

Coolant Distribution Units Part 1: Design

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The design of liquid-cooled data centers—defined here as data centers with direct-to-chip or direct-to-board liquid cooling—is different than the typical air-cooled data center. Traditionally, liquids have been kept out of the data center or kept under the raised floor of the facility. Now the cooling liquids are going direct to the processing chip's cold plate, and in some cases the server boards are completely immersed in a dielectric liquid. One of the fundamental components of most liquid-cooled data centers is the device that isolates the highly conditioned liquid that directly cools the IT equipment (ITE) from the facility chilled or process water system. This device is called a coolant distribution unit (CDU). The design of CDUs is covered in detail in ASHRAE's online Datacom Encyclopedia.¹ The primary purpose of this column is to provide a summary of the information provided in that reference as it relates to the design and control of these units.

CDU Basics

The application of the various types of CDUs depends on the requirements of the data center. There are many possible implementations of CDUs outside of those discussed in this column. ASHRAE's Datacom Encyclopedia^{1,2} discusses several different types of CDUs. Some commonly applied CDU types include:

1. CDUs with a liquid-to-liquid heat exchanger;
2. CDUs with a liquid-to-air heat exchanger;
3. Rack, row or facility level CDU using a liquid-to-liquid heat exchanger and a vapor compression system;
4. Internal IT equipment-based CDU that uses a docking station and cold plates.

Figure 1 shows the most common implementation of the CDU, the liquid-to-liquid CDU.

CDUs with liquid-to-liquid heat exchangers are

typically equipped with a plate heat exchanger, a pump (preferably redundant), liquid expansion tank, a valve controlling facility water flow, a fine-particle filter and a control system. These components are installed in a cabinet enclosure to aid in modular deployment.

A liquid-to-liquid CDU is designed to have two independent fluid coolant loops: the facility water system (FWS) loop and the technology cooling system (TCS) loop. Separating the TCS loop from the FWS loop aids in the ability to effectively protect sensitive ITE, such as from FWS contaminants, temperature and pressure anomalies. With discrete independent cooling loops, the TCS loop volume is reduced to just the piping

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needed to span and connect from the CDU to the deployed ITE server rows.

On the left side of *Figure 1*, facility water supply and return lines connect to the FWS side of the liquid-to-liquid heat exchanger. The FWS water absorbs heat from the TCS through the heat exchanger plates. The rate at which the heat is absorbed is controlled with the flow control valve. The FWS may be a chilled water system; may allow for heat rejection directly to ambient air using a cooling tower, dry cooler, or other heat rejection device; or even be part of a heat recovery loop such as district heating.

In *Figure 1*, dual pumps are shown. They deliver liquid to and from the ITE and through the heat exchanger. They are installed in series with a particulate filter required for the TCS loop. The particulate filter could be in a bypass loop to facilitate removal and replacement. ITE cold plates often feature microchannels with narrow pathways for coolant flow, which offer high heat transfer efficiency. To avoid clogging or degradation of the narrow cold plates, the TCS loop coolant must be pure and free of contaminants. Generally, this requires filtration between 25 microns and 50 microns and corrosion-resistant piping materials (consult ITE OEM guidance, as some require ≤ 20 microns).

Figure 2 shows another common implementation of the CDU: an air-cooled CDU. Air-cooled CDUs contain an air-to-liquid heat exchanger in place of a liquid-to-liquid heat exchanger. Fans (typically redundant) move data center air across the air-to-liquid heat exchanger to reject heat from the electronics. These systems create a tertiary cooling loop by exchanging TCS heat to the data center air. The heat in the data center air will ultimately be rejected by the room air cooling system (e.g., FWS with a computer room air handler [CRAH] or refrigerant with a computer room air conditioner [CRAC]).

Air-cooled CDUs are common in smaller deployments when the facility is completely air-cooled and without a facility water source, such as at direct expansion (DX)-cooled data centers. They are also often used where high-density cooling of the electronics is only needed for a small portion of the servers.

