Prepared for the General Services Administration
By The National Renewable Energy Laboratory

December 2018

Alternative Water Treatment Technologies for Cooling Tower Applications

Dylan Cutler

Jesse Dean

Jennifer Daw, P.E.

Dan Howett, P.E.

The Green Proving Ground program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

Disclaimer

The work described in this report was funded by the U.S. General Services Administration [and the Federal Energy Management Program of the U.S. Department of Energy] under Contract No. IAG-11-01815 and Task No. WFK91002.

Acknowledgements

GSA's Proving Ground: Kevin Powell – Director, Jay Fine

United States General Services Administration (GSA) Region 8: Silas Campbell, Douglas Rothgeb, Jessica Higgins, Tyler Cooper, Charlie Reinhardt, Douglas Baughman and Laura Magee

Tenfold Information Design Services: Andrea Silvestri

National Renewable Energy Laboratory: Chris Gaul, Otto VanGeet, Gregg Tomberlin

For more information contact:

Dylan Cutler

Senior Engineer

National Renewable Energy Laboratory

Phone: (303) 275 – 3873

Email: dylan.cutler@nrel.gov

Table of Contents

Executive Summary

Background

This GSA Proving Ground (GPG) project assessed the performance of three alternative water treatment systems (AWT) for cooling tower water treatment applications at the Denver Federal Center (DFC) in Denver, Colorado. Cooling towers are commonly applied to water cooled chilled water plants in medium to large commercial buildings and are the point in the system where heat is dissipated to the atmosphere through the evaporative cooling process. Cooling towers also 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 over 26% of water use associated with heating and cooling. Reducing water consumption is a priority for the General Services Administration (GSA) due to Executive Order 13693, Energy Policy Act of 1992, and regional water shortages. These factors have brought about the investigation of cost effective opportunities to reduce water use, such as AWT technologies for cooling towers.

The current state of water treatment in GSA buildings is to use conventional chemical based cooling tower water treatment to maintain cooling tower water quality and contract out this specialized service to a third-party company specializing in such service. Traditional water treatment approaches rely on chemicals to extend the ability of the water to hold scaling minerals in solution and kill off 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 blown down and made up with fresh water to maintain system water quality parameters. In addition, the use of chemicals creates a waste issue and can cause building owners to incur additional disposal fees or sewer charges. The application of AWT's in place of traditional chemical water treatment has the potential to: 1) Lower make-up water costs, 2) Lower sewer costs, 3) Lower material costs, 4) Reduce chemical use, and 5) Increase chiller efficiency.

Study design and objectives

Three different AWT's were evaluated for this report. The AWT installed at Building 25 is manufactured by Water Conservation Technology International (https://www.water-cti.com/technology.html) uses a proprietary salt-based high efficiency softening system to remove hardness from make-up water, requiring little to no standard cooling tower water treatment chemicals. The Building 67 AWT system is manufactured by Terlyn (http://www.terlyn.com/cooling-tower-water-conservation-program-overview-video/) and provides a water treatment approach using a corrosion inhibitor, biocide, and a proprietary scale inhibitor. This system still utilizes chemical additions to regulate water quality; however, these chemicals have different compositions and are used in different quantities than a traditional system. The Building 95 AWT uses a controlled hydrodynamic cavitation process to provide chemical-free water treatment using two side-stream water loops. Building 25 - a multi-use facility of laboratories, data centers, and office space; Building 67 - a 14-story high rise; and Building 95 – an office and laboratory building. Traditional chemical water treatment was existing in all buildings prior to the AWT installations. The system at Building 95 had been uninstalled prior to the writing of this report and it was not possible to collect adequate water consumption data for comparison with the other two technologies (at buildings 25 and 67).

The three AWT technologies evaluated in this report were assessed according to two main criteria set out by GSA in the original 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 systems in reducing GSA water costs and operation and maintenance (O&M) costs.

This report addresses both water and cost savings associated with AWT technologies, and the water quality provided by the AWT technologies. Common make-up water quality and local weather conditions allowed for comparison of different AWTs installed in three different buildings. The principal variable that changed between the three different test buildings was the quantity of cooling required, and therefore the amount of heat rejected (and water evaporated) by the cooling tower. In order to normalize the results for cooling demand met by the tower, the principal metric that was evaluated for water use reduction was water savings per ton-hour of cooling delivered (gal/ton-hr.). The normalization of water savings to cooling demand allowed for effective comparison of the 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 technologies assessed here.

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 each AWT in this study. The exact date ranges and quantity of these data are discussed in section IV. E.

The cooling rejected from each building was measured via the onsite building automation system (BAS) by monitoring the condenser loop (cooling tower) supply temperature, return temperature, and flow rates. The condenser water 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 each building during the period from May of 2013 to November of 2013 (a typical cooling season in Colorado).

The water quality was analyzed through assessment of the water quality reports delivered monthly by the AWT vendors, as well as monthly water quality reports performed by a third-party testing company. These reports evaluated: conductivity, pH value, total hardness, calcium hardness, magnesium hardness, “P” alkalinity, “M” alkalinity, silica high range, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, biological growth, and cycles of concentration (CoC).

Project Results/Findings

In order to accurately assess the water savings from these AWT systems, it was necessary to calculate pre-installation cooling tower water usage. For the AWT system at Building 67, make-up water was metered for one year prior to installation. For Building 25, the make-up water was only metered post installation of the AWT. In the case of Building 25, the post installation data was used to generate estimates of pre-installation performance, which were then compared to post-installation performance to calculate water savings (while normalizing for the effect of different temperatures and cooling demand during the pre/post install time periods).

Due to the various levels of pre- and post-installation data (pre and post data for Building 67, post data for Building 25, and neither for Building 95), different analysis approaches were required at each site. The key steps in the analysis approach for each building are as follows:

1) Building 67:

a. BAS metered data was taken from May 2013 to November 2013 to generate a correlation between cooling demand and outdoor air temperature.

b. Historical daily outdoor temperature data and day of the week (weekend vs weekday) was used to estimate the monthly cooling load (going back to January 2009 – the beginning of the advanced metering data period).

c. A regression analysis was conducted on monthly cooling demand versus the metered water consumption (one regression for pre-installation, and one for post-installation). The slope of the regression lines was calculated to obtain a gallon per ton-hour value for pre- and post-installation. The difference in the two slopes was used to calculate water saved in the post retrofit months.

2) Building 25

a. Due to the lack of pre-installation data on this system, cycles of concentration were recorded from the building logs for pre-installation months.

b. Pre-installation water consumption was calculated based on the change in cycles of concentration. This approach inherently accounts for weather normalization because the cycles of concentration calculation assumes the same period of operation for calculating the pre-installation water consumption.

c. This was compared to post-installation water consumption to calculate water savings.

3) For Building 95: As previously noted, this system was uninstalled prior to the writing of this report making calculation of water savings impossible.

The pre-retrofit water consumption was calculated for the cooling demand seen in the post-retrofit years 2012 and 2013. The calculated efficiency of the traditional water treatment system was used to calculate the water consumption that would have occurred with the old system in place, enabling the calculation of weather normalized water savings for each of the months post-retrofit. The monthly savings are shown in Table 1. Each system experienced a couple month period of calibration and elimination of built up scale; therefore, the savings were calculated starting in 2012 despite installation of the AWT systems in January of 2011 (for Building 25) and October of 2011 (for Building 67).

Table 1. Monthly water savings for 2011-2013 (gallons)

Month	2012		2013	
	Bldg. 25	Bldg. 67	Bldg. 25	Bldg. 67
Jan	5,497	44,707	8,830	42,604
Feb	13,421	37,690	6,491	38,867
Mar	3,830	66,601	7,836	50,092
Apr	21,667	71,881	18,275	55,270
May	25,117	86,761	26,930	81,031
Jun	50,585	110,658	40,409	105,032
Jul	73,187	119,705	76,667	113,927
Aug	62,193	114,247	82,485	113,619
Sep	48,304	94,524	73,088	95,857
Oct	35,643	66,333	59,251	61,389
Nov	15,175	57,349	26,608	35,170
Dec	12,018	42,526	8,830	-
Totals	366,637	912,983	435,702	792,858

The results of the water saving analysis for Building 25 AWT #1 demonstrated a 23% reduction in water use saving 401,170 gallons/yr .The results for Building 67 AWT #2 showed a 24% savings over the old water treatment system, saving 824,448 gallons/yr.

Table 2 shows the initial cost, water savings per year, and the operations and maintenance (O&M) savings associated with Buildings 25 and 67. Using these values the simple payback period and savings to investment ratio (SIR) of each technology is calculated. The O&M savings are calculated by comparing the annual costs associated with the new system to the previous water treatment O&M costs, as well as the decrease in GSA maintenance savings via a reduction in personnel time; this value can be positive or negative depending on the relative change in expenditures.

Table 2. Economics of AWT Systems in Buildings 25 and 67

Economic Parameter	Building 25 (AWT #1) at Local Water Rate $7.14/kGal	Building 25 (AWT #1) at GSA Avg Water Rate $16.76/kGal	Building 67 (AWT #2) at Local Water Rate $7.14/kGal	Building 67 (AWT #2) at GSA Avg Water Rate $16.76/kGal
Initial Cost ($)	$29,600	$29,600	$32,511	$32,511
Cooling Tower Size (tons)	1,500	1,500	1,200	1,200
Water Savings (Gal/yr.)	401,170	401,170	824,448	824,448
Water and Sewer Cost Savings ($/yr.)	$2,864	$6,724	$5,887	$13,818
Annual Increase in O&M ($/yr.)	($6,445)	($6,445)	$1,883	$1,883
Simple Payback with O&M (yrs.)	3.2	2.2	8.1	2.7
Savings to Investment Ratio	4.7	6.7	1.8	5.5

At a combined water and sewer rate of $7.14/kGal AWT #1 had an installed cost of $19,73/Ton, annual water savings of 401,170 Gal/yr, a simple payback period of 3.2 years and an SIR of 4.7 using a total project lifetime of 15 years. At the GSA national average water and sewer rate of $16.76/kGal, AWT #1 had an annual water cost savings of $6,724, a simple payback period of 2.2 years and an SIR of 6.7. AWT #2 at Building 67 had an installed cost of $27.1/ton, an annual water savings of 824,448 gallons per year, a simple payback period of 8.1 years and an SIR of 1.8. At the GSA national average water and sewer rate of $16.76/kGal, AWT #2 had an annual water cost savings of $13,818, a simple payback period of 2.7 years and an SIR of 5.5.

The savings due to reduced water consumption are highly favorable in both cases (higher in Building 67), yet the O&M costs decreased significantly in the case of Building 25 for AWT #1, whereas the costs increased in Building 67 for AWT #2. This has a large impact on economics associated with each technology. The increased O&M costs in AWT #2 were due to an increase in chemical costs for the system (which utilized a proprietary chemical that helps in the suspension of solids) and periodic replacement of a glass bead media filter. On the other hand, AWT #1 eliminated almost all chemical use and required a less expensive salt regeneration process for the O&M requirement in that system. Although there was an increase in chemical costs for AWT #2, there was a significant reduction in GSA maintenance hours for each technology. GSA maintenance hours reduced from 152 to 80 hours per year for AWT #1, saving $3,677 per year, and GSA maintenance hours were reduced from 132 to 69 hours for AWT #2, saving an additional $3,217 per year. For AWT #2, since the O&M contract increased by $5,100 per year, the net increase in O&M costs was $1,883.

This economic assessment does not take into account any of the potential energy savings from increased chiller efficiency (due to improved heat exchanger effectiveness). The building engineers for both Building 25 and Building 67 indicated that they were able to run the flat plate chillers more often due to improved chiller performance after AWT install, and in Building 67 it was stated that they were able to run with one less chiller the majority of the summer. Tracking the reduction in electricity consumption from the chiller plants was not in the scope of this analysis, and therefore is not included in the results. The decrease in energy costs would only improve the system economics and should be evaluated in future studies.

Each AWT was monitored during the demonstration period for adherence to acceptable water quality ranges defined by GSA. There was no pre-installation water quality data to enable comparison to the previous treatment system, yet the operations and maintenance contractors at Buildings 25 and 67 noted significant improvement in cleanliness of the towers and chillers.

Water quality data sampled by a third-party testing company, SJCI, and the O&M contractor demonstrated that Building 25 fell outside the desired ranges for conductivity (from 300% – 800%), pH (up to 13%) and alkalinity (from 68% - 300%). Building 67 fell outside the desired range for conductivity (from 5% – 290%). It should be noted that the specified project ranges are not absolute proof of success or failure of the AWTs in achieving adequate performance. By design many of the AWT systems maintain certain water quality parameters outside the range of the project specifications. The true measure of success of an AWT's performance is a function of many considerations including water quality, CoC, corrosion, scale, biological growth, ability to meet discharge permit requirements, O&M requirements, and cost. Due to the overall improvements in water quality and reductions in blow down water usage for two of the three AWT's evaluated in this report, both AWT #1 (Building 25 technology) and AWT #2 (Building 67 technology) was installed at six additional installations at the Denver Federal Center that had cooling tower make up water meters that collect 15 minute interval data on GSA's advanced metering system. The measured annual water savings and associated cost savings were calculated and combined with the O&M costs from this study to calculate an annual cost savings, simple payback period and savings to investment ratio (A combined water and sewer rate of $7.14/kGal was used for the annual water cost savings (Table 3). For the AWT #1 technology, GSA elected to use the vendor provided side stream filter system instead of the typical GSA scoped side stream filtration system, which reduced the cost and for the AWT #2 systems, GSA continued to install the glass media filter system. For Building 20, chemical costs were decreased to $400 per year, versus $1,883 per year for other facilities since this is a smaller facility with less cooling tower water usage than the other facilities.

Table 3 - Annual Water Savings and Economics for Additional Deployments at DFC

Denver Federal Center Facility	AWT System	Date Installed	Cooling Tower Size (Tons)	Installed Cost ($)	Annual Water Savings (Gal/yr.)	Annual Water Savings ($)	Annual Increase in O&M ($/yr.)	Total Annual Cost Savings ($/yr.)	Simple Payback (yrs.)	Savings to Investment Ratio (SIR)
Bldg.20	AWT Tech. #1	16-Nov	600	$31,057	718,597	$5,131	($6,445)	$11,576	2.7	5.6
Bldg.41	AWT Tech. #1	17-Jan	1,000	$36,976	1,809,921	$12,923	($6,445)	$19,368	1.9	7.9
Bldg. 85	AWT Tech. #2	14-Jan	500	$8,756	62,450	$446	$400	$46	>40	0.1
Bldg.56	AWT Tech. #2	15-Jan	1000	$28,557	661,160	$4,721	$1,100	$3,621	7.9	1.9
Bldg. 810	AWT Tech. #2	14-Jun	2 x 500	$31,047	1,131,450	$8,079	$1,883	$6,196	5.0	3.0
Bldg.810 USDA	AWT Tech. #2	16-Mar	3 x 500	$31,047	1,048,000	$7,483	$1,883	$5,600	5.5	2.7

For the additional deployments at the DFC, the simple payback ranged from 1.9 to 7.9 years for all installations other than Building 85. The AWT #2 vendor was performing water treatment services at Building 85 prior to the other installations and the sand filtration system was able to be installed at a much lower cost than the other facilities for this facility.

Background

A. INTRODUCTION

Air conditioning accounts for approximately 15% of all source energy used for electricity production in the United States alone (nearly 4 quadrillion British thermal units (Btu)), which results in the release of about 343 million tons of carbon dioxide into the atmosphere every year[i]. 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 process, and are commonly applied to water cooled chilled water plants in large commercial buildings. Reducing water consumption is a priority for the General Services Administration (GSA) and is especially important in the arid regions of the western US and any locations facing drought conditions.

Executive Order 13693 mandates that federal facilities reduce their potable water consumption 2% annually through FY 2025 or 36% by the end of FY 2025, relative to a FY 2007 baseline. This Executive Order revokes Executive Order 13514, which requires Federal agencies to reduce potable water consumption intensity through life cycle cost-effective measures relative to the agency's baseline. Given the large amount of water used by cooling towers, the investigation of new cooling tower water treatment technologies that can reduce water consumption is of particular interest.

