Rethinking Water Usage in Data Centers

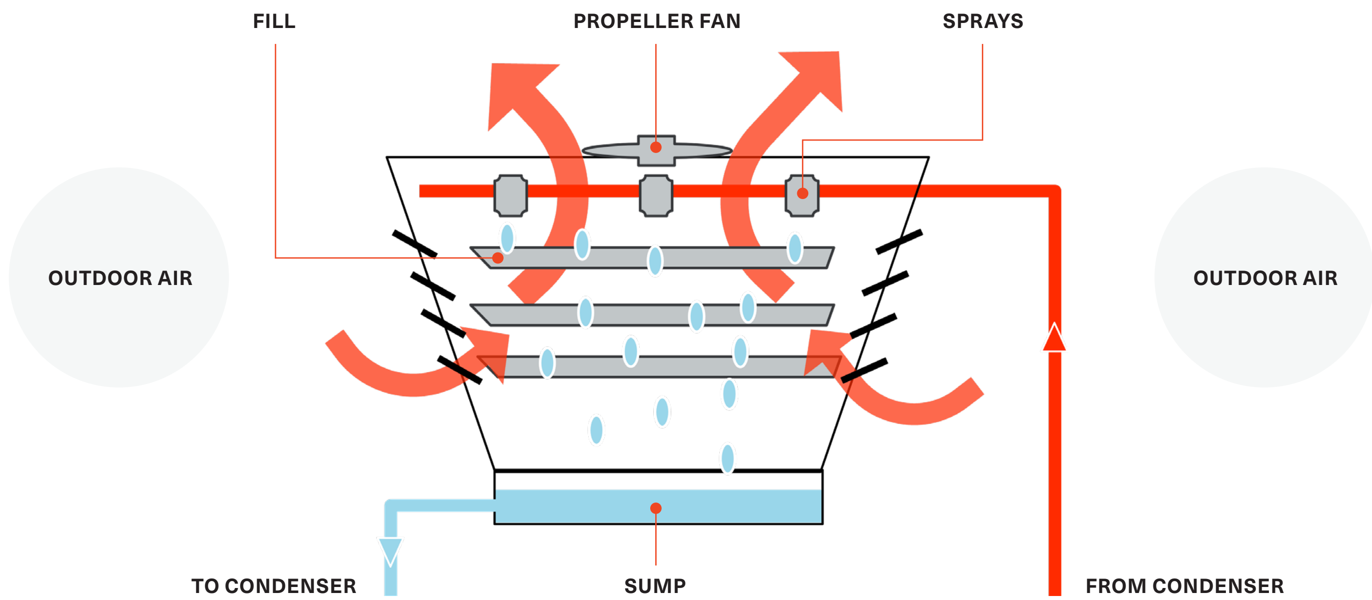
Water usage in data centers has become a hot topic, but there's an opportunity to cool more than just a chip in this debate.

The most efficient system types have been traditionally designed with open cooling towers. Due to increasing scale, often accompanied with growing community pushback, modern data centers are being designed as closed loop systems. As operators evaluate these approaches, they also have a responsibility to adopt technologies and practices that minimize water consumption and protect the long-term health of local community resources. How does this affect system design and are there any intermediate options?

Open Loop Cooling Towers: High Water Consumption

Water-cooled chillers traditionally leverage open cooling towers as a means of rejecting heat. As this method relies on evaporation to provide the cooling effect, its performance is reliant on the region's local wet bulb temperature as opposed to the more familiar dry bulb temperature that air-cooled units utilize. As the wet bulb temperature is always lower than the dry bulb temperature, the chiller runs at a lower total lift versus an air-cooled unit. This lower lift results in lower power draw and higher cooling efficiency, which is crucial for sustainability and cost management in data centers. In an effort to harness the wet bulb effect, a nozzle sprays water within the cooling tower's air stream. The majority of water is collected in the cooling tower's sump, but a portion of it is lost and must be replaced. The volume of water that needs to be added is referred to as make-up water.

Cooling Tower Components



Three main means of water loss in an open cooling tower:

Evaporation

Evaporation is the loss of water that dissipates during the cooling effect of the tower.

Drift

Drift is the loss of water due to blowing wind, where water is carried away from the tower but does not evaporate as cooling. This water isn't collected in the tower sump.

Blow Down

Blow down refers to a maintenance process. Water collected in the tower sump contains many minerals and deposits that can impact water quality and cooling performance. To help ensure quality, the water is drained periodically in a blow-down procedure. This water is lost from the system and needs to be replenished.

