4. Cooling Plant Optimization

Figure 1
Cooling Towers from a Chilled Water Cooling Plant

Data centers offer a number of opportunities in central plant optimization, both in design and operation. A medium-temperature chilled water loop design using 55°F chilled water provides improved chiller efficiency and eliminates uncontrolled phantom dehumidification loads (see Humidification Chapter). The condenser loop should also be optimized; a 5-7°F approach cooling tower plant with a condenser water temperature reset pairs nicely with a variable speed (VFD) chiller to offer large energy savings. A primary-only variable volume pumping system is well matched to modern chiller equipment and offers fewer points of failure, lower first cost, and energy savings. Thermal energy storage can be a good option, and is particularly suited for critical facilities where a ready store of cooling can have reliability benefits as well as peak demand savings. Finally, monitoring the efficiency of the chilled water plant is a requirement for optimization and basic reliable energy and load monitoring sensors can quickly pay for themselves in energy savings. If efficiency (or at least cooling power use) is not independently measured, achieving it is almost as much a matter of luck as design.

Principles

- Design for medium temperature chilled water (55°F) in order to eliminate uncontrolled dehumidification and reduce plant operating costs.

- Use aggressive chilled and condenser water temperature resets to maximize plant efficiency. Specify cooling towers for a 5-7°F approach in order to economically improve chiller performance.

- Design hydronic loops to operate chillers near design temperature differential (or dT), typically achieved by using a variable flow evaporator design and staging controls.

- Primary only variable flow pumping systems have fewer single points of failure, have a lower first cost (half as many pumps are required), are more efficient, and are more suitable for modern chillers than primary-secondary configurations.

• Thermal storage can peak electrical demand savings and improved chilled water system reliability. Thermal storage can be an economical alternative to additional mechanical cooling capacity.

• Use efficient water-cooled chillers in a central chilled water plant. A high efficiency VFD-equipped chiller with an appropriate condenser water reset is typically the most efficient cooling option for large facilities. The VFD optimizes performance as the load on the compressor varies. While data center space load typically does not change over the course of a day or week, the load on the compressor does change as the condenser water supply temperature varies.

• For peak efficiency and to allow for preventive maintenance, monitor chiller efficiency.

Approach

For large data center facilities, a chilled water system served by a central plant is the most efficient approach to providing mechanical cooling. There are many design decisions that impact the efficiency of a central plant; the issues discussed here are selected due to their prevalence in typical data center operation.

Use Non-condensing Chilled Water Temperature

A medium temperature chilled water loop supply temperature setpoint of 55°F or higher should be used to improve chiller efficiency and to prevent unnecessary and wasteful dehumidification. The temperature of the chilled water produced by the chiller plant has a significant impact on the efficiency of the chiller. Chillers are used to force heat from the chilled water loop into the condenser water loop. The temperature difference between the chilled water loop and the condenser water loop, also referred to as the "lift," impacts the chiller's efficiency – the bigger the lift, the lower the chiller's efficiency. Increasing the chilled water loop temperature helps reduce the lift the chiller must overcome. When centrifugal chillers are used, for every degree F increase in chilled water temperature, the chiller's efficiency improves by about 1 - 2%[1]. For example, an increase in chilled water temperature from 44°F to 54°F can be expected to cut chiller power use by 10-20%. In some cases by raising the temperature, the initial chiller selection can be altered since a smaller compressor and motor can be used on the chiller to provide the same capacity.

Medium chilled water temperature also prevents uncontrolled or 'phantom' dehumidification. Data centers are usually specified to operate with a space humidity setpoint that corresponds to a dewpoint of 52°F – 62°F[2] (controlled to around 50% RH). Any coil surface that is at a temperature lower than the space air's dewpoint will dehumidify to some extent, wasting cooling and harming humidity control of the space. To maintain humidity control, sensible cooling coils serving sensible cooling loads, such as data center cooling equipment, should be served with a chilled water temperature setpoint at or higher than the target humidity's dewpoint. Serving a data center load with a 44°F chilled water loop can result in continuous uncontrolled dehumidification of the space down to almost 35% RH (74°F drybulb, 46°F dewpoint) – near the bottom of the acceptable envelope for most facilities.

