Cooling Technologies Project Summary

October 2022

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1.0 Project Background

Cooling towers use a significant amount of water by design. Cooling towers recirculate water to remove heat from air conditioning equipment, chillers, and process equipment in buildings. The heat is removed by evaporation of water.

Water has long been a popular choice for cooling because it has a much higher capacity to absorb and transport and therefore remove heat than air, gasses, or other liquids. Water absorbs heat, then the heat is released as warm, moist air that evaporates and is discharged into the air outside of a building. Cooling towers can be responsible for up to X% of a building or site's total potable water usage. Therefore, improved management of cooling towers and/or adoption of alternative technologies represent a significant opportunity to save water.

The cost of water is rising. In recent years, the cost of water has increased faster than other costs and the general rate of inflation. Population growth continues to put pressures on water resources, especially in increasingly dense urban areas where cooling towers are more likely to be utilized. Climate change will negatively impact the predictability and reliability of water supplies. Climate change will further stress water resources as rising temperatures increase demands for water, especially for cooling. Concurrently, hotter temperatures and lower summer rainfall will also increase demands for water in other sectors, like residential and agriculture. Water efficiency strategies that reduce water use are critical to adapt to and mitigate risks from climate change. Significant amounts of energy are required to pump, transport, treat and deliver water. By reducing water use, these strategies can also reduce energy use, reduce the release of harmful greenhouse gases, and thus serve as an important strategy to combat climate change.

Many recognize the opportunity to reduce water demands by targeting cooling towers. Both the US Department of Energy (DOE) and the US Environmental Protection Agency (EPA) cite cooling tower management as a best practice for buildings.[1] The US Green Building Council's rating system, Leadership in Energy & Environmental Design (LEED), awards specific points for cooling tower management practices that conserve water.[2]

Water use in cooling systems can vary significantly by the type and size of the building as well as how the system is managed and maintained. For example, a X sf office building with a Y ton cooling tower, can use between XX gals and YY gals per year depending on basic water management practices.[3]

Water utilities are responding to water scarcity and resiliency challenges by offering programs and services to reduce end user water demands, among other strategies like addressing distribution system water loss. While some water utilities across North America offer financial incentives and/or technical assistance to customers who reduce water demands by increasing the water efficiency of cooling systems, most water utilities have not. Further, where programs do exist, they have not realized the anticipated savings. This project was initiated to help identify the barriers to greater customer participation and to

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[1] DOE: https://www.energy.gov/eere/femp/best-management-practice-10-cooling-tower-management,
EPA: https://www.epa.gov/greeningepa/water-management-plans-and-best-practices-epa

[2] LEED: https://www.usgbc.org/credits/data-centers-existing-buildings/v4-draft/wec3

[3] https://www.energy.gov/eere/femp/estimating-methods-determining-end-use-water-consumption

create resources to foster successful utility programs and drive market adoption of better practices and technologies.

AWE partnered with DOE’s Pacific Northwest National Laboratory (PNNL) to conduct a comprehensive study to address the needs identified by AWE members.

The five main objectives of this multi-year study:

1. Develop best practices for identifying traditional water-cooled facilities in urban areas;
2. Develop best practices for estimating consumptive and non-consumptive water demands for cooling;
3. Determine the conservation potential for improvements to traditional cooling technologies;
4. Determine the water savings potential of alternative cooling technologies; and
5. Develop practical guides, incorporating study results, to increase the effectiveness of cooling water use efficiency incentive and outreach programs.

The tools and guides developed through this study allow utilities to estimate the cooling demand and approximate number of cooling towers in their service area.

The tools estimate both the consumptive and non-consumptive water use from cooling towers and help assess the water efficiency opportunities from traditional improvements as well as possible savings from adoption of alternative cooling technologies.

Additional benefits from this project include development of resources that will help water utilities develop an inventory of the cooling towers in their service area, as well as developing strategies for effective incentive and outreach programs.

The tables on the following pages provide an overview of each task and the associated tools, guides, and/or other resources developed to meet the objectives.

Task 1: Develop Best Practices for Identifying Water-cooled Facilities in Urban Areas

✓ Deliverable

Cooling Tower Estimating Model (CTEM)

- Initial version of CTEM (v 1.0) reviewed by the Project Advisory Committee (PAC) members January 2020
- CTEM Version 3.0 with incorporated Water Quality Helper (latest version as of this report publication)
- Guide for Identifying Cooling Tower and Estimating Water Use included with v 1.0

Features

- CTEM estimates:
  - Number of large scale and commercial facilities with cooling towers in a utility's service area based upon six simple inputs
  - Number of cooling towers in total at those facilities
  - Potential water savings from improving water efficiency
- *Added value* - the tool includes a module to initiate a cooling tower inventory including:
  - Auto populated list of business names and addresses of large facilities likely to have cooling towers
  - Module for users to input commercial property data and the model will infer whether that property is likely to have a cooling tower
  - Data is exportable for creating of master cooling tower inventory

Application of Tool for Task 1

- CTEM can be utilized by utilities to determine whether there are an adequate number of potential cooling tower sites to consider a water efficiency program. This tool also estimates the potential water savings from improving water efficiency.
- Once a program is decided upon, the tool can be used to begin building and refining the utility's cooling tower inventory

Task 2: Develop Best Practices for Estimating Consumptive and Non-Consumptive Water Demands for Cooling

✓ Deliverable

Cooling Tower Estimating Model (CTEM)

- Initial version of CTEM (v 1.0) delivered for the Project Advisory Committee (PAC) members January 2020
- Version 3.0 with incorporated Water Quality Helper delivered March 2022
- Guide for Identifying Cooling Tower and Estimating Water Use included with v 1.0

Features

- CTEM estimates:
    - Total cooling capacity from cooling towers in the utility's service area
    - Total Annual cooling load from cooling towers in the utility's service area
    - Total consumptive (evaporative) water use from cooling towers in the utility's service area
    - Total Non-consumptive (blow down) water use from cooling towers in the utility's service area
- CTEM estimates high level water savings potential from increased cooling tower water efficiency in the utility's service area

Application of Tool for Task 2

- CTEM identifies the universe of savings potential for planning purposes
- CTEM gives utilities the ability to understand the makeup of their cooling tower market (i.e., a few large-scale sites or many commercial sites) to design an appropriate program format

Task 3: Determine the Conservation Potential for Improvements to Existing Cooling Tower Systems

✓ Deliverable

Water Quality Helper Module in CTEM

Delivered April 2021

Features

- Water Quality Helper identifies limiting factors in improving water efficiency based upon local water quality
- Knowing the water quality parameters, the Water Quality Helper tool points the user to solutions to improve efficiency [Cycles of Concentration (COC)]
- Refines water savings potential estimate

Application of Tools for Task 3

- Provides the utility a more in-depth understanding the water savings potential by general area as well specific locations.
- With this understanding of water quality factors, utilities can provide the most effective water efficiency solutions for those conditions.
- Utilities can also rate the priority level of concern for each water quality constituent and provide customers with a recommended course of actions to improve water efficiency.

Task 4: Determine Water Savings Potential of Implementing Alternative Cooling Technologies

✓ Deliverable

Alternative Technologies Report

Comparing Alternatives Tool (CAT)

Features

- Alternative Technologies Report includes the list of 21 potential alternative technologies considered for review that could replace cooling towers
- Alternative Technologies Report provides in-depth information on the four selected technologies for assessment (must be commercially available, verified water saving performance, and published cost). The four technologies assessed were:
    - Thermal Membrane Distillation (TMD)
    - Hygroscopic Cooler (HSC) – Hybrid System
    - Adiabatic Cooler (AC)
    - Thermal Membrane Distillation (TMD)
- The Comparing Alternatives Tool (CAT) assesses the water savings potential of these technologies as they are adopted over time.

Application of Tools for Task 4

- In-depth information on the four most viable, commercially available alternative technologies and the water savings at various levels of savings for the utility's building population
- Provides utilities with the ability to assess the water savings potential of different technologies over time based upon various adoption rates

Task 5: Develop Practical Guides, Outreach Materials, and Utility Incentive Programs

✓ **Deliverable**

How-to Guide

Excel-based Cooling Tower Audit Form + Return on Investment Calculator

Features

- Cooling tower basics
- Understanding cooling tower water treatment and maintenance and the key industry players
- Understanding types of cooling tower water efficiency upgrades
- AWE resources for cooling tower programs (CTEM, Water Quality Helper, Alternative Technologies Report, Market Penetration Model)
- Profiles properties with the best opportunity for cooling tower upgrades
- Identifies decision makers for building cooling tower upgrades
- Describes where to find these decision makers and how to best make contact
- Explains how to support decision makers in evaluating opportunities and making informed decisions
- Overviews various incentive structures and program formats to best incentivize the industry and the customer
- List of current cooling tower programs, their format, and utility representative

Application of Tools for Task 5

- Utility staff can use guide as a resource to determine viability of a program for their service area and understand how-to build a best-in-class program
- For utilities with an existing program, the guide may provide additional resources for improving their program and response level
- Provides a network for utilities to share program experiences and information

The following sections report provide detailed information on each of the project deliverables.

2.0 Cooling Tower Estimating Model

Section 2.0 provides an overview of the Cooling Tower Estimating Model and the accompanying guide, *Taking Inventory: A Guide for Identifying Cooling Towers and Estimating Water Use.* This section includes the basic inputs and outputs of CTEM, the associated benefits of the model, and a summary of the guide.

CTEM is a first-of-its-kind Excel-based model that utilizes characteristics of a service area and provides water suppliers with an estimate of the number of cooling tower units and the associated water use. The model also provides a mechanism to identify and record the location of facilities likely to have cooling towers. Notably, the model creates these facility-by-facility inferences based on statistical correlations between building features and their likelihood of having cooling towers obtained from national surveys. The companion guide provides straight-forward instruction on how to use the model, how to identify cooling tower locations and how to initiate a cooling tower inventory.

From a water efficiency perspective, CTEM and a cooling tower inventory serve multiple purposes:

- To understand the total water use and potential savings that result from improving cooling tower operations;
- To build a target list of facilities with cooling towers for potential water use efficiency program outreach; and
- To track participation and estimate water savings.

