Title

Field Validation of Electrochemical Water Filtration System on an Open Loop Cooling Tower at Nissan Manufacturing Plant in Canton, Mississippi

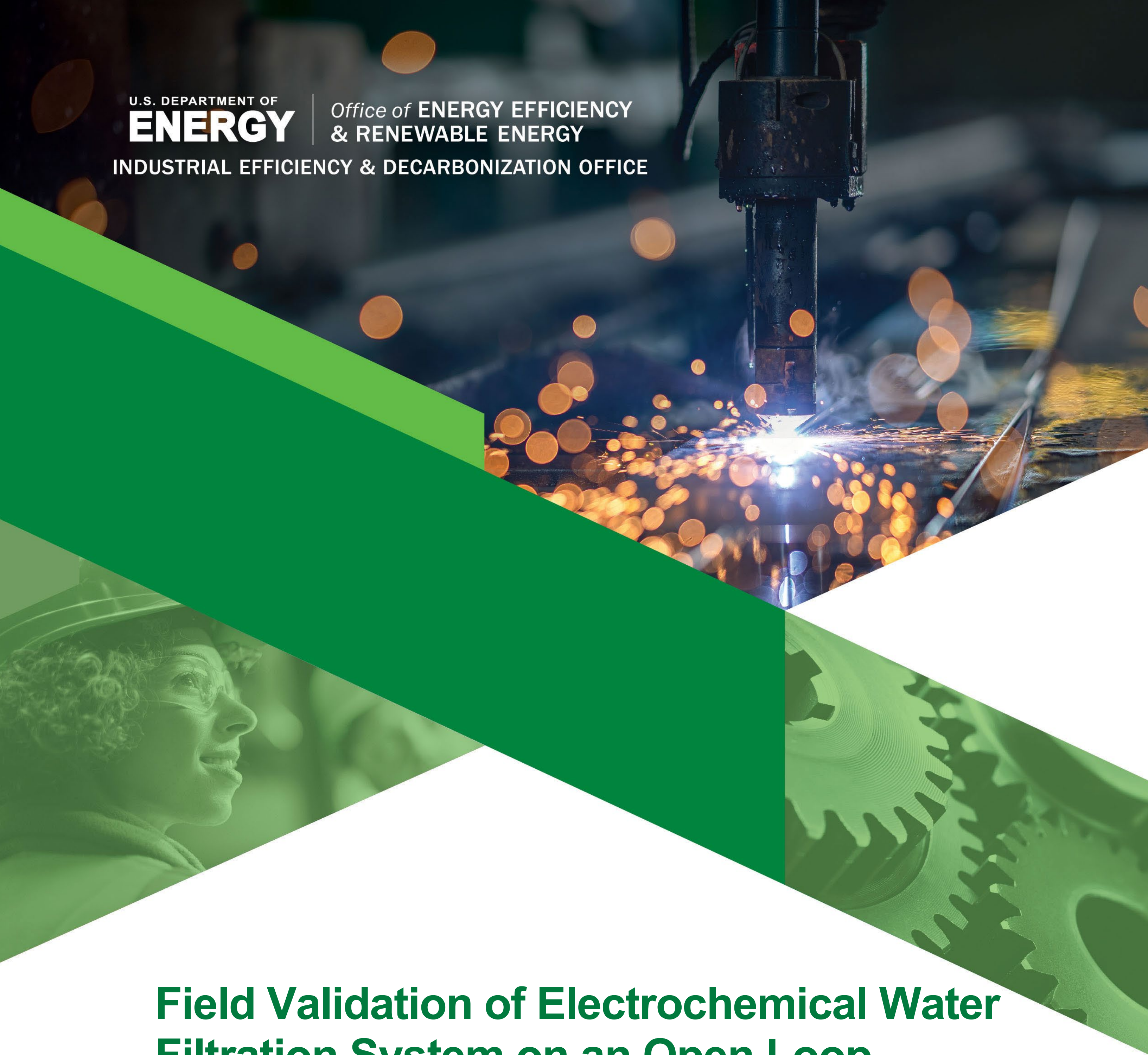
Authors
Earni, Shankar
Pevzner, Amy
Karki, Unique
et al.

Publication Date
2024-09-24

Peer reviewed

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE



Field Validation of Electrochemical Water Filtration System on an Open Loop Cooling Tower at Nissan Manufacturing Plant in Canton, Mississippi

Operating and Performance Technical Report
Industrial Technology Validation

September 2024

Disclaimer

The work described in this report was funded by the U.S. Department of Energy's Industrial Efficiency and Decarbonization Office, formerly known as the Advanced Manufacturing Office.

The Industrial Technology Validation (ITV) program is designed to address the need to identify, validate, and showcase the capabilities of new, emerging, and underutilized technologies in the industrial sector. The primary objective of ITV is to conduct robust evaluation and document performance data on these technologies to help expedite their commercialization and widespread deployment. By performing thorough validations and demonstrating the efficacy of these industrial technologies, the ITV program plays a crucial role in providing the necessary information for industry stakeholders to make informed decisions about their adoption. Each report conveys the performance results from a specific installation at a specific industrial site, following a specific methodology. Performance may vary for other installations of the same technology or if other methodologies are used to assess performance.

Technologies selected for evaluation by the ITV program can vary in their stage of commercialization. Depending on its stage, there will be some notable variations in the evaluation, such as scale of installation or data availability, that will influence the depth of each analysis and the ability to extrapolate findings.

For more information, contact:

John O'Neill
Technology Manager
Industrial Efficiency & Decarbonization Office
U.S. Department of Energy
john.oneill@ee.doe.gov

Authors

This report was prepared by DNV GL Energy Insights USA, Inc. and Lawrence Berkeley National Laboratory for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office.

Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Energy 350
1033 SE Main St #1
Portland, OR 97214

The authors of this report from Lawrence Berkeley National Laboratory are:

Shankar Earni, Ph.D.

Amy Pevzner

Unique Karki

Paul Sheaffer,

Prakash Rao, Ph.D.

Ernest Orlando.

The authors from Energy 350 are:

Ross Charland, P.E.

Josh Weissert, P.E.

Acknowledgments

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Industrial Efficiency and Decarbonization Office of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

The authors would like to thank the following individuals from Industrial Efficiency and Decarbonization Office, Department of Energy, for their guidance and leadership:

John O’Neill

Crystal Bell, Ph.D.

Anne Hampson.

The authors are grateful to the following individuals and their organizations for their review and valuable insight:

Michael Deru, Ph.D., National Renewable Energy Laboratory

Eric Dole, P.E., PSAP, Garver

Mark Philbrick, Industrial Efficiency and Decarbonization Office, Department of Energy.

The authors would also like to thank the following individuals and many more across several organizations that helped execute the Field Validation of Electrochemical Water Filtration System on an Open Loop Cooling Tower at Nissan Manufacturing Plant in Canton, Mississippi:

Brett Rasmussen, Nissan North America

Chris Goddard, P.E., Nissan North America

Paul McLaine, President, ElectroCell Systems

Ron Barley, BGA Energy Optimization Solutions, Inc.

Unique Karki, Lawrence Berkeley National Laboratory

Thomas Wenning, Oak Ridge National Laboratory

Peter Fiske, National Alliance for Water Innovation.

The authors would like to express their sincere gratitude to Eli Levine and Jillian Romsdahl, Ph.D., formerly of U.S. Department of Energy’s Industrial Efficiency and Decarbonization Office, for their vision and initial development of the Industrial Technology Validation (ITV) program.

List of Acronyms

°F	Degrees Fahrenheit
CF	Chemical flocculation
CHW	Chilled water
CHWR	Chilled water return temperature
CHWS	Chilled water supply temperature
COC	Cycles of concentration
CWET	Condenser water entering temperature
CV	Coefficient of variation
DC	Direct current
DWT	Dynamic Water Technologies
EC	Electrocoagulation
gpm	Gallons per minute
GOF	Goodness-of-fit
hp	horsepower
HOR	Heat of rejection
IPMVP	International Performance Measurement and Verification Protocol
ITV	Industrial Technology Validation
kW	Kilowatt
kWh	Kilowatt-hour
MGD	Million gallons per day
mmhos	Millimhos
NRA	Nonroutine adjustment
NRE	Nonroutine event
psi	Pounds per square inch

R^2	Coefficient of determination
RMSE	Root mean square error
SFP	Sand filtration pump
TDS	Total dissolved solids
TSS	Total suspended solids
WWTP	Wastewater treatment plant
yr	Year

Executive Summary

Project Background

The U.S. Department of Energy Industrial Efficiency and Decarbonization Office's Industrial Technology Validation (ITV) program aims to identify and demonstrate the performance of new, emerging, and underutilized technologies in the industrial sector to help inform decisions towards accelerating commercialization and deployment.

This ITV demonstration investigated the performance of an early-commercial electrochemical water treatment technology on a cooling tower at an automotive plant. Cooling towers are vital equipment for dissipating heat from industrial processes, but they face challenges related to scaling, corrosion, and the growth of biological contaminants. Effective cooling tower water treatment is therefore essential in reducing these contaminants and other total suspended solids (TSS) and total dissolved solids (TDS). Various treatment systems, such as sand-based filters, centrifugal separators, and disc filters are available, each having its advantages and drawbacks. ElectroCell Systems, a filtration technology provider, offers an electrochemistry-based water treatment system that is skid-mounted and can be configured as a side-stream filtration system.

Facility Description and Scope

This study evaluated the performance of an ElectroCell water treatment system compared to an existing filtration system at a Nissan manufacturing facility in Canton, Mississippi. The facility originally used a sand filtration system to eliminate TSS from cooling tower water. During the evaluation, researchers discovered there was no sand media in the filters, and water quality was solely maintained through a daily timed backwash cycle. The ElectroCell system, in contrast, employs a multistage electrochemical process using low- and high-voltage ionizers to generate an electrostatic field, which removes TSS from the water. The scope of the evaluation included 10 chillers, each rated at 2,500 tons; six cooling tower cells; and the relevant water treatment systems. The boundary was determined after reviewing all equipment affected by the new technology.

Study Objectives

The evaluation's goal was to assess the impact of the ElectroCell filtration system on energy, water, and chemical usage of a chilled water system with an open loop cooling tower. The objectives of this study were to assess and quantify the following claims made by ElectroCell Systems:

- **Energy use.** Cleaner water leads to less scaling, resulting in less fouling and improved heat transfer within the system, reducing chiller and cooling tower energy consumption.
- **Water use**. The electrochemical-based system provides cleaner water, reducing the need for blowdown and makeup water.

- **Chemical use**. The system reduces the reliance on chemicals for water treatment as less makeup water is required.

Methodology

The evaluation methodology followed a measurement and verification strategy based on the International Performance Measurement and Verification Protocol Option B (retrofit isolation with all parameter measurements) through comprehensive measurements and analyses of the affected systems. Data was collected from October 2020 to October 2021, when the incumbent system operated, and for the period between October 2021 to October 2022, when the ElectroCell System operated.

It is important to note that the team found there was no sand media in the filtration system after the evaluation was complete and there was no additional data to adjust for this. Therefore, the incumbent system referred to in this validation is a unique situation where the sand filtration system was not used as intended and water quality was maintained through a daily purge by means of the system's daily backwash cycle.

The methodology involved the development of mathematical models for various systems:

- **Energy model.** This model predicted energy use based on chilled water load and condenser water entering temperature for each chiller. It also predicted cooling tower fan energy using heat of rejection (HOR) and cooling tower approach temperature as independent variables. The energy use by the respective filtration systems was also considered.
- **Water model.** The makeup water model used system HOR to predict makeup water use.
- **Chemical treatment model.** The model used cooling tower blowdown to predict chemical treatment use.

Each model's goodness-of-fit characteristics were evaluated to ensure satisfaction of IPMVP's statistical requirements. The energy, water, and chemical impacts were determined by comparing actual use with the ElectroCell system to modeled use with the incumbent system.

