WHITE
PAPER

From Air to Liquid Cooling:

Why Containment is the Vital Link

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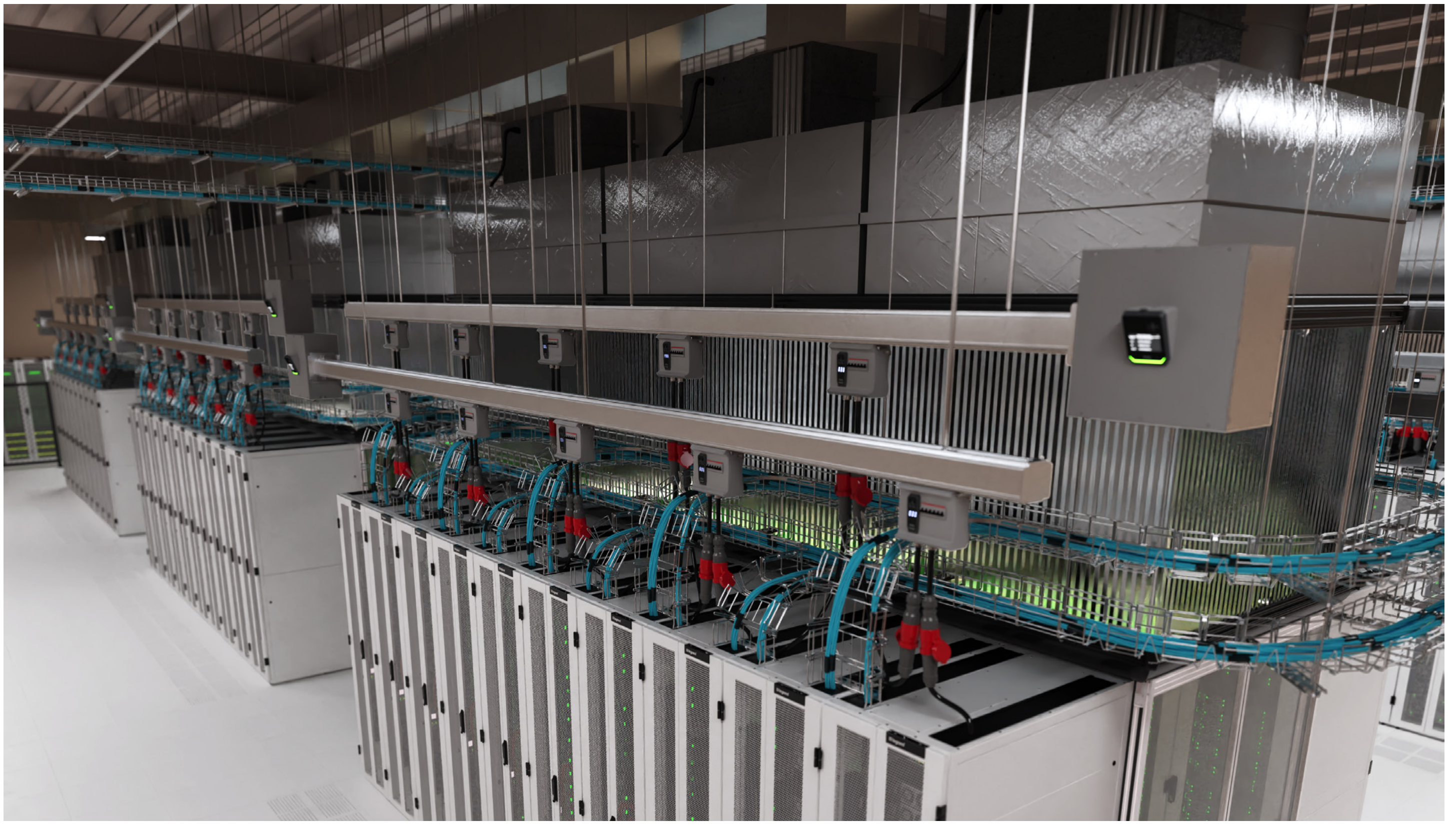


Executive Summary

As data centers face unprecedented demands, driven by the rise of AI workloads and next-generation servers, traditional air cooling is rapidly reaching its limits. With AI chips now pushing rack densities higher (from 10 kW per rack to 50 kW or more), the industry is about to reach a tipping point: While liquid cooling offers a path forward, making one giant leap from air to liquid is often impractical due to cost, complexity, and operational disruption.

This white paper explains why containment is the essential, non-negotiable next step in any modern data center's cooling journey. By physically separating hot and cold air, containment maximizes the effectiveness of existing cooling systems, stabilizes operating temperatures, and significantly improves energy efficiency and equipment reliability.

