Thermosyphon Cooler Hybrid System for Water Savings in an Energy-Efficient HPC Data Center

Results from 24 Months and Impact on Water Usage Effectiveness

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Technical Report
NREL/TP-2C00-72196
September 2018

Contract No. DE-AC36-08GO28308

NATIONAL RENEWABLE ENERGY LABORATORY

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Suggested Citation
Sickinger, David, Otto Van Geet, Suzanne Belmont, Thomas Carter, and David Martinez. 2018. *Thermosyphon Cooler Hybrid System for Water Savings in an Energy-Efficient HPC Data Center: Results from 24 Months and Impact on WUE*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-2C00-72196. https://www.nrel.gov/docs/fy18osti/72196.pdf

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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NOTICE

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. A portion of the funding was provided by USDOE Office of Energy Efficiency and Renewable Energy (EERE) using computational resources sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, and located at the National Renewable Energy Laboratory. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

Cover Photos by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.

Acknowledgments

This document was prepared by the National Renewable Energy Laboratory (NREL) as the final report for the partnership formed between Johnson Controls and two U.S. Department of Energy national laboratories—the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories—to deploy a thermosyphon cooler (TSC) as a test bed at NREL's high-performance data center.

NREL would like to thank key partner Johnson Controls for providing the TSC. Special appreciation goes to Tom Carter for ongoing support throughout the entire project and to Zan Liu for early support during the installation.

Another key partner was Sandia National Laboratories. Special appreciation goes to Dave Martinez for ongoing support throughout the project.

Key NREL team members include Kevin Regimbal as the program sponsor who monitored the program from the start and Roy Fraley who supported the TSC start-up along with ongoing operation. The authors would like to thank the team involved from NREL's Site Operations group that oversaw the TSC installation.

We would like to thank Devonie McCamey, Kristi Theis, and Katie Wensuc of NREL for communication support and editing this document as well as Joshua Bauer of NREL for graphic design support.

List of Acronyms

DOE	U.S. Department of Energy
ERE	Energy reuse effectiveness
ERW	Energy recovery water
ESIF	Energy Systems Integration Facility
EWIF	Energy water intensity factor
HPC	High performance computing
IT	Information technology
NREL	National Renewable Energy Laboratory
PUE	Power usage effectiveness (total system input energy (kWh)/IT input energy (kWh))
PV	Photovoltaic
TCHS	Thermosyphon cooler hybrid system
TSC	Thermosyphon cooler
WUE	Water usage effectiveness (water use (L)/IT input energy (kWh))

Executive Summary

In August 2016, the National Renewable Energy Laboratory (NREL) installed a thermosyphon hybrid cooling system to reduce water usage in its already extremely energy-efficient High-Performance Computing (HPC) Data Center. In its first year of use, the system saved 4,400 m^3 (1.16 million gal) of water, and 7,950 m^3 (2.10 million gal) during a 2-year period, cutting the use of water in the data center by about one-half.

NREL's 930-m^2 (10,000-ft^2) HPC Data Center is often called the most energy-efficient data center in the world: it has achieved a trailing 12-month average power usage effectiveness of 1.034, and it features a chiller-less design, component-level warm-water liquid cooling, and waste heat capture and reuse.

NREL considered the amount of water used by the cooling towers to be counter to the laboratory's sustainability mission, so a team of researchers from NREL, Sandia National Laboratories (Sandia), and Johnson Controls integrated the BlueStream thermosyphon cooler (TSC)—an advanced dry cooler that uses refrigerant in a passive cycle to dissipate heat—on the roof of NREL's Energy Systems Integration Facility, the building that houses the HPC Data Center. In combination with the existing cooling towers, the TSC forms an extremely water- and cost-efficient cooling system. In its first year of operation, on-site water usage effectiveness (WUE) was 0.70 L/kWh. In comparison, the WUE would be 1.27 L/kWh if NREL had continued using only heat-recovery and cooling towers. This on-site water savings was accomplished without negatively impacting the energy-efficient operation of the HPC Data Center.

The TSC system technology has the potential for application in data centers around the world, and it is currently being implemented by Sandia.

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1 Introduction

Improving data center operational efficiency requires focusing on both energy and water usage. The U.S. Department of Energy National Renewable Energy Laboratory (NREL) took a holistic approach to designing the world's most energy-efficient High-Performance Computing (HPC) Data Center. Completed in 2014, the 930-m^2 (10,000-ft^2) center is located inside the Energy Systems Integration Facility (ESIF), which is Platinum rated by the Leadership in Energy and Environmental Design certification program, on NREL's Golden, Colorado, campus. The HPC Data Center has maintained a trailing 12-month average power usage effectiveness (PUE) of 1.06 or better since opening, and it features a chiller-less design, component-level warm-water liquid cooling, and waste heat capture and reuse. In 2016, Johnson Controls partnered with NREL and Sandia National Laboratories (Sandia) to deploy a thermosyphon cooler (TSC) as a test bed at NREL's HPC Data Center and to quantify on-site water savings and energy usage. The thermosyphon cooler hybrid system (TCHS) integrates the control of a dry heat-rejection device with an open cooling tower. This paper provides the results from the first 24 months of the TCHS operation, showing how this system has cut the data center's on-site water usage in about half without negatively impacting the center's energy-efficient operation.

1.1 Thermosyphon Installation: A Brief Recap

The initial HPC Data Center configuration used cooling towers to eliminate the added expense of energy-demanding chillers. The cooling towers were more efficient and less expensive; however, even after waste heat capture and reuse potential was exhausted, they consumed approximately 9,500 m^3 (2.5 million gal) of water annually to support cooling the information technology (IT) load—approaching an hourly average of 1 MW (3.4 million Btu/h).