Project Results/Findings

This evaluation was designed to test ElectroCell System's claims that their technology reduces energy, water, and chemical treatment use compared to traditional systems. The ElectroCell System had no significant direct impact on chilled water system energy use, although the ElectroCell system itself, independent of its effect on the chilled water system energy use, used 95% less energy than the incumbent system. The water analysis showed 6%–17% less makeup water usage and less associated chemical treatment use; however, Nissan changed their chemical treatment plan during this evaluation, which could have influenced the results.

It should be noted that while the evaluation normalized to all pertinent available factors using rigorous M&V approaches and sound statistical techniques, other unknown factors outside of the evaluation boundary may have influenced the results. These findings are based on the evaluation of this technology at a given site, within a specific configuration, and under a defined set of operating conditions. It is important to note that any change in energy, water, or chemical use depends on the incumbent filtration system the ElectroCell system is replacing. Additionally, change depends on site-specific factors like ambient air quality, particulate matter presence, and seasonal variations. The quality of makeup water, including hardness, pH, and particulate levels, plays a significant role in water and chemical use, requiring careful consideration for implementation.

Table of Contents

List of Figures

List of Tables

SECTION 1

Introduction

1. Introduction

The U.S. Department of Energy's Industrial Efficiency and Decarbonization Office has introduced the Industrial Technology Validation (ITV) program, an initiative designed to address the need to identify, validate, and showcase the capabilities of new, emerging, and underutilized technologies in the industrial sector. The primary objective of ITV is to conduct robust evaluation and document performance data on these technologies to help expedite their commercialization and widespread deployment. By performing thorough validations and demonstrating the efficacy of these industrial technologies, the ITV program plays a crucial role in providing the necessary information for industry stakeholders to make informed decisions about their adoption. In turn, this will contribute to accelerating the transition towards more sustainable and efficient industrial processes.

Cooling towers are pivotal in dissipating heat generated by industrial processes. However, their operation encounters substantial challenges related to scaling, corrosion, and the proliferation of biological contaminants, all of which significantly impact operational costs. To address these issues, it is essential to implement effective cooling tower water treatment measures aimed at reducing the concentration of total suspended solids (TSS) and total dissolved solids (TDS) within the system. Several water treatment systems are available in the market, each with its own set of advantages and drawbacks (Duan et al. 2012). These systems include sand-based filters, centrifugal separators, and disc filters, among others. In this context, ElectroCell Systems offers a skid-mounted, electrochemical-based water treatment system that can be configured as a side-stream water filtration system. The system employs a three-stage process to remove TSS and control TDS.

Researchers conducted an evaluation of the ElectroCell water treatment system at the Nissan Canton plant in Canton, Mississippi, comparing its performance to an existing sand filtration system. It is important to note that the evaluation team learned after the testing period that there was no sand in the sand filtration system. While water passed through the empty vessels, water quality was maintained through a timed backwash cycle, purging water from the cooling tower loop. Thus, the baseline to which the new system's performance is compared is a unique, atypical situation.

The ElectroCell system employed a multi-stage electrochemical process to remove TSS and control TDS. The primary objective of this evaluation was to gauge the impact of the ElectroCell filtration system on energy consumption, water usage, and chemical usage within a chilled water system using an open loop cooling tower.

SECTION 2

Description: Facility, Technology, and Project

2. Description

2.1. Facility Description

The facility selected for this demonstration is the Nissan Canton plant in Canton, MS, which has been manufacturing vehicles since 2003. The plant has 6,500 employees and has produced more than five million vehicles. The facility operates 16 hours per day, from Monday through Friday, with a week of shutdown in summer and another in winter. The chilled water (CHW) plant serves a variety of heating, ventilation, and air conditioning (HVAC) loads throughout the facility. Some air handling units (AHUs) provide sensible cooling, while additional AHUs provide dehumidification to paint booths. The CHW plant is served by 10 2,500-ton chillers and a waterside economizer. The chillers and waterside economizer each have their own primary pump, although they are rarely used. Instead, 12 secondary pumps with variable frequency drives (VFDs) modulate their speed to pull water through the chillers. This pumping strategy is part of an optimized control program for efficient CHW pumping. CHW is maintained at 45°F. Heat is rejected via an open condenser water loop. The loop is served by one large cooling tower with six cells. Four 150-horsepower (hp) and two 250-hp cooling tower fans all use two-speed motors, controlling to a minimum condenser entering water temperature setpoint of 60°F.

2.2. Project Description

The measurement and verification (M&V) demonstration aimed to verify the impact on energy, water, and chemical use of a chilled water system due to the ElectroCell filtration system serving an open loop cooling tower.

2.3. Description of Incumbent System

Nissan Canton originally used a pressure sand filtration system that could remove particulates down to 10 microns. This system required daily backwashing, leading to excess water use. While a sand filter does not require much routine maintenance, the sand media typically must be replaced every several years to make up for the sand that is carried away during the backwash operation.

A traditional sand filter separates particulates from the water by pumping water through a pressurized vessel filled with sand media (Figure 1). The incumbent system at Nissan used a 75-horsepower (hp) pump, which ran continuously. Water passes through the sand media, where the particulates are captured, and the treated water is sent back to the cooling tower loop. This process is reversed during the backwashing cycle. Water is sent in the opposite direction, cleaning the filter by purging the particulate from the vessel. Backwashing is considered a source of blowdown, as the contaminated water is removed from the cooling tower loop.

Backwash volume control can either be time or demand based. With a time-based control, the system executes a backwash cycle on a timed schedule, for a defined duration of time. While reliable, this is less efficient than a demand-based control, which triggers a backwash cycle when the differential pressure in the vessel exceeds a pressure setpoint. The filtration system at the evaluation site originally employed a time-based control.

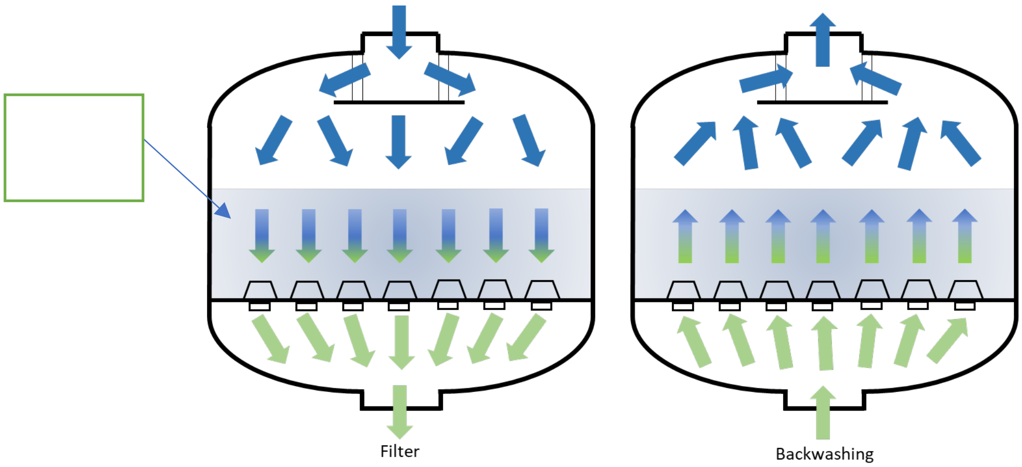


Figure 1. Pressure sand filter technology

Nissan employed a daily backwashing cycle for 15 minutes every morning at a rated flow of 1,000 gallons per minute (gpm), thereby purging 15,000 gallons daily. This significant volume of water kept the cooling tower loop clean, as the purged backwash volume constituted clean makeup water. This is important to note for the remainder of the report, as the incumbent system was not used as originally designed. However, based on information obtained from the site and their water contractor, the sand media in the filtration system gradually eroded from the system over time, thereby leaving no sand prior to this evaluation. As per the design intent, water quality was maintained by purging the water loop for 15 minutes daily. The daily purged water was then made up by clean makeup water. Although the sand media was removed, the system's timer control continued to operate the daily backwash purging cycle. The 15-minute duration was determined by the chemical treatment contractor and Nissan.

2.4. ElectroCell System Technology Description

Nissan installed the ElectroCell System in October 2021, replacing the incumbent system to treat the cooling water loop. Figure 2 shows a picture of the ElectroCell model (EC-6000) that was used for evaluation at Nissan.

The following is an excerpt of ElectroCell Systems' description of their technology from their application:

> *In the first stage, water is sent through a series of low-voltage direct current (DC) ionizers, which flocculate and coagulate suspended solids, creating larger particles from smaller particles. In the second stage, water is sent through static mixers, which collect particulate at the bottom of the mixer (Figure 3). The particulate is then removed through a bleed cycle, where water is sent through the mixers to empty the vessels for some time. The third stage uses a positively charged high-voltage DC ionizer cell, generating an electrostatic field. The*

electrostatic field collapses the laminar boundary of the water. Collapsing the laminar boundary should lead to better heat transfer.

Figure 2. ElectroCell Systems Model EC-6000 installed at Nissan Canton

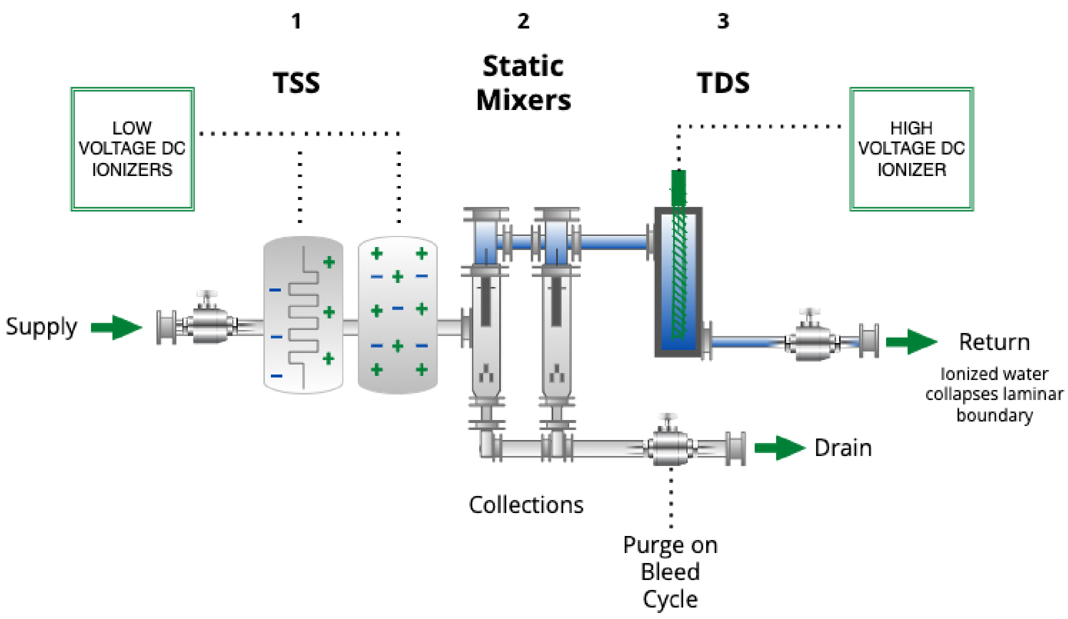


Figure 3. The three-stage ElectroCell system

SECTION

3

Technology Demonstration Intent

3. Technology Demonstration Intent

The primary objective of this study was to evaluate the energy, water, and chemical impact of implementing an ElectroCell system compared to the incumbent system within an open loop cooling tower. The evaluation focused on various performance metrics, comparing one year of operation with an incumbent system to one year with the ElectroCell system. The key performance indicators under evaluation are:

- Chilled water system performance (kilowatt-hours per year [kWh/yr])
- Makeup water use (gallons/yr)
- Water treatment ($/yr).

