EXECUTIVE SUMMARY

Demonstration of a High-Efficiency Evaporative Cooler for Improved Energy Efficiency in DoD Data Centers

ESTCP Project EW-201348

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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BNL	Brookhaven National Laboratory
COP	coefficient of performance
CRAH	computer-room air handler
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
HVAC	heating, ventilation, and air conditioning
IT	information technology
PFC	Polymer Fluid Cooler

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

This report provides a description of a demonstration program under the United States (US) Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) aimed at reducing energy use for data center cooling. The technology planned for this demonstration involves hybrid evaporative cooling. Water is cooled in outdoor towers that can operate either in a wet or dry mode (*hybrid*). The cooled water is directed indoors to existing air handlers. Relative to mechanical water chillers this approach of using “free” ambient cooling offers the potential for up to 75% energy-use reduction. The demonstration was planned for the Port Hueneme Naval Base in Ventura County, California. Prior to the installation of the planed equipment, the decision was made not to proceed with the actual hardware installation phase of the project. This report documents the planning and analysis work that was completed prior to the installation. Detailed design plans and construction specifications for the installation have been prepared and are submitted as an annex to this report.

Currently most data center equipment is cooled with standard vapor-compression heating, ventilation, and air conditioning (HVAC) equipment. Conditioned air at 55°F is supplied to computer equipment, which is then returned at 75–80°F, where it is cooled and re-delivered. Consequently, the cooling system is the largest source of inefficacy due to the limitations of the standard refrigeration cycle. Practices such as free cooling, direct-to-chip cooling, and evaporative cooling are being explored to help reduce the energy burden associated with cooling systems. A fortuitous development in modern computing systems is their ability to operate at higher ambient conditions (80–85ºF). In fact, in 2008, ASHRAE increased the maximum recommended supply temperature for data centers from 77°F to 80.6 °F. Higher supply temperatures allow the cooling requirements to be reduced and increase the coefficient of performance (COP) of cooling systems. Perhaps most importantly, higher supply temperatures allow the use of alternative refrigeration strategies, such as evaporative cooling systems, which consume *significantly* less energy than traditional refrigerant-based HVAC systems. This trend of increasing electronics/IT operating temperatures is expected to continue.

During this project, two specific evaporative cooler products were considered for the planned demonstration. The first of these is a Polymer Fluid Cooler (PFC), which includes a novel outdoor heat exchanger with small diameter polymer tubes. The second is a Hybrid Cooler with a design optimized to take advantage of sensible (non-evaporative) cooling to the greatest degree possible, minimizing annual water use. At the start of the project the PFC was the planned cooler and much of the installation design work was developed around this unit. Late in 2016, the manufacturer announced that they had made a decision to drop the PFC product from their portfolio and they withdrew from the project. At this point and following a review of the market, a project decision was made to convert the design to the Hybrid Cooler product.

In the PFC system, circulating water enters the cooler and passes through the inside of the tubes in the polymer heat exchanger. Water from a separate source is sprayed over the heat exchanger while outside air is drawn upwards using a variable-speed draft fan. As the spray water evaporates, it cools the fluid in the heat exchanger. Analysis and testing of the PFC system shows that up to 75% of the difference between dry- and wet-bulb temperature can be achieved with a well-designed PFC system. This enables such a system to meet ASHRAE air supply requirements with significant energy savings. To run the system in dry mode, the spray water is simply turned off, and the water is cooled by heat exchange with the lower-temperature ambient, saving water and reducing energy consumption.

The Hybrid Cooler uses metal heat exchangers to cool the data center circulating water by exchange with outside air. Relative to the PFC this unit is much taller and heavier. This unit has two heat exchangers with circulating water flow in series. The top heat exchanger operates only in a dry mode and the bottom heat exchanger can operate either wet or dry. The system was designed to have a high dry-bulb switchover temperature above which the water sprays on the lower heat exchanger would need to be used. With this unit, during dry mode operation, the spray pump is simply turned off. In wet mode, a portion of the cooling load is met with the top heat exchanger in a dry mode, reducing water consumption.

2.0 OBJECTIVES

Generally, the objectives of the planned demonstration were to show that: the evaporative cooling system can be integrated with an existing mechanical chiller cooling system; the system can meet the cooling demand of the data center for nearly 100% of the year; and the energy savings and water use targets can be met. Highlights of the project Performance Objectives are listed in Table ES-0-1, below.

