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Large closed-circuit cooling tower. It combines a heat exchanger and a cooling tower into one relatively compact design.

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Water-cooled HVAC and industrial cooling systems offer many significant benefits over air-cooled cooling systems ó most notably the ability to achieve lower process fluid temperatures and corresponding pressures, resulting in :

1. Lower system energy usage;
2. Smaller equipment size and cost; and
3. Reduced maintenance and extended life of mechanical equipment.

The advantages of evaporative cooling stem from several key factors. First, cooling towers use the ambient wet-bulb temperature of the entering air as the heat sink, which is typically 10°F to 30°F (5.5°C to 16.7°C) lower than the dry bulb, depending on the local climate. The lower the temperature of the heat sink, the more efficient the process.

Second, the evaporative cooling process involves both latent and sensible heat transfer (primarily latent) where a small portion of the recirculating flow is evaporated to cool the

remaining water. For every pound of water evaporated into the airstream, approximately 1,050 Btu of heat is rejected.* In contrast, a pound of air at standard conditions has a heat content of only 0.24 Btu/lb-°F (1.0 kJ/kg-°C), meaning that much greater air volume is required to reject the same heat load in air cooled (sensible only) cooling systems as compared to evaporatively cooled systems. For instance, a typical open cooling tower requires 250 cfm per ton (97 m³/h per kW) of heat rejected while air-cooled condensers, operating at a higher condensing temperature, require 600 to as much as 900 cfm per ton (233 to 349 m³/h per kW) with correspondingly higher fan horsepower (kW).

"Due to water's ability to efficiently transport large quantities of heat over relatively long distances, water-cooled systems allow the economical separation of the compression and heat rejection equipment."

Third, cooling towers allow direct contact between the water and the air, which is a highly efficient process. This mixing occurs in the fill, sometimes called the wet deck, which is typically comprised of sheets of thermoformed plastic. The fill provides a large amount of low-cost surface area for air and water to contact each other.

These reasons combine to explain why evaporative cooling towers are smaller and require much less fan energy than air-cooled equipment. On the system side, water-cooled heat exchangers, such as refrigerant condensers or process units, also have higher overall heat transfer coefficients than their air-cooled counterparts. The system benefits from the lower cooling fluid temperature, which results in lower condensing temperatures and pressures, increasing process output with less energy input. Due to water's ability to efficiently transport large quantities of heat over relatively long distances, water-cooled systems allow the economical separation of the compression and heat rejection equipment. For example, the chiller can be located in a basement machine room and the cooling tower on the roof, many floors above. This typically is not an option with air-cooled systems. Multiple air-cooled systems on the roof, with their duct penetrations, also increase the chance of compromising the roofing system.

** Every pound of water evaporated into the airstream allows the air to carry away approximately 1,050 Btu (1 108 kJ) of energy from the process to be cooled. This value varies slightly with climate.*

Cooling Tower Configurations

A variety of highly efficient cooling tower fills are used to achieve high capacities in the smallest unit footprint possible. Factory-assembled tower designs can be either crossflow, with water falling downward and the air traversing across the fill sheet horizontally, or counterflow, with water flowing downward and air traversing vertically across the fill sheet. Crossflow designs, typically with relatively large fan plenums and externally accessible gravity water distribution systems, offer excellent features in terms of maintenance and access to critical tower components relative to other designs. Counterflow fill towers can offer a smaller footprint than crossflow fill models in the lower tonnage ranges, but tend to be taller than their crossflow counterparts, resulting in increased pump head, which translates to higher pump energy as well as the requirement for taller architectural screens. Counterflow towers also use pressurized spray systems typically not accessible for inspection without shutting down the tower. Larger cell sizes coupled with improved fill designs can produce capacities as high as 1,350 nominal tons (5935 kW) in a single factory-assembled cell. These larger cells shorten tower installation schedules and reduce the uncertainty due to weather, labor issues, etc. associated with field-erected towers.



Crossflow cooling tower installation on sports arena.