By comparing these key performance indicators, the study aims to provide insights into the effectiveness of the ElectroCell system in terms of energy, water, and chemical treatment requirements for the chilled water system served by the open loop cooling tower. Cleaner water leads to less scaling and fouling at the chillers and cooling towers. Theoretically, less fouling leads to better heat exchange at the chiller, which reduces the required lift at the compressor, resulting in better chiller performance.

The project scope includes chillers, cooling tower fans, and filtration systems. The CHW system is served by 10 chillers, each with a rated capacity of 2,500 tons. There are six cooling tower cells, four equipped with two-speed, 150-hp motors and the remaining two with two-speed, 250-hp motors.

SECTION 4

Evaluation Scope and Boundary

4. Evaluation Scope and Boundary

4.1. International Performance Measurement and Verification Protocol Option

The evaluation methodology followed the International Performance Measurement and Verification Protocol (IPMVP),[1] which was developed by the Efficiency Valuation Organization (EVO). The objective of the IPMVP is to develop a consensus approach to measuring and verifying efficiency investment.

The IPMVP outlines four options depending on the purpose, scope, and objective of the project. These four options are categorized into two general types: retrofit isolation and whole facility. Retrofit-isolation methods consider only the affected equipment or system, independent of the rest of the facility. Whole-facility methods consider the total building or facility energy use and de-emphasize specific equipment performance. The primary difference in these approaches is where the measurement boundary is drawn. Options A and B are retrofit-isolation methods, Option C is a whole-facility method, and Option D can be used as either, but is usually applied as a whole-facility method.

The M&V approach follows IPMVP Option B, retrofit isolation with all parameter measurements. Energy consumption, water, and chemical use were monitored by field measurements, trended for one year with the incumbent system and one year with the ElectroCell system. The ElectroCell system was installed in October 2021. The evaluation period includes one year of baseline with the incumbent technology from Oct. 28, 2020, to Oct. 27, 2021, followed by one year with the new ElectroCell system from Oct. 28, 2021, to Oct. 27, 2022 (Figure 4).

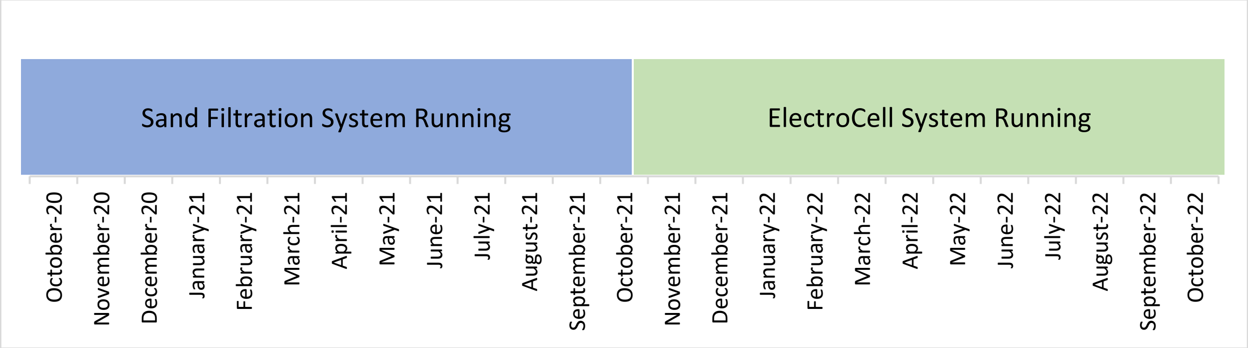


Figure 4. Timeline of evaluation period

4.2. Measurement Boundary Descriptions

The system boundary includes mechanical equipment, the chemical treatment program, and the automated controls system for both the chilled water system and chemical

[1] For more information about IMPVP standards, visit https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp.

treatment program (Figure 5). More specifically, the boundary includes the chillers, filtration systems, cooling tower, and chemicals.

4.3. Interactive Effects Beyond the Measurement Boundary

The evaluation and the analysis solely focused on the systems or components within the boundary described above. The effects of the systems outside the boundary are assumed to have a minimal impact on the systems and variables within the boundary that are considered for this evaluation.

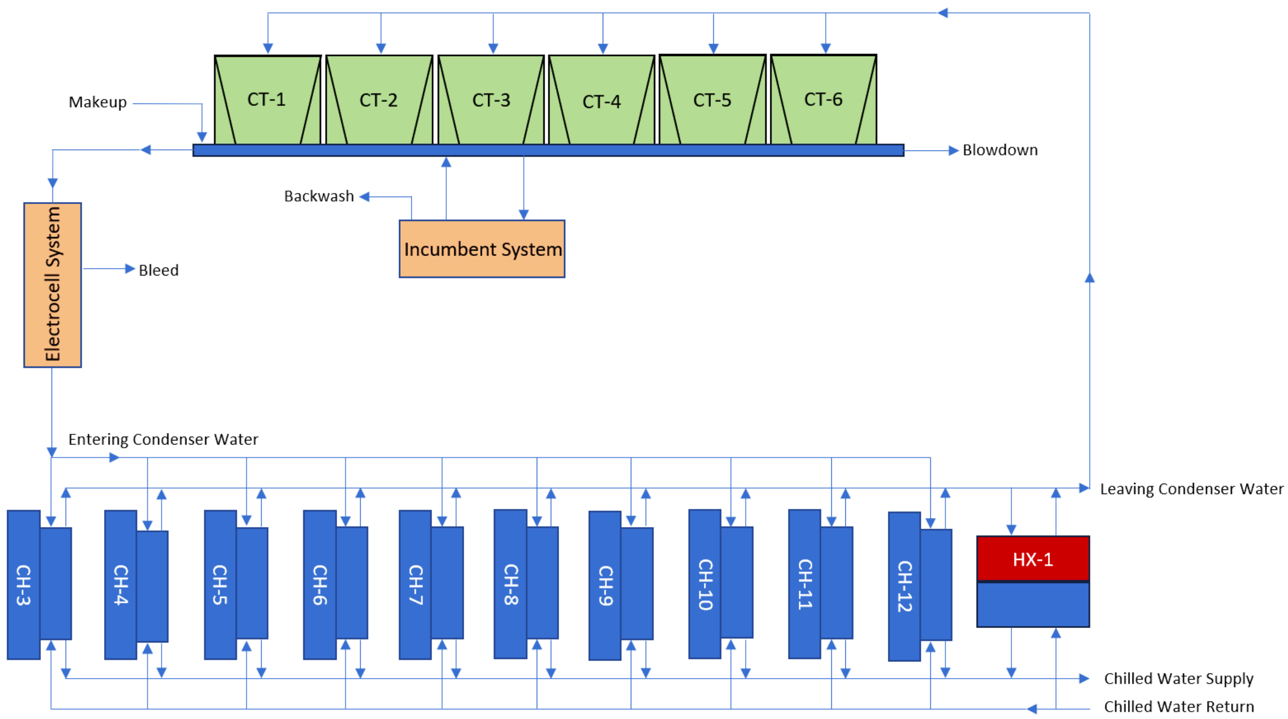


Figure 5. Measurement boundary for the CWS evaluation

SECTION

5

Data Collection and Adjustments

5. Data Collection and Adjustments

5.1. Data Collection

Based on the evaluation scope and boundaries, a list of data points was developed to assess the ElectroCell system's impact versus the incumbent system (Table 1). Most data were collected during a two-year period, from October 2020 through October 2022. (Data from October 2019 through October 2020 was also used to replace data from an erroneous sensor – see section 5.2.1 for a detailed explanation). Most data were obtained from Nissan through their existing data acquisition and control systems. Other data was obtained by installing additional loggers to supplement Nissan's data. ElectroCell Systems provided data from their skid for one year. The evaluation team conducted two site visits, in October 2021 and October 2022. Data collected for this evaluation is summarized in Table 1 below.

Table 1. Summary of Data Points

System	Data Point	Units	Sampling Rate
Chilled Water System (CHW)	Chiller load	Tons	Hourly
	Chiller power	kW	1 hour
	Evaporator entering water temperature	°F	Hourly
	Evaporator leaving water temperature	°F	Hourly
	Evaporator differential pressure	psi	Hourly
	Evaporator flow	gpm	Hourly
	Condenser entering water temperature	°F	Hourly
	Condenser leaving water temperature	°F	Hourly
	Condenser differential pressure	psi	Hourly

System	Data Point	Units	Sampling Rate
	Condenser flow	gpm	Hourly
	Cooling tower fan power	kW	Hourly
	Waterside economizer entering temperature	°F	Hourly
	Waterside economizer leaving temperature	°F	Hourly
	Waterside economizer evaporator flow	gpm	Hourly
	Waterside economizer entering condenser temperature	°F	Hourly
	Waterside economizer leaving condenser temperature	°F	Hourly
	Waterside economizer condenser flow	gpm	Hourly
	CHW system CHW load	Tons	Hourly
	Total chiller power	kW	Hourly
Filtration Systems	Incumbent system pump power	kW	Hourly
	ElectroCell power	Amps	Hourly
	ElectroCell pump VFD speed	(%)	Hourly
	Dry bulb temperature	°F	Hourly

System	Data Point	Units	Sampling Rate
Outside Air Conditions	Wet bulb temperature	°F	Hourly
	Outdoor air relative humidity	%RH	Hourly
Water	Makeup water usage	gallons	Daily
	Blowdown water	gallons	Daily
	Tower conductivity	mmhos	Daily
Chemical Treatment	3DT-128 (Inhibitor)	gallons	Weekly
	3DT-325 (Inhibitor)	gallons	Weekly
	3DT-337 (Inhibitor)	gallons	Weekly
	Bleach (Biocide)	gallons	Weekly

5.2. Data Cleaning

Data cleaning is a crucial step in the data preparation process and the foundation for subsequent data analysis. It involves identifying and rectifying errors or inconsistencies in datasets to ensure that data is accurate, reliable, and suitable for analysis. Cleaning was necessary when data sets were incomplete or included outlier data.

5.2.1. Energy

The chiller data used to develop the predictive incumbent technology models was scrubbed to include only data from when the respective equipment was operational. All null data was removed to create an accurate model to predict energy use for each chiller.

There was missing power data for Chiller 11 from Oct. 28, 2020, to Aug. 11, 2021, during the baseline period when the incumbent system was evaluated. To estimate the missing power data, a model was developed for Chiller 11 with available data from Aug. 11, 2021, to Oct. 27, 2021. This model met IPMVP statistical requirements for goodness of fit. While this is a shorter time period than that for the other equipment, this period did include warm summer weather into cooler fall weather. This range of data was adequate, as it included an ample range of loads to create an accurate part-load model.

The CHW load for Chiller 12 data was inflated, as the evaporator entering water temperature sensor slowly fell out of calibration and needed to be serviced (Figure 6). While the chiller capacity is 2,500 tons, the calculated chiller load reached as high as 6,000 tons at times. Data from 2019 and 2020 was used to create a predictive model for Chiller 12, before the sensor fell out of calibration.

This issue persisted until it was recalibrated on Feb. 23, 2022 (Figure 6). All Chiller 12 data that was collected before the sensor was recalibrated, including chiller power, was excluded from the evaluation.