In general building applications cooling towers are connected to the central water-cooled chillers that provide building cooling. In water cooled chilled water plants the condenser water absorbs the heat from the chillers and then passes it to the cooling towers where this water is exposed to the outside air. Some of the condenser water evaporates; the rest is returned to the chiller to repeat the cooling process. Since evaporation is a heat-absorbing process, the returning condenser water is cooler than the condenser water supply water to the cooling tower.

The evaporated condenser water must be replaced by the cooling tower make up water, typically coming from the cooling tower basin using a float valve, similar in concept to the float valves in older model toilets. Cooling tower make up water is typically provided by the city potable water supply and increases the building's water use.

The continuous evaporation of condenser water from the condenser water side of the cooling cycle also has another effect: since only pure water evaporates, it 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 (silica, calcium, magnesium, chloride), so the remaining condenser water will have an ever-increasing amount of impurities as progressively more water evaporates. These impurities eventually will precipitate out (since water can hold only so much), resulting in solid precipitate. This solid precipitate is commonly called scale and will collect on various surfaces it touches. 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.

There are two intertwined means of dealing with scale in a conventional chemical-based cooling tower water treatment system; injecting chemicals into the condenser water and regularly dumping a certain portion of the condenser water down the drain. These methods are intertwined because in traditional cooling tower water treatment systems they both must be used; one method alone will not produce proper cooling tower water quality.

1) Inject chemicals into the condenser water. Chemicals serve three purposes in cooling tower water management.
    a. Chemicals called “scale inhibitors” increase the waters ability to hold a higher concentration of minerals in the solution without causing scaling.
    b. Chemicals called “corrosion inhibitors” decrease corrosion in piping systems.
    c. Chemicals called “biocides” and “algaecides” mitigate biological growth in the cooling tower, where warm water is exposed to air.
2) Regularly dump a certain proportion of the condenser water down the drain. As explained above, over time the mineral content of cooling tower water will increase as the cooling tower operates more and more hours. Since the make-up water will have a lower chemical/mineral content, this dumping process , often called tower blowdown or bleed off, has the effect of lowering the chemical/mineral content of the remaining condenser water.

Chemical use has two consequences.

1) Chemicals cost money.
2) The remaining condenser water has a higher level of chemicals than the normal city water or groundwater in the area. Once a building is into the maintenance practice of adding chemicals, every blowdown of condenser water deposits a higher level of chemicals into the local sanitary or storm system than the normal local water contains. This may require special permission from local municipal sanitary/storm water departments and incur additional sewer water costs.

The common metric used to measure blowdown is cycles of concentration (CoC). CoC compares the concentration of solids of the recirculating cooling tower to the concentration of solids of the original raw make-up water. If the recirculating water has 3 times the concentration of solids that the raw make-up water has, then the CoC is 3.

This project assesses the readiness of several off-the-shelf, alternative cooling tower water treatment technologies for lowering GSA operating costs while maintaining proper water treatment. Alternative cooling tower water treatment (AWT) technologies potentially can lower GSA’s resource demands and operating costs through:

- lowering make-up water costs
- lowering sewer costs
- lowering or eliminating chemical costs
- increasing chiller efficiency (via less scale on condenser tube heat transfer surfaces), which will decrease electricity use and thereby lower electricity costs

B. OPPORTUNITY

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 1. Figure 1 shows that over 26% of water use is associated with heating and cooling is by far the dominant water use case due to the evaporative cooling demands associated with all water-cooled air conditioning systems and evaporative based air conditioners.

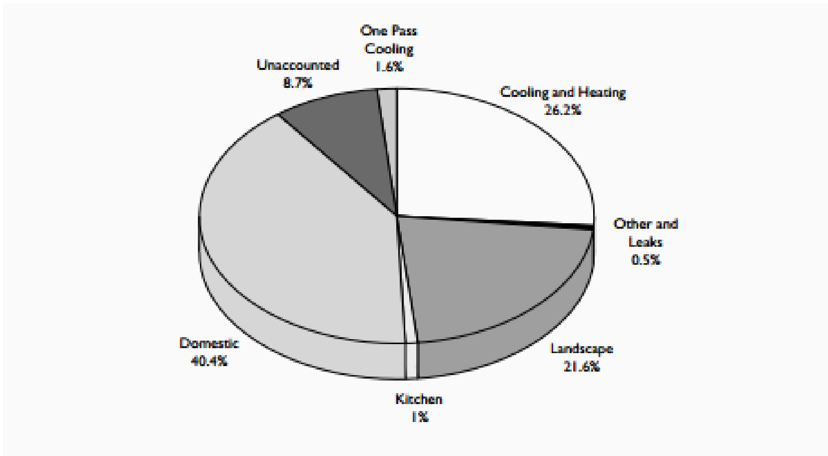

Figure 1. Office water end uses[1]

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 process, and are commonly applied to water cooled chilled water plants in large commercial buildings.

Cooling towers can be found in all states throughout the country, and this technology can save water in every climate zone. Although the technology can save water in every climate zone, facilities located in ASHRAE climate zones 1A, 2A, 2B, 3A, and 3B that utilize cooling towers will typically use significantly more cooling tower water than similarly sized systems in other climate zones due to the amount of cooling required in these regions. These regions require significantly more annual cooling than other regions which can lead to a more cost-effective implementation of AWT technologies. An ASHRAE climate zone map is provided in Figure 2.

[1] http://www.gsa.gov/graphics/pbs/waterguide_new_R2E-c-t-r_0Z5RDZ-i34K-pR.pdf. Accessed 12/10/13

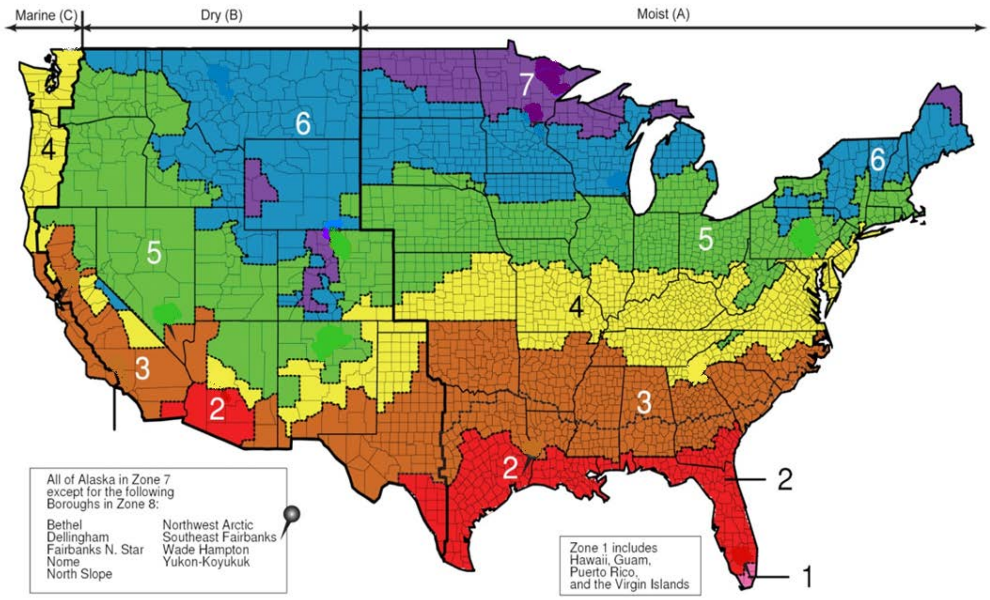

Figure 2. ASHRAE climate zone map

The Denver Federal Center (DFC) is located in climate zone 5B and GSA Region 8 has a total of fifty cooling towers. The cooling towers in GSA Region 8 are installed at thirty of the larger buildings in the region. 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.

C. SUSTAINABILITY

The concept of sustainability focuses on working within environmental, social, and financial constraints to both strive for balance and reduce impacts. In the context of this project, cooling towers rely on many resources, including chemicals, energy, and water, as well as manpower and funds to support their operation. AWT's are of particular relevance in their potential to optimize resource utilization and provide resiliency to potential resource shortages.

AWT technologies can be categorized as chemical and non-chemical systems. In traditional chemical treatment the application of biocides, corrosion and scale inhibitors, and brine for water softening, while effective, presents potential environmental concerns including the introduction of toxins to humans and the environment, nutrient loading to natural water bodies, and operational issues for the wastewater district.[ii] An approach to reduce the environmental impact of chemicals can be to use biodegradable alternatives; however the efficacy and availability of these products must be considered with respect to their application.[iii] Non-chemical systems may be viewed as a preferred solution from an environmental and operating cost perspective; however their ability to meet treatment goals must be weighed against these potential benefits.[iv] Both chemical and non-chemical systems have environmental and financial tradeoffs.

In arid climates, water is a particularly precious resource both to people and the natural environment. Cooling towers use a substantial amount of water; which is a tradeoff compared to the substantial electricity demands of air cooled systems. However, according to Morrison[v] "air-cooled systems consume 30% to 40% more power than water-cooled systems, and are one of the largest users of water in the country is power generation." Energy and water are intrinsically linked in the operation of cooling systems. Efforts focused on making optimal use of both resources will contribute to the longevity and long-term effectiveness of a technology.

D. DEMONSTRATION PROJECT LOCATION(S)

Three buildings at the Denver Federal Center were selected as the installation site for this study (Building 25, Building 67, and Building 95). Building 25 is a multi-use facility of laboratories, data centers, and office space. The cooling tower loop consists of three single cell cooling towers rated at 500 tons. Building 67 is a 14-story high rise with the cooling towers located on the roof. There are two separate towers, each tower is a single cell tower and each one is rated at 600 tons. These two towers serve as the condenser loop for the 450 and 900-ton chillers located in the nearby penthouse. Building 95 is an office and laboratory building with two 250-ton chillers and two 250-ton cooling towers.

Measurement & Verification Project Plan

A. TECHNICAL OBJECTIVES

AWT technologies were assessed according to two main criteria set out by GSA in the original 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 systems in reducing GSA operating costs (water/ sewer costs and operation and maintenance (O&M) costs).

This report addresses water savings, O&M costs, and water quality associated with AWT technologies. As described in the Section III.B., each AWT technology is unique in its operational premise and each has its own distinct advantages or disadvantages. The purpose of this study is not to compare the inner workings of a given technology, but rather to compare the system inputs, outputs, and delivered result.

B. TECHNOLOGY DESCRIPTION

Cooling tower structures vary greatly in size and design, but they all provide the same function: liberation of waste heat extracted from a process or building system through evaporation of water. In technical terms, cooling towers are engineered and designed based on a specified cooling load, expressed in refrigeration tons. The cooling load is determined by the amount of heat that needs to be extracted from a given process or peak cooling demand. The cooling tower must be adequately sized to reject this same amount of heat to the atmosphere.

Cooling towers and chillers require a constant water supply of adequate quality to ensure proper operation and to limit scale and corrosion impacts on the system. AWT technologies vary significantly with respect to how they provide the required water quality. To quantify the performance of the AWT technologies evaluated in this report, each technology was metered to provide data on the inputs, outputs, and delivered results (Figure 3).

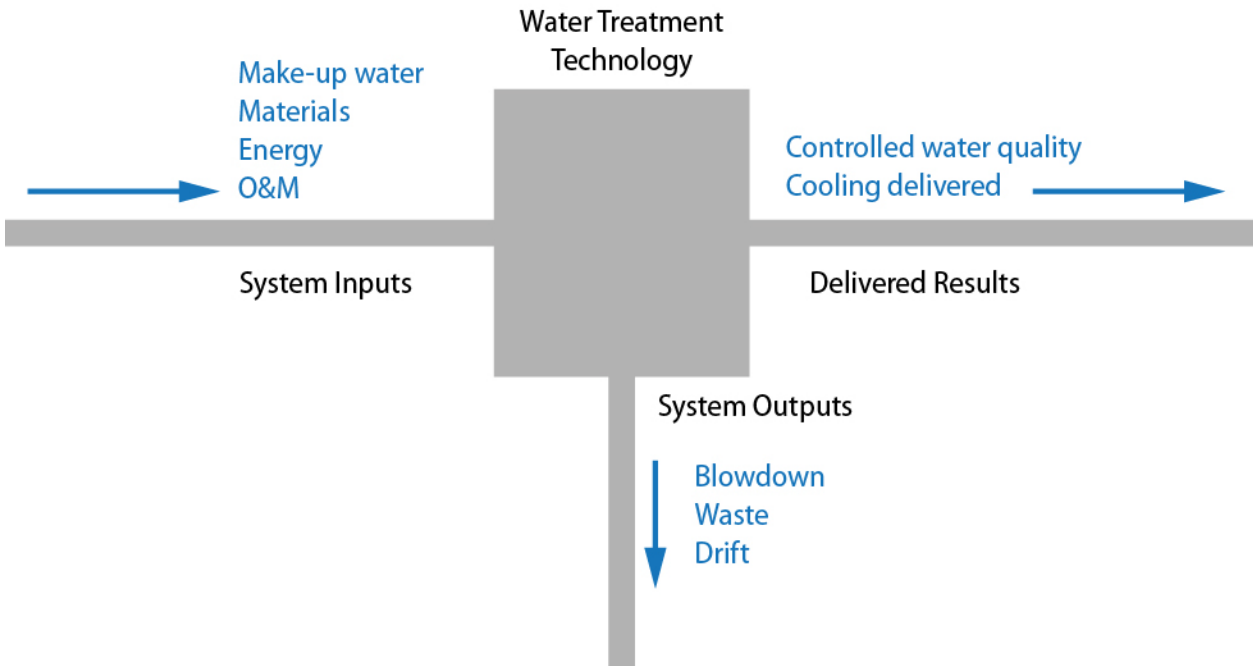

Figure 3. Conceptual model of the AWTs (Credit: Joelynn Schroeder, NREL)

System Inputs

The inputs to each water treatment system vary. In general, they can be described as follows. Specific details with respect to each AWT are included in the Technology Specification section.

- *Make-up Water:* The quantity of make-up water required to operate the system within required operating ranges is a function of the AWT's effectiveness and the potable water quality in a given area.
- *Materials:* AWTs may require the use of additional material inputs for their operation, including biocide, acid, or brine. The quantity of chemical required varies by AWT and water quality at the site.
- *Energy:* Operation of each AWT requires additional energy for Programmable Logic Controllers (PLCs) or pumps that is incremental to the existing cooling tower operation.
- *Operations & Maintenance:* Periodic cleaning to reduce scale and corrosion or the replacement of filter materials to keep the system in good working order varies by AWT and site conditions.

System Outputs

The outputs from each water treatment system vary. In general, they can be described as follows.

- *Blowdown Water:* The quantity and quality of blowdown water is a function of the AWT's ability to maintain acceptable water quality and the CoC of the system. The quantity and quality of blowdown water that can be discharged may be limited by local sanitary sewer permitting requirements.
- *Waste – if this exists (in addition to blowdown water stream):* The amount and quality of waste generated by the system, such as brine solution or filter backwash, have specific disposal concerns that vary by AWT.
- *Drift:* The amount of water lost to the environment as a part of the evaporative cooling process. Drift is a function of tower geometry and would not vary based on the AWT.

Delivered Result

- *Adequate Water Quality:* The condenser water loop needs to be maintained at appropriate concentrations of Total Dissolved Solids (TDS), and pH, and other water quality metrics as defined by the RFP to prevent damage to piping and equipment.
- *Cooling Delivered:* The chiller is able to operate effectively, supplying adequate chilled water to the building for maintained occupant comfort.

The main goal of this study is to evaluate the potential for water savings in the technologies under consideration. This is evaluated in terms of gallons per ton-hour (gal/ton-hr.) of cooling delivered to the building. This metric quantifies the gallons used for each ton-hour of cooling, and therefore enables a comparison between buildings with different total cooling demand.

