

Liquid-Cooling Trends In Data Centers

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In previous columns, the use of airside or waterside economizers was explored as a method to reduce the energy use in datacom facilities. The goal of all these systems, whether air-cooled or water-cooled, was to provide a cooling airstream to the electronic equipment, which is typically arranged in racks positioned throughout the facility.

ASHRAE has published thermal guidelines for datacom facilities that allow higher air temperatures in the conditioned space that can extend the hours of economization and hence increase the energy savings substantially. To further improve the efficiency of the cooling system and handle ever-increasing heat loads, these racks are placed in hot aisle/cold aisle configurations often with strategically placed blanking plates to help direct the cooling airstream optimally over the electronic equipment while simultaneously keeping the warm leaving air from mixing with the cool incoming air (*Figure 1*).

Despite such efforts to improve cooling with air, significant growth in heat loads and heat density per rack has challenged the ability of air to provide adequate, reliable, and economic data center cooling. Higher heat loads generated by electronic equipment can have detrimental side effects, such as reduced equipment availability, wasted floor space, and inefficient cooling system operation. To help meet these ever-increasing challenges, the use of liquid cooling is growing, prompting ASHRAE TC 9.9 to develop the ASHRAE Datacom Series book *Liquid Cooling Guidelines for Datacom Equipment*

Centers, as well as several white papers. Like the thermal guidelines for datacom facilities cooled by air, ASHRAE has established a set of temperature guidelines for liquid-cooled facilities depending on the Liquid Cooling Class, defined as W1 through W5, as shown in *Figure 2*.

The overall goals of these liquid cooling implementations include benefits such as:

- Enabling higher rack power densities to decrease required data center footprint;
- Efficiently transferring waste heat to the facility water system (FWS);
- Allowing liquid-cooling loop temperatures to be as warm as possible to:
 - Increase the efficiency of rejecting the heat to the atmosphere while significantly increasing the hours of economization;
 - Enable captured heat to be used for other beneficial purposes;

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- Reducing the overall volume of airflow needed by the equipment racks, lowering fan energy;
- Increasing computing performance, extending server life, and reducing the risk of failure of the electronics, all thanks to cooler operating temperatures;
- Increasing usable data center space by reducing the size or even eliminating traditional cooling equipment, such as chillers and air handlers; and
- Reducing overall energy use of the datacom facility by increasing cooling efficiencies and thus power usage effectiveness (PUE).

Keep in mind that water and other heat transfer fluids can move, on a pound-for-pound basis, nearly 4.2 times the amount of heat as compared to air. As water is also significantly denser than air, on an equivalent volumetric flow rate basis, water can transport over 3,700 times more heat than air. This significantly reduces the “pumping” (fan) energy along with the thermal transport conduit size (duct versus pipe) within the facility.

So just what is “liquid cooling”? In our context, liquid cooling refers to bringing a cooling fluid close to the heat source, which ultimately are the processor chips and other electronics in the data center. This is not a new concept as many high-powered mainframes of the past had liquid-cooling circuits inside the cabinetry to carry away the large quantities of heat generated. The specific problem was that the density of the heat load did not allow enough air to flow through the electronics to keep them from overheating and subsequently failing. The industry moved to cooling with air as mainframes were replaced with distributed computing and air proved to be a lower cost alternative. Additionally, many data center managers were concerned about bringing cooling fluids in close proximity to the electronics where a leak could affect reliability and uptime.