CTEM, through only a few inputs, provides the capability of estimating:

- Cooling demand in a specific water supplier service area;
- Number of facilities with cooling towers;
- Number of cooling towers located at those facilities; and
- Associated consumptive and non-consumptive water use for those cooling towers.

CTEM uses combinations of physical, empirical, and statistical methods for determining the regional cooling tower use estimates and inferred likelihoods of buildings with cooling towers.

To develop CTEM, PNNL completed a thorough review and assessed publicly available datasets related to cooling towers in North America. This data was used to develop the underlying algorithms utilized in the model. Other information related to locational characteristics that inform cooling tower use, such as weather, population, and commercial building stock, was also utilized in this process.

It was determined that there were two main categories of facilities using cooling towers that must be distinguished: 1) large industrial and institutional facilities and 2) commercial facilities.

Large industrial locations such as power plants, refineries, airports, hospital, universities, and data centers likely feature large cooling towers for production and process cooling requirements.

Commercial buildings typically represent a much larger percentage of locations in high-density urban areas and vary greatly in size, layout, vintage, and function. Unlike large industrial, which use cooling technologies for process and production purposes, commercial buildings primarily use cooling for occupancy comfort. Instead of cooling towers, commercial buildings may use packaged direct expansion units (DX) or air-cooled chillers rather than cooling towers to cool the interior space.

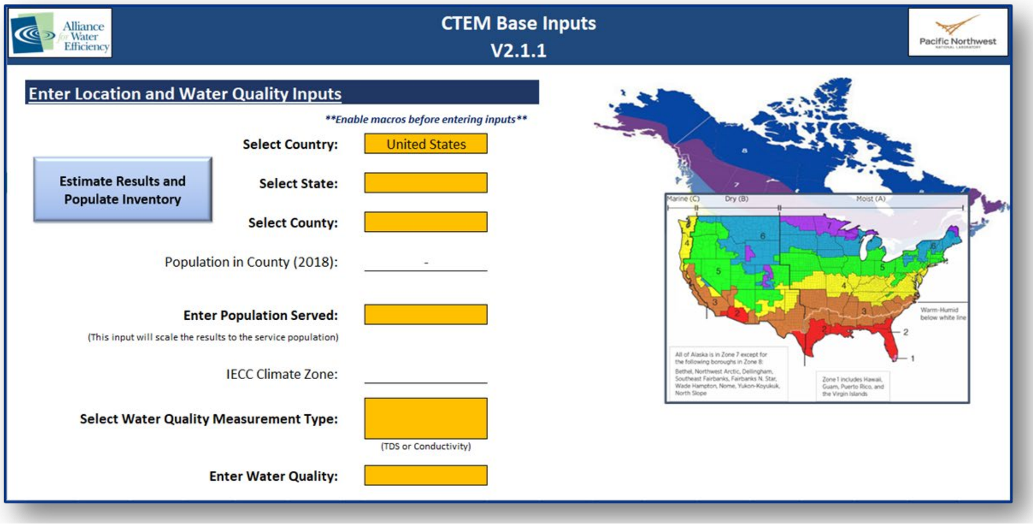
PNNL analyzed several data sources to establish statistical patterns for the types of cooling used in commercial buildings in urban areas. Research revealed statistical correlations that allowed for estimating the number and capacity of cooling towers used in commercial buildings based on census data.

Further, it was found that cooling tower annual usage/load estimates for both large and commercial facilities were well defined by physical models that accounted for the differences in climate and weather between urban areas.

Once statistical and physical methodologies were determined and tested for these facility categories, the Excel-based modeling framework was developed.

The minimum, or base inputs, for the model include (as shown in **Figure 1**):

- Country (United States or Canada)
- State or Province
- County (for U.S. locations)
- Service Population
- Water Quality [measured in total dissolved solids (TDS) or conductivity]



CTEM Base Inputs
V2.1.1

Enter Location and Water Quality Inputs

Enable macros before entering inputs

Select Country: United States

Select State:

Select County:

Population in County (2018): -

Enter Population Served:
(This input will scale the results to the service population)

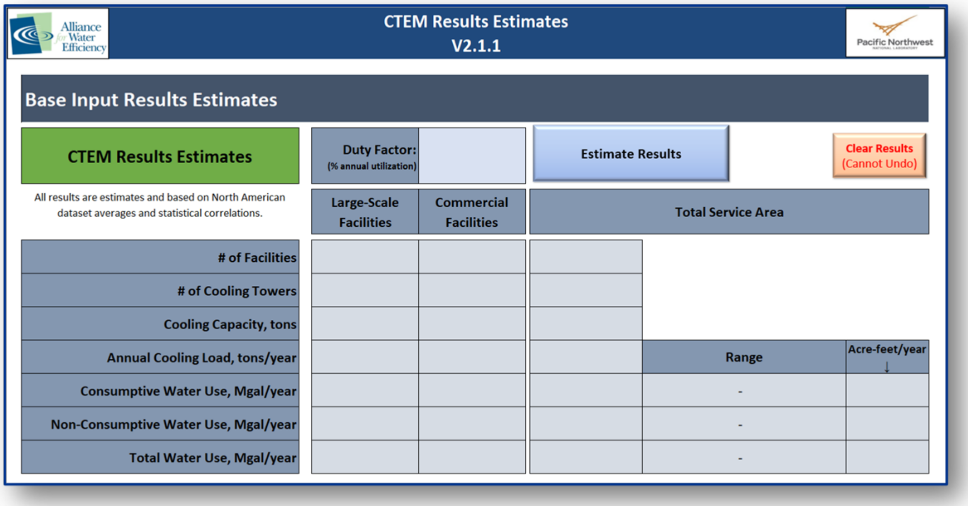
IECC Climate Zone:

Select Water Quality Measurement Type:
(TDS or Conductivity)

Enter Water Quality:

Figure 1. CTEM Base Inputs

From these base inputs, the model estimates the number of water-cooled facilities, number of cooling towers, total cooling capacity, consumptive and non-consumptive water use, and total water use in million gallons per year and acre-feet per year (as shown in **Figure 2**).



CTEM Results Estimates
V2.1.1

Base Input Results Estimates

CTEM Results Estimates

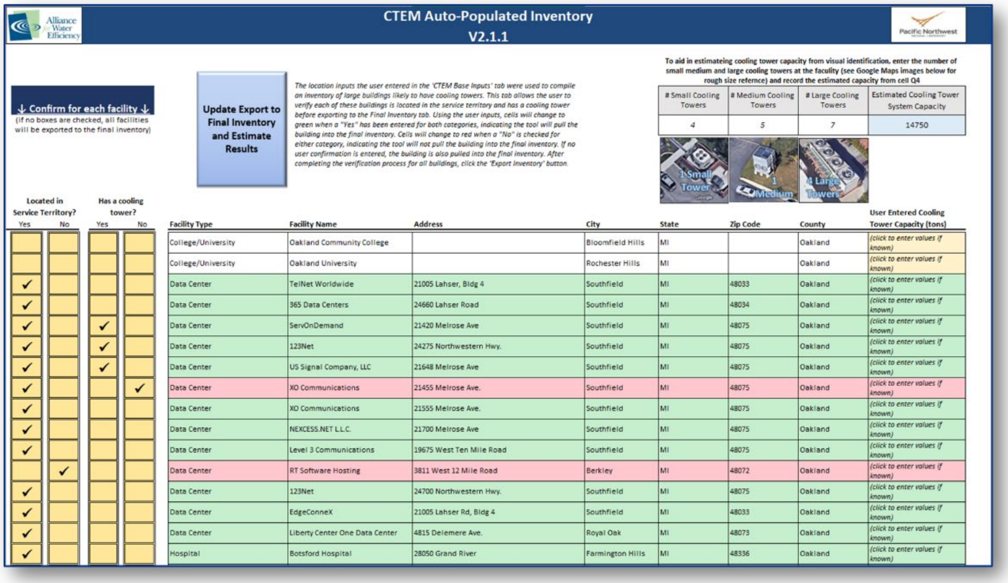
All results are estimates and based on North American dataset averages and statistical correlations.

Duty Factor: (% annual utilization)

	Large-Scale Facilities	Commercial Facilities	Total Service Area	Range	Acre-feet/year ↓
# of Facilities					
# of Cooling Towers					
Cooling Capacity, tons					
Annual Cooling Load, tons/year					
Consumptive Water Use, Mgal/year				-	
Non-Consumptive Water Use, Mgal/year				-	
Total Water Use, Mgal/year				-	

Figure 2. CTEM Base Input Results

Additionally, the base Inputs module generates an auto-populated list of select large facilities likely to have cooling towers in the given service area[4] providing a preliminary auto-generated cooling tower inventory (shown in **Figure 3**).



CTEM Auto-Populated Inventory
V2.1.1

↓ Confirm for each facility ↓
(if no boxes are checked, all facilities will be exported to the final inventory)

The location inputs the user entered in the 'CTEM Base Inputs' tab were used to compile an inventory of large buildings likely to have cooling towers. This tab allows the user to verify each of these buildings is located in the service territory and has a cooling tower before exporting to the Final Inventory tab. Using the user inputs, cells will change to green when a "Yes" has been entered for both categories, indicating the tool will pull the building into the final inventory. Cells will change to red when a "No" is checked for either category, indicating the tool will not pull the building into the final inventory. If no user confirmation is entered, the building is also pulled into the final inventory. After completing the verification process for all buildings, click the 'Export Inventory' button.

