Cooling Tower Efficiency Guide Property Managers

IMPROVING COOLING TOWER OPERATIONS

How to Use This Guide

This guide is structured in two Parts. Part I outlines the steps necessary to improve cooling tower operations including a simple checklist for easy reference. Part II provides more detailed information and reference material. While Part I can be used as a standalone document, the reader is encouraged to read the entire document to ensure understanding of the material and refer to Part II as needed.

Revision Date: March 2013

Contents

PART I

Purpose and Scope

This guide has been developed to assist facility managers with the operation of their cooling tower systems and to improve their understanding of the water/energy nexus with the goal of reducing energy, water and chemical consumption of the cooling systems through improved operations. By reinforcing strong operational practices, introducing new concepts and raising overall awareness of cooling tower operations, it is expected that a system will more likely be operated at or near peak efficiency.

Background

This guide leverages existing approved methods and procedures and best practices used today. It is based on AT&T's approach and incorporates learning from the company's collaboration with Environmental Defense Fund examining water use in cooling towers.

This guide is best used alongside other corporate standards from groups such as Environmental, Health and Safety, Design and Construction and Maintenance.

The goals of the property manager with respect to cooling tower operations should be to:

1. Protect the health and safety of building occupants and technical personnel as related to the treatment of water and the handling of associated chemicals.
2. Maximize the efficiency of HVAC equipment.
3. Protect equipment from scale, corrosion, and deleterious micro-bio activity such that cleaning and repairs of equipment due to water problems are not required.

Achieving these goals will save energy, water, chemicals and costs while improving sustainability by reducing consumption of scarce resources.

Cooling Tower Operations Checklist

Optimal cooling tower operations can most successfully be achieved if the following steps are followed:

1. **Determine makeup water quality** – Obtain from your municipality or work with your water treatment vendor to determine makeup water quality. This will enable the establishment of target Cycles of Concentration (COC).
2. **Establish target Cycles of Concentration (COC)** – Based on makeup water quality, set a practical COC goal using the Target Cycles of Concentration.
3. **Monitor COC and water performance frequently** – Keeping the system running at peak COCs while staying within water performance levels will maximize efficiency and protect equipment.
4. **Automate where possible** - Utilize automated monitoring and alarms when available and cost effective. Implement direct chemical feeds at the makeup distribution. Enable BMS logging.
5. **Protect the equipment** – Adhere to all regular maintenance schedules. Utilize coupon racks, Eddy Current testing and other methods to ensure no corrosion, scale buildup or bio-fouling is occurring.
6. **Engage your vendor** – Work with your water treatment vendor to ensure the system is being maintained within all control limits and each step above is being performed.
7. **Share your success**

PART II

Cooling Water Systems

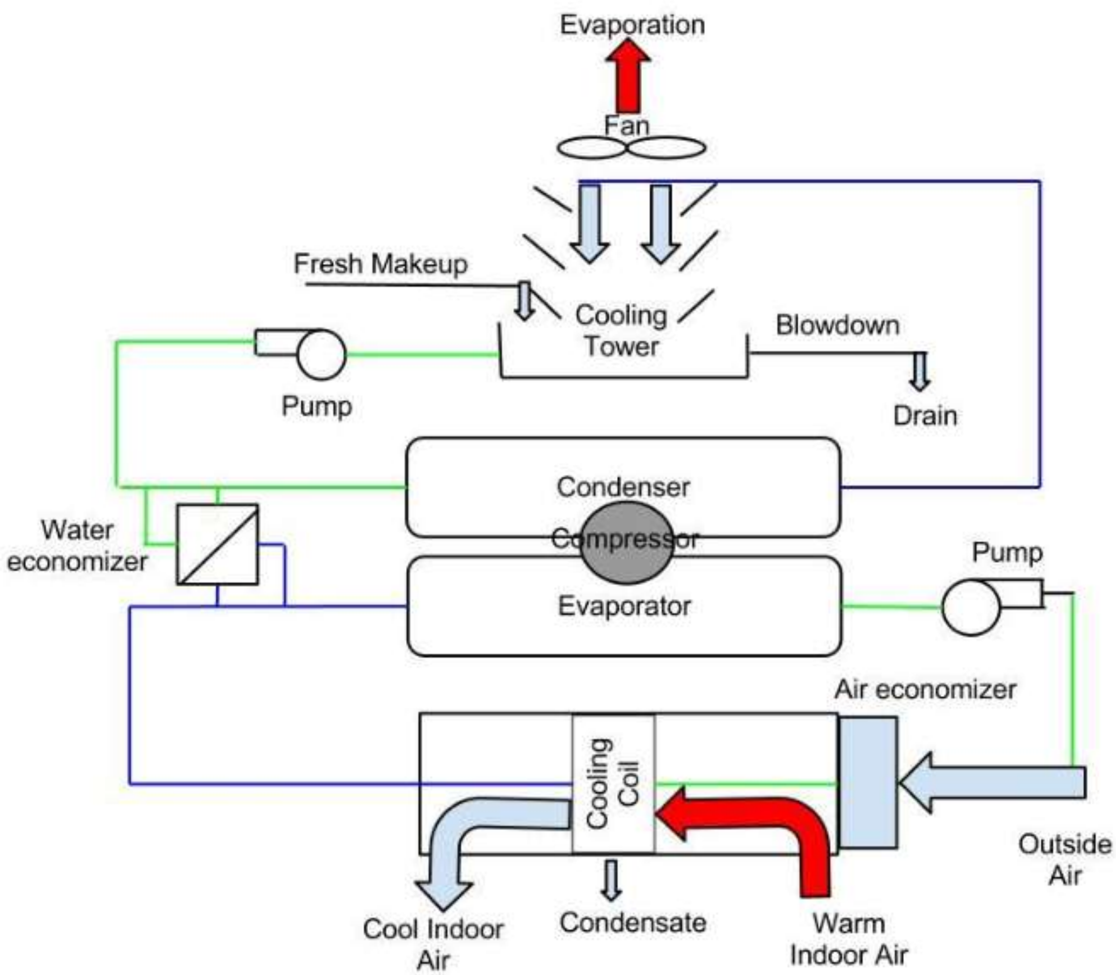


Illustration of a typical HVAC cooling water system
Source: Harfst & Associates, Inc.

Typical Cooling Towers

The purpose of a cooling tower is to conserve water by recycling it through the chilled condenser. Cooling towers used in HVAC service are commonly induced draft design where the fan is located on the top of the tower. The air flow is typically directed across the water flow, but counter-flow designs are also prevalent.

Components

Basin

The basin is located under the tower fill. It is used to collect and hold cold water. It is also where fresh makeup is added to replace losses due to evaporation and blowdown.

