White Paper

December 2012

The Use of In-Cabinet Ducting to Improve Inlet Air Temperatures

Optimizing Airflow in Side-to-Side Network Switches

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Introduction: The Importance of Improving Inlet Air Conditions

A sustainable cooling system design that follows industry best practices is essential to the success of modern data center deployments. Optimized cooling management and a more efficient energy system are the results, which means IT equipment is safe from unplanned downtime due to overheating and significant operational expense (OpEx) savings are realized.

Network switches deployed in data centers often utilize side-to-side airflow cooling, which requires less vertical space and increases port density. Given proper inlet air conditions, these switches are well designed to cool themselves. However, large bundles of cabling can impede airflow and hot exhaust air can recirculate to the intake, raising inlet temperatures and inhibiting the switches' self-cooling ability.

For network equipment that utilizes side-to-side airflow patterns, in-cabinet ducting can optimize cooling system efficiency by establishing front-to-back airflow patterns throughout the cabinet. Through the use of CFD (Computational Fluid Dynamics) analysis and testing, ducting solutions have been developed that improve inlet air conditions for cabinet applications.

This white paper explores the importance of applying a ducting solution to improve inlet air conditions and presents a test scenario on 800mm wide cabinet deployments to illustrate the associated benefits such as improved space utilization, reduced fan energy consumption, and an optimized cooling air flow for contained deployment. It also explores the specific benefits of the Panduit Net-Access™ In-Cabinet inlet ducts and identifies how this ducting solution supports thermal management issues to provide a fully integrated data center solution.

The information in this white paper was presented by Panduit and Cisco at the 28th IEEE Semiconductor Thermal Measurement and Management (SEMI-THERM) Symposium, held March, 2012 in San Jose, CA.

Thermal Challenges When Deploying Side-to-Side Airflow Switches in Cabinets

Network switches in data centers are often cooled using side-to-side airflow because this architecture allows the front surface of the chassis to be dedicated to I/O, maximizing port density and helping to minimize overall switch height. Unlike the more common front-to-back airflow seen in servers, for side-to-side airflow, air enters one side of the chassis, passes laterally through the main body of the switch, and exhausts on the opposite side. Front-to-back airflow switches are available but have historically required larger chassis to obtain the same number of ports. It should be noted that even in side-to-side breathing switches, power supply modules may utilize a separate front-to-back airflow path. A typical side-to-side airflow is shown in Figure 1.

Data center equipment is frequently installed in cabinets arranged in rows with open aisles to their front and rear. Supply air from the heating, ventilation and air conditioning (HVAC) system is delivered to the cold aisle on the front side of the equipment row where it is drawn into the active equipment. Heated exhaust vents to the hot aisle behind the row. This arrangement is repeated throughout the room, creating the hot aisle/cold aisle arrangement prevalent in data centers.

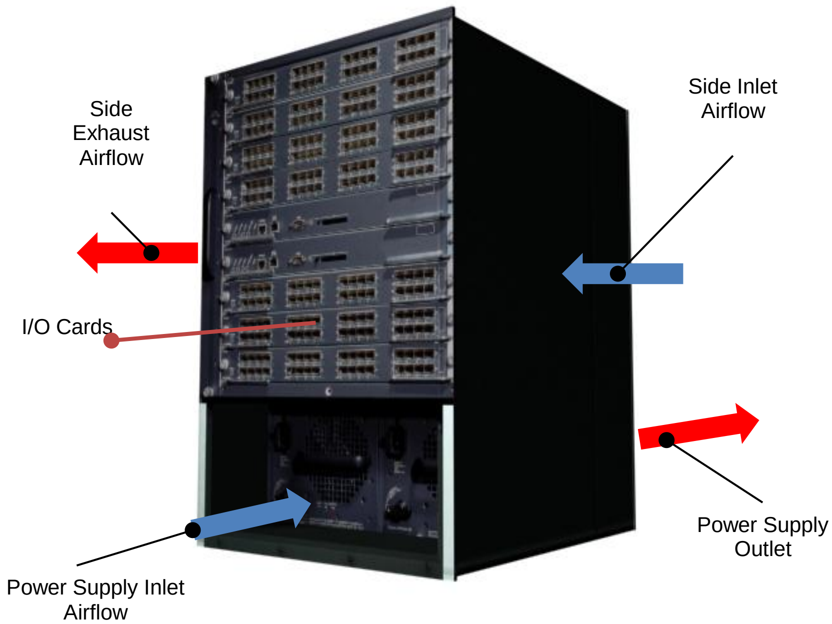


Figure 1. Common side-to-side airflow switch.