To aid in estimateing cooling tower capacity from visual identification, enter the number of small medium and large cooling towers at the faculity (see Google Maps images below for rough size refernce) and record the estimated capacity from cell Q4

# Small Cooling Towers	# Medium Cooling Towers	# Large Cooling Towers	Estimated Cooling Tower System Capacity
4	5	7	14750

Located in Service Territory?		Has a cooling tower?									
Yes	No	Yes	No	Facility Type	Facility Name	Address	City	State	Zip Code	County	User Entered Cooling Tower Capacity (tons)
				College/University	Oakland Community College		Bloomfield Hills	MI		Oakland	(click to enter values if known)
				College/University	Oakland University		Rochester Hills	MI		Oakland	(click to enter values if known)
✓				Data Center	TelNet Worldwide	21005 Lahser, Bldg 4	Southfield	MI	48033	Oakland	(click to enter values if known)
✓				Data Center	365 Data Centers	24660 Lahser Road	Southfield	MI	48034	Oakland	(click to enter values if known)
✓		✓		Data Center	ServOnDemand	21420 Melrose Ave	Southfield	MI	48075	Oakland	(click to enter values if known)
✓		✓		Data Center	123Net	24275 Northwestern Hwy.	Southfield	MI	48075	Oakland	(click to enter values if known)
✓		✓		Data Center	US Signal Company, LLC	21648 Melrose Ave	Southfield	MI	48075	Oakland	(click to enter values if known)
✓			✓	Data Center	XO Communications	21455 Melrose Ave.	Southfield	MI	48075	Oakland	(click to enter values if known)
✓				Data Center	XO Communications	21555 Melrose Ave.	Southfield	MI	48075	Oakland	(click to enter values if known)
✓				Data Center	NEXCESS.NET L.L.C.	21700 Melrose Ave	Southfield	MI	48075	Oakland	(click to enter values if known)
✓				Data Center	Level 3 Communications	19675 West Ten Mile Road	Southfield	MI	48075	Oakland	(click to enter values if known)
	✓			Data Center	RT Software Hosting	3811 West 12 Mile Road	Berkley	MI	48072	Oakland	(click to enter values if known)
✓				Data Center	123Net	24700 Northwestern Hwy.	Southfield	MI	48075	Oakland	(click to enter values if known)
✓				Data Center	EdgeConneX	21005 Lahser Rd, Bldg 4	Southfield	MI	48033	Oakland	(click to enter values if known)
✓				Data Center	Liberty Center One Data Center	4815 Delemere Ave.	Royal Oak	MI	48073	Oakland	(click to enter values if known)
✓				Hospital	Botsford Hospital	28050 Grand River	Farmington Hills	MI	48336	Oakland	(click to enter values if known)

Figure 3. CTEM Auto-Populated Inventory Example

The model includes an additional User-Input Inventory module (shown in **Figure 4**) which allows the user to input commercial or real property information. The model then infers whether each location is likely

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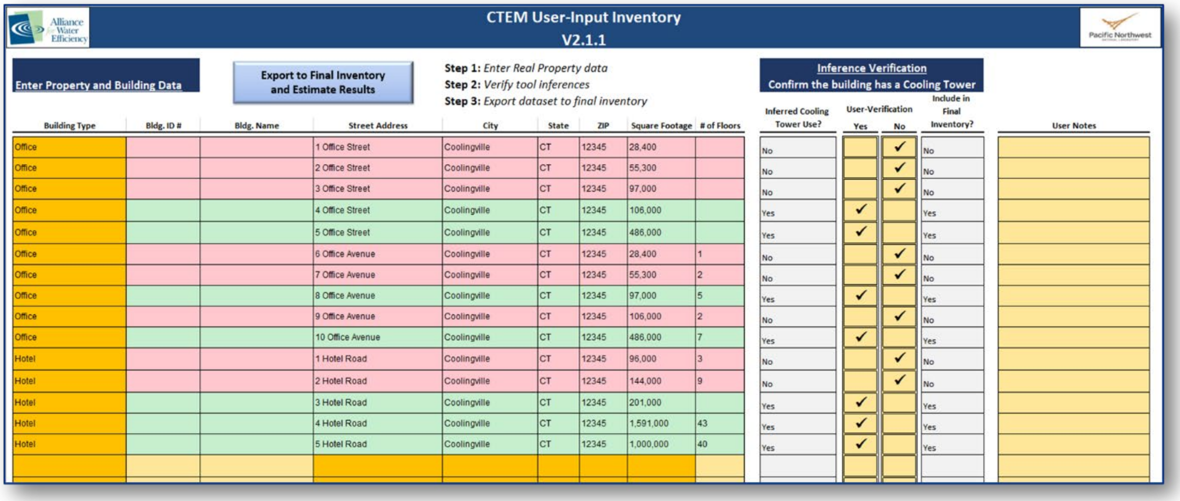
[4] It should be noted these lists were incorporated at the time of the development of CTEM and may not reflect recent construction or demolition of large industrial processing facilities or large institutional facilities that typically feature evaporative cooling.

to have a cooling tower. The user has the ability to verify the existence or non-existence of a cooling tower at individual sites and whether to include the building in the final inventory.



CTEM User-Input Inventory
V2.1.1

Step 1: *Enter Real Property data*
Step 2: *Verify tool inferences*
Step 3: *Export dataset to final inventory*

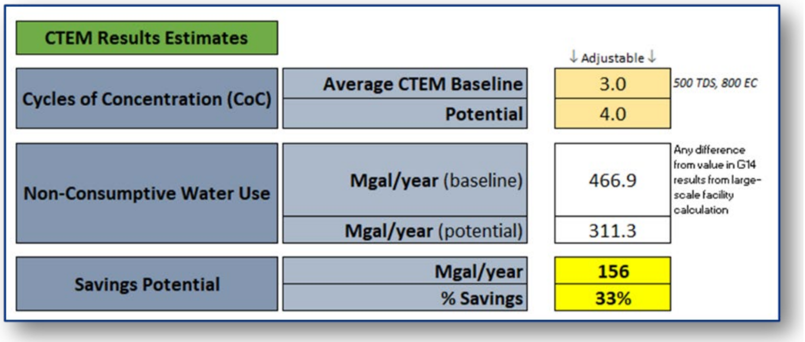
Inference Verification
Confirm the building has a Cooling Tower

Building Type	Bldg. ID #	Bldg. Name	Street Address	City	State	ZIP	Square Footage	# of Floors	Inferred Cooling Tower Use?	User-Verification Yes	User-Verification No	Include in Final Inventory?	User Notes
Office			1 Office Street	Coolingville	CT	12345	28,400		No		✓	No	
Office			2 Office Street	Coolingville	CT	12345	55,300		No		✓	No	
Office			3 Office Street	Coolingville	CT	12345	97,000		No		✓	No	
Office			4 Office Street	Coolingville	CT	12345	106,000		Yes	✓		Yes	
Office			5 Office Street	Coolingville	CT	12345	486,000		Yes	✓		Yes	
Office			6 Office Avenue	Coolingville	CT	12345	28,400	1	No		✓	No	
Office			7 Office Avenue	Coolingville	CT	12345	55,300	2	No		✓	No	
Office			8 Office Avenue	Coolingville	CT	12345	97,000	5	Yes	✓		Yes	
Office			9 Office Avenue	Coolingville	CT	12345	106,000	2	No		✓	No	
Office			10 Office Avenue	Coolingville	CT	12345	486,000	7	Yes	✓		Yes	
Hotel			1 Hotel Road	Coolingville	CT	12345	96,000	3	No		✓	No	
Hotel			2 Hotel Road	Coolingville	CT	12345	144,000	9	No		✓	No	
Hotel			3 Hotel Road	Coolingville	CT	12345	201,000		Yes	✓		Yes	
Hotel			4 Hotel Road	Coolingville	CT	12345	1,591,000	43	Yes	✓		Yes	
Hotel			5 Hotel Road	Coolingville	CT	12345	1,000,000	40	Yes	✓		Yes	

Figure 4. CTEM User-Input Inventory Example

For further adjustments, the PNNL team incorporated advanced functionality that projects the water savings potential should the aggregate COC be increased in in the service territory (shown in **Figure 5**), allowing the user to adjust the duty factor[5] if the CTEM estimated value is lower or higher than anticipated (shown in **Figure 6**).

It is important to note that properties will have different COC, dependent upon local water quality and cooling tower management. The best means to understand this factor is to conduct an on-site visit or obtain a history of water treatment reports documenting actual COC.



CTEM Results Estimates		↓Adjustable↓	
Cycles of Concentration (CoC)	**Average CTEM Baseline**	3.0	*500 TDS, 800 EC*
	Potential	4.0	
Non-Consumptive Water Use	**Mgal/year** (baseline)	466.9	Any difference from value in G14 results from large-scale facility calculation
	Mgal/year (potential)	311.3	
Savings Potential	**Mgal/year**	**156**	
	% Savings	**33%**	

Figure 5. CTEM Water Savings Potential Function

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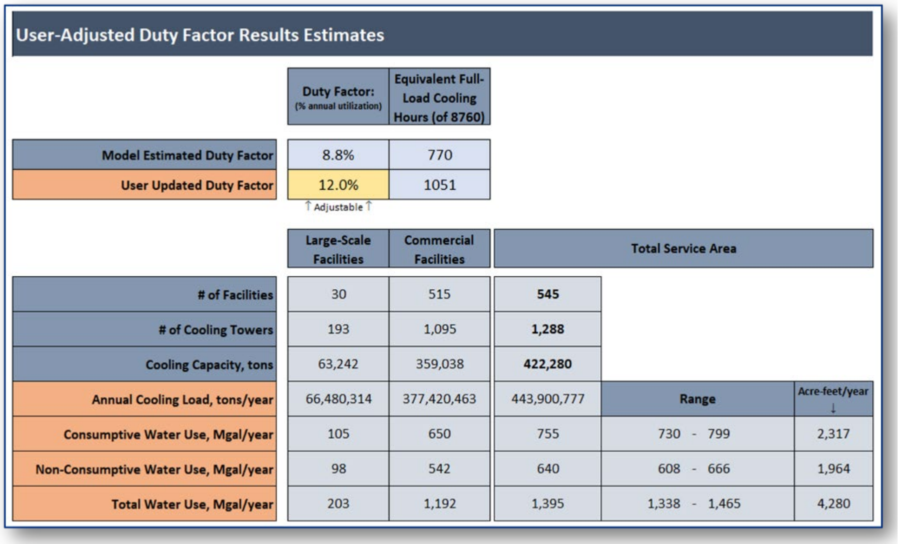
[5] For more information on what the duty factor represents and how it is determined in CTEM, see Appendix A.



