Data Center
Solutions

2008

Driving Data Center Efficiency Through the Adoption of Best Practices

COOPER B-Line

Executive Summary

Energy costs can account for up to 30 percent of a company's IT budget. With the continuing increase in energy costs and concerns over the impact of greenhouse gases on the Earth's climate, businesses are focusing on finding ways to reduce power consumption without adversely affecting business objectives. This paper focuses on ways to achive that end using best practices and cabinet based innovations aimed at helping to reduce the total cost of ownership for data room or data center applications.

Introduction

A good measure of a data center's efficiency can be gained by looking at the relationship between the power directly drawn by the servers verses the total power drawn by the data center.

$$\text{Data Center Efficiency} = \frac{\text{Power Drawn Directly By The Servers}}{\text{Power Drawn By The Data Center}}$$

Typically less than 50% of the electrical power consumed by a data center is directly attributed to powering the servers running the applications that generate the revenue streams. The balance of the power, as shown in Figure 1. below, is used to "support the IT load" and power the "support infrastructure".
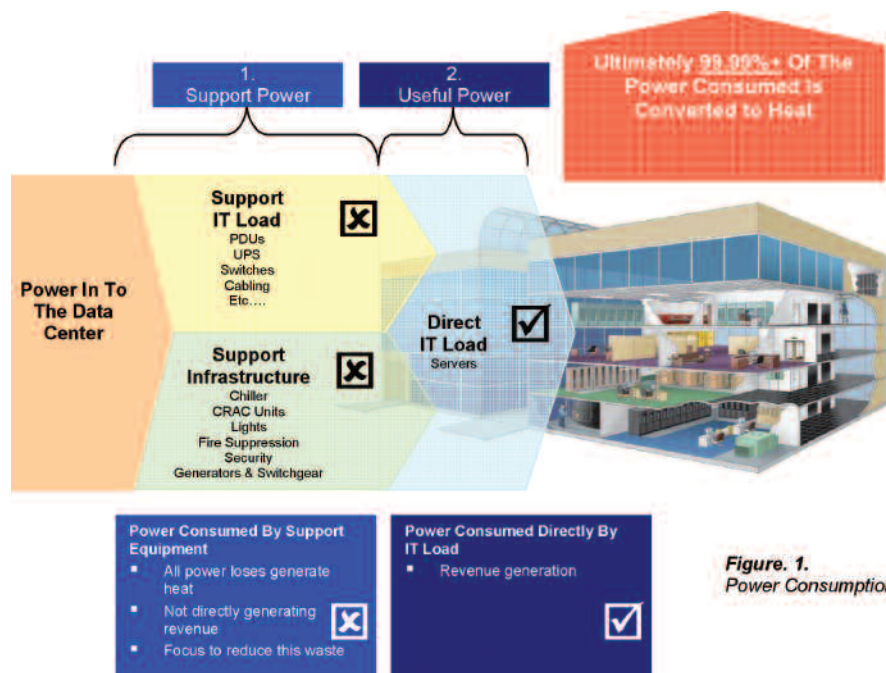

Figure. 1.
Power Consumption

Clearly, server manufacturers and equipment vendors are actively pursuing ways of improving the power efficiency of current and next generation servers. The adoption of solutions such as virtualization has the potential to reduce the number of servers required to perform a given computing task.
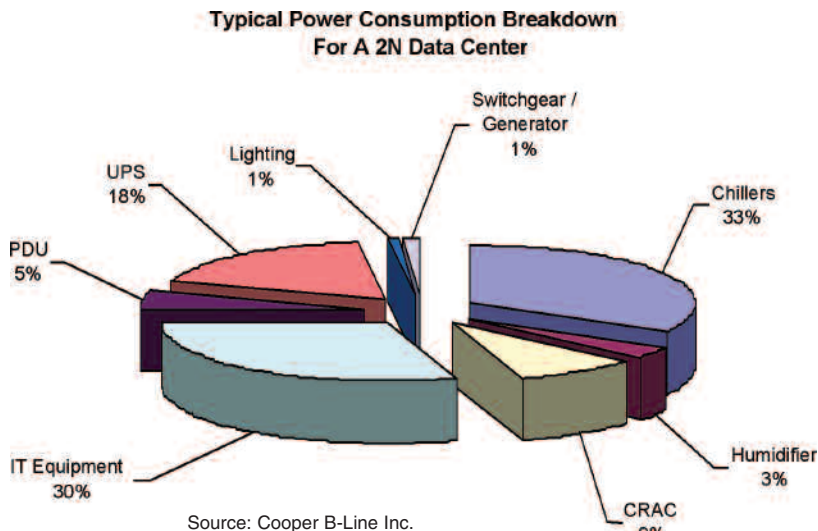
In simplistic terms, the removal of a single 500W server has the effect of reducing the power burden on the facility by 1kW as the demands on the "support IT load" and "support infrastructure" are also reduced. Unfortunately, the improvements in equipment power efficiencies and new operating concepts are being outpaced by the demand for increased computing capacity. IT systems are now being relied on to drive innovation and process improvements as today's cutting edge applications become tomorrow's every day requirements.

The recent reported doubling in e-mail traffic is a direct result of mobile e-mail adoption by the masses. Clearly, such developments place increased demands on IT infrastructure which, in turn, drives the demand for additional data center capacity. For the purpose of this paper, we are going to assume that the drive to improve the power efficiency of the active equipment (direct IT load) is the responsibility of the equipment vendor. We will, therefore, focus on the efficiency related to "support IT load" and "support infrastructure".
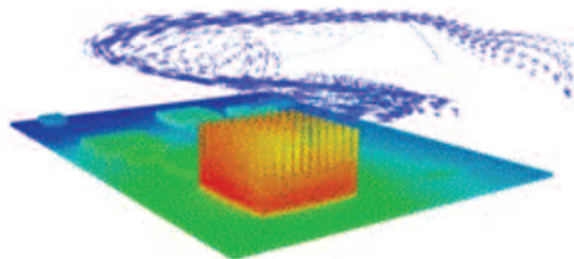
Power Consumption

Before we start to look at these areas in detail, it is important to understand how each of these facets impact the total power requirements of the data center. The chart below details the typical breakdown of power consumption for a 2N data center establishment.

As you can see from the chart on the right, around 45% of the total power consumed by a typical 2N data center can be directly attributable to maintaining a stable environment within the data center data hall. To understand why so much power is consumed managing this, we need to look at the operational design of a piece of active equipment.