In mid-2016, the NREL, Sandia, and Johnson Controls team installed the Johnson Controls BlueStream TCHS. It was placed upstream of the HPC Data Center cooling towers on the roof of the ESIF (see Figure 1) to create a hybrid cooling system.

As detailed in the report on the *Thermosyphon Cooler Hybrid System for Water Savings in an Energy-Efficient HPC Data Center: Modeling and Installation*,[1] the integration of the TSC into the existing energy recovery water (ERW) loop required only a 1-day outage to the HPC Data Center. The outage was needed to cut the ERW return pipe (prior to the cooling tower heat exchanger) to install a control valve between the existing taps. New pipes were installed to these taps to act as supply-and-return lines to the TSC unit along with an additional control valve.

The other construction activities were conducted without impacting HPC Data Center operations, and they included a slight structural modification to the outside cooling tower platform to accommodate the TSC placement, running pipes from inside the ERW tie-in points to the outside platform to connect to the TSC, electrical runs for the TSC panels and fans, lightning protection, and integrating controls with the building management system. A crane was used on two different occasions: first to lift steel pipe, followed by the steel platform material and the TSC unit itself. The TSC was placed on a platform intended for future cooling towers. Sufficient

[1] See https://www.nrel.gov/docs/fy17osti/66690.pdf

metering was also added to quantify power and water differences when the TSC is running and when it is turned off. The TCHS became operational in August 2016.

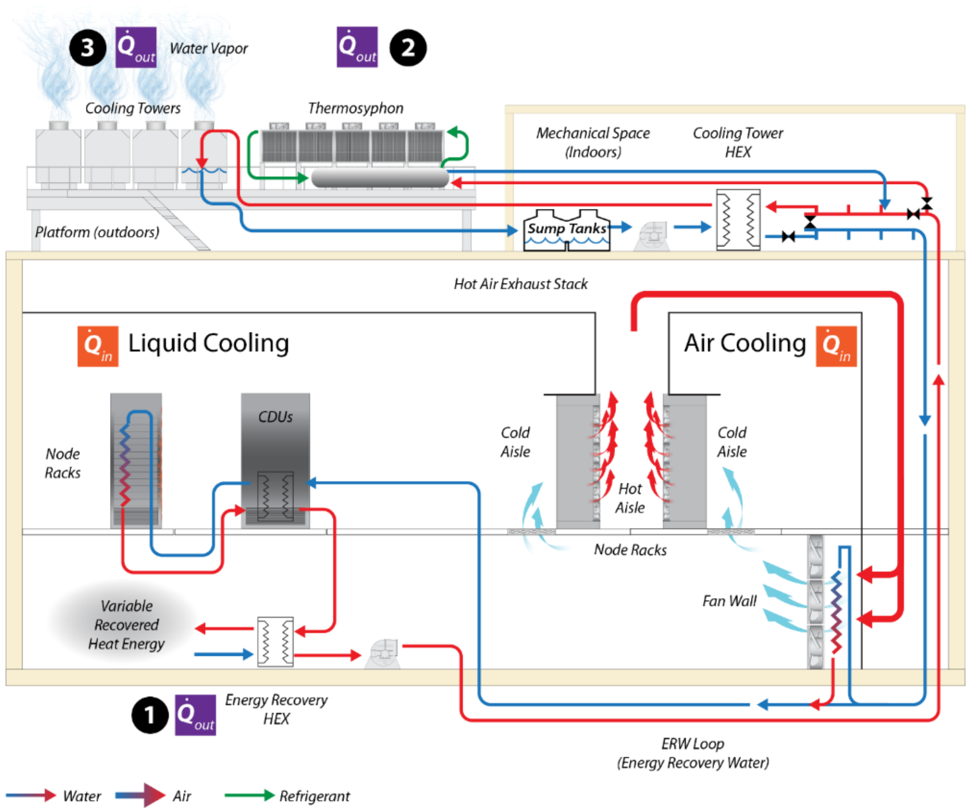

Figure 1. Cooling system schematic for the HPC Data Center located in the ESIF

Heat rejection options: (1) energy recovery/building heat, (2) TSC, (3) cooling towers

1.2 ESIF HPC Data Center Cooling System: A Brief Recap

All heat energy from the data center IT equipment is captured to the ERW closed-loop system (see Figure 1). The three heat-rejection options for this IT load operate according to the following hierarchy:

1. When possible, heat energy from the energy recovery loop is transferred through the energy recovery heat exchanger to the building process hot water loop to help heat the building or campus (shown in the bottom left of the schematic).
2. After reuse potential is exhausted, warm ERW flows to the fourth-floor mechanical space (upper right of schematic). When temperatures permit, heat is dissipated through the TSC.
3. The remaining heat is transferred from the ERW loop to a tower water open loop via the cooling tower heat exchanger.

The Johnson Controls BlueStream system coordinates the operation for optimum water and operating cost efficiency—using wet cooling when it is hot and dry cooling when it is not. The unique design and controls of the TSC allow it to safely cool the primary cooling loop water and prevent freeze-ups even during subfreezing ambient temperature conditions.

1.3 Data Center Metrics: PUE, ERE, and WUE

The Green Grid developed the WUE metric to address water usage in data centers (Patterson 2011).[2] Tracking the power usage effectiveness (PUE), energy reuse effectiveness (ERE), and WUE allows a data center to determine the efficiency of its operation in terms of energy and water usage.

