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Energy Research and Development Division

FINAL PROJECT REPORT

Cooling Tower Water Treatment Using Industrial Vortex Generator Technology for Water and Energy Savings

Gavin Newsom, Governor
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DISCLAIMER

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Cooling Tower Water Treatment Using Vortex Process Technology for Water and Energy Savings is the final report for Contract Number EPC-15-087 conducted by the Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

ABSTRACT

The industrial vortex generator technology for cooling towers (IVG-CT) provides an innovative low-energy physical method for treating water in cooling towers for commercial and industrial applications, providing water, energy, and chemical savings. The researchers installed and evaluated the technology at two commercial building host sites in Southern California: a hotel (two 450-ton chillers) and large pharmaceutical company (two 1250-ton chillers). IVG-CT can supplement traditional water treatment practices with a more environmentally sound, repeatable, and efficient approach that achieves water savings by safely increasing cooling tower cycles of concentrations, a metric used to measure the amount of water being reused in the cooling tower, and energy savings by improving the heat transfer in the chiller heat exchanger. The IVG-CT is a plug-and-play side-stream water treatment unit combining multiple physical treatments. Reduction in scaling and fouling of heat exchangers, coupled with removal of microbubbles and hydrodynamic cavitation, helps increase the overall heat transfer of the cooling tower. Measurement and verification consisted of monitoring equipment power consumption and chiller cooling capacity for a year. A comparison of kilowatt-hours per ton-hour for each chiller before and after installation of IVG-CT (following the International Performance Measurement and Verification Protocol) showed a reduction of chiller plant energy of between 5.4 percent and 6.4 percent at the two sites. The results confirmed substantial water and chemical savings at both host sites: 30 percent for the hotel site with typical practices and 15 percent for the pharmaceutical site with best practices. Chemical use cost reductions ranged from more than 30 percent at the hotel site to around 45 percent at the pharmaceutical site.

Keywords: Physical water treatment, cooling tower, vortex, chiller, energy efficiency, water, chemical

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EXECUTIVE SUMMARY

Introduction

The function of cooling towers is to reject waste heat to the atmosphere by cooling water to a lower temperature, typically by evaporation. Approximately 98 percent of commercial building cooling towers in the United States and California use only chemical water treatment provided by a well-established market channel of chemical companies and service providers. This conventional and industry-rooted approach consumes a significant amount of water, chemicals, and energy. Commercial buildings alone spent 13,124 gigawatt-hours in cooling and 6,937 gigawatt-hours in refrigeration in 2012. Larger cooling equipment and refrigeration systems use water-cooled systems for efficiency. The Electric Power Research Institute estimates that 1,179 million gallons of potable water are used in cooling towers for commercial buildings alone. Given California's current prevailing drought conditions, this is a major concern.

The use of physical water treatment technologies for water-cooled cooling towers is growing in the United States and has been more widely used in the European Union where restrictions on chemical discharge and environmental policies encouraging lower chemical usage are widespread. Physical water treatment technologies offer advantages in controlling the primary water metrics of scale, corrosion, fouling, and bacteria.

The industrial vortex generator technology for cooling towers (IVG-CT) is a physical water treatment that offers water, energy, and chemical savings. This is done by increasing the amount of water being reused in the cooling tower, improving the heat transfer in the chiller's heat exchanger through reduced scaling and fouling and removing entrained microbubbles from the condenser water flowing to the chiller. In addition, the IVG-CT treated water has a higher density and lower viscosity and improves heat transfer in the chiller heat exchanger. This is an innovative low-energy physical water treatment method for cooling towers at the commercial and industrial scale that is intended to supplement traditional water treatment practices with a more environmentally sound approach. This technology was developed and has been demonstrated at 72 chemical-free installations in Europe.

Project Purpose

The goals of this technology demonstration and implementation project are to: (a) assess the efficacy (effectiveness) of the innovative low-energy use IVG-CT technology by documenting energy and water savings from cooling towers in commercial buildings through a full-scale operation; and (b) conduct a market knowledge transfer of the water and energy saving results of this technology to commercial and industrial end users to facilitate broader market adoption of this under-used technology. The technical innovation, developed by the manufacturer Watreco AB, of Sweden, offers reductions in water and energy use and lower chemical usage in cooling towers in accordance with former Governor Edmund G. Brown's Executive Order B-29-15 (April 2015) to make California more drought-resilient. The technology is intended to supplement traditional water treatment practices with a more environmentally sound, consistently repeatable, and efficient approach.

Project Approach

The researchers demonstrated and evaluated the IVG-CT system for water, energy, and other savings at two sites in California. The first site was a large hotel, the Marriott Westin Mission Hills Golf Resort and Spa, in Rancho Mirage, California (Climate Zone 15), and represented an application where cooling tower water treatment represents common maintenance practices for commercial buildings. The second site was a large biopharmaceutical company, Amgen in Thousand Oaks, California (Climate Zone 6), and represented best-in-class water treatment and maintenance practices. The primary objective of the demonstration projects was to show water savings; energy and other savings were secondary. The technical advisory committee members represented utilities and research/industrial professionals with relevant experience to guide the project scope and direction.

The measurement and verification plan followed the International Performance Measurement and Verification Protocol and consisted of equipment monitoring prior to and after installation of the IVG-CT technology at both host sites. Equipment monitoring parameters included power consumption and chillers' cooling capacity as well as parameters that direct affect the chiller cooling capacity and power consumption such as chilled water delivery temperature, condenser water entering the chiller, and chiller part load capacity. Researchers recorded the data in 15-minute time intervals at the hotel host site and one-hour intervals at the pharmaceutical host site. The preinstallation data at the hotel site were limited to a very short period. Researchers collected and analyzed post-installation data for both sites for a minimum of 12 months.

Project Results

Based on the International Performance Measurement and Verification Protocol approach for energy savings analysis, there were 6.4 percent net energy savings at the pharmaceutical site and 5.4 percent net energy savings at the hotel site.

The measurement and verification results confirmed substantial water savings and chemical reduction at both host sites: 30 percent for the hotel site with typical practices (cycle of concentration was increased from 2.3 to 5.9) and 15 percent for the pharmaceutical site with best practices (cycle of concentration was increased from 3.6 to 7.8). Chemical use cost reductions ranged from greater than 30 percent at the hotel site to approximately 45 percent at the pharmaceutical site.

The water savings were calculated using the measured cycles of concentration (a metric used to measure the amount of water being reused in the cooling tower) of the cooling tower water before and after the installation of the IVG-CT. These data were cross checked with makeup water meter data. The thermal conductivity of the makeup water and the cooling tower sump water were monitored continuously and used to calculate cycles of concentration.

The water savings resulted in about 30 percent avoided water use (1.8 million gallons) for the hotel site. Besides the avoided use of incoming city water for makeup, the site also reduced the amount of water discharged to the sewers as cooling tower blowdown. Based on a water rate of $4.67/centum cubic feet (CCF, or hundred cubic feet) and sewer rate of $2.55/ CCF, the site water savings correspond to an annual avoided cost of $17,738 for the hotel site.

For the pharmaceutical site, the water savings resulted in around 15 percent avoided water use (1.5 million gallons). Besides the avoided use of incoming city water for makeup, the site also reduced the amount of water discharged to the sewers in the form of cooling tower blowdown. Based on a water rate of $4.67/CFF and sewer rate of $2.55/CCF, water savings from this site correspond to an annual avoided cost of $15,417.

Chemical usage cost reductions ranged from greater than about 30 percent or $11,000 annually (typical maintenance at the hotel site) to around 45 percent or $45,000 annually (state-of-the-art maintenance at the pharmaceutical site).

In addition, operational and maintenance savings are expected from a reduced number of condenser tube cleanings because the IVG-CT system keeps heat exchanger surfaces cleaner from scale buildup. Thus, less frequent need for tube cleanings would reduce maintenance costs. Additionally, the vortex process technology system comes with continuous monitoring that can further support efficient operation and the cooling tower operation diagnostics.

Additional energy savings correspond to the substantial embedded energy savings (energy intensity of water) from the water savings, namely the energy saved from pumping and treating the city water, which also corresponds to greenhouse gas emissions savings that are region specific.

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

Technology transfer is a crucial step in introducing the IVG-CT product to a wider audience and a key objective of the Electric Program Investment Charge projects. Explaining and showcasing the technology and applications of vortex process technology and ensuring they are appropriately considered for industry best practices will increase understanding of this equipment by industry stakeholders with the goal of encouraging them to include these systems in specifications for new commercial and industrial projects and major modernizations.

The research has been presented and shared with cooling tower and heating, ventilation, and air conditioning industry audiences through presentations at conferences and industry meetings. These include project review meetings with the California Energy Commission and project technical advisory meetings, project findings and updates to host site managers, Southern California Edison Customer Programs and Services, and the Metropolitan Water District. Additionally, the research has been shared with Electric Power Research Institute utility members through the Power Delivery and Utilization Advisory Meetings and Customer Technologies End-of-Year Program Webcast. A technology readiness guide for this technology was also published in which IVG-CT received a score of 70 out of 100, which corresponds to coordinated early deployments in the end-use technology pipeline.

Electric Power Research Institute members and other mutual contacts will facilitate utility incentive and rebate programs. The market connections effort could produce several informational products designed to influence the market participants and overcome the market barriers. Also, there is an opportunity to connect the outcomes of the vortex process technology project to California Title 24 upcoming standards updates principally by relating pertinent project results to California Energy Commission buildings and codes standards personnel.

Benefits to California

The IVG-CT uses many fewer chemicals compared to traditional chemical treatment. In the European Union, the vortex process technology system operates in 70 locations. The chiller plant can reduce the chemicals purchased and reduce maintenance costs. The plant also reduces discharge of toxic elements in the blow down water, reducing sewer charges. Reduced chemical usage on site also helps reduce the overall carbon footprint of the cooling tower chemical production and distribution supply chain and saves water by increasing the cycle of concentration as compared to base standard practices. The latter is very important in California communities where fresh water supply is limited and prevailing drought conditions are a major concern.

Also, water that is not used onsite reduces overall system water pumping energy and sewer treatment costs. The embedded energy cost of the avoided water pumping is positive. Energy savings can be realized due to improved heat transfer and chiller efficiency. Reducing the amount of chemicals (and consequent handling of these chemicals) used in water treatment increases safety for chiller plant operators and water service technicians. Using fewer chemicals also prevents scaling and keeps heat exchanger surfaces clean. Cleaner heat exchanger surfaces extend the time between condenser cleanings, and the technology can, over time, reduce lime scale, which also improves reliability and efficiency. Building maintenance facilities can benefit from the monitoring equipment diagnostics for improved chiller plant operation, as well as reduced resource expenses (chemical savings, water savings, and energy savings).

CHAPTER 1: Project Overview and General Project Tasks

Background and Motivation

The function of cooling towers is to reject waste heat to the atmosphere by cooling water to a lower temperature, typically by evaporation. Approximately 98 percent of cooling towers in the United States and California use only chemical water treatment provided by a well-established market channel of chemical companies and service providers. This conventional and industry-rooted approach consumes a significant amount of water, chemicals, and energy. Commercial buildings alone spent 13,124 gigawatt-hours (GWh) in cooling and 6,937 GWh in refrigeration in 2012 (GFO-15-317 solicitation Attachment 12). Though much of the smaller equipment is air cooled, the larger cooling equipment and refrigeration systems use water-cooled systems for efficiency. The Electric Power Research Institute (EPRI) estimates that 6,985 GWh, or around 35 percent of the total 20,061 GWh used for cooling and refrigeration, is used in water-cooled equipment. EPRI also estimates that 1,179 million gallons of potable water is used in cooling towers for commercial buildings alone. Given California's current prevailing drought conditions, this is a major concern.

Water in cooling towers needs to be treated to control microbial growth, scale formation, and metal corrosion. The heat transfer effectiveness of the cooling tower must also be maintained since it directly affects the energy consumption. Over the last 10-plus years, various physical water treatment methods have been available for managing cooling tower water with varying degrees of success. The use of physical water treatment technologies for water-cooled cooling towers is growing in the United States and has been more widely used primarily in the European Union where restrictions on chemical discharge and environmental policies encouraging lower chemical usage are widespread. Physical water treatment technologies offer advantages in controlling the primary water metrics of scale, corrosion, fouling, and bacteria.

Cooling Towers

Cooling towers are heat exchangers that use water and air to transfer heat from chiller systems to the outdoor environment. The energy efficiency of a chiller depends on cleanliness of the heat exchangers: a cleaner surface will have higher heat exchange effectiveness that will lead to higher system efficiency. A key consideration in managing cooling tower operations is to reduce — or if the water quality or treatment process allows, eliminate — mineral deposition or scale formation on heat exchanger surfaces and microbial fouling. These substances act as insulation and reduce heat transfer, compromising chiller efficiency. For example, a calcium carbonate scale of 1.12 millimeters (mm) fouling thickness (0.044-inch thickness) is estimated to increase pressure drop by 70.3 percent, which would increase energy consumption. Additionally, biofilm has almost five times less fouling thickness (0.24mm) than scale and would further increase pressure drop by 13.7 percent (Kakac, 2012). Every water management solution has a limit on how much water can be reused without solid deposition negatively affecting heat transfer efficiency (energy consumption) and asset protection. Increasing the cooling tower's cycles of concentration (COC), a metric used to measure the amount of water being reused in the cooling tower, promotes water savings but can negatively affect efficiency from increased scaling.

Tower performance degradation occurs on almost all towers. According to the Cooling Technology Institute,[1] more than 55 percent of cooling towers, including new towers, fail to meet their performance specification. Another key element in optimizing cooling tower/chiller plant performance is to understand the existing tower thermal performance versus the design performance. If the cooling tower can provide water that is 1°F (–17°C) colder due to more efficient heat transfer, the chiller plant efficiency can increase 2 percent to 3 percent or more, as indicated from manufacturers' chiller performance data.

There are three basic types of cooling towers: open, closed circuit, and hybrid. Hybrid is usually a combination of a closed water and an air-cooled portion of the cooling tower.

- Closed circuit: There is no direct contact between the air or cooling tower water and the cooling fluid or refrigerant. The system contains an external and an internal circuit. The internal circuit consists of tube bundles (closed coils) that are connected to a heat exchanger for the hot refrigerant, which is cooled and returned in a closed loop. The external circuit is used to cool the internal circuit by recirculating and evaporating water like an evaporative condenser. Air is drawn through the recirculating water cascading over the outside of the hot tubes.
- Open circuit: The heat exchanger cools down the water by making use of direct contact with air. The water that requires cooling is directed to the upper part of the cooling tower and is spread in a thin and even film over a media or packing material. This method takes advantage of the large heat exchange surface area. The cooled water will then be gathered in the basin (or sump) and can be recirculated directly into the cooling process.

Warmed water from the chiller is sprayed downward as air is blown upward with the fan. This lowers the temperature of the water and evaporates part of it, increasing the concentration of the minerals and solids (Figure 1). Ultimately, every water management solution has a limit on how much water can be reused without solid deposition negatively affecting heat transfer efficiency (energy consumption) and asset protection. Increasing the cooling towers' COC promotes both water and energy savings with improved heat transfer and system efficiency.

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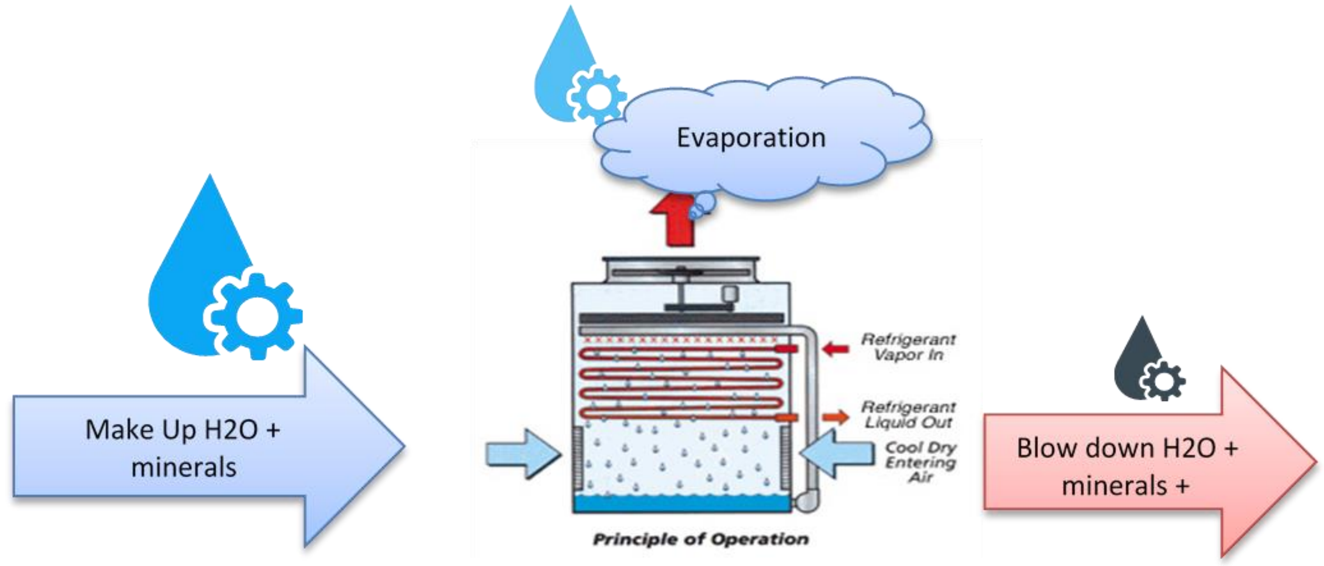
[1] https://www.coolingtechnology.org/

Figure 1: Basic Cooling Tower Configuration and Principle of Operation



Source: Electric Power Research Institute

Cycles of Concentration

The amount of water being reused in the cooling tower is measured using cycles of concentration, or COC. COC refers to the mineral concentration of the condenser water in relation to the makeup water (water that is added to compensate for evaporation losses, drift, and blowdown). The COC of the system can be calculated using the following equation, where makeup refers to the fresh water added to the system and blow-down refers to the water being drained from the system.

$$\boldsymbol{COC = \frac{Makeup\ water\ gallons/minute}{Blowdown\ water\ gallons/minute}}$$

The blow-down is necessary to limit scaling from the water. A higher COC means less blow-down compared to the makeup water. Typical COC in commercial applications is 2 to 4. Depending on water conditions and ongoing monitoring, significant added benefit can be achieved by taking COC to eight or more cycles. When systems operate at high cycles, managing corrosion rates, suspended solids, and microbial growth may become more challenging unless there is good quality monitoring procedure and supply water. A sound water efficiency metric is to compare water consumption at current COC, and then optimize the COC based on metrics such as the Langelier Saturation Index (LSI) as in the new 2019 California Title 24 code standard,[2] pH and conductivity monitoring, cost/return on investment, and best practices. The typical relationship between makeup water consumption in gallons per minute (gpm) and COC is depicted in Figure 2.

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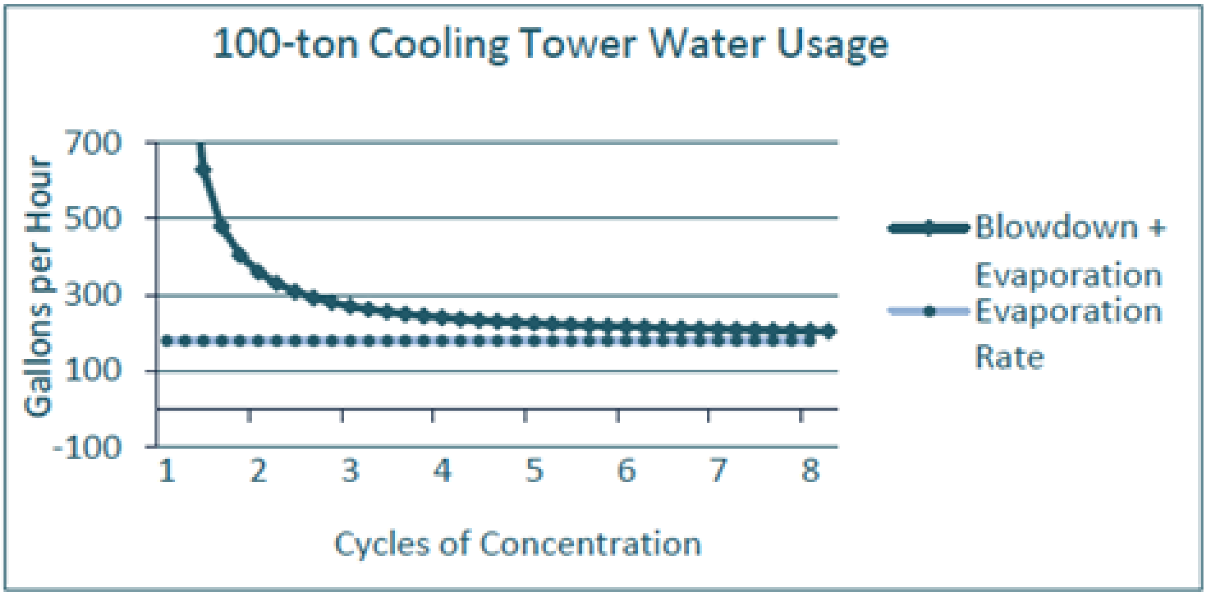
[2] Effective July 1, 2014, establishes mandatory requirements for the efficient use of water in the operation of open (direct) and closed (indirect) cooling towers. The building standard applies to the new construction and retrofit of commercial, industrial, and institutional cooling towers with a rated capacity of 150 tons or greater.

Figure 2: Correlation Between Cooling Tower Water Consumption and Cycles of Concentration



Source: Electric Power Research Institute

Project Goals and Objectives

The goals of this technology demonstration and implementation project are to: (a) assess the efficacy of an innovative low-energy use physical water treatment (PWT) technology, the industrial vortex generator technology for cooling towers (IVG-CT), by documenting water and energy savings from the IVG-CT for cooling towers in commercial buildings through a full-scale implementation; and (b) conduct a market knowledge transfer of this technology to a variety of commercial and industrial end users and stakeholders to communicate the water and energy saving results to facilitate the broader market adoption of this under-used physical water treatment technology that supports the reduction of lime scale, reduction of chiller energy usage footprint, reduction of hazardous chemical use, and reduction of overall water use. The technical innovation, developed by the manufacturer Watreco AB, of Sweden, will reduce water and energy usage and lower chemical usage in cooling towers in accordance with former Governor Edmund G. Brown Jr.'s Executive Order B-29-15 (April 2015) to make California more drought-resilient. The technology has been used and achieved some initial market adoption in Europe, with the opportunity to be used in the United States. The technology is intended to supplement traditional water treatment practices with a more environmentally sound, consistently repeatable, and efficient approach. Resistance from market participants who have an interest in the status quo, such as chemical and water treatment companies and those who are skeptical of any new technology such as the PWT approach, is to be expected.

The project objectives is to demonstrate the technology's benefits, understand market barriers, and then communicate to key market stakeholders, this innovation would remain unnoticed.

Project Scope

The scope of this project was to conduct a full-scale demonstration and evaluation of the IVG-CT at two different project host sites. The researchers used the International Performance Measurement and Verification Protocol (IPMVP), the Isolated System Retrofit approach,[3] as the best practices technique to determine water and energy efficiency with field measurements of relevant energy and operating data (please refer to Appendix A for methodology) for at least 12 months. The project also engaged customers in discussions of the perceived benefits while acknowledging their concerns over funding cycles, buying decision process, market factors, and financial requirements.

Project Specifics

Lead Organization

As the award prime recipient, EPRI is responsible for the overall project execution and management, leading the technical approach, and analysis. EPRI is a tax-exempt, non-profit organization that conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public, on a non-discriminatory basis. An independent organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety, and the environment. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to nearly 40 countries. EPRI's principal offices and laboratories are in Palo Alto, California; Charlotte, North Carolina; Knoxville, Tennessee; and Lenox, Massachusetts.

EPRI’s interdisciplinary team members bring expertise in both water and energy sectors through its private-public partnerships among the utilities and industrial centers. EPRI’s technical leaders, engineers, and scientists provide expertise in technology development, demonstration, measurement and verification, and data analytics.

Partners

Cypress Ltd. led the technology implementation efforts, which included equipment selection, procurement, installation, and implementation of the International Performance Measurement and Verification Protocol. Cypress has proficiency and a track record in conducting many measurement and verification (M&V) and assessment projects for California utilities. The lead engineer is a registered professional engineer in three states and a certified M&V professional who has conducted extensive M&V projects at many chiller plants and commercial, industrial, and government facilities. Cypress coordinated the IVG-CT system installation efforts for each host site, with the technology distributor H2oVortex.

H2oVortex, based out of Luxembourg, is the worldwide distributor of IVG-CT that was developed in Sweden by Watreco. The IVG-CT is manufactured using a 3D printing technology. It is and has been commercially available, but it is relatively new to the United States market. In the European Union, there are more than 70 cooling tower installations.

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[3] Efficiency Valuation Organization International Performance Measurement and Verification Protocol Core Concepts – Oct 2016 https://evo-world.org/en/.

Kick-Off Meeting

The project kick-off meeting took place on September 15, 2016, at the California Energy Commission (CEC) in Sacramento, California. The meeting discussion reviewed the overall project goals and objectives, as well as the administrative logistics. The team also discussed the confirmation of project host sites and potential surveys for project benefits.