Hybrid wet-dry closed-circuit cooling towers.

Closed-circuit cooling towers, typically used on closed-loop systems for water-source heat pumps or air compressor cooling, have evolved significantly. A closed circuit tower, also known as a "fluid cooler," combines a heat exchanger and a cooling tower into one relatively compact design. The fluid to be cooled, usually water or an aqueous glycol solution, is kept clean and contaminant-free in a closed loop, separate from the open loop spray water and airflow on the outside of the coil, or tube bundle. Newer designs, known as "combined-flow" units, significantly improve performance by using an open fill section to lower the spray water temperature compared to coil-only designs. The size of the coil section can be reduced for a given duty, lowering the unit weight and reducing the cost of

the supporting steel. Additionally, most of the evaporation occurs in the fill section of these combined-flow towers, reducing the potential for scale on the coil heat transfer surface.

These advances have improved the functionality of closed circuit towers as well as lowered the point where they can be economically justified over open towers in many applications. For instance, by closing the condenser water loop, condenser tube bundle cleaning can be nearly eliminated while the chiller operates at peak performance at all times. If any fouling and scaling occurs, it does so on the open side of the tower, where it can be easily controlled through a proper water treatment program. The chiller energy savings and reduced maintenance expenses often can offset the higher cost of the closed circuit tower.

Closed circuit towers can offer a hydraulic advantage on certain projects. Open towers must be installed above the heat source, while closed circuit towers can be located below since the process fluid is contained in a closed loop and the spray water recirculates within the tower itself. This flexibility can help solve site location problems for architects and engineers.

Thermal Performance

Independent certification of thermal performance is increasingly required, with most manufacturers participating in the Cooling Technology Institute (CTI) certification program under CTI STD 201 (note that the CTI performance test code is CTI STD 105 for open cooling towers and CTI 105S for closed circuit cooling towers). The California Energy Code, known as Title 24, mandates the use of CTI certified open cooling towers in its 2005 edition (note that no requirements exist for fielderected towers, which are not often used in HVAC applications). This same requirement is being considered for the 2004 edition of the ANSI / ASHRAE / IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, adopted by many building codes in the United States.

As most other components of the system are certified, specifying CTI certification on cooling towers reduces the likelihood, as well as the resultant liability, for deficient towers on a project for the consulting engineer, contractor, and the owner, while also eliminating the need for costly field performance tests.

Thermally deficient cooling towers result in higher energy usage from two perspectives: first, the tower must operate longer at maximum fan horsepower while trying to attain the design cold water temperature, and second, the system (chiller) must consume more energy because it must operate at all times at a higher than necessary

condensing pressure (head) to satisfy the load due to higher fluid temperatures provided by the cooling tower.

Certification is important *because temperature matters*, since even small deviations from the expected design have a substantial impact on the system over time. For instance, a cooling tower that is 20% deficient elevates the leaving water temperature by approximately 2.5°F (1.4°C). Typically, this higher water temperature, will result in 6% more energy being consumed by the chiller. On a 500-ton (2197 kW) system during peak conditions, this 6% penalty translates into approximately 17 kW of additional energy usage, resulting in higher electricity bills for the owner. Furthermore, the cooling tower has to work harder, at all times, not just at peak conditions, to meet the load, adding to the overall energy penalty. A tower that is 20% deficient can cost an owner from three to eight times the original purchase cost of the cooling tower over its operating lifetime in terms of higher total energy costs.¹

Besides the substantial energy penalty, this additional energy consumption imposes an unnecessarily greater load on the electrical grid during the critical peak periods and results in higher demand charges to the owner. Society also pays a price in terms of higher pollution levels resulting from this wasted energy.