WUE is a site-based metric of the total water usage for the data center water, including evaporated water for cooling, such as in a cooling tower and humidification. At the ESIF HPC Data Center, the largest water usage is in the cooling towers. The units of WUE are L/kWh.

$$WUE = \frac{Annual\ site\ water\ usage}{IT\ energy}$$

The Green Grid also developed WUE_{SOURCE}, which is a source-based metric that includes the water used on-site and the water used off-site in the production of the energy used on-site. Typically, this adds the water used for electrical energy generation at the power plant to the water used on-site. The units of WUE_{SOURCE} are also L/kWh.

$$WUE_{SOURCE} = \frac{Annual\ site\ water\ usage + Annual\ source\ energy\ water\ usage}{IT\ energy}$$

If a site reduces its water usage but does so with an increase in energy usage, then WUE_{SOURCE} should be used to consider the trade-offs between design changes; however, if a reduction in water usage on-site is accomplished without an increase in energy usage, then WUE is appropriate to make comparisons, and it is more easily measured.

[2] See https://www.thegreengrid.org/en/resources/library-and-tools/238-Water-Usage-Effectiveness-%28WUE%29%3A-A-Green-Grid-Data-Center-Sustainability-Metric-

2 Results

This section provides:

1. Sample data of HPC Data Center load and heat sinks
2. Data center metrics for first year of TSC operation
3. Cumulative saving results from 2 years of TSC operation
4. Additional notes regarding TSC performance.

2.1 Heat Rejection Options: Sample Data

Figure 2 shows the HPC Data Center load and heat sinks for 2 days of operation in October 2016. The bottom graph shows the outdoor dry bulb temperature, which varied between 4.4°C–16.7°C (40°F–62°F). The dashed horizontal black line marks a transition point for NREL's particular system conditions, wherein the TSC is programmed to operate more aggressively when the dry bulb temperature drops to lower than 9.4°C (49°F). Referring to the top graph in Figure 2, the purple line shows the IT equipment load, which varied between 900–950 kW (3.07–3.24 million Btu/h). The red line shows the amount of waste heat from the IT equipment that was used to heat the building. The difference between these two lines is the amount that needs to be rejected to the atmosphere. Originally this was handled by only the cooling towers, but now it is shared by the thermosyphon. The heat rejected by thermosyphon is shown in green, and it rejected the most during these 2 days. The heat rejected by the cooling towers is shown in blue. This graph nicely shows the interaction among the ESIF's HPC Data Center heat-rejection options.

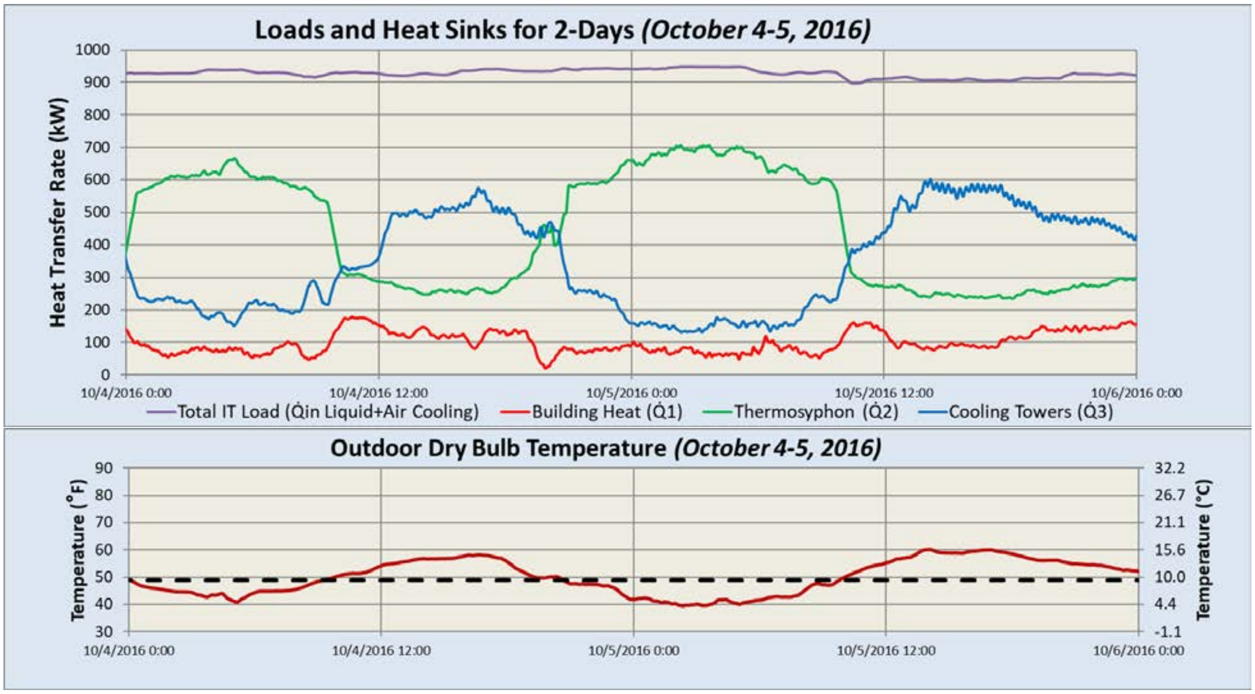

Figure 2. Sample data showing typical loads and heat sinks

2.2 First Year of Thermosyphon Operation: Data Center Metrics

The section provides the data center metrics for the first full year of thermosyphon operation: from September 1, 2016, through August 31, 2017. The hourly average IT load was 888 kW (3.03 million Btu/h), and the IT energy for the year was 7,776 MWh (26,533 million Btu). The annual PUE and ERE metrics were as follows:

$$PUE = \frac{Facility\ energy\ +\ IT\ energy}{IT\ energy} = \mathbf{1.034}$$

$$ERE = \frac{Facility\ energy\ +\ IT\ energy\ -\ Reuse\ energy}{IT\ energy} = \mathbf{0.929}$$

The graph in Figure 3 shows the PUE values 1 year before the thermosyphon was installed, followed by the first year of the TSC in operation. The PUE is particularly useful for checking operational changes at a same site throughout time. The extra pump energy required to flow water through the ERW loop to the TSC and the TSC fan energy usage of the unit is accounted for in the PUE calculation. Although some minor changes were made during this time frame (e.g., the addition of some IT equipment), a review of the monthly mean PUE values does not show any negative impacts on the data center’s energy efficiency when adding the TSC to save water on-site. With that in mind, the authors think that the WUE metric alone is appropriate to make comparisons on water savings.

