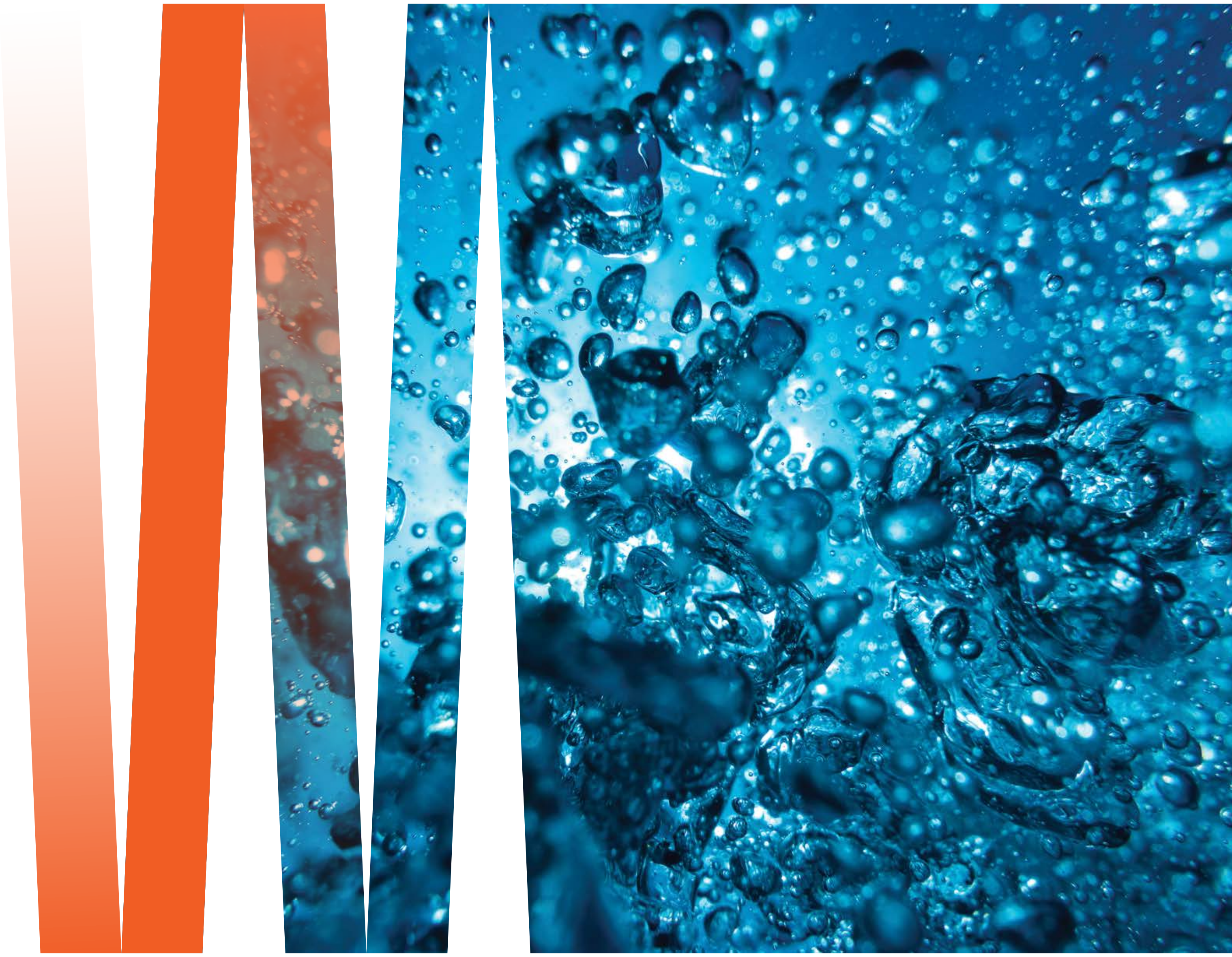
How chilled water systems meet data center availability and sustainability goals

White paper



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Executive summary

The data center industry continues to develop larger data centers to meet capacity demands, while at the same time taking steps to significantly reduce the impact of data centers on the environment. Companies like Vertiv design with sustainability in mind, developing data center solutions that help meet the needs of the present without compromising the ability of future generations to meet their own needs.

Cooling systems, and in particular, chilled water systems can play an important role in this evolution. They allow owners and operators to develop new data centers that efficiently address both direct and indirect emissions, which are factored into the total equivalent warming impact (TEWI) metric.

Today's chilled water systems reduce direct emissions by limiting the amount of refrigerant used compared to other technologies and enabling the use of new, greener refrigerant types available in the market. These systems also reduce indirect emissions when they adopt new technologies and the system is optimized via best practices regarding system control, which are described in this paper.

The ability of a chilled water system to drive down both direct and indirect emissions can help critical facility operators to achieve a lower TEWI. Chilled water systems can also effectively balance water and energy usage for efficient cooling systems to support a low water usage effectiveness (WUE, as defined by the Green Grid).

