WHITE PAPER

Data Center Airflow Management Basics: Comparing Containment Systems

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Data Center Airflow Management Basics: Comparing Containment Systems

Introduction

In the past decade, many companies have become aware of the advantages of data center airflow management practices that include containment systems. It is also now well understood that as the average heat load per cabinet rises, simply arranging cabinets in a traditional open hot aisle/cold aisle configuration is not an effective approach. Industry associations have considered indirect and direct liquid cooling as possible solutions for high density applications, but using a containment system with perimeter cooling is still a very capable solution for today's average rack densities and the anticipated densities over the next decade. Furthermore, containment systems support retrofit from hot aisle/cold aisle, economizer applications and free air cooling.

This white paper, by Chatsworth Products (CPI), examines and compares three data center containment systems and demonstrates that there are important differences to consider that distinguish one system over the others. It will help you to determine the best containment option for your data center requirements and your business goals.

Fast Fact

Containment separates hot and cold air, allowing you to reduce the volume of air delivered to cool equipment, which leads to a number of improved efficiencies and also typically reduces cooling energy costs. For more details on these factors, please read the companion paper, *Data Center Airflow Management Basics: Economics of Containment Systems.*

The Three Methods of Containment

There are three basic methods of complete containment. This section describes each system and lists benefits and challenges that should be considered with each system.

Ducted Exhaust Cabinets (CPI: Vertical Exhaust Ducts)

Ducted exhaust cabinets are enclosed server rack cabinets with an attached Vertical Exhaust Duct.

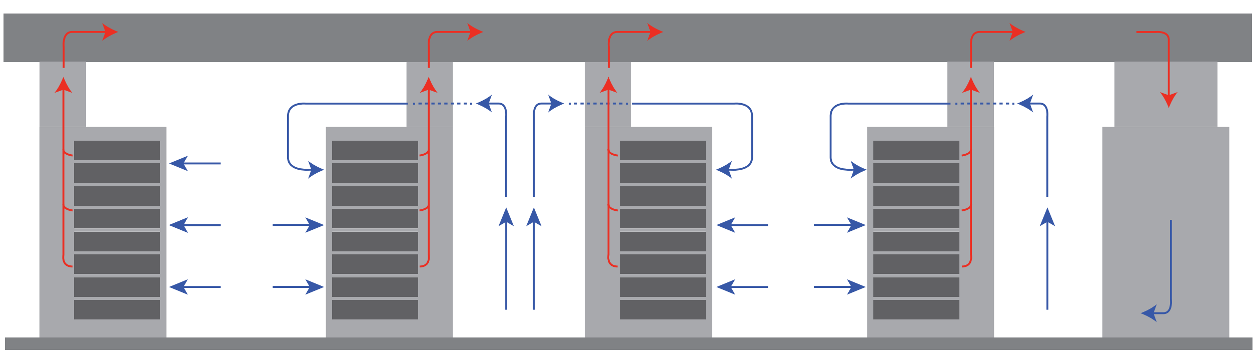

FIGURE 1: Sectional view of several ducted exhaust cabinets with Vertical Exhaust Ducts showing airflow through the cabinets and through the room. Note: Hot exhaust air is isolated and removed from the room through the Vertical Exhaust Ducts .

As pictured in [Figure 1] above, the hot exhaust air given off by the servers is enclosed within the cabinet, completely isolating the air from the room. The hot air exits the cabinet through the overhead vertical exhaust duct, which directs the hot air into a plenum above the drop ceiling and back to the cooling units (shown) or to outside vents.