Table ES-0-1. Highlights of Project Performance Objectives

Performance Objective	Success Criterion
Ability of the hybrid evaporative cooler to meet the data center cooling load	Required operation of the main mechanical chillers less than 100 hours per year.
Cooling Energy Savings	Minimum of 50% energy reduction, annual average.
Data Center Peak Load	75% Reduction in peak load during hot conditions in the late summer and fall.
Water Usage	Annual water consumption not greater than that of a conventional, gas-fired power plant with a cooling tower.
Temperature	System capable of control within acceptable range. Current target 81°F.

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3.0 TECHNICAL APPROACH

The PFC first planned for use in this project has a series of horizontal, small diameter polymer tubes with building circulating water flowing through in parallel. Water from a separate source is sprayed over the heat exchanger while outside air is drawn upwards using a variable-speed draft fan. As the spray water evaporates, it cools the fluid in the heat exchanger. Up to 75% of the difference between dry- and wet-bulb temperature can be achieved with the PFC system. The use of a polymer—rather than metal—heat exchanger minimizes issues with fouling and water contamination, which simplifies water treatment and minimizes maintenance. The layout of the PFC is horizontal, and the overall height is short. The outside air makes one pass through the polymer tube bundle. To run the system in dry mode, the spray water is simply turned off, and the water is cooled by heat exchange with the lower-temperature ambient, saving water and reducing energy consumption.

Relative to the PFC unit, the Hybrid unit, selected after the PFC was withdrawn by the manufacturer, uses metal heat exchangers to cool the data center circulating water by exchange with outside air. The Hybrid unit, which has two stacked heat exchangers, is taller than the PFC unit and it is considerably heavier. The top heat exchanger operates only in a dry mode and the bottom heat exchanger can operate either wet or dry. The system was designed to have a high dry-bulb switchover temperature above which the water sprays on the lower heat exchanger would need to be used.

With the PFC unit, it was originally planned to install a total of four horizontal modules which provides a total nominal capacity of 100 tons. The current cooling load at the NITC data center is on the order of 45 tons, and the additional capacity was planned for potential future expansion and to allow for operation in a dry mode for as much of the year as possible. In discussions with the manufacturer of the Hybrid unit, however, it became clear that the cost for their unit at the 100-ton capacity would be much greater than the originally proposed price for the PFC unit. After considerable discussion, the project team decided to evaluate a system with a capacity closer to the current actual cooling load at the facility. Table ES-0-2, below, provides a comparison of technical features for the Hybrid unit selected with a two-module PFC unit which would provide a similar capacity. Costs are estimates only for the purchase of the systems, not including installation.

Table ES-0-2. Comparison of Features of the PFC (sized at 50 tons capacity) and the Proposed Hybrid Model.

Characteristic	Unit	PFC	Hybrid
Weight (dry)	*lbs*	3,377	11,712
Weight (wet)	*lbs*	4,633	15,572
Height	*ft*	7	16
Width	*ft*	8	9
Length	*ft*	15	9
Fan Power	*kW*	6	15
Pump Power	*kW*	1	2
Total Power	*kW*	7	16
Nominal Cooling Capacity	*Btu/hr*	660,000	756,000
Nominal Cooling Capacity	*Tons*	55	63
Estimated Capital Cost	*$*	75,000	125,800

A very simple plan for the integration of the Hybrid evaporative cooler with the data center chilled water system is illustrated in Figure ES-0-1. With this arrangement, chilled water can be delivered to the indoor loop and computer-room air handler (CRAH) units in one of three ways:

1. Using just the existing mechanical chillers with the hybrid evaporative cooler bypassed.
2. Using just the hybrid evaporative chiller with the chilled water circulating through the heat exchangers on the idle mechanical chillers.
3. Using the hybrid evaporative chiller as a precooler in series with the operating mechanical chillers.

With mechanical chillers, the supply water temperature to the indoor CRAH units is 44°F and nominal return to the chillers is 54°F. Chiller flow at nominal maximum capacity is 179 gpm. Nominal flow of each pump is 126 gpm. With the hybrid evaporative coolers, the supply temperature is 70-75°F. The control for the variable speed drives can be adjusted to yield a target return temperature from the data center.