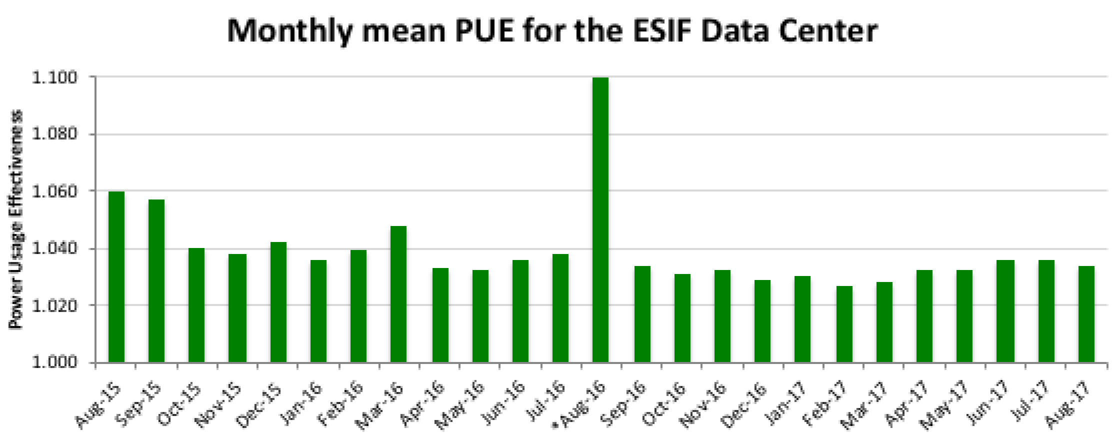

Figure 3. Monthly mean PUE for the ESIF HPC Data Center

August 16 is when TSC became operational. Figure shows PUE for months 1 year prior and 1 year after installation. (The PUE jump for August 16 was caused by a planned outage for an unrelated project).

To review water usage, Figure 4 shows the site water usage along with estimated water savings per month. Actual site water usage by the cooling towers is shown in blue. Estimated water savings from energy reuse is shown in red. Water savings from operating the TSC is shown in green. The graph on left in Figure 4 shows the seasonal relationship between the cooling towers and the TSC. From November through April of the first year, the TSC rejected the most heat. The pie chart on the right shows the annual heat-rejection percentages: building heat reuse accounted for 10.5%, the TSC for 42.5%, and the cooling towers for 47%.

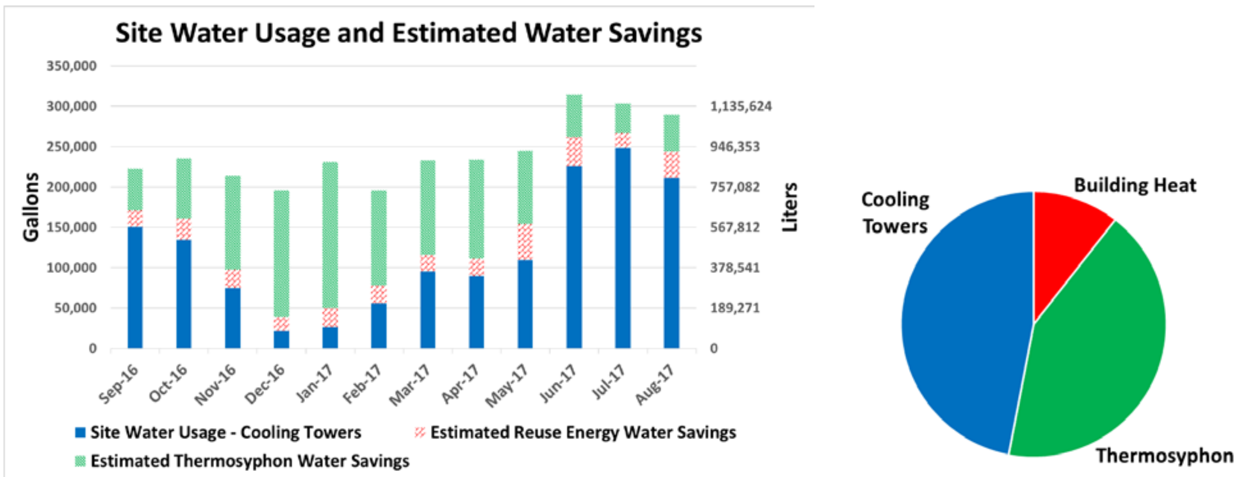

Figure 4. First year of TSC operation site water usage and estimated water savings

During the first year of the TSC operation, on-site WUE was:

$$WUE = \frac{Annual\ site\ water\ usage}{IT\ energy} = \mathbf{0.7\ L/kWh}$$

If the ESIF HPC Data Center had used only cooling towers, then the WUE would have been 1.42 L/kWh. If it had continued using only heat-recovery and cooling towers, then the WUE would have been 1.27 L/kWh. Keeping in mind that energy recovery occurs first in this system, the average entering water temperature to the thermosyphon was 28.9°C (84°F), and the individual monthly averages were in this range as well (plus-minus 2°F). For more insight into WUE_{SOURCE} and how renewables such as solar photovoltaic (PV) impact overall water usage, see Section 3.2.3.

