PNNL-SA-89222

Building Re-Tuning Training Guide: Central Utility Plant Heating Control

Summary

The purpose of the central utility plant (CUP) heating control guide is to show, through examples of good and bad operations, how CUP heating can be efficiently controlled.

This guide will focus on hot water boilers and their operations. Hot water boilers are closed systems that simply heat water up to a desired temperature that does not involve a phase change from liquid to gas. This simplifies the design process, but requires the addition of pumps to move the water in the piping loop.

Standard hot water boilers are not designed to allow the return water temperatures to be lower than 140^{o}F to 180^{o}F (verify with specific boiler manufacturer's design recommendations). If the return water temperatures drop too low, the boiler may experience combustion gases condensing inside the boiler stack or inside the boiler firing chamber, which can cause harm to the boiler in the form of corrosion (aggressive sulfuric acids) etc. Newer condensing boilers, however, are designed to operate with return temperatures below 140^{o}F, and to handle the combustion gases condensing inside the boiler's components (stack and firing chamber). For newer condensing boilers, achieving lower return temperatures should be the target to extract as much heat as possible from the combustion gases before they exit the boiler and boiler flue stack (stack losses). These losses are typically between 15% and 30%. Thus, the overall efficiency of conventional boilers is between 65% and 75%, while high efficiency condensing boilers range from 85% to 95%.

A direct effect on boiler efficiency (standard or high efficiency condensing boilers) is the excess air required for complete combustion. Typically, around 4% excess air with an O_2 trim is required for complete combustion, but too much excess air can cause higher stack temperatures, and can decrease boiler efficiencies by as much as 20%.

The temperature of the hot water plant should be reset automatically, based upon the loads in the building (the average of the heating-coil-valve commands) or based upon the outdoor-air temperature. If the boilers are only used for comfort heating, they should be shut down (if possible) during the summer months. Failure to shut down the boilers during warm summer months, or neglecting reset opportunities for the hot water supply temperature, in all likelihood will lead to increased fan, heating and cooling energy consumption.

Data needed to verify CUP efficient heating control

To analyze and detect deficiencies in CUP heating control, for single-duct variable-air-volume (SDVAV) air-handling units (AHUs), the following parameters must be monitored using the trending capabilities of the building automation system (BAS):

- Outdoor-air temperature (OAT)
- Heating-coil-valve signal (HCV)
- Hot water supply temperature (HWST)
- Hot water supply temperature set point (HWSTSP)
- Hot water return temperature (HWRT)
- Hot water loop differential pressure (HWLDP)
- Hot water loop differential pressure set point (HWLDPSP)

The recommended frequency of data collection is between 5 and 30 minutes. When analyzing CUP heating control, the trends to look for include:

- Is reset utilized on the hot water supply temperature?
- Is the loop delta-T (HWST-HWRT) low?
- Is the hot water loop differential pressure constant and if so, can it be reset at partial load conditions?

Is reset utilized on the hot water supply temperature?

Hot water heating boilers designed for temperature variation can reset the hot water supply temperature set point to meet the needs of the zones being served. When the zone heating loads decrease, the hot water supply temperature set point will automatically drop in response, and the zone temperatures can stabilize better because the hot water valves can modulate without fear of overheating the spaces. Typical controls reset the hot water supply temperature set point based on the outdoor-air temperature. If the building loads are the only requirement for the hot water heating boilers, then the hot water supply temperature set point can also be reset based on time of day or another appropriate scheduling variable. To investigate reset opportunities for the hot water supply temperature set point, review the plot of hot water supply temperature and outdoor-air temperature versus time. The hot water supply temperature is controlled to meet the set point, but the set point is what is actually reset. Figure 1 below gives an example of an office building with terminal box reheat for a 2-week period in November in which the outdoor-air temperature varies between 40°F and 80°F, and the hot water supply temperature is constant at 160°F. This is an example of bad operation because the hot water supply temperature is never changed to take advantage of warmer outdoor conditions. Figure 2 shows a closer look at the data in Figure 1, highlighting 2 days within this 2-week time period.

