# Server Rack Heat Dissipation using Fan assisted Cold Air Containment

Server Racks Australia

V1.2 White Paper #1

## Executive Summary

**The increase in power density of rack-mount IT equipment has forced Data Centre managers to manage airflows to cool servers. The first effective cooling solution was a raised floor, hot/cold aisle configuration. However, due to restrictions on airflow through server cabinets and a dependency on underfloor to above floor differential pressure (*underfloor pressure*), this solution was highly variable and only suitable for at best medium power densities (typical maximum heat load of 4kW). As Data Centers look to accommodate racks with heat loads upward of 10kW, it is evident that a better cooling solution be used. Fan-assisted cold air containment (e.g. the iPAMM™) solves the major pitfalls of the hot/cold aisle solution, namely:**

- **Providing consistent and controlled inlet air temperatures.**
- **Increasing volumes of air flow.**
- **Removing reliance on underfloor pressure to drive air flows.**

**This allows the iPAMM to support heat loads upward of 9kW in line with modern Data Centre demands. This paper discusses in depth the behaviour of each of these cooling solutions, focussing on the environments in which each solution is viable.**

## 1 Introduction

The past 20 years of technological development has resulted in exponential improvements in the performance of computer equipment, with processor speed approximately doubling every two years (according to Moore's Law). This has subsequently resulted in an increase in equipment power densities, giving rise to two issues. The first being increased air temperatures, while the second is data centre power efficiency due to increased electricity consumption.

The production of unwanted heat has forced Data Centre managers to play an active roll in server cooling, with a managed airflow approach to server rack cooling the industry standard course of action. Without managed airflows to remove heat build-up, it is inevitable that dangerous heat levels will occur within the equipment, significantly reducing the MTBF. At the same time, increased power consumption within data centres has resulted in both a rise in electricity costs and an increasingly negative effect on the environment. The modern Data Centre must therefore provide effective cooling while also being efficient, which is a difficult compromise to achieve.

Despite managed airflow solutions becoming progressively more sophisticated in parallel with power density increases, cooling solutions have historically lagged behind power densities. That is, the cooling solution is often designed post-mortem as a solution to already existing over-heating issues. As such, the solution must be designed to function in existing infrastructure as it will typically be retrofitted, although this is not always the case. For this reason, there are few cooling solutions offered presently that offer both effective and efficient cooling.

This paper describes the evolution of Data Centre cooling solutions, describing quantitatively and qualitatively the performance of the most common solutions, while critically analysing the conditions under which these solutions are viable.

## 2 The first steps to cooling

The birth of managed airflows occurred with the inclusion of fans within the rack-mount IT equipment, providing airflows sufficient to dissipate significant heat from the equipment components. However, without control over the temperature of the air entering the server (inlet air), this was insufficient to guarantee server equipment would function within its allowable operating temperature. Management of the airflows to these fans was required to guarantee the inlet air temperature and thus ensure healthy operating conditions.

The use of Computer Room Air Conditioning (CRAC) Units followed as a simple and logical method of inlet air temperature control. However without proper airflow management, there was no guarantee that the cool air would enter the inlet air stream of the server, with the air more likely to pass directly back into the CRAC unit having done no effective cooling, as shown in Figure 1.

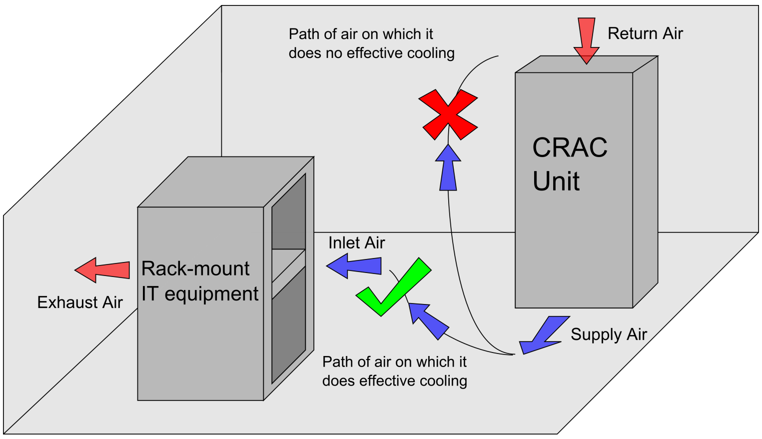


Figure 1: **The airflows generated by a CRAC unit and server in a Data Centre with no managed airflows.** The supply air from the CRAC Unit is not guaranteed to reach the inlet air stream of the server under this configuration.

