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selecting cooling towers for efficiency: Range or approach?

from the editor …
It's tempting to rely on ARI standard rating conditions for flow rates and temperature differences when designing chilled water systems. But as valuable as these benchmarks are for verifying performance, they are unlikely to reflect optimal conditions for the entire system … especially as mechanical efficiencies improve and customer requirements change.

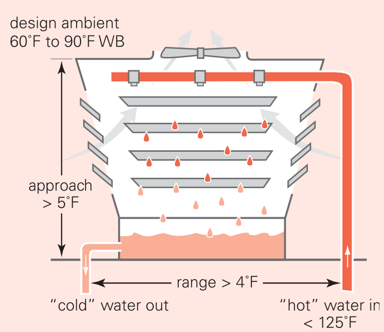
The same caveat applies to current rules of thumb, such as a 10°F ΔT across the cooling tower or a condenser water flow rate of 3 gpm/ton. Basing the design of the condenser water loop on either of these parameters may short-change the performance potential of the system and overlook opportunities to reduce costs.

In this issue, veteran applications engineer, Don Eppelheimer, explores the chiller–tower relationship by demonstrating that a wider cooling tower range not only delivers cost savings but may also improve the efficiency of the entire chilled water system.

When was the last time you revised your specifications or selection parameters for cooling towers? Or do you specify unique parameters for cooling tower selection on every job? Some HVAC designers specify 3 gpm of cooling water per ton of chiller capacity; others specify less. Still others base their selections on something other than flow, such as a condenser ΔT of 85/95 in humid climates or 80/90 in less sultry locales.

99/85/78	95/85/78
90/80/71	102/83/78

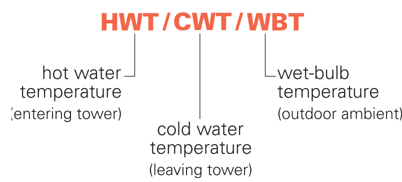
Are your tower selection guidelines listed above? Do you know what each number represents and why those particular values are significant?



CTI STD-201. Just as the Air-Conditioning and Refrigeration Institute (ARI) develops performance standards to certify chillers, the Cooling Technology Institute (CTI) provides a certification program to validate the performance of cooling towers. Unlike chillers, however, *there is no standard set of selection conditions for cooling towers*. Towers that receive certification under CTI STD-201 will provide predictable performance within the operating limits illustrated above. For more information, visit the CTI web site at *www.cti.org*.

Tower selection 101

The thermodynamic realm of cooling towers can be defined by just three temperatures …



… the "hot" water entering the cooling tower, the "cold" water leaving the tower, and the design ambient wet bulb of the geographic region where the tower will be used.

Approach is the temperature difference between what is being produced and the "power source" that creates the product. In the case of a cooling tower, the "product" is cold water leaving the tower and ambient wet bulb is the driving force that creates the cold water. If a cooling tower produces 85°F cold water when the ambient wet bulb is 78°F, then the cooling tower approach is 7°F.

The **effectiveness** of a heat exchange process can be gauged by examining the approach temperature. For example, a cooling coil that can produce 48°F leaving air with 42°F entering water (an approach of 6°F) is more effective than a cooling coil that only can produce 50°F leaving air with the same 42°F entering water (an approach of 8°F). The same will hold true for cooling towers. For a given type of cooling tower, a closer (smaller) approach temperature indicates a more effective tower.[1] Selecting a cooling tower with a close approach will supply the chiller condenser with cooler water … but the capital cost and energy consumption of the tower will be higher, too.

Still, the cooling tower isn't the most grievous energy consumer in a chilled water system. Different tower selections can afford opportunities to increase the overall efficiency of the system.

Mechanical efficiency refers to the fan power that's required to circulate ambient air over the cooling tower fill. Different types of cooling towers differ in their mechanical efficiencies.

Experience leads us to the best thermal efficiency for cooling towers used in a particular market or geographic location. It's quite likely that the same cold water temperature has been used to select cooling towers in your area for years. However, approach temperature only represents the efficiency of the cooling tower's evaporation process. It not only says little about the efficiency of the chilled water system, but the *effect* of tower approach on chilled water system efficiency also is limited. What drives

[1] Note that *effectiveness* refers to the thermal efficiency of the cooling tower fill and the evaporative process; do not confuse it with the mechanical efficiency of the cooling tower fan.

Precepts of tower sizing. Four fundamental factors affect tower size: heat load, range, approach, and ambient wet-bulb temperature. If three of these factors remain constant, then changing the fourth factor will affect tower size in this way:

- Tower size varies directly and linearly with the heat rejection load.
- Tower size varies inversely with range.
- Tower size varies inversely with approach.
- Tower size varies inversely with wet-bulb temperature.

[From *Cooling Tower Performance: Basic Theory and Practice*, a June 1986 paper published by Marley Cooling Technologies and available online at http://www.marleyct.com/pdf_forms/CTII-1.pdf]

the efficiency of the chilled water system is the cooling tower *range*.

