Air Distribution Architecture Options for Mission Critical Facilities

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White Paper #55

Legendary Reliability®

Revision 1

Executive Summary

There are nine basic ways to use air to cool equipment in data centers and network rooms. These methods vary in performance, cost, and ease of implementation. These methods are described along with their various advantages. The proper application of these cooling techniques is essential knowledge for Information Systems personnel as well as Facilities Managers.

Introduction

The cooling of data centers and network rooms has emerged as a significant challenge as the density of computing equipment increases. Server consolidation projects, along with the shrinking physical size of servers and storage systems, has resulted in high power density and high heat density. Even though the typical per-enclosure power consumption in a data center remains on the order of 1kW, equipment may be configured that draws over 15kW per enclosure. This strains the capability of the average data center, which is only capable of reliably cooling 2-3kW per enclosure by design. Furthermore, the introduction of high density enclosures into a data center creates the potential for “hot spots” within the room that the cooling system may not be able to address, since traditional designs assume relatively uniform cooling patterns within a data center.

The cooling system for a network room or data center consists of a Computer Room Air Conditioning (CRAC) unit and the associated air distribution system. A Computer Room Air Handling (CRAH) unit may be used instead of a CRAC in larger data centers. All cooling systems use a CRAC and or a CRAH unit of some kind, which come in various capacities and remove the heat energy from the room. However, the primary distinctions that affect the capability of cooling systems are rooted in the distribution system. It is the configuration of the distribution system that primarily distinguishes the different types of data center cooling systems; this is the principal subject of this paper.

The nine types of cooling systems

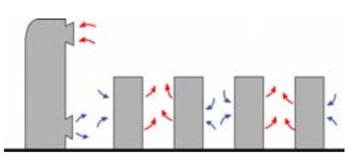
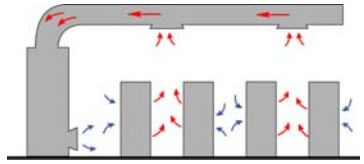
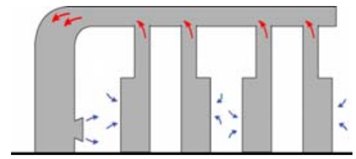
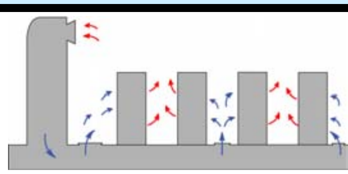
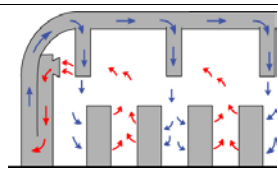
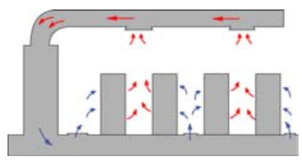
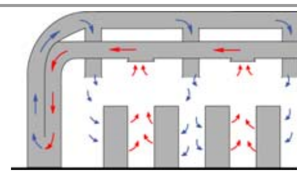
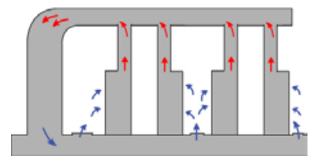
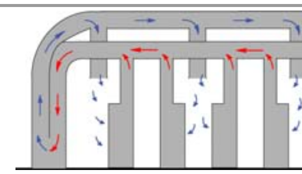
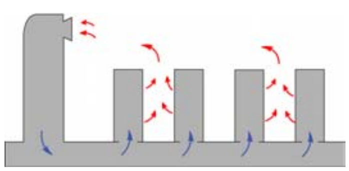
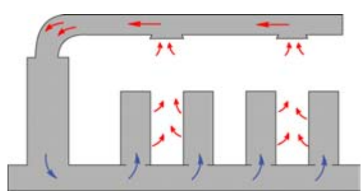
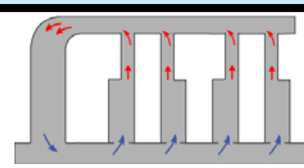
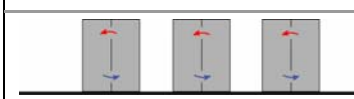
Every cooling distribution system has a supply system and a return system. The supply system distributes the cool air from the CRAC unit to the load, and the return system takes the exhaust air from the loads back to the CRAC. For both the supply and the return, there are three basic methods used to convey air between the CRAC and the load, which are:

