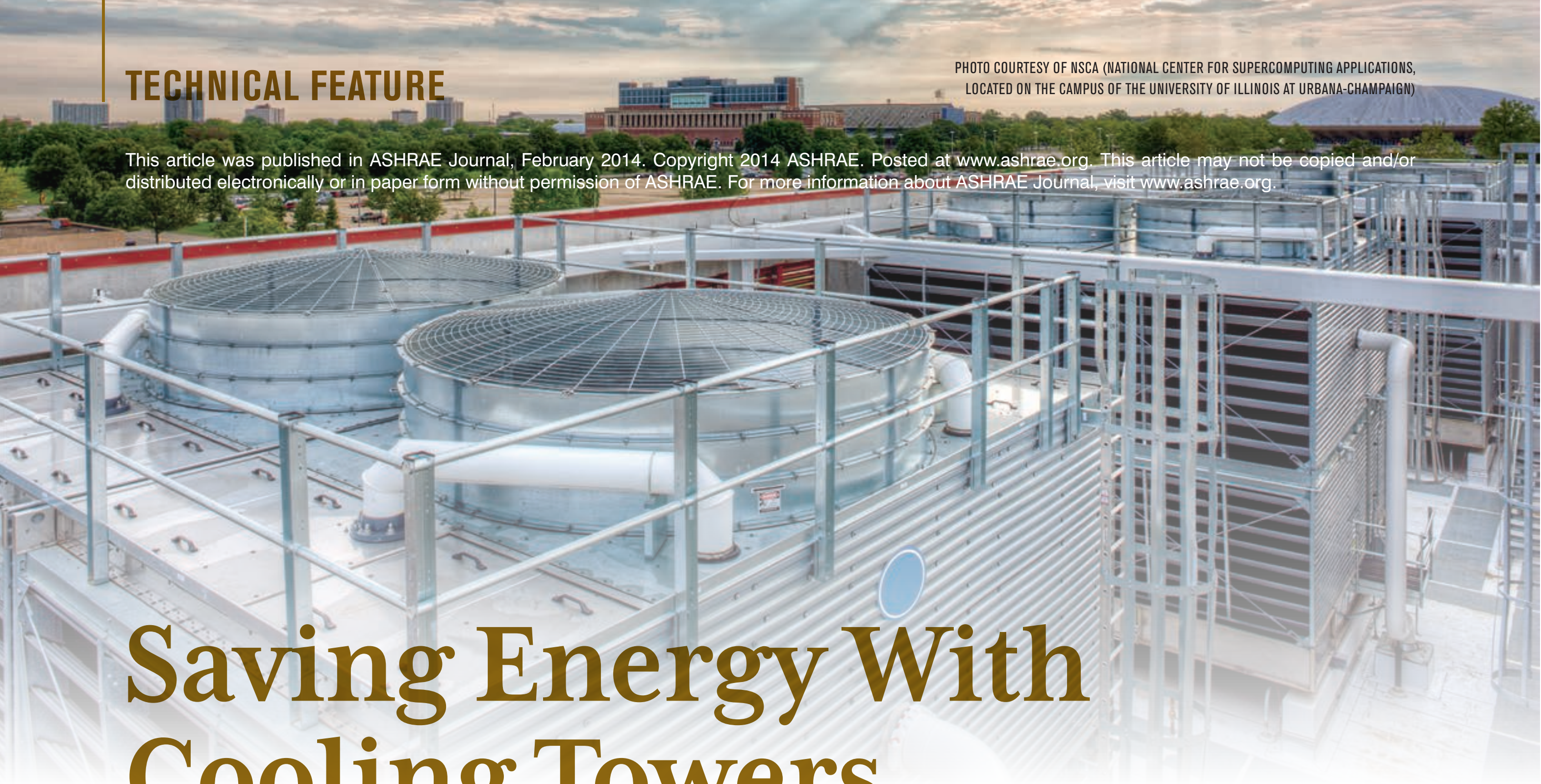

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Saving Energy With Cooling Towers

BY FRANK MORRISON, MEMBER ASHRAE

Water-cooled systems offer lower energy use than air-cooled alternatives. Many years ago, the first water-cooled systems used potable water directly in the condenser to provide heat rejection with the cooling water wasted to a drain. Cooling towers were developed to recycle more than 98% of this water, resulting in tremendous reductions in water and energy use as these systems grew in both size and popularity.

