TECHNICAL RESOURCE

Strategies to Reduce Energy and Lower Operating Costs

Overview

When thinking of reducing the energy consumption of the cooling tower-chiller system, many assume that large expenses will be incurred. However, this does not have to always be the case if certain design considerations are made. This article offers a few, simple, cost effective suggestions for achieving energy reductions in the system. There are numerous design possibilities for achieving energy reductions, yet the following ones are some of the best ideas in the industry based on cost effectiveness and their proven histories in saving energy.

When considering heat rejection equipment, the two primary goals of conserving energy are to reduce the environmental impact of a given system and decrease the associated cost of that system. Systems that consume less energy reduce carbon dioxide (CO_2) emissions from power generation and lower recurring costs for purchasing that energy. Broadly, some energy saving strategies are:

- Energy saving strategies…
    - …use VFDs to save energy
    - …reduce energy by using design-based methods (oversized units)
    - …decrease energy use at the source of power generation by using evaporative equipment (well to wheel based energy reduction)

VFDs

The fan motor of the cooling tower is a large source of energy consumption. Applying energy saving components, such as a variable frequency drive (VFD), will result in significant energy savings. VFDs use electronics to adjust the input of power to the fan motor, varying the fan speed in the process.

Fans vary their airflows in order to compensate for changes in ambient air and load conditions. VFDs are more efficient at varying airflow compared to fan cycling, fan discharge dampers, or mechanical speed changers. VFDs have built-in sensor controls that automatically adjust fan speeds to the exact requirement based on the current conditions. VFDs reduce energy consumption by simply slowing the motor at times, while still maintaining the proper airflow. Fan power is proportional to the cube of fan speed (**Equation 1**), allowing small decreases in speed to greatly reduce energy consumption. Thus, slowing a fan to 80% of its original speed will decrease the fan motor's energy consumption by 50%.

Equation 1:

For a centrifugal or axial fan with constant diameter and changing speed,

$$P_1 / P_2 = (n_1 / n_2)^3$$

Where P_1 is the initial power consumption, P_2 is the final power consumption, n_1 is the initial fan speed, and n_2 is the final fan speed.

When started, fan motors have a high inrush current that results in a large energy draw. This energy penalty is avoided by using VFDs, which act as soft starters by varying speed at a programmable rate. The energy savings from VFDs reduce annual operating costs.

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Reducing Energy by Using System Based Designs

Approach temperature, the difference in temperature between the water leaving the cooling tower (entering the condenser) and the entering wet bulb (EWB), has a more significant influence on cooling tower size and energy consumption than any other parameter affecting the cooling tower sizing. Chiller energy, which represents over 85% of the full load system energy usage, is reduced as a function of approach temperature. Thus, focusing on how best to run the cooling tower to achieve an approach temperature that optimizes chiller operation is a prime consideration. In all but the lowest wet bulb temperatures (<66°F EWB), when the cooling tower is designed to improve the chiller's efficiency, the energy savings from the chiller will far surpass additional cooling tower energy usage in such designs[3].

System Based Design: Reduce the Entering Condenser (Leaving Cooling Tower) Water Temperature

Using a system based design to reduce energy consumption means selecting and/or operating system components in a manner that uses the least amount of energy annually. Chiller energy consumption can be reduced considerably with a decreasing approach temperature. Lowering the approach temperature can be achieved by reducing the entering condenser water temperature. The lower the entering condenser water temperature, then the lower the condensing pressure, which means less work that must be done by the compressor. For a centrifugal chiller, every 1°F (0.56˚C) reduction in condenser water temperature will improve the compressor efficiency by 1.1%[1]. There are two ways to take advantage of lower condenser water temperature:

- **System based design (A):** Design the system from the outset to have a lower approach temperature for the design-day by using a physically larger unit than the application calls for. The larger unit accommodates a bigger, lower HP fan which uses less energy to operate.
- **System based design (B):** Operate the system by running the cooling towers to drive the condenser water temperature as low as possible by utilizing high fan speeds on non-design day wet-bulb temperatures.