Architectural Considerations for Ducted Exhaust Cabinets (CPI: Vertical Exhaust Duct):

Benefits:

- Simplest method to deploy and change; cabinet based
- Most cost-effective method to deploy
- The exhaust duct is the "hot aisle"
- The entire room is the "cold aisle," and provides supply air
- Cabinets can be placed anywhere in the room and in any orientation, traditional hot aisle/cold aisle configuration is recommended for best use of space, but strict "hot aisle/cold aisle" rows are not required
- No additional aisle clearances are required to deploy a ducted exhaust cabinet; the locations of building columns and support structures do not impact deployment
- It eliminates the need for a raised floor
- Cold supply air can be delivered from anywhere in the room, strict "front of cabinet" delivery is not required
- Auxiliary equipment can be placed anywhere and still be sufficiently cooled, because the room is cool
- If a raised floor exists, leakage through the tiles is mostly into the "cold aisle" and not wasted bypass air
- Minimal or no changes are required to the fire suppression system – sprinklers must cover the room

Challenges:

- This system requires an overhead plenum and the addition of collars on air handler units to create a complete closed return
- This system requires ducts to be placed above each cabinet; the ducts must be able to extend to the overhead plenum
- Some devices do not offer a Vertical Exhaust Duct option, requiring a third party to supply the duct; CPI may offer a custom solution
- Fan speeds on the air handlers should be adjusted to closely match equipment requirements; this may require some units to be shut off or upgraded with variable speed fans
- Optimizing operating conditions may require the addition of some instrumentation or HVAC controls

Hot Aisle Containment (HAC)

Hot aisle containment (HAC) is the most popular type of containment solution used today. In this method, a configuration of duct work and baffles are set up over the hot aisle, with doors blocking the aisle entrances at either end.

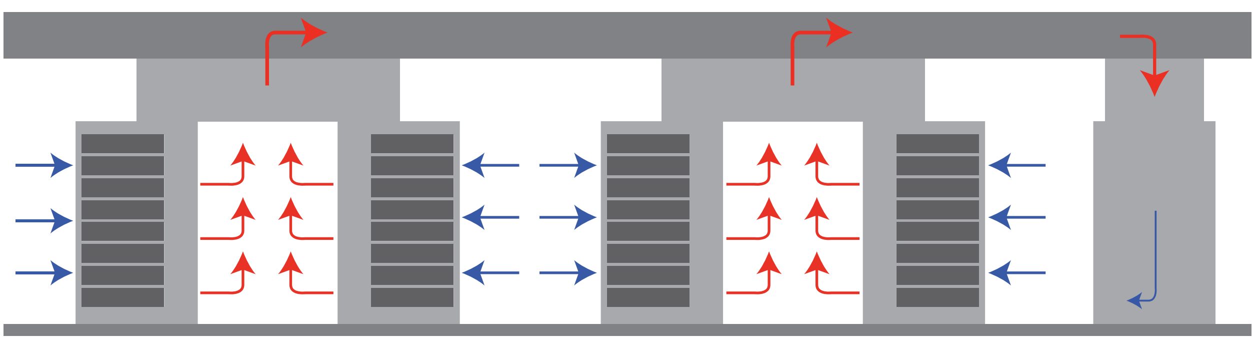

FIGURE 2: Sectional view of a HAC solution with ducts constructed over the hot aisles, showing airflow through the contained aisles and the room.
Note: Hot exhaust air is isolated and removed from the room through the ducts over the contained hot aisles.

As shown in [Figure 2] above, the HAC solution contains and isolates the hot exhaust air from the room, preventing it from reaching the adjacent cold aisles and mixing with the cold air. The hot exhaust air in the hot aisles is then returned to the cooling units, usually through drop ceiling plenums.

Architectural Considerations for HAC:

Benefits:

- Contained aisles are the “hot aisles”
- The entire room (except the contained hot aisle) is the “cold aisle,” and provides supply air
- It eliminates the need for a raised floor
- Cold supply air can be delivered from anywhere in the room; strict “front of cabinet" delivery is not required
- Auxiliary equipment can be placed anywhere and still sufficiently cooled, because the room is cool
- If a raised floor exists, leakage through the tiles is mostly into the “cold aisle” and not wasted bypass air
- Minimal or no changes are required to the fire suppression system – sprinklers must cover the room and contained aisle

Challenges:

- More complicated to deploy and change compared to Ducted Exhaust Cabinet (CPI: Vertical Exhaust Duct)
- More expensive method to deploy compared to Ducted Exhaust Cabinet (CPI: Vertical Exhaust Duct)
- Cabinets must be placed in adjacent hot aisle/cold aisle rows and deployed in pairs to create “hot aisles”
- This system may require row lengths to be evenly sized, parallel and aligned; the CPI solution can be deployed over uneven aisles
- Additional aisle clearances may be required for the doors at the ends of each aisle; the CPI solution has sliding doors and requires no additional clearance for door swing
- This system requires an overhead plenum and the addition of collars on the air handler units to create a complete closed return
- This system requires a duct to be constructed over the hot aisle; the duct must be able to extend to the overhead plenum
- Overhead pathway may penetrate the HAC, requiring additional efforts to mitigate leakage
- Local code authorities may require large clearance gaps between the duct and the ceiling
- The contained aisle may reach an “uncomfortable” temperature for staff
- Depending on internal temperature, local code authorities may consider the contained hot aisle to be a hazard location, and require additional safety equipment or signage
- Fan speeds on the air handlers should be adjusted to closely match equipment requirements; this may require some units to be shut off or upgraded with variable speed fans
- Optimizing operating conditions may require the addition of some instrumentation or HVAC controls

Cold Aisle Containment

Cold aisle containment (CAC) configurations are typically used to retrofit data center environments where a raised floor cooling system already exists.

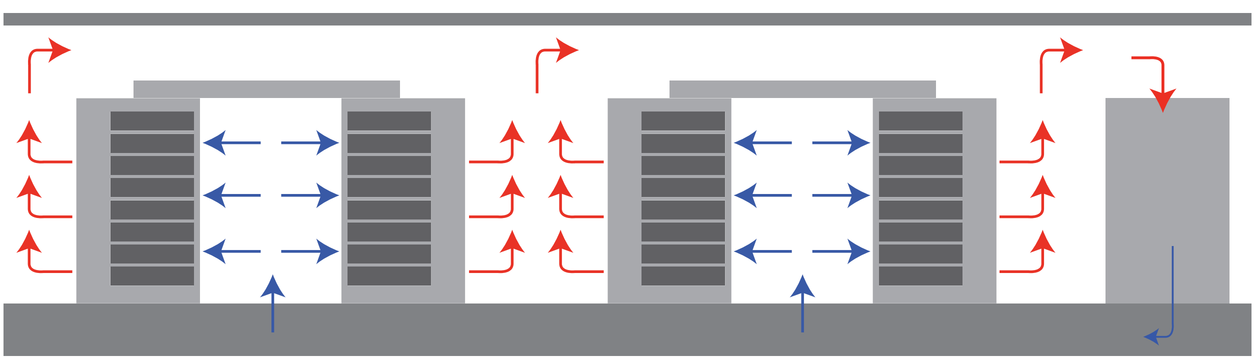

FIGURE 3: Sectional view of a CAC solution with ceilings constructed over the cold aisles showing airflow into the contained aisles and through the cabinets and back to the cooling units through the room. Note: Hot exhaust air is isolated within the room by the ceilings over the contained cold aisle.

As seen in [Figure 3] above, a roof and/or partitions are set up over the cold aisle, with doors at either end. This isolates the cold intake air within the cold aisle, keeping it separate from the hot air in the neighboring hot aisles. The hot exhaust air rises up freely in the hot aisles, and returns through the room to the air handlers.

Architectural Considerations for CAC:

Benefits:

- This system is an easy retrofit for existing hot aisle/cold aisle environment, especially over a raised floor supply air plenum
- The contained aisle is the "cold aisle" and provides supply air

Challenges:

- More complicated to deploy and change than ducted exhaust cabinet (CPI: Vertical Exhaust Duct)
- More expensive to deploy than ducted exhaust cabinet (CPI: Vertical Exhaust Duct)
- The room is the "hot aisle"
- Cabinets must be placed in adjacent hot aisle/cold aisle rows and deployed in pairs to create "cold aisles"
- This system may require row lengths to be evenly sized, parallel and aligned; the CPI solution can be deployed over uneven aisles
- Additional aisle clearances may be required for the doors at the ends of each aisle; the CPI solution has sliding doors and requires no additional clearance for door swing
- Cold air must be delivered into the contained "cold aisle," either through a raised floor or overhead ducts
- This system typically uses a raised floor design
- The available airflow can be difficult to control to meet equipment requirements
- The containment ceiling structure over the contained cold aisle must be constructed around building columns and other support structures
- Overhead pathway may need to be moved and elevated above the cabinets to provide sufficient clearance for the containment ceiling structure
- Requires fire suppression system to be extended into the contained space (These changes may be high cost items)
- The room may reach an "uncomfortable" temperature for staff
- Auxiliary equipment will be in a "hot aisle" space, which may reduce performance
- If a raised floor exists, leakage through the tiles is mostly into the "hot aisle," lowering the return air temperature to cooling units, which may lower cooling unit efficiency
- Fan speeds on the air handlers should be adjusted to closely match equipment requirements; this may require some units to be shut off or upgraded with variable speed fans
- Optimizing operating conditions may require the addition of some instrumentation or HVAC controls

Which Type of Containment Should You Use?

Intel and T-Systems conducted experiments[1] in 2010 in the Munich-based Euroindustriepark, which suggested there was no efficiency advantage for one form of containment over another. The relative cooling performance of all three systems was roughly the same. However, recent CFD modeling created by CPI suggests that there is an efficiency advantage for ducted exhaust cabinet (CPI: Vertical Exhaust Duct) and HAC under certain conditions.

The type of containment system you select for your data center should be based on your own business requirements and architectural limitations. Whichever method you use, it must sufficiently isolate hot from cold air within the data center. In each case, you will need to consider the following.

An Effective Seal is Critical

To achieve as much isolation as possible between the cold supply air and the hot exhaust air, it is important to use good seals in your containment system. This includes seals within and around cabinets and between cabinets and containment system components.

Benefits of an effective seal include:

- Prevents interior air recirculation and bypass airflow within the cabinets
- Allows the cooling system air handlers to be adjusted to support minimal pressure variations in the room and to maintain a slight pressure differential between the open and contained spaces
- Maximizes efficiency of energy use. The better the seal, the more control you have to reduce fan speeds to closely match the volume of supply air demand from servers. As a result, return exhaust air is delivered at higher temperatures to the cooling units
- Provides the lowest operating cost in terms of energy savings

When selecting a containment solution, you should take seal into account. Containment vendors typically describe system seal performance in terms of leakage, typically a percentage based on a particular volume of airflow to each cabinet under a specific operating pressure. When comparing these values, be aware that conditions may not match. The volume of airflow should be the maximum sustainable volume across the entire room at the planned static pressure during operation. For example, CPI defines our containment system performance as 3000 CFM (5097 CMH) of exhaust airflow per cabinet at .05 inches of water (.01 kPa) with less than 5% leakage.

Prevent Interior Recirculation and Bypass Airflow Within and Around Cabinets

Effective airflow management and cooling cost reduction requires the elimination of bypass airflow within or through the cabinet, utilizing the following best practices, as shown in [Figure 4] below.

- Use proper racking techniques to block airflow around rack-mount equipment
- Use blanking panels to seal all unused rack-mount spaces to block airflow between rack-mount equipment
- Use air dams and seals around rack-mount equipment to prevent recirculation of hot air around the sides of the equipment.
- Use seals around cable openings in the cabinet body and raised floors
- Use seals between cabinets to block airflow between cabinets into the contained space
- Use panels to block airflow under the cabinet into the contained space