In order to prevent this short cycling, a managed airflow approach was taken. This involved channeling the air to the front of the server via a *cold aisle*, and managing the resultant hot exhaust air, via a *hot aisle*, such that effective cooling can be guaranteed and inefficiencies can be minimised. This technique was the first viable, and longest standing, air management solution that is still in use in Data Centres today.

## 3 Raised floor plenums and Hot/Cold aisle

The most common method for creating a hot/cold aisle Data Centre is via a raised floor, as shown in Figure 2. In this configuration, the supply air from the CRAC Unit is directed under the raised floor, pressurising the underfloor plenum with respect to the ambient room; this pressure differential ($\Delta$P) drives cool air from underfloor into the room via vented floor tiles. Data Centre managers were now capable of strategically locating cold aisles in the inlet air stream of servers, successfully partitioning it from the hot exhaust air. Although a well engineered Data Centre will be successful in isolating hot and cold air streams, some degree of mixing is inevitable. Another advantage of this managed approach is its capacity to maintain healthy operating conditions for medium power density equipment.

The main disadvantage of this solution is its performance is heavily dependant on Data Centre conditions. Two conditions in particular play an important role in the effectiveness and efficiency of the cooling solution:

- ***The restriction of airflow through the server enclosure, and***
- ***The underfloor plenum pressure***

The following sections will address each of these conditions, identifying the effect they have on

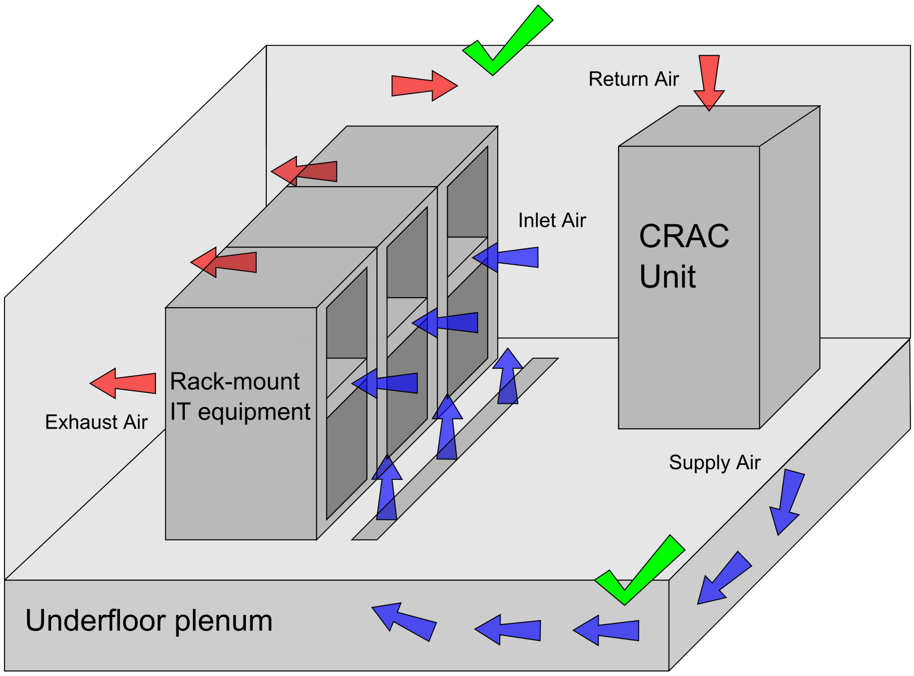


Figure 2: **The airflows generated by a CRAC unit and server in a raised floor hot/cold aisle Data Centre.**

effectiveness of hot/cold aisle systems, while also establishing some baseline performance characteristics.

### 3.1 Air flow through the server enclosure

Servers in a Data Centre do not sit in open air conditions; they instead are located within a server cabinet that has both a front and rear door, both of which have perforations to allow airflows into the cabinet. Despite these perforations, the doors resist the flow of air into the cabinet, with the perforation size and pattern determining the magnitude of this effect. As it is the air that absorbs and removes the heat from the server (a smaller volume of air will result in increased temperatures and vice versa), the rack type becomes an important parameter in classifying rack performance.

The size of the perforations on the door has traditionally been considered in a purely cosmetic and engineering sense e.g. size determined by strength, rigidity etc. However, the physical security of not only the computer assets themselves, but the business processes that they represent, are an ever increasing consideration in modern Data Centres. In this light, some racks are required to be secure on top of offering cooling solutions. This led to the development of a secure class door (Class C)[1] that has smaller perforations to comply with security standards, at a cost of further restricting air flow through the cabinet.

