# The Chilled Water and Hot Water Building Deferential Pressure Setpoint Calculation — Chilled Water and Hot Water Pump Speed Control

Chenggang Liu
Research Associate
Energy Systems Laboratory
Texas A&M University
College Station, TX

Homer L. Bruner, Jr., CEM
Mechanical Systems Specialist
Utilities Office of Energy Management
Physical Plant Department
Texas A&M University
College Station, TX

Song Deng
Senior Associate
Project Manager
Energy Systems Laboratory
Texas A&M University
College Station, TX

W. Dan Turner, Ph.D., P.E.
Professor & Director
Energy Systems Laboratory
Texas A&M University
College Station, TX

David E. Claridge, Ph.D., P.E.
Professor & Associate Director
Energy Systems Laboratory
Texas A&M University
College Station, TX

## ABSTRACT

More and more variable frequency devices (VFD) are being installed on the chilled water and hot water pumps on the TAMU campus. Those pump speeds are varied to maintain chilled water or hot water building deferential pressure (DP) or return temperature or flow rate at their setpoints. The chilled water and hot water DP setpoint or return temperature setpoint or flow rate setpoint was a constant value or reset based on outside air temperature. In some buildings, the chilled water and hot water DP setpoints were reset based on flow rate, but in many instances those setpoint schedules were either too low to maintain enough building DP requirement or too high and consumed excess energy. The building DP reset schedule based on flow rate is studied and compared with the other pump speed control methods. Because the building DP setpoint based on flow rate method is achieved by tracking the load change, it saves energy than the other methods. In this paper its calculation procedure is generated and the example of the building DP calculation is given.

## INTROUCTION

The campus of Texas A&M University in College Station consists of 160 buildings. 114 buildings are located on the main campus and the rest 46 buildings are located on the west campus. More and more variable frequency devices (VFD) are installed on chilled water and hot water pumps. The variable speed pump has reduced the over-pressuring of water systems and reduced pump maintenance caused by the excessive radial thrust often found in constant speed pumps. The electricity consumption by variable speed pumps is a fraction of that of constant speed pumps. Also the over-pressure of water systems can result in the increase of chilled water and hot water consumption with the leaking control valves on the cooling and heating coils. Variable speed pumps save cooling and heating energies. However, most of these advantages are lost when proper speed control is not maintained in variable speed pumping systems.

## PUMP SPEED CONTROL SCHEMES

In most cases, the speed of a chilled water or hot water pump is varied to maintain the chilled water or hot water building differential pressure (DP) at its setpoint. Figure 1 demonstrates pump speed control logic to maintain the building DP at its setpoint. The pressure sensors or transmitters send pressure signals to the energy management and control system (EMCS). The building DP of the chilled water or hot water will be calculated and compared with its setpoint by EMCS. Then the control signal for the VFD is sent to the local controller to drive a pump speed. When water loop DP is higher than the

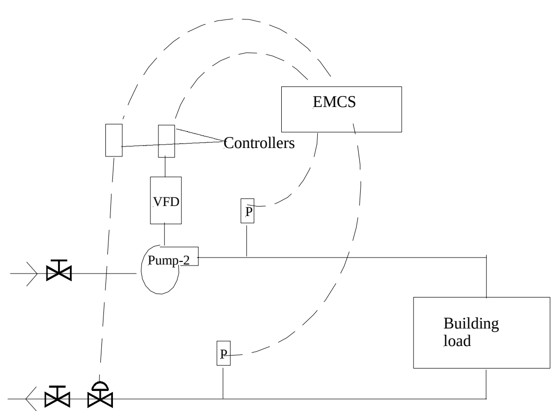


Figure 1. Pump speed control to maintain the building DP at its setpoint

building DP setpoint, pumps will be turned off by EMCS and the building control valve will be controlled to maintain the building DP at it setpoint. Whenever the pump is on, the building return control valve is full open.

The constant value of building DP setpoint is simple, but it will waste energy when the building has part load, because the maximum load requires a high DP. Usually, the building DP setpoint is reset based on the flow rate, or outside air temperature, or the coil valve position.

