VERTIV WHITE PAPER

Calculating the Impact of Water Usage on Data Center Costs and Sustainability

Executive Summary

The Data Center Sustainability Challenge

Today, the drive for sustainable operations not only means reducing carbon emissions, but also conserving water, one of our planet's most critical natural resources. Those objectives can appear in conflict as operators turn to data center cooling systems that use water to reduce energy consumption and thus carbon emissions. The clearest example of this is the increased use of evaporative cooling technologies, which can reduce energy consumption compared to other technologies, but at the cost of relatively high water use.

Balancing the sometimes-conflicting goals of increasing energy efficiency and reducing water usage is further complicated by the need to tailor data center cooling design to the specific location of the data center. More than other data center systems, cooling system design is impacted by local climate and resource availability, as well as more general data center considerations such as scalability, reliability and maintainability.

When water availability is managed separately from electricity, it can be even more challenging to evaluate the true cost — financially and environmentally — and make an informed decision on the most sustainable and cost-effective cooling solution for a particular location.

The argument can be made that the overall conservation of energy facilitates water conservation because most sources of electricity consume water in the power generation process. Based on a 2017 study by the Department of Energy's Argonne National Labs, the average water consumption factor for electricity in the United States is 0.576 gallons/kwh.

Thus, using water in the data center can result in a net reduction of water consumption if the amount of water used in the data center is less than the water saved in power generation through reduced demand.

Yet, this is typically not the case, and moreover, there are technologies today that offer very efficient cooling without consuming any water, allowing energy efficiency and water conservation objectives to be met simultaneously. When considering the use of water on data center operations and sustainability, the following factors need to be considered:

- Energy efficiency benefits
- Initial cost and maintenance
- Availability of water and cooling system reliability
- Impact of increased water usage on sustainability objectives
- Efficiency of systems that do not use water at the source
- Operating temperatures of the data center
- Total cost of ownership (TCO)

Growing Awareness of Data Center Water Usage

Not long ago, data center power usage effectiveness (PUE) averaged above 2.0. Today that number is below 1.6 with colocation data centers routinely achieving PUE of 1.2 or below.

These improvements were driven by a combination of increased pressure to reduce data center operating costs and increased awareness of the environmental impacts of growing data center energy consumption that accompanied the cloud computing era.

Now, as hyperscale and colocation operators continue to expand their footprint to bring services closer to users, data centers are being located in areas where water resources are scarce. At the same time, many have adopted water-intense economization systems as their preferred method of cooling. This has put the spotlight on data center water usage. For example, in April 2020, Time magazine published an article titled: The Secret Cost of Google's Data Centers: Billions of Gallons of Water to Cool Servers.

While PUE has become the dominant efficiency metric for the data center industry, water usage effectiveness (WUE) is growing in importance. Organizations now face the challenge of balancing small improvements in PUE against the environmental and financial costs of higher WUE.

Efficiency Benefits of Using Water for Cooling Data Centers

The use of water in a data center cooling system improves efficiency by reducing the outdoor temperature at which the system is operating to the wet bulb temperature. The wet bulb temperature is the temperature you feel when you jump out of a swimming pool on a hot summer day. By operating the cooling system at the wet bulb temperature, the number of hours the system can run without mechanical cooling, or in economizer/free-cooling operation, is greatly increased.

The impact of this adjustment can be shown when comparing the same chilled water systems using an air-cooled chiller with and without adiabatic cooling. The adiabatic system uses either an evaporative pad or atomizing spray in front of the coils to bring the temperature close to wet bulb temperature. For more details on adiabatic cooling chillers see the Vertiv white paper: "Free-Cooling, Evaporative and Adiabatic Cooling Technologies in Data Centers."

Figure 1 shows the reduction in energy consumption of adding an adiabatic misting system to the chiller in terms of the partial PUE (pPUE or PUE attributable to the cooling system), as well as the associated WUE for the two systems.

Based on this example, using an adiabatic system to reduce the outdoor temperature to the condenser and free-cooling coils improves the pPUE by approximately 0.01, which equates to 208,000 kWh/year. Correspondingly, it increases the WUE from 0 to 0.165, which equates to 4.3 million gallons of water annually or the equivalent of that consumed by approximately 40 U.S. households. The overall net effect of evaporating water on the system is improved energy efficiency and increased water usage.

There are other technologies like indirect evaporative cooling that can take greater advantage of the evaporation of water and outdoor air to further drive efficiency. For more information, see the Vertiv white paper: "Indirect Evaporative Cooling Technologies in the Data Centre."

This technology can provide significant improvements in energy efficiency when compared to a chilled water system with an adiabatic air-cooled chiller as shown in Figure 2.