Specifications

While there are more precise ways of determining the amount of make-up water required for an open cooling tower, a rough estimate is as follows:

- **Evaporation** = ~ 0.0224 gpm/ton
- **Drift** = ~ 0.0004 gpm/ton
- **Blow Down** = ~ 0.0108 gpm/ton
- **Total** = ~ 0.0336 gpm/ton

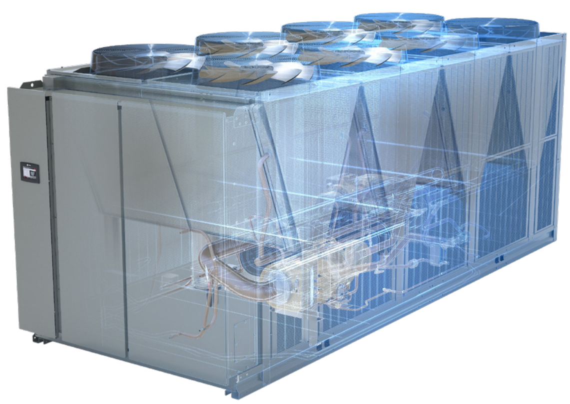
While water loss from open cooling towers is seemingly nominal, when scaled for cooling requirements for data center applications it's a sizeable consumption rate. For example, a 50MW data center may consume > 475 gallons of water per minute and a 1GW data center may consume > 9500 gallons of water per minute. This equates to more than 4x the average household use per month. And with global data center capacity expected to multiply dramatically over the next three decades, the cumulative water demand from cooling-tower-based systems could escalate to levels that place significant strain on local water supplies and community infrastructure.

Closed Loop Air-Cooled Chillers: Zero Water Consumption

To eliminate water usage entirely from chiller operation, air-cooled chillers are a viable solution. These units rely on an air-to-refrigerant coil mechanism to reject heat into the atmosphere. While this cooling approach supports water conservation, it comes at a cost. The two main detractions are chiller efficiency (air-cooled chillers rely on dry bulb temperatures for sensible heat rejection creating a larger lift condition) and unit quantity as they are generally available in smaller capacity sizes.

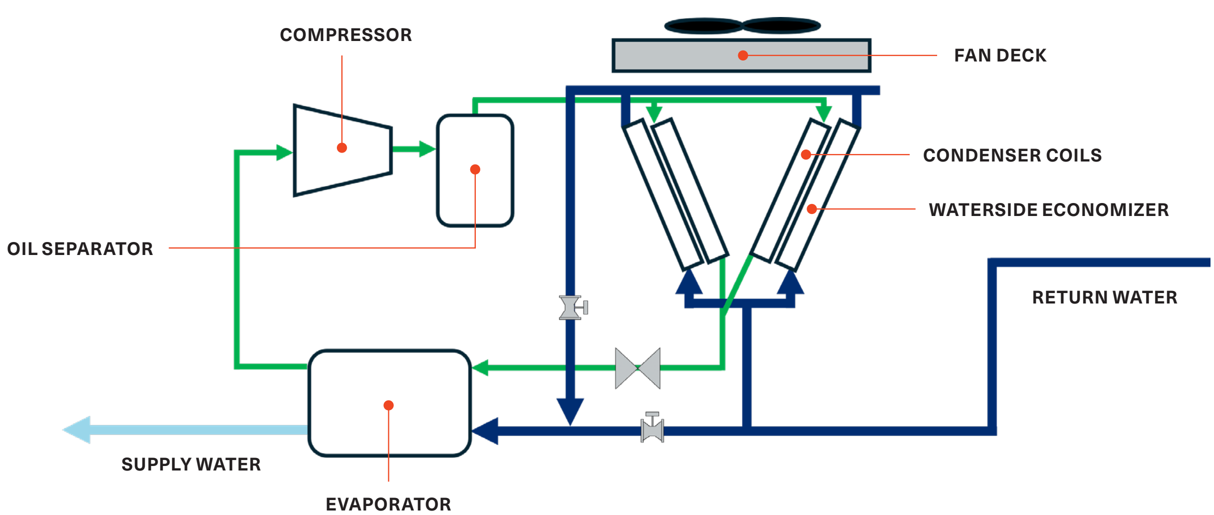
Air-cooled units can be outfitted with free cooling techniques like low compression free cooling or waterside economizers installed in series with the evaporator. In the case of a unit available with a waterside economizer, these units employ a water-to-air coil mechanism that allows the facility water to flow through them when conditions are favorable i.e. return water temperature is greater than the outdoor ambient temperature. If the temperature differential between the return water and the outdoor ambient is great enough, full capacity cooling can be achieved without the need for mechanical cooling from the chiller. However, even if full capacity cannot be achieved, the water can still be pre-cooled prior to the mechanical cooling at the evaporator. This increases efficiency by reducing the power draw of the air-cooled chiller, leading to lower power consumption, which is a useful tool for improving energy efficiency and reducing operational costs in data centers.