The combination of low TEWI and low WUE makes chilled water systems one of the most sustainable choices for data center thermal management in terms of energy and water efficiency. These systems have been adapted to follow the evolution of data centers to non-raised floor designs and can help facilitate the transition to liquid cooling.

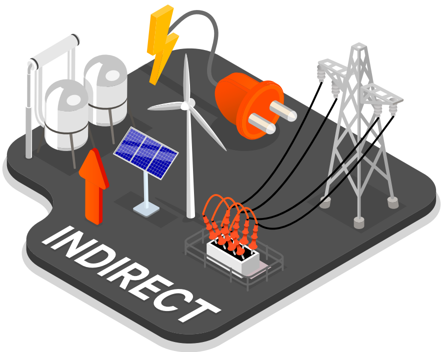
Evaluating the environmental impact of data center thermal management systems

Sustainability has become one of the most important strategies for businesses and government organizations and will be a major force shaping the future.

Thermal management systems — the systems that remove heat from data centers — can play a major role in improving the carbon profile of data centers because, in many facilities, approximately 25-35% of data center energy consumption can be attributed to air conditioning.

For a complete picture of a cooling system's environmental impact, operators must consider direct and indirect emissions.

- **Direct emissions** measure the impact on the atmosphere linked to a direct release due to a leak of a refrigerant fluid. Refrigerant fluids can have a significant greenhouse effect, thus increasing the world average temperature. In fact, refrigerant gases such as HFCs are considered "climate super-pollutants" with thousands of times the "global warming potential" of carbon dioxide. Global warming potential (GWP) is a measure of the contribution to the greenhouse effect of a gas relative to the effect of CO_2, which has a reference potential equal to one.



- **Indirect emissions** take into account the production of electricity used by the system during its operation. There is, therefore, a direct correlation between efficiency and indirect emissions when carbon-based energy sources are used. The more efficiently a unit operates, the less energy is required and the lower its impact on indirect emissions. Indirect emissions can also be reduced by increasing dependence on low-impact renewable energy sources.

TEWI is the algebraic sum defined under the Montreal Protocol, which represents the direct and indirect effects of the total carbon emissions of a cooling technology through its operating cycle. As a result, it serves as a valuable metric in evaluating how well a particular cooling system can support the move to carbon neutrality because it encompasses both the role of refrigerants and the energy consumed by the system.

Calculating TEWI

$$\mathbf{TEWI = (direct\ effect) + (indirect\ effect) = [GWP * L * n + (GWP * m + (1 - \alpha_{recovery})] + (n * E_{annual} * \beta)}$$

with:

GWP = Global warming potential (CO_2 eq. kg)

L = Leakage rate per year (kg/year)

n = System operating time (years)

m = Refrigerant charge (kg)

$\alpha_{recovery}$ = Recycling factor

E_{annual} = Energy consumption per year (kWh)

β = CO_2 emission per kWh

Analyzing the environmental impact of chilled water systems

By using TEWI as the measure of a cooling system's total carbon dioxide impact, it can be seen that chilled water systems have among the greatest potentials for reducing a data center's carbon footprint.

Direct effects of chilled water systems

There are several reasons chilled water systems are effective at reducing direct emissions. First, they have a limited overall refrigerant charge per kilowatt (kW) of cooling. In some cases, the refrigerant may not even be required as with data centers located in cold climates where heat is released through drycoolers or cooling towers. Other types of cooling systems, such as forced air systems, would require the use of refrigerants under these circumstances and typically yield a higher refrigerant charge/kW of cooling.

In a chilled water system, the refrigerant is stored in the chiller units. A chiller is a complete solution with a ready-to-use refrigerant circuit. The refrigerant circuit is also typically tested in the factory to exclude leakages, and further tested on-site after installation. This minimizes the potential risk of refrigerant losses. It is also common to use monitoring systems to identify a refrigerant leak in operation, allowing the unit to be stopped to prevent all the refrigerant from leaking.

Finally, chilled water systems can use a range of refrigerants to limit the impact on the atmosphere, including hydrofluoroolefin (HFO) and HFO-blended refrigerants that have a much lower GWP than traditional refrigerants, and are likely to become more common as the industry evolves. Further, chilled water systems are safer and more cost effective than alternative refrigerant cooling systems such as forced air HVAC systems, which would bring flammable refrigerants within data halls posing significant risk of combustion and requiring costly safety monitoring devices.

The U.N. Kigali Amendment, which was established to significantly limit the future production and consumption of hydrofluorocarbon (HFC) refrigerants, calls for an 80-85% reduction in the use of HFC refrigerants by the end of 2040. In addition, different regions across the world have set their own thresholds to limit the use of HFC refrigerants and encourage greater use of those with low environmental impact such as HFO refrigerants. For example, the U.S. Environmental Protection Agency mandated a phasedown of HFCs by 85% over the next 15 years, and the EU Commission implemented F-gas regulations that would limit the sale of HFCs to one-fifth of 2014 sales by 2030. The phase-down of HFC refrigerants is expected to prevent the emissions of up to 105 million tons of CO_2.