The goal of these technologies is not only to conserve water in cooling tower operations, but to 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 not able to be quantified for this report, due to the fact that the metering of the systems was put in place after the systems were installed. Therefore, there is no measured data on energy consumption before installation of the new systems that would enable an accurate evaluation of improved chiller operation. The probable benefits are discussed qualitatively in the report

The AWTs addressed in this report are commercialized technologies. Given their commercialized state, the AWTs evaluated in this report are at a Technology Readiness Level 8 (meaning the system is incorporated in commercial design, with actual system/process completed and qualified through test and demonstration.

C. FACILITY DESCRIPTION

Building 25, Building 67, and Building 95 at the Denver Federal Center were selected as the installation sites for this study. The buildings housing the AWT technologies are a combination of office and laboratory buildings (building 25 and 95 has office / labs, building 67 is an office building) of varying sizes. For the laboratory buildings, the internal loads require the cooling towers to operate more hours per day and for months of the year than a typical 9-5 office building in CO. They are all medium to large office buildings (small buildings do not tend to use water-cooled chillers). Traditional chemical water treatment was existing in all buildings prior to the AWT installations.

The three different buildings selected for this study each had a different AWT technology installed in order to decrease the water consumption of their respective water-cooled chiller plants. The ability to have all three AWT technologies in close proximity (all sit on the main Denver Federal Center campus) enables a consistent comparison with respect to weather (dry bulb, wet bulb, and wind speed) and incoming water quality (all from the same water mains).

A summary of each of the three buildings is provided in Table 4.

Table 4. Overview of Selected Facilities

AWT System/Technology	AWT Installation Sites, Building Sizes, and Cooling System Details
Building 25	Denver Federal Center, Building 25, W. 6th Avenue, Denver, Colorado <u>Building Facts:</u> 360,797 square feet (SF), office / lab building, housing 425 occupants <u>Cooling System:</u> (2) 500-ton chillers; (3) 500-ton cooling towers; (1) flat plate heat-exchange

Building 67	Denver Federal Center, Building 67, W. 6th Avenue, Denver, Colorado Building Facts: 342,722 SF, office building, housing 1200 occupants Cooling System: (1) 900-ton chiller, (1) 450-ton chiller; (2) 600-ton cooling towers, (1) flat plat heat-exchanger
Building 95	Denver Federal Center, Building 95, W. 6th Avenue, Denver, Colorado Building Facts: 163,206 SF, office/lab building, housing 130 occupants Cooling System: (2) 250-ton chillers; (2) 250-ton cooling towers

Both of the buildings that received detailed monitoring under this technology demonstration (Building 25 and Building 67) had the ability to record time series data for specific points associated with the chiller plant through their building automation system (BAS). This enabled the detailed monitoring described in the Test Plan section (section IV. D).

D. TECHNOLOGY SPECIFICATION

Three different types of AWTs are evaluated in this report, including: a salt-based system in Building 25[vi], a chemical-based system in Building 67[vii], and a hydrodynamic cavitation system in Building 95[viii]. A description of the primary components of each system is described for each facility.

Building 25

The Building 25 AWT #1 is manufactured by Water Conservation Technology International (https://www.water-cti.com/technology.html) and the system controls scale, corrosion, and biological growth without the use of chemicals. Using a proprietary salt-based high efficiency softening system the hardness is removed from make-up water (Figure 4). The removal of low solubility ions reduces scale potential in the cooling tower, and increases solubility of TDS allowing soluble silica (from 200 -1,000 mg/l) in make-up water to polymerize to saturation equilibrium. Polymerized silica protects metals from high TDS, corrosion and scale. And high TDS/ pH levels in the water reduce biological growth. This AWT technology is comprised of twin fiberglass ion exchange media tanks, alternating polyethylene regeneration tanks, a brine tank, and metered usage controls providing web-based remote access for reporting and control. The water softener regenerates based on volume, typically 2-3 times per week in the summer and 1 time per week in the spring and fall. The regeneration process uses 70 gallons of water and the brine solution is discharged to the sewer.[ix] [x]

Technology Summary:

- Scale Prevention: Silica that is normally associated with scaling is altered through the water softening process to non-scaling forms.
- Corrosion Inhibition: The altered silica composition inhibits corrosion.
- Biological Growth Control: Biological growth is generally controlled by the heightened pH. Biocide may be added if necessary.

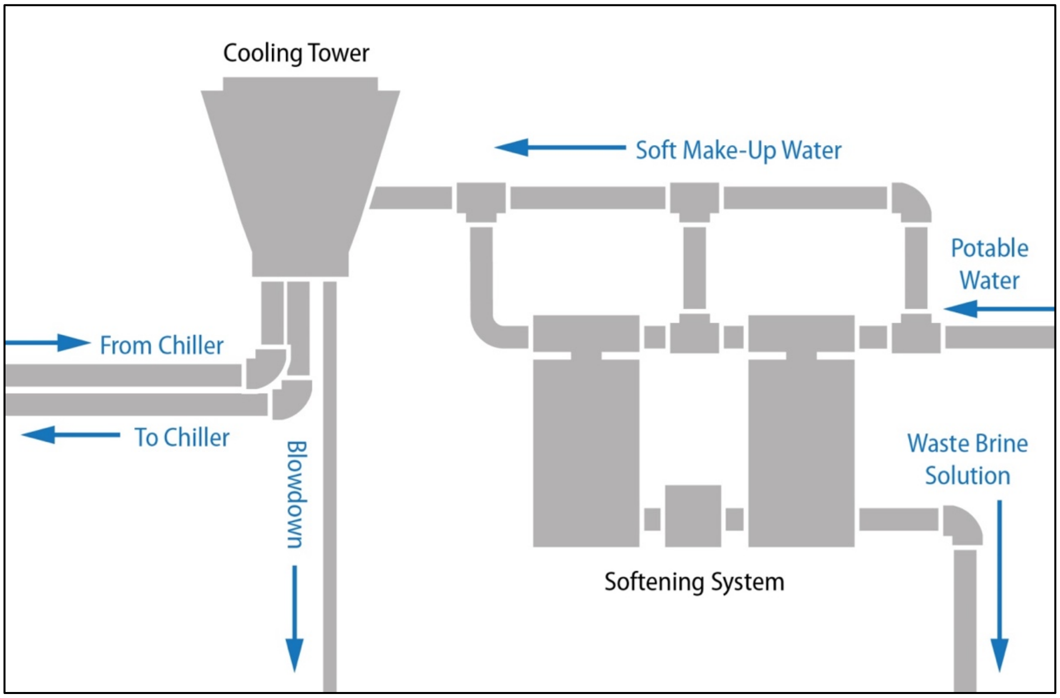

Figure 4. Representative diagram of system layout for Building 25 (Credit: Joelynn Schroeder, NREL)

Building 67

The Building 67 AWT #2 system is manufactured by Terlyn (http://www.terlyn.com/cooling-tower-water-conservation-program-overview-video/) and provides a more conventional water treatment approach that relies on scale and corrosion control while reducing blowdown (Figure 5). An advanced formulation of several hydrolytically stable, high strength polymers and bonding materials designed to systematically control hardness ions and other soluble elements through sequestration, threshold stabilization, and crystal modification. A PLC continuously monitors CoC in the cooling tower system water and the amount of fresh water being added to the system. Remote monitoring of the controller provides notification if parameters fall outside the desired range. The controller is set for 50 CoC based on TDS concentrations, and automates blowdown when this level has been reached. Peristaltic pumps feed chemicals into the system. The water meter communicates with the controller to help determine the need for chemical dosing. The controller opens and closes the bleed valve to blow down the system water when 50 CoC have been reached. The controller monitors potable water use and injects scale inhibitor, corrosion control, and biological control reagents accordingly.xi A glass media filter was added to this system by the installer to filter out particulate matter from the cooling tower such as dirt, sand, and other forms of debris. The filter backwashes for 30 seconds once a day, with roughly 300 gallons of backwash water discharged to the sewer.

Technology Summary:

- Scale Prevention: A semipermeable membrane filters out suspended solids, thereby preventing these from nucleating and precipitating out.
- Corrosion Inhibition: Industry standard corrosion inhibitors are used.
- Biological Growth Control: Conventional biocides must be added to the cooling tower water.

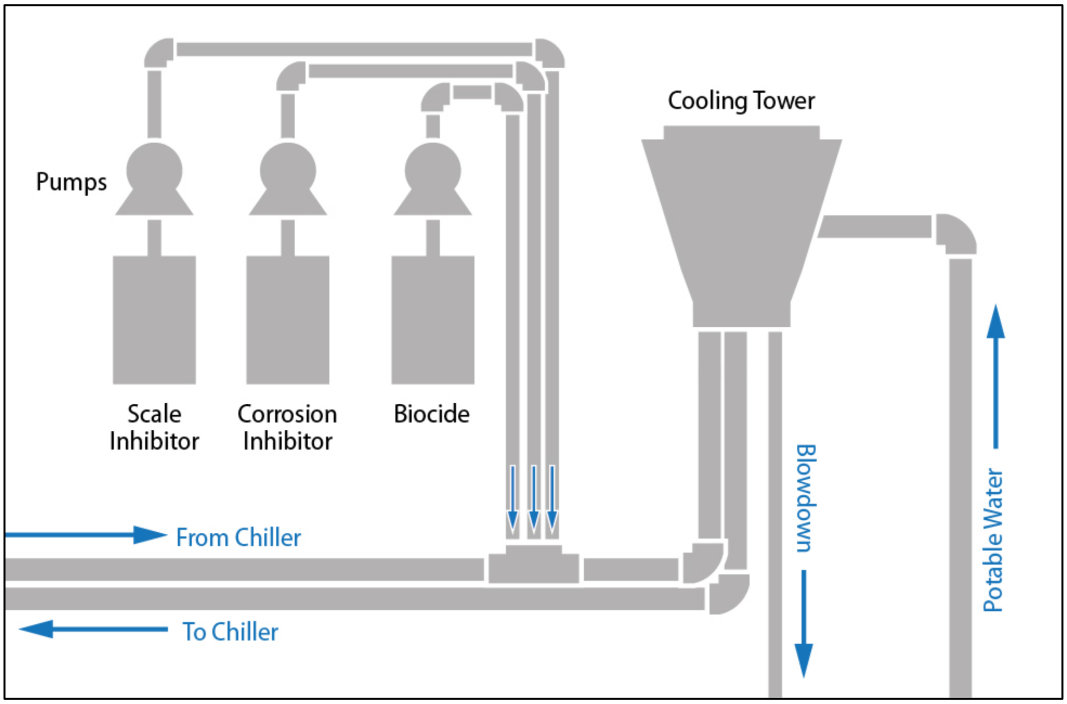

Figure 5. Representative diagram of system design for Building 67 (Credit: Joelynn Schroeder, NREL)

Building 95

The Building 95 technology uses a controlled hydrodynamic cavitation process to provide chemical-free water treatment. The system consists of two side-stream water loops that connect to the cooling tower sump. In one loop, water is passed through the treatment chamber and returned to the sump (Figure 6). In the second side-stream the filtration loop pumped water passes through a pair of horizontally opposed nozzles, increasing the water velocity. Collision of water from the opposing nozzles creates kinetic force and subsequent cavitation in the water. Within the system, strong vacuum forces form, which strip carbon dioxide from the water, and maintain an alkaline pH. High pH creates an environment where calcium carbonate forms colloids, which are filtered from the water stream to control the build-up of scale. Cavitation can create high localized temperatures and energetic forces, which also can control bacterial growth. The basin sweeping system directs dirt and debris toward the filter intake[xii].

Technology Summary:

- Scale Prevention: This creation of intense vortices results in collisions between any forming mineral crystals.
- Corrosion Inhibition: The increased concentration of (small) mineral crystals in the water raises its pH.
- Biological Growth Control: Conventional biocides must be added to the cooling tower water.

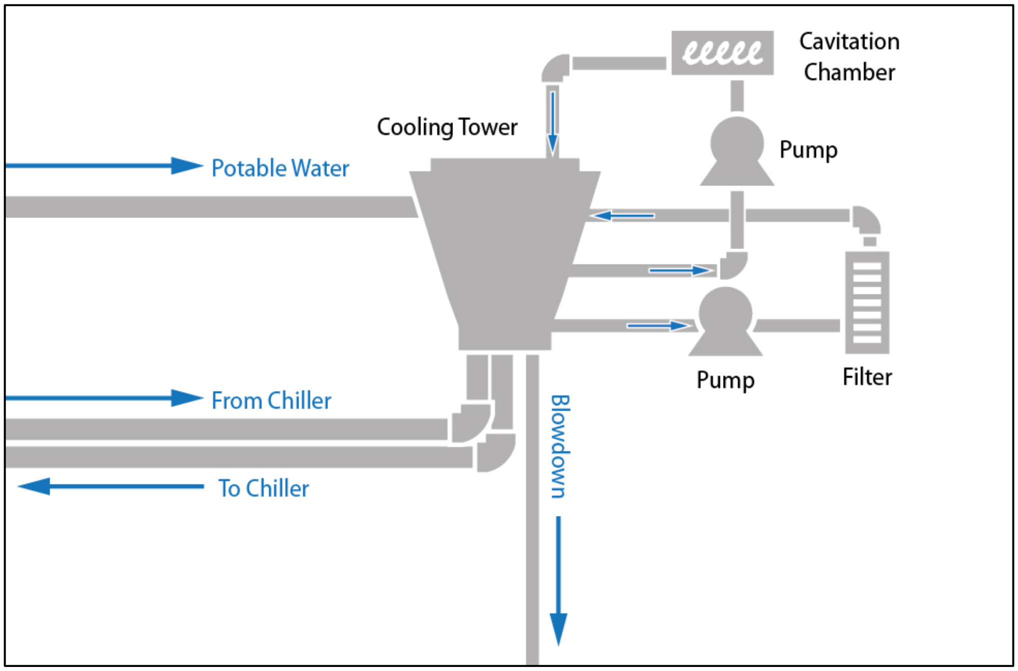

Figure 6. Representative diagram of system design in Building 95 (Credit: Joelynn Schroeder, NREL)

E. TECHNOLOGY DEPLOYMENT

The AWT system for Building 67 was deployed in October of 2011. It was installed in the penthouse of Building 67 and new make-up and blowdown pipes were routed from the AWT system to the two cooling towers. The system includes water treatment chemicals, a double-walled holding bin where the chemicals can mix with the condenser loop water, a crushed glass filter, and a controller that monitors various water characteristics (including a continuous reading on TDS) and water flows through the system. This controller is connected to both the make-up and blowdown water meters and the system logs these values on a 60-minute basis, allowing for calculation of monthly make-up and blowdown values. The TDS meter and make-up water meter associated with the system are shown in Figure 7.

Figure 7. Meters associated with Building 67 AWT system (Credit: Tyler Cooper, GSA)

The AWT system for Building 25 was installed in January of 2011. It was installed against the east wall of the chiller room of Building 25. This system consists of two holding tanks where the brine solution can treat the incoming make-up water (Figure 8 and Figure 9), a controller that monitors water characteristics and meters make-up and blowdown water, and a supplemental chemical feed monitor for water treatment on an as-needed basis as it circulates through the condenser loop.

Figure 8. Piping, controller and chemicals associated with the Building 25 AWT system (Credit: Dylan Cutler, NREL)

Figure 9. Tanks for treating the make-up water entering the Building 25 AWT system (Credit: Dylan Cutler, NREL)

Both systems take up relatively small areas within the mechanical rooms. The main elements of the treatment systems' controls can be mounted in a 4 ft x 4 ft area in the mechanical room. For the system in Building 25, there is also some space requirement due to the two brine tanks (approximately 8 ft^2 of floor space). The system in Building 67 requires floor space for both the 5-gallon contains of chemicals (approximately 3, 5-gallon containers) and for the double-walled mixing basin and sand filter(6-8 ft^2 of floor space).

The Building 95 system was installed in October of 2011. This was a rack mount system that did not occupy much of the mechanical room space. The additional floor space required for the Building 95 install was for a floor mounted inline filter (Figure 10).