The building DP setpoint based on flow rate method is achieved by tracking the load change. When cooling or heating load increases or decreases, the flow rate increases or decreases. Figure 2 demonstrates that the required building DP changes according to the chilled water or hot water flow rate. Points A and B in the figure 2 are system operating points. When the building cooling load decreases, the system operating point moves left from A to B along the system curve. The DP setpoint based on flow rate can be calculated by the following equation (1).

$$DP_{setpoint} = k * (\text{flow rate})^2 \qquad (1)$$

Here k is a factor of the system characteristics. The k factor can be calculated from the fraction of the pipes and fittings. For a real existing system, the k factor can be calculated by a reversed equation (2).

$$k = DP_{measured} / (\text{flow rate})_{max}^2 \qquad (2)$$

Here $DP_{measured}$ is the building DP measured when the flow rate is met with maximum load. To meet maximum loads, control valves on AHUs need to be full open unless the pump is designed with diversity.

Usually the building has several zones. To determine the capacity of the pump, one needs to know the peak load of the totality of the building served by the pump. This is usually less than the simple sum of the individual peak loads because of noncoincidence. The term diversity is used to designate the ratio of the actual system peak to the sum of the individual peak loads. In practice, one often finds a diversity around 0.6 to 0.8 for large buildings.

The building DP setpoint based on outside air temperature method is limited to the building in which the heat flow across the exterior envelope influences its interior cooling and heating loads. In other words, the cooling and heating loads mainly depend on outside air temperature. For the building, which has large heat gains from occupants, lights, and equipment, the pumps speeds are not controlled economically by the outside air temperature method. Table 1 and table 2 give an example of the chilled water and hot water building setpoints based on outside air temperatures for Heldenfels building. This is a quick and easy method to implement.

Table 1. Chilled water DP setpoint

| | | | | |
|---|---|---|---|---|
| $T_{oa}$ (•) | 50 | 60 | 70 | 90 |
| DPsp (psi) | 6 | 8 | 10 | 15 |

Table 2. Hot water DP setpoint

| | | | | |
|---|---|---|---|---|
| $T_{oa}$ (•) | 50 | 60 | 70 | 90 |
| $DP_{sp}$ (psi) | 10 | 8 | 6 | 4 |

Another means of controlling pump speed, the coil

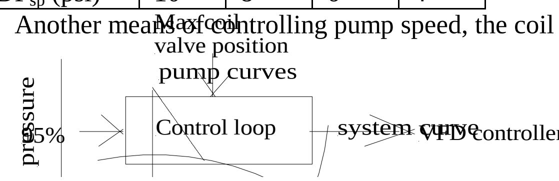


Figure 4. Pump speed control logic to maintain the max coil valve position at 95%

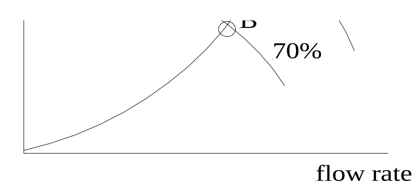


Figure 2. Variable speed pump operating points

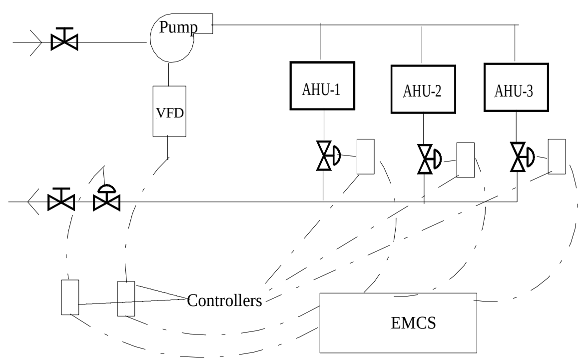


Figure 3. Pump speed control to maintain the max coil valve position at its setpoint of 95%

valve position method can be used. Figure 3 demonstrates pump speed control logic to maintain the max open valve at its setpoint of 95% open. Figure 4 demonstrates this control logic. All valves are monitored and the max open valve position is fed into the pump speed control loop in EMCS. The output of the control loop is sent to the pump VFD controller. If water is from campus loop and water loop pressure is high enough to maintain the max open valve position at its setpoint, the pump is turned off. Then the building control valve will take over to maintain the max open valve at it setpoint. If the cooling valve is not functional, such as stuck at partially open or actuator leaking, or is overridden at full open, the pump speed control loop will send max output to the pump VFD controller. This will result in higher energy consumption, before the problem is fixed.

