Pacific Northwest
NATIONAL LABORATORY

PNNL-SA-89198

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

Summary

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

Chillers come in many design configurations including air-cooled and water-cooled. The smallest chillers are air-cooled, but may use a refrigerant instead of water as the final cooling medium at the air-handling unit (AHU) cooling coil. Direct expansion (DX) cooling systems use one or more motor-driven compressors to compress a refrigerant gas, which is then routed to a condenser or cooler mechanism located outside. The compressor(s) can be located inside or outside near the condenser coil(s). Piping between the compressor(s) and condenser coil(s) provides the means for the refrigerant gas to be moved between components. If the piping distance or elevation difference between the compressor(s) and condenser mechanism is significant, this can cause problems during moderate cooling load periods. One or more condenser fans draw outdoor air through the condenser coil(s), removing most compression heat and causing the compressed gas to cool to a liquid. As the valve opens at the cooling coil in the AHU, liquid refrigerant begins to flow, causing a pressure drop. This pressure drop results in reduced temperatures below ambient. The cooled liquid then removes heat from the air by passing over the cooling coil and experiences a phase change back to a gas, then goes back to the compressor, where the compression cycle starts again.

Air-cooled water chillers use water as the final cooling medium and rely upon the refrigerant cycle previously described, to cool the water that is circulated through the chiller's evaporator where heat is removed by the refrigerant gas, causing it to "flash," or phase change from a liquid to a gas. This heated gas is routed to the compressor(s) and then to the condenser coils that have multiple fans that stage on or off as required, to reject the heat to the outdoors. Because air-cooled water chillers have their condenser coils and fans mounted on the same unit as the compressor(s) and evaporator, this design requires that an air-cooled water chiller be mounted outside of the building (or in a part of the building that can accept heat rejection).

More complex chiller systems are water-cooled, where condenser water is routed from a chiller located inside the building to one or more cooling towers that are located outside. The cooling towers are designed to transfer the compression heat from the chiller to the outdoor air, and can use any number of designs to provide evaporative cooling of the condenser water. However, because multiple chillers, cooling towers, and pumps are interconnected via piping and control valves, the configuration and complexity of the control system grows exponentially.

This guide will focus on water-cooled chillers, and their operations related to the chilled water supply set point and loop differential pressure set point. The temperature set point of the chilled water supply should be automatically reset, based upon the loads in the building (the average of the AHU cooling-coil valve commands) or the outdoor-air temperature. Additionally, the design delta-T between the chilled water supply and return temperatures should be met at all times to ensure optimal efficiency of the chilled water use. Failure to correct/mitigate this situation, in all likelihood, will lead to increased fan, heating and cooling energy consumption.

Data needed to verify CUP cooling control

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

- Outdoor-air temperature (OAT)
- Cooling-coil-valve signal (CCV)
- Chilled water supply temperature (ChWST)
- Chilled water supply temperature set point (ChWSTSP)
- Chilled water return temperature (ChWRT)
- Chilled water loop differential pressure (ChWLDP)
- Chilled water loop differential pressure set point (ChWLDPSP)

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

- Is reset utilized on the chilled water supply temperature?
- Is the loop delta-T (ChWRT-ChWST) low?
- Is the loop differential pressure set point constant and if so, can it be reset at partial load conditions?

Is reset utilized on the chilled water supply temperature?

Water chillers require reset on the supply temperature to meet the needs of the AHU cooling coils being served. When the AHU cooling loads decrease, the chilled water supply temperature set point will automatically increase in response and the AHU discharge-air temperatures can stabilize better because the chilled water valves can modulate better without fear of overcooling the discharge air. Typical controls reset the chilled water supply temperature set point based on the outdoor-air temperature, and the actual chilled water supply temperature is controlled to meet the set point. If the building loads are the only requirement for the chilled water, then the chilled 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 chilled water supply temperature set point, review the plot of chilled water supply temperature and outdoor-air temperature versus time. Figure 1 below gives an example of an office building for a 2-week period in November in which the outdoor-air temperature varies between 40°F and 80°F, and the chilled water supply temperature is pretty stable around 45°F. This is an example of bad operation because the chilled water supply temperature set point is never changed to take advantage of cooler outdoor conditions (i.e., when the OAT is less than 60°F). Figure 2 is an example of good operation, where the chilled water supply temperature set point is reset by 5°F when the OAT is less than 60°F. This reduces the load on the chillers, and saves energy during advantageous outdoor conditions.