Liquid cooling can take many forms. One of the simplest involves finned coil modules, either with or without fans, that are supplied with a cooling fluid and produce a cooling airstream directed toward the racks. Such

FIGURE 1 Sealed hot aisle/cold aisle rack configuration. (NREL report number BR-7A40-47201, February 2010, original source Rumsey Engineers)

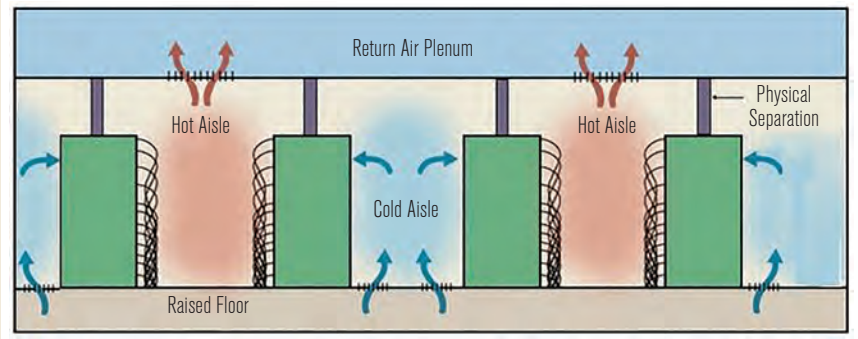
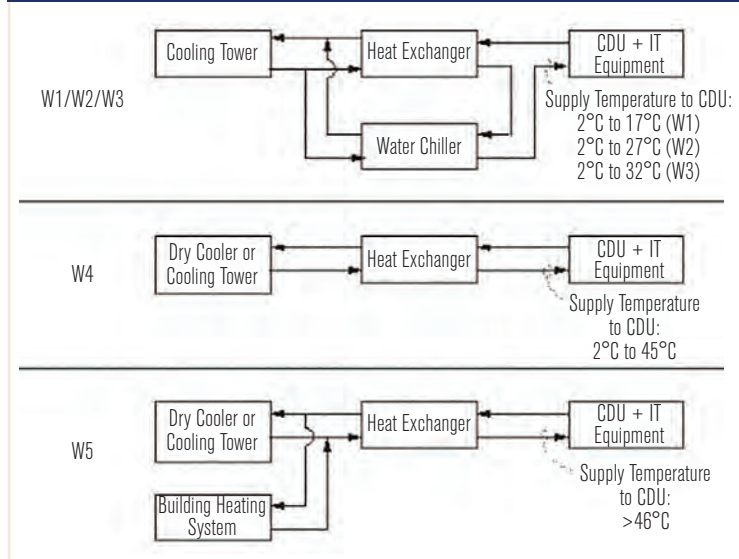


FIGURE 2 Typical infrastructure design schematic for each liquid cooling class.



units are placed in the aisles of the data center, including in-row and overhead locations to either deal with hot spots or provide dedicated cooling on specific high-power racks. These cooling modules can also be placed in the racks or cabinets themselves. While the cooling fluid is closer to the electronics in these embodiments, note that air continues to perform the cooling function at the actual heat sources.

The real opportunity for liquid cooling lies in bringing the cooling fluid more directly in contact with the heat sources in the data center. Because the electronics operate at a much higher temperature (up to 212°F [100°C] or more), the ability of warmer liquid flows to carry away this heat is significantly increased thanks to the greater temperature difference. *Liquid-cooled datacom equipment* has liquid circulated within the datacom equipment for heat removal. The heat from this fluid can be rejected directly to the facility water system (FWS) as shown

in Figure 3. These arrangements are often utilized on higher-powered racks in a data center.

Liquid-cooled electronics defines the cases where liquid is supplied directly to the electronics at the board level for cooling with no other form of heat transfer, as shown in Figure 4. The use of such liquid-cooling systems can range from cooling all the electronics in a data center to cooling only the higher-powered equipment in a facility to ensure its performance as well as reduce overall cooling load. This latter method can often be found in mixed use, colocation-type data centers.

The fluid used in liquid cooling can be either water or a refrigerant, depending on the specific system. Aqueous glycol solutions are typically not used within the data center due to the logistical challenge of cleaning up a leak inside the facility. When glycol is required for freeze protection of outside heat rejection equipment, an isolation heat exchanger is often used with water on the opposite side. Alternatively, a freeze-protected dry cooler employing a refrigerant loop can be utilized.