Typical Power Consumption Breakdown For A 2N Data Center

- Switchgear / Generator 1%
- Lighting 1%
- UPS 18%
- PDU 5%
- IT Equipment 30%
- Chillers 33%
- Humidifier 3%
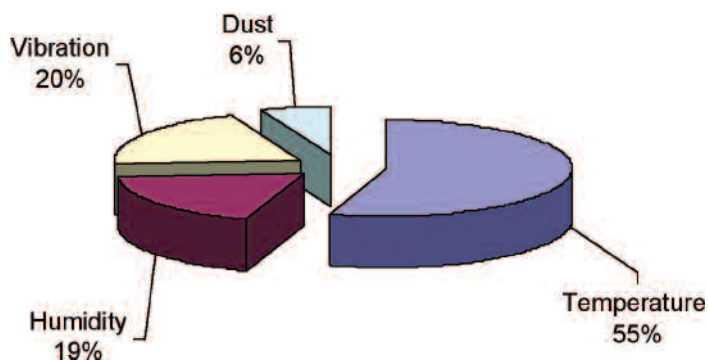- CRAC 9%

Source: Cooper B-Line Inc.

The Processor

The heat generated by any active equipment is derived from the transistors incorporated within the processing circuit. Both the speed and the density of the transistors have a significant impact on heat dissipation requirements. The issue of any electrical component is temperature - too cold and the unit fails, too hot and the unit overheats and fails.

Research carried out by BCC, Inc. culminating in "Report GB-185R", demonstrates that over half of electronic equipment failures can be directly attributed to temperature.

The Processor

Source Of Electronic Failures

- Vibration 20%
- Dust 6%
- Humidity 19%
- Temperature 55%

Source: BCC,Inc., Report GB-185R

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Active Equipment Design

In broad terms, we have touched on the importance of managing the environment in which the processor is deployed. We are now going to explore why it is important to try to maintain a tighter control on the deployment environment. The chart below shows the effect of temperature on the clock speed of a processor. In this case, a 10°C temperature reduction results in a 2% increase in clock speed.

A 2% variance may not seem significant, but now consider this in relation to a data center where hundreds of servers are deployed. In simplistic terms, one additional 2U server would have to be deployed every five cabinets to negate the loss in processing capacity. Not only could this significantly impact on the physical layout of the data room, but it would also impact on the infrastructure required to support all the additional servers. Remembering that the deployment of a 500W server equals adding a 1kW burden onto the power demands of the facility, the running costs of the facility start to increase exponentially.

Clockspeed Versus Temperature
Data for a 1,500MHz CPU

Source: Kryotech and IBM report
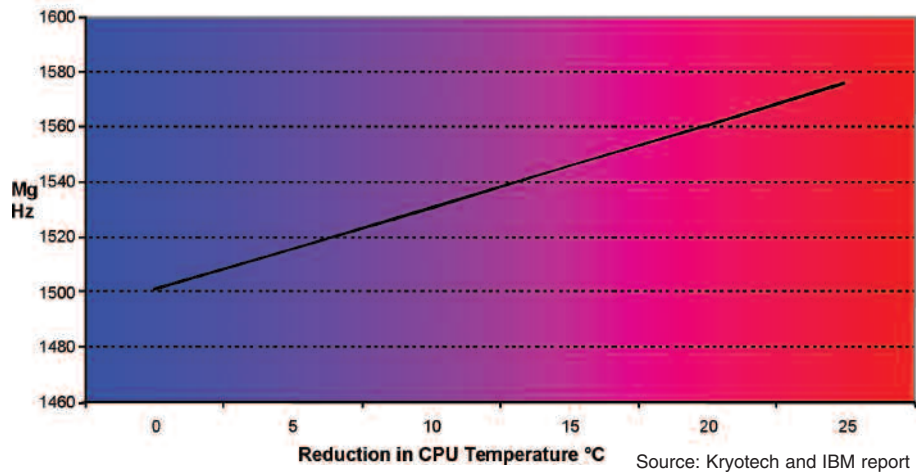
It is not just the computing efficiency that is affected by the temperature. The chart shows the typical impact on a processor when it is run at temperatures outside its design limits. While it may be possible for a processor to run for a period at temperatures well above its designed rating, it will have an effect on the system's lifespan, reducing its mean time between failure (MTBF). Clearly, in order to design and deploy an active piece of equipment, it has to be designed to operate in a given environment. The hardware design will have been based on maintaining the processor / processors at an optimum temperature and would have been based on calculating the heat transfer rate similar to the calculation below.

**The Effect Of Temperature On CPU Lifespan**

Source: MIL-HNBK-217 Standard
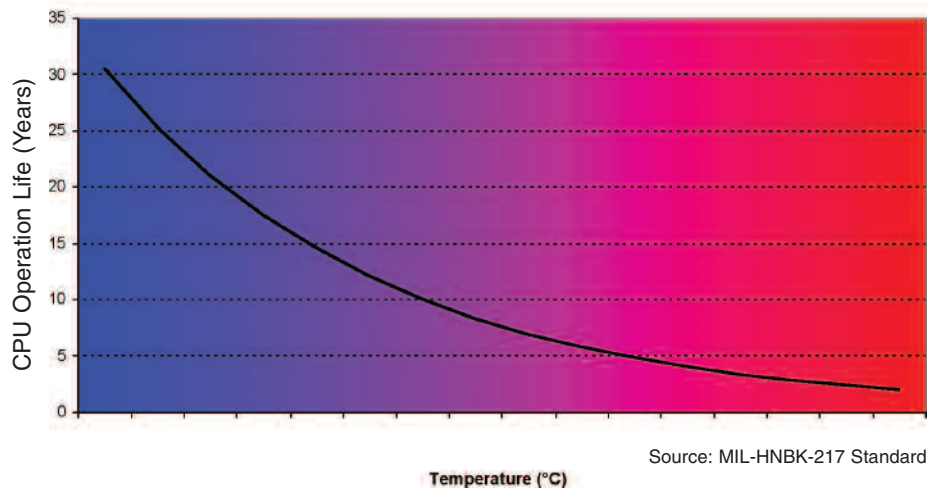
$$Q = hA(T_w - T_f)$$

Q = the heat transfer rate
h = the convection heat transfer rate
A = surface area
T_w = the temperature of the surface
T_f = the temperature of the fluid

As you can see, the only variable that can be influenced by the end user or equipment installer is the value Tf, the temperature of the cooling fluid (in this case the air around the processor). Obviously, maintaining the same pocket of air around the processor will see the cooling efficiency reduced to a point where the air and the processor are at the same temperature. With this, it is essential that air be circulated over the processor to remove the heat from the system. Fan assisted forced air is still the most common cooling method utilized by the equipment manufacturers. As you can see from the diagram on the right, fans in the rear of the unit air draw air in through the front of the unit and across the active components where heat is transferred from the active component to the flowing air. The warm air is then expelled out of the rear of the unit to allow fresh air to be drawn in again. The rate and direction of flow is often managed by variable speed fans linked to on board temperature monitors. It should be noted that some active equipment is designed to operate with side-to-side air convection and can utilize a combination of front to rear as well as side-to-side. When deploying any active equipment, the air inlet conditions should be checked against the manufacturer's specifications.

