Evaluation of
Potential Best Management Practices
-
Commercial-Industrial Cooling Water Efficiency

Prepared for

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Commercial - Industrial Cooling Water Efficiency

1.0 Background

Commercial and industrial (mechanical) cooling systems have become commonplace throughout the United States and the world over the last 60 years. Improved indoor environments due to air conditioning systems enhance the productivity of millions of workers around the world. In addition, commercial and industrial refrigeration systems lengthen the shelf life of perishable foods, minimizing exposure to harmful bacteria and spoilage, thereby allowing the transportation of these foods over vast distances. Industrial cooling systems help make many processes and products possible we normally take for granted. Since the advent of the ammonia and vapor compression refrigeration cycles, these systems have become an increasingly more important in numerous aspects of our daily lives even though we are largely unaware of their presence.

The largest and most efficient cooling systems use water to cool the refrigerant in ammonia and vapor compression cycles. Evaporated water carries away the heat necessary to do this. However, much water is wasted in the controlling of solids concentrated in the cooling water left behind. Water supplies vary in quality from site to site, primarily in the amount and type of dissolved solids which, in turn, require a customized chemical selection and water treatment strategy. In certain areas, chemical treatment against scale formation only seems to have a marginal effect, thus necessitating frequent cleaning of heat exchange surfaces. This is true even though the science of chemical water treatment has improved. Leaving the application of chemicals to the discretion of the water treatment specialists, who may or may not have the knowledge to treat a condenser water systems, rarely maximizes water efficiency.

This paper discusses several available technologies that improve the treatment of condenser water, thereby reducing the amount sent to the drain (sewer). Technologies include chemical water treatment, which is the traditional and accepted approach to condenser water treatment, and some newer, non-chemical technologies that approach this important area quite differently than traditional methods. We focus on those technologies that have shown the best track record for long-term water efficiency and successful operation.

Appendix A provides additional background information regarding cooling systems, which will help readers to become acquainted with the various technologies and industry terminology.

Appendix B concentrates on water treatment technologies and terminologies.

1.1 History

As early as 1882, companies such as Frick and Vilter were manufacturing large steam driven reciprocating ammonia systems for industry that replaced ice as the primary refrigerant. In 1928, Frigidaire discovered a new class of refrigerants, halocarbons or chlorofluorocarbons (CFC's), which were not as dangerous as ammonia and allowed for smaller compressor design. However, it was not until the introduction of the electrically driven hermetic centrifugal water chiller introduced by the Trane Company in 1938, with its compact design, that cooling of larger, multi-story buildings and industrial processes became feasible. This was previously not practical with smaller chillers with reciprocating compressors or with steam driven reciprocating chillers. Centrifugal chillers are still the mainstay in today's larger systems, with tonnages ranging from about 300 tons (1 ton = 12,000 btuh) up to about 4,000 tons in a single chiller unit. (One ton cools approximately 350 square feet of conventional office or other open space.) Larger systems are comprised of several chillers piped in parallel. Absorption chillers range in size from about 100 tons up to approximately 2,000 tons and use steam or hot water to drive the refrigeration process, but are less common because they are relatively inefficient and require specialized service and maintenance. Absorption chillers are always used in conjunction with cooling tower technology.

Helirotor technology was originally introduced by Frick (now York), Vilter and Dunham-Bush. This newer generation of chillers became very common in the 1980's when Trane, and later Carrier in the 1990s, introduced their own versions of this technology. The helical rotary, or "screw" compressor chillers, are available in both air-cooled and water cooled configurations, ranging in tonnage from about 100 tons through 500 tons. Since the helirotor compressors are a positive displacement compressor, they work very well in low temperature/process ammonia applications. Frick and FES, a German Company, are two of the larger suppliers of this technology in low temperature applications.

Water-cooled systems below 100 tons in size use older reciprocating technology, although this is a dated and relatively inefficient technology. Beginning in the mid-1990s, reciprocating technology has steadily been replaced with scroll compressor technology primarily developed and employed by Trane. Scroll chillers range from 20 tons and up. Although chillers are made in sizes smaller than 20 tons, they are very rare and constitute a very small percentage of the total market. Water Source Heat Pump (WSHP) and Self Contained Variable Air Volume (SCVAV) systems, which are condenser water loop systems, primarily utilize either type of compressor technologies mentioned above.

The history of condenser water treatment is dominated by chemical treatment. Chemical treatment has done an adequate job over the years, but the quality of the treatment is subject to human error, chemical limitations, reliability of the treatment equipment, exactness and continuity of control, and the diligence and integrity of the individual(s) maintaining the system. It is estimated that about 99 percent of all chilled water and condenser water (those systems employing cooling towers or closed circuit coolers) are treated chemically. In the past, operators and chemical treatment specialists have mainly focused on keeping the wetted surfaces clear of scale, biological growth and corrosion, *not* on water efficiency. This is understandable given that in the best of circumstances, , proper water treatment is a very difficult task requiring constant attention by the chemical treatment specialist, and because water was also relatively inexpensive. Consequently, all decisions regarding water use were left to the chemical treatment specialist who had no concern for or stake in efficiency.

1.2 HVAC Systems

Generally speaking, buildings (with their heating-ventilation-air conditioning – HVAC system) are constructed with the lowest cost system available. There are exceptions, particularly when the HVAC decision is driven by the owner who demands higher reliability, quality, lower sound levels, lower energy consumption or any of a list of reasons to move up to a better-performing system. Chilled water and other water-cooled systems are generally preferred among all available choices. Additional information regarding HVAC systems is provided in Appendix A.

DX Air Cooled Applications

In most homes, low-rise apartments and small commercial buildings, some version of a direct expansion (DX) system is found. These systems are generally smaller; a vapor compression refrigerant runs through the refrigeration circuit with the product being cold air that is blown by an internal fan system into the room. These systems are usually rooftop "packaged" units, typically found on a strip mall or small office building (one or two story building), or a split system, similar to what is installed in the typical California home, low rise apartment houses and in many smaller commercial buildings. Some of the largest rooftop and split system units in the 100-ton range can serve buildings up to six stories. Another type of DX system is the packaged terminal air conditioner (PTAC), which are those compact units that are typically located beneath the window. The product of each of these system types is cold air – no chilled water is involved. There is no water consumption in any of these system types so they do not enter into consideration for this analysis. They are mentioned simply to acquaint the reader with the various systems and where they are generally used in different types of building applications.

Water-Cooled Applications

As the building square footage increases, particularly in the vertical direction, the system choices available to the system designer become more limited. When a building is larger than 25,000 square feet and almost always when it is taller than the five or six stories, the only practical solution to central air conditioning is to run a chilled water or condenser water loop throughout the building. Many industrial processes require chilled water for cooling the space where the product is manufactured and sometimes this chilled water is also used to cool the equipment in the process itself.

There are two types of water-cooling systems in use today:

1) Condenser water cooling (loop) systems where the coolant is sent to a cooling tower and heat is removed through the process of evaporation. The temperature attained is a function of the ambient wet bulb condition and loop temperatures can be maintained between 60° and 90°F.

2) Chilled water systems, which are further broken down into air-cooled and water-cooled systems. Loop temperatures typically range between 39° and 50°F. Only water-cooled chilled water systems are analyzed in this report since air cooled chillers utilize an air-cooled

condenser to remove refrigerant heat even though its product is chilled water. Appendix A provides more detail about this subject.

Water-cooled systems are much more efficient than air-cooled systems, including the air-cooled DX systems, and they can be made in much larger sizes while consuming minimal space. A 500-ton air-cooled chiller might be 11 feet wide and 45 feet long, the maximum dimensions that can be shipped on the back of a flat bed truck. The largest DX air-cooled packaged rooftop unit is around 120 tons in capacity and is about the same dimensions as the 500-ton chiller.

Water-cooled systems also require better-trained technicians to maintain them and better subsystem technologies to assist in the maintenance and proper care of these systems. Water-cooled systems typically cost more than DX systems of equivalent tonnage.

Condenser Water Systems

Condenser water systems appear in two types of configurations, one where the compressor bearing units are inside the building ceiling plenum, the other when the units are in individual mechanical rooms next to the working space. They are (1) the water source heat pump (WSHP) system that was very popular in the 1980s and early 1990s and (2) a new concept called the vertical self-contained VAV (SCVAV) system. The WSHP system typically has very small air conditioning units placed above the ceiling in two- through five-ton sizes, whereas the SCVAV systems have units sized in the 40- to 100-ton range. Condenser water loop temperatures range between 60° and 90°F.

Chilled Water Systems

Chilled water systems (CWS) are designed to deliver water to another device called an air handler or a fan coil unit. These units accept the cold water into an internal coil with water passing through the inside of the tubes. Room air is recirculated from the room and back to the return side of the air handler or fan coil where it is then filtered and passed through the exterior of the coil. The cold chilled water in the tubes absorbs heat from the air passing around it, thus cooling the air as heat is given up to the water. Typically, the chilled water temperature is between 38° and 47°F, easily driving the temperature of the air delivered to the space to 55°F from a 70° to 75°F return temperature.

1.3 Applications

All water-cooled systems have advantages and disadvantages, but the important thing to remember is that they all require cooling towers or closed loop coolers for heat dissipation.

The building applications where chilled water or condenser water systems are found will be larger structures of at least 25,000 square feet (requiring 75 tons of capacity). It is not until buildings reach this size that it is economically feasible to invest in the more expensive water-cooled system types.

Figure 1 illustrates that as building size grows, the likelihood of finding a CWS increases, especially on buildings of 100,000 square feet (300 tons) and above.[1] The data shown account for both air- and water-cooled systems but does *not* account for those buildings with condenser water systems (with WSHP and SCVAV systems) and industrial process cooling loops. Data were not available for these systems types. However, these systems fit into smaller buildings ranging in tonnage from about 75 tons (25,000 square feet) up to about 600 tons (200,000 square feet), which would have the effect of making the three middle columns of Figure 1 somewhat larger.

Figure 1. PERCENT CHILLED WATER SYSTEMS BY BUILDING TONNAGE

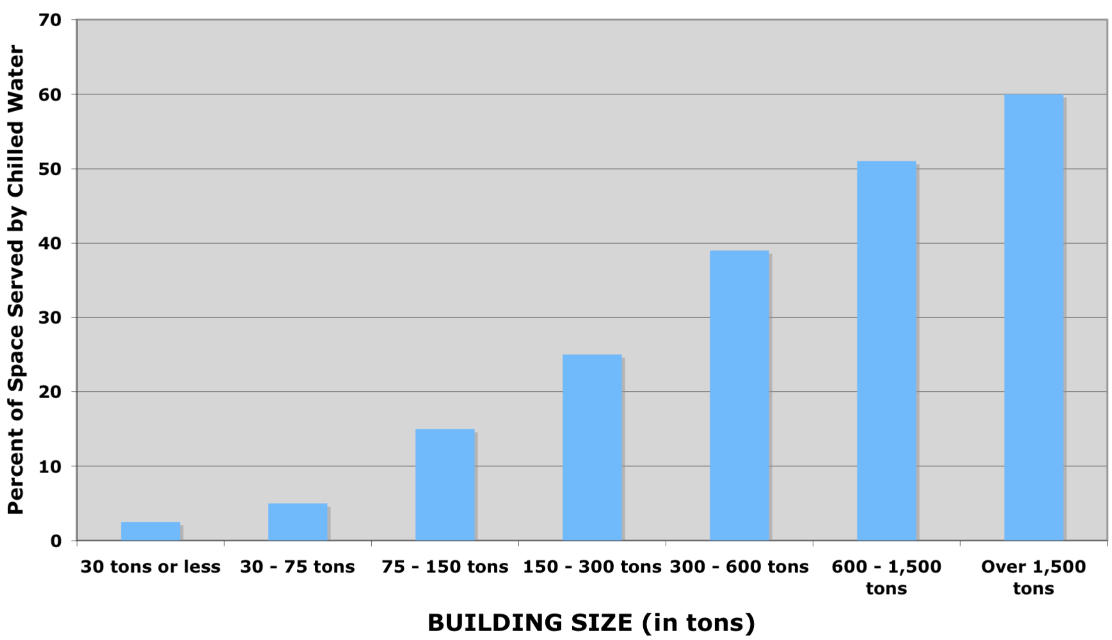
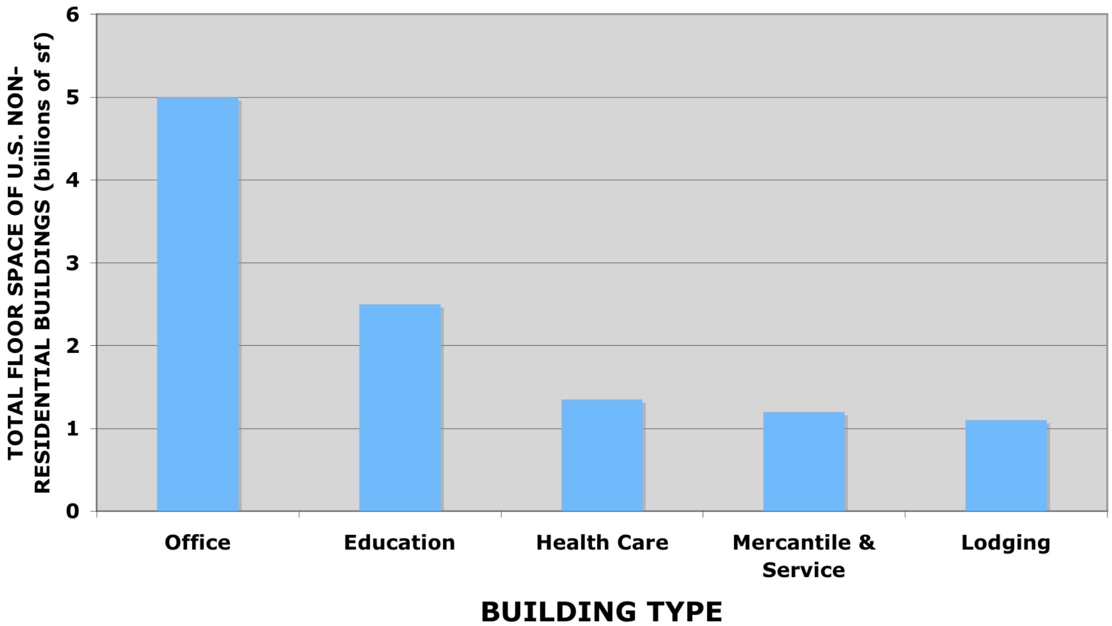


Figure 2 shows an estimated breakdown of CWS by building type expressed in terms of square footage.[2] Again, these figures do not include square footage for condenser water systems due to lack of data. Condenser water systems are used almost entirely in commercial office building applications, which, if included, would enlarge the office column in Figure 2 well above the 5 billion square foot level shown for chilled water systems.

[1] E-SOURCE, *Chilled Water Systems,* Chapter 8
[2] E-SOURCE, *Chilled Water Systems,* Chapter 8

Figure 2. CHILLED WATER COOLING SYSTEMS BY PRINCIPAL BUILDING USE (1992)



1.4 Current Condenser Water Treatment Methodology

As mentioned earlier, approximately 99 percent of all cooling towers and closed circuit coolers are treated chemically. The conventional water treatment system in the United States utilizes chemical additives that are typically administered through an automated system. The basic automation includes a TDS (total dissolved solids) meter to monitor the concentration of solids in the water. When the upper limit for TDS concentration (commonly referred to as *cycles of concentration*) is reached, it triggers an automated blow down or bleed valve to open. When this occurs, blow down water is sent from the cooling tower to the sanitary drain (sewer). As the level of water in the cooling tower sump is lowered, the blow down valve is closed and a valve in the make-up (municipal) water line is automatically opened. The municipal make-up water is of relatively low TDS. As it is introduced back into the system it thus dilutes the condenser water loop when it is mixed with the water remaining in the sump. The system also utilizes metering pumps for the administration of various chemicals taken from stored drums. The higher the TDS is allowed to concentrate in solution, the greater the potential water efficiency. However, at the same time, the higher the TDS concentration, the greater the risk of scale, biological growth and corrosion.

The delivery system and the treatment strategy devised by the chemical supplier are designed to control the three areas of concern just mentioned. For the vast majority of customers, chemical treatment has been the only treatment methodology available in the past. The system owner usually accepts without question the results that the chemical supplier is able to achieve, good or bad. Unfortunately, most owners cannot tell the difference.