This example highlights why data center operators should spend some time investigating the trade-offs associated with water usage. You can see a significant improvement in pPUE but also higher water consumption. The overall net benefit in this example is a pPUE improvement of 0.02, doubling the improvement achieved with the air-cooled chiller having an adiabatic system, generating an annual energy savings of 572,791 kWh compared to that system. This represents an 18% reduction in overall energy consumption compared to the adiabatic free-cooling chilled water system and 24% improvement over an air-cooled chilled water system. However, each improvement is enabled by increased water usage.

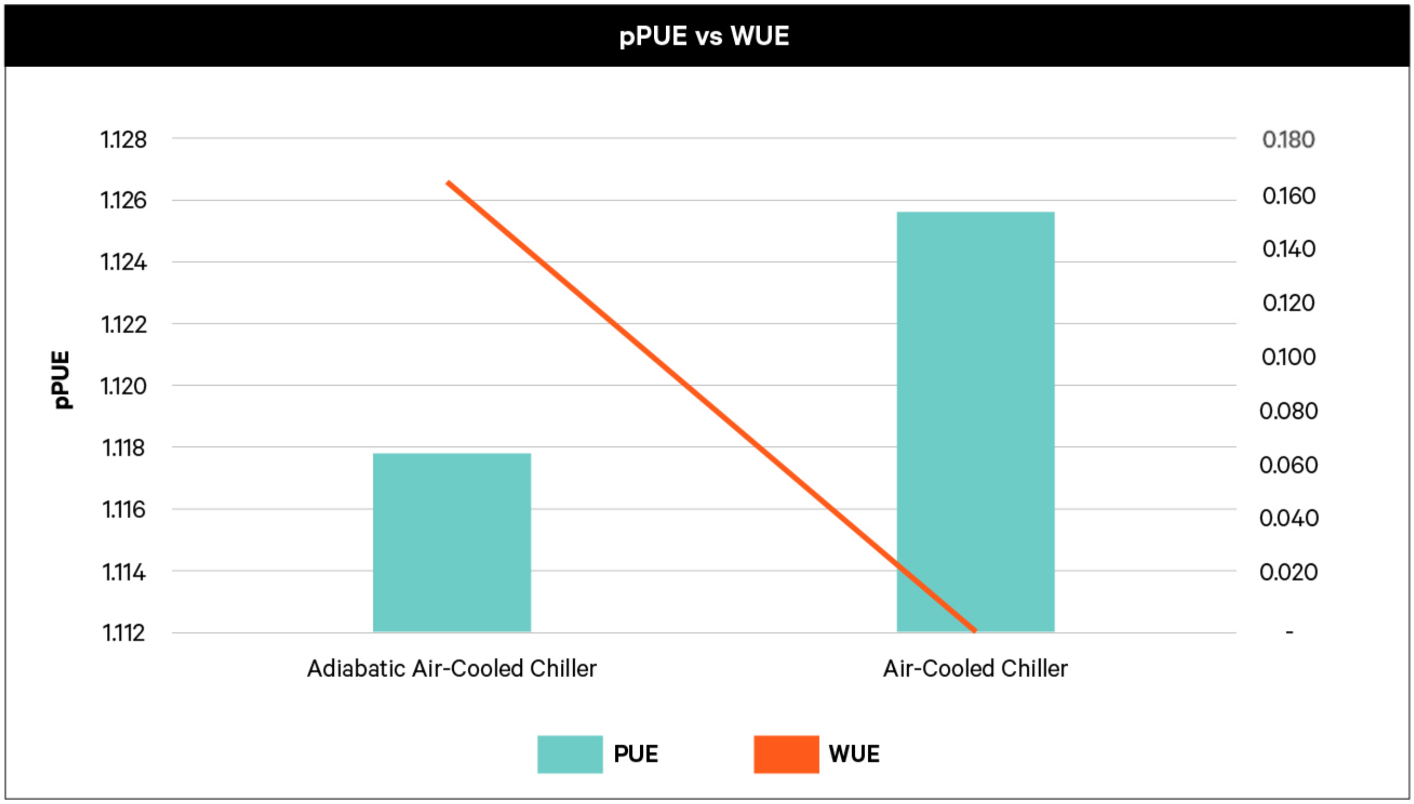

Figure 1. *pPUE and WUE of air-cooled chiller with and without an adiabatic misting system for a 3 MW data center located in Ashburn, Virginia (USA)*

