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AUGUST 21-23, 2018 • CLEVELAND, OHIO

Cooling Tower Water Management Best Practices

- Introductions
- Cooling tower water treatment overview
- Alternative water treatment field test results
  - Alternative chemical treatments
  - Water softeners
  - Advanced oxidation process
  - Electrolysis
- Discussion

HVAC Research Team Call

- September 6, 2018 1-2 ET
- Field Test Results of New HVAC Technologies
  - High performance circulator pumps
  - Air scrubber technology that removes CO_2 and VOCs
  - high-performance variable speed screw chillers
- Registration at https://attendee.gotowebinar.com/register/7751571883832957 45

Cooling Tower Basics

- Evaporation removes about 1,000 Btu/lb of water
- Evaporation rate ~ 1.8 gal/ton-hr (varies with conditions and load)
- Evaporation leads to concentration of minerals and chemicals
- Control scale, corrosion, and biological growth with water treatment (usually chemicals) and blowdown

Credit: Michael Deru, NREL

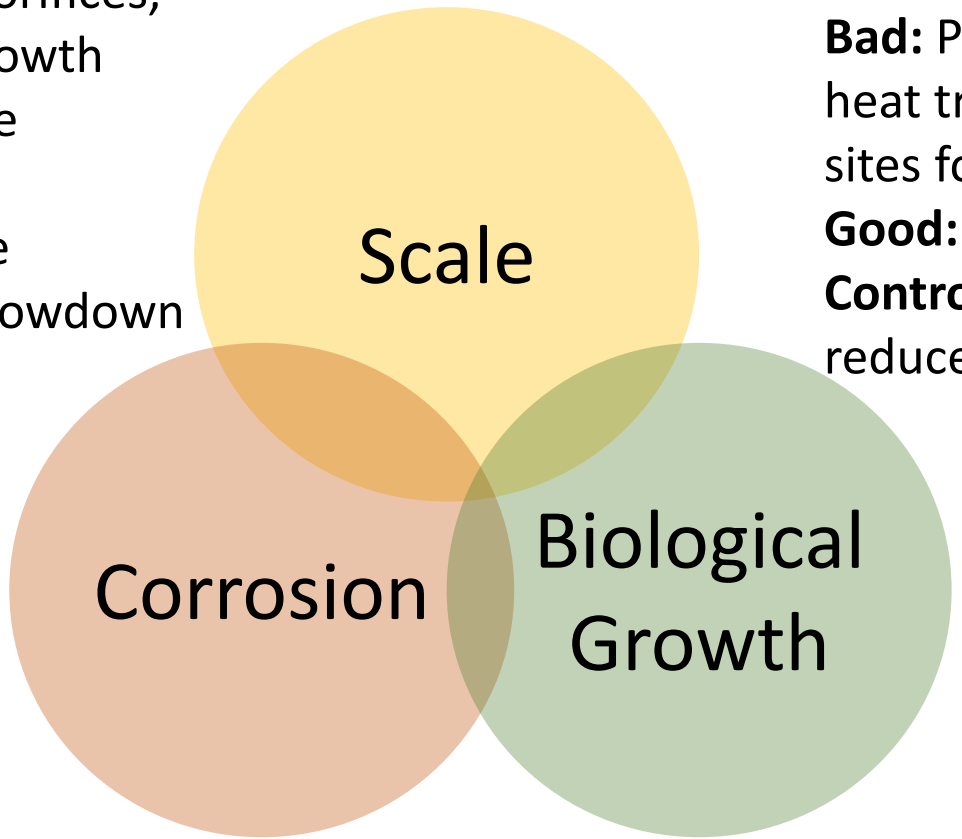
Balancing Cooling Tower Water Quality

Scale

Bad: Reduce heat transfer, plug orifices, sites for corrosion or bacteria growth
Good: Small amounts can reduce corrosion
Control: Scale inhibitors, remove minerals, balanced chemistry, blowdown

Biological Growth

Bad: Potential health hazard, reduce heat transfer, plug orifices, biocorrosion, sites for corrosion or scale
Good: None
Control: Biocides, balanced chemistry, reduce light, blowdown



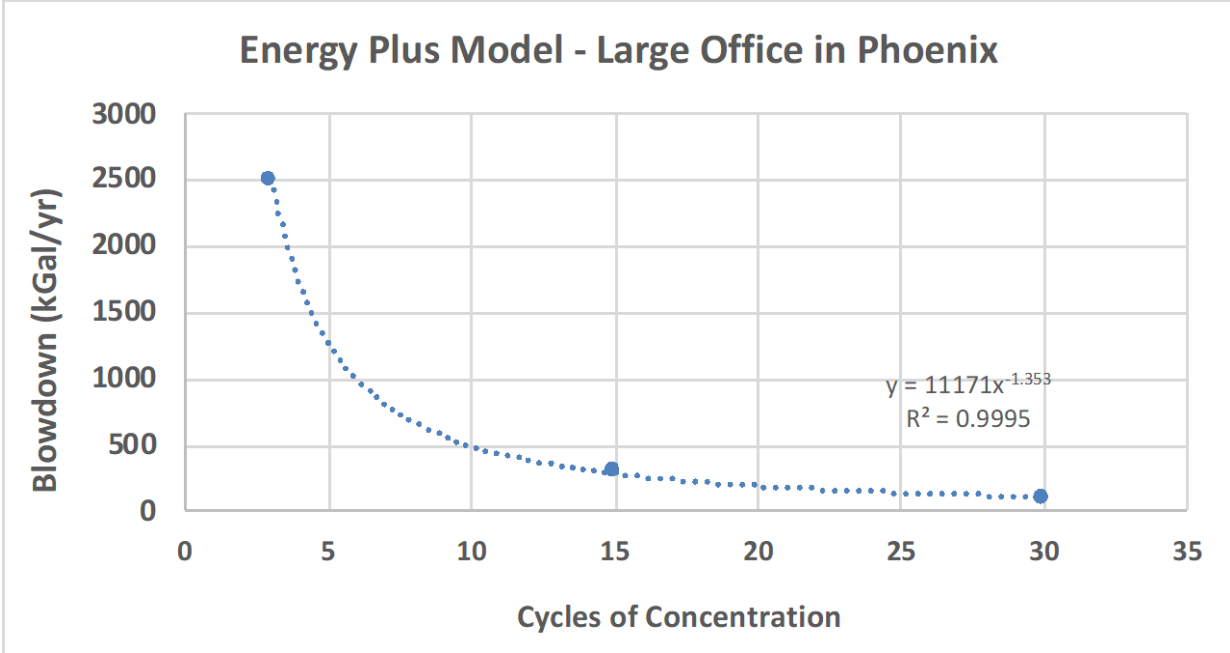
Corrosion

Bad: Corrosion, sites for biological growth
Good: None
Control: Corrosion inhibitors, balanced chemistry