The maximum concentration of TDS or cycles of concentration vary from geographic area to geographic area and must be understood by the people administering the chemical treatment. A treatment strategy devised and administered by the chemical supplier must take into account the solubility of the various scale-forming constituents, the pH of the water, and water temperature. Initially, this water treatment specialist must form the strategy from empirical data and knowledge of the local water supply. Later, after a few months of operating experience, visual results and laboratory analysis, adjustments are made as judged necessary by the chemical supplier. The success of any program is dependent upon the quality of the chemical itself, the diligence and knowledge of the individual administering the program, and the integrity of that individual.

1.5 Evolution Toward New Technology Condenser Water Treatment

The U.S. EPA and state environmental agencies have slowly been prohibiting the use of the most dangerous chemicals used in the treatment of cooling water. Hexavalent chromates have been banned since the early 1990s as they were found to be carcinogenic. Other chemicals continue to come under scrutiny with many requiring double containment as a minimum safety precaution. As this trend of chemical elimination continues, the chemical industry must continue the costly process to find new substitutes as replacements for banned substances. This fact alone may drive the industry toward non-chemical treatment systems. However, at this time, it appears as though it will take many years for this to happen.

Chemical costs have contributed to the move away from this method of treatment as well. Generally, as a rule of thumb, chemicals cost about $1.00 per installed ton per month. A 1,000-ton system would therefore cost about $12,000 per year for a traditional chemical treatment program. Some non-chemical systems enjoy payback periods fewer than 3 years based upon chemical cost savings alone.

Water and sewer costs have also continued to rise, primarily over the past 15 years. As operators realize that these costs play an increasingly important role in building operating costs, there has been increasing attention given to water efficiency in condenser water cooling systems by conservation-minded owners and operators.

Finally, poor overall results, including scaled condenser tubes, biological growth in the cooling tower, and/or high corrosion rates with chemical water treatment have also contributed to the switch to non-chemical systems with the promise of better results and often, greater water efficiency.

It is clear that some non-chemical treatment systems work very well in selected applications with defined water conditions. Two technologies appear to work well in all applications regardless of water conditions, VRTX's and Dolphin's. Both provide superior operation in the three required areas of scale, biological and corrosion control while providing a much greater degree of water savings than the typical chemical program. It is believed that, at a minimum, the concentration of TDS (cycles of concentration) can be doubled with these new technologies. A given program need not be tied to these technologies alone, but all technologies can be considered if results are measured and the program incentive is tied to field-verified water savings and to measured scale, biological and corrosion results. Appendix B discusses all of the available technologies including magnetic (permanent magnets), electromagnetic (using DC current), electrostatic, AC Induction, electro-ionization, ozone and depressurization/kinetic energy.

1.6 Effect of Cycles of Concentration (CoC) Upon Water Efficiency

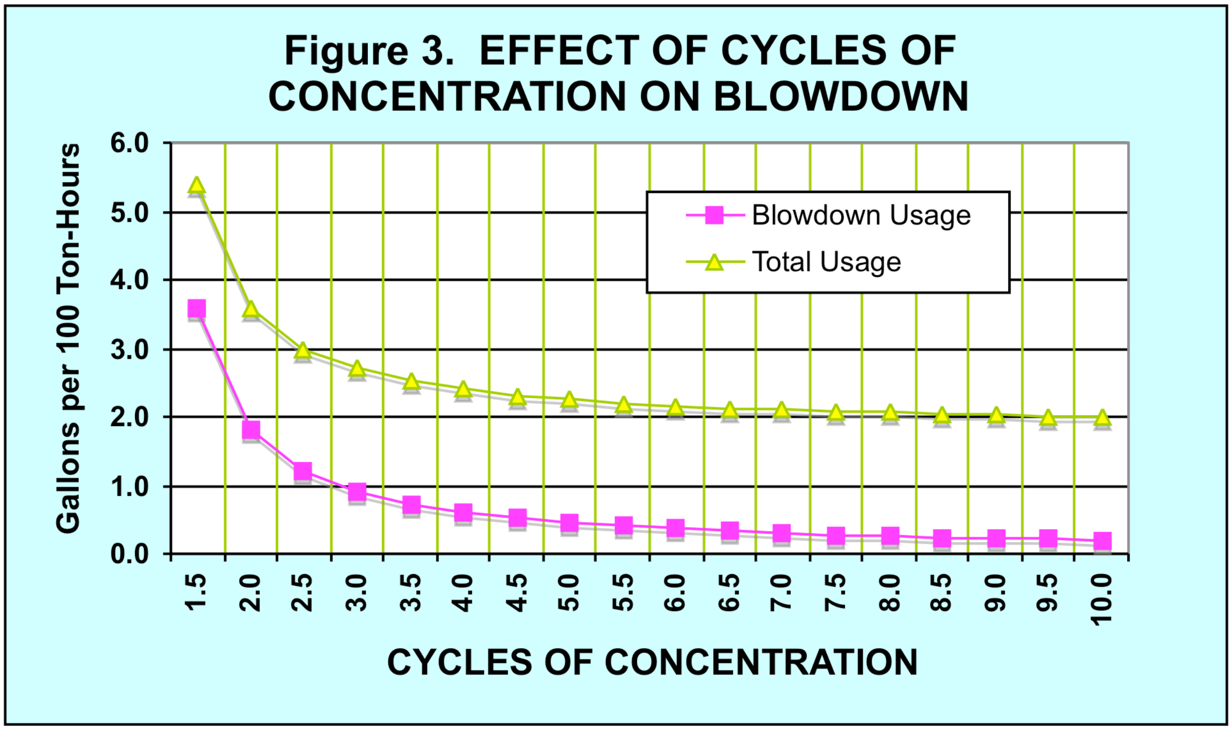
As water evaporates, it leaves behind dissolved solids that are brought into the condenser water system. These solids are indistinguishable from the water itself as they are "in solution", i.e., part of the water. Particulates in solution are sub-micron sized and cannot be removed through common filtration means but require some means of membrane filtration for their removal. Membrane filtration wastes anywhere from 20 to 50 percent of the water it filters as effluent, depending upon the inlet pressure to the membranes. By itself, membrane filtration is not considered to be a water-saving technology for condenser water systems.

As the CoC goes up, certain molecules of minerals begin to precipitate as they reach their individual solubility level at a given condenser water temperature. Precipitation (dropping out of solution) is only bad with certain types of common molecules such as those containing calcium, magnesium, and those two together with silica, which are the primary constituents of scale. Scale formation leads to poor heat transfer in the chiller condenser, thereby requiring more energy to perform at a given air conditioning or refrigeration load. Additionally, scale can assist in the formation of biological fouling and corrosion of metallic surfaces. These subjects are discussed further in Appendix B. For a water-efficient system, the overall goal should be to increase CoC, delivering a lower blowdown rate and conserving water, while, at the same time, not causing long-term deterioration of the condenser water system.

Generally speaking, but not in all cases, water in the northern part of California is relatively clear of scale-forming minerals. On the other hand, water taken from the Colorado River and certain underground well sources tends to contain much higher levels of these materials. As a result, CoC's in the northern parts of California tend to run higher than in the southern parts of the state and are believed to average around 3.0 for the average application in California. This is based upon experience in the field where CoC's were seen as low as 2.0 in San Diego applications, while known to reach as high as 5.0 with effective chemical treatment programs in the north..

Figure 3 shows the effect of cycles of concentration upon overall water consumption and blowdown. The chart looks at a typical 100 ton-hour system[3].

[3] A ton-hour is defined as one ton of load per hour for 100 hours, 100 tons for one hour, or something in between.



Evaporation

Evaporation of one pound of water removes 1,000 BTUs of thermal energy. One condenser water ton is defined as 15,000 BTUs (includes compressor heat). Water weighs 8.34 pounds per gallon. Therefore, one ton-hour requires 15,000 BTUs per ton / 1,000 BTUs per pound / 8.34 pounds per gallon = 1.8 gallons of evaporation is required to dissipate one ton of heat.

Blowdown and total water consumption

Blowdown (also termed bleed) is defined as evaporation (gallons) / (CoC – 1.0). It can be seen in Figure 3 that as the CoC is increased, the blowdown rate decreases. At a CoC of 1.5, the blowdown is 360 gallons for a 100 ton-hour system; the evaporated water is 180 gallons, thus totaling 540 gallons of water consumption. By doubling the CoC to 3.0, the evaporated water volume remains the same at 180 gallons. However, by concentrating the water solids to this level, the blowdown is now only 90 gallons and the total water consumption drops to 270 gallons, or one-half the total consumption at 1.5 CoC. By doubling the CoC again to 6.0 cycles of concentration, the evaporated water remains the same at 180 gallons while the blowdown is further reduced to 36 gallons. Total consumption drops to 217 gallons. This constitutes a 60 percent water savings when compared to the 1.5 CoC application and a 20 percent savings over the 3.0 CoC application. Savings continue to increase up to about 8.0 CoC, beyond which point the additional savings attributed to increasing CoC becomes very marginal.

It is generally believed that the CoC can be doubled (in most applications) from the average of 3.0 to the higher 6.0 by utilizing one of the newer, more prominent technologies such as VRTX or Dolphin.

1.7 Size of Water-Cooled Chilled Water and Condenser Water Market

To estimate the total market in California, information was obtained from the Trane Company about the number and dollar value of large tonnage chilled water system (CWS) shipments (all chillers over 100 tons and all vendors) into California during the 26-year period from 1978 to 2003[4]. Total shipments for this period of time were 74,201 chillers at an average tonnage of 371 tons each, equaling an estimated 27.5 million total tons. This 26-year period approximates the real life expectancy of a centrifugal, helirotor or absorption chiller. Because most of these units are likely to still be in service, this is considered a reliable estimate of the current size of the market in California.

Shipping information regarding WSHP systems was also obtained from the Trane Company and spanned the ten years from 1995 through 2004 for all vendor shipments into California[5]. The total shipments for the 10-year period amounted to 76,547 units. The average unit size was 3 tons (these fit in the ceiling plenum) making the total tonnage approximately 230,000 tons installed during this period of time. Extrapolating this amount for the prior 10-year period would double the numbers to 153,094 units and about 460,000 tons installed in California. The life expectancy for one of these units is approximately 20 years.

Information regarding SCVAV unit shipments was not available. However, this system type constitutes a very small portion of shipments when compared to CWS and WSHP systems. An educated guess based upon local knowledge in the San Diego market is that SCVAV shipments constitute approximately 5 percent of the total WSHP shipments for the same period of time, or about 23,000 tons statewide.

Total installed tonnage in California represented by this shipment data and estimates, then, amounts to approximately 28 million tons of water-cooled and condenser water systems.

2.0 Water Savings Estimates and California Potential

Estimating water savings for non-chemical treatment technologies considered in this paper requires the use of conservative assumptions regarding (1) the estimated average statewide cycles of concentration under current practice and (2) the equivalent full load hours[6] of operation by building type. The metric for equivalent full load ton-hours is used quite often in basic energy comparisons between systems or equipment types. For the purpose of this analysis, tonnage of each system type was provided by Trane. Tons installed by building type was calculated by applying the percentages derived from the information shown in Figure 2[7] and multiplying each by the total tonnage for each system type (CWS, WSHP and SCVAV). Ton-hours was calculated next by multiplying the equivalent full load hours by the tonnage in each category.

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[4] Trane Company, ARI statistics of large tonnage chillers into California between 1978 and 2003.

[5] Trane Company, ARI statistics of WSHP shipments into California between 1995 and 2004.

[6] Equivalent full load hours is computed based upon taking all of the loads in a building over the course of a year and then equating them to hours where the chiller is assumed to run at full load with no part load operation. This metric is expressed in ton-hours. This conversion is done to keep the calculations as simple as possible.

[7] Assuming that California is similar to the U.S. statistics in Figure 2 in terms of percent building type of total tonnage.

Next the comparison of water consumption was performed at 3.0 (a conservative estimate of the statewide average) and 6.0 CoC. This was calculated by multiplying the ton-hours of operation for each building type by the gallons per hour for the specific CoC. The water consumption per ton-hour at 3.0 cycles is 2.7 gallons and 2.16 gallons at 6.0 cycles of concentration. The numbers can be derived from Figure 3, where the effect of CoC on water consumption is shown. The difference between the two represents potential statewide savings that could be achieved with the application of improved or new technologies. Based upon these calculations (detailed in Table 1 below), we estimate that over 10,000 acre-feet of annual water savings are available in California with full implementation of the new technologies to existing systems.

Table 1: Estimate of Total Yearly Water Savings For All Systems

Building Type	System Type	Equivalent Full Load Hours	Percent Tonnage of Total	Tons	Ton-Hours of Operation Per Year	Annual Water Consumption at 3 Cycles (Acre-Feet)	Annual Water Consumption at 6 Cycles (Acre-Feet)	Water Savings (Acre-Feet)
Office	Centrifugal, Helirotor	1310	0.47	1,318,446	1,727,691,481	14,313	11,451	2,863
Education		1344	0.23	645,197	867,144,660	7,184	5,747	1,437
Healthcare		4368	0.13	364,677	1,592,907,039	13,197	10,557	2,639
Mercantile		2184	0.11	308,572	673,922,209	5,583	4,467	1,117
Lodging		1835	0.06	168,312	308,778,903	2,558	2,047	512
			SUB-TOTAL	2,805,204	5,170,444,293	42,836	34,269	8,567
Office	Absorption	1310	0.47	85,897	112,559,691	933	746	187
Education		1344	0.23	42,035	56,494,771	468	374	94
Healthcare		4368	0.13	23,759	103,778,438	860	688	172
Mercantile		2184	0.11	20,104	43,906,262	364	291	73
Lodging		1835	0.06	10,966	20,117,051	167	133	33
			SUB-TOTAL	182,760	336,856,214	2,791	2,233	558
Office	WSHP	1310	0.90	413352	541,491,120	4,486	3,589	897
Lodging		1835	0.10	45928	84,277,880	698	559	140
			SUB-TOTAL	459,280	625,769,000	5184	4147	1037
Office	SCVAV	1310	1.00	23,000	30,130,000	250	200	50
					TOTAL	**51,061**	**40,848**	**10,212**

3.0 System Cost

System costs in the year 2000 for the VRTX system were made available by the manufacturer. Since 2000, most manufacturers have instituted price increases of approximately 15 percent and such an increase is included in the system cost for VRTX estimates that follow. In addition to the system cost, installation labor and materials must be included in the total cost, along with a 25 percent contractor installation margin. Overall, typical installed costs range from $40 per ton on larger systems up to over $160 per ton on smaller systems, with the average for most commonly sized systems at approximately $70 per air conditioning ton. For the average chiller size of 371 tons as noted in section 1.7, the installed system cost would therefore be approximately $26,000 in 2005 dollars.

Current (2005) system costs for the Dolphin system were obtained from the manufacturer along with approximations of installation costs, which were based upon their installation experience. The costs assume a retrofit installation that will be more costly than a typical new construction scenario. Again, a 25 percent contractor margin is added to reflect actual installation costs. A 160-ton system was quoted at approximately $16,000 including installation and contractor margin. This equates to $100 per ton. An actual price quotation on a recent 2,400-ton project, again including installation and margin, was approximately $100,000 or about $42 per ton. For the average system of 371 tons, the cost would be about $21,000 installed, or about $57 per refrigeration ton.

Conventional chemically treated systems likewise have a cost associated with installation. These systems require a conductivity controller[8]; chemical pumps (required to pump the various treatment chemicals from their holding containers into the condenser water system); a make-up water meter, which is used to control the amount of acid (pH) of the condenser water system; and an array of small bore piping used to deliver the various treatment chemicals into the condenser water system. Installed system costs for these systems range from $12,000 for small systems to over $30,000 on larger systems, depending upon the complexity of the installation. If we were to assume a $20,000 installed cost for our 371-ton system, this would equate to an approximate cost of $54 per nominal ton.

VRTX and Dolphin systems yield additional savings not associated with water and sewer cost savings. The chemical costs associated with the treatment of conventional condenser water systems are ongoing and must be added to the operation costs of those systems. However, VRTX and Dolphin require little or no addition of chemicals in most applications. Chemical costs vary by provider, quality of the chemical program being provided, and by the quality of the water being treated. Low-maintenance programs can cost as little as $0.50 per ton per month. In this case, a 1000-ton system would cost 1,000 x 12 months x $0.50 or $6,000 per year. More sophisticated programs can cost three times this amount or about $18,000 per year for the same 1,000-ton system. Generally speaking, the more sophisticated programs tend to run higher cycles of concentration and protect the equipment from degradation for a longer period of time. Using our same 371-ton system as an example, and an average chemical cost of $1.00 per ton per month, this expected chemical cost would be estimated at 371 x 12 x $1.00 = $4,450 per year.