2.3 Two Years of Thermosyphon Operation: Cumulative Savings

The graph in Figure 5 shows the cumulative water and cost savings from the first 2 years of thermosyphon operation, which was reached on August 2, 2018. The blue line and scale on the left show the gallons of cooling tower water saved, which was 7,950 m^3 (2.10 million gal). For reference, an Olympic-size swimming pool holds 2.5 million L (660,000 gal) of water—so the water saved equals 3.2 Olympic-size pools. Starting in mid-November in Year 1, gallons saved and operational savings began to significantly increase because cooler weather set into the Denver area. The seasonal pattern can be observed in Year 2. The green line and scale on the right shows the cumulative operational savings, estimated at $5,455 (combining energy + water costs). For NREL, even though the system does save operating costs, the decision to use the TSC is primarily one of sustainability rather than one of a system economic payback to save the most water with this operation while maintaining data center energy-efficiency levels.

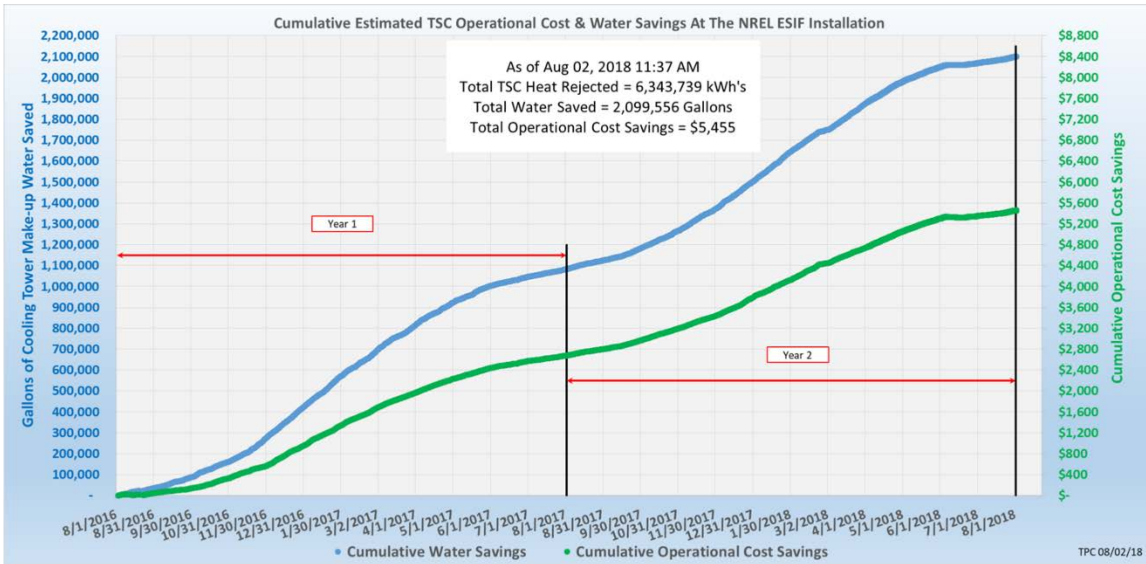

Figure 5. Cumulative site water and cost savings from first 24 months of thermosyphon operation

2.4 Performance Notes

The thermosyphon is an additive piece of technology. For most operational cases, the user needs to have sufficient cooling tower capacity to handle the entire IT load on the hottest hours of the year (when the thermosyphon cannot contribute). The upside to this is added system resiliency. Among best practices revealed by the system: NREL is now performing cooling tower preventative maintenance work on cooler days when energy reuse and the TSC can handle the entire heat rejection of the IT load. Recently, NREL avoided a data center outage for a repair on the cooling tower loop by performing repair work on a cold day.

3 Further Discussion

This section provides:

1. Information on the TSC—addressing common questions that include differences between a dry cooler, system control, economic payback, and identifying other TSC benefits
2. Details about water usage at the ESIF—ranging from water measurements, water rates, and impact of renewables on WUE_{SOURCE}
3. An update on Sandia's plans to incorporate multiple TSCs, including a range of water savings of a single TSC based on operating conditions, as well as the future contribution of multiple TSCs when a new 7-MW data center expansion is operating at max capacity.

3.1 Thermosyphon: Additional Information

A hybrid heat-rejection system optimizes the use of two cooling technologies—one wet (an open cooling tower) and one dry (a TSC unit)—in a single, integrated operating system. Typically used in conjunction with a traditional cooling tower, a TSC can reduce annual water consumption by up to 80%. The controls on the TSC allow it to operate in a highly efficient manner across a vast range of weather and load conditions. The TSC fans automatically modulate to use the most efficient combination of water and air-cooled systems in response to utility rates, ambient and system temperatures, and system loads. The system's modular design is highly scalable, with the ability to incrementally add multiple units in parallel to handle the largest cooling requirements. Within the thermosyphon cooler, refrigerant circulates naturally and efficiently through a thermosyphon process between the unit's evaporator and condenser without the need for any compressors or pumps.

The TSC can also be used as an efficient dry water-side economizer or deployed as a stand-alone dry cooler.