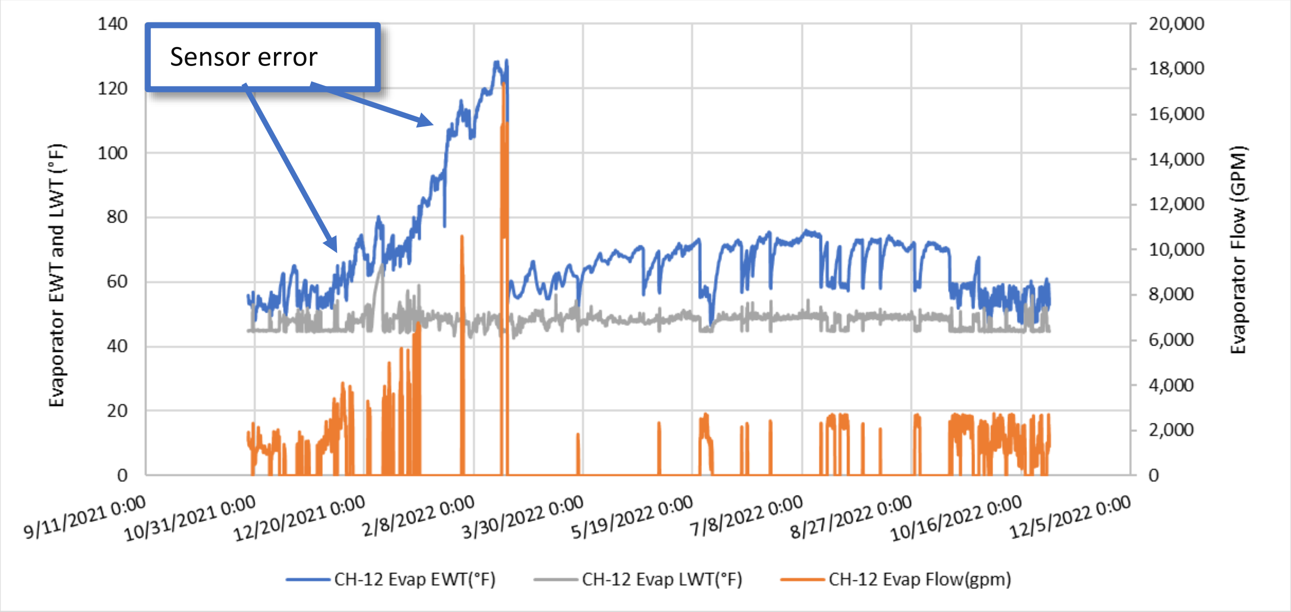


Figure 6. Chiller 12 temperature data from ElectroCell performance period

In addition, the power meter on the ElectroCell system was missing power data from Oct. 28, 2021, to Dec. 31, 2021. An average of ElectroCell system's power consumption was taken from Jan. 1, 2022, to Oct. 28, 2022, and then used to replace the missing data from the beginning of the performance period.

5.2.2. Water

Nissan did not track the backwash volume of the incumbent system. The backwash volume was a source of blowdown. According to Nissan's chemical treatment contractor, they backwashed for 15 minutes at 1,000 gpm every morning. The backwash volume is assumed to be 15,000 gallons per day, which was added to the volume captured by the blowdown meter for the incumbent system performance period. This was deemed to be a sound approach as the backwash cycle was on a timer, and the backwash flow rate was confirmed by the chemical treatment contractor. The combined volume was used for the chemical treatment model, which used blowdown as an independent variable.

SECTION 6

Calculation Methodology

6. Calculation Methodology

6.1. Evaluation Methodology

The evaluation methodology, which follows IPMVP Option B (retrofit isolation with all parameter measurements), analyzed field data collected from the impacted systems to construct predictive models for energy, water, and chemical use (Figure 7). Specifically, it compares the modeled energy, water, and chemical use with the incumbent system to actual usage with the ElectroCell System.

Collected data was used to create predictive models representing use of the incumbent system. These predictive models were then compared to actual data from ElectroCell system operation. The models predict use of the incumbent system as if it continued operating during the period of ElectroCell system operation. The purpose was to account for any potential variations in operating conditions and assess the impact of the ElectroCell system.

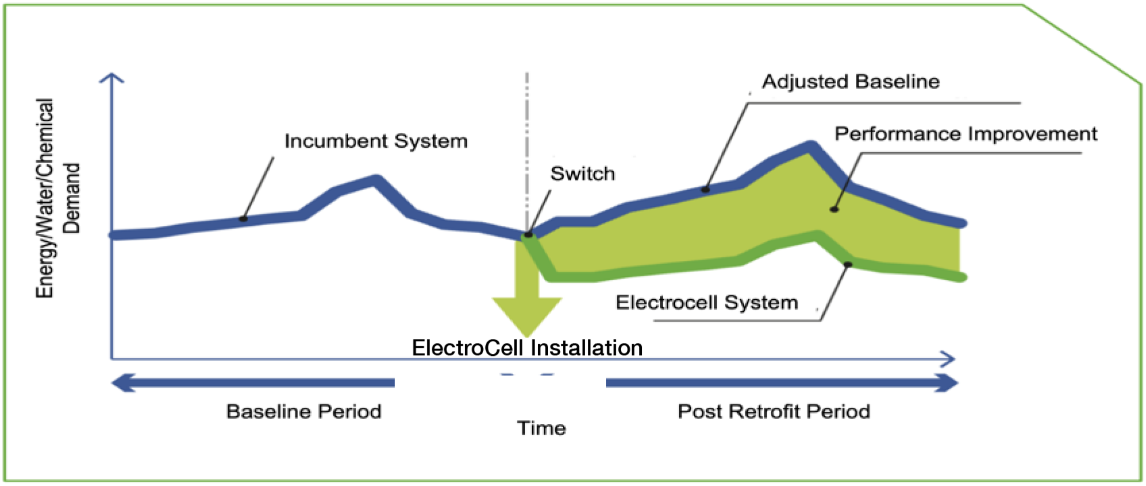


Figure 7. Evaluation methodology

These adjustments, which allow a fair comparison of energy and water usage in two different periods, are fundamental to IPMVP's methods for calculating energy and water savings. The savings (or "performance impact") is calculated by comparing the energy and water use with the incumbent system to the energy and water use with the ElectroCell system after making "routine and non-routine adjustments" (see below) to account for any changes between data collection periods, as shown in the following equation.

$$Savings\ Impact = Energy\ and\ Water\ Use_{Incumbent} - Energy\ and\ Water\ Use_{Electrocell\ System} \pm Routine\ Adjustments\ \pm Non - Routine\ Adjustments$$

6.1.1. Routine Adjustments

Routine adjustments are used to account for expected variations in independent variables (e.g., outdoor temperatures, occupancy levels, day-type, and production metrics). Making routine adjustments involves developing a mathematical model to correlate energy or water use to the appropriate independent variables. This approach can be used to predict energy or water use in the absence of a new technology, which can then be compared to actual energy or water use to calculate the performance improvement attributable to the new technology. The following section, on model development, describes the routine adjustments made for the energy consumption associated with the chilled water system, as well as the water and chemical usage of the open cooling tower system.

6.1.2. Nonroutine Adjustments

Nonroutine adjustments (NRAs) are made to account for nonroutine events (NREs), which are unexpected changes in energy use within the measurement boundary that are unrelated to the energy measure or technology being evaluated.

Nissan Canton switched from city water to well water from July 29, 2022, to Sept. 11, 2022, (i.e., during the ElectroCell performance period) due to a water shortage in the county. The well water was significantly dirtier in terms of TDS compared to the original city water source, leading to considerably more makeup water use and, in turn, blowdown. Makeup and blowdown volume from the rest of the year were used to predict what the water use would have been had Nissan Canton not switched water sources.

6.2. Model Development

6.2.1. Energy Use

The selected key performance variable for the CHW system energy model was electricity consumption. This includes all the electricity consumed by the relevant components of the CHW system, including the cooling tower fans and filtration pumps.

Each component of the CHW system was modeled separately to calculate total system energy consumption. To understand the relationships, independent variables were identified using engineering principles and statistical analysis was conducted to validate their significance in terms of their predictive capability for the key performance variable. Separate models were developed to predict energy for each of the 12 chillers and the cooling tower fans.

Chiller Energy

Based on the analysis, chilled water load (CHW load) and condenser water entering temperature (CWET) were found to be the most significant variables in predicting chiller energy use. Chilled water load represents the amount of cooling the chiller provides, whereas CWET is the temperature of the condenser water entering the chiller, which affects chiller performance and is affected by outdoor air wet bulb temperature.

CHW Load is calculated for each of the chillers using the following formula (Turner 2004):

$$CHW\ Load\ (Tons) = \frac{500 * Flow\ (gpm) * (CHWR - CHWS)\text{°F}}{\frac{12{,}000\,\frac{Btu}{h}}{1\ Ton}}$$

Where Flow is the chilled water flow rate in gallons per minute, CHWR is the chilled water return temperature in °F, and CHWS is the chilled water supply temperature in °F. Separate models were created for each of the 12 chillers.

Based on the regression model, Chiller Power (kW) can be expressed as:

$$Chiller\ Power\ (kW) = CHW\ Load\ (Tons) * x_1 + CWET\ (\text{°F}) * x_2 + c$$

Where x_1 and x_2 are the regression coefficients for the independent variables CHW Load and CWET, respectively, and *c* is the intercept term. The coefficients and intercept terms for each model are summarized in Table 2 below. The regression coefficients (x_1 and x_2) represent the change in the dependent variable (Chiller Power) resulting from a one-unit change in the predictor variable, with all other variables held constant.

The goodness-of-fit (GOF) characteristics for all models are assessed using the following metrics. (See additional background and information in Appendix A.)

- Coefficient of determination (R^2): This metric measures the extent to which variations in the dependent variable *y* can be explained by the regression model.
- Coefficient of variation of root mean squared error (RMSE): This metric describes how well the model fits the data. It is not affected by the degree of dependence between the independent and dependent variables, making it more informative than R^2 for situations where the dependency is relatively low.
- Net determination bias (Bias): This is the percentage error in the model predicted energy use compared to actual energy use. The bias for all the models was calculated to be zero.

All GOF metrics for this model—including R^2 (85%–98%), zero bias, and CV_{RMSE} (3%–10%)—are shown in Table 3 and meet IPMVP criteria. For example, the regression analysis for Chiller 3 indicates that the coefficient of determination (R^2) is 95%, meaning that 95% of the variation in chiller power draw can be explained by the model using chiller load and CWET as independent variables. This meets IPMVP criteria and was adequate for calculating savings.

The actual chiller energy used to create the predictive model is compared to predicted energy use in Figure 8, which shows the predictive model aligns with actual use.

Table 2. Regression Model Characteristics for Each Chiller

Chiller	Chiller Load Coefficient (x_1)	CWET Coefficient (x_2)	Intercept (c)
3	0.46	5.58	-370.9
4	0.46	7.07	-303.1
5	0.34	8.80	-418.6
6	0.44	8.08	-480.7
7	0.47	7.89	-306.3
8	0.49	3.31	-127.3
9	0.42	7.58	-415.2
10	0.39	8.78	-485.1
11[2]	0.47	0.66	48.6
12	0.41	4.67	-223.6

Table 3. Goodness-of-Fit Characteristics for Each Chiller

Parameter	IPMVP Recommendation	3	4	5	6	7	8	9	10	11	12
R^2	>=75 %	95%	97%	85%	98%	95%	97%	94%	91%	98%	95%
Bias	0	0	0	0	0	0	0	0	0	0	0
CV_{RMSE}	<=20 %	6%	5%	9%	3%	6%	5%	6%	10%	4%	9%
Chiller Load - t statistic - slope	>=2	147.4	214.5	100.9	230.6	112.1	115.7	146.2	72.9	118.8	118.5
CWET - t statistic - slope	>=2	16.5	32.1	25.3	41.7	20.6	10.3	23.9	17.8	1.8	11.8

[2] There was missing power data for Chiller 11 from Oct. 28, 2020, to Aug. 11, 2021, during the baseline period. This much smaller data set that was used for model development resulted in regression coefficients looking different compared to the coefficients for some of the other chillers.