Hardware Design
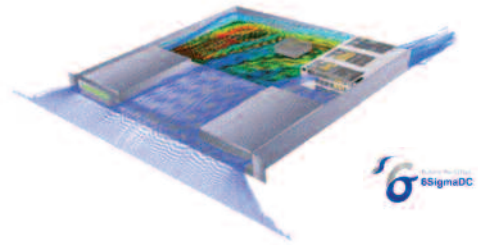
To provide an indication of typical system flow rates, 325m³/h (200cfm) of air is required to dissipate 1kW of heat. Conventionally, equipment manufacturers are designing equipment to operate in a clean room environment with an ambient temperature between 20°C - 35°C (68°F - 95°F) and relative humidity of 20% – 80%. According to the Industry Cooling Consortium (comprising of Dell, Cisco, HP, IBM, Nortel among others) we are currently in the middle of the steepest growth rate in heat densities (watts per m³) relating to the development of computing and communication equipment in history.

## Product Heat Density Trends 2000 - 2010
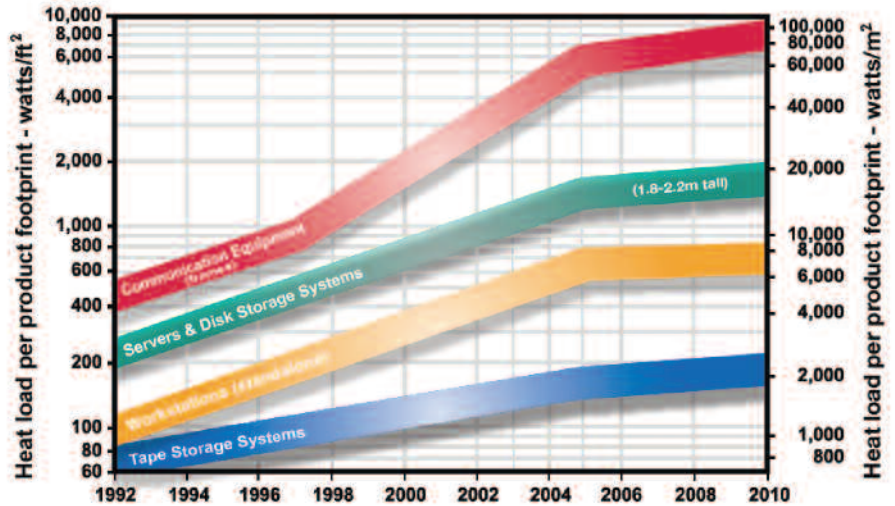
Year of First Product Announcement / Year of First Product Shipment

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Optimizing The Cooling Infrastructure

Given the continuing demand for increased processor power, the drive to increase both the speed and density of transistors seems set to continue. As a consequence, it would appear that both power and cooling densities are set to increase as well. The art when deploying any active equipment is to optimize the operational environment. By giving some forethought to deployment, users can achieve optimum processing capacity, while at the same time minimizing operational costs. The key to all of this is that the integrity of the system cannot and should not be jeopardized.

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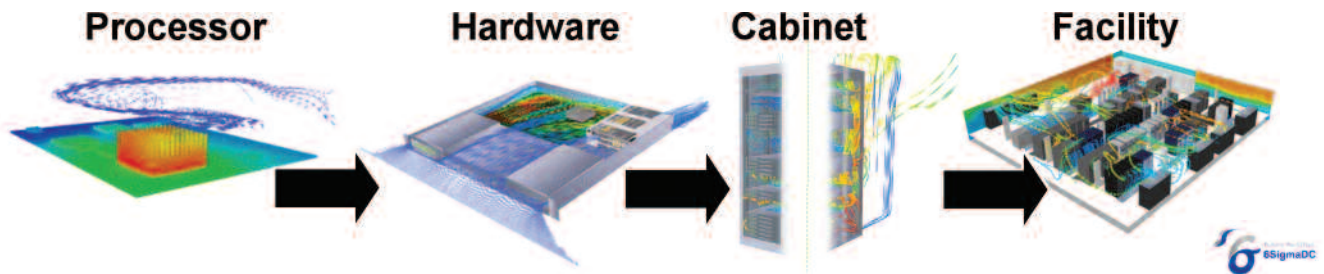
At first glance, it may be tempting to simply turn the CRAC (Computer Room Air Conditioning) unit control temperature down to maintain a lower feed temperature and reduce the temperature of the data room (a 22°C control temperature will see something like a 15°C air temperature off of the CRAC). This action may be not as beneficial as anticipated and will certainly be wasteful since a 1°C reduction in control temperature could see operational costs increasing by up to 4%.

The key to driving cooling efficiencies is maximizing the use of the cold air generated by the CRAC unit. Various studies have shown that data centers employing conventional pressurized raised floor structures often fail to manage bypass air. Bypass air is defined as the air which leaks out into areas other than where it provides a useful cooling effect.

Bypass air can account for 50-80% of the air fed from the CRAC unit to the under floor void. Sealing off gaps and leaks in the floor structure can significantly reduce bypass air, generating increased static pressure in the under floor void. By increasing the static pressure, the installation can operate with a more uniform air delivery to any point on the floor. This allows an improved flow rate at the vented tile positions and provides more air to where it is productive. The four main causes of bypass air are as follows:

1. **Unsealed entry points into the data room** – This can be easily remedied by installing automatic door closers and instilling the discipline to keep doors shut. Also, any cable or pipe entries should be sealed with plenum rated foam or other such appropriate material.

2. **Missing floor tiles** – Typically, this manifests itself at the cut tile positions around the periphery of the room where a tile may have been missed during the original installation or where the tile has been pulled up and not replaced.