The result will be a progressive shift — similar to what occurred when chloroflourocarbons were phased out under the Montreal Protocol in 1993 due to their impact on the ozone layer — from traditional refrigerants such as R134a and R410A to low-GWP refrigerants, such as R1234ze, R1234yf and R454B.

However, most of these new HFO refrigerants are flammable or partially flammable. This raises new challenges during the data center design phase, especially if the refrigerant is used inside the white space or in direct contact with the air sent to IT equipment.

Chilled water systems offer a solution to this challenge by keeping flammable refrigerant outside the white space. Because the chillers are, in most cases, positioned outside or inside a machinery room, it is possible to use flammable or partially flammable refrigerants more easily than with other cooling systems.

To demonstrate how these refrigerants reduce the environmental impact of chillers, consider how the change impacts two commonly used types of chillers:

- Chillers for small and medium data centers with scroll compressors traditionally used R410A with a GWP of 1924 (AR5). Now they are available with R454B, which has a GWP of 466; R32 with GWP of 677; or natural refrigerants such as R290.
- Chillers for medium and large data centers with screw or centrifugal compressors traditionally used R134a, which has a GWP of 1300. Now they are using R513A, which has a GWP of 573 or R1234ze which has a GWP below 1.

Therefore, chilled water systems represent a highly effective alternative to traditional cooling systems while also reducing direct emissions as they do not require major investments or changes to the existing data center design.

Indirect effects of a chilled water system

One significant indirect effect of a cooling system is linked to use of electricity. The most common metric used to evaluate cooling system efficiency is partial power usage effectiveness (pPUE). pPUE is the ratio between the sum of energy used by the IT load and the cooling system divided by the energy used by the IT load. The lower the value, the more efficient the cooling system. A pPUE of 1 would represent a data center in which every watt of energy is being used by IT equipment and the cooling system uses no energy.

Today's chilled water systems, including Vertiv-supported systems, have the potential to support pPUE values lower than 1.1 in cities like Ashburn by using the optimization strategies described in the next section.

Optimizing chilled water systems

Following are the optimization strategies that help chilled water systems to achieve excellent efficiency. Simulations demonstrating the effectiveness of each of these strategies are provided in the appendix of this paper.

Increasing air and water temperatures

Just a few years ago, the standard working temperature of a data center white space was approximately 24 degrees Celsius. Today, it isn't unusual to have data centers running between 24 and 25 C in front of the servers, with return air to the indoor cooling units at 36 to 37 C. Water temperatures have seen a similar evolution, rising from the 10-15 C that was common in the past to 15-18 C and even higher. Some large hyperscalers have raised inlet temperatures for computer room air handler (CRAH) units above 20 C.

This significant rise in temperatures calls for an increased use of free-cooling technologies, which use colder ambient air (colder than the supply chilled water set point) to perform cooling rather than the refrigeration cycle of the chiller. Such systems can exploit cold external air temperatures as the main source of cooling, limiting the use of the direct expansion (DX) systems to cover the peaks occurring in the hottest periods of the year. This is enabled by moving from simple chillers to more advanced solutions such as free-cooling chillers. This combines free-cooling's very high efficiency with continuous cooling availability under any condition ensured by the DX system. In addition, the embedded control of the free-cooling chillers can enable "mixed mode" operation where the compressor intervenes during mid-season conditions to compensate for the higher air temperatures that limit free-cooling.

Optimizing the chilled water system control

A second step to maximize chilled water system efficiency is to optimize the system as a whole by coordinating operation of the external units with the internal ones. This is accomplished by using chilled plant managers that can coordinate the operation of all units within the chilled system. With this level of control, plant managers can optimize multiple chillers operating in variable flow to reduce the consumption of the pumps and increase the return temperatures of the fluid to the chillers.

In some cases, plant managers can also implement operating temperature optimization logic in relation to the different operating conditions of the data center. These controls include dynamic water control capabilities that can optimize the operating water temperature in relation to the data center load, drastically improving the efficiency of the chillers while also ensuring the optimal temperature at the front of the servers.

Improved compressor technology

In a data center located in a mild climate, a large part of the total energy absorption is due to the chiller compressor. The use of innovative and efficient compressor technologies can therefore help achieve improved compressor efficiency. In recent years there has been an increased use of inverter driven compressors which allow significant benefits in terms of efficiency. Freecooling chillers that use inverter driven screw compressors or oil free centrifugal compressors are thus now available to enhance the energy efficiency of chilled water systems and consequently cut down electricity consumption.

Adiabatic system

Another innovative way to improve the efficiency of a chilled water system is with free-cooling chillers using adiabatic technology. The adiabatic system (especially if used with an adiabatic pad system) is suitable for extensive use throughout the year and not only in peak conditions, leading to significant benefits. In an adiabatic system, the ambient air is humidified and cooled without incurring any additional energy costs by passing the air through wet pads. The air is then delivered at a lower temperature to the free-cooling and condensing coils, achieving a higher free-cooling capacity and more efficient compressor operation, respectively.