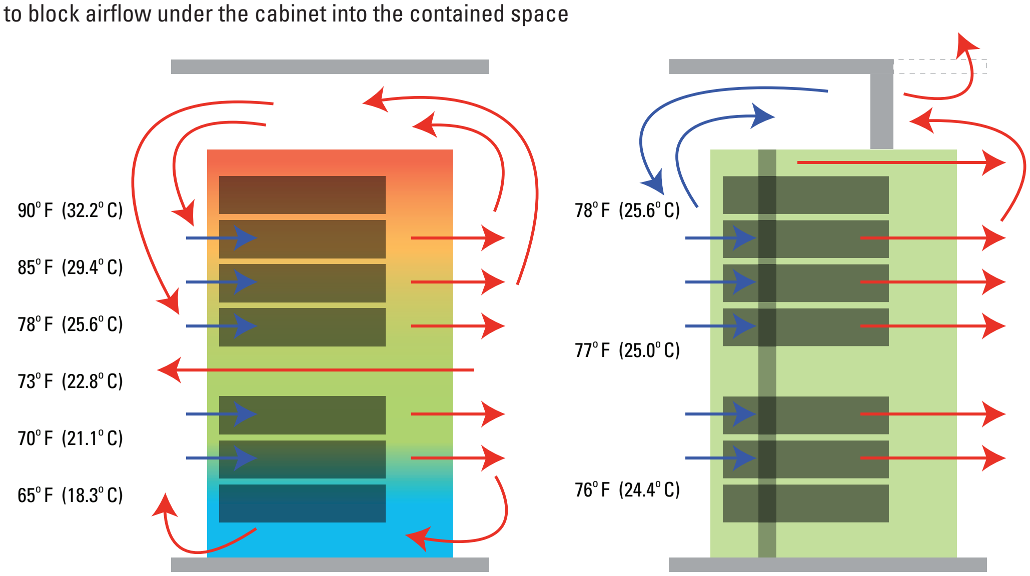

FIGURE 4: Sectional view of cabinets showing bypass airflow around equipment (left) and showing good airflow management guiding air through equipment and blocking recirculation (right). It is critical to utilize baffles and blanking panels within cabinets to seal openings that would allow air to bypass equipment. All air that passes through the cabinet should pass through equipment, and transfer heat away from equipment and out of the cabinet.

These steps should be taken prior to implementing any further containment project. Blocking bypass airflow through cabinets (and openings in raised access floors used for airflow delivery) is a critical component of any effective airflow management solution and may temporarily solve cooling issues without the need for additional ducted exhausts or aisle containment. Additionally, there is the need for a procedure and staff discipline for installing blanking panels when equipment is removed and installing seals when new floor openings are created.

Managing Pressure

Establishing a "good seal" in your containment system is not just a matter of having containment barriers without leaks. It also requires total pressure management of the contained environment, particularly with CAC. A complete containment architecture should include an effective pressure differential management system. This may include updating or introduction of HVAC controls.

Leverage Engineering Analysis

Once the basic steps of blocking bypass airflow within the cabinet are achieved and the decision is made to implement a full containment system, a Computational Fluid Dynamics (CFD) model can be created to demonstrate the results of adding containment.

Some containment vendors can provide a basic analysis that may include a CFD model of the space to describe before and after conditions and relative supply and return temperatures. It can also be used to estimate a portion of the savings from reduced cooling system energy requirements. CPI offers a Containment Pre-Installation Site Survey service.

Alternately, a formal engineering study will consider the entire cooling system, individual component contributions, and full impact of partial year economization for that specific site. It can also consider performance under various conditions, for example, the recommended and allowable ranges suggested in the *RP-1499, ASHRAE Datacom Series 1, Thermal Guidelines for Data Processing Environments*[2]. An engineering study provides a much more detailed estimate to include any site upgrades or changes when implementing the containment solution.

Major Differences Between Containment Systems

The table below provides a checklist of major considerations for each type of containment system and summarizes major differences between containment systems. Rank the solutions to match your requirements based on a comparison of the benefits and challenges presented above and the relative performance, complexity and cost differences presented below.

Summary Conditions	**Ducted Exhaust Cabinet (CPI: Vertical Exhaust Duct)**	**Hot Aisle Containment (HAC)**	**Cold Aisle Containment (CAC)**
Condition in Contained Space	Hot, Return Air	Hot, Return Air	Cold, Supply Air
Estimated Leakage, Containment System, Good Seal[1]	< 5%	5%	5%
Estimated Leakage, Raised Floor (Supply Plenum), Good Seal[2]	0%	7%	10%
Estimated Leakage, Drop Ceiling (Return Plenum), Good Seal	3%	3%	0%
N+1 Cooling Deployment	Room	Room/Aisle	Room/Aisle
Minimum IT Deployment Increment	Cabinet	Pair of rows	Pair of rows
Required Containment System Components			
Blanking panels for each unused U in the rack	X	X	X
Front perimeter baffles for inside cabinets	X	X	X
Seals for cable entry into cabinets	X	X	X
Seals for base of cabinet	X	X	X
Top Mount Vertical Exhaust Duct	X		
Aisle doors, two sets		X	X
Aisle ceiling			X
Aisle duct		X	
Aisle drop panels, as needed		X	X
Architectural Considerations			
Raised floor or overhead cold air ducts			X
Drop ceiling or other hot air return plenum	X	X	
Duct collars for air handlers	X	X	
Fire detection and suppression in contained space		X	X
Lighting in contained space		X	X
Does it interfere with network cable pathways		X	X
Does it interfere with power pathway		X	X

