WHITE PAPER

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Solving the AI Cooling Challenge: Lessons from the Front Lines of Data Center Cooling

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Published: August 2025

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Why Cooling Is Now a Business-Critical Strategy

Artificial intelligence (AI) and high-performance computing (HPC) is changing the game—but not just by driving up cabinet load densities. They're fundamentally altering how we plan, design, and manage cooling strategies in the data center. What used to be a siloed decision handled by facilities or mechanical engineers is now a shared responsibility across IT, operations, and infrastructure design.

For more than 30 years, Chatsworth Products (CPI) has helped organizations build smarter, more efficient infrastructure—leading the industry in airflow management, and now delivering next-generation, cabinet-integrated liquid cooling solutions. Given the experience of thousands of deployments across diverse environments, providing a clear view of what works, what scales, and new technologies.

Drawing on that expertise, this paper shares practical guidance and proven strategies to help you:

- **Maximize your current infrastructure**
- **Navigate thermal transitions with confidence**
- **Deploy hybrid air/liquid solutions that meet tomorrow's demands today**

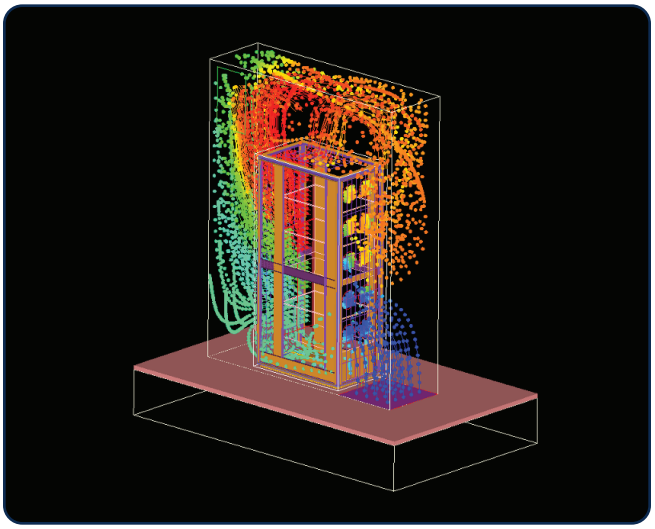
Why the Cabinet Is the Starting Point for Smarter Cooling

AI and HPC aren't just raising heat—they're redefining how we plan and manage infrastructure. And one of the biggest shifts is how that heat is managed.

Cooling is now inseparable from the cabinet that houses the compute. Layout, airflow paths, manifold integration, and cable-routing choices all start—and succeed or fail—inside the cabinet.

While the terms "rack" and "cabinet" are often used interchangeably in the industry, they refer to fundamentally different solutions. An open-frame rack is simply a structural framework for mounting equipment, with no enclosure to manage airflow. A cabinet, by contrast, is a fully enclosed, engineered system—with side panels, doors, and sealing options—that enables precise control of airflow, supports integrated cable management, and provides the foundation for effective cooling, power distribution, and high-density equipment deployments.

Cooling decisions now directly impact cabinet layout, power provisioning, space utilization, and long-term scalability. Cabinet selection isn't just about dimensions and aesthetics—it affects thermal zones, airflow containment, cable pathways, and more – and it should be able to last through the lifecycle of the data center, including multiple ITE refreshes. A misstep at the cabinet level can create ripple effects that derail efficiency and limit future growth.



CFD image showing air recirculating around components and over the cabinet top, mixing with exhaust and causing inlet temperature rise and heat buildup inside the cabinet.

We're seeing a shift toward highly integrated infrastructure design. Cooling must be considered alongside everything else from the beginning—not added as an afterthought. This interconnectedness is especially crucial as new workloads push per-cabinet densities beyond traditional air-cooling limits.

Legacy strategies like increasing CRAC capacity or adding perforated tiles are no longer enough. Today's environments demand adaptive cooling built into the physical infrastructure itself. The most effective solutions combine airflow management, strategic containment, intelligent power distribution, and liquid cooling where needed—all engineered to work together inside the cabinet.

Data center cooling has become a systems-level design challenge. And that means the cabinet is no longer just a housing unit—it's the thermal backbone of your deployment.