CTI certification of closed circuit cooling tower performance often is overlooked, but is equally as important. Because closed-circuit towers often are used on distributed loads such as watersource heat pump loops, the effect of a deficient unit can be masked to the equipment owner. However, the same performance penalties and increased operational costs mentioned earlier exist for thermally deficient closed-circuit towers. For instance, when a water-source heat pump trips due to high head pressure during peak loading, a deficient tower often is to blame, not the heat pump. In addition to the energy advantages, supplying the proper cooling fluid temperatures at all times extends equipment life, in this case by allowing the heat pump compressor to operate at a lower temperature against lower head pressure.

Materials of Construction

Based on historical data, the average life of a cooling tower is estimated at approximately 20 years. Well-maintained towers often can operate well beyond that. Most towers are designed such that airmoving components and heat transfer media can be replaced when necessary, often resulting in higher unit performance as technological advances occur in the industry. The key to longevity is keeping the base structure of the tower usable,

especially the cold water basin, so both the original choice of materials and a regular maintenance and water treatment program are crucial to maximizing tower life.

The most cost-effective material of construction for towers today is G-235** hot dip galvanized steel, from both a structural and corrosion resistance standpoint. G-235 is the heaviest mill galvanizing commercially available, and offers a substantial amount of protection as compared to the lighter zinc thicknesses in use several decades ago, providing reliable corrosion protection for most HVAC and industrial system water chemistries. The most common upgrade from G-235 galvanized steel is Type 304 stainless steel. Parts that are submerged during operation and/or at shutdown can benefit the most by upgrading to stainless steel.

Critical components, such as cold-water basins, often use either stainless steel, plastic, or coated metals to add to longevity and/or guard against upsets in cooling water chemistry. Plastic basins generally are limited to small towers for structural reasons, while stainless steel basins can be used on all sizes. Some manufacturers weld the seams on stainless basins for improved leak resistance. Corrosion-resistant plastic or composites are used in the spray water distribution systems where possible on both open and closed circuit towers. Light-weight, corrosion-resistant fiberglass reinforced polyester (FRP) also is popular for casing panels for corrosion resistance and lighter weight.

*** Note that the G-235 designation refers to 2.35 ounces of zinc per square foot (717 g per m²) of the steel sheet.*

Energy-Efficient Fan Systems

The market has moved from centrifugal fans in favor of lower energy axial fans, reducing horsepower by 50% or more for the same capacity. This push for efficiency has been driven by the rising cost of energy and the impact of energy codes. For instance, Title 24 in California is restricting centrifugal fan cooling towers more than 300 cooling tower tons (1319 kW heat rejection) in the prescriptive approach to compliance, allowing their use only where ducted installations are required, sound requirements predominate, or when oversized to the point where they meet the energy requirements of axial fan towers.

These new codes require that any fan motor greater than 7.5 hp (5.6 kW) use a means of reducing power consumption at off peak loads and/ or lower ambient temperatures. Variable frequency drives (VFDs) are typically used to meet this requirement in cooling towers. VFDs also eliminate the need for motor starters, helping to offset the cost of the drives. Lower horsepower pony motors, usually sized for one-third of the horsepower of

the primary motor, also can be used. This method is an advantage when motor redundancy is desired to increase system reliability.

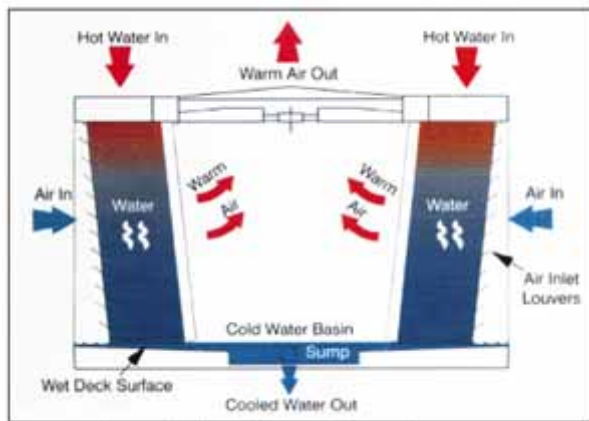


Figure 1 : A typical crossflow cooling tower.