Containment also acts as a bridge, giving data centers a way to scale up rack densities and thermal loads over time to support higher demands without the need for immediate, large-scale infrastructure overhauls to accommodate liquid cooling.

By prioritizing containment as a foundational strategy, data center operators can safeguard reliability, boost efficiency, and prepare for the new landscape ahead.

Introduction

The demands placed on data centers are accelerating fast, especially with AI workloads on the horizon and already in place in many businesses. These facilities are not only processing more data than ever before but also requiring new types of hardware to support advanced applications. To operate, this new hardware requires significantly more power than traditional computing equipment.

How much more heat will have to be managed? It's difficult to know for sure. Future power requirements and associated heat loads depend on several unpredictable variables, such as:

- How quickly AI applications are adopted
- The power demands of the specific chips in use
- The efficiency of cooling and power infrastructure (less efficient systems waste energy as heat, creating more heat to manage)

As capacity increases in sync with AI workloads, however, one thing is clear: Traditional open-air cooling will become obsolete, and advanced airflow management and cooling will play a critical role in maintaining reliable data center operations.

Reaching the Limits of Air Cooling: Now What?

Most data centers currently rely on open-air cooling to dissipate heat, supporting average rack densities between 10 kW and 15 kW. Meanwhile, the density for AI racks begins at 50 kW, far exceeding the capacity that traditional open-air cooling systems can handle. These high-density deployments call for liquid cooling to manage intense heat loads.

Making a direct leap from air cooling to liquid cooling, however, can be impractical for many data center operators. Liquid cooling is a significant capital investment that often requires a major infrastructure overhaul, which can result in significant downtime as updates are made. It's also difficult to implement in phases because of the number of changes required to integrate it.

To reduce costs and minimize disruption, data center operators will need to find effective ways to bridge the gap between current-state air cooling and future-state liquid cooling as computing demands evolve. This transitional phase will be key to sustaining performance amid AI-driven increases in rack density and thermal loads.

Containment: How to Bridge the Cooling Gap

Containment is set to serve as the critical link in the transition from traditional air cooling to full liquid cooling.

As power infrastructure becomes a bottleneck, containment can help data centers manage it effectively by reducing cooling overhead and improving power usage effectiveness (PUE).

WHAT IS CONTAINMENT?

When the cold air supplied by a data center's cooling system mixes with the hot air exhausted from servers, this makes cooling less efficient and increases energy use and costs. The mixing of hot and cold air forces the cooling system to work harder to maintain safe and consistent operating temperatures, leading to higher operating expenses and jeopardizing data center performance.

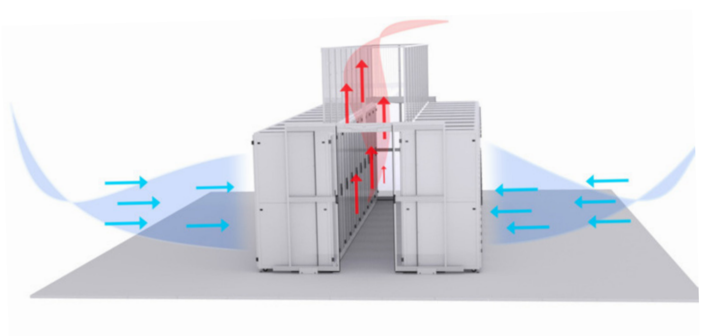
Containment works to physically separate cold supply air from the hot exhaust air produced by servers and other equipment, preventing the two streams of air from mixing. This approach offers many benefits:

- **Improves cooling efficiency:** By separating hot and cold air, cooling systems can work more efficiently. When the air that returns to CRAC/CRAH units is hot and dry, the units perform at their best.
- **Reduces energy consumption:** Because the volume of air that requires cooling and circulation is dedicated to hot air, cooling units can operate at lower speeds or run less often (or sometimes even be powered down), which lowers energy use.
- **Increases equipment lifespan:** Servers receive the right amount of cool air at the right temperature and humidity, reducing temperature fluctuations and hot spots that compromise performance and shorten service life. Stable temperatures minimize thermal stress and maintain the proper environment for equipment operations.

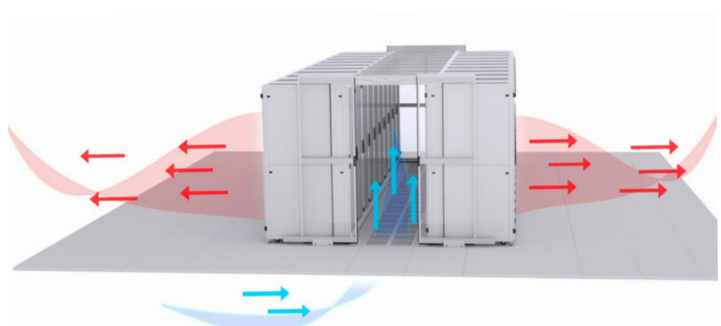
WHAT CONTAINMENT OPTIONS EXIST?