[8] A conductivity controller is a device that measures the conductivity of the water and is set to trigger blow-down of the water and the addition of chemical when the conductivity (high TDS and Cycles) limit is reached.

4.0 Cost Effectiveness

The anticipated system life for the VRTX system is estimated at 20 to 25 years, approximately the same as the chilled water systems that they serve. The weighted average equivalent full load ton-hours for all building types is 1,843 ton-hours. Therefore, the water savings on a 371 ton chilled water system would be 1,843 equivalent full load ton-hours x 371 tons, or 684,000 ton-hours. At a 3.0 CoC, this system would consume approximately 5.7 acre-feet of water annually[9]. At 6.0 CoC, the water consumption would drop to approximately 4.5 acre-feet annually[10]. The net water savings would amount to 1.14 acre-feet per year for the estimated lifetime of 20 years, 22.8 acre-feet of water.

At a net initial cost of approximately $26,000, the cost of the total system would calculate to approximately $1,140 per acre foot saved. This does *not* take into account any long-term energy savings due to clean condenser tubes or chemical cost savings to the owner. From the standpoint of the owner, the annual savings become significant when the savings related to utilities (water and sewer) are combined with chemical savings. Figure 4 illustrates the owner's savings potential for the typical 371-ton system (initial cost of $26,000) at various combined water-sewer rates.

We expect that Dolphin treatment systems will last the same 20 to 25 years although the oldest known systems are only about two years old at this date. Using the same weighted average equivalent full load, 1843 ton-hours and 584,000 ton hours of operation for the 371-ton system, the same annual savings of 1.14 acre-feet of savings would be expected. Life time savings of 22.8 acre feet would also be expected.

Using the initial installed cost of $20,000 for the 371-ton chiller plant as stated above, the cost of this system would be approximately $1,030 per acre foot saved. Again, Figure 4 illustrates the expected benefit to the owner.

Because each such system is custom designed to meet the specific requirements of the building cooling system, we recommend that a water agency or municipality considering an incentive program directed at encouraging system upgrades to either a VRTX or Dolphin system incorporate it into a process water program. Process water programs generally provide for variable subsidies for system upgrades and replacements based upon engineering calculations and subsequent measurements of the actual system designed for the purpose. That is, the subsidy is different for each installation, instead of being based upon pre-determined equipment-based amounts.

[9] Computed as follows: 684,000 ton-hours x 2.7 gallons per ton-hour = 5.67 AFY.
[10] Computed as follows: 684,000 ton-hours x 2.16 gallons per ton-hour = 4.53 AFY.

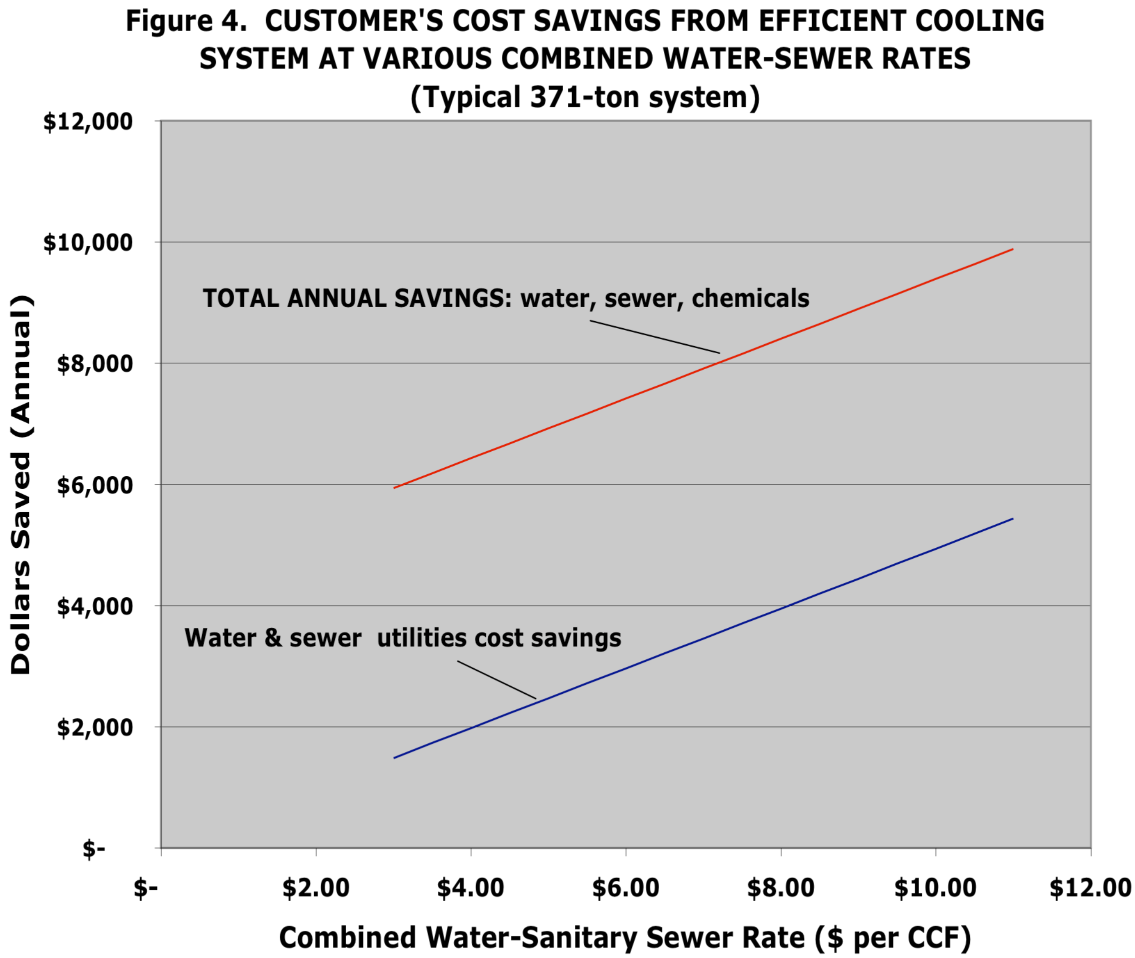


Figure 4. CUSTOMER'S COST SAVINGS FROM EFFICIENT COOLING SYSTEM AT VARIOUS COMBINED WATER-SEWER RATES
(Typical 371-ton system)
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$-
TOTAL ANNUAL SAVINGS: water, sewer, chemicals
Water & sewer utilities cost savings
Dollars Saved (Annual)
$-
$2.00
$4.00
$6.00
$8.00
$10.00
$12.00
Combined Water-Sanitary Sewer Rate ($ per CCF)

Appendix A

Commercial – Industrial Cooling Principles and Systems

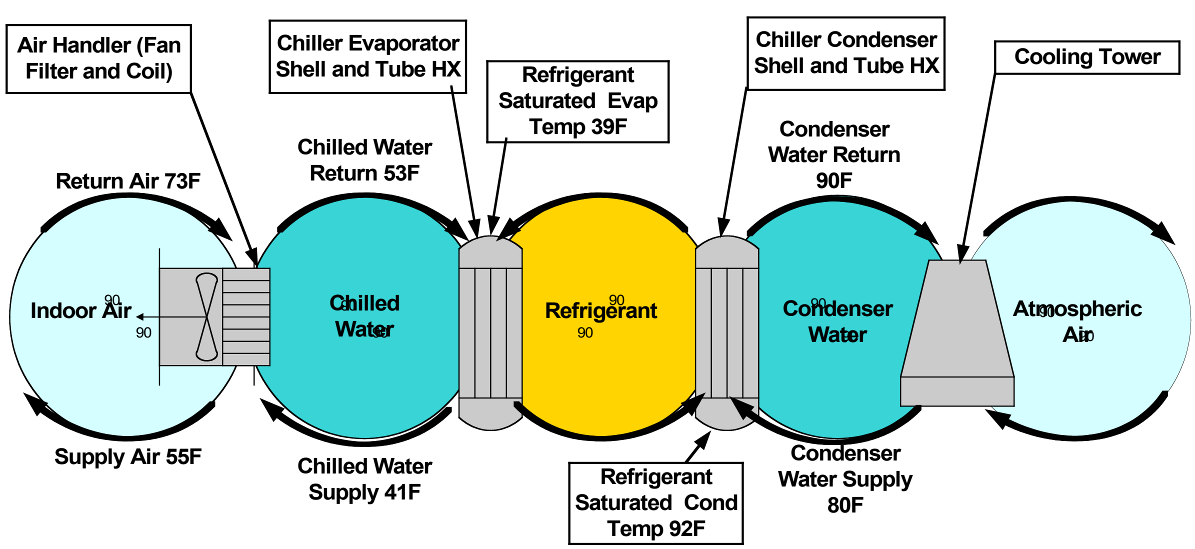
History

As early as 1882, companies such as Frick and Vilter were manufacturing large steam driven reciprocating ammonia systems for industry, replacing ice as the primary refrigerant. In 1928, Frigidaire discovered a new class of refrigerants, halocarbons or chlorofluorocarbons (CFC's) that were not as dangerous as ammonia and allowed for smaller compressor design. However, it was not until the introduction of the electrically driven hermetic centrifugal water chiller introduced by the Trane Company in 1939, with its compact design, that cooling of larger, multi-story buildings and industrial processes became possible. Centrifugal chillers are still the mainstay in today's larger systems in tonnages ranging from about 300 tons to about 3500 tons per single chiller unit. A new generation of chillers entered the market in the 1980s, the helical rotary or screw compressor chiller, in both air-cooled and water-cooled configurations, ranging in tonnage from about 100 tons though 500 tons. Frick, Vilter and Dunham-Bush introduced this technology and Trane, Carrier and others have since followed suit. Since the helirotor compressors are a positive displacement compressor, they work very well in low temperature/process ammonia applications.

Air Conditioning Heat Exchange Process

Figure 1 below shows the entire air conditioning process for a water-cooled chilled water system. Five loops with four heat exchanges are necessary for the system to work. Each heat exchange process can be thought of as a sponge, each of which is used for absorbing and rejecting heat.

Figure 1: Air Conditioning Heat exchange Process - Water Cooled System



Referring to Figure 1, moving from left to right and beginning inside the building, chilled water at 38° to 45°F is pumped through devices called air handlers or fan coil units in order to transfer heat from the interior room into the chilled water loop. The air handler and fan coil units have internal coils through which the cold water passes and cools the return air (from the building space) passing through the external part of the coil. Essentially, the chilled water loop absorbs heat from the air passing through it, dropping the air temperature to approximately 55°F. Air is then recirculated back to the room where it absorbs heat from the room. The air then recirculates back to the air handler and the process starts over again. As the chilled water cools the room air, and absorbs its heat, it rises in temperature and must be re-cooled so that it can repeat the process. To do this, the chilled water loop (which is a closed loop with no evaporation) sends water back to the chiller.

Typically, the chilled water supplied to the air handler is at a temperature between 38° and 47°F, easily driving the air temperature delivered to the building space down to 55°F from a 70 to 75°F return temperature. In turn, the chilled water loop rises in temperature 10 to 20°F, depending upon the design, before being sent back to the evaporator shell and tube heat exchanger of the chiller.

The chilled water loop is cooled by refrigerant inside the chiller, which is hermetically sealed from the atmosphere. Refrigerant in the evaporator is at a temperature of approximately 39°F in order to yield an exiting water temperature of 41°F. The refrigerant absorbs heat from the chilled water, and the refrigerant returns back to the compressor as a gas. In a vapor compression cycle, the refrigerant is compressed and then passes into the condenser where heat is removed from the refrigerant by the condenser water loop. Typically, condenser water returns to the chiller condenser heat exchanger between 80° and 85°F depending upon atmospheric conditions (wet bulb temperature). As it passes through the condenser it absorbs heat from the hot refrigerant and will typically gain 10 to 20 degrees before it exits and returns to the cooling tower. By absorbing heat from the refrigerant, the refrigerant is cooled and passes back into the evaporator, thus completing its loop.

The condenser water is pumped into the water boxes on the top of the cooling tower where it is distributed through the media. Within the cooling tower, the water is broken up into smaller and smaller particles as it is exposed to the surrounding air. Because the air is dry, relative to the molecules next to the water droplets, a certain percentage of the water flashes into a vapor where it is essentially absorbed into the air outside of the building. As this process takes place, the remaining condenser water is sub-cooled as air absorbs its heat. Approximately 1000 BTUs[11] of heat are removed from the condenser water for each pound of water evaporated. The cooling tower is sized so that the total drop in condenser loop temperature is approximately 10 to 20°F before it returns to the chiller condenser heat exchanger.

Cooling Systems Description

All mechanical (vapor compression) cooling systems compress a gas to a state of high pressure and high temperature at which point the gas must be cooled to a high pressure, low temperature liquid prior to entering an expansion device, where it becomes a low pressure and temperature liquid, ready to absorb heat from the process in the evaporator. At this point, the refrigerant gains heat, converts back to a low pressure and temperature gas and reenters the compressor

[11] BTU – British Thermal Unit; a measure of heat energy

where the process starts all over again. During the cooling phase, while the refrigerant is in the condenser, two mediums are used for this cooling: air or water. *Air-cooled* systems, although described below, are not of any significant interest to water conservation professionals.

Water-cooled systems are further broken into two categories: *once-through* and *evaporative systems*. *Once-through* systems use municipal water, lake or river water to cool the refrigerant. They generally take in water, use it in one pass through the condenser, and then send it to drain or back to the original river or lake source. These systems will not be discussed in this analysis. Only cooling systems where the water is used in an evaporative process to cool the refrigerant are considered and addressed in this analysis. In these systems, a portion of the water is vaporized, taking advantage of the principle of *latent heat of vaporization* of water where heat is absorbed in the process, thus cooling the remaining liquid. This allows the water to be sent back into the condenser for additional cooling where the process repeats itself over and over again.

System Application

DX air-cooled applications

Generally speaking, buildings (and their heating-ventilating-air conditioning – HVAC) are constructed at the lowest cost system available. DX (direct expansion) systems fit this requirement best, and is therefore the most prevalent system found in California. Several versions of DX systems are available and they come in tonnages from about one-half ton (6,000 BTU-hours) up to about 125 tons in the largest rooftop style units. There are exceptions as to when an owner or engineer will drive the HVAC decision to a higher-end system, namely, when the occupant demands higher quality, lower sound levels, and lower energy consumption. The decision might be made for any combination of these reasons or a host of other reasons to move up to a better performing system. Generally, on homes and small commercial buildings, some type of a DX system is installed, which is either a rooftop “package” units, typically found on a strip mall (one or two story building) or a split system, similar to what is installed in the typical California home and in many smaller commercial buildings. Some of the largest rooftop units, up to the 125-ton range, can serve buildings of up to six stories. Another type of DX system is the packaged terminal air conditioner (PTAC), which are those units typically installed beneath a window. There is no water consumption in any of these DX system types. Because these are all air-cooled systems, they are not considered in this analysis.

Water-cooled applications

As the building square footage increases, particularly in the vertical direction, the system choices become more limited to the system designer. When a building is larger than 25,000 square feet and almost always when it is taller than five or six stories, the only practical solution to building air conditioning is to run a chilled water or condenser water loop throughout the building. Once this decision is made, the building will have either a cooling tower or closed loop cooler, with the one exception being when an air cooled chiller is employed. Chilled water is also required in many industrial processes applications.

The main advantage of water-cooled systems is that they are much more efficient than air-cooled systems. They also tend to last much longer, 30 years or more in some cases. On the negative side, water cooled systems require better trained maintenance personnel and better subsystem technologies to assist in the maintenance and proper care of these systems. Water-cooled systems typically cost more than air-cooled systems of equivalent tonnage. Finally, water-cooled systems consume water.