Figure 10. Building 95 AWT System (Credit: Doug Baughman, GSA)

F. TEST PLAN

The test plan focuses on calculating water savings and water quality associated with the AWT systems. It was especially important to be able to evaluate the AWT systems in a manner that allowed for comparison between the systems and between other buildings in the GSA building stock.

The system at Building 95 had been uninstalled prior to the writing of this report and it was not possible to collect adequate data for comparison with the other two technologies.

The two components that need to be measured to account for water savings are (1) water consumption and (2) cooling demand of the building. AWT water consumption is tracked in three different ways in this study. The exact date ranges and quantity of these data are discussed in the following section (IV. E):

1) Monthly make-up and blowdown water use
2) Daily make-up and blowdown meter readings

The cooling demand for the building can be tracked by monitoring the condenser loop (cooling tower) supply temperature, return temperature, and flow rates. Given this data, it is possible to establish the amount of heat rejected by the cooling tower over time. These values are established by trending the BAS output for the chiller plant in each building during the period from May of 2013 to November of 2013 (a typical cooling season in Colorado).

Water quality was assessed through water quality reports delivered monthly by the O&M contractor and a third-party testing company. These reports evaluated: conductivity, pH value, total hardness, calcium hardness, magnesium hardness, “P” alkalinity, “M” alkalinity, silica high range, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, biological growth, and CoC.

Instrumentation Plan

The goal of the instrumentation plan for this technology demonstration focused on metering the cooling tower, specifically to quantify the water use in each building. The cooling demand / heat rejection for each building is required to establish a gallon per ton-hr. metric for evaluating the efficacy of the different AWT systems. To develop this measurement, the BAS in each building was configured to export a daily report on the following points:

- Condenser water supply and return temperatures (°F)
- Condenser water pump status (ON/OFF), including one point for each pump
- Cooling tower fan status (ON/OFF), including one point for each fan
- Chiller water supply and return temperatures (°F)
- Chiller status (ON/OFF), including one point for each chiller
- Chilled water loop pump status (ON/OFF), including one point for each pump
- Outdoor air temperature (°F) and humidity (%)

All of these data were collected at 15-minute intervals from May of 2013 (August 2013 for Building 67) through November of 2013.

The other data required to establish the efficacy of the AWT systems was the water consumption of the different systems over time. The water consumption data came from three different data sources:

- Monthly building meter data (including pre- and post-retrofit data) from the advanced metering initiative at the DFC. This water use was measured at a whole building level from January of 2009 to October of 2013.
- Monthly water use for the cooling tower make up water, as provided by the two system manufacturers. These data spanned from January of 2010 to November of 2013 for Building 67 and from January of 2012 to September of 2013 for Building 25.
- Daily make-up and blowdown water for May 2013 through September 2013 (for Building 25) and August 2013 through November 2013 (for Building 67). These metered data were gathered from the controllers installed with the AWT systems. These controllers logged both blowdown and make-up water readings from pulse meters installed with the system.

The last piece of data collected for the analysis was the average daily outdoor air temperatures from January 2009 to October of 2013. This data was collected from the Denver Centennial weather station (historical data was downloaded from wunderground.com[xiii]). This data was used to estimate the cooling demand for the pre-installation time frame, which was then correlated with the historical water consumption data outlined above to generate weather-normalized water consumption data for each building.

GSA has developed the following water chemistry standards as a guideline to determine the acceptability of cooling tower water quality for a given AWT (Table 5). Operations staff and AWT vendors performed monthly monitoring of these parameters to characterize performance of a system. It should be noted that adherence to these ranges is not the only indicator of an AWT's success. The operation of each AWT is unique and as a 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 AWTs a site should consider site-specific water quality constraints, whether due to influent potable water or discharge permit limitations, and make an AWT selection 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	>2
Total Hardness (ppm)	500 - 1500
Phosphate (ppm)	43327
Conductivity (mmHos)	<2400
Bacteria Count (cfu)	<80000
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

Results

A. Water Savings

In order to accurately assess the water savings from these AWT systems, 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 are normalized for weather variation. The weather normalization ensures that a cooler or warmer than average month does not impact the calculated water savings.

Building 67 recorded make up and blowdown water consumption both before (for 21 months prior) and after installation of the AWT. Building 25 only had post retrofit water consumption data for the AWT system. In order to calculate pre-retrofit water consumption for the Building 25 system, the CoC of the old water treatment system was recorded (obtained from the building operational logs). The two different calculation methods are presented below.

<u>Building 67:</u>

The steps in calculating the savings for building 67 are as follows:

1) BAS metered data was taken from August 2013 to November 2013 to generate a correlation between cooling demand and outdoor air temperature
2) Historical daily outdoor temperature data was used to estimate monthly cooling loads
3) A regression analysis was conducted on monthly cooling demand versus the metered water consumption (one regression for pre-installation, and one for post-installation)
    a. The slope of the regression lines was calculated to obtain a gallon per ton-hour value for pre- and post-installation
4) The difference in the two slopes was used to calculate water saved in the post retrofit months

Step 1 – Correlation between Cooling Demand and Outdoor Air Temperature

The BAS system data provided the supply and return temperature from the cooling towers, as well as the operating status of the condenser water loop pumps. This enables the calculation of heat rejected from the cooling tower using the equation:

$$Q = \dot{m} C_p \Delta T,$$

- Q is the heat rejected by the system
- $\dot{m}$ is the flow from the constant speed pumps
- C_p is the specific heat of water
- ΔT is the difference in temperatures between the entering condenser water and the exiting condenser water

Due to the fact that the temperature differential (ΔT) was calculated on the condenser water loop (not the chilled water loop), it isolates out any impacts of chiller efficiency. In this case, therefore, Q represents the heat rejected through evaporation of the condenser water.

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 cooling demand for the buildings for historical periods where the BAS trend data was not available.

Figure 11 shows the regression of daily condenser water heat rejection versus daily average outside air temperature. The regression equations shown on the graphs are the equations used to correlate cooling demand to operating conditions. The regression lines are not shown in the figures due to the fact that they are bi-variate regressions which are not able to be plotted on a 2-dimensional graph, but both independent variables are shown (outdoor air temp, and the weekend/weekday – shown by series color).

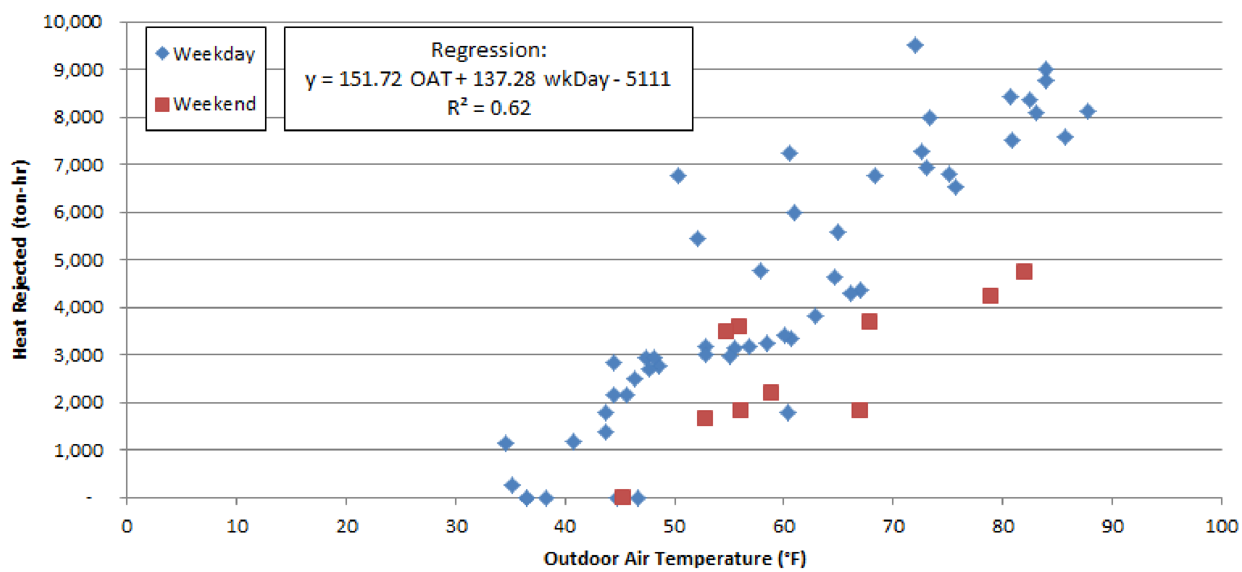

Figure 11. Correlation between air temperature and cooling demand for Building 67

Step 2 – Estimate historical monthly cooling loads

The linear regression performed in step 1 was used in conjunction with historical temperature data (daily average outdoor air temperatures) to estimate daily cooling demand for each building. This was done for the period of January 2009 through November of 2013. The monthly cooling demand for each building is shown in Figure 12.

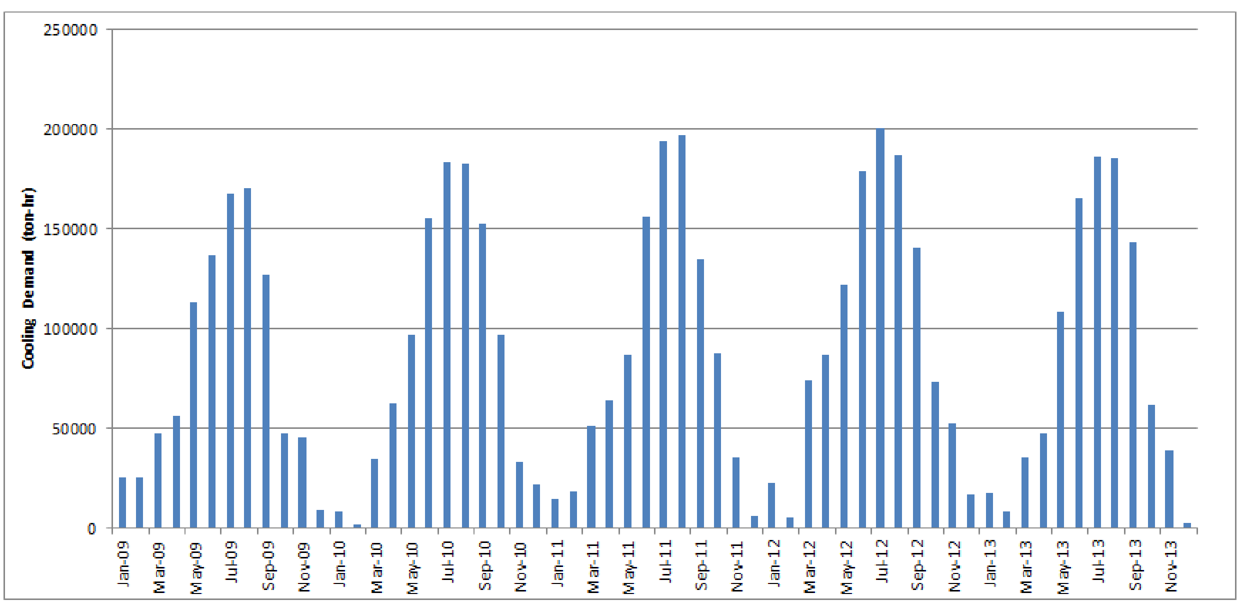

Figure 12. Estimated monthly cooling demand for Building 67

Step 3 – Perform regression on monthly cooling demand versus metered water consumption

To quantify water savings, it is necessary to know consumption before and after the installation; the subtraction of these two values results in water saved due to the new technology. The issue with this simple subtraction is that the data was not normalized for weather. A July month after the install could have been much warmer (causing more water use) than the July month before the install, making the simple difference calculation not valid.

In order to perform the weather normalization, a regression was performed that compared monthly cooling demand to the metered water consumption. This was done for the pre-retrofit period and the post-retrofit period. The regression lines and plotted data are shown in Figure 13.

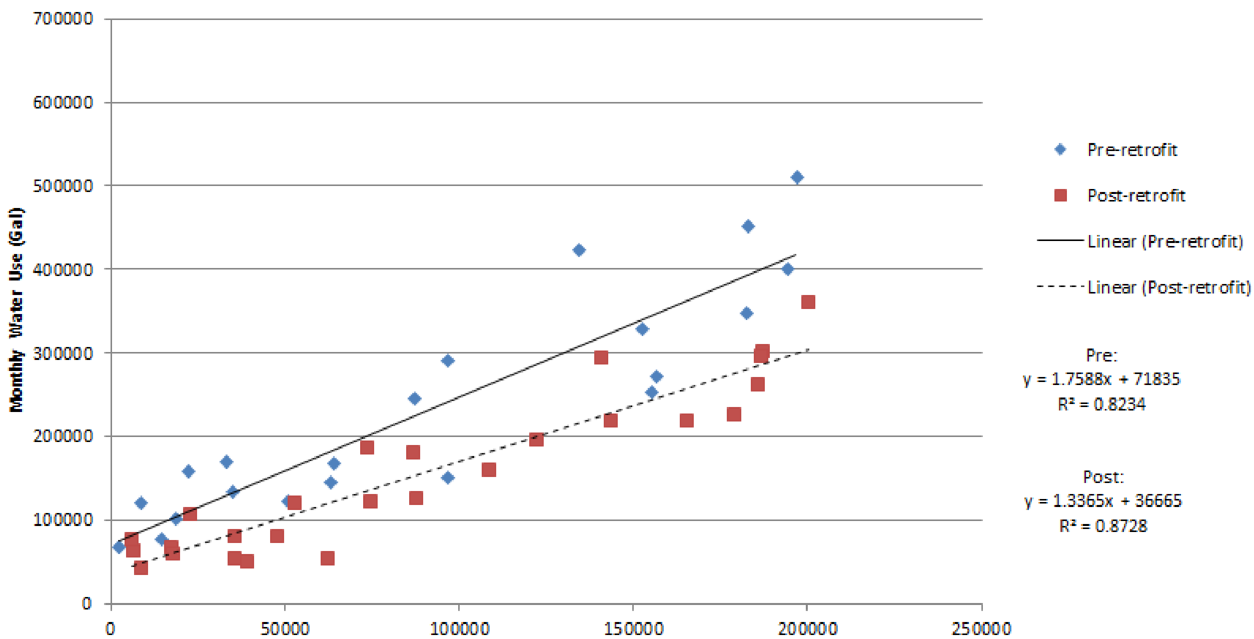

Figure 13. Regression of monthly water use to cooling demand (Building 67)

Step 4 – Calculate Water Savings for Post-retrofit Months

The difference in the slope of the pre- and post-retrofit regression lines equates to the gallons saved per ton-hour of cooling, due to the implementation of the AWT technologies. This amounted to 0.422 gal/ton-hour for (a 24% savings over the old water treatment system). The pre-retrofit regression equations were used to calculate the water consumption that would have occurred with the old system in place, and the post-retrofit equations were used to calculate the water consumption for the new system. These calculations were done for each of the post-retrofit months (using the same monthly cooling demand in each equation). The monthly savings are shown in Table 6.

Table 6. Monthly water savings for Building 67 from 2012-2013 (gallons)

Month	2012	2013
Jan	44,707	42,604
Feb	37,690	38,867
Mar	66,601	50,092
Apr	71,881	55,270
May	86,761	81,031
Jun	110,658	105,032
Jul	119,705	113,927
Aug	114,247	113,619
Sep	94,524	95,857
Oct	66,333	61,389
Nov	57,349	35,170
Dec	42,526	
Totals	912,983	792,858

It is also important to note that there is a limit to how much water can be saved by these systems. This is due to the evaporation component of cooling tower water use; this is what provides the cooling to the condenser loop and cannot be eliminated from the water consumption. 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)
- Q is the cooling required by the tower (can be calculated using $\dot{m}C_p\Delta T$ as discussed above)
- 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. The system in Building 67 achieved 98% of available cooling tower water savings.

Building 25:

Due to the fact that Building 25 did not have any pre-retrofit water consumption data, a different analysis technique was used to calculate the water savings for Building 25. For Building 25 the monthly water logs for the old water treatment system were accessed and the recorded CoC was obtained for each of the months in 2009. This data is shown in

Table 7. It should be noted that these are only spot measurements and do not necessarily show the actual average CoC maintained by the prior water treatment system; that being said, the consistency in the data demonstrates that this was approximately where the prior system was controlling the cycles.

