coils with modulating and on-off control valves are installed in the same loop of a chilled water system, it is necessary to install automatic balance valves on the coils with on-off (two position) control valves. This applies to systems with direct return as shown in *Figures 1 and 6*.

II. Reverse Return Systems (*Figures 8 and 9*)

Reverse return systems, *Figure 8*, were used extensively with three-way valves on cooling coils. Due to their energy waste, such control valves should not be used on new chilled water systems. They should be replaced with two-way control valves wherever economically possible on existing systems.

Balance valves were always used to balance the flow in these older systems with three-way control valves. Usually, there was considerable discussion as to whether automatic or manual balance valves were to be selected. Manual balance valves were adequate on most installations.

Reverse return systems still offer advantages on some applications of chilled water. If the coils are equipped with modulating valves, there is no need for any type of balance valve. The pressure drop across each coil is relatively constant as shown in *Figure 9*.

If most of the coils are equipped with two position (on-off) control valves, reverse return piping allows the use of manual balance valves in place of automatic balance valves. This insures that design flow is achieved in each coil. It is clear from *Figure 9* that the differential pressure across the coils and the control valves does not include the variable friction loss of the header piping. Therefore, a control valve with a lower differential pressure rating can be used without fear of the valves being damaged due to excessive differential pressure on these valves.

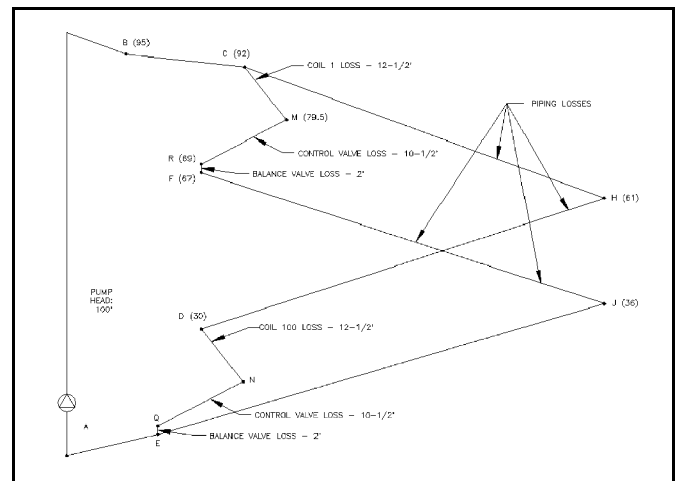


Figure 9: The pressure gradient for the variable volume, reverse return system with two-position coil control valves and balance valves.

Balance Valves on Pump Discharges

Balance valves should not be used on the discharge of most pumps! This includes multiple duty valves. One of the greatest energy losses in HVAC water systems is caused by balance valves on pump discharges.

On variable speed pumps, the pump speed and programming control should eliminate any overpressure. If overpressure exists, the pump control or programming is inadequate. There is no excuse for a balance valve on the discharge of a variable speed pump!

On constant speed pumps, if overpressure exists, the discharge shut-off valve should be adjusted to eliminate the overpressure until the pump impeller can be trimmed to eliminate the condition. There may be unusual system conditions that justify a balance valve on the discharge of a constant speed pump, but all other alternatives should be explored first.

The use of balance valves on pump discharges results in a continuous loss of energy. Every effort should be made to eliminate this energy loss in chilled water systems.

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Balancing Chilled Water Systems

Often, the argument is raised that the balance valve is necessary to prove design flow through a cooling coil. Most balance valves are equipped with two ports to verify the flow rate. The use of balance valves for this purpose is to condemn the system forever to an unnecessary friction loss and the resulting energy consumption.

A simpler and more energy effective procedure is to measure the pressure drop across the coil itself. The pressure loss in the coil is at least as precise as that of a balance valve, and there is no continuous loss of energy. The cooling coil loss included in these applications is 12.5 ft which is more than ample pressure drop to prove that design flow exists in a coil.

Summary of Systems

Following is a review of the various types of chilled water systems as to the use of balance valves. These suggested uses are those that will be applicable in most cases.

Variable Volume Systems

1. Direct return type:
 - a. With modulating type, coil control valves: None.
 - b. With two position coil control valves: Automatic balance valves on all coils.
2. Reverse return type:
 - a. With modulating coil control valves: None.
 - b. With on-off coil control valves: Manual balance valves.

Constant Volume Systems with Three-way Coil Control Valves

These systems are not recommended for most new installations.

- a. Direct Return Systems: Manual balance valves.
- b. Reverse Return Systems: Manual balance valves.

Conclusions

It is necessary for the designer of a chilled water system to understand 1) when to use balancing valves, and 2) what type of balance valve is applicable. He or she can do this by developing a pressure gradient diagram for the proposed system

under various design conditions. Normally, these diagrams are developed with the system at full-load condition and at specific part-load conditions.

The great energy waste caused by improper use of balance valves on pumps and cooling coils must be eliminated to demonstrate that we are striving to achieve energy efficient, chilled water systems.

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