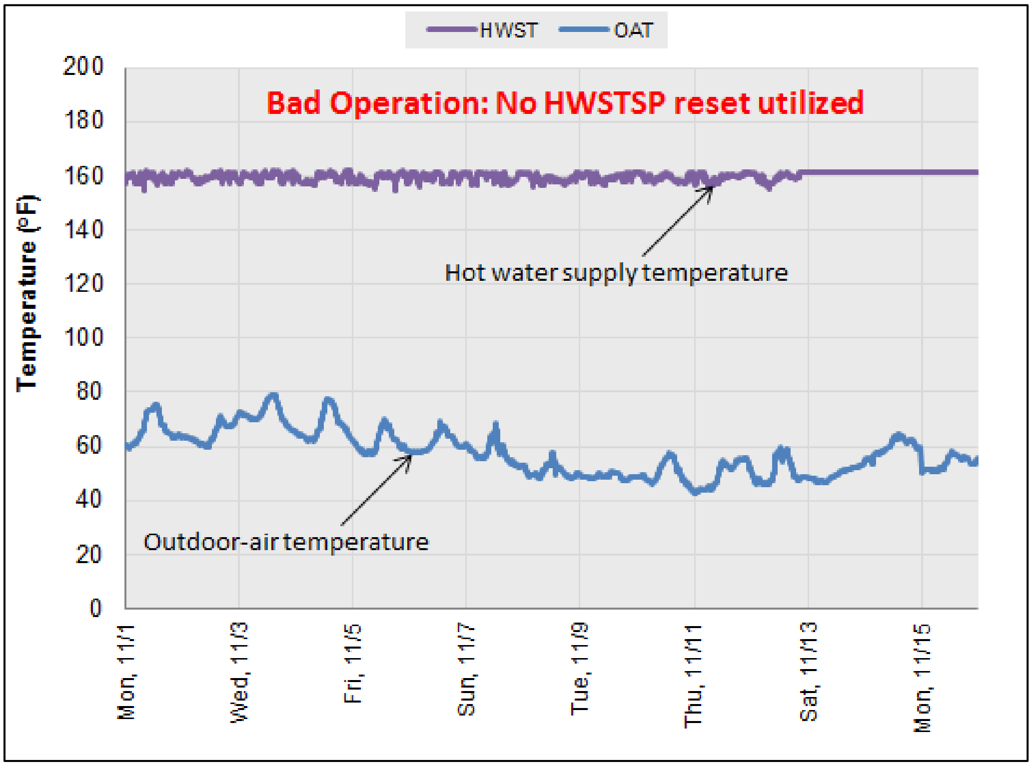

Figure 1: Example of bad operation, when the hot water supply temperature set point is not reset during advantageous outdoor conditions.

