Assessing the Performance of Cooling Towers and Their Effect on Chiller Efficiency

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ABSTRACT

Traditionally, energy recommendations from energy audits have been concerned with the energy use of cooling towers for point of use energy, such as variable speed fans, and pumping savings. The actual energy use of a cooling tower is small, and is only a portion of the energy involved in the entire cooling system. The majority of the energy used is to perform the work necessary to compress the refrigerant at the chiller, and is most commonly defined by the term coefficient of performance.

The efficiency of a tower is based on the original design conditions as well as the type of tower (evaporative, draft driven). Inefficiencies can occur due to under or over sizing, controls that are not properly functioning, flawed strategies for operation, and basic lack of maintenance that can create fouling of the exchangers.

This paper explores the efficiency relationship between the tower and the chiller, but more specifically develops a methodology to measure and estimate this efficiency on a short one or two day assessment. Modern inexpensive devices allow for measurement and monitoring of air temperature, humidity, process cooling temperatures and sump temperature to be measured on a short term basis. More importantly, these devices can be installed quickly by plant personnel and can be left in place for a week or more and possibly even mailed back to the auditor with the collected data.

This paper includes information about how to determine the appropriate design conditions for the tower, its temporal performance, as well as tips from major tower manufactures on design, performance, and maintenance.

The Towers

Essentially a cooling tower is a type of heat exchanger. Its role is to remove heat from a process, usually either a direct manufacturing process or from the condenser of a chiller. There are three different types of heat exchangers, shell and tube, plate and frame, and open quenching. For the most part we will not be discussing the open quenching function, except in rare cases. Each of these types of heat exchangers has its advantages and disadvantages. Shell and tube exchangers are not as efficient as plate exchangers, but are easier to clean. Plate exchangers can clog easily and therefore are usually used only in a clean environment. On the positive side, just about the only limitation to their efficiency is the size (and therefore cost) of the unit.

Towers are categorized into open and closed system units. In the open unit, the fluid is exposed to the environment for evaporative cooling. This is the most effective, but is usually not the choice of designers, as contaminant can be introduced into the working fluid and consequently into the heat exchanger, where it can both influence the performance of the exchanger as well as causing permanent damage.

Within the categories of open and closed, towers are further divided into induced draft, where the fan is placed in the exiting, moist air; or forced draft where the fan is in the dry, entering air. Further, the design of the tower can either have a counterflow of air movement or a crossflow of air. In the counterflow style, the air is moving upward and the water trickles through the medium, or fill. In the crossflow type, the air is *moving horizontally through the fill while the water is once again being pumped from the base to the top of the tower and is cooled and it is dropping. Crossflow towers use less energy per ton of cooling than do counterflow towers. Each type has its advantages and disadvantages, as will be discuses later.

The capacity of the water flowing through a tower is defined as a “nominal cooling ton”, which is generally set at 3gpm / ton. This represents the heat removed by cooling the water from 95ºF to 85ºF at a wet bulb temperature of 78ºF. Therefore a nominal cooling ton is rated at 15,000 Btu/hr, which is more than sufficient to match the condenser fluid of 12,000 Btu/hr plus the heat of the motor.

The Chillers and Auxiliary Equipment

Today’s chillers are more efficient than in previous years. Centrifugal water chiller efficiencies have improved from .8kW per ton in the 1970’s to less than 0.50kW per ton today[2]. Replacing these chillers is a great opportunity to save energy, if it is past its useful life. In that case many options are open to the plant manager, including changing the size of the chiller, the size of the towers, the pump, the fans, and the controls. It has been proposed that downsizing the towers in order to allow for economies of scale in the auxiliary systems can be the right choice, but what if you are stuck with the system you have? We will show that evaluating the performance of the system as well as the more inexpensive modifications will yield energy and dollar savings, both as a plant manager, and as an auditor who may have only a day to inspect the set-up.