Another relevant metric in evaluating cooling system sustainability is WUE which is calculated by dividing the annual site water usage in liters by the IT equipment energy usage in kilowatt-hours (kWh). This metric is particularly valuable for those operating in or considering expansion into a high stress water region.

The issue of high water usage in data center cooling is mainly related to open loop systems where water is used to spray heat exchangers to enlarge the operating field or to take advantage of free-cooling savings.

Adiabatic chillers and evaporative outdoor packaged solutions are open loop systems but use onboard controllers to enable the use of water strictly when needed based on redundancy, efficiency, or cooling demand. The controller's primary job is to prevent water from being wasted, reducing the WUE of the data center.

Water is also used when air within the white space needs to be humidified, and in specific conditions, air conditioning provides both latent and sensible cooling capacity. Vertiv designs its floor-mount units with wide exchange surfaces to provide sensible cooling capacity without the need for humidification. If well manufactured, the water loop is completely sealed, and once filled, requires no additional water (i.e., no water wasted). Efficient use of water can help drive down the pPUE of the system and that can be achieved by limiting water use to certain conditions through effective use of controls.

Heat recovery

Heat recovery can increase the efficiency of the chiller water system by allowing heat captured from the data center to be reused for other purposes. Instead of cooling the heat load, heat is effectively captured by the system and can be used to meet heating demand in other parts of the building, neighboring buildings, or a district heating network. This strategy can be applied to legacy data centers, even when captured heat temperatures are low by using a heat pump to increase the temperature.

Cooling storage

Cold water storage tanks are an effective means for reducing energy consumption, as these tanks serve as thermal energy storage (TES) that help alleviate power plant loads during peak demand. Facilities ramp up their chiller systems at night to make cold water, taking advantage of lower night-time rates. These facilities then rely on this stored cooling capacity for day-time cooling.

Supporting non-raised floor applications

To build data centers more quickly and keep up with growing demand while controlling costs, developers of large data centers — colocation and hyperscale operators with 2-5 MW for each data hall — are moving away from raised floor designs. This trend has prompted the need to switch from standard perimeter chilled water CRAH units to a new approach. This is because standard units, when applied to a non-raised floor data center environment, can introduce the risk of high-velocity airflow at the front of the first row of racks, creating negative pressure to the servers. For small and medium data centers of less than 2 MW per hall, a partial transition to non-raised floor designs is more likely.

This airflow problem can be addressed by applying new solutions that create positive pressure in front of the racks. Vertiv has designed several products with a larger delivery surface area to allow for balanced pressure throughout the server rows. The main solutions are perimeter chilled water systems specifically for non-raised floor applications and several thermal wall units that have designs based on an air handling unit concept.

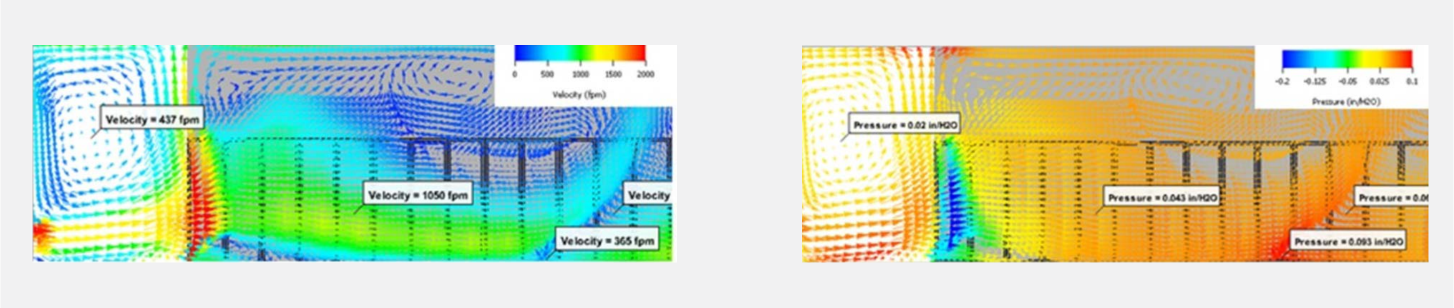


Figure 2. *Standard perimeter chilled water CRAH units create high velocity airflows that translate into negative pressures at the front of the first racks.*