Technical Advisory Committee Meetings

One technical advisory committee meeting via webinar was held on April 11, 2017. The committee members represent utilities and research/industrial professionals with relevant experience who offer guidance for the project's scope and direction. The committee members who agreed to support the project in an advisory role are shown below.

Technical Advisory Committee Members

- Utilities
    - Paul Delaney, Southern California Edison
    - Christina Weber, Pacific Gas and Electric
    - Matt Smith, San Diego Gas and Electric
    - Jim Parks, Sacramento Municipal Utility District
    - Mark Fernandes, Los Angeles Department of Water and Power
- Manufacturers Professionals
    - Mark Winter, Evapco/Dolphin
    - Elise Zoli, Cooling Tower Institute
    - Yohann Rousselet, BAC
    - Eric Rasmussen, SPX
    - Ken Mortensen, SPX
- End-User/Operations Professionals
    - Russ Koehler, Amgen
    - Jerry Meek, Genentech
    - Ralph Renee, NetApp
    - Eric Schlotthauer, Disney
    - Kyle Goehring, Jones Lang LaSalle
- Academia
    - David Zoldoske, California State University, Fresno
- EPRI Water Team
    - Richard Breckenridge
    - Jeffrey Preece

Critical Project Review Meetings

The first critical project review meeting was held on January 10, 2017, at the CEC in Sacramento, California. The meeting focused on the equipment installation for the project host sites. Participants included CEC and EPRI project staff. The second and third critical project review meetings were held via webcast/phone on October 3, 2018 and March 1, 2019.

Deliverables

The deliverables for this project included progress reports, benefits questionnaires, technology transfer plan, and the final project report. The team submitted progress reports to the CEC by the 10th of each month and summarized the research efforts and monthly accomplishments. The benefits questionnaires described the potential benefits to ratepayers in California and are summarized in Chapter 5. The technology transfer plan is provided in Chapter 6.

CHAPTER 2:
Cooling Tower Water Treatment Technologies

This chapter reviews existing chemical and non-chemical PWT systems used to control scaling, minimize biological growth, and inhibit corrosion in cooling tower water.

Chemical Treatment of Cooling Tower Water

Chemicals are typically used in cooling tower water treatment to extend the ability of the cooling water to hold scaling materials in suspension, to minimize corrosion by neutralizing acidity, and inhibit biological growth through use of algaecides and biocides. These chemicals (for example, phosphoric acid to inhibit scale formation, bases such as lime or carbonates to reduce increased alkalinity, and chlorine or bromine for biologic control) are often harmful in themselves, potentially affecting the water supply and the environment.

In addition to this treatment, side-stream filtration and ultrafiltration (treating approximately 10 percent of the circulating water) are often used to remove suspended solids from cooling tower water. Blowdown treatment or bleed from the cooling tower disposes of concentrated liquid and solid waste prior to reuse or discharge. In cooling towers, cycles of concentration is a ratio that measures how concentrated solids are in the cooling tower process water compared to the fresh makeup water. (Generally, this is done by measuring the conductivity of the blowdown.) The higher the cycles of concentration, the better the cooling tower can tolerate impurities and the less makeup water will be needed.

Some of the chemicals used for biologic and scaling control are clearly corrosive and need to be monitored and carefully balanced to prevent damage to the cooling tower surfaces. Buildup of scale and biofilms on cooling tower surfaces will inhibit heat transfer and adversely affect cooling tower performance.

Nonchemical Treatment of Cooling Tower Water

Non-chemical and PWT methods are available for scale, corrosion, and biologic control that avoid the use of problematic chemicals. Some of these systems are described below.

Fixed Field Magnetic Systems

Fixed field magnetic systems cause otherwise scale-forming materials to precipitate on suspended solids instead of on heat exchanger surfaces. The non-adherent aragonite form of calcium carbonate that is produced by these systems (versus the hard, adherent calcite that results in detrimental scaling) can be removed mechanically or by blowdown or flushing.

Several manufacturers provide neodymium rare earth magnet systems, principally for residential water systems to purify water and provide anecdotal data on their efficacy.[4] A

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[4] Trentaron, Magnetic Water Technology, Life Source Water Systems.

water softener manufacturer[5] has provided citations of 34 studies including those from Pennsylvania State University[6] and Purdue University[7] showing that magnetic water treatment products do not work in all water conditions nor do they work in a consistent, predictable manner. While the magnetic products discussed are not of the size needed for cooling tower water treatment, the principles of operation are similar.

Pulsed Power and Electrodynamic Field Systems

Pulsed power and electrodynamic field systems generate a combination of variable magnetic flux density with a variable electric field. The induced electric fields alter the surface charge on suspended solids and particulate and force precipitation on selected surfaces that can periodically be removed and cleaned.

An ASHRAE brief discusses pulse powered chemical-free water treatment with some caveats on use of the technology with soft water and with high chloride or silica content.[8]

Dolphin Water Care[9] presented several articles on its web site describing a pulsed power electromagnetic system that controls microbial populations by encapsulation and electroporation. According to these articles, encapsulation involves bacteria attaching themselves to the forming and growing calcium carbonate powder and ultimately being trapped in the powder as it continues to grow. Electroporation compromises and destroys bacteria cell membranes as the cells are exposed to electromagnetic fields. Corrosion control is achieved by maintaining the treated water at or above calcium carbonate saturation, which results in high pH levels. Alkaline cooling water typically ensures adequate protection to mild steel and copper alloys and thus, no corrosion inhibitors are required, and equipment life is maximized without the use of chemicals. Cooling tower water treated with pulsed power results in the precipitation of calcium carbonate as powder in the bulk water solution as opposed to precipitation of calcium carbonate crystal type scale on the equipment surfaces, which can reduce heat transfer efficiency and shorten equipment life.

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[5] A major water softener manufacturer cites laboratory tests by independent third parties suggesting that magnetic water treatment devices do not deliver the benefits of soft water. Additionally, third party research has consistently concluded that these products do not work in all water conditions nor in a consistent predictable way.

[6] Magnetic Water Treatment Devices, Penn State College of Agricultural Sciences, Pennsylvania State University 2016.

[7] Alleman, J., Quantitative Assessment of the Effectiveness of Permanent Magnet Water Conditioning Devices. Purdue University, Sponsored by and protocol by Water Quality Association, 1985.

[8] "Pulse-Powered Chemical-Free Water Treatment," ASHRAE GreenTip Number 14, in ASHRAE Green Guide 2006. According to the authors, bacteria are contained in the non-adherent mineral power and cannot reproduce resulting in low bacteria populations. The water chemistry maintained by pulse powered technology is noncorrosive, operating at the saturation point of calcium carbonate (a cathodic corrosion-inhibiting environment). The low bacteria count and reduction or elimination of biofilm reduces concern about microbial influenced corrosion. The absence of aggressive oxidizing biocides eliminates the risk of other forms of corrosion.

[9] Dolphin Water Care, Various downloads describing pulsed power system. January 2020.

ASHRAE study 1361-RP[10] described at the end of this section did not find pulsed power technology to be an effective biocide.

Cavitation Systems

Cavitation systems can cause the formation and collapse of low-pressure bubbles in a water stream imparting a shock wave and resultant high temperature region within the water flow. The energy created during the implosion promotes precipitation of minerals in the water stream.

A paper given at the 2008 Cooling Technology Institute Conference in 2008[11] presented several non-chemical technologies with a discussion of hydrodynamic cavitation, citing a VTRX technologies[12] unit that creates cavitation by rotating slotted discs at high speed. The cavitation chamber is used to create calcium carbonate crystals, and suspended solids are removed using a filtration system, thus reducing the need for blowdown.

A description of a cavitation-based system where water is pumped under high pressure into a cavitation chamber and forced to rotate and collide at high velocity though opposing nozzles is included in literature from Ecowater Systems.[13] The authors assert that controlled hydrodynamic cavitation provides scale control by changing water chemistry to precipitate carbonate scale and that cavitation kills biologics by breaking down cell walls. They also state that the vacuum produced by cavitation strips carbon dioxide (CO_2), elevating the pH, and creating a low-corrosion environment.

Electrolysis Systems

Electrolysis systems pass an electric current between two electrodes. Precipitation of minerals occurs at the cathode. These systems can also be used to inhibit biological growth by formation of chlorine gas at the anode.

An electrolysis system tested by the National Renewable Energy Laboratory[14] used a titanium anode and a basic solution at the cathode to promote scaling to the cathode. Water savings were achieved but since the baseline did not exhibit scaling, the opportunity for energy savings was not present. Biological control seemed reasonable.

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[10] Vidic, Radisav, Ducia, Scott M., Stout, Janet E., "Biological Control in Cooling Water Systems Using Non-Chemical Treatment Devices", ASHRAE Project 1361-RP, April 2010.

[11] McLachlan, David and Cho, Young I., "Physical Water Treatment for Cooling Towers, " Presented at the 2008 Cooling Technology Institute Annual Conference, February 4-7, 2008.

[12] Acquired by EcoWater systems in 2014.

[13] Controlled Hydrodynamic Cavitation, Chemical-Free Cooling Tower Water Treatment System," Ecowater Systems, June 2014.

[14] Tomberlin, Gregg, Dean, Jesse and Deru, Michael, "Electrochemical Water Treatment for Cooling Towers," NREL for GSA, December 2018.

Articles by Cooling Quality Management (CQM)[15] describe its electrolysis technology that claims to permit twice the cycles of concentration in the blowdown water, with 60 percent to 100 percent blowdown savings. Cooling water is pumped into a reaction tank, where a series of disk-shaped cathodes, or negatively charged electrodes, are placed in the reactor. Anodes, or positively charged electrodes, are located between the cathodes. The electrolysis process creates a high pH level at the cathode, inhibiting corrosion. Existing minerals in the water adhere to the disk-shaped cathodes, preventing those minerals from depositing on heat transfer surfaces as scale. As the cathodes rotate, a blade adjacent to each cathode mechanically wipes them clean from those minerals, which are then disposed at the drain. On the anode, electrolysis generates chlorine and other free radicals, which eliminate bacterial growth and disinfect water and also prevent algae and mussel colonies formation, without chemical additives.

Ultrasonic Systems

Ultrasonic systems impart high-frequency sonar energy that can cause mechanical damage to bacteria cell walls. Like cavitation devices, ultrasonic energy can also produce low-pressure bubbles, which can collapse and contribute to the damaging of bacteria cell walls.

Ultraviolet Light Systems

Ultraviolet (UV) light systems irradiate a water stream with UV-C wavelength light in the 100-280 nanometer range. When UV-C light penetrates the cell of a microorganism, it typically breaks down the DNA, altering functions such as the DNA replication process necessary for cell division and thus disturbing the ability of the subject microorganisms to procreate.

Ozone Systems

Ozone systems can be used as a disinfectant when contact is made between the ozone and microorganisms. It is difficult to maintain an effective residual of ozone throughout a cooling-water system because of ozone's high reactivity and fast dissipation. Successful application of ozone for biological control requires that sufficient ozone-generating capacity be provided to sustain a level of ozone residual that will control microbial contamination throughout the cooling-water system.

An ASHRAE study[16] evaluated non-chemical PWT devices (magnetic, pulsed electric field, electrostatic, ultrasonic, and hydrodynamic cavitation) as means of microbial control.[17] No statistically significant difference in microbial concentrations was observed in the test cooling tower for any of the devices as compared to an untreated tower used as a control.

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[15] "Cooling Tower Water Treatment – Chemical-Free", CQM (Cooling Quality Management), downloaded 1-07-20.

[16] Vidic, Radisav; Ducia, Scott M.; Stout, Janet E., "Biological Control in Cooling Water Systems Using Non-Chemical Treatment Devices," ASHRAE Project 1361-RP, April 2010.

[17] The authors provide a thorough literature review of each technology with regard to its ability to control bacterial growth.

Industrial Vortex Generator Technology for Cooling Towers

The IVG-CT is a low-energy use PWT developed in Sweden by Watreco,[18] and distributed worldwide by H2oVortex. It is manufactured in Sweden using a 3D printing technology. Combining this nonchemical physical treatment technique with (a) ongoing monitoring of performance and (b) appropriate chemical balancing if required[19] yields significant benefits compared to the traditional 100 percent chemical treatment methods. IVG-CT is a side-stream water treatment process that uses a combination of these physical treatment disciplines:

1. Removal of entrained microbubbles in water stream
2. Hydrodynamic cavitation
3. UV-C light microbiological control system
4. Filtering (basin water and makeup water)
5. Local and remote monitoring and control system

The IVG-CT side-stream water treatment unit is itself 3D printed and then assembled into a plug and play unit or "skid" and is a self-contained and monitored system with added filtration and UV-C light protection. The system dynamically monitors and controls blowdown of the cooling towers to the optimal target to maximize COC, consistent with current building code standards in California Title 24. The following provides the manufacturer's description of the functions and science behind the vortex process technology (VPT).

The vortex flow from the system creates extreme pressure gradients and forces to limit or exclude the buildup of lime within the cooling tower supply. The vortex generator shapes the fluid flow in three stages:

- Preformer: The inlet of the vortex generator provides a smooth outward direction of the flow through toroidal motion toward a set of well-defined channels.
- Channels: After the preformer, the fluid is directed through the channels, each with vortex-forming geometry. Each channel delivers a very high velocity stream of vortex flow tangentially into a vortex chamber.
- Vortex chamber: In the vortex chamber, the vortices from the channels are wound together. A strong and stable vortex flow is formed inside the vortex chamber.

The VPT device shown in Figure 3 removes microbubbles in the water due to the low pressure in the center of the vortex. This pressure vacuum is generated within the vortex (analogous to a tornado) due to the dynamic forces. There is a dynamic between the inertia and centripetal forces in the intense rotation that makes the pressure higher at the periphery, so the microbubbles move toward the vacuum in the center. This means that a strong pressure gradient is created in the vortex. The microbubbles that are present will migrate toward the center where the lowest pressure is (Archimedes principle), and this is accelerated due to the

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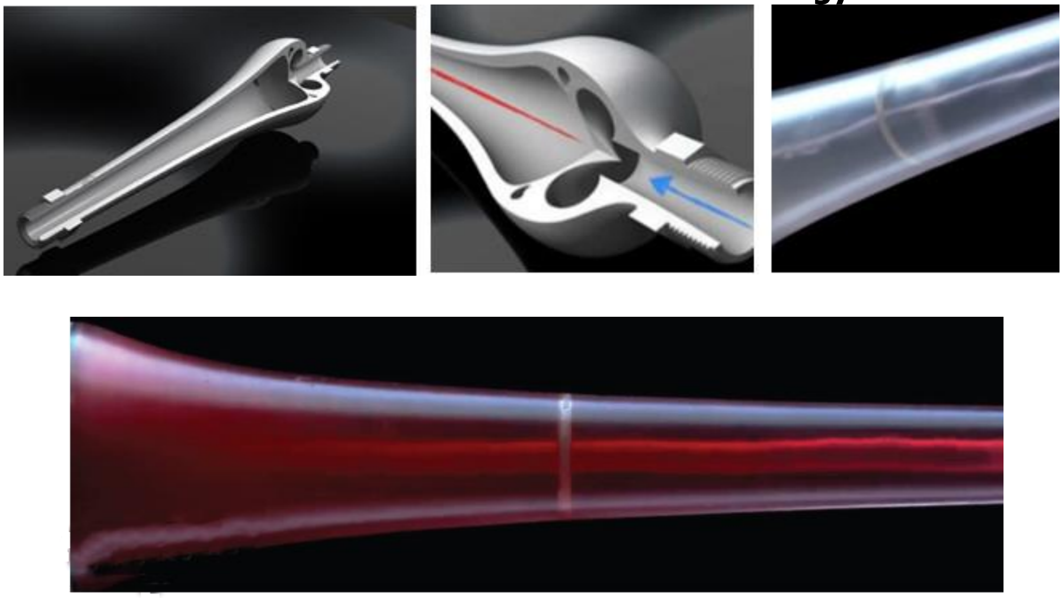
[18] Watreco AB Industrial Vortex Generator (IVG) patents are based on Vortex Process Technology (VPT) http://www.watreco.com/engelska.php H2O Vortex (www.h2ovortex.com) is a Luxembourg-based company focusing on commercializing and distributing sustainable and energy saving solutions to a wide variety of global markets.

[19] Depending on the quality of the make-up water.

high-pressure gradient. The bubbles will expand due to the lower pressure and combine with other bubbles, forming a string of gas in the center.

Figure 3: Vortex Process Technology – Core Component of Industrial Vortex Generator Technology



Source: Electric Power Research Institute

To remove air microbubbles from water, the typical process has historically been to heat the water to remove the air from the water. A relevant VPT example is that of water being used for making ice. Water without microbubbles gives better ice quality compared to ice that is made with water containing a higher volume of air. Microbubbles range from as large as 1/25th inch (1,000 micrometers) to 1 micron (µm) or 1/25,000th of an inch (see Table 1). Anything smaller is considered a nanobubble.

Table 1: Inch, Micrometer, and Micron Comparison

micrometer	µm	inch
25.4	25,400	1
1 mm	1000 uM	0.0393
0.001	1 uM	0.0000393

1–10 µm – length of a typical bacterium; ~ 100 µm diameter human hair

Source: Electric Power Research Institute

With the VPT unit, some of the air in water (both dissolved air and undissolved air microbubbles) can be removed by lowering the pressure. Gases (air) within water are very dependent on the pressure of the system. The concentration of a gas (such as air) in a fluid is directly proportional to the partial pressure in the system – this is Henry's Law.

$$c = pg / k_H$$

where

c= solubility of dissolved gas
k_H= proportionality constant depending on the nature of the gas and the solvent (water in this example)
p_g= partial pressure of gas (Pa, pounds per square inch [psi])

For example, at 75 psi, similar to city water pressure, the water at 50°F (10°C) would have about 14 percent air by volume. If the water drops only to just atmospheric pressure of 14.7 psi, the percent of air drops to 2.3 percent. So, for 100 gallons of water, 11.7 gallons of air can be removed – passively. The VPT unit creates an intense sub pressure lower than 1 bar or 14.7 psi within its vortex.

The VPT combines these effects to force the precipitation of calcium carbonate. The calcium crystallization process is related to the pressure gradient and the sheer forces inside the vortex due to the interaction among water, calcium ion, and carbon dioxide (CO_2). The physics and chemistry of the crystallization process are explained in detail in the following section. CO_2 solutes in the water as a function of pressure (higher pressure = higher solubility) and a higher CO_2 concentration solution is slightly acidic. This means the pH level varies along the pressure gradient, so that there is lower pH at the periphery and higher in the center of the vortex. This has been found when different samples from the center and the periphery of the vortex were tested and different pH levels demonstrated. The calcium ion precipitates and forms calcium carbonate ($CaCO_3$) at a specific pH level, and in the VPT it forms in the bulk water away from the walls. The water does not form scaling on the walls of the VPT itself. The calcium carbonate forms aragonite and eventually calcite, the hard crystal seen in lime scaling, due to the dynamic treatment in the vortex with its high sheer forces (Kim et al, 2009). These precipitates are not as likely to coat warm surfaces such as heat transfer surfaces, which will reduce lime scale and can be both filtered with nanofilters and blown down as part of the typical tower maintenance (Wang et al, 2013).

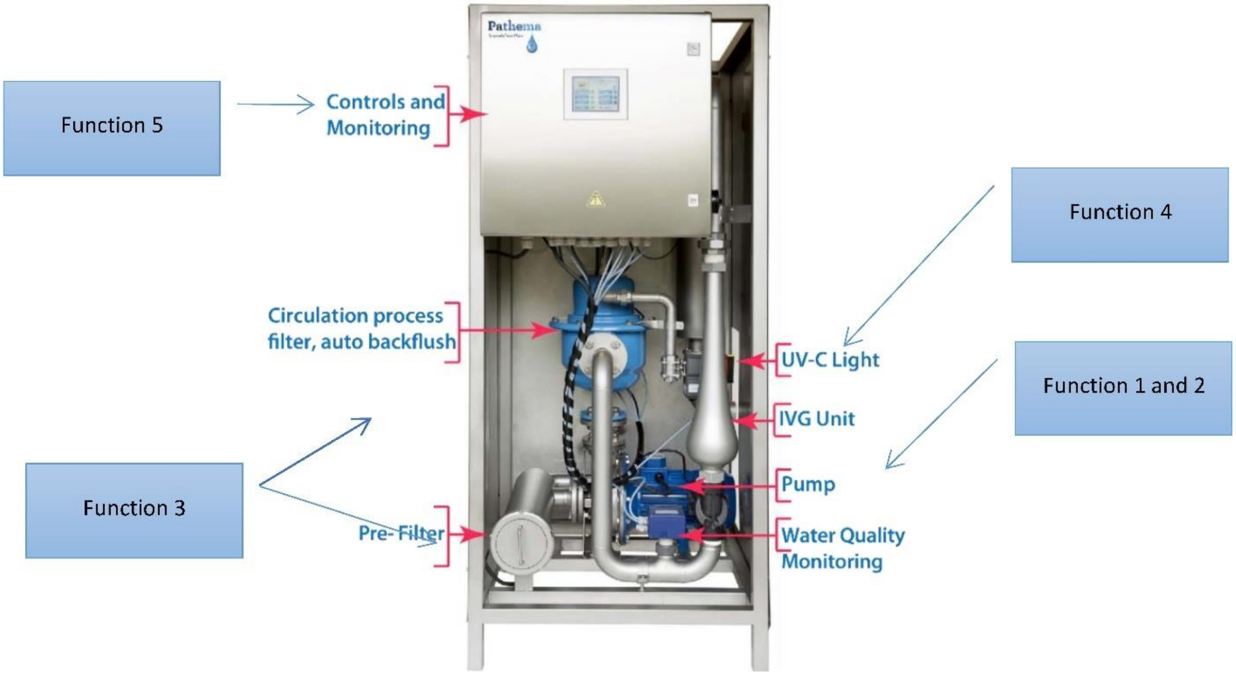
The reduction in the scaling and fouling of the cooling tower coupled with the lower viscosity (due to removal of microbubbles) increases the overall heat transfer in the chiller heat exchanger. This improves overall plant efficiency with reduced chiller power loads. When enough lime particles have been formed under the extreme conditions of cavitation in the system, the chemical balance is shifted so that lime is dissolved rather than formed. This will dissolve both new and old lime.

There are five primary functions for the VPT components, shown in Figure 4, and explained by the manufacturer.

- The first function is to eliminate and/or significantly reduce lime scale. In water treated using the VPT system, soluble forms of calcium such as calcium bicarbonate $(CaHCO_3)_2$

are transformed into calcite and preferentially aragonite, which do not attach to pipes, nozzles, or other surfaces.

Figure 4: Vortex Process Technology Components and Functions



Source: Electric Power Research Institute

- The second is to remove microbubbles. The de-gassing of air causes a decrease in viscosity[20] from 3 percent to 17 percent and has better heat transfer properties than water that is not degassed. This also assists in scale control and partial bacteria cell wall disintegration. The unbound gases (air, CO_2) are removed from the water by controlled cavitation, a vacuum in the middle of the vortex, due to the design of the unit.
- The third is to filter the water. By automatically filtering the cooling water continuously, the lime particles and other materials are filtered out of the water. There are manual and automatic filters that provide a range of 20 microns of filter material.
- The fourth is to disinfect the water using a UV-C microbiological control system based on the natural disinfecting properties of sunlight. The short wavelength (100–280 nanometers) damages DNA and is therefore ideal for this purpose. When UV-C light penetrates a microorganism's cell, it typically breaks down the DNA, which forms thymine dimeres. Various DNA functions such as the DNA replication process necessary for cell division are also disturbed, so microorganisms cannot procreate. The VPT and UV-C reactor are mounted directly in water flow as part of the cooling side-stream assembly or "skid" and are sized based on flow requirements. This can be used in various water, wastewater, and other disinfectant applications including drinking water. The UV-C sensor ensures water is receiving the amount of radiation needed, and its status is monitored and alarmed and has an inspection window.
- Function five is the integrated monitoring and controls. Industrial grade supervisory control and data acquisition (SCADA) control panel with sensor inputs is used for both

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[20] Tested by the Polymer Technology Group Eindhoven BV at University of Eindhoven, NL (2011, Jan 31 report).

local and/or remote monitoring. COC are controlled based on water quality conditions, including conductivity, and/or flow-based controls. The automatic blowdown control is based on the Langelier Saturation Index (LSI) consistent with California Title 24. Typical metrics are documented for performance and control blowdown, either through the controller or site-based testing. These metrics include conductivity, pH, alkalinity, calcium, magnesium hardness, total hardness, silica, actual cycles, makeup and bleed water volume, and water temperatures. The LSI is also used to determine maximum achievable COC based on local water supply.

The IVG-CT system installation and commissioning process were straightforward. The complete VPT system package including all piping, electrical, and controls wiring was received in shipping containers for each site. The electrical and piping connections were installed at the sites. The commissioning was performed by the factory trained technicians. The systems field performance was monitored and adjusted remotely through cellular network communications. The system performance adjustments were made to control makeup water flow rate to achieve certain cycles of concentration. The IVG-CT controls system provided data for the cooling tower basin water conductivity as well as the makeup water conductivity. Thus, this allowed control of the makeup water flow rate to maintain a desired level of conductivity or cycles of concentration in the cooling tower. The pretreatment of makeup water and removal of impurities from the cooling tower water through nanofilters allowed higher cycles of concentration in cooling tower operation. The IVG-CT system also controlled periodic back flush of the nanofilter to keep it clean.