Water Loop Enhancements

The distribution system can be de-coupled to allow for a varying number of pumps to be operated, or better, to allow a variable speed drive motor to be utilized to match the tower requirements. Since the efficiencies of chillers has improved so much in recent years, it has been proposed that it is actually possible to save energy by slowing down the flow The pumping savings realized by reducing a tower from 3 gpm to 2 gpm can more than offset the additional cost of operating the chiller. There is also the claim that designing the flow rate at slower speeds can save on capital costs of pumps, fans, and piping. This has been disputed, however, by Kirsner in a recent HVAC&R publication.

Tower Performance

In discussing the performance of towers a few terms need to be defined. The difference between the temperature of the air coming and the cooler water leaving the tower is called the “approach”. The difference between the temperature of the cooler water and the inlet, or “high point” of the water is called the “range.”

The efficiency of a cooling tower is determined by three factors:

The amount of heat that is added to the condenser (or other heat source) loop
The amount of water delivered to the tower
The ambient wet bulb temperature

Design performance is established and published by ASHRAE and others, but attempts at evaluating the chiller performance, or efficiency at different tower performance levels have been elusive. The common design calculation, the e-NTU method is typically used when specifying equipment, but evaluation of an existing unit performance is generally done on an empirical basis; that is the chiller and tower combination are chosen for their optimum performance at certain conditions, and then tested at other conditions. The results can sometimes be found on the specification (spec) sheets of the chiller companies.

These design conditions have changed over the years to become more realistic. Original design conditions were established in Atlanta, therefore the number of hours that most systems around the country operated at their peak was only one percent. All hours below that temperature, which is in the 90ºF range, the chiller is running off peak. Now, chillers are being designed whose peaks are in a more reasonable range. Therefore, the chiller is running at an off peak performance both above and below this design condition.

Table 1 shows chiller performance of two different chillers at varying ambient temperatures. The bin temperature used in this case is for the Baltimore/Washington area. Note that the chiller with the lower nominal efficiency rating does not use more energy than the higher rated chiller whose design rating peak performance is for a lower temperature.

Table 1. Chiller Performance Comparison

.50 kW/TR, Poor Off-design .						**55 kW/TR, Excellent Off-design**		
Temp. Bin (°F)	**Opg. Time (hrs)**	**Chlr. Load (TR)**	**Typ. ECWT (°F)**	**Power Use (kW)**	**Energy Use (kWh)**	**Typ. ECWT (°F)**	**Power Use (kW)**	**Energy Use (kWh)**
95-99	6	500	83	246	1,477	83	266	1,598
90-94	72	464	81	222	15,957	81	237	17,066
85-89	243	427	79	197	47,844	79	208	50,569
80-84	428	391	77	175	74,768	77	183	78,427
75-79	631	355	75	154	97,307	75	161	101,864
70-74	925	319	75	138	127,227	73	142	131,646
65-69	858	282	75	121	104,121	68	120	102,763
60-64	755	246	75	107	80,422	63	101	75,936
55-59	688	210	75	93	63,702	58	84	57,705
50-55	671	174	75	80	53,388	55	72	48,031
Total					**666,213**			**665,605**

Source: HVAC&R Engineering Update, York International

Although cooling towers can be used at higher humidity, most of the cooling effect comes from the evaporation of the water. Only about 1% of the water is evaporated in the process and needs to be replaced, however, care must be taken in the treatment of that water, as the evaporation increases the concentration of any contaminates. As mentioned earlier, losses at cooling towers also means energy losses at the chiller, or compressor. Water in a tower that is not properly maintained can run as much as 10°F higher than design. This can cost you up to 3.5% more energy for every degree warmer the cooling water becomes. (Electric Ideas Clearinghouse)

Maintenance and Water Quality

So, now you have established that the leaving water temperature is higher than it should be, the first thing is mechanical damage to the fill. There are three types of fill – film, splash, and trickle type. A film of water runs down the surface in the first type, the splash type breaks the water into droplets, and the trickle type is a combination of both. Their effectiveness can be reduced by mechanical damage, scale, dirt, or biological materials, such as algae.