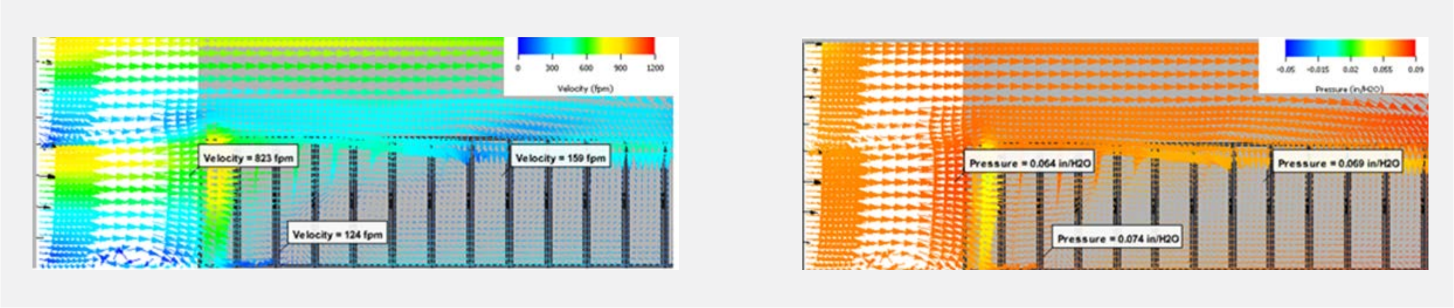


Figure 3. *Chilled water units for non-raised floor applications help lower airflow velocities to balance pressures across the row.*

Non-raised floor applications require greater expertise and effort in the design phase, particularly to guarantee the right airflow and cooling distribution to each rack. Raised floor applications are less challenging because designers simply need to ensure that positive pressure is maintained under the floor, adjusting airflow delivery with the floor grills.

Non-raised floor applications also introduce challenges when implementing accurate static pressure control measurements, mostly because the space to be measured is significantly larger. For this reason, Vertiv, in addition to developing the right products for this application, also developed several software functionalities.

One of these functions can use the Delta T (ΔT) control approach to cooling a non-raised floor data center which presents a number of benefits compared to focusing solely on air pressure. Using air pressure in combination with ΔT, which measures the difference in return and supply air temperatures, goes one step further and brings additional benefits. Air pressure control can still be used to allow cooling units to provide a certain minimum amount of airflow while enabling fan speed to be determined by temperature.

Vertiv is continually developing new solutions to meet the demand for both raised and non-raised floor applications with indoor products that deliver efficiency, cooling density, reliability, and improved control.

Looking to the future: liquid cooling

Businesses across a wide range of industries are turning to artificial intelligence and other processing-intensive applications to create competitive advantage. These applications require high density computational platforms, resulting in a rapidly changing thermal challenge for data centers to manage.

There are no energy efficient alternatives to liquid cooling for some of the fastest-growing business applications that data centers with high rack densities are being expected to support. The process of introducing liquid cooling into an air-cooled data center requires careful planning and engineering, but the technologies and best practices are available today to support a successful and minimally disruptive deployment.

When introducing high-density racks, it's necessary to determine how much of the total heat load each system will handle, how much cooling capacity is required, the amount of capacity to be displaced by the liquid cooling system, and the remaining air-cooling capacity required. Technologies to consider when deploying a liquid cooling system include rear-door heat exchangers, direct-to-chip liquid cooling, and immersion cooling. The combination of chilled water systems and liquid cooling helps data center operators realize sustainable thermal solutions for their critical facilities.

Benefits of chilled water systems

There are multiple benefits that position chilled water systems to become one of the most applied global cooling technologies in the data center space in the coming years.

Sustainability: A new era has started for the data center industry, prompting operators to find alternatives to traditional HFC refrigerants that improve overall system efficiency and reduce energy consumption. The chilled water system is one of the first cooling technologies to incorporate low-GWP refrigerants in the chiller units. In addition, these systems can achieve pPUE values below 1.1 by adopting the newest technologies available in the market with an optimization and integration of the overall chilled water system.

Design: Many new refrigerants are flammable or partially flammable, and this must be considered in the design phase, especially when the refrigerant will be used inside the white space or in direct contact with the air delivered to IT equipment. For this reason, chilled water systems offer an excellent solution because they are typically installed outside, keeping any flammable refrigerants out of the data center.

Flexibility: The chilled water system provides flexibility in terms of the positioning of outdoor cooling units because they do not require a fixed configuration and there are no physical limits (aside from the pump size) for the proximity of the units.

Continuity: If the chilled water piping does not have enough thermal inertia to provide cooling during a loss of power, auxiliary cold-water storage tanks can significantly increase a data center's thermal reserve. When chillers stop, due to a power loss, water from the tanks can supplement the chilled water supply to keep the data center environment cold enough and close to normal operating temperatures. Cold water tanks have a much lower initial cost than other approaches. Based on the tank dimension, it's possible to calculate the time the system can maintain cooling during an outage.

High-density Support: As of today, liquid-cooling is one of the most efficient methods to achieve high density cooling for some of the fastest-growing business applications data centers are being expected to support. While there are liquid-only data centers being developed and some new air-cooled data centers are being designed to accommodate liquid-cooled racks in the future, the most common scenario that operators are facing today is integrating liquid cooling into existing air-cooled facilities that lack the infrastructure to support it. Having a chilled water system design simplifies this transition and provides greater flexibility to combine different indoor units for different applications and IT densities.