Physics Behind Vortex Generator

Scale Elimination

As a result of the heating of the cooling water, lime scale may occur that will deposit on the condenser and other heat exchange surfaces. $CaCO_3$ is usually in solution in the form of calcium bicarbonate. The following equation, Equation 2, is an equilibrium reaction:

$$\boldsymbol{Ca(HCO_3)_2\,(aq) \leftrightarrow CaCO_3\,(S) + CO_2\,(aq) + H_2O(l)}$$

In turn, CO_2 is also in solution and is an equilibrium reaction, as shown here in Equation 3:

$$\boldsymbol{CO_2\;(aq) \leftrightarrow CO_2\,(g)}$$

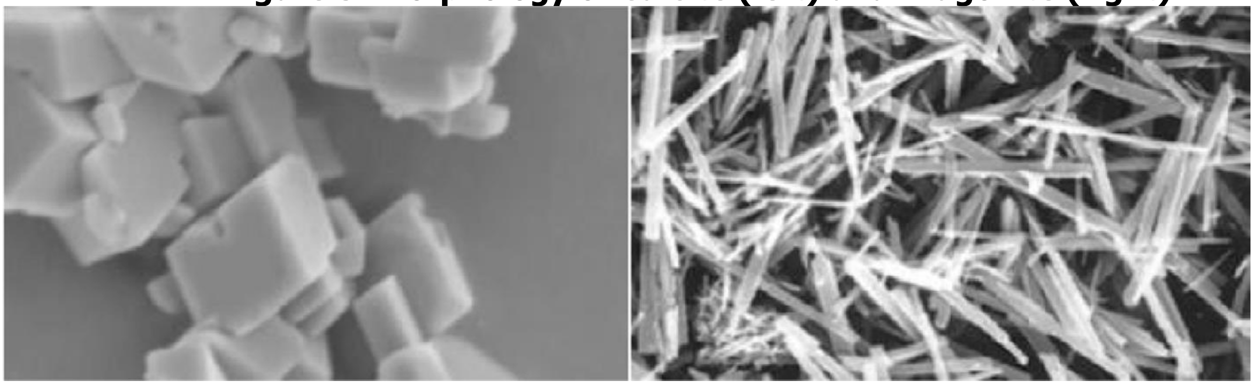
The solubility of CO_2 decreases as water temperature increases. When operating the evaporative condenser, the water warms up and shifts the equilibrium of Equation 3 to the right. Since the equilibrium reactions are linked together, Equation 2 will also shift to the right and form solid $CaCO_3$. If the equilibrium of Equation 3 can be shifted earlier by means of degassing, insoluble calcium carbonate is indirectly also formed.

The IVG-CT brings the water in a powerful rotation that balances pressure in a vacuum using the industrial vortex generator (IVG). This continuous process changes the structure of the treated water by degassing micro and nano gas bubbles, such as CO_2. This degasification prevents the deposit of lime scale to the surface of the evaporative condenser. The cooling water is therefore not decalcified, but the crystallized lime in suspension will not adhere to the zinc heat exchangers where the coolants repel heat. When the crystals grow to a degree of problem due to congestion and/or settling, they are filtered out. Crystallizing lime instead of removing it during treatment is a crucial difference from traditional methods. Lime removal greatly affects the pH and corrosion risks of the cooling water, and in general terms, the resulting water is known as "aggressive." Lime is a natural corrosion inhibitor and upon removal, the corrosion control of the zinc layers in the evaporative condenser must be chemically absorbed. In the IVG-CT, the lime stays in the water for as long as possible without depositing, and thus controls the corrosion risks. Upon successful operation of these principles, reduced chemical use for the evaporative condenser is realized.

Crystallization

The $CaCO_3$ that is formed in the IVG-CT crystallizes differently than its typical formation. Aragonite and calcite crystals shown in Figure 5 are formed. During the formation of $CaCO_3$, the forces of the PWT prevent the crystals from attaching to the heat exchanger surfaces. Instead, the crystal remains dissolved and suspended in the water. Because of the aragonite and calcite cultures that arise in the vortex, even more aragonitec calcite crystals will form in a later process in the evaporative condenser. These later-formed crystals will further crystallize on the crystal cultures that have already formed in the vortex. The length of the vortex, and thus the cavitation tunnel, determines the amount of extraction of the unbound gasses. When more carbon dioxide (CO_2) gas is extracted by the vortex, more $CaCO_3$ from the polymorph aragonite will form.

Figure 5: Morphology of Calcite (left) and Aragonite (right)



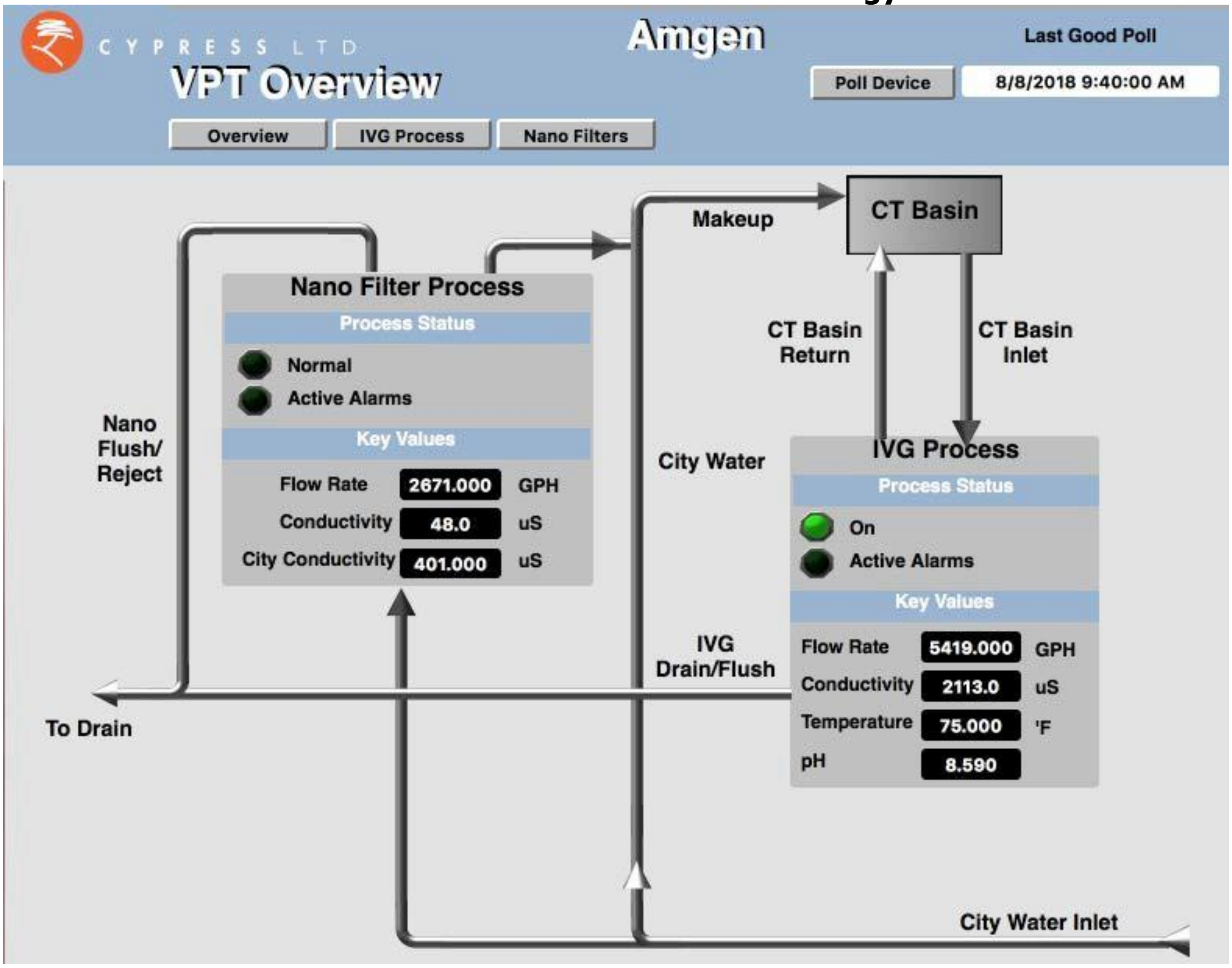
Source: Electric Power Research Institute

The most important property of aragonite is that it does not adhere. The $CaCO_3$ that is formed remains dissolved in water and will not attach to the surfaces, so treatment with salts or chemicals is no longer necessary. Furthermore, aragonite is harder than calcite, and aragonite usually grows in needle-shaped crystals (acicular), while calcite has a leaf-shaped habitus. The harder aragonite can erode or dissolve old calcite layers, and thus further improve heat transfer in the chiller.

Industrial Vortex Generator Technology for Cooling Towers Data Monitoring Service

To make sure the supported cooling tower water treatment system performs as designed and provides real-time data tools, a 24/7 SCADA system and service was installed as part of the IVG-CT system (see Figure 6, Figure 7, and Figure 8).

Figure 6: Supervisory Control and Data Acquisition Dashboard for Industrial Vortex Generator Technology – Screen 1



Last Good Poll: 8/8/2018 9:40:00 AM

Nano Filter Process

Process Status

- Normal
- Active Alarms

Key Values

Flow Rate	2671.000	GPH
Conductivity	48.0	uS
City Conductivity	401.000	uS

IVG Process

Process Status

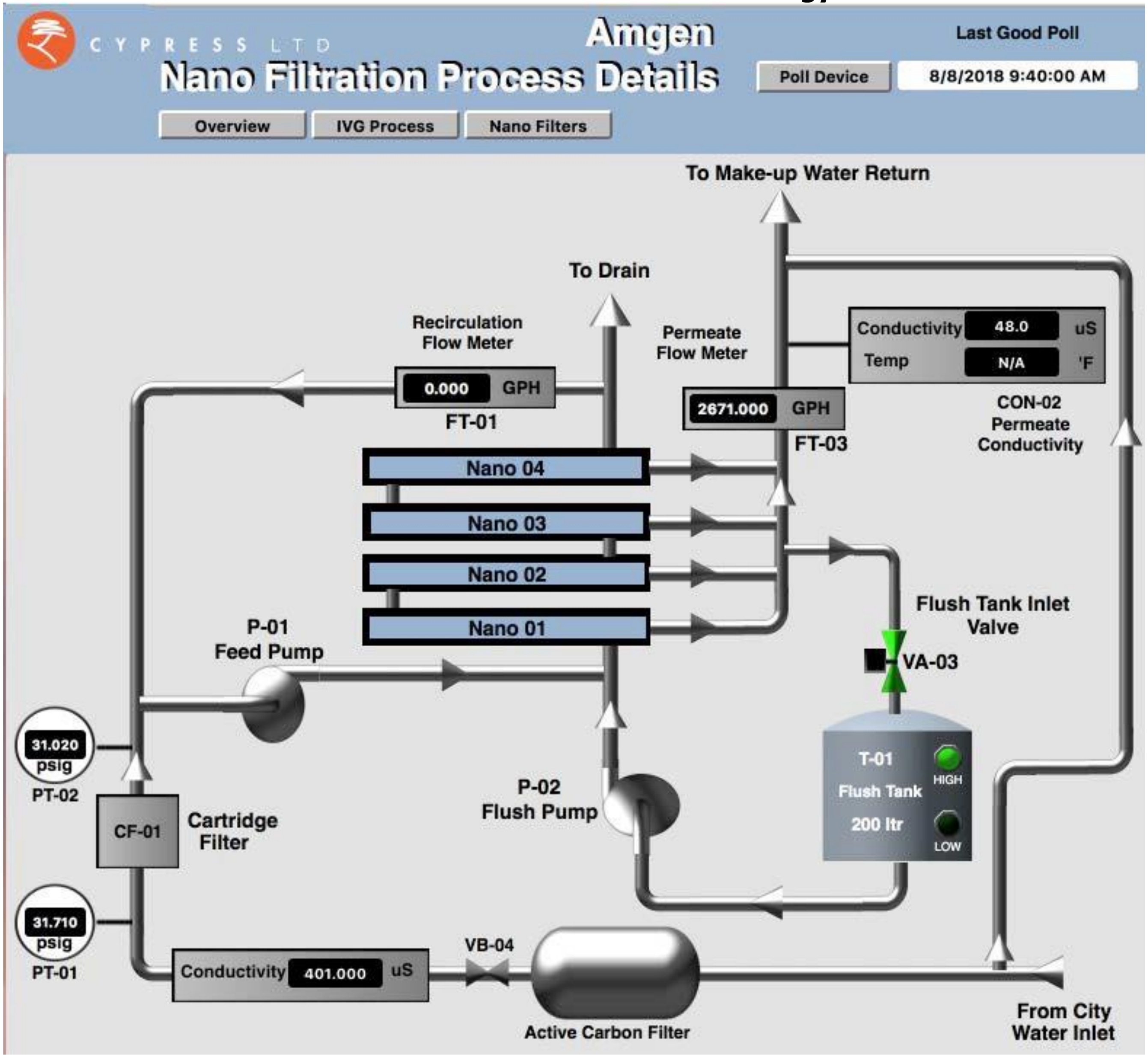
- On
- Active Alarms

Key Values

Flow Rate	5419.000	GPH
Conductivity	2113.0	uS
Temperature	75.000	'F
pH	8.590	

Source: Electric Power Research Institute

Figure 7: Supervisory Control and Data Acquisition Dashboard for Industrial Vortex Generator Technology – Screen 2



Amgen

Nano Filtration Process Details

Last Good Poll: 8/8/2018 9:40:00 AM

FT-01 Recirculation Flow Meter: 0.000 GPH

FT-03 Permeate Flow Meter: 2671.000 GPH

CON-02 Permeate Conductivity: Conductivity 48.0 uS, Temp N/A 'F

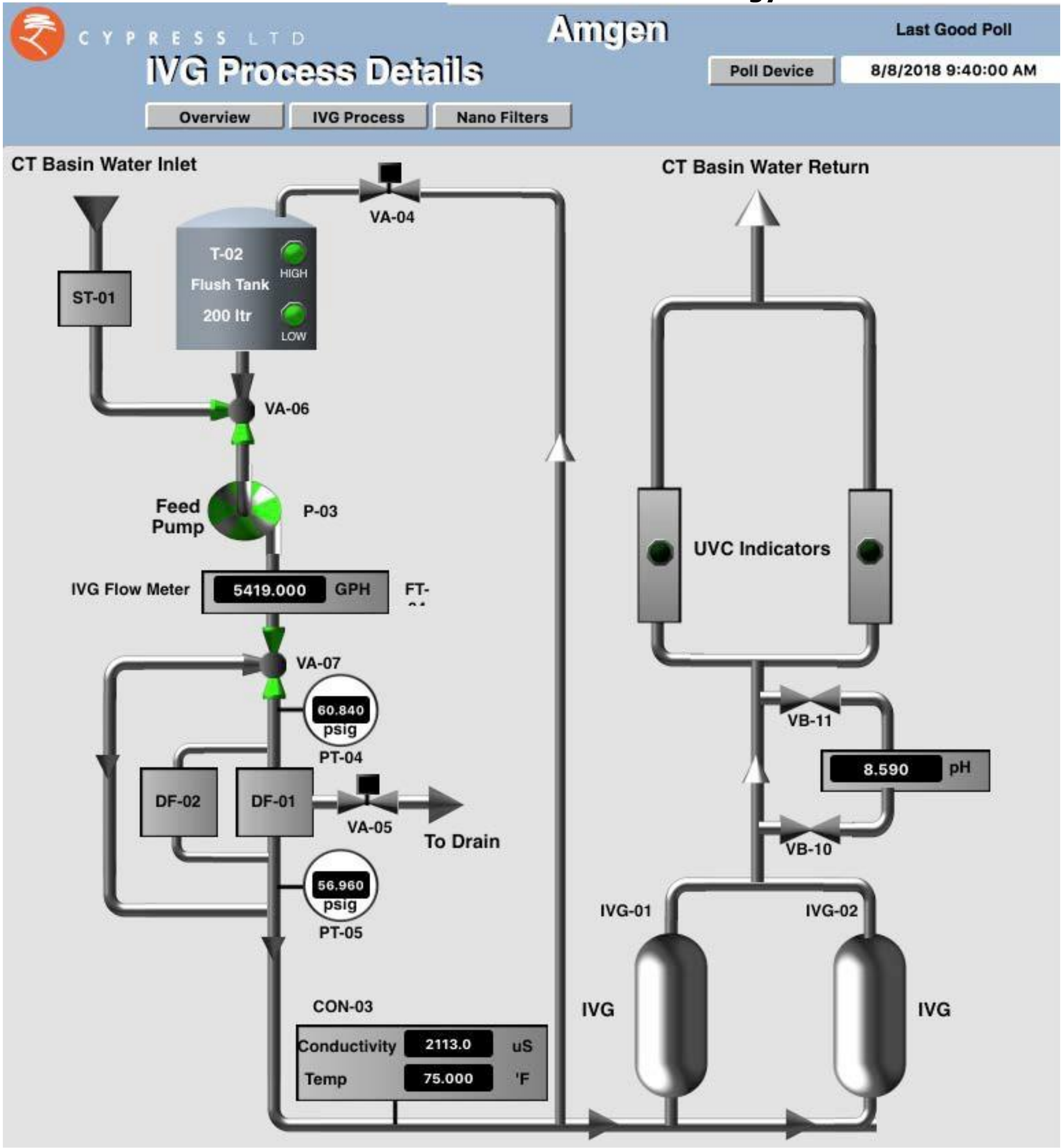
PT-02: 31.020 psig

PT-01: 31.710 psig

Conductivity: 401.000 uS

Source: Electric Power Research Institute

Figure 8: Supervisory Control and Data Acquisition Dashboard for Industrial Vortex Generator Technology– Screen 3



Source: Electric Power Research Institute

Profile of Supervisory Control and Data Acquisition Services

- Always on: The local programmable logic controller (PLC) detects any changes in normal operation, whether the changes are immediate and obvious or incremental and subtle.
- Seamless integration: The system is seamlessly integrated with the H2O Vortex IVG-CT equipment, and all monitoring is done through the integral PLC controller and cellular

communications to EPRI’s 24/7/365 service center and secure servers in Hemet, California.

- Monitors any/all points: The system provides monitoring of critical sensor-based inputs that yield insights into the operations of the cooling towers.
- Data acquisition: Real-time acquisition of field data in the form of either sensor-based digital and/or analog inputs or a digital data stream, or in many cases, both. This real-time data acquisition process is managed and executed via a cellular data communication link.
- Data analysis: Can provide a synopsis of relevant metrics for cooling tower performance ranging from cooling tower water use, water temperatures, dry bulb/wet bulb, flow rates, pH, and conductivity, as well as access to historical and forecast reports and critical alarms.
- Information delivery: This is accomplished using commercial off-the-shelf data acquisition and communications technology, coupled with advanced cloud-based dashboard software.

CHAPTER 3:
Site Analysis, Equipment Selection, Procurement, and Installation

This chapter details the selection of project host sites as well as the equipment details, technology functionalities, procurement, and installation.

Test Site Description

Two host sites were selected to demonstrate the IVG-CT for cooling tower water treatment.

Marriott Westin Mission Hills Golf Resort and Spa

The Marriott Westin Mission Hills Golf Resort and Spa host site is a hotel located in Rancho Mirage, California. It has two 450-ton chillers and associated cooling towers. Figure 9 and Figure 10 illustrate the cooling tower at the hotel host site. The operation and maintenance of this system is representative of a typical commercial building system. Prior to the IVG-CT installation, the energy management and controls system (Trane Trace®) was only logging about two weeks of data for archiving. Historical data was requested and downloaded but the available data prior to the installation of the IVG-CT was limited to May, June, and July 2016. After the installation of the IVG-CT, data was stored for a minimum of one month, downloaded, and archived. Upon start-up, the system was operated for several weeks to commission all operating needs. This data was not used for purposes of M&V data.

Figure 9: Cooling Tower in Hotel Host Site

Source: Electric Power Research Institute

Figure 10: Close-Up of Cooling Tower at Hotel Host Site

Source: Electric Power Research Institute

Amgen Pharmaceutical Company

The Amgen host site has a set of two cooling towers operating in parallel serving two chillers at 1,250 tons capacity each in a central plant in Thousands Oak, California. These were installed in early January 2017. The baseline period for data capture was based on the existing towers, and the post-installation data reflected the new cooling towers as well as chiller tube cleaning prior to the new cooling towers being placed into service. The chilled water plant was very well monitored with process control instrumentation and controls using the Optimum® system. This installation is representative of the industry best practices in operation, maintenance, and performance monitoring of a chilled water plant. Environmental and operational data collected from the controls systems were archived. Records of data collected from manually read meters were also maintained. Figure 11 and Figure 12 show the Amgen pharmaceutical building cooling towers and chillers, respectively.

Figure 11: Cooling Towers at Pharmaceutical Host Site

Source: Electric Power Research Institute

Figure 12: Chiller at Pharmaceutical Host Site

Source: Electric Power Research Institute

Procurement Process

The IVG-CT was developed in Sweden and has already achieved initial market adoption in Europe. The equipment for this project was procured from Europe and assembled on site in California. The units for both project test sites were fabricated and installed in modular containers in February 2017, and seismic requirements for anchoring the units were also completed. The units were shipped from the Netherlands in March 2017, with the Amgen pharmaceutical unit shipped in a 20-foot container and the hotel unit shipped in a 10-foot container. Both units cleared customs and arrived at Los Angeles in May 2017. Table 2 lists the actions and dates involved in procuring the equipment.

Table 2: Equipment Procurement Schedule

Phase	Date of Completion
Fabricate and install equipment in modular containers	4/7/2017
Finalize any seismic requirements for anchoring units	4/20/2017
Shipping for 20-ft. container	2/22/2017
Shipping for 10-ft. container	3/8/2017
UL Certification (for controls wiring) of pharmaceutical unit	3/31/2017
Shipping of the 20-ft. container: pharmaceutical unit	3/18/2017
Shipping of the 10-ft. container: hotel unit	3/18/2017
Final site install drawing, costs, timing, cranes	7/30/2017
Equipment arrives in Los Angeles	5/17/2017
Clear Customs	5/17/2017
Equipment installed at sites	hotel 6/25/2017 pharm. 7/12/2017

Source: Electric Power Research Institute

Installation Considerations

Figure 13, Figure 14, and Figure 15 illustrate the installation process and considerations during the IVG-CT equipment install at the hotel host site. Figure 16 shows the chiller plant schematic (PLC diagram) with labels for the location of the temperature and flow meter sensors points.

Figure 13: Hotel Host Site Inspection

Source: Electric Power Research Institute

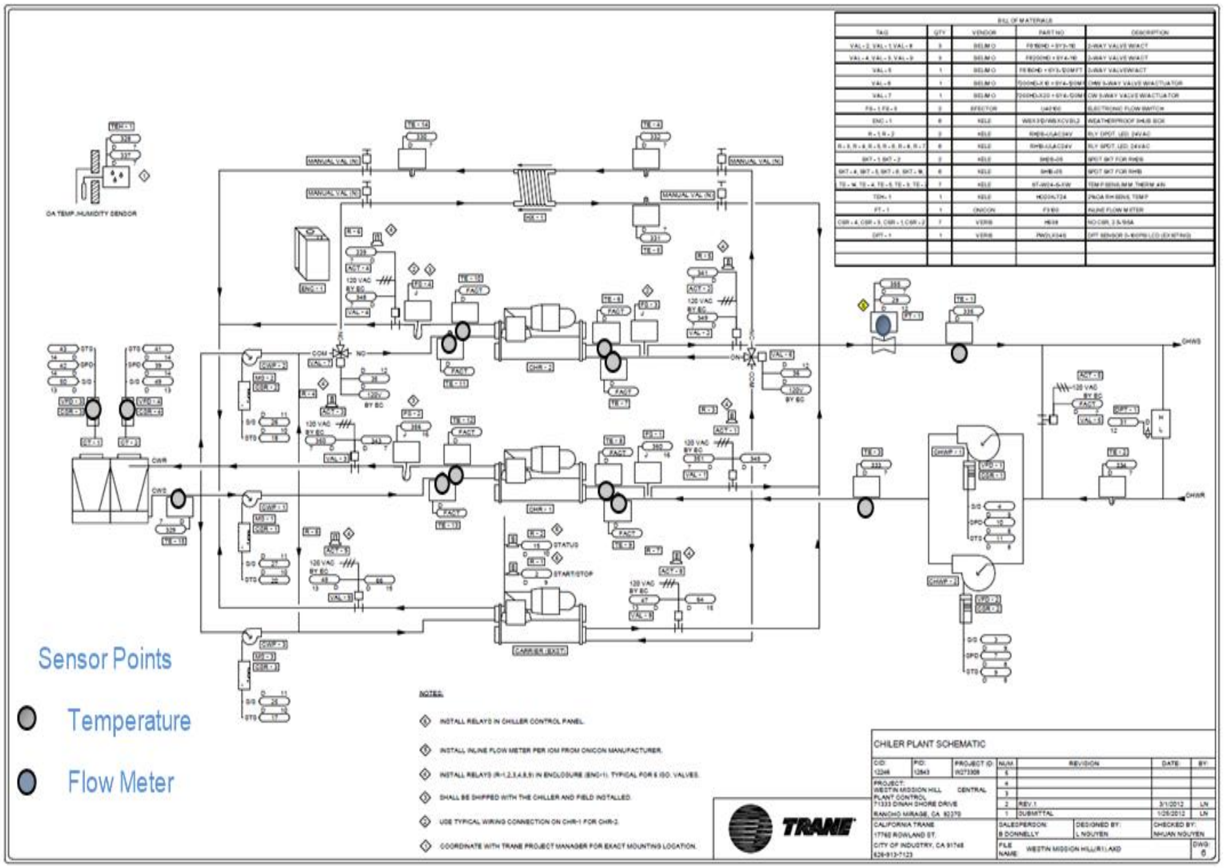
Figure 14: Installed IVG-CT Equipment at Hotel Host Site

Source: Electric Power Research Institute

Figure 15: Installed IVG-CT Equipment at Hotel Host Site

Source: Electric Power Research Institute

Figure 16: Hotel Site Cooling Tower Plant PLC Diagram with Sensor Points (Temperature and Flow Meter)



Source: Electric Power Research Institute

The IVG-CT equipment was installed at the hotel host site on June 25, 2017, and at the pharmaceutical host site on June 12, 2017. The hotel control system does not retain significant historical data as it is overwritten approximately every two weeks. The pharmaceutical site energy management system provided historical data back to 2015 and 2016 and during the IVG-CT system test period. The 2015 data were used as a baseline for water use for comparison with the IVG-CT system test data.