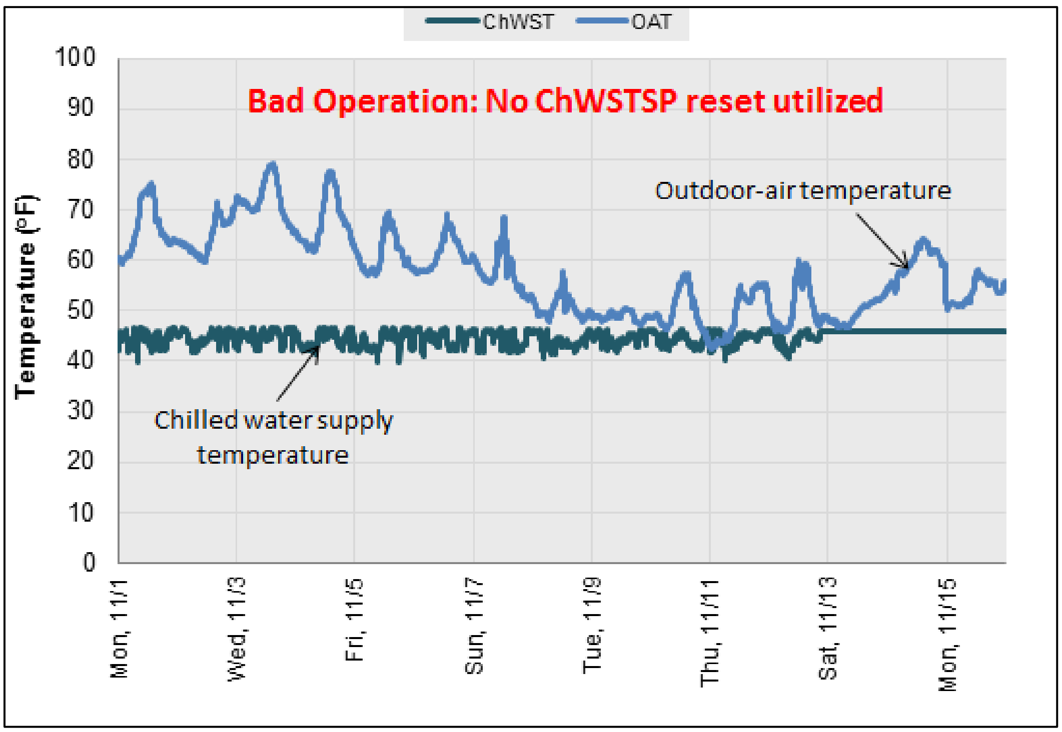

Figure 1: Example of bad operation, when the chilled water supply temperature set point is not reset during advantageous outdoor conditions (i.e., OAT less than 60°F).