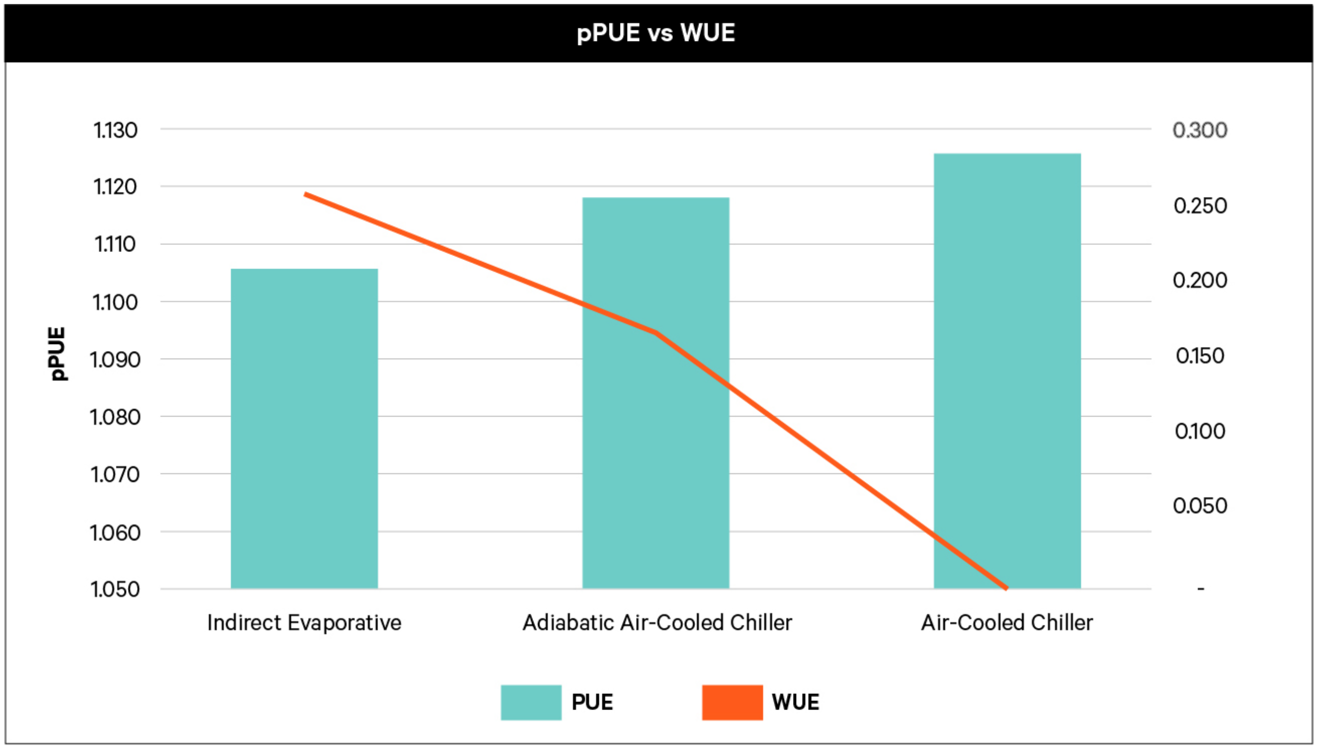

Figure 2. pPUE and WUE for indirect evaporative cooling system compared to air-cooled chiller with and without an adiabatic system for a 3 MW data center located in Ashburn, Virginia (USA)

There are many other examples for how the use of water can improve efficiency, but these represent some of the more common in today's data centers. It is worth noting that the amount of savings and water usage will vary based on climate. A general rule of thumb is that in dryer climates you see a greater improvement in energy efficiency by using water, but as a result, the net rate of water consumption will increase proportionally. Those locations may also present the greatest challenges in terms of water availability.

The operational scenarios shown in Figure 2 can be designed to employ water saving features to reduce water usage. And while that is true in some of these scenarios, the tests were run primarily to maximize energy savings. There are several control features that can be deployed in these systems to minimize water consumption, and they should be considered when evaluating water-using technologies.

Another key benefit that water usage has in the overall optimization of the data center is reducing the peak power requirements of the cooling system. The peak power is the maximum power draw the system consumes on the hottest design day of the year. Since the evaporation of water reduces the operating temperature, the peak power required to operate during the hottest day is reduced. The savings in peak power will vary based on the technology and location.

In the case of an indirect evaporative cooling system, the peak power savings can be in the range of 10-30% less than an air-cooled chiller solution depending on the environment. This savings can be realized in the capital expenditures for the power distribution system in the data center including generator, switchgear, and conductor sizing. It is important to consider the impact that a reduction in peak power will have on these data center elements when designing systems that use water.

The dramatic savings associated with data center water usage is what drives so many facilities to consider these types of technologies. The rest of this paper will explore some of the trade-offs of water usage and other considerations that could offset the significant advantages of using water. These trade-offs are not intended to steer data center designers away from using water, but rather to highlight some potential impacts on sustainability.

Cost and Maintenance Considerations of Using Water

Using water as part of the cooling process for data centers can reduce energy costs but there are other cost factors that also need to be considered, including utilities, water treatment and added maintenance.