Since then, water-cooled systems have steadily improved their performance. For instance, the efficiency of a 500 ton (1757 kW) water-cooled centrifugal chiller has improved by over 50% since 1975[1] as indicated by the requirements of ASHRAE/IES Standard 90.1 (hereafter referred to as Standard 90.1). Cooling towers have also evolved from centrifugal fan units to much more energy-efficient axial fan designs with improved heat transfer surfaces, known as fill. In addition, independent certification of thermal performance for open circuit cooling towers per the Cooling Technology Institute's Standard 201* has become widely accepted in the marketplace and became required by Standard 90.1 in the 2007 edition.

While the efficiency improvements of individual system components have certainly lowered overall energy use, even greater improvements are possible by optimizing the way cooling systems are designed and operated. For instance, the full load energy use in a 500 ton (1757 kW) water-cooled chiller system, based on Standard 90.1-2013 minimum efficiencies, is roughly broken down as follows: chiller – 77%, cooling tower – 8%, condenser pump – 7%, and chilled water pump – 8%. With the chiller accounting for the majority of the energy use, many contend that it makes sense to operate the cooling tower fan and condenser pump such that compressor energy use is reduced—since it is by far the largest motor in the system.

For instance, to lower chiller energy, the cooling tower is often operated at full fan speed and flow until ambient conditions allow the minimum condenser water temperature limit to be reached. Below this level, the fan speed of the cooling tower is modulated, typically by a variable speed drive (VSD), to maintain the setpoint. This is essentially the operating sequence for the water-cooled baseline buildings found in Appendix G of Standard 90.1-2013, which uses 70°F (21.1°C) as the lower condenser water setpoint (though this value

*CTI Standard 201 has been replaced by two 2013 standards: STD 201-OM, *Operations Manual for Thermal Performance Certification of Evaporative Heat Rejection Equipment* and STD 201RS, *Performance Rating of Evaporative Heat Rejection Equipment.*

is above the low limit for almost all chillers). In practice, this lower limit varies and is dependent on the type of chiller. The closer to full load the system runs, the greater the energy savings from such strategies. However, most chiller systems operate at less than full load for the majority of time.

While it may seem counterintuitive, many designers and operators have found that using less cooling tower energy reduces overall system energy at many off-design conditions. At such conditions, ancillary equipment (condenser pumps and cooling tower fans) operating at full design speed becomes a larger portion of the system energy use, especially when variable speed chillers are used. Reducing cooling tower fan speed can reduce associated fan power significantly while increasing chiller power only marginally. For example, slowing the tower fan speed to 80% of design reduces tower fan power by about half, while only raising the cooling tower leaving water temperature about 3°F (1.7°C). Depending on the specific load point, the increase in chiller energy consumption from the higher condenser water temperature may or may not be less than the reduction in cooling tower energy. The key is to balance the performance of the system components so overall performance is optimized. Articles such as Taylor's[2,3,4] excellent series on chilled water system design provide more details on such strategies.

Closer Approach Selections

Another method to reduce system energy is to select a cooling tower using a closer approach than might be typical for a particular area. The tower approach is defined as the difference between the water temperature leaving the cooling tower minus the entering wet-bulb temperature. When a closer design approach is chosen, the resulting cooling tower provides colder water to the chiller condenser, even on a design day, which in turn reduces compressor energy. This, of course, assumes the system designer has not taken advantage of the colder design water temperature to reduce the condenser surface area of the chiller.

The added cooling tower cost and potentially greater tower fan horsepower and pumping head must be evaluated versus the expected chiller energy savings. Facilities with constant year-round loads, such as those experienced in data centers or certain manufacturing facilities, typically derive the greatest benefit from this technique.

PHOTO 1 Four cell crossflow open circuit cooling tower.

Fan Speed Control

There are several specific methods to optimize cooling tower energy use. First, as required by Standard 90.1-2013, cooling tower fan speed must have the capability to be controlled proportional to the leaving fluid temperature or condensing temperature/pressure.[5] This can be accomplished in several ways, including the use of two-speed motors or variable speed drive technology. For multi-cell cooling towers, all of the fans should be operated simultaneously at the same fan speed, maximizing the heat transfer surface area used in the evaporative cooling process, for the lowest energy use. This is opposed to the traditional manner of fan cycling (on/off) that provides step control (for example, Tower 1 fan on, then Tower 2 fan on, etc., as the load increases). This operating sequence becomes even easier to apply today with the widespread use of cost-effective variable speed drives (VSD), though the sequence can also be used with either multi-speed or pony motors.