Containment can be implemented in two different ways. Both use physical barriers (single doors, double doors, panels, etc.) to enclose certain aisles.

- Hot aisle containment (HAC) encloses the hot aisles at the back of servers (where hot server air is exhausted). This ensures that hot air is directed back to the cooling system without mixing with the cold supply air. In this scenario, the rest of the room remains cool.
- Cold aisle containment (CAC) encloses the cold aisles at the front of servers (where cold air is supplied to servers). This ensures that only cold air reaches the equipment, turning the rest of the room into a return path for hot air.



Hot aisle containment (HAC)



Cold aisle containment (CAC)

Whether implementing a HAC or CAC system, most containment systems work with virtually any data center layout and configuration or type of cabinet or rack, regardless of brand/model, height, width, depth, or door design.

Containment solutions can be deployed in any data center environment, whether you're building a new data center or operating one that's been in service for decades.

Deciding between HAC and CAC depends on several factors related to your data center's design, operational requirements, and goals, including:

- Existing infrastructure (flooring type, ceiling height, overhead obstructions, air systems, etc.)
- Density/heat load
- Sustainability goals (hot aisle containment is generally considered more efficient)
- Operational environment (personnel access requirements, maintenance practices, etc.)
- Layout and rack configurations

The Transition Zone: Bridging Air and Liquid Cooling

Because computing demand is constantly increasing, there will come a time when your data center enters the "transition zone" (when rack densities reach between 20 kW and 40 kW). As demands rise, traditional air cooling won't be able to keep up, but full liquid cooling won't be practical, affordable, or feasible yet. The tipping point comes when the heat generated by your equipment exceeds what traditional air cooling can manage ... but the shift to liquid cooling is not yet possible.

Implementing a containment system is the first step in the evolution from air cooling to liquid cooling. It maximizes the performance of existing air-cooling systems to immediately improve cooling efficiency, optimize airflow, and stabilize operating temperatures. As a bridge solution, it allows data center operators to scale toward supporting higher rack densities and thermal loads without having to make major infrastructure changes right away.

What might this transitional evolution look like in its full form?

While every situation is unique, data center cooling typically follows an incremental progression as laid out in the following order:

ColdLogik Rear Door Heat Exchanger

1. TRADITIONAL OPEN-AIR COOLING

Using room-level air conditioning to manage heat

Density	Benefits	Drawbacks	Environment
▪ Low (less than 15 kW)	▪ Simple to design, operate, and maintain ▪ Low upfront costs ▪ Simple to scale to a certain point	▪ Limited capacity ▪ Not energy efficient ▪ Creates temperature fluctuations and hot spots	▪ Legacy/smaller data centers

2. CONTAINMENT

Using barriers to physically separate cold and hot air streams to improve airflow management

Density	Benefits	Drawbacks	Environment
▪ Moderate to high (10 kW to 30 kW)	▪ Improved energy efficiency ▪ Eliminates hot spots ▪ Simple to scale ▪ Easy to maintain	▪ Density ceiling ▪ Installation may require infrastructure adjustments ▪ Uncontained aisles can be uncomfortable (too warm)	▪ Growing/large-scale data centers

3. REAR DOOR HEAT EXCHANGERS

Moving cooling closer to the heat source (server exhaust air) by mounting liquid-cooled coils to the back of each rack

Density	Benefits	Drawbacks	Environment
▪ High (25 kW to 80 kW)	▪ Very energy efficient ▪ Space efficient ▪ Easy to scale/retrofit	▪ More maintenance due to reliance on fans ▪ Potential for leaks ▪ Can be difficult to install/implement	▪ High-density data centers that require flexibility

4. DIRECT-TO-CHIP LIQUID COOLING

Delivering coolant directly to CPUs and GPUs to remove heat at its source

Density	Benefits	Drawbacks	Environment
▪ Very high (50 kW to 100 kW+)	▪ High cooling efficiency ▪ Removes heat at the source ▪ Optimizes space	▪ Risk of leaks ▪ Complex deployment/infrastructure ▪ Limited coverage	▪ Hyperscale/cloud/AI data centers

5. IMMERSION COOLING

Submerging servers in dielectric fluid for complete heat removal

Density	Benefits	Drawbacks	Environment
▪ Extremely high (100 kW to 250 kW+)	▪ Complete heat absorption ▪ Low noise ▪ Optimizes compute density	▪ High capex and opex costs ▪ Takes up more space ▪ Risk of leaks	▪ AI and HPC data centers

The Hidden Costs of Skipping Containment, and Why It's a Necessary Step

If you opt to skip containment along your data center's journey from traditional air cooling to liquid cooling, you may unintentionally introduce performance risks and inefficiencies.