The restriction of air flow through servers is a static variable that, after the initial set-up of the Data Centre, remains constant i.e. once a door type (and therefore perforation size) is chosen, the volume of air drawn through the servers remains constant. The two common perforation sizes that exist in current product ranges are Commercial Grade (6mm x 30mm) and Class C (25mm x 3mm). The volume restrictions that occur due to the use of each door is shown in Table 1[1].

Table 1: Volume of air drawn through server for different door types.

| **Door Type** | **Volume** $(l/s)$ | **Percentage of open air volume** |
|---|---|---|
| Open Air (No Restriction) | 475 | 100% |
| Commercial Grade | 440 | 93% |
| Class C | 400 | 85% |

[1]The Class C or SCEC rack

## 3.2 Underfloor Pressure (△P)

The underfloor pressure is indicative of the force with which air enters the cold aisle from the vented floor tiles. For large ΔP, the air enters the room with high velocities, while the velocities decrease as the pressure decreases, to the point where little to no air enters the room at ΔP=0. The underfloor pressure condition therefore dictates the temperature of the air along the inlet of the servers e.g. for small ΔP, the inlet air is hotter than for larger ΔP.

The underfloor pressure is a dynamic variable that varies over the life of a Data Centre; as new racks are added and more vented floor tiles are introduced to a cold aisle, the underfloor pressure reduces. This is therefore the key variable in determining cooling performance. Underfloor ΔP typically ranges between 0 and 15Pa across Data Centres and the inlet air temperatures (for both Commercial and Class C) experienced within this ΔP range are shown in Figure 3 and Figure 4[2].

Evidently, the provision of air to servers located in the top of the rack is compromised at lower ΔP, reducing the cooling efficiency and effectiveness. An increased inlet air temperature reduces the capacity of the air to dissipate heat while attempting to maintain healthy operating temperatures; that is, higher inlet air temperatures result in a reduced maximum heat load. In addition, the energy used by the CRAC unit to cool the supply air is wasted as the air absorbs heat on the path to the inlet air stream. This is a major inefficiency that is difficult to control as it is dependant on the ambient room conditions, thus it will vary between Data Centres, as well as with Data Centre conditions. Given this variability, potential efficiency gains from altering the inlet air temperature can not be exploited as there is a lack of correlation between the underfloor temperature, a parameter that can be controlled, and the inlet air temperature.

Despite these pitfalls, hot/cold aisle Data Centres are viable options under a specific set of

[2]For an outline of the experimental procedure used to gain this data, see Appendix A

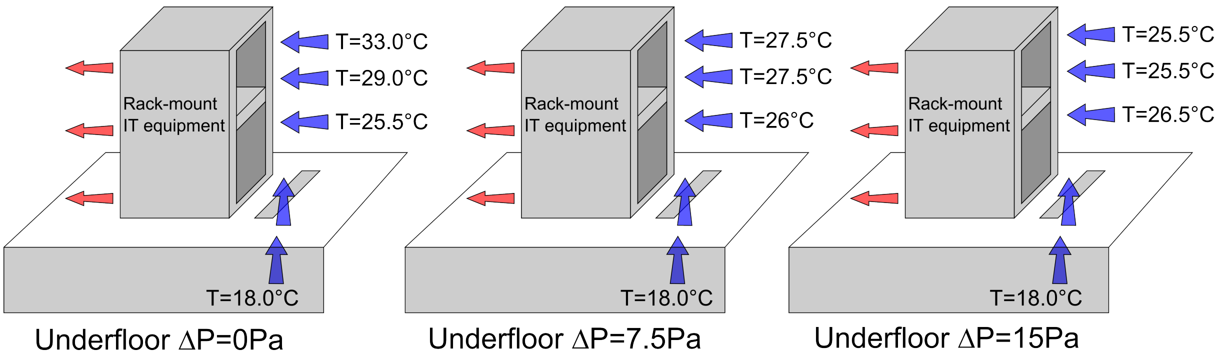


Figure 3: **Performance of Commercial grade rack with perferated front door using hot/cold aisle management with a raised floor and vented floor tiles.** The three images show the vertical inlet air temperature profile for $\Delta$P=0 (left), 7.5 (centre) and 15Pa (right). Underfloor $\Delta$P typically seen in Data Centres ranges between 0 and 15Pa.

conditions, as detailed in the following section.

## 3.3 Environment in which a Hot/Cold aisle Data Centre is effective

The environment in which a hot/cold aisle system can be used is dependant on a number of factors, including (but not limited to):

- The supply air temperature provided by the CRAC Unit,
- The heat load generated by the IT equipment,
- The underfloor $\Delta$P,
- The healthy operating temperature of the IT equipment, and
- The volume of air drawn by the IT equipment.