The cooling towers at the pharmaceutical site were newly installed in 2017 so there was no detectable scale buildup prior to IVG-CT installation. After the IVG-CT installation, the pharmaceutical site cooling towers at PS6 site were shut down for maintenance during September and October 2017. The chillers were then shutdown over the holidays, December and January 2017. Additionally, the cooling towers did not operate for most of April and May 2018.

Testing of the IVG-CT system was conducted at the hotel site and at the pharmaceutical site from August 1, 2017 to November 30, 2018.

Figure 17 and Figure 18 illustrate the installation process and considerations during the IVG-CT equipment install at the pharmaceutical host site. Figure 19 shows the chiller plant schematic (PLC diagram) with labels for the location of the temperature and flow meter sensors points.

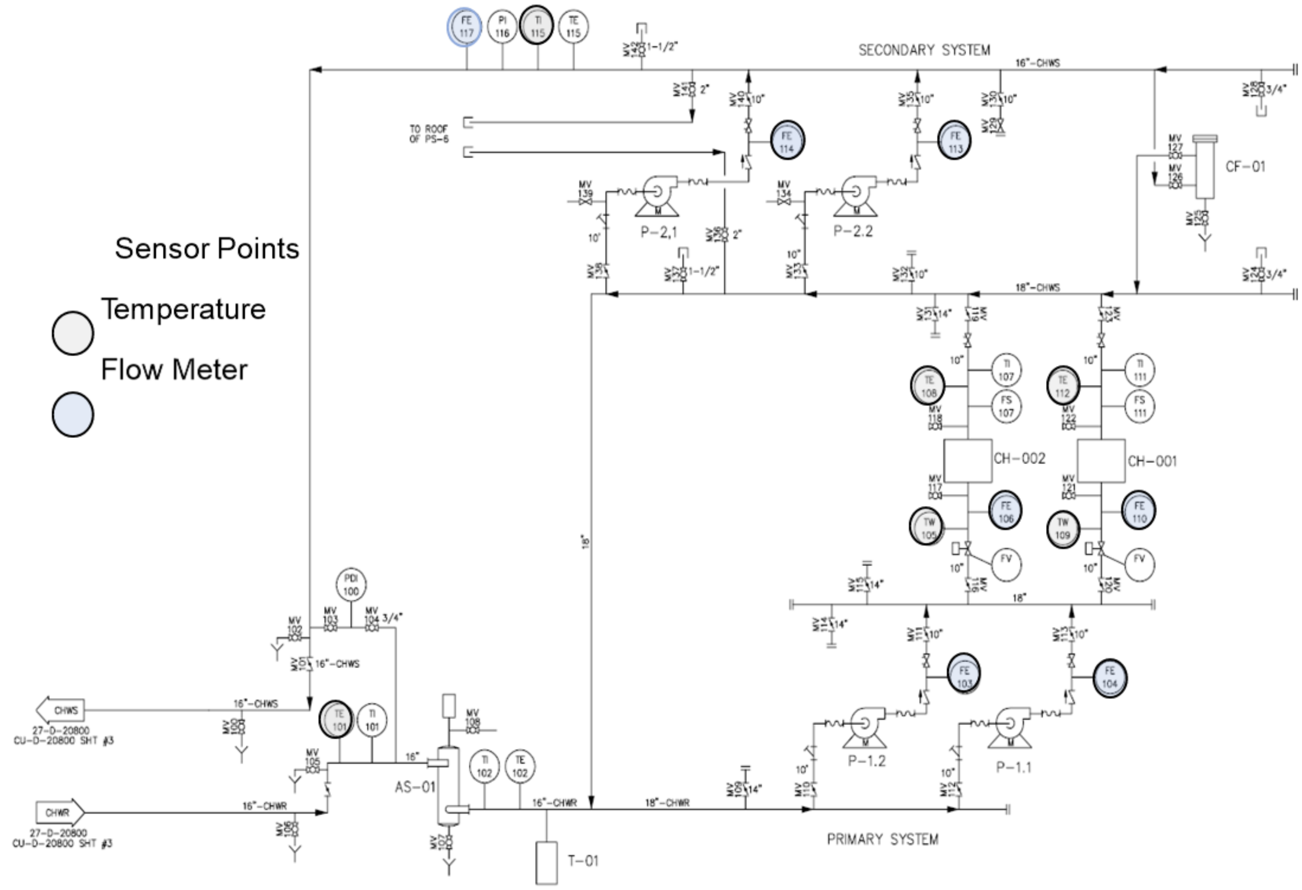
Figure 17: Pharmaceutical Host Site Inspection

Source: Electric Power Research Institute

Figure 18: IVG-CT Modular Install at Pharmaceutical Host Site

Source: Electric Power Research Institute

Figure 19: Pharmaceutical Site Cooling Tower Plant Programmable Logic Controller Diagram with Sensor Points (Temperature and Flow Meter)



Source: Electric Power Research Institute

Data Capture

For the pharmaceutical site, the Optimum® data collection system was used. Amgen pharmaceutical set up specific data files for download using this web system. Data were downloaded each month for the baseline and have been continued monthly for the post-installation data included for this report. The data included specific information related to each chiller as well as the plant, system, and various other variables that may not have been used for analysis but were collected to ensure the overall data captured was complete for the project.

Data were collected on an hourly basis for each variable. Specific to this analysis, the following data points are summarized:

- Chiller 1 kilowatt (kW)/ton – The system captures the actual efficiency for this chiller on a spot basis. This data was used as it provides a chiller specific data point that is based on actual measurements taken at the chiller installation.
- Chiller 2 kW/ton – The system captures the actual efficiency for this chiller on a spot basis. This data was used as it provides a chiller specific data point that is based on actual measurements taken at the chiller installation.

- Chiller 1 – Supply and Return Water Temperature – This was used to calculate the delta T for the same point where the chiller efficiency (kW/ton) was captured.
- Chiller 2 – Supply and Return Water Temperature – This was used to calculate the delta T for the same point where the chiller efficiency (kW/ton) was captured.
- Chiller 1 kW – This was used so the overall tons being supplied could be calculated for each point where the chiller efficiency was provided.
- Chiller 2 kW – This was used so the overall tons being supplied could be calculated for each point where the chiller efficiency was provided.
- Outside Air Temperature and Humidity – These were captured and used for specific regression analysis.
- Condenser Supply and Return Temperatures – These were captured and used for specific regression analysis.
- Chiller 1 Evaporation and Condenser Pressure – These points were captured and used at the request of EPRI to provide a delta P for the chiller.
- Chiller 2 Evaporation and Condenser Pressure – These points were captured and used at the request of EPRI to provide a delta P for the chiller.
- Plant Ton Hours – This provided the overall conversion from the data analysis to provide monthly chiller energy (kWh) based on actual ton hours collected.
- Cooling Degree Days – This was captured for the airport near the site from an accredited site10. This data was used to evaluate and adjust data to accommodate weather differences between the periods.

Each data point was captured based on an hourly time stamp beginning at the start of the month and through the last day of each month for the period covered by the analysis herein.

The Marriot Westin Mission Hills hotel host site uses TRANE Trace® Energy Management software to collect data. The pharmaceutical site incorporates the Optimum® energy management system for data collection and archiving. The hotel host site as noted herein had limited pre-installation data and fewer data points that could be collected. Additionally, its control system does not retain historical data and is overwritten approximately every two weeks, thus the baseline data were limited (pre-VPT install). Table 3 lists the data monitoring points available at the hotel site and what was selected for the analysis.

Table 3: Data Monitoring Points at Hotel Host Site

Data Points from Trane Tracer with Description	Comment
Chiller 1: Active Cool/Heat Setpoint Temperature	
Chiller 1: Actual Running Capacity	
Chiller 1: Chilled Water Setpoint	
Chiller 1: Chiller Auto Stop Command	
Chiller 1: Chiller Mode Command Baseline	
Chiller 1: Condenser Entering Water Temperature	**Required**
Chiller 1: Condenser Leaving Water Temperature	**Required**
Chiller 1: Condenser Saturated Refrigerant Temperature Circuit 1	**Required**
Chiller 1: Condenser Water Flow Status	
Chiller 1: Current Limit Setpoint	
Chiller 1: Differential Refrigerant Pressure Circuit 1	**Required**
Chiller 1: Drive Output Power Circuit 1	
Chiller 1: Evaporator Entering Water Temperature	**Required**
Chiller 1: Evaporator Leaving Water Temperature	**Required**
Chiller 1: Evaporator Water Flow Status	
Chiller 1: Operating Mode	
Chiller 1: Running Mode	
Chiller 1: Unit Power Consumption	**Required**
Chiller 2: Active Cool/Heat Setpoint Temperature	
Chiller 2: Actual Running Capacity	
Chiller 2: Chilled Water Setpoint	
Chiller 2: Chiller Auto Stop Command Multistate Baseline	
Chiller 2: Chiller Mode Command Baseline	
Chiller 2: Condenser Entering Water Temperature	**Required**
Chiller 2: Condenser Leaving Water Temperature	**Required**
Chiller 2: Condenser Saturated Refrigerant Temperature Circuit 1	**Required**
Chiller 2: Condenser Water Flow Status	
Chiller 2: Current Limit Setpoint	
Chiller 2: Differential Refrigerant Pressure Circuit 1	**Required**
Chiller 2: Drive Output Power Circuit 1	
Chiller 2: Evaporator Entering Water Temperature	**Required**
Chiller 2: Evaporator Leaving Water Temperature	**Required**
Chiller 2: Evaporator Water Flow Status	
Chiller 2: Operating Mode	
Chiller 2: Running Mode	
Chiller 2: Unit Power Consumption	**Required**
Chiller Plant: Chiller Plant Enable	
Chiller Plant: System Chilled Water Flow	**Required**
Chiller Plant: System Chilled Water Return Temperature	**Required**
Chiller Plant: System Chilled Water Setpoint	

Data Points from Trane Tracer with Description	Comment
Chiller Plant: System Chilled Water Supply Temperature	**Required**
Chiller Plant: System Mode	
UC600 - CHILLER PLANT: CH-1 CHW* ISO VALVE CONTROL	
UC600 - CHILLER PLANT: CH-2 CHW ISO VALVE CONTROL	
UC600 - CHILLER PLANT: CHW BYPASS VALVE	
UC600 - CHILLER PLANT: 1 VFD* SPEED CONTROL	
UC600 - CHILLER PLANT: 2 VFD SPEED CONTROL	
UC600 - CHILLER PLANT: FLOW METER	
UC600 - CHILLER PLANT: Condenser Water Supply Temp	
UC600 - CHILLER PLANT: Condenser Water Temperature Setpoint	
UC600 - CHILLER PLANT: FAN 1 VFD SPEED CONTROL	
UC600 - CHILLER PLANT: FAN 2 VFD SPEED CONTROL	
UC600 - CHILLER PLANT: 3 WAY VALVE CONTROL	
UC600 - CHILLER PLANT: HX CDW RET TEMP	
UC600 - CHILLER PLANT: HX CHW SUPPLY TEMP	
UC600 - CHILLER PLANT: OUTSIDE AIR HUMIDITY	**Required**
UC600 - CHILLER PLANT: OUTSIDE AIR Temperature	**Required**
Westin Mission Hills Chiller Plant: Average Plant Operating Tons	**Required**
Westin Mission Hills Chiller Plant: Chiller Average Cond Leaving Temp	**Required**
Westin Mission Hills Chiller Plant: Chiller Average Evap Leaving Temp	**Required**
Westin Mission Hills Chiller Plant: Current Chiller Plant Tons	**Required**
Westin Mission Hills Chiller Plant: Delta Temp Cond	**Required**
Westin Mission Hills Chiller Plant: Delta Temp Evap	**Required**
Westin Mission Hills Chiller Plant: Free Cooling Requested	
Westin Mission Hills Chiller Plant: Enthalpy	
Westin Mission Hills Chiller Plant: Wetbulb Temp	**Required**
Additional Power Monitoring	
Chiller 1 True Power Meter	**Required**
Chiller 2 True Power Meter	**Required**
Plant Service Entrance, Power meter	**Required**

***velocity frequency drive, *CHW=Chiller Water**

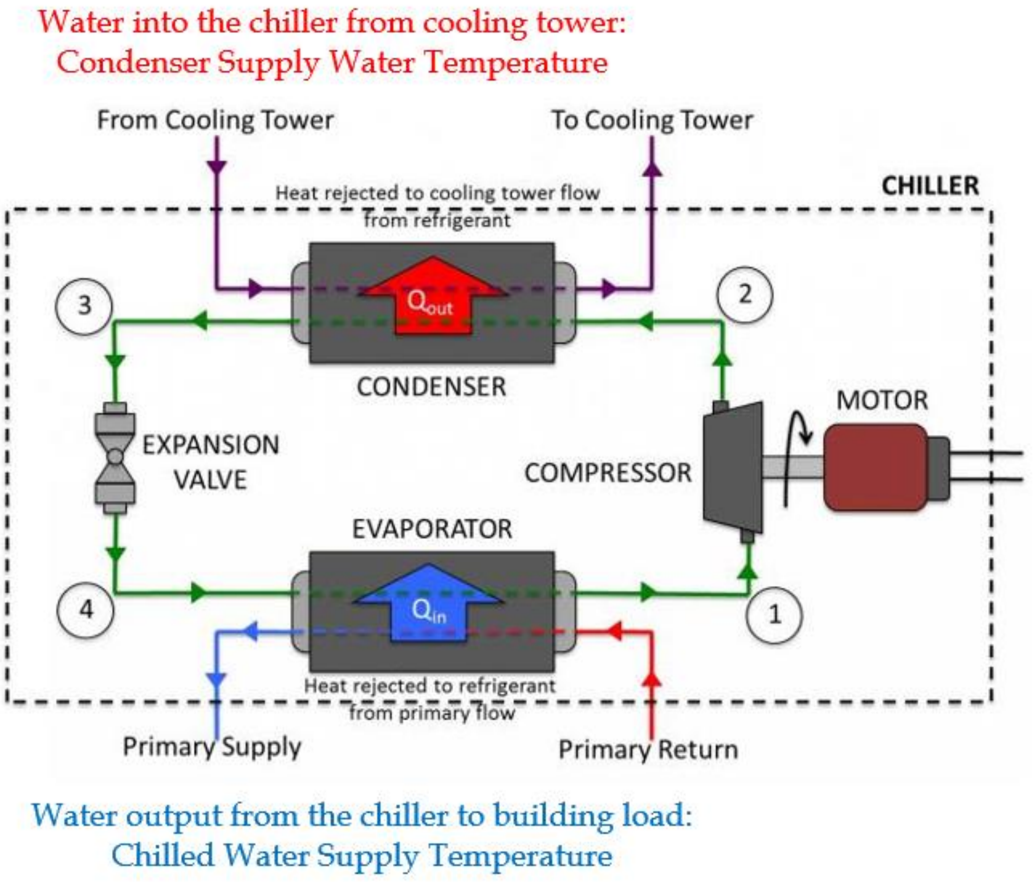
Source: Electric Power Research Institute

CHAPTER 4: Equipment/Technology Monitoring and Evaluation

System Under Study

While the IVG-CT system increases the cycles of concentration of the cooling tower, thus reducing water and chemical usage, its effect can also be realized at the chiller equipment level: specifically, the IVG-CT-treated water has higher density, lower viscosity, and cons water quality in the chiller's condenser. This change could affect the chiller efficiency with improved heat transfer across its heat exchangers (Figure 20).

Figure 20: Chiller Components Diagram



Source: Electric Power Research Institute

Overview of Chiller Energy Efficiency

A chiller's operation depends primarily on the following three operating parameters:

1. Chiller evaporator pressure/temperature
2. Chiller condensing pressure/temperature
3. Chiller load

Compressor power in a chiller depends on the suction and discharge pressures; the higher the difference in pressures, the more power is required. Compressor power depends on the refrigerant mass flow; more refrigerant flow (that is, capacity) requires more power. The suction and discharge pressures correlate to the saturated suction and saturated discharge temperatures — temperatures corresponding to the respective pressures. The actual refrigerant suction temperature is typically higher due to superheat in the evaporator. Similarly, the actual discharge temperature at the compressor outlet is higher, and the condensed refrigerant temperature is typically lower than the saturated discharge temperature due to subcooling of the refrigerant in the condenser. Both superheat and subcooling are essential in smooth operation of the chiller, and their values may vary under different operating conditions. They are most affected by the refrigerant mass flow rate (that is, capacity); when a chiller is operating at low capacity, its evaporator and condenser are ”oversized” and produce low evaporator superheat but more condenser subcooling.

It is impractical to measure these operating parameters in the field, so secondary parameters such as chilled water and condenser water temperatures are used. For chilled water, the temperature of water leaving a chiller is used (chilled water supply temperature). It is a good proxy for the refrigerant-saturated suction temperature. The chilled water leaving temperature will be affected by the chilled water flow rate in the heat exchanger. Similarly, condenser water entering a chiller (condenser water supply temperature) is used as a proxy to the condensing pressure or saturated condensing temperature. Again, the condenser water flow rate can affect the condensing pressure. In a field scenario, the chilled water flow rates before and after the treatment remain nearly same, so the effect of the flow rate is estimated to be negligible. The following three operating parameters were used for the chillers’ field performance measurements:

1. Chilled water supply temperature
2. Condenser water supply temperature
3. Chiller operating capacity (ratio of chiller operating capacity to its nominal capacity)

These parameters can be easily measured in the field. These operating parameters may not be constant during the measurement interval. If the interval is small, it is more likely that chilled water and condenser water temperature variations are negligible. As the IVG-CT system improves the water quality by removing microbubbles, which improves the heat transfer in the chiller condenser, chiller efficiency is expected to increase at any condenser water supply temperature and chiller capacity.

Additionally, the chiller compression ratio can also be used to assess the chiller’s performance. As the compression ratio increase, the chiller’s compressor will consume more energy. This metric is approximated by evaluating the ratio of the evaporating to condensing pressure if the data are available and reliable.

Technology Evaluation Methodology

The International Performance Measurement and Verification Protocol (IPMVP) Isolated System Retrofit approach[21] was used as the best practices technique to determine energy and water efficiency with field measurements of relevant energy and operating data (please refer to Appendix A for methodology). All critical variables need to be measured or monitored in pre-install and post-install conditions. This method is applicable where systems can be isolated and variables easily measured. From the data collected at both sites, the energy required per unit of cooling provided was calculated before and after the installation of the IVG-CT.

The chiller performance data (energy and cooling capacity) for both chillers at each host site were evaluated as follows.

For the pharmaceutical site (Method 1 Appendix A):

1. Each data point was collected using the Optimum® platform.
2. The chiller efficiency was then tabulated based on a load range for each chiller and summarized by averaging the efficiency across the load range.
3. These were tabulated for each chiller for each month based on load range and efficiency.
4. The results were then extrapolated to monthly energy by using the actual ton hours provided for each month and allocating each chiller based on the number of actual hours that the efficiency data were verified.
5. Once the monthly energy was developed, the annual information was determined by applying the following adjustments:
    a. Baseline Adjustments – One month in the baseline period showed a real anomaly in the data captured. For October 2016, the energy data and the ton hours showed an excessive amount of energy being used. It was unclear if this was due to instrumentation, but without an adjustment, the savings would have been much higher and likely overstated. To ensure that the savings were not overstated, the October energy data were discounted by 30 percent. This provided a more realistic assessment in looking at the baseline as compared to the post-installation conditions.
    b. Post-Retrofit Adjustments:
        i. The pharmaceutical site cleaned the chiller tubes in early 2017 as part of the overall cooling tower replacement project. The data were adjusted by 25 percent in efficiency to account for this change in the chiller performance. This site had a very good maintenance record and based on the time frame from the previous maintenance activity, a value of 25 percent was probably higher than the actual performance improvement seen. Again, to ensure the savings were conservative, this adjustment

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[21] Efficiency Valuation Organization International Performance Measurement and Verification Protocol – 2012 Edition; www.evo-world.org and Core Concepts EVO IPMVP 2014_Dec2014-3.pdf.

provided a realistic assessment of the remaining identified savings related to the IVG-CT.

ii. Cooling Degree Days Adjustment – For the post period the weather data indicated that the cooling degree days were about 10 percent higher than the baseline. To be conservative, the adjustment for CDD was reduced to 20 percent of the 9.5 percent increase in cooling requirements at the site. The need to ensure the results were not overstating the savings required that any adjustment be considered carefully. With the full 9.5 percent savings, the overall results would show a savings of more than 10 percent. Given the uncertainty in the savings associated with the tube cleaning, it was determined that an actual CDD adjustment each month of just less than 2 percent would provide for the increased cooling requirement while maintaining conservative outcomes for the overall assessment.

iii. Ton Hours – The data indicated that the post period provided about 11 percent more ton hours as compared to the baseline data. An adjustment to the post data was made based on the actual ton hour difference and the overall average efficiency of each chiller for that particular month to accommodate a fair comparison to the baseline period.

iv. For any month where the net adjustments provided negative energy consumption values, the value was reset to zero.

For the hotel host site (Method 1 Appendix A):

The data collection was limited prior to the installation of the IVG. The existing control system did not retain historical data, thus there was limited baseline data. Subsequent to the installation of the IVG, the data were captured on a monthly basis to provide necessary post-installation data analysis. The following was determined:

- Baseline data consisted of May 2017 (one week), June 2017, and July 1 – 10, 2017.
- The IVG-CT was installed and began operation on July 11, 2017.
- Post-IVG-CT data was collected starting with July 12 – 31 through August 2018, or a total of approximately 14 months of post-installation data.

While there was clearly a small sample of baseline data, there appeared to be enough loading on the chiller plant to provide a comparative analysis at various load conditions. At the hotel site, the following data points were used for their energy analysis:

- The Trane Trace (TT) system was used to log data for each month. While other points were also collected and stored, the basic structure of the Measurement and Verification Plan was to use the chiller efficiency in kW/ton as the basis for conclusions. The points listed previously provided this data and more for the overall assessment.
    - Chilled water supply temperature
    - Chilled water return temperature
    - Chilled water flow
    - Chiller 1 kW
    - Chiller 2 kW

  - Outside air temperature
  - Condenser supply temperature
  - Condenser return temperature
- An onsite logger was installed and recorded the IVG-CT energy consumption to provide a net savings with the device. For this report, it is noted that there was no consistent data for the use of the nanofiltration. The data included herein only provides an estimate based on the IVG-CT pump and not the other loads within the IVG skid.
- The data was compared to on-site monitoring to verify that these points were within reasonable accuracy for usage.

Water and Other Savings

The water savings were demonstrated by measurement of water used and based on measurement of COC in the cooling tower before and after the application of the IVG-CT solution. The COC is expected to increase at both host sites, and the corresponding gallons of water saved would depend on the pre- and post-IVG-CT. Water use measurement was primarily from water meters in the makeup water and bleed or discharge water lines. These data were recorded manually from makeup water meters periodically, and water meters were installed to read the data automatically with the IVG-CT SCADA system.

Data on the chemical usage were gathered from the chemical service providers' records. Figure 21 shows the chemical feed system. The service providers were requested to maintain and provide detailed and timely records of chemical volumes and use, where practical.

Figure 21: Cooling Tower Chemical Feed System at Pharmaceutical Site

Source: Electric Power Research Institute

Results

International Performance Measurement and Verification Protocol Energy Savings

The following summarizes the energy savings results following the IPMVP. While there is confidence in these energy savings numbers, the M&V analysis is not as complete as would be preferred due to the limited data comparing the pre- and post-IVG-CT chiller operation. The Recommended Future Physical Water Treatment Research and Implementation section in

Chapter 7 addresses future assessment considerations. More details on the energy analysis for each site are provided in 0.