Lessons from the Field: Three Insights from Decades of Solving Data Center Cooling Issues

Insight #1: Airflow Only Works If You Control It

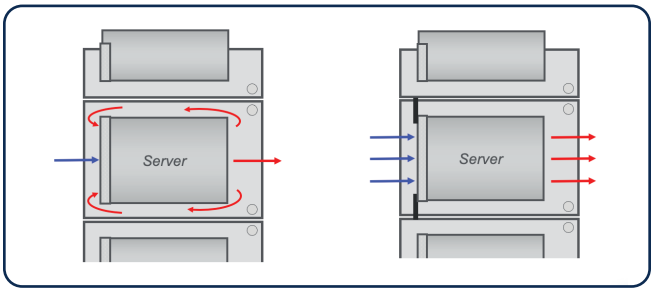
The issue isn't how much air you have—it's whether that air is doing its job. Air is meant to travel through the server, transporting the heat away from the device. But in many deployments, the air bypasses the equipment entirely or hot air recirculates back into the device(s).

Referred to as bypass airflow or thermal recirculation, this is where most inefficiencies begin. Recirculated air drives up energy costs, creates hotspots, and strains HVAC systems. It's also the root of most cooling-related performance issues, especially in higher-density environments.

Aisle containment strategies can help, but they don't guarantee thermal segregation. Small gaps within the cabinet—around brush openings, open U spaces, or poorly sealed panels—can still allow hot and cold air to mix. The result is airflow chaos inside the cabinet, regardless of how well the room is contained.

That's why CPI approached the problem differently.

Long before liquid cooling entered the mainstream, we pioneered cabinet-level "passive cooling" techniques that managed airflow with surgical precision at the cabinet level—without adding fans or expanding mechanical systems.



Left: Without airflow management, warm exhaust mixes with the cold air supply. Right: Proper management with accessories prevents recirculation.

This wasn't theoretical. We've demonstrated the results across countless real-world deployments, backed by computational fluid dynamics (CFD) analysis. In one recent example at the University of Chicago, thermal scans at the compute showed the hottest zone was right where it should be – on the ZutaCore® cold plate. The coldest areas were right where they were needed most – at the front of the device and within the device. That level of contrast proves the power of cabinet airflow management.

Takeaway: It's not about increasing the amount of air. Focus on controlling the air you have. Strategic airflow management is the fastest, most cost-effective way to reduce energy use, protect equipment, and prepare for next-gen workloads.

Insight #2: Let Physics Do the Work

Controlling airflow inside the cabinet is only part of the equation. The next challenge is how you remove that heat—efficiently and predictably. CPI answered that by using the physics already present in the environment to our advantage.

In many states, regulations now require containment in certain environments, but they don't define how well it needs to work. That leaves the effectiveness of cooling up to execution—and CPI makes execution easy.

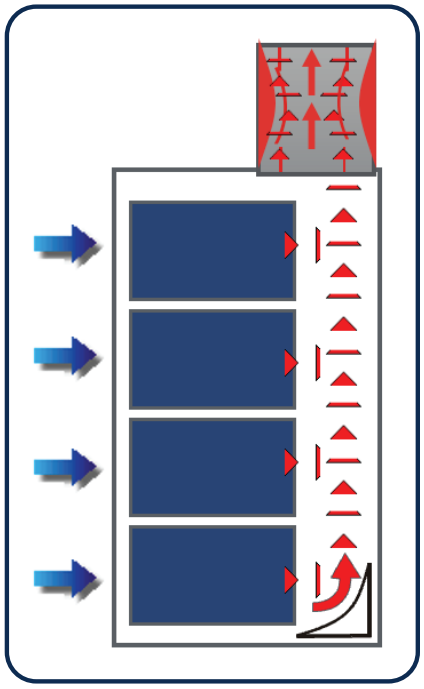
We recognized early on that warmer air moves upward because it's pushed by the cooler, denser air around it—a natural effect that helps drive airflow. Instead of adding complexity, we used the physics already present in the environment to our advantage.

CPI's cabinet design is grounded in two key scientific principles: Bernoulli's principle and the Venturi effect. These principles—commonly applied in jet propulsion and fluid dynamics—enable CPI's patented Vertical Exhaust Duct (VED) to harness thermal momentum and direct airflow with precision.

As hot air exits the back of servers, Bernoulli's principle—which states that as airflow velocity increases, pressure decreases—creates a natural draw, or suction effect, within the cabinet. This airflow is then further accelerated by the Venturi effect, which leverages the chimney's specific shape and size to generate a low-pressure zone that pulls hot air upward. The result is an efficient, passive cooling system that channels exhaust air through the duct without the need for additional fans or energy.