Switches are designed to cool themselves over a prescribed range of operating conditions, commonly from 0°C to 40°C. However, the nature of side-to-side airflow in typical hot aisle/cold aisle installations can have adverse effects on the conditions at the switch inlet. For example, the side inlet is not immediately adjacent to the cold aisle. As a result, a mix of air from both the cold aisle and the hot aisle is drawn to the inlet, raising the average inlet temperatures.

In addition, heated air leaving the exhaust side of the switch is blocked by the side of the cabinet. The heated air no longer traveling in a coherent stream, fills the cabinet extending to the inlet on the opposite side of the switch. Also, large bundles of cables from the switch ports may fill the open areas between the front equipment rails and the sides of the cabinet, impeding airflow from the cold aisle and increasing the proportion of air drawn from the hot aisle. The heated exhaust air may also flow forward towards the cold aisle. As a result, a large amount of the inlet air may actually be comprised of heated exhaust air that has been recirculated within the cabinet, driving up inlet temperatures as illustrated in Figure 2.

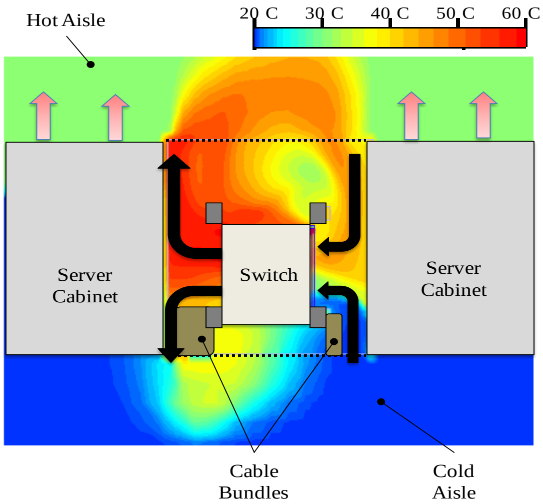


Figure 2. Inlet and exhaust air temperatures for a side-to-side airflow switch in a cabinet application – top view with switch cabinet panels hidden.

Due to the tendency of side-to-side airflow switches to draw in preheated air, their inlet temperatures are often significantly greater than the cold aisle temperature. Data centers have historically been operated with relatively low supply air temperatures, as low as 15°C to 20°C. Assuming a temperature increase of 15°C between the cold aisle and switch inlet, the switch will be ingesting air between 30°C and 35°C. Despite the relatively low temperature air supplied to the data center, the switch could be running within 5°C of its operating limit.

The data center HVAC systems used to remove the heat generated by servers, switches, and storage equipment can consume between 30% and 50% of the total facility power. Decreasing the amount of power needed to cool the facility has economic benefits and has become a major trend for data centers.

One method of reducing HVAC system energy consumption is to raise the temperature of the air supplied to the data center. Chiller-based HVAC systems may reduce energy usage by 1 to 4% for every 1°C the temperature is increased. A second major trend is the use of economizers to cool the data center. When operational, economizers utilize outside air to provide cooling, which eliminates the need to run the HVAC system compressor. Raising supply air temperature allows economizers to be used for warmer outside air conditions, leading to less compressor use and greater energy savings. However, these new data center cooling trends create additional thermal management challenges for side-to-side airflow switches.

For example, raising the cold aisle temperature to 25°C and factoring in the same 15°C rise in air temperature from the cold aisle to the switch inlet means the switch will be drawing in air at 40°C, its maximum operating temperature. Therefore, it is important to eliminate or minimize the temperature rise from the cold aisle to the switch inlet to ensure cooling air at the proper temperature is delivered.

A best practice in data centers using cabinets is to physically separate cool supply air from heated exhaust air. This can be done both inside and outside of the cabinet. Inside cabinets with front to rear airflow, barriers are formed from blanking panels and structures such as vertical air dams which are typically placed in line with the front equipment rails. With side- to-side airflow switches, this approach to separation will block access to cool air, allowing inlet air to be drawn from the rear of the cabinet and the hot aisle into the switch inlets.

Exterior to the cabinet, physical structures may be constructed to fully contain either the hot or cold aisle, preventing exterior exhaust recirculation or cold air bypass. Alternatively, each cabinet may use solid rear doors to trap and direct exhaust air through a Vertical Exhaust Duct (VED) to the HVAC air return system. These exterior containment structures require the implementation of blanking panels and air dams to be effective. Otherwise, exhaust recirculation and cold air bypass will occur within the cabinet.