Challenging to maintain balanced water chemistry

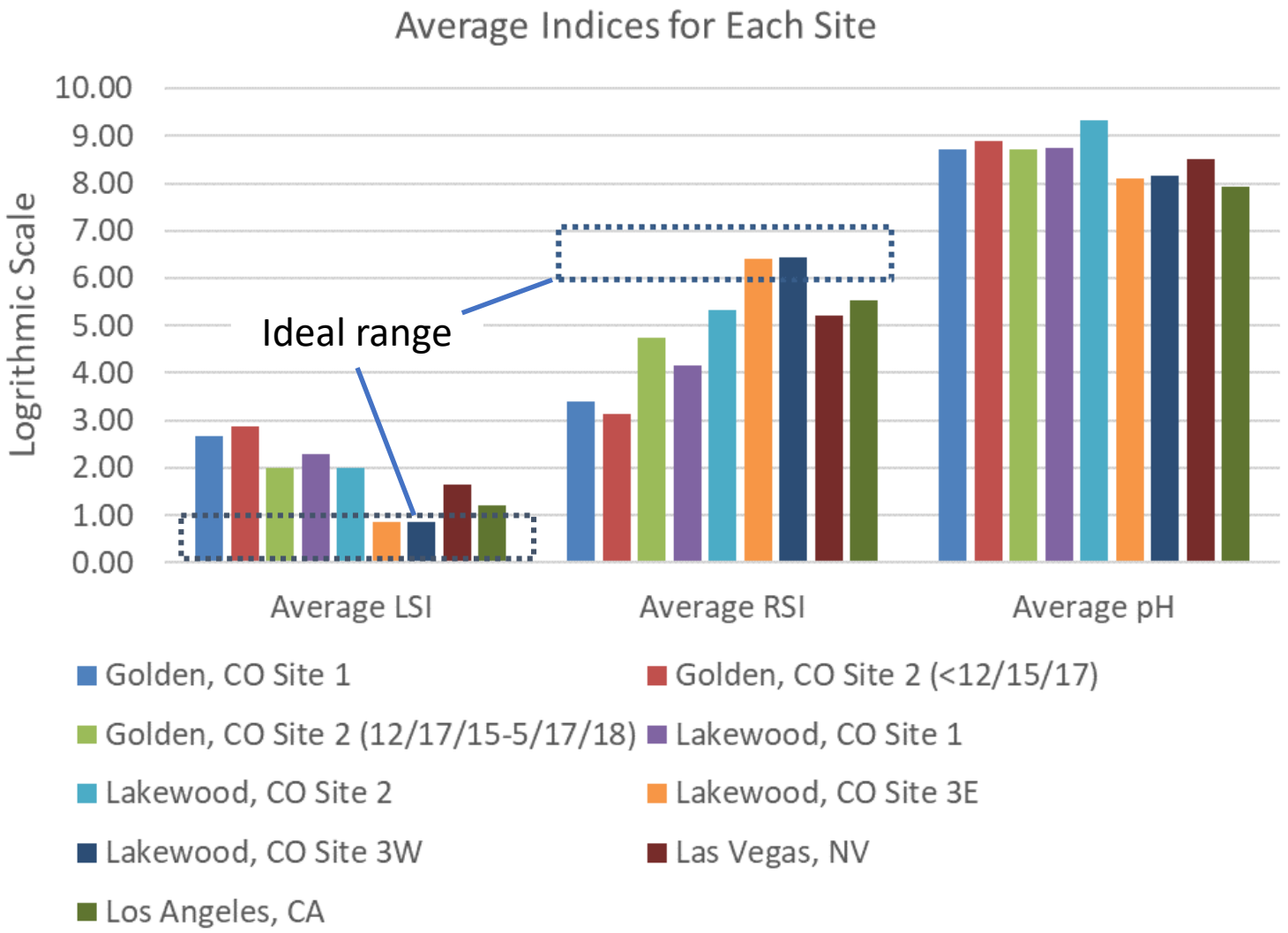
Cooling Tower Cycles of Concentration

- Cycle of Concentration (CoC) – Ratio of concentration in dissolved solids blowdown vs makeup water
- Typical CoC – 2.5 to 7
- At a CoC of 3, around 33% of cooling tower water make up is wasted as blowdown



Realize lions share of savings from CoC of 3 to CoC of 10, savings level off after CoC of 15

Corrosion vs. Scale



- Analyzed 2-15 years of data from 8 CTs
- Most CTs maintained in a moderate to high scale condition
- Ryznar and Langelier Saturation indices predict the balance between scale and corrosion potentials

Genetic Biological Sampling

- Tested 9 towers in Denver CO area
- Significant growth in 8 towers
- No negative health concerns
- No Legionella!
- Bio-corrosion bacteria in 7 towers

Unique Bacteria Genus	Sites Containing Genus
Acinetobacter	2
Aeromonas	4
Alishewanella	1
Arthrobacter	2
Bacillus	***4***
Chryseobacgerium	3
Delftia	1
Flavobacterium	***2***
Halomonas	1
Pseudomonas	***7***
Rheinheimera	3
Shewanella	3
Stenotrophomonas	2

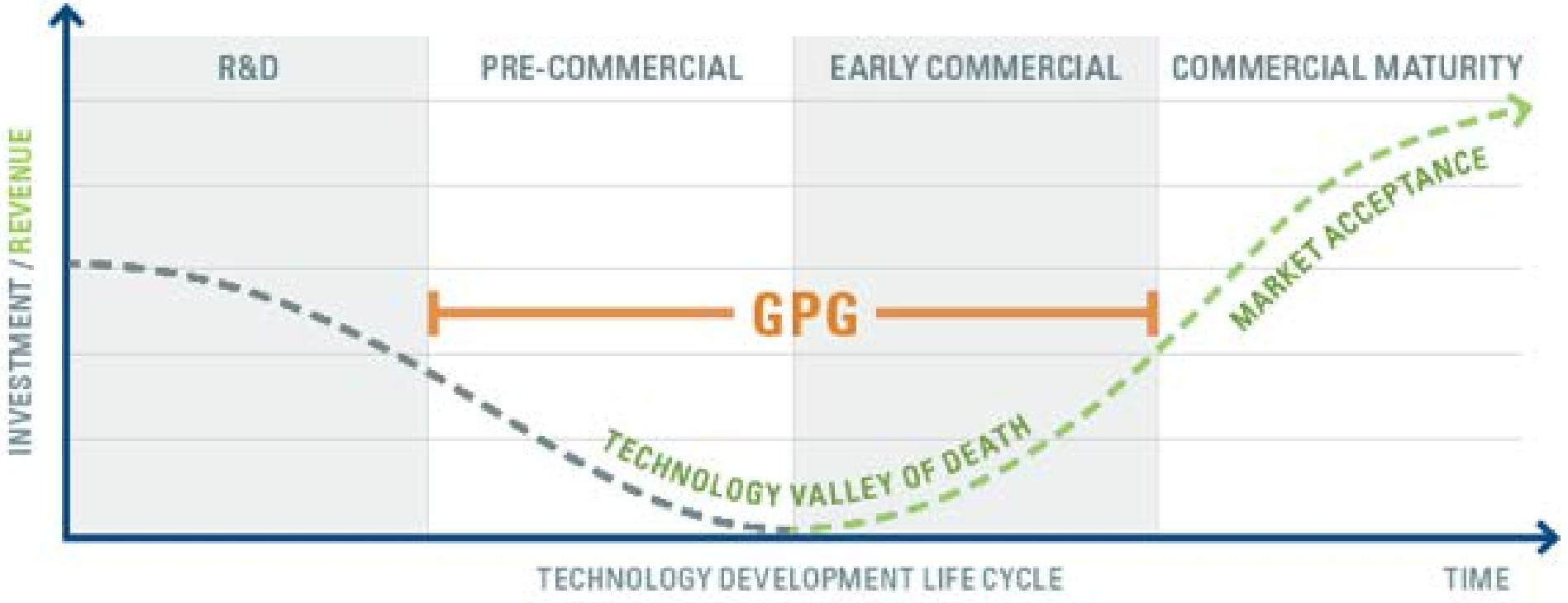
Technology Testing Programs

- Department of Energy: High Impact Technology (HIT) Catalyst
  - 14 technology tests available with several more coming
- General Services Administration: GSA Proving Grounds (GPG)
  - 34 reports, 23 technologies, 14 technologies deployed
- Department of Defense: Environmental Security Technology Certification Program (ESTCP)
  - Many technologies