- Pharmaceutical Host Site: When compared to usage without the technology (baseline), the findings from the start date[22] of August 1, 2017 through March 31, 2018, demonstrate clear energy benefits.
    - Energy: 6.4 percent avoided chiller energy usage
        - Nine months: 171,966 kilowatt-hours (kWh)
        - Estimated annual: 225,000 kWh
        - Annual avoided cost @ $0.12/kWh: $27,000
- Hotel Host Site: When compared to usage without the technology (baseline), the findings for 12 months from September 1, 2017 through August 31, 2018 demonstrate water, energy, and chemical savings benefits.
    - Energy: 5.4 percent avoided chiller energy usage[23]
        - Annual: 94,374 kWh
        - Annual avoided cost @ $0.1181/kWh: $11,145

Water and Chemical Savings

The following sections provide information on the water saving and chemical reductions achieved during the test period at the hotel and pharmaceutical sites. The information presented herein was obtained through Cypress, Ltd reports analyzing the hotel site[24] and the pharmaceutical site.[25] Water savings for the hotel site were found to be approximately 28 percent to 30 percent and chemical savings were estimated to be at least 30 percent. For the pharmaceutical site, water savings were found to be 12 percent to 15 percent and chemical savings were found to be around 45 percent.

Water and sewer savings at the hotel and pharmaceutical sites are attributed to increased COC in the cooling tower after the IVG-CT system was installed, compared to the pre-installation baseline. As water is circulated through the system, evaporation occurs, and a small amount is lost in drift. Contaminants in the water remain behind and the evaporated water must be replaced with new water. Treatment by the nanofilters lowers makeup water conductivity and total dissolved solids entering the cooling tower, allowing it to operate at a higher COC. As the

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[22] System installed mid-July 2017; PS6 chillers not operating a large part of April – May 2018, and June – July data included in water findings.

[23] The interim report found 6.4 percent net energy avoided. The 1 percent difference is due to higher run time of the nano-filter during the very hot summer months of 2018, resulting in a larger parasitic load as compared to the September – February timeframe.

[24] Water Energy Nexus Application: Industry Vortex Generator- Cooling Towers (IVG-CT), Cooling Tower Project Report for Marriott, Cypress Ltd. Interim Report, October 2018, Revision 4.

[25] Water Energy Nexus Application: Industry Vortex Generator- Cooling Towers (IVG-CT), Status Update for AMGEN, Cypress Ltd. Interim Report, August 30, 2018, Revision 3.

concentration of minerals increases in the basin due to evaporation, a portion of the water is dumped to drain (blowdown) and the nano-treated makeup water is added. The blowdown set point in microsiemens (µS) directly affects COC and water use. The IVG-CT system permitted the hotel and pharmaceutical cooling towers to operate at a higher COC after the IVG-CT installation compared to how the cooling tower operated prior to the installation.

The substantial water savings also correspond to substantial embedded energy savings in the water, namely the energy saved from pumping and treating the city water — that is, the energy intensity of water, which also corresponds to greenhouse gas emissions savings that are specific regionally.[26]

Water and Chemical Savings at the Hotel Host Site

At the hotel site, with the IVG-CT system operating, a portion of the cooling tower makeup water is also treated by nanofilters and then mixed with city water at an average 60:40 ratio. Treatment by the nanofilters lowers makeup water conductivity and total dissolved solids entering the cooling tower by a significant amount, allowing the system to operate at a higher COC. As the concentration of minerals increases in the basin due to evaporation, a portion of the water is dumped to the drain (blowdown) and the nano-treated makeup water is added.

The IVG-CT technology was installed and commissioned in mid-late July 2017. For the purpose of determining water and chemical savings for this project, the period from September 1, 2017 to August 31, 2018 has been analyzed. COC is defined as the ratio of the average cooling tower basin conductivity / the average conductivity of the mixed (nano plus city) makeup water expressed in microsiemens (µS). The IVG-CT system has continuous (24/7) monitoring of several variables, including cooling tower conductivity and the nanofilter treatment system and city water conductivity. Water chemistry spot tests are also used to look at cooling tower performance.

Figure 22 shows the varying conductivity of the cooling tower basin over time, from September 2017 through August 2018. There were different operating conditions in place, which are reflected in the varying conductivity values. Over the period, the blowdown setpoint was moved from a setpoint of 930µS, to 1,100µS, to 1,500µS, yielding an average COC of 5.9.

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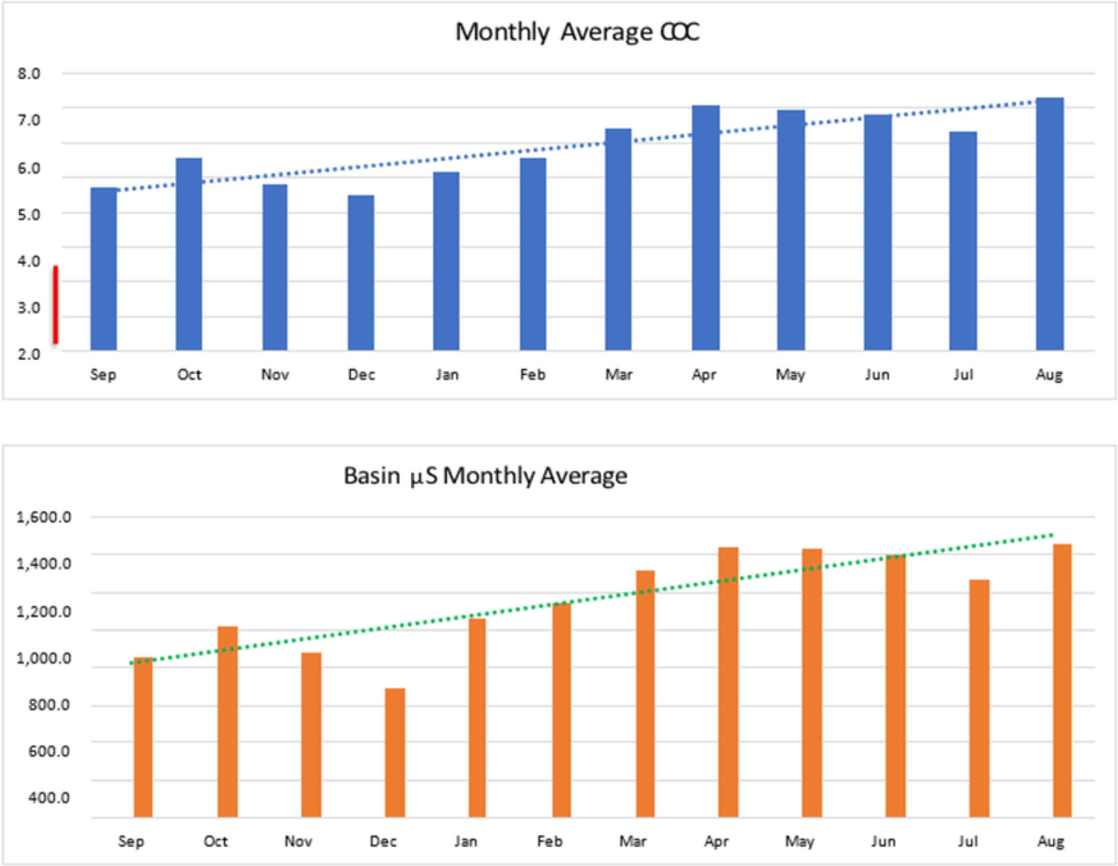
[26] Spang, Holguin, and Loge, "The estimated impact of California's urban water conservation mandate on electricity consumption and greenhouse gas emissions", *Environmental Research Letters*, 13 (2018) 014016. https://doi.org/10.1088/1748-9326/aa9b89.

Figure 22: Average Tower Basin Conductivity and Cycle of Concentration Values for Hotel Site



Baseline COC = 2.3

Source: Electric Power Research Institute

Conductivity Values - MakeUp Water for the Hotel Site

There are two measured values for makeup water conductivity used for determining COC, and they are based on the water treatment operating conditions of the nanofilters: 1) baseline makeup value, which is prior to the installation of the IVG-CT system; and 2) when the nanofilter system which conditions the makeup water entering the cooling tower and operates whenever the chillers operate and there is a need for make-up water. The first period is the baseline value for a COC of 2.3 and is the average of all test reports available from the hotel site prior to installation.

The other value for makeup is the average conductivity for makeup provided by the IVG-CT's nanofilter system operation. That value is considerably lower than the typical city water conductivity. The nanofilter operation for the IVG-CT system treats city water and produces a permeate output at an average of 21µS. There were measured fluctuations in city water conductivity typically from 275µS to 325µS.

Over a monitoring period of August 1, 2017 to October 9, 2018, city water had an average of 288µS based on data monitoring every five minutes over the period.

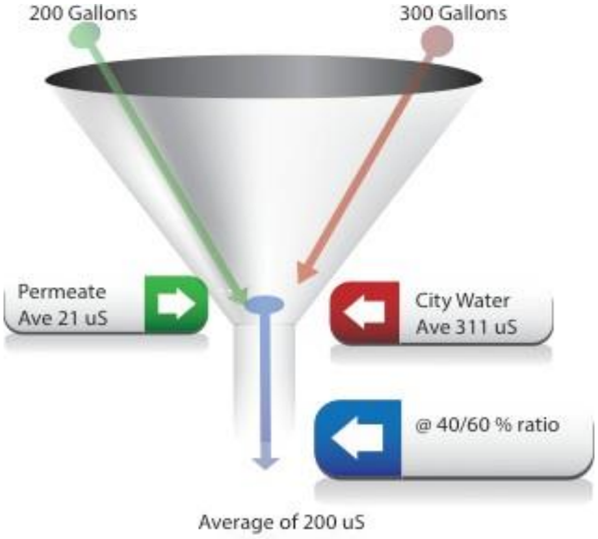
Nanofilter Operation for the Hotel Site

The nanofilter system's PLC-[27] based velocity frequency drive control cycle turns on after it measures city water required by the cooling tower for makeup when the tower makeup float valves require water. It continues to run until there is no call for cooling tower makeup water. Nano treatment run time can vary from a few minutes to more than 15 minutes each time there is a call for cooling tower makeup water. The nanofilter treats a portion of the incoming city water and provides treated water output at an average of 21µS. As shown in Figure 23, the nano-treated permeate is then mixed with city water during the run time based on a typical 60:40 ratio of city to nano-treated water. The average mixed makeup water that is then input to the cooling tower is 200µS.

Blowdown

Blowdown is required to control the COC. The blowdown flow is sent to the drain/sewer by the IVG-CT control logic and in addition to evaporation and drift, represents water loss for the cooling tower system. Decreasing the blowdown frequency increases COC. The objective for achieving optimum cooling tower efficiency is to operate at a safe maximum COC and minimize blowdown; this is expressed in the following equation. Blowdown = Evaporation / (Cycles - 1)

Figure 23: Example 60:40 City: Nano Mix for the Hotel Site



Blowdown = Evaporation / (Cycles - 1)

Source: Electric Power Research Institute

MakeUp Water Usage

As part of this project, a dedicated makeup water meter (Carlon meter) was installed on the system to measure the total water added to the system to offset the evaporation and blowdown losses. Table 4 shows 30 percent reduction in water use using measured data and 28 percent using modeled data. This reduction in water use also reduces discharge into the

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[27] Programmable Logic Controller (PLC) by Siemens Corp and nanofilters by GE.

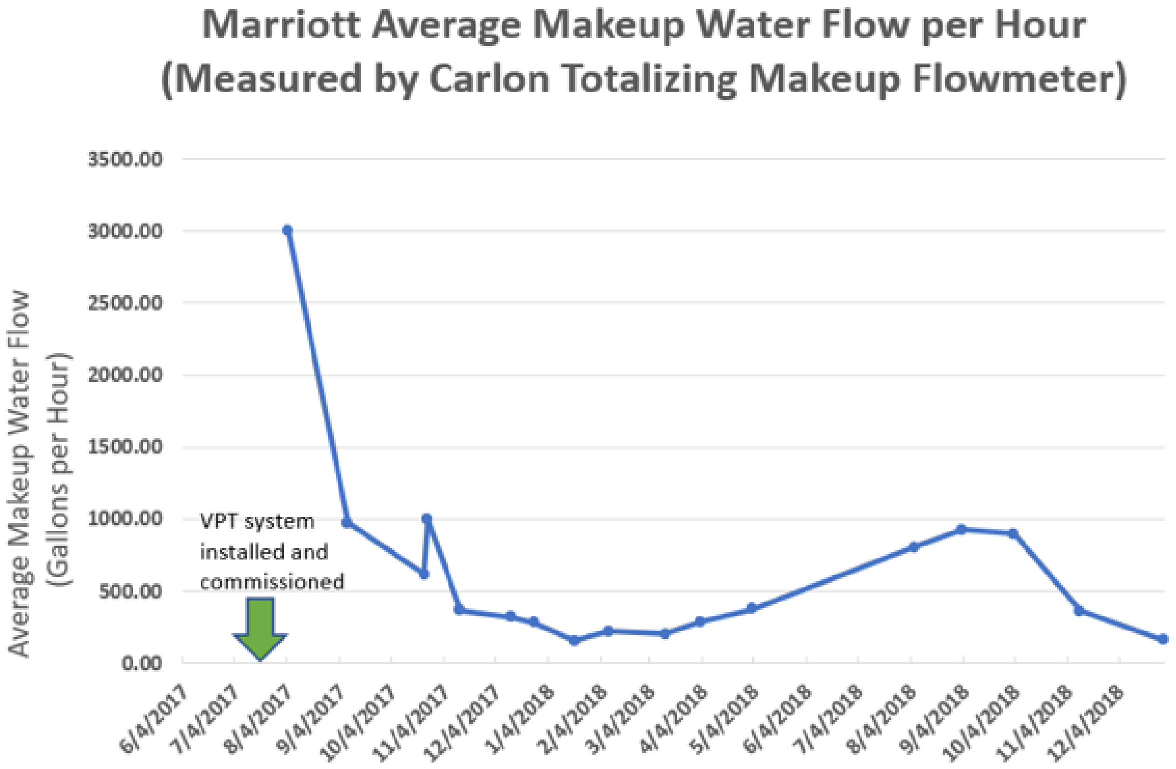
sewer. The starting COC was 5.9 and the average operating COC was 5.9 after the IVG-CT installation. Chemicals will be reduced more than 30 percent based on the reduction in water use. Measured makeup water flow is shown graphically in Figure 24.

Table 4: Modeled and Metered Water Usage and COC

	Based on Calibrated COC Model (Gallons)	Based on Metered Data (Gallons)	% Avoided Water (Metered)	Cycles of Concentration (COC)
Tower Makeup Water **Baseline**	6,582,122	n/a		2.3
Gross Makeup **Post**	4,475,766	4,617,000		5.9
Nano Reject	268,546			
Net Makeup Post	4,744,312	4,617,000		
Avoided Water Use	1,837,810	1,965,122	30	

Source: Electric Power Research Institute

Figure 24: Makeup Measured Water Flow for the Hotel Site



Source: Electric Power Research Institute

Evaporation

For entering air temperatures from 50°F (10°C) to 90°F (32.2°C), the fraction of water evaporated typically ranges from about 0.5 percent to 1 percent, with an average value of about 0.75 percent evaporation rate, including drift. There are other similar methods to determine evaporation, but the ASHRAE 90 approach is suitable for this status update report and forecasting. This approach is used in determining the average predicted annual amount of water based on the size of the chillers and actual estimated full load hours for the chiller**.**

IVG-CT Nanofiltration

As mentioned previously, the IVG-CT system uses nanofiltration, a membrane filtration-based method based on nanometer-sized pores, to treat incoming water prior to its being sent to the cooling tower as makeup water. The nanofiltration membranes have pore sizes ranging from 1 – 10 nanometers, smaller than those used in microfiltration and ultrafiltration, but larger than those in reverse osmosis. The prime benefit of this part of the system is to filter out most of the contaminants going into the cooling tower, allowing higher COC.

Further Improvements in Water and Chemical Usage

The data show a steady increase in basin conductivity and an average COC of 5.9 for the period when the IVG-CT had blowdown control and nanofilter operation as compared to the baseline of 2.3 COC. The avoided water based on the pre- and post-installation data for the report period shows a water savings at 30 percent (1.9 million gallons) based on available meter data and 28 percent based on the calibrated model. Going forward, slightly higher water savings and chemical avoided costs higher than what has already been achieved could be realized by operating at a COC of 7 to 8. Chemical savings should be at least as great as the water savings with a strong possibility that chemical usage can be reduced even more than water usage due to the vortex generator substituting for the chemicals used to reduce scaling.

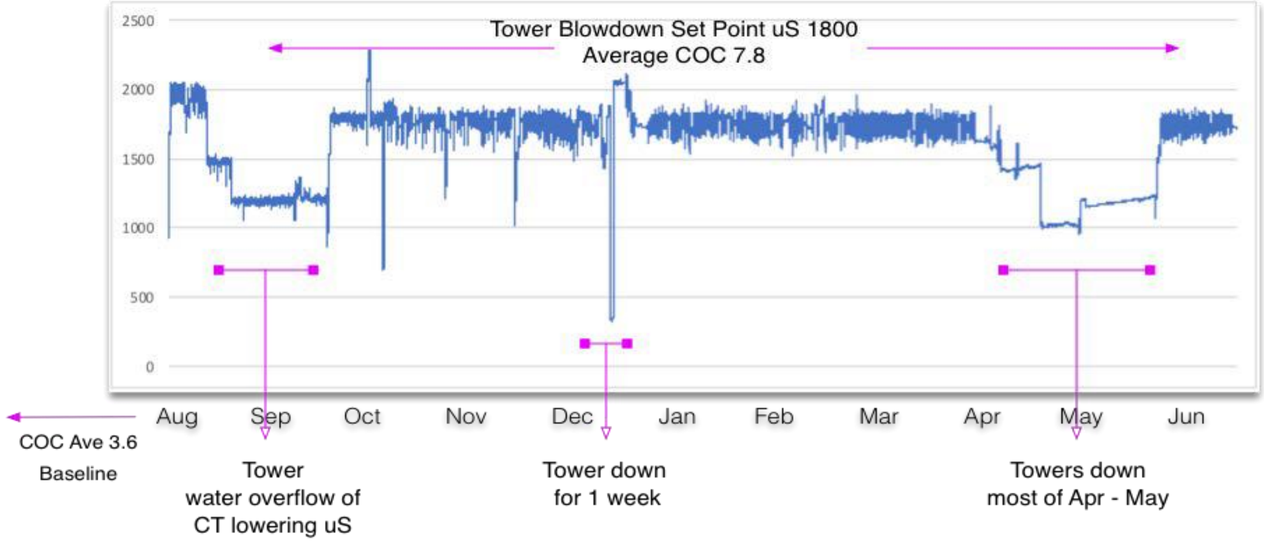
Water and Chemical Savings at the Pharmaceutical Host Site

Water/sewer savings at the pharmaceutical site are attributed to increased cycles of concentration (COC) in the cooling tower after the IVG-CT system was installed, compared to the pre-installation baseline. As water is circulated through the system, evaporation occurs, and a small amount is lost in drift. Contaminants in the water remain behind and the evaporated water must be replaced with new water. In the case of the pharmaceutical site, with the IVG-CT system operating, a portion of the cooling tower makeup water is treated by nanofilters and then mixed with city water. Treatment by the nanofilters lowers makeup water conductivity and total dissolved solids entering the cooling tower, allowing it to operate at a higher COC. As the concentration of minerals increases in the basin due to evaporation, a portion of the water is dumped to drain (blowdown) and the nano-treated makeup water is added. The blowdown set point in microsiemens directly affects COC and water use. The VPT system has permitted the pharmaceutical site's PS6 cooling tower to operate at a higher COC after the IVG-CT installation compared to how the cooling tower operated prior to the installation. The use of the technology results in saving water, energy, and chemicals, as compared to the baseline COC prior to the installation of the technology.

The IVG-CT technology was commissioned in mid-late July 2017; for the purpose of water and chemical savings, the research team used the time period from August 1, 2017 to July 1, 2018 for this analysis. During April and May of 2018, the cooling towers were down because of chiller pump maintenance. COC is defined as the ratio of the average cooling tower basin conductivity / the average conductivity of the makeup water, expressed in microsiemens. The IVG-CT system has 24/7 monitoring of several variables, including cooling tower conductivity and the nanofilter treatment system. Water chemistry spot tests and the ratio of conductivity makeup water to basin cooling tower water conductivity are also used to look at cooling tower performance.

Figure 25 and Table 5 shows the varying conductivity of the cooling tower basin over time, from August 2017 through June 2018. Different operating conditions were in place, which are reflected in the varying conductivity values. Over the period, the blowdown setpoint was at 1,800µS, with an average COC of 7.6. Going forward, starting in August of 2018, it was recommended that the setpoint be raised to 2200µS, which would provide a COC of 9.0.

Figure 25: Conductivity of Cooling Tower Basin Water (µS) and Average Cycle of Concentration (COC) Values at Pharmaceutical Site



Source: Electric Power Research Institute

Table 5: Cycles of Concentration at Various Setpoints

COC	Period	Average Basin µS	Average Mixed Makeup µS
3.6	Based on available EnviroAqua reports Baseline: Prior to IVG-CT installation	2566	714
8.7	August 2017 to October 2017: Start-up period with high Nano run time	1724	198
7.7	October 2017 to March 2018	1810	235
7.8	June to July 2018	1751	226
9.0	August 2018 going forward	2200	245

Source: Electric Power Research Institute

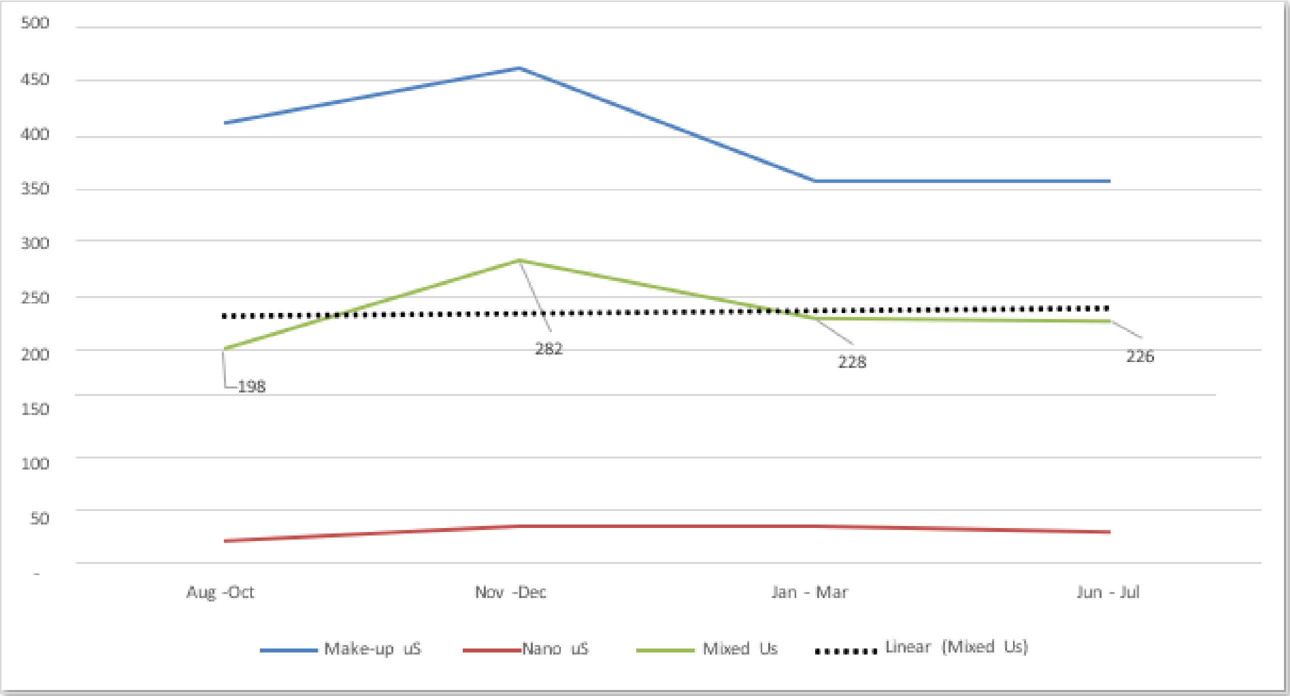
Conductivity Values — Make-Up Water for the Pharmaceutical Site

There are two measured value averages for makeup water conductivity used for determining COC, and they are based on the water treatment operating conditions of the nanofilters: 1) baseline makeup value, which is prior to the installation of the IVG-CT system; and 2) when the nanofilter system which conditions the makeup water entering the cooling tower and operates whenever the chillers operate, and there is a need for makeup water. The first period is the baseline value for a COC of 3.6 and is the average of all test reports available. The other value for makeup is the average conductivity for makeup provided by the IVG-CT's nanofilter system operation. That value is considerably lower than the typical city water conductivity. The nanofilter operation for the IVG-CT system treats city water and produces an average output of 30µS. City water conductivity fluctuates from around 500µS to 325µS. There was a short period of time in March of 2018 when the city water µS reached as high as 725µS. Over the monitoring period, the trend has been downward with an average of 396µS.