In another embodiment, the electronics can be fully immersed in a non-conductive cooling liquid, such as mineral oil or a refrigerant. For these applications, an isolation heat exchanger is also used to cool the immersion fluid, which is typically viscous, saving pumping energy while avoiding level issues in the immersion baths for the servers as shown in the system in Photo 1. Immersion cooling has several additional advantages:

- No cooling fans are required in the servers, offset by any additional pumping energy, resulting in the potential for lower PUE values;
- Oxidation is reduced because the electronics are not exposed to large volumes of air, which can carry particulates, gases, etc.;
- Failures due to thermal expansion/contraction are eliminated; and
- The immersion fluid provides greater resiliency in the event of a cooling system failure—up to 30 minutes versus approximately two minutes for cooling systems using air.

Successful application of liquid cooling in a datacom facility requires following key design considerations centered on the piping of the liquid throughout the electronic space. These include, but are not limited to the following:

- Route liquid piping below the electronics—avoid overhead piping that can drip on the equipment wher-

FIGURE 3 Liquid-cooled datacom equipment.

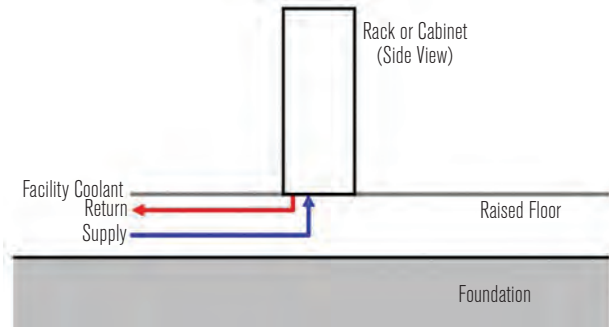
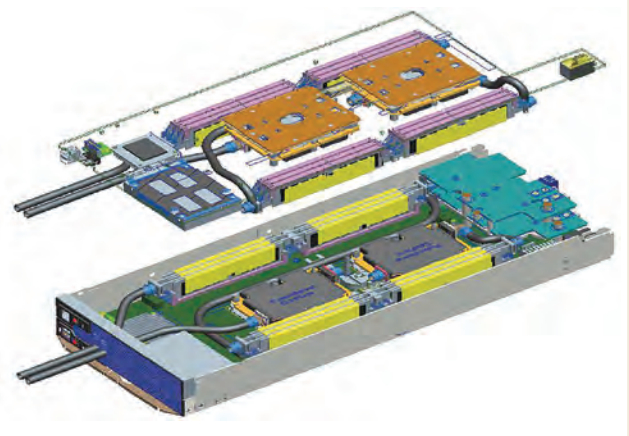


FIGURE 4 Flexible hose connects CPU cold plates and other cooling structures in a server.



ever possible;

- Confine piping to pipe galleries, chases, utility pits, etc., wherever possible;
- Use higher liquid-cooling loop temperatures where possible along with the appropriate insulation on piping to avoid the possibility of condensation;
- Use shut-off valves to enable safe servicing and modification of sections of the liquid-cooling loop;
- Properly locate balancing and/or control valves in the liquid-cooling loop to balance flows to each area;
- Properly size the circulating pumps and where possible, use variable speed pumping to enhance temperature control and save additional energy;
- Oversize piping, use large radius elbows, etc. and specify premium pump motors, all of which offer short paybacks due to 24/7 operation;
- Allow for expansion and contraction in the pipe-work as well as design for seismic forces;
- Where required, use good quality, drip-less quick connects and flexible hoses that run to and from the

liquid-cooling loop and the liquid-cooled equipment;

- Select the appropriate piping and heat exchanger materials and an appropriate water treatment system for the closed liquid-cooling loop (TCS);
- Monitor and maintain the proper fluid quality in both the FWS and the technology cooling system (TCS);
- Evaluate the various piping layouts that are possible, considering reliability, redundancy, serviceability, flow balancing, system complexity, and lastly installation costs (piping is not an area to cut costs in a liquid-cooled datacom facility!); and
- Consider any future expansion plans for the facility, including the use of higher power racks.