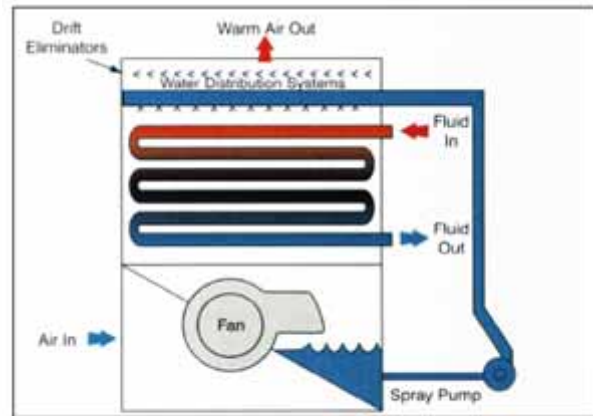


Figure 2 : A typical forced draft counterflow centrifugal fan cooling tower.

Cooling tower fan systems also have evolved to meet the stringent sound requirements found on many projects. This is discussed in greater detail in the next section.

Sound

Sound is an important issue on many projects. To meet the dual requirements of low energy use and quiet operation, the industry has responded with a variety of solutions. The simplest methods include proper site selection and oversizing of the tower to reduce fan speed. For example, a tower with a single-side air entry can be oriented such that the air entry side is directed away from the sound sensitive area. Physically oversizing the tower can reduce the fan speed required for a given thermal duty, reducing the sound level, as sound is proportional to fan speed. The fan horsepower also is reduced, providing an energy benefit to offset the higher first cost.

When these techniques are not sufficient to meet sound requirements, a variety of low sound, high-efficiency axial fans are available. These fans use wider chord fan blades and/or more fan blades to allow the fan to move the required air at a slower rotational speed, thus lowering the sound level. Attenuation packages are available when very low sound levels are required for a critical site. The cost of sound attenuation, including the effect on performance, must be evaluated vs. simpler methods such as oversizing the tower to meet the sound criteria for a project. Note that with either low-sound fans or attenuation, lower sound levels often come at the expense of lower airflow. The system designer must ensure that the manufacturer's ratings are adjusted to account for any decrease in thermal performance from this reduction in airflow, and verify that the ratings

with the low sound fans and/or attenuation are CTI certified as may be required by the applicable energy codes.

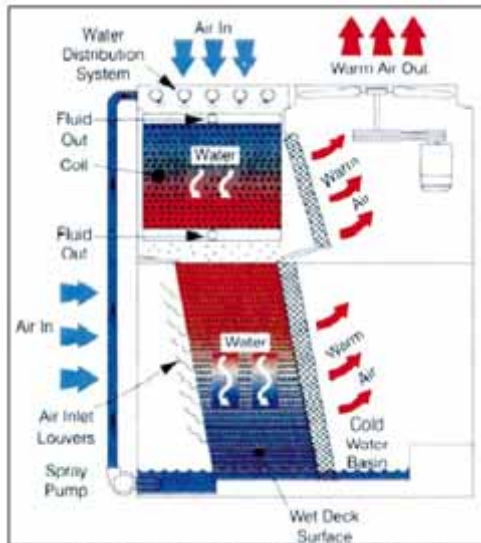


Figure 3 : A typical coil / fill (combined flow) closed circuit cooling tower.

VFDs also can be used to provide sound control. In most cases, the steady sound of an efficient cooling tower fan is not objectionable, and tends to blend in with other background noise. What people find objectionable is the abrupt stopping and starting of the fan system. Properly setting the tower control sequence to avoid excessive cycling of fan motors is important in this regard, as well as to protect the motors from overheating. VFDs solve this issue by allowing a soft start of the fans, followed by a gentle ramping up and down of the fan speed in line with the load requirement. Soft-starters also can be used to eliminate startup noise. However, these devices do not provide the close capacity control and energy savings of VFDs, which can justify the additional cost of a VFD. Overall, the energy savings coupled with reduced stress on the motor and belts are an added bonus, while providing compliance with the energy codes.