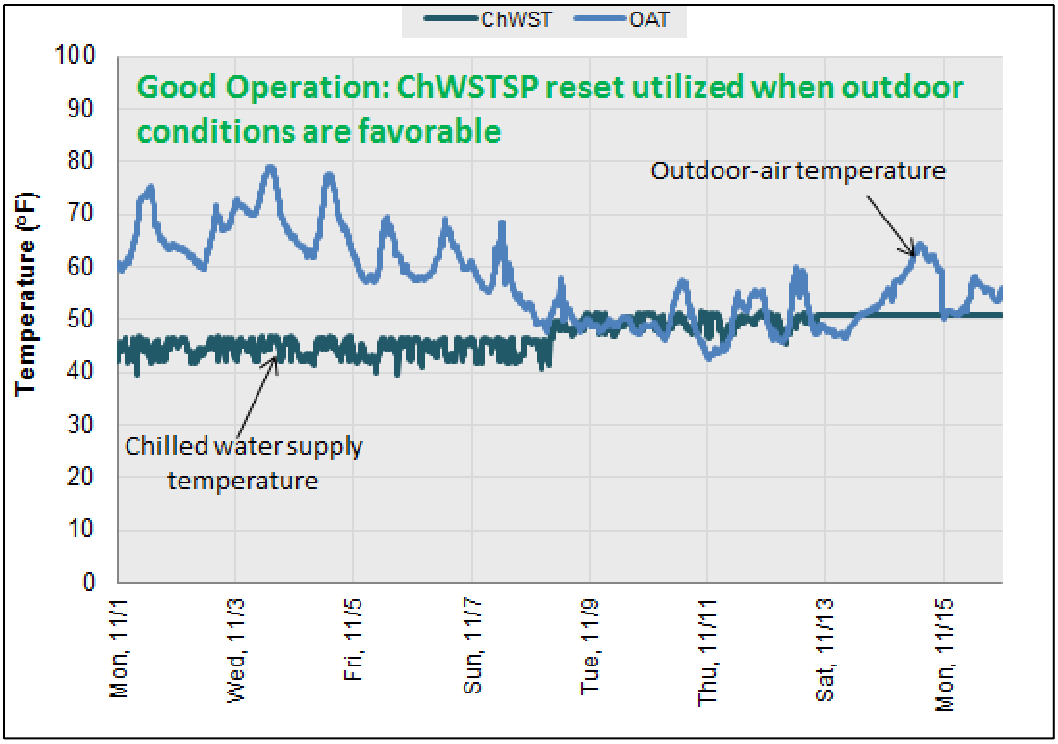

Figure 2: Example of good operation, where the chilled water supply temperature set point is reset when the outdoor conditions are favorable.

Figure 1 and Figure 2 offer examples of bad and good operation when utilizing the outdoor-air temperature as the variable to reset the chilled water supply temperature set point. Now consider resetting the chilled water temperature set point based on the load served by the AHU. A variable to consider when implementing reset on the chilled water supply temperature set point is based on load as indicated by the cooling coil valve positions for all air handlers served by the chiller. If the maximum open valve is less than 90% to 95% open, the chilled water supply temperature set point can be increased and if there is more than one valve open 100%, the chilled water supply temperature set point should be decreased. Figure 3 is a plot of outdoor-air temperature, chilled water supply temperature, and cooling-coil valve signal versus time for a 2-week period. This is an example of bad operation because the cooing-coil valve signal indicates a low load condition, yet the chilled water supply temperature is not reset to a higher temperature. In reality, the chilled water supply temperature set point should be reset to a higher value that allows the cooling-coil-valve signal to reach fully open to satisfy the load. Only then, if the discharge-air temperature is not being met, should the chilled water supply temperature set point be reset to a lower value. Figure 4 is an example of good operation, where the chilled water valve is open 40% when the chilled water supply temperature is around 45°F, then is reset to approximately 50°F, and the cooling-coil-valve signal opens to 95% open.