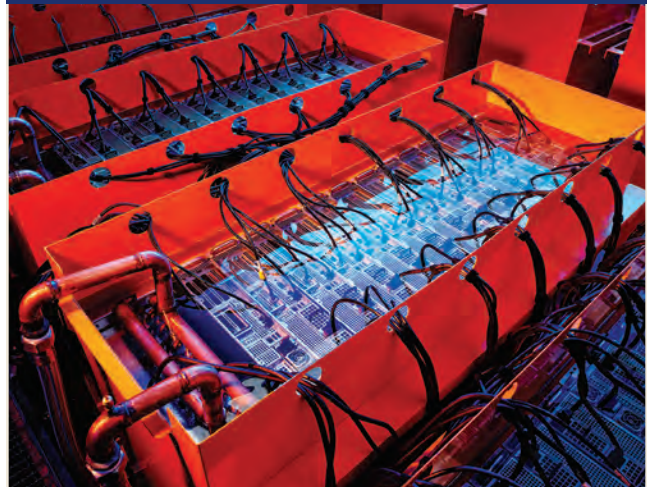
Another important consideration is the temperature control system, which is important to protect the electronic equipment, prevent condensation, and save energy. Many liquid-cooled data centers utilize coolant distribution units (CDU) to help properly distribute and temper the fluid entering the electronics from the TCS. CDUs, which may be internal or external to the racks, typically house a heat exchanger, one or more circulating pump(s), and service valves. These units also isolate the TCS from the FWS, which allows the use of a different fluid while reducing the potential leak volume and the risk of condensation. Because of their importance, CDUs will often be placed on a UPS to ensure continued operation in the event of a power interruption.

For further detail on liquid-cooled data centers, be sure to read the feature article in this month's Journal, "Moderating the Impact of Integrating Water-Cooled Servers into Data Centers" (Page 20).

Heat Rejection Options

Liquid-cooled equipment and electronics offer abundant opportunities for handling higher power in a facility in an energy-efficient manner. The use of water-side economization complements this trend by being able to provide a less energy intensive and lower cost source of cooling. For instance, a processing chip may operate at 185°F (85°C) which can be readily cooled by a fluid stream with an inlet temperature of 104°F (40°C).^{*} As discussed earlier, specialized racks are also available that completely submerge the servers in a non-conductive liquid. Heat is then rejected from this fluid either

PHOTO 1 Liquid-cooled high performance server array with cooling distribution unit (CDU) in tank. Courtesy DownUnder GeoSolutions



directly or indirectly to the cooling system. In all these cases, temperature control is essential to keep from undercooling or overcooling the electronics or causing thermal shock due to very cold fluid cooling very hot chips. Hence, the frequent use of CDUs to control the fluid temperatures to what is required in the various areas of the facility.

Liquid-cooling systems offer the possibility of designing 100% water-side economization cooling systems for the electronics (Classes W2 through W5, depending on design temperatures and climate). Cooling of the economizer fluid can be handled through a variety of heat rejection methods, like those described in our March 2019 column on "Designing Waterside Economizers—Part 3." Due to the need to protect the liquid-cooling loop inside the data center, all heat rejection options involve closed circuit cooling to ensure a clean, closed system, reducing fouling and system maintenance. This system also accommodates variable speed pumping, which offers the potential for further energy savings. Keep in mind that even in a fully liquid-cooled data center, a more conventional, though smaller HVAC system would still be required to maintain the overall room conditions for both the building environment and the datacom technicians who work in the facility. Since liquid cooling is available, these HVAC systems are often water cooled.

Heat rejection options for a liquid-cooled data center depend on the specific needs of the facility driven in

^{*}Liquid Cooling in Data Centers. ASHRAE Transaction Paper CH-09-025, T. Cader, L. Westra, V. Sorel, and A. Marquez, 2009, page 235.

part by the operating temperature of the liquid-cooling loop and the local climate. For centers requiring relatively cold design fluid temperatures or are in a “hot” climate, a conventional chiller, either water-cooled or air-cooled, can be used (typically Class W1 or W2). The higher the fluid temperature that can be tolerated by the equipment, the more efficient the chiller will operate and the greater opportunity for economization. Both air- and water-cooled chillers can be equipped with economizer circuits to allow a reduction in the mechanical cooling energy as outside temperatures and loads decrease throughout the year.