To illustrate the potential energy savings, let's look at the case of a four-cell cooling tower with and without variable speed fan drives as shown in *Photo 1*. With full water flow over all cells, operating the fans in two cells at full speed with the fans in the other two cells idle produces essentially the same leaving water temperature off the tower as when running the fans in all four cells at approximately 56% fan speed. However, by running all fans simultaneously at the lower speed, the fan energy is reduced by more than 60% compared to step control

ABOUT THE AUTHOR Frank Morrison is manager, global strategy at Baltimore Aircoil Company in Jessup, Md. He is chair of ASHRAE TC 3.6, Water Treatment, and a voting member of ASHRAE SSPC 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings.

thanks to the fan laws.† In addition to the significant energy savings, this control sequence has other benefits, including:

- Significantly improved condenser water temperature control;
- Fan system maintenance is minimized thanks to the lower average fan speed and reduced starts and stops;
- The cooling tower has a lower sound profile due to the lower average fan speed coupled with the soft fan starts and stops; and
- All fan motors are regularly exercised without the need for a lead/lag arrangement.

This simple energy-saving technique can be effectively applied on both new and existing installations. Of course, both the minimum fan speed and flow requirements for the specific cooling tower design must be followed per the manufacturer's recommendations.

Note that this fan control method for multi-cell cooling towers and other heat rejection equipment has been added as a requirement in Standard 90.1-2013 along with a 5% increase in the minimum efficiency for axial fan, open circuit cooling towers. Additionally, a limitation on the use of centrifugal fan, open circuit cooling towers over approximately 300 nominal tons (1318 kW) was incorporated in the 2010 edition of the Standard helping to accelerate an important market

PHOTO 2 Multi-cell counterflow open circuit cooling tower installation.

†Assumes full design water flow over each cell in both cases; exact percentage savings will vary depending on the specific wet bulb, load conditions, and the estimation of the natural draft cooling capacity of the two cells with the fans off.

trend towards the use of cooling towers with lower energy axial fans. It is important to note, however, that centrifugal fan units can still be used on projects under 300 nominal tons (1318 kW) and, without a size restriction, on installations where unit sound attenuation is required, when like-for-like replacements are necessary, or for indoor ducted applications. The latter is often used in colder climates or where building security is an issue.

Lower Energy Cooling Towers

Another effective technique to reduce cooling tower fan energy is to increase the amount of heat transfer surface in the cooling tower thereby reducing the required airflow and associated air pressure drop through the tower. This, in turn, reduces the fan motor size required for the same thermal duty. Motor size reductions of 25% to 50% are often economically practical on many projects. The additional first cost of the cooling tower, along with the larger support grillage, is offset in part by lower fan motor wiring and VSD costs. Depending on the specific model chosen, the tower height may increase resulting in higher pumping costs, but this is usually a relatively small factor and can be minimized by the judicious selection of the cooling tower. Combining all of these factors, the higher net first cost is paid for by the large fan energy savings, often producing a simple payback of two years or less. These energy savings can also contribute toward earning LEED points for the building.

Tower Flow Turndown

After optimizing chiller and cooling tower fan energy, designers and operators should then evaluate condenser water flow turndown on open circuit cooling towers as a further means for reducing system energy use. Several important factors must be considered. First, the fill in the cooling tower must be properly wetted at all times to avoid wet/dry areas that can lead to scaling in the fill pack. Scaling is the accumulation of solids from the water at the wet/dry interface. The amount of scaling depends on how well the entire fill pack is wetted as well as the recirculating water quality in the cooling tower, which is measured by such indicators as the level of total dissolved solids.

Uncontrolled scale can block both air and water flow through the heat transfer media, which forces the cooling tower fan to use more energy to meet the design condenser water temperature setpoint. Under high load conditions, this can also result in an increase in chiller energy consumption or, if severe, chiller surge. In addition, too low a flow over the tower can result in winter icing issues, which will be covered in more detail in the March issue in an article by Paul Lindahl.

