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Optimizing Campus Chilled Water Connections

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Campuses and institutions often use centralized plants with chilled water distribution infrastructure to provide cooling to multiple buildings for the various operational and packaging benefits that come with a central utility plant scheme. The way these buildings connect to the chilled water distribution infrastructure can have a significant impact on the performance of the central plant and on the HVAC systems in the building. Although several articles have been written about this topic over the years,[1–4] the author has recently observed examples where campus chilled water design fundamentals have been misapplied, so our design community may benefit from a refresher.

Optimizing Pumping Energy Performance

Chilled water distribution pumps located at the central plant are often the largest consumers of pump energy on a campus due to the entire campus chilled water flow moving through them. Inspecting the pump head equation in *Figure 1* reveals that an effective way to reduce their power draw and overall energy consumption is to lower their operating pressure requirements. This is where design of campus chilled water building connections comes in.

The most efficient campus pumping scheme involves operating the central plant chilled water distribution pumps with just enough pressure to overcome the friction and fitting losses required to pump water through the distribution piping with a small margin of additional pressure to achieve a slight positive pressure delta at the most remote building connections. This approach is described by this author as the "lazy river" strategy and relies on booster pumps to be provided at buildings that require more head pressure than the coincident campus distribution pressure available at their connection. *Figure 2* shows an example of a boosted-secondary pumping building connection. These building booster pumps are effectively operating in series with the central plant chilled water distribution pumps and are controlled to meet the pump head pressure requirements specific to their local HVAC loads.

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Note that there is no decoupler, also known as a common leg. This ensures minimum pump energy and maximum chilled water ΔT, as explained in the case study building below (See "Case Study—Northern California University Example: Tertiary Blending Vs. Series Building CHW Pump" subhead on Page 74.) A bypass around the pumps with a check valve is provided to allow the plant secondary pumps to meet building chilled water demand for buildings close to the plant that have sufficient differential pressure from the secondary pumps.

The control logic is to first try to meet flow demand with the plant secondary pumps and staging on the building pumps if differential pressure available from the campus distribution is insufficient. The building chilled water pumps shut off if the lead pump is at minimum speed for a period of time and building chilled water differential pressure is above setpoint, indicating that the campus secondary chilled water pumps are providing the required chilled water differential pressure.

The boosted-secondary pumping example in *Figure 2* shows the building differential pressure sensor in what the author refers to as the "trim and respond" position. Locating the building differential pressure sensor near the discharge of the building chilled water pumps provides first-cost and operational benefits by minimizing length of controls wiring and locating the sensor in a location that is easily serviceable. The data collected can also be used to trend the overall building pressure demands, which can be helpful for troubleshooting and evaluating building demand history.

To efficiently operate the building chilled water pumps with the building differential pressure sensor in this configuration, it is essential that a functional "trim and respond" algorithm[5] is used to actively reset the building differential pressure setpoint. When properly implemented, a "trim and respond" algorithm uses the differential pressure sensor as a proxy for building demand, and the physical location that the sensor is installed no longer becomes a factor for determining how low the differential pressure setpoint can be reset to. Additionally, locating the differential pressure sensor near the building chilled water pumps can reduce the potential for "lag" between changes in building demand and response from the pumps and enhance the responsiveness of the system.

Dedicated building pumps can also provide a margin of operational resiliency if the campus distribution pumps are unable to or are not being properly controlled to maintain a positive pressure differential at the building connection. In this scenario, a dedicated building pump in a boosted-secondary configuration could be used to "assist" the campus distribution pumps in overcoming distribution pressure losses to a limited degree based on available motor horsepower from the dedicated building pump.

FIGURE 1 Pump power equation.

$$P=\frac{(Q)(H)(SG)}{3960(\eta)}$$

P=Power, Horse Power
H=Head, ft
Q=Flow, gpm
SG=Specific Gravity
η=Pump Efficiency, Decimal

FIGURE 2 Boosted-secondary pumping building connection example with building ΔP sensor in "trim and respond" position.