Fill

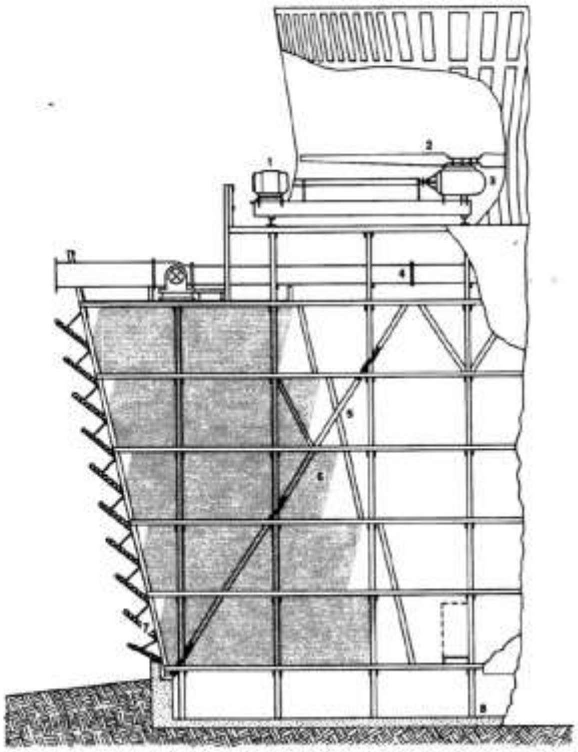
This is the internal section of the tower where the water flow is broken up into droplets or thin films. This maximizes the surface area of the water that comes into contact with the air. Two types of fill are common; (1) splash fill and (2) film fill. Splash fill consists of bars or slats that break the water flow into droplets. Film fill is a compact plastic, honeycomb-like material that creates a large surface area to optimize cooling efficiency. Film fill is more prone to fouling with suspended solids and other debris.

Distribution and Fan Deck

Water is distributed over the fill by sprays, ports or v-notch weirs located near the top of the tower. The fan deck supports the motor and fan. The stack is cylinder-shaped structure that directs the air flow up and away from the tower.

Cell

This represents an independent unit of the tower operation that is handled by a single fan. A mid-wall is installed to separate the tower into individual cells. Thus a tower is often described as one-cell, two-cell, three-cell, etc.



1 **Electric motor** drives cooling tower fan.

2 **Fan blades** move air through the cooling tower to remove heat by evaporation and sensible heat removal.

3 **Speed reducer** converts the high rpm, horizontal rotation of the drive shaft into the vertical, low rpm motion of the fan shaft.

4 **Header pipe** distributes cooling water to the top of the tower deck.

5 **Interior supports** provide structural strength to the cooling tower.

6 **Fill** is made of corrugated plastic or splash bars to break water flow into thin films or small droplets for enhanced efficiency.

7 **Louvers and casing** eliminate splash out and reduce windage losses.

8 **Cold water basin** collects the cooled water for distribution by the cooling water pumps.

Source: Power Special Report, "Cooling Towers", March 1973

Measuring Performance

Operation

In order to be able to effectively measure your system's overall performance it is important to first determine how many cooling ton-hours it handles on a periodic basis. The concept of a cooling ton-hour is similar to that of a kilowatt-hour, it is one ton of cooling provided for one hour of time. To calculate cooling ton-hours, you need to know the cooling capacity of your system as well as its utilization profile.

Knowing how many cooling ton-hours your system handles enables you to quantify water, energy and chemical use on a per cooling ton-hour basis. This makes it easier to compare system performance across different sites.

Furthermore, cooling ton-hours can be used to help quantify overall building cooling efficiency when examining the use of chillers, air-side economizers and water-side economizers.

Capacity

Cooling towers are usually described by their tons of cooling capacity. The cooling capacity indicates the rate at which the cooling tower can transfer heat.

One ton of cooling is equal to the removal of 12,000 BTUs (British thermal units) per hour from water.

Cooling tower capacities at commercial or industrial facilities may range from as few as 50 tons to 1,000 tons or more. Larger facilities may be equipped with multiple cooling towers.

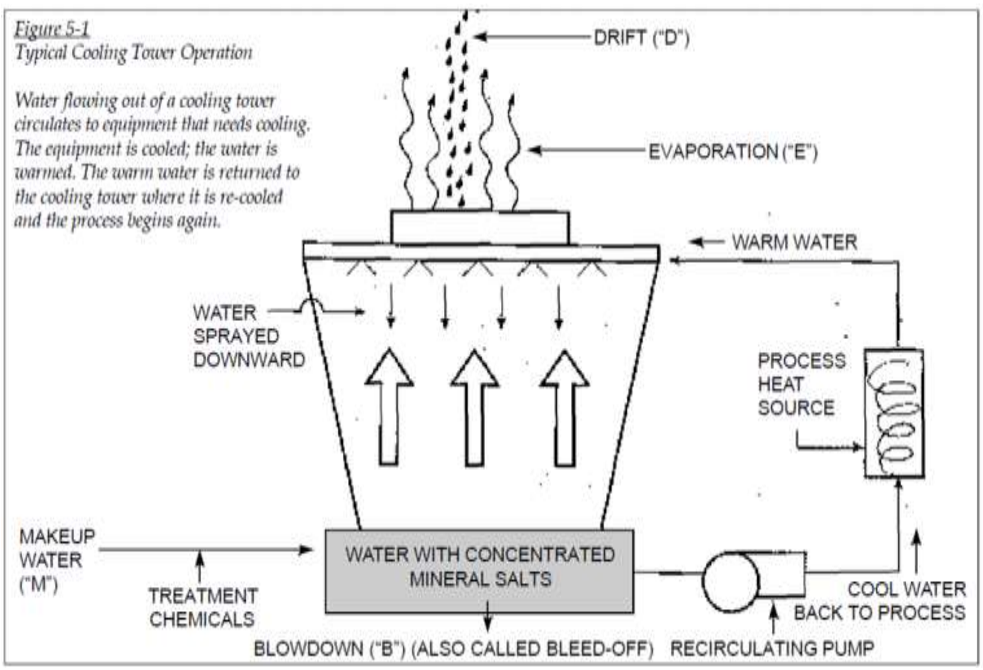
Utilization

Not all cooling towers operate at full capacity year-round. Therefore, it may be necessary to determine the utilization profile of your system. This involves identifying how much of your system's total cooling capacity is utilized and how often to arrive at an annual number of cooling ton-hours.

For example, suppose a site has two 500-ton cooling towers that it operates 5 days per week for 20 hours per day. The site operates its towers at 100% capacity in the summer, 75% in spring and autumn and 50% in winter. If we assume 13 weeks per season, this equates to 1.3 million cooling ton-hours in the summer (13 weeks x 5 days/week x 20 hours/day x 1,000 tons of total cooling capacity x 100% utilization), 975,000 cooling ton-hours in the spring and autumn and 650,000 cooling ton hours in winter. This adds up to an annual total of 3.9 million cooling ton-hours.

How Water is used in a Cooling Tower System

The diagram below illustrates water use in a cooling tower system.



Source: "A Water Conservation Guide for Commercial, Institutional and Industrial Users" – New Mexico Office of the State Engineer, 1999

The purpose of a cooling tower is to conserve water by recycling it through the chiller condenser. The tower achieves its purpose by transferring heat from the cooling water to the air by evaporative and convective heat transfer.

Cooling towers usually cool circulated water by 10°F in air conditioning systems and up to 15°F to 30°F in power plants and manufacturing facilities such as electronics, chemical plants, etc. The temperature differential across the tower is termed "range."