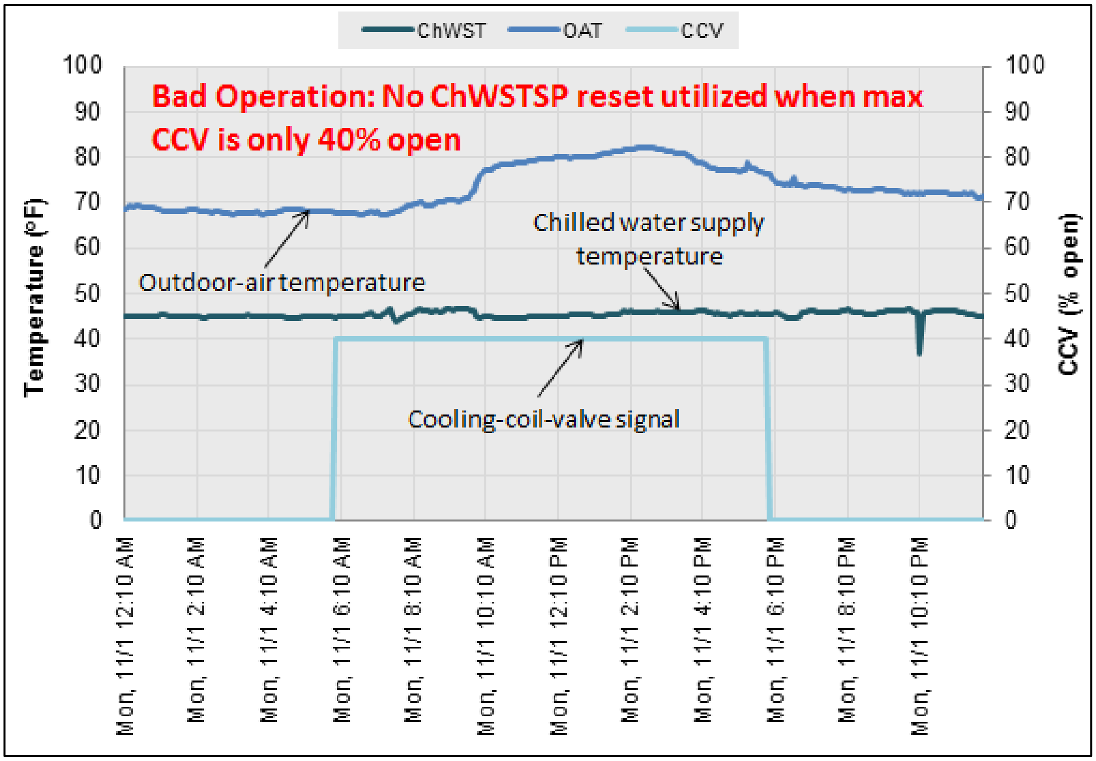

Figure 3: Example of bad operation, where the cooling-coil-valve signal only indicates 40% open and the chilled water supply temperature set point remains unchanged.