Emerging Technology Framework

Leading by example

GPG accelerates market acceptance by assessing innovative building technologies in real world environments and deploying those that deliver



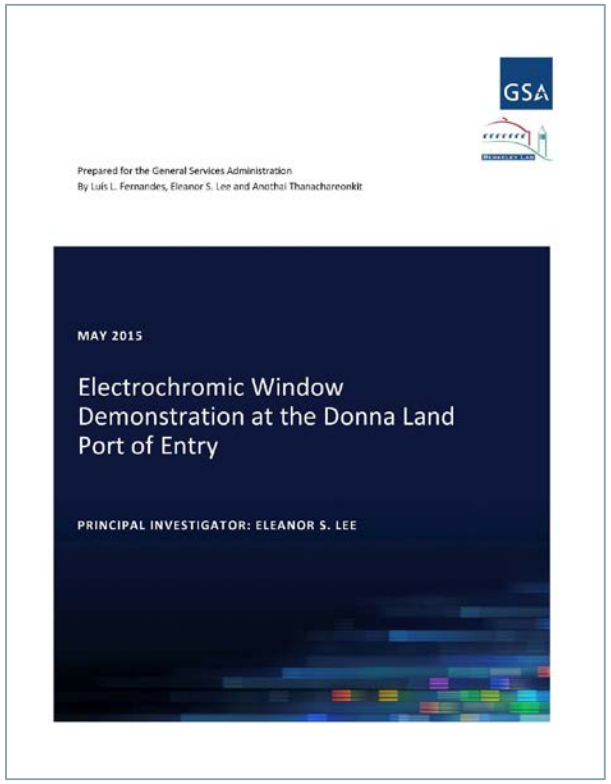
Reference: https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/about-gsa's-proving-ground-gpg

GSA Green Proving Ground Objectives

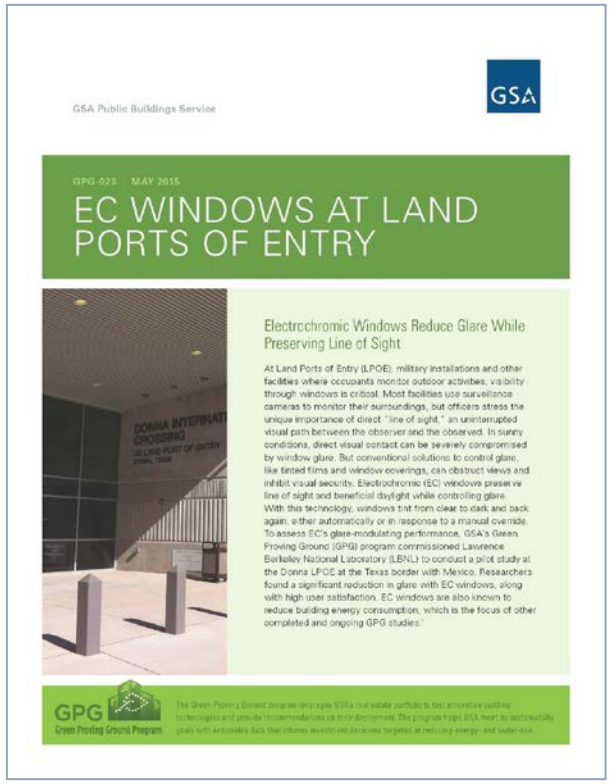
- Identify promising technologies at the edge of commercialization
- Pilot technology installations within GSA's real estate portfolio
- Partner with Department of Energy national laboratories to objectively evaluate real-world performance
- Recommend technologies with broad deployment potential for GSA

Reference: https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/about-gsa's-proving-ground-gpg

Communicating M&V Outcomes from GSA Test Beds



Technical report



4-page Findings

Infographic

Webinar Series

Reference: https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/about-gsa's-proving-ground-gpg

Technologies Tested by GPG with Published Results

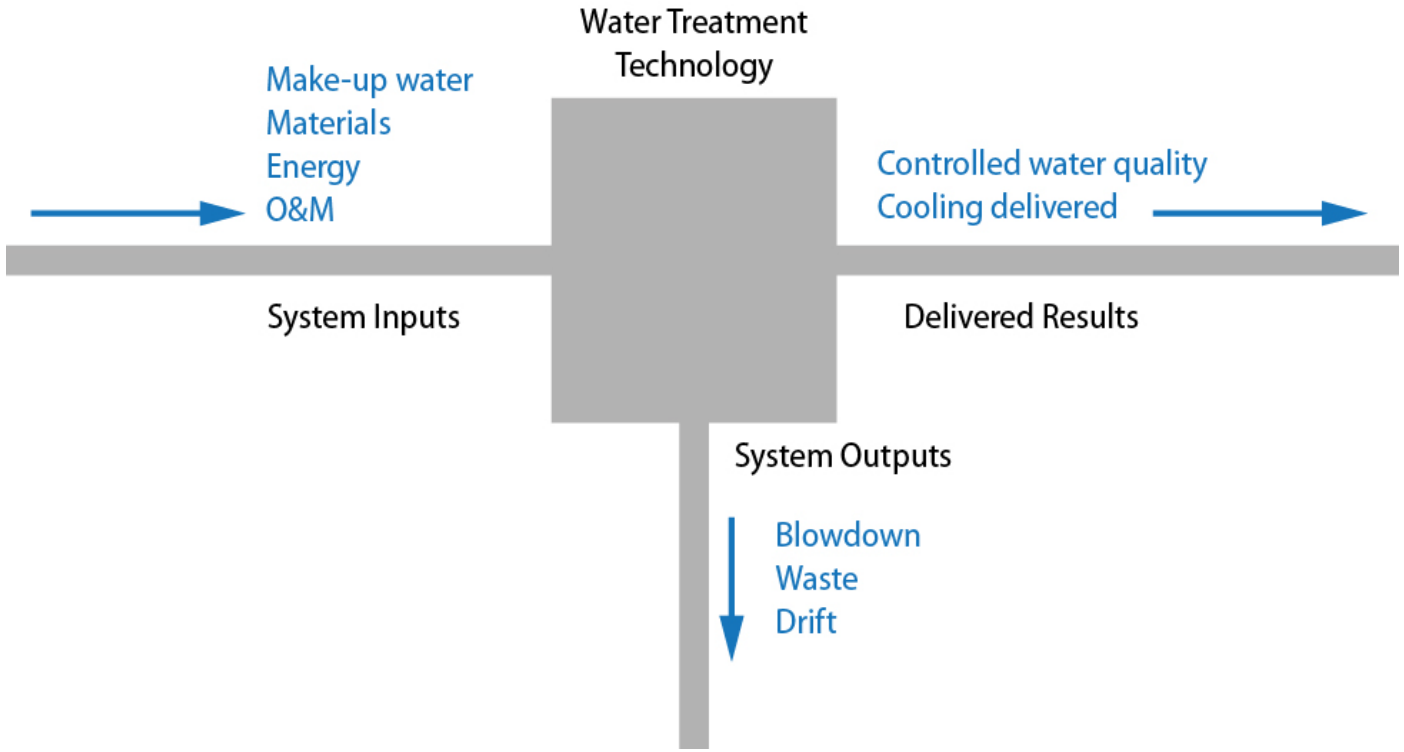
Building Envelope	HVAC	Lighting	Energy Management	Water	On-Site Renewables
High-R Window Panel Retrofits	Condensing Boilers	Occupant Responsive Lighting	Wireless Sensor Networks	Weather Station for Irrigation Control	Photovoltaics
Thermochromic & Electrochromic Windows	Variable Refrigerant Flow	Integrated Daylighting Systems	Advanced Power Strips	Wireless Soil Moisture Sensors for Irrigation Control	PV Guidance
Vacuum Insulated Panels for Roofing	Variable-Speed Maglev Chiller	Wireless Advanced Lighting Controls	Control Optimization System for Chiller Plants	Non-Chemical Prevention of Hard Water Scale	Photovoltaic-Thermal System
Solar Control Films	Synchronous & Cogged Fan Belts	LED Fixtures with Integrated Controls	Socially Driven HVAC Optimization		Wood-Pellet-Fired Biomass Boiler
Electrochromic (EC) Windows for LPOEs	Multi-staged Indirect Evaporative Cooler	LED Downlight Lamps for CFL Fixtures			Honeycomb Solar Thermal Collector
EC Windows with Dynamic Controls for General Office Space	Variable-speed Direct-drive Screw Chiller	Linear LED Lighting Retrofits			
Low-e Window Films	Wireless Pneumatic Thermostats				
	Smart Ceiling Fans				

