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Addressing Rising Power Densities in the Data Center Starts with an Integrated Cabinet Foundation

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Published: September 2023

chatsworth.com

Introduction

As data centers deploy emerging digital services and high-performance computing (HPC) technologies, such as artificial intelligence (AI), machine learning (ML), and advanced data analytics, they face rising rack power densities of over 20 kilowatts (kW), with extreme density racks reaching 80kW or higher. Increasing power density leads to higher heat generation, which demands more effective cooling solutions to prevent equipment failure and costly downtime. At the same time, data center cooling accounts for 30 to 50% of total energy consumption.[1] Rising energy prices and the need to comply with increasingly stringent energy consumption regulations and sustainability initiatives require highly efficient cooling solutions in addition to closely monitoring data center power.

Liquid cooling technology has emerged as a highly effective and efficient solution to these challenges. The global data center liquid cooling market is projected to grow from $2.1 billion in 2022 to $6.4 billion by 2027.[3] According to the Uptime Institute, rack densities higher than 20 to 25 kW make advanced liquid cooling more economical and efficient.[4] However, deploying these solutions on an ad hoc basis requires complex and costly reconfigurations and upgrades. Cabinet systems that use a modular, holistic approach to integrating thermal and power management facilitate cost-effective scalability for data centers to support increasing rack power densities while optimizing energy efficiency.

The Need for Liquid Cooling

Early data centers in the 1990s with average power densities of less than 2kW/rack were typically able to keep equipment cool by simply deploying a hot aisle/cold aisle configuration to limit cold supply air from mixing with hot exhaust air. As processing and power densities grew, data centers needed to add more cooling capacity and lower supply temperatures to prevent hotspots. This solution was highly inefficient and expensive, which created the need for more effective air isolation via the following passive cooling methods:

- Airflow management—Solutions like cabinet blanking panels, air dams, sealing, and grommets block airflow around the sides and top of equipment and through open rack units and cable openings to prevent exhaust air from recirculating around equipment. Proper cable management within cabinets also helps prevent cables from restricting airflow.

- Cold aisle containment (CAC) *Figure 1:* —For use with raised-floor environments, in-row cooling, or data centers without overhead hot air return space or duct systems, CAC solutions direct cold air into the contained intake space between two cabinet rows. With CAC, the area outside the contained space becomes the hot aisle, elevating the room temperature.

Figure 1: Cold aisle containment (CAC) directs cold air from the raised floor into the contained intake space between two cabinet rows.

- Hot aisle containment (HAC)— HAC solutions direct hot exhaust air out of the contained hot aisle to overhead return air systems. With HAC, the area outside the contained space becomes the cold aisle, resulting in a colder, more comfortable room temperature.

Figure 2: Hot aisle containment (HAC) directs hot exhaust air out of the contained hot aisle to overhead return air systems.

- Vertical exhaust duct (VED)— VED solutions, also called chimneys, function like HAC but are used at the individual cabinet level to direct hot exhaust air to the overhead return air system. VED solutions keep hot air out of the aisles and working space, resulting in a cooler, more comfortable room temperature without needing a complete HAC system.

Figure 3: Vertical exhaust ducts (VEDs) are used at the individual cabinet level to direct hot exhaust air to the overhead return air system.

Passive cooling solutions support increased rack power density and improve cooling efficiency by isolating cold intake air from hot exhaust air, allowing for higher air supply temperatures and preventing costly computer air conditioning (CRAC) overprovisioning. However, as average power densities climb beyond 20kW per rack and higher, passive cooling may no longer sufficiently prevent hot spots without again adding cooling capacity and lowering supply temperatures. Additionally, not every data center space can adequately accommodate containment solutions and VEDs that require a raised floor or overhead return air systems.

