By David Knapp

Comparing Containment Systems for Data Center Airflow Management

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

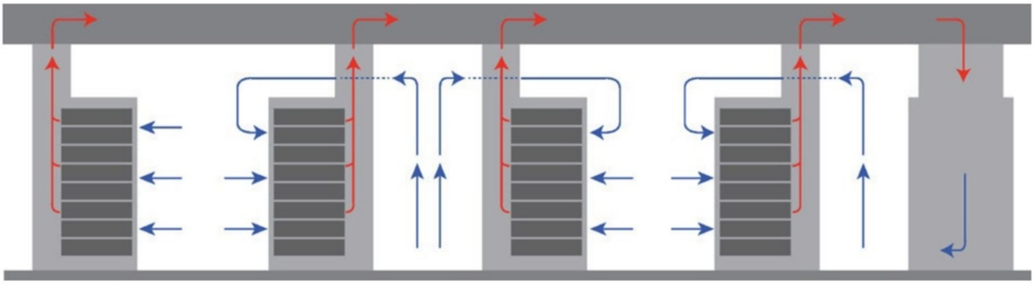

FIGURE 1: Sectional view of several ducted exhaust cabinets with vertical exhaust ducts showing airflow through the cabinets and through the room. NOTE: Hot exhaust air is isolated and removed from the room.

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 article examines and compares three data center containment systems and demonstrates that there are important differences that distinguish one system over the others. Understanding these differences can help the user to determine the best containment option for a data center's specific requirements.

The Three Methods of Containment

Containment separates hot and cold air, reducing the volume of air delivered to cool equipment, which leads to a number of improved efficiencies while, typically, reducing cooling energy costs. 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.

1. **Ducted exhaust cabinets** (DEC) are enclosed server rack cabinets with an attached vertical exhaust duct.

As pictured in Figure 1, 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 or to outside vents.

Architectural considerations for DECs include a number of benefits. First, they are the simplest and most cost-effective method to deploy and change. In this cabinet-based approach, the exhaust duct is the hot aisle and 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. The DEC arrangement also 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. Finally, minimal or no changes are required to the fire suppression system (sprinklers must cover the room).

The challenges of DECs include the fact that the system requires an overhead plenum and the addition

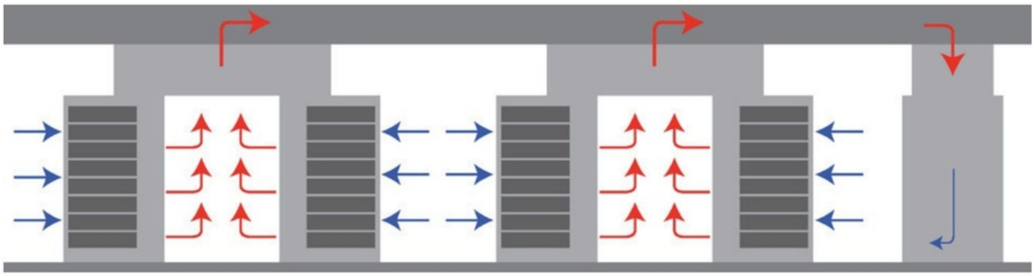

FIGURE 2: Sectional view of a HAC solution with ducts constructed over the hot aisles, showing airflow through the contained aisles and the room. NOTE: Hot exhaust air is isolated and removed from the room through the ducts over the contained hot aisles.

of collars on air handler units to create a complete closed return, and 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.

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. In addition, optimizing operating conditions may require the addition of some instrumentation or heating, ventilation, and air-conditioning (HVAC) controls.

2. **Hot aisle containment** (HAC) is the most popular type of containment solution used today. In this method, a configuration of duct work and baffles is set up over the hot aisle, with doors blocking the aisle entrances at either end (Figure 2). 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 HACs include the fact that contained aisles are the hot aisles and the entire room (except the contained hot aisle) is the cold aisle, and provides supply air. HAC 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. Again, minimal or no changes are required to the fire suppression system.

HAC is more complicated and more expensive to deploy and change than the DEC system. 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. Additional aisle clearances may be required for the doors at the ends of each aisle; some solutions have sliding doors and require 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, and also that a duct be constructed over the hot aisle; the duct must be able to extend to the overhead plenum. The 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 and, depending on internal temperature, they may consider the contained hot aisle to be a hazard location, and require additional safety equipment or signage.

The contained aisle may reach an uncomfortable temperature for staff. 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.

