

©ASHRAE www.ashrae.org. This article was published in the December 2025 ASHRAE Journal. This article may not be copied nor distributed in either paper or digital form without ASHRAE's permission. For more information about ASHRAE, visit www.ashrae.org.

Part 3: Commissioning, Maintenance and Operations

Liquid Cold Plates

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

This is the third and final installment in a series on liquid-cooled server cold plates. Part 1 traced the arc from early mainframes to today's artificial intelligence-era heat fluxes,¹ and Part 2 unpacked plate architecture and performance envelopes.² We now turn to what ultimately determines success in production: how systems are commissioned, maintained and operated over time.

Why Commissioning/Maintenance & Operations Matter More in the Artificial Intelligence Era

As single devices approach extreme watt densities, and racks routinely exceed tens of kilowatts, thermal ride-through (the ability of a system to maintain desired temperatures in the event of an upset condition, such as loss of utility power), hydraulic stability and coolant quality are no longer optional—they are critical. TC 9.9's resiliency guidance³ identifies two primary operational risks: performance loss from throttling and rapid temperature excursions that can damage hardware. The antidote lies in both design discipline (thermal inertia, redundancy, modeling) and operational rigor (commissioning [Cx], telemetry and load-management practices).

Equally important is the demarcation between the facility water system (FWS) and the technology cooling system (TCS), typically enforced by a coolant distribution unit (CDU).⁴ This isolation ensures proper chemistry, pressure, filtration and serviceability—and strongly supports the recommendation of connecting only one IT platform per CDU loop to minimize blast radius and simplify life-cycle management.

Design Prerequisites that Enable Successful Cx

Before field work begins, three design prerequisites must be confirmed:

- **Metallurgy and chemistry alignment.** While options for materials are plenty, it is imperative they are not incompatible or that incompatibility exists between the materials and the fluid chemistry. *Table 1* lists typical materials and fluid properties for a water system. Chemistry should be validated with corrosion coupons and microbiological sampling on a defined cadence.
- **Hydraulic windows and filtration.** While allowable pressure drops have a fairly wide range, consideration must be given to maintaining a uniform flow through all similar devices and being able to maintain this flow during hot-swappable servicing with balanced bypass piping. A quality filtration system is paramount. Dual-stage filtration should be used. A typical specification would be 25 µm to 50 µm strainers for full flow, a 5 µm sidestream cartridge filter and filter alarms set at 1.5 psi (1034 kPa) ΔP. Some cold plates may require more stringent filtration.
- **Platform isolation via CDUs.** Treat each major IT platform as a contained domain. CDU-based isolation

David Quirk, P.E., is CEO and Justin Seter is strategic initiatives director at DLB Associates. Dustin Demetriou, Ph.D., is chair of the ASHRAE TC 9.9 IT subcommittee.

simplifies maintenance, reduces contamination spread, and lowers the mean time to repair (MTTR) when service is required.

Commissioning: From Factory To Integrated Thermal Ride-Through

Commissioning begins well before the TCS fluid touches the cold plate. A typical installation and commissioning framework consists of five levels:

- **L0: Design Review.** Validate basis-of-design against vendor service-class targets (e.g., S30 $\leq 86^{\circ}\text{F}$ [30°C]). Confirm hydraulic budgets, heat exchanger sizing and control sequences.

- **L1: Factory Acceptance Test (FAT).** Conduct hydrostatic tests at 1.5 $\times$ design pressure, capacity sweeps up to nameplate and verify quick restart after power loss. Document results in Cx turnover packages. Remove fluid after FAT.

- **L2–L3: Flush, Passivate and Pre-Start.** Perform high-velocity flushing with an alkaline clean, citric rinse and deionized (DI) water final rinse. Particulate levels should be low, such as <5 mg/L. Verify cleanliness per ISO 4406 $\leq 16/14/11$ before connecting racks.⁵

- **L4–L5: Functional & Integrated System Tests.** Confirm safeties (leak detection, pump failover, bypass logic) and conduct full dual-medium load bank tests. Acceptance criteria typically include an acceptably low supply temperature rise on a utility trip and significant flow recovery within 15 seconds. The IT manufacturer can provide more specific recommendations. (See "What to Prove in the IST" sidebar for more on integrated system tests.)

Additional Cx guidance can be found in ASHRAE's Datacom Encyclopedia.⁶

Instrumentation & Telemetry

Commissioning must lock in a telemetry baseline. Sensors need to be highly accurate, such as resistance temperature detectors (RTDs) ($\pm 0.2^{\circ}\text{F}$ [0.1°C]), differential pressure sensors ($\pm 0.25\%$) and conductivity/pH meters ($\pm 1\%$, ± 0.05 respectively). Key parameters should be streamed at intervals of less than one second to detect hydraulic shocks or thermal excursions. Archive sub-second data for 90 days and 15 second aggregated data for 3+ years, or as needed to meet service level agreement (SLA) verification requirements.

TABLE 1 Sample metallurgical and chemistry alignment for water.

MATERIAL/CRITERIA	SPECIFICATION
Piping Materials	316 SS, High-Purity Copper or Low Zinc Brass
Hoses	EPDM or Fluoroelastomers
pH	8 to 9.5
Nitrite	600 ppm to 800 ppm
Biocide	Required, Non-Oxidizing
Corrosion Inhibitor(s)	Required

TABLE 2 Sample maintenance matrix for water.

TASK	INTERVAL	TARGET
Inline Conductivity Trending	Continuous	<200 $\mu\text{S}/\text{cm}$
pH Trending	Continuous	8.0 to 9.5
Filter ΔP Monitoring	Continuous	Alarm at 1.5 psi
Biocide Residual Test	Weekly	>75 ppm
Sidestream Sampling	Quarterly	Turbidity <5.0 NTU
Coupon Inspection	Semiannual	<0.5 mg/cm ² Loss

IT-Side Validation

When possible, use thermal test vehicles (TTVs) to validate vendor flow and pressure specs and determine minimum time-to-throttle under worst-case loss-of-flow events. These results guide IT workload migration strategies during outages.