Cooling towers cannot reduce the water temperature to below the ambient wet bulb temperature of the outside air. Wet bulb temperatures are a function of the dry bulb temperature and dew point. The resultant wet bulb can be determined from a Psychrometric Chart or from calculations performed by a local weather station. Cooling towers are rated by how close they can get to the wet bulb temperature. This is termed the "approach." For example, a cooling tower with a 7°F approach is capable of reducing the supply water temperature to within 7 degrees of the wet bulb.

Most chillers are designed to operate at a cooling water supply temperature of 85°F with a 95°F return temperature to the cooling tower. However, lower cooling water supply temperatures improve chiller efficiency by 1% to 2% for every 1°F decrease in supply temperature. Conversely, chiller efficiency is adversely affected for every 1°F increase in supply temperatures. Consult the chiller manufacturer to determine the design range for the condenser water supply temperature.

Relationship between Makeup, Blowdown, Evaporation and Drift

Makeup = Blowdown + Evaporation + Drift (a handy mnemonic: "Make the BED")

There are several different methods to calculate water use in a cooling tower. However, any reasonable method must be able to identify the amount of makeup water as well as the amount of water lost to blowdown and evaporation. Drift losses are usually assumed to be minimal.

The easiest way to measure makeup and blowdown water is to install meters in the appropriate locations. Then, using the equation above, the amount of water lost to evaporation can be calculated as the difference between makeup and blowdown. In the absence of water meters, the following sections outline how you can estimate makeup, blowdown and evaporation rates.

All water use should ideally be measured in gallons per hour in order to provide a comparable level of granularity to energy use, which is usually measured in kilowatt-hours.

Evaporation

As a rule of thumb, for each 10°F drop in temperature across the tower, one percent of the recirculated cooling water is evaporated into the atmosphere. If the recirculation flow rate of the cooling water is not known, assume a rate of 3 gallons per minute per ton of cooling with a 10°F temperature differential.

Evaporation, gpm = (0.001) X Recirculated Flow Rate, gpm X Temperature Differential (°F) X Evaporative cooling factor (f)

Not all of the temperature drop across the tower is due to evaporative cooling. Depending on outside temperature and humidity conditions, some of the cooling is due to convective heat transfer. This is caused by the physical contact of the colder air with the warmer water. If the air temperature is warmer than the water, essentially all cooling is evaporative and the "f" factor is 1.0. In the winter, however, when air temperatures are low, more convective cooling takes place. As a general rule of thumb, an annual average "f" factor is 0.70 to 0.80. This says that, on average, 70 to 80% of the cooling that takes place in a cooling tower is evaporative with 20 to 30% convective.

Blowdown or Bleed

All water sources contain various levels of dissolved or suspended solids. When water evaporates from the cooling tower, these solids are left behind, causing the solids remaining in the bulk cooling water to become more concentrated. If this is allowed to continue without limit, eventually the solubility of the dissolved solids is exceeded resulting in the formation of mineral scale and sludge deposits in the chiller condenser, tower fill and basin.

Concentrated solids can build up in the form of scale, causing blockages and corrosion to the cooling system materials. Also, multiplication of algae and other biological matter can lead to corrosion, plugging of film fill and eventually collapse of film fill.

Over-concentration of the dissolved and suspended solids is controlled by tower blowdown (aka bleed). A controlled flow of concentrated cooling water is sent to drain in order to removed these solids from the system. This is termed blowdown or bleed.

The blowdown rate, as measured in gallons per hour or gallons per minute, controls the concentration of dissolved solids and suspended solids in the system. Increasing the blowdown rate decreases the solids. Decreasing the blowdown rate increases the solids.

Blowdown is best measured by a water meter appropriately installed in the line. However, if no meter is available, the blowdown rate can be estimated from the relationship between blowdown and cycles of concentration as indicated by the following formula and as discussed in a following section.

$$\text{Blowdown} = \frac{\text{Evaporation}}{(\text{Cycles} - 1)}$$

Makeup

Water that is lost from the cooling tower by evaporation and bleed must be replaced with fresh source water. Otherwise, the tower would go dry. As discussed previously, water lost by evaporation can be calculated from the recirculation rate, temperature range (dT), and evaporative cooling factor. The blowdown can be determined from meter readings or by calculation.

The best method to monitor the cooling tower makeup demand is to meter it. Cooling towers should be equipped with water meters on the makeup and blowdown lines.

The following equation expresses the relationship between makeup, blowdown and evaporation.

Makeup Volume = Blowdown Volume + Evaporation Volume

Cycles of Concentration

Cycles of concentration (COC) refers to the concentration ratio between the makeup and the blowdown. This can be determined by the calculation of the ratio between the makeup volume (gallons) and the bleed volume (gallons). Or it can be expressed as the ratio between the dissolved solids in the cooling water to the dissolved solids in the makeup. Either method should produce the same result (+/- 10%). For example, when the solids concentration in the cooling tower has doubled or tripled its concentration over that in the makeup water, then there are two or three cycles of concentration.

Most cooling towers operate within a COC range of 3 to 10. Three cycles is generally considered as minimum efficiency whereas 10 cycles is considered good efficiency. Operating cooling towers as once-through systems, i.e. 1 cycle of concentration, represents very poor efficiency and is prohibited in many areas because of the large volume of water this consumes.

The conductivity (micromhos/cm) of the cooling water and makeup are commonly used to determine the cycles of concentration.