User-Adjusted Duty Factor Results Estimates

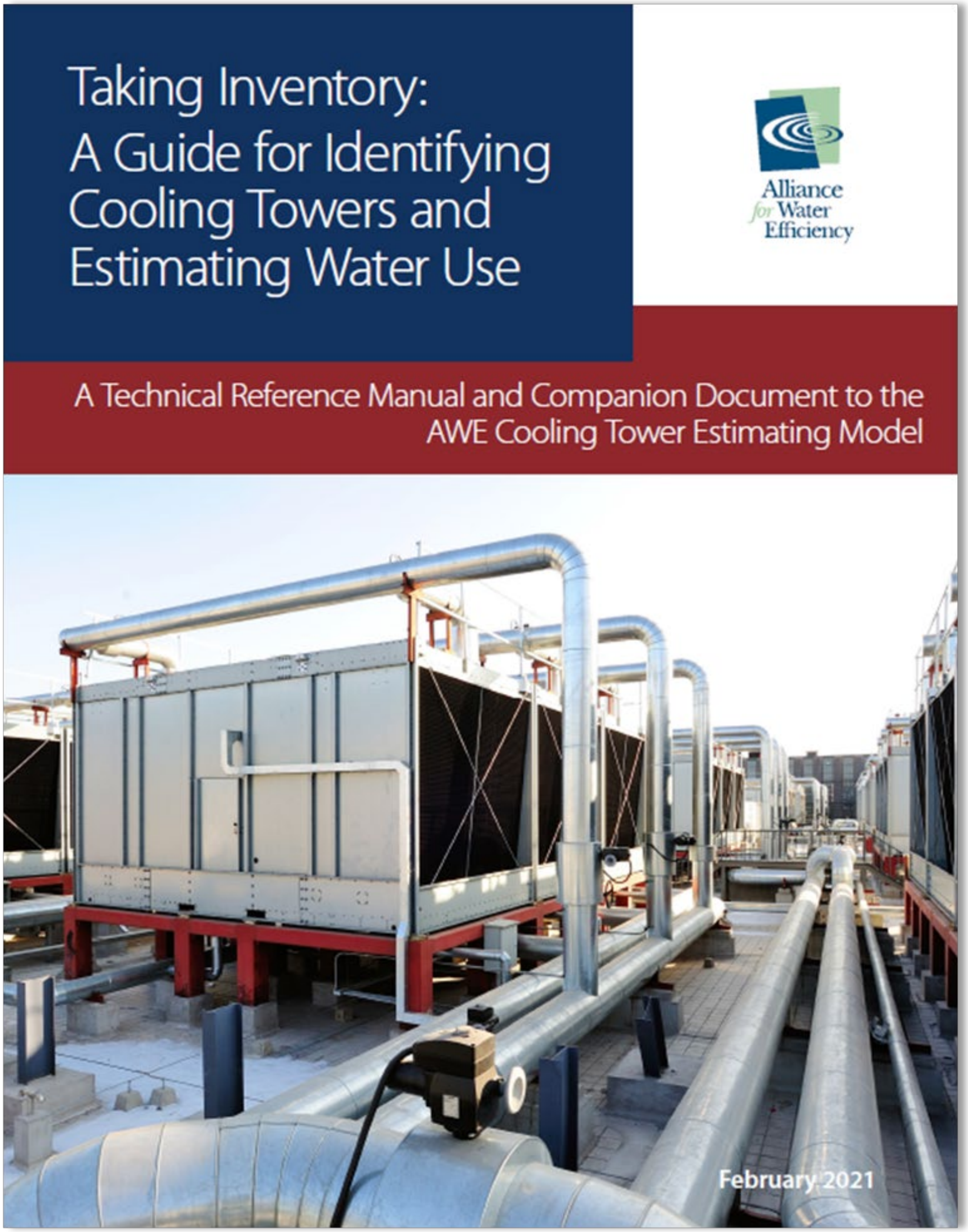
	Duty Factor: (% annual utilization)	Equivalent Full-Load Cooling Hours (of 8760)
Model Estimated Duty Factor	8.8%	770
User Updated Duty Factor	12.0%	1051
	↑ Adjustable ↑	

	Large-Scale Facilities	Commercial Facilities	Total Service Area		
# of Facilities	30	515	**545**		
# of Cooling Towers	193	1,095	**1,288**		
Cooling Capacity, tons	63,242	359,038	**422,280**		
				Range	Acre-feet/year ↓
Annual Cooling Load, tons/year	66,480,314	377,420,463	443,900,777		
Consumptive Water Use, Mgal/year	105	650	755	730 - 799	2,317
Non-Consumptive Water Use, Mgal/year	98	542	640	608 - 666	1,964
Total Water Use, Mgal/year	203	1,192	1,395	1,338 - 1,465	4,280

Figure 6. CTEM User-Adjusted Duty Factor Feature

PNNL and AWE collaborated to develop an accompanying guide, *Taking Inventory: A Guide for Identifying Cooling Towers and Estimating Water Use* (cover shown in **Figure 7**). The guide includes an overview of cooling tower basics, water use efficiency options, tips for verifying the presence of cooling towers, and details for using CTEM and the underlying calculations and assumptions used in the model.

CTEM and the accompanying guide are available to view and download from the Cooling Technology Study page ↗ on the AWE website.



Taking Inventory:
A Guide for Identifying Cooling Towers and Estimating Water Use

Alliance for Water Efficiency

A Technical Reference Manual and Companion Document to the AWE Cooling Tower Estimating Model

February 2021

Figure 7. AWE Guide for Identifying Cooling Towers and Estimating Water Use

3.0 Water Quality Helper

Section 3.0 provides a general description the Water Quality Helper tool. For this task, the PNNL team designed the Water Quality Helper as a standalone resource as well as an integrated module in CTEM. The tool helps users identify limiting water savings opportunities based on local water quality and points the user to potential solutions to improve the COC, thereby reducing the amount of blowdown lost from the system.

The water quality parameters included in the tool are:

- Total dissolved solids
- Conductivity
- Hardness
- Chloride
- Silica
- Alkalinity
- pH

These parameters can be determined by water quality testing or by obtaining reports from the source water provider (often available online). The tool functions with any, or all, of the water quality values entered. When water quality parameters are entered, as shown in **Figure 8**, the tool automatically estimates that parameter's industry standard threshold to determine the limiting COC for that respective constituent (aside from pH[6]).

Based on the inputs, the tool will determine the priority level of concern for each constituent and provide recommendations to improve the water efficiency (e.g., increase COC). The tool will indicate which are the primary and secondary limiting factors based on the water quality.

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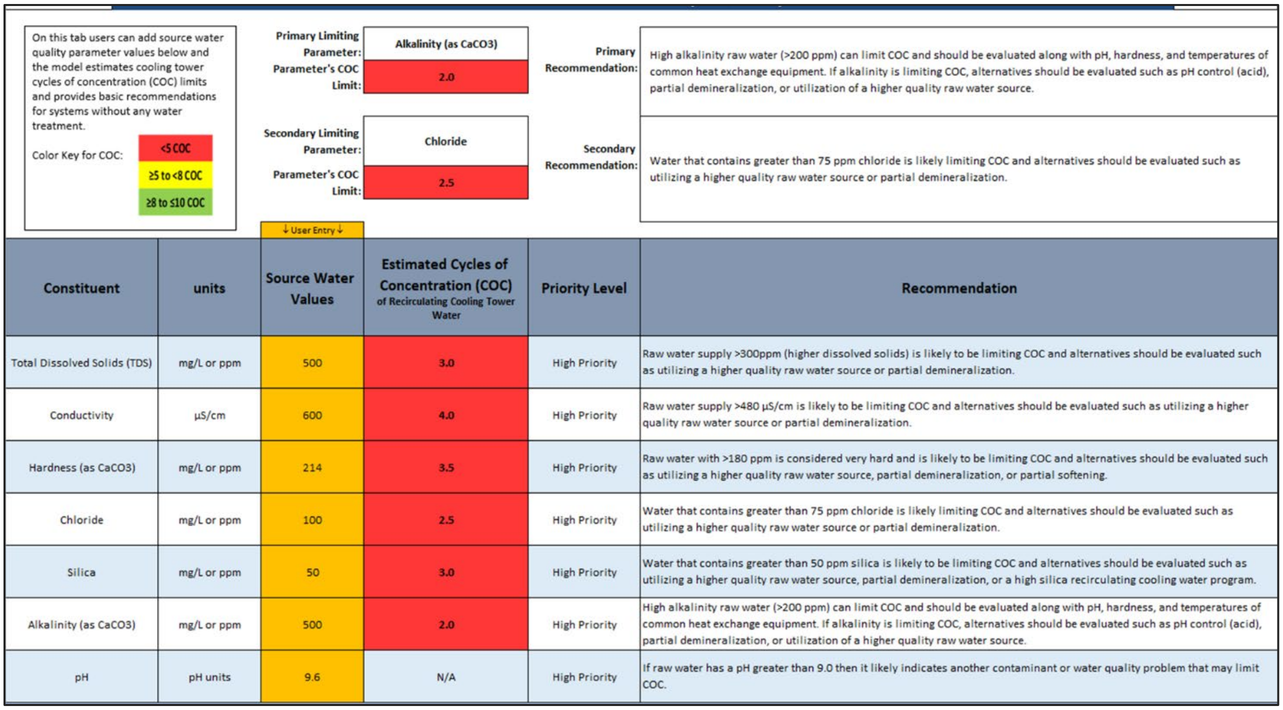
[6] pH does not impact the limit of COC for the system but can indicate other water quality concerns that may damage the cooling tower operation and efficiency.



On this tab users can add source water quality parameter values below and the model estimates cooling tower cycles of concentration (COC) limits and provides basic recommendations for systems without any water treatment.

Color Key for COC: 🟥 <5 COC 🟨 ≥5 to <8 COC 🟩 ≥8 to ≤10 COC

Primary Limiting Parameter: Alkalinity (as CaCO3)

Parameter's COC Limit: 2.0

Primary Recommendation: High alkalinity raw water (>200 ppm) can limit COC and should be evaluated along with pH, hardness, and temperatures of common heat exchange equipment. If alkalinity is limiting COC, alternatives should be evaluated such as pH control (acid), partial demineralization, or utilization of a higher quality raw water source.