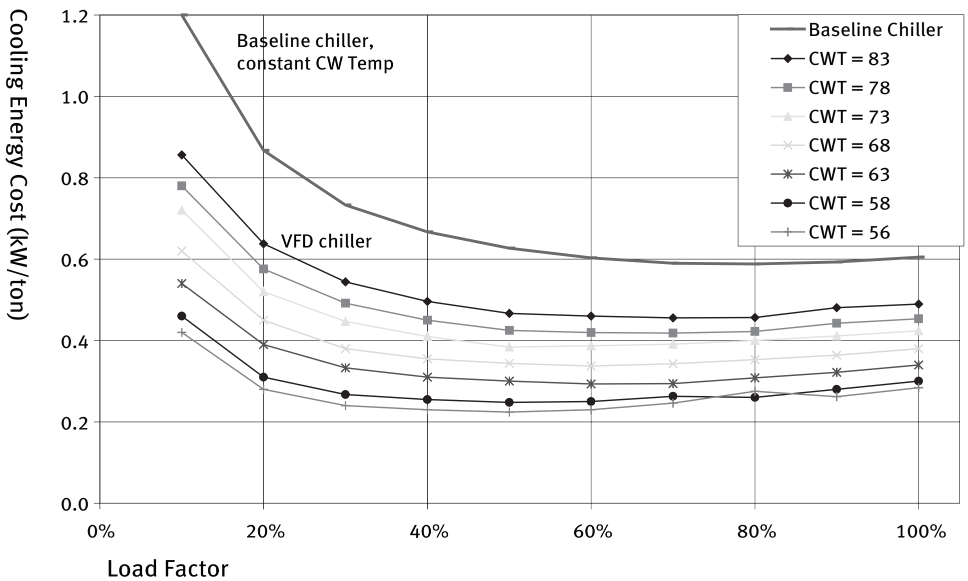
Dehumidification, when required, is best centralized and handled by the ventilation air system, while sensible cooling, the large majority of the load, is served by medium temperature chilled water at 50-60°F. This is standard procedure for controlling critical facilities that require tight humidity control to ensure profitable process yields, such as semiconductor photolithography cleanrooms or pharmaceutical manufacturing facilities. Assigning sole humidity control duties to the ventilation system offers both high efficiency and control accuracy. Ideally, a direct expansion (DX) unit with a water-cooled condenser, potentially using chilled water return if tower water is unavailable for the condenser, can be used. An air-cooled DX unit may still be justified, since the load served by the inefficient air cooled unit is outweighed by the energy savings of keeping the central plant at a medium temperature setpoint. In some climates, it is appropriate to reset a central plant's chilled water temperature down during short periods that require dehumidification, but the additional energy cost should be considered. With a chilled water dehumidification reset, the chilled water plant efficiency will drop during peak power periods in dehumidification driven climates, resulting in higher demand charges for some data center operators.

Design and Control Cooling Tower System for Low Condenser Temperatures

Reducing the lift to optimize chiller efficiency involves both a higher chilled water temperature and a lower condenser water temperature. Cooling towers with an approach of 5-7°F should be used and a reset implemented to maintain a condenser water temperature of 5-7°F above the ambient wetbulb temperature . Low air pressure drop cooling towers (typically draw-through) equipped with variable speed fans should be used and the maximum number of towers and/or cells should be operated in parallel at any given time. Minimum water flow requirements for proper tower media wetting typically determine the maximum number of towers and/or cells that can operate. The minimum allowed condenser temperature should be determined by the chiller manufacturer during selection, and usually is around 50 – 60°F. Use of a constant condenser water temperature of 70°F, or even higher, is a major cause of wasted energy in electrical chiller plants. Typically, chillers that allow a lower minimum condenser water temperature offer higher efficiency, a factor that should be considered when selecting a chiller; a 'more efficient' chiller may actually yield poorer energy performance than a slightly less efficient chiller that is better able to capitalize on low condenser water temperatures available at night or during the winter. The condenser water temperature actually available is determined by the climate, design and control of the cooling tower system.

Figure 2 shows the reduction in cooling energy, measured in kilowatts of power required to produce a ton of cooling (12,000 btu/hour), as the Condenser Water Temperature (CWT) is reduced. The single top blue curve is a baseline chiller operating without a condenser water reset. The curves below the baseline are the performance of an equivalent VFD chiller at various CWT. A VFD tends to allow the greatest utilization of low condenser water temperatures and provides better performance at part loads. Unlike most office applications, data centers have a large cooling load 24 hours a day. The large load even during cool outside air temperatures is a huge efficiency opportunity – as seen by the chiller performance data in Figure 2, chillers' power use can be literally halved by taking advantage of the cooler condenser water that can be produced by towers operating in cool conditions. Economizer and/or Free Cooling are other options to be considered that can optimize plant operation during mild outdoor conditions.

