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GSA Guidance—Alternative Water Treatment Systems for Cooling Towers

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GSA's Proving Ground program and DOE's High Impact Technology (HIT) Catalyst program enable federal and commercial building owners and operators to make sound investment decisions in next generation building technologies based on their real-world performance.

Executive Summary

From 2014-2017, the U.S. General Services Administration's (GSA's) average nationwide water rates increased 41%. Rapidly escalating costs, mandated water-reduction targets, and the fact that an average of 28% of commercial office building water use is associated with heating and cooling led the GSA Proving Ground to select six alternative water treatment (AWT) technologies for in-field validation.[1] AWT technologies claim significant reductions in the amount of water consumed by chilled water plant cooling towers, which provide cooling for 80% of GSA floor space. This report summarizes the first four evaluations, which were conducted by the National Renewable Energy Laboratory (NREL). Two additional evaluations will be completed in 2020 to 2021.

The in-field validation studies found that all four systems maintained water quality while significantly reducing cooling-tower water consumption, with annual water savings ranging from 23%-32%. Operations and maintenance (O&M) procedures associated with cleaning the cooling towers dropped by 50%, and the simple payback period was under three years at the 2017 GSA average water/sewer cost of $16.76/kilogallon (kgal) across all four demonstrations. Energy use of AWT systems was measured for all demonstrations. Chiller energy savings were only measured for one of the four demonstrations, but facility staff observed improved chiller performance with cleaner condenser tubes. Results will vary by location.

Note that each AWT system relys on a proprietary technology offered by 4 individual vendors. In selecting an AWT technology, agencies are encouraged to get estimates and choose the most cost-effective system for their location. Ongoing maintenance costs should be considered when selecting an AWT system. Three of the four evaluated technologies either completely eliminated or significantly reduced the amount of cooling-tower water treatment chemicals used. For AWT to be implemented broadly, local O&M teams must receive adequate training on the new systems, and GSA O&M contracts should be revised to capture savings and incentivize use.

Table 1 presents a summary of the completed evaluations. The three Denver Federal Center (DFC) evaluations were streamlined, relying on existing metering systems and building automation system (BAS) data, and did not have the same level of 3rd party instrumentation installed as the test bed in Savannah, Georgia. As a result, not all metrics in Table 1 were measured at the DFC. Full reports on the AWT technologies tested can be found at https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies.

[1] EPA (Environmental Protection Agency). "Saving Water In Office Buildings." Accessed December 10, 2018. https://www.epa.gov/sites/production/files/2017-01/documents/ws-commercial-factsheet-offices.pdf.

Table 1. AWT Results

	Electrochemical Treatment Dynamic Water Technologies Juliette Gordon Low FB Savannah, Georgia	**AOP** Silver Bullet Building 95 DFC	**Salt-Based System** WCTI Building 25 DFC	**Chemical Scale Inhibition** Terlyn Building 67 DFC
Cooling Tower Size (tons)	300 (2 x 150)	500 (2 x 250)	1500 (3 x 500)	1200 (2 x 600)
Baseline Cycles of Concentration (CoC)	4	Not measured[1]	4	Not measured[1]
AWT Technology (CoC)	100+	11	30-75	13-18
Makeup Water Savings (%)	32%	26%[2]	23%	24%
Water Savings Per Ton-Hour of Cooling (Gal/ton-hr)	0.64	Not measured[1]	0.58	0.42
Blowdown Reduction (%)	99.8%	Not measured[1]	99%	94%
Reduction in Cooling Tower Maintenance Costs ($/yr)	- 50%/32 to 16 hrs $1,200 savings	- 50%/52 to 26 hrs $1,327 savings	- 47%/152 to 80 hrs $3,677 savings	- 48%/132 to 69 hrs $3,217 savings
Water Treatment Maintenance Contract Annual Cost ($/yr)	+ $1,920 ($4,080 to $6,000)	- $1,195 ($3,200 to $2,005)	- $2,768 ($7,649 to $4,881)	+ $5,100[3] ($8,400 to $13,500)
Electricity Use of AWT (kWh/yr)	+ 27,492	+ 5,250	NA	NA
Electricity Cost of AWT @ GSA Average Rate $0.11 kWh ($/yr)	+ $3,049	+ $582	NA	NA
Equipment Cost ($)	$30,340	$22,040[4]	$18,100	$17,103
Installation Cost ($)	$15,000	$1,385	$11,500	$15,408
Installed Cost Per Ton ($/ton)	$151	$47	$20	$27
Technology Life Span (yrs)	15	15	15	15
Simple Payback Period (yrs)	**3.0**	**2.2**	**2.2**	**2.7**
Savings-to-Investment Ratio (SIR)	**5.0**	**6.9**	**6.7**	**5.5**
Qualitative Chiller Performance (Energy savings not measured)	No change; no scale in baseline condenser tubes.	Reduced condenser tube fouling shown in borescope.	Improved chiller performance as reported by O&M staff.	Improved chiller performance as reported by O&M staff.
Chemical Use Reduction	100% chemicals eliminated	100% scale and corrosion inhibitors eliminated; biocide used as needed for biological growth.	Brine used for scale and corrosion inhibition; biocide used as needed for biological growth.	No reduction in scale inhibitor, corrosion inhibitor, or biocide.
Water Chemistry Outside GSA Ranges	Chlorides	Oxidation Reduction Potential	Conductivity, pH, Akalinity	Conductivity
Installation	< 2 days	< 1 day	~2 days	~1 week, including side-stream filtration
Footprint and Weight	1' x 4' x 5.5' 500 lbs	2' x 4' x 1' 101 lbs	~ 8 ft² of floor space two brine tanks, weight unkown	~8 ft² of floor space three 5-gallon containers, double-walled mixing basin and sand filter, weight unknown

[1] CoCs—the ratio of solids in the blowdown water to solids in the makeup water—is the most common metric used to represent water efficiency in cooling towers. DFC evaluations relied on existing metering systems and BAS data and did not install secondary data acquisition systems so no measurements were taken, including baseline CoCs for Building 67.

[2]Savings calculated from BAS data, +/- 4% measurement uncertainty

[3]Building 67 maintenance contract costs include quarterly tower cleaning.

[4]Cost is for one unit for towers up to 2,000 tons; draws ~5,000 kw/yr of electricity.