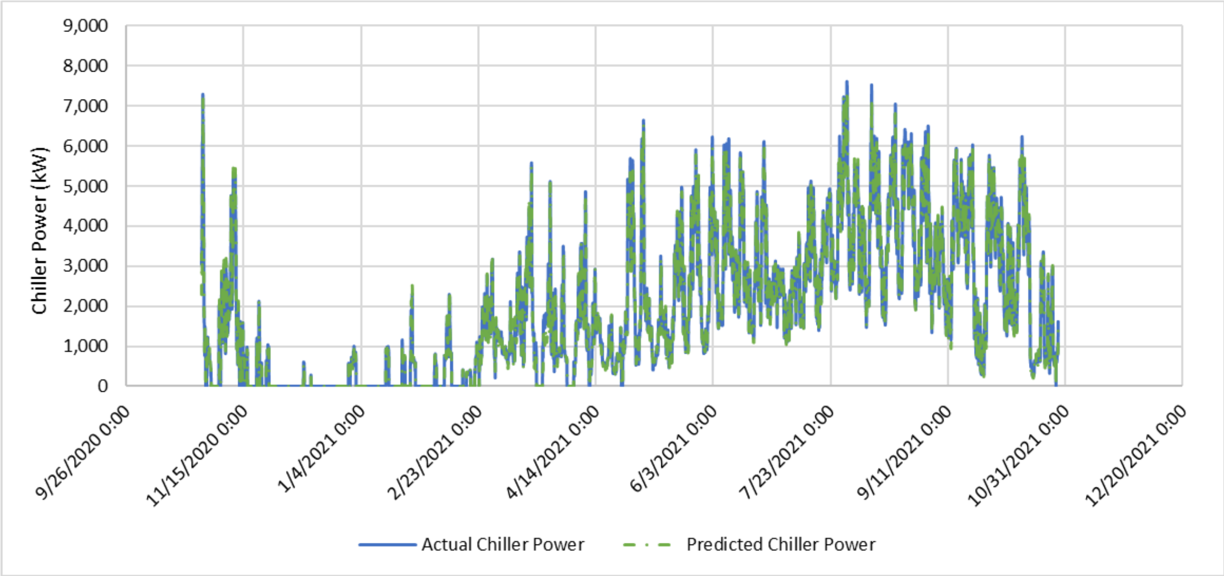


Figure 8. Actual versus predicted CHW energy use for the incumbent system

Cooling Tower Energy

A model was developed to predict the cooling tower fan energy as a function of the independent variables. The heat of rejection (HOR) and cooling tower approach temperature were found to be the most statistically significant independent variables.

HOR is the total heat introduced to the cooling tower. The cooling tower loop at Nissan Canton rejects heat from the 12 chillers. HOR is one of the main drivers of cooling tower fan energy consumption. It is also weather-dependent, as the CHW system serves air handling units that must condition outdoor air. HOR, in thousands of British thermal units (BTU) per hour (MBH), was calculated using the following formula:

$$HOR\ (MBH) = \left(CHW\ Load\ (Tons) * \frac{12MBH}{1\ Ton}\right) + \left(Chiller\ Power\ (kW) * \frac{3.412\ MBH}{1\ kW}\right)$$

Where CHW Load is the total cooling load of the chillers and Chiller Power is the total power draw by the chillers.

Cooling Tower Approach is the temperature difference between the CWET and ambient wet-bulb temperature (WBT), as expressed in the following:

$$Cooling\ Tower\ Approach\ (°F) = CWET(°F) - WBT(°F)$$

The CWET achievable by the cooling tower is constrained by ambient wet-bulb temperature for a given cooling tower approach. While HOR represents the load on the cooling tower, the cooling tower approach represents the relationship between CWET and ambient conditions.

Based on the regression analysis, the cooling tower power can be predicted in terms of the load on the cooling tower (heat of rejection) and weather conditions (cooling tower approach). Predicted cooling tower power is calculated using the following equation:

$$Cooling\ Tower\ Power\ (kW) = 0.001649 * HOR - 5.6578 * Approach + 140.1984$$

Where HOR is the heat of rejection for the cooling tower and Approach is the cooling tower approach temperature. The model details and goodness of fit (GOF) metrics for this model are shown in Table 4. Both independent variables (HOR and cooling tower approach temperature) were found to be the most statistically significant based on the regression analysis. Cooling tower range, cooling tower leaving temperature, and ambient wet bulb temperature were also considered as independent variables. Cooling tower range was not as statistically significant as heat of rejection, as it only considers the temperature difference across the cooling tower and not cooling tower flow. Cooling tower approach is calculated based on the cooling tower leaving temperature and wet bulb temperature and was therefore more statistically significant. Using any of these independent variables in conjunction with heat of rejection and cooling tower approach would also result in collinearity in the model.

Table 4. Goodness-of-Fit Characteristics of the Cooling Tower Model

Paramete r	Description	IPMVP recommendation	Cooling Tower
R^2	Coefficient of determination	>= 75%	68%
Bias	Net determination bias	0	0
CV_{RMSE}	Coefficient of variation of the root mean squared error	<= 20%	37%
HOR - t stat	Chiller load - t statistic - slope	>= 2	140.1984
Approach - t-stat		>= 2	62.67
Int - t-stat	CWET - t statistic - slope	>= 2	87.79

The coefficient of determination (R^2) and CV_{RMSE} of the model do not quite meet IPMVP requirements. The cooling tower fans cycle between two speeds to maintain the CWET setpoint. The actual cooling tower energy consumption is compared to predicted use in Figure 9 below. The stepped-value nature of the data may indicate why the cooling tower model statistics were poorer than the chiller models.

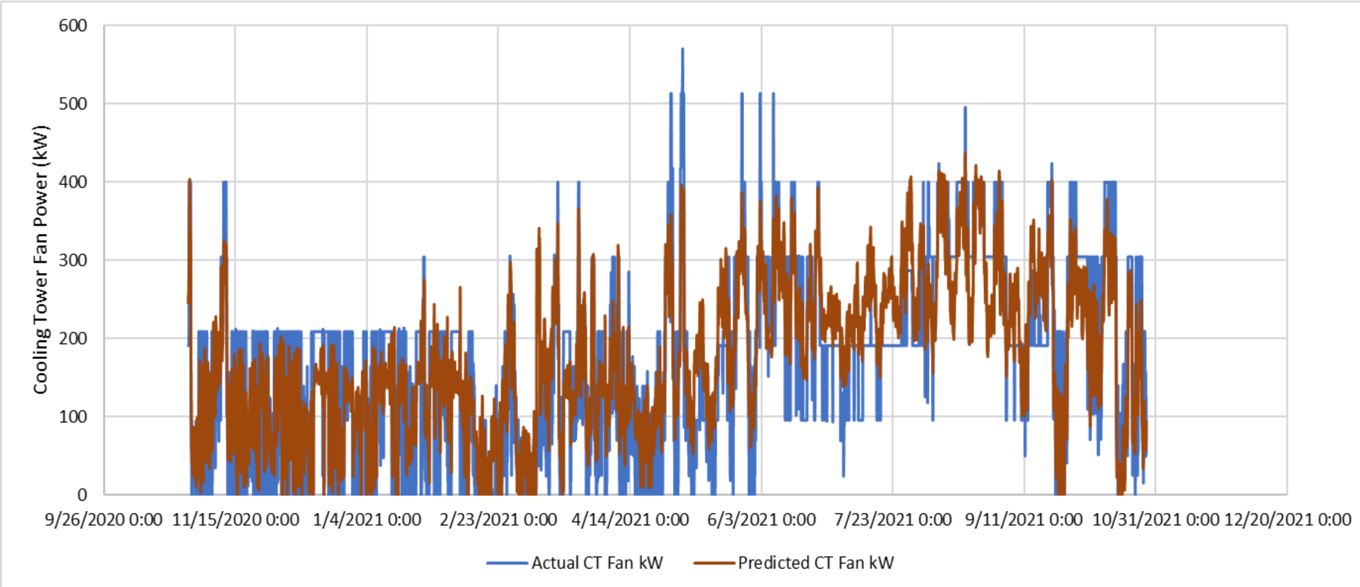


Figure 9. Actual versus predicted cooling tower energy use for the incumbent system

However, it is important to note that a low R^2 value and higher CV_{RMSE} does not necessarily mean that a model is not useful for calculating savings. The coefficient of determination, R^2, measures the extent to which variations in the dependent variable *y* can be explained by the regression model. Also, higher savings uncertainty specified by higher CV_{RMSE} indicates the error band in the model is higher than usual. The absolute cut off criteria provides guidelines to assess the model strength in its ability to predict energy or water use. It should be noted, however, that the desired end is not baseline model development, but rather the calculation of savings to assess the impact of the technology. The strength of the model should be reviewed in relation to the savings in terms of the ratio of the expected uncertainty in the savings to the total savings. ASHRAE Guideline 14 requires that the savings uncertainty be less than 50% of the annual savings at 68% confidence. IPMVP recommends the savings be more than twice the standard error of the baseline value. Additional uncertainty analysis using the actual savings is described in the results section (Section 8).

Filtration Energy

The control system actively measured the power consumption of the incumbent system. Trend data for the incumbent system was collected from Oct. 28, 2020, to Oct. 27, 2021, and showed that the system ran continuously. The incumbent system used a constant-speed, 75-hp motor whose average draw was 59.5 kW. A power meter was installed in the ElectroCell panel when the ElectroCell system was installed, but this meter was missing data from Oct. 27, 2020, to Dec. 8, 2020. The vendor recommends occasionally adjusting the flow rate on the ElectroCell system, usually before or after the cooling season, as more condenser flow is required during the cooling season when additional chillers are operating. This was evident in the power data collected, in that the power draw almost doubled beginning in June 2022 (Figure 10). Average power consumption was taken from before the flow rate was adjusted to estimate usage for the period with missing data.

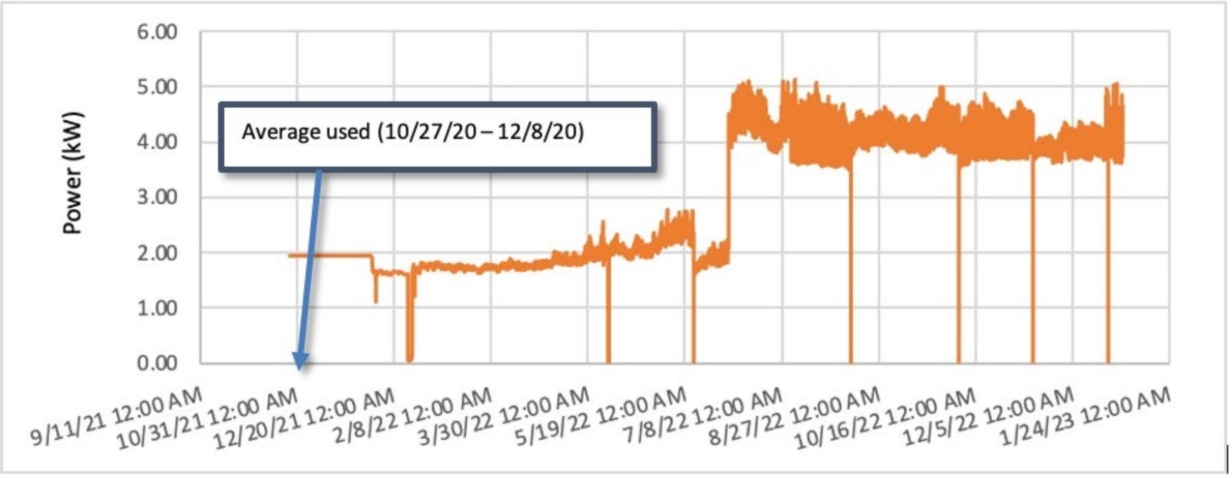


Figure 10. ElectroCell system power draw

6.2.2. Water Use

A weekly model was developed to predict the makeup water use as a function of independent variables. Heat of rejection (HOR), which is a function of the load on the cooling tower, was the most significant factor in predicting makeup water use. Even though daily data was available, the daily total use was manually read from a totalized meter. The difference between the previous day's reading and the current day's reading was used to calculate daily use. Some days had missing readings, but rolling up to a weekly level eliminated this issue.