## BUILDING DP CALCULATING PROCEDURE

The procedure here is for calculating building chilled and hot water (DP) setpoint based on the flow-rate. For the existing system, the flow rate coefficient, k factor, will be calculated with equation 2. That is

$$k = DP_{measured} / (GPM)_{max}^2 \qquad (2a)$$

The k-factor varies from system to system or from building to building. The building DP will be measured when the flow rate, GPM, is met with maximum load of the system. Actually, this procedure is how to find k-factors of building chilled and hot water systems.

The procedure is taken under following conditions.

1. The flow meter and water pressure sensors are calibrated.
2. The pump is in good working condition.
3. The air is removed from the piping system.
4. The coils of units are back flushed.
5. The design flow rate and pressure drop of terminal equipment, such as air-handling unit (AHU) and fan-coil unit, are obtained. The total design flow-rate of the terminal units is compared with the pump design flow-rate.
6. The terminal flow will be measured indirectly by reading the pressure drop across the coil of a terminal unit.
7. When there is diversity (DF) between the pump and total terminal flows ($GPM_{pump}$ and $GPM_{units}$), the corrected design pressure drop ($P\text{-drop}_{corrected}$) across the coil of the terminal unit needs to be calculated with following equation 3.

   $$P\text{-drop}_{corrected} = FD^2 * P\text{-drop}_{design} \qquad (3)$$

   Here $P\text{-drop}_{design}$ is the design pressure drop across the coil of a terminal unit. DF is the flow diversity between the pump and the total terminal flows and is obtained from the flowing equation.

   $$(FD) = GPM_{pump} / GPM_{units} \qquad (4)$$

8. The building HVAC system is studied. An attention is paid on the type systems, equipment and their capacities. The location of the control valves, balancing locks, flow measuring station and pressure measuring station are known.

The Calculating Procedure is described as below. It is your basic water balance procedure. The procedure is same for both chilled and hot water systems.

1. Open the building control valve fully.
2. Open the building manual valves fully.
3. Open control valves on each AHUs and fan-coil units fully. When there is a diversity, valve position is proportional to the diversity.
4. Open balancing valves and manual valves on each AHUs and fan-coil units fully.
5. Command the pump speed of 100%.
6. Take coil DP measurement on the first AHU from the pump. The first AHU can be located in the basement or on the 1st floor. Compare measured coil pressure drop ($P\text{-drop}_{measured}$) with its design $P\text{-drop}_{design}$. The $P\text{-drop}_{measured}$ should be equal with or greater than the $P\text{-drop}_{design}$, because the 1st unit is closed to the pump. If $P\text{-drop}_{measured}$ is greater than the $P\text{-drop}_{design}$, reduce $P\text{-drop}_{measured}$ to the $P\text{-drop}_{design}$ by closing the balancing valve on the unit. If there is no balancing valve, use the control valve on the unit.
7. Take coil DP measurement on the rest of the units located on the floor as same as the first unit. Compare measured coil pressure drop with their design. If $P\text{-drop}_{measured}$ is greater than the $P\text{-drop}_{design}$, reduce $P\text{-drop}_{measured}$ to the $P\text{-drop}_{design}$ by closing the balancing valve on the unit.
8. Repeat step 7 for the units on the next floor through the top of the building.
9. Take coil DP measurement on the last unit, on top of the building , from the pump. The last unit from the pump can be located on the top floor or on the roof. The pressure drop across the coil on the last unit should be equal or greater than its design. If $P\text{-drop}_{measured}$ is greater than the $P\text{-drop}_{design}$, reduce $P\text{-drop}_{measured}$ to the $P\text{-drop}_{design}$ by reducing the pump speed.
10. Repeat step 6 through step 9 until coil DP of all units match their design. The coil DP of the first unit through the units on the top floor could be decreased, if the pump speed

is reduced in step 9. If so, increase P-drop $_{measured}$ to the P-drop $_{design}$ by opening the balancing valve on those units. If the coil DP is still less than its design when the balancing valve is fully open, increase the pump speed and perform balance again.