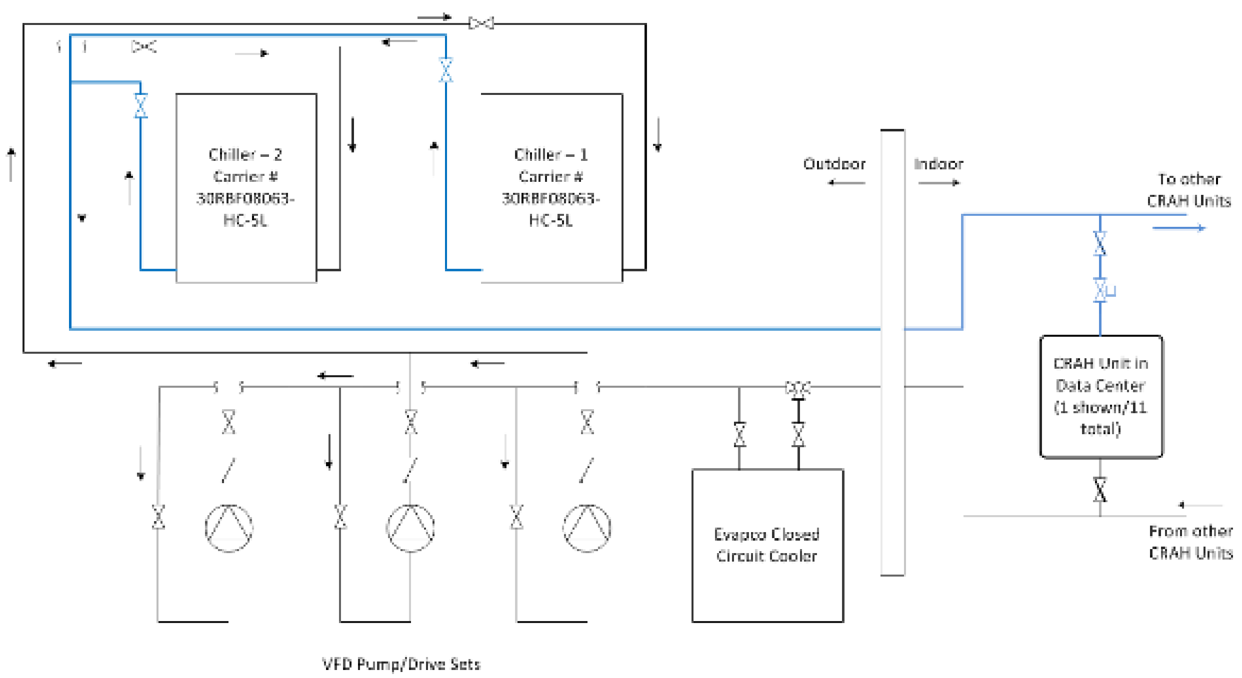

Figure ES-0-1. Basic Illustration of the Integration of the Hybrid Evaporative Cooler with the Existing Chilled Water Loop.

As an alternative to the planned design, the use of thermal storage to supplement the performance of a hybrid evaporative cooler has also been added. Thermal storage could be cooled to a low temperature either by the evaporative cooler at night or by the mechanical chiller. The mechanical chiller could be the large chillers already in place or a small auxiliary chiller designed only to pre-cool the thermal storage in advance of ambient weather conditions where the evaporative cooler is not likely to be able to meet the data center load. If the thermal storage is cooled by a small auxiliary chiller or by the evaporative cooler at night (for example), the needed for the large mechanical chillers could be completely eliminated.

Also evaluated as an alternative is a direct-to-chip cooling scheme. At the Port Hueneme data center demonstration site, the servers are all air cooled. In parallel with this project, an ESTCP project led by Asetek has been ongoing involving direct-to-chip data center liquid cooling.

Termed *RackCDU*, the Asetek system captures heat from the hottest part of the rack with direct liquid cooling. During this project a conceptual study was done of the potential for integration of the Asetek system with a hybrid evaporative fluid cooler. This small study was done specifically for the PFC included in the first part of the project.

The primary benefit of Asetek's direct-to-chip liquid-cooling is that it provides free cooling for data centers in any location where 105 ºF water can be consistently supplied year-round. The ideal choice for heat-rejection in this system is a *dry cooler*, because of its simple, closed-loop plumbing, low power consumption, and zero water use. While a large fraction of DoD data centers around the world have a maximum dry-bulb temperature that will allow the use of a dry-cooler for *RackCDU* year-round, many more do not. For these data centers, one of two options generally exist: 1) integrate a mixing system that taps into the facility's chilled water supply to reduce the *RackCDU* water temperature on those days when the dry-bulb temperature is too high; or 2) use a traditional wet cooling tower to provide heat-rejection.