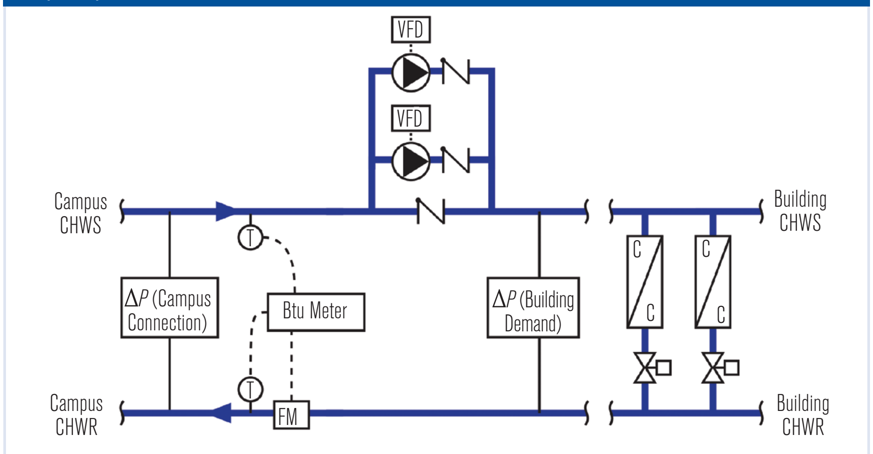


FIGURE 3 Waterside heat transfer equation. Note: conversion coefficients are based on pure water. Glycol mixtures will need to be corrected for changes in fluid properties (e.g., specific heat) based on how much glycol is used.

$Q=m \times cP \times \Delta T$
Q (Btu/h) = 500×gpm×ΔT

Optimizing Chilled Water ΔT

High temperature differential between chilled water supply and return temperatures, ΔT, is desirable for the decreased volumetric flow rate required to deliver a given rate of cooling energy. *Figure 3* shows the waterside heat transfer equation demonstrating this relationship. Optimizing chilled water Δ*T* has an immediate benefit to chilled water pumping system sizing and power requirements.

It must be emphasized that a high Δ*T* is not something that the central plant can "make happen" through control logic at the plant. Rather, Δ*T* is determined by the buildings, and the plant can only react to the flow buildings require and the Δ*T* they produce. While low Δ*T* can be caused by many factors,[1–4] one common error that is readily avoided is incorrectly selecting coils.

The author recommends using Taylor's[6] recommendation of selecting every coil at the maximum density allowed by ASHRAE Standard 62.1's cleanability limit, typically eight rows and 10 fins per in. (~3.9 fins per cm). This approach will generally yield the highest chilled water Δ*T* performance and the most flexibility to accommodate varying coil conditions.

Campuses that use thermal energy storage (TES) systems benefit greatly from high Δ*T*, as the cooling capacity of the storage tank is directly proportional to the Δ*T* at which the campus chilled water system operates. TES systems consist of large volumes of chilled water that are "charged" to a relatively low chilled water temperature, e.g., 39°F (3.9°C) to maximize the capacity and benefit from the investment placed in these storage tanks (*Figure 4*). The campus chilled water distribution pump differential pressure sensor that controls secondary pump speed is placed at the plant, but its setpoint is reset by the output of control loops, maintaining a slight positive pressure at each building served.

FIGURE 4 Example campus TES system.