- Flooded
- Locally Ducted
- Fully Ducted

In a Flooded distribution system, the CRAC and the loads eject or draw in bulk air from the room, without any special ductwork in between them. In a Locally Ducted distribution system, air is provided or returned via ducts which have vents located near the loads. In a Fully Ducted system, supply or return air is directly ducted into or out of the loads.

Each of the three methods, Flooded, Locally Ducted, or Fully Ducted, can be used in either the supply path or the return path. This gives rise to 9 possible combinations, or types of distribution systems. All of these types have been used in various circumstances, and occasionally different types are mixed together in the same data center. Some of these methods require a raised floor, and some may be used with either a hard floor or a raised floor. The 9 types are illustrated in Table 1.

Table 1 *– The 9 types of cooling systems*

	Flooded Return	Locally Ducted Return	Fully Ducted Return
Flooded Supply	 **Small LAN rooms < 40kW** Simple installation Low cost Cools up to 3kW per rack	 **General use** Cools racks to 3kW No raised floor needed Low cost / ease of install	 **Hot rack problem solver** Cools racks to 8kW Retrofittable (vendor specific) No raised floor needed Increased CRAC efficiencies
Locally Ducted Supply	 Raised floor environments  Hard floor environments **General use** Cools racks to 3kW	 Raised floor environments  Hard floor environments **General use** Cools racks to 5kW High performance / High efficiency	 Raised floor environments  Hard floor environments **Hot rack problem solver** Cools racks to 8kW Retrofittable (vendor specific)
Fully Ducted Supply	 **General use** Enclosures / mainframes with vertical airflow Raised floor environments with poor static pressure	 **General use: mainframes** Enclosures / mainframes with vertical airflow Raised floor environments with poor static pressure	 Raised floor environments  Hard floor environments **Hot rack problem solver** Cools racks up to 15kW Specialized installation

Note 1: The term “Ducted” refers to any type of plenum that can be used for supply or return. The ducts in the fully ducted return carry the hot exhaust air off the rear of the enclosures.

Note 2: For purpose of this WP, assume a nominal kW requires 160cfm (cubic feet per minute) of airflow which is based on a typical airflow of IT servers today.

Table 1 illustrates each combination of supply and return method. In general, the cost and complexity of the cooling systems is lowest at the top and left of the Table, and increases for the types that are down and to the right as the complexity of the ducting system increases.

A critical goal of a data center cooling system is to separate the equipment exhaust air from the equipment intake air in order to prevent equipment from overheating. This separation also significantly increases the efficiency and capacity of the cooling system. When equipment power density increases, the corresponding increase in exhaust air volume and intake air volume makes it more difficult to prevent equipment from drawing exhaust air from itself or neighboring equipment into its intake. For this reason partial or complete ducting of the supply air to the equipment intake or return air from the equipment exhaust becomes necessary as power density increases.