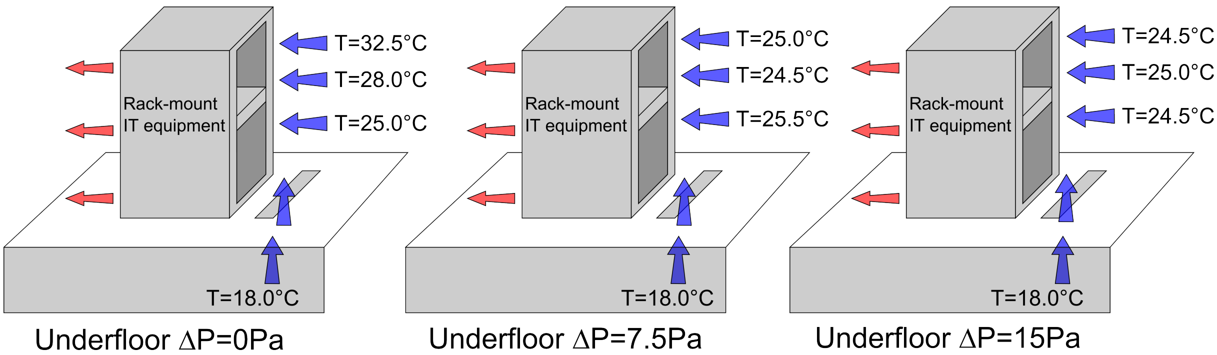


Figure 4: **Performance of Class C rack with perferated front door using hot/cold aisle management with a raised floor and vented floor tiles.** The three images show the vertical inlet air temperature profile for ΔP=0 (left), 7.5 (centre) and 15Pa (right).

We will consider two different environments and the heat loads they are capable of supporting. The first is an ideal environment, where each parameter is optimised to support the largest possible heat load (e.g. Commercial Racks are used to optimise air volumes, a large underfloor ΔP is present etc.). The second is a typical Data Centre environment, where the conditions are consistent with those found in a typical Data Centre (e.g. secure Class C racks are used which restrict air volumes, the underfloor ΔP is low etc.). The parameter values in each case are shown in Table 2[3].

The relationship between outlet air temperature and heat load for each scenario is shown in Figure 5[4]. Note that the trends begin at different points along the outlet air temperature scale in accordance with the inlet air temperature. For the maximum allowable outlet air temperature, the supported heat load is highlighted. This is the maximum heat load that the configuration is capable of supporting. Although this indicates that under ideal conditions a hot/cold aisle Data

[3]For the purpose of this exercise, we will assume that all servers draw the same volume of air per rack unit (RU) in open air, with this value being 11.2l/s.
[4]A sample calculation used to produce this graph is shown in Appendix B

Table 2: Parameter value for both the ideal and typical hot/cold aisle Data Centre conditions.

| Parameter | Ideal Value | Typical Value |
|---|---|---|
| Rack Type/Volume | 42RU Commercial / 430l/s | 42RU Class C / 400l/s |
| Supply air temp. | 16°C | 18°C |
| Underfloor Pressure | 15Pa | 0Pa |
| Resultant inlet air temp. | 22.5°C | 27.5°C |
| Allowable outlet air temp. | 40°C | 35°C |

Centre can support up to 9kW in a rack, the difficulty in creating and maintaining these conditions inevitably limits hot/cold aisle Data Centres to 4kW per rack. Even so, the ability to accommodate such loads was a major advancement from previously non-existent air management techniques. However, as Data Centres look to accommodate racks with heat loads upward of 10kW, it is evident that they must evolve from the traditional hot/cold aisle solution.