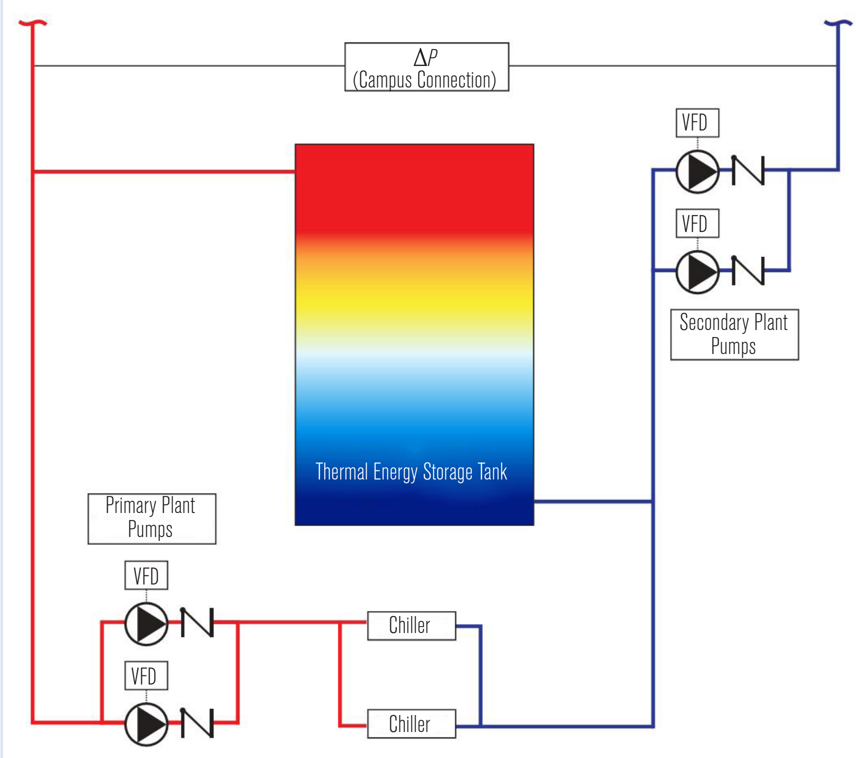
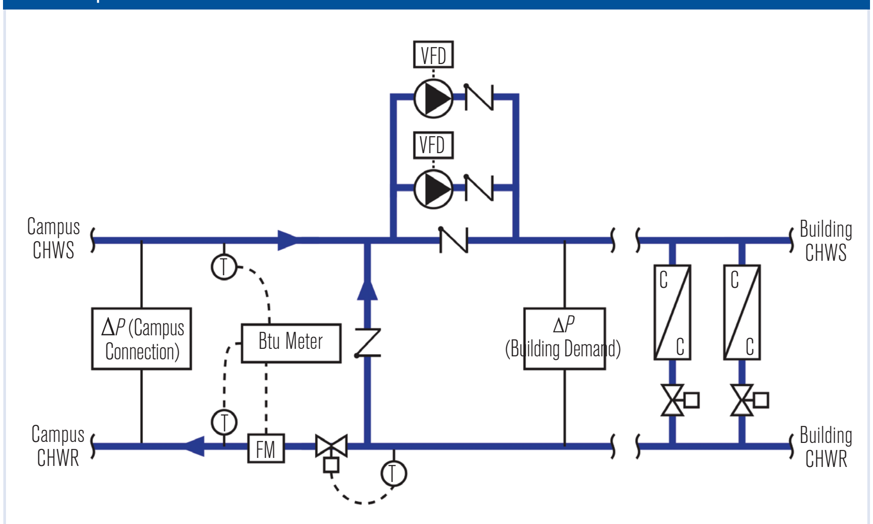


FIGURE 5 Campus chilled water decoupled direct building connection aka "bypass/tempering" building connection example.

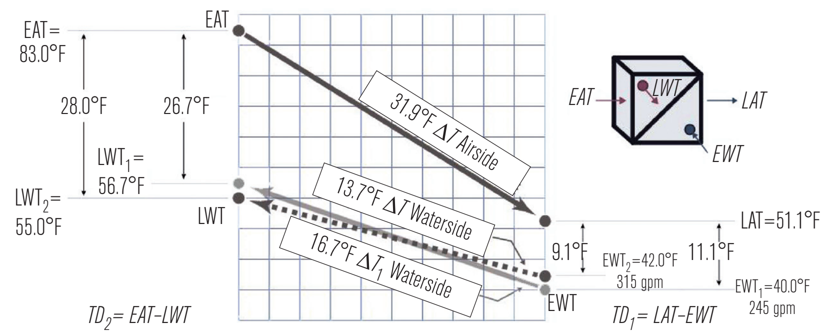


Existing TES systems designed based on lower Δ*T* criteria can have their cooling capacity expanded by an increase in chilled water return temperature; increasing Δ*T* performance can increase the resilience of this utility. Conversely, TES systems can also have their effective cooling capacity diminished by a decrease in chilled water return temperature, so designing for and maintaining high chilled water Δ*T* is essential to achieve optimum performance.

