Pressure Sustaining Valves
How They Helped Solve Insufficient Plant Static Pressure on Large Campus Loops at Texas A&M

By Hui Chen, P.E., Member ASHRAE; James Riley; Amy Chen; Les Williams; Wyatt Hahn, Associate Member ASHRAE; Robert Henry, P.E.

Texas A&M University (TAMU) has implemented numerous energy conservation initiatives on its utility plants and buildings that have achieved $210 million in cost avoidance through increased operating efficiencies since 2002. Two of these plants, TAMU’s Central Utility Plant (CUP) and Satellite Utility Plant 3 (SUP3), provide low temperature hot water (LTHW) and chilled water (CHW) to over 230 buildings with over 16 million ft² (1,486,448 m²) through the hydronic network on main campus (Figure 1).

Negative pressures on the top coils of the campus’s four tallest buildings were identified during LTHW and CHW plant optimization projects in 2016. Negative pressure in buildings that exceed the plant static pressure (PSP) is a common problem on large hydronic loops, and is often overlooked. This problem causes excessive pump power consumption and introduces air into the water system, causing noise, corrosion, and most importantly, decreases heat transfer efficiency. A study was previously performed on several buildings to find a solution to the problem, and it looked at several possibilities such as raising PSP, installing heat exchangers, or installing pressure sustaining valves (PSV) on the return pipes of each of the buildings experiencing the issue. After extensive examination of the different possible solutions, PSVs were chosen as the best option because the heat exchanger option was too costly due to existing building spacing constraints, and raising PSP would cause leaks widely throughout the hydronic loop because large portions of it are over a century old. Consequently, PSVs were installed on four buildings, as of February 2018, and the tuning and adjustments were completed after the installation.

This article presents a PSV operation study that was carried out as an extension of the previous study in order to qualify the practicality of the solution. Hydronic loops pressure distributions and simulations are used for scenario comparison and identifying PSV pump requirements. The field PSV operation is analyzed to determine the PSV’s performance. This article addresses the concerns of effects that PSVs have on building pump requirements, nearby buildings’ flow return, and building pump power consumption. Building A was one of the four buildings previously identified with negative top coil pressure, and is the focus of this case study. This study provides a technical guide for both large hydronic loop and building design, operation, and improvement.

Pressure Distribution Profile and Pump Requirements
A detailed plant, loop, and building pressure analysis was performed to analyze building pump requirements for different scenarios based on the Bernoulli² and

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the Darcy-Weisbach equations. Building pump requirements vary with primary loop pressure, building friction pressure loss, and the difference between PSP (in ft w.c.) and top coil height. Figure 2 is a simplified schematic of TAMU’s large hydronic loop that includes the CUP and Building A. It diagrams the current PSP at 50 psig (344 kPag) at an elevation above sea level of 465 ft (142 m), and the top coil elevation above sea level of 548 ft (167 m). The building top coils are 198 ft (60 m) above the plant elevation. The PSP only yields 115 ft (35 m) of head, which causes the negative pressures in the top coils since Building A was built in 1974. Pressure distribution profiles for three scenarios were generated to evaluate pump requirement and further identify whether the PSV option is the best solution. These pressure distribution profiles are displayed in Figure 3: (a) raising whole loop PSP; (b) pre-PSV operation; and (c) with PSV and positive top coil pressure. The purpose for listing scenario (a) here is just for reference even though this scenario has already been invalidated in the previous study. These pressure distribution profiles are drawn based on trend pressure values on the plant and building as shown in the simplified schematic (Figure 2). In the Figure 3, the vertical axis indicates pressure value and the horizontal axis shows approximate
The building pressure profile analysis confirms the building pump head and power for the PSV option is much lower than the pre-PSV operation. When PSP is lower than top coil pressure in height, the PSV is able to gain hydraulic pressure to meet the top coil’s requirement. Options 1 and 3 belong to closed hydronic system operation while Option 2 is a “half” open hydronic system because air infiltration from leaks and water will coexist in the top coil outlet just above PSP.