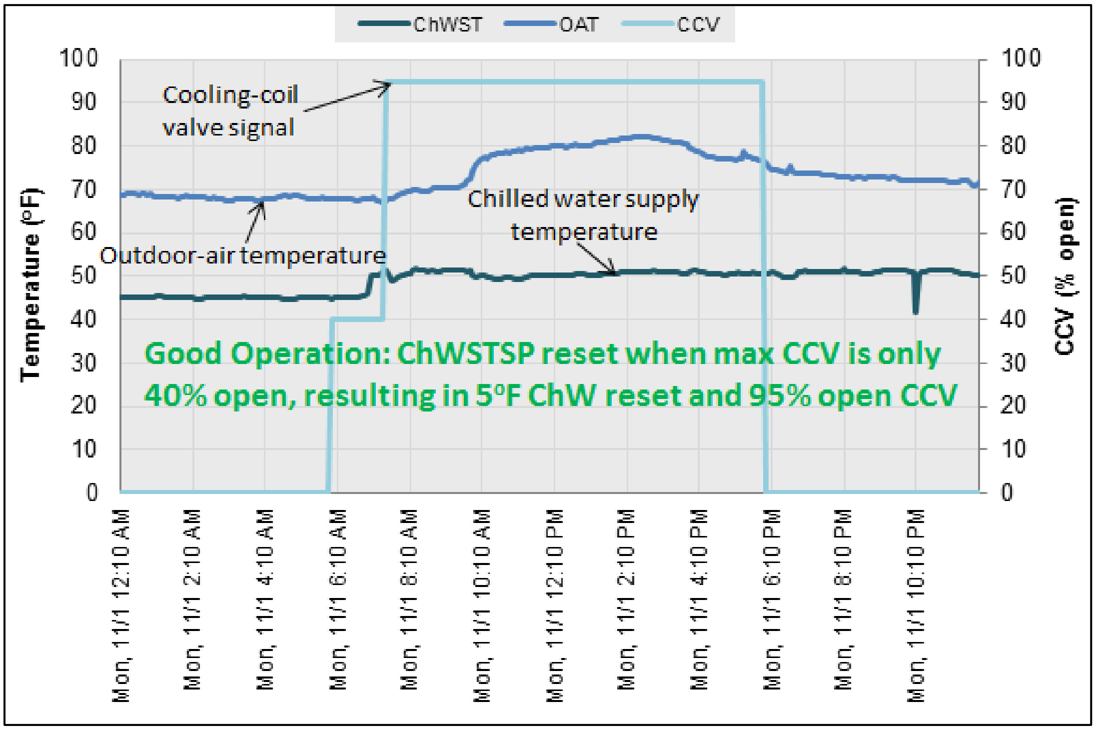

Figure 4: Example of good operation, where the chilled water supply temperature set point is reset by 5^{o}F, and the cooling-coil-valve signal responds by opening 95%.

Suggested Action

If there is no chilled water reset utilized, implement one according to the outdoor-air temperature, zone load, time of day, or another appropriate scheduling variable such as building occupancy. Increase the chilled water supply temperature set point by 0.5^{o}F at a time to prevent the chiller from tripping off. Also, do not increase the set point any higher than 5^{o}F from the design value.

A typical control sequence with a chilled water supply temperature set point reset embedded might look like this: As the outdoor-air temperature (OAT) rises from 60^{o}F up to 100^{o}F, the chilled water supply temperature set point will decrease from 52^{o}F down to 42^{o}F. This sequence provides a 10^{o}F change in the ChWSTSP, over a 40^{o}F temperature change in the OAT. This means that for every 4^{o}F change in outdoor-air temperature, there will be a 1^{o}F change in the ChWSTSP. This makes it easy to determine the chilled water supply temperature set point at any OAT value. For instance, if the OAT value is 80^{o}F with this sequence, the ChWSTSP value would be 47^{o}F. If the OAT value is 90^{o}F with this sequence, the ChWSTSP value would be 44.5^{o}F.

Another control sequence with a reset embedded might look like this: As the average cooling-coil-valve signal (ACCV) increases from 25% open up to 75% open, the chilled water supply temperature set point will increase from 42^{o}F up to 52^{o}F. This sequence provides a 10^{o}F change in the ChWSTSP over a 50% change in the ACCV. This means that for every 5% change in the average cooling-coil-valve signal, there will be a 1^{o}F change in the ChWSTSP. This makes it easy to determine the chilled water supply temperature set point at any ACCV value. For instance, if the ACCV value is 50% open with this sequence, the ChWSTSP value would be 47^{o}F. If the ACCV value is 25% open with this sequence, the ChWSTSP value would be 52^{o}F.

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

Is the loop delta-T (ChWRT-ChWST) low?

If the difference in the chilled water return and supply temperatures is low (less than 8^{o}F), this could indicate problems such as too low chilled water supply temperature set point or not enough demand for chilled water (i.e., partial load conditions). When this happens, the chilled water supply temperature set point should be reset to maintain the design loop delta-T. Figure 5 below shows an example of bad operation, where the loop delta-T is less than 5^{o}F for a 2-week period. Figure 6, however, shows an example of good operation, where the loop delta-T is roughly 10^{o}F for the same outdoor conditions, as in Figure 5. The difference is that the chilled water supply temperature in Figure 6 is roughly 48°F instead of 43°F. This reset of the supply temperature set point for similar outdoor conditions increases the loop delta-T, and decreases the energy consumption for this time period because less energy is required to maintain the warmer loop set point. The target loop delta-T set point on chilled water is 10°F, unless otherwise specified by the manufacturer. This differs from the target loop delta-T on the hot water, which is 20°F.