Development of Ducting Solutions

Ducting offers a potential solution for delivering cool air to the switch inlet or directing exhaust away from the inlet of the active equipment. Proper ducting channels the air to the switch inlets and allows the inlet air to remain at a uniform temperature. For a ducting system to function effectively, the duct must physically fit the switch while avoiding interferences with cabinet structures, cabling, and other components of the physical infrastructure. The airflow impedance of the duct must be minimized so it does not affect system fan performance and forced convection cooling of components. Similarly, the duct must not fundamentally alter airflow patterns within the switch.

The Panduit Net-Access™ In-Cabinet Duct System consists of inlet ducting which delivers cool air directly from the cold aisle into the intake fans of the switch. This ensures proper cooling airflow for improved network performance and availability. The Panduit Net-Access™ In-Cabinet Duct System also features an open design and provides superior cable management to ensure proper airflow.

Preliminary Evaluation

Initial concepts for the ducting design were evaluated using a commercially available CFD analysis software package to model the balance between system airflow and duct size. Each model included row level physical infrastructure components (e.g. cabinet, cabling, cable management structures, perforated floor tiles, etc.) to determine their effects on the switch.

Analysis

The analysis focused on a 14 RU side-to-side airflow switch, shown in Figure 3. The switch chassis was modeled to reflect expected worst-case heat dissipations. Two sets of fans (main fans and supervisor fans) drove side-to-side airflow. The main fans occupied the three bottom rows, each row having 4x 120mm fans. The 6x 80 mm fans supervisor fans were located on the top row.

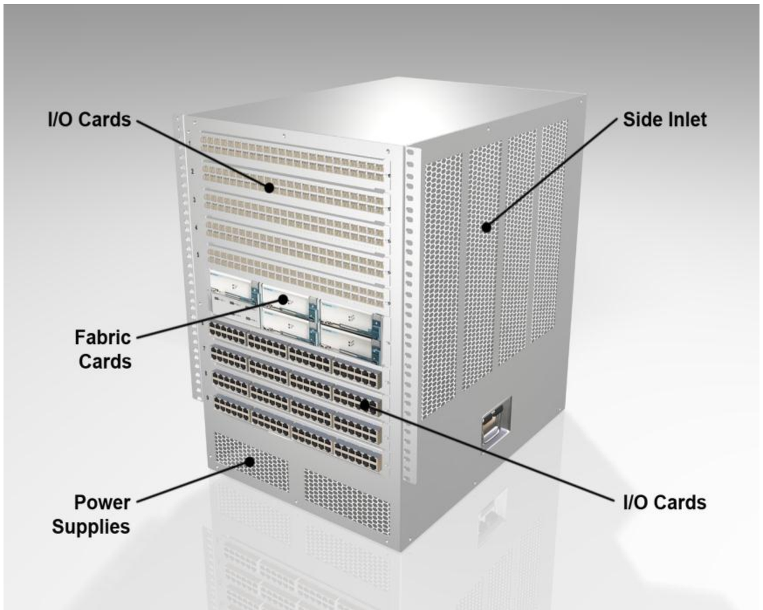


Figure 3. 14 RU side-to-side airflow switch with cards and power supplies.

Airflow impedance for the cards was simulated with simple planar resistances placed in the middle of each slot, positioned perpendicular to the airflow. The completed switch model was then placed into a detailed cabinet with cabling and other physical infrastructure components. Finally, a potential duct concept was added to complete the CFD model.

Testing

The most promising designs evaluated by CFD were prototyped for testing. Testing occurred in the Panduit Thermal Lab constructed to simulate typical data center environments. Cold air from a Computer Room Air Handler (CRAH) was supplied to the cabinets through perforated tiles in the raised floor. Exhaust air exited the room through return vents to the drop ceiling plenum before returning to the CRAH.

Prior to testing the various design concepts, the switch was installed in a cabinet to establish baseline performance under ideal conditions. The ideal test set-up was configured to eliminate any airflow resistances near the switch's inlet or exhaust. Additionally, recirculation issues were eliminated by supplying excess conditioned air to the switch through a perforated floor tile to the right (inlet side) of the cabinet. No other equipment was installed in the lab during this testing.

For testing purposes, the switch was configured to operate at maximum heat dissipation. Switch fan speed and volumetric airflow were controlled manually based on inlet air temperature. Testing was performed for cold aisle conditions of 32°C to 52°C to ensure performance over extreme conditions. The high end of the test range exceeded the operational specifications of the switch.