FIGURE 6 Coil heat transfer equations.

$Q = U \times A \times LMTD$	$LMTD = \dfrac{TD_2 - TD_1}{\ln(TD_2/TD_1)}$
Q=Amount of Heat Transferred Btu/h U=Heat Transfer Coefficient Btu/h·ft^2·°F A=Effective Surface Area for Heat Transfer ft^2 $LMTD$=Log-Mean Temperature Difference Across the Coil Surface, °F	TD_1=Leaving-Air and Entering-Water Temperature Difference at the Coil, °F TD_2=Entering-Air and Leaving-Water Temperature Difference at the Coil, °F

FIGURE 7 LMTD calculations for changing entering water temperature.



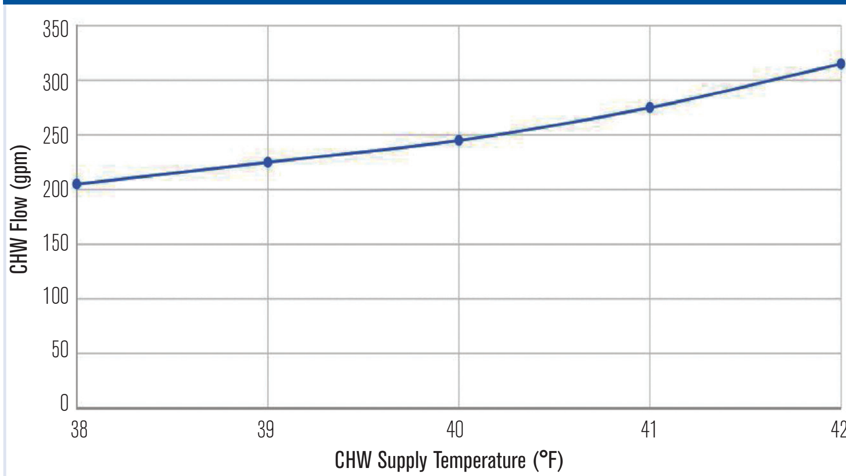
At 16.7°F ΔT Waterside, 31.9°F, ΔT Airside:

$$LMTD = \frac{26.7°F - 11.1°F}{\ln(26.7°F/11.1°F)} = 17.8°F$$

At 13.0°F, ΔT Waterside, 31.9°F ΔT Airside:

$$LMTD = \frac{28.0°F - 9.1°F}{\ln(28.0°F/9.1°F)} = 16.8°F$$

FIGURE 8 Chilled water supply temperature vs. chilled water flow rate through coil (constant EAT and LAT conditions).



Designers and operators may occasionally come across campus chilled water building connections that use a bypass line that is often combined with a control valve to selectively divert building return water to blend with campus chilled water to deliver warmer chilled water to the HVAC systems within the building (*Figure 5,* Page 70). This bypass line is also known as a decoupled direct building connection or "bridge" connection.

The author speculates that designers that incorporate this feature into their campus chilled water system building connection are attempting to increase chilled water ΔT by supplying warmer chilled water to encourage warmer chilled water return temperatures. However, this logic does not track with how heat exchangers function (*Figure 6*).

While maintaining constant airside conditions, increasing the chilled water supply temperature will reduce log-mean temperature difference (LMTD) and result in higher chilled water flow as the HVAC system attempts to maintain leaving air temperature setpoint through the chilled water coil (*Figures 7* and *8*).

Chilled water flow will start to increase, and initially the U-factor will also increase somewhat over a very limited range as a result of higher water-tube velocity. This may result in the coil being able to maintain leaving air temperature setpoint over a limited increase in chilled water supply temperature, but at the expense of chilled water ΔT. However, as the chilled water supply temperature becomes warmer, the coil will inevitably be unable to maintain the leaving air temperature setpoint; the coil leaving air temperature will rise, resulting in a loss in control of supply air temperature setpoint and reduction in coil cooling capacity. See

Figures 9 and *10* for coil simulation software outputs demonstrating the impact on performance from increasing the temperature of chilled water supplied to the coil.

FIGURE 9 Chilled water supply temperature vs. leaving air temperature.