A hybrid evaporative cooler is seen as an ideal solution to combine with *RackCDU*. During days when the dry-bulb temperature is low enough for a dry-cooler, the system runs in dry mode, offering a zero-water-consumption solution. On those days when the dry-bulb temperature is too high, the unit adds evaporative cooling to achieve the target supply water temperature. While this approach does consume some water, the total water consumption is expected to be dramatically less than a traditional cooling tower, which consumes water at all times. Even in locations where dry-coolers are a viable option, an evaporative cooling system will reduce the required footprint of the heat-rejection system, which must always be sized for the hottest day. At the Port Hueneme site, the use of direct-to-chip cooling would eliminate the need for the backup mechanical chillers.

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4.0 PERFORMANCE ASSESSMENT

An analysis was done of the expected energy performance of the two evaporative cooler concepts evaluated in this project and energy savings relative to the baseline mechanical chiller. An analysis of the annual hours for which the hybrid evaporative cooler concept can run in a dry mode and the annual hours for which the hybrid evaporative cooler concept will not be able to meet the cooling load of the data center was also completed.

For the current mechanical chillers (baseline case) the total annual energy use is estimated at 291,883 kWh. Using $0.15/kWh, the total annual cost of power is $43,782.

With the PFC unit the projected annual electrical power use would be 61,320 kWh for a reduction of 79% relative to the mechanical chillers. Using $0.15/kWh, the total annual cost of power is $9,198. The total annual water consumption is estimated to be 1,305,309 gallons per year. This unit is projected to meet the cooling demand of the data center for all but 2 hours of the year.

With the Hybrid evaporative cooler, the annual power consumption is projected to be 143,664 kWh. Using $0.15/kWh, the total annual cost of power is $21,549. This is a reduction of 51% relative to the mechanical chiller baseline. This nominal performance point is based on a wet- bulb temperature of 65°F, which is exceeded for 111 hours annually in Port Hueneme, based on Typical Meteorological Year data. Annual water consumption is projected to be 403,920 gallons per year.

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5.0 PLAN FOR TESTING FOR CONFIRMATION OF PERFORMANCE

The following basic test approach has been developed to achieve the objectives stated above.

Fundamental Problem: The use of conventional mechanical cooling equipment to reject data center server-generated heat leads to high electrical energy use. Replacement of this type of cooling equipment with ambient evaporative coolers offers the potential to achieve at least 50% electrical energy savings.

Demonstration Question: Can an evaporative cooler achieve this potential energy savings while meeting the cooling needs of the data center?

Once the hybrid evaporative cooler and sensing/ data acquisition have been installed and verified, the following test approach has been developed to assess the energy savings by using the hybrid evaporative cooler over traditional mechanical chillers.

- *Test Protocol 1 (primary)*: The data center room temperature would be set at a fixed, elevated temperature of 82-85°F. The actual target setpoint would be finalized, based on the initial commissioning. Every two weeks, the hybrid evaporative cooler and the traditional chiller(s) would be alternated to maintain the data center at 85°F. When the chiller is running, the hybrid evaporative cooler would be bypassed completely. Similarly, the chillers would be offline when the hybrid evaporative cooler is providing cooling (but made available if the hybrid evaporative cooler cannot satisfy the load). Local weather conditions would be monitored during this time to account for weather variations during the tests. The total test duration would run for a period of at least several months, or ideally one year, to assess the energy savings as a function of ambient conditions and season.
- *Test Protocol 2*: A second test option is to again alternate between the hybrid evaporative cooler and chiller(s) every two weeks; however in this case, the data center ambient temperature would be elevated at, say, 85°F, for the hybrid evaporative cooler but then reduced to a more typical data center temperature of, say, 72°F when the chiller is engaged. This would give a more realistic estimate of the energy savings for an existing data center run at a typical room temperature of 72°F that is replaced by the hybrid evaporative cooler running at an elevated temperature. Data collection would be identical as in the previous test. Note that the transition time from high to low temperature and back again would need to be determined in coordination with Port Hueneme personnel. Also, although data would be collected during the transition periods, the energy comparisons would only use the steady-state values for the ambient temperature to establish a fair comparison.
- *Test Protocol 3*: A third possible test protocol would be a hybrid approach in which an intermediate interior ambient temperature is set, to 77 or 80°F, that the hybrid evaporative cooler could not maintain completely by itself. The chiller would thus run; however, the hybrid evaporative cooler would be used to precool the returning chiller water. Results from this test configuration would be useful for climates that are only moderately favorable for an evaporative cooler but in which some benefit however from a hybrid evaporative cooler could still be derived, even if it did not carry the entire load the data center completely by itself.

As noted above, a decision was made not to proceed with the installation of the equipment and on-site validation of the projected performance.