UNMANAGED RESIDUAL HEAT

Liquid cooling targets direct heat removal for high-power components, leaving other hardware, such as networking equipment or storage devices, still dissipating residual heat. The hot air then circulates within the data center space, creating hot spots and potentially impacting the effectiveness of liquid cooling.

Even with liquid cooling in place for high-power components, residual heat from other devices circulates unchecked. Containment ensures that whatever heat remains, whether it's from storage devices, power distribution units, or switches, is managed effectively. This prevents the hot spots and unstable temperatures that would be prevalent throughout the data center otherwise.

AIRFLOW DISRUPTION

Containment is essential for controlling airflow as a critical step. By controlling airflow, containment stabilizes operating temperatures and optimizes the performance of current infrastructure.

When containment isn't deployed in a liquid-cooled environment, hot and cold air still mix. This can lead to unpredictable temperatures, inefficient cooling, and high energy costs. Liquid cooling technologies will be forced to compensate for inefficiencies caused by uncontrolled air recirculation—even though they're not designed to do so.

EQUIPMENT STRESS AND DOWNTIME

Hot air can stress equipment, shortening its lifespan and increasing the risk of overheating and downtime.

Containment helps reduce that stress and improve reliability. By establishing containment as the foundational step, data centers can maximize the performance of air-cooled systems and future liquid-cooled deployments. It acts as a foundational improvement to manage increasing thermal loads more effectively until the transition to full liquid cooling is possible.

LIMITED COOLING CAPACITY

Without containment, advanced liquid cooling systems may not be able to handle the higher thermal loads present in high-density deployments. Containment increases a data center's cooling capacity to support higher rack densities. It can also act as a backup if active cooling systems fail.

With containment in place, rack densities and thermal loads can continue to increase to meet future demands without compromising reliability or efficiency. Whenever you're ready to introduce liquid cooling, your data center will be primed for efficient heat removal. This makes it easier to target and integrate liquid cooling solutions where they're needed most.

Tips to Make Sure Containment Is Done Right

As your data center evolves, containment lays the groundwork for more advanced cooling strategies in the future. A stable, predictable thermal environment is essential, whether your eventual goal is to rely on air cooling for as long as possible, integrate liquid-assisted solutions, or transition to full liquid cooling.

To get the most out of your investment, follow these tips to make sure your containment solution performs as expected.

- **Consider hybrid solutions.** Transitional or hybrid approaches to cooling strategies are a viable option (deploying rear door heat exchangers alongside containment, for example).
- **Plan now for future workloads.** When deploying containment solutions, keep future needs in mind, even if your current requirements are modest. This upfront planning will help avoid unnecessary costs and disruptions in the future.
- **Choose the right containment type.** Choosing between HAC and CAC isn’t a straightforward decision. The choice should be made based on facility layout and rack configurations, existing infrastructure, and operational goals.
- **Engage the right teams.** Involve all stakeholders—including facilities, IT, and operations—in the planning and deployment process to ensure alignment with everyone’s goals.
- **Continue to optimize.** Monitor temperature and airflow patterns after containment is deployed to identify opportunities to further improve or optimize its performance.

Start Your Data Center Evolution Off Strong

As a low-risk, high-impact upgrade, containment should be the non-negotiable first step in your approach to modern data center cooling. While skipping it introduces risk and inefficiency, even in high-tech environments, containment can deliver immediate improvements in energy efficiency, equipment reliability, and operational resilience.

Containment bridges the gap between legacy air cooling and advanced liquid cooling, ensuring efficiency and flexibility along your path to scalability and preparing for AI workloads.

About Legrand Containment Solutions

Legrand’s hot aisle and cold aisle containment systems maximize cooling efficiency and equipment reliability. With flexible, modular designs that adapt to various facility layouts, ceiling heights, and operational requirements, every system is engineered for high efficiency, typically preventing more than 95% of air mixing at normal operating pressures.

With in-house engineering and nationwide project management, Legrand can support data centers from initial design through installation, offering air leakage testing and certification to ensure optimal performance and compliance with evolving data center standards.

To learn more visit

legrand.us/critical-power-and-infrastructure/aisle-containment

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