Nanofilter Operation

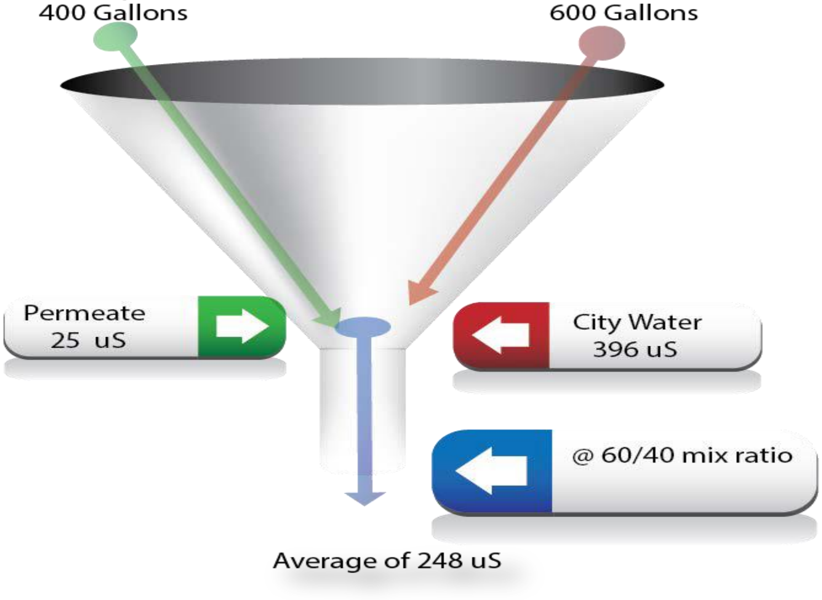
The nano system's PLC-based velocity frequency drive control cycle turns on after it measures city water required by the cooling tower for makeup when any of the four makeup valves at PS6 call for water. It continues to run until there is no call for cooling tower makeup water. Nano treatment run time can vary from a few minutes to more than 15 minutes each time there is a call for cooling tower makeup water. The nanofilter treats a portion of the incoming city water and provides treated water output at an average of 30µS. It is then mixed with city water during the run time based on a typical 60:40 ratio of city to nano-treated water. During the initial startup months, the city:nano mix was 45 percent city water and 55 percent nano as shown in Figure 27. Figure 26 shows the average mixed makeup water that is then input to the cooling tower ranges from 200µS to 285µS.

Figure 26: Makeup Water Conductivity



Source: Electric Power Research Institute

Figure 27: Example 60:40 City:Nano Mix



Source: Electric Power Research Institute

MakeUp Water Usage

Makeup water meter data at the pharmaceutical's PS6 was available for 2015 and 2016 and during the assessment period covered by this report. For baseline makeup water use, a full year of 2015 data was used as the cooling towers were replaced and taken out of service starting in the fall of 2016 through May 2017. Total baseline makeup water was found to be 10,512,560 gallons (the sum of 4,264, 460 for PS-6-1 and 6,248,200 for PS-6-2).

Evaporation

For entering air temperatures from 50°F (10°C) to 90°F (32.2°C), the fraction of water evaporated typically ranges from about 0.5 percent to 1 percent, with an average value of about 0.75 percent evaporation rate, including drift. There are other similar methods to determine evaporation, but the ASHRAE 90 approach is suitable for this status update report and forecasting. This approach is used in determining the average predicted annual amount of water based on the size of the chillers and actual equivalent full load hours for the chiller.

Industrial Vortex Generator Technology for Cooling Towers Nanofiltration

As mentioned previously, the IVG-CT system uses nanofiltration, a membrane filtration-based method based on nanometer sized pores, to treat incoming water prior to it being sent to the cooling tower as makeup water. The nanofiltration membranes have pore sizes ranging from 1 – 10 nanometers, smaller than those used in microfiltration and ultrafiltration, but larger than those in reverse osmosis. The prime benefit of this part of the system is to filter out most of the contaminants going into the cooling tower, allowing higher COC.

Table 6 shows the key variables at differing COC values.

- Water use with an average baseline 3.6 COC
- Water use with an average COC of 7.8 for August 2017 – June 2018

The values for tons and equivalent full load hours that are used in the calculation are 2000 tons and 2825 equivalent full load hours.

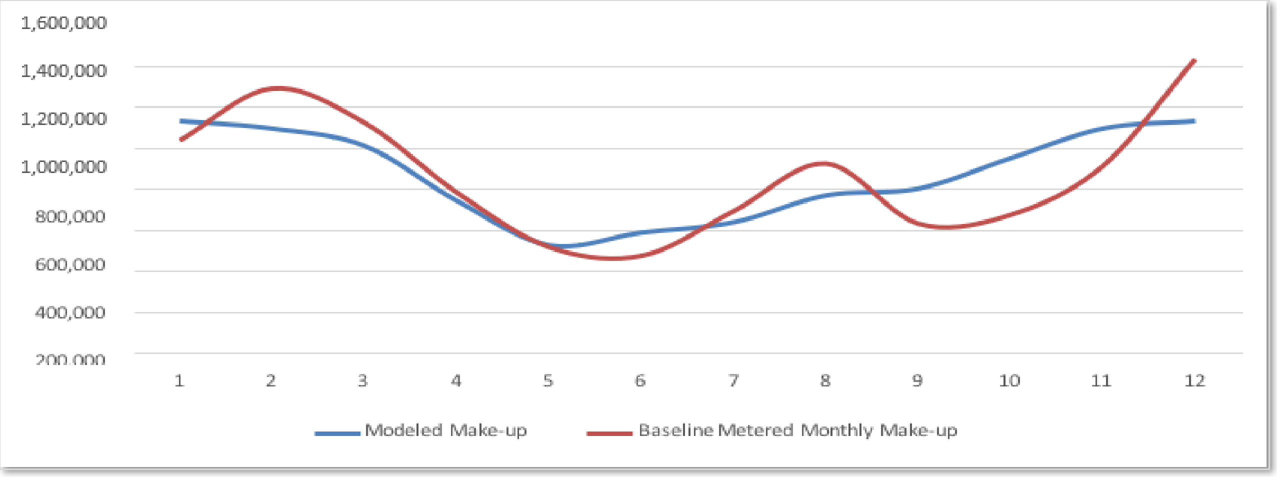
Table 6: Baseline and Post-Industrial Vortex Generator Technology for Cooling Towers Water Usage

Item	PS6 Metered	Calibrated Model
Makeup Base	10,512,560	10,554,167
Gross Makeup Post	8,452,830	8,741,335
Nano Reject	462,456	535,766
Net Makeup Post	8,915,286	9,277,101
Avoided Water Use/% Savings	1,597,274/15.2%	1,277,066/12.1%

Source: Electric Power Research Institute

Using metered data for PS6 from August 2017 – June 2018 and an interpolation for July 2018, Figure 28 shows a very close relationship between metered and modeled makeup and the actual makeup post-IVG-CT installation.

Figure 28: Comparison of Pharmaceutical Site Metered and Modeled Makeup Water



Source: Electric Power Research Institute

Chemical Usage at the Pharmaceutical Site

Using billing data, Table 7 illustrates the chemical savings achieved through use of the IVG-CT, compared to baseline chemical usage.

Table 7: Average Chemical Usage Before and After Industrial Vortex Generator Technology for Cooling Towers Installation

Usage	Savings
Average $/day before IVG-CT install	$93,075
Average $/day after IVG-CT install	$41,662
Total avoided chemical cost, $/day	$51,412 (45%)

Source: Electric Power Research Institute

Operational Savings

The host sites' facilities managers offered feedback on several operational notes.

1. Cooling tower/chiller plant maintenance schedule:
    a. The standard practices that each host site used for chiller and tower maintenance was not changed during the assessment period. The hotel staff reported that during the regularly scheduled (every three years) maintenance of the chiller / condenser heat exchanger, they had never seen it so clean and free from scaling. Their cooling tower baffle cleaning was unchanged. The IVG-CT monitoring system data benefited the staff by informing them of the need to repair tower makeup float valves and conduct more frequent cyclone filter cleaning, and the staff was appreciative of the added data provided.
    b. At the pharmaceutical site, the towers were new, and the chiller heat exchanger was cleaned during the installation of the towers so there were no observations to report and no changes in the typical chiller/tower maintenance. The reduced chemical use, however, was noted.
2. Benefit of the monitoring/diagnostics dashboard:
    a. During the assessment period, neither site had direct access or control of the IVG-CT SCADA system. Reported observations were shared with staff. If, for example, excess water use was noted the system staff was alerted to take action such as replacing or adjusting, makeup water valves. If basin water conductivity was observed to be out of range, the system adjusted control variables to maintain target levels. In early 2020, the pharmaceutical site decided to connect via web access to the IVG-CT SCADA system to assist in its ongoing tower operations.
3. Training with IVG-CT system — ease of use, general benefits:
    a. During the summer of 2019, each site participated in hands-on operational training and received a full set of operational manuals, parts lists, and related IVG-CT documentation.
    b. The pharmaceutical site is considering installing the IVG-CT system on one of its main, 8,250-ton chiller systems and may allocate future capital for its purchase.

CHAPTER 5: Benefits to Ratepayers

This pilot project demonstrates the potential benefits IVG-CT offers in terms of water usage savings, energy efficiency, reduced use of chemicals resulting in less air and water pollution, and savings in operational costs that benefit California ratepayers and support former Governor Edmund G. Brown's Executive Order B-29-15 (April 2015) to expedite actions needed to reduce the harmful impacts from water shortages in the state. The following paragraphs describe specifically how broader implementation of the IVG-CT technology achieves these benefits.

Technology Potential Benefits

An overview of the benefits of the IVG-CT is shown in Table 8 and a more detailed discussion of the specific categories can be found in the following subsections.

Table 8: Potential Benefits of Industrial Vortex Generator Technology for Cooling Towers IVG-CT

Goal	Benefits
Reduced Water Usage	Allows higher cycles of concentration and reuse blowdown water for other purposes such as irrigation, lowering sewer charges.
Energy Efficiency	Delivers chiller kWh savings due to improved cooling tower efficiency, improved heat transfer in cooling equipment, and the reduction in system cooling usage.
Reduced Chemical Usage	Reduces toxic elements in blowdown water, less stress on water treatment and run off. Reduces risks of chemical treatment health and safety, environmental impacts. Delivers a more sustainable solution by reducing chemical usage.
Operational Cost Savings	Delivers higher cooling tower efficiency on peak during the hottest periods where the better heat transfer would allow a lower return temperature back to the chiller and better chiller efficiency.

Source: Electric Power Research Institute

The IVG-CT also has potential liabilities, such as added complexity and energy use, and requires additional capital cost and power input. Furthermore, as this project is a pilot demonstration at two commercial building sites with differing system comparison conditions and operating conditions in California, the technology will benefit from having additional demonstration sites to further validate the benefits of the IVG-CT.

Lower Cost

The IVG-CT is a PWT device that uses fewer chemicals compared to traditional chemical treatment. The chiller plant operator can reduce the chemicals purchased and reduce maintenance costs. The IVG-CT also reduces toxic elements in the water, lowering sewer charges. Additionally, it provides water savings by increasing the cycle of concentration. Energy savings can also be realized due to the improved heat transfer and chiller efficiency.

Greater Reliability

The IVG-CT can keep heat exchanger coils clean and prevent scaling in the cooling towers. With cleaner heat exchanger coils, the maintenance period can be extended between condenser coil cleaning. Thus, the chiller reliability can be improved. The technology will over time reduce lime scale, which also improves reliability and efficiency.

Increased Safety

The IVG-CT improves safety of the chiller plant by reducing the amount of chemicals used in water treatment. This lowers the concentration of toxic elements in the water and improves the safety of the chiller plant operators and water service technicians.

Environmental Benefits

The IVG-CT reduces the amount of chemical usage for scale control. It also allows the system to increase the cycles of concentration and reduce the amount of water usage. The wastewater can also be recycled, and the amount of chemicals in the discharge water will also be reduced. The chiller plant efficiency will be increased due to better heat transfer, thus reducing the system energy consumption.

Public Health

The IVG-CT reduces the amount of chemical usage for water treatment and lowers the amount of toxic elements in the discharge water. This reduces the amount of chemicals within the blow-down water discharged into the sewers.

Consumer Appeal

Building maintenance facilities can benefit from the monitoring equipment diagnostics for improved chiller plant operation, as well as reduced resource expenses (chemical savings, water savings, and energy savings).

Energy Security

The IVG-CT reduces the amount of lime and biofilm buildup in the cooling tower. The chiller plant efficiency will be increased due to better heat transfer, thus reducing the system energy consumption. A conservative estimate of 5 percent in the cooling electricity savings (assuming a 5 percent annual increase in penetration) results in annual electricity savings of approximately 100 million kWh (by the fifth year) and cumulatively at 366 million kWh over five years.

CHAPTER 6:
Technology/Knowledge Transfer Activities

The objective of the technology transfer effort was to transmit the project's findings to the relevant stakeholders, increase their understanding and adoption of the relevant technology, and thereby increase the public benefits of EPIC's investment in the program. This technology transfer plan[28] reviewed existing cooling tower water treatment technology; examined the features of the IVG-CT with regard to its potential benefits and liabilities; addressed potential market barriers affecting the implementation of IVG-CT technologies; described actions needed to overcome these barriers; and identified actions undertaken in this project.

The technology transfer plan involved the following steps:

- Engage customers' feedback in discussions of perceived benefits while acknowledging the customers' concerns over funding cycles, buying decision process, market factors, and financial requirements.
- Increase awareness to the relevant audience about viable alternatives to chemical water treatment.
- Communicate the water and energy saving results to facilitate the broader market adoption of this under-used technology for commercial and industrial applications.
- Identify key market participants and their market functions, along with issues affecting their product preferences. Compare features that are important to decision makers to the features embodied in the IVG-CT, providing a focus for emphasizing those attributes that could result in product selection. Evaluate the role of State and Federal code and standards regulatory bodies to support opportunities for improved cooling tower maintenance and operation.
- Employ a range of communication channels including meetings, workshops and symposia, peer-reviewed publications and websites of industry-relevant organizations, trade associations and professional societies, government/regulatory agencies, utility emerging technologies, and incentive program managers. Project information was disseminated through existing channels and infrastructure to facilitate efficient and effective market connection. Key meetings and publications were identified so that papers and articles could be tailored specifically for those venues.

The next sections focus on summarizing the technology/knowledge transfer activities deployed in this project.

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[28] *Cooling Tower Water Treatment Using Vortex Technology for Water and Energy Savings, Technology Transfer Plan*, March 2020.

The types of activities and informational products for the IVG-CT project included:

- Fact sheet
- Journal articles
- Technical papers
- Presentation at industry conferences
- Poster (or presentation) at EPIC symposiums
- Utility meetings and conferences
- EPRI Utility Advisory Council meetings
- Word-of-mouth contacts using the materials

Fact Sheet

The fact sheet format consists of the following material:

- Description of the situation (Describe the problem and the current technology being used.)
- Technology (Describe the technology, what it looks like, how it works, and how this differs from current practice. Provide a schematic or photo of the technology.)
- Advantages and opportunities (Clearly outline the advantages of the new or improved technology and situations where it can best be applied.)
- Applications (Offer examples of effective applications with initial cost and operating cost.)
- Sources of information (Provide authoritative references, opportunities to obtain additional information, and technical assistance in implementing the new or improved technology.)
- Other issues (Present information on ancillary issues, applicable codes and standards, health and human performance improvement and other details not covered in the main body of the fact sheet.)

A substantial amount of the fact sheet material will be useful for all audiences. Additional material will also be provided with more details addressing areas of concern to a specific market participant. EPRI submitted a final project fact sheet as a key deliverable for distribution to all audiences in March 2020.

Presentations

Associated presentation materials for explaining the benefits of the IVG-CT were prepared for delivery at key venues to increase understanding of this equipment by cooling tower designers, specifiers, and researchers as well as electric utility representatives involved in encouraging improved cooling tower efficiency, with the goal of encouraging IVG-CT systems in new projects and major modernizations. These presentations are a key focus of the technology transfer, providing an avenue to disseminate key information to dealers, retailers, manufacturers, consulting engineers, contractors, utilities, government employees (including regulators), and engineers.

A project review was held at the Amgen pharmaceutical site, May 3, 2019, with a presentation made to Southern California Edison (SCE) Customer Programs and Services. Information tweeted by SCE resulted in the receipt of 76 responses from industry.

A project review was held at the Marriott Westin Mission Hills hotel site, May 15, 2019, with a presentation made to Metropolitan Water District (MWD). Interim results were reviewed, discussions were held about possible incentives through MWD and possible demonstration at MWD headquarters in Los Angeles.

Industry Conferences

A presentation regarding IVG-CT was made at the EPRI Cooling Tower Conference, August 2018, in Baltimore, Maryland. The audience consisted mainly of power plant operators and managers, and the presentation focused on the key technology benefits of the IVG-CT and preliminary project findings.

California Energy Commission Meetings

A project review was held at the first Technical Advisory Committee meeting in a webinar on April 11, 2017, focusing the work to be performed in the VPT project.

A final project meeting was held with the CEC CAM on April 23, 2020. The meeting was held through a webinar setting to observe COVID-19 restrictions. The EPRI team presented the overall project findings followed by questions and discussions with the CEC CAM.

Codes and Standards Activities

One of the key standard-setting activities related to the IVG-CT is ASHRAE Guideline 22-2012, "Instrumentation for Monitoring Central Chilled-Water Plant Efficiency.". The features of the IVG-CT was provided to the ASHRAE technical committees that have oversight on the operation and other major standards activities during the 2020 ASHRAE Winter Conference from February 1-5, 2020, in Orlando, FL.

The EPRI team had planned to follow up and attend TC 3.6 Water Treatment and TC 8.6 Cooling Towers and Evaporative Coolers Technical Committee Meetings during the 2020 ASHRAE Annual Conference in Austin, TX, to disseminate project information to influential ASHRAE members concerned with codes and standards for cooling tower water treatment technology. However, due to the COVID-19 pandemic, the conference was changed to a virtual setting, and many TCs did not have the same level of engagement. The EPRI team will continue to attend ASHRAE meetings in the future and disseminate the project findings as appropriate.

Also, EPRI will pursue the opportunity to connect the outcomes of this IVG-CT project to California Title 24 upcoming standards updates principally by relating pertinent project results to CEC buildings and codes standards personnel.

EPRI Meetings and Activities

EPRI has regular meetings with key market participants that will be used to transfer the information developed in this project to these key participants.

Such meetings include EPRI advisory meetings with influential utility members that are used to shape EPRI research, develop demonstration and marketing opportunities for technologies, and provide a conduit for the advisors to impart information to colleagues at their "home" utilities. Advisory meetings are held twice a year (spring and fall), usually in February and September. EPRI disseminated information on IVG-CT technology at the Power Delivery and Utilization Advisory Meetings.

A presentation of the project findings was included as part of EPRI Customer Technologies End-of-Year Program Webcast on December 9, 2020. Attendees included EPRI project engineers and utility member representatives.

The project results are also included in the Technology Readiness Guide in 2020. This product is produced annually by the EPRI Customer Technologies program, providing readiness assessments of end-use technologies in various stages of development. The IVG-CT received a score of 70 out of 100, which corresponds to Coordinated Early Deployments in the end-use technology pipeline.

Word-of-Mouth Contacts

The team has created a word-of-mouth effort seeking to involve opinion leaders in the process of convincing them of the benefits of the VPT. Program technical staff have worked closely with influential market participants to ensure that the project is shaped to meet their needs and that the results are accepted by their peers.

As indicated, program staff have attended key meetings to impart information to professionals and other influential market participants. Program staff have interacted with federal and state government personnel, professionals at technical meetings, utilities, customers and users at utility energy centers across the state, and a range of experts and market participants.

CHAPTER 7: Conclusions and Recommendations

The project was successful in its goal to demonstrate water and energy savings using the industrial vortex generator technology for cooling towers. The technology is intended to supplement traditional water treatment practices with a more environmentally sound, consistently repeatable, and efficient approach.

The project also demonstrated significant energy and chemical savings, further supporting California's Global Warming Solutions Act of 2006 (AB 32) to reduce greenhouse gas emissions in California.

Project Summary

The industrial vortex generator technology for cooling towers is a physical water treatment process that offers water, energy, and chemical savings by increasing the cooling tower's cycles of concentrations while improving the heat transfer in the chiller's heat exchanger through reduced scaling, fouling, and removal of entrained microbubbles from the condenser water flow to the chiller. The physical mechanism involves (a) the coalescence of calcium carbonates under high pressure through a vortex generator into larger particles that can be filtered out with nanofiltration, thus keeping the heat exchanger surfaces clean from scale buildup; and (b) the reduction of microbubbles in the water through the creation of low pressure in the core of the vortex, which improves heat transfer in the heat exchanger and reduces the need for use of chemicals. This technology was selected for field demonstration at two sites for its effectiveness in water, energy, and operational cost savings such as chemicals that are used in conventional cooling tower water treatment.

The field demonstrations were conducted at two southern California sites: a large hotel, the Marriott Westin Mission Hills Golf Resort and Spa, and a large biopharmaceutical company, Amgen. At the pharmaceutical site, the IVG-CT system was installed during the chilled water plant upgrade that included a new cooling tower along with the IVG-CT system. In addition, the condenser water and chilled water heat exchanger tubes were cleaned during that same period. While this site represented state-of-the-art maintenance practices, the hotel site represented common practices in the HVAC industry. The cooling tower maintenance was outsourced to a water treatment and maintenance company, which attended to the system on a periodic basis and adjusted the chemical feed and cooling tower make-up water treatment.

The IVG-CT system installation and commissioning process was straightforward. The complete IVG-CT system package including all piping; electrical and controls wiring was received in shipping containers for each site. The systems field performance was monitored and adjusted remotely through cellular network communications. The system performance adjustments were made to control make-up water flow rate to achieve certain cycles of concentration. The project used the International Performance Measurement and Verification Protocol (IPMVP) as the best practices technique to determine water and energy efficiency with field measurements of relevant energy and operating data comparing the performance of the chiller plants pre-IVG-CT versus post-IVG-CT over a minimum of 12 months.

Project Results

Based on the IPMVP approach, the energy analysis results show a net energy savings of between 5.4 percent and 6.4 percent at the two host sites evaluated.

Additional energy savings correspond to the substantial embedded energy savings (energy intensity of water) from the water savings, namely the energy saved from pumping and treating the city water, which also corresponds to greenhouse gas emissions savings that are region specific.

Significant water savings were observed at both sites. At the hotel site, the COC was increased from the value of 2.3 before the treatment with IVG-CT to a value of 5.9 after treatment with the IVG-CT system over time, providing water savings of 30 percent. At the pharmaceutical company site, the COC was increased from the value of 3.6 before treatment to a final value of 7.8 after the treatment over time, providing water savings of 15 percent.

Chemical usage cost reductions ranged from greater than ~30 percent or $11,000 annually (typical maintenance at the hotel site) to about 45 percent or $45,000 annually (state-of-the-art maintenance at the pharmaceutical site).

In addition, operational and maintenance savings are expected where the number of condenser tube cleanings could be reduced since the IVG-CT system keeps heat exchanger surfaces cleaner from scale buildup, resulting in less frequent tube cleanings, thus reducing maintenance costs. Additionally, the vortex process technology (VPT) system comes with continuous monitoring that can further support efficient operation and the cooling tower operation diagnostics.

Recommended Future Physical Water Treatment Research and Implementation

The project team recommends consideration of the following efforts as future projects to advance understanding and market acceptance of physical water treatment for cooling towers.

1. Encourage enterprises to pursue the many utility incentive programs applicable to IVG-CT systems installed as a retrofit on existing commercial and process cooling towers.
2. Encourage California utilities to work together on saving water and energy by adopting programs such as Southern California Edison's existing custom solution code that can be used for electrical savings incentives on technologies such as cooling tower water treatment. Coordination and cooperation between electric and water utilities would maximize the benefits for areas hit especially hard by drought conditions. The H2OVortex system can significantly reduce water and chemical consumption and provide improved energy efficiency of the cooling system.
3. Expand use of the vortex technology demonstrated in this project, as it removes microbubbles from water and is applicable to processes that require de-aeration, including ice rinks, boiler makeup water, and central water heating systems for multifamily and college campuses that need both hot water and steam. Physical removal of microbubbles contributes to better equipment performance, reducing fossil heat inputs and the corresponding greenhouse gas emissions.

4. Expand pilot projects of evaluation sites within California and possibly the rest of the United States. EPRI could explore creating a program with member utilities throughout the country demonstrating the technology over a wide range of water, chemical, and energy cost conditions. While the project team is confident that it collected enough data to support the M&V analysis, overall understanding of the water, energy, and chemical savings will improve with the analysis of additional sites of varying applications.
5. Leverage future pilot projects to expand upon the knowledge gained in the Southern California field studies documented in this report.
6. Study the vortex phenomena both visually and with thorough, precise instrumentation to provide insight into the fluid dynamics, chemistry, and resulting heat transfer of the IVG-CT system. This should be done by an independent party, such as a university with a propensity for detail.