Secondary Limiting Parameter: Chloride

Parameter's COC Limit: 2.5

Secondary Recommendation: Water that contains greater than 75 ppm chloride is likely limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source or partial demineralization.

↓User Entry↓

Constituent	units	Source Water Values	Estimated Cycles of Concentration (COC) of Recirculating Cooling Tower Water	Priority Level	Recommendation
Total Dissolved Solids (TDS)	mg/L or ppm	500	3.0	High Priority	Raw water supply >300ppm (higher dissolved solids) is likely to be limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source or partial demineralization.
Conductivity	µS/cm	600	4.0	High Priority	Raw water supply >480 µS/cm is likely to be limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source or partial demineralization.
Hardness (as CaCO3)	mg/L or ppm	214	3.5	High Priority	Raw water with >180 ppm is considered very hard and is likely to be limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source, partial demineralization, or partial softening.
Chloride	mg/L or ppm	100	2.5	High Priority	Water that contains greater than 75 ppm chloride is likely limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source or partial demineralization.
Silica	mg/L or ppm	50	3.0	High Priority	Water that contains greater than 50 ppm silica is likely to be limiting COC and alternatives should be evaluated such as utilizing a higher quality raw water source, partial demineralization, or a high silica recirculating cooling water program.
Alkalinity (as CaCO3)	mg/L or ppm	500	2.0	High Priority	High alkalinity raw water (>200 ppm) can limit COC and should be evaluated along with pH, hardness, and temperatures of common heat exchange equipment. If alkalinity is limiting COC, alternatives should be evaluated such as pH control (acid), partial demineralization, or utilization of a higher quality raw water source.
pH	pH units	9.6	N/A	High Priority	If raw water has a pH greater than 9.0 then it likely indicates another contaminant or water quality problem that may limit COC.

Figure 8. Water Quality Helper Example

The Water Quality Helper is available as a stand-alone resource and is incorporated as a module in CTEM. Both are available to view and download from the Cooling Technology Study page on the AWE website.

4.0 Alternative Technologies Analysis

Section 4 provides an overview of the Alternative Technologies Market Penetration Model, named the Comparing Alternatives Tool (CAT) and the accompanying Alternative Technologies Report. This component of the study assessed several alternative technologies and examined how, and if, their integration and deployment could meet a water supplier's service area's cooling demand while providing water savings. Although considered "alternative" to mainstream standard cooling towers, these technologies are currently available and in use at sites today.

A variety of alternative cooling technologies were recommended for consideration for this task. PNNL and AWE requested suggestions for alternative cooling technologies from the utility partners to formulate an initial list of candidate alternative cooling technologies. The three criteria requirements for these technologies were that they must be:

1. Commercially available
2. Verified water savings performance
3. Published capital costs

A total of 21 technologies were recommended. Ultimately, four alternative cooling technologies, that met the high-level criteria, were selected. The selected technologies are:

- Thermosyphon hybrid cooling
- Hygroscopic cooling
- Thermal membrane distillation
- Adiabatic cooling

To assess the impact of these technologies, the PNNL team used their previous experience developing novel market penetration methods to create an Excel-based model[7] for estimating the water savings potential of the four selected alternative water treatment technologies over time for a given utility's service territory. The Comparing Alternatives Tool uses the number of cooling towers and estimated associated water use in a water supplier's service territory from CTEM see Section 2.0 for example CTEM inputs and outputs). These inputs, as shown in **Figure 9**, form the baseline water use of the market penetration analysis.

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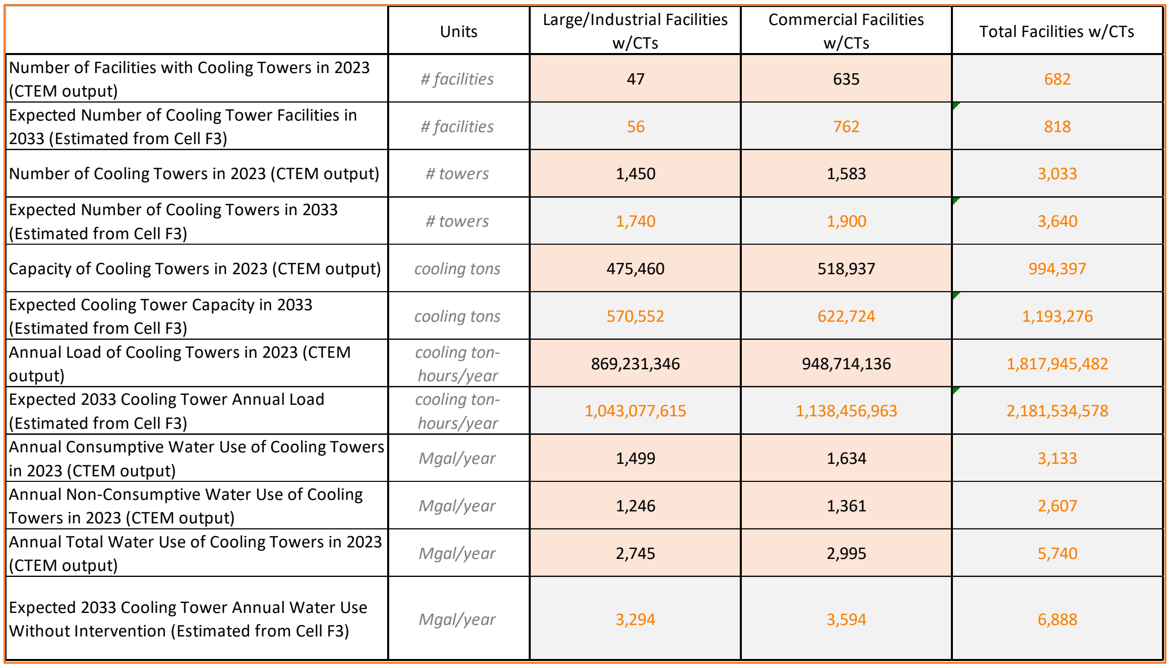
[7] Disclaimer: The model uses fixed condition forecast estimates for systems-level analysis and planning; the projections are not future predictions or assurances.



	Units	Large/Industrial Facilities w/CTs	Commercial Facilities w/CTs	Total Facilities w/CTs
Number of Facilities with Cooling Towers in 2023 (CTEM output)	*# facilities*	47	635	682
Expected Number of Cooling Tower Facilities in 2033 (Estimated from Cell F3)	*# facilities*	56	762	818
Number of Cooling Towers in 2023 (CTEM output)	*# towers*	1,450	1,583	3,033
Expected Number of Cooling Towers in 2033 (Estimated from Cell F3)	*# towers*	1,740	1,900	3,640
Capacity of Cooling Towers in 2023 (CTEM output)	*cooling tons*	475,460	518,937	994,397
Expected Cooling Tower Capacity in 2033 (Estimated from Cell F3)	*cooling tons*	570,552	622,724	1,193,276
Annual Load of Cooling Towers in 2023 (CTEM output)	*cooling ton-hours/year*	869,231,346	948,714,136	1,817,945,482
Expected 2033 Cooling Tower Annual Load (Estimated from Cell F3)	*cooling ton-hours/year*	1,043,077,615	1,138,456,963	2,181,534,578
Annual Consumptive Water Use of Cooling Towers in 2023 (CTEM output)	*Mgal/year*	1,499	1,634	3,133
Annual Non-Consumptive Water Use of Cooling Towers in 2023 (CTEM output)	*Mgal/year*	1,246	1,361	2,607
Annual Total Water Use of Cooling Towers in 2023 (CTEM output)	*Mgal/year*	2,745	2,995	5,740
Expected 2033 Cooling Tower Annual Water Use Without Intervention (Estimated from Cell F3)	*Mgal/year*	3,294	3,594	6,888

Figure 9. Example Market Penetration Inputs

The tool also allows the user to specify the anticipated growth (expressed as a percentage) of the cooling demand met by cooling towers for their service territory, as shown in **Figure 10**.

