

New TC 9.9 Technical Bulletin

Liquid Cooling: Resiliency Guidance for Cold Plate Deployments

BY TOM DAVIDSON, MEMBER ASHRAE; DAVID QUIRK, P.E., MEMBER ASHRAE; JUSTIN SETER, ASSOCIATE MEMBER ASHRAE; DUSTIN DEMETRIOU, PH.D., MEMBER ASHRAE

Proper design of mission critical facility cooling systems requires intimate knowledge of the software applications served, which have recently trended toward artificial intelligence (AI) and machine learning requiring high-density processors. The market share of hybrid and liquid cooled servers in data centers is projected to grow significantly during the next decade, especially for AI applications. Many unanswered questions exist pertaining to high-availability operation of liquid-cooled IT equipment. One thing ASHRAE TC 9.9 has done in response to the speed of this transition is releasing a 2024 Technical Bulletin titled “Liquid Cooling: Resiliency Guidance for Cold Plate Deployments.”¹ This column summarizes guidance in that bulletin.

Many recommendations in the Technical Bulletin are also contained in the Liquid Cooling section of ASHRAE’s Datacom Encyclopedia² but were repeated in the bulletin both for emphasis and to increase readership. The Datacom Encyclopedia was released by ASHRAE earlier in 2024 on a subscription basis. It provides access to all 14 ASHRAE Datacom books and allows for updates and revisions with greater frequency than revisions to individual books would permit.

Technical Bulletin Design Recommendations

Six design recommendations are listed in *Table 1* and discussed in more detail here.

Design Recommendation 1: Use a Coolant Distribution Unit

Use a cooling distribution unit (CDU) to ensure demarcation between the facility water system (FWS) and technology cooling system (TCS) within the data center. The TCS and FWS are two different fluid loops in the data center with different requirements.

A significant issue in fluid quality for information technology equipment (ITE) water cooling systems (TCS loop) has been a misapplication of fluid quality recommendations. The ITE manufacturer’s coolant

Tom Davidson is senior mechanical engineer, David Quirk, P.E., is president and Justin Seter is strategic initiatives director at DLB Associates. Dustin Demetriou, Ph.D., is vice chair of the ASHRAE TC 9.9 IT subcommittee.

quality specifications must be followed to ensure a highly reliable TCS. It is important to bring a fluid quality expert onboard during the design phase to ensure that all materials used in construction of the TCS loop are compatible with the fluid quality requirements of each and every piece of ITE.

Design Recommendation 2: Thermal Inertia

Employ thermal inertia to avoid hardware thermal damage due to large load changes and power loss.

The reason additional thermal inertia is more important in liquid cooling than in an air cooling application is that loss of liquid coolant could result in compute components throttling or overheating a) in less time than it takes an emergency generator to come on-line and/or b) where application migration is available, before the ITE load can be migrated to a remote facility.

Specific recommendations in the bulletin include:

- Deploy uninterruptible power supply (UPS) systems to enable continued operation of the FWS and TCS upon a loss of facility utility power.
- Use thermal energy storage (TES) systems to provide cooling water supply in case a chiller plant or cooling source loses power. A stratified TES tank can continue providing cooling to the ITE through the transition to generator power.
- Implement buffer tanks for the storage of cooling water return (can be either FWS or TCS) to protect the cooling plant from a sharp spike in temperature or load that could shut down the ability to cool.

Design Recommendation 3: Active Redundancy

Incorporate active redundancy during changeover from primary to redundant systems. Experience by ITE manufacturers has demonstrated as much as a 27°C (48.6°F) jump in TCS temperatures due to the changeover of CDU pumps without active redundancy.

Active redundancy refers to an operational strategy in which the $N + 1$ (reserve) components of a system are part of normal operation. When a critical component drops out, the redundant unit is already operating and typically just needs to speed up to fully perform its back-up function, reducing the time it would take to start operating from offline.

In many cases, high-power device temperatures would not be able to ride through failure events without the

TABLE 1 List of design recommendations.

CDU: Use a cooling distribution unit
Thermal Inertia: Increase the system's thermal inertia
Redundancy: Use active redundancy on TCS/FWS loop pumps
Modeling: Perform transient modeling of the technology cooling system/facility water system
Installation: Understand the installation planning requirements of the ITE
S-Class: Consider a lower S-class only in a high-density zone for higher power ITE

time savings of active redundancy. Previous research with medium-power processors (relative to today's high-power graphical processing units) indicate that the time between CDU pump failure and ITE processor throttling can occur in as little as 23 seconds.³

Design Recommendation 4: Transient Modeling

Perform transient modeling to verify the performance of systems, products and components that do not have empirical data from prior testing.