Sound requirements often can be more stringent during evening hours, especially for facilities near residential areas. As the wet-bulb and heat load also are typically lower at that time, a tower holding a fixed leaving water temperature with a VFD is able to operate at reduced fan speeds, lowering the sound during these critical hours. This advantage is offset when the chiller can benefit by allowing the leaving water temperature to fall with wet bulb, reducing head pressure and thus chiller energy consumption, but requiring the tower to operate at a higher fan speed.

Water Issues

Cooling towers originally were used to replace wasteful "once-through" systems, saving approximately 95% of the water by recycling the water. Water use in a cooling tower is tied to two factors: the heat rejection load and the blowdown rate, which is the amount of water that is discharged to prevent the accumulation of solids in the cooling water. The evaporation due to the heat load is approximately 1,050 Btu/lb (2442 kJ/kg) of water, as mentioned earlier. The blowdown rate determines the water chemistry, or cycles of concentration, of the recirculating water, and can vary depending on makeup water quality, the treatment program, and the tower's construction materials. A subtle point often overlooked is that water used in evaporative cooling is eventually returned to the environment either through evaporation or blowdown, vs. other natural resources, such as oil or natural gas, that are consumed when used.

The cost and availability of water in North America is becoming an increasingly important issue, though one that is often misinterpreted when it comes to cooling towers. Infrastructure upgrades to comply with U. S. federal water standards, replace aging systems around the country, and meet the growth in population are leading water utilities to recover these investments through higher rates, though these increases are to relatively low base rates. Recent droughts in some areas have increased awareness. The growing trend towards privatization of water systems provides greater economies of scale and more rapid application of new technologies in the industry, helping to temper the need for increases in water rates.

Even with recent increases, the additional power cost associated with air-cooled equipment far outweighs the cost of water in a typical commercial building or process plant. Interestingly, on a macro-basis, air-cooled systems often can use as much or more water than a watercooled system. This is because aircooled systems consume 30% to 40% more power than water-cooled systems, and one of the largest users of water in the country is power generation. Latest figures from the United States Geological Survey (USGS) show the average water use for power generation is 26 gallons (98 L) per kWh. Thus, society pays for water use either at the power plant or the local level. Coupled with the environmental aspects of power generation and transmission line losses, conserving energy at the point of use makes sense.

Cooling tower water usage is a relatively small component of overall water usage in a typical commercial building, averaging between 20% and 30%, after domestic (sinks, lavatories, etc.) and landscape use. A cooling tower rejecting a 400-ton (1759 kW heat rejection) load at typical HVAC conditions will evaporate approximately 12 gpm, or 720

gph (0.75 L/s) at peak load. Applying a typical load factor of 50% to the system (average load divided by peak capacity) for 12 operating hours per day, results in 4,320 gallons/day (16,353 L/day) that is evaporated on an average day. Adding in 1,440 gallons/ day (5451 L/day) for blowdown at a typical four cycles of concentration gives a total usage of 5,760 gallons/ day (21,804 L/day). Based on a typical water rate of \$1.50/1,000 gallons (\$0.6/1000 L),* this water costs the building owner about \$9 per day, or a fraction of the electricity costs associated with the cooling system, even after including sewage and water treatment chemical costs.

Several low-cost methods can reduce cooling tower water consumption. The first is to set a proper bleed rate for the tower. As the evaporation rate is dependent on the load, which can vary widely, a constant bleed rate usually discharges more water than required. While this tends to improve the tower's water chemistry, higher water and sewage bills result. A properly operating conductivity meter can automatically control bleed to the proper amount required to maintain the desired tower chemistry in the system at all times. Because of their advantages, water utilities, such as the San Diego County Water Authority and the Contra Costa Water District in California, offer rebates of as much as \$500 towards the installation of conductivity meters to control bleed rates.