To avoid such issues, the minimum flow rate over the cooling tower as specified by the manufacturer must be maintained, which may involve shutting down some cells as chillers are cycled off. Additionally, the cooling tower must be designed to handle the expected flow turndown, which usually involves features such as weir dams and/or a combination of spray nozzles that can properly span the expected range of water flows while providing adequate wetting of the fill pack at all times. This applies to whether a crossflow (*Photo 1*) or counterflow (*Photo 2*) design is specified. Crossflow towers typically use gravity flow basins to distribute the cooling water over the fill pack as shown in *Figure 1,* while counterflow towers have pressurized water distribution systems as shown in *Figure 2.* Similarly, the flow limits through the condenser must also be checked as low velocities below the manufacturer's recommended minimum can result in fouling of the condenser tubes. This in turn increases system energy consumption by increasing chiller energy use while forcing the cooling tower to work harder to meet the necessary condenser water temperature that is being called for by the system.

Second, a portion of the pumping head on an open circuit cooling tower is fixed, which lowers the potential pump energy savings compared to those that are achievable with closed loop systems such as the chilled water piping or a closed condenser loop that uses a closed circuit cooling tower. Though important, these factors typically place condenser pump savings last in line after the chiller, cooling tower fan, and chilled water pump. Thus the designer and operator must evaluate the potential energy savings of reducing the water flow over the cooling tower with the operating risk to the system. These cautions apply whether the system uses 2.0 gpm/ton or 3.0 gpm/ton (0.036 L/s·kW to 0.054 L/s·kW) on the condenser loop. While in many cases the system energy is reduced with the lower condenser design flow,[6] note that there is even less

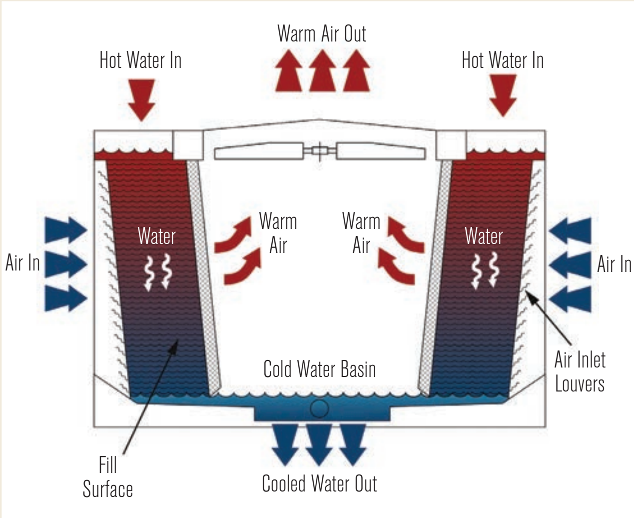

FIGURE 1 Induced draft, axial fan, crossflow open circuit cooling tower.

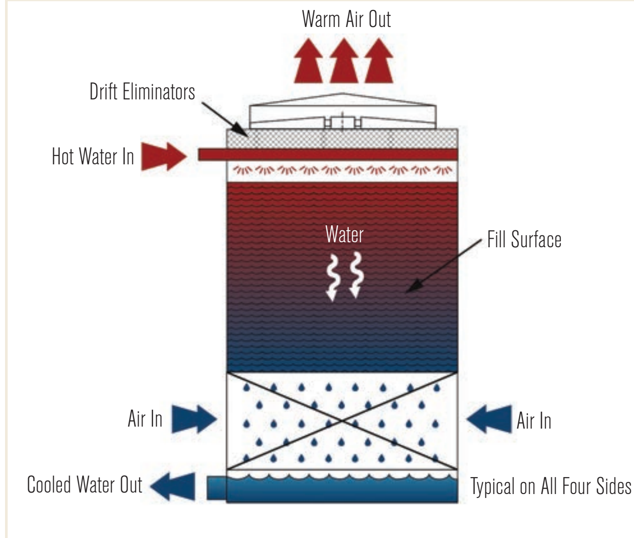

FIGURE 2 Induced draft, axial fan, counterflow open circuit cooling tower.

potential condenser pump energy savings to capture, which further alters the risk/reward ratio.

Standard 90.1-2013 now requires that all open circuit cooling towers on water-cooled chiller systems with either multiple or variable speed condenser water pumps have the capability of a minimum 50% flow turndown. Note, however, that there are no requirements or guidelines for implementing condenser flow turndown in the standard at this time as each system is unique. As such, system designers and operators should consult with their chiller and tower manufacturer for specific flow turndown recommendations for their system. As mentioned previously, the local makeup water quality, the expected water treatment program, and the sophistication of the control system required should also be evaluated.