Figure 2
Proposed VFD Chiller Performance vs Load Factor and CW temperatures



Design Cooling Water System to Operate near Design Chilled Water delta T at Part-load

Chillers are optimized to operate with a specific supply and return temperature difference for example, a return water temperature of 65°F and a supply water temperature of 55°F, which would be referred to as a "10°F delta-T." An efficient chilled water system design will operate the chiller at or near its design delta-T over all the expected load conditions, even at part load conditions. In data centers, the high-reliability cooling requirements of the space and the unpredictability of future demands tend to cause designers to specify oversized cooling systems that operate at part load. Full load is typically only reached when the data center is heavily built out and weather conditions result in high condenser water temperatures that add to the chiller's actual compressor load. There are several design steps required to achieve a good part-load delta-T system; most include eliminating unnecessary bypasses (particularly three-way coil valves), and using a pumping system that allows the chiller to operate at or near the design delta-T during the expected part load operation.

Variable flow pumping is required in order to allow the chiller to operate at design delta T during part load conditions. Traditional chiller design maintains a constant flow through the chiller, which inevitably results in the delta T (the difference between the warm water entering the chiller versus the chilled water leaving the chiller) being directly proportional to the load. A 50% load will result in a delta T that is 50% of the design value. This type of operation results in unnecessary pumping power use and often leads to inefficient chiller staging control, with an additional chiller (and condenser water pumps and towers) being staged on before the operating units are fully loaded.

Primary only variable speed pumping is quickly gaining in popularity. It is more efficient, costs less to build and has fewer points of failure. Figure 3 shows a standard primary pumping configuration. Since data center facilities always maintain a high minimum load, in operation, the single bypass is always closed, indicating that none of the pumping energy is being

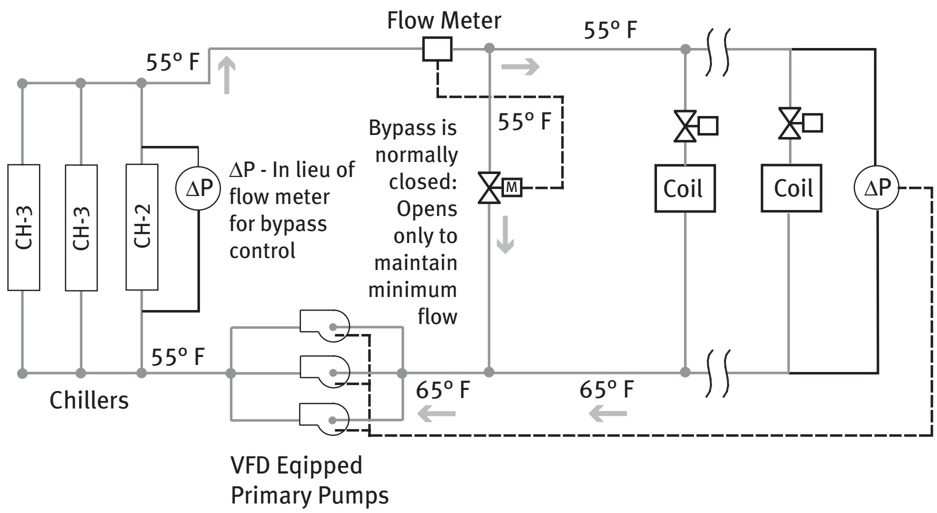


Figure 3
Primary Only
Chilled Water Pumping
Schematic

wasted on powering bypass flow that never leaves the plant room. Much has been written in ASHRAE literature and other sources on this strategy. This strategy is very effective on modern chillers, whose electronic controls allow them to operate well with variable flow. Often chilled water pumping costs can be reduced by 30% to 50%. The staging and control of a primary only pumping system is no more complex than the traditional primary-secondary approach, but it is different. ASHRAE publications and chiller manufacturer white papers(1 Trane white paper) are good sources of information on this configuration.

Thermal Storage

Properly designed thermal storage can offer an efficient method of increasing plant capacity without adding chillers and should be considered for critical facilities. Thermal storage has three main benefits. First, it takes advantage of off-peak electric rates which are typically significantly lower. Second, chilled water systems operate more efficiently when outside air temperatures are lower. Third, chilled water storage adds redundancy and can often substitute for one or more back up chillers. Water storage is preferred over ice because water is simpler, cheaper, more efficient, and more reliable – although it requires more space. Using multiple tanks will provide system redundancy and emergency backup cooling potential. Thermal storage can be linked to free cooling systems, such as water side economizers using cooling towers. In some dry climates, a comprehensive system design can combine free cooling and thermal storage to provide an almost full-time lifeline (maintaining space within the over-temperature but permissible range) cooling backup to mechanical cooling.