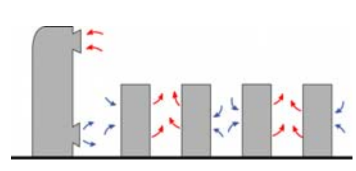
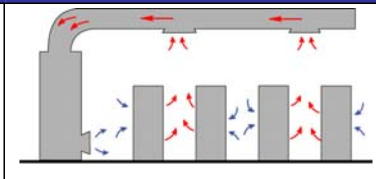
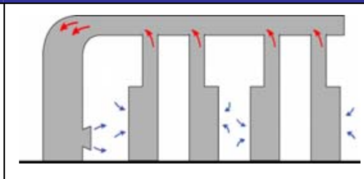
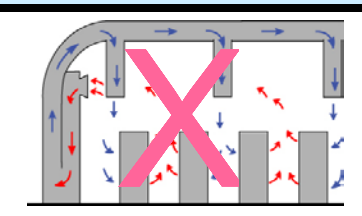
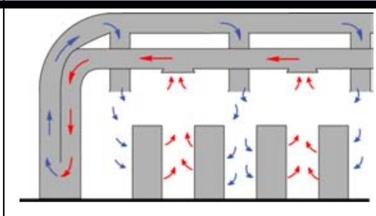
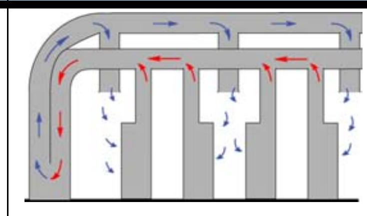
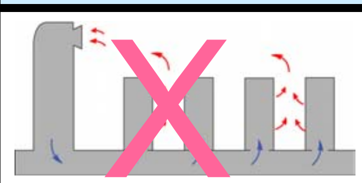
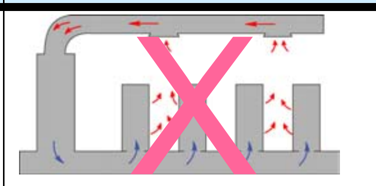
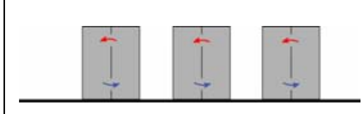
There are additional general statements that can be made about the 9 cooling system types. Fully Ducted supply systems are typically used in raised floor environments where underfloor obstructions have caused low static pressure problems that prevent cool air from getting to the front of enclosures as shown in Figure 1B. Fully Ducted supply systems are also used with specialized equipment that provides for direct input air ducting such as mainframe computers. Fully Ducted return systems are primarily used in combination with other systems and can be used in mixed density environments.
The four combinations of Flooded and Locally Ducted distribution make up the vast majority of all installations. To further review the advantages and limitations of these approaches, the next sections of this paper segregate installations into two types: those using a raised floor and those not using a raised floor.

Types of cooling in the hard floor environment

While the standard common concept of the data center includes a raised floor, data centers of any size can be, and commonly are, constructed without a raised floor. The vast majority of LAN and Network rooms do not use a raised floor. Many newer multi-megawatt data centers do not use a raised floor. Traditional reasons for using a raised floor no longer exist in the modern data center, and there are significant drawbacks to using a raised floor including specialty engineering, cost, design time, headroom requirements, earthquake susceptibility, safety hazard, security hazard, floor loading, access ramps and other problems. These factors are discussed in more detail in APC White Paper #19, “Re-examining the Suitability of the Raised Floor for Data Center Applications”. For these reasons, the hard floor environment is generally preferred for new construction, and is always preferred for smaller data centers and network rooms. The 9 types of cooling systems for hard floor environments are shown in Table 2.

In a hard floor environment, the implementation of a locally ducted supply depends on overhead ductwork and venting as diagrammed in the second row of Table 2. While the combination of locally ducted supply and locally ducted return appears complex in Table2, this is actually the most common way that commercial buildings are cooled; where ceiling mounted supply and return grilles are spread within the conditioned space.

***Table 2** – The 9 types of cooling systems in a hard floor environment*

	Flooded Return	Locally Ducted Return	Fully Ducted Return
Flooded Supply	 **Small LAN rooms < 40kW** Simple installation Low cost Cools up to 3kW per rack	 **General use** Cools racks to 3kW No raised floor needed Low cost / ease of install	 **Hot rack problem solver** Cools racks to 8kW Retrofittable No raised floor needed
Locally Ducted	 **Not Recommended** Difficult to prevent air mixing	 **General use** Cools racks to 5kW High performance / High efficiency	 **Hot rack problem solver** Cools racks to 8kW Retrofittable
Fully Ducted Supply	 **Not applicable**	 **Not applicable**	 **Hot rack problem solver** Cools racks to 15kW Retrofittable Specialized rack and CRAC