For more information on liquid cooling, see the Vertiv white paper, Understanding Data Center Liquid Cooling Options and Infrastructure Requirements.

Conclusions

In a landscape of rapid expansion, the data center space is not likely to consist of just one environment, and Vertiv™ Liebert® chilled water systems for thermal management ensure a consistent approach globally. The chilled water system can be perfectly adapted to today's data center requirements, achieving immediate benefits while ensuring flexibility for the future.

Appendix

Chilled water simulation

Vertiv analyzed several optimizations strategies for chilled water systems to demonstrate the impact those optimizations can have on the different parameters analyzed.

The simulations were performed on a 15 MW data center with three data halls (5 MW each) situated in Ashburn, Tokyo and Dubai. The chilled water cooling system serving each data hall is comprised of:

- 5 (N+1) chillers - 1250 kW nominal capacity
- 28 (N+1) CRAH units - 185 kW.

The simulation considers a data center loaded at 80% maximum IT load (12 MW), as this represents a significant working condition for the current data center. All data halls have also been considered to be loaded at the same percentage.

We have considered five different scenarios:

Chilled water simulation for Ashburn

A. Baseline

A chilled water system working at a temperature of 10 to 15 C, composed of five standard chillers and 28 CRAH units, resulting in a pPUE value of 1,217.

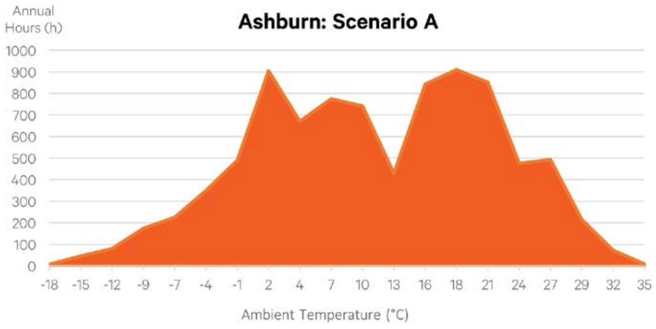


Figure 1. *Ashburn profile: Traditional Chilled Water System*

B. Increasing air and water temperatures

Increasing the water temperature of the chilled water system, working from 10 to 15 C to 20 to 28 C, and the return air temperature from 26 to 36 C provides a supply air temperature to the server below 25 C that is in compliance with recommendations from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), while introducing a free-cooling chiller instead of a standard chiller reduces the pPUE value from 1,217 to 1,128.

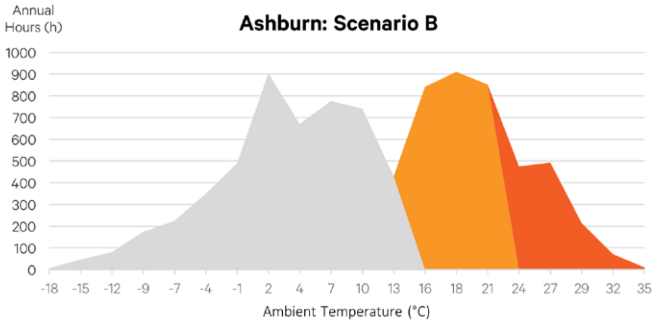


Figure 2. *Ashburn profile: With increased air and water temperatures*

C. Optimizing the chilled water system control temperatures

In addition to configuration B, a plant manager has been integrated to optimize the water flow control and leverage the dynamic water control system reducing the pPUE value even further, from 1,128 to 1,117.

D. Improved compressor technology and low-GWP refrigerant

In addition to configuration C, a free-cooling chiller with inverter driven compressor and low-GWP refrigerant has been added, thus reducing the aforementioned pPUE value even further, from 1,128 to 1,106.

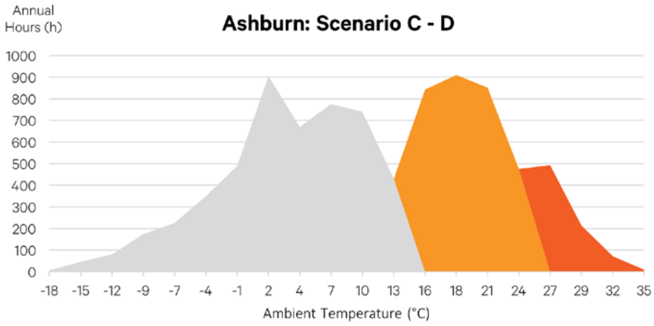


Figure 3. *Ashburn profile: With optimized chilled water system control, improved compressor technology and low-GWP refrigerant*

E. Adiabatic system

In addition to configuration D, by adding an adiabatic configuration to the five chillers, the system can reach a pPUE of 1,094, further explained in Figure 4.

Figure 4 also illustrates that with the adiabatic system the chilled water system never fully works in direct expansion mode but is able to in free-cooling or mixed mode, thus improving overall efficiency and reducing costs.