$$\text{COC} = \frac{\text{Bleed, micromhos/cm}}{\text{Makeup, micromhos/cm}}$$

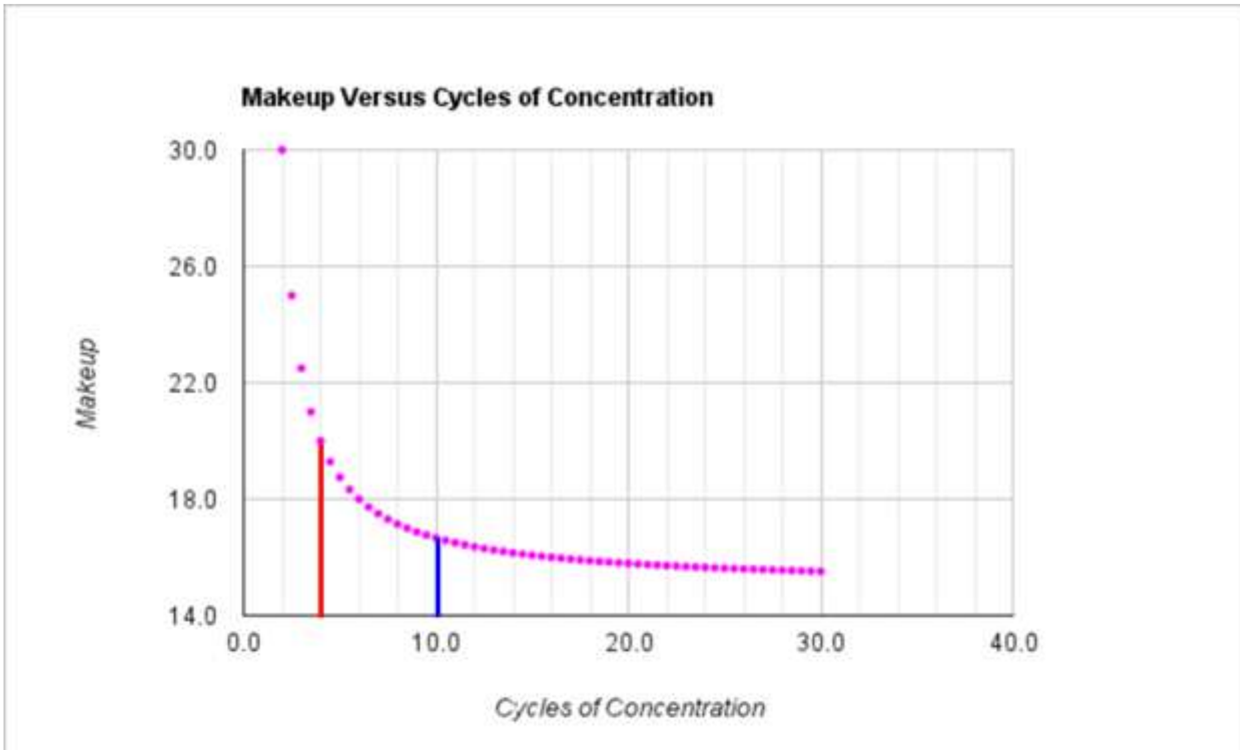
You can also estimate COC using other water data such as magnesium hardness, chloride or sulfate. Note that calcium hardness is not always a dependable indicator of COC since calcium salts tend to precipitate if over-concentrated.

In addition, you can determine COC by calculating the ratio between the makeup volume and the bleed volume. This is easily done if the cooling tower has meters on the makeup and bleed lines.

Cycles of Concentration = Makeup Volume ÷ Blowdown Volume

Relationship Between Cycles of Concentration and Makeup Demand

Makeup demand and COC are related to the temperature drop across the tower and the recirculation rate. As indicated in the following graph, the fresh source water demand decreases rapidly as the COC increases to 5. As the cycles increase above 10, the incremental reductions in makeup demand decrease, but at a much slower rate. However, maximizing cycles of concentration conserves water and reduces the amount of water treatment chemicals required.



Source: Harfst & Associates, Inc.

Relationship between Cycles of Concentration, Evaporation and Blowdown

Blowdown is required to control the cycles of concentration. The blowdown flow is sent to drain and thus, in addition to evaporation, represents a major water loss from the system. Increasing the blowdown rate decreases COC. Decreasing the blowdown increases COC. The objective for achieving optimum cooling tower efficiency is to operate at maximum COC and minimum blowdown. This is expressed in the following equation.

$$\text{Blowdown} = \frac{\text{Evaporation}}{(\text{Cycles} - 1)}$$

Determining Maximum Cycles of Concentration

The makeup water chemistry largely determines the maximum cycles of concentration permissible in a cooling water system. Certain salts, like calcium and magnesium, have limited solubility at higher COC. These are the impurities that are most likely to form scale deposits and insoluble sludge in the chiller condenser and cooling tower. Four (4) mineral salts play the biggest role in limiting the maximum COC. Other limiting factors may exist, but preventing scale deposits caused by these impurities is the biggest challenge faced by cooling tower operators.

- Calcium carbonate
- Calcium phosphate
- Calcium sulfate
- Silica

The objective is to set the cycles of concentration such that the solubility limit of these salts is not exceeded. To keep these salts from depositing in the system, the COC must be maintained at a level at or below the lowest COC calculated for calcium carbonate, calcium phosphate, calcium sulfate and silica. The Cycles of Concentration Estimator Tool will help you determine the maximum permissible cycles based on the makeup water chemistry.

Note that 3 of the 4 salts contain calcium. By softening the makeup to remove calcium and magnesium hardness (water hardness), the limitation on COC imposed by this impurity is removed. This permits the operation of the cooling system at much higher COC than otherwise possible when using raw, unsoftened source water.

As mentioned previously, a typical efficiency goal is to operate the cooling tower at 10 cycles of concentration without unwanted mineral scale deposits and sludge. Many cooling towers operate in the 5 to 7 COC range, but this can often be increased to 10 or more resulting in a savings in water and chemical consumption.

Water Treatment Requirements

Cooling tower efficiency can be enhanced by the addition of certain water treatment chemicals to increase the solubility of calcium salts, mitigate corrosion, minimize fouling and control the growth of microbiological organisms like algae, bacteria, mold and fungi. The list of water treatment chemicals, equipment and non-chemical devices is extensive. The following is a review of the more common water treatment methods for improving the efficiency of cooling towers.

Chemicals

Open recirculating cooling systems may require the addition of several types of chemicals to minimize corrosion, scaling and fouling. The chemicals are added in proportion to the cooling tower makeup. The chemical dosage is generally expressed as parts per million of the product in the recirculating cooling water or blowdown. (Blowdown chemistry is the same as the cooling water chemistry.) The dosages for cooling water chemicals generally fall within the 50 ppm to 300 ppm range. Remember that if the chemical is added to the makeup, its concentration increases in the cooling tower by a factor equal to the cycles of concentration. For example, 20 ppm of chemical in the tower makeup concentrates to 120 ppm in the cooling tower at 6 cycles of concentration. If the tower operates at 10 COC, only 12 ppm of chemical (40% less) is required in the makeup to produce the same 120 ppm dosage in the cooling water. Hence, higher COC reduces chemical consumption.

The list below can be used to help classify chemical volumes and costs into different buckets. Doing so makes it easier to understand how much money is being spent on chemicals to treat a specific problem such as corrosion or scale.

Scale Inhibitors

Scale inhibitors work in one of two ways. Either the chemical keeps the scale-forming impurity in solution or it allows it to precipitate as a non-adherent sludge that can be removed by filtration or blowdown. These are the typical sparingly-soluble calcium salts mentioned previously.

Solubility Method: This is the most common water treatment approach. It is achieved by either adding a chemical scale inhibitor such as phosphonate or polymer to increase the solubility of calcium salts or by the addition of acid to reduce the carbonate alkalinity and control the pH. However, because of the safety hazard associated with storing, handling and applying strong acids, this approach is less popular than the non-acid scale inhibitor method.

Precipitation Method: This treatment option allows the scale-forming impurities to precipitate as a sludge that can be removed by filtration or blowdown. Polymers are used to keep the sludge fluid and dispersed for easier removal from the system. The key to success with this method includes making sure that the solids removal system, such as filters, are maintained in proper working order.
Various chemical additives are used to prevent or minimize scale deposition. Phosphonates such as PBTC, HEDP and AMP are commonly used to increase the solubility of calcium salts and thus permit the operation of the cooling tower at higher cycles of concentration. The use of phosphonates in the absence of calcium, as when soft water is used as makeup, is unnecessary and can increase the corrosion of steel and copper.