An air-cooled CDU will consume more power than a liquid-cooled CDU due to the need for fans to move air across the air-to-liquid heat exchanger. Water has a

FIGURE 1 Rack, row or facility-level CDU using a liquid-to-liquid heat exchanger.¹

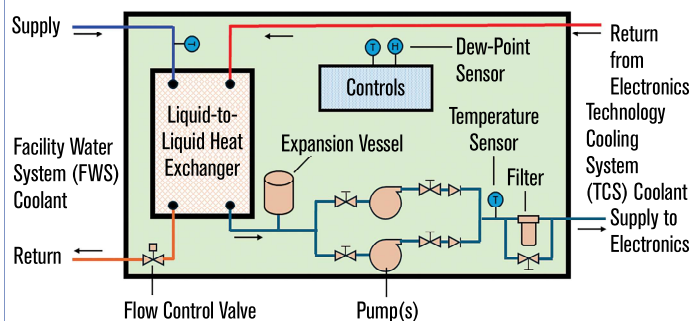
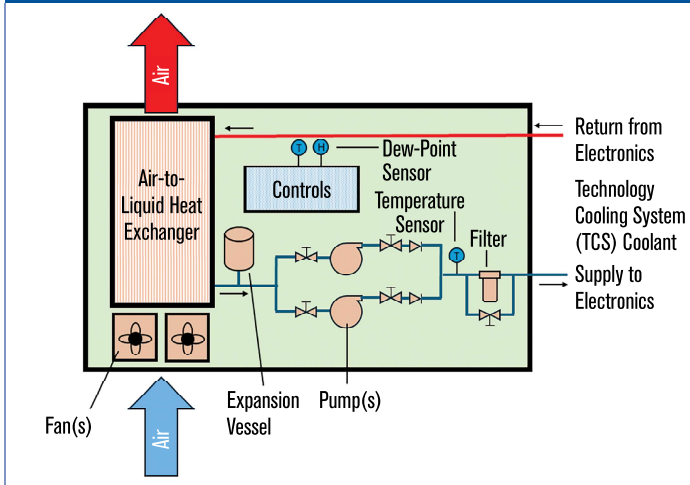


FIGURE 2 Rack, row or facility-level CDU using an air-to-liquid heat exchanger.¹



specific heat capacity about four times higher than air, which means it can absorb more heat per unit mass. Another efficiency advantage of a liquid-to-liquid CDU is that it may also be able to reject heat directly to the atmosphere without use of a chiller, whereas a liquid-to-air CDU almost always rejects heat to an air system that is cooled at least part of the year by mechanical cooling.

The third and fourth common types of CDUs are CDUs using a liquid-to-liquid heat exchanger and a vapor compression system, and, lastly, internal IT equipment-based CDUs using a docking station and cold plates. These types are covered in greater detail, inclusive of diagrams, in the ASHRAE Datacom Encyclopedia.¹

CDU Controls

All CDUs have control systems, and the requirements and functions of these systems are similar.

The control system in a CDU will control the TCS pump operation and the FWS flow control valve using a variety of sensors (temperature, pressure and dew point). The control system is the heart of the CDU operation

and reacts to ITE load fluctuations as well as to system anomalies that require specific responses.

One of the primary CDU control requirements is to maintain the TCS liquid temperature at least 2°C (3.6°F) above the dew-point temperature of the air in the data hall to prevent condensation either near or within the servers. Ideally, there is an independent humidity control system that controls the space dew point, but the CDU needs to be able to recognize unexpected conditions and adjust accordingly.

The other primary requirement of the CDU is to maintain the TCS liquid at a proper flow rate and temperature to absorb the heat produced by processors/servers. Experience has shown that TCS liquid temperature control is difficult at low load, and as such recommendations for PID-loop control have been published in the literature.³

CDU Reliability

Common CDU deployments consist of $N+1$ CDUs per predetermined quantity of ITE rows or load depending on data center owner and tenant risk requirements. Typically, the TCS loop pumps in a CDU are $2N$, but many are not hot-swappable. Hot-swappable refers to the ability to replace the pump without shutting down the system or causing interruption of the cooling operation. Pumps should also incorporate active redundancy, wherein both pumps are normally operating. TCS temperatures have been reported to rise as much as 27°C (48.6°F) during switchover from primary to redundant pumps without active redundancy.⁴ Losing partial flow from a CDU immediately after a pump failure is less impactful than losing full flow after a pump failure. These are key factors in system design.

The word “interruption” cannot be understated. Published research with medium-power processors indicates that the time between CDU pump failure and ITE processor throttling can be as little as 23 seconds.⁴ CPUs, GPUs, and >1 kW accelerators will likely throttle even faster. An effective CDU design will consider all possible scenarios where an interruption can occur and mitigate the effects to the system. Factors such as loss of power are considered, and redundant electrical feeds are provided. Loss of control is considered, and $2N$ control sensors are also provided. Bypasses around critical flow pathways for critical components are designed to allow for maintenance events and

replacement (e.g., the bypass around the particulate filtration). Thermal expansion is considered with expansion tanks. Alarms are in place for TCS fluid loss detection. Venting and air separation are deployed for removal of air. Every single component in a TCS loop and CDU (fittings, valves, components, piping material, fluid material, filtration, etc.) must be critically examined, vetted and deployed in accordance with the ITE/cold plate manufacturer.