Broad Deployment Potential for GSA

General AWT M&V Framework

Typical M&V Points

- Condenser water supply and return temperatures (°F)
- Condenser water pump status (ON/OFF)
- Cooling tower fan status (ON/OFF)
- Chiller water supply and return temperatures (°F)
- Chiller status (ON/OFF)
- Outdoor air temperature (°F) and humidity (%)
- Cooling Tower Make Up Water meter (Gal)
- Blowdown Water Meter (Gal)
- Chiller Plant Electrical Meter (kWh)



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

Primary Objective: Measure cooling tower water savings measured in gal/ton-hr

GSA Required Cooling Tower Water Quality

- Water quality was tracked on monthly basis to ensure compliance with GSA Acceptable Ranges

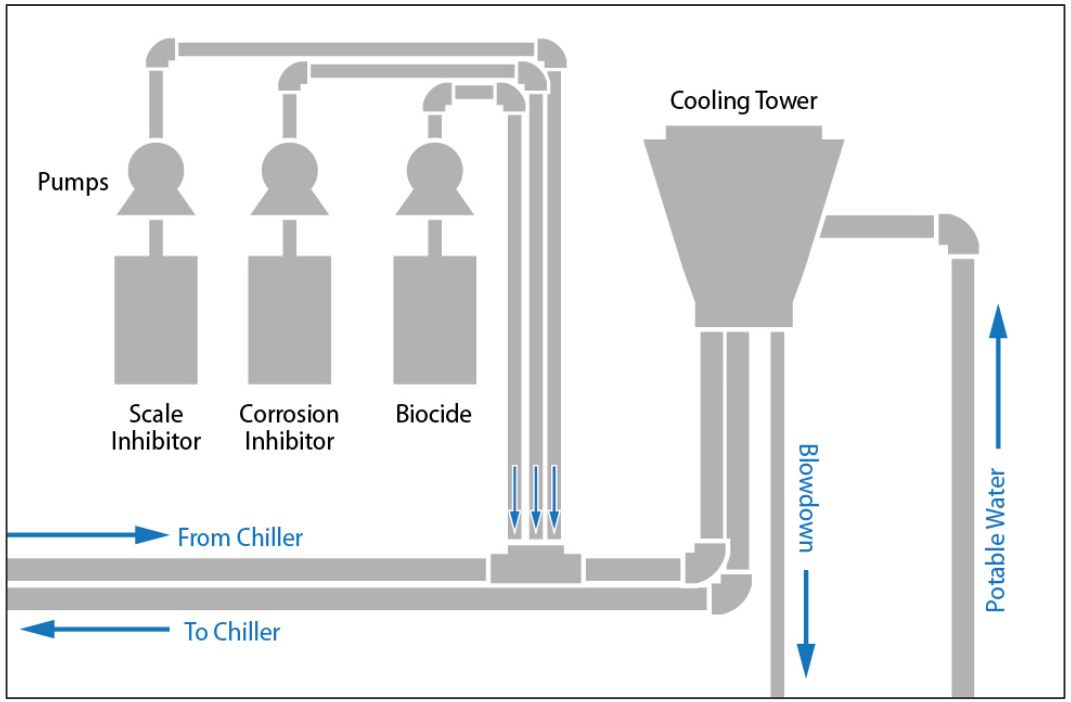
- Additional biological testing was conducted by NREL

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

AWT #1 Technology Description

Terlyn Water Treatment

- Uses a very strong scale inhibitor, new PLC controller, side stream crushed glass media filter
- Controller set 13-18 CoC's based on TDS
- Filter is backwashed for 30 seconds once a day, using 300 gallons/day



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

Manufacturer Reference: http://www.terlyn.com

AWT #1 Facility Description

Building Location

- Denver Federal Center
- Building 67

Building Facts

- 342,722 ft^2 Office building
- 1,200 occupants

Cooling System

- (1) 900-ton chiller, (1) 450-ton chiller
- (2) 600-ton cooling towers
- (1) flat plat heat-exchanger

AWT #1 Water Savings and Water Quality

Water Savings

- Measured CoC ranged from 13-18
- Measured 94% reduction in blowdown

Water Quality

- Realized significant reduction in scaling,
  - Increased run time of tower free cooling, 6 °F reduction in set point
- Observational improvements in water quality
- Conductivity (microsiemens): Control Range <2,400; maintained = 2,540 - 7,000 (5% - 290% outside range)