Softeners

Water softeners are a mechanical means of preventing scale deposition in cooling towers and heat exchangers. Softeners function by pre-treating the cooling tower makeup to remove calcium and magnesium hardness. Calcium and magnesium hardness in the makeup is removed as the water passes through the softening system. The low-solubility calcium and magnesium ions are exchanged for sodium, which is very soluble. This process removes the limitations on cycles of concentration imposed by calcium. Softeners also eliminate the need for chemical scale inhibitors.

Softeners have a limited exchange capacity for hardness. The softener must be periodically regenerated with salt to restore the softening capacity. During this procedure the ion exchange resin is backwashed to remove dirt and debris, regenerated with salt (NaCl) brine, slow rinsed and then fast rinsed before being returned to service. Since the spent brine and rinse water is sent to drain, it is important that the softener be regenerated as efficiently as possible to minimize source water withdrawals and wastewater discharge.

Corrosion Inhibitors

Corrosion is best described as a reaction between a metal and its environment. Various forms of chemical and mechanical corrosion have been identified in cooling water systems. These include:

Galvanic corrosion: This is the corrosion of two dissimilar metals that are coupled together in a water environment.

General corrosion: This is the uniform corrosion of metal surfaces that results in metal thinning.

Under-deposit corrosion: This is the localized corrosion that can occur under any type of deposit on the metal surface.

Crevice corrosion: This term applies to corrosion that occurs in a slight separation between two pieces of metal such as when two plates have been bolted together.

Microbiologically influenced corrosion (MIC): Microbiological deposits and slimes can create an environment that is corrosive to steel and other metals. The organisms produce acids as a by-product of their metabolism. The acids are very corrosive and attack the metal.

Erosion corrosion: Water moving at high velocity or water that contains suspended solids can physically wear away the metal surface. This generally reveals itself as thinning of the metal at bends in the piping system or at other points where the water flow accelerates over the metal.

A corrosion inhibitor is any substance which effectively decreases the corrosion rate when added to a water environment. An inhibitor can be identified most accurately in relation to its function: removal of the corrosive substance, passivation, precipitation or adsorption.

Two common methods for controlling the corrosion rate in cooling water systems are used. In the first method, various chemical corrosion inhibitors are available that promote the formation of a passive film on the metal surface such as phosphate, polysilicate and yellow metal inhibitors like azoles.

The other method is to maintain the cooling water pH above 8.5 by allowing the cooling tower to build COC and thereby increase the bicarbonate and carbonate alkalinity. Alkalinity promotes the formation of a passive (less prone to corrosion) metal surface on steel, copper and stainless steel.

Maintaining a high pH/high alkalinity environment serves as a natural bacteriostat, which helps to control microbiologically influenced corrosion (MIC).

Antimicrobials

Biocides are added to water to protect the cooling tower and heat exchangers against biological infestation and growth. Cooling tower users frequently apply biocides to the circulating cooling water to control the growth of microorganisms and algae.

Microbiological organisms fall into three general categories; algae, bacteria and fungus. Algae are more plant-like in that they use sunlight and green chlorophyll for their metabolism. Bacteria are more animal-like in that they use nutrients in the water for their energy.

Bacteria are also classified by how they use oxygen. Aerobic organisms, just like humans, require oxygen for their survival. Anaerobic organisms, however, live in the absence of oxygen. Fungus and molds live off dead organic materials such as the wooden components of cooling towers.

Chemical biocides are commonly used to control the population of algae and bacteria in the recirculating cooling water. Two classes of antimicrobials are used: oxidizing biocides and non-oxidizing biocides.

Oxidizing biocides react and destroy bacteria by breaking down their cell wall, and reacting with organic nutrients in the water. Bacteria do not develop immunity to oxidizing agents. The three common oxidizing biocides used in industrial and commercial cooling towers are chlorine, bromine and peroxide.

Chlorine remains the most common biocide used in cooling tower treatment. It is generally added as liquid sodium hypochlorite (10.5%) or as a dry form of calcium hypochlorite (HTH) (65%). Regardless of physical form, chlorine dissolves in water to produce hypochlorous acid (HOCl) and hypochlorite (OCl-). Vendors typically recommend applying chlorine at a pH of 6.5 to 7.5 based on the claim that it is less toxic at higher pH. However, if the cooling tower is run at high COC and pH values above 9.0 with continuous chlorination, the synergistic effect of high pH and alkalinity plus a continuous chlorine residual produce a toxic environment to all forms of bacteria and algae.

Bromine is a close cousin to chlorine. Various bromine release agents are marketed for cooling tower treatment. These include dry brominated/ chlorinated hydantoins, stabilized liquid bromine, and bromine salts (sodium bromide). Sodium bromide is dosed in combination with an oxidizing agent such as chlorine, peroxide or ozone. These bromine products are more expensive than liquid chlorine. The vendors claim that, although more expensive, bromine is cost-justified because it reacts faster at pH values in the 7.5 to 10.0 range. However, as mentioned previously, chlorine when applied at high pH/alkalinity produces a combined effect that is toxic to bacteria.

Hydrogen peroxide is another oxidizing agent that offers the advantage of being very friendly to the environment. Peroxide reacts and decomposes to form water (H2O). This offers an advantage over environmental concerns that chlorine and bromine react with organics to form by-products that are potential carcinogens. Peroxide is available in 30% active solutions for use in cooling tower applications.

Non-oxidizing biocides are used alone or in combination with oxidizing biocides. These chemicals are toxic poisons that kill bacteria and algae by reacting with their metabolism and reproduction. These products are also toxic to humans and should be handled with care.

Various non-oxidizers are used in cooling water treatment programs. Each has a particular benefit in controlling troublesome problems that are not being controlled by chlorine, bromine or peroxide. The most common non-oxidizing biocide in use is isothiazolone. This is a broad spectrum biocide that is effective across a broad pH range of 4.5 to 9.3. However, it is very hazardous upon contact with the skin and eyes. It should only be stored, handled and applied according to the manufacturer's directions.

Closed Chilled Water System Treatment Requirements

The closed chilled water loop circulates through the coils in the air handlers and evaporator section of the chiller. As such, it is separate from the open cooling water cycle that flows through the cooling tower and the condenser section of the chiller.

The temperature of the chilled water loop is typically maintained within the range of 40° to 55° F as compared to the open recirculating water temperature across the cooling tower of 85° to 95° F.

Water Treatment

The primary purpose of treating the water in the chilled water loop is to prevent corrosion, although some systems suffer from deposition and bacteria growth.

Water losses are generally minimal from a closed loop unless the system is subject to leaks or periodic draining. If the source water contains appreciable hardness, it should be softened upon initial fill and thereafter for makeup. In general, soft water is a better option for chilled water loops than hard water.

Several programs are commonly used in closed chilled water systems. The most common option for HVAC chilled water loops is a blend of sodium nitrite, borax and an azole such as tolyltriazole. The nitrite is an effective corrosion inhibitor for steel, borax creates a pH buffer in the 9.0 to 9.5 range, and the azole serves as a corrosion inhibitor for copper and other yellow metals. The sodium nitrite residual is maintained within a 500 to 1000 ppm target. Other inhibitor formulations have been used that supplement the nitrite inhibitor with molybdate, but this approach is less-cost effective.