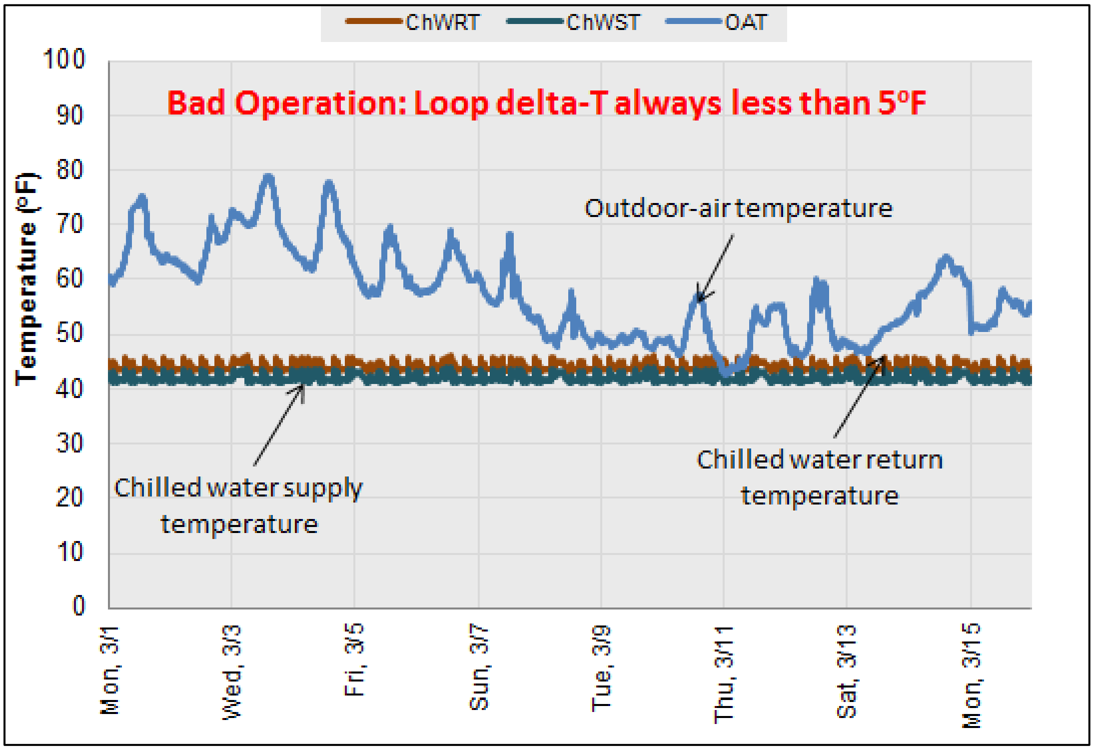

Figure 5: Example of bad operation, where the loop delta-T is less than 5°F, indicating too low chilled water supply temperature set point.