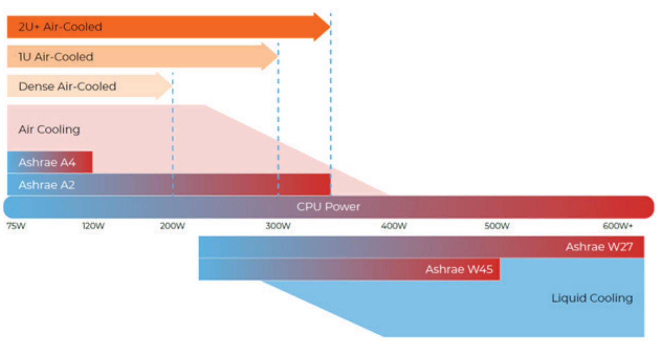

Figure 4: Transition from air cooling to liquid cooling based on CPU power and ASHRAE air-cooled and liquid-cooled classes for equipment operation. Source: ASHRAE

Liquid cooling offers better heat conduction capabilities than air and enables higher rack power densities. As shown in Figure 4, standard 1U and 2U servers become increasingly difficult to cool via air as central processing unit (CPU) power increases from 300W to 400W.[5] Only liquid cooling can cool equipment with a CPU power of 400W or higher.

There are three main types of liquid cooling solutions:

Rear Door Heat Exchangers

This solution involves using liquid-filled coils in the rear door of the cabinet, where hot exhaust air from the equipment passes through the coils and returns to the room at ambient temperature. The heated liquid is returned to a Coolant Distribution Unit, where it is typically cooled via a chilled water loop and pumped back through the coil. Rear door heat exchangers can be either active or passive, with active exchangers incorporating integrated fans. Although this solution requires plumbing for the cabinet, it supports standard IT equipment mounted in traditional 19" EIA cabinets.

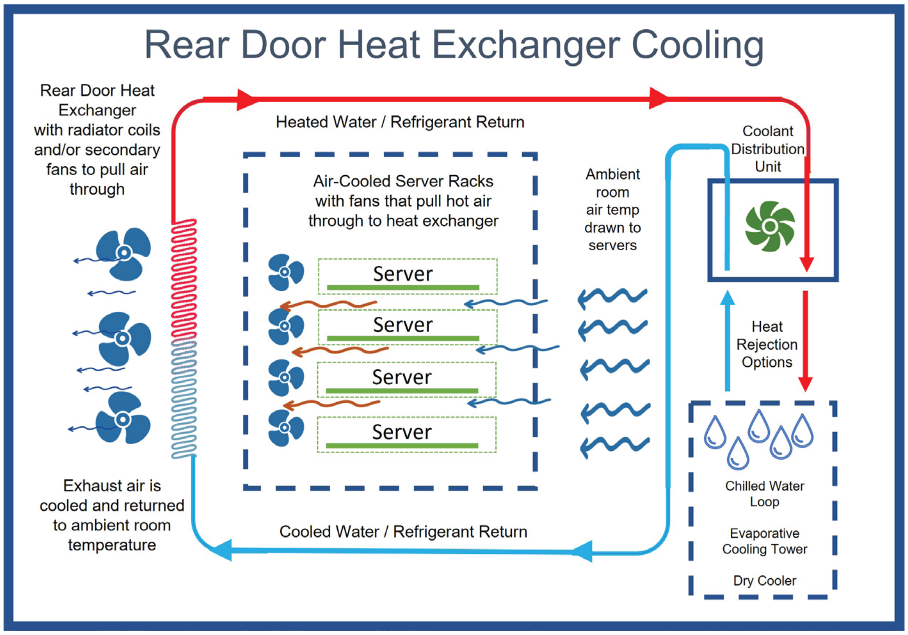

Figure 5: Rear door heat exchanger liquid cooling solution. Source: grcooling.com

Liquid Immersion Cooling

In this approach, electronic components are submerged in a coolant, typically a dielectric fluid, in a tank or sealed enclosure. Immersion cooling can be single-phase or two-phase, with two-phase offering enhanced cooling capabilities through evaporation and condensation. Immersion cooling rejects heat via a heat exchanger and the building chilled water loop. Immersion cooling comes with high initial costs due to requiring specialized servers, IT equipment, and cabinets. The nature of the rack orientation also requires equipment to be lowered in and out vertically, typically via an overhead lift. This orientation can also inhibit vertical scalability within a cabinet, lowering power density per square foot and requiring more floor space.