Maintenance: Continuous Cleanliness and Predictive Insight

Maintenance starts immediately after Cx—even before IT installation. Continuous flow through all circuit legs prevents stagnation and biofouling. Tune chemistry and cleanliness before connecting cold plates.

Cold plates act as microfilters with channels often <100 μm . Particles exceeding $\sim 50\%$ of this width can clog fins and degrade thermal performance. Differential pressure alarms on filters, hot-serviceable duplex housings and slow-closing valves are essential safeguards. *Table 2* provides a sample maintenance matrix. Predictive analytics now enable maintenance to evolve from reactive to preventive. Gradient-based regression models can forecast filter ΔP saturation seven days in advance, auto-generating work orders to preempt downtime. Typical mean time to recovery goals should include less than 15 minutes for a duplex filter swap, and less than 4 hours for a CDU heat exchanger replacement; these downtime intervals have SLA implications.

Smaller, platform-scoped CDUs reduce maintenance

blast radius and simplify spare strategy—a clear advantage over monolithic cooling loops.

Operations: SLAs, Load Control and Ride-Through

Operational protocols must extend SLA metrics beyond air temperatures to include liquid parameters. Sample parameters for water are shown in *Table 3*. Buffer or thermal energy storage (TES) volume should provide ≥ 30 second ride-through while CDU pumps remain online via UPS until generators assume the load.

Software load management is equally vital—avoid block load steps that exceed infrastructure response times. Align IT orchestration (e.g., virtual machine migration, throttling) with CDU telemetry alarms for seamless transitions during thermal or flow anomalies.

Conclusions

Liquid-to-chip cooling longevity rests on the triad of sound metallurgy, disciplined commissioning and continuous maintenance. Platform-isolated CDUs, fine filtration, real-time telemetry and predictive analytics form the backbone of reliable high-density compute

TABLE 3 Sample liquid operational parameters for water.

METRIC	RECOMMENDED RANGE
Inlet Temp. (S-Class)	S20 to S40 Tiered Limits
Rate-of-Change	$\leq 1^\circ\text{C}/\text{min}$
Rack ΔP	4 psi to 12 psi
Conductivity	$\leq 200\ \mu\text{S}/\text{cm}$
Filter ΔP Alarm	1.5 psi
Dissolved O_2	$< 0.1\ \text{ppm}$
Sulfide	$< 1\ \text{ppm}$
Sulfate	$< 10\ \text{ppm}$
Chloride	$< 5\ \text{ppm}$
Bacteria	$< 100\ \text{CFUs}/\text{mL}$
Total Hardness (as CaCO_3)	$< 20\ \text{ppm}$
Total Suspended Solids	$< 3\ \text{ppm}$
Residue After Evaporation	$< 50\ \text{ppm}$

operations. With these practices, operators can sustain performance and uptime as thermal loads push the boundaries of modern data center design.

As AI workloads grow and component-level heat flux intensifies, next-generation cold plate systems may evolve to include:

- Two-phase cooling loops;
- Real-time orchestration of IT loads based on fluid conditions; and
- Standardization across platforms via open compute project (OCP) and ASHRAE alignment.

This series focused on today's state-of-the-practice liquid-to-chip systems. Future installments may explore hybrid topologies, immersion and direct-die designs. Stay tuned for additional liquid-cooling guidance from ASHRAE's TC 9.9 Committee.

References

1. Demetriou, D., D. Quirk. 2025. "Liquid cooling cold plates, part 1: history." *ASHRAE Journal* (9).
2. Shelnutt, A., D. Quirk. 2025. "Server cold plates, part 2: design." *ASHRAE Journal* (11).
3. ASHRAE. 2024. TC 9.9 "Liquid Cooling Resiliency Guidance for Cold Plate Deployments." TC 9.9 Technical Bulletin (TB-LC-A, 2024). Atlanta: ASHRAE.
4. Quirk, D., D. Demetriou, T. Davidson, J. Deal. 2025. "Coolant distribution units, part 1: design." *ASHRAE Journal* 67(6).
5. ISO. ISO 4406-2021: "Hydraulic fluid power – Fluids – Method for coding the level of contamination by solid particles. International Organization for Standardization. <https://tinyurl.com/3eurzzaz>
6. ASHRAE. 2025. "Commissioning, ver 2.0." ASHRAE TC 9.9 Datacom Encyclopedia. <https://www.datacom.ashrae.org> ■

What to Prove in the IST

Integrated system testing (IST) is the true proving ground for cold-plate reliability. Beyond leak checks, it must confirm the system's resilience under live failure conditions.

Key IST Objectives (Sample):

- **Thermal Ride-Through.** Demonstrate $\leq 3.5^\circ\text{F}$ (1.9°C) supply temperature rise and $\geq 90\%$ flow recovery post-utility trip.
- **Validate pump failover and bypass logic** with no more than 10% transient overshoot.
- **Leak Isolation.** Confirm automatic isolation valves close $< 1\ \text{s}$ after detection (if applicable).
- **Control System Interlocks.** Simulate high rate of change ($> 1.8^\circ\text{F}/\text{min}$ [$> 1^\circ\text{C}/\text{min}$]) and leak detection events; ensure building management systems and data center infrastructure management (BMS/DCIM) logs match field behavior.
- **IT Coordination.** Verify that throttle/migration scripts execute within the platform's minimum time-to-throttle.

The IST should conclude with a full post-test report documenting all parameters, deviations and recovery curves—serving as the baseline for operational acceptance.