Monitoring Your System

Water Quality

pH

pH is a measurement of how acidic or how alkaline a substance is on a scale of 0 to 14. A pH of 7.0 is neutral (the concentration of hydrogen ions is equal to the concentration of hydroxide ions), while measurements below 7.0 indicate acidic conditions and measurements above 7.0 indicate basic or alkaline conditions. The pH scale is logarithmic (each incremental change corresponds to a tenfold change in the concentration of hydrogen ions), so a pH of 4.0 is ten times more acidic than a pH of 5.0 and one hundred times more acidic than a pH of 6.0.

The pH of cooling water is typically maintained in the alkaline range, which is above 7. Some pH-controlled treatment programs use acid to maintain the pH in the non-scaling range of approximately 6.5 to 7.5. Other non-acid treatment programs allow the pH to increase above 8.5. When cooling towers are operated at high COC, the pH may move into the 9.0 to 10.0 range. This has the advantage of being outside the amplification range for most forms of bacteria and algae, which reduces the demand for biocides.

Hardness

Hardness refers to the presence of dissolved calcium and magnesium in the water. These two minerals are particularly troublesome in heat exchange applications because they are inversely soluble - meaning they come out of a solution at elevated temperatures and remain soluble at cooler temperatures. For this reason, calcium and magnesium-related deposits will be evident in the warmest areas of any cooling system, such as the tubes or plates of heat exchangers, or in the warm top regions of the cooling tower fill where most of the evaporation occurs.

Water treatment programs strive to enhance the solubility of calcium and magnesium hardness through the use of chemical additives such as phosphonate or acid for pH control. In general, the solubility of calcium falls within the 350 to 450 ppm range expressed as calcium carbonate. The other alternative is to pre-treat the cooling tower makeup to reduce the hardness to zero (0) ppm. Or the soft water can be blended with hard water to produce a makeup of any desired hardness level.

Alkalinity

Alkalinity is the presence of acid neutralizing or acid buffering minerals in the water. Primary contributors to alkalinity are carbonate, bicarbonate and hydroxide. Additional alkaline components may include phosphate, ammonia and silica, though contributions from these ions are usually relatively small.

The alkalinity of the cooling water can be reduced and controlled by the addition of mineral acids like sulfuric and hydrochloric. One part of acid (100% active) is required to neutralize 1 part of alkalinity. The dosage of acid is generally controlled by pH measurement. This corresponds to a total alkalinity that falls within the 100 to 300 ppm range. The concentration of calcium hardness and total alkalinity determine the solubility of calcium carbonate.

Conductivity

Conductivity is a measurement of the water's ability to conduct electricity. It is a relative indication of the total dissolved mineral content of the water as higher conductivity levels correlate to more dissolved salts in solution. Conversely, purified water has very little dissolved minerals present, meaning the conductivity will be very low.

The conductivity in the cooling tower is controlled by blowdown. Increasing the blowdown rate decreases the conductivity. Decreasing the blowdown increases the conductivity.
The ratio between the cooling water conductivity and the makeup conductivity is commonly taken as a measure of the cycles of concentration.

System Concerns

Corrosion

<u>Definition</u>

Corrosion can be defined as the wastage or loss of base metal in a system.

<u>Causes</u>

Water in an open recirculating cooling system is corrosive because it is saturated with oxygen. Systems in urban areas often pick up acidic gases from the air which depress the pH and increase the corrosion potential. These gases are the same as those that produce acid rain.

<u>Impacts</u>

Corrosion products enter the bulk water stream as troublesome suspended solids. In addition, serious process contamination and/or discharge problems can result from active corrosion. The accumulation of corrosion products on the pipe surface reduces the carrying capacity of lines and requires expensive mechanical or chemical cleaning. The loss in head caused by this accumulation requires increased pump pressures and consequently higher pumping costs.

<u>Monitoring</u>

Corrosion can be monitored using preweighed corrosion coupons. Coupon weight loss provides a quantitative measure of the corrosion rate and the visual appearance of the coupon provides an assessment of the type of corrosion and the amount of deposition in the system.

Corrosion coupons are installed in ASTM racks and exposed for 30 to 90 days. Since most cooling systems are fabricated from steel, copper, brass, stainless steel and galvanized steel, determining corrosion rates on these metals is most informative. Upon removal, the coupons are examined, cleaned, and re-weighed. The weight loss is used to calculate the corrosion rate expressed in mils per year.

Metal	Very Good	Good	Fair	Poor	Very Poor
Mild Steel	< 1	1 to 3	3 to 5	5 to 10	>10
Mild Steel HX	<0.2	0.2 to 0.5	0.5 to 1.0	1.0 to 1.5	>1.5
Copper	<0.1	0.1 to 0.2	0.2 to 0.3	0.3 to 0.5	>0.5
Galvanized Steel	<2	2 to 4	4 to 8	8 to 10	>10
Stainless Steel		<0.1			>0.1

90-day Corrosion Coupon Evaluation, mils per year

Scale

Definition

As water evaporates in a cooling tower or an evaporative condenser, pure vapor is lost and dissolved solids concentrate in the remaining water. If this concentration cycle is allowed to continue, the solubilities of various solids will eventually be exceeded. The solids will then deposit in the form of scale on hotter surfaces, such as condenser tubes. The deposit is usually calcium carbonate. Calcium sulfate, silica and iron deposition may also occur, depending on the minerals contained in the water.

Causes

Deposits consist of two general types: crystalline inorganic deposits (when solubility limits are exceeded) and sludge (when suspended solids settle). The most common scale-forming salts include calcium carbonate, calcium phosphate and magnesium silicate. Manganese and barium are less common but equally troublesome scale formers found in certain areas of the country. Corrosion products such as iron oxide also can be significant contributors to scale formation.

Impacts

Deposition inhibits heat transfer and reduces energy efficiency. Deposits insulate the metal surface from the cooling water, restricting heat transfer. If the deposit formation is severe, hydraulic restrictions to flow may further impact the cooling system's ability to carry heat away from the process.

The thin-film plastic fill that is in common use in many cooling tower is susceptible to fouling due to insolubles that tend to clog the narrow water and air passages. This reduces the efficiency of the cooling tower. Once formed, fouling deposits are difficult, if not impossible, to remove from the plastic fill. Thus, it is important to minimize scale deposition in order to prolong the useful life of the cooling tower and minimize maintenance expense.

Monitoring

Deposition tendencies can be observed on corrosion coupons or heated apparatus, such as test heat exchangers. A comparison of various mineral concentrations and suspended solids levels in the makeup water to those in the blowdown may indicate the loss of some chemical species due to deposition. This is known as a hardness balance. Theoretically, if the hardness in the makeup is not removed by blowdown, it accumulates in the system as undesirable scale or sludge. Cooling systems can be operated at higher cycles of concentration and/or higher pH when appropriate scale inhibitors are applied.

Biological Activity

Definition

Biological concerns can be categorized as either microbiological or macrobiological. These manifest as algae, bacteria, fungus, mold and higher life forms such as nematodes and protozoa.

Causes

Cooling towers create a very favorable habitat for the growth of microorganisms. Warm water temperatures, nutrients, dissolved oxygen and sunlight produce an environment for the exponential growth of these organisms.