HOR is the total amount of heat introduced to the cooling tower and is the primary driver of makeup water use. It is also weather-dependent, as the CHW system serves HVAC loads. HOR was calculated using the following formula:

$$HOR\ (MBH) = CHW\ Load\ (Tons) * \frac{12MBH}{1\ Ton} + Chiller\ Power\ (kW) * \frac{3.412\ MBH}{1\ kW}$$

Where CHW Load is the chillers' total cooling load and Chiller Power is the total power consumption of the chillers.

The model to predict makeup water use with the incumbent system to account for any changes in the operating conditions can be defined as follows:

$$MU = 0.14 * HOR + 99{,}612$$

Where MU is the makeup water use and HOR is heat of rejection expressed in MBH. The significance of the independent variable and goodness of fit characteristics of the makeup water regression model are shown in Table 5.

Table 5. Goodness-of-Fit Characteristics of the Makeup Water Use Model

Parameter	Description	IPMVP recommendation	Value
R^2	Coefficient of determination	>= 75%	86%
CV_{RMSE}	Coefficient of variation of the root mean squared error	<= 20%	19%
HOR - t stat	HOR - t statistic - slope	>= 2	18.09
t-stat	t-statistic - intercept	>= 2	1.23
Bias	Net determination bias	0%	0%

Most of the GOF metrics met IPMVP criteria, validating the model as adequate for calculating water use savings. The intercept term was retained in the regression model even though t-statistic was found to be not significant, in order to not force the regression line through the origin. The actual water use data is compared to the predictive model in Figure 11 to illustrate the model's validity.

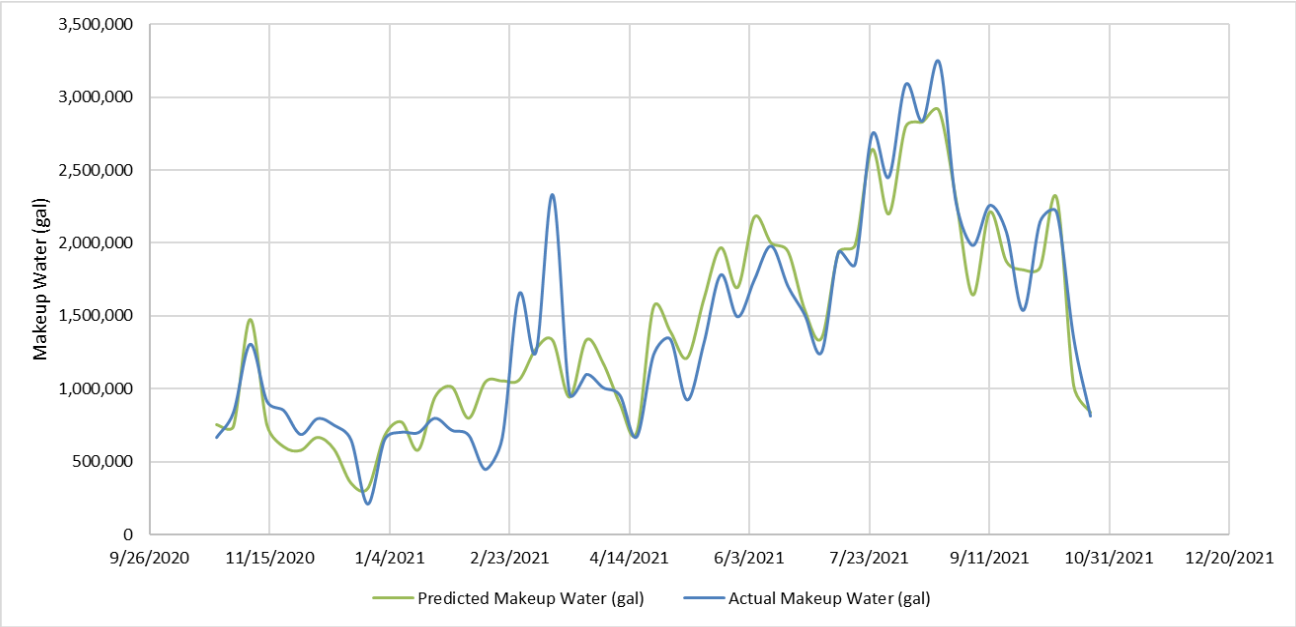


Figure 11. Actual vs. predicted makeup water use

Water Model: Nonroutine Adjustments

With the predictive makeup water model for the incumbent system defined for routine adjustments, an NRA was needed to account for the ElectroCell system's change in water source (NRE) from July 29, 2022, to Sept. 11, 2022. The actual makeup water use data for this period was replaced by a predictive model using HOR as the independent variable. This model developed was based on data from the remainder of the year, when the cooling tower used the original water source. The predictive model accounting for the new water source as an NRA along with actual data is shown in Figure 12. The adjusted makeup water use with the ElectroCell system is compared to the original makeup water use in Figure 13.

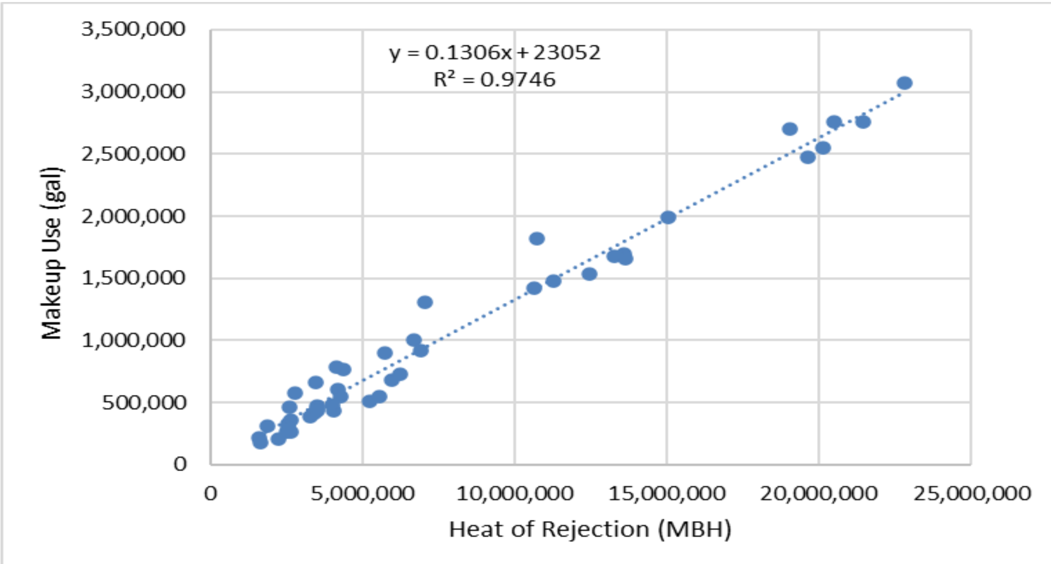


Figure 12. ElectroCell predicted makeup water use adjusting for water source NRE

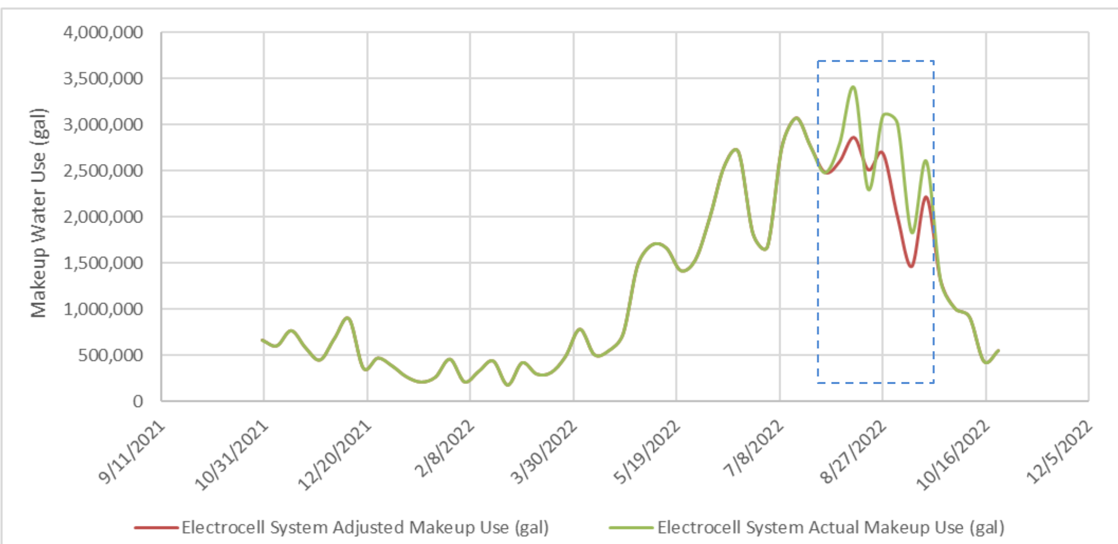


Figure 13. ElectroCell system adjusted makeup water use

6.2.3. Chemical Treatment Use

During this evaluation, Nissan used inhibitors 3DT-128, 3DT-325, 3DT-337, and bleach. Bleach is used as a biocide, while the other three chemicals are used as inhibitors. It should be noted that Nissan eliminated the use of 3DT-128 on May 1, 2021, during the incumbent sand filtration pump (SFP) system performance period. All other chemicals saw an increase in use during the ElectroCell performance period. The change to the chemical treatment program during the evaluation adds uncertainty to the results that is difficult to quantify. The actual chemical treatment use for both performance periods is summarized in Table 6 below. Note a negative value in Table 6 indicates increase in usage.

Table 6. Actual Chemical Treatment Use per Period

Actual Chemical Treatment Use	3DT-128	3DT-325	3DT-337	Bleach
SFP Actual (gal/yr)	1,103	85	455	4,215
ElectroCell Actual (gal/yr)	0	245	680	6,855
Change (gal/yr)	1,103	-160	-225	-2,640

Chemical treatment costs were normalized to weekly blowdown. Blowdown is the water in the cooling tower loop that is removed when the water conductivity reaches its threshold. As water evaporates from the cooling tower, dissolved solids become highly concentrated in the loop, which causes the conductivity of the cooling tower loop to rise. Cooling tower water is removed through blowdown and replaced with clean makeup water to maintain the conductivity setpoint. With this understanding, blowdown was selected as the independent variable. The water quality in the loop solely impacts blowdown.

The backwash volume of the incumbent system and the bleed volume of the ElectroCell system were included in the blowdown volume to study the full impact of the ElectroCell system. Based on discussion with plant personnel, the incumbent system backwashed daily for 15 minutes at 1,000 gpm, which equates to 15,000 gal/day or 5,475,000 gal/yr. The ElectroCell system bleed cycle was changed for the cooling season, but trend data showed the annual bleed volume of the system was 149,312 gal/yr.

As with the water model, blowdown also needed a non-routine adjustment to account for the NRE water source change between July 29, 2022, and Sept. 11, 2022. A blowdown per gallon of makeup water use rate was calculated for all weeks when the ElectroCell system used the original water source. This equated to 0.14 gallons of blowdown per gallon of makeup water. Adjusted blowdown was calculated by applying this rate to the ElectroCell system adjusted makeup gallons, calculated in the water model.

To calculate chemical treatment savings, a per gallon blowdown rate was then calculated for each chemical for the one-year period with the incumbent system (SFP) and applied to the blowdown use in the one-year period with the ElectroCell system (Table 7).

Table 7. Chemical Treatment Use Per Adjusted Blowdown

Chemical	SFP Chem Treat (gal)	SFP Blowdown + Backwash (gal)	SFP Chem Treat / Blowdown (gal/ million gal)	ElectroCell Blowdown + Bleed (gal)	EC Chem Treat / Blowdown (gal/ million gal)	SFP Predicted Chemical Use (gal)	EC Actual Chemical Use (gal)	EC Chem Treat with NRE Adjustment (gal)
3DT 128	1,103	10,404,000	106	8,621,862	0	914	0	0
3DT 325	85		8		28	70	245	235
3DT 337	455		44		79	377	680	652
Bleach	4,215		405		795	3,493	6,855	6,571

6.3. Summary of Important Assumptions

This analysis is based on actual measured data from Nissan's control system, along with supplemental power metering on the ElectroCell system to augment existing data.