Design (A) Example: Design Day - 78°F (25.6°C) EWB

Traditionally, energy saving cooling systems are designed to be wet and employ centrifugal chillers. Typically, these systems have an output of 3 USGPM/ton operating at an entering condenser water temperature of 85ºF (29.4°C) and a EWB of 78ºF (25.6˚C), consuming approximately 0.62 kW/ton by constantly operating at a 7 ºF (3.8°C) approach temperature (**Figure 1**). If this same system were designed for lower energy consumption on the design-day at 78ºF (25.6°C) WBT, one example is that it would be designed to operate at a 5ºF (2.7°C) approach temperature, resulting in 83ºF (28.3°C) entering condenser water temperature, instead of the typical 7ºF (3.8˚C) approach temperature and would consume approximately 0.59 kW/ton (**Figure 1**). Such a system will be physically larger and come at an initial cost premium; however, the resultant savings will pay this premium back quickly and offer even greater long term savings than the traditionally designed system, as explained in the following energy and cost savings section.

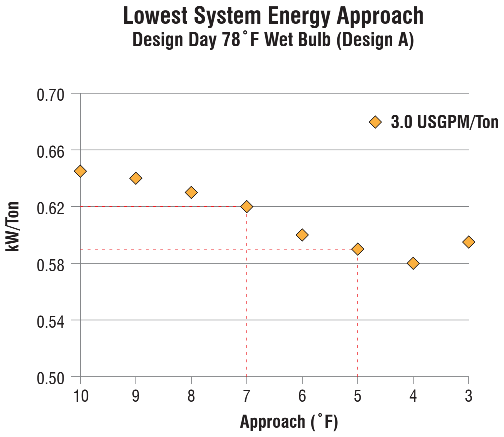

Figure 1. Lowest System Energy Approach temperature 78 ºF Wet Bulb. Adapted from “Optimization of Water Cooled Chiller Cooling Tower Combinations” by J. Furlong and F. Morrison, 2005, CTI Journal, 26 (1), pg. 12-19.

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Design (B) Example: Days Other Than the Design Day- 72°F (22.2°C) EWB

Consider the same system from the Design (A) example, but on a day other than the design day where the EWB is now 72ºF (22.2˚C). By running the fans at full speed, even greater energy savings can still be achieved. Keeping the cooling tower fans running at full speed will reduce the condenser water temperature from 83ºF (28.3˚C) to 78ºF (25.6˚C) (rather than allowing the fans to modulate and maintain a steady 83ºF (28.3˚C) condenser water temperature as in the Design (A) example) to achieve a 6°F (3.4˚C) approach temperature. This new design will result in the system energy consumption reducing to 0.54 kW/ton (**Figure 2**). Such a reduction will save more than enough energy to compensate for the energy penalty of running the fans at full speed.

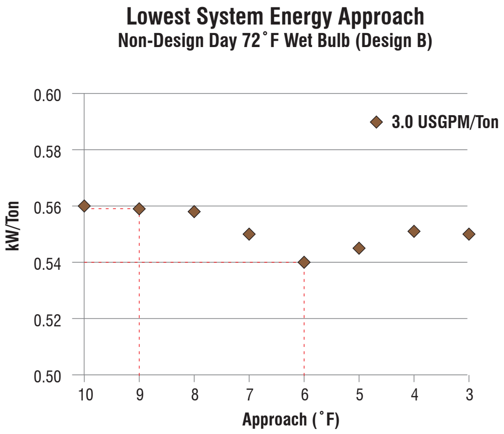

Figure 2. Lowest System Energy Approach temperature 72ºF Wet Bulb. Adapted from "Optimization of Water Cooled Chiller Cooling Tower Combinations" by J. Furlong and F. Morrison, 2005, CTI Journal,26 (1), pg. 12-19.

NOTE: The CTI STD 201 program will certify cooling towers down to a 5°F (2.8°C) approach temperature.

NOTE:

A KW SAVED - WHAT'S IT WORTH?