Table 7 - Cycles of Concentration for summer 2009

Date	Conductivity - Make Up	Conductivity - Blow Down	Cycles of Concentration
9-May	890	240	3.71
9-Jun	1,240	280	4.43
9-Jul	1,180	280	4.21
9-Aug	1,280	280	4.57
9-Sep	1,340	280	4.79
9-Oct	1,340	280	4.79
Average:			**4.42**

A mass balance on the water in the cooling tower can be represented by[xiv]:

$$MakeUp = Evap + Drift + Blowdown$$

In order to determine the water savings for Building 25 it was necessary to calculate the difference in make-up water.

$$\Delta Makeup = (Evap_{Post} + Drift_{Post} + Blowdown_{Post}) - (Evap_{Pre} + Drift_{Pre} + Blowdown_{Pre})$$

In order to calculate the savings for the same level of cooling demand (weather normalized), we know that evaporation must be equivalent (same cooling load met). It also follows that the drift component would be equivalent (same climatic effects). Therefore, the only difference between pre- and post- retrofit make-up water consumption is the amount of blowdown required. Since the post retrofit blowdown was reduced to zero in 2012 and 2013, the above equation can be simplified to:

$$\Delta Makeup = Blowdown_{Pre}$$

Blowdown can be calculated as follows:

$$Blowdown = \frac{Evap}{CoC - 1}$$

Therefore, the water savings can be calculated using the above equation with the evaporation for the post-retrofit data, and the CoC from the pre-retrofit system (average value of 4.42 used). The calculated monthly savings are shown in Table 8.

Table 8. Monthly water savings for Building 25 from 2012-2013 (gallons)

Month	2012	2013
Jan	5,497	8,830
Feb	13,421	6,491
Mar	3,830	7,836
Apr	21,667	18,275
May	25,117	26,930
Jun	50,585	40,409
Jul	73,187	76,667
Aug	62,193	82,485
Sep	48,304	73,088
Oct	35,643	59,251
Nov	15,175	26,608
Dec	12,018	8,830
Totals	366,637	435,702

The total annual water savings for building 25 ranged from 336,637 gallons in 2012 to 435,000 gallons in 2013.

B. 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. Tests are performed for biological growth including iron-related bacteria, sulfate reducing bacteria, slime forming bacteria, fluorescing pseudomonas, and blue-green algae. Chemicals and biological treatment dosage and water blowdown rate are adjusted as required. Make-up water is tested frequently to determine the appropriate levels for chemical dosing. Acceptable water quality ranges for this project are presented in the Instrumentation Plan section of this report. GSA typically runs a cooling tower that uses standard chemical-based water treatment between 3 to 6 CoC. Blowdown may need to be increased if other indicators determine an adverse impact on the tower. However, this should be balanced with water conservation goals.

The following paragraphs present water quality data for the AWT technologies from two reporting sources: San Joaquin Chemicals, Inc. (SJCI), a third-party company, and the O&M contractor for each building. These data have been summarized below and are presented in detail in the Appendix.

It should be noted that no pre-installation water quality data was available to enable comparison to the previous treatment system. However, the O&M contractors at Buildings 25 and 67 noted significant improvement in cleanliness of the towers and chillers with the new AWT systems. The AWT system at Building 95 was not performing adequately according to O&M staff and was subsequently decommissioned.

Building 25

Analysis of the water quality data shows that some of the control ranges in the project specifications are not being maintained for the following criteria:

- Conductivity (microsiemens): Control range <2,400; maintained = 8,700 - 20,000 (300% - 800% outside range)
- pH value: Control range = 7.3–9.0; maintained = 9.6–10.2 (up to 13% outside range)
- "M" Alkalinity (as $CaCO_3$): Control range = 100–1,000 ppm; maintained = 1,680 – 3,004 (68% - 300% outside range)

CoC during the demonstration period for this AWT ranged from 12 – 80 (values of 3-5 were observed during the first 3 months of operation, but this was impacted by cleanout from previous operation). The lower values of 12-15 were impacted by tower clean out lowering the operating cycles. Improved efficiency from this AWT decreased blowdown by 99% during the demonstration period.

Building 67

Analysis of the water quality data shows that some of the control ranges in the project specifications are not being maintained for the following criterion:

- Conductivity (microsiemens): Control Range <2,400; maintained = 2,540 - 7,000 (5% - 290% outside range)

The CoC during the demonstration period ranged from 13 – 18. Improved efficiency from this AWT decreased blowdown by 94% during the demonstration period.

It should be noted that the specified project ranges are not absolute proof of success or failure of the AWTs in achieving adequate performance. By design many of the AWT systems maintain certain water quality parameters outside the range of the project specifications. While high TDS and conductivity levels can lead to corrosion and high alkalinity levels can cause scale build up in cooling tower system pipes O&M staff observed no adverse effects on the system with these parameters falling outside specified ranges in Buildings 25 and 67.

Building 95

Analysis of the water quality data shows that except for one instance the control ranges in the project specifications are being maintained. The CoC during the demonstration period ranged from 3 – 10.

The range of CoCs attained by each of the AWT systems was plotted in Figure 14 for the monitored period during the demonstration.

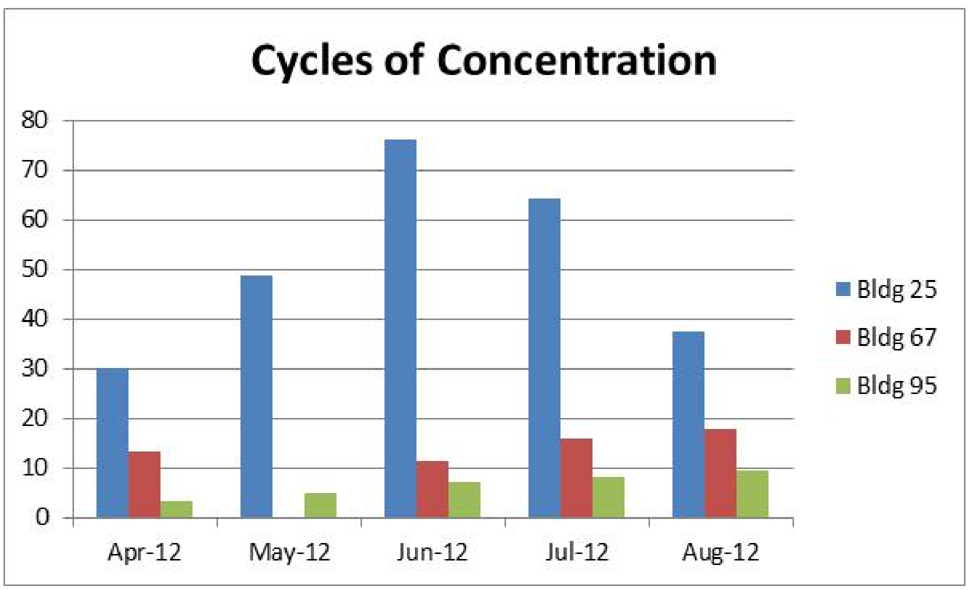

Figure 14. Observed CoC during SJCI Test Period

c. Preventative Maintenance Savings

Typical preventative maintenance (PM) practices for GSA cooling tower water treatment systems include the use of chemicals, chemical feeding, maintaining proper water conditions, and controlling bleed off. Water treatment methods are intended to protect the life of equipment, maximize heat transfer, and minimize scale, corrosion, solid matter buildup, biological growth, and water usage.

Building 25

GSA indicated that the amount of time required for PM on Building 25 became significantly less with the new treatment system, roughly 16 hours less time per quarter and requiring 1 staff member instead of 2 to perform cleaning. Corrosion coupons showed no signs of corrosion, nor were any signs visible on the chiller end bells or chiller tubes during scheduled maintenance. Because of cleaner cooling tower operations O&M staff was able to increase the programmed run time of the flat plate heat exchanger. According to GSA's O&M staff, Building 25 has eliminated the use of scale inhibitor, but still uses some biocides to protect against algae. However, as a function of the treatment technology more salt is being consumed to meet the demand.

Building 67

According to GSA the loosening of residual scale was observed in Building 67 at first deployment of the technology. As technology use continued, the released scale was cleaned out of the system and operation of the chillers/towers improved. The O&M Project Manager indicated that the equipment overall was much cleaner and cleaning the tower as part of PM became much easier: O&M staff was able to hook a hose to the suction side of the sand filter and vacuum the tower without draining it. The amount of cleaning time associated with this AWT has been dramatically reduced; however, glass filter beads will still need to be replaced every 3 years to uphold system operations. This system does require higher cost chemicals to attain these improved operating conditions.

O&M staff also indicated that the technology helped with maintaining the chiller tubes and flat plate exchanger surfaces. There was a noticeable increase of efficiency of the flat plate exchanger, allowing for a larger operating range and a higher transition temperature where the building shifts from free-cooling to initial chiller activation[xv]. It was stated that the 400-ton chiller can now handle up to 85°F outdoor air temperatures before bringing an additional chiller on-line to meet cooling demands. O&M staff has also observed that the flat plate collector can go 6°F higher before needing to switch to mechanical cooling, which is believed to be due to a cleaner system. While it was not possible to quantify the exact energy and cost savings associated with improved performance of the chiller and flat plate heat-exchanger operation (due to lack of sub-meter data and coincident energy efficiency improvements throughout the building that impact whole building energy use), it is clear that the improved operation will reduce energy use at the site. It is recommended that future work evaluate the energy impact of improved chiller operation.

Building 95

Due to the location of the Building 95, the tower receives continuous sun and wind exposure. GSA staff believes this may have led to algae growth that plagued the system for most of the demonstration period. The amount of debris (including algae and dirt) that accumulated in the basin led to an increase in maintenance for this system. The O&M Project Manager indicated the tower required 4 times the normal cleaning along with the flow switches requiring regular cleaning. The vendor addressed the algae issue immediately, treating it with biocide, and installed a copper silver ionizer to deter the algae growth; however, the problem still persisted. No signs of corrosion were present based on the regular samples taken. To operate this technology 2 filtration pumps were required, posing an energy demand of 7.5 HP and 10 HP when cooling towers are in use.

D. Economic Analysis

The economic evaluation of these technologies was based on the annual savings for each technology, the initial cost of the technology, and the yearly operation and maintenance costs. Using these values, the net present value (NPV) of each project was calculated, as well as the simple payback period. NPV was calculated in this report according to the National Institute of Standards and Technology (NIST) Handbook 135[2] with an assumed system life of 15 years, a discount rate of 3%, and a water cost escalation rate of 6.2% (as determined by historic Denver Water master meter rate increases over the past 4 years, see Table 9). The O&M costs were assumed to escalate at the NIST inflation rate of 0.9%.

Table 9. Denver water rates of the past four years (master meter outside the city)

Year	Water Cost ($/1000 gallons)	Increase over previous year (%)
2011	$3.5	-
2012	$3.6	6%
2013	$3.8	5%
2014	$4.0	9%

The savings due to reduced water consumption were calculated using utility rates provided by GSA. These rates were: $3.45 - $3.81/ 1,000 gallons (from 2011 – 2013) for a Denver Water master meter outside the City and $1.84/thousand-gallon for sewer costs. A combined water and sewer rate of $7.14/kGal from 2017 utility bills was used for the calculations. 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 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.

Table 10 shows the initial cost, water savings per year, and the O&M savings associated with Buildings 25 and 67. For AWT #1 the equipment costs were $18,100, the labor costs were $11,500, total installed cost of $29,600. For AWT #2 the equipment costs were $17,100, and the labor costs were $15,400, for a total installed cost of $32,500. Using these values the simple payback period and SIR of each technology is calculated. The O&M savings are calculated by comparing the annual costs associated with the new system to the previous water treatment O&M costs; this value can be positive or negative depending on the relative change in expenditures. It should be noted that the high escalation rate for water costs has a significant impact on the NPV calculation, making both systems cost effective over a 15-year analysis (despite the relatively long simple payback value for Building 67).

[2] Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2013. Annual Supplement to Handbook 135 and NBS Publication 709. U.S Department of Commerce. http://www1.eere.energy.gov/femp/pdfs/ashb13.pdf. Accessed 12/15/13

The savings due to reduced water consumption are highly favorable in both cases (higher in Building 67), yet the O&M costs decreased significantly in the case of Building 25, whereas the costs increased in Building 67. This has a large impact on economics associated with each technology. The increased O&M costs in Building 67 were due to an increase in chemical costs for the system (which utilized a higher quality chemical product) and periodic replacement of a glass bead media filter. On the other hand, Building 25 eliminated almost all chemical use and required a less expensive salt regeneration process for the O&M requirement in that system. Although there was an increase in chemical costs for AWT #2, there was a significant reduction in GSA maintenance hours for each technology. GSA maintenance hours reduced from 152 to 80 hours per year for AWT #1, saving $3,677 per year, and GSA maintenance hours were reduced from 132 to 69 hours for AWT #2, saving an additional $3,217 per year. For AWT #2, since the O&M contract increased by $5,100 per year, the net increase in O&M costs was $1,883.

This economic assessment does not take into account any of the potential energy savings from increased chiller efficiency (due to improved heat exchanger effectiveness). The building engineers for both Building 25 and Building 67 indicated that they were able to run the flat plate chillers more often due to improved chiller performance after AWT install, and in Building 67 it was stated that they were able to run with one less chiller the majority of the summer. Tracking the reduction in electricity consumption from the chiller plants was not in the scope of this analysis, and therefore is not included in this analysis. The decrease in energy costs would only improve the system economics and should be evaluated in future studies.

Table 10. Economics of AWT systems in Buildings 25 and 67

Economic Parameter	Building 25 (AWT #1) at Local Water Rate $7.14/kGal	Building 25 (AWT #1) at GSA Avg Water Rate $16.76/kGal	Building 67 (AWT #2) at Local Water Rate $7.14/kGal	Building 67 (AWT #2) at GSA Avg Water Rate $16.76/kGal
Initial Cost ($)	$29,600	$29,600	$32,511	$32,511
Cooling Tower Size (tons)	1,500	1,500	1,200	1,200
Water Savings (Gal/yr.)	401,170	401,170	824,448	824,448
Water and Sewer Cost Savings ($/yr.)	$2,864	$6,724	$5,887	$13,818
Annual Increase in O&M ($/yr.)	($6,445)	($6,445)	$1,883	$1,883
Simple Payback with O&M (yrs.)	3.2	2.2	8.1	2.7
Savings to Investment Ratio	4.7	6.7	1.8	5.5

At a combined water and sewer rate of $7.14/kGal AWT #1 had an installed cost of $19,73/Ton, annual water savings of 401,170 Gal/yr, a simple payback period of 3.2 years and an SIR of 4.7 using a total project lifetime of 15 years. At the GSA national average water and sewer rate of $16.76/kGal, AWT #1 had an annual water cost savings of $6,724, a simple payback period of 2.2 years and an SIR of 6.7. AWT #2 at Building 67 had an installed cost of $27.1/ton, an annual water savings of 824,448 gallons per year, a simple payback period of 8.1 years and an SIR of 1.8. At the GSA national average water and sewer rate of $16.76/kGal, AWT #2 had an annual water cost savings of $13,818, a simple payback period of 2.7 years and an SIR of 5.5.

Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITIES

GSA installed AWT systems in three buildings located in Colorado in an effort to see whether AWT technologies could maintain adequate water quality while conserving water and reducing operating costs. Systems from three different manufacturers were installed in the three buildings. The determination of adequate water quality was to be made based on a previously-developed set of benchmarks (see section IV.E. - Instrumentation).

The AWT systems at Buildings 25 and 67 both generated water savings as compared to the previous water treatment systems. They generated water use reduction of 23% and 24% respectively over the previous systems. The Building 95 system received negative reviews from on-site maintenance personnel and this system was removed by on-site maintenance personnel within a year of the date it was brought online. This made it impossible to calculate quantitative water savings for this system. Based on this and the previously discussed results, the systems in Buildings 25 and 67 show promise for widespread use in GSA buildings.

