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Electrochemical Water Treatment for Cooling Towers

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Executive Summary

Background

Cooling towers are an integral component of many refrigeration systems, providing comfort or process cooling across a broad range of applications. They are the point in the system where heat is dissipated to the atmosphere through the evaporative cooling process. Cooling towers are commonly found in industrial applications and are also often applied to water-cooled chilled water plants in medium to large commercial buildings. Cooling towers used in medium to large commercial buildings are the focus of this paper.

Cooling towers consume a large amount of water. Cooling tower-related water consumption is one of largest potable water loads within buildings in the United States, with substantial building water use associated with heating and cooling. Reducing water consumption is a priority for the U.S. General Services Administration (GSA) and Executive Order 13834[1] and regional water shortage concerns. These factors have brought about the investigation of cost-effective opportunities to reduce water use, such as alternative water treatment (AWT) technologies for cooling towers.

Traditional water treatment approaches rely on chemicals to extend the ability of the water to hold scaling minerals in suspension, minimize corrosion and prevent biological growth. This treatment protects the chillers and cooling tower equipment; however, even when chemicals are used regularly, a certain percentage of condenser water must be drained and made up with fresh water to maintain system water quality parameters. In addition, the use of chemicals sometimes creates a waste disposal issue and can cause building owners to incur additional fees, such as disposal or sewer charges. To manage cooling tower water treatment GSA typically contracts with a company for a fixed fee specializing in conventional chemical maintenance.

While there are many vendors of AWT systems, this project assesses the effectiveness of one technology provided by Dynamic Water Technologies. This project assesses the effectiveness of this technology at lowering GSA's operating costs while maintaining proper water treatment. The application of the this AWT technology in place of traditional chemical water treatment has the potential benefits of:

- Saving water and water/sewer costs by reducing the amount of blowdown required, allowing the system to operate at higher cycles of concentration;
- Eliminating the need for water treatment chemicals for scale, corrosion and biological growth;
- Increasing chiller efficiency by preventing scaling and removing some of the existing scale, which improves heat transfer; and
- Maintaining very low corrosion rates.

The technology was installed at the Juliette Gordon Low Federal Building located in Savannah, Georgia. The building is approximately 242,000 square feet. The building has two cooling towers utilizing traditional chemical water treatment for the cooling water circulating through the two chiller condensers.

Measurement taken at the site included the flow of makeup water to the cooling towers and the blowdown flow rate from the cooling tower basins. Additionally, energy measurements include the electrical energy from the chillers, chiller water pumps, condenser water pumps, cooling tower fans, and the energy used by the AWT skid and slip stream pump.

[1] https://www.fedcenter.gov/programs/eo13834/

The performance objectives for this evaluation are shown in **Error! Reference source not found.** 1 below.

Table 1. Performance Objectives

Quantitative Objectives	Metrics & Data	Success Criteria	M&V Results
Water/Sewer Savings	Metered water consumption Metered blowdown	> 25% makeup water savings > 75% blowdown/sewer	**Met** – Water savings at 31.6%. Blowdown volume reduction was 99.8%.
Energy Savings	Metered chilled water system energy consumption	> 10% chiller energy savings	**Not Met -** No energy savings. Energy use added from technology.
Maintenance Savings	Maintenance records for current cost of chemicals and labor	100% reduction in added chemicals and decrease in maintenance costs, including reduced costs for mechanical cleaning	**Met -** Chemical usage eliminated. Mechanical cleaning costs were reduced
Equipment Life	Level of corrosion	Decrease in corrosivity as documented in corrosion coupons	**Not determined –** Coupons not installed
Water Quality	Water quality monitoring	Water quality meets site-specific standards (may include conductivity, pH, hardness, alkalinity, silica, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, and biological growth)	**Met -** Chlorides increased. Vendor claims not a corrosion issue. Verification recommended. Other factors in normal range
Cost Effectiveness	Savings-to-Investment Ratio (SIR)	> 1.0 SIR	**SIR Met** - 1.03
Objective	**Success Criteria**	**Metrics & Data**	**M&V Results**
Ease of Installation	Positive feedback during interview with installer. Time required to install & configure Labor associated with install	< 2 days to install and commission one cooling tower	**Met** System set-up is a skid with a slipstream tie-in at two locations only
Operability	Positive feedback during interview with operations & maintenance staff Usability opinion of facility operators	Facility operators have no issues with technology	**Met** Cleaning was lessened
Site Safety	Chemicals compared to reactor	Elimination of hazardous chemicals, safety of titanium reactor anode	**Met** Chemical use was eliminated

It was anticipated that the primary cost savings for this technology would be water, electric energy, chemicals and maintenance labor costs.

Testing consisted of a baseline period where data was collected prior to the installation of the AWT system. At the conclusion of the baseline period, the AWT technology was installed and data was collected with the new technology in service for comparison. The data acquired during the testing period was adjusted to account for differences in ambient temperature and cooling system duty during the two test periods.

Water savings exceeded the target goal by removing solids in the AWT system and reducing the amount of blowdown that would have been required to remove those solids. The baseline water consumption of the system was measured from June 8,2017 to July 16, 2017 and the AWT water treatment system was monitored from July 18,2017 to October 23rd,2017. The water consumption during the testing period was 639,280 gallons. It was calculated that the amount of water that would have been consumed without the AWT system in place was 934,772 gallons. The water savings from the AWT system is therefore, 31.6%. Water and sewer savings were estimated to be $6,662 annually.

The quantity of blowdown during the baseline period was 77,817 gallons. It was calculated from this data that the amount of blowdown that would have been discharged during the testing period without the AWT system in place was 209,492 gallons. The actual blowdown during the testing period was 307 gallons, or a reduction of 99.8%.

AWT systems can save energy usage by reducing scale build up on condenser tubes. The savings can be substantial as heat transfer is lessened exponentially as buildup on the surfaces occurs. In this case, the system did not have buildup during the baseline testing and does not normally see any substantial fouling of condenser water heat exchanger tubes. Consequently, the weather normalized energy usage from the baseline period to the testing period were found to be negligible. Although the potential for energy savings was not proven, the removal of a large amount of solids by the AWT reactor could potentially improve system cleanliness and create energy savings. There was an increase in energy usage from the reactor and the circulation pump used by the technology.

During the testing period when the AWT system was operating, onsite chemicals were no longer needed to treat the cooling tower water. After running the AWT system for over four months without injecting chemicals, the system did not show any adverse effects. The normal buildup of biological growth in the cooling tower was diminished according to the maintenance staff. The chemical savings were estimated to be $4,080 per year and the reduced cleaning labor costs were estimated at $1,200 per year.

The total annual savings for the system is estimated to be $4,062 which includes costs for the vendor to service and clean its system. The cost of the AWT system equipment was $28,340 including shipping. The largest unknown remaining cost is the cost of installation. The total cost to GSA for this installation was $43,057. The vendor estimates that the installation cost without the cost burden of the GSA procurement process would be $15,000. While it is in the vendor’s best interest to quote a smaller installation cost, the simplicity of the system and the minimal interface with the existing equipment would likely entail a lower installation cost than what was realized. Procurement should be easier after multiple installations, as well. Per GSA’s request, NREL calculated the economics at both values and at an interim average value of $29,029 to install the system. This technology does not require further study and is ready for further commercial implementation. The payback period for all three cases are outlined below:

Table 2. Economic Summary

Description	GSA Install Costs	Vendor's Install Estimate	Interim Install Cost Estimate
COSTS			
UET 1x4 Reactor (dual anode)	$28,340	$28,340	$28,340
Shipping	$2,000	$2,000	$2,000
Installation/Startup	$43,057	$15,000	$29,029
TOTAL INSTALLED COST	$73,397	$45,340	$59,369
ANNUAL SAVINGS			
Technology power usage (@$0.10 kWh)	-$2,749	-$2,749	-$2,749
Vendor's O&M Contract Costs	-$6,000	-$6,000	-$6,000
Cooling Tower Cleaning Savings	$1,200	$1,200	$1,200
Water Savings	$7,531	$7,531	$7,531
Chemical Savings	$4,080	$4,080	$4,080
TOTAL ANNUAL SAVINGS	$4,062	$4,062	$4,062
SIMPLE PAYBACK (Years)	**18.1**	**11.2**	**14.6**
SIR (Savings to Investment Ratio)	**0.83**	**1.34**	**1.03**

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I. Introduction

A. WHAT WE STUDIED

A cooling tower is a heat rejection device that rejects heat to the atmosphere from a water cooled chilled water plant. The heat is rejected to the atmosphere through the evaporative cooling process, and cooling towers are commonly applied to water cooled chilled water plants in medium and large commercial buildings. The continuous evaporation of condenser water leaves behind any mineral content it carried upon entry into the condenser water system. The make-up water has a natural amount of mineral impurities (*e.g.*, silica, calcium and magnesium), so the remaining condenser water will have an ever-increasing amount of impurities as progressively more water evaporates. These impurities eventually precipitate out (since water can hold only so much of these impurities in suspension), resulting in solid precipitate. This solid precipitate is commonly called scale and will collect on various surfaces it is in contact with. Scale has a detrimental effect on heat transfer surfaces; it lowers the efficiency of the heat transfer process, causing the chiller to use increasingly more energy over time to produce the same amount of cooling. Typical water treatment consists of injecting chemicals into the condenser water for the following three purposes:

- Chemicals called "scale inhibitors" alter the natural ability of water so that it can hold a higher concentration of minerals.
- Chemicals called "corrosion inhibitors" decrease corrosion in piping systems.
- Chemicals called "biocides" and "algaecides" mitigate biological growth in the cooling tower where warm water is exposed to air.

In addition to the use of chemicals to treat the cooling tower water, a portion of the cooling tower water is typically dumped down the drain. This is commonly known as tower blowdown or bleed-off. When blowdown takes place, fresh makeup water is introduced, which increases cooling tower water usage.

Therefore, blowdown has the effect of lowering the chemical/mineral content of the remaining condenser water and lowers the cycles of concentration (CoC) of the cooling tower.