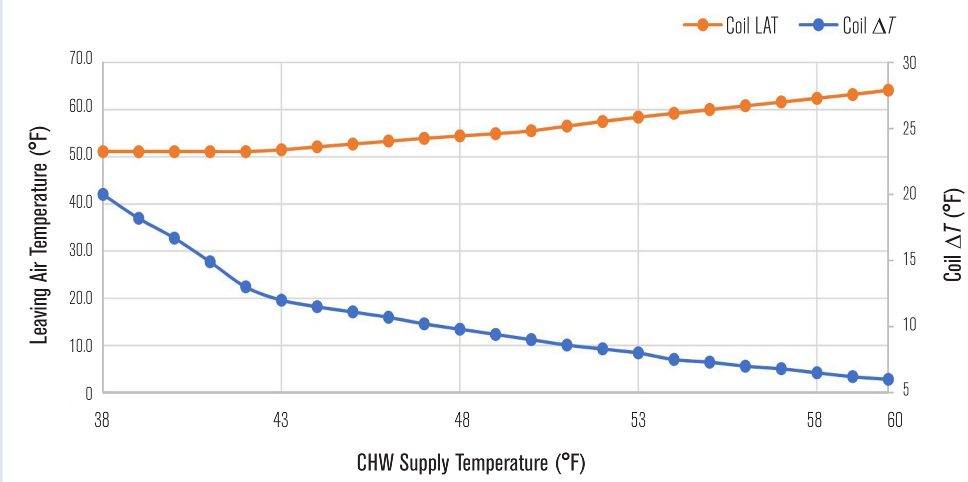


FIGURE 10 Chilled water supply temperature vs. total coil capacity.

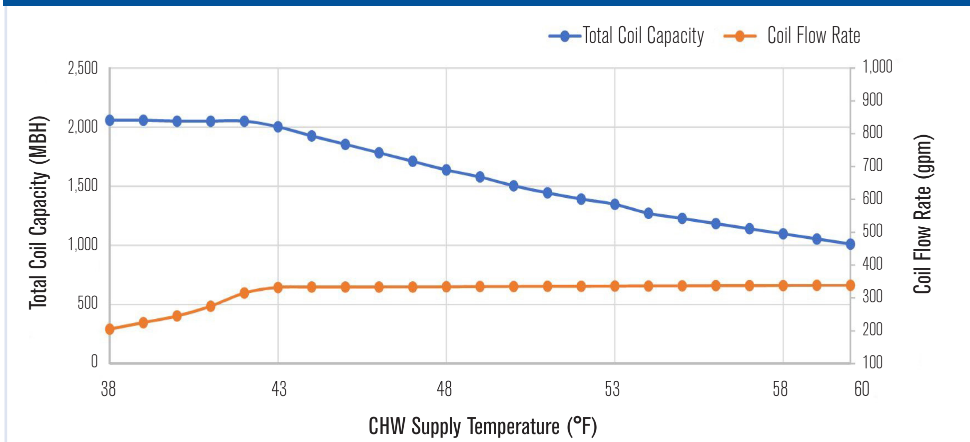
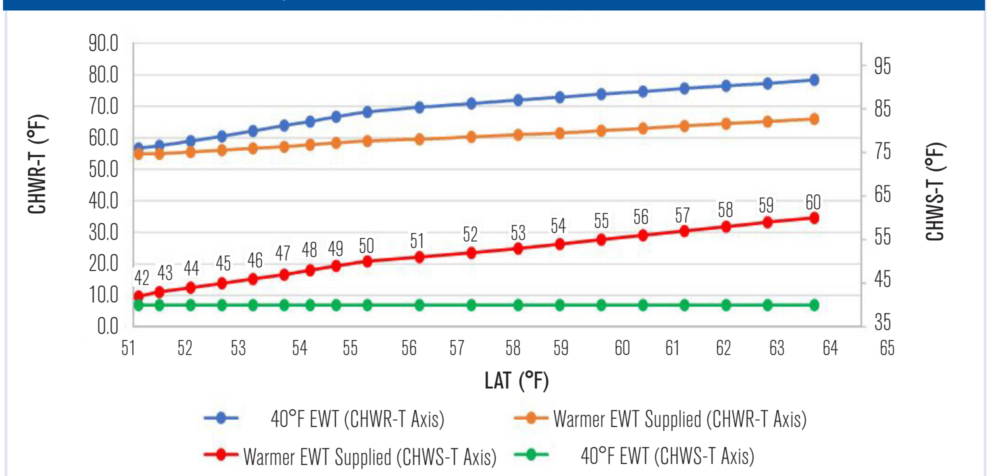


FIGURE 11 LAT vs. CHW return temperature.