3. **Incorrectly positioned vented tiles** – The conventional standard for rack or cabinet layouts within a data room environment is to organize a layout comprising of hot aisles and cold aisles (we will touch on this in more detail shortly). Utilizing this convention, vented floor tiles are positioned in the cold aisle to allow the cold air from the raised floor plenum to be fed to the front of the rack or cabinet. Contrary to some thoughts, a vented tile positioned in the hot aisle does not help to remove the hot air. It simply cools the hot air and offers no cooling effect for the active equipment. Likewise, a vented tile positioned in front of a passive cabinet (cabling cabinet, etc.) is likely to perform little or no cooling function.

4. **Holes and openings in the floor tiles** – Conventionally, floor tiles will have holes and openings cut in them to allow cables and pipe work to transition from the under floor void for termination in the rack or cabinet space. These solutions, other than the costly cutting of tiles, are readily available. But which ever method is employed, care should be taken to seal the gaps around the cable or pipe entry to stop leakage and maintain the pressure in the floor void.

The chart below provides some insight into the possible improvements in server inlet temperatures based on enhanced flow rates through the raised floor vented tiles. By doubling the air flow rate through the vented floor tile, it is possible to achieve a 11.5% increase in cooling capacity.

The Data Room Environment

Having now worked to reduce the bypass air in the data room, we can now look at setting the CRAC units up to run efficiently. We touched on earlier how the control temperature of the data room affects the supply temperature off of the CRAC unit. The efficiency of a CRAC unit improves as the ΔT widens (the delta T is the difference in temperature between the supply air temperature from the CRAC and the return air temperature back to the CRAC). As a general rule of thumb, a 1°C reduction in the ΔT would see around a 10% reduction of efficiency of the CRAC unit caused by the fact that the CRAC unit also works to maintain a balanced relative humidity within the data room.

Cooling Efficiency Linked To Tile Flow Rates

In the ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers Inc.) publication "Thermal Guidelines for Data Processing Environments" TC9.9, the following recommendations are made governing the operating environment of a Class 1 data facility.
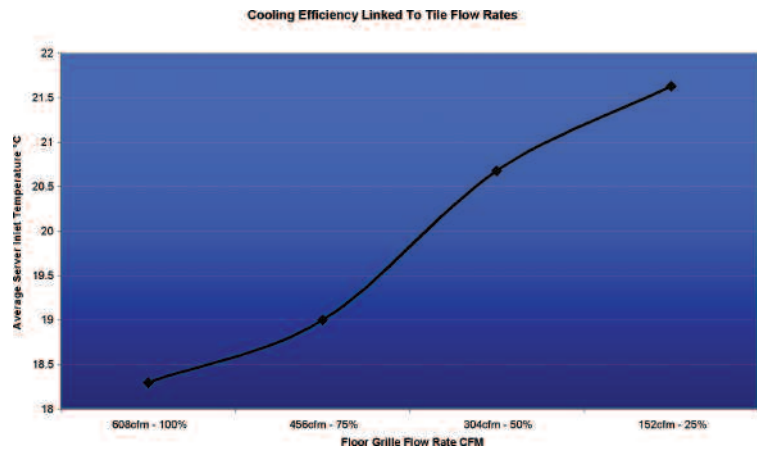
Recommended Range:	20 - 25°C (68 – 77°F)
Allowable Temperature Range:	15 - 32°C (59 – 90°F)
Maximum Temperature Rate of Change:	12.8°C (9°F)
Recommended Relative Humidity:	40 – 55%
Allowable Relative Humidity:	20 – 80%

We have looked at improving the static pressure under the floor which will improve the air delivery performance to the rack or cabinet. We have also looked at improving the efficiency of the CRAC unit and setting the control temperature to an optimum level within the data room. By optimizing these areas, not only should the air performance at the rack or cabinet position improve, the operational costs of the cooling infrastructure should also be reduced.

Data Room Layouts

We are now going to look at the implications of rack and cabinet placement within the data room, as well as look at the implications of positioning the CRAC units, cabling infrastructure and other supply services in an attempt to understand how these impact on the cooling efficiency of the data room.

Air is a gaseous liquid and like all liquids, moves in the path of least resistance, on occasion doing some strange things. Research carried out by independent bodies has shown that the air streams from individual CRAC units tend not to mix in the floor void. Further, if the CRAC units are positioned too closely together or at right angles to one another the air stream from one CRAC unit can impinge on the stream from other causing cooling dead spots under the floor. The diagrams below detail the air flow paths and associated velocities of the air fed of two CRAC units. Notice the areas where there is no air flow denoted by the darker blue color.
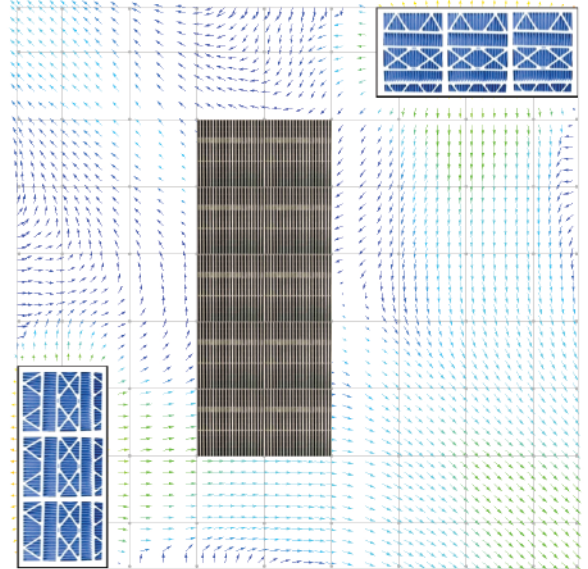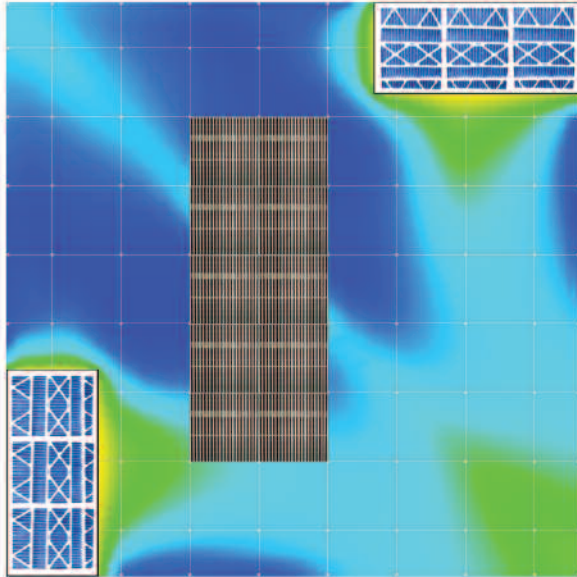

Depending on the room layout or on how the support infrastructure has been deployed, it may be necessary or beneficial to duct air from the CRAC unit direct to a zone or rack/cabinet position. It is, however, more common that the cold air from the CRAC be simply directed to the pressurised raised floor plenum as shown in the diagram below.