The AWT reactor uses electrolysis to split water actively using 15 Amps of direct current to create an acidic solution at the anode (a titanium rod) and a basic solution at the cathode (reactor shell). The process promotes scaling of the hard minerals and silica to the reactor instead of on the tower and in the heat exchanger tubes. Additionally, this process strips hydrogen ions from the chloride naturally present in the water creating chlorine, which acts as a biocide and eliminates the need to add a chemical biocide. The figure below shows the piping diagram of the cooling tower system with the AWT reactor skid. As shown, there is a slipstream that is extracted from the main condenser water loop that flows to the AWT reactor skid and then fed back into the cooling tower. This slipstream requires a small circulation pump.

A schematic of the vendor's system is shown below in Figure 1. The schematic shows that the vendor's technology does not treat the entire cooling water stream, but only a slip stream that is a fraction of the total flow.

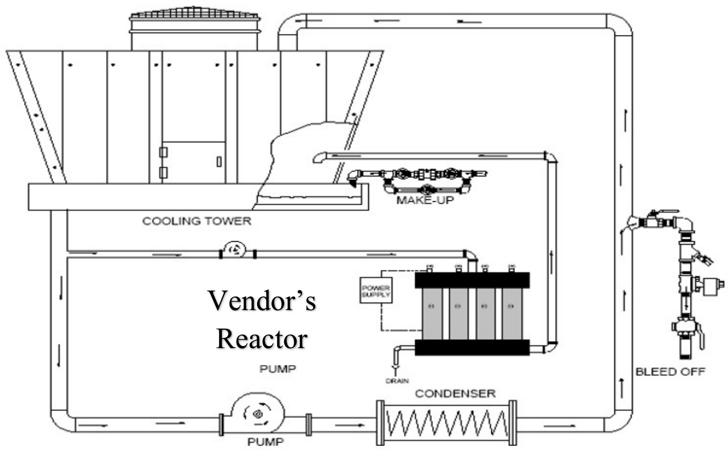


Figure 1. Piping Diagram of Cooling Tower System with AWT Reactor Skid

The two components that need to be measured to account for water savings are (1) water consumption and (2) cooling demand of the building. Water consumption was measured via an onsite water meter and tracked on a monthly basis for the whole building. Make-up water and blowdown were also directly metered and water consumption was recorded on a daily basis for both the baseline and the testing period in this study.

The heat rejected was measured via the onsite building automation system (BAS) by monitoring the condenser loop (cooling tower) supply temperature, return temperature and flow rates. The cooling load data was correlated to hourly outdoor air temperature and humidity values to establish the amount of heat rejected by the cooling tower as a function of outdoor air temperature. These values are established by trending the BAS output for the chiller plant in the building during the period from June to July of 2017.

The water quality was analyzed through assessment of the water quality reports delivered monthly by the AWT vendor, as well as monthly water quality reports provided by the site's water treatment contractor. These reports evaluated: conductivity, pH value, total hardness, alkalinity, silica, chlorides and cycles of concentration (CoC).

The goal of the AWT system is to not only conserve water in cooling tower operations, but to also deliver cooling to each building as efficiently as possible. The impact of the improved chiller operation (due to reduced scale) or reduction in cooling tower operation was quantified.

The AWT system evaluated in the report is a commercialized technology. Given its commercialized state, the system evaluated in this report is at a Technology Readiness Level 8[2] according to NASA definitions.

[2] https://esto.nasa.gov/files/trl_definitions.pdf

B. WHY WE STUDIED IT

Cooling tower-related water consumption is one of largest potable water loads within buildings in the United States. A breakdown of water consumption in office buildings is provided in Figure 2 and shows that about 28% of water use is associated with heating and cooling due to the evaporative cooling demands associated with all water-cooled air conditioning systems and evaporative based air conditioners.

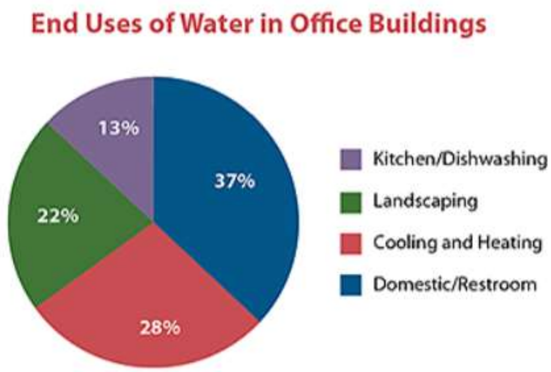


Figure 2. Office water end uses[3]

Cooling towers can be found in all states throughout the country, and this AWT technology could save water in most if not all climate zones. Although the technology can save water in practically all climate zone, facilities located in hotter climates with a cooling season that lasts for more than five-six months per year will have higher cooling tower utilization and consequently have greater potential for cooling tower water savings.

Although the number of cooling towers in each GSA region is unknown, it is expected that each region has numerous cooling towers that could assist in reducing water consumption for each GSA region.

TRL 6 Prototype System Verified (System/process prototype demonstration in an operational environment).
TRL 7 Integrated Pilot System Demonstrated (System/process prototype demonstration in an operational environment).
TRL 8 System Incorporated in Commercial Design (Actual system/process completed and qualified through test and demonstration).
TRL 9 System Proven and Ready for Full Commercial Deployment (Actual system proven through successful operations in operating environment and ready for full commercial deployment).
TRL 10 Program Management and Market Development/Support Activities

[3] https://www.epa.gov/watersense/types-facilities

II. Evaluation Plan

A. EVALUATION DESIGN

Study design and objectives

The technology evaluated in this report was assessed according to two main criteria set out by GSA in the original request for proposals (RFP).

1) Effectiveness of AWT in meeting a predetermined set of criteria that constitutes proper water quality. These criteria were developed by a consultant to GSA under a previous contract and were used in this study to determine whether the AWT systems assessed met the water quality criteria.
2) Effectiveness of AWT system in reducing GSA operating costs (water costs, energy costs and operation and maintenance (O&M) costs)

Common make-up water quality and local weather conditions allowed for comparison of baseline vs. the AWT case (see section II.E for a detailed description of the technology). The principal variable that changed between the baseline and the AWT Case was the quantity of cooling required and, therefore, the amount of heat rejected (and water evaporated) by the cooling tower. The normalization of water savings to cooling demand allowed for effective comparison of the AWT technology to standard water treatment technologies. It also enables the estimation of savings for other buildings. With appropriate metering of the water consumption and cooling demand at other GSA sites it is possible to predict potential water savings that may be achievable with the AWT system assessed here.

This report addresses water, energy and cost savings associated with the AWT system, and the water quality provided by the AWT system. To quantify the performance of the AWT system, metering equipment was installed to measure data for inputs, outputs and delivered results. This data were used to model the overall performance of the AWT system with respect to water use, energy use and water quality. This performance based modeling approach enabled the comparison of AWT system to the baseline water treatment system using the same framework. Using the data gathered from the baseline and the testing period, the performance objectives were analyzed for compliance.

Table 3. Quantitative Objectives

Quantitative Objectives	Metrics & Data	Success Criteria
Water/Sewer Savings	Metered water consumption Metered blowdown	> 25% makeup water savings > 75% blowdown/sewer savings
Energy Savings	Metered chilled water system energy consumption	> 10% chiller energy savings
Maintenance Savings	Maintenance records for current cost of chemicals and labor	100% reduction in added chemicals and decrease in maintenance costs, including eliminated costs for mechanical cleaning is less than the annualized costs for cleaning and maintaining the new system
Equipment Life	**Level of corrosion**	Decrease in corrosivity, as documented in corrosion coupons
Water Quality	Water quality monitoring	Water quality meets site-specific standards (attributes of interest may include conductivity, pH, hardness, alkalinity, silica high range, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, and biological growth)
Cost Effectiveness	SIR	> 1.0 SIR

Table 4. Qualitative Objectives

Objective	Metrics & Data	Success Criteria
Ease of Installation	< 2 days to install and commission one cooling tower	Positive feedback during interview with installer Time required to install & configure. Labor associated with install
Operability	Facility operators have no issues with technology	Positive feedback during interview with O&M personnel. Usability opinion of facility operators
Site Safety	Elimination of hazardous chemicals, safety of titanium reactor anode	Chemicals compared to reactor

The two components that need to be measured to account for water savings are (1) water consumption and (2) cooling demand of the building. Water consumption was measured via an onsite water meter and tracked on a monthly basis for the whole building. Make-up water and blow down were also directly metered and water consumption was recorded on a daily basis for both the baseline and the AWT case in this study.

The chiller energy used from each monitoring period was measured via the onsite data acquisition system by monitoring the condenser loop (cooling tower) supply temperature and return temperature. The condenser loop flow rate was determined from pressure drop readings across the condenser pumps. The cooling load data were correlated to hourly outdoor air temperature and humidity values to establish the amount of heat rejected by the cooling tower as a function of outdoor air temperature.

The water quality was analyzed through assessment of the monthly water quality reports. These reports evaluated conductivity, pH value, total hardness and nitrites.

Water Quality

GSA has developed the water chemistry standards shown in table 5, as a guideline to determine the acceptability of cooling tower basin water quality for a given water treatment technology. Operations staff and water treatment technology vendors performed monthly monitoring of these parameters to characterize performance of the system. It should be noted that adherence to these ranges is not the only indicator of a technology's success. The operation of a water treatment technology is unique and as the function of the materials used in its design may result in water quality that falls outside the ranges defined in the project specifications. These chemistry standards were established for guidance in this particular project location. In the application of these criteria, a site should consider site-specific water quality constraints, whether due to influent potable water or discharge permit limitations, and make selections accordingly.