This led to one of CPI's most enduring innovations: the Vertical Exhaust Duct (VED). By sealing off escape routes inside the cabinet and directing exhaust upward, we created a natural pathway for hot air to leave the cabinet using thermal momentum—not additional fans. The result? Better thermal isolation, reduced fan speeds, and lower energy consumption.

While some view liquid technologies as the successor to traditional air containment, CPI believes both have important roles to play in today's evolving data center environments. The value of airflow containment remains undeniable—especially in facilities where introducing new plumbing, floor plan changes, or complex retrofits isn't feasible. That's why we continue to invest in air containment designs that work in harmony with more advanced strategies.



An air director guides exhaust air into the Vertical Exhaust Duct, where the restriction increases velocity.

A key part of this approach involves leveraging the pressure differential created by existing Computer Room Air Handler (CRAH) and the compute. CPI solutions allow heat to evacuate the cabinet using upward thermal momentum, minimizing energy use and maximizing efficiency.

We've brought this concept to modern environments with solutions like Elevate® Adjustable Containment, which integrates traditional air containment principles with flexible, scalable containment. It's a system that adapts to your infrastructure, not the other way around.

Takeaway: Air containment isn't outdated—it's foundational. By capitalizing on natural convection and existing CRAH infrastructure, CPI offers a physics-first foundation that helps customers reduce energy usage, eliminate unnecessary complexity, and maintain room to scale.

Insight #3: Air Isn't Obsolete – But It Does Have Limits

CPI has seen real-world deployments where air-cooled cabinets operate effectively at 50 kW or more. But as server heat becomes denser and more concentrated, air cooling begins to lose its effectiveness—not because it disappears, but because it can't efficiently extract heat from high-power components in a targeted way.

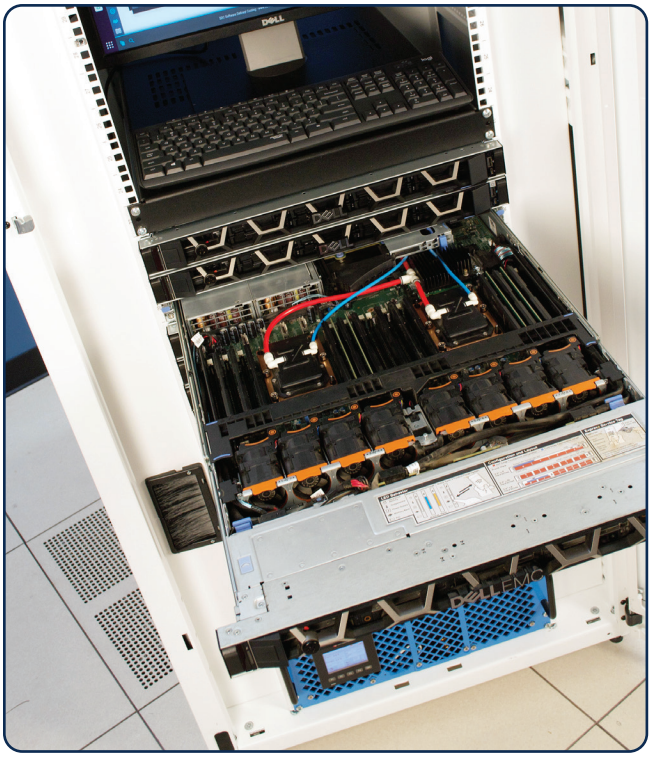
That's where direct-to-chip (D2C) liquid cooling steps in. It offers precision heat removal at the source—capturing 70% or more of the heat load directly from the processor and transporting it out of the cabinet using cold plates to a heat rejection unit. Unlike immersion cooling, which often requires large infrastructure changes, CPI's approach integrates liquid cooling directly into the cabinet without massive plumbing retrofits or floorplan redesigns.

This move toward waterless cooling is accelerating industrywide. As Uptime Intelligence notes, "In the current operating environment, with sustainability and water use representing significant concerns for investors, clients and the local community, waterless systems are increasingly preferred for cooling data centers. Several colocation operators—including Compass, Edged, and Novva—have already committed to installing air-cooled systems to improve the efficiency of their cooling systems and eliminate water use[1]."

It's important to note that liquid cooling doesn't eliminate the need for airflow management. Components such as memory modules, VRMs, and other board-level elements still require efficient air cooling to maintain safe operating temperatures. CPI's cabinet design ensures that both air and liquid work together, forming a hybrid cooling strategy that's more scalable and efficient than either method alone.