11. When coil DP of all units match their design, read water flow-rate ($GPM_{balanced}$) and building supply (Ps) and return pressures (Pr).
12. The flow-rate coefficient (k) is obtained from following equation.

$$k_{cal} = (Ps - Pr) / (GPM_{balanced})^2 \quad (5)$$

13. The chilled or hot water building DP setpoint ($DP_{sp}$) is set based on the following equation.

$$DP_{sp} = k_{cal} * (GPM)^2 + P_{ad} \quad (6)$$

Here $P_{ad}$ is pressure added to the setpoint for control valves to be adjusted for the requirement of flow rate. The range of $P_{ad}$ is 1 psi to 2 psi based on our field experience.

## AN EXAMPLE OF $DP_{sp}$ CALCULATING

The West Campus Library is located on the west campus of Texas A&M University (TAMU) in College Station. The Energy Systems Laboratory (ESL), TAMU, calculated the chilled water and hot water building DPsp in February 02, during the Continuous Commissioning (CC[SM]) under direction and in cooperation with the TAMU Physical Plant Energy Office. As an example, the chilled water $DP_{sp}$ calculation of the Library is presented below.

The building chilled water system is shown in Figure 5. Two chilled water pumps serve the chilled water of the building. One stands by to the other. The design flow-rate for each chilled water pump is 560 GPM. There are eight AHUs serving the building. Two of eight AHUs are outside air units, which treat outside air for the rest six AHUs serving the floor area. A fan-coil unit serves the printer room only. The pressure drop across the cooling coil for each unit is 6 psi. The total design chilled water flow-rate of the system is 670 GPM. The diversity of chilled water flow rate, FD, is 0.836. The corrected design pressure drop across cooling coil, P-drop, is 4.2 psi. With the chilled water system balanced, 16.4 psi building DP was measured with the chilled water flow rate of 500 GPM. The calculated k factor, $k_{cal}$, is 0.0000656. $P_{ad}$ of 1.5 psi is selected in this example. The new equation of chilled water building DP setpoint, $DP_{sp}$, is as following with a minimum programming value of 4 psi.