Table 5. Water Quality Criteria (as defined by GSA)

Test	Acceptable Ranges
T alkalinity (ppm)	100 - 1000
pH	7.3 – 9.0
Chloride (ppm)	10 - 500
Cycles of concentration	>2
Total Hardness (ppm)	500 - 1500
Phosphate (ppm)	8 - 15
Conductivity (mmHos)	<2400
Bacteria Count (cfu)	<80,000
Water Appearance	Clear
Iron (ppm)	<4
Calcium Hardness (ppm)	<500
Magnesium Hardness (ppm)	<100
Chlorides (ppm)	<250
Salt (ppm)	<410
Sulfates (ppm)	<250
Silica (ppm)	<150
ORP (mV)	>300
90-day Copper Coupon (mpy)	<0.2
90-day Mild Steel Coupon (mpy)	<3
90-day Galvanized Steel (mpy)	<4
90-day Stainless Steel (mpy)	<0.1

B. INSTRUMENTATION PLAN

The goal of the instrumentation plan for this technology demonstration focused on metering water and energy use of the building cooling towers and chillers. To develop this measurement, instrumentation was added for the following data points described in Table 6:

Table 6. Monitoring Points and Instrumentation

Monitoring Point	Sensor/Monitor	Notes
Condenser water flow rate	Pump differential pressure readings	Remote indication capability
Blowdown flow rate	FTB4600 series totalizing flow meter	1/2 inline PVC line
Blowdown conductivity	Existing Site Meter (Lakewood Model 140 controller)	Mounted in line. Tie into 4-20 mA output
Makeup water flow rate	FTB4600 series totalizing flow meter	3/4 inline, replace existing meter
Chiller power (x2)	CTs and watt-hour meter	3-400 A CTs, WNC- 3Y-480 wattnode
Cooling tower fan power (x2)	CTs and watt-hour meter	3-50 A CTs, WNC- 3Y-480 wattnode
Chilled water pumps (x2)	CTs and watt-hour meter	3-50 A CTs, WNC- 3Y-480 wattnode
Condenser water pumps (x2)	CTs and watt-hour meter	3-50 A CTs, WNC- 3Y-480 wattnode
AWT reactor skid	CTs and watt-hour meter	
Slip-stream pump	CTs and watt-hour meter	
Condenser inlet water temperature (x2)	Thermocouple	Mounted in well
Condenser outlet water temperature (x2)	Thermocouple	Mounted in well
Chiller status	Derived from electric metering	
Ambient dry bulb temperature	Vaisala HMP60 T&RH sensor with shield	
Ambient relative humidity	Included in T&RH sensor above	
Data logging equipment	3 Campbell Scientific CR1000 data loggers with cell phone modem, required peripheries, and other supplies	

C. TEST BED SITE

One GSA building in Savannah, Georgia was selected as the installation site for this study: Juliette Gordon Low Federal Building. There are two cooling towers at the building and traditional chemical water treatment was used in the towers prior to the AWT installation.

The AWT reactor uses electrolysis to split water actively using 15 Amps of direct current to create an acidic solution at the anode (a titanium rod) and a basic solution at the cathode (reactor shell). The AWT system treats a slipstream that is pulled off of the main condenser water loop that flows to the AWT reactor skid and then fed back into the cooling tower. This slipstream requires a small circulation pump.

The system includes the reactor skid and the slipstream circulation pump, which are shown in Figure 3.

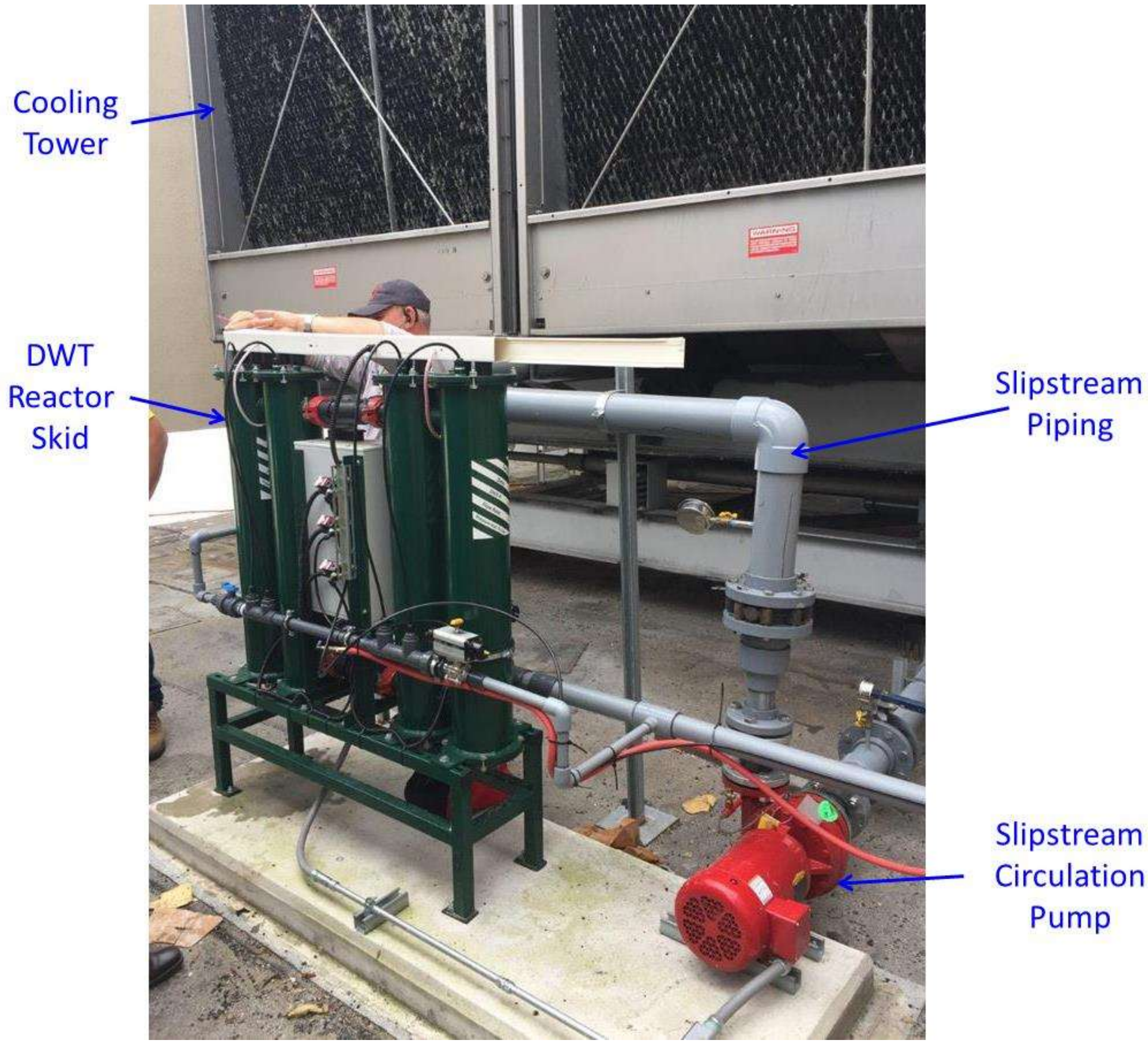


Figure 3. AWT System and Associated Piping and Pumping (Credit: Gregg Tomberlin, NREL)

Photos of cleaning the AWT reactor are shown below. The left photo shows pulling the reactor anode (titanium rod) from the reactor shell (cathode). The center photo shows the magnesium and calcium buildup on the anode and the right photo shows the anode after cleaning. Cleaning of the reactor is easily accomplished by scraping off buildup from the anode. No chemicals are used in the process.

Figure 4. Cleaning the AWT System (Credit: Gregg Tomberlin, NREL)

D. METHODOLOGY

The effectiveness of the technology was demonstrated by comparing test data during a baseline demonstration period with test data after the AWT system was installed. Testing was performed during the peak cooling season when the chillers were operating on regular basis.

After all instrumentation was installed and tested, the data collection began for the baseline test period. The demonstration test period with the AWT system installed began after baseline data had been collected. A schedule using the months of June to July for the baseline period and July to October for the demonstration test period is shown in Figure 5.

Baseline Testing Period
June 8, 2017 through July 16, 2017

Demonstration Testing Period
July 18, 2017 through October 23, 2017

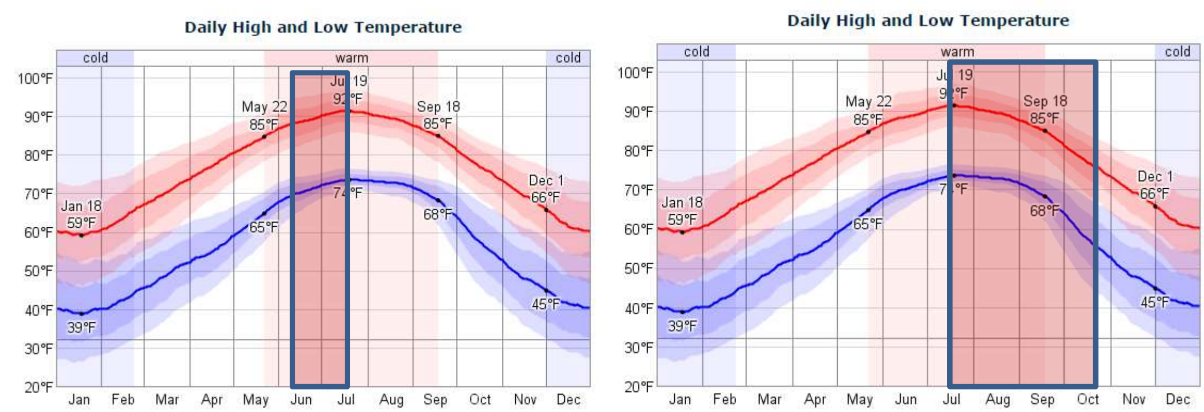


Figure 5. Baseline and Testing Schedules

The data obtained was used to evaluate if the AWT system represents an improvement in the system's use of water and chemicals. The local water cost at this site averaged $6.64 per kgal which was used to calculate annual water cost savings. Additionally, the savings in water was calculated using the much higher GSA regional average water cost of $16.76 per kgal[4]. Annual chemical savings and any savings in maintenance costs are added to the system's overall savings. No energy savings were realized or included in the economics. The savings were compared to the costs, including capital costs and any additional maintenance costs required by the AWT system. The results yield both a simple payback in years and a savings-to-investment ratio (SIR).