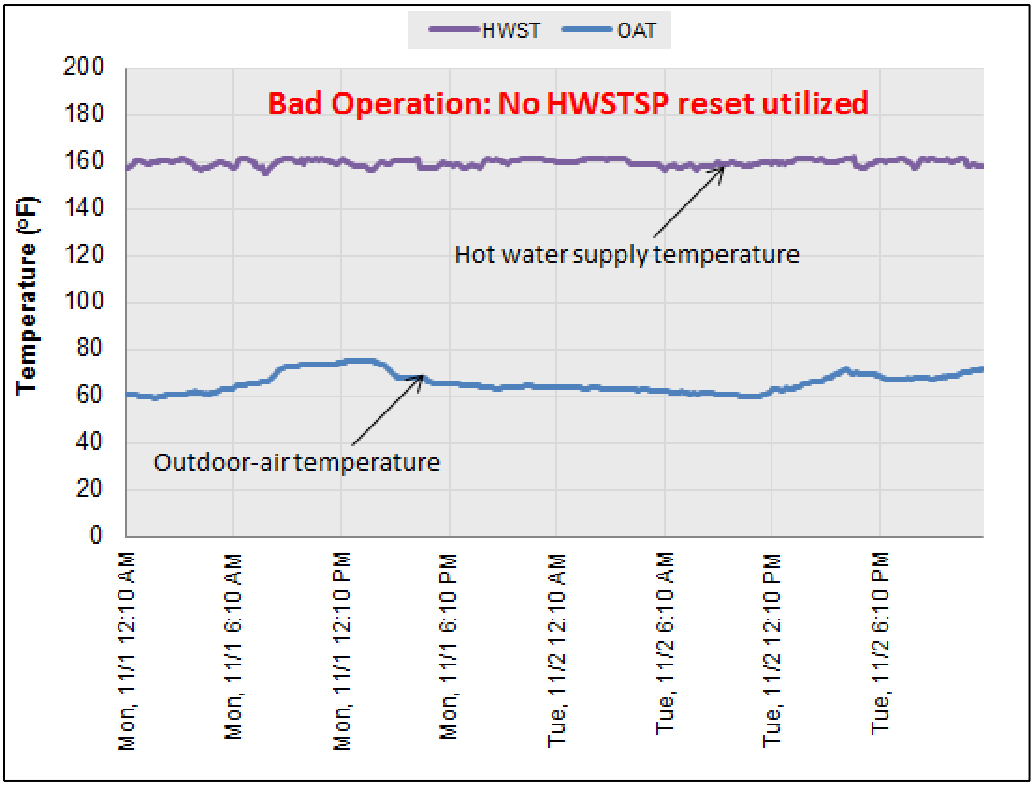

Figure 2: Closer inspection of 2 days within the 2-week period from Figure 1. During this 2-day period, the OAT never goes below 60°F but the HWSTSP is not reset.

As you can see from Figure 2, the outdoor-air temperature never gets below 60°F during this 2-day period, and yet the hot water supply temperature is maintained at 160°F. Figure 3 shows an example of good operation for this building, where the hot water supply temperature is set to 150°F for the first week, when the outdoor-air temperatures are above 60°F, and then reset to 160°F the second week, when the outdoor-air temperatures fall below 60°F.

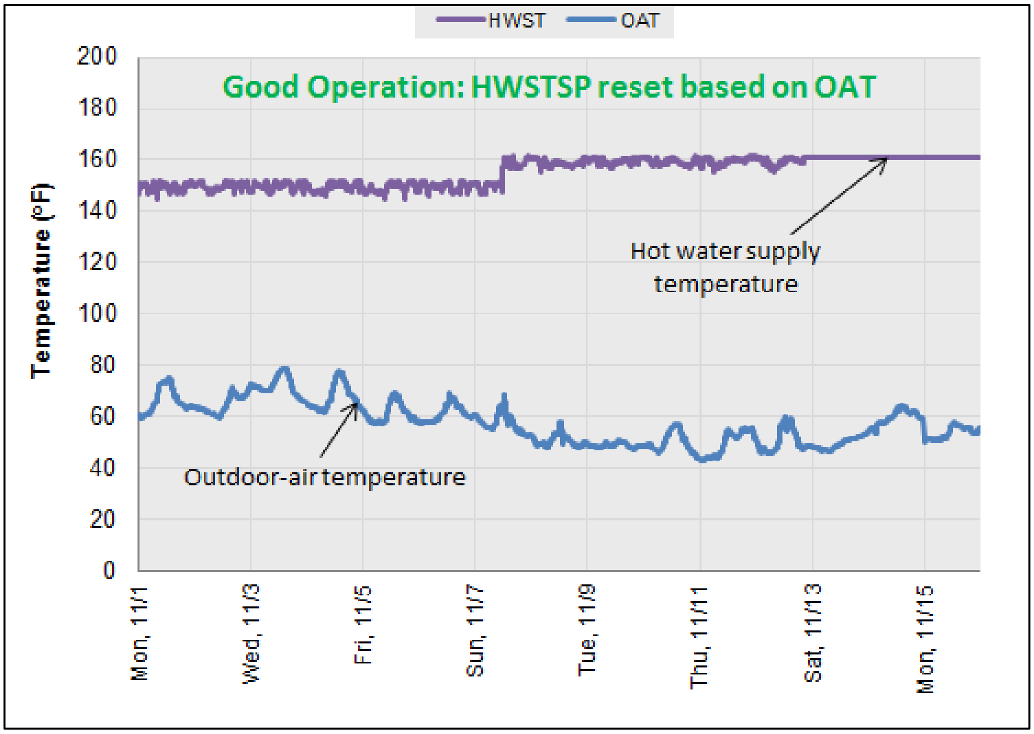

Figure 3: Example of good operation, where the hot water supply temperature set point is reset based on the outdoor-air temperature.