Cabinet Duct Applications

The duct design for cabinet applications must enable proper inlet airflow and temperature while accommodating the switch's power and connectivity requirements. Typically, cables are routed from the switch to the side of the cabinet outside the equipment mounting space as shown in Figure 4. The cables then run vertically, in front of the vertical air dams, to patch panels or out of the cabinet. In the worst-case cabling configuration, using 336 Category-6A Ethernet cables per switch, the cable bundle has a cross-sectional area of 257 cm^2. The cable bundle occupies the entire side area of the cabinet in front of the vertical air dam. Initial duct design concepts drew air from the front of the cabinet, through a hole in the right vertical air dam to the right side of the switch. However, it was determined that cable management requirements, especially for a two-switch deployment with twice the number of cables, made this ducting concept impractical because the cable mass could completely block the duct inlet.

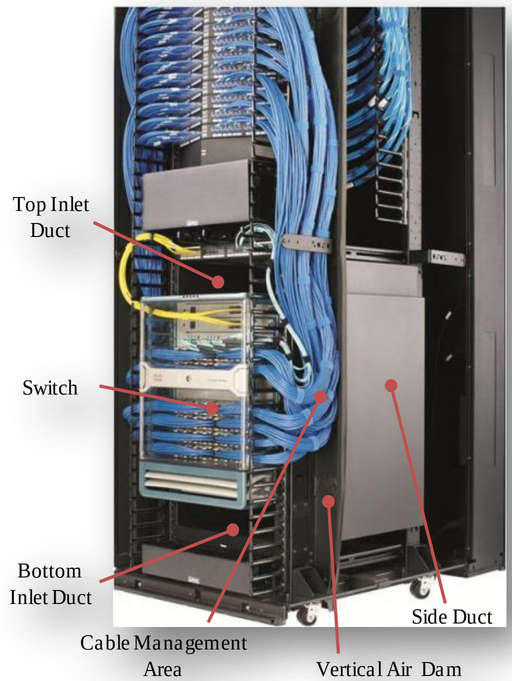


Figure 4. Cable management for a single switch deployed in an 800mm wide cabinet with a ducting solution. The front door and cabinet side panel are removed for clarity.

To alleviate the obstruction caused by the cabled bundle, a duct system with inlets between the equipment rails was developed for an 800mm (31.5″) wide cabinet. Duct boxes reside above and below the switch, each 3 RU in height. Each box is open to the front and the right side. A third duct box resides to the right of the switch and connects the top duct box to the bottom duct box. This allows air to be drawn in from the front of the top and bottom ducts. The switch then draws air in from the side duct and exhaust air exits the switch on the left side. Blanking panels and vertical air dams force the exhaust air out the rear of the cabinet. The physical design can be seen in Figure 4 and the airflow path is illustrated in Figure 5.

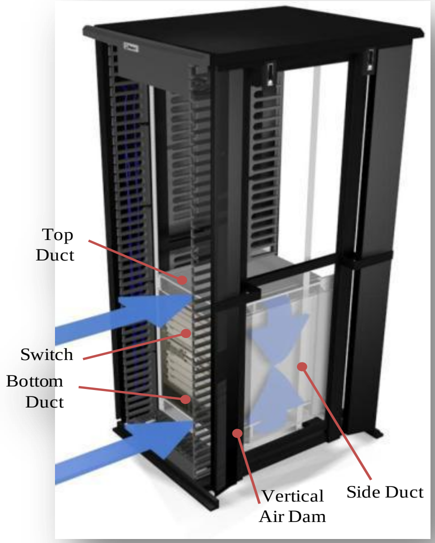


Figure 5. Airflow path for cabinet duct design. Cabinet doors, side panels and blanking panels are hidden for clarity.

Analysis
The CFD analysis investigated the effect of the duct design on both airflow patterns and volumetric flow. The entire volumetric flow for the switch must pass through the two relatively small inlet ducts and make several sharp turns which can cause a loss of airflow. Table 1 shows the predicted loss of airflow for the line and supervisor cards.

Table 1. Predicted loss of volumetric flow for switch inlet duct at the maximum fan speed.

	Inlet Duct
Line Cards	10.8%
Supervisor Cards	11.2%

Testing was performed in an 800mm wide cabinet with two switches installed in a vertical exhaust duct application. Blanking panels were installed within the cabinet and vertical air dams were placed outside the equipment rails to complete the physical separation of inlet and exhaust air. To simulate data cabling, additional obstructions were placed outside of the equipment rails in front of the air dams.