For the coil performance referenced in this article, the basis of design coil was selected with the following parameters to match the case study coil discussed below:

- 6 rows, 9 fins per in. (3.5 fins per centimeter);
- 40°F (4.4°C) entering chilled water temperature;
- 83.0°F (28.3°C) entering air temperature;
- 51.1°F (10.6°C) leaving air temperature;
- 56.7°F (13.7°C) leaving chilled water temperature; and
- 9.0 ft (26.5 kPa) head water pressure drop.

In practice, the chilled water pumps may be selected for a margin of additional head capacity and pump power when compared to design load. But as pump power has an approximate cube relationship with flow, the pump will rapidly exceed its design operating point as chilled water supply temperature is increased. To better approximate anticipated performance in the field, chilled water flow is increased as the chilled water supply temperature is increased to attempt to maintain the leaving air temperature setpoint until a maximum waterside pressure drop of ~23 ft (68.7 kPa) was reached across the coil.

As the temperature of chilled water supply is increased, the chilled water return temperature will also eventually begin to increase after the coil is no longer able to maintain its design leaving air temperature. At this point, the coil cooling capacity becomes diminished as the chilled water return temperature rises.

If operational load conditions exist where a higher leaving air temperature is acceptable, supplying colder chilled water will achieve higher coil ΔT than supplying warmer chilled water (*Figure 11,* Page 73).

FIGURE 12 Building campus chilled water diagram with initial observations recorded.

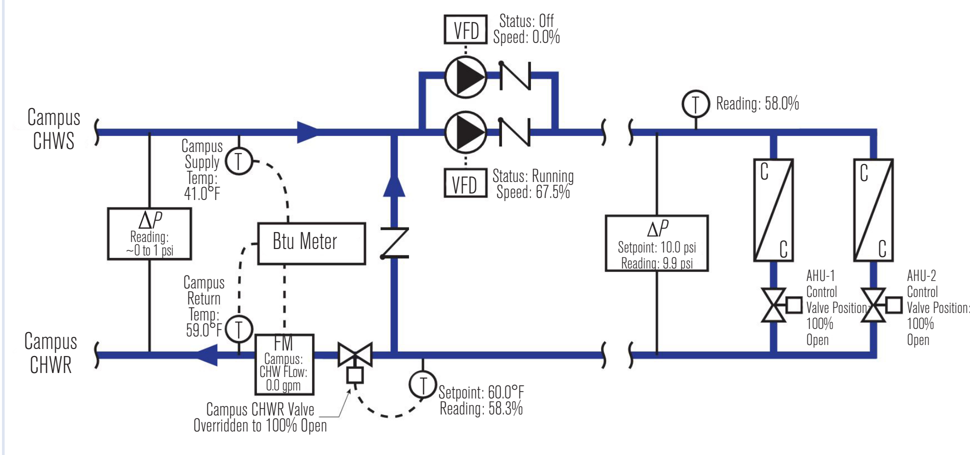
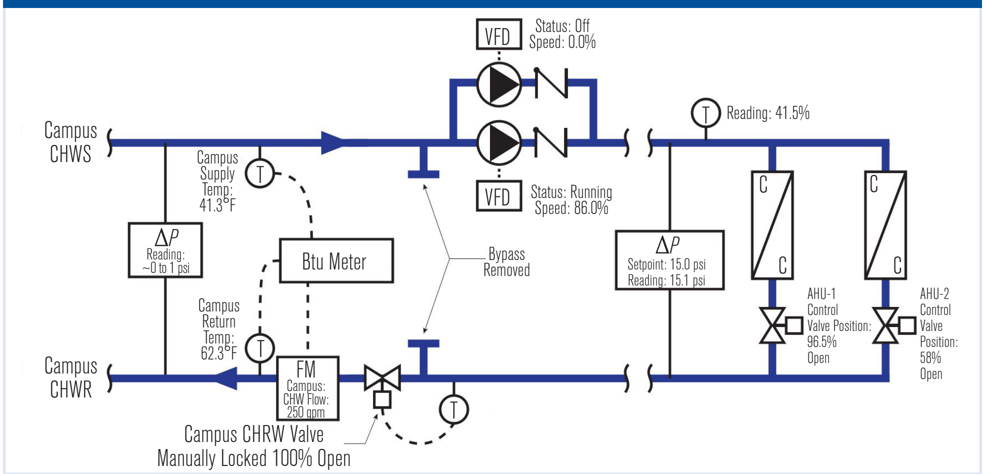