Suggested Actions

If there is no hot water supply temperature set point reset utilized, implement one according to the outdoor-air temperature, zone load, time of day, or another appropriate scheduling variable such as building occupancy. Generally, try and maintain 160°F to 180°F during the winter season, and 120°F to 140°F during the summer season (for non-condensing boilers, the hot water return temperature should not be less than 140°F). Reset the hot water supply temperature set point within these ranges to meet the building demand. For warmer outdoor-air temperatures, start the hot water supply temperature set point on the lower end of the range (i.e., 120°F to 140°F for summer and 160°F for winter), and reset as outdoor-air temperatures get colder. If the boiler is only used to provide reheat to the terminal boxes, consider turning them off when outdoor-air temperatures are consistently above 80°F.

A typical control sequence with a hot water supply temperature set point reset embedded might look like this: As the outdoor-air temperature drops from 60°F down to 20°F, the hot water supply temperature set point will increase from 140°F up to 180°F. This is a 40°F temperature change on both the OAT and the HWSTSP. This makes it truly linear and easy to determine the set point at any OAT value. For instance, if the OAT value is 40°F with this sequence, the HWST set point value would be 160°F. If the OAT value is 30°F with this sequence, the HWST set point value would be 170°F.

Another control sequence with a reset embedded might look like this: As the average heating-coil-valve signal (AHCV) increases from 25% open to 75% open, the hot water supply temperature set point will increase from 130°F up to 180°F. The AHCV is the average of all heating-coil-valve signals served by the hot water boiler. This is a 50°F temperature change on the HWSTSP and a 50% change on the AHCV. This makes it truly linear and easy to determine the set point at any AHCV value. For instance, if the AHCV value is 50% open with this sequence, the HWST set point value would be 155°F. If the AHCV value is 25% open with this sequence, the HWST set point value would be 130°F.

These sequences are both different means of embedding an automatic hot water supply temperature set point reset that responds in linear fashion to either the outdoor-air temperature, or the building demand (based upon a calculated average value of the heating-coil-valve signals). The values used can be modified to suit the specific boiler and building load requirements.

Is the loop delta-T (HWST-HWRT) low?

If the difference in the hot water supply and return temperatures is low (less than 8°F), this could indicate that the hot water supply temperature set point is too high or that there is not enough demand for hot water (i.e., partial load conditions). When this happens, the hot water supply temperature set point should be reset (reduced in this case) to maintain the design loop delta-T. By doing this, the heating-coil-valves open wider, allowing for more heat transfer from the water to the coil to the air, resulting in a wider delta-T. Figure 4 shows an example of bad operation, where the loop delta-T is less than 10°F for a 2-week period. Figure 5, however, shows an example of good operation, where the loop delta-T is roughly 20°F for the same outdoor conditions as in Figure 4. The difference is that the hot water supply temperature in Figure 5 is set to 150°F instead of 160°F. This set point difference of the supply temperature for similar outdoor conditions increases the loop delta-T, and decreases the energy consumption for this time period

As the hot water loop delta-T decreases below the delta-T set point (recommended set point is 20°F), the hot water supply temperature set point shall be decreased by 2°F increments once every 10 minutes. A delta-T decrease signifies a load change (decrease). The decrease action shall not drop the hot water supply temperature set point below the minimum set point (140°F or as set). Conversely, as the hot water loop delta-T increases above the delta-T set point (signifying a load increase), the hot water supply temperature set point shall be increased by 2°F increments once every 10 minutes. The increase action shall not raise the hot water supply temperature set point above the maximum set point (180°F or as set).