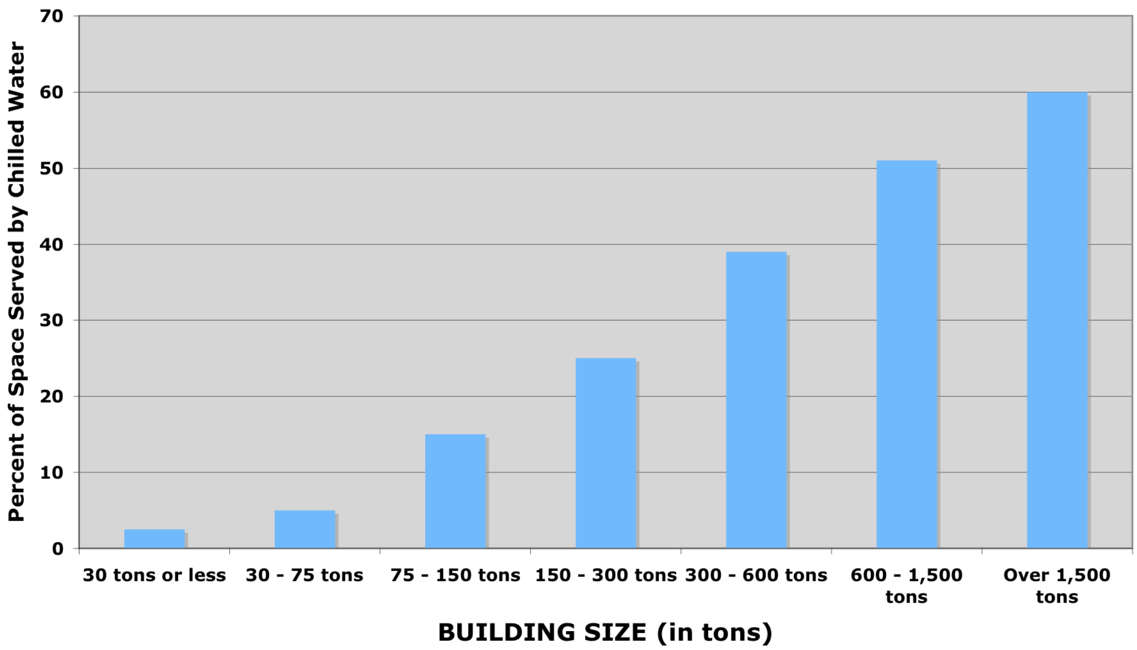
The other types of evaporative water loops include condenser water loops. Condenser water systems are primarily found in two types of air conditioning systems and in some industrial processes that do not require the temperatures of chilled water. Condenser loop temperatures generally range from 60° to about 95°F depending upon the application, and upon whether the cooling device is a cooling tower or a closed loop cooler. Lower temperatures are always attainable in cooling towers when compared with closed loop coolers, but, in some systems, open loop cooling towers are not advised because they introduce dirt, scale and biological growth in the condenser piping system and, more importantly, into the HVAC equipment being cooled. The two types of systems where condenser water is used are the water source heat pump system (WSHP) and self -contained variable air volume (SCVAV) system. The WSHP system typically has very small air conditioning units placed above the ceiling in 2- through 5-ton sizes (for zoning), whereas the vertical self contained systems have units in the 40- through 100-ton size range. Zoning is accomplished with small variable air boxes for temperature control. Typically, these systems do not employ open loop cooling towers but rather closed loop evaporative coolers. These are both popular systems in California and are seen throughout the major metropolitan office building inventory. Figures showing closed loop coolers and cooling towers are included later in this appendix.

Chilled Water System Classifications

Figure 2 illustrates that as building size grows, the likelihood of finding a chilled water system increases, especially on buildings of 100,000 square feet (300 tons) and above.[12] The figure accounts for both air and water cooled systems but does not account for those buildings with condenser water loops with WSHP and SCVAV systems and industrial process cooling loops.

[12] E-SOURCE, Chilled Water Systems, Chapter 8

Figure 2. PERCENT CHILLED WATER SYSTEMS BY BUILDING TONNAGE



Air-Cooled Chilled Water Systems

Refrigerant cooling is accomplished in the condenser in one of two ways, air cooling or water cooling. Smaller systems, i.e., 40-50 tons of refrigeration (TR) and below, are overwhelmingly designed as air-cooled systems because of first cost considerations and, in some cases, because of the lack of a reliable water supply for cooling. However, the first cost advantages of air-cooled systems over water-cooled systems are often offset by huge increases in energy consumption, especially as systems approach 300 to 500 tons. Secondly, the space requirements (footprint) for systems over 500 tons begin to become impractical in many applications. Figure 3 shows a basic air-cooled chilled water system configuration. Because the means of cooling is air, this is not one of the system types to be analyzed within this report.

Water-Cooled Chilled Water Systems

Water-cooled systems are typically larger than air-cooled systems, with the smallest systems starting at 5 tons, but more typically, a small water-cooled system would be thought of as being in the 20-30 ton range. Naturally, as the size of the building and/or cooling load increases, so does the probability of finding a water-cooled system as opposed to any of the previously mentioned system configurations. By the time the building size reaches approximately 50,000 square feet (75 tons), water-cooled systems start to become more prevalent. When the building size reaches 200,000 square feet (300 tons), most chilled water systems are water-cooled. When properly designed, water-cooled systems consume roughly one-half the energy of an equivalent air-cooled system operating at full load on “design day”. Figure 4 shows the major components of a water-cooled chilled water system, which matches up with the air conditioning heat exchange process described earlier in this appendix.

Figure 3: Air Cooled Chilled Water System

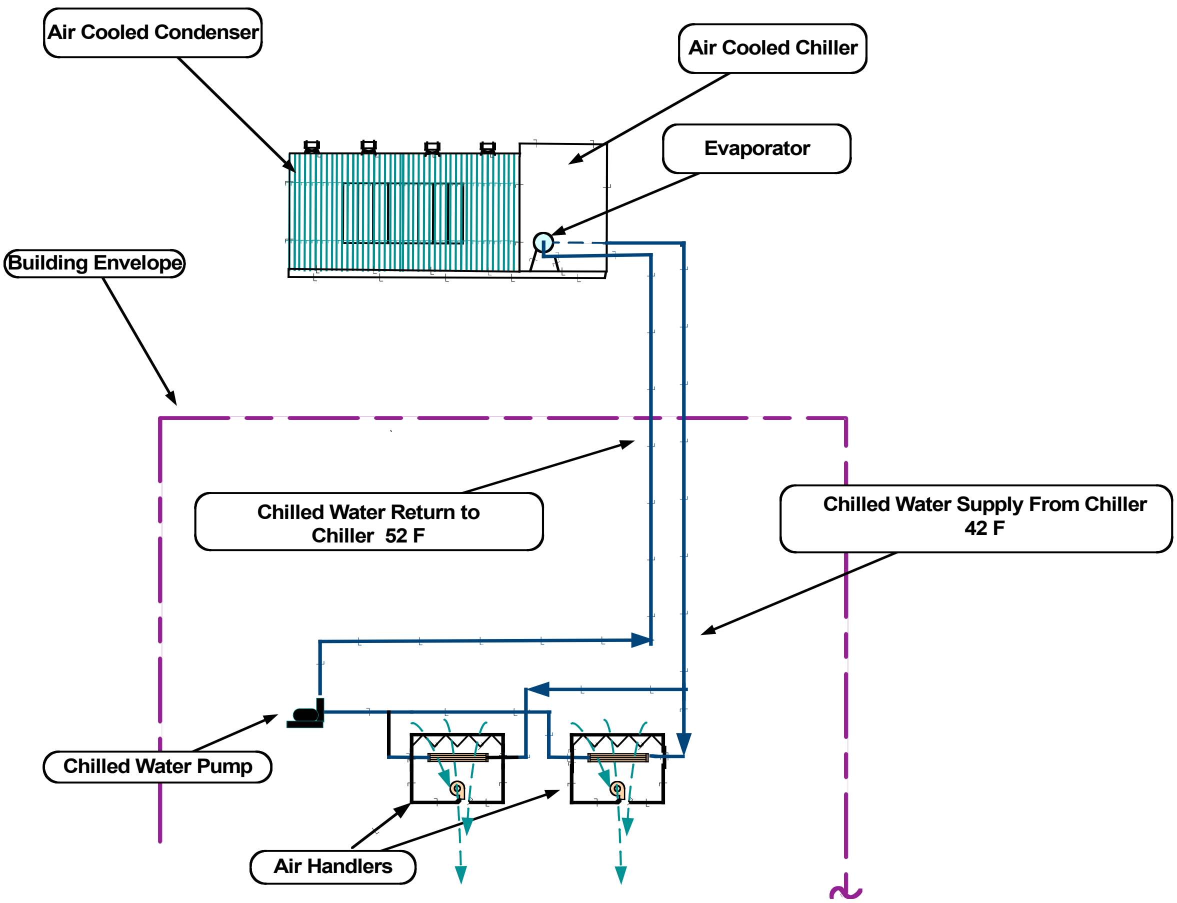
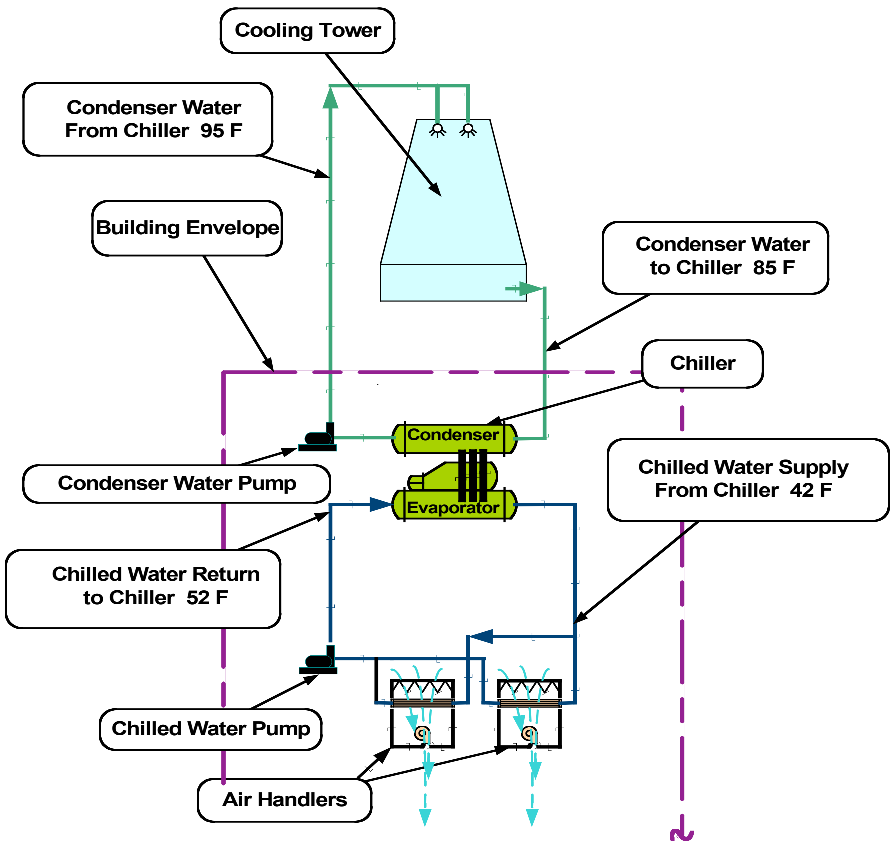


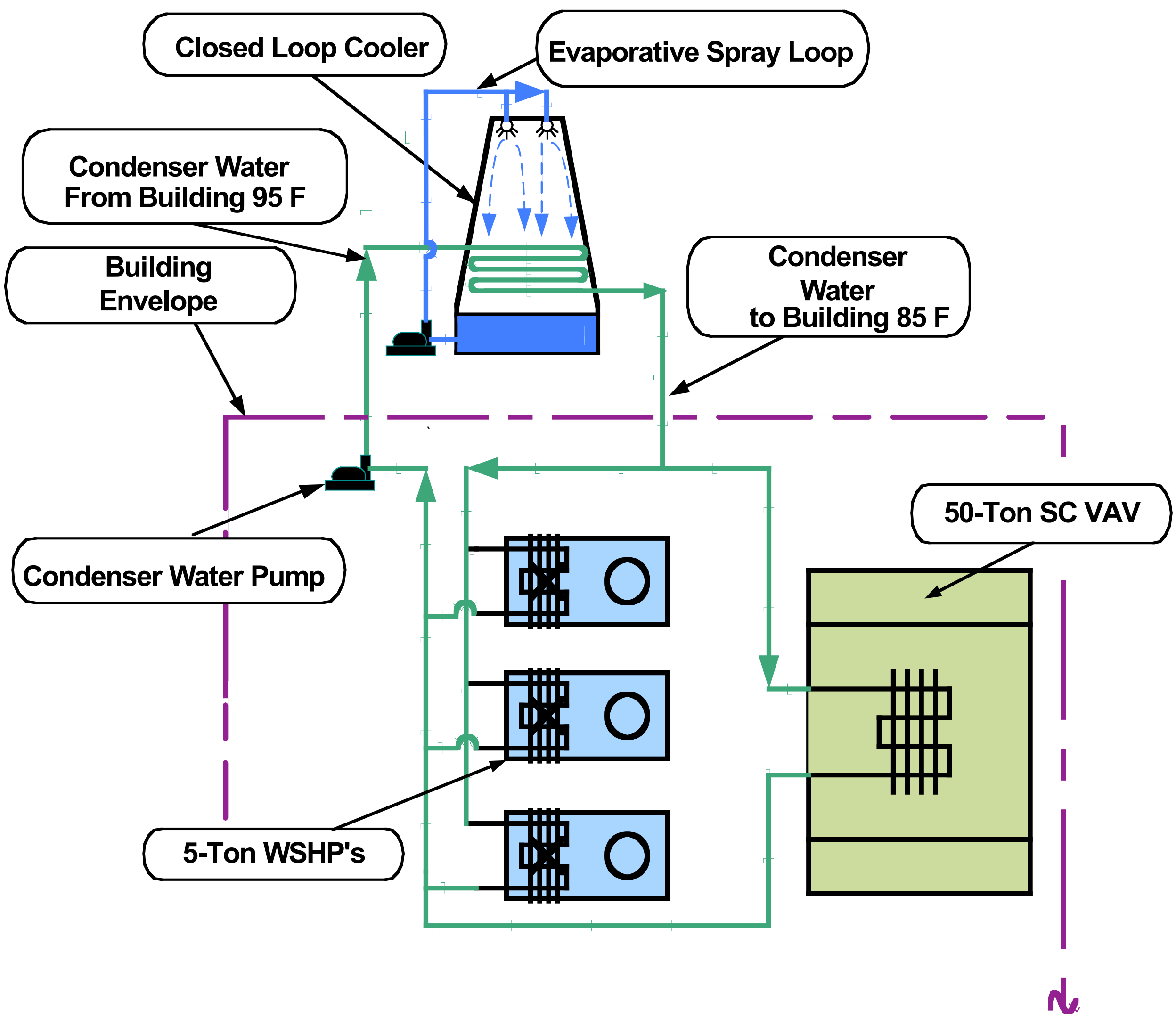
Figure 4: WATER COOLED CHILLED WATER SYSTEM



Condenser Water Systems (WSHP & SCVAV Systems)

Figure 5 illustrates a combined water source heat pump and a self contained variable air volume system. Typically, they do not appear in the same building but are shown here for simplicity. Both systems are similar in that they use condenser water with temperatures ranging between 60° and 90°F. They are almost always served by a closed loop cooler in order to keep internal water to the refrigerant heat exchangers clean on the water side. The closed loop is not exposed to the atmosphere but the open spray loop is. The heat exchange is not as efficient as in open cooling towers but this is a necessary compromise.

Figure 5: WATER SOURCE AND SELF CONTAINED SYSTEMS



Heat Rejection Devices

Heat rejection equipment is broken down to two main categories: (1) cooling towers as shown in Figure 6, where the condenser water loop serving the chillers is exposed to the atmosphere and is directly evaporated and (2) closed loop evaporative coolers as shown in Figure 7, where the condenser water loop is closed and is not directly exposed to the atmosphere.