ElectroCell power data was missing from Oct. 27, 2021, to Dec. 8, 2021. It is assumed that the average power use for this period was consistent with the rest of the winter and spring operation until the setpoint was changed on June 10, 2022.

SECTION 7

Measurement and Verification Results

7. Measurement and Verification Results

This evaluation compared the effect of the ElectroCell system on an open cooling tower compared to the incumbent system at Nissan Canton. Changes in energy, water, and chemical treatment use were quantified by comparing actual use (with the ElectroCell system) to predicted use (as if the incumbent system remained in operation). The results are summarized below.

7.1. Energy Use

The ElectroCell system had no meaningful impact on chiller and cooling tower energy use but consumed significantly less energy than the incumbent system.

- **Chillers.** The chiller energy model showed a slight increase in energy use with the ElectroCell system compared to the incumbent system (Table 8). However, when uncertainty is factored in, this slight increase in energy use is assumed to be negligible and attributable to randomness in data.
- **Cooling tower.** The cooling tower energy model also showed a very slight increase in energy use with the ElectroCell system. Considering the model statistics and uncertainty, the evaluation was unable to prove whether the ElectroCell system affected cooling tower energy use.
- **Filtration systems.** The ElectroCell system used 95.1% less energy than the incumbent system. The incumbent used a 75-hp constant speed motor that ran continuously. In contrast, the ElectroCell system used a 10-hp pump controlled by a VFD, which ran at a reduced speed.

Table 8. Total Energy Savings for the Chilled Water System

	Predicted Energy Consumption with Incumbent System (kWh/yr)	Actual Energy Consumption with ElectroCell System (kWh/yr)	Impact kWh/yr	Impact (%)
Chiller Energy	18,273,430	18,287,651	-14,221	~0%
Cooling Tower Fan Energy	1,772,301	1,786,342	-14,041	~0%
Filtration System Energy	521,042	25,295	495,746	95.1%

Itemized savings for the chillers and cooling tower are shown in the appendix.

7.2. Water Use

The analysis of makeup water usage by the cooling tower showed that the total annual makeup water consumption for the ElectroCell system period was 62.4 million gallons. This was 6%–17% less than the incumbent system's predicted water usage (Table 9) and was found to be statistically significant.

Table 9. Annual Makeup Water Use, Incumbent System Versus ElectroCell System

	SFP Predicted Makeup Water (Mgal/yr)	ElectroCell Adjusted Makeup Water (Mgal/yr)	Impact (Mgal/yr)	Impact (%)
Makeup Water	70.4	62.4	4–11.9	6%–17%

It should be reiterated that the incumbent system had no sand media during the evaluation. The incumbent system still employed a daily backwash cycle controlled by a timer, purging cooling tower water from the loop. With this atypical operation, the fractional savings uncertainty of the predictive model was found to be acceptable (<50%); the excessive purging created additional uncertainty in the model, as the daily purging volume was constant throughout the year and not controlled to any water quality setpoints in the loop (e.g., conductivity).

Lastly, the impact on water use can further be explained by looking at cycles of concentration (COC) in Figure 14. COC is the ratio of the concentration of dissolved solids in the blowdown water compared to the makeup water. Theoretically, a ratio of 1 would mean that all water in the loop is makeup water, and no water is being recirculated. Maximizing cycles of concentration is key for water conservation, as water gets more use before its removal from the system.

With the incumbent technology, the average COC was around 4.0 during the cooling season and 2.0 in the winter. These swings can be attributed to the fact that Nissan purged a constant amount of daily volume of water year-round, but the cooling tower evaporated much less water in the winter at lower loads.

With the installation of the ElectroCell System, the COC increased to about 6.0, as Nissan raised the conductivity setpoint in the loop from 700 to 1,000 mmhos, and blowdown was controlled to a conductivity setpoint rather than daily purges. With the daily purge of the incumbent technology, the conductivity of the loop very rarely approached 700 mmhos.

Figure 14. Cycles of concentration, incumbent versus ElectroCell systems

Table 10. Chemical Treatment Usage, Incumbent System Versus ElectroCell System

Chemical	SFP Predicted Chem Treat (Gal)	SFP Predicted Chem Treat Cost ($)	EC Chem Treat With NRE Adjustment (Gal)	EC Adjusted Chem Treat Cost ($)	Annual Savings (Gal)	Annual Cost Savings ($)	Annual Percent Savings (%)
3DT 128	914	$7,247	0	$0	914	$7,247	100%
3DT 325	70	$401	235	$1,337	-164	($936)	-233%
3DT 337	377	$3,102	652	$5,363	-275	($2,261)	-73%
Bleach	3,493	$953	6,571	$1,794	-3,078	($840)	-88%
Total	4,855	$11,703	7,458	$8,494	-2,603	$3,210	27%

7.3. Chemical Treatment Use

The evaluation found the ElectroCell system resulted in total chemical treatment cost savings of 27% (Table 10). It should be reiterated that Nissan eliminated the use of the inhibitor 3DT-128 during the evaluation. All chemical treatment savings come from the elimination of 3DT-128. There was an increase in use with the ElectroCell system for the remaining two inhibitors (3DT-325 and 3DT-337) and bleach. Based on the information obtained from the site and the water contractor, each of the chemicals had a controller that injected chemicals based on the observed water chemistry. The chemical data used to calculate the impact were based on manually entered data recorded at the operator's discretion. This lack of periodicity and granularity in the data made it difficult to develop models, and thereby adding higher uncertainty to the chemical impact. While this uncertainty in chemical impact is not ideal, the makeup water savings were statistically valid, and it could be inferred that less water use in the system will result in less chemical treatment.

SECTION 8

Summary and Conclusions

8. Summary and Conclusions

8.1. Overall Technology Assessment at the Demonstration Site and Final Results

The objective of this evaluation was to evaluate the performance impact of replacing the incumbent filtration system with an ElectroCell electrochemical water treatment system within an open loop cooling tower at Nissan Canton. This evaluation followed an M&V strategy based on IPMVP Option B (retrofit isolation with all parameter measurements) to analyze the ElectroCell system's impact on energy, water, and chemical use. The evaluation showed a 6%–17% reduction in makeup water consumption and a 27% decrease in chemical treatment costs. No impact on energy consumption associated with the chillers and cooling tower was observed, which could be attributed to the chiller tubes and heat exchangers being cleaned and maintained under a regular preventative maintenance program. However, in cases where the baseline chiller condenser tubes and heat exchangers surfaces were not cleaned, opportunities for energy savings could exist. According to Nissan personnel, the chillers get punched and cleaned every other year as part of their routine operations and maintenance schedule. The Nissan facility team noted that the chillers had been taken down and cleaned last year, and that the tubes had appeared cleaner than normal based on a visual inspection.

The evaluation methodically normalized data for all relevant factors using rigorous M&V approaches and sound statistical techniques. However, it is important to acknowledge the potential influence of unidentified factors beyond the evaluation boundary that might have affected the results. Table 11 provides a summary comparing the evaluation results with ElectroCell's claims from their ITV application.

Table 11. Summary: Energy, Water, and Chemical Use

	ElectroCell Claimed Savings (%)	Measured Savings (%)
CHW Energy Consumption	10%–12%	0%
Water Use	15%–20%	6%–17%
Chemical Treatment Use	Less chemical treatment required	27%

The GSA Proving Ground evaluated alternative water treatment technologies for in-field validation, including an electrochemical-based system. GSA's validation studies found that the electrochemical system that was validated maintained water quality while significantly reducing cooling tower water consumption, with annual water savings but no measurable energy savings or increase in chiller performance (Dean, Tomberlin, and Silvestri 2020). This finding aligns with the finding from this evaluation at Nissan. According to the GSA analysis, the lack of energy performance improvement was attributed to the chiller tubes and heat exchangers being cleaned and maintained as part of regular preventative maintenance program. However, if chiller condenser tubes and heat exchangers are not in good condition, opportunities for additional energy savings may exist.

8.2. Lessons Learned and Considerations for Future Evaluations

The condition of the condenser tubes was not assessed during this evaluation. Future evaluations should measure the condition of the tubes before and after the study through non-destructive testing techniques. The ability of the ElectroCell system to clean any existing fouling was not tested during this evaluation, as the testing configuration was not suited to this. A different testing configuration and more controlled O&M practices of condenser tube cleaning may enable evaluation of this aspect.

ElectroCell Systems' claim that the system breaks down laminar boundaries to provide better heat exchange was not tested. Incorporating additional instrumentation to calculate the Reynolds number could test this claim. Also, the ability of the ElectroCell system to remove TDS was not directly evaluated. Targeted measurements of TDS at the inlet and the outlet of the ElectroCell system could have provided better insight.

Results will vary based on the type and existing control of the incumbent filtration system. This should be clearly understood when considering results. The incumbent system in this evaluation had no sand media during the evaluation. The system purged approximately 15,000 gallons/day of the cooling tower loop water through a daily timed backwash cycle. Loop conductivity never exceeded the threshold setpoint with this excessive blowdown or purging, which kept the cycles of concentration low. If the incumbent system had sand media in the filters and the backwash volume were also controlled to the conductivity setpoint in the loop, the incumbent system could have used less water, resulting in less savings.

8.3. Deployment Considerations

This evaluation focused on an open-loop cooling tower system situated within an automobile plant. The cooling tower loop rejects heat from chillers. The condenser water undergoes heat dissipation through evaporation in the cooling tower through the flow of fluid over a fill structure for heat exchange. The cooled water gathers in a basin before being cycled back to the facility's cooling loop. This technology's relevance extends to closed-loop cooling towers that dissipate heat and adopt various water treatment systems that demand significant makeup water use.

The effectiveness of this technology depends on several site-specific factors, encompassing variables like ambient air quality, the presence of airborne particulate matter, and seasonal fluctuations. Such conditions can lead to issues such as biological growth or mineral buildup, necessitating additional chemical treatments. Cooling tower performance correlates closely with wet bulb temperature, resulting in differing efficiency and output levels across diverse locations. Evaporative cooling systems tend to excel in arid climates with low wet bulb design temperatures.

Another critical factor impacting technology performance is the quality of the makeup water. Makeup water with elevated hardness, pH, or TDS levels typically requires higher water and chemical use compared to a cleaner source. Open loop cooling towers with dirtier water sources make them prime candidates for achieving savings through the implementation of this technology.

8.4. National Impact

The water usage for cooling, condensing, and steam in the U.S. manufacturing sector is estimated to be between 9,098 and 10,255 million gallons per day (MGD). Out of this total, the overall open tower cooling water withdrawal rates are calculated to be approximately 5,710 and 6,436 MGD, while the evaporative cooling tower water withdrawal rates are estimated to be between 2,447 and 2,758 MGD (Karki and Rao 2023). The water reductions observed from the evaluation's electrochemical treatment were used to estimate the overall impact of this technology. The reductions ranged from 6% to 17%, with a weighted average of 11%.

The total potential reductions in water withdrawal for the listed manufacturing subsectors (Table E.1 in the Appendix) under 100% adoption of electrochemical treatment range from 278 to 313 MGD, and from 3 to 4 MGD under a 10% adoption scenario. In the top five manufacturing subsectors, the adoption of electrochemical treatment could lead to reductions in water withdrawal. Specifically, estimates suggest that with 100% adoption, water withdrawal could decrease by up to 108 MGD in the primary metals sector, 77 MGD in chemicals and petrochemicals, 63 MGD in paper manufacturing, 29 MGD in petroleum refining and coal, 21 MGD in food manufacturing, and 2 MGD in transportation equipment.