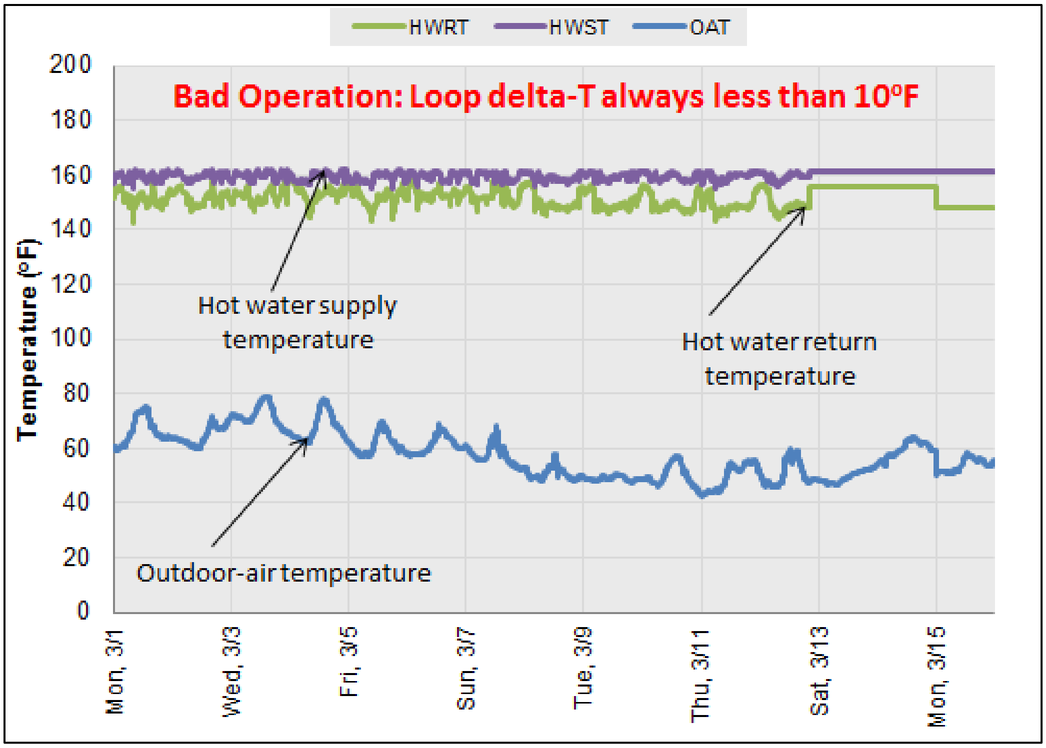

Figure 4: Example of bad operation, where the loop delta-T is less than 10°F for the time period.

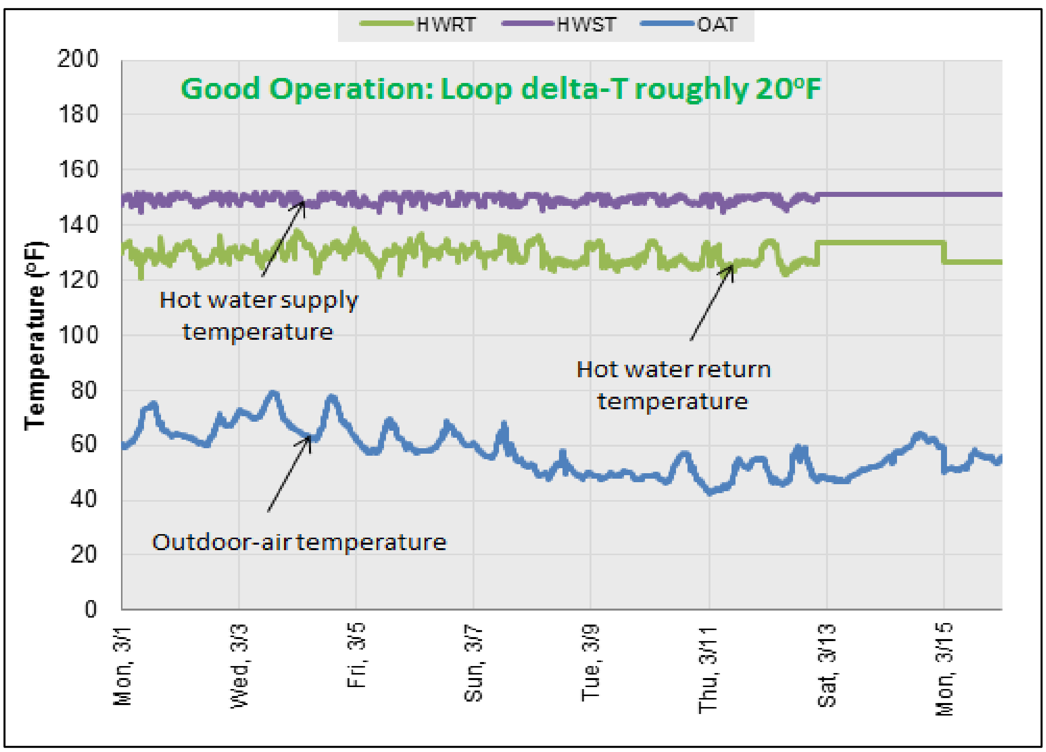

Figure 5: Example of good operation, where the hot water supply temperature is lower for similar outdoor conditions as in Figure 4, thus increasing the loop delta-T, while decreasing energy consumption.