In general, it is fair to say that the quicker something can fail, the more important transient modeling becomes. Computational fluid dynamics (CFD) and flow network modeling co-simulation tools can model a combination of fluid mass and thermal transport. These tools have been widely validated and used for designing energy efficient liquid cooling systems.⁴ These tools have also proven valuable in answering questions pertaining to complex transient operating conditions associated with data centers using thermal capacitance values published for air-cooled servers.⁵ Establishing the transient response of a liquid-to-chip cooling application is paramount. CFD and flow network modeling tools can be valuable to establish sizing for thermal inertia systems and for understanding the impact of equipment failures on the flow distribution network.

Design Recommendation 5: ITE Manufacturer Requirements

Obtain and carefully follow all liquid-cooled ITE manufacturer's requirements. The extreme ITE power makes this more critical than ever.

The ITE manufacturer's requirements include (but are not limited to) TCS temperature requirements (S-classes), flow rates, pressure drop, maximum operating pressure, fluid quality and wetted materials. Ask the ITE manufacturer about temperature rate-of-change requirements as well.

TABLE 2 TCS liquid-cooling classes (S-classes).²

TCS FLUID CLASS	EQUIPMENT ENVIRONMENT SPECIFICATIONS FOR LIQUID COOLING		
	TYPICAL INFRASTRUCTURE DESIGN		MAXIMUM TCS SUPPLY TEMPERATURE °C*
	COMMON FWS FACILITIES	TCS FACILITIES	
S30	Chiller/Cooling Tower	CDU	30
S35			35
S40	Cooling Tower		40
S45	Cooling Tower/Dry Cooler		45
S50	Dry Cooler		50

*Minimum water temperature for all classes is 2°C (3.6°F) above the measured data center air dew point to avoid condensation.

It is important to understand the heat capture ratio (the ratio of heat rejected to the TCS coolant to the total heat generated within the ITE) and the ITE air temperature requirements (recommended and allowable range). As power density increases, the heat capture ratio becomes important for sizing the necessary air-cooled load. Liquid-cooled ITE might still present a significant HVAC load—in some cases exceeding the average air-cooled rack density found today in many data centers.

Designers are strongly encouraged to use online, software-based planning tools provided by many ITE manufacturers. These tools should provide planning guidance for the heat capture ratio based on the environmental conditions.

TC 9.9 recently published a new liquid cooling ITE thermal template in the Datacom Encyclopedia, which is meant to encourage common availability of necessary installation planning data for liquid-cooled ITE.

Design Recommendation 6: High Density Zones

Consider lower S-Classes (lower TCS coolant inlet temperatures) to ITE, but only in high-density zones.

At the time of publication, the S-classes, corresponding to the maximum inlet temperature of the ITE, range between 30°C and 50°C (86°F to 122°F). Table 2 provides more detail.

As chip power continues to trend higher, this could drive the need for colder temperatures. TC 9.9 anticipates revisions to the S-classes in the future, which will be published in the Datacom Encyclopedia.

Lower S-classes should only be used in high-density zones so as not to impact the energy efficiency of the entire site. In general, warmer liquid cooling temperatures are more efficient as they allow cooling

equipment to operate with greater thermodynamic efficiency and with more economizer hours. Assuming that the equipment requiring lower S-classes is only a portion of the data center, the use of multiple temperature loops, cascade cooling or other topologies could be employed to minimize the energy impact. Figure 1 and Figure 2 show cooling topologies that are typical for both low temperature TCS (S30, S35) and higher temperature TCS (S40, S45 and S50).

The bulletin also notes that a lower S-class can provide additional ride-through time before ITE will initiate a throttling event.

Technical Bulletin Operation Recommendations

Four operational recommendations are listed in Table 3 and discussed in more detail here.

Operation Recommendation 1: Coolant Quality

Ensure programs are in place to monitor coolant quality and filtration as directed by the ITE manufacturer. It is essential that the facility have water treatment experts on staff, or partner with a qualified fluid treatment service provider, to provide the proper expertise on fluid chemistry and treatment. Cooling fluids of poor quality can cause adverse effects in a liquid system such as reduced cooling capacity, increased energy consumption and premature equipment failure.

FIGURE 1 Typical cooling infrastructure for S-classes S30 and S35.²

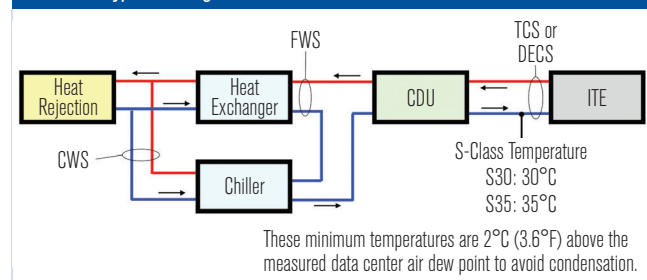
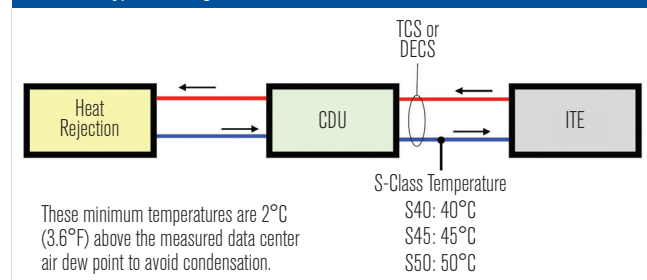