Delivering treated water to an industrial facility requires the water to be extracted from the water source, treated, conveyed to the facility, and returned to the source. Each of these steps requires the consumption of energy, referred to as the "embedded energy" of the water supply and wastewater network. An estimated weighted average energy intensity for the embedded energy of water supply is 2,069 kWh/MG (Rao, McKane, and de Fontaine 2015), Based on this estimate and an emissions factor of 0.000699 metric tons CO_2/kWh,[3] the carbon impact of various adoption scenarios can be calculated. For instance, with 10% adoption, the corresponding figure is estimated to be around 1,029 metric tons of CO_2 per year.

[3] Per EPA estimate. To learn more, visit https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references.

References

Dean, Jesse, Gregg Tomberlin, and Andrea Silvestri. 2020. *GSA Guidance—Alternative Water Treatment Systems for Cooling Towers.* Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy20osti/73940.pdf.

Duan, X., J.L. Williamson, K.L McMordie, Stoughton, and B.K. Boy. 2012. *Side Stream Filtration for Cooling Towers.* Richland, WA: Pacific Northwest National Laboratory. U.S. Department of Energy Federal Energy Management Program. https://www.energy.gov/sites/default/files/2013/10/f3/ssf_cooling_towers.pdf.

Karki, Unique and Prakash Rao. 2023. "Techno-economic analysis of the water, energy, and greenhouse gas emissions impacts from the adoption of water efficiency practices in the U.S. manufacturing sector." *Resources Conservation and Recycling* 196: 107054. https://10.1016/j.resconrec.2023.107054.

Rao, Prakash, Aimee McKane, and Andre de Fontaine. 2015. "Energy Savings from Industrial Water Reductions." Presented at 2015 ACEEE Summer Study on Energy Efficiency in Industry, Buffalo, New York.

Turner, W.C., 2004. Energy Management Handbook. Fairmont Press, 2004.

Appendix A Calculations

A.1 Background: Goodness-of-Fit Statistics

Coefficient of Determination

One of the metrics to assess the fitness of the model is coefficient of determination, R^2, which measures the extent to which variations in the dependent variable *y* can be explained by the regression model. The possible ranges for R^2 are between 0 and 1, with a value of 0 indicating that none of the variations can be explained by the model, and therefore the model provides no guidance in understanding the variations in *y* using the selected independent variables. On the other hand, an R^2 of 1 means that the model explains 100% of the variations in *y*. Typically this value falls somewhere in between, but generally the greater the coefficient of determination, the better the model describes the relationship of the independent variables and the dependent variable. International Performance Measurement and Verification Protocol states that a minimum acceptable R^2 value is 0.75.

Root Mean Squared Error (Standard Error of the Estimate)

Root mean squared error (RMSE), or standard error of the estimate (SE), is an indicator of the scatter, or random variability, in the data, and hence is an average of how much an actual *y*-value differs from the predicted *y*-value. It is the standard deviation of errors of prediction about the regression line.

Coefficient of Variation of the Root Mean Squared Error (CV_{RMSE})

CV_{RMSE} is the RMSE normalized by the average *y*-value. Normalizing the RMSE makes this a non-dimensional that describes how well the model fits the data. It is not affected by the degree of dependence between the independent and dependent variables, making it more informative than R-squared for situations where the dependence is relatively low.

Bias

Bias (or net determination bias) is simply the percentage error in the energy use predicted by the model compared to the actual energy use. The sum of the differences between actual and predicted energy use should be zero. If the net determination bias = 0, then there is no bias. ASHRAE Guideline 14-2002 accepts an energy model if the net determination bias error is less than 0.005%. Often, bias may be minor, but it will still affect savings estimates. If the savings are large relative to the bias, bias may not be important, but in many cases bias may be influential.

t-Statistic

The t-statistic is a measure of the significance for each coefficient (βi) and hence the related independent variable's contribution to the overall model. The larger the t-statistic, the more significant the coefficient is to estimate the dependent variable. The coefficient's t-statistic is compared to the critical t-statistic associated with the required confidence level and degrees of freedom. For a 95% confidence level and a large number for degrees of freedom (associated with a lot of data), the comparison t-statistic is 1.96. Measure the t-statistic for every independent variable used, and if the t-statistic is lower than the critical value (such as 1.96) for any variable, reconsider your model. International Performance Measurement and Verification Protocol[4] specifies the t-statistic must be greater than 2.0 for the independent variable to be significant.

A.2 Background: Fractional Savings Uncertainty

Model predictions come with inherent uncertainties from various sources that include measurement and modeling. While the uncertainties associated with measurements are assumed to be negligible, uncertainties for the model need to be assessed to understand the confidence associated with the savings and performance improvement from the proposed technology. These uncertainties can be quantified by determining the savings uncertainty at a specific confidence level. This confidence level is chosen to be 95%, which indicates there is a 5% chance of being wrong. This uncertainty, when presented as a percentage of the average metered savings, is known as fractional savings uncertainty (FSU). A lower FSU signifies greater confidence in the accuracy of the savings estimates. In essence, smaller FSUs indicate more reliable and trustworthy predictions of savings. FSU for the models were calculated following ASHRAE Guidelines 14[5], Business Professionals of America measurement and validation guidelines[6], and International Performance Measurement and Verification Protocol measurement and uncertainty guide.[7] FSU for a normalized regression, considering autocorrelation, can be calculated as:

$$FSU = \frac{\Delta E_{save}}{E_{save}} = \frac{1.26 * t}{m * \underline{E}_{EC,n} * F}\sqrt{MSE'^{\left(1+\frac{2}{n'}\right)}m}$$

Table A.1. Fractional Savings Uncertainty Variables

Acronym	Meaning
$\frac{\Delta E_{save}}{E_{save}}$	FSU for a regression in percentage
t	t-statistic, 95% confidence interval, infinite degrees of freedom (1.96)
m	Number of periods in post-retrofit period

[4] International Performance Measurement and Verification Protocol 10000-1.2012.
[5] ASHRAE Guidelines 14 – Measurement of Energy and Demand Savings.
[6] Business Professionals of America Measurement and Validation Guide.
[7] International Performance Measurement and Verification Protocol Uncertainty Guide.

$\underline{E}_{EC,n}$	Mean energy use per period with the ElectroCell system
F	Savings in percentage
MSE	Mean squared error of the regression model
n'	Number of independent observations w/ autocorrelation

A.3 Summary of Energy and Water Savings With Statistics

Table A.2. Energy Savings From Chilled Water System[8]

	Predicted Energy Consumption With Sand Filtration Pump (kWh/yr)	Actual Energy Consumption With ElectroCell System (kWh/yr)	Impact (kWh/yr)	Impact (%)	FSU (%)	Lower CL (kWh)[9]	Upper CL (kWh)
Chiller Energy	18,273,430	18,287,651	-14,221	~0%	4%	-14,746	-13,696
Cooling Tower Fan Energy	1,772,301	1,786,342	-14,041	~0%	125%	-31,622	-3,540
Filtration System Energy	521,042	25,295	495,746	95.1%	N/A	N/A	N/A

Table A.3. Annual Makeup Water Use, Incumbent System Versus ElectroCell System

	Sand Filtration Pump Predicted Makeup Water (gal/yr)	ElectroCell Adjusted Makeup Water (gal/yr)	Impact (gal/yr)	Impact (%)	FSU (%)	Lower CL (gals)[10]	Upper CL (gals)
Makeup Water	70,391,738	62,451,857	7,939,881	11.3%	49.9%	3,980,435	11,899,327

[8] Itemized savings for the chillers and cooling tower are shown in Appendix B-1.
[9] At 95% confidence level, i.e., is the percentage of times you expect to reproduce an estimate between the upper and lower bounds of the confidence interval.
[10] At 90% confidence level.

A.4 Itemized Energy and Water Savings

Table A.4. CHW System Energy Consumption per Component

CHW Equipment	Predicted Energy Consumption With Sand Filtration Pump (kWh/yr)	Energy Consumption With ElectroCell System (kWh/yr)	Savings (kWh/yr)
CH-3	1,328,520	1,273,267	55,254
CH-4	2,965,133	2,887,862	77,272
CH-5	3,217,108	3,321,068	-103,961
CH-6	2,580,881	2,597,798	-16,917
CH-7	92,866	83,860	9,006
CH-8	466,179	578,157	-111,977
CH-9	2,864,366	2,759,329	105,037
CH-10	1,423,376	1,489,866	-66,490
CH-11	2,226,381	2,158,388	67,993
CH-12	1,108,620	1,138,058	-29,438
CT	1,772,301	1,786,342	-14,041
Total	20,045,731	20,073,993	-28,262
Savings Percentage			-0.14%
$FSU_{heterogeneous}$			4%
Savings Uncertainty			-1,271

A.5 Fractional Savings Uncertainty

As discussed, model predictions often come with inherent uncertainties from various sources. These uncertainties can be quantified by determining the savings uncertainty at a specific confidence level. This uncertainty, when presented as a percentage of the average metered savings, is known as fractional savings uncertainty (FSU). The calculated FSU for each of the chillers and the cooling tower as well as the heterogeneous FSU is shown in Table E.1.

$$CHW\ System\ Energy\ Model\ Heterogeneous\ FSU = \frac{\sqrt{FSU_{CHi} * S_{CHi} + FSU_{CT} * S_{CT}}}{S_{total}}$$

Table A.5. Variables for Fractional Savings Uncertainty Calculations

Variable	Definition	Unit
FSU_{CHi}	FSU for each of the chiller (3-12) models	%
S_{CHi}	Energy Savings for each of the chiller (3-12) models	kWh/yr
FSU_{CT}	FSU for cooling tower	%
S_{CT}	Energy Savings per cooling tower	kWh/yr
S_{total}	CHW System Energy Model Savings	kWh/yr

Table A.6. Fractional Savings Uncertainty Analysis for Each Chilled Water System Component

	CH-3	CH-4	CH-5	CH-6	CH-7	CH-8	CH-9	CH-10	CH-11	CH-12	CT
t stat	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
m	2,445	3,385	4,008	2,105	1,534	1,258	2,130	816	522	1,252	8,746
$E_{baseline,n}$	930	985	907	997	967	933	854	715	946	777	174
F	4%	3%	-3%	-1%	10%	-24%	4%	-5%	3%	-3%	-1%
MSE	3,588	2,056	6,122	1,624	3,705	1,861	2,364	4,879	1,348	5,229	4,250
n’	759	645	580	1,044	759	966	755	788	864	711	398
p	0.84	0.86	0.88	0.79	0.84	0.80	0.84	0.83	0.82	0.85	0.91
n	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760

Table A.7. Fractional Savings Uncertainty Analysis for Makeup Water

	Makeup Water
FSU	49.87%
t-stat	1.68
F	11.3%
MSE	70,286,623,715
n	52
m	53
$E_{base,n}$	1,396,564

A.6 Market Impact Analysis

Table A.8. National Impact of Electrochemical Treatment on Evaporative Cooling Tower Water Usage in Manufacturing Subsectors

NAICS Code	Manufacturing Subsector	Evaporative Cooling Tower Water Withdrawal (Million Gallons per Day [MGD])		Electrochemical Treatment Impact on Evaporative Cooling Tower Water Withdrawal (MGD)			
				100% Adoption		10% Adoption	
	Manufacturing Subsector	Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
331	Primary Metals	841	948	96	108	1	1
325	Chemicals and Petrochemicals	604	681	69	77	1	1
322	Paper Manufacturing	493	555	56	63	1	1
324	Petroleum Refining and Coal Product Manufacturing	226	255	26	29	0	0
311	Food Manufacturing	161	182	18	21	0	0
336	Transportation Equipment Manufacturing	20	22	2	2	0	0
Grand Total		**2,448**	**2,757**	**278**	**313**	**3**	**4**

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

For more information, visit: energy.gov/eere/iedo

DOE/EE-2893 • September 2024