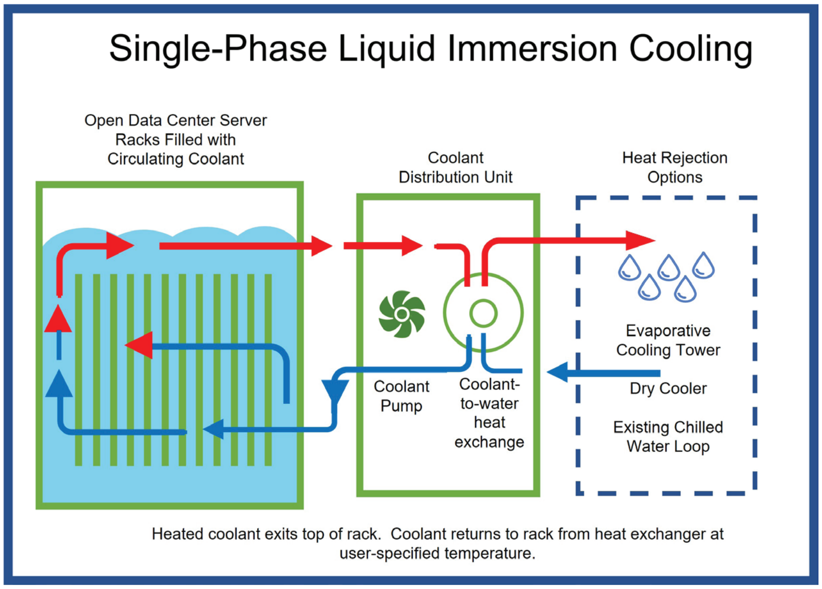

Figure 6: Single-phase liquid immersion cooling solution. Source: grcooling.com

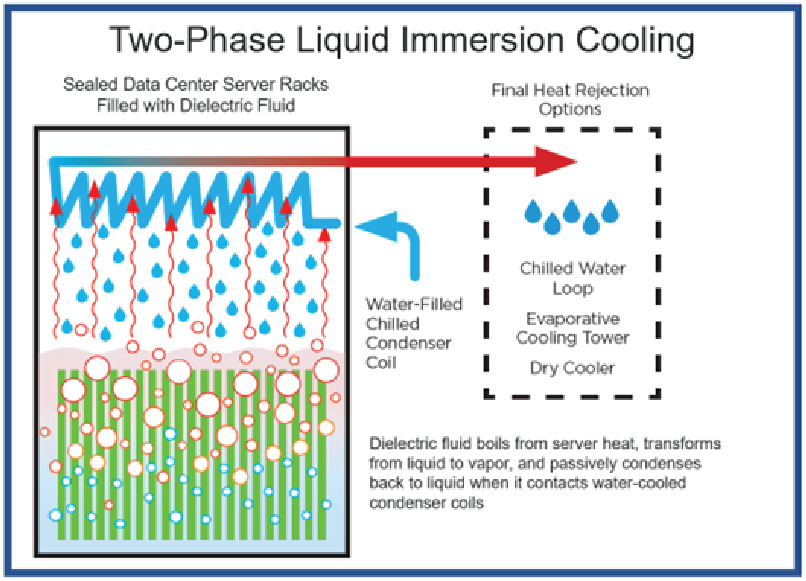

Figure 7: Two-phase liquid immersion cooling solution. Source: grcooling.com

Direct On-Chip Cooling

Also referred to as cold plate or direct liquid cooling, direct on-chip cooling provides the most efficient heat transfer with the ability to cool CPU power up to 1000W. As shown in Figure 8, direct on-chip cooling involves pumping chilled water or dielectric fluid to cold plates that attach to heat-generating components within the equipment, such as CPUs, graphical processing units (GPUs), and field programmable gate arrays (FPGAs). Direct on-chip cooling can be single or two-phase, with two-phase systems always using dielectric fluid.