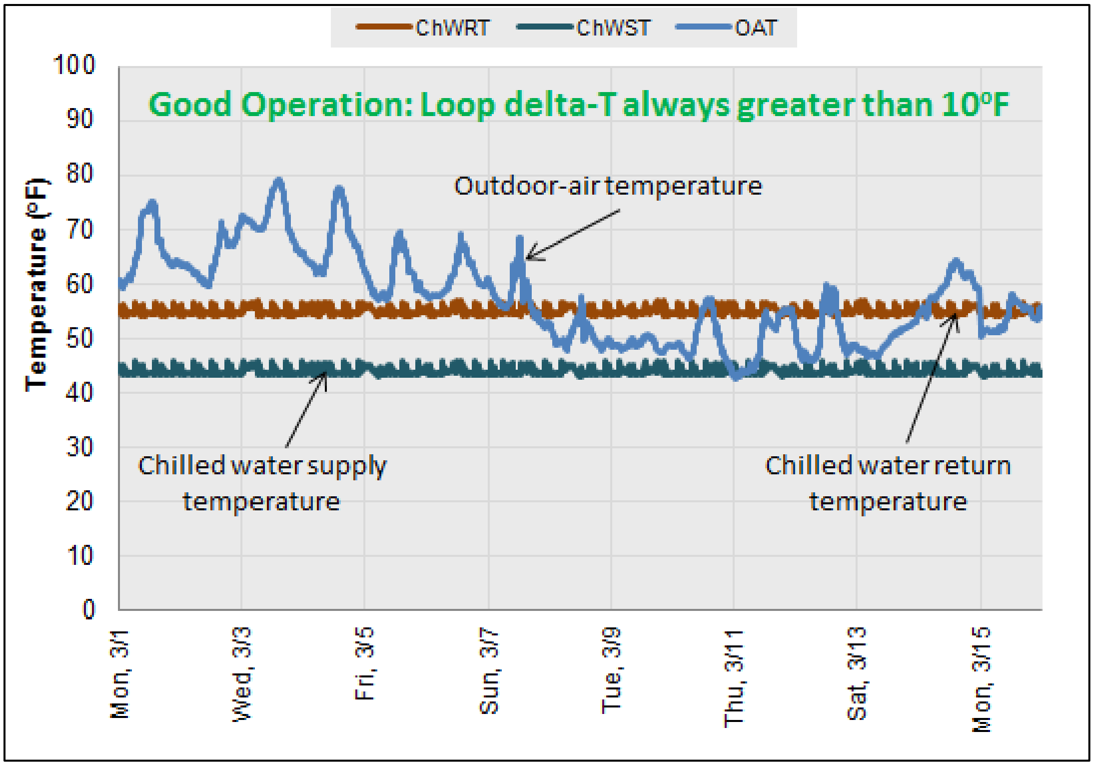

Figure 6: Example of good operation, where the chilled water supply temperature set point is higher for similar outdoor conditions as in Figure 5, thus increasing the loop delta-T to the design conditions.

Suggested Actions

If the chilled water supply and return temperatures are within 1 or 2 degrees of each other, and this occurs during the winter season, consider shutting down the chiller, because this is an indication that there is no demand for chilled water at the AHU(s). If this is occurring during the summer time, rather than shutting down the chiller, set an aggressive reset on the chilled water supply temperature set point to increase the temperature supplied to the AHU cooling coils. The reset should be based on outdoor conditions, AHU load (building demand), time of day, or other scheduling variable such as building occupancy. As mentioned above, the target loop delta-T on chilled water is 10°F. This should be targeted whenever the chiller is on.

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

By reducing the chilled water loop differential pressure set point, cooling coil control valve leaking and pumping costs can be avoided. Also, additional boiler cost can be reduced in cases where excess cold air in the building from cooling coil control valve leakages or other system anomalies (i.e., poor controls etc.) causes simultaneous heating and cooling. Without a differential pressure set point reset, a constant set point will almost always make the variable frequency driven chilled water pump work too hard. A variable set point should be implemented based on the maximum cooling-coil-valve position across all air handlers in the building. If the maximum cooling-coil-valve position is less than 95% open, then there is an opportunity for differential pressure set point reset. Figure 7 shows an example of bad operation, where the ChWLDP is relatively constant at 10 psi when the maximum cooling-coil-valve signal is always less than 50% open. The chilled water loop DP set point should be reset so that the maximum cooling-coil-valve signal is at or near 100% open, as seen in Figure 8.