For most facilities, evaporative heat rejection, which is based on the wet bulb of the air (which is typically lower than the dry bulb), offers the highest number of potential hours of economization. By designing for higher TCS liquid temperatures (i.e., 85°F [29.4°C]), chiller-less data centers can be considered (Class W4). Open circuit cooling towers offer the most efficient operation thanks to the direct cooling of the recirculating water by the entering air to the unit (*Photo 2*). However, because of the need for clean, closed loops, open circuit cooling towers must be isolated from the FWS by plate & frame heat exchangers. The approach across the heat exchanger, typically about 3°F (1.7°C), must be considered in the design. As an example, for a cooling tower producing 85°F (29.4°C), the design fluid temperature to the liquid-cooled equipment would be 88°F (31.1°C) from the other side of the heat exchanger.

A closed-circuit cooling tower, or fluid cooler, can also be used, which combines the function of an open circuit cooling tower and a heat exchanger together into one compact unit (*Photo 3*). The coil in the unit is typically hot dip galvanized steel though stainless steel coils are also available if required due to corrosion considerations. The fluid from this unit can be used directly in the FWS, eliminating the need for a separate plate & frame heat exchanger. Fluids other than water can also be cooled in closed circuit cooling towers, such as aqueous glycol solutions, which may be required in colder climates.

Open circuit cooling towers can operate with entering water temperatures up to a maximum of approximately 120°F to 140°F (51.7°C to 60.0°C), depending on the fill type and material. Closed circuit cooling towers generally have an entering fluid temperature limit of approximately 180°F (82.2°C). While open circuit cooling towers

PHOTO 2 Open circuit cooling towers on a liquid-cooled data center. Courtesy of National Center for Supercomputing Applications (NSCA)



PHOTO 3 Closed circuit cooling towers being installed on a liquid-cooled data center in Houston. Courtesy of DownUnder GeoSolutions



will typically offer the lowest fan horsepower for the cooling tower, both tower types offer lower fan and system energy use than air-cooled alternatives while being able to achieve lower design fluid temperatures. Since a closed loop is required, the cost of a closed-circuit cooling tower will be comparable to an open circuit cooling tower coupled with a plate & frame heat exchanger for the same cooling duty. Closed-circuit units can also be selected to operate dry in the event of a water disruption to the facility. Their dry capability can be enhanced by finning the coil surface in the unit.

For areas where makeup water is expensive or in short supply, hybrid closed circuit cooling towers are available which contain both evaporative and finned heat exchange sections. These units are capable of operating in either “wet” (evaporative) mode or dry mode, saving water and reducing visible plume during colder weather. Hybrid units can be selected for

relatively high dry bulb switch points between wet and dry operation. Alternatively, conventional closed-circuit cooling towers or open circuit cooling towers coupled with plate & frame heat exchangers can be paired in series with dry coolers. The dry coolers begin to handle part of the load as the outside air temperature drops until the air temperature is cold enough that the dry coolers can handle the entire load. The evaporative heat rejection units essentially function as trim coolers when needed to provide the design liquid temperature.

For facilities located in moderate climates that are designed to operate with relatively warm supply fluid (113°F [45°C] or higher), dry coolers can be utilized for the heat rejection duty. The main advantage is that makeup water is not needed in a dry cooler based system, nor a backup water supply. Offsetting this advantage is much higher fan horsepower for the same thermal duty (though no open loop recirculating spray pump is required), along with a significant increase in the plan area required for the heat rejection equipment. Like closed circuit cooling towers, the use of glycol must be considered in sub-freezing climates. Alternatively, freeze-protected dry coolers employing a thermosyphon refrigerant loop can operate with water in the closed cooling loop.