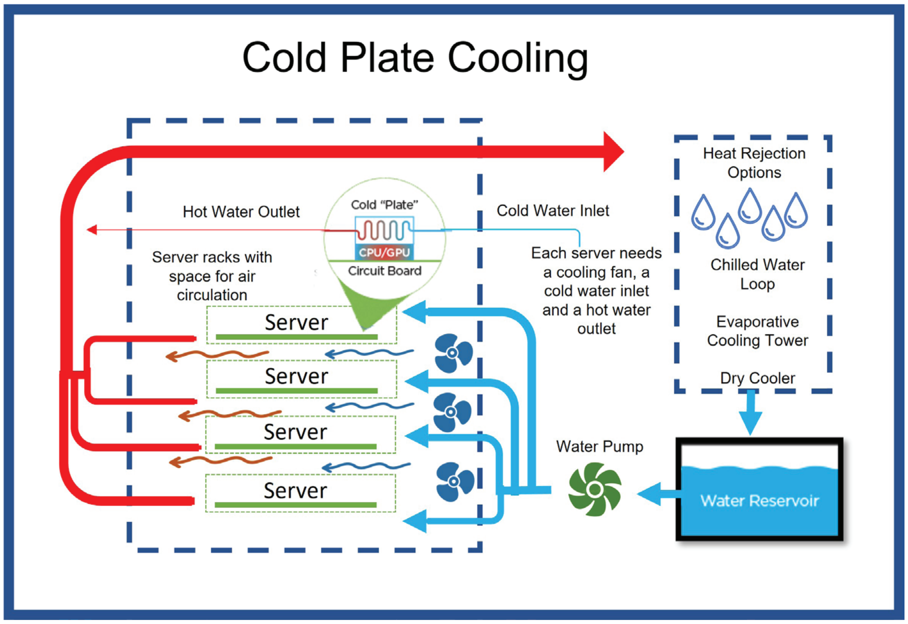

Figure 8: Direct on-chip, or cold plate, cooling solution. Source: grcooling.com

Selecting the Right Cooling Solution

Passive cooling solutions remain widely used and viable for high rack power densities up to 30 kW. Selecting the right passive cooling solution depends on the data center's overall design, configuration, and operations. For example, CAC requires a raised floor and is best for scenarios where an overall hotter room temperature is not a problem, such as unmanned data centers or data centers that do not contain other equipment in open racks. CAC is also an ideal solution for data centers without an overhead ceiling space and for spaces with low ceiling heights. In contrast, HAC and VEDs require overhead return air space and are ideal for data centers that require an overall cooler room environment.

When rack densities push beyond 20 KW, it may be time to consider migrating to a liquid cooling solution. Several factors to consider when selecting a liquid cooling solution include ease of adoption, deployment cost, reliability, efficiency, and sustainability. Passive rear door heat exchangers rely on the airflow provided by equipment fans mounted in the cabinet but can cause increased load on those fans as temperature rises. In contrast, an active rear door heat exchanger supports higher rack power densities and avoids relying solely on equipment fans. Both passive and active rear door heat exchangers require cabinets with adequate load capacity and the ability to replace standard rear doors easily. Choosing a cabinet from a manufacturer who can pre-install and ship cabinets with rear door heat exchangers can save considerable time and labor for new deployments. Rear door heat exchangers can also be an ideal solution for lower power densities in data centers that do not have a raised floor or an overhead air handling space.

Direct on-chip liquid cooling is ideal for extremely high power densities of 50kW or higher in HPC environments. It is the most effective liquid cooling because it is applied directly to processors to extract and disperse heat. Direct on-chip liquid cooling increases server efficiency by lowering the power draw when the fans are not in use, allowing data centers to raise the ambient air temperature and save on power and cooling costs. Two-phase direct on-chip liquid cooling offers the advantage of using dielectric fluid with boiling and condensation processes that use no water in the system, protecting equipment from corrosion and other water-related threats. A two-phase direct on-chip liquid cooling system consists of the following primary components:

- Cold Plates sit on the processors in the server and allow the dielectric fluid to boil and vaporize the heat away from the processors and servers, never directly contacting electronics.

- Heat Rejection Units (HRUs) move dielectric fluid to the servers via manifolds and ensure efficient vapor condensation and rejection of the heat it contains. HRUs are self-contained, fully autonomous units with independent sensors, pumps, controllers, and multi-level leak detection and prevention supporting higher rack power densities. Depending on a data center's design and specifications, air or water can be utilized as the cooling source. Figure 9 shows the solution with an air HRU.

- Distribution manifolds distribute the dielectric fluid to the cold plates via outlet ports and return vaporized fluid to the HRU via inlet ports.