Suggested Actions

If the hot water supply and return temperatures are within 1 or 2 degrees of each other, consider shutting down the boiler, because this is an indication that there is no demand for hot water at the zone levels. If this is occurring during the winter time, rather than shutting down the boiler, set an aggressive reset on the hot water supply temperature set point to decrease the temperature supplied to the zones. The reset should be based on outdoor conditions, internal load conditions (average heating valve signal), time of day, or other scheduling variable such as building occupancy.

Is the hot water loop differential pressure constant and if so, can it be reset at partial load conditions?

By reducing the hot water loop differential pressure, heating coil control valve leaking and pumping costs can be avoided. Also, the additional chiller cost can be reduced in cases where excess heat in the building from heating coil control valve leakages or other system anomalies (i.e., poor controls etc.) cause simultaneous heating and cooling. Without a differential pressure reset, a constant set point will almost always make the variable frequency driven hot water pump work too hard. A variable set point should be implemented based on the maximum heating coil valve position across all air-handlers or terminal box reheat valve positions in the building (see suggested actions below for cases where one is preferred over the other). If the maximum heating coil valve position is less than 95% open, then there is an opportunity for DP reset. Figure 6 shows an example of bad operation, where the loop DP is constant at 10 psi when the maximum heating coil valve position is always less than 50% open. The loop DP should be reset so that the maximum heating coil valve position is at or near 100% open, as seen in Figure 7.

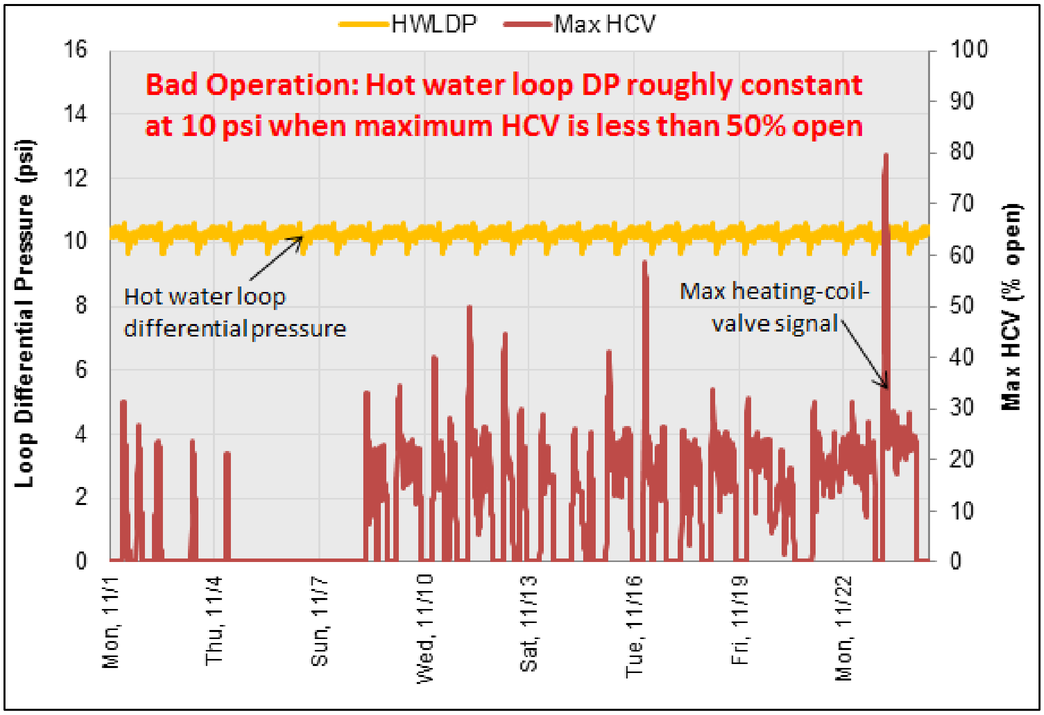

Figure 6: Example of bad operation, where the loop differential pressure is not reset when the maximum heating coil valve is always less than 50% open.