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I. Introduction

A. WHAT WE STUDIED

Many multistory commercial buildings larger than 200,000 ft^2 rely on central chilled water plants to deliver the required air conditioning to the building. A key component of water cooled by chilled water plants is a cooling tower, which cascades water across a medium (a fill) that is designed to maximize exposure of water droplets to the surrounding air, with the resulting evaporation cooling the water and allowing heat to be effectively transferred to the atmosphere. But as water is evaporated, minerals and chemicals become concentrated in the water that remains, which can lead to accelerated scale (mineral deposits) and corrosion problems. Biological growth in the cooling tower water also presents challenges and can lead to fouling, biocorrosion, and potential negative health impacts. The typical approach to controlling scale, corrosion, and biological growth is a combination of chemical treatment, careful monitoring, and blowdown—discharging water to the sanitary sewer from the bottom of the cooling tower basin, where dissolved solids are most concentrated. Makeup water is introduced to dilute the remaining solids and chemicals and to replace water lost through blowdown and evaporation.

Compared with traditional chemical-based solutions, which use corrosion inhibitors, scale inhibitors, algaecides, and biocides, three of the evaluated alternative water treatment (AWT) technologies completely eliminate or significantly reduce the amount of cooling-tower water treatment chemicals used. All four of the evaluated AWT technologies, including the one chemical-based AWT system, significantly reduced cooling-tower makeup water consumption.

Electrochemical Water Treatment from Dynamic Water Technologies

The AWT system deployed at the Juliette Gordon Low Federal Building test bed in Savannah, Georgia uses an electrochemical process within a reactor. A small amount of direct current is applied to create an acidic solution at the anode (a titanium rod) and a basic solution at the cathode (the reactor shell). Total power draw from the skid is 0.456 kW, and total power draw from the circulator pump is 2.94 kW. The process promotes scaling of hard minerals and silica in the relatively easy-to-clean reactor instead of in chiller condenser tubes and the cooling tower itself. Additionally, this process strips hydrogen ions from the chloride naturally present in water and creates chlorine, which acts as a biocide and eliminates the need to add other chemicals to the water. The technology does not treat the entire cooling water stream at once, but rather a continuous 10%-20% of the total flow through a side stream filtration system. The size of the system depends on cooling tower capacity and incoming city water quality, but it can be retrofitted to any process-water system. At the test bed location with two 150-ton cooling towers, the system had four reactors, each 5 feet tall, mounted on a 4-foot-by-2-foot skid and weighing just under 500 lbs for all four reactors.

Figure 1. Scraping scale off the reactor rod of the electrochemical water treatment system.

Photo by Gregg Tomberlin, National Renewable Energy Laboratory (NREL)

Advanced Oxidation Process from the Silver Bullet Water Treatment Company

The AWT system deployed at Building 95 at the Denver Federal Center (DFC) in Denver, Colorado uses an advanced oxidation process (AOP) to pull air from the surrounding environment, which then passes through patented sleeves that contain ultraviolet (UV) lamps and other proprietary components that modify the air's composition. This creates a highly reactive mixed-oxidant gas, which contains negatively charged oxygen atoms. The mixed oxidant gas is diffused into the cooling-tower open loop, forming hydroxyl and other free radicals. The hydroxyl radicals and other oxidants help oxidize minerals and contaminants in the water, kill bacteria, reduce biofilm, and break down calcium buildup. The dissolved oxidants also combine with water molecules to create hydrogen peroxide, which acts as a long-lasting biocide, killing bacteria and reducing biofilm and biocorrosion. With the AOP system, no standard cooling-tower water treatment chemicals are required, though a small amount of commercial biocide is occasionally added under special circumstances, such as the accumulation of pollen or other debris in the tower water, which can lead to algae growth. The unit draws 0.6 kW of electricity at all times during the cooling season. The AOP system is available in two sizes: 20" x 15" x 6" for cooling towers of up to 400 tons (1,200 gallons per minute [GPM]) and 45" x 24" x 10" for towers of up to 2,000 tons (6,000 GPM). The technology can be wall or floor-mounted. An airline with a diffuser is routed from the AOP device to the cooling tower basin; otherwise, the cooling tower is left unaltered.

Figure 2. Inside of cabinet AOP technology

Photo from Silver Bullet

Salt-Based Ion Exchange System from Water Conservation Technology International (WCTI)

The salt-based AWT system deployed at the DFC Building 25 test bed uses a proprietary salt-based water softening system that removes hardness from makeup water without having to add additional cooling-tower water treatment chemicals. The removal of low-solubility ions reduces scale potential in the cooling tower and increases solubility of total dissolved solids (TDS), allowing soluble silica in makeup water to polymerize to saturation equilibrium. This AWT technology is comprised of twin fiberglass ion exchange media tanks, alternating polyethylene regeneration tanks, a brine tank, and metered usage controls that provide web-based remote access for reporting and control. The equipment required approximately 8 ft^2 of floor space to treat three 500-ton cooling towers.

Figure 3. Brine tank of the salt-based ion exchange system

Photo by Dylan Cutler, NREL

Chemical Scale-Inhibition System from Terlyn Industries

The chemical scale-inhibition system deployed at the DFC Building 67 test bed modifies a conventional approach to water treatment to enable a significant increase in the cycles of concentration (CoC), the ratio of solids in the recirculating water to solids in the makeup water. This technology relies on a chemistry that differs from traditional chemical-based cooling-tower water treatment approaches in that it fosters formation of several hydrolytically stable, high-strength polymers and bonding materials designed to systematically control hardness ions and other soluble elements and uses a programmable logic controller (PLC) to continuously monitor CoC and the amount of makeup water being added to the system. The controller is typically set for 50 CoC and automates blowdown when this level has been reached. The controller can also provide remote monitoring and alarms when water quality parameters fall outside the desired range. The chemical scale-inhibition system for the test bed's two 600-ton cooling towers required 8 ft^2 of floor space for three 5-gallon containers, and a side-stream filtration system, recommended by the manufacturer, consisting of a double-walled mixing basin and glass media filter.