Table 11 through Table 13 present a summary of study results based on the model used for evaluation.

Table 11. Summary of Inputs to the Three AWT Systems

AWT	Make-up Water	Materials	Energy Required	O&M
Building 25	Decreased 23%	Brine	120 V controller	Decreased with AWT, but chemical costs increased
Building 67	Decreased 24%	Biocide, Scale Inhibitor Corrosion Inhibitor	120 V controller	Decreased with AWT, but glass media filter may offset this reduction
Building 95	Decreased (exact percentage not quantified)	Biocide	7.5 and 10 HP pumps	Increased due to algae growth

Table 12. Summary of Outputs Associated with the Three AWT Systems

Outputs		
AWT	Blowdown Water	Waste
Building 25	Decreased 99%	70 gallons per regeneration
Building 67	Decreased 94%	300 gallons per backwash
Building 95	Decreased (exact percentage not quantified)	None

Table 13. Summary of Delivered Results from the Three AWT Systems

Delivered Result		
AWT	Water Quality	Cooling Delivered
Building 25	Outside ranges for conductivity, pH, alkalinity	As required (potential increase in system efficiency)
Building 67	Outside range for conductivity	As required (potential increase in system efficiency)
Building 95	Ranges met	As required

It should be noted that, in spite of the fact that the final RFP dictated that adherence to the project specifications determined whether the technologies provided adequate water quality, these ranges should not be taken as absolute proof of success or failure of the AWT technologies in achieving adequate water quality. Many of these AWT systems by design maintain certain of these indices outside the range of the project specifications (e.g., pH is elevated as a means of corrosion control, so consequently, phosphate levels are lower than pH level targets using conventional chemical control).

Due to the overall improvements in water quality and reductions in blow down water usage for two of the three AWT's evaluated in this report, both AWT #1 (Building 25 technology) and AWT #2 (Building 67 technology) was installed at six additional installations at the Denver Federal Center that had advanced 15-minute cooling tower make up water meters. The measured annual water savings and associated cost savings were calculated and combined with the O&M costs from this study to calculate an annual cost savings, simple payback period and savings to investment ratio (Table 14).

For the AWT #1 technology GSA elected to use the vendor provided side stream filter system instead of the typical GSA scoped side stream filtration system, which reduced the cost and for the AWT #2 systems, GSA continued to install the glass media filter system. For Building 20, chemical costs were increased to $400 per year, versus $1,883 per year for other facilities since this is a smaller facility with less cooling tower water usage than the other facilities.

Table 14 - Annual Water Savings and Economics for Additional Deployments at DFC

Denver Federal Center Facility	AWT System	Date Installed	Cooling Tower Size (Tons)	Installed Cost ($)	Annual Water Savings (Gal/yr.)	Annual Water Savings ($)	Annual Increase in O&M ($/yr.)	Total Annual Cost Savings ($/yr.)	Simple Payback (yrs.)
Bldg.20	AWT Technology #1	Nov-16	600	$31,057	718,597	$5,131	($6,445)	$11,576	2.7
Bldg.41	AWT Technology #1	Jan-17	1,000	$36,976	1,809,921	$12,923	($6,445)	$19,368	1.9
Bldg. 85	AWT Technology #2	Jan-14	500	$8,756	62,450	$446	$400	$46	>40
Bldg.56	AWT Technology #2	Jan-15	1000	$28,557	661,160	$4,721	$1,100	$3,621	7.9
Bldg. 810	AWT Technology #2	Jun-14	2 x 500	$31,047	1,131,450	$8,079	$1,883	$6,196	5.0
Bldg.810 USDA	AWT Technology #2	Mar-16	3 x 500	$31,047	1,048,000	$7,483	$1,883	$5,600	5.5

For building 41 the water usage went up for the post retrofit year of 2017 due to an issue with the blowdown solenoid valve that didn't get fixed for 3 months. For building 41 for the first four months of 2018, the system is showing considerable water savings and the savings for the new cooling tower AWT were extrapolated for the remaining months in 2018. For all of the additional AWT technology #2 installations, the measured blow down for the months preceding the installation of the AWT were reduced to close to 0 gallons a month, representing a 97.8% to 100% reduction in blow down across all systems.

For the additional deployments at the DFC, the simple payback ranged from 1.9 to 7.9 years for all installations other than Building 85. The AWT #2 vendor was performing water treatment services at Building 85 prior to the other installations and the sand filtration system was able to be installed at a much lower cost than the other facilities for this facility.

B. BEST PRACTICE

One common theme for these systems was the fact that they all took some troubleshooting effort after the initial installation. Cooling tower water treatment is a unique sub-trade in which other tradesmen (HVAC technicians, plumbers, controls technicians) rarely engage. This phenomenon is borne out by the fact that traditional chemical water treatment (sales, installation, and maintenance of systems) is done by specialized professionals who concentrate on water treatment. Therefore, if GSA is to successfully implement this technology on a broad scale, rigorous installation methods and criteria must be laid out by GSA (see Section VI.E).

Best practice should also include integration of these AWT systems with building management systems or use of PLCs to allow operation of AWT systems to be adjusted and monitored remotely. Use of this strategy explains some of the success at the Denver site.

C. BARRIERS AND ENABLERS TO ADOPTION

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), as well as seasonal changes (e.g. pollen) have the potential to affect the observed operation of each technology evaluated. These factors can contribute to biological growth or mineral deposits that require chemicals and additional maintenance towers.

The main challenge to widespread GSA deployment of these technologies is proper installation of the AWT systems. Cooling tower water treatment is a specialized niche in the building maintenance industry. To perform it properly one must possess in-depth knowledge in several disparate subject areas: building heating, ventilating, and air conditioning; water chemistry; and biological algae growth. If the on-site forces have received no training in these new AWT systems, this situation creates additional difficulties in successful implementation.

D. MARKET POTENTIAL WITHIN THE GSA PORTFOLIO

The first step in evaluation of further deployment of these AWT technologies is the identification of buildings in that 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 technology will perform well economically. To assist GSA in identifying sites that have high potential water and/or cost savings, NREL modeled water savings potential using the whole-building modeling software EnergyPlus. The “Large Office” building model was selected from the Commercial Reference Buildings that are developed and maintained by the DOE/NREL[xvi]. 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 sixteen different ASHRAE climate zones (see Figure 15). The reference buildings also include three different vintages of construction: “pre-1980”, “post-1980”, and “new construction” (compliant with ANSI/ASHRAE/IESNA Standard 90.1-2004). For the modeling analysis included in this report, the “post-1980” construction model was utilized.

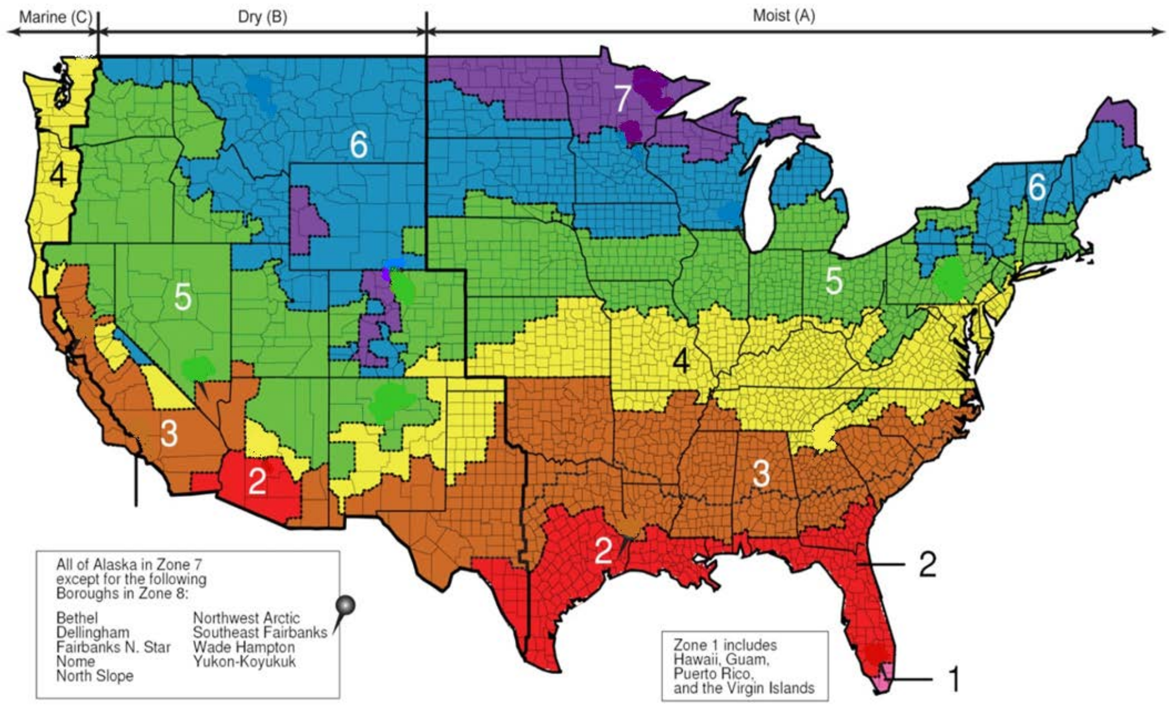

Figure 15. ASHRAE climate zone map

The large office building model is a 498,588 ft^2 office building that is cooled via a water-cooled chiller. The standard cooling tower model in EnergyPlus defaults to blowdown operation that maintains a CoC of 3 and the cooling tower size ranged from 3,619 tons to 5,212 tons depending on location. In order 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 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 technologies in this report. Figure 22 shows the annual evaporation (in thousands of gallons water), and decrease in annual blowdown water use for 3, 15, and 30 CoC. The cities with larger numbers of cooling degree days and more arid climates (the “B” 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 16).

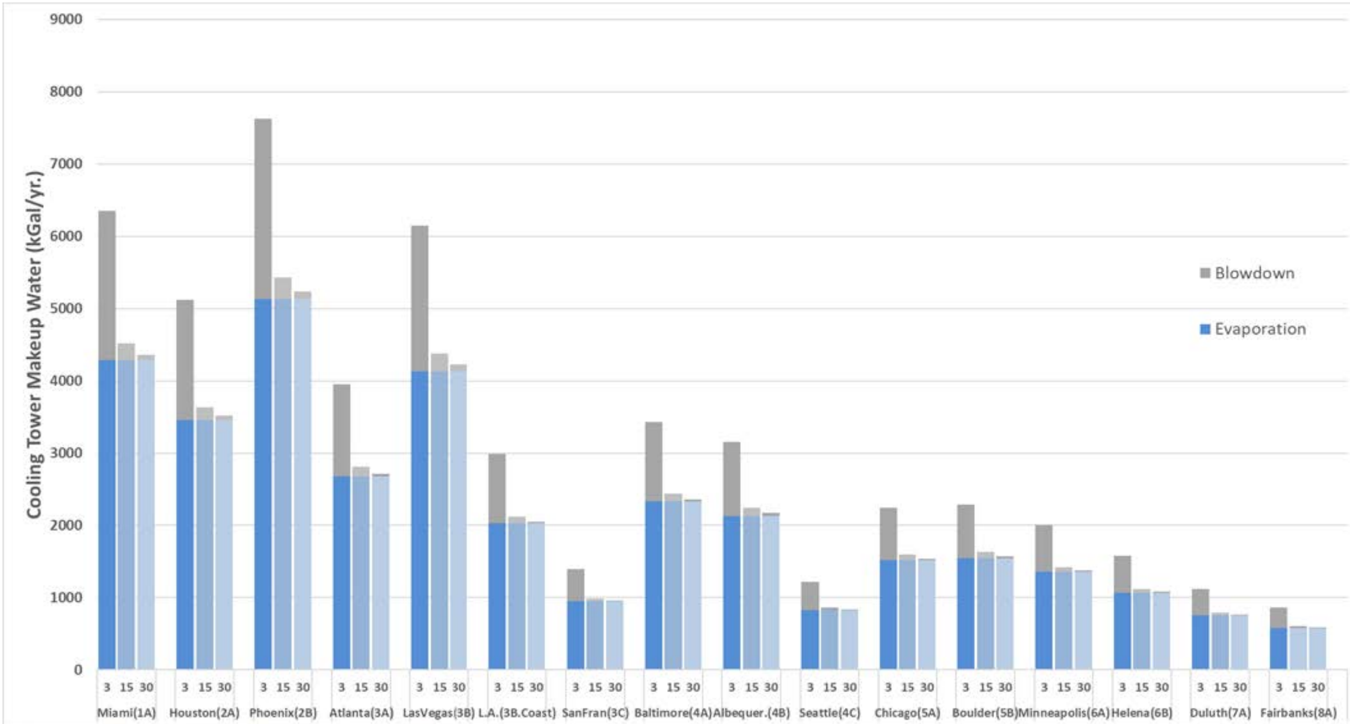

Figure 16. Modeled water evaporation and blowdown usage across ASHRAE climate zones, showing decreased blowdown from 3 to 15 to 30 CoC.

The water usage numbers were then translated into annual cost savings using site specific water rates. Combined water and sewer rates are based on current local municipal rates as of May, 2018, and are provided in Table 15. 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 17.

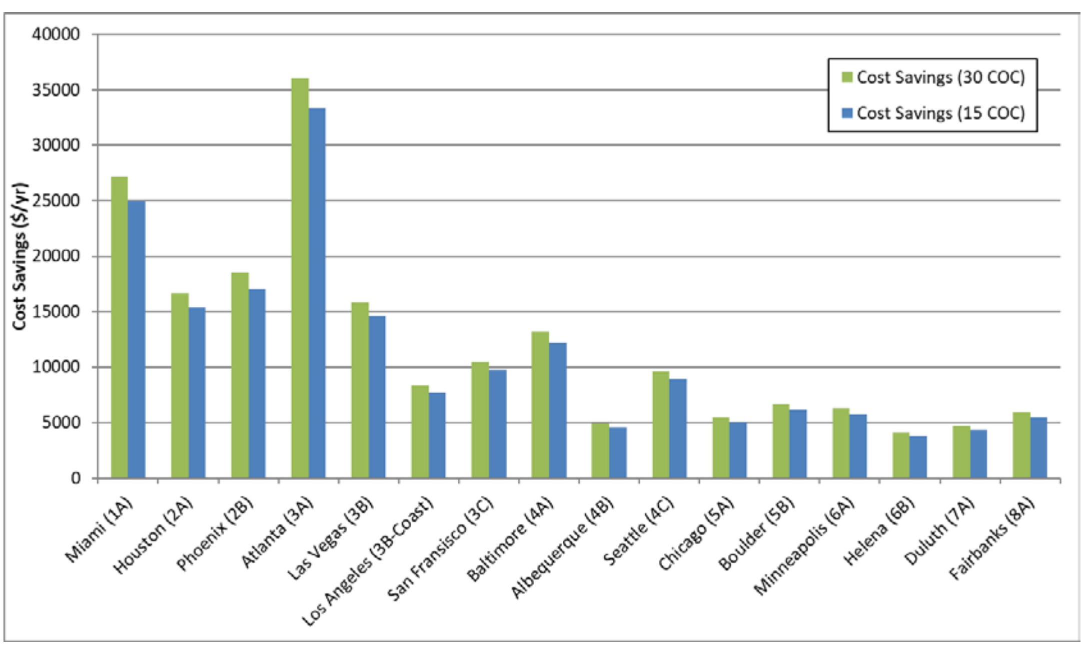

Figure 17. Estimated yearly cost savings by climate zone

The wide variation in water costs between the different cities results in a significantly different picture in cost savings than 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. Table 15, below, gives the water rates used in this evaluation (current as of May, 2018).