AWT #1 Economics

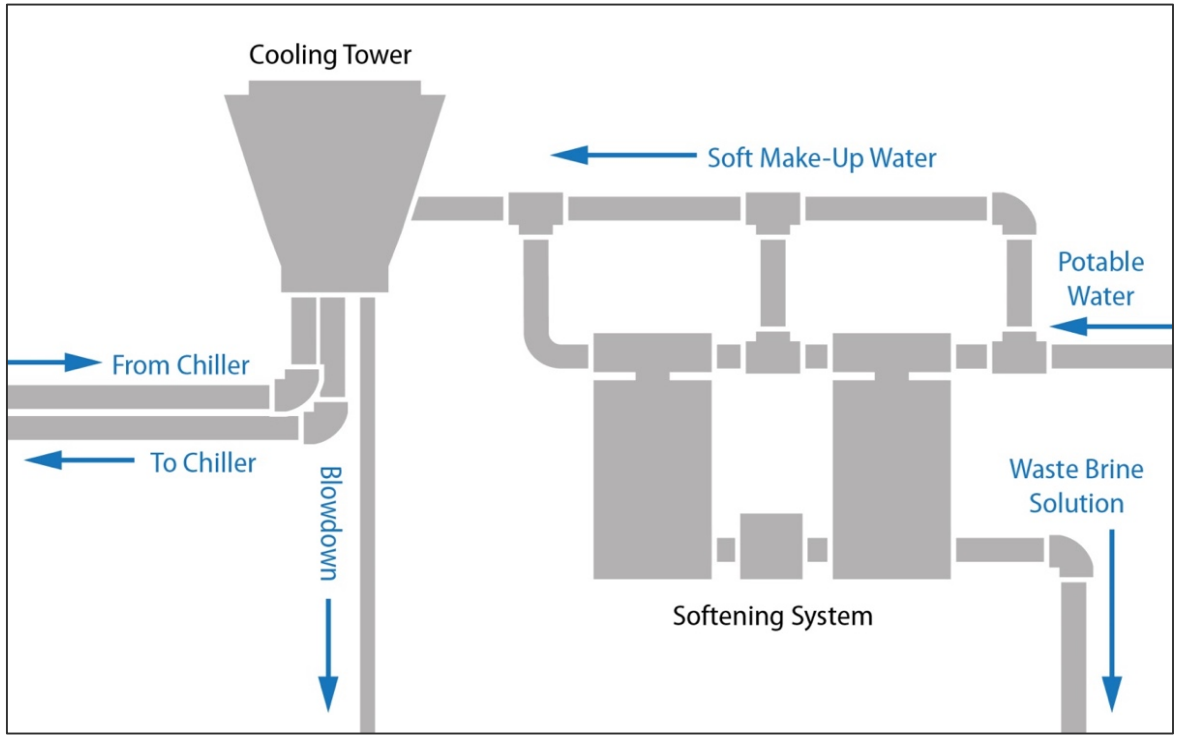
- Installed costs higher than normal due to Fed Gov. added factors, and side stream filtration
- O&M costs increased due to increased scaling chemical costs and side stream filtration O&M
- Local rebates would have offset ~50% of installed cost if Fed Center was not on one master water meter

Economic Parameter	Building 67 (AWT #2) at Local Water Rate $7.14/kGal	Building 67 (AWT #2) at GSA Avg Water Rate $16.76/kGal
Initial Cost ($)	$39,900	$39,900
Cooling Tower Size (tons)	1,200	1,200
Water Savings (Gal/yr.)	824,448	824,448
Water and Sewer Cost Savings ($/yr.)	$5,887	$13,818
Annual Increase in O&M ($/yr.)	$3,300	$3,300
Simple Payback with O&M (yrs.)	15.4	3.8
Savings to Investment Ratio	1.3	5.3

AWT #2 Technology Description

Water Conservation Technology International

- Salt based water softening system to remove hardness
  - Polyethylene regeneration tank and brine tank
- No need for corrosion or scale inhibitor, very little biocide
- Regeneration uses 70 gallons, 2-3 times/week in summer, 1 time/week spring / fall



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

Manufacturer Reference: https://www.water-cti.com/technology.html

AWT #2 Facility Description

Building Location

- Denver Federal Center
- Building 25

Building Facts

- 360,797 square feet ft^2, office / lab building
- 425 occupants

Cooling System

- (2) 500-ton chillers
- (3) 500-ton cooling towers
- (1) flat plate heat-exchange

AWT #2 Regeneration and Brine Tank

AWT #2 Controller

AWT #2 Water Savings and Water Quality

Water Savings

- Measured CoC ranged from 12-80
- Measured 99% reduction in blowdown

Water Quality

- Realized significant reduction in O&M
- Increased run time of tower free cooling
- Observational improvements in water quality
- 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)

Monthly Water Savings

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

AWT #2 Economics

- Installed costs higher than normal due to Fed Gov. added factors, and side stream filtration
- O&M costs decreased due to reduce chemical usage / staff time
- Local rebates would have offset ~50% of installed cost if Fed Center was not on one master water meter

Economic Parameter	Building 25 (AWT #1) at Local Water Rate $7.14/kGal	Building 25 (AWT #1) at GSA Avg Water Rate $16.76/kGal
Initial Cost ($)	$29,600	$29,600
Cooling Tower Size (tons)	1,500	1,500
Water Savings (Gal/yr.)	401,170	401,170
Water and Sewer Cost Savings ($/yr.)	$2,864	$6,724
Annual Increase in O&M ($/yr.)	($2,768)	($2,768)
Simple Payback with O&M (yrs.)	5.3	3.1
Savings to Investment Ratio	3.8	6.5

Additional AWT #1 and #2 Deployments

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	($2,768)	$7,899	3.9
Bldg.41	AWT Technology #1	Jan-17	1,000	$36,976	1,809,921	$12,923	($2,768)	$15,691	2.4
Bldg. 85	AWT Technology #2	Jan-14	500	$8,756	62,450	$446	$1,000	($554)	-15.8
Bldg.56	AWT Technology #2	Jan-15	1000	$28,557	661,160	$4,721	$2,200	$2,521	11.3
Bldg. 810	AWT Technology #2	Jun-14	2 x 500	$31,047	1,131,450	$8,079	$3,300	$4,779	6.5
Bldg.810 USDA	AWT Technology #2	Mar-16	3 x 500	$31,047	1,048,000	$7,483	$3,300	$4,183	7.4

AWT #3 Technology Description

Silverbullet

- Uses a combination of ozone (O_3), hydrogen peroxide (H_2O_2), and/or UV lights to generate highly reactive hydroxyl (OH•) and oxygen free radicals
- Air tube is ran into cooling tower basin and pumps AOP treated air into cooling tower basin
- Elimination of scale inhibitor, corrosion inhibitor, potential elimination of biocide

Silver Bullet Interior Cabinet

Manufacturer Reference: http://www.silverbulletcorp.com/commercial-cooling/

AWT #3 Facility Description

Building Location

- Denver Federal Center
- Building 95

Building Facts

- 163,206 ft^2, two-story
- Office / laboratory building

Cooling System

- (2) 250-ton water-cooled centrifugal chillers
- (2) induced draft cooling tower