Impacts

The proliferation of biological organisms in a cooling system results in many of the same problems caused by scale deposition and corrosion. Significant microbiological growth causes equipment fouling, restricts heat transfer, promotes microbiologically induced corrosion (MIC) and creates possible flow restrictions.

Monitoring

Many techniques are available to monitor biological fouling. Those that monitor biological growth on actual or simulated system surfaces provide a good measure of system conditions. Bulk water counts of various species may be misleading.

In general, total anaerobic bacteria counts should be maintained at less than 10,000 colony forming units (CFU) in the bulk cooling water. The microbiological counts obtained from surface swabs should be less than 1,000,000 colony forming units (CFU). The sulfate-reducing bacteria (SRB) should be undetectable.

Maintaining Equipment

Maintenance Checklist

Refer to Appendix C for the standard maintenance routines as defined by RS Means.

Vendor Management

Selecting a Vendor

Factors to consider when evaluating different vendors are cost, reliability, energy efficiency, etc. A Property Manager's objective is to secure service oriented water treatment chemical and services vendors at the lowest possible fixed cost, for material and services, while meeting the Water Management Goals. Service capabilities will be key decision-making criteria. However, cost, safety information systems and other value-added services will also be important factors.

Contract Types

Water treatment chemical vendors and Consultants are typically used to assist facilities with the selection, application and control of the cooling water treatment program. Depending on the knowledge, capability and availability of the facility staff, the Property Manager may outsource some or all of these services. Several options exist for setting up the service agreement. These include:

Full service agreement: The contractor supplies chemicals and support services under a turnkey agreement whereby the vendor assumes full responsibility for the application and control of the water treatment program. The cost for labor and laboratory services may be included in the purchase price of the chemicals, or as an alternative, the cost for products and services are included in a fixed monthly or annual fee. This bundles products and services into one service agreement for convenience.

Limited agreement: The Property Manager retains an independent, third-party Consultant to select, apply and control the water treatment program. Chemicals are purchased from a list that matches the specifications as prepared by the Consultant. This unbundles products and services to eliminate any potential for a business conflict of interest.

Materials only agreement: The Property Manager purchases chemicals from a local supplier, but the on-site staff is responsible for the application and control of the water treatment program. This offers low cost, but it requires some technical knowledge on best practices for cooling water chemistry.

Evaluating a Vendor

Once the vendor is in place, it is important to ensure the vendor is performing at the required level of service. The following are recommended Key Performance Indicators (KPIs) for evaluating service vendor performance and examples of data that support KPI compliance. These include quantitative results from corrosion coupons, energy efficiency calculations and other metrics.

Open Cooling Towers

Deposit and fouling control

- Prevent the accumulation of suspended solids in heat exchange equipment, tower fill, tower basin and distribution piping
- Cooling tower scale/corrosion inhibitor must be directly monitored and controlled.
- Hardness balance indicates no build up of calcium or magnesium salts
- Inhibit (prevent) calcium carbonate scale formation or other inorganic scale formation in heat exchange equipment including cooling towers

Corrosion control

- Maintain the corrosion rate on system metals within the Excellent to Good rating for 90-day ASTM results

Bacteria control

- Limit total bacteria count to 10,000 colony forming units per milliliter (cfu/ml) in the bulk cooling water
- Limit the total bacteria count to 1,000,000 CFU on surfaces
- Limit sulfate reducing bacteria (SRB) to “zero”
- No algae present on tower distribution basins or drift eliminators

Closed Systems

Bacteria control

- Limit sulfate reducing bacteria (SRB) to “zero”
- Limit total bacteria growth to 1,000 CFU/ML

Softeners

Meet design specifications with respect to salt consumption, regeneration frequency and hardness reduction. **(If system is equipped)**

Service

- Adherence to Service Plan
- Customer Satisfaction Survey
- Semi- annual review with company contract manager
- Timeliness of Delivery
- Process Improvements
- Remove and properly dispose of all empty chemical containers from facilities. (Drums, Pails, Bottles)
- Provide a service call report, via email, for each site with a detailed status of each system and the actions taken **per visit**

Other Potential Services

- Building utility and water usage reduction surveys and planning
- Product consulting and application assistance
- Product training and/or recommendation
- Safety training

Water Treatment Acceptable Values

Suspended Solids	< 25 for film fill
Total Dissolved Solids (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

References

http://www.gewater.com/handbook/cooling_water_systems/index.jsp
spxcooling.com/pdf/Cooling-Tower-Fundamentals.pdf
http://www.ose.state.nm.us/water-info/conservation/pdf-manuals/cii-users-guide.pdf

Suggested Additional Reading

APPENDIX A

New Technology Introduction [To be developed]

Cooling Tower Calculator [To be developed]

APPENDIX B

Terms and Definitions

Acronym / Term	Definition
A&E	Architectural and Engineering
Adj.	Adjustable
AFF	Above finish floor
AHJ	Authority Having Jurisdiction
AHU	Air-handler Unit
AMCA	Air Movement and Control Association, Inc.
ANSI	American National Standards Institute
APLV	Actual Part Load Value
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEMARR(retired)	Building Energy Management and Redesign Retrofit
Bin Temperature	One method commonly used to illustrate the range of design temperature conditions over the entire year is the bin hour profile. A "bin" is simply a five-degree range of temperatures, along with the number of hours of occurrence between summer and winter design temperatures
C&E	Construction & Engineering
CEV	Controlled Environment Vault
CFM	Cubic feet per minute
CO	Central Office
COLD	Central Office Layout and Design
Consultant	A non-payroll worker or vendor hired by the company
CRAC	Computer Room Air Conditioner
CRAH	Computer Room Air Handler
CRE	Corporate Real Estate
DDC	Direct Digital Control
Domestic	The United States and its territories including, Puerto Rico, Virgin Islands and Guam
DX	Direct Expansion
EC	Electrically Commutated
EDGE	Energy Design Guidelines for Our Environment
EH&S	Environment, Health & Safety
EPA	Environmental Protection Agency
F	Fahrenheit
FPM	Feet Per Minute
GNFO	Global Network Field Operations
GTSO	Global Technical Space Operations
HVAC	Heating, Ventilation and Air Conditioning

Acronym / Term	Definition
IAQ	Indoor Air Quality
IDC	Internet Data Center
IEEE	Institute for Electrical and Electronics Engineers
IMC	International Mechanical Code
International	Anything outside the United States and its territories
IPLV	Integrated Part Load Value
LCCA	Life Cycle Cost Analysis
MERV	Minimum Efficiency Reporting Value
NEBS	Network Equipment Building System
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PD&C	Planning, Design and Construction
Pete's Plug	Temperature and pressure test plug
PM	Property Management
PPM	Parts Per Million
SLA	Service Level Agreement
SMACNA	Sheet Metal and Air Conditioning Contractors National Association, Inc.
Telcordia	Consultant used to develop telecommunication standards
TSO	Technical Space Operations
UL	Underwriters Laboratory
VFD	Variable Frequency Drive
VIV	Variable Inlet Vane