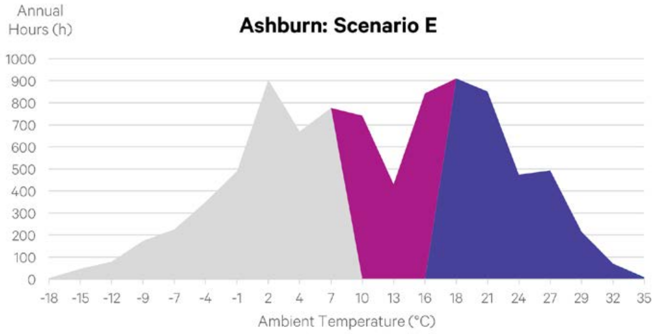


Figure 4. *Ashburn profile: Including the adiabatic system*

Ashburn 12MW	pPUE	WUE [l/kWh]	TEWI (10y) - total ton of CO$_2$			Freecooling hours [h]	FC + Mixed mode [h]
			Direct	Indirect	Total		
Baseline	1.217	0.000	689	109572	110261	0	0
Increasing air and water temperatures	1.128	0.000	344	64441	64785	4892	7496
Optimization of the chilled water system control	1.117	0.000	344	59250	59594	4892	7971
Improved compressor technology and Low GWP refrigerant	1.106	0.000	1	53735	53735	4892	7971
Adiabatic system	1.094	0.277	1	47234	47235	5734	8751

Table 1. *Ashburn profile: Summary of the impact that each improvement provides to the overall chilled water system.*

Chilled water simulation for Tokyo

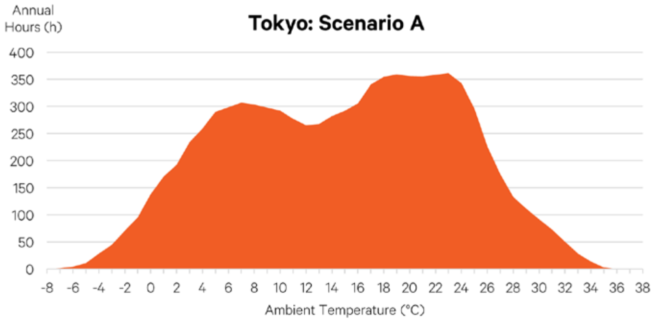


Figure 5. *Tokyo profile: Traditional Chilled Water System*

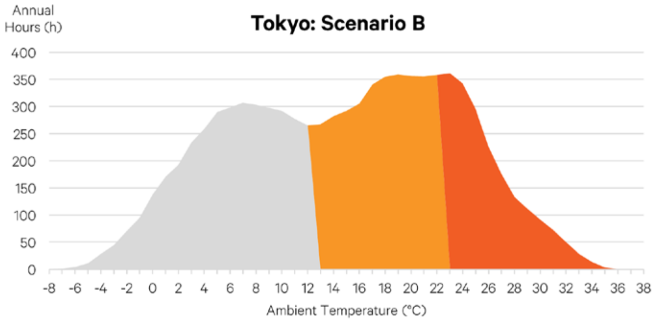


Figure 6. *Tokyo profile: With increased air and water temperatures*

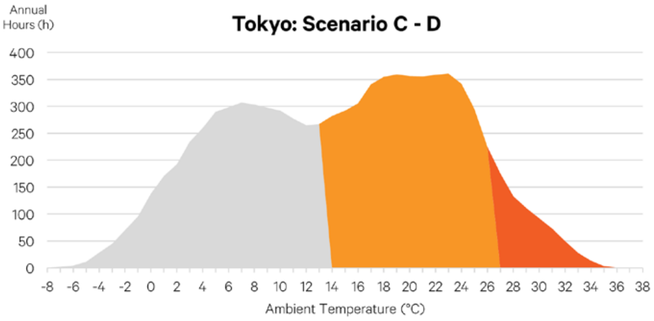


Figure 7. *Tokyo profile: With optimized chilled water system control, improved compressor technology and low-GWP refrigerant*

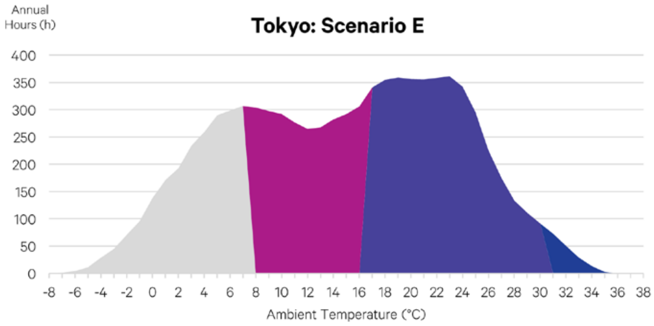


Figure 8. *Tokyo profile: Including the adiabatic system*

Tokyo 12MW	**pPUE**	**WUE [l/kWh]**	**TEWI (10y) - total ton of CO_2**			**Freecooling hours [h]**	**FC + Mixed mode [h]**
			Direct	**Indirect**	**Total**		
Baseline	1.235	0.000	735	102937	103671	0	0
Increasing air and water temperatures	1.144	0.000	372	63044	63417	3581	6854
Optimization of the chilled water system control	1.132	0.000	372	57902	58274	3849	8079
Improved compressor technology and Low GWP refrigerant	1.118	0.000	1	51656	51657	3849	8079
Adiabatic system	1.108	0.253	1	47290	47290	4729	8591