LIST OF ACRONYMS

Term/Acronym	Definition
BMS	building management system
CEC	California Energy Commission
CO_2	carbon dioxide
COC	cycles of concentration
COP	coefficient of performance
CCF	Hundred cubic feet
DNA	Deoxyribonucleic acid
EPRI	Electric Power Research Institute
gpm	gallons per minute
GWh	gigawatt-hours
IOU	investor-owned utilities
IPMVP	International Performance Measurement and Verification Protocol
IVG	industrial vortex generator
kW	kilowatt
kWh	kilowatt-hours
LSI	Langelier Saturation Index
M&V	measurement and verification
mm	millimeters
PLC	programmable logic controller
PWT	physical water treatment
SCADA	supervisory control and data acquisition
TC	Technical Committee
UV	ultraviolet
VPT	vortex process technology

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APPENDIX A:
International Performance Measurement and Verification Protocol Plan

The International Performance Measurement and Verification Protocol (IPMVP) Option B – Isolated System Retrofit[29] was used as the primary methodology for savings analysis. This option requires that all variables must be measured or monitored in pre- and post- conditions. This method is applicable where systems can be isolated, and variables easily measured and is summarized as follow.

International Performance Measurement and Verification Protocol

The International Performance Measurement and Verification Protocol (IPMVP) allows four (4) different types of Measurement and Verification Options. The selection of the most appropriate Option provides for assurance of savings verification while ensuring costs are not excessive compared to overall project implementation cost. The following provides a brief overview of the Options available under IPMVP.

- Option A – Partial Measurement Retrofit: This Option allows for measurement of at least one variable pre- and post-retrofit as a method of savings verification. Using this option is typically limited to systems where the variables that are not being measured are static. A good example would be a lighting retrofit where the fixture wattage can be measured and the operating hours either stipulated or monitored for only a short time to establish annual figures. Where lighting systems are consistent (office buildings, restaurants, and so on) with set hours this Option provides a good cost-effective method of establishing baseline and post retrofit values.
- Option B – Isolated System Retrofit: This is like Option A except it requires that all variables must be *measured or monitored in pre and post conditions*. This method is applicable where systems can be isolated, and variables easily measured. Where Option B has difficulty is when the variables are either difficult or impossible to measure or the system cannot be easily isolated from the overall electrical system for measurement. A good example of using this option would be for pumping motor efficiency improvements where the motor and pump data can be easily measured over a set time frame.
- Option C – Whole Building Assessment: This is basically using utility or building level metering to determine savings. Sometimes this is referred to as the "billing guarantee" option. This approach only works when the building data is consistent over time, and the measure that is being considered is significant when compared to the overall building load. Where the measure has many variables or is small compared to the overall building electrical data, this approach will not produce results that identify

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[29] Efficiency Valuation Organization International Performance Measurement and Verification Protocol – 2012 Edition; www.evo-world.org and Core Concepts EVO IPMVP 2014_Dec2014-3.pdf. http://www.minimiseusa.com/images/Core%20Concepts%20%20EVO%20IPMVP%202014_Dec2014-3.pdf.

system or component savings. A good example of this type of Option application would be for a processing facility where the load is consistent, and the proposed measure is to improve all lines of production by over 35 percent.

- Option D – Computer Simulation: This option provides for simulation of the building inputs and calibration to available electrical utility data or sub-meter data that may be available. This is an excellent option to use where the facility has a highly variable load and the measurement of the variables would be costly and difficult.

Regarding selecting the best option for any project, the following are primary considerations:

- Number of variables affecting energy calculations
- Difficulty of measurement of any variable included in the project
- Load variation within the facility
- Availability of data from facility control system
- Overall cost of M & V implementation versus the cost of the project and estimated savings

This project involves the installation of an IVG and nano filtration system to increase efficiency of the cooling tower and chiller systems in a central plant. Two sites have been selected for installation, one is a pharmaceutical manufacturing and research facility, the second is a hotel resort. This plan is specific to the manufacturing facility. With respect to electrical energy, there are two possible energy savings opportunities. First the chiller may operate at a lower KW/Ton parameter due to a more efficient removal of heat through use of the device. Secondly, the cooling tower may use less energy if the efficiency of the cooling tower is increased. Both are dependent on the overall settings through the plant (temps, flow, and so on), the outside air temp and humidity, and the building loads.

Measurement and Verification Option

This plan proposes using a modified Option A/B for the energy assessment. Under the IPMVP protocol this requires monitoring of at least one variable and this plan attempts to monitor the full range of variables (Option B) for the IVG portion of the data collection. Because all historical data that will be collected and analyzed will be for a cooling tower that is not in service this may require some additional testing or engineering to determine the overall savings of the product compared with any savings due to the installation of a new cooling tower.

Measured Variables

The plan proposes using the following data points available from the third-party contractor. This data will be collected for a minimum of one year prior to the installation of the IVG for purposes of establishing the pre-baseline. In addition, the data will be collected and assessed from the time the new cooling tower is installed through the installation of the IVG to determine the adjustment to the baseline data due to the new cooling tower. Data will be stored and collected online through an approved sign on system. The required points will be used to develop the savings analysis. The "for verification" points will be used to verify other data sources or confirm the calculations that will also be collected as single data points. The "for information" points will be collected to establish any significant changes through the monitoring period and to ensure any analysis completed is not subject to different settings at the plant or load.

Savings Calculations – Method 1

For the Amgen site, the savings will be based on a change in chiller and total plant efficiency. The methodology employed will be as follows:

Calculation of Plant Tons

This calculation will be made using the following data variables:

- System supply chilled water temperature (SCHWS)
- System return chilled water temperature (SCHWR)
- System flow (SF)

All three of these variables are in the data to be collected. The tons are then calculated as:

Tons Refrigeration (TR)= ((SCHWR- SCHWS) X (SF) X 8.34 X 60)/12,000

The kW will be measured directly from one or both chillers (CHkW)

Calculation of kW/TR (Chiller(s)) (CHkW/Ton)

From the above, the kW/TR of the chillers will be calculated as follows:

CHkW/Ton = (CHkW)/Tons

Plant Efficiency: Once the chiller efficiency has been established the total plant efficiency will be established as follows:

- Conversion of Pump speed to kW (PkW): Data collected by field test will establish the conversion from percent speed to kW. Then the pump kW will be documented and tabulated.
- Conversion of Fan speed to kW (FkW): Data collected by field test will establish the conversion from percent speed to kW. Then the fan kW will be documented and tabulated.
- Total Plant kW (TOTkW): The total plant kW will be calculated as follows:

  TOTkW = CHkW + PkW = FkW
- Total Plant efficiency will then be calculated as follows (TOTPkW/Ton)

  TOTPkW/Ton = TOTkW/Tons
- Savings will be calculated as follows:
  - Chiller Savings (CHSAV) = (Pre CHkW/Ton – Post CHkW/Ton) x Ton-Hours (either on an hourly basis or by extrapolation as described herein)
  - Plant Savings (PLSAV) = (Pre TOTPkW/Ton – Post TOTPkW/Ton) X Ton-Hours (either on an hourly basis or by extrapolation as described herein)

For savings calculations, data will be filtered so that loading comparisons between any established baseline and subsequent retrofit are in similar groups (typically referred to as BIN analysis where data is segregated into appropriate BINS for analysis against the post retrofit data in similar or exact BINS). This approach will allow a full but conservative approach to determining the energy savings of the product.

Savings Calculation – Method 2

In addition to the overall chiller and plant efficiency detailed herein, a second method will be used at this site to verify savings due to the product installation. For each chiller, data are available that specifically calculates the approach temperature ($T_{CondenserWaterIntoChiller} - T_{ChilledWaterOut}$) across the evaporator and condenser of the chiller. This data would show an improvement in approach after the IVG has been properly installed and commissioned. The analysis under this method will determine the percent change in approach for similar BINs and will use the same extrapolation methodology described for the chiller and plant efficiency savings analysis.

Once both methods have been developed and analyzed, the results used will be from the most conservative approach, if results differ for each method, in terms of savings identified for publication as the "verified" savings.

Adjustments

Depending on the method that is utilized for extrapolation or if historical data is used as a proxy, there may be a required adjustment to accommodate any of the following:

- Significant changes in Outside Air conditions if historical data is used compared to actual monitored data.
- Significant changes in plant load or plant operation during the monitoring period.

All adjustments must be fully documented and assessed by using engineering models or calculations that can include assessment of CDD (cooling degree days) or building/plant simulation. Should more detailed plant modeling be required additional scope of services for M & V will be required.

Extrapolation

After establishing the baseline (historical and pre-IVG, post new tower data collection), the monitored data will be extrapolated to an annual savings figure in kWH by using either actual plant historical profile compared to monitored period with any adjustments, or using the proxy testing and extrapolation using monitored total monthly load profile data to arrive at an annual assessment of savings.

Instrumentation

Accuracy of the installed power meters must be within the range of expected savings (4 percent maximum error).

Required Certification

All analysis and reports must be signed and stamped by a Registered Professional Engineer (California): A Certified Measurement and Verification Professional

APPENDIX B: International Performance and Measurement and Verification Protocol Results

Amgen Host Site Data Analysis and Results

When compared to usage without the technology (baseline), the findings from the start date of 8/1/2017 through 3/31/2018 demonstrates clear energy benefits. As a note, the PS6 cooling towers did not operate for most of April and May; June and July water information are included in this report.

- Energy: 6.4 percent avoided chiller energy usage
    - Nine months: 171,966 kWh
    - Estimated Annual: 225,000 kWh
    - Annual Avoided Cost @$0.12/kWh: $27,000

Table B-1: City Water used for Cooling Tower Make-Up

	PS6 Metered	Calibrated Model
Make-up Baseline	10,512,560	10,554,167
Gross Make-up Post	8,452,830	8,741,335
Nano Reject	462,456	535,766
Net Make-up Post	8,915,286	9,277,101
Avoided Water Use	**1,597,274**	1,277,066

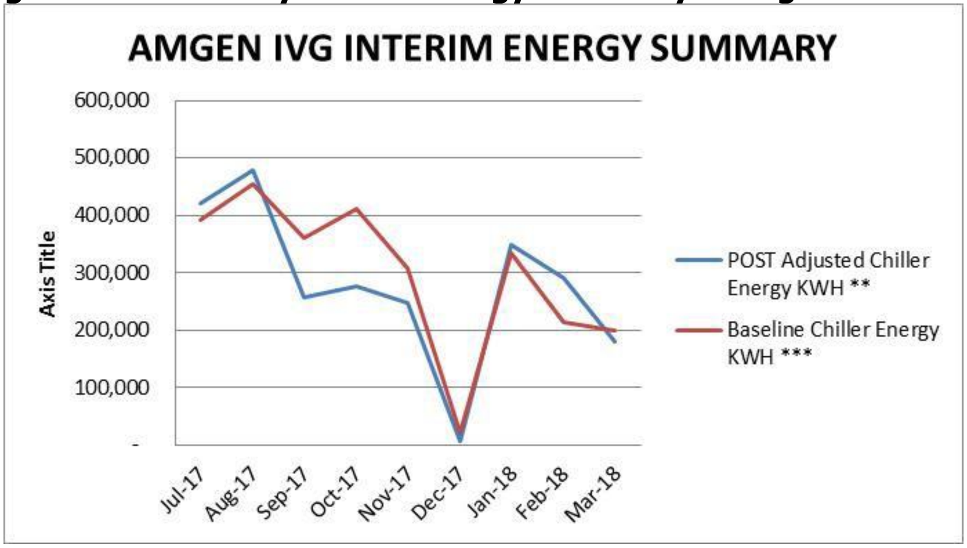
Source: Electric Power Research Institute

International Performance and Measurement and Verification Protocol Energy Analysis Results

The results of the energy analysis performed at Amgen’s Thousand Oaks site are shown below. Based on results to-date for a representative period, Figure B-1 shows Amgen’s projected estimated energy savings for the IVG (Industrial Vortex Generator). This is based on the overall net savings for nine months based on the IPMVP standards. Under the Plan requirements, 2016 data was used as the baseline for all comparative analyses. Data collected after the installation and commissioning of the IVG-CT (full month beginning in July 2017) is used, with adjustments allowed under the M & V Plan to provide the post energy consumption. For this analysis, the data centered on each chiller to avoid further complication due to the cooling tower replacement project in early 2017. The summary included herein includes the actual IVG consumption by month as an adjustment (Figure B-1), providing a net savings to Amgen for the nine months of just over 170,000 KWH, or 6.4 percent of base energy consumption or 225,000 annualized. With a blended rate of $0.12/kWh, the annualized avoided energy amounts to approximately $26,000 per year in energy savings.

Overall, this shows that the project has realized energy savings for the facility. These results are very similar to the realized savings at the second facility (Resort Location) and slightly higher than the expected 4-6 percent savings.

Figure B-1: Monthly Chiller Energy Summary - Amgen Host Site



Source: EPRI

Table B-2: Amgen Summary of Energy Savings

AMGEN -- POST INTERIM DATA

Description	Month									Total
	Jan-18	Feb-18	Mar-18	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	
Total Adjusted Chiller Energy KWH **	348,097	290,956	180,508	421,286	478,028	256,882	276,425	248,668	5,898	2,506,747
Ton Hours (1000's)	2,422,875	2,553,232	4,427,599	2,796,886	5,726,648	5,997,116	7,061,139	5,486,505	4,731,982	41,203,982

AMGEN -- BASELINE INTERIM DATA

Description	Month									Total
	Jan-16	Feb-16	Mar-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	
Baseline Chiller Energy KWH ***	333,394	214,603	199,584	392,581	455,225	360,000	410,700	309,077	21,282	2,696,447
Ton Hours (1000's)	3,938,103	3,253,856	2,264,145	4,906,107	7,470,719	5,854,716	6,207,290	3,339,526	127,438	37,361,900

AMGEN -- DIFFERENCE

Description	Month									Total
	J	F	M	J	A	S	O	N	D	
Gross Savings KWH	(14,703)	(76,353)	19,077	(28,706)	(22,802)	103,118	134,275	60,410	15,384	189,700
IVG Skid Consumption	280	2,201	1,422	1,422	4,266	2,977	360	2,604	2,201	17,734
Net Savings	(14,983)	(78,554)	17,654	(30,128)	(27,068)	100,141	133,915	57,806	13,183	171,966

AMGEN --% CHANGE

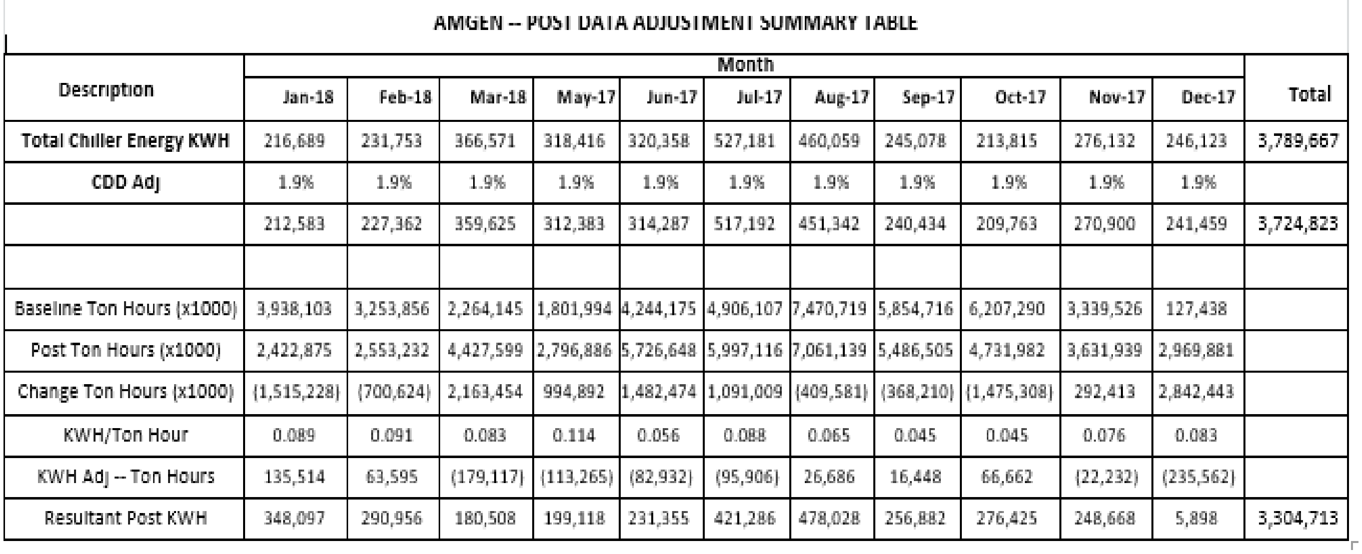
Description	Month									Total
	J	F	M	J	A	S	O	N	D	
Net Savings	-4.3%	-27.0%	9.8%	-7.2%	-5.7%	39.0%	48.4%	23.2%	N/A	6.4%

**NOTE:	Post Chiller KWH includes adjustments for Ton Hour and CDD Differences and any net usage below 0 KWH

Source: EPRI

Table B-3 shows the results of the baseline and post-install adjustments. Note that while all 12 months for analysis are included, the Status Update compares the actual months of post data collection (July 2017 thru February 2018) against the baseline months for the same period shows the cooling degree day results. Note that a monthly adjustment was not made due to the large variance month to month. If a monthly adjustment were made, December would show a substantial savings, when in fact, the energy consumed was less than 2 percent of annual consumption. The average 9.5 percent annual change was used as an "average" adjustment for each month and then adjusted as shown above in Table B-2.

Table B-3: Amgen- Post Data Adjustments



AMGEN -- POST DATA ADJUSTMENT SUMMARY TABLE

Description	Month											Total
	Jan-18	Feb-18	Mar-18	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	
Total Chiller Energy KWH	216,689	231,753	366,571	318,416	320,358	527,181	460,059	245,078	213,815	276,132	246,123	3,789,667
CDD Adj	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	1.9%	
	212,583	227,362	359,625	312,383	314,287	517,192	451,342	240,434	209,763	270,900	241,459	3,724,823
Baseline Ton Hours (x1000)	3,938,103	3,253,856	2,264,145	1,801,994	4,244,175	4,906,107	7,470,719	5,854,716	6,207,290	3,339,526	127,438	
Post Ton Hours (x1000)	2,422,875	2,553,232	4,427,599	2,796,886	5,726,648	5,997,116	7,061,139	5,486,505	4,731,982	3,631,939	2,969,881	
Change Ton Hours (x1000)	(1,515,228)	(700,624)	2,163,454	994,892	1,482,474	1,091,009	(409,581)	(368,210)	(1,475,308)	292,413	2,842,443	
KWH/Ton Hour	0.089	0.091	0.083	0.114	0.056	0.088	0.065	0.045	0.045	0.076	0.083	
KWH Adj -- Ton Hours	135,514	63,595	(179,117)	(113,265)	(82,932)	(95,906)	26,686	16,448	66,662	(22,232)	(235,562)	
Resultant Post KWH	348,097	290,956	180,508	199,118	231,355	421,286	478,028	256,882	276,425	248,668	5,898	3,304,713

Source: EPRI

Table B-4: Cooling Degree Day Summary

Month	CDD	Month	CDD	Difference	% Diff
Jan-16	14	Jan-17	11	(3)	-21.4%
Feb-16	134	Feb-17	17	(117)	-87.3%
Mar-16	74	Mar-17	119	45	60.8%
Apr-16	128	Apr-17	140	12	9.4%
May-16	76	May-17	144	68	89.5%
Jun-16	302	Jun-17	287	(15)	-5.0%
Jul-16	400	Jul-17	414	14	3.5%
Aug-16	366	Aug-17	405	39	10.7%
Sep-16	297	Sep-17	308	11	3.7%
Oct-16	188	Oct-17	278	90	47.9%
Nov-16	123	Nov-17	106	(17)	-13.8%
Dec-16	9	Dec-17	82	73	811.1%
Total	2,111		2,311	200	9.5%
Actual Adjustment CDD					**9.5%**
Selected Adjustment CDD					**1.9%**

Source: EPRI

Monthly Data Analysis

For each month, a detailed data analysis was completed. This included each month for the baseline period (January – December 2016), and each month for the Post-IVG period (actual data collected from May 2017 to current). The analysis was completed as follows:

1. Data was assessed for each chiller focusing on the data points provided for each chiller efficiency (KW/Ton).
2. The data was then filtered to provide only the acceptable efficiency points that could be used to determine actual individual chiller efficiency.
3. The data was then assessed based on a load range for chiller loading.
4. The data was then summarized by load range to provide an average efficiency for each load range where available.
5. The results were then extrapolated to a monthly KWH usage based on the actual ton hours produced by the plant, and the percentages of usage for each chiller during that actual month.

Table B-5 shows a result of this analysis – in this example, June 2017 is used. For this type of analysis, the actual measured efficiency at the load range was used, along with the percentage of time for the month that the plant showed that type of load to arrive at the energy in kWh for each chiller. This method provides that the results will always arrive at the actual measured ton hours that were captured from the Optimum® system. The Technical Appendix contains each monthly data analysis summary as well as all the detailed analysis completed to arrive at the monthly summaries.

Table B-5: Amgen Efficiency Summary (June 2017 Monthly Analysis, Hours)

Load Range (TONS)	Ch 1 KW/Ton	Hours	% Hour	Ch 2 KW/Ton	Hours	% Hour
Under 200	0.705	7.000	7.5%			0.0%
201-300	0.646	3.000	3.2%	0.694	2.000	10.0%
301-400	0.621	6.000	6.5%	0.690	2.000	10.0%
401-500	0.713	9.000	9.7%			0.0%
501-600	0.663	12.000	12.9%			0.0%
601-700	0.625	12.000	12.9%	0.490	1.000	5.0%
701-800	0.555	17.000	18.3%	0.445	4.000	20.0%
801-900	0.588	13.000	14.0%	0.491	5.000	25.0%
901 - 1000	0.616	13.000	14.0%	0.692	1.000	5.0%
Above 1000	0.730	1.000	1.1%	0.708	5.000	25.0%
Total Hours		93.000	100.0%		20.000	100%
% Chiller 1	82.3%					
% Chiller 2	18%					
Total Month Plant Tons	7,954					
Total Month Hours	720					

Source: EPRI

Table B-6: Amgen Efficiency Summary (June 2017 Monthly Analysis, Tons)

Load Range (TONS)	Ch 1 KW/Ton	Tons	KWH	Ch 2 KW/Ton	Tons	KWH
Under 200	0.705	492.706	15,488.51	-	-	-
201-300	0.646	211.160	2,606.82	0.694	140.773	1,244.99
301-400	0.621	422.319	10,021.76	0.690	140.773	1,237.07
401-500	0.713	633.479	25,896.85	-	-	-
501-600	0.663	844.638	42,801.21	-	-	-
601-700	0.625	844.638	40,363.18	0.490	70.387	219.71
701-800	0.555	1,196.571	71,939.82	0.445	281.546	3,195.86
801-900	0.588	915.025	44,556.49	0.491	351.933	5,506.24
901 - 1000	0.616	915.025	46,700.76	0.692	70.387	310.21
Above 1000	0.730	70.387	327.56	0.708	351.933	7,940.50
Totals		6,545.948	300,702.97		1,407.731	19,654.59
Total Chiller KWH	320,358					

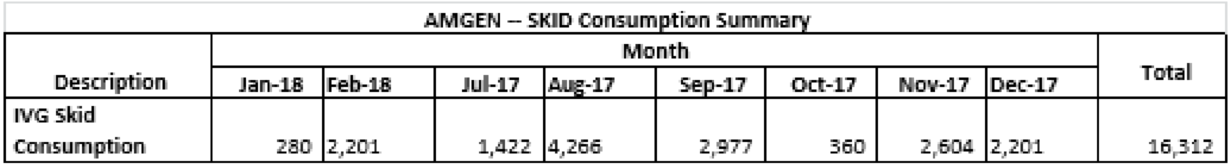
Source: EPRI

For this type of analysis, the actual measured efficiency at the load range was used, along with the percentage of time for the month that the plant showed that type of load to arrive at the energy in kWh for each chiller. This method provides that the results will always arrive at the actual measured ton hours that were captured from the Optimum® system.

Industrial Vortex Generator – Energy Consumption

The unit consumption has been captured by use of a Wattnode® and HOBO® data logger installed in May of 2017. This data provides the actual monthly energy (kWh) used by the industrial vortex generator (IVG) for the post installation period (February 2017 is estimated based on December 2017 consumption – February IVG consumption data was not available at the time of this report). This was used to provide an adjustment for net savings as a result of the device installation. The data shows that the unit was offline for most of October and has a lower consumption for July than expected. Further data collection will be "averaged" for the final assessment report. Table B-7 summarizes the data for this adjustment.

Table B-7: IVG Energy Consumption Summary



AMGEN – SKID Consumption Summary

Description	Month								Total
	Jan-18	Feb-18	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	
IVG Skid Consumption	280	2,201	1,422	4,266	2,977	360	2,604	2,201	16,312

Source: EPRI

Amgen Savings Analysis

The savings was based on comparing actual Chiller 1 and Chiller 2 data by month between the baseline period and the post installation period with adjustments as described herein. The savings provide a monthly summary of energy for just the chillers. The remaining plant was not included, to avoid further adjustments based on the cooling tower replacement project.