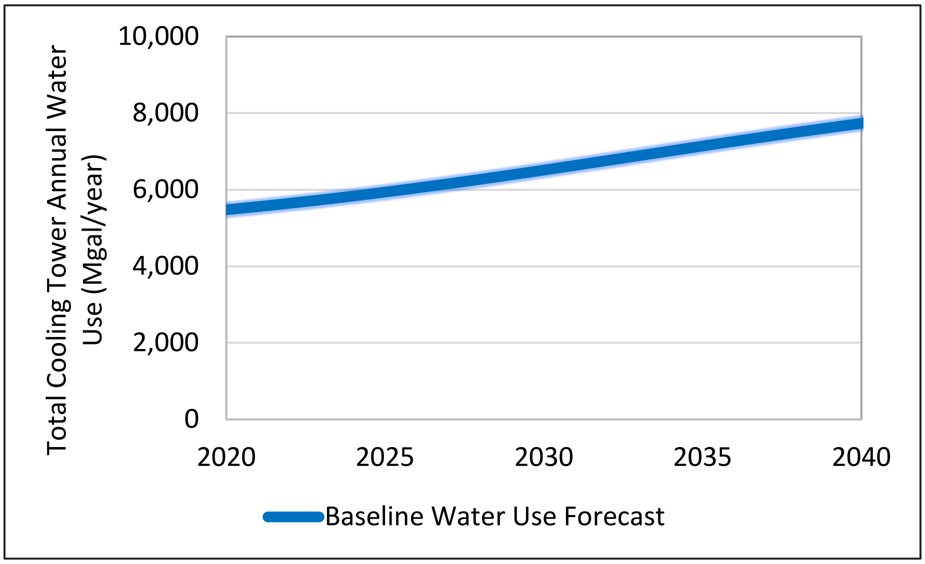
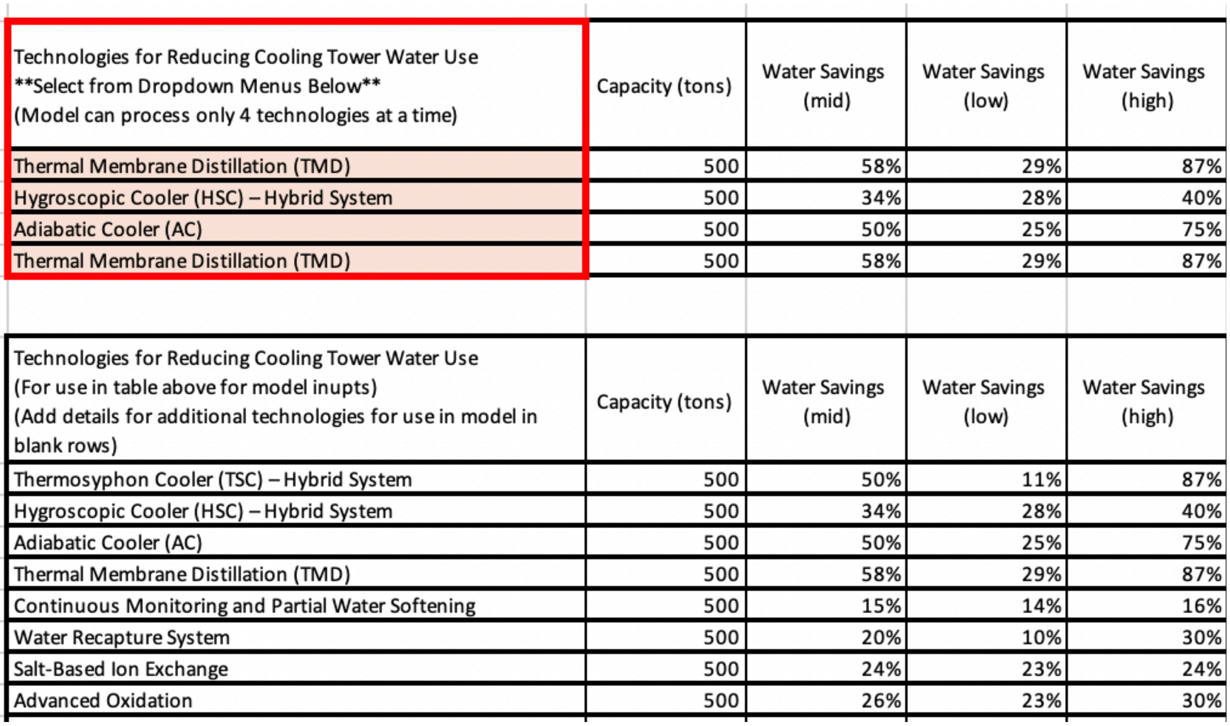


Figure 10. Example Baseline Water Use Forecast

With this baseline, the model allows the user to investigate four different alternative cooling technologies at a time, as selected from the drop-down menu at the top of the Alt Techs Details tab (highlighted in the red box in **Figure 11**).



Technologies for Reducing Cooling Tower Water Use **Select from Dropdown Menus Below** (Model can process only 4 technologies at a time)	Capacity (tons)	Water Savings (mid)	Water Savings (low)	Water Savings (high)
Thermal Membrane Distillation (TMD)	500	58%	29%	87%
Hygroscopic Cooler (HSC) – Hybrid System	500	34%	28%	40%
Adiabatic Cooler (AC)	500	50%	25%	75%
Thermal Membrane Distillation (TMD)	500	58%	29%	87%

Technologies for Reducing Cooling Tower Water Use (For use in table above for model inputs) (Add details for additional technologies for use in model in blank rows)	Capacity (tons)	Water Savings (mid)	Water Savings (low)	Water Savings (high)
Thermosyphon Cooler (TSC) – Hybrid System	500	50%	11%	87%
Hygroscopic Cooler (HSC) – Hybrid System	500	34%	28%	40%
Adiabatic Cooler (AC)	500	50%	25%	75%
Thermal Membrane Distillation (TMD)	500	58%	29%	87%
Continuous Monitoring and Partial Water Softening	500	15%	14%	16%
Water Recapture System	500	20%	10%	30%
Salt-Based Ion Exchange	500	24%	23%	24%
Advanced Oxidation	500	26%	23%	30%

Figure 11. Alternative Technology Selection Illustration

The user enters the adoption goal for each alternative cooling technology for both large facilities and commercial buildings.

Table 1, below, provides an example of two variations of a 20% overall adoption rate. Scenario 1 applies a 5% uniform or equal adoption rate for each of the four alternative technologies, while scenario 2 targets only salt-based ion exchange for the same overall adoption rate. The inputs can be altered iteratively and varied to optimize the outputs.

Table 1. Adoption Rate Scenario Example

	Scenario 1: Equal Adoption		Scenario 2: Focused Adoption	
Alternative Technology	Large Facilities	Commercial Facilities	Large Facilities	Commercial Facilities
Adiabatic Cooler	5%	5%	0%	0%
Water Recapture System	5%	5%	0%	0%
Salt-Based Ion Exchange	5%	5%	20%	20%

Alternative Technology	Scenario 1: Equal Adoption Large Facilities	Commercial Facilities	Scenario 2: Focused Adoption Large Facilities	Commercial Facilities
Continuous Monitoring and Partial Water Softening	5%	5%	0%	0%
Total Adoption Rate	20%	20%	20%	20%

Based on these inputs, the tool provides graphic trends for water savings projections and energy impact for the selected scenarios. The table also includes basic economic indices for both adoption rate scenarios to give the user a high-level perspective of the capital costs implications for the theoretical alternative technology adoption scenarios.

For the example scenarios in Table 1, the model's graphic trend output (shown in **Figure 12**) shows the forecasted impact over time. In this example, the water savings for both scenarios are similar; however, the energy demand increase for scenario 1 is significantly higher than the energy demand increase for scenario 2.

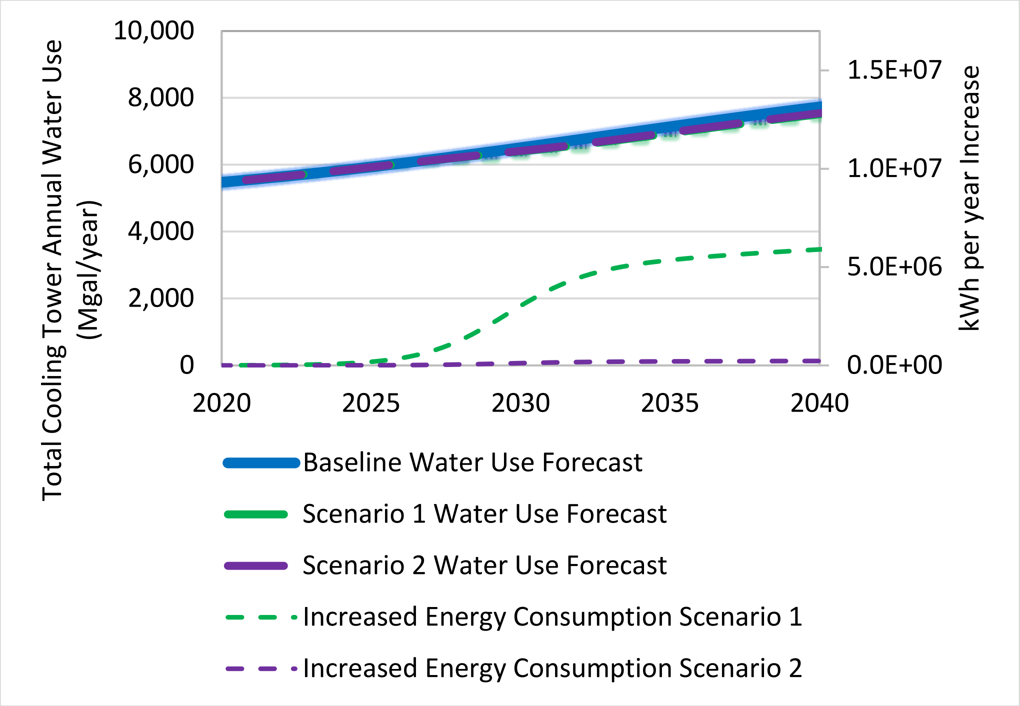
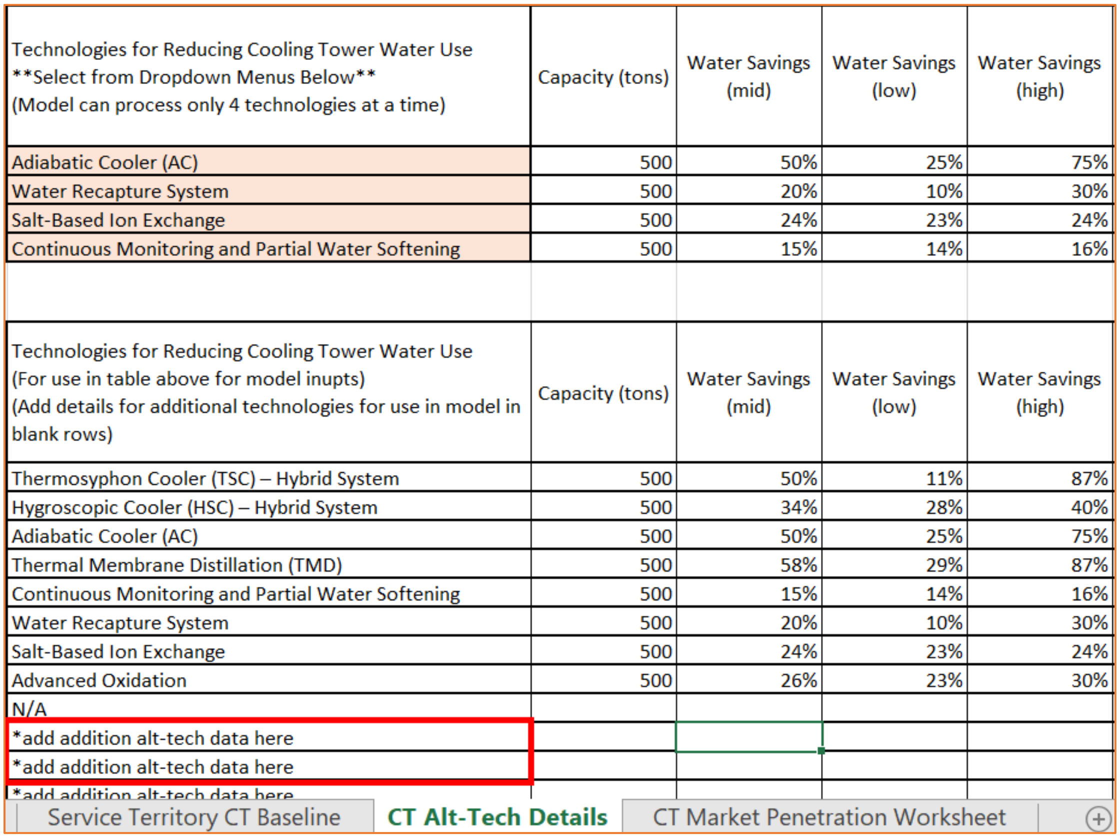


Figure 12. Example Forecast Trends for Water Savings and Energy Impact

The model currently has data for the four alternative cooling technologies (those that fully replace a traditional cooling tower) and the four alternative water treatment technologies (technologies that can be added to a traditional cooling tower and alter the water treatment program). The tool can allow for additional alternative technologies to be added as they become commercially available as shown in **Figure 13**, below.