Range is the temperature difference between the hot and cold water at the tower. *Increasing the range* will reduce the capital cost and energy cost of the tower; it also will reduce the capital cost and energy consumption of the condenser water system. However, increasing the cooling tower range is only possible if the chiller is capable of producing warmer leaving condenser water. Selecting chillers for *warmer* leaving condenser water will increase chiller energy consumption and may also increase the dollar-per-ton cost of the chiller.

This begs the question: What cooling tower range results in the lowest capital cost for the chilled water system? Further, what cooling tower range results in the lowest annual energy cost for the chilled water system? This author firmly believes that *increasing cooling tower range* from 9.4°F to 14°F or more *will reduce capital cost AND annual energy cost.*[2]

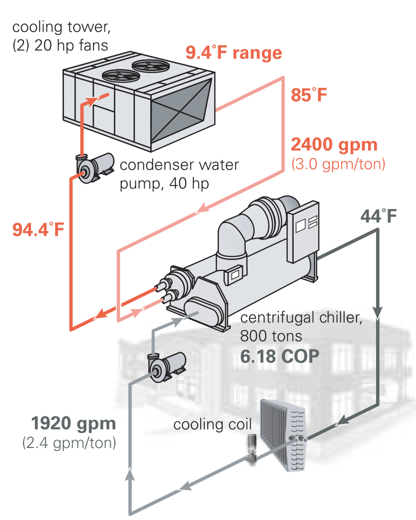
Opportunity to engineer

Now, we come to the fun part of the design process … the opportunity to exercise a bit of engineering judgment. There is a thermodynamic price to pay when the cooling tower range is increased. That penalty occurs at the chiller. We can pay that price now by specifying a more efficient chiller, or we can pay it later by allowing the increased cooling tower range to diminish chiller COP. The following example illustrates this concept.

Alternative 1: Base design. A middle school in Tennessee requires a chilled water system with 800 tons of cooling capacity (Alternative 1 *schematic*). To meet the specification, the engineer has proposed an 800-ton centrifugal

[2] Tumin Chan echoes this sentiment in his *Engineered Systems* article, "A Chiller Challenge." You can find it at <http://www.esmagazine.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2503,76249,00.html>.

Alternative 1: Base design



chiller; the unit under consideration was selected at ARI conditions and is the lowest cost centrifugal machine that complies with ASHRAE Standard 90.1's minimum efficiencies. Pressure drops through the evaporator and condenser do not exceed 25 ft.

The engineer also proposed a two-cell, cooling tower with two 20-hp, variable-speed fan motors. The tower's cross-flow design was selected for its reliability, ease of maintenance, and low height. The tower selection is based on a range of 9.4°F and a flow rate of 2400 gpm, which is provided by a 40-hp condenser water pump. With the help of energy modeling software, the engineer estimates annual energy consumption as follows:

ANNUAL ENERGY USE	
cooling tower range	*9.4°F*
centrifugal chiller	259,776 kWh
cooling tower	66,911
condenser water pump	85,769
TOTAL CONSUMPTION	412,456 kWh

Alternative 2: Wider range, smaller tower. Increasing the cooling tower range can provide several benefits, including quieter operation, a smaller footprint, lower capital investment, and less energy use.

The design team first investigated the capital cost savings of increasing the cooling tower range to 14°F (Alternative 2 *schematic*). In addition to reducing the initial cost of the cooling tower by 13 percent, it also reduced the tower footprint by 25 percent and its weight by 23 percent.

Another benefit of increasing the tower range from 9.4°F to 14°F is the drop in condenser flow rate from 2400 gpm to 1600 gpm. The corresponding reductions in pressure drop decreased the required pump power from 40.16 bhp to 15.89 bhp, even though

"Having your cake and eating it, too." In most cases larger ∆Ts and the associated lower flow rates will not only save installation cost, but will usually save energy over the course of the year. This is especially true if a portion of the first cost savings is reinvested in more efficient chillers. With the same cost chillers, at worst, the annual operating cost with the lower flows will be about equal to "standard" flows but still at a lower first cost.

[From *CoolingTools Chilled Water Plant Design Guide*, Pacific Gas and Electric (PG&E), <http://www.hvacexchange.com/cooltools/>]

the condenser water piping wasn't resized:

PRESSURE DROPS		
condenser water flow	*2400 gpm*	*1600 gpm*
condenser	26.41 ft	12.34 ft
cooling tower	12.23 ft	12.16 ft
condenser piping	11.56 ft	5.32 ft

Reselecting the centrifugal chiller based on 99°F water leaving the condenser (due to the 14°F tower range) didn't affect its capital and installation costs, but warmer condenser water increased the chiller's annual energy consumption. An energy analysis confirmed, however, that the substantial capital cost reductions for the cooling tower and condenser water pump would not increase the overall operating cost of the chilled water system. Power reductions at the cooling tower and condenser water pump exceeded the chiller's additional power consumption. Ultimately, the projected energy consumption for the entire chilled water system is 8 percent less than the base design:

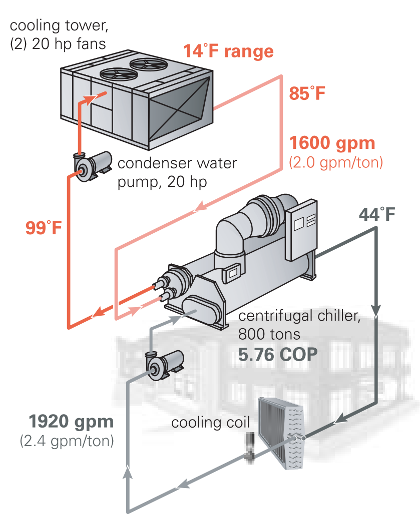
ANNUAL ENERGY USE		
cooling tower range	*9.4°F*	*14°F*
centrifugal chiller	259,776	278,389 kWh
cooling tower	66,911	64,878
condenser water pump	85,769	33,936
TOTAL CONSUMPTION	412,456	377,203 kWh

Alternative 3: Wider range, optimized system. The school-district administration in our example was concerned about the capital costs of their buildings and equipment, but even more attentive to energy/operation and maintenance costs—the *total* cost of ownership.

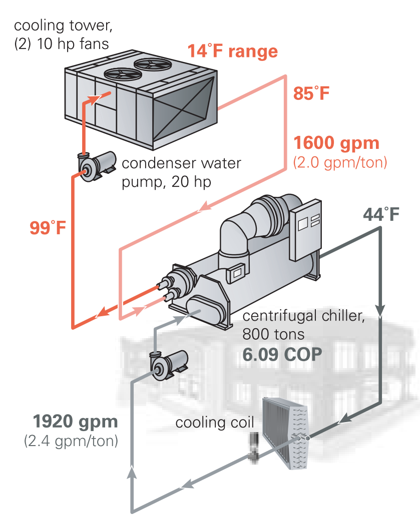
Since available space for the cooling tower wasn't a selection issue, the design team adopted a different tack. Could the benefit of a wider cooling tower range be "redirected" to improve the efficiency of the chilled water system? What would happen if the range was increased without downsizing the cooling tower fill?

To find out, the design engineer used the 14°F range and the dimensions of the original tower to reselect the tower for a third time (Alternative 3 *schematic*). This combination of

Alternative 2: Wider range, smaller tower



Alternative 3: Wider range, optimized system



parameters reduced the fan horsepower requirement from 40 hp to 20 hp, which yielded financial benefits on two fronts:

- A 5 to 6 percent reduction in the projected capital cost for the tower due to smaller fans, motors, and drives
- A 51 percent reduction in the annual energy consumption projected for the tower

Our engineer then reselected the centrifugal chiller, choosing heat-transfer options that would allow it to operate more efficiently at the higher tower range. These enhancements raised the cost of the chiller, but by less than 5 percent of the original estimate.

Table 1 summarizes the results of all three selections in this example. The lowest *total* owning and operating cost resulted from increasing the tower range, coupled with cooling tower and chiller selections aimed at *affordable* efficiency.

Developing the energy data shown in Table 1 isn't difficult. The chiller manufacturer can easily provide full- and part-load efficiency data for the chiller of your choice at various condenser flow rates, while selection software from the cooling tower manufacturer will provide the required tower performance data. Energy modeling tools, such as Trane's *Chiller Plant Analyzer* (which was used to generate the data in this newsletter), simplify comparisons of various chiller–tower–pump combinations.

Closing thoughts

When it comes to reducing both the capital cost and operating expense of a chilled water system, cooling tower range can be a particularly potent tool.

The greater the range, the greater the design team's latitude to find creative and effective solutions to project constraints, such as the budgets for capital investment and operating expense (as in this example), or limitations related to noise or available space. •

By Don Eppelheimer, applications engineer, and Brenda Bradley, information designer, Trane. You can find this and previous issues of the *Engineers Newsletter* at http://www.trane.com/commercial/library/newsletters.asp. To comment, e-mail us at comfort@trane.com.

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Table 1. Summary of selection results for example chilled water system

	Alternative 1: Base design	*Alternative 2: Smaller tower*	*Alternative 3: Optimized system*
Cooling tower range	*9.4°F*	*14°F*	*14°F*
Condenser water flow	*2400 gpm*	*1600 gpm*	*1600 gpm*
Cooling tower parameters			
Footprint	18.75 × 22.08 ft	17.0 × 18.08 ft	18.75 × 22.08 ft
Weight	38,050 lb	29,136 lb	37,726 lb
Cells	2	2	2
Fan power (total)	40 hp	40 hp	20 hp
Static lift	12.23 ft	12.16 ft	12.23 ft
Pressure drops			
Condenser	26.41 ft	12.34 ft	20.68 ft
Cooling tower	12.23 ft	12.16 ft	12.23 ft
Pipes, valve fittings	11.56 ft	5.32 ft	5.32 ft
Pump power required	40.16 bhp	15.90 bhp	20.39 bhp
Chiller efficiency	6.18 COP	5.76 COP	6.09 COP
Annual energy consumption			
Centrifugal chiller	259,776 kWh	278,389 kWh	263,325 kWh
Cooling tower	66,911 kWh	64,878 kWh	32,437 kWh
Condenser water pump	85,769 kWh	33,936 kWh	43,547 kWh
Total for system	412,456 kWh	377,203 kWh	339,309 kWh

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