Selecting the right type to use in a hard floor environment

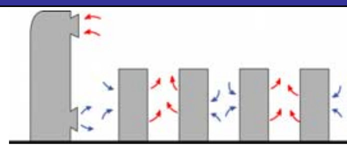
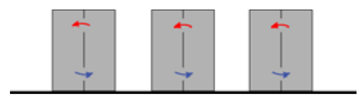
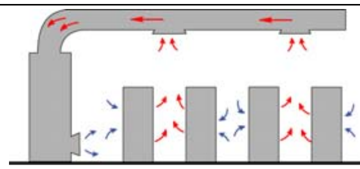
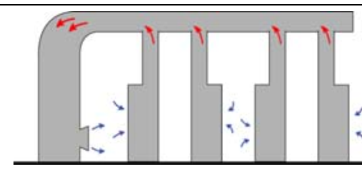
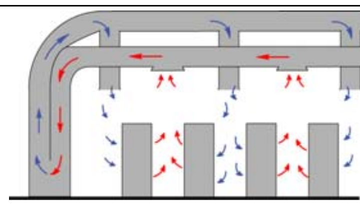
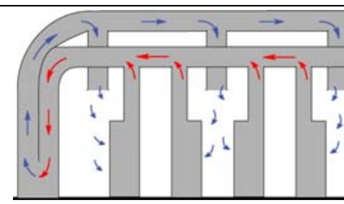
The understanding of the various types of cooling systems is an essential foundation to establishing when it is appropriate to use each type. Despite the variations in individual circumstances, it is possible to give general guidance as to when each type should be used. Systems that are larger in size or have higher power density requirements generally require more complex design, which will typically include ducting.

The key to an effective design approach is this: to design a cooling system for the required average power density but have the cooling capability to adapt to high density enclosures where they occur. High density enclosures typically represent only a fraction of the total load but their location in the data center cannot be reliably predicted in advance. <u>The fear of not being able to adequately cool potential "hot spots" within a data center using conventional raised floor designs has lead to extensive oversizing of the cooling plant and</u>

air distribution system, causing an extensive increase in capital and expense costs yet still not achieving the desired result. Ducting of the supply air or the cooling air provides the ability to address high heat density areas while avoiding the costs of cooling system oversizing.

Table 3 shows how to select the right type of cooling system for a hard floor environment. Bigger size and higher density drive to more complex ducting solutions, and for each type of system a means is provided to incorporate a few high density racks which significantly exceed the average per-rack power consumption.

***Table 3** – Selecting the cooling system for a hard floor environment*

If the system has the following characteristics	Use the following base cooling approach	With the following solution for high density enclosures
Is under 10 racks or 40kW		
Is under 100 racks or 150kW with only occasional high density racks		
Is part of a multi-zone larger room or with high density racks		