Technologies for Reducing Cooling Tower Water Use **Select from Dropdown Menus Below** (Model can process only 4 technologies at a time)	Capacity (tons)	Water Savings (mid)	Water Savings (low)	Water Savings (high)
Adiabatic Cooler (AC)	500	50%	25%	75%
Water Recapture System	500	20%	10%	30%
Salt-Based Ion Exchange	500	24%	23%	24%
Continuous Monitoring and Partial Water Softening	500	15%	14%	16%

Technologies for Reducing Cooling Tower Water Use (For use in table above for model inupts) (Add details for additional technologies for use in model in blank rows)	Capacity (tons)	Water Savings (mid)	Water Savings (low)	Water Savings (high)
Thermosyphon Cooler (TSC) – Hybrid System	500	50%	11%	87%
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Adiabatic Cooler (AC)	500	50%	25%	75%
Thermal Membrane Distillation (TMD)	500	58%	29%	87%
Continuous Monitoring and Partial Water Softening	500	15%	14%	16%
Water Recapture System	500	20%	10%	30%
Salt-Based Ion Exchange	500	24%	23%	24%
Advanced Oxidation	500	26%	23%	30%
N/A				
*add addition alt-tech data here				
*add addition alt-tech data here				
*add addition alt-tech data here				

Figure 13. Location for Additional Alternative Technologies

In a similar fashion to the accompanying report for CTEM, the PNNL team assembled a companion Alternative Technology Report with the release of the Alternative Technology Market Penetration Model. In this report, PNNL details the underlying approaches and assumptions used to develop the model and provides a case study scenario for the San Antonio metropolitan area.

It must be noted that with substantial savings in water use in cooling systems tradeoffs such as capital and reoccurring operating expenses and energy cost impacts are expected. This study did not include rigorous economic evaluations; however, the results from the Market Penetration Model can be used to help inform life cycle cost analysis and payback period calculations to help utilities make decisions for incentive or outreach/education programs.

The Comparing Alternatives Tool and the accompanying report are available to view and download from the Cooling Technology Study page on the AWE website.

5.0 How-to Guide for Creating a Successful Cooling Tower Water Efficiency Program

Section 5 provides an overview of the How-to Guide for Creating a Successful Cooling Tower Water Efficiency Program.

The guide was created to provide an educational and practical resource for water supplier professionals considering offering a Cooling Tower Water Efficiency Program for their customers.

The guide provides valuable information on how to increase water efficiency in cooling towers. It provides a comprehensive look at the design and operations of cooling towers and the critical water efficiency upgrades and opportunities for water savings in today's industry.

Later sections cover program considerations and provide valuable information about effective program design, operations, and marketing. Additional resources and website links are provided throughout the guide for easy access.

The guide will walk the reader through the following:

- Understanding cooling tower water treatment and maintenance programs
- Various cooling tower efficiency upgrades
- An overview of AWE resources
- Types of facilities with the best opportunity for cooling tower upgrades
- Key stakeholders and decision makers
- Considerations for incentive programs, education, and outreach

In addition to the How-to Guide, the PNNL team has developed an integrated Excel-based audit template and simple return on investment calculator to help locations evaluate the performance of their cooling tower systems and high-level options to improve their performance and efficiency.

The How-to Guide is available to view and download from the Cooling Technology Study page ↗ on the AWE website.

Summary

As the world's population increases and average temperatures rise due to climate change, the need for effective cooling technology will continue to grow. The resources created from this Cooling Technology Study aim to help water supply professionals create, optimize, and maintain effective and water-efficient cooling programs for their customers. With proper planning and execution in conjunction with the resources from this study, water suppliers can employ cooling tower programs to reduce water demand while meeting cooling needs into the future.

Appendix A – Duty Factor Determination

The Facility Energy Decision System (FEDS) is a PNNL-developed building/facility energy modeling tool that simulates building systems and energy use. FEDS was used to model specific building types in provided in CTEM (offices, hospitals, hotels, large schools, etc.) that use cooling towers. These building types were simulated in the various IECC climate zones around in US and Canada to provide hourly cooling load profiles (provided in tons of cooling). **Figure 14** is an example of an hourly cooling load profile for a 400,000 square foot mid-rise office building in Washington State. These cooling loads were built into CTEM to estimate cooling tower sizing and load characteristics.

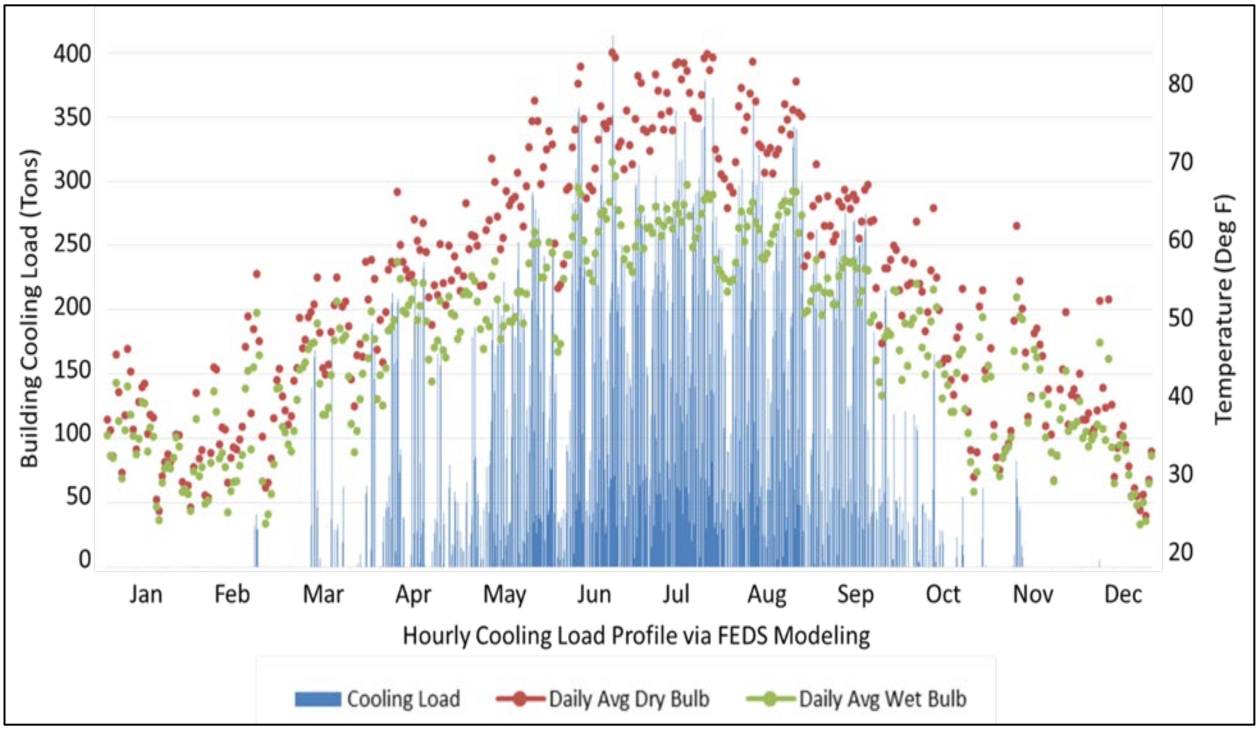

Figure 14. FEDS Generated Hourly Cooling Demand with Wet and Dry Bulb Temperatures

A generic 500,000 square foot office building was built in FEDS whereby the cooling load profile for the building was modeled for each IECC climate zone over a one-year period. The peak hourly load and total annual load were determined for each climate zone (**Figure 15**) and used for conversion between capacity estimates (tons) and annual cooling loads (ton/year) for sample cities in each climate region. This data was also used to estimate the average cooling tower duty factor for the climate region.