Utility Considerations

Just like the supply of electricity, the use of water requires permitting and approval from the local utilities. It not only requires a utility to supply enough water to the site to support the cooling load, but the site must also have enough wastewater discharge capacity to deal with draining and maintaining systems that use water.

Data centers will have these utilities available for personnel, but when considering using these utilities in the volumes required as regulations change over time and policies for conservation of water and wastewater evolve, the availability of these utilities could be impacted through the life of the data center and should be reviewed with the utilities as part of the overall facility plan. This can become a challenge given that, in most cases, the utility supplying the water is different than the wastewater utility. While you may be able to secure enough water to the site, you may not have the permission or ability to discharge enough water to maintain proper water quality.

As a result, operators need to consider the cost of water to operate the system plus the cost of the wastewater to discharge and drain the system as part of normal operation and maintenance. An example of these costs for various cooling systems is shown in Figure 3.

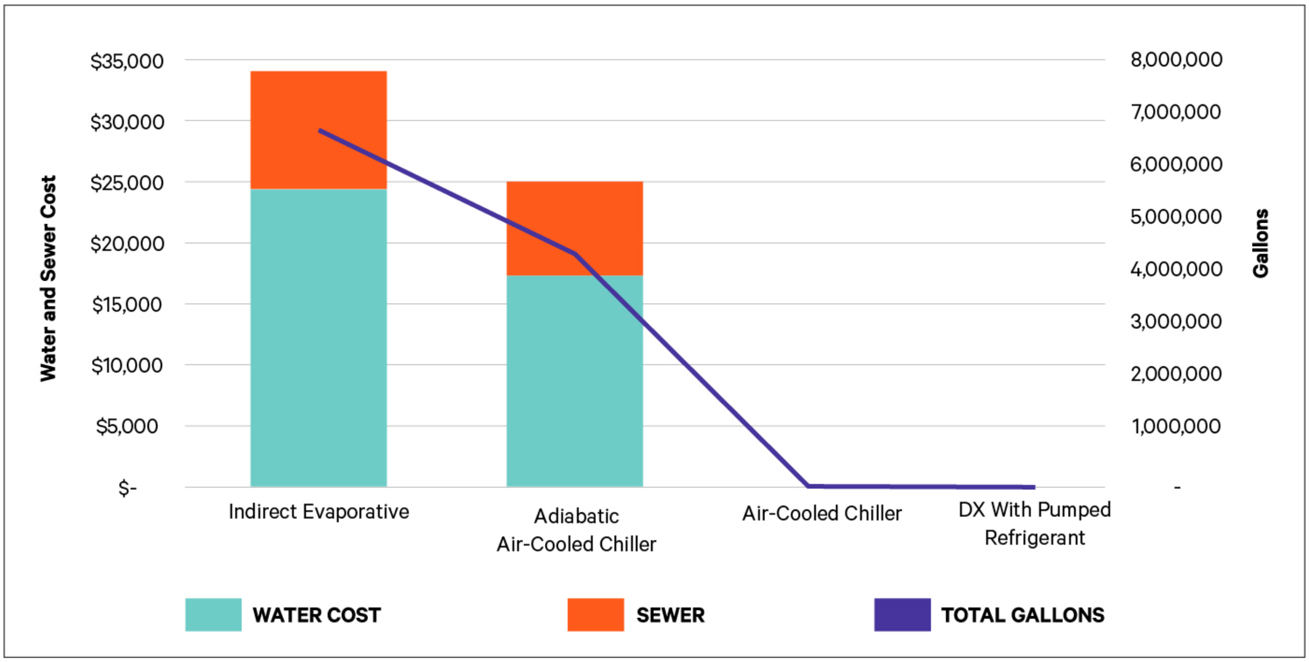

Figure 3. *Comparison of water utility and wastewater costs by system type for a 3 MW data center in Ashburn, Virginia (USA)*

Water Treatment

It is common for many of the systems that use water to use evaporative pads or water recirculating systems to help minimize the amount of water being used. In either case, these water collection systems require the water to be treated to prevent biological growth like algae. Chemical treatment or other means is also required to maintain pH levels and control chemical concentration levels of the water that can cause fouling of the heat exchangers or evaporative media being used.

The risk of legionella is also a concern. Systems that use water require proper treatment and regular testing to ensure there is no health risk to the data center or surrounding areas that could be impacted by the legionella bacteria that can spread through airborne water vapor.

Common water treatment methods include:

- Chemical dosing
- Reverse osmosis filtration
- Pulse-powered treatment

In addition to treatment for mitigating biological growth and maintaining quality, water has to be monitored for solid deposit buildup. The process of evaporating water on a heat exchanger leaves behind a residue of the solids. These solids build up in the water sumps and on the media, requiring frequent maintenance to clean and or replace. During normal operation of systems with sump-based water recycling, the amount of solids in the water is monitored by checking parameters such as conductivity. When conductivity levels reach a threshold, the water is dumped down the drain.