Figure 4. Chemical containers and side-stream filtration system used by the chemical scale-inhibition system

Photo by Doug Baughman, U.S. General Services Administration (GSA)

II. Demonstration Results

In-field validation at the four AWT test beds found that each evaluated technology was able to reduce water consumption, with annual cooling tower make up water savings ranging from 23%-32%. Multivariable linear regression models were created to extrapolate water savings over the entire year. Where measured, blowdown was nearly eliminated. Though the AWT systems maintained water quality adequate to control scale, corrosion, and biological growth, each system had at least one parameter that deviated from GSA standards. (see Table 3 – Water Quality for additional information). Falling outside GSA's specified ranges is not necessarily a problem. These ranges were defined for traditional cooling-tower chemical treatment systems and in many instances are not applicable to AWT systems. An update to GSA standards for AWTs could be useful to clarify this discrepancy. It should be noted that the DFC test-bed evaluations were grandfathered into the GSA Proving Ground (meaning they did not go through the standard RFI process) and relied on existing automated metering infrastructure (AMI) instrumentation and did not have the same level of measurement and verification as the test bed in Savannah, Georgia.

A. QUANTITATIVE RESULTS

Water Savings

Measured reduction in cooling-tower water blowdown, cooling-tower makeup water savings and percent savings compared to the baseline for the four systems are provided in Table 2. A 94%-99.8% reduction in measured blowdown was achieved in the three test beds that captured this metric.

Table 2. Water Savings

Technology	Blowdown Reduction (%)	Baseline Cooling Tower Water Makeup Use (gallons/yr)	AWT Cooling Tower Water Makeup Use (gallons/yr)	Makeup Water Savings (gallons/yr)	Percentage Makeup Water Savings Compared to Baseline
Electrochemical (Savannah Test Bed)	99.8%	3,588,156	2,454,299	1,133,857	32%
AOP (DFC Test Bed)	Not measured	2,003,273	1,475,482	527,791	26%
Salt-Based (DFC Test Bed)	99%	1,253,900	852,730	401,170	23%
Chemical Scale Inhibition (DFC Test Bed)	94%	2,244,900	1,420,452	824,448	24%

Water Quality

All four technologies were able to control bacteria, including Legionella bacteria. By design, however, many of the AWT systems maintain water quality parameters that deviate from the standards for chemical treatments. When the CoC is significantly increased, the scaling potential of the water increases, but the non-chemical water treatment technologies address this through the design of their technology, and the one chemical-based solution uses a much better scale inhibitor. Across all four technology test beds, GSA operations and maintenance staff reported a significant reduction in scale. A subsequent internal NREL study conducted in August 2018 found that the AWT systems at the three DFC test beds continued to maintain adequate water quality and that the AOP had the lowest levels of biological growth of any cooling-tower water treatment systems that were evaluated. Based on this finding, the evaluation team notes that advanced oxidation technology is not likely to require any chemicals in most installations. A listing of the average monthly measured water quality, versus the GSA-stated acceptable ranges, is provided in Table 3.

Table 3. Water Quality*

Test	GSA Acceptable Ranges	Electrochemical	AOP	Salt-Based	Chemical-Scale Inhibition
T alkalinity (ppm)	100-1,000	280.9	304	1,680-3,004	569
pH	7.3-9.0	8.49	8.73	9.6-10.2[1]	8.525
Chloride (ppm)	10-500	276.5	-	1113	595
Cycles of Concentration (CoC)	>2	>100	11	30-75	13-18
Total Hardness (ppm)	500-1,500	683.6	600	77.75	1,616
Phosphate (ppm)	43,327	-	-	7.083	2.883
Conductivity (mmHos)	<2,400	1,951.3	-	8,700-20,000	2,540-7,000
Bacteria Count (cfu)	<80,000	-	960		
Water Appearance	Clear	Clear	Clear	Clear	Clear
Iron (ppm)	<4	0.01	0.27	0.524	0.133
Calcium Hardness (ppm)	<500	-	9.88	71.5	1,030
Magnesium Hardness (ppm)	<100	-	-	51.5	587
Chlorides (ppm)	<250	276.5	181	1,113	595
Salt (ppm)	<410	-	-	1,837	985
Sulfates (ppm)	<250	-	-	1,907	934
Silica (ppm)	<150	129.0	47.46		-
ORP (mV)	>300	223.3	194	-	-
90-Day Copper Coupon (mpy)	<0.2	-	0.13	-	-

[1]Higher pH is by design, changed water chemistry allows pH levels from 9-10 to create effective corrosion inhibitor.

*Although some parameters fall out of the designated range, all systems improved water quality and a detailed discussion of water quality is provided in each report.

Energy Impact

AWT systems can save energy by reducing the accumulation of scale and biofilm on condenser tubes. The savings can be substantial, because heat transfer decreases exponentially as buildup occurs. Vendor claims for electricity savings range from 5%-15%, but these claims are highly dependent on the existing condition of the chiller condenser tubes and heat exchangers. If the chiller tubes and heat exchangers are clean and included as part of regular preventative maintenance program, very little savings potential exists. Conversely, if the baseline chiller condenser tubes and heat exchangers are not in good condition, significant opportunities for energy savings exist. The electrochemical test bed in Savannah was the only demonstration that included detailed instrumentation of chiller electricity usage and chiller load, pre- and post-installation. No measurable energy savings or increase in chiller performance was seen because the condenser tubes were clean at the beginning of the demonstration. NREL's assessments at the DFC did not measure energy savings, but facility staff reported reduced scale and biofilm and improved chiller operations at all three test beds. At the AOP test bed, after two years of operation, a borescope of the two chiller tube condenser bundles revealed a decrease in condenser tube fouling from the baseline chemical treatment system. At the same time, each AOP unit used 1.2 kW of electricity 24/7, increasing annual energy use by 5,256 kW. Building engineers at the salt-based and chemical-scale inhibition test beds observed reduced scale and were able to run the flat-plate chillers more frequently, which implies increased energy efficiency.

B. QUALITATIVE RESULTS

Installation

Installing all four AWT systems was straightforward and did not permanently alter the infrastructure of the existing cooling towers. All systems can run effectively without internet connectivity, though GSA site staff noted that connectivity would improve performance for all systems other than Silverbullet (AOP), as it would allow for remote monitoring and control by both GSA staff and the technology's vendor or a licensed distributor.