3.1.1 TSC versus Dry Cooler

The TSC is a dry cooler specifically designed to efficiently operate in an open cooling tower loop in subfreezing ambient conditions. In the TSC, compared to a typical dry cooler:

- The water is confined to the short single-pass tubes in the evaporator bundle. Cleaning, if necessary, can be accomplished by removing the end bells of the evaporator, much like cleaning the tube bundle of a chiller condenser. Dry coolers typically have long multipass circuits to increase water flow and water-side heat transfer efficiency, making them difficult to internally access and clean.
- The evaporator bundle can be designed in either a 1- or 2-pass configuration and is designed for very low pressure drop to minimally impact the annual system pumping energy. The water pressure drop in dry coolers is typically much higher because of their increased flow per circuit and longer circuit paths.
- The controls on the TSC continuously adjust the speed of the TSC fans under all operating and ambient conditions to ensure that the economic value of the water being saved always exceeds the economic value of the extra fan energy consumed by the TSC. Dry cooler fan systems are typically not controlled to minimize system operational costs.

- Under cold ambient conditions when there is a loss of heat load, the flow in the refrigeration circuit is stopped to greatly minimize the heat loss from the evaporator bundle and protect the water in the evaporator tubes from freezing. This permits the efficient use of the primary cooling loop water directly in the TSC evaporator. There is no need to use glycol in the main cooling loop. Glycol in this loop increases the heat transfer fluid costs, can pose an environmental hazard, and typically reduces the heat transfer efficiency of all associated heat exchangers in the cooling loop. The use of water in a dry fluid cooler in areas subjected to subfreezing ambient conditions is dangerous. Any loss of heat load during these subfreezing conditions can quickly lead to freezing and subsequent bursting of the tubes.

3.1.2 System Control

The controls on the TSC allow the system to continuously modulate seamlessly between the optimum mix of dry and wet cooling as weather and system conditions change throughout the year. The TSC fan control algorithms and sensors continuously monitor the system and ambient conditions to ensure that the economic value of the water saved by the TSC outweighs the economic value of the additional fan energy consumed by the TSC fans. To accomplish this, the TSC control algorithms continuously monitor two key inputs:

1. The magnitude of the thermal driving force as represented by the temperature difference between the entering hot water temperature and the local dry bulb temperature
2. The ratio between the water and energy costs as represented by the local water-to-energy cost equivalence ratio. This number is calculated by taking the fully burdened cost of water ($/1,000 gal) divided by the cost of electrical energy ($/kWh). It represents the number of kilowatt hours of electrical energy that have the same economic value as 1,000 gal of water.

The net result is that relative increases in either the magnitude of the thermal driving force or the water-to-energy cost-equivalence ratio leads to increases in the TSC fan speeds and the amount of dry cooling and decreases in the relative magnitude of these values lead to slowing of the TSC fan speeds.

3.1.3 Economic Payback

For systems with continuous 24/7 loads, the two biggest drivers for economic payback are:

1. High fully burdened water costs (cost of water + sewer charges + chemical treatment)
2. Large differentials between the average annual entering hot water temperature and average annual dry bulb temperatures.

Johnson Controls has a simple economic payback tool to understand the estimated system payback under various scenarios.

Additionally, if a site is concerned about its water footprint or has concerns about the continual availability of water to operate its cooling systems, the use of a hybrid cooling system can greatly reduce these concerns and increase the facility's operational resiliency.

Data centers with 24/7 loads and increasing loop temperature levels represent an ideal application for hybrid cooling systems. Other applications that could benefit from this hybrid cooling approach include:

- Condenser water loops on thermoelectric power plants
- Heat-rejection loops associated with many industrial and manufacturing processes
- The year-round base load on a large chiller plant.

3.1.4 Additional Hybrid System Operational Benefits

Not only can hybrid cooling systems save significant amounts of water while simultaneously reducing system utility expenses, but they can also provide the following benefits:

- Reduction of cooling tower plume: During colder weather, visible plume is caused by the moisture in hot humid air exiting the cooling tower and condensing in the colder ambient air, leading to a dense localized fog referred to as a plume. As more of the heat load is transferred to the TSC, less heat and moisture needs to be rejected by the cooling tower, and this reduces the plume. Depending on the number of TSC units installed, it might be possible for the TSCs to handle the entire thermal load during colder ambient conditions, and this would totally eliminate the cooling tower plume.
- Elimination of cooling tower icing issues: Again, depending on the number of TSC units installed, it might be possible to have the TSC units handle the entire thermal load at dry bulb temperatures above the point at which cooling tower icing might be an issue. In this case, water flow over the towers can be stopped, and problems associated with cooling tower icing can be eliminated.
- Increased heat-rejection system resiliency: The TSC units represent additive cooling capacity to the base cooling tower system. If problems occur with the base cooling tower system, this could lead to a data center outage. Depending on the ambient dry bulb conditions, partial or full heat-rejection capacity could be maintained using only the TSCs in operation. Having the additional TSC heat-rejection capacity also provides additional maintenance flexibility by allowing cooling tower cells to be shut down for routine maintenance while still providing full system heat-rejection capacity, allowing the data center to continue to operate at full capacity.

3.2 ESIF Water Information

3.2.1 ESIF Cooling Tower Water Measurements

The schematic in Figure 6 illustrates the water flow and water metering system of the HPC Data Center water cooling system. City water fills the water softener tanks, which are occasionally regenerated to the sewer through Meter 2. The majority of the softened water is mixed with additional city water and fills the two sump tanks. A side stream sand filter cleans the water and is flushed with city water to the sewer a couple of times a month. The water in the sump tanks is pumped up to the cooling towers. Once the water makes it to the cooling towers, it either evaporates, is passed back into the two sump tanks, or is part of the blow down to the sewer. The total water consumption is calculated by summing meters 1 and 2 with the estimated blow down from the sand filter. Meter 3 is used to calculate cycles of concentration.

Measurements were recorded regularly for each of the meters by two separate entities to verify water consumption and savings. Taking manual readings is sufficient for establishing WUE; however, it is recommended that digital water meters be installed for easier tracking.