III. Demonstration Results

A. QUANTITATIVE RESULTS

Water Savings

To accurately assess the water savings from the AWT system, it was necessary to calculate pre-installation cooling tower water usage. Makeup water and blowdown was metered prior to the installation of the AWT system at the Juliette Gordon Low Federal Building from June 8 to July 16, 2017 in order to develop a baseline. The AWT increased the CoC by modifying the conductivity setpoint on the cooling tower controller. The initial setting was 680 microsiemens (µS). During the test period, the setting was raised to 1,400 µS and finally 2,500 µS. The figure below shows the metered data for the makeup water and blowdown along with the startup time of the AWT system. As shown, there was a 99% reduction in blowdown after the installation of the AWT system. The baseline CoC averaged 3.9. Once the AWT system was engaged, very little water was blown down making the CoC increase into uncharted territory when using the water balance calculation. The high removal of solids internally make this type of CoC calculation a less valuable indicator for comparison with other types of technologies.

Linear regression is used to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. The baseline regression model was used to predict how much water the baseline system would have used compared to the new system. A confidence interval of 95% was applied to the model to also predict the savings estimates upper and lower bounds.

[4] Average water costs of all 11 GSA regions for fiscal year 2017.

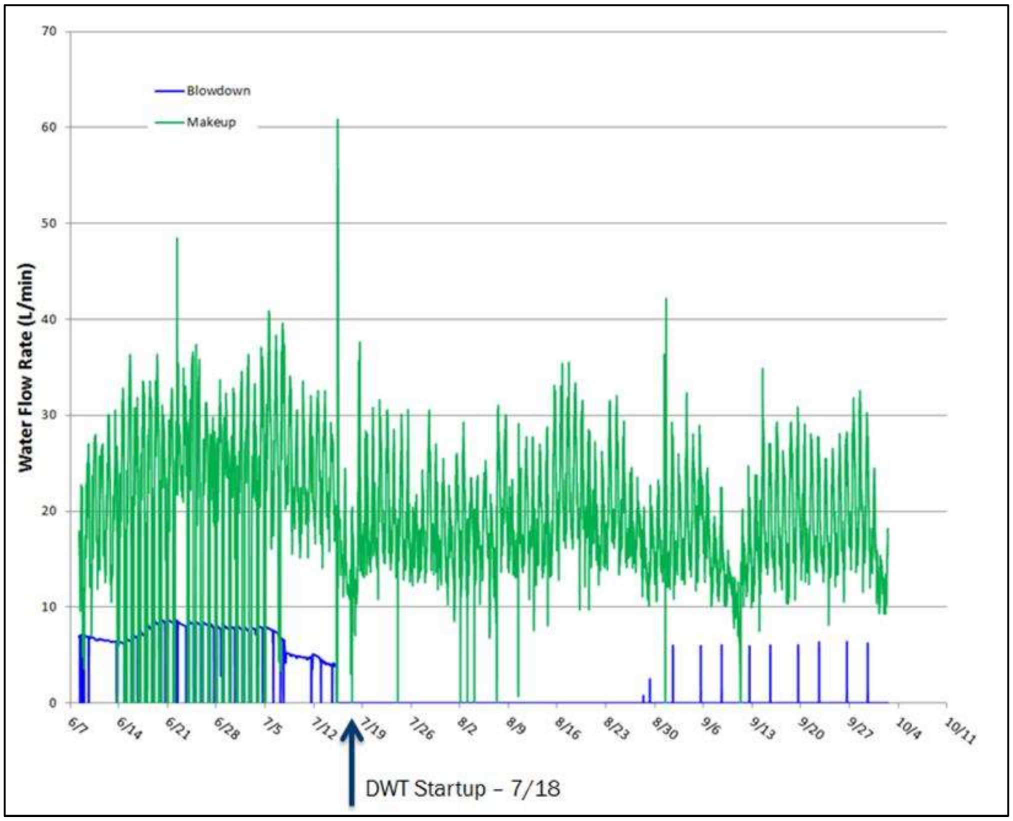


Figure 6. Make-up Water and Blowdown Metering Pre-AWT and Post-AWT Installation

Data Analysis Using a Linear Regression Model

The first multi-variable linear regression model was created using the following input variables to correlate hourly cooling tower make-up water usage as a function of chiller plant condenser ton hours or chiller plant energy usage and outside air conditions.

- Outside Air Temperature (OAT) – hourly outside air temperature recorded from NREL's onsite data loggers
- Outside Air Relative Humidity (OA_RH) – hourly outside air relative humidity recorded from NREL's onsite data loggers
- Chiller Plant Electricity (Chiller_Elec) – hourly total chiller plant energy usage from a combination of chillers, pumps and cooling towers, calculated based on NREL's onsite data logger readings
- Chiller Plant Ton Hours (Chiller_Ton.Hrs) – hourly total chiller plant condenser ton hours, calculated based on NREL's onsite data logger readings

- Weekday/Weekend (Wkd_Wknd) – Each weekday was given a designation of 1 and each weekend day and federal holiday was given a designation of 0 to account for days when the facility is unoccupied and to account for its impacts on chiller energy usage and cooling tower make-up water usage.

All of the variables other than the Weekday / Weekend variables were converted into coded variables that had values ranging from -1 to 1 to give them all the same range of possible values and to help improve the fit of the model. A linear regression model that included all terms as explanatory variables was created, including both squared and interaction terms between explanatory variables to identify the variables with the highest statistical significance (P value less than 0.05). From this statistical significance analysis, a final linear regression model that had the highest R^2 and lowest normalized root mean square error was created and is provided in Equation 1.

Equation 1. Baseline Hourly Cooling Tower Makeup Water Regression

$$Cooling\ Tower\ Makeup\ Water = c_0 + (c_1 \cdot CChiller\_Elec) + (c_2 \cdot WKD\_WKND) + (c_3 \cdot COAT \cdot COA\_RH) + (c_4 \cdot COAT \cdot CChiller\_Elec)$$

where:

CChiller_Elec = coded hourly chiller energy usage [-1=min to +1=max]

WKD_WKND = weekday or weekend/holiday [1 = Weekday or 0 = Weekend]

COAT x COA_RH = coded outside air temperature times coded outside air relative humidity[-1=min to +1=max]

COAT x CChiller_Elec = coded outside air temperature times coded chiller electricity usage [-1=min to +1=max]

The linear regression model was selected to ensure that the explanatory variables used in the model have p-values less than 0.05. The explanatory variables that had the highest statistical impact were coded chiller plant energy usage, Weekday/Weekend, coded outside air temperature and coded outside air relative humidity, which would all be expected to impact the hourly cooling tower make-up water usage. The adjusted R^2 for the model is 90.35% and the normalized root mean square error for the model is 6.24%. The coefficients for each explanatory variable are provided in Table 7.

Table 7 – Hourly Baseline Cooling Tower Make-up Water Linear Regression Model Coefficients

Hourly Baseline Model Variables	Coefficient Values
r squared	0.9035
Intercept	271.10
CChiller_Elec	228.55
WKD_WKND	16.26
COAT	72.67
COA_RH	-59.52
COAT x COA_RH	-68.88
CChiller_Elec x COAT	-29.66

A final check of model prediction was performed that compared the actual cooling tower make-up water to the modeled cooling tower make-up water in Figure 7, and it shows that that there is a good correlation between the two.

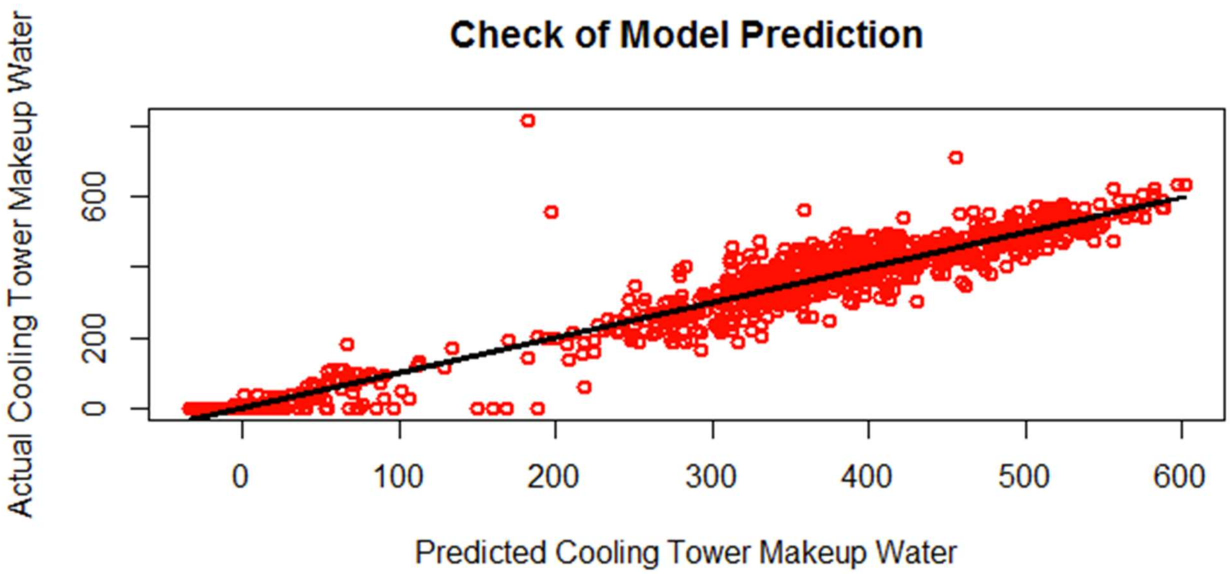


Figure 7 – Hourly Baseline Period Cooling Tower Make-up Water vs Predicted Cooling Tower Make-up Water Usage (kgals)

In the regression analysis, since the data available for 6/8/2017, was a partial day, the baseline period for the regression analysis was 6/9/2017, to 7/16/2017, and the predicted hourly cooling tower make-up water usage was output and compared to the measured data. For the entire baseline period, the cooling tower make-up water usage was 301,438 gallons, and the predicted cooling tower make-up water usage was 301,535 gallons, with a percent difference of the two of 0.032%, indicating a very good fit for the baseline model.