The exact cost of water treatment systems will vary based on the technology used and the amount of water being consumed by the cooling system. For planning purposes, the cost to treat the water coming into the system to ensure compatibility with cooling system components will be in the range of $50,000 to $100,000 at 100 gallons per minute (GPM). If additional treatment is required for softening and desilcizing the water to minimize scaling and solid buildup, costs can range from $100,000 to $250,000 for a 100 GPM system.

In all cases it is recommended that qualified technicians maintain quality for the water serving the cooling system. Poor water quality can lead to shortened equipment life, cause unplanned downtime, and potentially be a health threat to those in the facility and surrounding area. The facilities maintenance staff should be properly training and/or partnering with a qualified water quality contractor to ensure proper maintenance of the facility water.

Impact of Water on Facility Uptime

Like electricity, water and wastewater systems are utilities required to operate a cooling system that uses water. When designing a facility to use water for cooling these systems need to have the proper level of redundancy and back-up to deliver the desired level of availability.

To meet the Uptime Institute's Tier III or IV levels of availability, a data center using evaporative cooling needs to have enough water storage on site to operate for 12 hours without water availability from the utility. In a Tier III design, this system will need to be concurrently maintainable, meaning some level of redundancy is needed to enable maintenance while the system is in operation. In the case of a Tier IV facility, the water storage systems and operations need to be fully redundant. Typically, in evaporative cooling systems, water storage is accomplished through either an integral or centralized approach:

- Integral: Belly tanks integrated as part of the air-handling unit or chiller to provide sufficient water during an outage
- Centralized: Central water tanks that are tied into the facilities water supply and treatment systems

The cost of deploying the necessary amount of water storage will vary based on the total amount of water consumed. As an example, for a 3 MW facility deploying indirect evaporative cooling, the cost of the tanks and associated piping would range from $125,000 to $200,000. This is not a trivial cost and should be considered when looking at the total cost for the system relative to a water-free solution.

Some facilities have designed in multiple sources of water from the utility to gain the right level of redundancy and meet their availability objectives, but this may not be a viable option for most locations and would require coordination with the water and wastewater utilities.

Impact of Water Usage on the Environment

Water is a critical natural resource and the conservation of water is becoming more of a concern for more municipalities around the world. This conservation is typically managed based on the climate of a given location and the availability of water. This is somewhat self-regulating based on the cost of water in areas where it is less available, making it less appealing to use water.

However, the U.S. Environmental Protection Agency (EPA) estimates at least 40 states will have water shortages by 2024 and some municipalities have already indicated they will not guarantee future water availability for cooling systems. On a global scale, sources show that the population has doubled in the past 40 years but use of water has quadrupled. The Water Resources Group forecasts that global water demand may outstrip sustainable use by 40% as soon as 2030.

Combine this continued pressure on the global water supply with the fact that water is the most dominant greenhouse gas, contributing to global warming through an amplifying effect, and it becomes critical to consider the impact of water usage on data center sustainability goals.

This fact has been studied and reported by the National Oceanic and Atmospheric Administration (NOAA), NASA, and many climate scientists around the world. NASA's report, "Water Vapor Confirmed as a Major Player in Climate Change," references several studies that prove the added moisture in the air causes a doubling of the effect that CO2 alone plays in global warming. The added moisture in the air comes as a result of increased evaporation due to higher surface temperatures. Naturally this moisture comes from our oceans and lakes; however, today's man-made sources are adding to humidity into the air as with cooling systems and power plants that evaporate water.

While the study of water's contribution to global warming continues to evolve, the positive feedback and amplifying effect is well proven. The study of the positive feedback loop that water vapor has on global warming is focused on the lower part of our atmosphere called the troposphere. This is the water vapor we experience as part of our natural weather patterns in the form of clouds, rain, and humidity in the air. The difference that water has in the troposphere compared to CO_2 in the atmosphere is that it is more temporary. The vapor in the air eventually returns to earth in the form of rain as temperature and weather patterns change. Although temporarily present, the water vapor is playing a key role in amplifying the increase in global warming. If water vapor in the air could be reduced, this amplifying effect would be diminished.

There are more recent findings that are showing that water could be playing a more permanent role in global warming as well. A study by the Cooperative Institute for Research (CIRES) at the University of Colorado Boulder shows that 5-10% of the global warming impact is coming from water vapor in the stratosphere. The stratosphere is the upper part of the earth's atmosphere where CO_2 collects. The World Metrological Organization recently published details from 2000-2009 studies that show that increases in water vapor in the upper troposphere and lower stratosphere (UTLS) lead to radiative cooling at these levels and induce warming at the surface.