<u>Electrochemical Water Treatment</u>

The skid, wiring, and plumbing of the electrochemical system took less than two days to install. The electrochemical installation is separate from the main cooling system, and if the skid can be located close to the cooling-tower water supply and return piping, the slip-stream piping runs will be short, which is optimal. Also, the system requires compressed air, and because GSA does not allow third parties to tie into the building air system, a separate compressor is needed, though this expense is minimal.

This electrochemical system was sized for 300 tons of cooling and had four reactors, each five feet tall, mounted on a 4-foot-by-2-foot skid and weighing just under 500 pounds. In other locations, the size of the equipment and the number of reactors will vary based on cooling-tower size and water quality. A potential installation challenge is getting the equipment, which is unitary, up to the roof, where most cooling towers are located. Though placement on the roof is not necessary, installation elsewhere would require a longer pipe run.

<u>AOP</u>

Out of all AWT systems that were evaluated, the AOP system was the quickest to install. Mounting a small box to the wall and connecting an injector air hose to the cooling tower basin took about three hours. The AOP system is available in two sizes—20" x 15" x 6" and 43 lbs for cooling towers up to 400 tons (1,200 GPM) and 45" x 24" x 10" and 101 lbs for towers up to 2,000 tons (6,000 GPM).

<u>Salt-Based System</u>

The salt-based system for Building 25's three 500-ton cooling towers took two days to install and required approximately 8 ft^2 of floor space for two brine tanks. A new controller that monitors water characteristics and meters makeup and blowdown water was installed, and a supplemental chemical feed monitor was installed for water treatment on an as-needed basis as it circulates through the condenser loop. It should be noted that this system should only be applied to packed cooling tower systems and is not effective for cooling towers that do not have a separate basin associated with the tower.

Chemical Scale-Inhibition

The chemical scale-inhibition system for Building 67's two 600-ton cooling towers also required 8 ft^2 of floor space to accommodate three five-gallon containers and a side-stream filtration system recommended by the installer. The filtration system required additional plumbing, with dedicated supply and return lines, which added to installation time. The entire system took about one week to install, more time than the other AWT systems evaluated. If the existing cooling tower already has a side-stream filtration system, this would significantly reduce installation time and cost.

Operations and Maintenance

All AWT systems reduced operations and maintenance (O&M) procedures associated with cleaning the cooling towers by about half. In some cases, the cost of annual third-party contracts to maintain the water treatment system was reduced, but increased in others because local O&M contractors did not have experience with the technology. Training local staff or water treatment providers in the maintenance of these AWT systems is critical to ensure performance.

Electrochemical Water Treatment

The electrochemical system requires weekly water testing and quarterly cleaning. Cleaning involves removing the reactor rods and scraping off the accumulated scale. This process takes about four hours. All chemicals were eliminated, and maintenance was reduced from monthly to quarterly, though the annual maintenance contract increased from $4,080 to $6,000. Because the vendor does not have a nationwide presence, the maintenance contract requires flying service engineers from Phoenix to the facility in Savannah to perform the four-hour on-site maintenance. GSA is now working to train local staff.

AOP

The AOP system requires weekly water testing and monthly system inspection, which entails inspecting the UV sleeves, verifying that they are producing oxidant gas and ensuring that carbonite is not collecting in the diffuser. A new diffuser design should reduce maintenance to quarterly inspections. In addition, the diffuser must be replaced every six months, the UV sleeves every year, and the compressor every other year. The cost of the annual ongoing maintenance contract was reduced by $1,195, from $3,200 to $2,005. The DFC also had direct experience with the importance of training local staff. Based on positive test-bed outcomes, an additional AOP system was installed at a separate location. Initially, the technology did not perform as expected because the contractor was not properly trained and was not maintaining the system. Later, the vendor (also located in Denver) took over servicing the unit and it performed as expected.

Salt-Based

The salt-based system requires daily testing to maintain the water chemistry and enable higher CoCs. Annual maintenance contract costs were reduced by $2,768, from $7,649 to $4,881, because salt is less expensive than conventional water treatment chemicals. Based on positive test-bed outcomes, two additional salt-based systems were installed at the DFC. One of these systems did not save water because the distributor responsible for installing and operating the system did not follow the system's protocols. The region is now working directly with the vendor to correct the operating problems and with GSA to obtain cybersecurity approval for the remote access controller.

Chemical Scale-Inhibition

The chemical scale-inhibition system requires weekly water testing to maintain the water chemistry. The cost of the annual maintenance contract, including the cost of chemicals, increased from $8,400 to $13,500, due to the use of higher-quality chemicals. Based on the positive test-bed results, four additional chemical-scale inhibition systems were installed at the DFC. In 2018, regional staff learned that one of these systems was no longer operating, because the O&M contractors were not maintaining it properly. Facility staff is working directly with the vendor to correct the operating issues.

C. COST-EFFECTIVENESS

All four AWT systems were found to be cost-effective, both at the test bed and when normalized for GSA average water costs. Results will vary by location.

Table 4. Economic Assessment

	Electrochemical Water Treatment	AOP	Salt-Based	Chemical Scale Inhibition
Testbed Cooling Tower Size (tons)	300 (2 x 150)	500 (2 x 250)	1500 (3 x 500)	1200 (2 x 600)
Equipment Cost[1] ($)	$30,340	$22,040	$18,100	$17,103
Installation Cost ($)	$15,000	$1,385	$11,500	$15,408
Total Installed Cost ($)	$45,340	$23,425	$29,600	$32,511
Installed Cost per Ton ($)	$151	$47	$20	$27
Annual Cooling Tower Maintenance Cost ($)	- $1,200	-$1,327	-$3,677	-$3,217
Annual Maintenance Contract Cost ($)	+ $1,920	- $1,195	- $2,768	+ $5,100
Annual Energy Usage of AWT (kWh)	27,492	5,250	N/A	N/A
Annual Electricity Cost for AWT @ avg. GSA rate of $0.11 ($)	$3,049	$582		
Annual Water Savings (kGal)	1,133,857	527,791	401,170	824,448
Annual Water Savings at avg. GSA water/sewer rate $16.76 ($/kGal)	$19,003	$8,846	$6,724	$13,818
Simple Payback Period (years)	**3.0**	**2.2**	**2.2**	**2.7**
Savings-to-Investment Ratio (SIR)	**5.0**	**6.9**	**6.7**	**5.5**

[1]Equipment life span is 15 years.