6.0 SITE INTEGRATION ISSUES

In planning the demonstration of the evaporative cooler at the Port Hueneme site, in discussion with technical staff at the data center, some concerns were raised about raising the data center temperature to 80-85°F needed to achieve the greatest level of energy savings. While these concerns were unique to this data center, other data centers considering such an energy efficiency conversion may face related concerns.

Operations Center Temperature: The NITC data center has an operations center which is manned 24 hours daily. One of the 11 indoor CRAH units provides cooling to this operations center. With the hybrid evaporative cooler in operation, the circulating chilled water will be at 70-75°F and the temperature of the operations center will rise above the level associated with the much colder chilled water from the mechanical chillers. Unlike the data center floor, there is no significant source of internal heat gain in the operations center and it is unlikely that the temperature will rise to the 80-85°F level. In this project it was planned to evaluate temperature and comfort in this space during initial tests of the hybrid evaporative cooler system and, based on this, make a decision about the need for additional cooling. If, with the hybrid evaporative cooler, addition temperature control is needed for this space, temporary portable air conditioners could be used.

Highly Temperature-Sensitive Server Racks: At the Port Hueneme data center some of the server racks are considered highly temperature sensitive (Tape and SANS Drives) and the data center operators are very reluctant to allow even tests at elevated temperatures. The maximum allowable temperature for these devices was reported by staff personnel to be 100 °F. Running the overall datacenter at an elevated temperature, say 80 or 85°F, rather than 72~74°F provides less head-room, and thus less reaction time, if there is a failure in the primary cooling system. One option considered for the demonstration was moving these few racks to a different location. After evaluation, however, this was not seen as a feasible option. The path forward selected for this situation was to simply monitor the temperatures during the initial phases of the demonstration to see if, in fact, an acceptable temperature was exceeded for these racks. If this were the case, then either the maximum temperature in the data center would be constrained to ensure this temperature is avoided or a single-rack cooling system would be used either temporarily or permanently.

Maintenance Operations in the Data Center: Another concern raised by the data center management staff is exposure of crews doing maintenance in the data center to uncomfortably warm temperatures. For a short work project this is not seen as a major concern. Longer maintenance projects, during the course of the demonstration at least, might need to be scheduled and the system operated on the mechanical chillers for this time period.

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7.0 COST ASSESSMENT

The project team decided to stop work on this project before requesting bids for the installation work. At the proposal stage, an estimate for this, by one of the manufacturers, was made at $125,000. As the design work progressed and better information was available on the complexities of the project, the project team recognized that this estimate was too low. The detailed specifications included in Annex I to this report were prepared to enable local installation contractors to bid on the entire scope of the installation. This bid process was not completed. The economics of the overall project for the Port Hueneme site are summarized in Table ES-0-3 below, using an assumption that the installation cost would be $300,000. This is based on preliminary discussions with potential contractors and also a cursory review by the Brookhaven National Laboratory (BNL) facilities group.

Table ES-0-3. Summary Cost Analysis

	PFC Unit	Hybrid Unit
Equipment Capital Cost	$75,000	$125,000
Estimated Installation Cost	$300,000	$300,000
Total Project Cost	$375,000	$425,000
Baseline System (mechanical chillers) annual electric cost	$43,782	$43,782
Annual electric cost with evaporative cooling system	$9,198	$21,549
Annual electric cost savings	$34,584	$22,233
Payback (years)	10.8	19.2

This simple payback analysis shown above assumes that the site has an existing mechanical chiller system and that the evaporative cooler would be added to this as a cost savings measure. In an alternative scenario in which an evaporative cooler would be used instead of a mechanical chiller either at a new facility or where an existing mechanical chiller is at the end of its life, the payback would likely be zero years as the evaporative cooler would both cost less and use less energy.

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8.0 DECISION NOT TO PROCEED

As originally planned, the supplier of the major equipment for the demonstration—the evaporative cooler—was to develop detailed designs for the installation, seek bids for the installation work, select the installation contractor, and oversee the installation work. This team member withdrew from the project. Factors which influenced the decision to drop this product included cost relative to alternative technologies, decisions made by a key potential customer, water quality in specific target market areas, and the relatively large footprint of their unit. This team member was replaced by another equipment supplier which was not able to take on the installation work, leaving this to be managed by the lead organization, BNL. After completion of the installation design work, BNL management reviewed the work to be done and the risks involved. This led to a decision that the management of the subcontracting and oversight of the installation work was too far from the normal work of the lab so represented an unacceptably high risk.