If the outdoor ambient temperature is greater than the return water temperature, the return water bypasses the waterside economizers and enters the evaporator directly.



Trane® Ascend™ Air-Cooled ACR Model Chiller

Waterside Economizers (Direct Free Cooling)



Note: *Not all air-cooled chillers are available with a water-side economizer.*

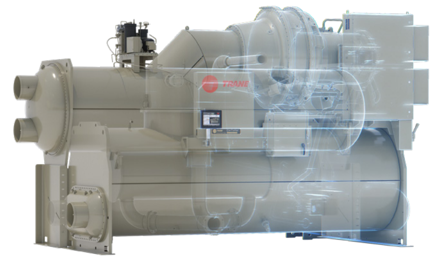
Closed Loop Water-Cooled Chillers: Zero Water Consumption

Cooling solutions exist that blend both water and air-cooled technologies. One approach is to utilize water-cooled chillers combined with dry fluid coolers in lieu of the traditional open cooling tower. This combination supports natural resource conservation as it eliminates water usage entirely from the cooling process. Like many system design decisions, there is a trade off. The elimination of water usage carries a penalty of increased power usage.

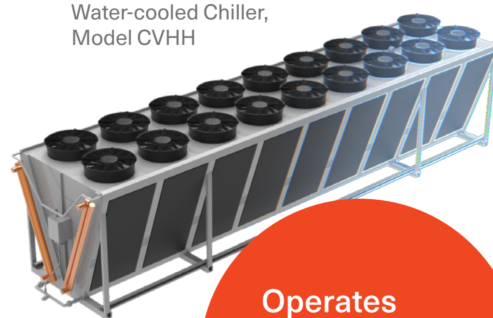
Dry fluid coolers operate via air-to-water heat exchangers that allow larger water-cooled chillers to leverage outdoor ambient for heat rejection. The use of dry fluid coolers allows larger capacity water-cooled chillers to operate like an air-cooled chiller with zero water usage. As with air-cooled chillers, this method results in more lift during high ambient conditions leading to an increase in power consumption and utility cost. In addition, the number of dry fluid coolers required to meet cooling requirements comes with a sizeable footprint.

Typically, dry fluid coolers are simply piped within the chiller's condensing water loop in lieu of the open cooling tower. When an isolation heat exchanger is employed, dry fluid coolers can also be utilized for full free cooling when the ambient temperature is low enough. Below that temperature, mechanical cooling from the chillers is not required.

[Learn more about closed loop system design](#)