Figure 6: COOLING TOWER

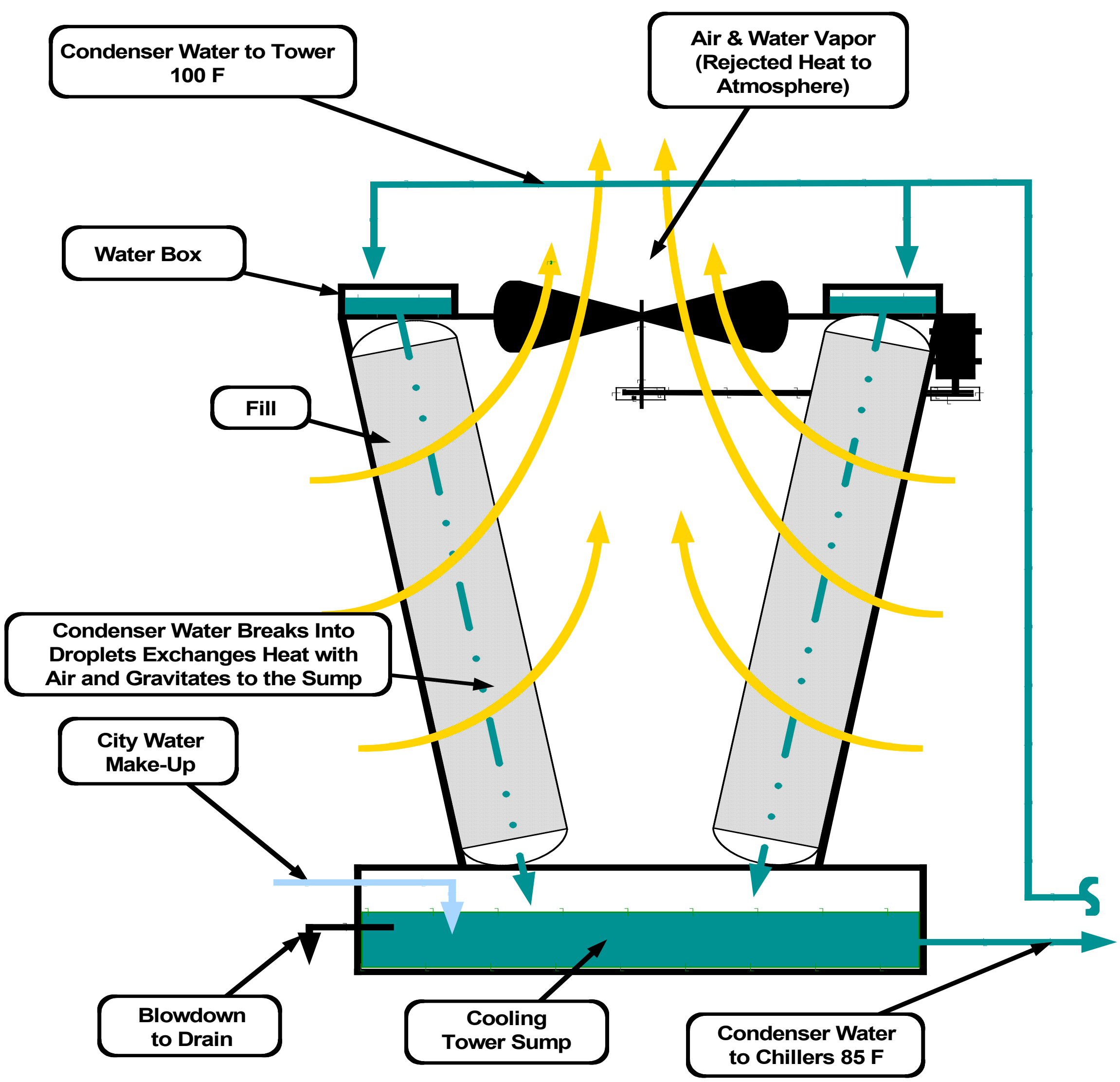
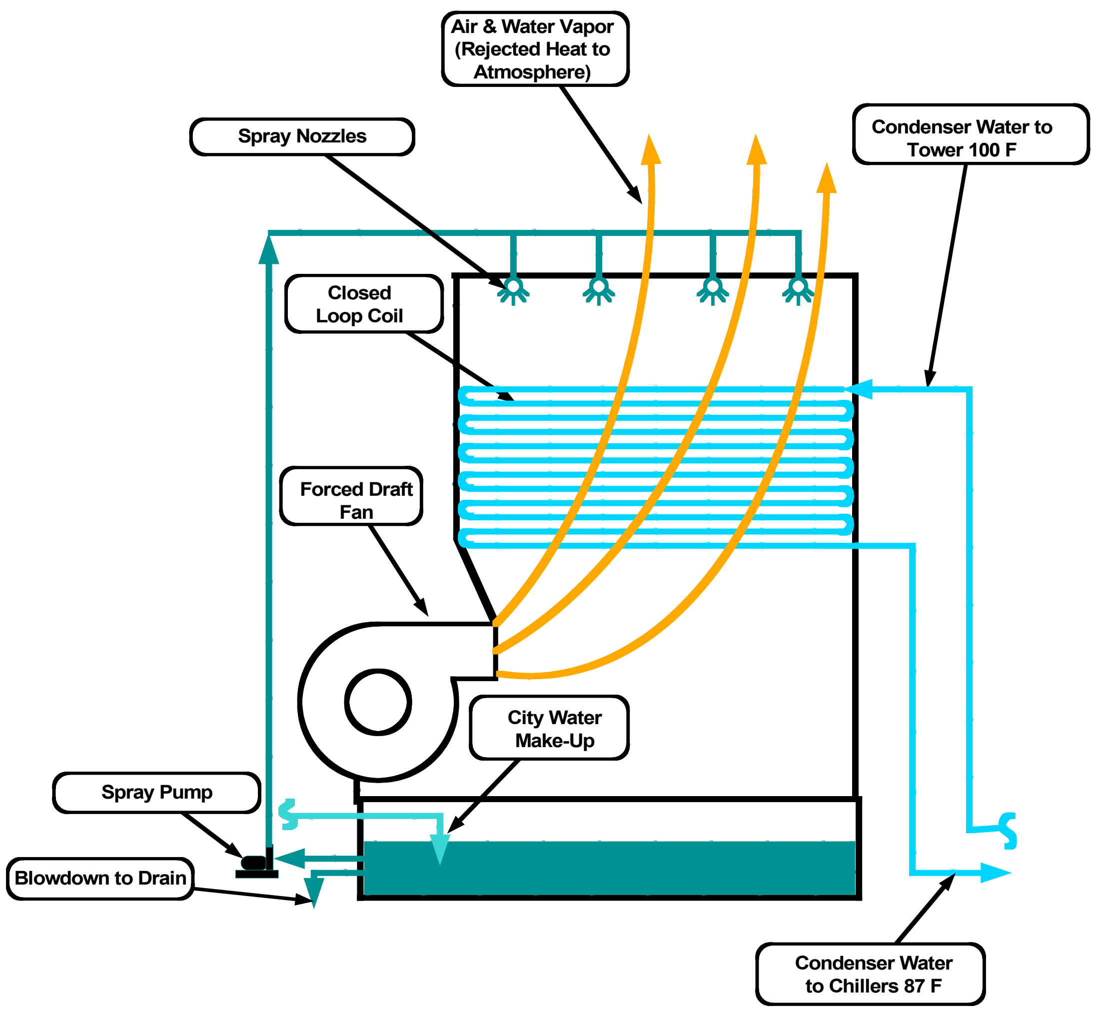


Figure 7: Closed Loop Evaporative Cooler



Cooling towers are configured in a draw-through (induced draft) configuration, as shown in Figure 6, or are in a blow-through (forced draft) configuration where the fans are positioned near the cooling tower sump and are turned on to push air through the fill which is located above the fans near the top of the tower. When the cooling load is low and the air temperatures are low, induced draft towers take advantage of their natural "stack effect" and provide a fair amount of cooling without turning on the fan motor. Blow-through configurations cannot provide the same amount of cooling without fan operation.

In an open loop cooling tower, the water is evaporated directly from the condenser water itself. Thus, dissolved solids in the water begin to concentrate. If not controlled, some of the minerals will precipitate out of solution and form scale.

In closed loop system shown in Figure 7, water is sprayed over a heat exchanger located inside the closed loop cooler. This secondary loop (evaporative spray loop) of water is subject to evaporation and the water within this loop undergoes mineral concentration as water is evaporated. However, the closed loop water, i.e., the water that runs out to the water source heat pump or self contained unit air conditioners, never evaporates because it is never exposed to the atmosphere. It is completely free of the scale and dirt that is prevalent in open condenser water loop systems. As a result, the heat exchange surfaces of the individual air conditioners remain very clean. Especially on the smaller water source heat pumps, it is very difficult to clean the coaxial tube condenser coils. If they are not kept clean, the units become very unreliable and maintenance can become a very troublesome problem.

This method of indirect evaporation creates an "approach" temperature of a few degrees between the closed loop temperature and the temperature of the open "secondary" loop, where water is sprayed over the closed loop cooler coil mentioned earlier and shown in Diagram 6 above. The air conditioning equipment loses some efficiency with higher condensing temperatures as a result.

Both systems operate on the principle of water evaporation. For every pound of water evaporated, 1000 BTUs (8,700 BTUs per gallon of water) of heat energy is absorbed into the vapor that is created, thus reducing the temperature of the condenser water. The ability of the air to absorb water and convert it to a vapor depends on what is called "wet bulb depression" or the difference between the dry bulb temperature and the (lower) wet bulb temperature. The lower the wet bulb temperature, the more water that can be absorbed, and the lower the temperature attained by the condenser water. This temperature differential of the condenser water to the design wet bulb temperature is called the approach temperature. As this mixture of air, which is now saturated with moisture, leaves the envelope of the cooling tower, it is forced into the open atmosphere. Fans, either induced draft (draw-through) or forced draft (blow-through) provide the means for air flow. Generally speaking, the lower the condenser water temperature, the more efficient the heat exchange within the condenser of the HVAC equipment and the lower the energy consumption.

Cooling Tower Operation

As seen in Diagrams 5 and 6, cooling tower and closed loop cooling equipment is relatively simple in design. Condenser water enters the cooling tower, after removing heat from the chiller, having gained 10° to 20°F in the process. The water is pumped into the water boxes in cooling towers and into the closed circuit coil bundle in the closed circuit cooler. The water boxes collect and distribute the water over the fill or media which breaks the water up into discretely sized droplet's, sized for the optimal contact with air and therefore absorption of heat. This water continues to drop or gravitate through the media as air also moves across this media in a cross flow direction until the water reaches the sump at the bottom of the tower. This is the element of the process whereby heat is removed and absorbed into the vapor which has been created by the heat gain. Ideally, the water vapor is removed from the tower confines by the high velocity of air flow and is distributed into the atmosphere above the tower to be swept away by prevailing winds. The sump is simply a basin or collecting place in the bottom of the tower. Water levels can vary, depending upon tower design, from six inches to as much as several feet deep. From here, the water travels through a suction screen (prohibits larger debris from entering the condenser water piping) and into the return piping to the chillers where the process starts all over again. The sump contains blowdown piping that is used to flush out condenser water to the sanitary sewer drain connection. It also has the make-up water connection to the municipal water system, which supplies fresh water when required. A valve located on the make-up line automatically opens when the float valve (similar to the float valve in a household toilet) or electronic level sensor calls for additional water.

The initial stage of cooling may simply involve having the condenser water pump run and distribute water to the water boxes. The fan may not need run at low operating loads in this type of tower since there is a natural convective air flow, sometimes called “stack effect” through the tower. The tower fan is turned on when the convective air flow can no longer maintain the condenser water temperature within the desired set points. Most cooling tower fans will either have a two-speed fan motor or a variable speed drive (frequency inverter) to match the tower cubic feet per minute (CFM) of airflow and corresponding capacity to the air conditioning or refrigeration load.

In a closed loop evaporative cooling system, the condenser water loop never “sees” the atmosphere, therefore staying very clean and not experiencing any water evaporation. This has the net effect of keeping the heat exchange surfaces of the air conditioning or refrigeration equipment very clean and at optimal energy efficiency. Control is staged in a similar manner to a cooling tower in that the first stage is to simply run the condenser water through the internal coil. Convective air flow removes enough heat to satisfy the heat transfer requirement when a low operating loads. The second stage would be to turn on the fan at low speed. The third stage then initiates the spray pump which takes water from the sump and sprays it over the closed loop coil. This is the water that evaporates and removes heat from the condenser water inside the coil. The final stage of cooling would be to turn the fan on high speed. Because the condenser water must transfer heat through the internal coil of the closed loop cooler, an additional approach temperature is introduced thus elevating its temperature slightly over the corresponding temperature from a cooing tower with no coil.

Cooling Tower Manufacturers

The market place for cooling tower and closed loop coolers is populated with many participants from around the world. The dominant manufacturers in the United States are: Baltimore Aircoil, Evapco, and Marley. These companies produce a wide range of products that are pre-engineered, “packaged” off the shelf designs with certification of performance. They are supported by a large network of dealers and service technicians throughout the United States. Smaller manufacturers of packaged cooling towers and closed loop coolers are Recold and Delta. Another group of specialty tower manufacturers are the group that includes Tower Engineering, Inc., Ceramic Cooling Tower, Tower Performance, Inc.., Cooling Tower Systems, Inc. and Cooling Technology, Inc. This latter group custom designs towers to meet individual needs of a particular facility or customer to fit site space, architectural, sound or other requirements.

Tower construction materials vary from the most common, galvanized steel, to stainless steel, concrete, wood, fiberglass, and an assortment of plastics. Tower tonnages range from small 5 to 10 tons up to several thousand tons.

Appendix B

Condenser Water Treatment Systems

Background

The history of condenser water treatment has primarily been that of chemical treatment. Chemical treatment has done a modestly adequate job over the years, but the quality of the treatment is subject to human error, the quality of the chemicals, the diligence and integrity of the individual technician or specialist performing the work. The main concern of the operators and chemical treatment specialists has been to keep the wetted surfaces clear of scale, biological growth and corrosion. This is a very difficult task that depends upon the constituencies inherent in the water and requires constant attention by the chemical treatment specialist.

In general, very little attention has been paid to water efficiency. The main focus has been on the condition of the wetted surfaces of the system equipment and only occasionally on system efficiency. Because it has been the general belief that water is inexpensive, and when coupled with a lack of understanding of water treatment by system operators, the subject of water efficiency is never raised. Consequently, all decisions regarding water have been left to the chemical treatment specialist who has no stake in the potential savings or operating costs.

Today, several technologies are available that promise or ensure greater water savings when compared to the traditional chemical treatment approaches. In some cases, these technologies also do not require the constant attentiveness and thoroughness required of a comprehensive chemical treatment program.

A technology review and brief description of available treatment systems follows, together with an overview of the advantages and disadvantages of each such technology. It is important to note that these technologies must not only perform all of the basic water treatment requirements (the elimination or prevention of scale, biological growth, and corrosion) but also perform as water efficient technologies. All requirements must be satisfied in order to be recommended as a viable water-efficiency measure or practice.

Condenser Water Treatment Program Requirements

The most basic requirements of any water treatment system are three fold:

Scale Control – prohibit the buildup of scale (typically calcium or silica scale) on heat exchanger surfaces. The heat transfer coefficient "k" of calcium carbonate is k=0.4625 (Btu/Hr ft °F) and for silica k= 0.04625 (Btu/Hr ft °F). This is a very low heat transfer coefficient when compared to copper which is k = 227.2 (Btu/Hr ft °F).[13] Calcium and silica scale are effective insulators.

Scale precipitates as molecules bond to one another or to colloidal particles in the condenser water. This occurs through natural bonding of opposite charges within the atomic structure of the various molecules. As these particles grow, they move from the state of being in solution to

[13] Drexel University, 1999. *Overview of Electronic Descaling Technology*, Professor Young I. Cho, Department of Mechanical Engineering, July.

one of being in suspension and finally to precipitation where the water can no longer hold them and they either attach themselves to wetted surfaces or drop from gravitational force to low areas of relatively low water velocity. Larger particulate can be filtered, with the finest filters being around 5 microns. However, colloidal particles can be in the 0.01 to 5 micron size range and, as such, settling times for such particles are very slow and they are not filterable without the use of membrane technology. A 0.01 micron sized particle will contain approximately 7 million calcium carbonate molecules and a 1.0-micron particle will contain around 10 billion molecules of calcium carbonate.[14]

Corrosion Control – prohibit the corrosion of metal surfaces, such as: copper tubes in the chiller condenser tube bundle; steel piping throughout the system; and zinc in the galvanized steel of the cooling tower. Corrosion rates of 2 – 5 mils per year (mpy) (1 mil = 1 one thousandth of an inch) are considered acceptable and a rate of 0 – 2 mils is excellent. Corrosion generally occurs when oxygen attacks the surface of iron, copper or zinc and oxidizes it, releasing ferrous and hydroxyl ions into the surrounding water. A secondary reaction then occurs when further (secondary) oxidation takes place, changing the ferrous ion into a ferric ion. Similar reactions occur in copper and zinc. Corrosion can take place in several ways:

General Corrosion - Uniform loss of metal across the entire exposed surface.

Pitting Corrosion – Localized corrosion over a small portion of the exposed surface.

Crevice Corrosion - Also a localized form of corrosion where certain anions such as chlorides promote a chemical reaction with hydrogen (H^+) ions or hydroxide (OH) ions in water (hydrolysis).