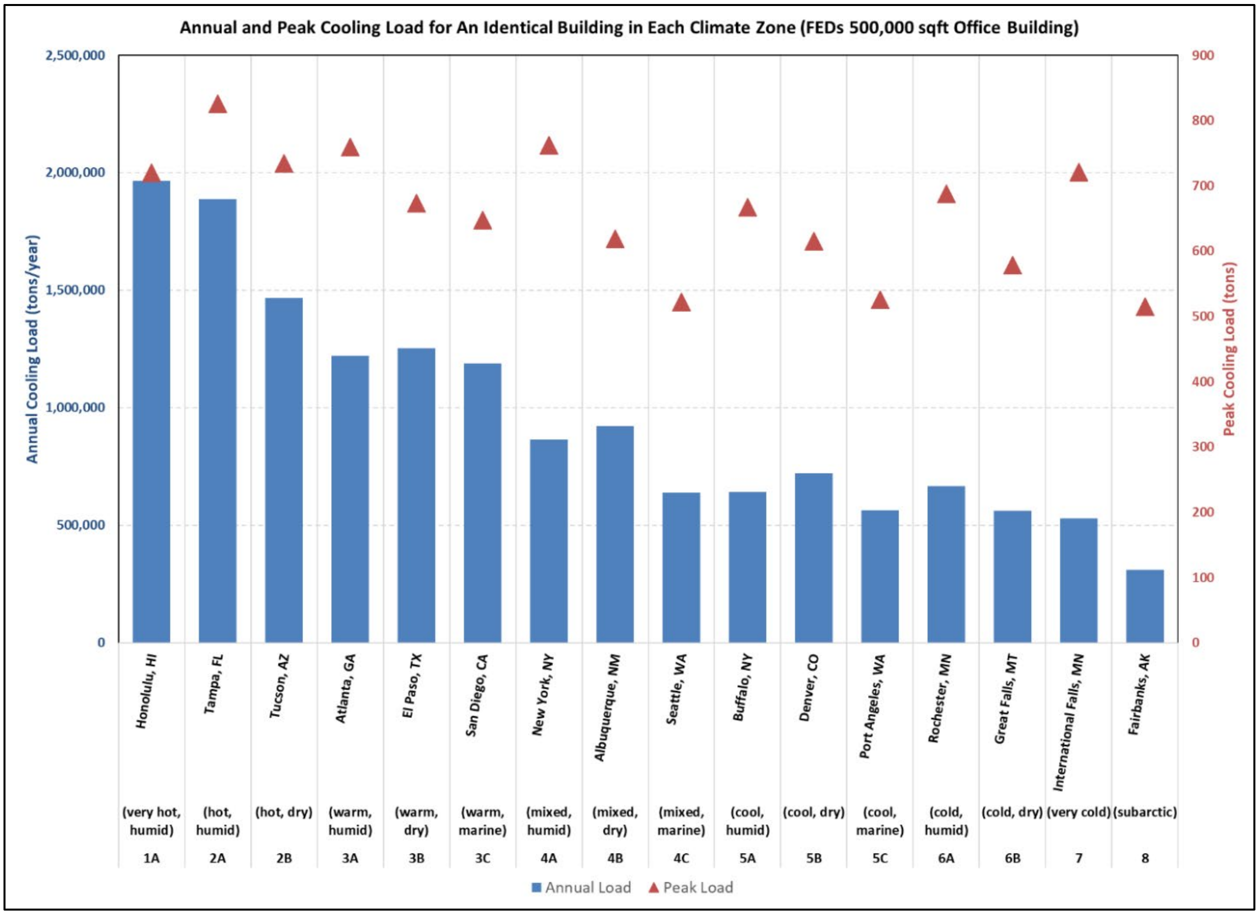

Figure 15. FEDS Climate Zone Modeled Results

For additional information on the duty factor and how it is calculated and can be altered in CTEM, please refer to the accompanying guide, *Taking Inventory: A Guide for Identifying Cooling Towers and Estimating Water Use*, available to view and download from the Cooling Technology Study page on the AWE website.

Appendix B – Alternative Cooling Technology Information

Continuous Monitoring and Partial Water Softening

The continuous monitoring and partial water softening technology consists of continuous programmable logic control and side-stream filtration with partial water softening. Side-stream filtration removes suspended matter and assists in microbiological control for the cooling system. The continuous programmable logic control monitoring calculates the COC, determining the quantity of blowdown water required to satisfy water chemistry requirements by continuously optimizing the makeup water hardness.

A case study from 2020 monitored the performance of this technology on a building located in Las Vegas, Nevada, documenting 15% water savings over the duration of the study. It was noted that makeup water quality variability and adherence to the recommended water treatment will affect the water savings potential.

To accommodate these statements, the sensitivity analysis used in the market penetration analysis considered a midpoint of 15% with a low of 14% and a high of 16% for anticipated overall water savings.

Water Recapture System

The water recapture system captures and condenses water vapor for reuse to reduce the consumption of fresh water. The water recapture system consists of a dome-shaped wire mesh covering that sits over the outlet of the cooling tower. Prior to being exposed to the wire mesh, the water vapor flows through electrodes that ionize the exhaust stream. The wire mesh is charged by electricity and electrostatic attraction forces draw the water vapor out of the air. As it condenses it falls and is collected for reuse in the cooling tower system.

Multiple studies were researched, including analysis for a system on an induced draft wet cooler and a study of the technology at a desalination plant in Texas. Variable ambient conditions and operating procedures produced a broad range of savings potential from 10% on the low end to 30% on the high end.

Salt-Based Ion Exchange

Salt-based ion exchange treats make-up water with a water softener, replacing scale-forming components (such as calcium and magnesium) with highly soluble sodium or potassium ions. Because sodium and potassium are more soluble and less likely to form troublesome deposits than calcium and magnesium, the system can operate at higher COC.

A multi-year case study was performed at a federal building in Denver, Colorado that included measuring and documenting monthly water use and daily makeup and blowdown from the cooling tower system. Measured and verified water savings between 23% and 24% was observed over the course of the study.

Advanced Oxidation

Advanced oxidation treatment injects negatively charged oxygen atoms into the recirculating cooling water. During this process, ambient air is transported through patented sleeves containing ultraviolet lamps and other proprietary components to create negatively charged oxygen atoms which diffuse into the cooling tower water and form highly reactive hydroxyl and other radicals. These highly reactive ions breakdown scale deposits, oxidize minerals, and reduce bacteria thereby increasing the COC and reducing the quantity of blowdown water.

A rigorous case study of this technology was performed for the US General Services Administration's Green Proving Grounds from 2014 to 2017 on a federal building in Denver, Colorado. Observed and modeled performance over the course of the study produced analogous results with a range of water savings between 23% and 30% depending on chiller performance, building occupancy, operational variability and ambient conditions.

Thermosyphon Cooling

A thermosyphon cooling (TSC) is an advanced dry cooler that uses refrigerant in a passive cycle to dissipate heat. This type of technology is a hybrid heat-rejection system, which optimizes the use of two cooling technologies—one wet (an open cooling tower) and one dry (a thermosyphon cooler unit)—in a single, integrated operating system.

TSC can reduce total annual water volume consumption when used in combination with a traditional cooling tower. A study was conducted by the Electric Power Research Institute to examine water saving potential for hybrid systems that combine traditional cooling towers with thermosyphon technology. The study found that in a mild climate (San Luis Obispo, California), total water volume savings ranges from 30% to 88%. In a hot and arid climate (Yuma, Arizona), total water volume savings ranges from 15% to 71%. The substantial range of water savings potential is due to wide variance in the control strategy, including the maximum allowable system pressure and the thermosyphon fan speed.

Hygroscopic Cooling

A hygroscopic cooling (HSC) system works similarly to a traditional cooling tower, but instead of pure water as the cooling fluid, a hygroscopic liquid desiccant fluid is used, such as calcium chloride (CaCl2) mixed with water. In a traditional cooling tower, most of the heat is transferred through evaporation, mainly driven by outdoor conditions such as relative humidity. Hygroscopic coolers however transfer more heat through convection rather than evaporation when the outdoor air is cooler than the temperature set point of the system. When outdoor air temperature exceeds this threshold, the system switches to evaporative cooling. The system can be controlled to optimize this process, thereby reducing water use by reducing the amount of evaporation. HSC systems also save water through the elimination of blowdown. Unlike traditional cooling towers, hygroscopic coolers remove dissolved solids by precipitating and then filtering the solids out of the fluid for reuse.

The University of North Dakota performed a study of HSC towers for the US Department of Defense Environmental Security Technology Certification Program. The study aimed to test this technology to determine the water savings potential. The study found that by increasing the COC from 4 to 20, a hygroscopic cooler can theoretically achieve a 30%-50% water savings, and case study findings of 36% water savings in a mild climate (Monterey Bay, California) and 31% water savings a warm-dry climate (Fort Irwin, California).

Adiabatic Cooling

Adiabatic cooling systems work by using evaporation to pre-cool the air flowing through a closed loop coil. Adiabatic coolers run in two modes: wet (or "pre-cooler") operation and dry operation. Wet operation is only activated during peak demand conditions (e.g., times of high outdoor temperatures and/or during high internal cooling loads conditions). A fan draws warm air through an adiabatic unit where humidity is added to the air. When the humidity comes into contact with the warm air, water evaporates and heat is dissipated, similar to how a swamp cooler works. When outdoor temperatures are low and cooling loads are minimal, the system operates in dry mode, operating similar to a conventional finned dry cooler where heat is dissipated to the ambient air via convection.

Adiabatic systems can be closely controlled, which optimizes the system between the two operation modes. Water is only used when conditions require evaporative cooling, thereby reducing water demand compared to traditional cooling towers. Adiabatic cooling systems have a wide range of water savings because water use is heavily influenced on the operating conditions and how the system is controlled. The expected range of water savings is between 25% to 75%.

Thermal Membrane Distillation

Thermal membrane distillation (TMD) is a water treatment option for cooling-tower blowdown water, which can be reused in cooling-tower makeup thereby reducing the use of freshwater supply. Membrane distillation is a separation process that works by filtering water through a hydrophobic membrane, which only allows the passage of water vapor through the membrane’s pores. The process works by heating the blowdown water, which causes a phase change from vapor to liquid, resulting in a pressure change that drives the vapor across the membrane. The vapor condenses to clean liquid water as “product water”, which can be reused in the system. The use of geothermal production wells provide low temperature geothermal energy (<90^{o}C) to heat the source water. This geothermal energy can be used to power the TMD process in areas where geothermal energy is available. Membrane distillation systems can be configured for a single pass or with source-water recirculation to achieve high recovery.

A 2013 theoretical experiment using direct contact membrane distillation in cooling towers reported a water savings potential range of 68% to 87%, without and with the use of additional chemical treatment respectively. A subsequent study performed in 2018 leveraged industry standards and practical operating conditions and reported 29% makeup water volume savings by implementing TMD in a cooling tower system. The large range in water savings between the two studies is due to the 2013 study is a theoretically achievable water savings potential while the 2018 study is based on industry practices and case study averages.

Cooling Technologies Project Summary

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