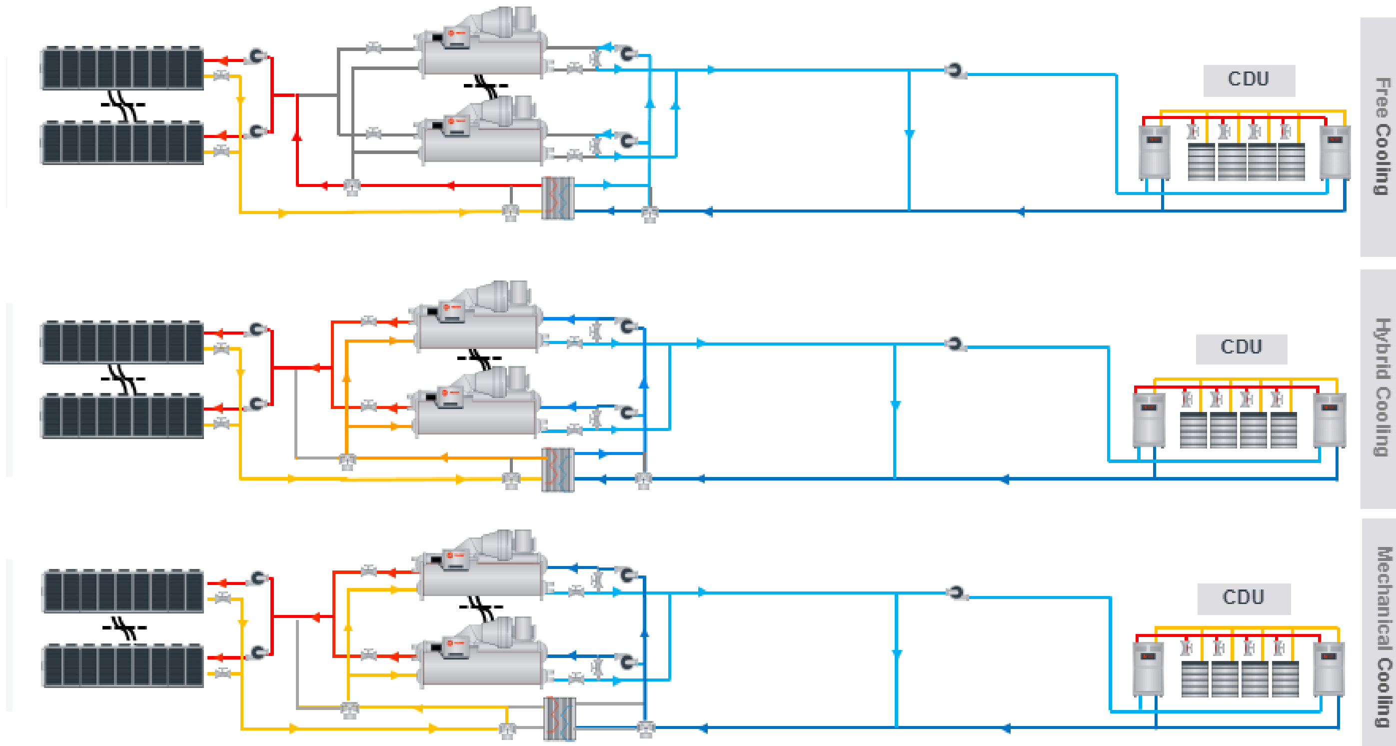
Trane® CenTraVac Water-cooled Chiller, Model CVHH



Dry Cooler

Operates without water from an open cooling tower.

Dry Fluid Coolers – Free Cooling / Mechanical Cooling



Note: *The outdoor ambient temperature that facilitates full free cooling capacity is dependent on the number of dry fluid coolers installed and the cooling load present in the data center.*

Adiabatic Assist: Minimal Water Consumption

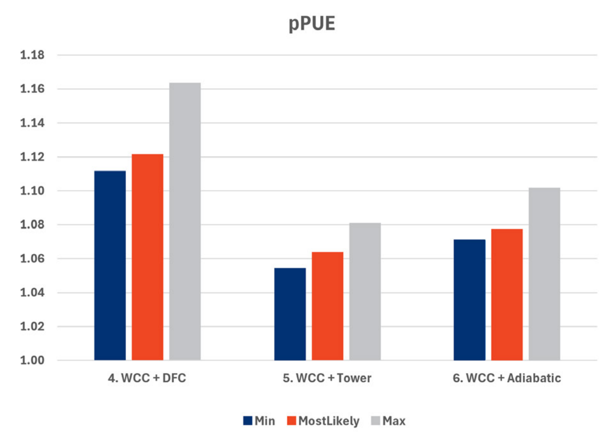
One method that allows a hybrid air-cooled/water-cooled solution in data centers is to utilize an adiabatic assist on the dry fluid coolers or the air-cooled chillers. The adiabatic assist consists of water being sprayed on a media, such as a screen or pad, that is located upstream of the air coil. When air is pulled through this wetted media, it evaporates to lower the air temperature that enters the air coil. In this manner, the adiabatic assist utilizes the local wet bulb temperature as opposed to the local dry bulb temperature, reducing the operational lift of the chiller and increasing its efficiency. This approach can be used on a traditional air-cooled air-to-refrigerant condenser coil, the waterside economizers utilized in air-cooled free cooling units, or dry fluid coolers.