Types of cooling in the raised-floor environment

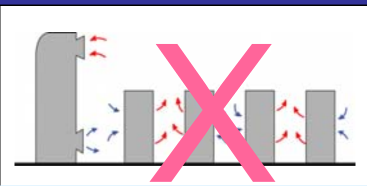
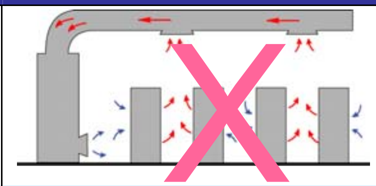
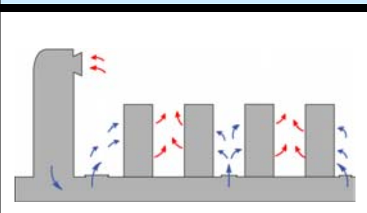
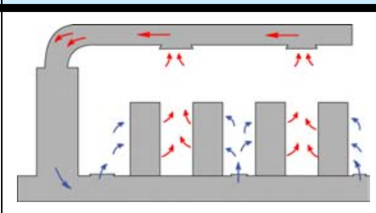
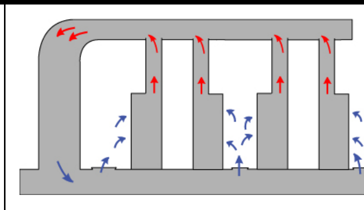
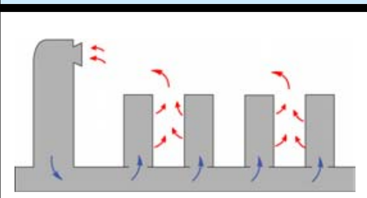
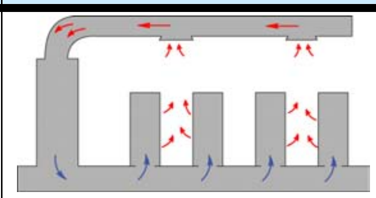
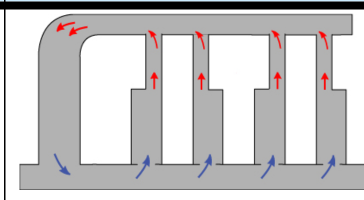
Although the hard floor design approach is preferred for new construction, there are situations where the use of the raised floor is applicable. The raised floor approach is applicable when:

- There is already an existing raised floor in the facility that can be reused
- Mainframe computers with under floor air intake are being installed
- There is a need to run significant amounts of water piping throughout the computing area

Note that the need to run power or data wiring is not a reason for a raised floor. The raised floor should not be used for power or data wiring in any case due to the significant degradation of cooling system performance which can result; overhead power and data wiring is a best practice in high density data centers. This degradation is caused because power and cabling under the floor interrupt the planned air flow patterns, obstructing air or redirecting the flow. In addition, the need to access cabling underfloor forces operations personnel to open floor tiles to add or remove cable, further interrupting air flow to critical IT equipment.

The 9 types of cooling systems for raised floor environments are shown in Table 4.

***Table 4** – The 9 types of cooling systems in a raised-floor environment*

	Flooded Return	Locally Ducted Return	Fully Ducted Return
Flooded Supply	 **Not recommended** No advantage if raised floor exists	 **Not recommended** No advantage if raised floor exists	 **Not recommended** No advantage if raised floor exists
Locally Ducted	 **LAN Rooms, low density** Simpler installation Cools racks to 3kW	 **General use** Cools racks to 5kW High performance / High efficiency	 **Hot rack problem solver** Cools racks to 8kW Retrofittable
Fully Ducted Supply	 **General use** Enclosures / mainframes with vertical airflow Raised floor environments with poor static pressure	 **General use** Enclosures / mainframes with vertical airflow Raised floor environments with poor static pressure	 **Hot rack problem solver** Cools racks to 15kW Specialized rack and CRAC

In a raised-floor environment, the implementation of a locally ducted supply is provided through the raised floor as diagrammed in the second row of Table 2. Given that a raised floor exists and is capable of being used for a locally ducted supply, the use of a flooded supply has no advantage and should not be considered. Therefore Table 4 indicates that flooded supply cooling types are not recommended for raised floor environments.

The use of overhead return ducts focuses the return suction near the equipment hot air exhaust. Fully Ducted return allows for the elimination of air mixing, thus allowing for uniformed inlet temperatures at the rack (particularly near the top of enclosures) and increased efficiencies at the CRAC. Furthermore, return ducts can be adjusted to maximize return suction near data center hot spots.[1]