Silver Bullet Interior Cabinet

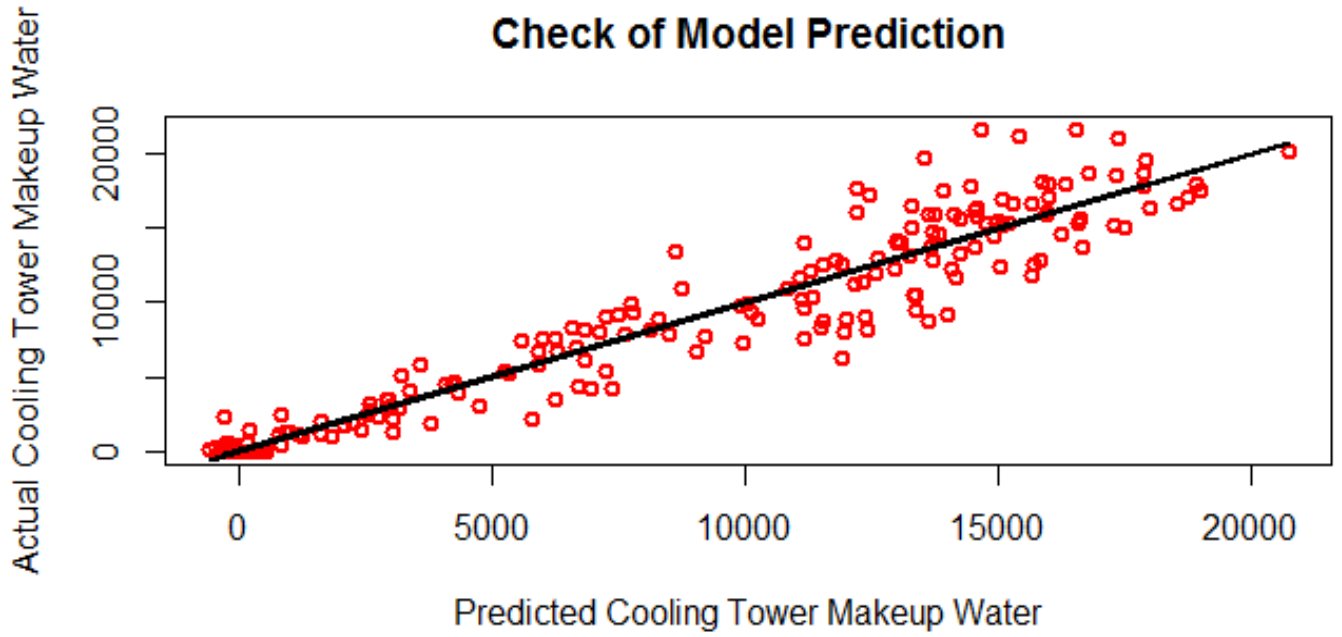
AWT #3 Performance Objectives

Quantitative Objectives	Success Criteria	Metrics & Data	M&V Results
Water Savings	>10% reduction in cooling tower water makeup (gal/ton-hr)	- Cooling tower makeup water - Chiller plant energy usage - Outside air conditions	Met: Annual water savings 22.7% to 29.7%
Reduction in Chemical Costs	>90% reduction in annual chemical costs	-Pre- and post- annual chemical costs	Met: Elimination of all chemicals other than biocides.
Water Chemistry	Meets or exceeds GSA cooling tower water chemistry requirements	- Pre- and post- water chemistry reports	Met: GSA water chemistry requirements
Cost Effectiveness	Simple payback; Savings to Investment ratio (SIR)	- Payback < 10 years; SIR> 1.	Met: SPP of 3.4 yrs.; SIR of 6
Qualitative Objectives	Success Criteria	Metrics & Data	M&V Results
Ease of Installation	Less than 2-day installation time	Labor hours to install technology	Met: Less than 1 day to install

AWT Regression Modeling

Baseline Daily Cooling Tower Makeup Water Regression

$$Cooling\ Tower\ Makeup\ Water = c_0 + (c_1 \cdot WKD\_WKND) + (c_2 \cdot CEnergy) + (c_3 \cdot CDewpoint) + (c_4 \cdot CEnergy^2) + (c_5 \cdot CEnergy \cdot CDewpoint)$$



AWT #3 Water Savings and Water Quality

Water Savings

- Measured CoC ranged from 5.1-14.4
- Measured 26.3% reduction in makeup water (blowdown not measured)

Water Quality

- Realized reduction in chiller condenser tube fouling
- Elimination of scaling / corrosion inhibitor, uses small amount of biocide
- ORP of 194, GSA range > 300

Month	2017 Cooling Tower Makeup (Gal/Mon)	2014 Weather Normalized Baseline Water (Gal/Mon.)
1-Jan	928	0
1-Feb	15,042	18,301
1-Mar	46,706	54,556
1-Apr	52,254	66,350
1-May	54,904	107,543
1-Jun	282,322	375,419
1-Jul	398,206	506,684
1-Aug	298,039	445,116
1-Sep	190,375	275,749
1-Oct	61,146	108,623
1-Nov	35,554	44,930
1-Dec	40,005	0
Totals	***1,475,482***	***2,003,273***

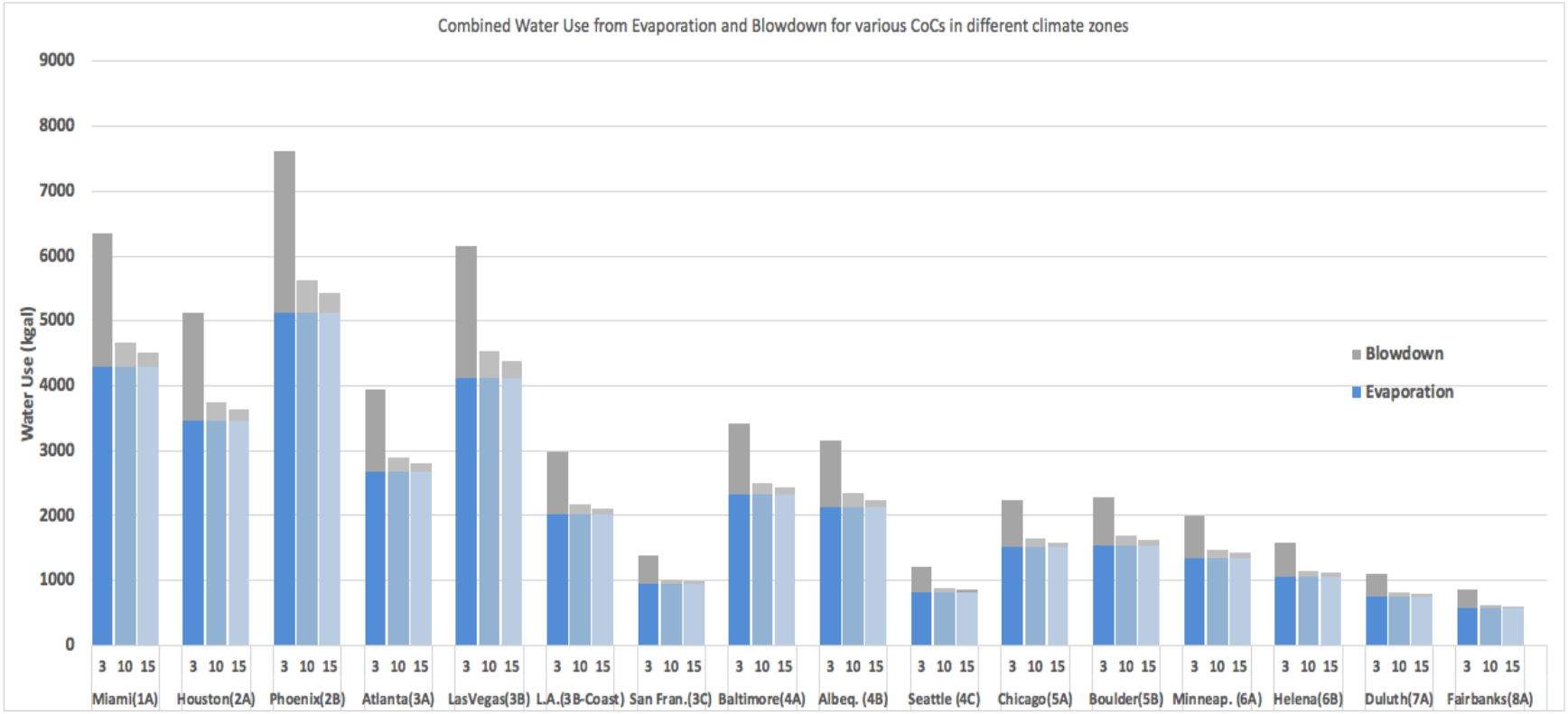
AWT #3 Economics

- Installed costs higher than normal due to Fed Gov. added factors, and side stream filtration
- O&M costs decreased due to reduce chemical usage / staff time
- Local rebates would have offset ~50% of installed cost if Fed Center was not on one master water meter