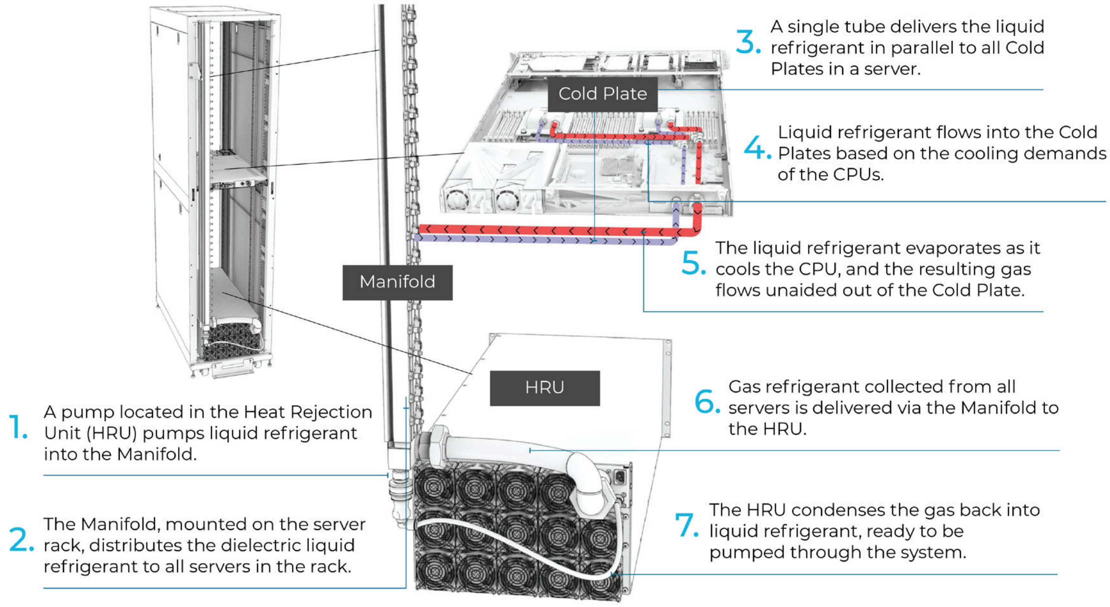

Figure 9: Two-phase direct on-chip, closed-loop dielectric liquid cooling solution with an air HRU. Source: zutacore.com

Unlike liquid immersion cooling, direct on-chip liquid cooling can be easily retrofitted into existing data center environments and allows servers to remain horizontally positioned within standard cabinets. Two-phase direct on-chip solutions also require less dielectric fluid than immersion cooling for greater efficiency and reduced cost while preventing the risk of overloading weight capacities. In addition, leaks in an immersion cooling system can cause all equipment to go offline. Leaks in a direct on-chip solution only impact individual servers.

The Value of Power Management and Monitoring

While the right cooling solution can have a significant impact on effectively and efficiently cooling higher power densities in the data center, power distribution units (PDUs) must also support increasing rack power densities. Continually monitoring power usage to improve power usage effectiveness (PUE) and reduce energy consumption is also paramount.

Intelligent PDUs can provide real-time and remote monitoring of power parameters and usage, giving data center operators visibility into power consumption – informing decisions regarding resource allocation and optimization. Intelligent PDUs can also be outfitted with various sensors to monitor environmental conditions such as temperature, humidity, and airflow. PDU sensors can also detect leaks, smoke, and other hazards. These sensors provide a simple, automated environmental monitoring solution that alerts critical thresholds to prevent downtime. They can also serve as an indicator of leaks or malfunctions within a cabinet-level liquid cooling solution.

With human error and security breaches a major cause of downtime, properly controlling and managing access to IT equipment within cabinets is imperative. Some advanced intelligent PDUs can seamlessly integrate with electronic cabinet door locks via controller modules to enable power, management, and control of cabinet-level security and provide an audit trail of access control attempts. Integrating cabinet locks with PDUs can eliminate the need for additional cabling infrastructure to connect and power locks.

Intelligent PDUs backed by a centralized data center infrastructure management (DCIM) software platform enable configuring, managing, and reporting on data collected from PDUs across the entire data center via a single dashboard. Centralized management is ideal for reporting PUE and tracking power usage against known capacity, helping data center operators identify areas for improvement and optimize capacity, power, cooling, and space planning. Intelligent PDUs that support common communications protocols, such as SNMP, command-line interface (CLI), and application programming interfaces (APIs), as well as MODBUS or BACNet, can also effectively integrate with gray space equipment, active cooling solutions, and other third-party data center technologies for complete visibility and insight into the health of all data center assets and operation.