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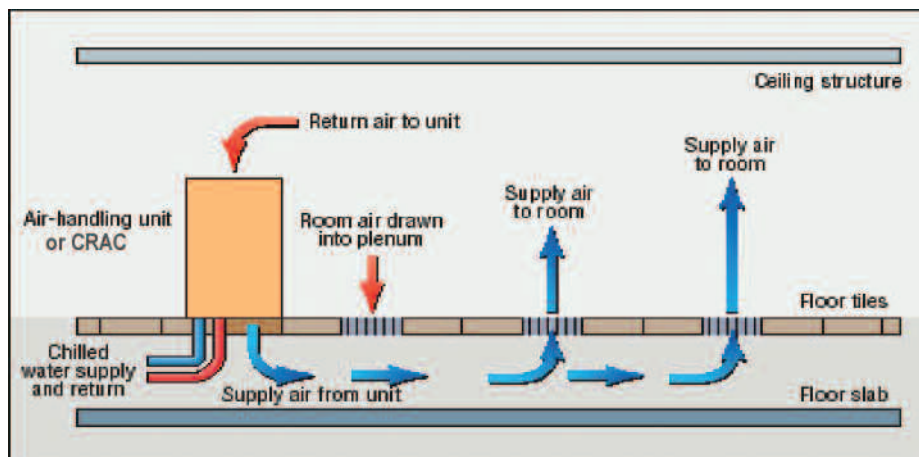
It is often the perception that locating the cabinet with the densest heat load close to the CRAC unit provides the best cooling capacity. As you can see from the diagram below, this is not often the case as the velocity of the air feed coming off the CRAC unit can create a negative air pressure above the vented tile space. In this case, not only would no cooled air be supplied to the rack / cabinet position, but this configuration would end up dragging ambient warm air from the data room down into the floor void reducing the cooling efficiency of the cold air.

We have reviewed the possible impact of locating a vented tile too close to the CRAC unit. We are now we are going to look at the importance of defining the positioning of the hot and cold aisles and how their operation may be affected by the relative position of the CRAC units.

Like the perception that a vented tile close to the CRAC unit would provide optimum air feed, it is often a misperception that locating the cold aisle opposite the CRAC unit would provide the optimum cooling effect. Remembering that air flows down the path of least resistance, it is likely that the cold air being fed up through the vented floor tiles would simply short circuit the racks / cabinet cooling circuit and flow back to the CRAC unit without ever entering the cabinet and providing any significant cooling effect.
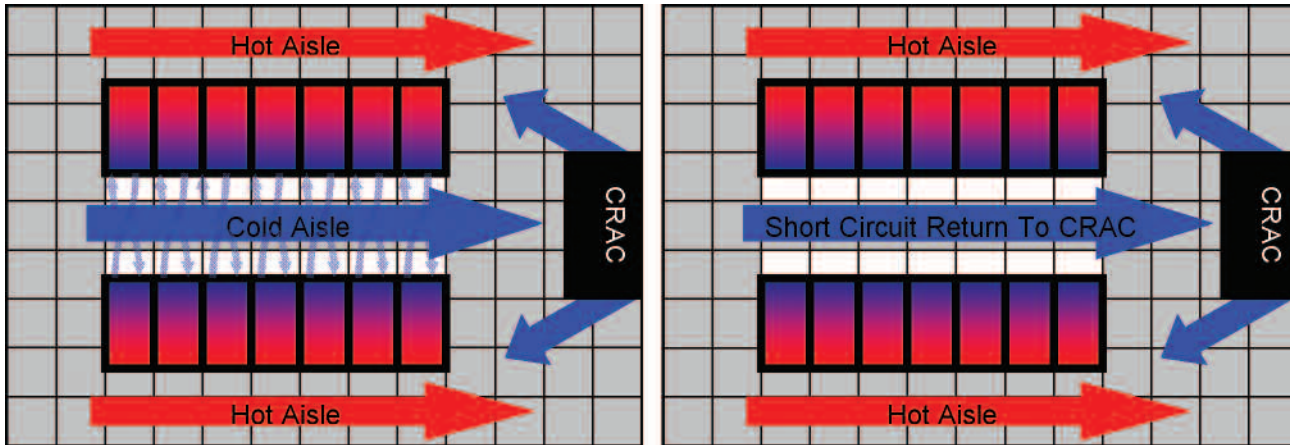
If you find you have an operational site where perhaps you are forced to position the cabinets with the cold aisle opposite the CRAC unit, you can significantly reduce the short circuiting of the cold air by simply installing end of aisle doors on the end of the aisle closest to the CRAC unit.

Remembering that we have improved the static floor pressure to obtain a more uniform air feed at any tile position, we can now look at optimizing the hot and cold aisle layout. This time we have reversed the cabinet layout to position the hot aisle opposite the CRAC unit. This layout helps to promote the cold air being drawn through the cabinet, as well as shortening the path for the hot air to return to the CRAC unit.
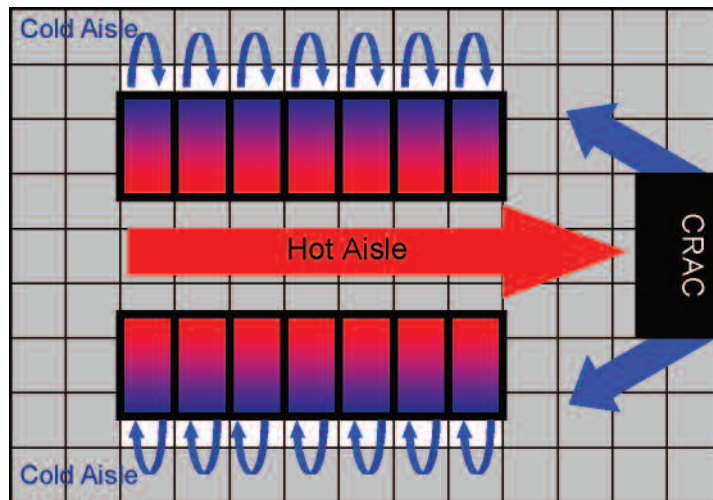
External Rack or Cabinet Configuration

The next step to improving the cooling efficiency is to look at the rack or cabinet structure. As you should have now gathered, the key to improving cooling efficiency is the segregation of your cold air feed from your hot air return.