Water Economizers for Computer Rooms

January's article by Mick Schwedler[7] covered the proper application of water economizers, cautioning the reader to properly account for the changes in cooling tower approach temperature at lower wet-bulb temperatures. Reflecting this same phenomenon, a change to the requirements for water economizers that are primarily used for computer room applications was implemented in Standard 90.1-2013. Unlike a comfort cooling application where the load decreases in winter, the load in a typical computer room remains relatively constant throughout the year, independent of climate variations. The high year-round load coupled with the increasing approach temperature at lower wet bulbs results in a cooling tower selection that is oversized for the summer duty.

Since many computer facilities are lightly loaded during their first few years of operation, system control can suffer, which is a serious concern for computer system operators due to their need for high reliability and system uptime in such facilities. To reduce the oversizing, the switchover design temperature requirement for full economization was revised from a single fixed design temperature for all computer rooms (wet bulb for cooling towers and dry bulb for dry coolers) to one that varies by climate zone. The lower design temperature reduces the size of the heat rejection device required for the water economizer which in turn reduces first cost as well as improves system control under low load conditions.

Closed Circuit Cooling Towers and Evaporative Condensers

While this article primarily discussed open circuit cooling towers, the fan speed control requirements mentioned earlier also apply to closed circuit cooling towers, evaporative condensers, dry coolers, and air cooled condensers. Minimum efficiencies and thermal performance certification requirements for closed circuit cooling towers were added in the 2010 edition of Standard 90.1. Closed circuit cooling towers combine the function of a cooling tower and heat exchanger in one compact device, keeping the process fluid clean in a closed loop.

Furthermore, minimum efficiencies for evaporative condensers used in both ammonia and halocarbon applications have been added with the 2013 edition. Evaporative condensers are similar to closed circuit cooling towers except that a refrigerant is condensed within the coil. Evaporative condensers are often used in cold storage warehouses, food processing facilities, supermarkets, industrial processes, and, to a limited extent, HVAC systems.

PHOTO 3 Regular cooling tower maintenance pays off.

Maintenance Benefits

Finally, no matter what the specific system design, paying regular attention to the cooling tower (along with other system components) through a comprehensive maintenance and water treatment program can save time, money, and energy while increasing the cooling tower's life expectancy. Owners and operators with a working knowledge of cooling tower preventive maintenance and upgrade technology can also take advantage of cost-saving ideas and procedures,[8] such as replacement fill kits or the more energy efficient operating sequences described earlier. Be sure to refer to the cooling tower's operating and maintenance manual for the appropriate maintenance requirements and service intervals. In addition, the article on cooling tower maintenance in the Bibliography is a good source of best practices that can be used to keep your cooling towers operating at peak efficiency.

Conclusion

Water-cooled systems save energy compared to air cooled alternatives for cooling duties. Proper selection, design, operation, and maintenance of evaporative heat rejection equipment used in such systems offer the opportunity to further optimize system energy usage. Evaluating sub-system and system performance, as opposed to the performance of individual system components, is a path to significantly improve overall building performance. This energy saving opportunity will be explored by SSPC 90.1 as the Committee begins development of the 2016 edition of Standard 90.1.

References

1. Path B water cooler chiller per Richard Lord, Carrier Corporation and Vice Chair, SSPC 90.1.
2. Taylor, S. 2011. "Optimizing Design and Control of Chilled Water Systems—Part 2: Condenser Water System Design" *ASHRAE Journal* 53(9):26.
3. Taylor, S. 2012. "Optimizing Design and Control of Chilled Water Systems—Part 4: Chiller & Cooling Tower Selection." *ASHRAE Journal* 54 (4):60.
4. Taylor, S. 2012. "Optimizing Design and Control of Chilled Water Systems—Part 5: Optimized Control Sequences." *ASHRAE Journal* 54(6):56.
5. ANSI/ASHRAE/IES Standard 90.1-2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* Paragraph 6.5.5.2.
6. Copeland, C.C. 2012. "Improving Energy Performance of NYC's Existing Office Buildings." *ASHRAE Journal* 54(8):38.
7. Schwedler, M. 2014. "Effect of Heat Rejection Load and Wet Bulb on Cooling Tower Performance." *ASHRAE Journal* 56(1):16.
8. Babcock, G. 2005. "Because temperature matters: maintaining cooling towers." *ASHRAE Journal* 47(3):51. ■