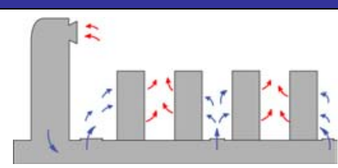
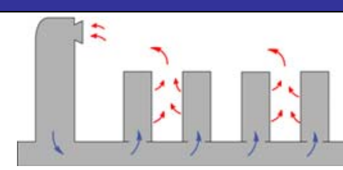
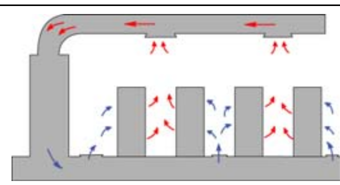
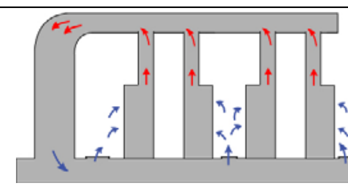
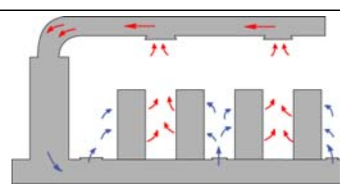
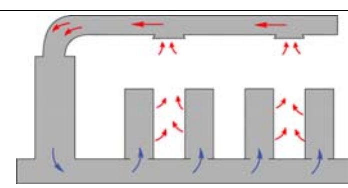
Selecting the right type to use in a raised-floor environment

The understanding of the various types of cooling systems is an essential foundation to establishing when it is appropriate to use each type. Despite the variations in individual circumstances, it is possible to give general guidance as to when each type should be used. Systems that are larger in size or have higher power density requirements generally require more complex ducting.

The key to an effective design approach is the same as for the hard floor system: to design a cooling system for the required average power density but have the cooling capability to adapt to high density enclosures. High density enclosures typically represent only a fraction of the total load but their location in the data center cannot be reliably predicted in advance.

Table 5 shows how to select the right type of cooling system for a raised-floor environment. Bigger size and higher density drive to more complex ducting solutions, and for each type of system a means is provided to incorporate a few high density racks which significantly exceed the average per-rack power consumption.

***Table 5** – Selecting the cooling system for a raised-floor environment*

If the system has the following characteristics	Use the following base cooling approach	With the following solution for high density enclosures
Under 3kW per rack average, with very high ceilings or under 100kW total power		
High average per-rack power or over 100kW total power		
Alternate high density solution for mainframe environment.		

[1] This is particularly true if the return grilles are installed as part of a suspended ceiling system. In such a system return grilles can be easily moved where needed.

Cooling system design considerations

Once the appropriate type of cooling system is selected, there are other elements that must be integrated into the system design. These include the following factors

- Layout of racks in alternating rows
- Location of CRAC units
- Quantity and location of vents
- Sizing of ductwork (refer to Note 1)
- Proper internal configuration of racks

These considerations have a significant impact on the system performance, particularly when the room size is on the large end of the application range, or the power densities are high. **The vast majority of existing data centers designs do not correctly address the above factors and suffer from unexpected capacity limitations, inadequate redundancy, and poor efficiency.** Therefore it should not be assumed that these considerations are routine; facilities managers and IT managers need to understand them. A more complete discussion of these issues is presented in APC White Paper #49, “Avoidable Mistakes that Compromise Cooling Performance in Data Centers and Network Rooms”.

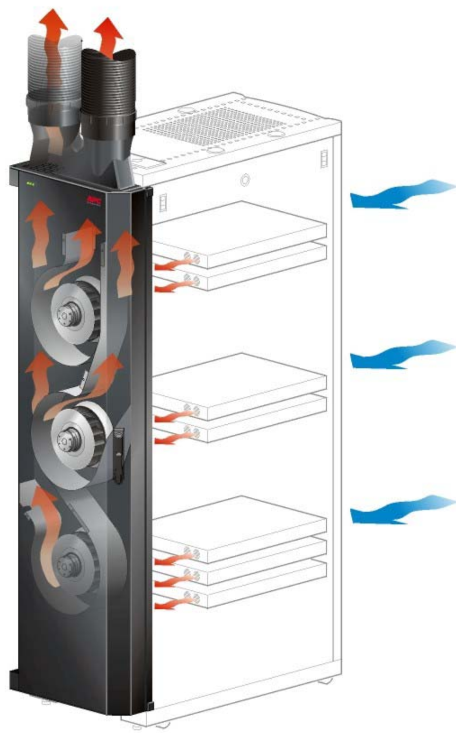
Examples of specialized air distribution components