Only about one percent of the water flow evaporates and needs to be replaced every hour. Water evaporation rate can be estimated at 3 gpm per 100 ton of cooling. Even so, as the evaporation takes place, there is a concentration of minerals and other contaminants that need to be controlled. Drift can also add to the amount of water lost each day, by 0.05% to 0.2% according to the North Carolina Department of Environment and Natural Resources. The amount of a contaminant in the water added (blowndown) divided by that of the make-up water is the "Concentration ratio" and is calculated in cycles. This is measured by ph, tds, alkalinity, and, conductivity. Concentration ratios can get up to 6, but usually maintained around 2-4. There can also be bacterial growth, and dissolved solids – usually $CaCO_3$. This is usually treated with sulfuric acid, but care must be taken as sulfuric acid is an aggressive corrosive, and these must be used in conjunction with an anti-corrosive. Measurements that can be taken and a list of items to identify when on a one day assessment are shown in Table 2. Side stream filtration and ozone injection are other ways that these contaminates can be controlled. It should be noted that all type of treatment (for microbes, deposition, and for corrosion, etc.) affect each other.

Calculating the Energy Savings

There are two ways of calculating the unnecessary energy usage by using the following estimates. The first, if using the data sheets, is to measure the leaving air and the leaving water temperatures and to compare these to the value on the spec sheets say it should be (usually 10ºF). If you are unable to measure the temperature of the leaving air, then it can be assumed that the leaving air is at the same temperature as the ambient air, but at 100% humidity. This is obviously not completely accurate, but will underestimate the savings. The spec sheets of some chiller compressors show the power (kW) usage at different temperatures, as shown earlier in the report. If the spec sheets are not available, it can be assumed that the range should be design conditions. The Cooling Technology Institute offers a "rule of thumb" that the power draw is reduced by one percent per degree down to 70ºF.

Another way to calculate the energy lost is to calculate the amount of heat that is not rejected because of elevated temperatures, as lost capacity. This way of estimating the energy lost is to assume that the kW remains the same (another bold assumption). Then, the kW/ton can be re-calculated and used to equate to lost electricity at the chiller by assuming additional run time. This is only true, again down to about 70ºF.

What Can be Done in One Day?

The energy auditor, especially the generalist on a limited time frame and budget struggles to view pieces of equipment as a system. However, by using a few tools, and making a few assumptions, the performance of a cooling tower can be judged, and recommendations made. Studies have shown that these savings at the chiller almost always outweigh those made to the peripherals; although the two are not exclusive.

Table 2. Chiller / Cooling Tower Data Collection Sheet

Chiller	
Brand and Model #:	
Capacity:	
Approximate Age:	
Rated Amps	Measured:
Maintenance Condition: (1-10)	
Pumps	
Number and Model number:	VSD
Flow Rate (gpm) Design	Measured:
Fans	
Number and Model Numbers	VSD
Crossflow or Counterflow	
Cooling Tower	
Brand and Model Number	
Capacity:	
Fill Type (Film, Splash, Trickle)	Condition:
Warm water	
Cool Water	
Leaving Air Wetbulb	Estimated?
Ambient Wetbulb	
Water treatment (CTI)	**Acceptable values**
Suspended Solids	< 25 for film fill
TDS	< 5000 ppm
PH balance	6.5 - 9
Chlorides	< 750 Galvanized
	< 1500 Stainless
CaCO3	< 800 ppm
Sulfates, if calcium over 800	< 800 ppm
if calcium under 800	< 5,000 ppm
Silica (SiO2)	< 150 ppm
Iron	< 3 ppm
Manganese	< 0.1 ppm
Ammonia, if copper is present	< 50 ppm

Source: Cooling Technology Institute

References

Electric Ideas Clearinghouse, Bonneville Power Administration November 1991; *Optimizing Cooling Tower Performance*

Trane Corporation; *Evaluating and Improving Chiller Plant Efficiencies*

Kisock, Kelly, University of Dayton Industrial Assessment Center; *Cooling Tower Theory*