III. Summary Findings and Conclusions

A. LESSONS LEARNED

Tower Performance is Location-Specific

Incoming water quality variables such as hardness, TDS, alkalinity, conductivity, seasonal changes to water quality, airborne particulate matter, and local insect populations all impact cooling-tower water treatment system strategies and effectiveness. These factors influence the level of biological growth, scaling, and corrosivity that needs to be controlled and the amount of particulate matter that needs to be removed. For example, if the cooling tower will be subject to significant airborne debris from the local environment, in addition to the AWT technologies described, a tower basin sweep needs to be installed. If a high level of TDS is in the incoming water, the installation of a side-stream filtration system with a backwash glass media system is recommended.

Water Savings are Site-Specific

Sites in hot climates with long cooling seasons and long cooling-tower run times will typically have the largest water savings. Water quality also impacts performance. Locations with excessively hard water, high pH, or high TDS typically operate at lower CoCs, and the baseline systems will use more water treatment chemicals, having the greatest opportunity for savings.

Biofilm in Conjunction with Scale Impacts Efficiency

In addition to scale, biofilms have a significant impact on heat-transfer efficiency. The high water content of biofilms creates an insulating layer that inhibits energy transfer to a much greater degree than mineral scale alone. All AWT systems need to adequately control and reduce biological growth.

Majority of Water Savings Captured at CoC of 10

CoCs are the most common metric used to represent water efficiency in cooling towers; high CoCs are related to low levels of blowdown and low CoCs are related to high levels of blowdown. Typically, CoCs for GSA facilities using traditional chemical water treatment are 3-6, indicating a relatively high volume of cooling-tower-makeup water consumption is used for blowdown. Water savings from reducing blowdown and increasing the CoC is nonlinear, however, with the majority of makeup water savings coming from increasing CoCs from 3-10 (Figure 5).

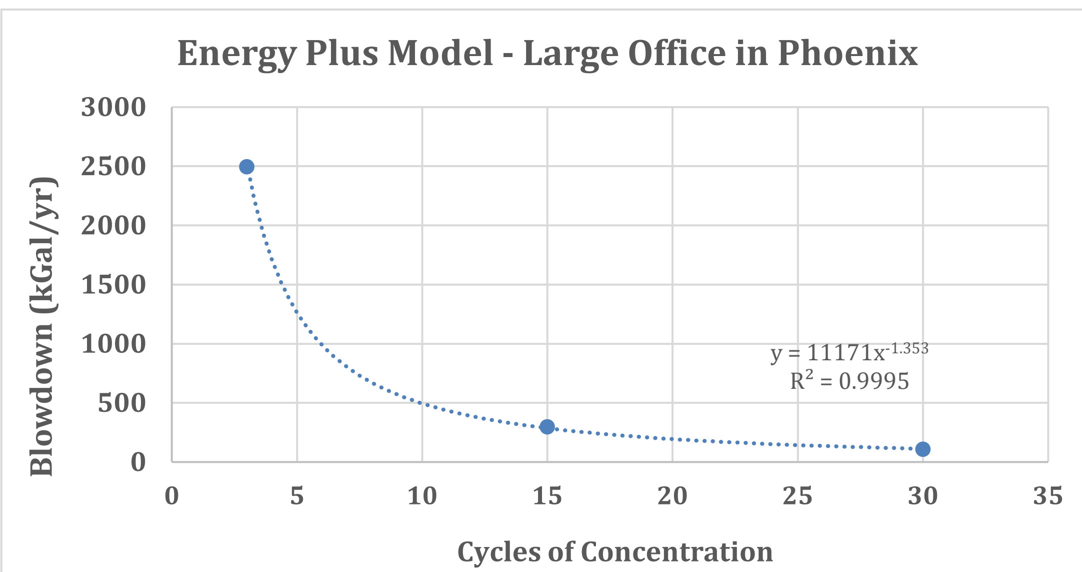

Figure 5. Modeled blowdown versus COCs for a large office building in Phoenix.

For a large office building (498,588 ft^2) located in Phoenix, Arizona, increasing CoC from 3-10 results in an 80% reduction in blowdown. The reduction in water usage starts to level off above a CoC of 15, as illustrated in Figure 5, and the site would only realize an additional 8% reduction in blowdown from increasing the CoCs from 15 to 30.

B. BEST PRACTICES

- AWT systems characterized in this report rely on proprietary technology offered by a four individual vendors. Install AWT systems validated by GSA's Proving Ground or other third-party verification and have adequate sales, manufacturer support, and warranty;
- Design AWT systems for the specific facilities in which they will be installed;
- Work with the local water utility to capture water rebates where available;
- Consider integrating AWT technology with building management systems or programmable logic controllers to help monitor performance;
- IT connectivity is not required, but remote monitoring, enabled by connectivity, can help vendors ensure their systems are working as designed;
- Consider installing an add-on side-stream filtration system. This is particularly important for open cooling towers, which are prone to collect dirt and debris, or in locations where the incoming water has a high level of TDS. When installing a new cooling tower or doing a major renovation, consider adding a tower sweeper to deal with sediment that collects at the bottom of the basin;
- Savings from reduced or eliminated chemical use will be challenging to realize unless O&M contracts can be modified to reflect this reduced cost. Successful operation of AWT systems requires changes to O&M practices and contracts;
- Train local maintenance teams on the installed AWT systems; and
- Consider leasing an AWT system, if that is an option. DFC staff indicated that for future installations of the AOP technology they would pursue leasing instead of purchasing as part of the service contract with the vendor. The cost of the lease, combined with a service contract, is comparable to the cost of traditional chemical treatments. Also, leasing avoids upfront costs, and because the legacy treatment system is left unaltered during AWT installation, treatment can revert to the previous model if issues arise.

C. DEPLOYMENT RECOMMENDATIONS

AWT systems characterized in this report rely on proprietary technology offered by four individual vendors. In selecting an AWT technology, get estimates, and choose the most cost-effective system for your location. Consider ongoing maintenance costs in your selection. Three of the four evaluated technologies either completely eliminated or significantly reduced the amount of cooling-tower water treatment chemicals used.

When interviewing vendors of AWT technology, review the following:

- Space, weight, and access required to install technology
- Cybersecurity considerations—is equipment IP-addressable? Does it require or benefit from internet connectivity?