As we saw when we looked at the design of the active equipment, the key to maintaining an acceptable operating temperature is ensuring sufficient cold air passes through the active unit. How we achieve this within the cabinet structure depends on the preferred method of air entry into the rack or cabinet. This is typically achieved in two ways:

1. Perhaps the most common method is utilising a vented door on the front of the cabinet. This allows the cold air being forced up from the vented tile in front of the rack or cabinet position to be drawn through the door and then through the active equipment. In this scenario, it is common to have a vented door on the rear of the cabinet allowing the hot air to be expelled out the rear of the cabinet into the hot aisle.

2. The alternate method is to direct the cold air into the front of the cabinet creating a cold air chimney between the inside of the door and the face of the front 19-inch mounting angles. Like option 1 above, it is common to have a vented door on the rear of the cabinet allowing the hot air to be expelled from the cabinet envelope.

For the benefit of this paper, we are going to look at the issue of door configuration, based on option 1 above. The four diagrams below all depict cabinet layouts having the same active components totalling a 3kW load fitted in the same unit height locations, all operating in the same ambient environment. In each case, the only difference in the cabinet structure are the doors, top panel configurations and the deployment of internal baffling to segregate the hot and cold air within the cabinet structure.
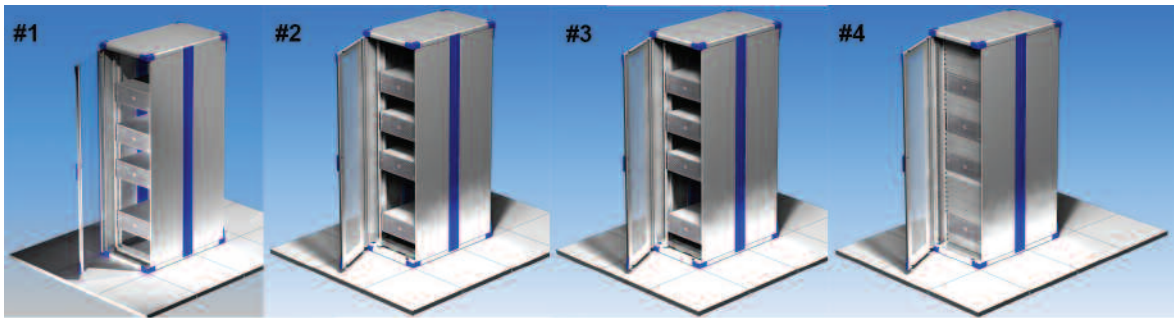
Type #1 - CABINET - 42U 600W x 1000D
- **Glass Front Door**
- **Steel Rear Door**
- **Top Panel Configuration:**
  - Two Plain Panel & One Vented Panel
- **No Internal Baffling Or Blanking**

Type #2 - CABINET - 42U 600W x 1000D
- **56% Vented Front Door**
- **56% Vented Front Door**
- **Top Panel Configuration:**
  - Two Plain Panel & One Vented Panel
- **No Internal Baffling Or Blanking**

Type #3 - CABINET - 42U 600W x 1000D
- **80% Vented Front Door**
- **80% Vented Rear Door**
- **Top Panel Configuration:**
  - Two Plain Panel & One Vented Panel
- **No Internal Baffling Or Blanking**

Type #4 - CABINET - 42U 600W x 1000D
- **80% Vented Front Door**
- **80% Vented Rear Door**
- **Three Plain Top Panels**
- **19" Blanking Panels**
- **Vertical Side Brush Strip Blanking**
- **Top & Bottom Blanking**

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The graph shows the results of the simulations based on these scenarios. According to the server equipment manufacturer's recommendations, the four identical servers are designed to run with a maximum inlet temperature of 35°C (95°F), which is denoted by the black horizontal line. The other two graphed lines represent the "average server inlet temperature" and the "maximum inlet server temperature". The convergence of these two values indicates that the cold air is being uniformly distributed to from the bottom to the top of the rack or cabinet.

The Effect Of Rack Or Cabinet Configuration On Cooling Efficiency - 3kW Load
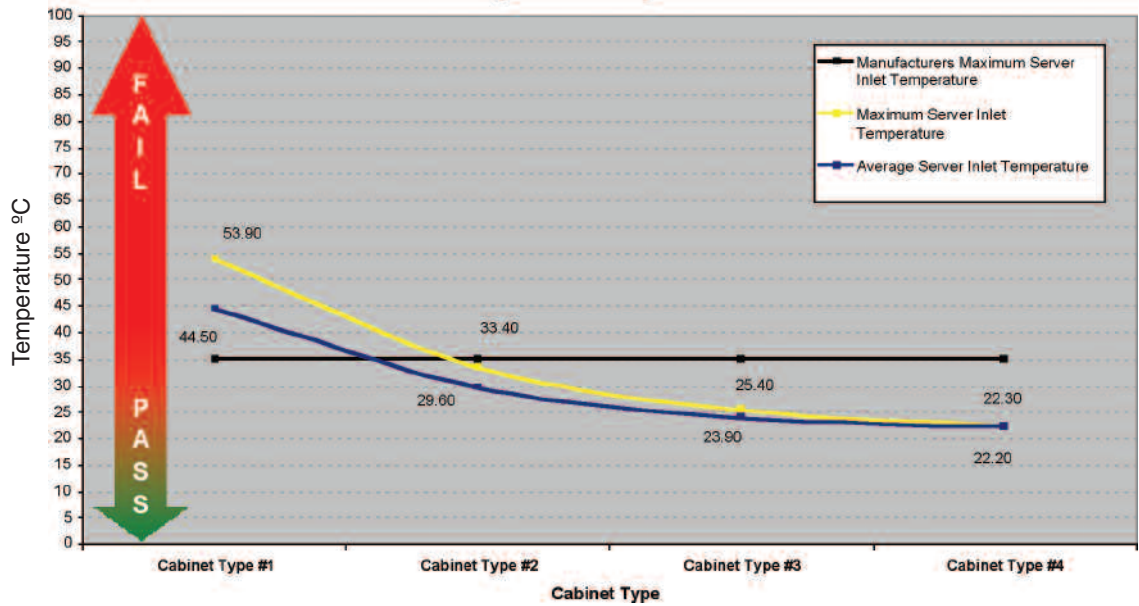
Clearly in this scenario "Cabinet Type #1" would cause the active equipment to overheat causing premature failure. The cabinet configuration detailed in "Cabinet Type #2" would just about see the active equipment operating at maximum temperature, but any small change in the local ambient environment would, in all likelihood, generate an overheating event. "Cabinet Type #3" and "Cabinet Type #4" would see the system operating efficiently with a safety margin allowing for some change in operating environment.