	Baseline (Before)	Tested Technology (After)[1]	Difference w/ Local Sewer+Water Rate ($7.14/kGal)	Difference w/ GSA Avg Water Rate $16.76/kGal
Installation[3]	N/A	$21,125	$21,125	$21,125
Annual Maintenance	$5,855/yr.	$3,333/yr.	$2,522/yr.	$2,522/yr.
Annual Water Consumption (Gallons/yr.)	2,003,273	1,475,482	527,791	527,791
Annual Water Costs ($/yr.)	$14,303	$10,535	$3,768	$8,846
Simple Payback	yrs		3.4	1.9
Savings-to-Investment Ratio	Integer value between 0 and 100		6.0	10.8

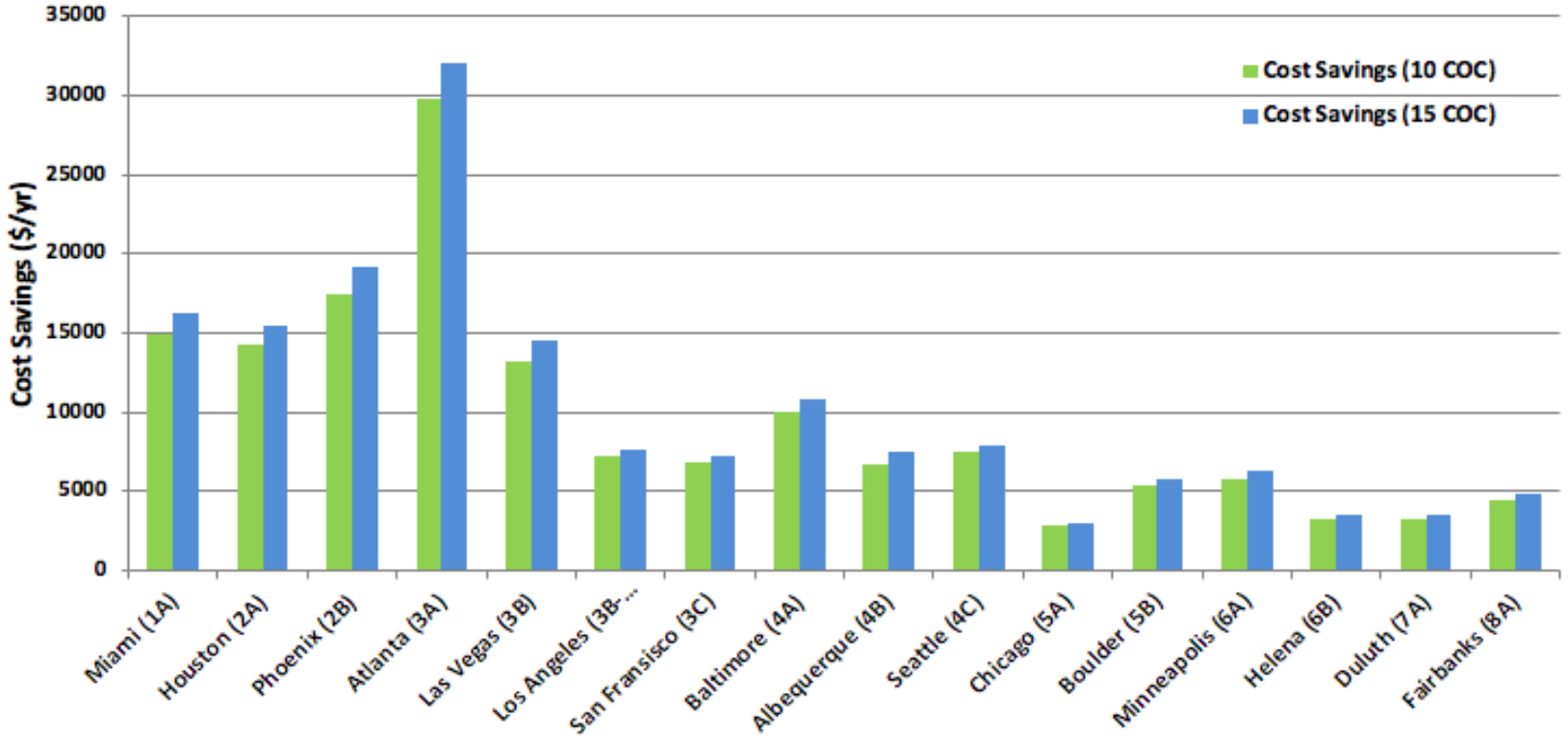
AWT #3 Energy Modeling

- Energy Plus Commercial Building Reference Model
- Post 1980 construction, Large office building, 498,588 ft^2
- Modeled 3 CoC baseline, 10 CoC, 15 CoC