The air distribution designs described in the previous sections primarily use common CRAC units, ductwork, suspended ceiling plenums, and raised floors. These components have been in routine use for decades and are familiar to the industry. Examples are not provided in this paper. However, some of the Fully Ducted approaches that address high-density applications are accomplished using components that are relatively new in the market. Representative examples of these components are shown here to illustrate their function and usage.

Fully ducted return components

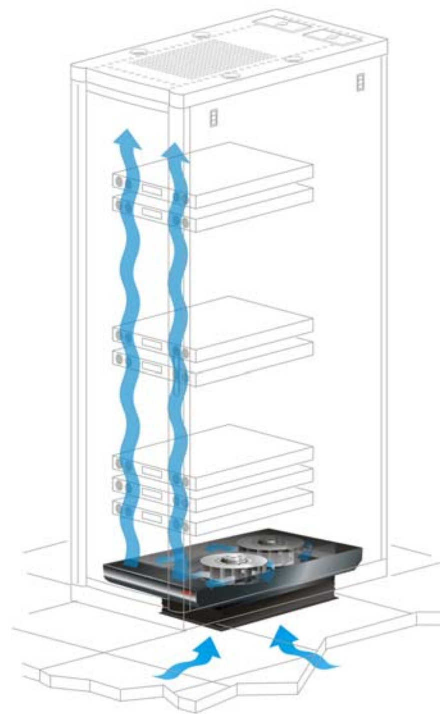
An enclosure with a Fully Ducted return captures all the air leaving the rear of the rack and routes it to a CRAC return plenum. In order to overcome airflow resistance associated with the air capture and ducting, and to assist with overcoming any other airflow resistance associated with cabling or a rack front door, such a ducted system will require supplemental fans when the power density is sufficiently high. An example of a rack-mounted device which provides this function is shown in Figure 1A.

***Figure 1A** – Rack-mounted Fully Ducted air return unit*



APC model ACF101BLK Air Removal Unit

***Figure 1B** – Rack-mounted Fully Ducted air supply unit*



APC model ACF001 Air Distribution Unit

Fully Ducted supply components

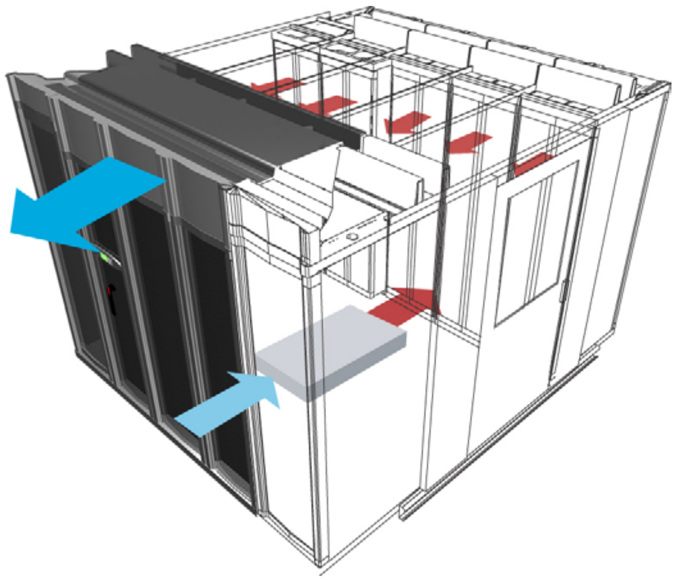
An enclosure with a Fully Ducted supply routes undiluted CRAC supply air to equipment air intakes in order to overcome airflow resistance associated with the air ducting, and to assist with overcoming any other airflow resistance associated with cabling or a rack rear door, such a ducted system will require supplemental fans when the power density is sufficiently high. An example of a rack-mounted device which provides this function is shown in Figure 1B.