As you can see from the chart above, by deploying internal cabinet baffling to segregate the cold air feed from the hot air return you can achieve around a 1.7°C (3°F) improvement in the average air inlet temperature (around a 7% improvement). When we looked at the CRAC units earlier we saw that by reducing the control temperature by 1°C we increased the operational costs for the CRAC unit by around 4%.

If we now look at increasing the heat load from 3kW to 8kW per rack or cabinet you can see that the overheating issues we saw when we looked at the 3kW load for "Cabinet Type #1" have been exacerbated with server inlet temperatures in excess of double the maximum recommended inlet temperature.

You can now see that "Cabinet Type #2", which just about provided adequate cooling capacity with a 3kW load, is no longer able to maintain an acceptable operating environment for the servers. "Cabinet Type #3" and "Cabinet Type #4" continue to provide sufficient cooling capacity.

When we looked at the 3kW load and the cooling efficiency gains between "Cabinet Type #3" and "Cabinet Type #4" (which had the internal baffling), we saw on average a 1.7°C (3°F) improvement in server inlet temperatures. If we now look at the comparison between the same two cabinet configurations, but with an 8kW load the deployment of the baffles provides somewhere near a 6.7°C (12°F) server inlet temperature improvement, equating to a 25% improvement.
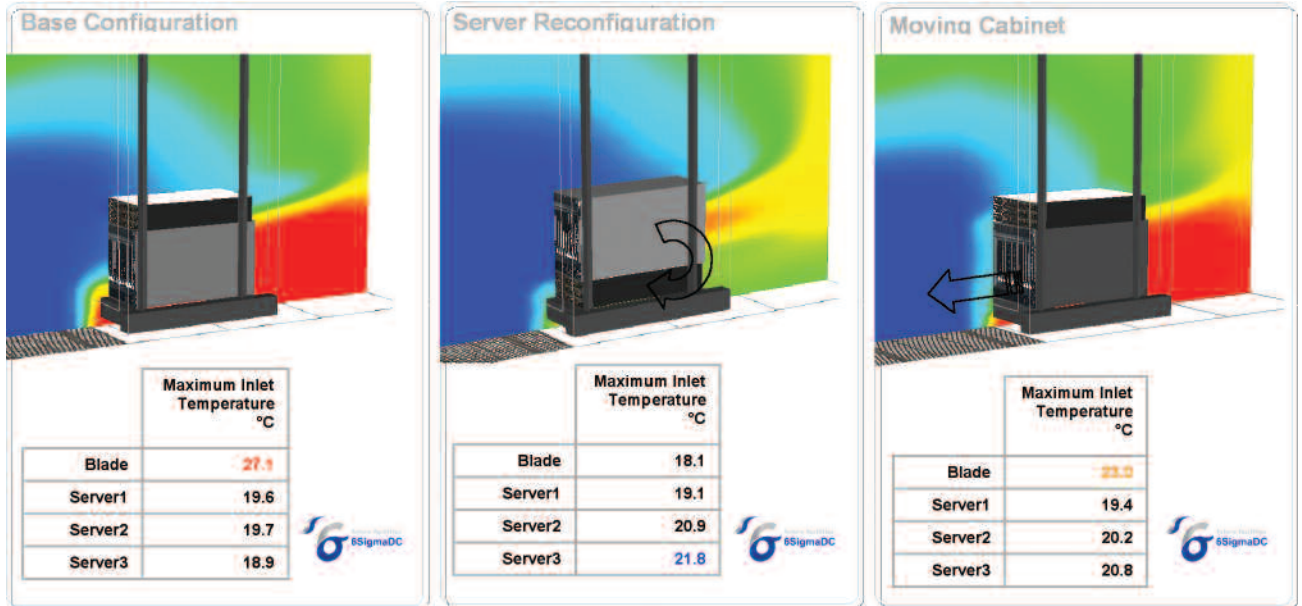
The Effect Of Rack Or Cabinet Configuration On Cooling Efficiency - 8kW Load
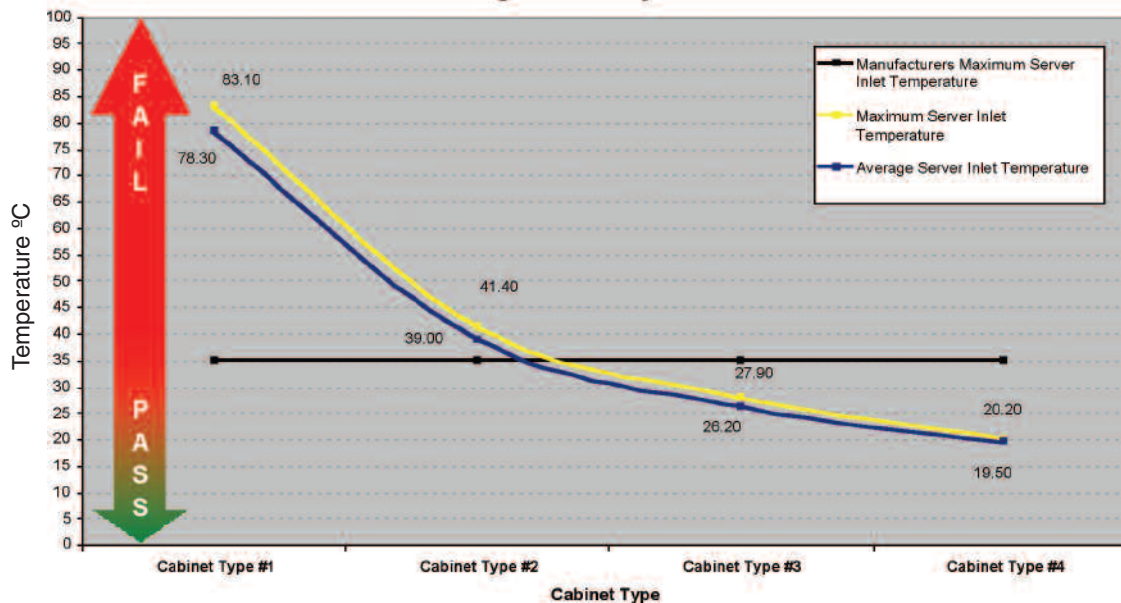
Equipment Configuration

Typically, once the rack or cabinet has been configured and positioned in a suitable location within the data room, all thoughts then turn to the deployment of the active and passive 19-inch equipment. Equal care should be taken when designing and deploying the equipment into the rack or cabinet structure. It is all too easy to make assumptions which can have an adverse effect on the operating efficiency of the equipment. Some of the most common problems surrounding equipment cooling relate to the positioning and management of cabling, which can sometimes obstruct or impede the flow of air to the active equipment.