Underdeposit Corrosion – One of the most prevalent in condenser water-cooling systems. Scale formed on the surface of metal traps dissolved oxygen behind the scale. Oxygen oxidizes the metal atoms on the surface. The deposit prohibits scale inhibitors from gaining access to the corrosion site.

Galvanic Corrosion – Associated with dissimilar metals connected by an electrolytic solution. Generally speaking, the greater the difference in metal "nobility" the greater the galvanic corrosion rate. Hydrogen ions in the vicinity of the metal surface accelerates the removal of electrons from the metal surface causing a weakening of the atomic bonds of the atoms on the metal surface which break away.[15]

Biological Control – prohibit the growth of living organisms in the condenser water system. The two main areas of concern are: 1) plant life, such as "biofilm", "bioslime" or algae, and 2) bacteria.

Algae can generally be seen by the naked eye and is most prevalent in the recesses of the cooling tower structure, especially in areas exposed to direct sunlight. Biofilm or bioslime may be invisible to the naked eye and grows on any wetted surface of the condenser water system. It is

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[14] McLachian, David, PhD, 2002. Fundamentals of Water Treatment, Electrostatic Technologies, Inc., Fluid Treatment Solutions, Inc.
[15] Gulf Coast Chemical Commercial, Inc., 1999. *Corrosion*, Revised, June 29..

believed that it acts as a kind of glue for the attachment of scale crystals, thus accelerating scale accumulation and/or can form an anaerobic layer of biofouling covered by an aerobic layer of biofouling. As a result, little oxygen and nutrients reach the anaerobic layer accelerating the growth of anaerobic bacteria and upon the death of the bacteria, localized acids promote corrosion in metals, particularly steel and iron.[16]

Bacteria found in condenser water systems can be very harmful to people. The Cooling Technology Institute (CTI) target value for controlling bacteria is 10,000 CFU/ml (colony forming units). It is important to keep bacteria under control for the maintenance personnel working on or around the cooling tower(s). Legionnaires' Disease (Legionella Pneumophelia), a deadly pneumonia contracted by the inhalation of water droplets containing the bacteria, has gained much notoriety since the first known outbreak in Philadelphia in 1976 when 29 people died from this single incident. The Center for Disease Control (CDC) in Atlanta estimates that the disease infects 10,000 to 15,000 persons annually in the United States and that approximately 39 people die per week from the disease without anyone knowing that the cause of the death was Legionella.[17] (some citations here would be very useful) Although Legionella can, and most often does come from the water in domestic plumbing systems, condenser water systems present a perfect habitat for legionellae bacteria where it is warm (80° to 120°F) and where surfaces covered with biofilm and scale are protected from biocides. Although the U.S. Government and the State of California do not require testing for bacterial levels, including testing for legionellae bacteria, liability does exist for the owner/operator should someone become infected with the disease that could be traced back to their cooling tower site.

A comprehensive water treatment program keeps all three aspects, i.e., scale control, corrosion control and biological control, under control and the cooling tower in good working order while, at the same time, maximizing water efficiency.

Traditional Chemical Treatment

The conventional water treatment system for cooling towers in the United States utilizes chemical additives that are typically administered through an automated system. The basic automation includes a TDS (total dissolved solids) meter to monitor the concentration of solids in the water. When the upper limit for TDS concentration is reached, it triggers an automated blow down or bleed valve to open. When that occurs, blow down water is sent from the cooling tower to the sanitary drain (sewer). As the level of water in the cooling tower sump is lowered, a valve in the make-up water line is automatically opened. Fresh municipal water of relatively low TDS is introduced back into the system, thus diluting the condenser water loop remaining in the cooling tower sump. The system also utilizes metering pumps for the administration of the various chemicals taken from stored drums. The delivery systems and the treatment strategy devised by the chemical supplier are designed to control the three important areas of concern discussed earlier. For the vast majority of customers, chemical treatment has been the *only* treatment methodology available through the years. The system owner usually accepts without

[16] Zeta Corporation website, 2005. Biofouling and Biocorrosion taken from *Role of Bacterial Adhesion in Biofilm Formation and Biocorrosion,* Marshall, K.C. and Blainey, B.L. (1991), in Biofouling and Biocorrosion in Industrial Water systems, eds, Fleming H. and Geesey, G.G., Berlin, Springer-Vertag.
[17] PM Engineer, 2000. *Legionnaires' Disease*, by Matthew R. Freije, July.

question the results that the chemical supplier is able to achieve, good or bad. Unfortunately, most owners cannot tell the difference.

The term "cycles of concentration" (CoC) or "cycles" is often used when referring to condenser water systems. CoC refers to how many times the solids in the municipal make-up water can be concentrated without incurring damage (scale, corrosion and/or biofouling) on the wetted surfaces of the system components. In basic terms, the higher the CoC, the higher the water efficiency of the system. This translates into less water being sent to drain for any corresponding delivery of air-conditioning tons and/or ton-hours of cooling. The maximum possible CoC varies from area to area and must be understood by the specialists administering the chemical treatment.

As an example, one CoC would mean that the municipal water level of dissolved solids is maintained in the condenser water loop. Stated another way, the amount of water evaporated equals the amount drained to the sanitary sewer system. For example, a water supply contains 30 PPM (parts per million) of a given mineral, and at that level, the water might allow concentration (with chemical additives) up to 5 times that concentration (five cycles) without risk of scale accumulation, resulting in a CoC of 5. In another geographic area, the water supply may have 125 PPM of the same mineral. Utilizing the same chemical treatment program, the condenser water can only be "cycled up" to a little over 1 cycle while still providing the same degree of scale protection (i.e., a CoC of 1). The constraining scale formation, or in some areas the biological constituencies, determine the allowable concentration levels.

A treatment strategy properly developed and administered by the chemical supplier takes into account the solubility of the various scale-forming constituents, the pH of the water, and water temperature, each one initially determined from empirical data, but later from actual experience with the facility and its cooling tower. The success of any program is dependent upon the quality of the chemical itself, the diligence and knowledge of the specialist administering the program, and the integrity of that person.

Scale Control

The chemical treatment strategy is fashioned around the worst constituent. Essentially, chemical additives keep the oppositely charged particles from bonding to one another and precipitating out of solution. In many parts of California, especially Southern California, calcium carbonate ($CaCO_3$) is the main ingredient in scale formation, and is the biggest concern of water treatment specialists. Other scale-forming molecules containing silica and magnesium are also prevalent but not to the same degree as calcium in its various forms, primarily calcium carbonate. Therefore, to save water, higher concentration levels of calcium and other scale-forming constituencies must be dealt with in the condenser water system by the chemical specialist.

To do this, pH control (lowering of pH) is administered and is accomplished with sulfuric (lower cost), hydrochloric or citric acid. When acid control is utilized correctly, attention is shifted from scale control to the other two concerns, i.e., corrosion and biological control that each become more complex and difficult as a result of low pH. Because of the dangers of handling and administering acid chemicals, the trend today is away from such programs. Instead, phosphonates (organic phosphates) are used when pH (acid) control is not available.[18] Phosphonates are often supplemented with polymers or co-polymers that are added to permit the concentration of calcium and other scale forming constituencies to levels above traditional chemical treatment strategy levels. These chemicals keep the calcium carbonate and other ions dispersed in the water, thus prohibiting attraction and the resulting crystalline growth and precipitation. An acceptable average for concentration levels in the State of California is 2.5 to 3.0 cycles with a well-run chemical program.

The TDS controller is set so that all dissolved solids never exceed a predetermined level. The worst constituent is typically hardness measured as calcium carbonate, $CaCO_3$. By keeping the TDS below a predetermined level, calcium is kept under the critical concentration level, thus prohibiting it from precipitating out of solution and forming scale. As the limiting TDS is reached, the bleed or blow-down valve is opened for a specific period of time thus diluting the concentration of all solids. This process repeats itself over and over again.

Saturated concentrations of calcium to higher levels will force calcium out of solution (precipitation) that will likely result in scale formation. It is important to note that the solubility of calcium goes down as the temperature of the condenser water rises, making the most likely location for scale in the chiller condenser tubes, the warmest point in the system. Heat energy increases the motion of water molecules, which, in turn, increases the motion of ions (charged particles), which collide thus increasing the chance of the formation of insoluble particulate matter (scale). As this process continues, the size and concentration of the calcium crystals increases to the point of insolubility where they no longer can stay in solution and precipitate out of solution into suspension. This is especially dangerous to system operation in that the most important heat exchange in a chilled water system is the one in the condenser. Small changes (additions) in scale formation in the condenser lead to large reductions in overall chiller efficiency and capacity.

No single chemical process has totally eliminated scale formation without side effects. Chemical treatment is a “balancing act” between the three basic needs of any program. As ecological constraints on the use of many chemicals continues to narrow the available choices, the effectiveness of chemical programs becomes more and more difficult, especially as they relate to scale related problems and how they affect operating costs, including energy and water consumption.

Corrosion Control

Since May of 1990, chromates used in many inorganic polyphosphate compounds have been banned from use in treating cooling water in comfort air conditioning systems. These chemicals were particularly effective in corrosion control and actually assisted in biological control because of their high toxicity of the chromates.[19] Corrosion control in copper based systems is primarily accomplished with alternative chemicals such as triazoles. These chemicals are used primarily to keep surfaces from pitting due to attack from oxidizing biocides. If triazoles are maintained at too low a level, the surface of the copper will not be sufficiently covered and corrosion will occur. Other inhibitors include molybdinate compounds, phosphates, nitrite salts and silicate

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[18] Harfst, William F., 1999. *Water Wars, Water treatment Strategies to Fight Contaminants in Facility Chillers and Boilers*, July 16.
[19] McLachian, David, PhD, ibid.

compounds that are used to coat the wetted surfaces and thus pacify them from oxygen attack. Biofouling, accumulated on the wetted surfaces can also cause corrosion. The treatment program also must effectively kill living organisms, thus prohibiting their growth in the system.

Biological Control

Microbiological growths such as algae, biofilm or bioslime, bacteria and mold can find suitable habitats for growth on the wetted surfaces of any condenser water system. This is likely to occur in the recesses of the cooling tower fill and in the spiral grooves of “enhanced” condenser tubes found in today’s chillers. As noted earlier, chromates have been banned from use since 1990. Now, the traditional biocides are oxidizing chlorides and bromides that are effective but sometimes lose their effectiveness against certain strains of living organisms. Additionally, when biofilm is allowed to build up for any lengthened period of time or where wetter surfaces are exposed to direct sun light, these chemicals are sometimes non-effective. Non-oxidizing biocides are now being used such as glutaraldehyde and isothiazolinone with some success.

A relatively new technology, Chlorine dioxide, has shown excellent results as a biocide but must be produced insitu with an independent system. Chlorine dioxide levels are maintained through direct real time monitoring to ensure effectiveness. Chlorine dioxide is a very strong oxidizer and is selective in the sense that it only oxidizes living matter such as bacteria and biofilm but will not go after metals such as zinc, copper and iron.

The administration of these chemicals at the time when they are needed and in the right proportion is somewhat of a balancing act. It takes the diligent care of a knowledgeable chemical treatment specialist to maintain a meaningful and effective program. Cost constraints do not often allow this luxury. The chemical supplier must devote their time to multiple accounts and attempt to keep everything running perfectly. It is important to keep in mind that changes in treatment systems happen quickly, but the deleterious results often occur gradually and take months or years to be discovered. Because of this, they are rarely noticed by the building owner. When lapses in the treatment program occur, the results are not manifested until years later and may require that the cooling tower be replaced.

Chemical Treatment Programs and Savings Verification

Because of the hit and miss nature of chemical treatment programs, consideration should be given to excluding this technology from a conservation program unless a very rigorous measurement and verification program is instituted and maintained by an independent third party. The chemical treatment company’s incentive compensation needs to be tied to the verified long-term efficiency of the cooling tower and the resulting water savings. This can be accomplished with the addition of meters on the tower make-up line and blowdown line. The ratio of the two readings gives the average cycles of concentration maintained. Periodic physical examinations of the cooing tower and chiller readings must be included in the program. The main areas to be specified are corrosion control held to within strict limits of metal depletion. Accurate logs should be kept of all readings and be readily available for the viewing of the third party inspectors. The best and most accurate way to keep logs is to do it automatically through an electronic system.

As mentioned earlier, a chemical treatment program is only as effective as the individual assigned to the given account and the time that is spent administering the adopted chemical program. Even with the most conscientious of specialists administering a chemical program, things can go wrong. If the specialist is not present during changes in the source water quality and/or constituency, the chemical program can be rendered ineffective in a matter of a few hours. In addition, empty chemical drums, inoperable chemical feed pumps, broken TDS meters, or valves, or a malfunctioning controller are all possible impediments to a successful program with sustainable water savings.

Non-Traditional Treatment Technologies

History

Traditional water treatment has been the domain of the chemical industry for the past 70 years in the HVAC industry. Results vary widely based upon the source of make-up (municipal) water and the chemicals used, but results also have a lot to do with the individual specialist supplying the chemicals and the profitability of the company providing the services. In some cases, the results of chemical water treatment have been marginal and even poor in the extreme, encouraging customers to look for better, less costly methods of water treatment.

The history of non-chemical water treatment is long and very controversial.[20] Magnets were the first non-chemical approach to water treatment to be tried. Benefits of magnetic lodestones were understood and used to decrease the formation of scale in cooking and laundry applications. This technology has been investigated and adapted for use in various water treatment applications since the turn of the 19th century. However, it was not until the availability of rare-earth element magnets, solid state electronics, and advanced ceramic materials, that non-chemical treatment systems became commercialized during the environmental movement starting in the 1970's[21]

Technologies utilizing magnetic, electromagnet and then electrostatic principles, dominate the non-chemical suppliers of water treatment technologies. Other technologies, not utilizing these principles, have also been introduced in more recent years and are also be discussed in this paper. In response to this trend away from the traditional treatment of water through chemistry, the chemical suppliers have responded with advanced chemical treatment programs that have demonstrated a better ability to deal with scale and biological fouling, thus allowing higher levels of water savings through reduced blow down.

Since the 1970s, scores of suppliers of non-chemical "systems" have come and gone. The claims for the effectiveness of their systems were matched only by the claims against them! Early systems, due to misunderstanding and misapplication of the technology, failed or the results did not meet the claims of the seller or expectations of the buyer. This, then, led to the general dismissal of this approach to the treatment of water. Chemical supply companies, who were temporarily displaced by the new technology, became very vocal in attacking all non-chemical technologies for understandable reasons.[22] This has been the primary resistance factor impeding a more rapid growth in non-chemical technologies.

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[20] Huchier, Loraine A., P.E. MarTech Systems, Inc., Lawrenceville, NJ, no date. *Non-Chemical Water Treatment Systems: Histories, Principles and Literature Review.*

[21] U.S. Department of Energy (DOE), 1998. *Non-Chemical Technologies for Scale and Hardness Control*, DOE/EE-0162.

[22] West, Burke A., P.E., no date. *Non-Chemical Water Treatment Technologies for Cooling Towers.*

New technologies entering the marketplace must always overcome serious obstacles. For the most part, newer technologies are developed and marketed by small under capitalized companies that do not have the backing necessary to fully develop the technology's efficacy with supporting documentation and testing. Most of the claims by the manufacturers are not substantiated with scientific field-testing and this naturally leads to skepticism on the part of knowledgeable building owners and engineers. The success of both laboratory controlled conditions and field testing have been unpredictable.[23]

For the most part, testing (if any) is performed by the manufacturers themselves, which has added to the skepticism about their claims. Comprehensive testing is very expensive and, for the most part, has been non-scientific. Because cooling system operation is very dynamic, fluctuating cooling loads, varying water conditions and temperatures make controlled testing very difficult. Additionally, manufacturers have tended to focus their attention on a particular area of performance and not on *all* aspects of water treatment necessary for a complete and comprehensive treatment program (i.e., scale, biological, and corrosion control). Results, then, are limited in scope and incomplete, often little better than anecdotal information. Additionally, most of the manufacturers and the people conducting their testing seem to have little or no knowledge of heat transfer equipment, particularly chillers and chiller performance. Their assessment of overall chiller efficiency and corresponding energy calculations appear to be limited and do not hold up with the chiller manufacturers. None of the technologies surveyed have successfully engaged the support of a major chiller manufacturer and thereby gained the support and understanding that they could bring in calculating energy consumption and verification of savings. Unfortunately, most of the firms engaged in this relatively new industry either do not know how to go about comprehensive testing or do not have the financial backing to run scientifically based testing to measure and validate results of their product. Further, without the staying power to learn and then fix a given problem, the easiest path for many was to walk away form the problem or give the money back to the buyer.