- Servicing requirements and availability of local support
- Required changes in O&M practices
- Appropriateness of technology to local water chemistry and environmental conditions
- Size of the cooling tower—some technologies are limited in the size of the cooling tower basin they can treat;
- Power consumption of the AWT system and local electricity rates
- System warranty.

Considerations for deployment:

- *Electrochemical Water Treatment*

  The electrochemical test bed had the highest installation cost but eliminated 100% of ongoing chemical costs. The maintenance requirements for the electrochemical system are very different from those of legacy systems, and the system will need O&M buy-in and training. The technology requires quarterly cleaning of the reactor rods (four hours per quarter). The system uses electricity; at the test bed, this resulted in an annual increase of 27,492 kWh.

- *AOP*

  The AOP test bed had the lowest installed cost and simplest installation process. The technology eliminated all scale and corrosion inhibitors and uses small amounts of biocide. In subsequent analysis of the three AWT systems at the DFC, the AOP system had the least biological growth. The technology's approach is very different from current practice and will need O&M buy-in and training.

- *Salt-Based*

  The salt-based system had the lowest installation cost per ton. It replaces scale and corrosion inhibitors with salt, and at the test bed, reduced annual chemical costs by over 80%, as salt is relatively inexpensive. The system requires daily water testing, which is more frequent than the other AWT systems evaluated.

- *Chemical Scale-Inhibition*

  This technology is most similar to conventional water treatment, but its proprietary chemicals increased annual chemical costs by $5,100, due to the higher quality of chemicals.

D. CONCLUSION

In-field validation at the four AWT test beds found that each evaluated technology was able to reduce water consumption, with annual water savings ranging from 23%-32%. Also, all four AWT systems were found to be cost-effective, both at the test bed and when normalized for GSA average water costs. Results will vary by location. None of the technologies required decommissioning the existing cooling-tower treatment system or any other mechanical system in the building, so the risk is low. For AWT to be implemented broadly, local O&M teams must receive adequate training on the new systems, and GSA O&M contracts should be revised to capture savings and incentivize use.

IV. Appendices

A. GSA DEPLOYMENT POTENTIAL

To evaluate the potential impact of AWT in the national GSA building portfolio, NREL used the whole-building modeling software EnergyPlus® to model water savings potential across the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) climate zones. The Large Office building model was selected from the Commercial Reference Buildings that are developed and maintained by the U.S. Department of Energy (DOE) and NREL.[2] The Commercial Reference Buildings are a set of EnergyPlus building models that represent typical building types and constructions and include climate-specific models (per building type) for each of the 16 different ASHRAE climate zones. For the modeling analysis included in this report, the Post-1980 Construction model was used.

The Large Office Building model is a 498,588 ft^2 office building cooled via a water-cooled chiller. The standard cooling tower model in EnergyPlus defaults to blowdown operation that maintains a CoC of 3.0. To evaluate the potential impact of AWT in the national GSA building portfolio, the Large Office Building model was simulated in 16 different U.S. cities, one representative city for each of the 16 ASHRAE climate zones. For each climate zone, the model was run three times: (1) with the cooling tower set to maintain a 3.0 CoC; (2) with the cooling tower set to maintain a 10.0 CoC; and (3) with the cooling tower set to maintain a 15.0 CoC. The EnergyPlus default of 3 CoC was established as the baseline, representative of a standard water treatment approach for water-cooled chillers. The 10.0 and 15.0 CoC simulations represent a range of concentrations that have been shown to be achievable by the AWT technologies evaluated by GSA. Figure 6 shows the annual evaporation (in thousands of gallons of water) and the annual water savings (over the baseline blowdown at 3.0 CoC) for 10.0 and 15.0 CoC. The cities with larger numbers of cooling degree days and more arid climates show the greatest water savings.

[2] DOE (U.S. Department of Energy). "Commercial Reference Buildings." Office of Energy Efficiency and Renewable Energy. Accessed April 14, 2014. http://energy.gov/eere/buildings/commercial-reference-buildings.

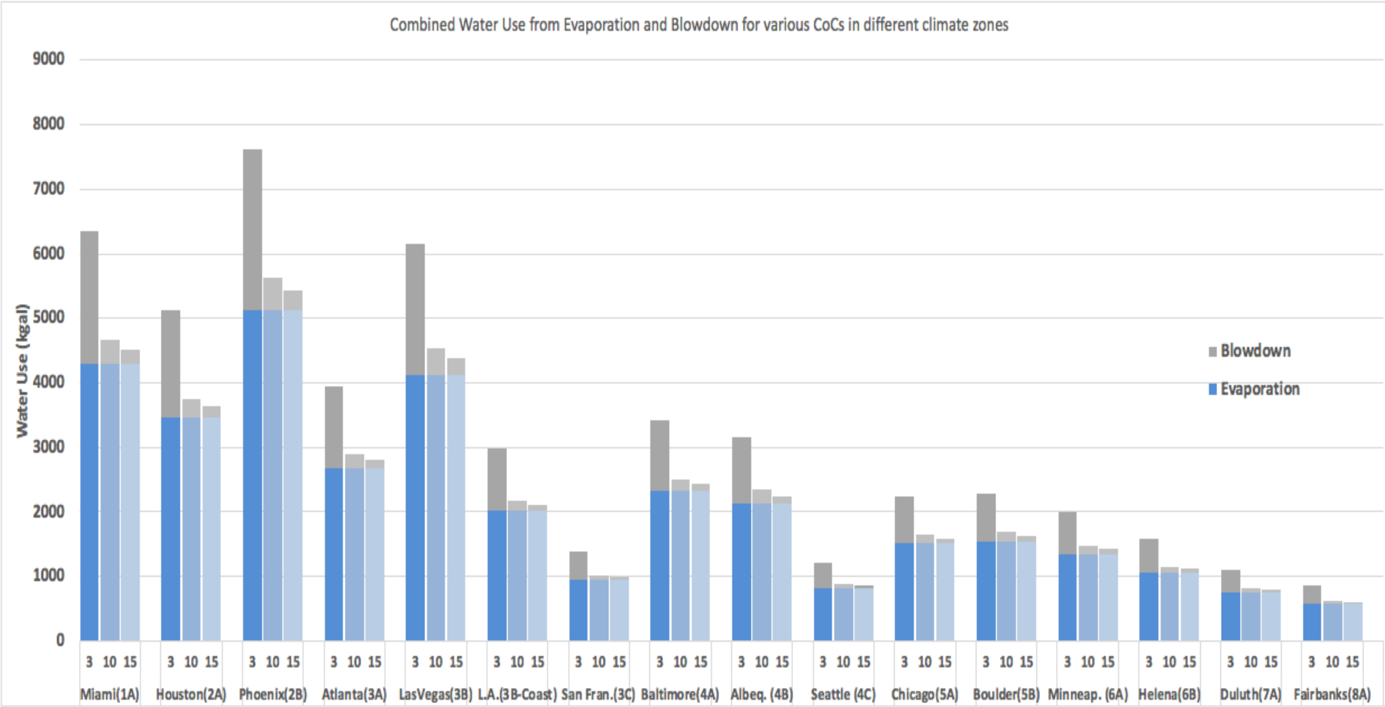

Figure 6. Modeled water evaporation and blowdown savings across ASHRAE climate zones