Recent analyses suggest that warming at the earth's surface may be sensitive to subparts per million (ppm) by volume changes in water vapor in the lower stratosphere. Research has found that a 10% decrease in stratospheric water vapor between 2000 and 2009 acted to slow the rate of increase in global surface temperature over this time period by about 25% compared to that which would have occurred due only to CO_2 and other greenhouse gases. These findings show that stratospheric water vapor is an important driver of decadal global surface climate change.

Water in the stratosphere is a more permanent change to our atmosphere, which could put more emphasis on studying its impact as is being done with gases such as methane. An indirect evaporative cooling system evaporates as much as one million gallons (3,785 metric tons) of water in the air per 1 MW of cooling per year. In comparison, this same system would contribute 1,784 tons of CO_2, assuming its power is coming from a coal-fired power plant. Therefore, the amount of water being produced annually is more than double that of the CO_2 it is contributing to the atmosphere. This begs the question of whether there will be future regulation or management of water vapor emissions. Either way, it is certainly something to consider when working toward a more sustainable future.

An additional consideration of using water is its impact on the surrounding environment. This is increasing uncertainty around resource availability for water-dependent systems.

Water-Free Cooling Technologies

When considering the financial and environmental costs of using water, data center operators should also evaluate the efficiency of free-cooling systems that do not use water or use very small amounts of water. These technologies include air-cooled chiller with economization, a direct exchange (DX) system with pumped refrigerant, and direct air economization with DX support.

Air-Cooled Chiller With Free-Cooling Economization

Compared to water-cooled chillers, air-cooled chillers eliminate the maintenance required for water treatment distribution and are easier to design and install because they are available as a packaged system. As a refrigerant-based system, the air-cooled chiller has a zero WUE and a pPUE of 1.13. Low equipment and installation costs, along with zero water costs, contribute to one of the lowest total 10-year cost of any system.

As with adiabatic air-cooled chillers, redundant units can be installed and be scaled to grow with demand. However, these units increase electric installation costs as they have a larger peak load than the adiabatic option that is additional to the upfront cost of the water distribution.

Vertiv™ Liebert® AFC

DX With Pumped Refrigerant

A DX system with pumped refrigerant provides the water-free benefits of the air-cooled chiller system with improved efficiency. The system offers a pPUE of 1.12.

DX systems have fewer components than chilled water systems, making them more reliable and easier to control. Units can be added in smaller blocks to grow with demand or support redundancy without first-day installation costs. They can be packaged or split to provide flexibility in installation and save data center floor space for IT equipment.

The installed system cost is very competitive with other systems and its low energy costs and zero-water design allow it to support aggressive sustainability goals while achieving the lowest total 10-year cost of any system.

Vertiv™ Liebert® DSE 400

Impact of Data Center Operating Condition

The analysis of data center costs and efficiency presented in this paper was conducted based on cooling system operating conditions in which supply air temperatures were set at 75 degrees Fahrenheit and return air temperatures at 97. For systems using chilled water, the entering water temperature was set to 64 degrees Fahrenheit, and the leaving water temperature was set to 76.

The cooling systems discussed may achieve higher efficiency with warmer entering water or air temperatures. This increases the economization time as the ambient temperature will be colder than the return temperature for more hours over the course of a year. For example, by raising the supply temperature from 76 degrees Fahrenheit to 80 and keeping the same 22-degree temperature differential, the DX system with pumped refrigerant can save 5% in annualized energy cost and increase economization by over 800 hours.

A larger difference between supply and return conditions (temperature differential or Delta T) reduces the flow of air and water, providing sizeable energy savings on the fans and pump motors in the DX system. By increasing the temperature differential from 22 degrees Fahrenheit to 25, the system can save almost 11% of annualized energy mostly driven by fan power. There are many examples of the effect increasing temperatures and operating points can have on efficiency.

The most extreme case is the use of direct evaporative cooling, which is a popular choice for many hyperscale data centers because of the system's ability to allow temperatures to fluctuate more drastically with the outdoor air. In doing this, these sites can eliminate some of the cost of compressorized/DX cooling to take care of the hottest days in the year. By allowing higher temperatures and extreme conditions, a direct evaporative with no DX now becomes feasible. This system can save up to 15% on energy compared to the indirect evaporative while using only a fraction of the water by allowing outside air to enter the data center directly. This, however, is not always possible as it may require the IT equipment to operate at higher-than-desired temperatures, and it would not be possible to maintain conditions within service level agreements in colocation.

No matter what type of cooling system is being considered, as designers and operators of data centers look to reach their sustainability targets, operating conditions should be a key consideration. Using factors such as supply air temperature and temperature differential as a lever to improve efficiency can not only save money, but could reduce pPUE to levels that greatly reduce or even eliminate the need to consume water to meet those goals.