Amgen Regression Results Summary

For this analysis, regression was completed with the same variables to be consistent between the two sites for the product installation. The one regression that consistently shows good results is comparing the total KW (each chiller) against the tons produced by the chiller. This may prove to be a good tool in generating a formula for "generic" savings but based on the other results, there is little correlation between the variables selected for comparison. Because this report is based on each chiller, there are some months where one of the chillers was not used so regression could not be completed. Note that the only regression with a good R^2 is the Tons and Total KW regression. The others show that regression is not a good tool for relating the variables considered. Table B-8 and Table B-9 show the example of June 2017 regression results

Table B-8: Amgen Regression Results - Chiller 1(June 2017)

Description	R Squared	Formula
OA and Tons	0.370	y = 57.452 +0.016*Calc Tons Ch 1
OA and TOT KW	0.517	y = 57.245 +0.032*CH1kW (kW)
Tons and KW/Ton	0.003	y = 645.49 +174.61*CH1_kW/Ton (kW/Ton)
Tons and TOT KW	0.875	y = 143.602 +1.545*CH1kW (kW)
TOT KW and KW/Ton	0.137	y = -11.662 +760.942*CH1_kW/Ton (kW/Ton)
KW/TON and Condenser Supply	0.074	y = 62.289 +9.53*CH1_kW/Ton (kW/Ton)
KW/Ton and Condenser Return	0.073	y = 69.063 +11.772*CH1_kW/Ton (kW/Ton)

Source: EPRI

Table B-9: Amgen Regression Results - Chiller 2(June 2017)

Description	R Squared	Formula
OA and Tons	0.086	y = 61.203 +0.005*Calc Tons Ch 2
OA and TOT KW	0.375	y = 58.821 +0.018*CH2kW (kW)
Tons and KW/Ton	0.000	y = 760.946 +19.538*CH2_kW/Ton (kW/Ton)
Tons and TOT KW	0.780	y = 250.615 +1.419*CH2kW (kW)
TOT KW and KW/Ton	0.193	y = 66.548 +630.792*CH2_kW/Ton (kW/Ton)
KW/TON and Condenser Supply	0.452	y = 60.244 +13.009*CH2_kW/Ton (kW/Ton)
KW/Ton and Condenser Return	0.349	y = 62.425 +23.267*CH2_kW/Ton (kW/Ton)

Source: EPRI

In summary, based on the level of analysis completed by the IPMVP method:

- The IVG is providing savings of just over 7 percent for project period. This is in line with the expected savings for the device.
- The total savings are net of the IVG consumption and any other adjustments as detailed herein.
- There was little correlation based on selected variables for regression. The Total KW for each chiller and tons produced by each chiller does show good correlation.

Marriott Host Site Data Analysis and Results

When compared to usage without the technology (baseline), the findings for 12 months from 9/1/2017 through 8/31/2018 demonstrate energy, water and chemical savings benefits.

- 5.4 percent avoided chiller energy usage3
- Annual: 94,374 kWh
- Annual Avoided Cost4 @$0.1181/kWh $11,145

Based on results to date for the Marriot site, Table B-10 shows the energy savings for the IVG (Industrial Vortex Generator):

Table B-10: Summary of Energy Savings - Marriott

Description	Value	Units
Plant Size	900	Tons
Equivalent Full Load Hours (EFLH)	3,062	Hours
Average PRE Efficiency	0.640	KW/TON
Calculated PRE Consumption	1,763,559	KWH
Estimated Simplifed Savings *	7.0%	
Gross Savings	123,325	KWH
IVG ACTUAL CONSUMPTION **	28,951	KWH
NET SAVINGS	**94,374**	**KWH**
% NET SAVINGS	**5.4%**	

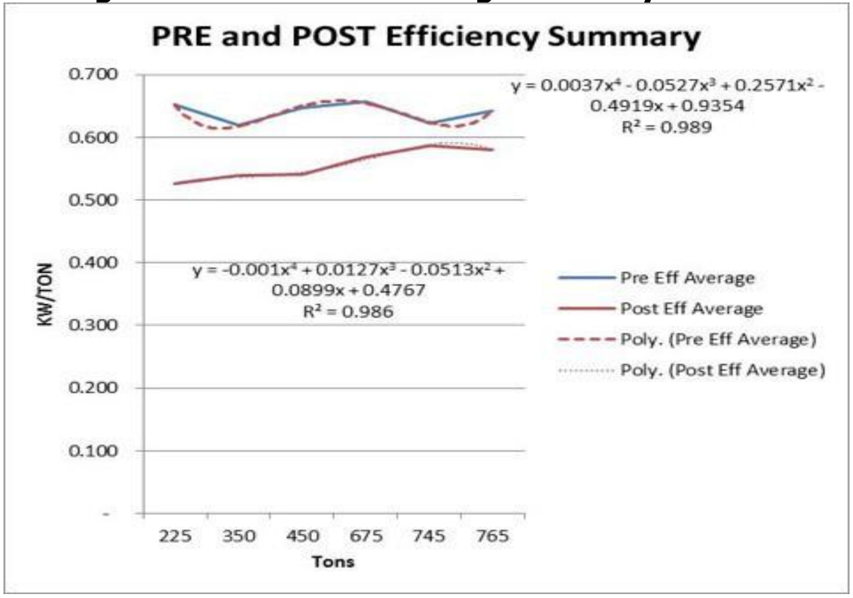
*** Savings Estimate is using 14 months of actual data to calculate the gross savings with the IVG**

**** IVG Consumption uses 9 months of actual data normalized to an annual figure using a simple straight line calculation**

Source: EPRI

The following provides the final assessment of energy savings based on a methodology that uses an averaging across the data collected to date and a calculation of the EFLH (Equivalent Full Load Hours) based on utility data provided. This methodology has shown consistent monthly savings through the months where post data was available. In addition, there were two separate methods employed and the savings shown above is based on the lowest calculated savings from these two methods to be as conservative as possible.

Figure B-2: Chiller Loading Efficiency Results



Source: EPRI

The curves have been fitted using a fourth-degree method to ensure the best possible R^2 value across the pre- and post- regions. For the final assessment the curves *show a savings at all levels of operation of the plant based on load in tons*. Additional energy details are described in other sections of this report.

The following describes the overall analysis:

1. Each data point was collected from the Trane Trace System. Several points are not used in this interim report but may be used for additional analysis as the project moves forward
2. Tons on the system were calculated using the following equation:

   Tons = ((Chilled Water Return Temp – Chilled Water Supply Temp) X Flow X 60 X 8.34)/12,000
3. Chiller kW was collected and totalized to provide total Chiller kW for each point
4. Efficiency was calculated as:

Chiller Efficiency (kW/Ton) = Total Chiller kW/Tons

5. The data was then tabulated across the full periods indicated in the data capture section for comparison to equivalent data in other periods.
6. For July the data was divided into pre and post periods. For purposes of all analysis July 11, 2017 was excluded (the day the IVG went into service).
7. The data was then analyzed between "pre" and "post" periods to arrive at expected savings.

Marriott Savings Analysis

Two methods were analyzed regarding the conclusions of this report. First the data was compared (pre versus post) across various operating percentages of the total chiller capacity. The percentages were selected to provide good comparative operating points where the outside air temps, delta T, and chiller loading were very close or similar. Secondly, specific points of loading were compared between the available pre-data (May, June, July) and the available post data (July, August, September, October, November, December). As noted herein there are limited point comparisons with dates beyond September due to the use of the free cooling system and lower overall chiller loading.

Method 1 – Looking at Chiller Loading Across all Available Values

For this analysis the data was filtered to provide a cross section of loading values that could be used for both pre and post conditions. Tables B-11 through B-13 summarize this analysis.

This method "averages" the values across these operating conditions to arrive at an overall average efficiency at each point on the curve. Then the savings at each point is averaged and the result is an estimated 7.0 percent savings with the IVG. This method provides a good representation of the average plant savings and when used with the calculated equivalent full load hours (EFLH) is a very good approximation of the annual energy savings for the device.

Table B-11: **Pre-Data Summary of Results – Marriott Site**

Description	**% Load/Tons**							
	25% 225 tons	**39% 350 tons**	**50% 450 tons**	**75% 675 tons**	**83% 745 tons**	**85% 765 tons**	**95% 855 tons**	**100% 900 tons**
May Efficiency KW/Ton	0.651	0.682	0.702					
June Efficiency KW/Ton	0.644	0.590	0.621	0.648		0.637		
July PRE Efficiency	0.659	0.584	0.620	0.665	0.623	0.648		
Pre Average	**0.651**	**0.619**	**0.648**	**0.657**	**0.623**	**0.643**		

Plant Capacity = 900 tons

Source: EPRI

Table B-12: **Post-Data Summary of Results – Marriott Site**

Description	**% Load/Tons**							
	25% 225 tons	**39% 350 tons**	**50% 450 tons**	**75% 675 tons**	**83% 745 tons**	**85% 765 tons**	**95% 855 tons**	**100% 900 tons**
July Post Efficiency		0.605	0.559	0.641	0.620	0.610		
Sept Post Efficiency	0.487	0.563	0.553	0.558	0.580			
Dec Post Efficiency	0.377							
August Post Efficiency	0.522	0.473	0.573	0.573	0.575	0.575	**0.376**	
November Post Efficiency	0.468	0.452						
October Post Efficiency	0.466	0.515	0.537	0.526		0.574		
Jan 2018 Post Efficiency	0.419							
Feb 2018 Post Efficiency	0.464							
March 2018 Post Efficiency	0.533	0.508						
April 2018 Post Efficiency	0.479	0.554	0.494					
May 2018 Post Efficiency	0.842	0.594	0.550	0.609				

Description	% Load/Tons							
	25% 225 tons	**39% 350 tons**	**50% 450 tons**	**75% 675 tons**	**83% 745 tons**	**85% 765 tons**	**95% 855 tons**	**100% 900 tons**
June 2018 Post Efficiency	0.516	0.516	0.515	0.511				
July 2018 Post Efficiency	0.743	0.569	0.551	0.585	0.569	0.558	0.461	
August 2018 Post Efficiency	0.530	0.575	0.529	0.548				
POST Average	**0.527**	**0.539**	**0.540**	**0.569**	**0.586**	**0.579**	**0.419**	

Plant Capacity = 900 tons

Source: EPRI

Table B-13: Summary of Pre- and Post-Data Results – Marriott Site

Description	Tons					
	225	**350**	**450**	**675**	**745**	**765**
Pre Average	0.651	0.619	0.648	0.657	0.623	0.643
Post Average	0.527	0.539	0.540	0.569	0.586	0.579
% Savings Each Load	11%	7%	9%	7%	3%	5%
Savings Average Across All Loads	**7.0%**					

Plant Capacity = 900 tons

Source: EPRI

Point by Point Comparison

This method took points at each of the pre-data months and compared to near identical loading in the post months. For this analysis, the pre-data used for comparison was:

- May Pre Peak – 533.2 tons of loading
- June Pre – 762.5 tons – this compares to values for July post peak and other post data at points very near this value
- July Pre at the same value for the June Pre for comparison to post data
- July Post Peak – 765 tons – used for comparison to June Pre
- Post – July, August, October – These months had points near the selected pre-points for analysis.

Table B-14 summarizes the results.

Table B-14: Average Point by Point Method Summary

Month	Tons	KW/Ton	Ch1 KW	Ch2 KW	OA	Delta T
May (PRE) Peak Data	533.20	0.624	184.00	149.00	104.00	8.6
July POST Data (May Pre Comparison)	533.20	0.593	165.00	152.00	100.1	8.6
July 2018 POST Data (May Pre Comparison)	533.20	0.513	138.213	135.50	89.588	8.7
Aug POST DATA -- MAY COMP	533.20	0.550	149.00	145.00	97	8.6
Aug 2018 POST DATA -- MAY COMP	533.20	0.532	143.900	139.967	90.267	9.033
Nov POST DATA -- MAY COMP	533.20	0.550	149.00	145.00	97	8.6
Sept POST DATA -- MAY COMP	533.20	0.559	144.00	298.00	95	8.6
Oct POST DATA -- MAY COMP	533.20	0.526	145.00	135.00	94	8.6
AVERAGE POST CONDITION	533.20	0.546	148	164	95	8.68

May comparison savings 6.7%; June comparison savings 7.7%; July comparison savings 9.5%; average across comparison savings 7.9%. Change in efficiency, 0.078; % savings IVG 6.7%. Note that the savings with this overall method are slightly higher (0.9 percent) than the averaging method used previously. To ensure the analysis provides a conservative estimate the lesser of the two methods or a savings of 7.0 percent was used for the final assessment.

Source: EPRI

This shows that each of the comparative post months was averaged and then the savings were calculated using the difference in KW/TON for the base as compared to the average post condition.

Error! Reference source not found.15 shows the June pre-comparison data.

Table B-15: June Point Comparative Detail

Month	Tons	KW/Ton	Ch1 KW	Ch2 KW	OA	Delta T
June PRE -- (Compare to July Post Peak)	762.49	0.635	246.1	238.1	101.6	12.3
July POST Peak Data	762.03	0.610	232.30	232.10	107.8	12.3
Aug POST DATA -- 85%	765.00	0.575	214.00	217.00	100	12.1
Oct POST DATA -- 85%	765.00	0.574	206.00	231.00	107	12
AVERAGE POST CONDITION	765.00	0.586	217	227	105	12.13

Summary: Change in efficiency, 0.049; % savings IVG, 7.7%.

Source: EPRI

Table B-16 shows the July pre-comparison data:

Table B-16: July Point Comparative Detail

Month	Tons	KW/Ton	Ch1 KW	Ch2 KW	OA	Delta T
July PRE Comparative Data (July Post)	762.49	0.648	251.10	243.20	110.6	12.3
July POST Peak Data	762.03	0.610	232.30	232.10	107.8	12.3
Aug POST DATA -- 85%	765.00	0.575	214.00	217.00	100	12.1
Oct POST DATA -- 85%	765.00	0.574	206.00	231.00	107	12
AVERAGE POST CONDITION	765.00	0.586	217	227	105	12.13

Summary: Change in efficiency, 0.062; % savings IVG, 9.5%.

Source: EPRI

Marriott IVG Consumption

The IVG pump always operates. There is also an associated nano-filtration system that operates on demand. At this site over nine months of actual energy consumption was collected for the final assessment of the net savings. The following table summarizes the value used for the load consumed by the IVG at this location.

Table B-17: IVG Consumption (kWh)

Description	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18
Actual IVG Consumption	2,244	2,277	1,936	2,374	2,478	2,137	2,758	2,908	2,600
Nine Month Total	21,714								
Annual Extrapolation	28,951								

Source: EPRI

The extrapolated energy consumption is subtracted from the savings to arrive at the conclusion and savings.

Marriott Regression Analysis

In addition, and as part of the overall data capture and analysis regression analysis was performed against various variables. These results were varied with many of the variable relationships showing no accurate regression characteristics. The following regressions were performed for each monthly data set:

- Outside Air Temperature in Degrees F was regressed against Plant Load in Tons (OA and TONS)
- Outside Air Temperature in Degrees F was regressed against Total Chiller KW (OA and TOTKW)
- Plant Load in Tons was regressed against Chiller Efficiency in KW/TON (TONS and KW/TON)
- Plant Load in Tons was regressed against Total Chiller KW (TONS and KW/TON)
- Total Chiller KW was regressed against Chiller Efficiency in KW/TON (TOTKW and KW/TON)
- Chiller Efficiency in KW/TON was regressed against Condenser Supply Temp in Degrees F (KW/TON and CONDSUP)
- Chiller Efficiency in KW/TON was regressed against Condenser Return Temp in Degrees F (KW/TON and CONDRET)

Marriott Regression Results Summary

The results of the regression show that using regression to establish a baseline would not be possible for this project. The variables considered for regression do not provide results that could use for example, outside air temperature to establish the total plant load, which in the past could provide a baseline. The results of the regression support the analysis that was completed herein using the available “pre” data for comparative purposes and an analysis that averages the results over various points.

Regression Examples

Outside Air and Plant Load

Table B-18 and B-19 summarize the results of this regression:

Table B-18: OA and TONS Regression Summary – Pre Data Summary

Month	R Squared	Formula (OA and TONS)
May	0.696	y = -374.517 +7.638*Outside Air Temp (Deg F)
June	0.619	y = -332.78 +7.703*Outside Air Temp (Deg F)
July	0.434	y = -399.508 +9.021*Outside Air Temp (Deg F)

Source: EPRI

Table B-19: OA and TONS Regression Summary – Post Data Summary

Month	R Squared	Formula (OA and TONS)
July	0.533	y = -209.98 +7.312*Outside Air Temp (Deg F)
Aug	0.413	y = -323.399 +8.325*Outside Air Temp (Deg F)
Sept	0.557	y = -534.862 +10.227*Outside Air Temp (Deg F)
Oct	0.426	y = -339.837 +7.131*Outside Air Temp (Deg F)
Nov	0.627	y = -300.785 +5.966*Outside Air Temp (Deg F)
Dec	0.312	y = -150.61 +3.451*Outside Air Temp (Deg F)

Source: EPRI

The results do not support using this variable for purposes of establishing a baseline. With a maximum R2 of just over 60 percent and a minimum of 31 percent using this approach would lead to a large uncertainty.

Outside Air and Total Chiller KW

Tables B-20 and B-21 summarize the results of this regression.

Table B-20: OA and TOTKW Regression Summary – Pre Data Summary

Month	R Squared	Formula (OA and TOT KW)
May	0.621	y = -269.491 +5.214*Outside Air Temp (Deg F)
June	0.548	y = -200.116 +4.672*Outside Air Temp (Deg F)
July	0.323	y = -229.997 +5.559*Outside Air Temp (Deg F)

Source: EPRI

Table B-21: OA and TOTKW Regression Summary – Post Data Summary

Month	R Squared	Formula (OA and TOT KW)
July	0.447	y = -131.808 +4.438*Outside Air Temp (Deg F)
Aug	0.319	y = -142.992 +4.294*Outside Air Temp (Deg F)
Sept	0.478	y = -305.969 +5.739*Outside Air Temp (Deg F)
Oct	0.403	y = -183.823 +3.652*Outside Air Temp (Deg F)
Nov	0.642	y = -123.24 +2.618*Outside Air Temp (Deg F)
Dec	0.590	y = -148.765 +2.51*Outside Air Temp (Deg F)

Source: EPRI

This shows the same varied result as the regression from OA to Plant Tons (which would be expected). Slightly lower correlation makes this a less desirable method to approach establishing an accurate baseline.

Tons and KW/TON

Tables B-22 and B-23 summarize the results of this regression.

Table B-22: TONS and KW/TON Regression Summary – Pre Data Summary

Month	R Squared	Formula (Tons and KW/Ton)
May	0.026	y = 0.594 +0*Tons
June	0.001	y = 0.587 +0*Tons
July	0.888	y = -10.225 +0.673*Tons

Source: EPRI

Table B-23: TONS and KW/TON Regression Summary – Post Data Summary

Month	R Squared	Formula (Tons and KW/Ton)
July	0.968	y = 0.1423x + 342.77
Aug	0.006	y = -44.637 +0.094*Tons
Sept	0.003	y = 0.525 +0*Tons
Oct	0.000	y = 0.47 +0*Tons
Nov	0.167	y = 0.623 -0.001*Tons
Dec	0.115	y = 0.014 +0.002*Tons

Source: EPRI

This shows little or no correlation between the variables and cannot be considered acceptable for establishing any relevant data.

Tons and Total Chiller KW

Tables B-24 and B-25 summarize the results of this regression.

Table B-24: TONS and TOTKW Regression Summary – Pre Data Summary

Month	R Squared	Formula (TONS and TOT KW)
May	0.895	y = -14.133 +0.684*Tons
June	0.879	y = 2.874 +0.604*Tons
July	0.888	y = -10.225 +0.673*Tons

Source: EPRI

Table B-25: TONS and TOTKW Regression Summary – Post Data Summary

Month	R Squared	Formula (TONS and TOT KW)
July	0.928	y = -19.196 +0.638*Tons
Aug	0.735	y = 29.49 +0.503*Tons
Sept	0.865	y = -6.671 +0.563*Tons
Oct	0.934	y = -8.956 +0.509*Tons
Nov	0.845	y = 14.622 +0.399*Tons
Dec	0.419	y = -10.728 +0.342*Tons

Source: EPRI

The results of this regression are like the outside air and tons regression. Again, the range and lack of certainty are still limited. Further there is no historical data for this regression which could be used to establish an accurate baseline.

Total Chiller KW and KW/Ton

Tables B-26 and B-27 summarize the results of this regression.

Table B-26: TOTKW and KW/TON Regression Summary – Pre Data Summary

Month	R Squared	Formula (TOT KW and KW/TON)
May	0.215	y = 0.541 +0.001*Total Chiller KW
June	0.019	y = 0.518 +0*Total Chiller KW
July	0.015	y = 0.597 +0*Total Chiller KW

Source: EPRI

Table B-27: TOTKW and KW/TON Regression Summary – Post Data Summary

Month	R Squared	Formula (TOT KW and KW/TON)
July	0.181	y = 0.524 +0*Total Chiller KW
Aug	0.003	y = 30.486 -0.126*Total Chiller KW
Sept	0.105	y = 0.446 +0.001*Total Chiller KW
Oct	0.066	y = 0.441 +0*Total Chiller KW
Nov	0.004	y = 0.532 0*Total Chiller KW
Dec	0.739	y = 0.022 +0.009*Total Chiller KW

Source: EPRI

This shows little or no correlation between the variables and cannot be considered acceptable for establishing any relevant data.

Chiller Efficiency and Condenser Supply Temp

Tables B-28 and B-29 summarize the results of this regression.

Table B-28: KW/TON and CONDSUP Regression Summary – Pre Data Summary

Month	R Squared	Formula (KW/TON and Condenser Supply Temp)
May	0.057	y = 74.781 +6.908*Chiller Only KW/Ton
June	0.005	y = 79.388 +0.513*Chiller Only KW/Ton
July	0.033	y = 78.671 +2.579*Chiller Only KW/Ton

Source: EPRI

Table B-29: KW/TON and CONDSUP Regression Summary – Post Data Summary

Month	R Squared	Formula (KW/TON and Condenser Supply Temp)
July	0.247	y = 64.584 +27.357*Chiller Only KW/Ton
Aug	0.002	y = 80.594 +0*Chiller Only KW/Ton
Sept	0.074	y = 75.926 +6.355*Chiller Only KW/Ton
Oct	0.185	y = 67.293 +21.322*Chiller Only KW/Ton
Nov	0.145	y = 67.923 +14.213*Chiller Only KW/Ton
Dec	0.816	y = 48.893 +36.426*Chiller Only KW/Ton

Source: EPRI

This result shows that using this regression would not provide accurate data to establish a full annual baseline. While one-point shows relevance the others clearly indicate that this would not be an acceptable approach.

Chiller Efficiency and Condenser Return Temp

Tables B-30 and B-31 summarize the results of this regression.

Table B-30: KW/TON and CONDRET Regression Summary – Pre Data Summary

Month	R Squared	Formula KW/Ton and Condenser Return Temp
May	0.324	y = 61.167 +28.583*Chiller Only KW/Ton
June	0.034	y = 80.955 +2.667*Chiller Only KW/Ton
July	0.029	y = 82.867 +4.75*Chiller Only KW/Ton

Source: EPRI

Table B-31: KW/TON and CONDRET Regression Summary – Post Data Summary

Month	R Squared	Formula KW/Ton and Condenser Return Temp
July	0.220	y = 64.164 +37.595*Chiller Only KW/Ton
Aug	0.020	y = 81.59 -0.002*Chiller Only KW/Ton
Sept	0.038	y = 76.637 +4.656*Chiller Only KW/Ton
Oct	0.068	y = 70.866 +11.514*Chiller Only KW/Ton
Nov	0.145	y = 68.546 +8.39*Chiller Only KW/Ton
Dec	0.760	y = 49.586 +29.229*Chiller Only KW/Ton

Source: EPRI

This shows the same result as the regression against Condenser Supply Temperature. Again, this is of little use for the overall analysis or establishing an accurate baseline.

APPENDIX C:
Industrial Vortex Generator UL Certification Notice of Completion

NOTICE OF COMPLETION
AND
AUTHORIZATION TO APPLY THE UL MARK

2017-04-04

Mr. Marco Aarts
Turbin BV
Kempenbaan 36
Rijen, 5121 DM,
Netherlands

Our Reference: File E491550, Vol. 1
Order: 11645570
Project: 4787872231
Your Reference: AMG201662
Project Scope: Limited Production Certification of 2 Ind. Control Panels; NITW, UL508A

Dear Mr. Marco Aarts:

Congratulations! UL's investigation of your product(s) has been completed under the above Reference Number and the product was determined to comply with the applicable requirements.

Any information and documentation provided to you involving UL Mark services are provided on behalf of UL LLC (UL) or any authorized licensee of UL.

We are excited you are now able to apply the UL Mark to your products and appreciate your business. Feel free to contact me or any of our Customer Service representatives if you have any questions.

Very truly yours,

Marco Klopman
Engineer Project Associate
Marco.Klopman@ul.com

Reviewed by:

Bruce A. Mahrenholz
CPO Director
Bruce.A.Mahrenholz@ul.com

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Source: EPRI

Figure C-1: Listing Certification on IVG System at Amgen’s Host Site

Industrial control panel	
UL file number	E491550
Serial/Diagram number	AMG201662
Rated voltage	3 x 480/277 Vac solidly grounded wye source + GND 60Hz
Full load amperage	22 A
Largest motor	9 A
Rated Short circuit capacity	50 kA rms symmetrical 480 V max.
Main supply fuse	30 A. Class J. SCCR 200 kA. min. 480 Vac
UL enclosure type	1

Source: EPRI