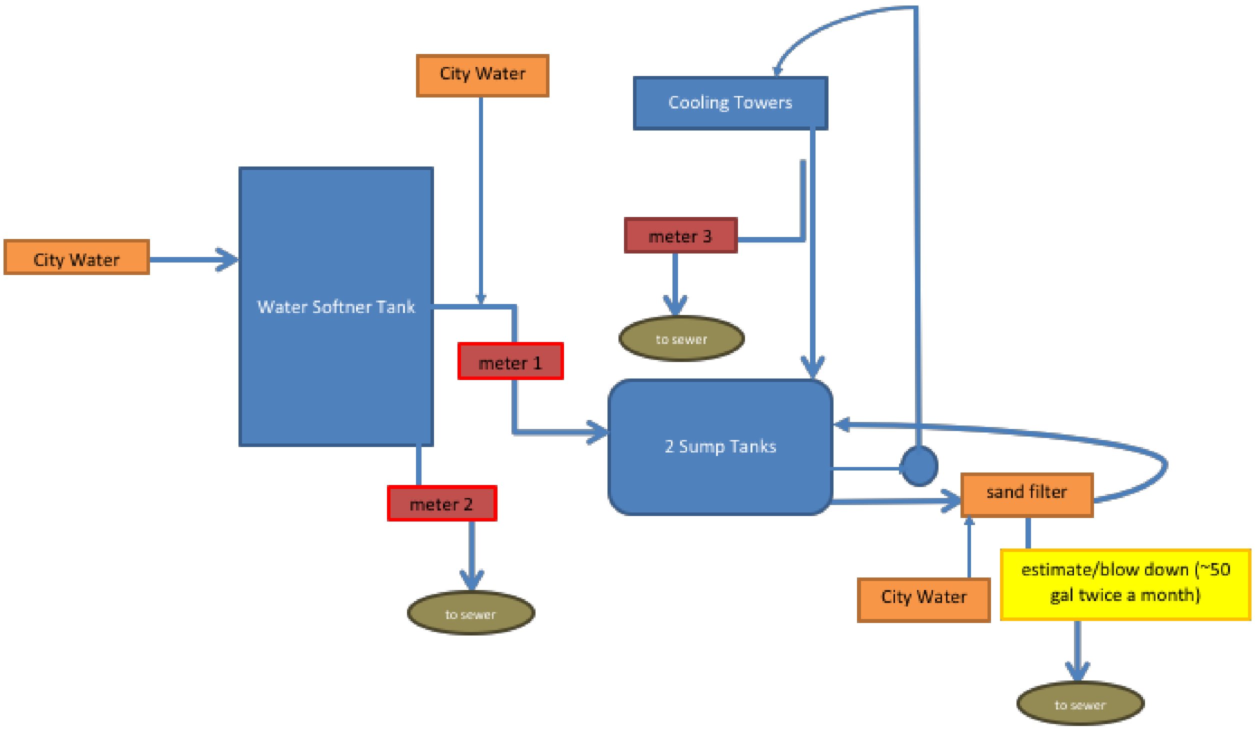

Figure 6. Water meter schematic

Detailed schematic of the water flow and meter placement of the HPC Data Center cooling tower loop

NREL uses a Green Water Treatment program which is a hybrid approach taken with split stream softening in combination with dosing of chemistry. Cycles of concentration are monitored though total dissolved solids (cooling tower TDS/make up TDS). Using this approach, the cycles of concentration (COC) for the cooling tower loop was 12.8 during the first year of TSC operation.

Note that the reported water use in this paper does not include the water used by a Makeup Air Unit (MAU) that maintains a minimum humidification level for the HPC Data Center because it is not metered.

3.2.2 ESIF Water Rates

In addition to water savings, the thermosyphon project results in water cost savings. Overall, NREL estimates to have saved $5,455 during the first 2 years of performance. It is important to note that water costs vary across the country. NREL had water costs that averaged $5.77 per kgal in Fiscal Year 2016, which appear to be toward the higher end of water costs based on water rates across the country.[3] (DOE 2017; American Water Works Association and Raftelis Financial Consultants, Inc. 2017); however, NREL pays a fixed monthly cost for its wastewater

[3] See https://www.energy.gov/sites/prod/files/2017/10/f38/water_wastewater_escalation_rate_study.pdf

based on a tap fee. This cost does not vary based on water usage, so NREL did not see any reductions in sewer costs from this project.

3.2.3 WUE_{SOURCE} and the Impact of Renewables

The source energy water usage is based on the facility's total energy usage. The energy water intensity factor (EWIF) is based on the water used to produce the energy at the power plant. EWIF values vary greatly by region and electrical energy generation source. The source for local EWIF values referenced in Patterson (2011) was the NREL technical report on *Consumptive Water Use for U.S. Power Production* (Torcellini, Long, and Judkoff 2003). From that report, the EWIF is 4.542 L/kWh for Colorado.

The total facility energy is the numerator in PUE. Multiplying the PUE and the EWIF determines the water us at the power plant in L/kWh.

$$WUE_{SOURCE} = \frac{Annual\ Site\ Water\ Usage}{IT\ Energy} + (EWIF \times PUE)$$

The WUE_{SOURCE} would have been 5.4 L/kWh using an EWIF 4.542 L/kWh for Colorado for the first year of TSC operation—before taking into account a PV system NREL has installed.