Table 2. *Tokyo profile: Summary of the impact that each improvement provides to the overall chilled water system.*

Chilled water simulation for Dubai

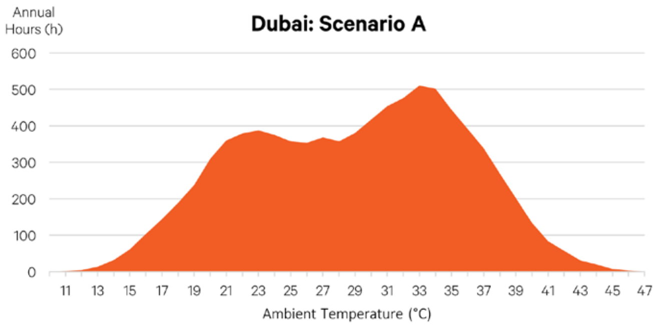


Figure 9. *Dubai profile: Traditional Chilled Water System*

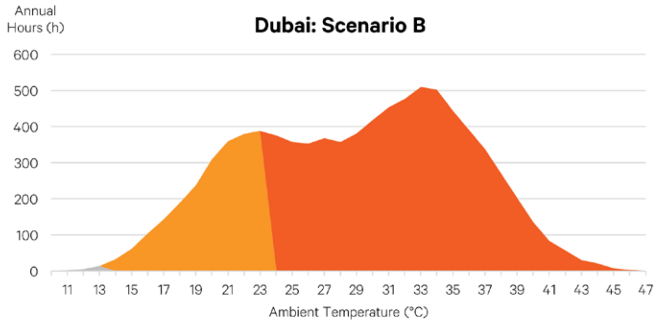


Figure 10. *Dubai profile: With increased air and water temperatures*

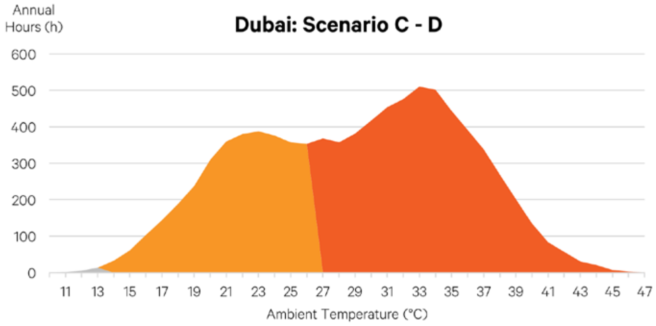


Figure 11. *Dubai profile: With optimized chilled water system control, improved compressor technology and low-GWP refrigerant*

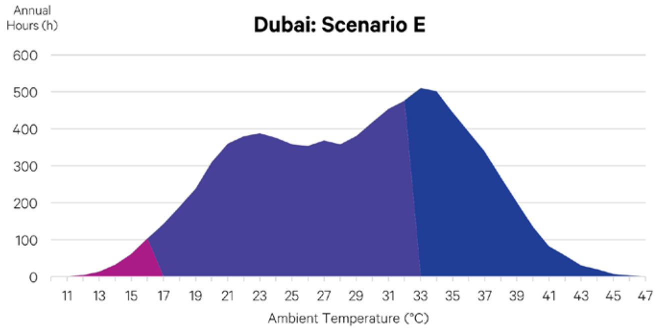


Figure 12. *Dubai profile: Including the adiabatic system*

Dubai 12MW	pPUE	WUE [l/kWh]	TEWI (10y) - total ton of CO_2			Freecooling hours [h]	FC + Mixed mode [h]
			Direct	Indirect	Total		
Baseline	1.300	0.000	767	189298	190065	0	0
Increasing air and water temperatures	1.244	0.000	391	153606	153997	20	2226
Optimization of the chilled water system control	1.234	0.000	391	147674	148065	20	3312
Improved compressor technology and Low GWP refrigerant	1.214	0.000	1	134765	134766	20	3312
Adiabatic system	1.174	0.988	1	109743	109743	218	5766

Table 3. *Dubai profile: Summary of the impact that each improvement provides to the overall chilled water system.*

Legend:

🟧 DX = Mechanical cooling
⬜ FC = Freecooling
🟧 MIX = Mixed mode
🟦 A + DX = Adiabatic + Mechanical cooling
🟪 A + FC = Adiabatic + Freecooling
🟪 A + MIX = Adiabatic + Mixed mode

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