To provide high availability, the devices of Figures 1A and 1B are typically provided with N+1 fans and dual-cord powering capabilities. In addition, fan speed may be controlled to optimize system performance.

Flooded supply ducted return components

A self-contained high-density cooling system composed of a set of enclosures and a dedicated CRAC unit. The 2 rows of enclosures face in the opposite direction so that the hot exhaust air is Fully Ducted from the center aisle into the CRAC return duct. This system is designed to be installed in a data center without impacting any other racks or existing cooling services. The system is thermally “room neutral” and will either take cool air from the room and discharge air back into the room at the same temperature or use its own airflow within a sealed enclosure. An example of this system is illustrated in Figure 2.

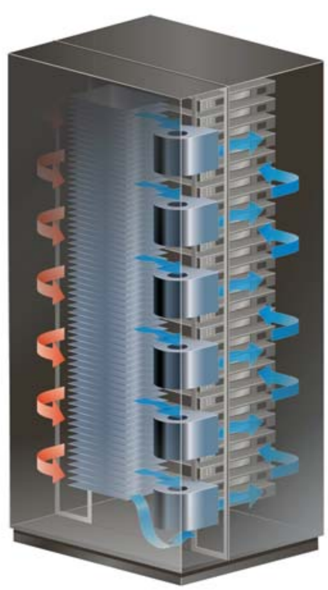
***Figure 2** – Integrated rack cooling system (multi rack)*



Fully Ducted supply and return

For very high density applications which are on a hard floor, for hot-spot problem solving, or for high density retrofits, systems that are Fully Ducted on both supply and return side offer flexibility and independence from existing environmental factors. The architecture options in previous Tables 2 and 3 show full supply and return ducting with an adjacent CRAC for high-density applications. Placing the CRAC nearby gives greater control of the airflow, and eliminates the large ductwork or plenum space which is otherwise required. An example of an integral rack and CRAC system that is Fully Ducted on both the return and supply side is shown in Figure 3.

***Figure 3** – Integrated rack cooling system (single rack)*



The example shows a server rack with an adjacent cooling coil/fan unit located at the side of the rack. The hot exhaust air from the servers is drawn through the cooling coils and the resulting cool air is re-circulated to the server air intakes.

Conclusions

Cooling systems for data centers and network rooms are primarily differentiated in the way they distribute air. Air supply and air return systems each have 3 different configurations which can be combined to create 9 basic types of cooling systems. Each of the 9 types of cooling systems has capabilities and benefits, which cause them to be preferred for various applications.

An understanding of the 9 types of cooling systems and their attributes can be used to develop guidelines for when each type should be used, and such guidelines are provided in this paper for both raised floor and hard floor applications.

The preferred method for building data centers is to use a hard floor in most cases. Contrary to popular belief, cooling methods for hard floor installations can provide the same or better capabilities and performance as the raised floor.

In general, Fully Ducted supply or Fully Ducted return is used for providing cooling to enclosures which are operating at power levels in the range of 5-15kW. Since enclosures drawing 5-15kW typically represent a small fraction of the enclosures in a data center, this method is typically used in combination with simpler methods. The use of Fully Ducted design applied only when and where needed allows data centers to be designed to average heat load but still be able to handle high density enclosures when needed.

About the Author:

Neil Rasmussen is a founder and the Chief Technical Officer of American Power Conversion. At APC, Neil directs the world's largest R&D budget devoted to Power, Cooling, and Rack infrastructure for critical networks, with principal product development centers in Massachusetts, Missouri, Denmark, Rhode Island, Taiwan, and Ireland. Neil is currently leading the effort at APC to develop modular scalable data center solutions.

Prior to founding APC in 1981, Neil received his Bachelors and Masters degrees from MIT in electrical engineering where he did his thesis on the analysis of a 200MW power supply for a Tokamak Fusion reactor. From 1979 to 1981 he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.