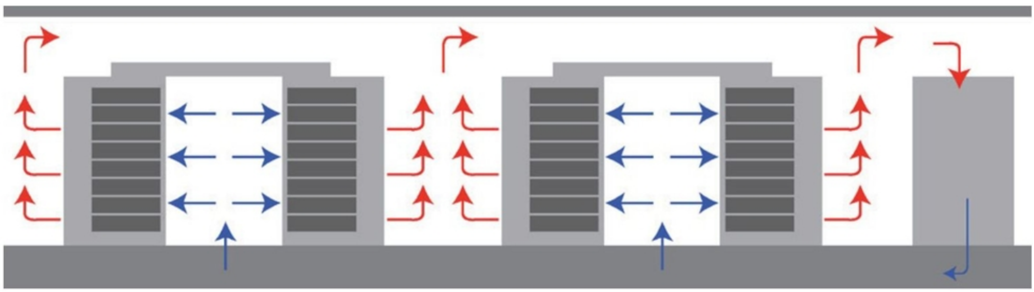

FIGURE 3: Sectional view of a CAC solution with ceilings constructed over the cold aisles showing airflow into the contained aisles and through the cabinets and back to the cooling units through the room. NOTE: Hot exhaust air is isolated within the room by the ceilings over the contained cold aisle.

Optimizing operating conditions may require the addition of some instrumentation or HVAC controls.

3. **Cold aisle containment** (CAC) configurations are typically used to retrofit data center environments where a raised floor cooling system already exists. As seen in Figure 3, a roof 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.

CAC is an easy retrofit for existing hot aisle/cold aisle environments, especially over a raised floor supply air plenum. The contained aisle is the cold aisle and provides supply air. However, it is more complicated and more expensive to deploy and change than a ducted exhaust cabinet. 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, although some solutions can be deployed over uneven aisles.

Among the challenges presented by this system is the fact that additional aisle clearances may be required for the doors at the ends of each aisle; one typical solution to this 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 (the system typically uses a raised floor design).

The containment ceiling structure over the contained cold aisle must be constructed around building columns and other support structures. Overhead pathways may need to be moved and elevated above the cabinets to provide sufficient clearance for the containment ceiling structure. CAC requires a fire suppression system to be extended into the contained space (these changes may be high cost items).

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.

Choosing the Right Containment System

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 computational fluid dynamics (CFD) modeling suggests that there is an efficiency advantage for ducted exhaust cabinet and HAC under certain conditions.

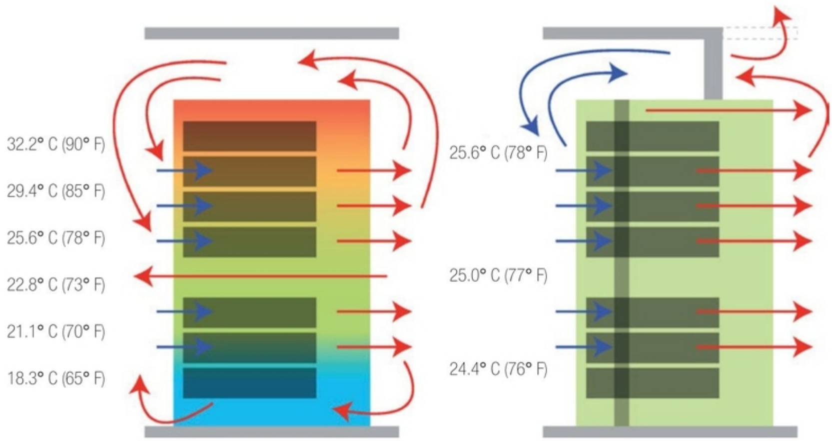

FIGURE 4: Sectional view of cabinets showing bypass airflow around equipment (left) and showing good airflow management guiding air through equipment and blocking recirculation (right). It is critical to utilize baffles and blanking panels within cabinets to seal openings that would allow air to bypass equipment.

The type of containment system selected for a data center should be based on specific business requirements and architectural limitations. Whichever method is chosen, it must isolate hot from cold air within the data center.

Why 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 the containment system. This includes seals within and around cabinets and between cabinets and containment system components. An effective seal prevents interior air recirculation and bypass airflow within the cabinets. It also 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.

In addition, the seal maximizes efficiency of energy use. The better the seal, the greater the ability to control the reduction of 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. Finally, an effective seal provides the lowest operating cost in terms of energy savings.

When selecting a containment solution, be sure to take seal performance 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.

Preventing Interior Recirculation and Bypass Airflow

Effective airflow management and cooling cost reduction requires the elimination of bypass airflow within or through the cabinet, utilizing best practices seen in Figure 4. Some key recommendations include:

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

SUMMARY CONDITIONS	DEC	HAC	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 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
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

TABLE 1: Considerations for selecting a containment system.

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. Five percent 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 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 percent. With CAC, cold air is delivered into the contained space through the raised floor or from overhead ducts. Although leakage would drop to 0 percent 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 percent, 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.

- Using panels to block airflow under the cabinet into the contained space.

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 the 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 introducing HVAC controls.

Leveraging 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 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.

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 Difference Between Containment Systems

Table 1 provides a checklist of major considerations for each type of containment system and summarizes major differences between containment systems. Rank the solutions to match the installation's requirements based on a comparison of the benefits and challenges presented above and the relative performance, complexity and cost differences presented in Table 1.

Conclusion

The type of containment system selected for a data center should be based on the enterprise's specific business requirements and architectural limitations. As this article demonstrates, the different systems comprise various combinations of components and relative cost which, depending on the specific site, will require different amounts of construction. Regardless of which system is selected, the reduction in cooling energy required for the site could be significant. ■

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