Use Variable Speed Chillers

Variable speed compressor chillers, often referred to as VSD or Variable Frequency Drive (VFD) chillers, currently offer the best performance for moderate to large data center loads (loads where centrifugal chillers are widely available). In order to capitalize on a VFD chiller's part load performance capabilities, a condenser water reset and low approach cooling tower system, as discussed above, are required. While data center internal loads do not vary much, the actual load on the chiller compressor does vary as the weather impacts the condenser water temperature. It is the reduction of condenser water temperature during non-design day conditions (which are 99.9% or more of the year for a critical facility plant) that allow the VFD chiller to offload and run more economically at part load.

Other Chiller Selection Considerations

Data on chiller efficiency should be requested from manufacturers during chiller selection and the chillers performance, including at part load, be a required part of equipment submittals. It is very important that the efficiency be compared at the condenser water temperatures and part-load ratios at which the plant is expected to operate. The standard ARI performance rating conditions assume a typical office building load that varies proportionally with the condenser water temperature/outside air conditions, which is not the case with data center operations. Internal data center loads are largely unaffected by the outside air conditions that impact the available condenser water temperature. Performance runs should be requested for a number of constant condenser waterr temperatures in order to allow a bin analysis that compares the chiller's efficiency over a year of operation serving the data center's actual predicted loads. Local weather data should be used for the bin analysis to capture the impact of varying condenser water temperature availability. VFD chillers tend to offer the best part load performance when compared to an equivalent (same condenser and evaporator heat exchanger configuration) constant speed chiller. While the chiller is not the only important element in an efficient plant design, it is the largest energy consumption; whole-plant design optimization and life cycle cost analysis should be utilized when selecting a chiller.

Monitor Plant Efficiency

Chilled water plants consume a large amount of energy, yet are rarely monitored in any way in order to verify design and operating efficiency. The small initial expense of installing basic monitoring is usually necessary to achieve and maintain design efficiency. Frequently the efficiency of even a brand new chiller is degraded by minor equipment or installation defect, such as uncalibrated internal sensors, incorrect refrigerant charges, loose wiring harness connections, or non-optimal compressor mapping. It is common to find that chiller energy use is 25-100% higher than specified due to a minor problem that could easily be fixed if it were recognized. Finding and correcting such errors can provide an immediate payback for permanent monitoring equipment. Continuous monitoring also can help to rapidly diagnose operational problems or pending equipment failures.

At a minimum, a monitoring system should be provided that determine and display the chillers kW/ton performance in real-time. Monitoring of the full plant kW/ton offers additional optimization opportunity and can often be achieved for minimal additional cost. A true-power kW sensor, which incorporates voltage, amperage and power factor measurements, should be selected to monitor chiller power. Plant delta-T should be determined using a matched set of stable temperature sensors that provide an accuracy of +/- 0.36°F or better. The delta-T is often in the range of only 4-9°F, so a closely matched and/or high accuracy pair of temperature sensors is required to achieve reasonable accuracy. For whole plant monitoring, VFD drives often offer an economical way to monitor power consumption of smaller, lower-priority loads such as pumps and towers.

Flow meters are the traditional weak link in plant monitoring equipment since high quality, high stability flow meters tend to be higher cost. Insertion-type flow meters with moving parts have been observed to foul unacceptably rapidly even in well managed closed-loop fluid streams. To provide diagnostic value, the flow meter must be reliable enough that 'odd' readings indicating a plant problem are not dismissed as an inaccurate flow meter. A flow meter based on electromagnetic induction or ultrasonic sensing provides the highest accuracy with exceptional long term stability and is recommended for reliable and accurate plant monitoring. A good practice is to ask the chiller manufacturer the type of flow meter used for their factory tests and use the same type for plant monitoring. This approach can eliminate finger pointing if the chiller is found to not be meeting submittal performance requirements as installed.

Related Chapters

Free Cooling via Waterside Economizer

Air-Side Economizer

Humidification Controls Alternatives

References

1) This is a rule of thumb. For more accurate data, consult the manufacturer of your chiller for a comprehensive performance selection.

2) Allowing a 62ºF dewpoint dehumidification setpoint (65% RH) or even higher would be an efficient, best practice approach and maintain the space well within common equipment specifications. See *Humidification Controls* for additional information.

Resources

• Variable-Primary-Flow Systems Revisited, Schwedler P.E., Mick, Trane Engineers Newsletter, Volume 31, No.4, 2002.

• *Thermal Guidelines for Data Processing Environments, TC9.9 Mission Critical Facilitie*s, ASHRAE, 2004.

• *Data Processing and Electronic Areas*, Chapter 17, ASHRAE HVAC Applications, 2003.

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• *ARI Standard 550/590- 2003, Water Chilling Packages Using the Vapor Compression Cycle*, Air-Conditioning and Refrigeration Institute, 2003

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