FIGURE 13 Reconfigured building campus chilled water connection with resulting performance observations.



Case Study–Northern California University Example: Tertiary Blending Vs. Series Building CHW Pump

The author recently had the opportunity to troubleshoot cooling issues at a building using a campus chilled water decoupled direct connection. He observed firsthand the significant impact the design and operation of a building campus chilled water connection can have on building performance.

The building connection being evaluated is located within a bookstore at a university in Northern California that had a campus chilled water TES system. The bookstore occupants initially reported losing the ability to provide cooling during summer conditions. Additionally, the loss in cooling capacity was observed to coincide with testing and balancing activities on the chilled water system for an adjacent new-construction building. The building operators initially believed the solution to this issue was restricting the amount of flow that the new neighboring building could draw from the campus. However, the solution ended up being modifying the configuration of the existing bookstore building connection to the campus chilled water system.

The initial site observations and diagram of the building campus chilled water connection are shown in *Figure 12*.

From the observations noted above, the building chilled water supply is being substantially blended with building return water to supply very warm water to the building chilled water coils. The elevated chilled water supply temperature to the coils eventually led to a degrading chilled water ΔT "death spiral" involving starved coils asking for more water, which ultimately leads to a loss in control of supply air temperature and very low chilled water ΔT, as low as 0.3°F (0.2°C) in this particular situation.

Upon further inspection of the field observation data, it was noted that the chilled water return temperature control valve was overridden to be fully open under these conditions to promote injection of campus chilled water into the building distribution. However, the essentially negligible pressure differential available from the campus distribution system at the building connection resulted in very little campus chilled water being supplied to the building and the majority of the building chilled water return being circulated back as supply to the building. The chilled water testing and balancing activities at the adjacent building exacerbated the effect of low campus differential pressure at the building point of connection, but was not the underlying root cause of the issue.

The solution recommended by the author and implemented by the owner was to physically remove the campus chilled water connection decoupler line and reconfigure the building campus chilled water connection to a "boosted secondary" pumping arrangement. *Figure 13* (Page 74) shows the resulting building performance after this modification was made.

Conclusions

Careful consideration should be given to the design of campus chilled water building connections to achieve optimum performance at a campus utility level as well as within each building. Design decisions can significantly impact the performance and resilience of the campus chilled water utility infrastructure.

"Lazy river" campus plant pumping schemes and direct-coupled building connections with boosted-secondary pumps tend to promote the lowest campus pumping energy, highest ΔT and greater operational flexibility and resiliency.

References

1. Peterson, K. 2014. "Improving performance of large chilled water plants." *ASHRAE Journal* (1).

2. Taylor, S. 2011. "Optimizing design & control of chilled water plants part 1: chilled water distribution system selection." *ASHRAE Journal* (7).

3. Taylor, S. 2006. "Chilled water plant retrofit—a case study." *ASHRAE Transactions* 112(2).

4. Taylor, S. 2002. "Degrading chilled water plant delta-T: causes and mitigation." *ASHRAE Transactions* 108(1).

5. Taylor, S. 2015. "Resetting setpoints using trim & respond logic." *ASHRAE Journal* (11).

6. Taylor, S. 2011. "Optimizing design & control of chilled water plants part 3: pipe sizing and optimizing ΔT." *ASHRAE Journal* (12). ■

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