Equivalent Full Load Hours **Estimate:**

Demand:

1kW x $12/kW-Mo x 6 Mo = $ 72/Yr

Energy:

1kW x 3000 h x $0.10/kWh = $300/Yr

Total Annual Value of 1 kW:

$72 (demand) + $300 (energy) = $372

Assumptions:

$12/kW-Mo, 6 months of operation,
3000 hours of operation, $0.10/kWh

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Oversized vs. Traditional Units: Energy and Cost Savings

Using weather data, product data, and heat rejection algorithms, it is possible to model the annual performance of evaporative equipment. This is particularly useful when comparing the seasonal performance of different units of equipment, particularly an oversized unit versus any traditional alternative. Consider two units with similar heat rejection ratings, yet different fan horsepowers. They can consume vastly different amounts of energy over the course of a year. For example, a compact, 40 HP model rated for approximately 500 nominal tons will consume more energy than an oversized, 15 HP model also rated for approximately 500 nominal tons. The greener, oversized model may come at an initial cost premium. However, this early premium will be more than offset by the savings that result from the energy reductions offered by such a design.

Table 1 compares a physically larger, oversized unit to a traditional unit that a particular application calls for, as explained in the Design (A) example. The baseline tower is designed for a 7°F (3.8˚C) approach temperature, while the oversized tower is designed for a 5°F (2.7˚C) approach temperature. The value of obtaining energy savings is best put into perspective alongside an analysis of the net present value of dollar savings offered by evaporative equipment designed for reduced energy consumption.

Type of Unit	Traditional	Oversized
Nominal Tons	502	557
Footprint (LxWxH)	9.8 x 20 x 12.1	13.9 x 24 x 12.3
EWT/LWT/EWB	95˚/85˚/78˚	93˚/83˚/78˚
Approach temperature	7°F	5˚F
First Cost Premium	baseline	$5,430
Fan HP	40	15
% Fan Energy Savings	baseline	54%
1 Speed Fan Op Cost	$18,780	$7,639
VFD Fan Op Cost	$10,936	$5,019
Pump Op Cost	$3,330	$3,385
Controls Cost	$9,714	$4,929
NPV of Energy Savings Over Tower Life	baseline	$75,404
dBA @ 50'	77.7	74.4

Table 1. Traditional Unit Versus Oversized Unit

Assumptions: energy charge of $0.10 $/kWh, demand charge of $12/kW, 1000 USGPM flowrate, 17 year tower life, 65°F absolute minimum entering condenser water temperature

NOTE: The analysis and pricing in **Table 1** was completed by BAC's Green Tower Program. You may contact your local BAC representative to provide you with an analysis that reflects your own set of constraints and operating conditions.

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As explained in the design (A) example, there are great benefits to using a physically larger cooling tower than the typical circumstances usually dictate. **Table 1** shows how going from a traditional 7°F (3.9˚C) approach temperature to a 5°F (2.8˚C) approach temperature can save energy and reduce operating costs. The lower HP of oversized towers significantly reduces the energy penalty of the fan motor; going from a 40 HP motor to a 15 HP motor reduces energy consumption by 54% in this case. A fan operated by a VFD will save a customer $5,917 ($10,936 - $5,019) in annual costs associated with energy usage if the customer designs an oversized tower. As discussed earlier, VFDs offer significant energy savings over 1 speed and 2 speed fans, and result in large cost savings regardless of the cooling tower size. Another key environmental and cost cutting benefit of a larger tower is sound reduction. In this example, the dBA rating at 50 feet is reduced from 77.7 dBA to 74.4 dBA. The lower HP fans in oversized units run more slowly than fans of more compact models, considerably reducing the sound that the fan creates. In certain applications, this is a cost-effective procedure to meet a low sound requirement.

The premium for designing a physically larger tower in this example is $5,430. Considering that the net present value of energy savings over the tower's life is expected to be $75,404, this represents a payback of far less than a year. Depending on the application, there are often many 'green' selections that offer payback periods of less than 2 years and many of these selections are far larger in size than would naturally be considered for the application.