Simulation Model and Scenarios

Generally, large hydronic systems are too complicated to manually test, so valid simulation software is becoming more widely accepted as a reliable source of information for understanding a hydronic system’s characteristics and deciding on the best solution for complicated problems. A commercially available hydraulic simulation software has been used for the analysis of the hydronic loop while varying primary pressure scenarios.

The software assumes incompressible, one-dimensional flow and uses principles of heat transfer and system energy balance to model pressures, flows, temperatures, and power consumption in the loop. The model was developed based on as constructed loop pipe dimensions, materials, and elevation, and calibrated using field data to obtain the most reliable results possible. Figure 3 shows a large campus loop simulation model with two plants (CUP and SUP 3), four tall buildings with PSVs, and others without PSVs. These two plants are approximately a mile apart with 90,000 ft (27,432 m) of underground piping throughout the loop.

The simulation assumes varying pumping speed to react to primary pressure variation and to keep the coil flow and design temperature differential constant. Two scenarios were evaluated: varying primary supply pressure and varying primary return pressure. In each case, a simulation was performed with the PSV installed as well as without it, so the effect of the PSV location. Each of pressure distribution diagrams in Figure 3 clearly shows primary plant pump head (Points 1–2), building pump head (Points 3–4), top coil inlet and outlet pressures (Points 5–6), and building return pressure at Point 7. The pre-PSV scenario (b) results in negative top coil outlet pressure, which is detrimental to the hydronic loop. Raising PSP (a) and installing PSVs (c) both eliminate negative top coil pressure, but raising PSP affects the entire hydronic loop and might lead to other issues, while the PSV option just affects individual buildings with insufficient PSP.

Table 1 summarizes the building pump head requirement for the three pressure distribution diagrams shown in Figure 3. The pumping head required varies as a result of building friction loss and other factors such as lifting water head. The Raising PSP option shown in Table 1 has the lowest building pump head requirement at 6 psig (41 kPag), which is only the friction head loss shown for comparison here. The PSV option requires a significantly lower required building pump head of 36 psig (248 kPag), compared to pre-PSV operation, which requires 42 psig (289 kPag) of pumping head. The building pressure profile analysis confirms the building pump head and power for the PSV option is much lower than the pre-PSV operation. When PSP is lower than top coil pressure in height, the PSV is able to gain hydraulic pressure to meet the top coil’s requirement. Options 1 and 3 belong to closed hydronic system operation while Option 2 is a “half” open hydronic system because air infiltration from leaks and water will coexist in the top coil outlet just above PSP.

Table 1

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>OPTIONS</th>
<th>RAISING PSP</th>
<th>W/O PSV</th>
<th>PSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSP in Height &gt; Top Coil in Height?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Top Coil Outlet Pressure ± psig</td>
<td>+16</td>
<td>-24</td>
<td>+8</td>
<td></td>
</tr>
<tr>
<td>Bldg. Friction Loss, psig</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Lift Head, psig</td>
<td>0</td>
<td>36</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Bldg. Pump Requirement, psig</td>
<td>6</td>
<td>42</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

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could be analyzed. In the first case, the primary return pressure was kept constant at 57 psig (393 kPag) while the primary supply pressure was varied from 45 to 70 psig (310 to 482 kPag). In the second scenario, the primary supply pressure was kept constant at 59 psig (406 kPag), while the primary return pressure was varied from 50 to 70 psig (344 to 482 kPag). The simulation's primary pressure data and ranges were based on trended yearly data patterns.