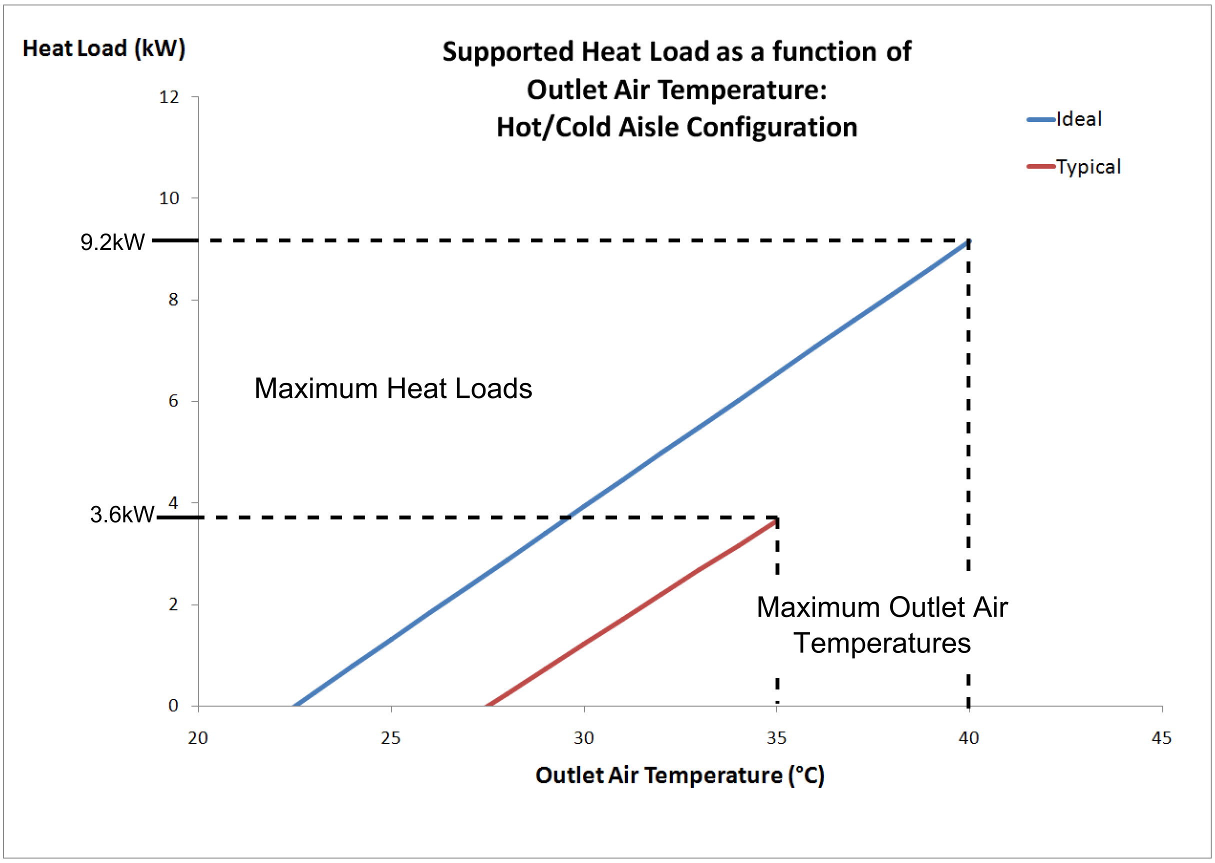


Figure 5: **The heat loads capable of being kept within healthy operating conditions in two rack environments: ideal Data Centre conditions (left) and typical Data Centre conditions (right), both in a hot/cold aisle configuration.**


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# 4 Fan assisted Cold Air Containment Solution

Fan assisted cold air containment solves three major pitfalls of a hot/cold aisle configuration:

1. ***The inlet air temperature is consistent and controllable via the underfloor air temperature.***
2. ***Removes the dependency on the underfloor pressure***
3. ***Removes the restriction on air flow and volume caused by perforated doors.***

Cold air containment in an existing raised floor Data Centre is achieved by extending the underfloor plenum into the front of the rack, creating a plenum in the front of the rack. A schematic of this is shown in Figure 6.

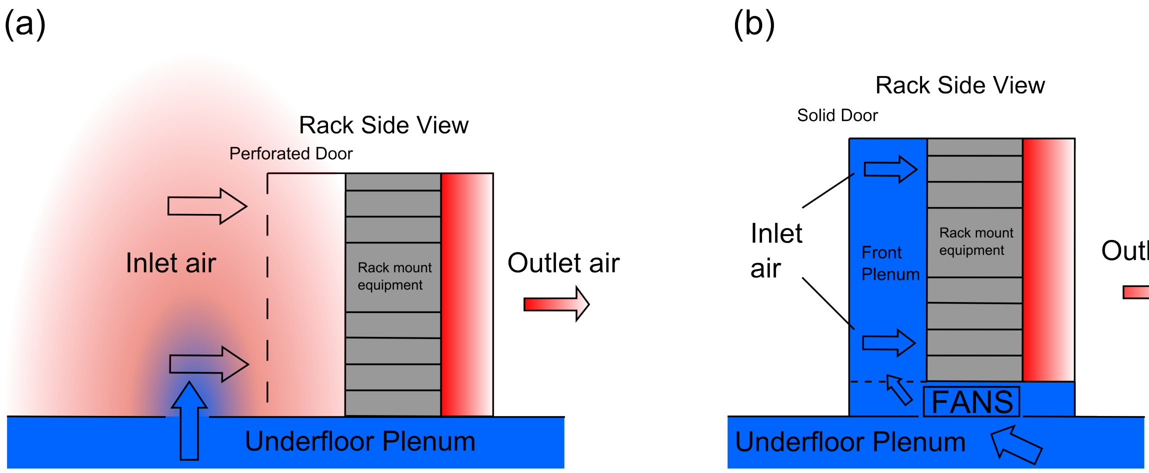


Figure 6: Schematic of the fundamental behavioural difference between a hot/cold aisle system (left) and a cold air containment system (right).