It All Starts with an Integrated Cabinet System

Cabinet systems are the foundation for cost-effectively supporting current and future rack power densities. Cabinet systems must provide scalability by seamlessly supporting airflow management accessories and HAC, CAC, and VED solutions, while providing sufficient load capacity, durability, space, and customization to facilitate migration to advanced liquid cooling solutions like rear door heat exchangers and direct on-chip liquid cooling. At the same time, they must provide space for seamless mounting and integration of intelligent PDUs, as well as any associated environmental monitoring and access control accessories. The right integrated cabinet solution is crucial for successfully implementing direct on-chip liquid cooling as they must effectively accommodate the manifold, as well as inlet and outlet connections for cold plates while still ensuring space for PDUs and cable management.

CPI's ZetaFrame® Cabinet System is the ideal foundation for addressing rising power densities and energy efficiency in the data center. The ZetaFrame Cabinet System uses a modular, holistic approach to integrate cable management, thermal management, power management, environmental monitoring, and access control—all working together as a single-vendor turnkey platform that reduces costs and optimizes efficiency, availability, security, and scalability.

The Zeta Frame Cabinet is a highly engineered, configurable cabinet that offers an industry-leading 4,000 lb. dynamic load capacity within an 800mm wide form factor, superior scalability, and enhanced high-density cable management.

- Fully integrates with airflow management accessories and passive cooling solutions, such, as CAC, HAC, and VEDs rack power densities up to 32kW.
- Provides the load capacity and design to easily retrofit with rear door exchangers and accommodate direct on-chip dielectric liquid cooling, even when racks are fully loaded and used with a shock pallet.
- Ample mounting space and provisions for a direct on-chip dielectric liquid cooling HRU and manifold while still providing room for PDUs and other necessary accessories.
- Customizable with pre-installed eConnect PDUs, cable management, electronic access control, liquid cooling, and other accessories for faster deployment.

eConnect PDUs seamlessly integrate with the ZetaFrame cabinet, delivering cabinet-level power management, environmental monitoring, and access control to reliably protect equipment and improve productivity and energy efficiency—even in the highest-density environments. Supports high rack power densities, accommodating up to 57kW on a single PDU.

- Provides real-time and remote monitoring of granular power parameters and usage down to the outlet level.
- Easily integrates with sensors to actively monitor temperature, humidity and airflow levels and set alarm thresholds to quickly detect and prevent hot spots, moisture build-up, low humidity, leaks, and other hazards that can degrade network equipment.
- Provides seamless software integration with active cooling solutions and cabinet access control.
- Backed by Power IQ® for eConnect, a DCIM software solution that provides a user-friendly and robus central management platform fo alerting, tracking, and reporting power usage, environmental conditions, and security information.

Built for Current and Future Needs

As power densities continue to rise, the ability of a cabinet system to integrate more effective cooling solutions and advanced power management and monitoring is paramount. By integrating advanced liquid cooling technology, densely configured cabinets can support higher core counts and workloads, allowing data centers to utilize real estate more efficiently. The benefits are unmatched when integrated with intelligent PDUs for power and environmental monitoring, access control for security, and centralized management.

The ZetaFrame Cabinet System is fully customizable and purpose-built to effectively protect and power technology today while providing the strength and configurability to scale for the future in any data center application or environment. With a commitment to environmental sustainability and reducing the carbon emissions associated with data centers, CPI collaborates closely with customers to deliver an integrated ZetaFrame Cabinet System with pre-installed thermal management and power management tailored to achieve power density requirements, comply with energy consumption regulations, and meet sustainability goals.

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Ashish Moondra has more than 25 years of experience developing, managing and selling rack power distribution, uninterruptible power supply (UPS), energy storage and Data Center Infrastructure Management (DCIM) solutions. Ashish has previously worked with American Power Conversion, Emerson Network Power and Active Power, and has been an expert speaker at various data center forums.

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He 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.

Contact us to design an integrated ZetaFrame Cabinet System for your specific needs and goals.

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