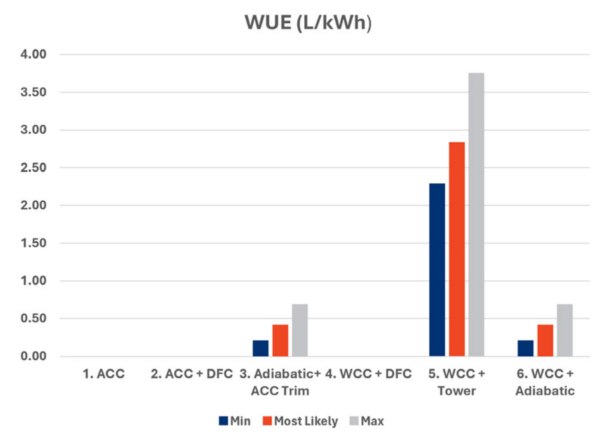
The addition of the adiabatic assist results in a higher air-side pressure drop for the fans of either the air-cooled chillers or the dry fluid coolers. When the outdoor ambient temperature is low enough not to require adiabatic assist, there is no water flow to the media. During these conditions, water usage is eliminated. Depending on construction, the adiabatic media may be removed when not required, eliminating additional air-side pressure drop.

Although adiabatic assist increases water usage compared to traditional air-cooled systems or dry fluid coolers, it is only activated during periods of elevated outdoor ambient temperatures and helps reduce the total number of units required. This results in a 70-80% reduction in overall water usage versus traditional open cooling towers, while allowing the system to run at a more efficient duty point. This strategy gives data center operators a powerful lever to reduce operating costs, manage resource constraints, and strengthen their sustainability performance. The selection of outdoor ambient conditions for activating adiabatic assist is determined by the data center customer, who balances water usage efficiency (WUE) with partial power usage effectiveness (pPUE).

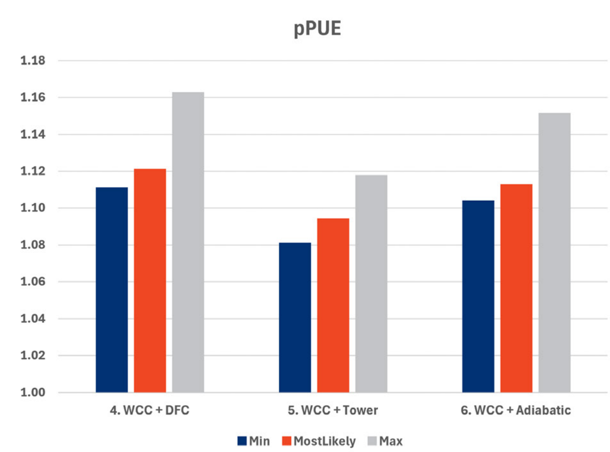
Estimates representing the relative tradeoff between WUE and pPUE for a hot, dry climate (Albuquerque, NM) and a cool, humid climate (Chicago, IL) for each of these options are shown below.

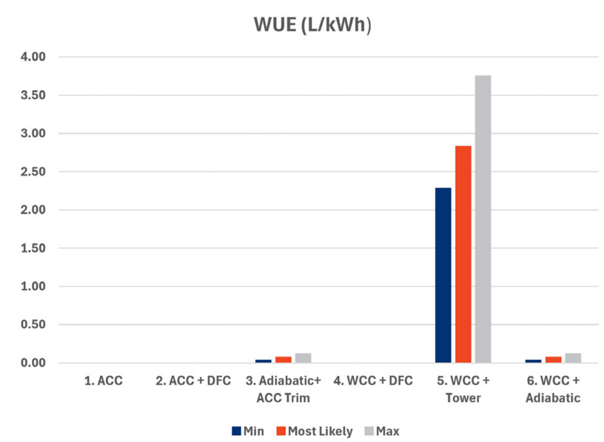
Dry Hot Climate-Albuquerque, NM





Cool Humid Climate-Chicago, IL





Note: *Demonstrative values shown, actual results may vary.*

As data centers scale into larger designs, the water consumption rate can be a large design factor. There are more options beyond the traditional air-cooled facility, which has lower efficiency but zero water consumption, and the water-cooled facility, which has higher efficiency but significant water consumption. These options include dry fluid coolers for water-cooled plants and/or a hybrid system with adiabatic assist. Ultimately, data center chiller plant optimization options can be tailored according to the facility's size, local ambient conditions, and customer priorities for balancing partial power usage effectiveness (pPUE) and water usage efficiency (WUE).
When evaluated responsibly, water-based cooling can offer a sustainable, community-minded approach—using resources more efficiently while reducing environmental impact and helping operators act as better stewards of the local water supply.

About the Author

Daryl Keys is a Lead Engineer in the HVAC Systems Development Group, bringing over 26 years of expertise in HVAC and hydronic systems. His current role focuses on hydronic systems development for data center and commercial building applications.

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