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In this scenario, vented floor tiles are replaced with solid tiles, while tiles underneath the rack are removed, leaving the bottom of the rack open to the underfloor plenum. This allows air to flow directly into the front of the rack, rather than into the ambient room. The perforated front door is also replaced by a solid front door to partition the inlet air from the air contained in the aisle. To assist with this process, fans located in the bottom of the rack increase the air flow and volume and to the front plenum. A product that utilises this solution is the SRA produced intelligent Plenum Air Management Module (iPAMM™).

The fan module increases the effectiveness of cooling by providing supplementary air to the servers, increasing the volume of air through the servers above the open air volume, as detailed in Table 3. As such, this solution can support increased heat loads compared to a hot/cold aisle configuration.

Table 3: Volume of air drawn through server for different door types

| **Rack Type** | **Volume** $(l/s)$ | **Percentage of open air volume** |
|---|---|---|
| Solid Door / Fan assisted | 500 | 105% |
| Open Air (No Restriction) | 475 | 100% |
| Commercial Grade | 440 | 93% |
| Class C | 400 | 85% |

The most significant advantage of this solution, however, is the consistent and constant supply of air to the inlet of the servers by the fan module, combined with the removal of dependency on underfloor $\Delta$P. These fans generate the same inlet air temperature across the vertical profile of the rack regardless of the underfloor pressure, as shown in Figure 7.

As can be seen, this solution provides a direct correlation between underfloor temperature and inlet air temperature regardless of underfloor pressure. More importantly, there is only a small amount of heat absorbed by air as it passes from underfloor to the inlet air stream, rendering it

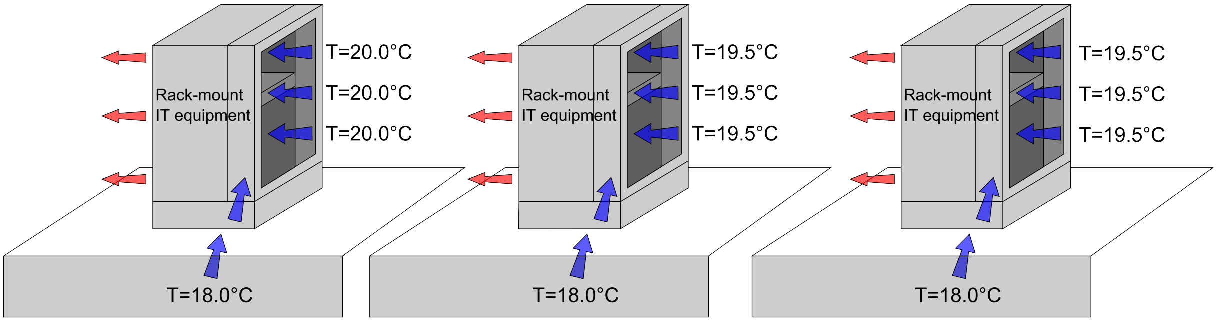


Figure 7: Performance of iPAMM$_{TM}$ Plus rack with a solid front door in a raised floor Data Centre. The three images show the vertical inlet air temperature profile for $\Delta P=0$ (left), 7.5 (centre) and 15Pa (right)

much more efficient than its hot/cold aisle counterpart. As this product makes use of a raised floor, it can be added to existing hot/cold aisle Data Centres with minimal infrastructure changes.

## 4.1 Environment in which Fan assisted Cold Air Containment is effective

As an example of the capabilities of this solution to improve on the performance of a hot/cold aisle configuration, take the example environments considered in Section 3.3, replacing the racks with iPAMMs. The updated conditions of each environment are detailed in Table 4.