The water savings numbers were then translated into annual cost savings using site-specific water rates. Combined water and sewer rates were obtained from local water utilities for each city (through the local water utility's website), assuming each site is on a 6-inch water line and uses more than 200,000 gallons per month. The annual water savings for each location were multiplied by the combined water rate for each city. Note that cost savings do not account for any change in O&M costs attributed to the AWT technology or costs associated with the energy draw attributed to the AWT technology. The results from this analysis are presented Figure 7.

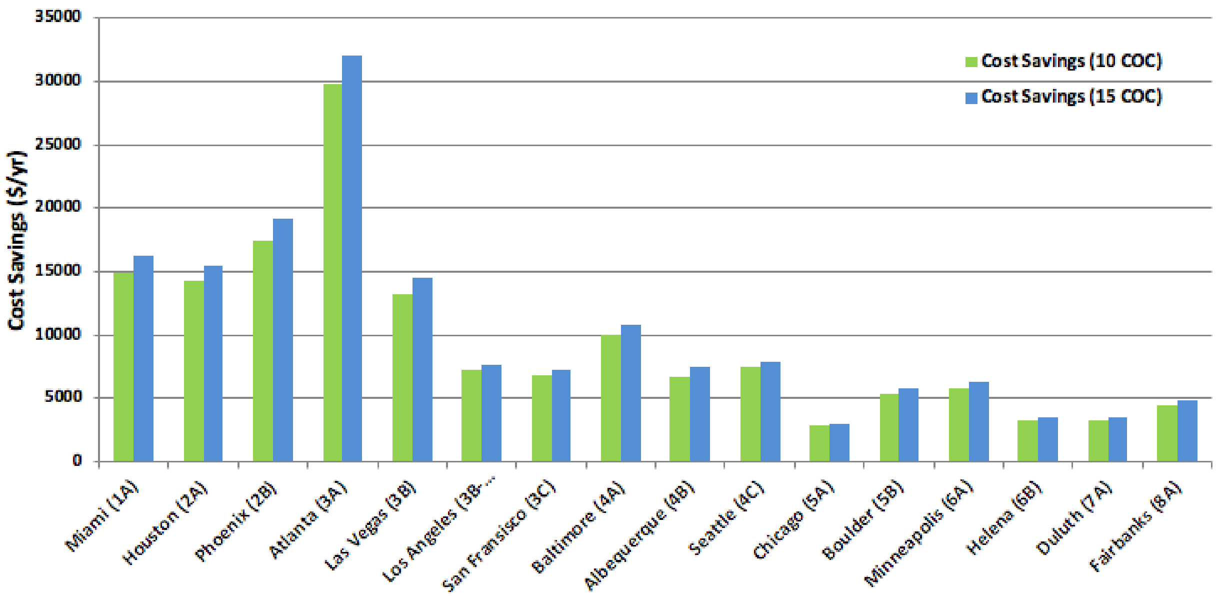

Figure 7. Estimated yearly cost savings by climate zone

The wide variation in water costs between the different cities results in a significantly different picture in cost savings than in water savings. Cities with high water rates (such as Atlanta, Georgia) generate the largest annual cost savings despite not having the largest total water savings. Table 5 gives the water rates used in this evaluation (current as of May 2018).

Table 5. Combined Water and Sewer Rates for Sample Cities across Each of the 16 ASHRAE Climate Zones (May 2018)

Location (Climate Zone)	Combined Water and Sewer Rate ($/kgal)	Location (Climate Zone)	Combined Water and Sewer Rate ($/kgal)
Miami (1A)	$13.62	**Albuquerque (4B)**	$4.98
Houston (2A)	$10.38	**Seattle (4C)**	$25.18
Phoenix (2B)	$7.76	**Chicago (5A)**	$7.76
Atlanta (3A)	$29.12	**Boulder (5B)**	$9.32
Las Vegas (3B)	$8.25	**Minneapolis (6A)**	$9.98
LA (3B-Coast)	$8.88	**Helena (6B)**	$8.30
San Francisco (3C)	$24.01	**Duluth (7A)**	$13.51
Baltimore (4A)	$12.30	**Fairbanks (8A)**	$22.07

To gain an appreciation of the market potential for GSA, approximate system costs were used to calculate a savings-to-investment ratio (SIR) for each city. Note that this calculation assumes the annual operating costs associated with these systems are the same after the install as they were with the original system. The ratios denoted here are rough estimates, considering the assumptions that the original system was operating at 3 CoC, the new system would achieve 10 CoC, and that the annual operating costs remain the same pre- to post-installation, yet they give a feeling for the critical variables driving economic viability of the system in various U.S. locations. The SIRs for a high installed cost assumption ($35,000) and a low-cost assumption ($20,000) are shown in Figure 6 and Figure 7, respectively. The figures show the modeled SIRs for a given water and wastewater combined rate across various climate zones. The SIR calculation assumes a 15-year project life, 10 CoC, $2,522/yr in O&M savings and on-site electrical costs that are based on the local electric rates.