APPENDIX C

Mechanical PM8.4-510-1 Cooling Tower up to 50 tons						93482	94482	98482	99482
		Labor Hrs.	**W**	**M**	**Q**	**S**	**A**	**SU**	**SD**
PM Components									
1	Check general condition of tower and associated equipment.	0.035				**X**	**X**	**X**	**X**
2	Clean inside of water sump; scrape, brush, and wipe as required; heavy deposits of scale should be removed.	0.598					**X**		
3	Inspect and clean spray nozzles.	0.200				**X**	**X**		
4	Clean tower drive belts and guard. Re-install belts and check proper tension and alignment. Replace belt guard and check for clearance.	0.080					**X**		
5	Bearings, all type - Check for proper operation and for unusual operation, lubricate.	0.050				**X**	**X**		**X**
6	Take an oil sample from bottom of gear reducer and check for water contamination. Check for proper oil level.	0.030				**X**	**X**		
7	Lubricate motor-base-adjusting screw.	0.020				**X**	**X**		**X**
8	Open tower make-up valve and fill tower and condenser lines. Check for proper fill valve operation and sump level. Bleed air.	0.211						**X**	
9	Check operation of unit for leaks, noise or vibration.	0.030				**X**	**X**	**X**	
10	Remove, clean and reinstall strainers.	0.300					**X**	**X**	
11	Check electrical wiring and connections; make appropriate adjustments.	0.255					**X**	**X**	
12	After determining that all valves, switches and controls are in the proper position and water in the system, start the condenser pump(s)	0.030						**X**	
13	Check for proper operation and temperature setting of tower fan controls.	0.020				**X**	**X**	**X**	
14	Drive dampers to full open and full close positions. Observe for leakage and conditions that prohibit opening and closing. Lubricate.	0.100				**X**	**X**	**X**	
15	Close cooling tower make-up valve and drain tower.	0.200							**X**
16	Close water supply valves for tower make-up and tower hose wash lines. Drain below roof level to prevent freezing. Disable chiller from operating.	0.200							**X**
17	Remove tower fan belts. Inspect for defects and wear. Check fan and motor sheaves for wear. Coat sheaves with a protective coating.	0.200							**X**
18	Inspect and clean around tower.	0.030				**X**	**X**	**X**	**X**
19	Fill out maintenance checklist and report deficiencies.	0.022				**X**	**X**	**X**	**X**
	Total Labor Hours/Period					**0.537**	**1.770**	**1.756**	**0.757**
	Total Labor Hours/Year	**5.357**				**1.07**	**1.770**	**1.756**	**0.757**

Mechanical PM8.4-510-2 Cooling Tower 51 to 500 Tons						93483	94483	98483	99483
		Labor Hrs.	W	M	Q	S	A	SU	SD
PM Components									
1	Check general condition of tower and associated equipment.	0.074				X	X	X	X
2	Clean inside of water sump; scrape, brush, and wipe as required; heavy deposits of scale should be removed.	1.271					X		
3	Inspect and clean spray nozzles.	0.400				X	X		
4	Clean tower drive belts and guard. Re-install belts and check proper tension and alignment. Replace belt guard and check for clearance.	0.120					X		
5	Bearings, all type - Check for proper operation and for unusual operation, lubricate.	0.200				X	X		X
6	Take an oil sample from bottom of gear reducer and check for water contamination. Check for proper oil level.	0.030				X	X		
7	Lubricate motor-base-adjusting screw.	0.020				X	X		X
8	Open tower make-up valve and fill tower and condenser lines. Check for proper fill valve operation and sump level. Bleed air.	0.211						X	
9	Check operation of unit for leaks, noise or vibration.	0.030				X	X	X	
10	Remove, clean and reinstall strainers.	0.800					X	X	
11	Check electrical wiring and connections; make appropriate adjustments.	0.255					X	X	
12	After determining that all valves, switches and controls are in the proper position and water in the system, start the condenser pump(s)	0.030						X	
13	Check for proper operation and temperature setting of tower fan controls.	0.020				X	X	X	
14	Drive dampers to full open and full close positions. Observe for leakage and conditions that prohibit opening and closing. Lubricate.	0.100				X	X	X	
15	Close cooling tower make-up valve and drain tower.	0.200							X
16	Close water supply valves for tower make-up and tower hose wash lines. Drain below roof level to prevent freezing. Disable chiller from operating.	0.200							X
17	Remove tower fan belts. Inspect for defects and wear. Check fan and motor sheaves for wear. Coat sheaves with a protective coating.	0.200							X
18	Inspect and clean around tower.	0.030				X	X	X	X
19	Fill out maintenance checklist and report deficiencies.	0.022				X	X	X	X
	Total Labor Hours/Period					**0.926**	**3.372**	**3.358**	**0.946**
	Total Labor Hours/Year	**9.528**				**1.85**	**3.372**	**3.358**	**0.946**

Mechanical PM8.4-510-3 Cooling Tower 501 through 1000 Tons						93484	94484	98484	99484
		Labor Hrs.	W	M	Q	S	A	SU	SD
PM Components									
1	Check general condition of tower and associated equipment.	0.109				X	X	X	X
2	Clean inside of water sump; scrape, brush, and wipe as required; heavy deposits of scale should be removed.	2.259					X		
3	Inspect and clean spray nozzles.	0.400				X	X		
4	Clean tower drive belts and guard. Re-install belts and check proper tension and alignment. Replace belt guard and check for clearance.	0.524					X		
5	Bearings, all type - Check for proper operation and for unusual operation, lubricate.	0.050				X	X		X
6	Take an oil sample from bottom of gear reducer and check for water contamination. Check for proper oil level.	0.070				X	X		
7	Lubricate motor-base-adjusting screw.	0.070				X	X		X
8	Open tower make-up valve and fill tower and condenser lines. Check for proper fill valve operation and sump level. Bleed air.	1.578						X	
9	Check operation of unit for leaks, noise or vibration.	0.109				X	X	X	
10	Remove, clean and reinstall strainers.	1.464					X	X	
11	Check electrical wiring and connections; make appropriate adjustments.	0.374					X	X	
12	After determining that all valves, switches and controls are in the proper position and water in the system, start the condenser pump(s)	0.030						X	
13	Check for proper operation and temperature setting of tower fan controls.	0.020				X	X	X	
14	Drive dampers to full open and full close positions. Observe for leakage and conditions that prohibit opening and closing. Lubricate.	0.500				X	X	X	
15	Close cooling tower make-up valve and drain tower.	1.100							X
16	Close water supply valves for tower make-up and tower hose wash lines. Drain below roof level to prevent freezing. Disable chiller from operating.	0.300							X
17	Remove tower fan belts. Inspect for defects and wear. Check fan and motor sheaves for wear. Coat sheaves with a protective coating.	0.500							X
18	Inspect and clean around tower.	0.030				X	X	X	X
19	Fill out maintenance checklist and report deficiencies.	0.022				X	X	X	X
	Total Labor Hours/Period					**1.380**	**6.001**	**7.235**	**2.181**
	Total Labor Hours/Year	**18.177**				**2.76**	**6.001**	**7.235**	**2.181**