**Building Pump and Primary Loop Pressure**

The simulation results in Table 2 are shown to compare building pump capacity and its power consumption for different scenarios (with and without PSV). Table 2 exhibits primary supply versus top coil pressure, pumping power, and pump speed for Building A. Without the PSV installed, the top coil inlet pressure was 10.2 psig (70 kPag) and the top coil outlet pressure was –27.0 psig (–186 kPag). With the PSV the top coil inlet pressure decreases from 10.2 psig to 5.2 psig (70.3 to 35.8 kPag), and the top coil outlet pressure becomes 3.1 psig (21.3 kPag). As primary supply pressure increases from 45 psig to 70 psig (310 kPag to 482 kPag), pumping speed decreased from 99% to 79% without the PSV, and 96% to 74% with the PSV. Pump head with PSV dropped on average 14%, around 11.5 ft (3.5 m), compared to the pre-PSV option. With the PSV the power consumption is about 2 hp (1.5 kW) lower than without the PSV, which declined about 13%. The PSV method is able to reduce CHW pump power at $2,380/year and has an estimated payback period of 3.5 years.

Field observations display that each existing pump was oversized and ran at full capacity before PSVs were installed, so the actual pump power savings from the PSV installation is more than the simulation estimation at Table 2. The second scenario simulation shows that both pump power and head differences (with PSV or not) are independent of primary return pressure.

**Return Pressure Blockage Identification**

One of the concerns that needed to be addressed was how the installation of PSVs on each of the tallest buildings on campus would affect the return loop pressures of nearby buildings. A hydraulic simulation for Building A (with PSV) and its surrounding Buildings E, F, and G (without PSVs), was performed for this hydronic return pressure blockage issue. Figure 5 shows the return
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pressure blockage identification map. Buildings F and G are downstream from Building A, while Building E is located upstream. Each building has a different demand flow and pump pressure requirement because of the building type, geographical location, and elevation. The “Return Pressure Blockage” simulation has two scenarios: with and without PSV installed at Building A. The building return pressure values only rely on primary return pressure, and not primary supply pressure.

Figure 6 shows the building return pressure versus the primary loop return pressure with PSV installed at Building A. Whenever primary return pressure increases, the nearby return pressures at each junction also increase. The different return building pressure values are all higher than their associated primary return pressure values at each junction, which is related to their physical location on the hydronic loop with respect to the plants. Building E has a higher return pressure than Building A because it is upstream of Building A, and the higher pressure value is consumed to overcome pipe friction loss between two buildings: A and E. There was no reduced or completely blocked flow identified on Building A’s return flow pipe. Also Building A does not block any flow from Buildings F and G because water flow and pressure converges at each junction. Therefore, it was determined that the installation of the PSV had no impact on the surrounding buildings.

PSV Operation & Performance

Sequences of Operation

CHW and LTHW distribution systems at the university consist of variable hydronic flow, primary pumping, and building pumping as shown in Figure 2. The hydronic system operation for plants and buildings is heavily related to ambient temperature and the university schedule. Based on primary and building pressure profiles, along with flow profiles and pump affinity laws, the sequences of PSV operation have been developed to make sure the top coil receives sufficient pressure to maintain the PSV upstream pressure at its PSV set point.

There are two types of PSV control, one is an automatic remote control and another is a standalone control. The PSV at the university has standalone control, so its pressure set point has to be physically set or adjusted on the valve, not remotely. A wire sensor connects the controller to the direct digital control (DDC) to provide PSV position data (percent open). The valve has an automatic modulation feature that reads the upstream pressure of the valve and then adjusts the position of the valve according to the pressure set point. The PSV operation is also directly connected to building pump control as an equation (1):

$$\text{Building Pump Speed} = \left( \frac{P_{\text{pri. supply}} - P_{\text{pri. return}} + \Delta P_{\text{bldg.}} + \text{Safety Factor}}{P_{\text{bldg. pump head}}} \right)^{1/2}$$

where

- $P_{\text{pri. supply}}$ = primary supply pressure
- $P_{\text{pri. return}}$ = primary return pressure downstream of the PSV
- $\Delta P_{\text{bldg.}}$ = pressure loss when building pump delivers water throughout the building, safety factor is for the top
coil and recommended to be around 3 to 5 psi (20 to 34 kPag) to ensure positive pressure at all times.

\[ P_{(\text{bldg. pump head})} = \text{actual pump head} \]

The speed of the pump needs to be modulated to keep the PSV upstream pressure equal to the PSV set point. If the PSV upstream pressure is higher than the PSV set point pressure, then the pump needs to decrease its speed and the PSV will adjust itself to increase flow to maintain the set point value. If, instead, the PSV upstream pressure is lower than PSV set point, the pump needs to increase its speed and the PSV also needs to modulate to reduce flow.