Well to Wheel Based Energy Use Reduction

Well to wheel based energy consumption identifies energy savings based on the overall energy efficiency at the source of power generation for the site. Power plants typically have a choice of cooling between air-cooled (dry) systems or wet-cooled (evaporative) systems. This choice is an important decision that will drastically affect how much energy is used over the lifetime of the plant. Air-cooled systems may minimize water use at plants but require too much power to do so efficiently. Dry cooling is impractical in power plants because of reduced thermal performance. Dry cooling requires heat to be transferred to the atmosphere without evaporation, which is known as sensible heat transfer. Sensible heat transfer is less efficient than evaporative heat transfer. In fact, for air-cooled systems achieve the same thermal performance as wet-cooled systems, a footprint twice as large is required. This makes the power plant larger and mechanically more complex, which will incur higher maintenance and energy costs[4].

The associated energy penalties with using air-cooled systems over wet-cooled systems in a power plant are substantial. The sensible heat transfer that air-cooled systems rely upon is directly related to the ambient dry-bulb temperature, which can fluctuate a range of 20°F - 25°F (11.1°C - 13.9°C) on any given day. Air-cooled systems are most efficient when they can maintain a turbine backpressure (steam turbines power the plant) at ambient dry-bulb temperatures of 90-95°F (32.2°C - 35°C). Yet air-cooled systems will find it difficult to maintain this optimum condition as the ambient temperature increases, which results in decreasing power generation efficiencies. On the hottest days of the year the energy usage and costs may become exorbitant as air-cooled systems fail to operate efficiently yet have to run during peak demand times when energy costs are highest. To compensate for this, air-cooled systems have to be designed for a larger footprint. This is no solution for saving energy either, as the larger mechanical room will require even more energy to power, incurring higher energy costs as a result.

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Dry cooling is so inefficient that air-cooled systems are currently not in use on any nuclear power plant. Air-cooled systems cannot handle system loads that are in the mid to upper range, while wet-cooled systems can handle any range of loads. During a time span of a decade from 1990-1999, only one air-cooled system was implemented at a new power plant required to generate over 200 MW[2].

Power generation facilities that use water do so in one of two setups:

1. Once-through systems that continuously pump water through the plant in order to provide cooling. The continuous source of water is typically provided from seas/rivers or man-made wells.
2. Closed cycle systems that discharge heat by using evaporative equipment.

Once-through systems pose a risk to the environment because of the impingement and entrainment of aquatic life in the system's pumping and piping since water is continuously pumped from seas and rivers. Also, once-through systems can change ecosystem conditions because water is discharged into its original source at higher temperatures than the ambient. Therefore, the most environmentally friendly solution that also offers the energy savings associated with wet-cooling is to employ closed cycle systems, which use evaporative equipment, at power plants. Using evaporative equipment allows plant owners to avoid the heavy energy penalties associated with air-cooled systems while impacting the environment less than once-through systems.

Conclusion

Using strategies to reduce energy consumption has a dual impact of conserving the environment and lowering a cooling system's costs.

- Use VFDs to optimize fan speed, consuming less energy
- Make cooling tower design/operating changes to operate the chiller as efficiently as possible (chillers account for more than 85% of the cooling tower-chiller system's energy)
    - Design a unit to have a lower approach temperature range
        - Oversize the unit to accommodate a lower HP fan
        - Run fans at full speed to lower the entering condenser water temperature, making the chiller do less work
- Use evaporative equipment instead of air-cooled equipment at power generation sites

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References

1. Actions You Can Take to Reduce Cooling Costs. Fact Sheet. Washington, DC: FederalEnergy Management Program, 2005.
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3. Furlong, James and Frank Morrison. “Optimization of Water Cooled Chiller-Cooling Tower Combinations.” CTI Journal (2005): 12-19.
4. Micheletti, Wayne and John Burns. Emerging Issues and Needs for Power Plant Cooling Systems. Washington, DC: National Energy Technology Laboratory, 2002.