Using the prediction curves and applying the data, the make-up water usage for the post-installation reporting period was 639,280 gallons and the baseline system was estimated to use 934,772 gallons, with a savings of 295,492 gallons for this period, or 31.6%. The estimated water usage for the baseline system using the lower bound was 913,403 gallons and the estimated make-up water usage for the baseline system using the upper bound was 956,142 gallons, representing a 30.0% and 33.1% savings respectively. Water savings averaged 31.6% from the baseline testing to the test period utilizing the AWT system. Make-up water flows and regression analysis parameters are shown below.

Table 8 – Make-up Water Test Period versus Modeled Make-up Water for Baseline (7/18/2017, to 10/23/2017)

Make Up Water Post Retrofit	Make Up Water Usage (gallons)
Make-up – Test Period	639,280
Make-up - Baseline fit	934,772
Make-up - Baseline lower	913,403
Make-up - Baseline upper	956,142

Table 9 – Quantitative Savings

Baseline Performance	*Technology Performance*	*% Savings Compared to Baseline*
934,772 gallons used	639,280 gallons used	31.6 %

The site water use reduction for a full 12 months is estimated to be 1,133,857 gallons.

Energy Savings

Energy savings claims for the AWT system are based on the technology's ability to remove scale from a system that has existing fouling and to keep systems that normally foul from fouling between cleanings. Scale build-up on heat exchanger tubes can reduce heat transfer substantially with only a thin layer of scale. This loss in heat transfer results in higher energy use to achieve the desired performance. The ability to clean the cooling water enough that it will diminish scale build-ups has the potential to create significant energy savings. The energy used in the system was measured on all relevant components for both the baseline period and the testing period. There was little or no change in energy consumption between the two periods of operation. The plant operating staff stated that the condenser tubes do not show scaling under normal operations and there is only a small amount of "dusting" on the tubes where material settles during shut down. Because the tubes are not fouled, there was no opportunity to decrease fouling and save energy. Therefore, the results of the energy savings are deemed to be zero, but the potential for energy savings may still exist where substantial condenser tube fouling exists.

Chemical Savings

The manufacturer of the AWT system claims that chemicals are not required when its system is in operation. The baseline period utilized the normal chemical injection scheme that costs the site about $4,080 per year. When the AWT testing period began, the chemical dosing systems were taken out of service and no chemicals were used for the remainder of the testing. For this savings to be considered, the resulting water quality needs to be in line with system norms and GSA standards. Additionally, inspection of the system after testing should show no increase in algae build-up at the cooling tower fill and basin. The final inspection showed a reduction in this biological build-up, allowing for a reduction in cooling tower cleaning frequency.

Water Quality

On a monthly basis, cooling towers are tested for effectiveness of water treatment, including pH, TDS, conductivity, biological dosage level, scale, and corrosion inhibitors. Chemicals and biological treatment dosage and water blowdown rate are adjusted, as required. Make-up water is tested to determine the appropriate levels for chemical dosing. GSA typically runs a cooling tower that uses standard chemical-based water treatment between 3 to 6 CoC.

The AWT system increases the cycles of concentration for the cooling towers which decreases blowdown and saves water. The blowdown can be decreased because the elements that the blowdown is trying to eliminate are collected in the AWT reactor. In any case, changes in the setting of the conductivity controller will reduce blowdown and water costs. Water testing was required to verify that the AWT system's approach did not negatively affect the water quality in ways that are unacceptable. Water quality while using the AWT system resulted in a water chemistry that is in line with GSA standards.

The only constituent that changed substantially was chlorides (Cl^-). Chloride levels rose with the AWT system from 92 ppm in the tower basin up to 400 ppm four months later. As the concentration of Cl- increases, stainless steel corrosion can take place although levels below 1,000 ppm are generally not concerning. The AWT system does leave a high concentration of calcium ions (Ca^{++}) in the water which will mitigate corrosion issues. In order to insure that this is not an issue, chloride levels should be monitored regularly and the use of corrosion coupons or a corrosion monitoring device that uses linear polarization resistance (LPR) should be used in all systems.

B. QUALITATIVE RESULTS

Building staff were interviewed after the testing was completed to understand any qualitative changes in operational or maintenance issues. Comments for relevant areas are shown below:

Ease of Installation

The AWT system consists of a skid with a small footprint. Setting the skid, wiring and plumbing are straightforward. The system does require compressed air and the manufacturer of the AWT system initially assumed that building air would be available for its use. It was communicated to the manufacturer of the AWT system that tying into GSA building air systems is not allowed practice. Consequently, the manufacturer of the AWT system purchased a compressor that was installed with the system. The installation is separate from the main cooling system only treating a portion of the flow. If the skid can be located close to the cooling water supply and return piping, the slip stream piping runs are short. The ties into the cooling water systems do not take much time or expense. Maybe the most challenging aspect is getting the skid to the upper levels of the building where the cooling towers are normally located. For the Juliette Gordon Low building, the skid was about four feet long and a little over a foot wide with a height of about five and half feet. The equipment weighs less than five hundred pounds dry. Most buildings are capable of handling equipment of this size without issue.

Operations and Staff Acceptance

Overall operation

Care of the water system was overseen by a chemical company with a representative that visited the site weekly to test the water and make any necessary changes to the water treatment system. The site reported that the AWT equipment did not present any difficult operational issues, although water testing is still required for the system. Since the chemical usage will be abandoned, the testing that was done by the chemical company must be done by another entity. This will be accomplished by contracting the manufacturer of the system for a maintenance contract that includes sampling. The costs for this contract are included in the economic analysis of the system.

Cooling Tower Condition (overall cleanliness)

Prior to testing the AWT system, there was a concern that removing the biocide from the water would result in a build-up of algae in the cooling towers. Site personnel stated that the cooling towers were in better condition and required less cleaning after using the AWT system. The AWT reactor generates chlorine and it lessened the buildup of a dark slimy substance that was normally present. This results in reducing the annual cleanings from four times to two. This translates to a $1,200 annual savings.

Chiller Condensers Condition (overall cleanliness)

No difference reported. The tubes typically have a slight “dusting” of loose particles that are brushed out during a cleaning. After utilizing the AWT system, the condition of the condenser tubes was the same. The manufacturer of the system claimed that their system would clean up existing condenser tube scale.

Input from the Facility Managers

In general, the site staff liked the AWT system. The only concern expressed was the availability of assistance going forward. Having a “chemical guy” that visits the site once a week generated a close working relationship. If anything went wrong, someone could be on site quickly or could answer questions by phone. This is an issue of customer service. The manufacturer of the system has not had a chance to prove its customer service capabilities as of yet.

The technology was well received overall. The operations and maintenance agreement will be important to the staff going forward. A clear and specific maintenance agreement regarding what is being provided and what is expected of the staff on site could mitigate concerns and reduce risk

Site Safety

Site safety can be affected by several factors. With regards to the AWT system, no new safety hazards were introduce by installing the skid and tie in points. Site safety is improved by the fact that chemicals will be removed from the site. Chemical usage is a common safety concern for transportation, changing chemical tanks, storage and feed systems. The removal of all chemicals will increase site safety for these reasons and the will eliminate the potential for dangerous chemical spills.

C. COST-EFFECTIVENESS

The primary savings on the project were projected to be water, electric energy, chemicals and maintenance labor costs; energy and water were anticipated to contribute the most savings. Water savings exceeded the target goal by removing solids in the AWT reactor and reducing the amount of blowdown that would have been required to remove those solids. Water related cost savings were estimated to be $6,662 annually.

Savings in energy can be realized when build-up on heat exchanger surfaces is removed or if build-up that normally occurs does not occur due to the systems performance. The savings can be substantial, as heat transfer is lessened exponentially as build-up on the surfaces occurs. In this case, the system did not have build-up during the baseline testing and does not normally see any substantial fouling of heat exchanger tubes in the condensers. This is the reason that no energy savings were observed in this time limited evaluation. The claimed cleaning effect of the system was not given an opportunity to perform as the system normally runs clean. This is not the case in all facilities and keeping the condenser tubes clean can have a dramatic effect on heat transfer and energy savings. The AWT system's ability to clean tubes or keep tubes clean remains unconfirmed, but could potentially increase savings by creating energy savings under different circumstances. There was an increase in energy usage from the reactor and the circulation pump used by the technology.

Chemical usage was eliminated during the AWT testing period. Lack of a biocide in the system might be a concern but the AWT system claims to generate biocide. After running the AWT system for over four months without injecting biocide, the system did not show any adverse effects. The normal build-up of biological growth in the cooling tower was actually diminished according to the maintenance staff. Not only does this create chemical savings, but the need to clean the cooling tower is estimated to be reduced by 50%. The savings realized from the elimination of chemical usage and the supply contract will be $4,080 per year. These savings are offset by the cost of the annual AWT maintenance contract estimated to be $6,000. This cost includes quarterly site visits for inspection and preventative maintenance, including AWT reactor cleaning. The cost also includes all consumables, water analyses and monthly water reports. Utilizing the manufacturer's annual service contract increases the system warranty from 10 years to 20 years.

The reduced cleaning labor costs will be about $1,200 per year. These figures account for the $6,000 annual cost for the manufacturer of the system to care for and maintain the system. The costs for AWT support include field trips to the site. The costs were calculated for site visits to Savannah, GA, but may vary for other locations due to increased travel costs.

The cost of the AWT system equipment was $30,340, including shipping. The largest unknown remaining is the cost of installation. The total costs to GSA for this installation was $43,057. The manufacturer of the AWT system estimates that the installation cost without the cost burden of the GSA procurement process would be $15,000. The simplicity of the system and the minimal interface with the existing equipment suggest a lower cost than what was realized. Procurement could be easier after multiple installations as well. Per GSA's request, NREL calculated the economics at both values and at an interim average value of $29,029 to install the system. The payback period for all three cases are outlined below.

The cost of water is a primary determinant in whether the economics are favorable. For this evaluation, an average water price was calculated using the last 12 months of data available. Table 10 below shows the data and the result of $6.64 per thousand gallons of water used. The costs shown include the price for sewer disposal.