**PSV System Performance**

Figure 7 and 8 illustrate the PSV operation on the CHW system at Building A on May 29, 2018. Building Pump 1 runs (Pump 2 idle, in parallel) from 68% to 90% provides daily average pressure head of 30 psig (206 kPag) to deliver the water to the top coils of the building and then back to primary return loop.

The PSV upstream pressure (blue line in Figure 7) keeps a constant pressure value of 90 psig (620 kPag), which is regulated by pump speed and modulation of PSV from 27% to 31% in Figure 8. Figure 8 shows the top coil inlet pressure remains about 7.8 psig (53 kPag), while top coil outlet pressure averages around 5.5 psig (37 kPag).

The field operation shows that the replacement of the pre-PSV pumps with large capacity pumps at Building A is not necessary because the PSV option requires smaller building pump capacity than pre-PSV. The daily field operation graphs...
clearly exhibit that both pump speed and PSV modulation converged at the PSV set point, and pump power consumption and pump head were reduced, compared to the existing pump without the PSV, a high operation performance as designed. The PSVs are in full operation at all four buildings which previously experienced negative pressures in their top coils, and all PSVs have been tuned, balanced and commissioned.

Table 3 shows an inspection of PSV’s operation as of May 15, 2018. The top coil outlet pressure stays around 5 psig (34 kPag) for all buildings, which provides some safety during operation should anything not act according to design. The building PSV position varies from 11.6% to 45.3%, which is related to the PSV’s distance from the plant and its modulation to keep its set point. In same way, pump speed is also related to each buildings demand flow, PSV set point, and distance from the plants. The inspection indicates these PSVs performed as designed.

Table 3  PSV operation and performance.

<table>
<thead>
<tr>
<th>BUILDING NAME</th>
<th>HYDRONIC TYPE</th>
<th>TOP COIL OUTLET PRESSURE PSIG</th>
<th>ΔT °F</th>
<th>PSV POSITION (%)</th>
<th>PUMP SPEED (%)</th>
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<tbody>
<tr>
<td>A</td>
<td>CHW</td>
<td>4.1</td>
<td>12</td>
<td>24.2</td>
<td>68</td>
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<tr>
<td></td>
<td>LTHW</td>
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<td>23</td>
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<tr>
<td>B</td>
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<td>25.4</td>
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<tr>
<td></td>
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<tr>
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<tr>
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<tr>
<td>D</td>
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<tr>
<td></td>
<td>LTHW</td>
<td>4.5</td>
<td>23</td>
<td>45.3</td>
<td>70</td>
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</table>

Conclusion

This follow-up study confirmed that the PSV method is an energy-saving as well as practical solution. The operation study revealed the installation of PSVs reduces pumping power by 13% and pump head by 14%. These improvements resulted in one existing CHW pump to save an estimated $2,380/year at Building A with an associated payback period of 3.5 years. The PSV solution not only saves money, but also eliminates the problem of insufficient PSP on the large campus loop and improves the hydronic loop performance. The PSV method does not cause any blockage on the return flow from surrounding buildings, and the high PSV operation performance indicates the building pump capacity for PSV method is much smaller than pre-PSV’s requirement. This study will help engineers fully understand hydronic loops, building pressure distribution, and building pump requirements. It offers a cost-effective solution and can be used as a resource for PSV design and operation for design engineers and facility personnel.

References

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