The diagrams below show how the positioning of equipment and the location of the rack or cabinet can affect the operational efficiency of the active equipment. The diagram tiled "base configuration" shows a single blade server and three 1U servers deployed in a cabinet. The velocity of the air coming up through the vented floor tile is typically seeing the cold air feed bypassing the blade server leading to a higher than necessary operating temperature.

Base Configuration

	Maximum Inlet Temperature °C
Blade	27.1
Server1	19.6
Server2	19.7
Server3	18.9

Server Reconfiguration

	Maximum Inlet Temperature °C
Blade	18.1
Server1	19.1
Server2	20.9
Server3	21.8

Moving Cabinet

	Maximum Inlet Temperature °C
Blade	23.0
Server1	19.4
Server2	20.2
Server3	20.8

As the processing capacity of a blade server is typically higher than a conventional server (remembering that higher processor densities yield greater heat loads requiring a greater air flow rate to dissipate the heat), it makes sense that the blade server is positioned to allow it to use the cold feed air to greater effect. By simply swapping the relative position of the blade server and the 1U servers, a more uniform operating environment is achieved as shown in diagram "server reconfiguration".

It may also be possible to improve the air feed to a particular cabinet rack space by simply damping the air feed or re-positing the rack or cabinet as shown in the diagram titled "moving cabinet". Care should be taken when moving a single cabinet as the effects of simply repositioning a cabinet could impact on the operational efficiency of the other cabinets in the local vicinity.

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Internal Rack or Cabinet Configuration

Most racks or cabinets comprise of an outer shell, which as we looked at earlier, can be easily configured to ensure sufficient air flow through the cabinet to maintain cooling capacity. The internal configuration of the rack or cabinet is typically a whole different matter with every cabinet differing in internal layout.

It is not uncommon for the internal cabinet envelope to be left open allowing hot and cold air crossover within the cabinet structure as shown in the diagram right. As you can see in the diagram on the right, the cold air is being drawn in up through the vented floor tile and through the front door. The air is then being drawn over the equipment and the now warm air is expelled in to the rear of the cabinet. At the same time, the cold air feed is free to flow internally down the side of the cabinet and circulate through any unused or un-blanked 19-inch opens. More importantly, the warm air expelled by the active equipment is also free to recirculate to the front of the cabinet where it can mix with the cold air feed. The recirculation of the return air has the effect of reducing the cooling efficiency as the warm air mixes with the cold air to increase the temperature of the cold air. Ultimately, with increasing heat densities, and if left unchecked, this could lead to the generation of hot spots and as we have seen can lead to premature equipment failure.

As we saw earlier in the graph "The Effect Of Rack and Cabinet Configuration On Cooling Efficieny – 8kW Load" there is a tangible benefit in employing internal baffling to improve rack or cabinet cooling efficiency. The diagrams below depict cabinets in cross section with active equipment installed. The diagram on the left hand side shows a conventional server type cabinet where the equipment is aspiring in the normal front to rear configuration. The diagram on the right hand side is depicting a cabinet layout where not only is equipment aspiring front to rear but also side to side.
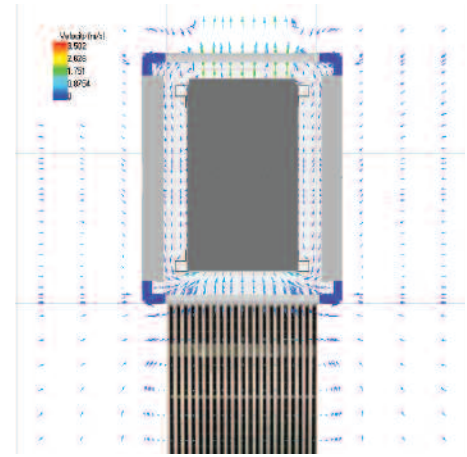
In both cases by employing simple baffles, it is possible to segregate the cold air feed from the hot air return. In so doing so, this will obtain maximum efficiency from this particular infrastructure deployment.
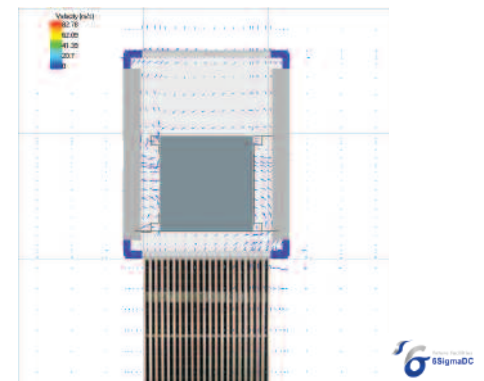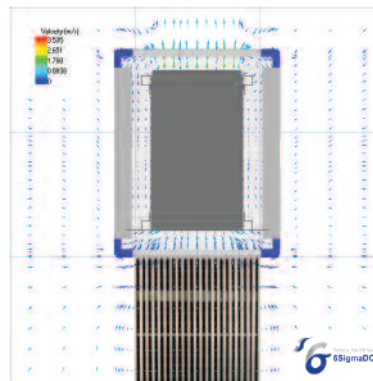
Conclusion

Up to 45% of the infrastructure running costs for a conventional data center using cold air as the cooling medium can be attributed to maintaining a suitable operating environment. Given the drive to increase equipment densities, the sometimes limited availability of power and the ever increasing cost of power this has to be a key area of focus to improve efficiency and drive increased capacity or reduced operational costs. The key to any operational cooling efficiency gains is simple; make the most of what you have. By reviewing and understanding how the infrastructure is configured you can look to improve on the areas of weakness. The key learning points are:

- Ensure that the cold air is delivered to where it is needed
- Avoid unnecessary hot air / cold air crossover
- Use a common sense approach to planning and deploying your infrastructure
- Verify what you think will happen is happening and if not investigate why
- Standardize and communicate your best practice objectives to all of your team
- Define, capture and publish suitable key performance indicators