Also of importance to the owner is the sewage charge for the tower bleed rate, which often equals or exceeds the water charge. As shown in the example, only a portion of the water (25%) metered into the unit is actually discharged into the sewer as blowdown. To account for this, many utilities allow owners to meter their blowdown separately, rather than use the full water reading as the sewer reading. The user only pays for what actually goes down the sewer, significantly reducing the sewage charge, offset by any metering fee charged by the utility.

+ Cycles of concentration (COC) is defined as the ratio of the concentration of dissolved solids (i.e., chlorides, sulfates, etc.) in the recirculating water to the concentration found in the entering makeup water. The higher the COC, the lower the bleed rate required.

** Note that this rate can vary widely from locality to locality. Local water (and often sewer) rates can be found on the Web sites of most local water utilities.*

Hybrid Wet-Dry Cooling Towers

While properly controlling the bleed rate and installing a separate blowdown meter are simple, high-return investments, other technologies exist for projects where water is expensive or in short supply. These new designs combine wet and dry cooling to reduce

water use, some as much as 70% compared to conventional towers. Typically, a dry finned coil section is combined in series with an evaporative section in these units. The dry finned section handles as much of the load as possible, with the unit able to operate completely dry at reduced ambient. Both open and closed circuit versions are available. Manufacturers of these designs can assist in the payback analysis to determine if such units are justified for a particular project, comparing the higher energy requirements of air-cooled equipment vs. the cost of water and energy for the hybrid design. Rebates for hybrid equipment also are available from some water utilities and can help offset the higher first cost.

These designs also have the added benefit of reducing or even eliminating the visible, fog-like exhaust air discharge, also known as plume, from the tower under most operating conditions. This is accomplished by reducing the amount of water evaporated into the discharge airstream while simultaneously reheating the discharge air with the incoming warm fluid. Plume is eliminated completely in the dry mode, which is operational during colder weather when plume is most likely to occur.

Water Treatment

The large variety of alternative construction materials allows users to match unit construction to the water quality available for their systems, while helping to protect the tower from temporary upsets. Water treatment programs must be designed for three requirements:

1. Scale control;
2. Protection of system components against corrosion; and
3. Control of biological contaminants, such as *Legionella pneumophila*, the bacterium that causes Legionnaires' disease.

The first two requirements help to ensure energy efficiency and longevity of the cooling system, while the third ensures safe operation.

Biological control is relatively easy to accomplish and is essential to the safe operation of the tower. ASHRAE has published Guideline 12-2000, *Minimizing the Risk of Legionellosis Associated with Building Water Systems*.

Traditional chemical water treatment has adapted to changes in the industry, developing new environmentfriendly treatment chemicals and control solutions. Electronic water treatment systems have grown in use as equipment owners seek ways to reduce

water treatment chemical costs and storage issues, as well as minimize the amount of maintenance required. However, the long-term effectiveness of these systems has not been established. A 2002 ASHRAE research study² found that these devices can work under the proper parameters for controlling scale accumulation. Claims of biological control of these devices have yet to be established by a formal study, and close monitoring of both the tower water chemistry and biological counts is prudent when using these devices. Ozone systems, using modern technology to maintain proper ozone level in the system, also are used to control biological activity. However, their relatively high first cost limits their use.

Last, cooling towers can collect and concentrate airborne dirt and debris over time. To control this buildup, the cooling tower should be located so as to minimize contaminant induction and a proper blowdown rate should be maintained. Sidestream filters or separators have proven valuable in this regard by effectively removing dirt and debris from the tower water. These devices are coupled with a basin-sweeping nozzle package, which is available either as original equipment in the tower or as a field-installed aftermarket item. Cleaner tower water makes water treatment regimens more effective while keeping the cooling loop cleaner, saving energy, reducing maintenance, and improving reliability of the entire cooling system.

Conclusion

Evaporative water-cooled systems, whether open or closed-circuit, are the best overall heat rejection solution for most installations. These systems offer design flexibility, save energy, and conserve resources while protecting and respecting the environment. The cooling tower industry continues to develop innovative products and services to meet the evolving needs of new and existing facilities.

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