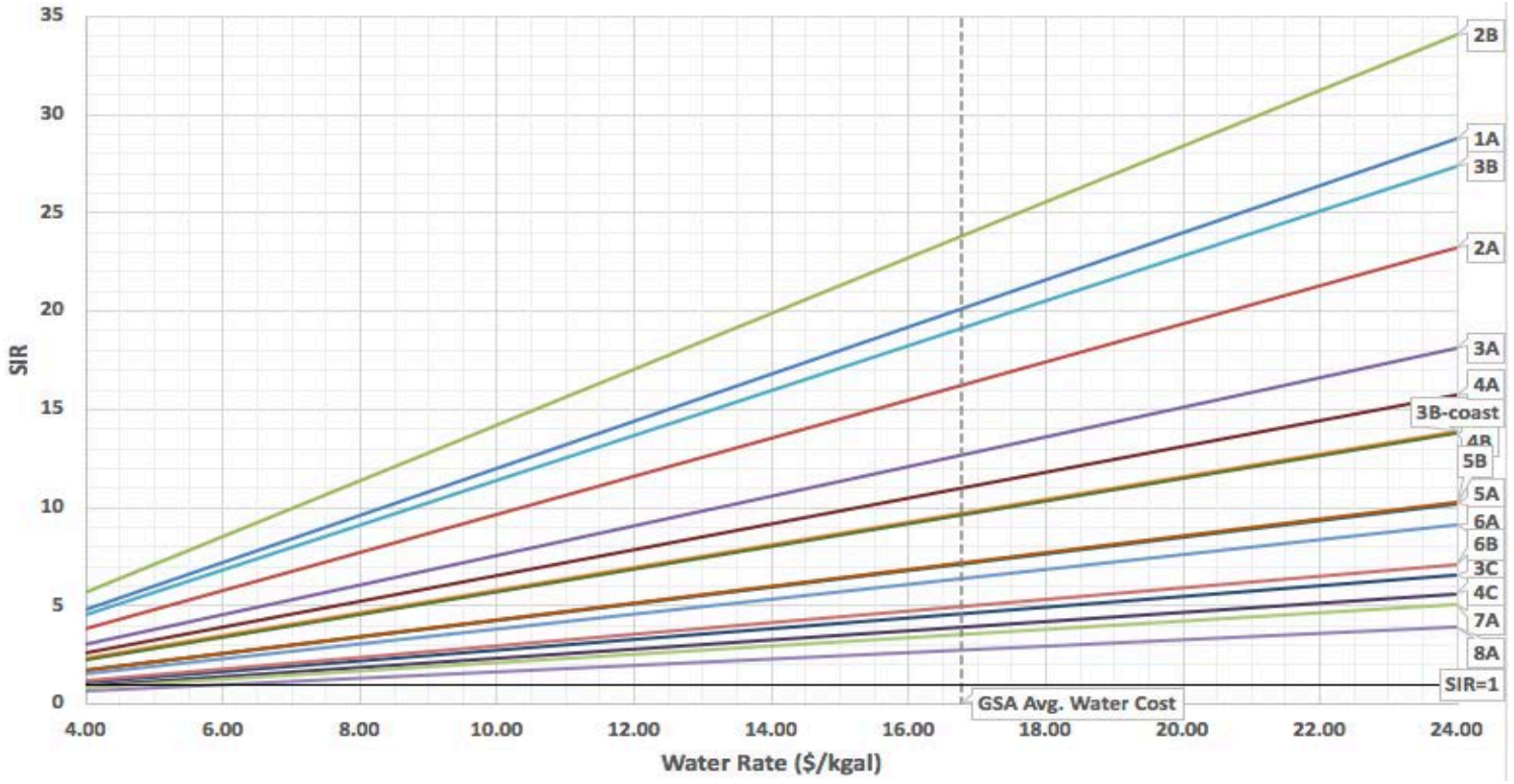
AWT #3 Energy Modeling

- Modeled water rates for each city
- Water rates vary significantly by city, cities with highest rates had highest savings



AWT #3 Energy Modeling

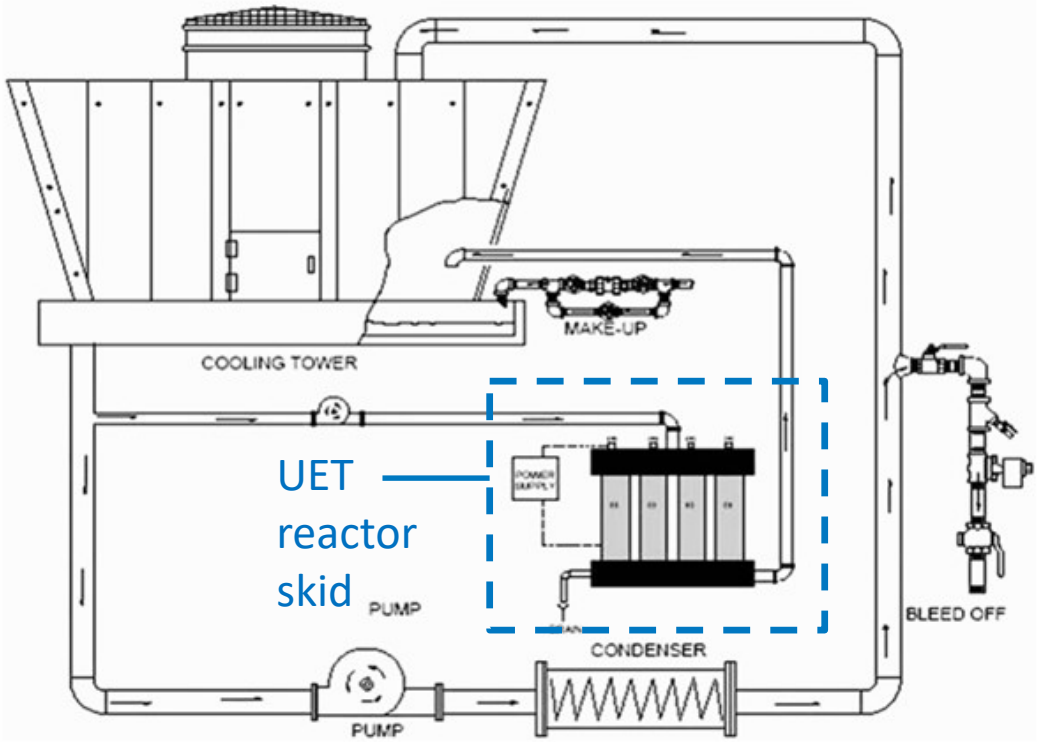
- Calculated SIR per location as a function of water rate (SIR>1)
- Used for high cost case of $25,000
- Does not include O&M cost savings



AWT#4 Technology Description

Dynamic Water Technologies & Universal Environmental Technologies

- Chemical free electrolysis



Scale control
Electro-catalytic process accelerates scale formation in the reactors
Scale is easily removed from reactors

Corrosion control
Maintains balanced pH and mineral content to minimize corrosion

Biological Growth control
Forms HOCl and Cl_2 from the chlorides in the water for biocides

Expected Performance

- Blowdown water (and sewer) savings of 25-95% (CoC 30 or more)
- Elimination of chemicals
- Energy savings – depending on the amount of scale in the baseline case

AWT #4 Facility Description

Test site #1

- 240,000 ft^2 federal office building, Savannah GA
- 2 250-ton chillers and 2 cooling towers
- 1 UET reactor skid
- Test period: June – October 2017

Test site #2

- 530,000 ft^2 office building, Los Angeles, CA
- 2 800-ton and 2-500 ton chillers and 4 cooling towers
- 2 UET reactor skids
- Test period: June – October 2018 (ongoing)

AWT #4 Water Savings and Water Quality

Water Savings

- Measured CoC > 30
- Measured 98% reduction in blowdown
- > 1 million gal saved annually

Water Quality

- No measured reduction in scaling
- Noticeable reduction in biological growth and cleaning requirements
- Observational improvements in water quality
- DWT maintains a high conductivity setting (6,000)

Scale removal from reactor cores

AWT #4 Test Site #1 Results

- Installed costs higher than normal due to tech demo costs and Fed Gov. added factors
- Revised cost used in analysis
- O&M costs increased slightly with annual service contract

Economic Parameter	Local Water Rate $6.64/kGal	GSA Avg Water Rate $16.76/kGal
Initial Cost ($)	$59,369	$59,369
Cooling Tower Size (tons)	500	500
Water Savings (Gal/yr.)	1,003,300	1,003,300
Water and Sewer Cost Savings ($/yr.)	$6,662	$16,816
Annual Increase in O&M ($/yr.)	($720)	($720)
Simple Payback with O&M (yrs.)	10	3.7
Savings to Investment Ratio	2.0	5.4

AWT#4 Test Site #2 Results

- Baseline period complete
- DWT-UET system start up on 7/9/2018
- Expected testing through October 2018

Questions

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Thank You