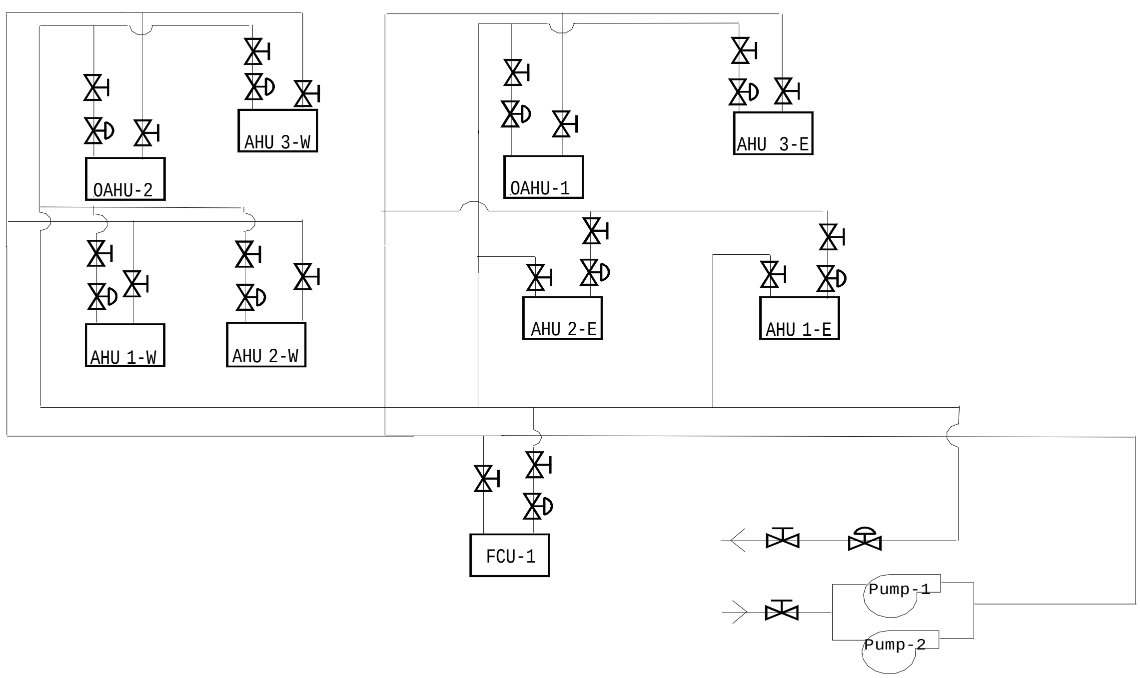


Figure 5. Chilled water system diagram of the Library

$$DP_{sp} = 0.0000656 * (GPM)^2 + 1.5 \quad (7)$$

The chilled water pump speed was varied to maintain the building DP at a constant setpoint of 17.5 the entire year. The new chilled water building

DP setpoint varies from 4 psi to 16.4 psi, when the flow rate changes from 0 PGM to 500 GPM. Figure 6 demonstrates the difference between the old and new chilled water building DP setpoints of the Library. The chilled water pump operated well with the new speed control schedule from February 02 to July 02.

## CONCLUSION

The control schemes for the chilled water and hot water pumps in HVAC systems are introduced in this paper. It is a good control scheme for pump speed control to maintain chilled water or hot water building DP at its setpoint, when setpoint is reset based on the flow rate. The building DP setpoint based on flow rate method is achieved by tracking the load change, it saves energy than the other methods. The calculation procedure of the building DP setpoint is generated and an example of the calculation is given. In the example, the pump power saving is achieved by the calculated building DP setpoint based on the flow rate.

## ACKNOWLEDGMENT

The work of this paper was sponsored by Texas A&M University, Physical Plant. We greatly appreciate support for this work from the Office of Energy Management and from other members of the Continuous Commissioning Group, Energy Systems Laboratory, Texas A&M University.

## REFERENCE

1. Larry Tillack and James B. Rishel. 1998. “Proper Control of HVAC Variable Speed Pump”, ASHRAE Journal, Nov. 1998, pp. 41-47.

2. G. Wei, M. Liu, David E. Claridge, Y. Sakurai. 2000. “Improved Air Volume Control Logic for VAV Systems”, Proc. Of the 12th Symposium on Improving Building Systems in Hot and Humid Climates, pp. 195-198.

3. C. Liu, W. Dan Turner, David E. Claridge, Song Deng, Homer L. Bruner, Jr. 2002. “Result of CC Follow-up in the G. Rollie White Building”, Proc. Of the 13th Symposium on Improving Building Systems in Hot and Humid Climates, pp. 96-102.

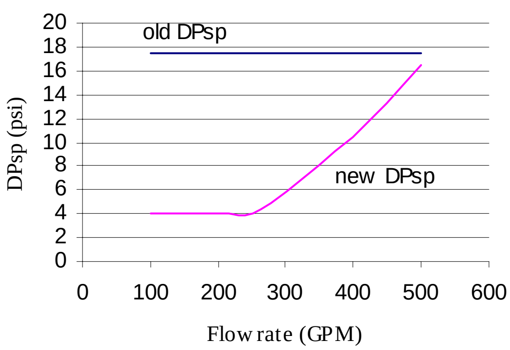


Figure 6. Comparing between the old and new DPsp

4. 2000 ASHRAE Handbook, HVAC Systems and Equipment. Chapter 39, Centrifugal pumps.

5. Jan F. Kreider, Ari Rabl, 1994. Heating and Cooling of Buildings—Design for Efficiency.