Almost all of the manufacturers surveyed are one-dimensional and focus on one aspect of water treatment, usually scale control or biological control. Several made reference to water conservation or water efficiency but did not elaborate on how it was accomplished or how much efficiency could be anticipated.

The emerging water treatment technologies vary from magnetic (permanent magnets), electromagnetic (using DC current), electrostatic, AC Induction, electro-ionization, ozone and depressurization/kinetic energy. Scores of companies have entered into the market as suppliers of water treatment technologies for condenser water systems. Unfortunately, many, if not most, have gone out of business.

The reasons for their failure are many. However, the primary reasons are that many overstated savings and performance claims, mainly because they either misunderstood the technology they were selling or they unknowingly misapplied the technology. When water conditions and chemistry, which vary greatly from location to location, were right, the project worked. When the same system was applied to another location with different characteristics, it might not have worked because the necessary analyses of site conditions were not taken into account at the new location. All water treatment technologies, including chemical, work best in recirculating

[23] Huchler, Loraine A. P.E., ibid.

systems with sufficient dosage and contact time.[24] The second reason for systems success occurs when they naturally precipitate aragonite (calcium) vs. calcite (calcium) crystals, the aragonite being softer and looser than calcite and therefore less prone to form monolithic sheet scale on wetted surfaces.

It is obvious that some of the companies continue to conduct business after many years and, as such, have been successful in their selling effort. That appears to some to be the best evidence of their success and the efficacy of their technology. Even Steven Lower, a retired professor from Fraser University in Vancouver, Canada states that his criticism is not to condemn the technologies discussed, but to warn the buyer that they should be extremely cautious and insist on strong measurable performance guarantees.[25] It is also true that the scientific community does not even agree as to how or why the technologies work and under what conditions the technology will work repeatedly on a long-term basis. However, there is wide recognition that there is interaction between magnetic, electromagnetic and electrostatic fields and crystallization of matter that affects scaling.

Magnetic and Electromagnetic Technologies

Magnetic technologies are the oldest of all water treatment categories to be discussed in this paper. The first patent on an electromagnetic water treatment device was awarded in 1890. Most of the literature found regarding this subject devotes itself to the treatment of scale and its prevention. Very little attention is devoted to that of corrosion and the treatment of biofouling and bacterial control. However, by virtue of the fact that the control of scale formation is the restraining factor to water efficiency in cooling towers, the technology is worth further investigation and discussion.

The application of magnetic water treatment requires the installation of a permanent or electrically induced magnetic force field (flux) in or around a non-magnetic pipe material through which the system water flows. The magnets can be placed on the makeup water line where the water is in contact with the magnetic flux one time but, generally, the magnets are instead placed on a recirculating line for maximum contact and maximum effect. The magnets can be either invasive (mounted inside the vessel or pipe) or non-invasive (wrapped around the pipe).

The general operating principle for magnetic technology is a result of a moving ionized fluid (flowing water which causes a minute electric current) through a magnetic field. When an ion passes through the magnetic field, a force (called the Lorentz Force) is exerted on each ion. These ionic forces within the cooling tower system ultimately result in the precipitation of colloidal particles. The attraction to these colloids, which act as naturally favored sites for nucleation (coagulation) and precipitation, is very favorable in comparison to formation of scale on the piping walls. Since a percentage of calcium carbonate is removed from the soluble state, the ionic equilibrium balance is such that the water is now able to reabsorb some existing scale.

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[24] West, Burke A. P.E., ibid.
[25] West, Burke A. P.E., no date. *Non-Chemical Water Treatment Technologies for Cooling Towers*, includes quotation by Steven Lower, Department of Chemistry, Simon Fraser University.

The second phenomenon is that the calcium precipitates out of solution as aragonite, a soft, loosely bonded crystal that is easily suspended and removed in blowdown. This is preferred over calcite, which has less desirable characteristics and is the primary constituent of surface scale.[26] (Some scientists believe the calcite precipitate to be more desirable than the aragonite version which is in direct opposition to other findings and the statement above.) It is believed that magnetic fields somehow break up the hydrogen bonds in water, releasing dissolved ions that promote nucleation of the smaller, more desirable aragonite crystals. There appears to be consensus on the patterns observed in magnetic water conditioning which are as follows:[27]

- Hydrogen bonding affects the surface tension or "wetness" of water. By breaking a very small percentage of these hydrogen bonds, its reactivity is increased.
- By flowing water through a strong magnetic or electrostatic force field, hydrogen bonds are broken.
- Multi-pass recirculating systems have better anti-scaling characteristics than single pass systems.
- Scale tends not to form where there is higher water velocity or turbulence.
- Calcium or magnesium will scale in water producing calcium carbonate once its saturation level is exceeded.
- The structure of calcium carbonate scale without other competing metals such as iron, copper, magnesium, and zinc will precipitate as calcite. With sufficient levels of these other metal ions, the precipitate will be the more desirable aragonite form.
- Aragonite is a less stubborn scale form than calcite and precipitates as a suspended solid or easily crumbles if deposited on a system surface.
- Silica must also be present for the calcium to precipitate in bulk solution versus on the boundary surfaces.
- The technology is not effective on silica scale.
- There is a "memory" characteristic in this treatment that keeps its anti-scaling properties for up to 143 hours after treatment
- No mention is made in how corrosion or biological fouling are dealt with.
- It is possible that in water containing "appreciable" levels of iron, the technology is not effective and is therefore not applicable.

The success of the technology requires several preexisting conditions and installation requirements to be met.[28]

- The magnetic field strength and intensity must be sufficient.
- The water flow rate and exposure time of the field on the water are critical.
- The properties of the water must include other minerals such as iron, magnesium and copper must be present to form the lesser tenacious scale, aragonite..
- The water must have sufficient silica to promote bulk solution precipitation.
- The magnet or electromagnet must be located away from high voltage sources

<u>Manufacturers (Magnetic)</u>

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[26] U.S. Department of Energy (DOE), ibid.
[27] West, Burke A. P.E., no date. *Non-Chemical Water Treatment Technologies for Cooling Towers*.
[28] West, Burke A. P.E., ibid.

Magnatech Corporation, Superior Manufacturing Division has been in business since the 1960s and is probably the best known of all magnetic system manufacturers. They support magnetic technology for several types of applications including condenser water treatment systems. They mention the formation of aragonite scale versus calcite by use of a cobalt alloy permanent magnet that has dual polarity. The Superior device is installed intrusively as a spool piece in a water recirculation line.

Manufacturers (Electromagnetic)

Triangular Wave Technologies is a multifaceted manufacturer of water treatment systems and devices including those used in condenser water treatment applications. Their device is a non-intrusive magnet wrapped around the pipe, typically of a recirculation line of the cooling tower. The literature addresses scale control very extensively; however, very little attention is given to biological or corrosion control.

Electronic/ AC Induced Electric Field Technologies

Electronic water conditioning technology was first seen in the late 1990s, making this a fairly new technology with respect to the others being considered. This technology uses a time-varying electronic current in a non-intrusive solenoid wrapped around a pipe to create an induced electromagnetic field inside the condenser water pipe. The magnetic field is grown, then shrunk to nothing, and then reversed. This process occurs over and over every few milliseconds. This changing magnet field, in turn, induces an electric current which is circumferential within the pipe as quantified by Faraday's law of induction. The electric current is directly proportional to the rate of change of the magnetic flux and its direction reverses with the reversal of the magnet field. Similar to that of magnetic or electromagnetic treatment systems, induced electric field technologies increase the repulsion and attraction intensity of ionic constituencies in the water, thus increasing the nucleation and precipitation occurrences. This occurs in bulk solution as aragonite crystals. These crystals are then easily removed in blow down or filtration.

Manufacturers

ED 2000. Originally developed by Dr. Cho, a professor at Drexel University, the technology appears to actually be a combination of an electromagnetic and an electrostatic device utilizing much of the same science and attaining similar (expected) results. This technology is sometimes called ED (electronic descaling) or EAF (electronic anti-fouling) technology. This manufacturer does not appear to be very active in the pursuit of new customers, at least not on the west coast. The system will be explained in the next paragraphs.

Clearwater Technologies Corporation, Dolphin System. This system is very similar to the ED 2000 in most all respects. In fact, a very worthwhile technical paper about the Dolphin technology makes reference to Dr. Cho's contribution.[29] This same paper goes into considerable depth regarding the technology, water efficiency as it relates to cycles of concentration, and energy efficiency. An important discussion relating to the measurement of cycles of concentration is given in this paper and explains how the traditional measurement of the ratios of

[29] Lane, John and Peck, David F., 2003. *Condenser Water Treatment Using Pulsed Power,* Cooling Technology Institute, February.

"condenser water concentration to that of the make up water" is appropriate for chemically controlled systems, but it is not germane to a Dolphin (and other) system(s) that remove calcium in bulk solution. A better method for determining cycles of concentration and water efficiency is by metering or by measuring the ratio of other soluble ion constituents such as chlorides or sulfates. This is by far one of the best papers regarding the efficacy of the technology as it relates to water efficiency while discussing all other necessary parts of a comprehensive water treatment program.

In brief, the Dolphin system works by the frequent (500 times per second) pulsing and reversals of a magnetic field that parallels the flow of water. As described above, this magnetic field, in turn, induces a circumferential electric field inside the pipe that grows and shrinks with the alternating magnetic field. Clearwater claims that there is an interaction between the two fields which enhances surface charge and precipitation behavior of charged particles although this interaction is not discussed in the literature.

The Dolphin literature does discuss biological control stating that the technology is "bacteriostatic" in nature, not a true bactericide that kills bacteria. Instead, the bacteria are not immediately killed but are "controlled". Dolphin claims that pulsed-power is the basis of low temperature pasteurization in the dairy industry as approved by the FDA in technology developed by Maxwell Laboratories in San Diego.

Corrosion control is attained indirectly in the Dolphin system by maintaining sufficient cycles of concentration to force the system into an alkaline state at the saturation point of calcium carbonate, which is a natural corrosion inhibitor.

This technology appears to be well-supported by the manufacturer and they take a total system approach to water treatment and savings. Clearwater does have a very large distribution network in the United States and has over 2,000 installations. This is a very popular technology at the present time and it is believed that there are several installations on commercial and industrial condenser water systems in California.

Electrostatic Water Treatment

The difference between magnetic or electromagnetic water treatment and electrostatic treatment is that instead of a magnetic field, an electric field is imposed on the water flow. The electric field, in turn, generates a magnetic field. The science as it affects the results of water treatment are similar to that of magnetic water treatment.

This technology is typified by an insulated cylindrical electrode placed intrusively into the water stream with an externally grounded outer metal housing. Water flows between the two components. A very high voltage, low amperage (micro-amps) electric current is placed on the electrode. The device can be placed in side stream or full flow water streams. The system design is such that the water will run through the device several times a day. Although the science is different, electromagnetic water treatment is very similar to that of magnetic water treatment in the way that ionic structures are affected. For the most part, the results are the same as stated in the previous section.

Two systems, the *Ion Stick* and the *Zeta Rod* are all coated electrodes inserted into the condenser water pipe. Water flows between the electrode and the outer walls of the pipe. Similar to the configuration cited above, all technologies create an electrostatic field between the electrode and the walls of the pipe.

The main discussion of this family of systems deals with scale control and removal of existing scale on wetted surfaces. Although some manufacturers claim bio-fouling control as well, very little information is given as to how this is actually accomplished.

It is believed that as hardness and alkalinity are driven to high limits with increased cycles of concentration, the piping and other metal surfaces are protected from corrosion.

Although this science is less established than magnetic water treatment and few technical papers are available for review, it is widely believed that this technology works best when suspended matter, and especially colloidal particles are kept in suspension. These particles act as nucleation sites for homogeneous nucleation of scale in bulk solution. It is this reaction in the bulk solution of the water stream that lessens the tendency to form scale on the heat transfer and other wetted surfaces of the condenser water system.[30]

<u>Manufacturers</u>

York Energy Conservation, Ion Stick. The Ion Stick was first marketed in 1978, primarily as a scale control device. The literature goes into some detail about the electrostatic field that is generated and its ability to enhance and intensify the electrical charge of positive and negative ions in the water, causing similar charges to repel with greater force and dissimilarly charged particles to attract with greater force. This intensified ionic activity is supposed to prevent scale formation on wetted surfaces but also allows some precipitation that is removed through blowdown or through a 10-micron side stream filtration system. The Ion Stick is nominally sized for full condenser water system flow for best results. The literature mentions it being mounted in the cooling tower sump or in an elbow of the condenser water piping. Either 115 VAC or 230 VAC is supplied to the system power pack where it is converted to DC voltage.

The only reference in product literature to biological and corrosion control is that the system is kept clean of scale, which lessens the effects of treating these concerns.

The literature also states that a conductivity meter is needed to keep cycles of concentration from becoming too great. It therefore recommends blowdown or bleed as the remedy for this occurrence. The literature also states that this technology may not be the complete replacement for chemical treatment.

No specific mention is made about water savings potential. Instead, most of the discussion concentrated on scale prevention, which exposes its focus on and predisposition toward energy conservation.

Zeta Corporation, Zeta Rod. The Zeta Rod was first marketed in 1990. The literature goes into great depth and explanation of the science behind the technology, particularly about the zeta

[30] Huchler, Loraine A., ibid.

potential, the force of the surface charge and the resulting repulsive forces on all wetted surfaces, particularly between colloidal particles in aqueous suspension. The literature speaks of a double layer of ionic particles surrounding colloidal particles that is essentially balanced in charge causing no further flocculation of particles and thus a stable dispersion. In water supplies with high concentrations of polyvalent ions such as calcium or iron, the system voltage must be increased from 10,000 VDC to the 30,000 VDC range for effective water treatment.

Biofouling, as addressed in the literature, is achieved in a similar manner to the way in which scale is prevented. That is accomplished primarily by the ability of the system to surround biological matter suspended in the water with layers of ions; those ions repel ions surrounding other biological matter thus keeping them from bonding with one another and forming a biofilm layer on wetted surfaces. Without a biofilm layer, the habitat and food for microbe reproduction is removed and prevented.

Corrosion control is discussed extensively in the literature, mentioning that the two most prevalent types of corrosion are galvanic and biocorrosion. Biocorrosion is addressed primarily by the prevention and elimination of the biofilm layer on wetted surfaces, thus preventing metabolic action and oxygen concentration on and under the biofilm surface. Secondly, as the depth of the biofilm increases, the lower layers become anaerobic as oxygen can no longer reach these lower layers of matter. Corrosion is accelerated in these areas as anaerobes are created which are able to metabolize metals. Their waste products contain acids, such as nitric, sulfuric and other organic acids, that further accelerate corrosion in these localized areas.

The technology is mounted in the recirculation pipe of the condenser water system but it also can be mounted in tanks or other locations as long as it is subjected to a constant flow of condenser water. The technology accepts 115 VAC or 240 VAC.

No mention is made as to the extent or potential for water savings although this must be assumed with higher cycles of concentration. Again, we see an overall focus on scale prevention and energy savings, not water efficiency.

Electrolysis (Ionization)/Electrostatic Water Treatment

This unique technology incorporates two technologies into one system. By passing water though an electrode cell, it imparts benefits much the same as electrostatic or magnetic water conditioners, making colloidal particles favored nucleation sites for crystalline growth and precipitation in bulk solution like that mentioned earlier. It is believed that biological matter is also destroyed as it passes through the relatively high electrical energy inside the electrode cell. However, this technology has enhanced biological control because it electrolytically generates and releases ionic copper and silver (or other metals such as zinc or magnesium) in order to attain a residual effect from these metals as biocides throughout the entire condenser water system.

Biological Control: The bactericidal effects of electrolytically generated copper and silver ions on bacteria and algae are well documented. Released copper and silver ions remain in solution and act continuously to kill biological materials at concentrations of 0.2 to 0.4 ppm (parts per million) of copper, and 20 to 40 ppb (parts per billion) (0.002 to 0.004 ppm) of silver. Copper/silver treatment is biocydal. This is in sharp contrast to typical chlorine/bromine-based treatments which are only bio inhibiting to much of the living matter in the condenser water. Chlorine concentrations degrade over time, requiring constant additions and changes to the strategy as organisms develop immunities to given chemical strategies. In systems that are shut down over the winter, chlorine levels drop, and the system lies unprotected from algae (and harmful pathogens) growth for months. This allows biological matter to form in chiller tubes, and elsewhere in the system, which encourages scale growth. Copper and silver remain in solution indefinitely, which prevents biological growth, even in systems that are shut down for very long periods of time.