The transition point—from air to liquid—isn't defined by a single kW threshold. Instead, it depends on server architecture, rack configuration, and the density of heat within the chassis. That's why CPI works closely with customers to evaluate when and where air starts to make less sense—and to ensure that the shift to liquid cooling is strategic, not reactive.

Takeaway: Air cooling still has a role to play—but it can't do everything. When density rises, hybrid cooling becomes essential. CPI helps you pinpoint that transition and deploy liquid cooling in a way that enhances your existing environment, rather than replacing it.



CPI's ZetaFrame® Cabinet with ZutaCore® HyperCool® two-phase, waterless, direct-to-chip liquid cooling, delivers a turnkey hybrid cooling solution.

The Cabinet Is an Extension of the Cooling System

AI, machine learning (ML), and accelerated computing workloads reshape thermal profiles, the cabinet is no longer just a static frame—it's an active, engineered solution for managing heat. More than ever, thermal performance must be built in from the start. That's why CPI has reimagined the cabinet not as a passive structure, but as a dynamic part of the cooling ecosystem.

This engineering is grounded in proven physics. CPI's patented cabinet design leverages the Venturi effect and Bernoulli's principle to naturally accelerate airflow and reduce pressure, allowing heat to be removed efficiently without the need for additional mechanical systems.

By applying principles like the Venturi effect and Bernoulli's principle, CPI has designed its cabinets to maximize airflow. This means heat can be managed naturally and efficiently within the cabinet itself—making it as effective as possible on its own, without relying on additional mechanical cooling.

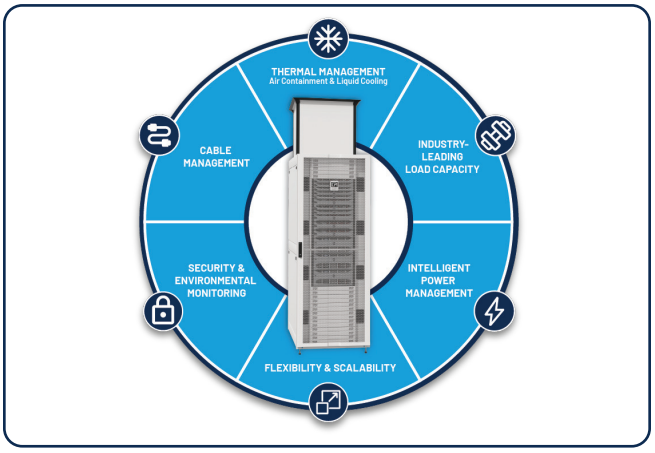
With compute density increasing and workloads becoming more dynamic, every element inside the cabinet plays a role—from the physical design and airflow containment to the power distribution and sensor integration. Each of these elements contributes to a cohesive cooling strategy that adapts to both current needs and future demands.

As Uptime Intelligence explains, "Selecting a data center cooling system no longer rests on the single criterion of finding the most energy-efficient cooling option. Instead, the chosen system needs to minimize both energy and water use, and operators should consider water scarcity, stress and availability over the lifetime of the data center. Incorporating these additional criteria into the design choices is likely to result in greater use of air-cooled systems as new data centers are designed and built[1]."

Our ZetaFrame® Cabinet System is the result of this evolution. Purpose-built to integrate with active containment, intelligent PDUs, and ZutaCore® HyperCool® direct-to-chip liquid cooling, it turns the cabinet into a precision thermal management platform—capable of supporting 100 kW+ densities without the need for extensive room redesigns.

But high-density cooling isn't solved with liquid alone. While D2C systems handle the bulk of processor heat, a significant portion—up to 30%—still comes from components like memory and power circuitry. That's why CPI's hybrid approach ensures intelligent airflow remains part of the equation, working in tandem with liquid to manage the total thermal load across the cabinet.

With sensors, environmental monitoring, and airflow containment integrated from day one, CPI's cabinet platform empowers data center operators with real-time visibility and control over thermal performance and energy use. By simplifying system configuration and accelerating deployment timelines, it reduces installation complexity and operational overhead. The result is a more sustainable, scalable cooling strategy that adapts as demands evolve—minimizing environmental impact while optimizing total cost of ownership.



The ZetaFrame® Cabinet System integrates airflow management, direct-to-chip liquid cooling, cable management, and power to optimize cooling performance.

Takeaway: The cabinet is no longer just for housing equipment—it's the front line of your thermal strategy. CPI designs cabinets that don't just house your servers; they enable your digital transformation.