The relationship between outlet air temperature and heat load for each scenario is shown in Figure 8[5]. Note that the trends begin at different points along the outlet air temperature scale in accordance with the inlet air temperature. For the maximum allowable outlet air temperature, the supported heat load is highlighted. This is the maximum heat load that the configuration

[5]A sample calculation used to produce this graph is shown in Appendix B

Table 4: Parameter value for both the ideal and typical hot/cold aisle Data Centre conditions.

| Parameter | Ideal Value | Typical Value |
|---|---|---|
| Rack Type/Volume | 42RU iPAMM / 500$l/s$ | 42RU iPAMM / 500$l/s$ |
| Supply air temp. | 16°C | 18°C |
| Underfloor Pressure | 15Pa | 0Pa |
| Resultant inlet air temp. | 18.0°C | 20.3°C |
| Allowable outlet air temp. | 40°C | 35°C |

is capable of supporting. In contrast to the hot/cold aisle performance, the iPAMM has a much higher maximum supported heat load under ideal conditions of above 13kW. Furthermore, the iPAMM$_{\text{TM}}$ improves on the performance of a typical hot/cold Data Centre, increasing the maximum supported heat load to ~9kW. On both fronts, the iPAMM drastically outperforms its hot/cold aisle counterparts. Therefore, as Data Centres look to accommodate racks with heat loads upward of 10kW, the iPAMM provides the ideal solution.

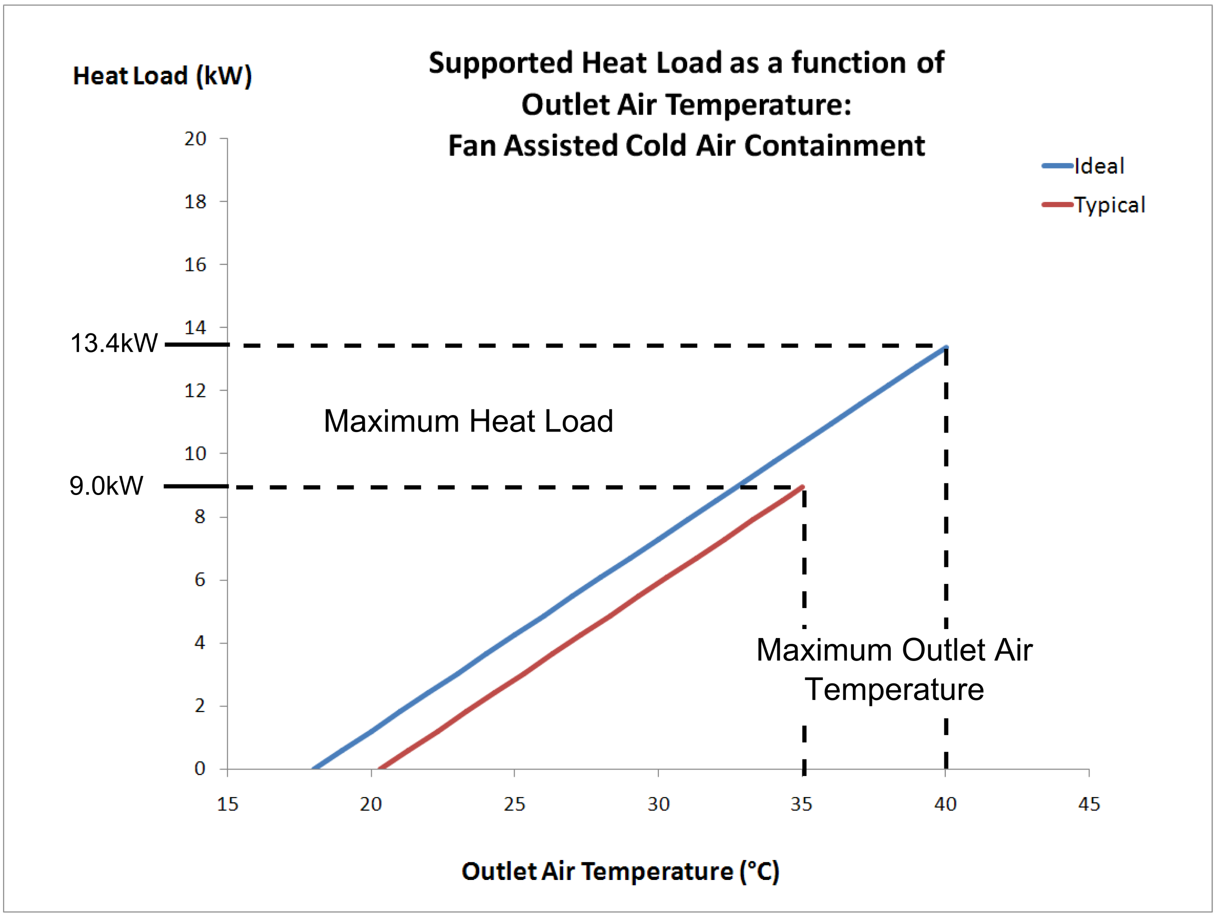


Figure 8: **The heat loads capable of being kept within healthy operating conditions in two rack environments: ideal Data Centre conditions (left) and typical Data Centre conditions (right), both in Fan assisted Cold Air Containment systems (iPAMMs).**

## 5 Conclusion

Data Centre cooling solutions have progressed rapidly in modern times in lieu of increased power densities in rack-mount computer equipment. The traditional hot/cold aisle cooling solution is realistically limited to heat loads of ~4kW due to the unstable nature of Data Centre conditions. Fan assisted cold air containment (e.g. the iPAMM™) is a more robust solution, realistically capable of cooling 9kW+ in a wide range of Data Centre conditions.