Also important to note is that there is currently no published data on acceptable rate-of-rise of liquid temperatures from failure scenarios associated with liquid-cooling systems supporting high-density processors. In addition to providing detailed engineering information necessary for facility designers to enhance server resiliency and to confidently adopt liquid cooling, proposed ASHRAE Work Statement 1972-WS, currently in review, intends to provide data to aid in the development of this rate-of-rise limit.

CDU Maintenance

Relative to air-cooled data centers, maintenance requirements of liquid-cooled data centers can be expected to be higher. Filtration requirements will be near the top of this list since every CDU will likely have a water filter requiring regular maintenance. Pump maintenance, calibration checks of sensors and the increased points list for the building automation system (BAS) will also be labor intensive.

CDU Energy Efficiency

In considering CDU energy efficiency, two things come to mind. One is pumping power. The other is the S-class of the TCS, the W-class of the FWS and the approach temperature of the CDU’s heat exchanger (HX).

Pumping power will be largely dependent on the differential pressure drop across the ITE cold plate, the CDU heat exchanger and the liquid filter. To a smaller extent, the pressure drop of the piping system and valves will also play a role. A higher flow velocity will typically result in a closer approach temperature but higher pump energy consumption. A design trade-off must be made.

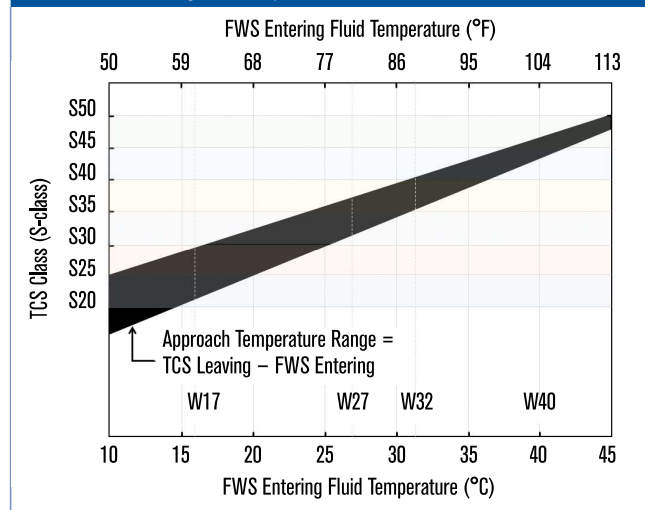
The FWS W-class is dependent on both the type of heat rejection (or heat recovery) and the liquid temperature classes of the TCS. Current classes range from W-17 (17°C [62.6°F]) to W45+ (>45°C [>113°F]).⁵ The TCS

S-class is dependent on the requirements of the ITE served. Current classes range from S-20 (20°C [68°F]) to S-50 (50°C [122°F]).⁶ Figure 3 shows a typical range of relationships between the FWS and TCS sides of a CDU. A typical approach temperature for a liquid-to-liquid CDU is 4.4°C to 8.3°C (8°F to 15°F). The approach temperature drops to as little as 2°C (3.6°F) when elevated W-class and S-class temperatures are used due to physical temperature limits of the processors, as shown in Figure 3. But the higher W-class and S-class temperatures can facilitate a significant improvement in overall data center energy efficiency if chillers can be avoided or heat recovery enabled.

Conclusion

CDUs are an integral part of a liquid-cooled data center when high-quality water or other liquids are used to cool ITE at the board or chip level. The purpose of this column has been to introduce the basics of CDU design, with consideration of TCS and FWS isolation, controls, reliability, maintenance and efficiency.

FIGURE 3 CDU approach temperature ranges based on CDU FWS entering fluid and TCS leaving fluid temperatures.



CDUs are discussed in more detail in ASHRAE's Datacom Encyclopedia.^{1,2,5,6} A method of test for CDUs is currently in the process of being added to ANSI/ASHRAE Standard 127, *Method of Testing for Rating Cooling Equipment Serving Data Center (DC) and Other Information Technology Equipment (ITE) Spaces*.⁷ The proposed addendum to Standard 127 is in the public review stage (2025). A companion column will discuss this method of test for CDUs in more detail once the standard is released for publication.

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