Table 15. Combined water and sewer rates for sample cities across each of the 16 ASHRAE climate zones

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
L.A. (3B-Coast)	8.88	**Helena (6B)**	8.30
San Fransisco (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 utilized to calculate a savings-to-investment ratio (SIR) for each city. It should be noted that this calculation assumes that the annual operating costs associated with these systems are the same after the install as they were with the original system. For the installations evaluated in this report, one of the systems reduced the annual operating costs (due to reduced chemical use) and another system increased the annual costs (higher cost chemical). The SIRs denoted here are a very rough estimate, considering the assumptions that the original system was operating at 3 CoC, the new system would achieve 30 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 SIRs for a high installed cost assumption ($60,000) and a low cost assumption ($45,000) for each technology are shown in Figures 18a – 18d. The figures show the modeled SIRs for a given water and wastewater combined rate across various climate zones. The SIR calculations assume a 15 year project life and 30 CoC.

AWT #1:

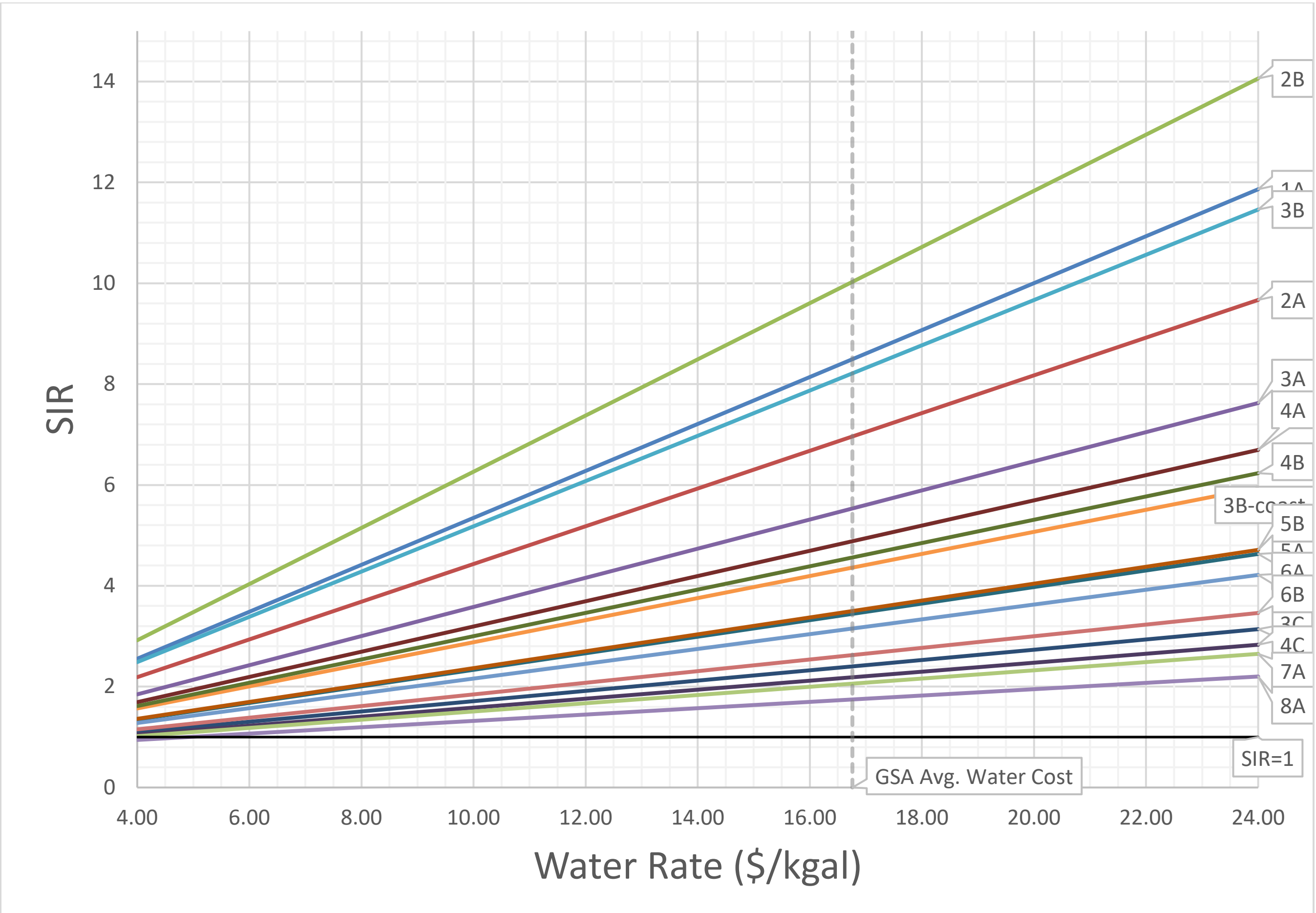

Figure 18a. AWT #1 - Savings to investment ratio for same system in evaluated climate zones for various water rates: high cost scenario

For the high cost scenario, AWT #1 is life cycle cost effective (SIR>1) across all 16 climate zones when the combined water and sewer rate is above $5.50/kGal.

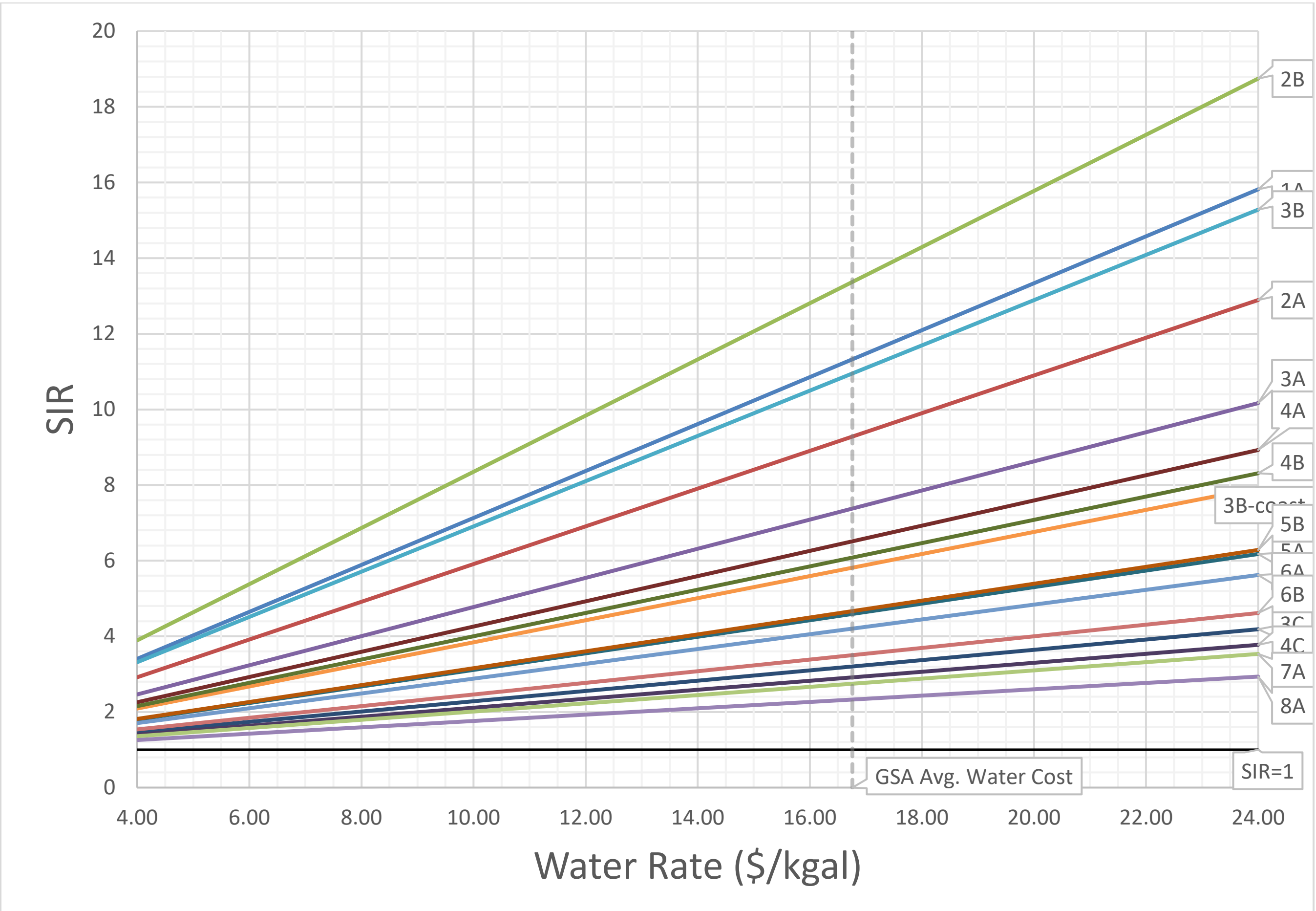

Figure 18b. AWT #1 - Savings to investment ratio for same system in evaluated climate zones for various water rates: low cost scenario

For the low-cost scenario, AWT #1 is life cycle cost effective (SIR>1) across all 16 climate zones when the combined water and sewer rate is above $4/kGal, as it was in each of the sixteen sample cities used in this study.

AWT #2:

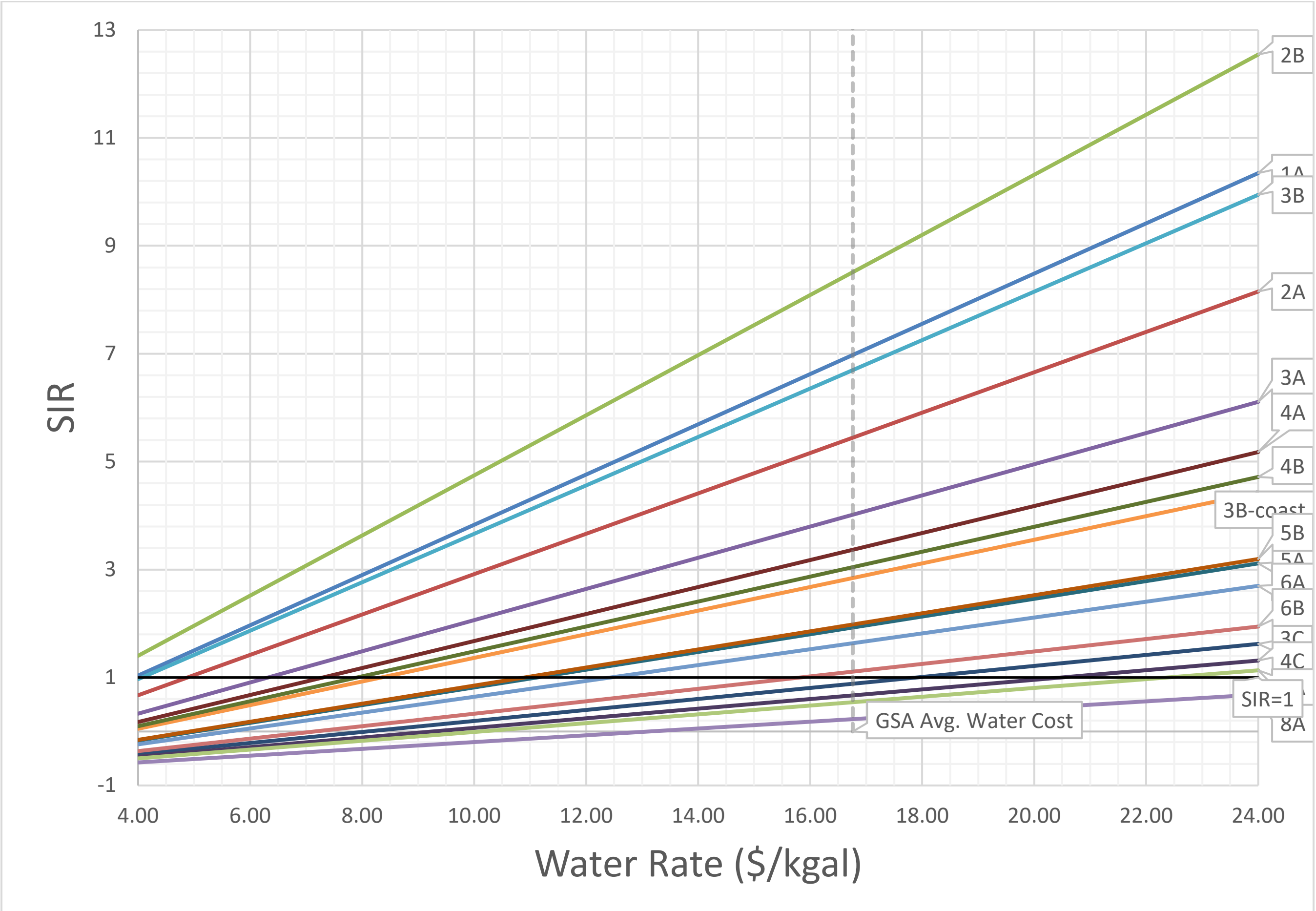

Figure 19a. AWT #2 - Savings to investment ratio for same system in evaluated climate zones for various water rates: high cost scenario

For the high cost scenario, AWT #2 is life cycle cost effective (SIR>1) in some climate zones at some combined water and sewer rates. At the GSA average water cost of $16.76/kgal, this technology is cost effective in 12 of the 16 climate zones.

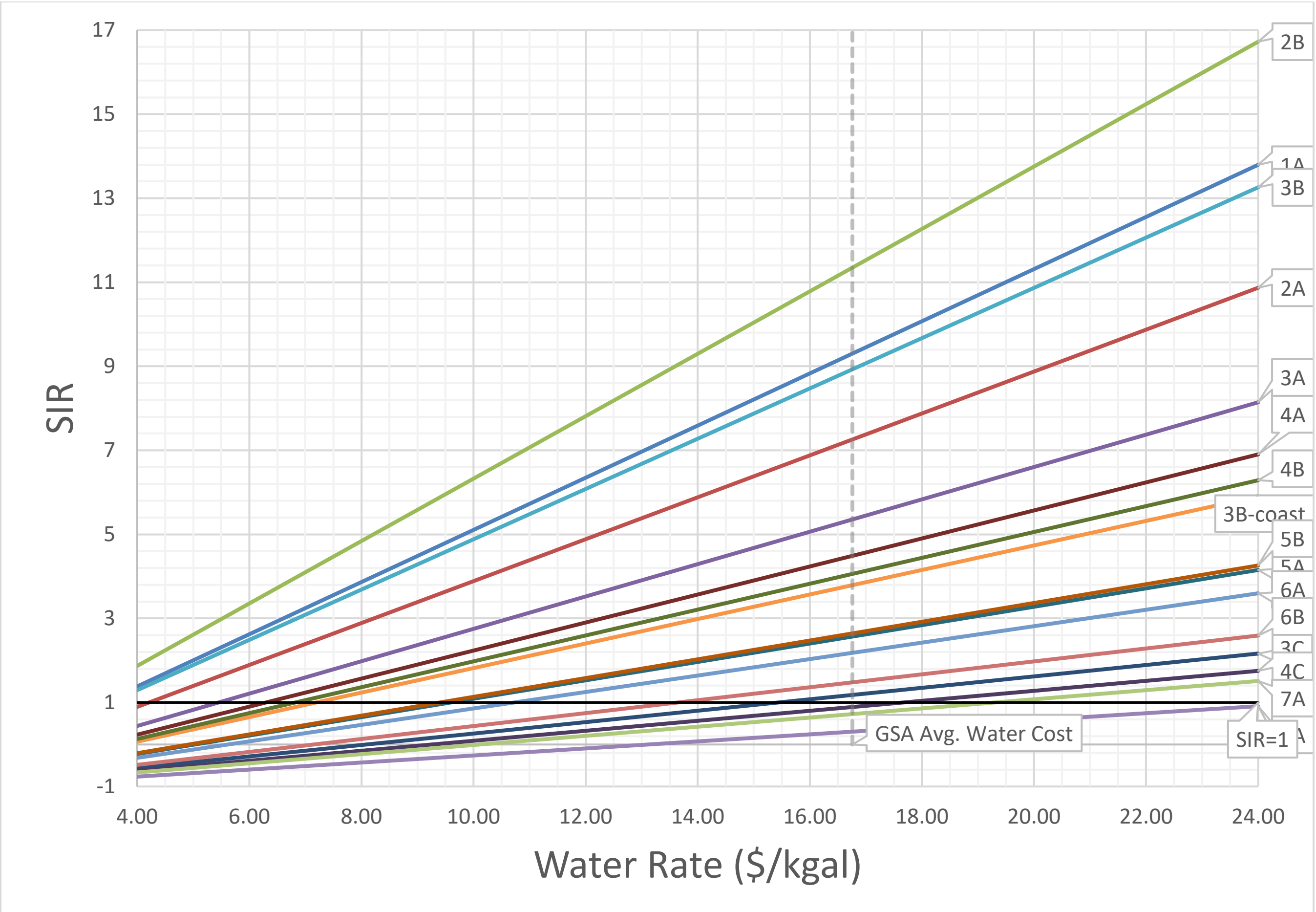

Figure 18b. AWT #2 - Savings to investment ratio for same system in evaluated climate zones for various water rates: low cost scenario

For the low-cost scenario, AWT #2 is life cycle cost effective (SIR>1) across many of the climate zones at typical water and sewer combined rates. At the GSA average water cost of $16.76/kgal, this particular AWT technology is cost effective in 13 of the 16 climate zones.