Table 10 – Historical Water Costs

Year	*Month*	***Usage***	***Cost***	***Cost/kgal***
2016	November	201,212	$1,319	$6.56
2016	December	201,212	$1,322	$6.57
2017	January	147,107	$983	$6.68
2017	February	147,107	$983	$6.68
2017	March	147,107	$983	$6.68
2017	April	330,242	$2,184	$6.61
2017	May	330,242	$2,184	$6.61
2017	June	434,089	$2,806	$6.46
2017	July	434,089	$2,806	$6.46
2017	August	434,089	$2,806	$6.46
2017	September	390,830	$2,720	$6.96
2017	October	390,830	$2,720	$6.96
	Total Annual	3,588,156	**Average**	**$6.64**

The cost of water and the overall water savings were added to Table 11, below, along with the other relevant cost factors to develop a simple payback period in years. While the average cost of water at the site is $6.64 per kgal, the average water cost across GSA regions is $16.76 per kgal. Additionally, the average water costs for GSA regions has increased by 41% between 2014 and 2017. These higher costs and the propensity for escalation work to substantially reduce the payback periods for the technology. A simple payback period was calculated for both water rates as shown below.

Table 11 – Economic Assessment Worksheet (Retrofit)

Description	GSA Install Costs	AWT Install Estimate	Estimated Install Cost Estimate
COSTS			
UET 1x4 Reactor (dual anode)	$28,340	$28,340	$28,340
Shipping	$2,000	$2,000	$2,000
Installation/Startup	$43,057	$15,000	$29,029
TOTAL INSTALLED COST	$73,397	$45,340	$59,369
ANNUAL SAVINGS			
Technology Power Usage (@$0.10 kWh)	-$2,749	-$2,749	-$2,749
AWT O & M Contract Costs	-$6,000	-$6,000	-$6,000
Cooling Tower Cleaning Savings	$1,200	$1,200	$1,200
Water Savings[5]	$7,531	$7,531	$7,531
Chemical Savings	$4,080	$4,080	$4,080
TOTAL ANNUAL SAVINGS	$4,062	$4,062	$4,062
Using Savannah Water Costs			
SIR (Savings-to-Investment Ratio)	0.83	1.34	1.03
SIMPLE PAYBACK (Years)	18.1	11.2	14.6
Using GSA Avg. Water Costs			
SIR (Savings-to-Investment Ratio)	3.18	5.14	3.93
SIMPLE PAYBACK (Years)	4.7	2.9	3.8

[1]Using current technology costs provided by vendor and installation costs.
[2]Equipment lifespan is 15 years.

Table 12, below shows the payback period sensitivity to water costs using the costs above for the estimated installation costs in the right hand column of Table 11.

[5] Based on water cost of $6.64 per thousand gallons (kgal).

Table 12 – Payback Sensitivity to Water Costs[6]

PAYBACK using GSA avg. EUAS2017 water cost of $16.76 per kgal	
Cost of Water ($/kgal)	**Simple Payback (years)**
$6.00	17.8
$8.00	10.6
$10.00	7.5
$12.00	5.9
$14.00	4.8
$16.00	4.0
$18.00	3.5
$20.00	3.1
$22.00	2.8
$24.00	2.5

IV. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

GSA installed the AWT system in the Juliette Gordon Low Federal Building in Savannah, Georgia, to test whether the technology could maintain adequate water quality while conserving water, saving energy, and reducing operating costs. (The determination of adequate water quality was made based on a previously developed set of benchmarks.)

The economics of the AWT system are shown in Table 11, above. The AWT system showed substantial water savings at 31.6%. The potential for energy savings was not yet proven, although the removal of a large amount of solids by the AWT reactor could potentially improve system cleanliness and create energy savings. Implementation decisions should not be made on the assumption of energy savings until further evidence is shown.

Calculating the water reduction based on chiller load (gals/ton-hr) provides a metric for comparison to other facilities. The evaporation portion can be calculated with the equation:

$$E = \frac{F \times Q}{\Delta H_{vap} \times 8.34\ lb/gal}$$

- E is the gallons of water evaporated
- F is a factor expressing the ratio of latent to sensible cooling (usually a value between 0.75 and 1, with a value of one dictating total latent cooling)

[6] Using interim install cost estimate from Table 11.

- Q is the cooling required by the tower (can be calculated using $\dot{m}C_p\Delta T$)
- ΔH_{vap} is the latent heat of vaporization of water (approximately 1000 Btu/lb at sea level and closer to 976 at Denver's altitude).

If Q is set to be 12,000 Btu (or one ton), the lower limit for gallons per ton-hr can be calculated as between 1.10-1.32 gal/ton-hr. (depending on F, the portion of cooling that is latent vs. sensible). The equivalent ton on the cooling tower side rejects 15,000 Btu/hr due to the heat-equivalent of the energy needed to drive the chiller's compressor, in which case the lower limit for condenser side gallons per ton-hr is 1.375 to 1.65 gal/ton-hr.

Baseline gal/ton hr = 1.63 x (15,000/12,000) = 2.0375 gal/ton-hr
New gal/ton-hr = 1.12 x (15,000/12,000) = 1.4 gal/ton-hr

The key variable in the economic calculations is the installation cost. The costs for a GSA installation are higher on the first installation than subsequent installations due to unfamiliarity with the system and the nuances associated with the install. The costs for this installation totaled $73,397 for skid mounted equipment that only cost $28,340. This ratio of installation costs to capital cost is high by industry standards. It is assumed that the costs for installation could drop substantially for future installations. Further investigation into the cost breakdown for this installation could reveal areas where money could be saved.

As shown in the economic assessment, three separate cases were run with three different installation costs. An average of the actual cost on this project and the manufacturer's cost estimate is shown in case cost reductions can be realized for future projects.

B. LESSONS LEARNED AND BEST PRACTICES

The installation of the AWT system only required a small footprint and a simple tie in process. Since the installation and the removal of the technology are not invasive to the balance of the system, risk is mitigated. For the AWT system, the slipstream water treatment can be valved out and chemicals re-introduced at any time. The risk is then limited to the capital outlay and some technologies can be installed on a trial basis and removed if performance is not per the guarantee.

Corrosion is a concern in water cooling systems. Testing corrosion is difficult and the standard methodology is to use corrosion coupons. Coupons are measured and weighed pieces of metal. They are made of the metals of interest like copper, mild steel or stainless steel. Measuring corrosion using coupons is tricky as they require long periods of testing to see results. Additionally, short term upsets that are corrosive are not measured. Scale build-up on coupons can shield them from corrosive agents yielding mixed results. Newer technologies can measure corrosive environments on an instantaneous basis. Linear Polarization Resistance (LPR) is an electrochemical method for measuring the corrosion rate of a material in primarily aqueous environments.

C. DEPLOYMENT RECOMMENDATIONS

Cooling tower performance depends on a variety of factors, many of which are location specific. Variables such as ambient air quality are specific to the site location and tower location on the site (*e.g*. airborne particulate matter), and seasonal changes have the potential to affect the observed operation of each technology evaluated. These factors can contribute to biological growth or mineral deposits that require additional chemicals.

Given that cooling tower performance is a function of wet bulb temperature, cooling tower performance and the amount of cooling delivered for each technology will also vary by site. Sites in dry climates with low wet bulb design temperatures are favorable for evaporative cooling systems. Variability in technology performance may also be a function of the type of cooling tower being used. The footprint of a given technology may vary with respect to the cooling tower size, and may impact the feasibility of its installation.

As important as the quantity of water used is the cost of water at the facility. Water cost savings is equal to the gallons saved times the cost per gallon. Areas with high water costs are of special interest.

Potable water quality is highly variable across the United States. The performance of these technologies is a function of the quality of influent water that is treated. Locations with high hardness, pH or TDS values typically have higher water and chemical usages. These are the sites that also have the greatest opportunity for savings. The AWT system is well suited for both retrofit and new construction applications.

Rebate opportunities may be available through local water utilities to implement water conserving technologies. The availability of these financial incentives can make the technology implementation even more cost effective.

Market Potential within the GSA Portfolio

The first step in evaluation of further deployment of these AWT systems is the identification of buildings in the GSA portfolio that have water cooled chillers. These are typically larger buildings where the high cooling loads benefit from the improved efficiency of water cooled chiller plants (and where the higher initial cost of a chiller plant is warranted due to higher loads).

The next step in site selection is identifying sites where the AWT system will perform well economically. To assist GSA in identifying sites that have high potential water and cost savings, or both, NREL modeled water savings potential using the whole-building modeling software EnergyPlus in a previous NREL/GSA GPG report entitled 'Alternative Water Treatment Technology System for Cooling Tower Applications'. The "Large Office" building model was selected from the Commercial Reference Buildings that are developed and maintained by DOE/NREL. 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 utilized.

The large office building model is a 498,588 ft^2 office building that is cooled by a water-cooled chiller. The standard cooling tower model in EnergyPlus defaults to blowdown operation that maintains a CoC of 3. To evaluate the potential impact of AWTs 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 3 CoC, (2) with the cooling tower set to maintain 15 CoC and (3) with the cooling tower set to maintain 30 CoC. The EnergyPlus default of 3 CoC was established as the baseline, representative of a standard water treatment approach for water cooled chillers. The 15 and 30 CoC simulations represent a range of concentrations that have been shown to be achievable by AWT systems in this report. Figure 26 shows the annual evaporation (in thousands of gallons water) and the annual water savings (over the baseline blowdown at 3 CoC) for 15 and 30 CoC. The cities with larger numbers of cooling degree days and more arid climates show the greatest water savings. It can be noted that the vast majority of the water savings are achieved by 15 CoC; across the 16 different cities, an average of 92% of the savings achieved at 30 CoC were captured at 15 CoC.