# 6 Appendix A: Experimental Set-Up

All data used throughout this paper was obtained through rigorous product tests conducted at Server Racks Australia in Queanbeyan, New South Wales. The testing environment consisted of a 300mm raised floor Data Centre, with a 20kW Liebert PEX CRAC Unit providing air to two fully equipped 42RU (600mm x 1050mm) SRA racks, of varying types (a third 42RU rack was located within the room, although no air was supplied to this rack so it had little bearing on the experiment outcomes). The test rack itself contained 10 *server simulators*, each consisting of a 4RU server chassis containing 3 fans and a variable resistive load (0-2kW). Each sever simulator was set to a heat load of $\sim$1kW, totalling a load of 10kW, when placed in the rack. The two remaining rack units where covered used blanking panels. The simulators' airflow was calibrated to a volume of 47l/s in accordance with flows measured through a variety of real servers. Given that any modern day server contains variable speed fans, their flow can vary between 50% and 100% of their rated flow, often dependant on an environmental setting within the server itself. There is, therefore, a large range of flows that a real server can achieve and thus a large range of flows to which the simulators can be calibrated.

In order to measure the performance of a particular rack type in a range of conditions, the underfloor $\Delta$P was varied using underfloor partitioning and fans. To measure different rack types, the rack containing the server simulators was converted between Class C, Commercial and iPAMM$_{TM}$ racks. The inlet air temperature was measured 50mm from the face of the simulator in four locations. The outlet air temperature was measured in 8 equally spaced locations on the rear door. The underfloor temperature was measured in two locations. Each experimental run was 24 hours in duration to ensure that the system was in steady state and no transient behaviour was witnessed. The experiment was constructed with variables defined as

A TREND Control Data Acquisition System was used to measure temperatures, pressures and

| Parameter | Dependant Variable | Independant Variable |
|---|---|---|
| Rack Type | | ✓ |
| Underfloor $\Delta P$ | | ✓ |
| Heat Load | | ✓ |
| Underfloor Temp. | ✓ | |
| Inlet Air Temp. | ✓ | |
| Outlet Air Temp. | ✓ | |

electricity consumption. The temperatures were measured using NTC Type thermistor with a published accuracy of $\pm 0.2°C$. The differential pressures were measured using a DPIA 2-Wire differential pressure transmitter, with a published error of $\pm 2.5$Pa. The electricity consumption (heat load) was measured with a TREND EM-MPO/STAR3DIN electricity meter with negligible error (as stated on the calibration data sheet).

# 7 Appendix B: Sample Calculation

Each environment had a defined underfloor temperature, underfloor ΔP and rack type e.g.

| Parameter | Value |
|---|---|
| Rack Type | 42RU Commercial |
| Supply air temp. | 16°C |
| Underfloor Pressure | 15Pa |

From the characteristic behaviour of the rack type in a Data Centre with these conditions, the inlet air temperature can be calculated. For the above example, the average inlet air, $T_{in}$, is calculated to be 22.5°C. The relationship between the outlet air temperature, $T_{out}$ and heat load, $Q_{max}$, is given by

$$Q_{max} = V \times C \times \Delta T_{out} - V \times C \times T_{in}, \tag{1}$$
$$= V \times C \left(T_{out} - T_{in}\right), \tag{2}$$

where $V$ is the volume of air passing over the heat load and $C$ is the volumetric heat capacity ($C = 1.218 \frac{kJ}{m^3 K}$). For the above example, assume that $V = 430 \frac{l}{s}$ and $T_{out}$=40°C (as we do in Section 3.3). The maximum heat load is therefore

$$Q_{max} = \frac{430}{1000} \times 1.218 \times (40 - 22.5), \tag{3}$$
$$= 0.524 \times 17.5, \tag{4}$$
$$= 9.16, \tag{5}$$
$$\approx 9.2kW. \tag{6}$$

Note that we have used $V$ in units of m/s in order to keep the calculation in SI units.