Balancing Energy Efficiency, Water Consumption and Total Cost

When the efficiency of water-free systems is compared to the previously discussed air-cooled chiller, adiabatic air-cooled chiller, and indirect evaporative systems (Figure 4), you see that the DX with pumped refrigerant solution has the same level of efficiency as an adiabatic chiller that uses water.

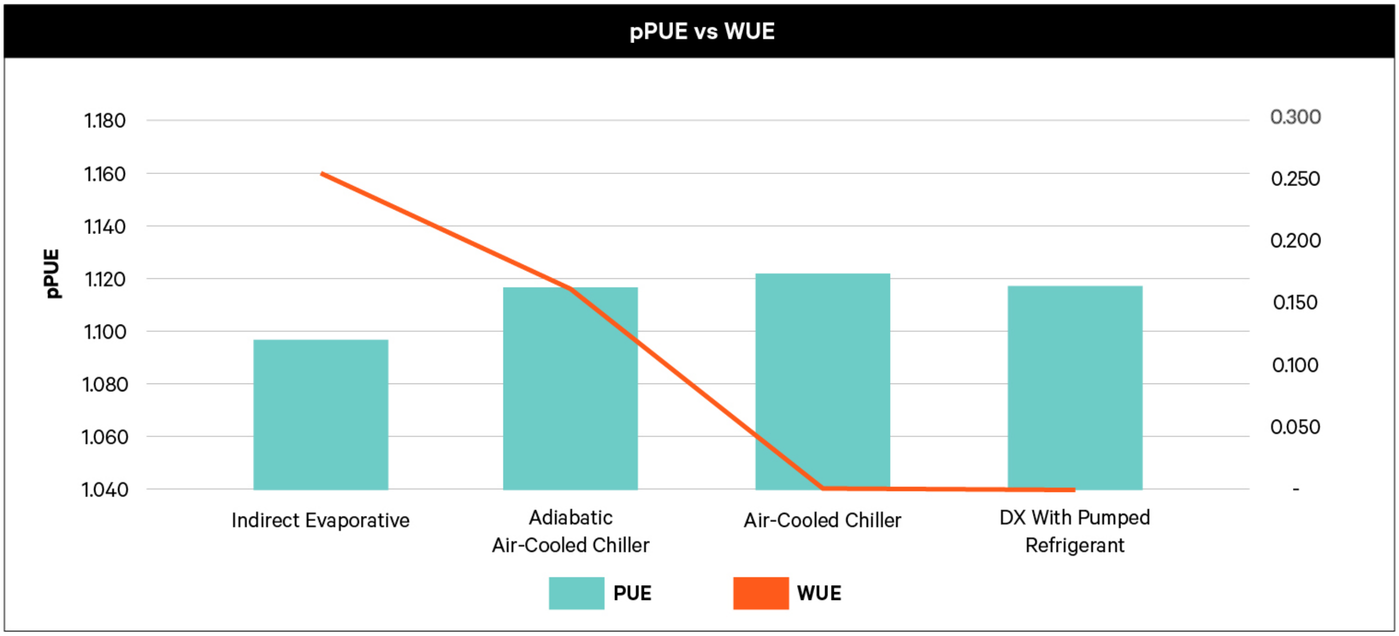

Figure 4. *Comparison of cooling efficiency and water usage of data center cooling technologies for a 3 MW data center in Ashburn, Virginia (USA)*

The indirect evaporative system offers the highest level of efficiency for this location. However, as discussed previously, there are several other factors to consider beyond energy usage. The treatment of water, maintenance, and water storage all factor into the cost of installing and operating the indirect evaporative system. Figure 5 shows the comparison of total cost of these systems over 10 years and the net impact that these added costs have on overall system and operational cost.