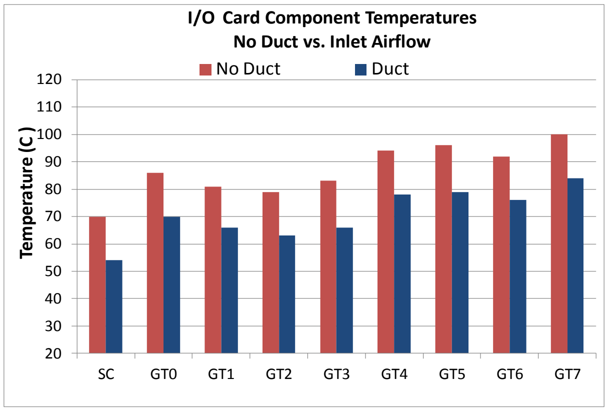
The first test investigated thermal performance of the switch in a cabinet without the inlet ducts installed. During the initial test at a cold aisle temperature of 32°C, air temperatures at the switch inlet were reported as high as 62°C. The extremely high recirculation temperatures prevented additional tests at higher cold aisle temperatures. Testing then proceeded with the inlet ducts installed on both switches in a cabinet with a VED.

Benefits

Comparing the results, the duct provided a significant thermal benefit. The reduction in inlet air temperatures provided the reduced inlet and component temperatures as shown in Table 2. Figure 6 shows component level data for an I/O card, comparing no duct versus inlet airflow.

Table 2. Average temperature improvement gained from the installation of the inlet duct.

Cold Aisle Temperature	32°C
Decrease in Inlet Air Temp.	20.0°C
Decrease in Component Temp.	14.6°C



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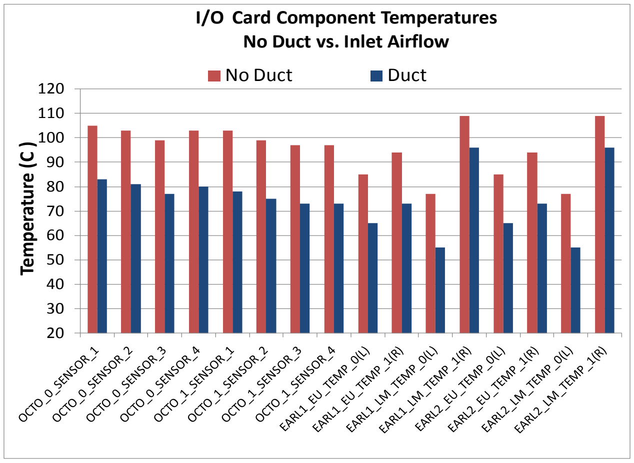

Figure 6. Specific components temperatures for the no duct versus the ducted case.

It should be noted that the lower temperatures for the ducted scenario were achieved despite a significant difference in fan speed. The very high inlet temperatures for the no duct case required the fans to operate at maximum speed. Inlet temperatures for the 32°C ducted scenario were low enough that the fans were run at minimum speed. The lower fan speed resulted in a 300W decrease in switch power consumption.

As demonstrated by the test data, the switch's thermal performance generally improved, while operating at a lower fan speed, with the installation of the inlet duct in cabinets that have VEDs. Therefore, the inlet duct design has been proven to enable side-to-side airflow switches used in containment deployments.

Conclusion

Increased inlet air temperatures caused by recirculation of exhaust air in side-to-side airflow switches can be improved through the use of ducting. The testing described in this white paper demonstrates the benefits of inlet ducting for cabinet deployments which include a path for air to travel from the cold aisle to the switch and physical separation of the inlet and exhaust sides of the cabinet. This separation within the cabinet allows the cabinet to be deployed in containment scenarios, improving thermal performance. The inlet ducting also increased airflow resistance, decreasing total volumetric airflow through the switch. However, this challenge was outweighed by the decrease in component temperatures made possible by the lower inlet air temperatures.

In addition, inlet ducts allow switches in cabinets to draw air directly from the cold aisle while providing physical separation of the inlet and exhaust sides of the cabinet. The improved thermal performance enabled by the ducting allows switches to operate at higher cold aisle temperatures. The increase in supply air temperature can improve the efficiency of traditional chiller-based HVAC systems or increase the hours of operation for economizer systems, which decreases the amount of energy required to cool the data center. The Panduit Net-Access™ In-Cabinet Duct System is comprised of thermal products that provide the optimum thermal performance and as an energy cost savings as well.

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