NREL has a 720-kW PV system dedicated to the ESIF that produced 1,180,133 kWh during the first year of TSC operation. The HPC Data Center used 71.7% of the energy at the ESIF during that time, so PV energy credit to HPC is 846,350 kWh annual. The total HPC energy consumption during the same period was 8,037,500 kWh, so the PV produced 10.5% of the annual energy usage. PV has zero water usage; however, it does not factor into the WUE directly. PV energy does reduce the WUE_{SOURCE} because 10.5% less energy was used from the grid, which results in a blended EWIF of 4.065 for this first year. Taking credit for the PV energy production, the WUE_{SOURCE} is reduced to 4.9 L/kWh.

3.3 Sandia Data Center Expansion: TSC Plans

In the near term, the new thermosyphon being deployed at the ESIF is of interest to data center collaborators from Sandia. The climate at the laboratory in New Mexico is similar to that of the laboratory in Colorado. Sandia is building a new 7-MW to 14-MW (23.88 million Btu/h to 47.77 million Btu/h) data center expansion to house liquid-cooled HPC equipment. On Day 1, they plan to have a 3-MW (10.24 million Btu/h) IT load with one installed thermosyphon becoming operational in August 2018. Annual modeling results are showing that a single thermosyphon should save 16,300 m^3 (4.3 million gal) of water for their operating conditions and would save more than $13,000 in operational costs. A notable difference from NREL's system: Sandia will send significantly warmer water to the thermosyphon unit, 40.6°C (105°F), compared to the 28.9°C (84°F) water that NREL sends to the thermosyphon unit after energy recovery. Depending on the results, Sandia is considering a large-scale system not only for data center use but also sitewide around the lab.

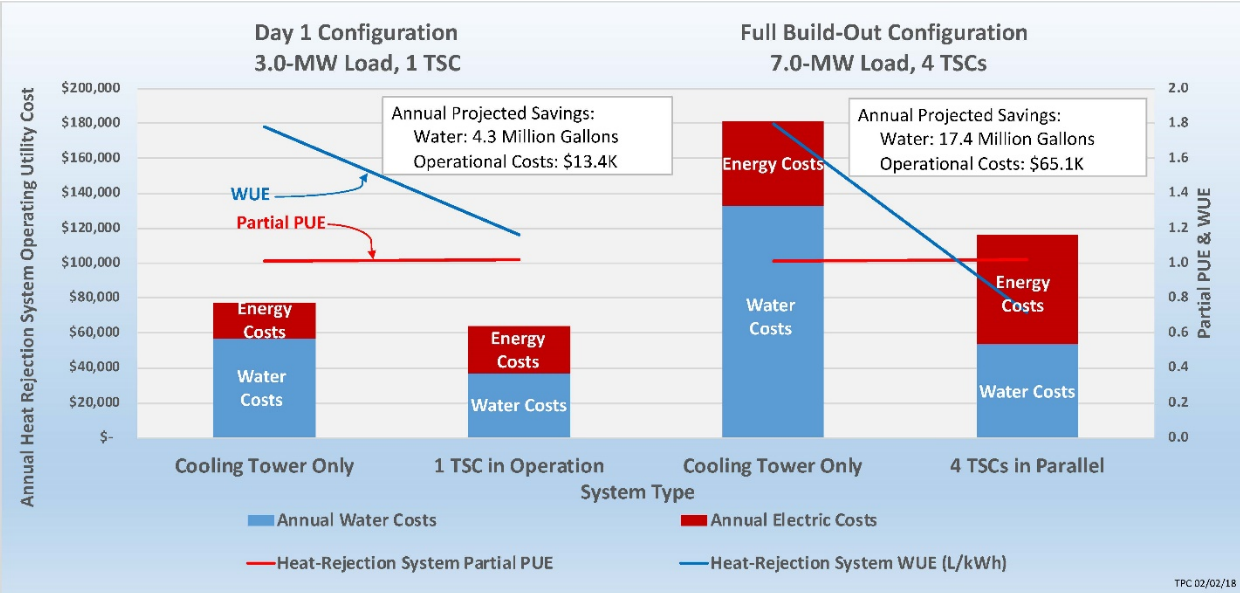

Figure 7. Sandia New Data Center Expansion – Projected Savings with 1 to 4 TSC's in Operation

Such savings and the advanced capabilities of the thermosyphon will gain increasing prominence as the world moves toward exascale computers that will provide 1,000 times the performance capability of today's supercomputers. The expected high energy consumption of an exascale computer will require both energy-smart and water-smart cooling solutions.

4 Conclusion

NREL considered the amount of water used by the HPC Data Center cooling towers to be counter to the laboratory's sustainability mission, so the lab decided to act as a project convener and offered the HPC Data Center to Johnson Controls to test its TSC technology. NREL and Sandia, long-time collaborators on HPC innovation, provided expertise, and together the project partners successfully installed and integrated the TSC into the ESIF ERW cooling system. The TSC system performed as expected based on modeling work by Johnson Controls.

In combination with the existing cooling towers, the TSC forms an extremely water- and cost-efficient cooling system. In its first year of operation, on-site WUE was 0.70 L/kWh. In comparison, the WUE would be 1.27 L/kWh if NREL had continued using only heat-recovery and cooling towers. The cumulative water and cost savings from the first 2 years of TSC operation, which was reached on August 2, 2018, was 7,950 m^3 (2.10 million gal) of water and $5,455 (combining energy plus water costs).

This on-site water savings was accomplished without negatively impacting the energy-efficient operation of the HPC Data Center. The TSC has operated with a high degree of reliability with no service required since installation. Data center uptime is crucial, and the TSC has added resiliency to the ESIF cooling system.

Tracking the PUE, ERE, and WUE proved useful in monitoring and evaluating this project. The TSC will continue to operate at NREL. The TSC system technology has the potential for application in data centers around the world, and it is currently being implemented by Sandia.

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