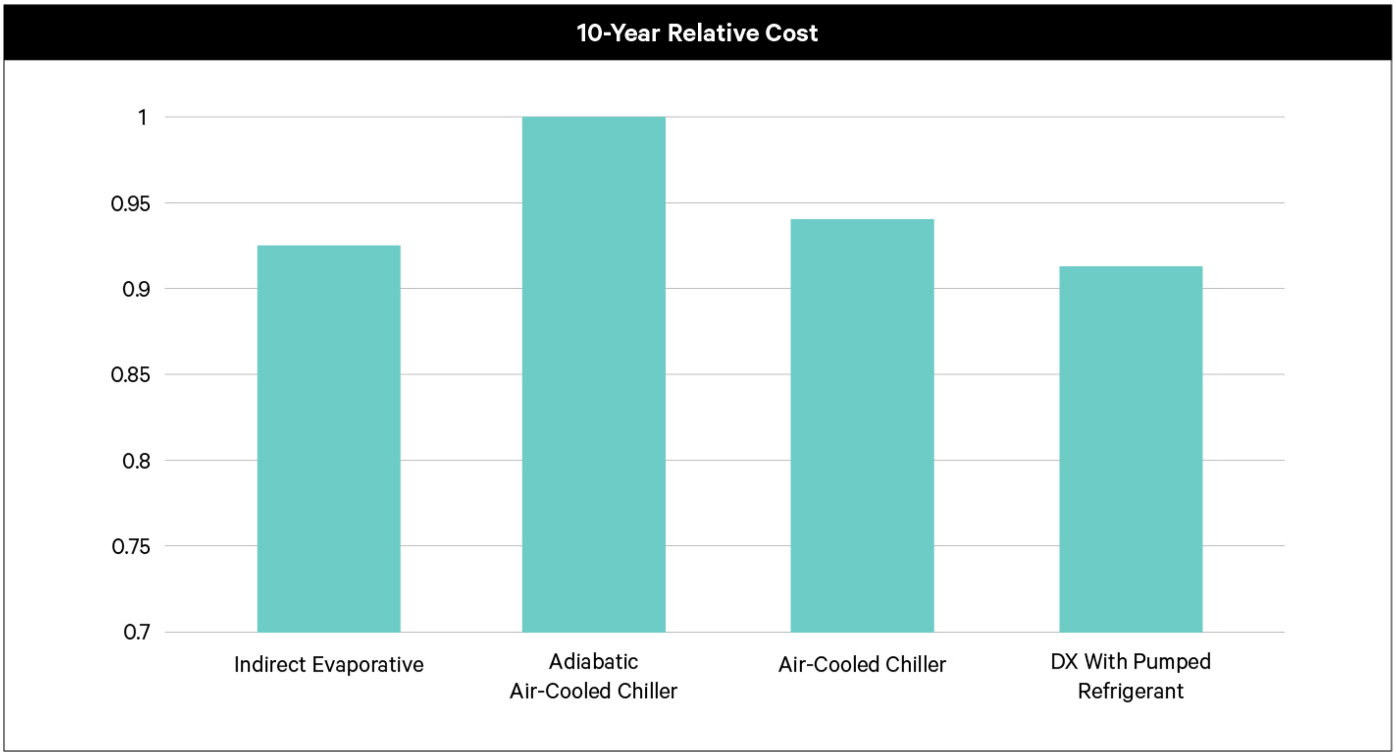

Figure 5. *Ten-year relative cost comparison of cooling technologies based on a 3 MW facility in Ashburn, Virginia (USA)*

While the energy costs are reduced in the systems that use water, the added cost of the systems to support the water and maintain water quality increase the overall cost of the system. Over a 10-year life, the systems that do not use water provide an overall lower total cost.

There are certainly variables that can change the performance and costs of these systems. If, for example, the location is in a colder climate, the DX systems will perform more efficiently but colder minimum ambient temperatures may call for a higher glycol concentration affecting performance on air-cooled chilled water systems. In dry climates, the water evaporating systems tend to be more efficient, assuming water is available. As noted previously, operating conditions can also impact energy efficiency.

Finally, some systems such as chilled water have scale economy that improves their cost per ton on larger systems but makes them less cost-competitive for smaller date centers. Building architecture and space availability also play a role in equipment selection. Packaged outdoor systems such as indirect evaporative, direct evaporative, and packaged DX with pumped refrigerant are preferred for data centers where cooling is located on the perimeter of the facility. Chilled water and split systems are preferred for multi-story buildings.

Conclusion

Choosing the Right Cooling System

The design of a data center cooling system is one of the most important decisions data center operators must make. The right choice will be tailored to an organization's availability and scalability requirements. It will minimize costs and support sustainability.

While water has been considered an enabler of increased efficiency and lower operating costs, the full impact of using water for data center cooling is often not fully considered.

As we've shown in this paper, water usage has direct environmental impact, particularly in areas where this resource is scarce. It also has an amplifying impact on carbon dioxide that is becoming increasingly well understood. Additionally, using water adds to annual operating costs through the considerable expense for water treatment and maintenance of the systems that use water.

This paper is not meant to suggest that water shouldn't be used in data center cooling, but to encourage data center operators to fully explore their alternatives and make sure they understand the pros and cons of using water early in the cooling system design process.

In many locations, water-free cooling systems provide levels of energy efficiency that are similar to the most efficient systems that use water. These systems can more than offset any downstream water savings that result from lower demand on power generation systems while offering equal, or in some cases, lower total cost.

Vertiv offers both evaporative cooling and water-free thermal management solutions for data centers, and partners with designers to determine the best solution based on location, environment, local regulations, and sustainability goals.

Performing a site specific analysis comparing these solutions is recommended for better understanding of the overall difference in technologies. This analysis also helps tailor the thermal management system to meet business objectives.

With more than 70 years of data center cooling experience, Vertiv has the expertise and tools to help you make the right choice.

Vertiv.com | Vertiv Headquarters, 1050 Dearborn Drive, Columbus, OH, 43085, USA