The buildings that have a large number of cooling degree days, high evaporation rates and good water quality can expect maximum water savings, whereas buildings in areas where typical wet bulb temperatures approach dry bulb design temperature 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 technologies. It is also important to consider the water quality of the locations under consideration. In this case Miami, Huston, Phoenix, Atlanta, and Las Vegas, all had payback periods under 5 years based on the higher installed cost estimate of $60,000 and all locations had pay back periods of less than 12 years based on the lower installed cost estimate of $45,000. Given that the additional deployments at the DFC had installed costs that were all less than $37,000, the simple payback would be even lower across all cities at the installed costs realized for the additional deployments at the DFC.

E. RECOMMENDATIONS FOR INSTALLATION, COMMISSIONING, TRAINING, AND CHANGE MANAGEMENT

A common challenge with the AWTs evaluated in this study was the lack of sufficient information on system installation and operations. This was due in part to the fact that the manufacturer representatives did not have much prior experience with government installations and did not provide the installation services that would have reduced project coordination challenges. In all cases there seems to have been a scarcity of information available to provide assistance and education in the design and installation of these AWT systems, including the following.

1) Clear statement of the design principles that should be followed in any installation of the particular AWT system. Design guidance documentation is required, similar to the design guidance provided by manufacturers of HVAC equipment in their literature. For instance, if an engineer or designer is designing a chiller, there are step-by-step guidelines (with example problems) about how to select a chiller (e.g., sizing, ancillary piping and devices)

2) Schematic layouts the designs should follow (e.g., specific and robust schematic plans showing all components, manufacturer-provided and off-the-shelf, required)

3) Theoretical explanations of the underlying fluid dynamics and thermodynamics involved when integrating these systems in cooling tower systems. For example, pumping head design information related to the specific AWT system-cooling tower system layout (series or parallel).

4) Trade manuals showing best practices in pump/pipe layout and integration of AWT systems into existing cooling tower systems.

5) Inclusion of the AWT metering systems into the BAS to assist with continuous monitoring of the systems.

In short, to ensure the proper design, installation, and functioning of AWT systems, the kind of process/product education and manufacturer support network that exists in the larger field of building HVAC design must be developed. It is also recommended to discuss the accompanying energy reduction possibilities early on in the project and plan for operational changes that may result from improved chiller plant operation and how to document those energy and cost savings.

Further considerations for the application of these AWTs include the influent water quality and waste generated by these systems. Influent water quality is a function of the source water being used. Based on the chemical make-up of the influent water the addition of a filter may be required to support effective operation of an AWT and prevent damage to the cooling tower and chillers. As noted in previous sections, the Building 25 and 67 technologies both generate waste streams through softener regeneration and filter backwash, respectively. While these systems both demonstrated a substantial reduction in blowdown, a small amount of waste (brine solution and filter backwash water) is produced as a function of their operations. The volume and chemical composition of these waste streams will vary based on cooling tower capacity and influent water quality. If in sufficient volume or concentration, discharge of these waste streams may be subject to restrictions from the sewer district.

Appendices

A. RESEARCH DETAILS

The detailed water quality results are presented in Figure 20 to 21.

Site: Denver Bldg 25	Control Range per Proj. Specs.	April 2012				May 2012				June 2012				July 2012					August 2012				
		NCWT Bldg				NCWT Bldg				NCWT Bldg				NCWT Bldg					NCWT Bldg				
		SJCI		Local O&M		SJCI		Local O&M		SJCI		Local O&M		SJCI			Local O&M		SJCI			Local O&M	
		Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	CoC	Raw	Tower	Raw	Tower	CoC	Raw	Tower
PHYSICAL PROPERTIES																							
Appearance	Clear	Clear	Clear											Clear	Yellow				Clear	Clear			
Conductivity (Micro Siemens) LAB	< 2400	352	8695	297	10452			250	12170			254	19375	340	19720	58	285	20132	321	4547	14.2	289	17503
pH Value	7.3 - 9.0	8.45	9.9	8.2	9.6			8.15	9.6			8.2	9.62	8.08	10.17		8.3	9.71	7	9.79		8.3	9.71
SCALE POTENTIAL																							
Total Hardness (as $CaCO_3$)	500 - 1500	6	44	0.1	18	NO	NO	0.1	16	NO	NO	0.1	4	117	114		0.1	6	110	137	1.2	0.1	36
Calcium Hardness (as $CaCO_3$)	< 500	4	16	0.1	8			0.1	8			0.1	2	76	200		0.1	3	86	62	0.7	0.1	18
Magnesium Hardness (as $CaCO_3$)	< 100	2	28			S	S			S	S			41	n/t				24	75	3.1		
ALKALINITY						A	A			A	A												
"P" Alkalinity (as $CaCO_3$)	none	0	372			M	M			M	M			0	1500				0	170	11.5		
"M" Alkalinity (as $CaCO_3$)	100-1000	62	1722	160	3004	P	P	164	3108	P	P	94	1680	60	4040	67.3	102	1974	60	692		125	1854
SILICA						L	L			L	L												
Silica (as SiO3) High Range	< 150	3.5	133	4.1	401	E	E	5.3	380	E	E	5.2	188	4.1	178	43.4	6.1	196	4.6	86.5	18.8	5.9	152
ANIONS																							
Chloride (as CL-)	10 - 500	24	810			R	R			R	R			21	2100	100			23	430	18.7		
Salt (as NaCL)	< 450	39.6	1337			E	E			E	E			34.65	3465				37.95	709.5			
Sulfate (as SO_4^{-2})	< 250	47	1000			T	T			T	T			51	3760	73.7			52	960	18.5		
CORROSION INHIBITORS						U	U			U	U												
Phosphate (as PO_4^{-3})	8 - 15	0.15	4.89			R	R			R	R			0.82	11.54	1.41			0.51	4.82	9.5		
CORROSION PRODUCTS						N	N			N	N												
Copper (as Cu)	N/A													0.03	1.17				0.06	0.24			
Iron (as Fe)	< 4	0.02	0.32	0.04	0.18	E	E	0.04	0.22	E	E	0.02	0.28	0.14	1.2		0.03	0.24	0.02	0.355		0.01	0.08
BIOLOGICAL						D	D			D	D												
BioSan Paddle	< 10^5	N/A	<100											N/A	10^6				N/A	n/r			
CoC			25		35				49				76		58			71		14			61

n/t = data not taken

n/r = Bio Paddle or dipping sample not returned by site

N/A = data not required by contract to be provided

CoC = Cycles of concentration, not required to be calculated under this contract

(yellow) highlighting denotes control range not being maintained

Figure 20. Building 25 Water Quality Data

Site: Denver Bldg 67	Control Range per Proj. Specs.	April				May				June				July					August				
		SJCI		Local O&M		SJCI		Local O&M		SJCI		Local O&M		SJCI			Local O&M		SJCI			Local O&M	
		Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	CoC	Raw	Tower	Raw	Tower	CoC	Raw	Tower
PHYSICAL PROPERTIES																							
Appearance	**Clear**	Clear	Clear							Clear	Clear			Clear	Clear				Clear	Clear			
Conductivity (Micro Siemens) LAB	**< 2400**	337	4467		3836				3990	221	2540		4779	341	5413	15.87		5492	313	5606	17.91		~ 7000
Total Dissolved Solids	**N/A**	219	3374																				
pH Value	**7.3 - 9.0**	7.23	9.02		8.83				8.83	7.14	8.53		8.85	7.37	7.37			8.9	6.54	9.18			8.9
SCALE POTENTIAL																							
Total Hardness (as $CaCO_3$)	**500 - 1500**	142	1530			NO	NO			87	984			116	1930	16.64			104	2020	19.42		
Calcium Hardness (as $CaCO_3$)	**< 500**	51	1020							60	808			86	1110	12.91			82	1180	14.39		
Magnesium Hardness (as $CaCO_3$)	**< 100**	91	510			S	S			27	176			30	820	27.33			22	840	38.18		
ALKALINITY						A	A																
"P" Alkalinity (as $CaCO_3$)	**none**	0	96			M	M			0	24			0	105				0	104			
"M" Alkalinity (as $CaCO_3$)	**100-1000**	51	458			P	P			34	390			60	540	9			68	560	8.24		
SILICA						L	L																
Silica (as SiO3) High Range	**< 150**	5.8	121			E	E			2.8	97.6			2.2	109.5	49.77			5.1	116	22.75		
ANIONS																							
Chloride (as CL-)	**10 - 500**	18	575			R	R			13	236			23	810	35.22			18	760	42.22		
Salt (as NaCL)	**< 450**	30.06	960.3			E	E			21.45	389.4			37.95	1337				29.7	1254			
Sulfate (as SO_4^{-2})	**< 250**	48	105			T	T			30	530			48	1400	29.17			52	1700	32.69		
CORROSION INHIBITORS						U	U																
Phosphate (as PO_4^{-3})	**8 - 15**	0.28	1.83			R	R			0.16	3.63			0.04	3.09	77.25			0.03	2.98	99.33		
CORROSION PRODUCTS						N	N																
Copper (as Cu)	**N/A**		0.47																0.17	0.24			
Iron (as Fe)	**< 4**	0.02	0.32			E	E			0.06	0.2			0.01	0				0.6	0.01			
BIOLOGICAL						D	D																
BioSan Paddle	**< 10^5**	N/A	< 10^2							N/A	n/r			N/A	10^5				N/A	n/r			
CoC			13								11				16					18			

n/t = data not taken
n/r = Bio Paddle or dipping sample not returned by site
N/A = data not required by contract to be provided
CoC = Cycles of concentration, not required to be calculated under this contract
(yellow) highlighting denotes control range not being maintained

Figure 21. Building 67 water quality data

Site: Denver Bldg 95	Control Range per Proj. Specs.	April				May				June				July					August				
		SJCI		Local O&M		SJCI		Local O&M		SJCI		Local O&M		SJCI			Local O&M		SJCI			Local O&M	
		Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower	Raw	Tower			Raw	Tower	CoC	Raw	Tower	Raw	Tower	CoC	Raw	Tower
PHYSICAL PROPERTIES																							
Appearance	**Clear**	Clear	Clear							Clear	Clear			Clear	Clear				Clear	Clear			
Conductivity (Micro Siemens) LAB	**< 2400**	321	1036	309	1055			130	635	184	1143	110	892	313	2390	7.64	267	2370	331	3165	9.56		
Total Dissolved Solids	**N/A**			206	703			118	615								178	1580				206	1620
pH Value	**7.3 - 9.0**	7.29	8.73	7.5	8.19			7.2	8.7	7.17	8.39	6.5	9	7.9	8.35		8.35	8.47	7.7	8.63		8.31	8.16
SCALE POTENTIAL																							
Total Hardness (as $CaCO_3$)	**500 - 1500**	160	369	103	368	NO	NO	57	283	64	404			130	796	6.12	99	871	132	1080	8.18	109	738
Calcium Hardness (as $CaCO_3$)	**< 500**	104	282	64	266			34	192	44	312			80	470	5.88	59	497	80	363	4.54	67	463
Magnesium Hardness (as $CaCO_3$)	**< 100**	56	87			S	S			20	92			50	326	6.52			52	717	13.79		
ALKALINITY						A	A																
"P" Alkalinity (as $CaCO_3$)	**none**	0	18			M	M				2			0	3				0	44			
"M" Alkalinity (as $CaCO_3$)	**100-1000**	52	172	48	95	P	P	33	168	26	192			54	224	4.15	51	296	56	318	5.68	49	235
SILICA						L	L																
Silica (as SiO3) High Range	**< 150**	5.6	11.2	5	11	E	E	5	12	4.7	24.7			2.3	28	12.17	2	32	2.4	39.5	16.46	2	29
ANIONS																							
Chloride (as CL-)	**10 - 500**	21	86	23	97	R	R	10	84	11	85			19	252	13.26	20	286	19	350	18.42	19	272
Salt (as NaCL)	**< 450**	34.65	141.9			E	E			18.15	140.3			31.35	415.8				31.35	577.5			
Sulfate (as SO_4^{-2})	**< 250**	30	150	54	222	T	T	34	190	23	205			50	490	9.8	36	566	53	680	12.83	48	639
CORROSION INHIBITORS						U	U																
Phosphate (as PO_4^{-3})	**8 - 15**	0.15	0.85			R	R			0.12	1.32			0.34	4.31	12.68			0.08	3.02	37.75		
CORROSION PRODUCTS						N	N																
Copper (as Cu)	**N/A**													0.89	0.14				0.96	0.14			
Iron (as Fe)	**< 4**	0.05	0.69			E	E			0.11	0.07			0.02	2.4				0.08	0			
BIOLOGICAL						D	D																
BioSan Paddle	**$< 10^5$**	N/A	$< 10^2$						$< 10^3$	N/A	n/r			N/A	10^5				N/A	n/r			
CoC			3		3				5		6		8		8			9		10			

n/t = data not taken

n/r = Bio Paddle or dipping sample not returned by site

N/A = data not required by contract to be provided

CoC = Cycles of concentration, not required to be calculated under this contract

(yellow) highlighting denotes control range not being maintained

Figure 22. Building 95 water quality data

References

[i] Building Energy Databook, 2011, http://buildingsdatabook.eren.doe.gov/
[ii] Wilson, A. 2011. Cooling Tower Institute Annual Conference. "The 3 R's of Sustainable Water Cooled Systems Operation."
[iii] Holliday, R., Geiger, G., Geuns, P. 2012. Cooling Tower Institute Annual Conference. "How Green is the Cooling System."
[iv] Holliday, R., Geiger, G., Geuns, P. 2012. Cooling Tower Institute Annual Conference. "How Green is the Cooling System."
[v] Morrison, F. ASHRAE Journal, July 2004. "What's Up with Cooling Towers."
[vi] Water Conservation Technology International. http://water-cti.com/technology.html Date accessed: 1/23/14.
[vii] TERLYN Industries. http://www.terlyntech.com/ Date accessed: 1/22/14.
[viii] VRTX: Dynamic Water Technology. http://vrtxtech.com/solution/ Date accessed: 2/26/14.
[ix] Water Conservation Technology International. http://water-cti.com/technology.html Date accessed: 1/23/14.
[x] Duke, D. Water Conservation Technology International. "Water Use and Discharge Minimization Using Silica/ZLD Approach for Evaporative Cooling Towers." Presentation, CONRAD 2007. http://water-cti.com/pdf/CONRAD_2007.pdf
[xi]TERLYN Industries. http://www.terlyntech.com/ Date accessed: 1/22/14.
[xii] VRTX: Dynamic Water Technology. http://vrtxtech.com/solution/ Date accessed: 2/26/14.
[xiii] http://www.wunderground.com/. Date accessed 12/12/13
[xiv] http://www.gewater.com/handbook/cooling_water_systems/ch_31_open.jsp Date accessed 7/13/15
[xv] "A water conservation initiative: Pilot Programs of Non Traditional Water Treatment Technology for Cooling Towers." Unpublished report, Doug Baughman, GSA.
[xvi] http://energy.gov/eere/buildings/commercial-reference-buildings. Date accessed 4/14/14,