To offset this higher fan energy and footprint while expanding the applicable climate zones of air-cooled alternatives, adiabatic fluid coolers can be considered. These units consist of a dry cooler with a wetted precooling section that adiabatically lowers the air temperature entering the finned coil section close to the wet-bulb of the entering air. The pre-cooling section typically consists of

evaporative cooling pads that are wetted with water from either a small integral sump that is drained multiple times per day or the potable water system on a once through basis. The design fluid temperature off these units is lower than that achievable from dry coolers but higher than traditional closed-circuit cooling towers. Water use is also less with this

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technology than that of either open or closed-circuit cooling towers for the same heat load.

No matter what heat rejection alternative is chosen, the ability of the system to reject the load at the specified temperature conditions is critical. To achieve the full energy-saving potential of liquid cooling, variable speed fan systems should be utilized on heat rejection equipment to enhance system control, minimize energy use, reduce fan system maintenance, extend fan system life, and comply with code requirements.

Furthermore, equipment with independently verified thermal performance should be specified or, in lieu of certification, a field test should be required. For instance, the thermal performance of open circuit and closed-circuit cooling towers should be certified per CTI STD-201RS, *Performance Rating of Evaporative Heat Rejection Equipment*, or a thermal test by a licensed, third-party testing agency should be performed, using CTI ATC-105 for open circuit cooling towers and CTI ATC-105S for closed circuit cooling towers. Note that the Cooling Technology Institute has recently published their *Acceptance Test Code for Dry Fluid Coolers* (ATC-105DS) which can be used to verify performance claims in the field for these devices. In Europe, Eurovent Certita offers a certification program for dry coolers. Additionally, an acceptance test code for adiabatic fluid coolers is currently under development by the CTI.

The higher fluid temperatures possible with liquid-cooling systems also increase the potential for the reclaim of the waste heat for many symbiotic uses such as building heating, greenhouses and fish farming (typically Liquid Cooling Class W5, but all classes have the potential for some heat recovery, depending on the leaving fluid temperature). This, in turn, can reduce the amount of heat that needs to be rejected to the atmosphere.

Lastly, natural sources can be utilized for cooling the liquid-cooling loop. These include seawater, lake, or ground source cooling if available. Each of these options present unique challenges that must be dealt with, such as corrosion and long-term reliability. A hybrid approach is often called for due to high expected uptime requirements for data centers, such as a ground source cooling system integrated with a closed-circuit cooling tower for redundancy in the likely event of problems with a well field in a cooling-only application.

Summary

With the relentless increase of heat loads within data-com facilities, the trend to liquid cooling is growing significantly. Higher temperature liquid cooling offers the prospect of greatly reducing or even eliminating the need for mechanical cooling by replacing it with 100% fluid economizer systems. The potential for heat reclaim is also enhanced thanks to the higher allowed fluid temperatures. Liquid cooling can be selectively utilized for handling the higher-powered racks in a data center, helping to unload the main cooling system. New, or greenfield datacom facilities should, at a minimum, be designed to accommodate the use of liquid-cooled electronics in the future.

Heat rejection options involve the use of closed-circuit cooling to maintain efficiency and reduce maintenance. Open circuit cooling towers with heat exchangers or closed-circuit cooling towers can be used for high efficiency heat rejection, while hybrid closed circuit cooling towers or adiabatic fluid coolers offer the advantage of lower water use. With higher operating liquid temperatures and the proper climate, dry coolers can be utilized to eliminate water usage but at a higher parasitic energy cost.

Like those data centers that rely on air for cooling described in our last column, the key to proper design of liquid-cooled data centers is to define the owner's project requirements along with those required by code. The design should not detract from the mission of the facility while preferably increasing both the redundancy and reliability of the operation. A total cost of ownership (TCO) analysis can be performed to help select the optimum cooling system for the data center, whether air or liquid cooled, from the many alternative designs available.

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