FIGURE 2 Typical cooling infrastructure for S-classes S40, S45 and S50.²



While the exact coolant fluid quality standards should be confirmed with the equipment manufacturer, *Table 4* lists typical water quality guidelines for FWS and TCS loops. It should be noted that *Table 4* does not provide guidance for particulate removal. Coolant monitoring programs for the TCS will very likely differ from those in the FWS due to precision machined surfaces (50-micron fluid channels or less) in liquid-cooled cold plates inside the ITE equipment.

Operation Recommendation 2: Commissioning

Use hydraulic and thermal commissioning to validate design assumptions and systems integrations using thermal test vehicles (TTV) or actual ITE gear. Simulation testing with and without load banks is an option, but note that the system reactions are likely to change when the final ITE gear is installed. Additional guidance on liquid-cooling commissioning is provided in Chapter 11.4 and Appendix B of Liquid Cooling Guidelines, available in the Datacom Encyclopedia.

Operation Recommendation 3: Load Migration Strategies

Use load migration strategies that will work within the server time-to-throttle based on worst-case failure of the resilient design. Significant coordination between ITE software engineers and facility engineers will be critical.

Many data centers have remote backup ITE. Where this is available, the ITE processing will ideally be switched over to the backup system for the duration of an outage before then being switched back. This process will be more successful if the timing of the migration is planned in advance of an actual outage and performed in carefully constructed groups to avoid network congestion and allow processor throttling without significant performance impacts.

Operation Recommendation 4: Software Loading

Limit software step/block loading/unloading to avoid problems in infrastructure system responses (mechanical and electrical).

The response time for some infrastructure equipment is much slower than the potential deployment of software workloads. In lieu of the fact that rate-of-rise/rate-of-fall guidelines for TCS temperatures have not yet been established, consider the deployment of workloads in steps/blocks to minimize the need for a rapid response of the TCS supply temperature (a potential

TABLE 3 List of operation recommendations.

Quality: Maintain the quality of the cooling fluid in the TCS loop
Commissioning: Perform hydraulic and thermal commissioning
Migration: Consider IT load migration strategies
Software: Limit step/block loading/unloading of software

TABLE 4 Typical water quality guidelines for FWS and TCS loops.²

PARAMETER	FWS	TCS
pH	7 to 9	8.0 to 9.5
Corrosion Inhibitor(s)	Required	Required
Biocide	—	Required
Sulfide	<10 ppm	<1 ppm
Sulfate	<100 ppm	<10 ppm
Chloride	<50 ppm	<5 ppm
Bacteria	<1,000 CFUs/mL	<100 CFUs/mL
Total Hardness (as CaCO ₃)	<200 ppm	<20 ppm
Conductivity	—	0.2 to 20 micromho/cm
Total Suspended Solids	—	<3 ppm
Residue After Evaporation	<500 ppm	<50 ppm
Turbidity	<20 NTU (Nephelometric)	<20 NTU (Nephelometric)

control issue) and increased stress on the ITE hardware from thermal cycling.

Summary

TC 9.9 recognizes that there is an explosive interest in liquid cooling due to the increasing deployment of liquid cooling both now and projected into the foreseeable future. As such, it strives to make as much relevant design and operational information available as possible. “Liquid Cooling: Resiliency Guidance for Cold Plate Deployments” is a free resource being made available to the public in this regard.¹ Additional information is available in the Datacom Encyclopedia.²

References

1. ASHRAE. 2024. “ASHRAE TC 9.9 Technical Bulletin. Liquid Cooling: Resiliency Guidance for Cold Plate Deployments.” ASHRAE. <https://tinyurl.com/5efwcbk2>
2. ASHRAE. ASHRAE TC9.9 Datacom Encyclopedia. ASHRAE. <https://datacom.ashrae.org>
3. Alkharabsheh, S. et.al. 2018. “Failure analysis of direct cooling system in data centers.” *Journal of Electronic Packaging* 140(2):020902.
4. Ellsworth, M. 2014. “Flow network analysis of the IBM Power 775 supercomputer water cooling system.” *Proceedings of the 14th IEEE ITerm Conference*.
5. Pardey, Z., et.al. 2015. “Proposal for standard compact server model for transient data center simulations.” *ASHRAE Transactions*, 121(1). ■