Scale Control: The mechanisms employed to remove minerals are electro-coagulation, mineral precipitation, crystallization and filtration. The first phase of the ionization process is initiated by the electrode flow cell, where an electrical charge is placed across the electrode, causing a simultaneous release of copper/silver ions which are discharged into the water. As with previous technologies discussed in this paper, the electric field causes an increased molecular activity and intensity creating a much greater number of collisions between positive and negatively charged particles, particularly colloidal particles and positive ions. These relatively large colloidal particles now act as nucleation sites for calcium and other positively charged (cation) particles having passed through the electric field of the flow cell. One of the manufacturers believes that the same principles associated with electro-coagulation and colloidal particles also apply to the copper and silver ions as well. It is claimed that these also act as nucleation sites, calcium crystallization causing a very pronounced and rapid reduction of calcium carbonate in solution. As the crystalline structures grow they are either filtered out of the water in the side stream filter or become so large that they fall to the bottom of the cooling tower sump as they can no longer remain suspended in the relatively low velocity water found there. It is believed that most of the calcium crystals formed are those of aragonite, which are easily removed through backwash of the filter, blowdown or manual vacuuming of the sump. Small crystals of aragonite scale form on the cathode of the flow cell, and are removed by the high velocity of the flowing water and by the reversal of polarity of the flow cell electrodes. Because all of this activity is done in bulk solution, the scale is formed around the nucleation crystals rather than on the condenser tubes or other wetted system surfaces.

Because the system water is demineralized of much of the scale forming calcium carbonate previously in solution, the water is such that it can now reabsorb calcium (existing scale) back into solution much the same as previously technologies discussed. This phenomenon eventually cleans all of the wetted surfaces of the system reducing corrosive effects and improving heat transfer.

Corrosion Protection: Corrosion occurs in a system due to several phenomena discussed earlier in this paper. Two of the primary reasons for corrosion are either galvanic or under deposit corrosion. System pH is normally maintained between 8.0 and 9.2. Under these conditions, metals establish a thin layer of natural protection, which is not penetrated by oxygen and which also minimizes electrolytic action. Because the wetted surfaces are kept very clean, problems associated with under deposit corrosion are also minimized.

<u>Manufacturers</u>

Baker Hydro Filtrations, Inc., Pure Treat, has been marketed and sold since the early-1990s as a complete system solution. Besides the flow cell technology and controls, this manufacturer offers the other technologies necessary for a complete installation, including the filtration, various media types, pumps, strainers, piping specialties and the local site support needed for first time installations.

In addition to the basic technology, Baker has been a leader in filtration media technology using a natural zeolite in many of their installations. The zeolite actually enhances the calcium removal process, unlike the other manufacturers that use sand or some variation of a centrifugal filter. The main difference advantage of this approach is that the zeolite does basic filtration down to 5 microns, automatically backwashes and serves as an additional nucleation site for calcium crystallization.

The micro environments immediately surrounding the individual zeolite media particles approach a supersaturated condition as additional cations are introduced and natural absorption and desorption occurs within the condenser water system. The media, selected for both its ion exchange capabilities and its unique surface structure, encourages precipitation of the scale forming species on its surface. As calcium carbonate crystalline growth occurs upon the surface of the media, the scale forming species within the water are precipitated within the vessel and begin to adhere to the media. Violent and frequent backwash is necessary to "fluidize" the bed, resulting in dislodgement of the calcium crystals from the media and removal. The Brinell hardness of the zeolite media, approximately 5.0, is greater than that of either calcite or aragonite so the mechanical dislodgement is easily achieved with frequent and highly agitated backwash cycles.

Some areas such as the San Francisco Bay area will not allow copper effluent to be discharged to sanitary sewer, therefore making this technology inappropriate for use there. This is the case even though the concentrations of copper and silver ions in these systems are well below EPA levels recommended for drinking water. These limits are 1.2 ppm for copper and 100 ppb for silver. The system operates at a maximum of 0.4 ppm copper and 300 ppb silver. Cooling tower discharges that contain these trace elements do not have any measurable negative effect on the environment. Overlooked unfortunately, is the positive effect of elimination of normal chemicals used in cooling tower treatment, which are very detrimental to the environment.

Oxion Water Technologies: is mentioned in several literature pieces and shows a robust web site with much product information. The technology appears to be very similar to that of Baker's Pure Treat system with the exception that this system uses copper and zinc instead of copper and silver. The literature states that the results are good with an entire section devoted to savings of chemical, water, energy, and maintenance costs.

Ozone Water Treatment

Ozone water treatment systems were first introduced in the 1890s and are gaining general acceptance in a variety of applications pertaining to the water industry. The power of ozone to disinfect water is well known in the industry. Today, ozone is primarily used for purification of drinking water at water treatment facilities and is in wide use internationally. Ozone has also been gaining acceptance as a viable means of treating condenser water systems since the mid 1980s.

Ozone works best in ambient water temperatures around the 65° to 70°F range and becomes increasingly less effective as temperature rises. Most condenser water systems are designed to operate in the 80° to 95° range where ozone is still potent. However, ozone becomes totally ineffective at 135°F and above.

Many companies selling ozone systems for cooling applications have gone out of business over the last 15 to 20 years. It is probably true that although their owners may have understood ozone technology, they probably did not understand commercial cooling systems operations and probably did not have the financial backing to see themselves through problem jobs. Historically, new companies that have introduced this technology, have overstated potential savings to the customer and they did not understand the importance of mineral constituencies in the water supply, which led to a range of scale and other problems.

The principle behind ozone treatment is that it is a very strong oxidant, O_3, that works well in most condenser water system temperature ranges. Ozone is a powerful oxidant that works 3,000 times faster and is 150 percent more effective and powerful than chlorine but without chlorine's dangerous properties. The ozone molecule is composed of three oxygen atoms that are very unstable (very reactive). Ozone (O_3) ranks second in oxidizing potential (fluorine gas is number one but is extremely toxic), whereas chlorine (bleach) is number 16 on the scale of oxidizing potential. Oxygen normally prefers to be in its stable diatomic state of two oxygen atoms, so when it is allowed to react, the third atom in an ozone molecule breaks away very quickly in the oxidation reaction. Ozone cannot be transported so it is manufactured on site with a fairly simple system consisting of an air dryer, ozone generator, venturi injector, side stream pump and a control system to measure the level of ozone in the system water. The system takes in ambient air to produce the ozone; this is done through a corona discharge in larger systems or UV (ultraviolet) process in very small systems.

Biological control is accomplished in a process called cell lysing, taking only seconds, whereas chlorine must be ingested by the cell, which takes up to 16 minutes for that process to occur. Residual ozone levels greater than or equal to 0.4 ppm or mg/L have been effective in achieving a 100 percent kill rate in two to three minutes for Pseudomonas fluorescens a biofilm producer. It has also been found that residuals as low as 0.1 ppm or mg/L will remove 70-80 percent of biofilm in a 3-hour exposure. Ozone levels less than 0.1 ppm or mg/L will reduce populations of Legionella pneumophila in condenser water systems by 80 percent.[31] There is no question regarding ozone's excellent ability to kill all forms of biological matter including bacteria, biofilm, fungi, viruses and the other airborne organic matter that enter the condenser water system from the municipal water supply or via the surrounding air. Because ozone degrades to O_2 or CO_2 once the third oxygen atom has oxidized another molecule, there are no residual hazardous or toxic chemicals to deal with in the wastewater stream.

Corrosion control can be tricky with the use of ozone. The phenomenal characteristics of ozone and its ability to oxidize can work against the system operator. If the cooling tower is subjected to too much ozone for too long a period of time, ozone will begin to oxidize the zinc in the galvanized metal of the cooling tower, copper in the condenser tubes of the chiller, and iron in the steel piping of the condenser water system. Generally, the operator controls the system to keep the pH above the 8.5 level where a natural pacification and ionic protection of the wetted surfaces takes place, thereby lowering the risk of oxidation to the metallic surfaces.

[31] Federal Technology Alert, *Ozone Treatment for Cooling Towers*, December 1995.

Scale prevention is the most difficult area for ozone to handle, especially in areas with high TDS, particularly calcium, but other mineral constituencies as well. The documentation for this process does refer to scale removal but only in cases where the scale is bound and interwoven with biofilm as the binder. Ozone does act as a mile coagulant which means that there will be some increase in the size of filterable particulate which is of some benefit. Ozone is not a good system choice when heavy levels of calcium and other scale forming constituencies are present.

Manufacturers

PuroTek has been a leader in the ozone industry for many years. They appear to have extensive experience in the treatment of condenser water systems with the use of ozone. However, there is no distribution network or local service network for this company.

Many ozone manufacturers have come and gone over the years. Two prominent manufacturers are *Ozonia North America* and *Clear Water Technology, Inc.,* both make a very wide range of ozone equipment used in multiple applications for multiple industries. Unfortunately, neither company supports the technology at the system level specific to commercial cooling applications. Literature addressing energy, chemical and water savings with the use of ozone was found on various websites.

Hydrodynamic Cavitation (HDC) Water Treatment

HDC technology has been around for approximately 15 years. It is one of the most innovative technologies employed today and is unlike all other technologies previously discussed. The technology essentially consists of two side-stream water loops typically connected into the sump of the cooling tower. One loop acts as a side stream filter. The second side stream loop is where condenser water passes through a pair of vortices and is accelerated to a very high velocity at the discharge. At the point of discharge, the two opposing water streams whose internal rotation is opposite from one another, collide, creating hydrodynamic cavitation, shear force and vacuum. This sudden lowering of pressure into a vacuum state forces the release of dissolved carbon dioxide (CO_2) from the water. This release of CO_2 in turn, causes calcium carbonate to immediately drop out of solution into suspension where it is removed by filtration.

Unlike many of the other technologies previously discussed, HDC is a somewhat more “bullet proof” technology because is impervious to alkaline or acidic source water, high or low pH, hardness, TSS or TDS, all of which are the parameters that render many of the other technologies less desirable. Additionally, it is relatively easy for operational personnel to see if this system is working, because it can be either remotely monitored or monitored on-site by physical observation of the pump status and the vacuum in the vortex chamber. These characteristics also make this technology one of the better ones to ensure long-term savings of water.

Manufacturers

VRTX is the only known manufacturer of this technology. This manufacturer has extensive literature posted on their website and other papers were found relating to the technology and potential for savings in energy, water and chemical.[32] This manufacturer takes the systems approach and does not leave the installation in the hands of the customer or a representative. They take an active roll in the sizing, installation and post-installation monitoring of the system performance, a definite plus in guaranteeing of water savings.

System Operation: Water is pumped into the pressure-equalizing chamber from the cooling tower sump. It is then channeled into precision-manufactured nozzles (vortices) that are configured in pairs to impart a specific rotation and velocity to the water streams. The circular motion of the water is accelerated as the stream from the first nozzle feeds into the second nozzle. The resultant discharge from the second stage is a conical stream. The opposing cones collide in the low-pressure stage (stabilizing chamber) to form a circular zone of very high shear force and high vacuum that is caused by the collapse of micrometer-sized bubbles and cavities. Essentially, the pressure change causes hydrodynamic cavitation with locally high temperature at the point of collision. This cavitation crushes solid particles, and the rapid change in pressure to a vacuum causes the cell walls of microorganisms to break, thus killing the cell. Finally, the hydrogen-bonding molecular arrays of water are broken down, thereby allowing entrapped gasses, such as CO_2, to be released and off-gassed to atmosphere. The remaining energy dissipates as turbulent flow, and the treated water exits the unit at ambient pressure.

Suspended matter is removed from the cooling tower sump via the second "side stream" loop that is designed to sweep the debris from the floor of the sump into the "zero gravity" filter or centrifugal separator. The filter is automatically backwashed to remove solid matter on a timed basis and is then sent to the sanitary waste system in the building.

Biological Control: VRTX technology is in sharp contrast to chlorine or bromine treatments that are bio-inhibiting – chlorine concentrations degrade over time, requiring constant additions. As mentioned earlier in this paper, for the cell to die, the cell must ingest chlorine or bromine bio-inhibitors. This often takes up to 30 minutes if and when the cell comes in contact with a chlorine molecule, and is therefore not always 100 percent effective.

On the other hand, VRTX technology causes a combination of physical changes to take place in the water that, together, disrupt the cell membranes of biological matter, ultimately destroying the cell. Every cell pumped through the system is subjected to vacuum, high pressure, kinetic energy, high velocity collision, shear energy, and high localized temperature. The pressure of the fluid inside the cell wall is in balance with ambient water pressure prior to its entrance into the VRTX. However, the pressure differential becomes relatively high once the cell enters the low-pressure stage that is in vacuum, resulting in a pressure imbalance between the inside and outside of the cell. The cell wall cannot withstand the pressure differential and the cell wall ruptures, dispersing the cell cytoplasm. After the low-pressure stage, localized high temperature and high pressure at the intersection point of the vortices also kills additional bacteria and cell life.

Scale and Hardness Control: Cooling systems build up scale over time due to the addition and concentration of soluble calcium often in the form of calcium bicarbonate. Calcium bicarbonate

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[32] Kitzman, Kevin A., Maziarz, Edward F., and Padgett, Bobby, Alcoa; Blumenschein, Charles D., U.S. Filter; and Smith, Alan, 2003. *Chemical vs. Non-Chemical Cooling Water Treatments – a Side-by-Side Comparison*, November.

can decompose to yield insoluble calcium carbonate and carbonic acid with any changes in temperature and pressure. Carbonic acid can further decompose to carbon dioxide and water.

$$Ca(HCO_3)_2 \Leftrightarrow CaCO_3 + CO_2 + H_2O$$

(Calcium bicarbonate) ⇔ (Calcium carbonate) + (carbon dioxide) + (water)

At a given temperature and pressure, this equation is in equilibrium with no chemical reaction taking place. Once the pressure is lowered to a vacuum in the low pressure stage, the CO_2 equilibrium is shifted between aqueous and gas phase, causing dissolved CO_2 to release to the gas phase. This phenomena, together with the high localized temperature created by the collision of the conical water streams, decreases the solubility of calcium in water and a simultaneous elevation of water pH, which, in turn, causes a massive formation of calcium carbonate precipitate. Soluble calcium carbonate species concentrations are thus depleted (by design) both via desorption of CO_2 and the precipitation of $CaCO_3$.

As the water stream leaves the Vortex unit it enters the sump of the cooling tower where the water pressure is stabilized (at atmospheric) and the velocity of the water slows down. Sub-micron particles of calcium carbonate called colloids are formed and flow with the water. These become thermodynamically favored to grow crystals composed of Ca^{2+} and HCO_3^- ions versus metal surfaces in the system. As the molecules coagulate, they become heavy and sink to the sump floor.

At this point, the resultant calcium scale is removed via the side stream filter or centrifugal separator and collection system. This device is periodically backwashed to remove entrapped calcium and other suspended matter. Since the bleed or blow down has been eliminated from the cooling tower treatment requirement, the only water to leave the system other than evaporated water or drift, is the very small quantity of water used to backwash the filter or centrifugal separator.

Corrosion Protection: Corrosion occurs in a system due to several phenomena mentioned earlier in this report. All waters are corrosive to some degree; however, the level of corrosive tendency will depend upon its physical and chemical characteristics. The materials that a given water supply will negatively affect may differ. Water that is corrosive to galvanized pipe may not be corrosive to copper. Corrosion inhibitors that protect one material may have no effect or may even be detrimental to other materials. Biological growth in a piping system can also cause corrosion by providing an environment in which physical and chemical interactions can occur. Several types of system level problems can occur if the condenser water systems are left untreated.

A major source of corrosion is the addition of the bio-inhibiting chemicals themselves. This is true especially when "shocking" is required as chemicals lose there effectiveness over time and a chemical alternative is administered. By the time this new chemical, usually bromine- or chlorine-based, is put into service, the biological growth in the system has gotten out of control such that a "super concentration" of biocide is required. These chemicals tend to be very corrosive.

As mentioned earlier in this paper, a layer of biofouling on any surface in the condenser water system acts as a haven for aerobic and anaerobic activity, bacteria formation, scale accumulation and potential corrosion. By eliminating biofouling, the potential for corrosive activity is greatly diminished.

The pH level is elevated to a level above 9.0. At values higher than 9.0, both iron and copper are protected from oxidation corrosion which cannot operate in an alkaline state. Under these conditions, metals are allowed to establish a thin layer of natural protection, which is not penetrated by system water or dissolved oxygen.