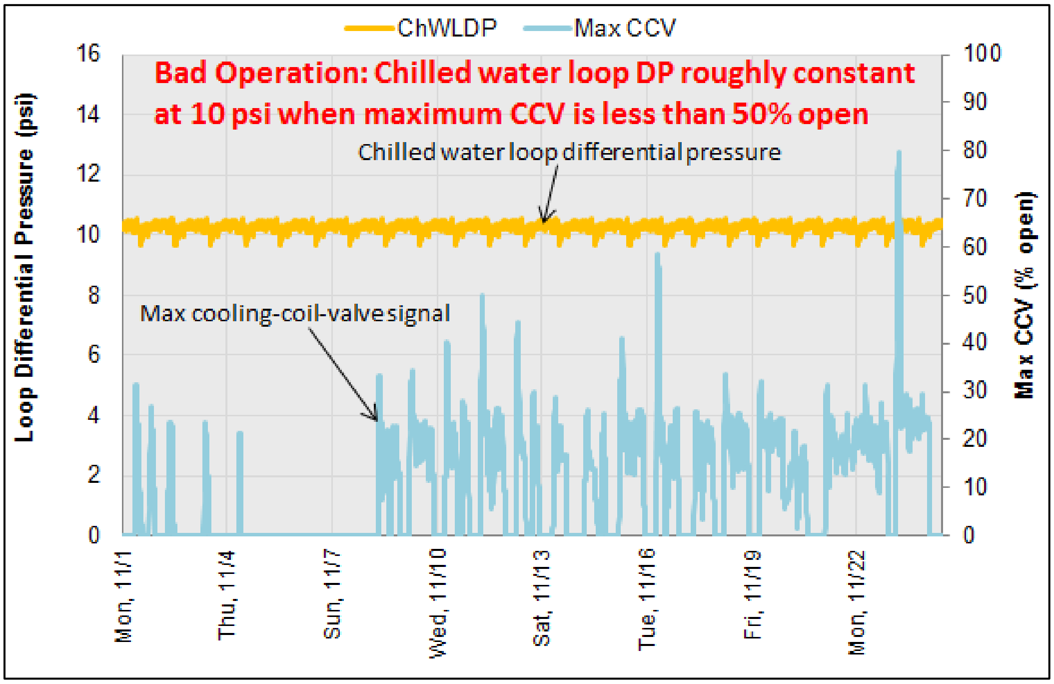

Figure 7: Example of bad operation, where the loop differential pressure is not reset when the maximum cooling-coil-valve signal is always less than 50% open.

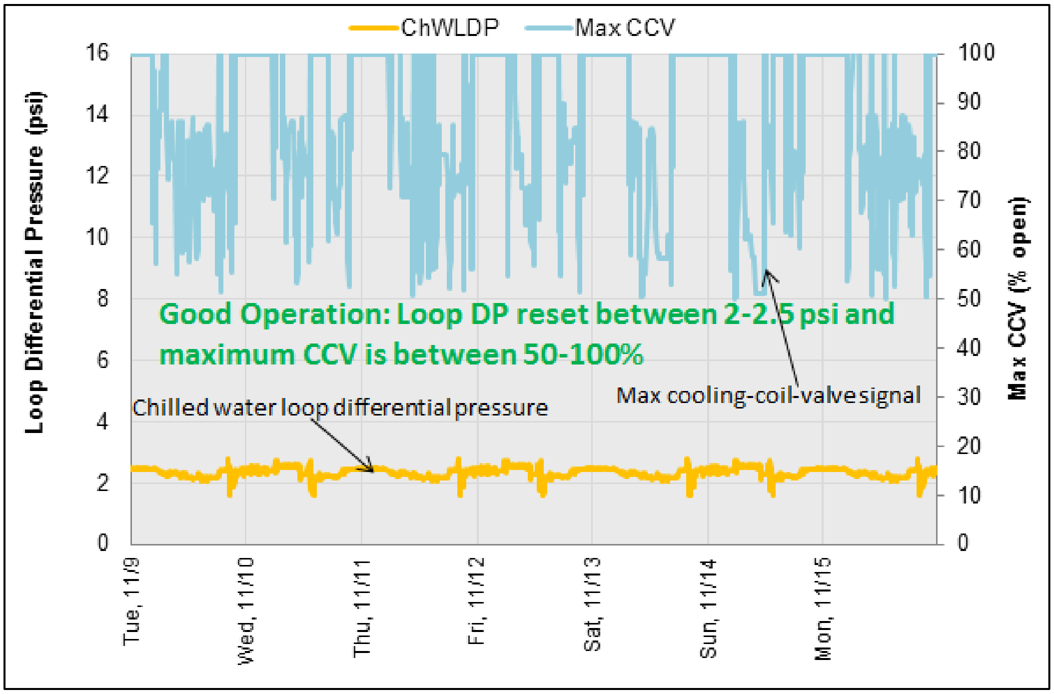

Figure 8: Example of good operation, where the loop differential pressure is reset between 2 and 2.5 psi while the maximum cooling-coil-valve signal is between 50% and 100% open.

Suggested Actions

If the chilled water plant is designed with variable frequency driven pumps and is designed for reduced flows in the building loop (without negative impact to the chilled water plant equipment – chillers, etc.), and there is no chilled water loop differential pressure (DP) set point reset being 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 schedule cannot be implemented, and the building is unoccupied at nights and on weekends, but the chilled 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 weekend operation.

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

These sequences are both different methods of embedding an automatic chilled water loop DP 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 cooling-coil-valve signals). The values used can be modified to meet the specific chiller and building load requirements.