Table continued

Design Considerations			
Conduct room CFD analysis	X	X	X
Engineering analysis for detailed first cost, savings, ROI	Optional	Optional	Optional
Applications for utility energy cost avoidance programs	Optional	Optional	Optional
Applications for other sustainable design programs	Optional	Optional	Optional
Design/implementation of cooling system controls	Optional	Optional	Optional
Installation Considerations			
Recommended to extend site life	X		X
Recommended for new construction	X	X	
Ease of initial installation	Easy	Moderate	Moderate
Ease of change – adding a new cabinet	Easy	Difficult	Difficult
Ease of change – removing/substituting a cabinet	Easy	Moderate	Moderate
Relative containment price	Low	Medium	Medium
Relative installation price	Low	Medium	Medium

Notes:

[1] Leakage from individual containment systems will vary depending on the degree of care used to seal openings when installed and modified. However, a similar seal can be created with any of the systems. 5% is listed as the target leakage for a good seal. This demonstrates the basic concept of containment systems having similar performance, as suggested by the T-Systems and Intel study. However, the overall performance should consider the additional leakage through raised floor and/or drop ceiling plenums, which is different for each system, and may impact overall costs. Higher leakage requires an increased volume of air, which means operating more cooling units/air handlers.

[2] When a slab floor is used, the Estimated Leakage, Good Seal would drop to 0%. With CAC, cold air is delivered into the contained space through the raised floor or from overhead ducts. Although leakage would drop to 0% with overhead ducts, the ducts will need to be very large to handle the air volume and the architectural space must be able to accommodate both the physical size of the ducts and the support structure for them. Likewise, if a CAC is used with in row cooling, leakage would be 0%, but the first cost to deploy and power the in-row cooling units and the operating costs for the cooling units will typically exceed that of a room-based perimeter cooling design.

Conclusion

The type of containment system that you select for your data center should be based on your own business requirements and architectural limitations. As this paper demonstrates, the different systems comprise different combinations of components and relative cost and depending on your specific site will require different amounts of construction. Regardless of which system you select, the reduction in cooling energy required for your site could be significant.

CPI offers all three styles of containment. Although the Vertical Exhaust Duct will prove the most efficient solution for many customers, HAC and CAC systems can be designed and installed to support similar performance. Our Field Application Engineers can help you determine the right solution for your site, make specific recommendations and provide some analysis on how the implementation of containment will impact your bottom line.

If you are implementing or upgrading airflow management or a data center containment solution, please contact CPI for assistance.

References

[1] Open Data Center Alliance, T-Systems and Intel. November 2011. *DataCenter 2020: hot aisle and cold aisle containment efficiencies reveal no significant differences.* White Paper. https://opendatacenteralliance.org/article/whitepaper-datacenter-2020-hot-aisle-and-cold-aisle-containment-efficiencies-reveal-no-significant-differences/

[2] ASHRAE. 2015. *ASHRAE Datacom Series 1: Thermal Guidelines for Data Processing Environments, Fourth Edition.* Technical Committee 9.9.

Acknowledgement

This paper presents the basics of airflow management and consolidates, summarizes and updates content from previous CPI white papers authored by Ian Seaton, retired.

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Contributors

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David Knapp has more than 18 years of experience in the telecommunications industry with CPI as a product-application expert and technical communicator in the roles of Technical Support, Technical Writer and Product Marketing Manager. He is currently focusing on data center, enterprise networking and power management solutions.

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