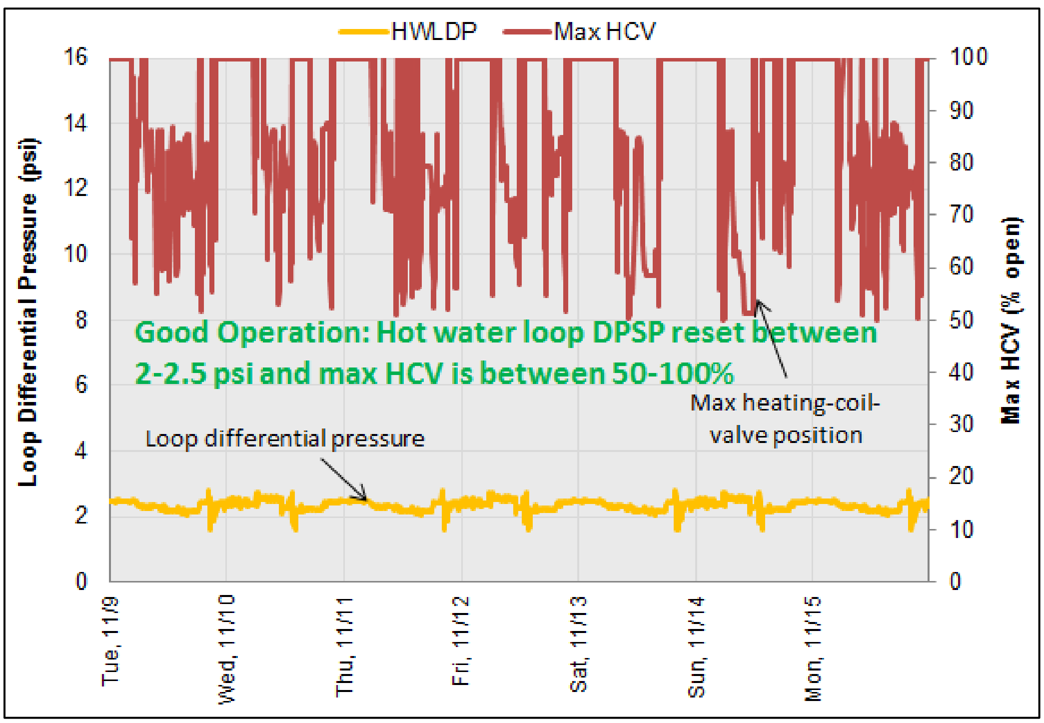

Figure 7: Example of good operation, where the loop differential pressure set point is reset between 2 psi and 2.5 psi while the maximum HCV is between 50% and 100% open.

Suggested Actions

If the hot water plant is designed with variable frequency driven pumps and is designed for reduced flows in the building loop (without negative impact to the hot water plant equipment – boilers, etc.), and there is no hot water loop DP set point reset utilized, implement one according to the outdoor-air temperature, AHU load (building demand), time of day, or another appropriate scheduling variable such as building occupancy.

If a reset cannot be implemented, and the building is unoccupied at nights and on weekends, but the hot water plant is required to run during these unoccupied periods, consider using a schedule to reduce the loop DP set point to 50% of its normal occupied setting. For instance, if the occupied loop DP set point is 15 psi, add a schedule to reduce it to 7.5 psi for nights and weekends.

A typical control sequence with a hot water loop DP set point reset embedded might look like this: As the average heating-coil-valve signal (AHCV) increases from 30% open up to 80% open, the hot water loop differential set point will increase from 8 psi up to 18 psi. This is a 10 psi change on the HWLDPSP and a 50% change on the AHCV. This creates a 1 psi change for every 5% average heating-coil-valve signal (AHCVC) change in value. For instance, if the AHCV value is 55% open with this sequence, the HWLDP set point value would be 13 psi. If the AHCV value is 30% open with this sequence, the HWLDP set point value would be 8 psi. If the AHCV value is 80% open with this sequence, the HWLDP set point value would be 18 psi.

These sequences are both different methods of embedding an automatic hot water supply temperature set point reset that responds either to a schedule (time of day – occupied/unoccupied) or responds in linear fashion to the building demand (based upon a calculated average value of the heating-coil-valve commands). The values used can be modified to suit the specific boiler and building load requirements.