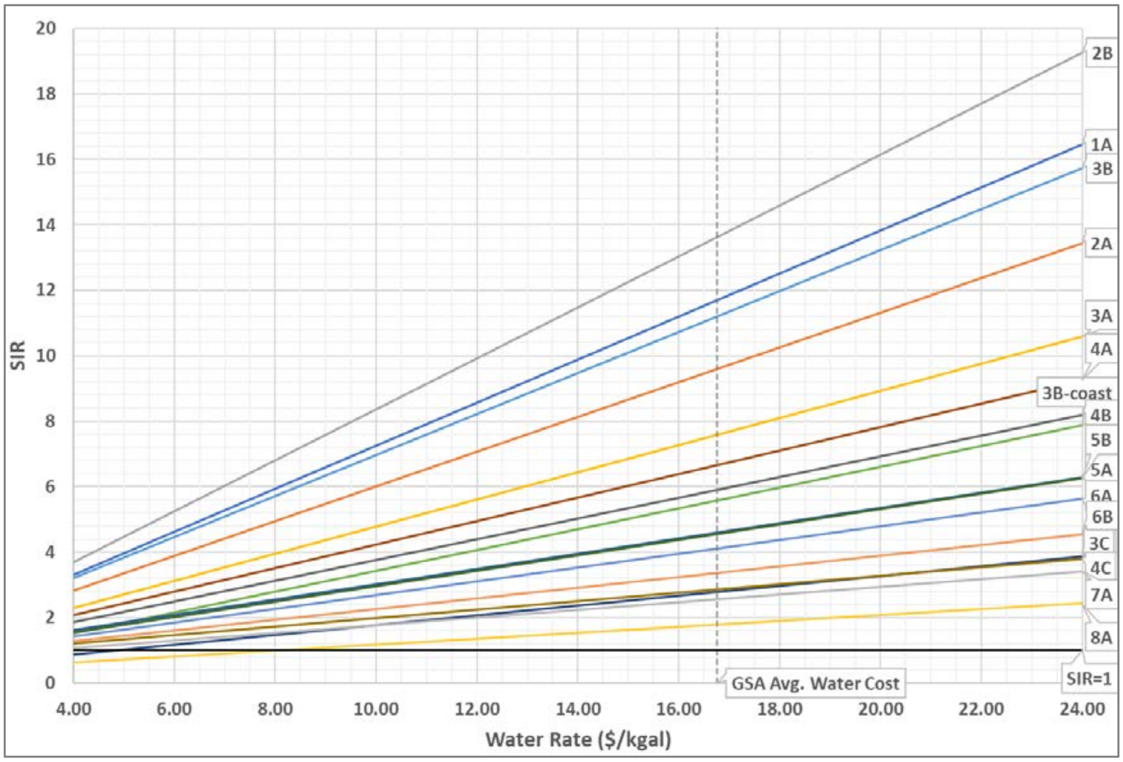

Figure 8. Savings-to-investment ratio for same system in evaluated climate zones for various water rates (high-cost scenario)

For the high-cost scenario, the AWT is life cycle cost-effective (SIR>1) across all 16 climate zones when the combined water and sewer rate is more than $8/kgal.

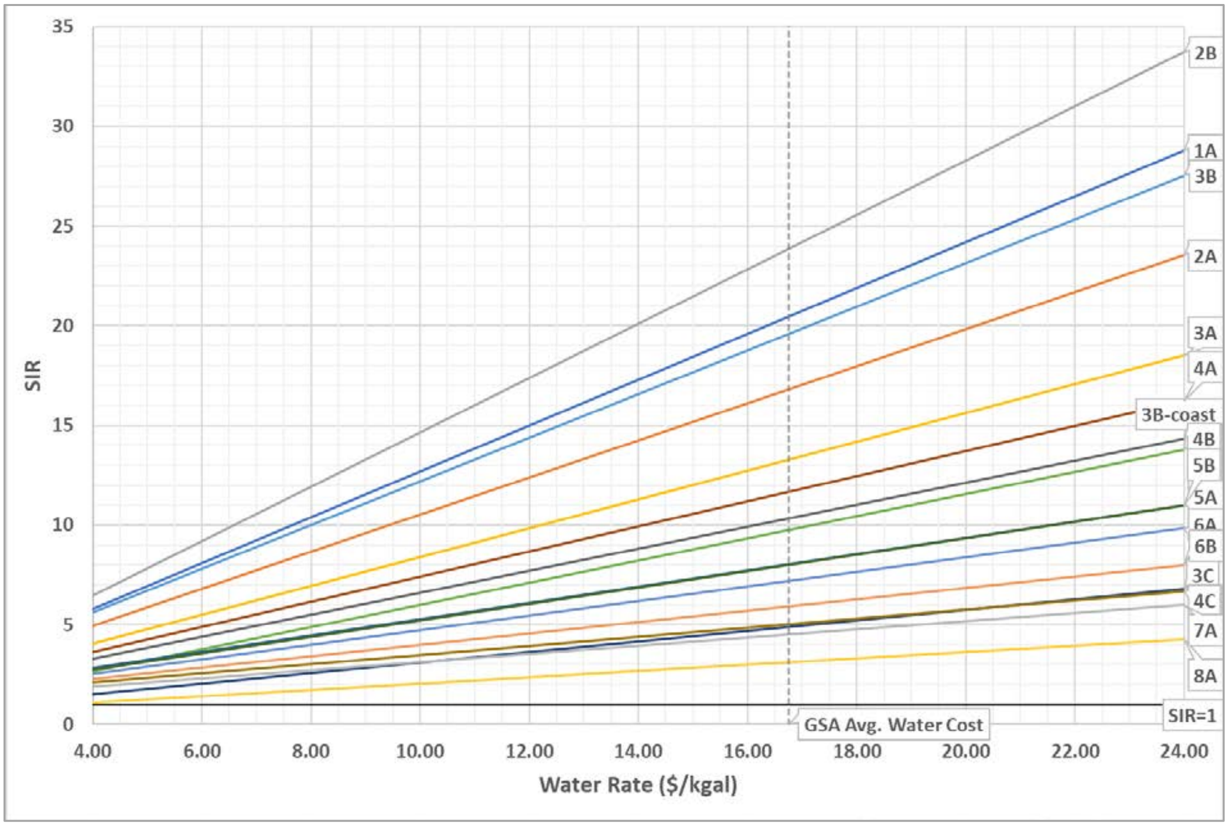

Figure 9. Savings-to-investment ratio for same system in evaluated climate zones for various water rates (low-Cost scenario)

For the low-cost scenario, the AWT is life cycle cost-effective (SIR>1) across all 16 climate zones when the combined water and sewer rate is more than $4/kgal.