Real-World Validation: University of Chicago Proves the Power of Direct-to-Chip Liquid Cooling

The University of Chicago needed solutions to support AI research and escalating compute density. Their IT Services team utilized CPI's ZetaFrame Cabinet System with integrated ZutaCore® HyperCool® direct-to-chip liquid cooling. The results were immediate and compelling:

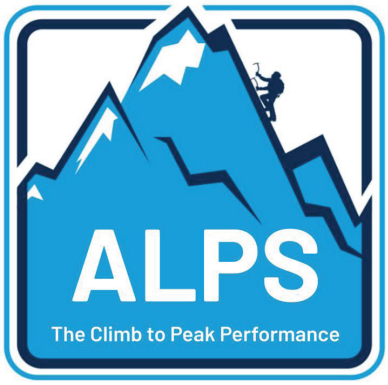
- **Cabinet temperatures dropped nearly 50°F, from ~130°F with traditional RDHx air cooling to ~80°F with liquid.**
- **Energy consumption fell by 37%, thanks to a reduction in fan load and targeted thermal extraction.**
- **No throttling—sustained performance for high-density, high-performance computing (HPC) workloads.**
- **Modular deployment—no major infrastructure changes required.**

This proof of concept utilized CPI's hybrid cooling solution: leveraging precision airflow management for board-level components while removing the bulk of heat load at the chip. For operators facing the limits of air cooling, this deployment underscores substantiates a practical, scalable path forward.

Takeaway: Cabinet-integrated liquid cooling is proven. CPI helps customers move beyond theoretical performance to real-world results.

Planning Ahead: Your Roadmap to Smarter Cooling

Understanding the current state of your cooling strategy is essential for making informed, forward-thinking decisions. As demands evolve, it becomes increasingly important to assess your environment holistically.



AIR

- Are rack inlet temperatures uniform, or are hot spots limiting cooling efficiency?
- Have airflow paths been fully sealed so air is forced through IT equipment, not around it?

LIQUID

- Have you identified workloads that would benefit from liquid or hybrid cooling?
- Does your team have the expertise to deploy and manage liquid cooling, or would an integrated system simplify adoption?

POWER

- Are you using slim-form-factor PDUs that preserve airflow space inside high-density cabinets?
- Can your PDUs accommodate multiple outlet types, reducing the number of PDUs (and cords) needed?
- Is your power distribution setup helping—or hurting—your cooling performance?

Let's Build It Right—Together

Cooling isn't just a component—it's a system, and CPI's approach reflects that reality. We don't just offer products; we deliver solutions that are thoughtfully engineered to perform cohesively—from the cabinet to the chip, and every connection in between.

As digital transformation accelerates and workloads intensify, it's more critical than ever to partner with a provider who understands the full picture. CPI brings decades of real-world experience in airflow management, containment, intelligent power distribution, and direct-to-chip liquid cooling. We've helped organizations of every size—from academic labs to hyperscale operators—maximize capacity, eliminate inefficiencies, and plan with confidence.

What sets us apart is our ability to meet you where you are. Whether you're designing a new data center, retrofitting an existing site, or scaling into AI and HPC workloads, we tailor our recommendations to your environment. Every system we design is modular, interoperable, and built to grow alongside your business.

From strategy and thermal modeling to deployment and ongoing support, we provide the expertise to help you make smarter infrastructure decisions and avoid costly pitfalls. Our collaborative approach ensures your thermal strategy is not only technically sound but also aligned with your operational goals.

References

[1] *Uptime Intelligence: Cooling systems: balancing cost, energy and water use*
Cooling systems: balancing cost, energy and water use

Contributors

Sam Rodriguez, Senior Product Manager, Cabinets, Containment & Industrial Solutions

Sam has over 31 years of experience in the communications market and has been an employee owner for 26 years. He has held several progressive roles including Senior Product Manager for Cabinet and Thermal Solutions, Technical Services Supervisor and Technical Support. As a Senior Product Manager, he manages CPI's ZetaFrame Cabinet System, RMR Industrial Enclosures and Aisle Containment portfolio. He has been an active BICSI member for 19 years and received his RCDD credentials in 2005. He is a leader of CPI's product development organization and contributes to the design and development of new innovative product solutions. In his current role, he is focused on developing CPI's Cabinet, Containment & Industrial Enclosures and Thermal Solutions to support the increasing requirements for Edge Deployments, IOT and IIOT applications.

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