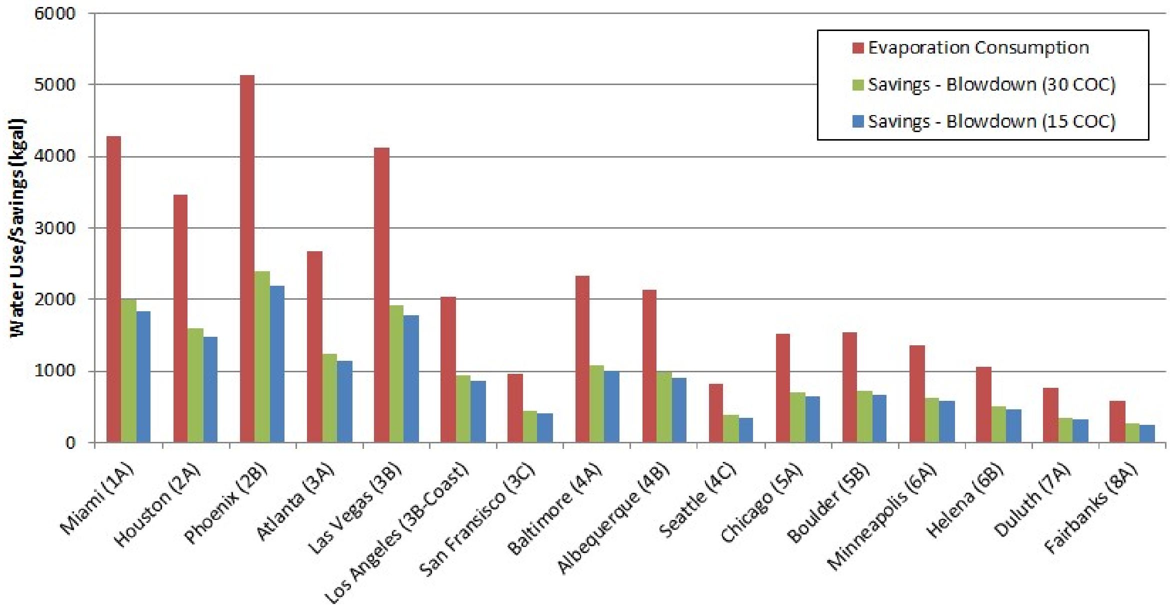


Figure 8. Modeled water evaporation and blowdown savings across ASHRAE climate zones

The water savings numbers were then translated into annual cost savings using site specific water rates. Combined water and sewer rates were obtained from an article published by American Water Intelligence based on a survey of water and wastewater rates in 50 U.S. cities in 2012.[i] The annual water savings for each location were multiplied by the combined water rate for each city. The results from this analysis are presented in Figure 9. The wide variation in water costs between the different cities results in a significantly different picture in cost savings than is seen in water savings. Cities with high water rates (such as Atlanta, GA) generate the largest annual cost savings despite not having the largest total water savings.

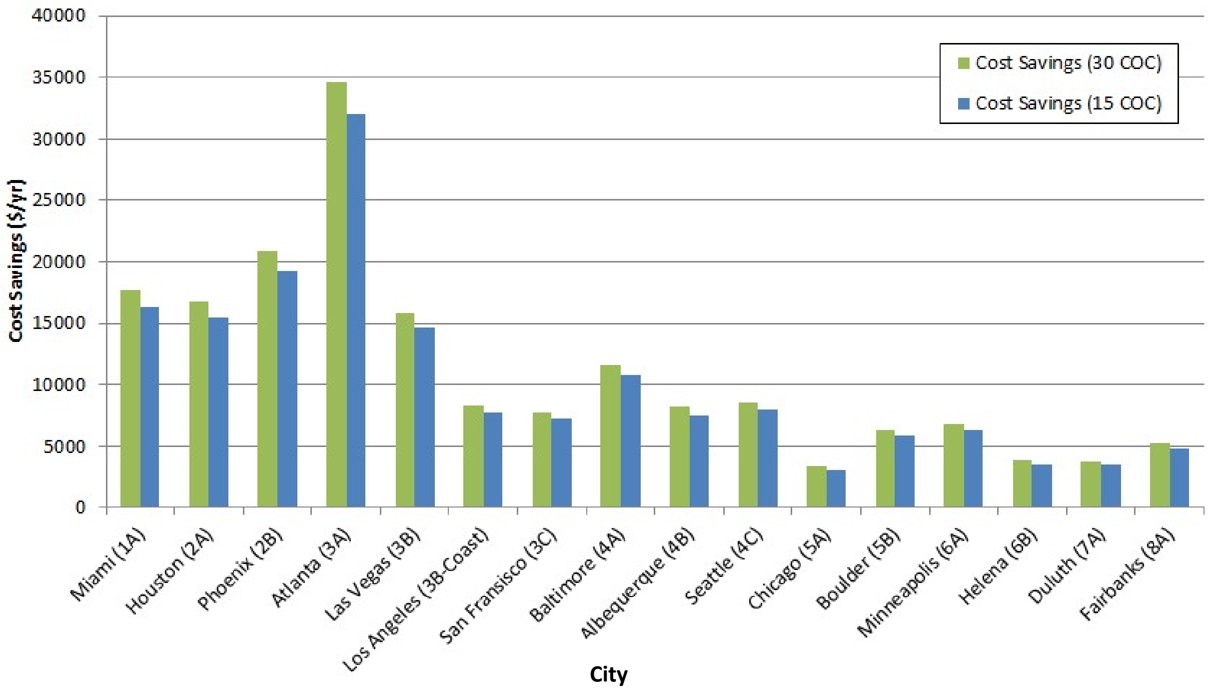


Figure 9. Estimated yearly cost savings by climate zone

To gain an appreciation of the market potential for GSA, approximate system costs were utilized to calculate a simple payback for each city. The paybacks denoted here are a very rough estimate, considering the assumptions that the original system was operating at 3 CoC, the new system would achieve 15 CoC and that the annual operating costs remain the same pre- to post-install, yet they give a feeling for the critical variables driving economic viability of the system in various U.S. locations. The simple paybacks for a high installed cost assumption ($60,000) and a low cost assumption ($40,000) are shown in Figure 10.

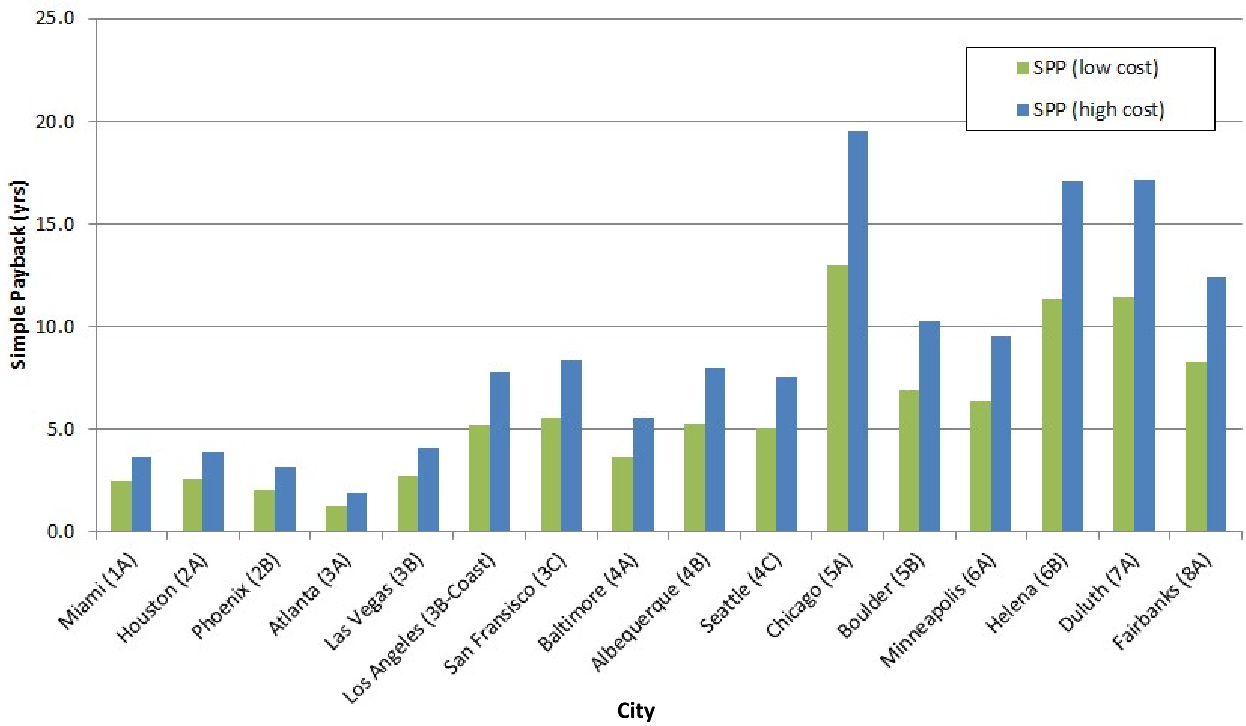


Figure 10. Simple payback period for same system in evaluated locations

The buildings that have a large number of cooling degree days, high evaporation rates and poor water quality can expect maximum water savings, whereas buildings in areas where typical wet bulb temperatures approach dry bulb design temperature (high humidity) will generally see less water use and, therefore, less water savings. The locations that have high water costs in addition to high water savings will result in the most economically favorable locations for GSA to pursue in its deployment of AWT systems. It is also important to consider the water quality of the locations under consideration.

V. Appendices

A. RESEARCH DETAILS

Water Savings

To accurately assess the water savings from the AWT system, it was necessary to obtain (or calculate) both pre- and post-retrofit water consumption. It is also necessary to have these consumption values for the same cooling demand so that the savings can be normalized for weather variation. The weather normalization ensures that a cooler or warmer than average month does not impact the calculated water savings.

Due to the fact that the temperature differential (ΔT) was calculated on the condenser water loop (not the chilled water loop), it excludes any impacts of chiller efficiency.

The heat rejected was calculated for each 15-minute time step and then summed over the course of the day. Daily values were also calculated for: average outdoor dry bulb, average relative humidity, minimum dry bulb, maximum dry bulb, and operating hours. Each of these variables (plus weekday/weekend status) was tested for correlation with the calculated cooling demand. The two significant variables identified were average outdoor air temperature and weekday/weekend (expressed as a -1 for weekend and 1 for weekday). These correlations were then able to be used to calculate make-up water for the building for historical periods where the BAS trend data was not available.

The data is shown in Figure 11. The regression equations shown on the graphs are the equations used to correlate cooling demand to operating conditions.

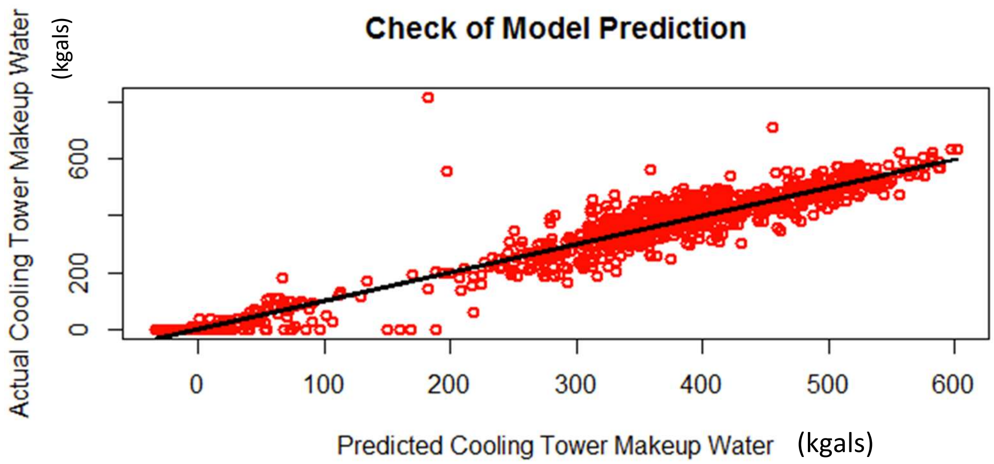


Figure 11. Correlation between air temperature and tower makeup

B. ECONOMIC ANALYSIS

The economic evaluation was based on the annual savings, the initial cost of the technology and the yearly operation and maintenance costs. Using these values, the simple payback period (in years) was calculated.

The savings due to reduced water consumption were calculated using utility rates provided by GSA. It was assumed that each gallon of water saved reduced the amount discharged to the sewer and subsequent costs incurred by the site. This is due to the fact that the water saved due to improved water treatment technologies was associated with the blowdown component of cooling tower water use. The blowdown, therefore, was not required to be discharged to the sewer system, saving that portion of the water costs.

Cooling tower water use is made up of three components: evaporation, blowdown and drift. The evaporation component provides the cooling to the chiller system and is not a function of the water treatment technology, but rather by the cooling required by the building. The drift component is determined by the physical characteristics of the cooling tower and the flow rate through the tower. Due to the fact that the cooling towers (and their associated pumps) were not altered during the water treatment technology installations, the drift component should not have changed from pre-to post-installation. Therefore, the water savings calculated in this report should be direct reduction in blowdown due to the ability to increase the CoC achieved in the condenser loop.

C. MANUFACTURER CUT SHEET

OBJECTIVE:

PRIORITIES	CURRENT	WITH DYNAMIC WATER
Reduce planned & eliminate unplanned shutdowns for mechanical or chemical cleanings	Scale, silica, and biological contaminants are removed by shutting down system for annual or unplanned mechanical or chemical cleanings	Excess mineralization causing scale/fouling will consistently be removed from cooling systems after historic scaling is removed, **significantly reducing the need for planned shutdowns and likely eliminating the unplanned shutdowns due to fouling. Silica is precipitated in our reactor.**
Extension of useful life of towers and cooling systems (reduce or eliminate corrosion)	Periodic Mechanical and/or chemical cleanings are necessary to free systems of fouling/scaling adding to reduction of equipment useful life	Significantly **reduce corrosion levels down close to zero ppm iron from water** and likely elimination of mechanical and/or chemical cleanings (like acid washing & hydro-lancing) and corrosion repairs, all of which effect useful life of equipment.
Elimination of handling, storage and adding chemicals and the control of bio-contamination through an electro-chemical process	Towers are currently under traditional chemical treatment.	Towers will have an effective water treatment **without the need for chemical additives**, as the UET system balances water naturally. This reduces safety concerns, insurance and training costs. **Bio-contamination will be controlled by a biocide created naturally from water.** There will be no need for chemical additives. Colony forming units will be reduced to a fraction of acceptable levels.
Water and Sewer Savings	Water is currently regulated at ~2.0 cycles (as of 1/15/17, where makeup is ~440 uS and basin conductivity ranges was at 860 uS.	DWT can increase the cycles of concentration to an 8,500 uS blowdown set point, or 19 cycles (as of 1/15/17 with makeup at ~440 uS).
Removal of historic scale and remove scale consistently in all wet areas –resulting in better efficiencies and Energy Savings	Scale and bio-contamination are currently under control with chemical treatment, but could be greatly improved. Mechanical removal is necessary if scale levels climb too high.	**Historic scale will be removed and collected within the UET reactor** as well as in the tower basin over the initial 1 to 6 month period. Both scale and bio-contamination removal will provide **measurable improvement in energy efficiencies.**
Removal of Silica	Current chemical methods are extraordinarily difficult	**DWT system will remove the silica in wet areas of the cooling system.**

EQUIPMENT REQUIRED FOR WATER TREATMENT:

- We have analysed your water and have sized our reactor system accordingly. For the best treatment of your 300 ton Freon cooling system, <u>one of our 1x4 reactor systems is needed</u>. The piping design and integration will be completed by our engineers subsequent to contract signing.

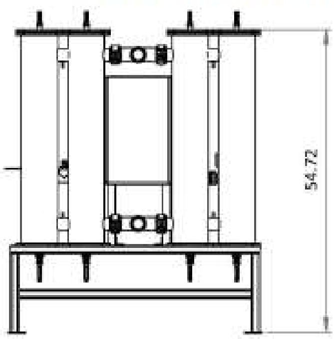
Itemization:

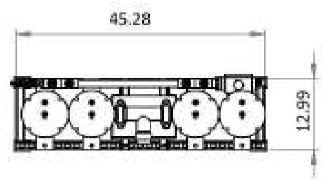
- 1x Standard UET 1x4 Reactor System
- 1x Advantage Megatron Real Time Monitoring System (with corrator) or Equivalent
- 1x Recirculation Pump(s)
- Necessary hardware and piping included with installation

DYNAMIC WATER
TECHNOLOGIES, LLC

INSTALLATION:

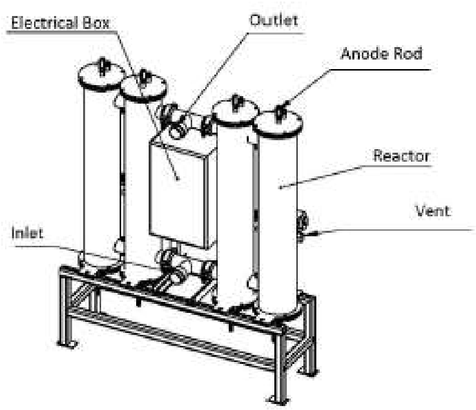
- 120 V power will be needed for the operation of the controller and the reactor anodes. Total power consumption will be at 16 amps per reactor system. Power needs to be accessible to the reactor. This is a client responsibility, *as electrical is not included in install costs.*
- The unit will be skid mounted and should not require any special foundations.
- The treatment will use a side stream taken from the basin. A recirculation pump is necessary, and *is included within our installation pricing.*
- 3 phase 230/460 V power will be needed for operation of the pump. Power needs to be accessible to the pump. This is a client responsibility, *as electrical is not included in install costs.*
- Installation can be done by customer if requested. Alternatively, if there is a preferred contractor for your facility, DWT is open to using them as well.
- Compressed air at 88 psi / 5 cubic feet per minute is necessary to run the UET reactor. This is a client responsibility, *as the air supply is not included in install costs.* DWT will add a compressor and bill if necessary.
- At least 4 feet of clearance is needed above the reactor system for servicing.
- A shade structure is needed for the reactors. This can be erected by Dynamic Water Technologies if no existing shade structure is available. Placing the reactors indoors is ideal.

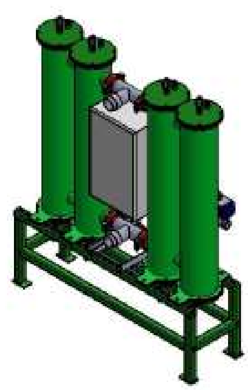




Measurements in Inches

Dry Weight: 485 lbs
Wet Weight: 760 lbs





D. IMPACT ON FACILITY OPERATIONS

As noted in section III. B., Qualitative Results, the AWT system had a very low impact on facility operations. It did reduce cleaning tower frequency and removed the nuisance and safety issues associated with chemicals used on site. When installing an AWT system, or any water treatment system, care should be taken in negotiating an operations and maintenance agreement with the original manufacturer or its partner. Providing good cleaning and servicing of the systems, as well as good customer service, are key to the acceptance of the system by the site staff. The agreements should not require that site personnel take on additional duties like water sampling or cleaning. Additionally, AWT representatives need to be available by phone or for site visits, when necessary.

E. IT SECURITY AND CONTINUITY OF CONNECTIVITY

No issues with continuity of connectivity were encountered. The system can operate in a “stand alone” basis without external connectivity. The provision for a secure connection could allow the manufacturer to monitor its system for any anomalies and to modify system settings to provide better performance between maintenance visits. This is an issue for each GSA building to consider.

F. TECHNOLOGY MARKET READINESS

The AWT system is commercially available and distribution and installation channels are in place. There are numerous installations of the AWT technology in the U.S. varying in size and application. Fabrication of these systems is relatively simple and the lead times for new installations is not expected to be lengthy.

G. TECHNOLOGY SPECIFICATIONS

If the technology evaluation has been successful and the technology has potential for deployment within GSA, GSA should support development of a technical specification that can use for procurement.

VI. References

[i] http://www.americanwaterintel.com/archive/3/9/analysis/utilities-gun-shy-water-and-sewer-rate-hikes-2012.html. Date accessed 4/14/14.