

# Server Rack Heat Dissipation in Next Generation In-Row Architectures

Server Racks Australia (SRA)

V1.2 White Paper #4





### **Executive Summary**

The modern environmental, or "green" movement of data centres has forced IT infrastructure providers to offer solutions capable of meeting more stringent requirements for energy efficiency, power density, adaptability and expandability. These increased requirements have led to the development of next generation data centre architectures based on the use of In-Row coolers. Next generation data centre architectures provide the flexibility and adaptability that traditional data centres lack, combined with targeted cooling, rather than room wide cooling. While as a whole, next generation data centre architectures provide gains in efficiency and effectiveness, different implementations can yield starkly different results. Through experimental testing of uncontained, Hot Aisle contained and Cold Aisle contained In-Row cooler based data centres, it was determined that the efficiency of air movement between the In-Row cooler and server inlet increased from 2% efficiency for an uncontained system, to 20% for Hot Aisle and 95% efficiency for a Cold Aisle containment configuration. Next generation data centre architecture provides solutions for many of the key limitations of traditional data centre architectures, increasing the load density, adaptability and expansion options for the modern data centre.

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# **1** Introduction

Rack mount equipment generates heat as a result of the processes it completes; the amount of heat a piece of equipment dissipates is approximately equal to the total electrical power delivered to it. This heat is absorbed by the ambient air in the server, and removed by airflows generated by fans within the equipment. A data centre must be constructed such that enough cool air is provided to the inlet of the equipment such that this heat can be absorbed without the equipment overheating, thus maintaining healthy operating conditions. A cooling system that satisfies this effective cooling requirement will perform optimally, reducing the mean time between failure (MTBF), hence reducing downtime and increasing server life. As such, initial (and now traditional) data centre architectures focussed solely on the provision of effective cooling, rather than efficient cooling.

Traditional architectures implement a room scale cooling solution, a primary example is a raised floor data centre. This typically involves only a few Computer Room Air Conditioning (CRAC) Units, located on the periphery of the room, that use fans to draw air from the ambient room, cool the air and distribute it to the inlet of the equipment. Due to the prevalence of air mixing between the hot and cold air streams, these architectures are limited to effectively cooling heat loads of only 3-5kW per rack with traditional racks, or 10-13kW per rack with next generation racks (iPAMM<sub>TM</sub>)<sup>1</sup>. As the power density of equipment increases in accordance with Moore's Law, heating requirements have quickly eclipsed the effective cooling capacity of traditional architectures. As such, next generation In-Row architectures are now implemented in data centres to effectively cool heat loads upward of 20kW per rack.

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 $<sup>^{1}</sup>$ For a discussion of these capabilities, including experimental results, see SRA White Paper #1: Server Rack Heat Dissipation using Fan assisted Cold Air Containment.



In-Row architectures are versatile and modular, allowing for cooling to be approached on a row or rack scale, with the capability to easily adapt this cooling solution throughout the life of the data centre in accordance with the data centre size, heat load etc. This architecture not only provides effective cooling for higher heat loads, but also much more efficient cooling.

This paper provides a qualitative comparison of traditional and next generation data centre architectures. It also describes and analyses some basic designs common to next generation architectures and details the environments in which these are effective and efficient.





# 2 Traditional Data Centre Architectures

The quantitative performance of traditional data centre architectures is not in the scope of this paper<sup>2</sup>, however it is important to understand the qualitative behaviour. A traditional architecture, as shown in Figure 1, relies largely on a well engineered hot/cold aisle design in order to be effective.





In this particular example, the CRAC Units on the perimeter of the room use fans to move large volumes of cold air into the underfloor plenum, keeping it at a positive pressure compared to the ambient room; this pressure forces the cold air through vented floor tiles located in front of the racks. The cool air is then drawn through the servers and expelled as hot exhaust air at the rear of

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 $<sup>^{2}</sup>$ For a discussion of these capabilities, including experimental results, see SRA White Paper #1: Server Rack Heat Dissipation using Fan assisted Cold Air Containment.



the rack. Despite the ability of this solution to provide cooling to low power density data centres, there are a number of problems associated with this design that prohibit its use in medium to high power density applications. These include:

### • Air mixing

There is no complete physical partition between the hot and cold airstreams, thus this architecture relies completely on airflows generated by the CRAC Unit, and to a lesser extent the server fans, to maintain separation. As both of these flows are highly variable and unpredictable, it is near impossible to keep the two airstreams separated. The resultant air mixing has a number of adverse effects, including:

- an increase in inlet air temperature, which reduces the capacity to do effective cooling,
- a decrease in return air temperature to the CRAC Unit, which reduces the operating efficiency, and
- hotspots in both the inlet and exhaust of the equipment.

#### • Flooding the cold aisle

As there is a tendency for hot exhaust air to mix with the cool inlet air, traditional data centre architectures rely on flooding the cold aisle with air to guarantee the supply air temperature to the equipment. This method is extremely wasteful, with some data centres supplying twice as much cool air as is required to effectively cool the equipment. This wastage significantly increasing data centre running costs as:

- the excess cool air reduces the return air temperature to the CRAC Units, which reduces their operating efficiency, and
- the CRAC Unit fans are forced to operate at a higher power than necessary to achieve effective cooling.

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#### • Inability to adapt to variable and increasing heat loads

As more racks are added to a data centre, or the power density of these racks increases, there is little scope for adaptability within a traditional architecture. Take, for example, a data centre that requires extra racks to be added. As more racks are added to the room, more vented floor tiles are introduced to the cold aisle, which reduces the underfloor pressure. This in-turn reduces the volume of cold air available to the servers, increasing the prevalence of air mixing, thus reducing the maximum heat loads supported by this architecture. On the other hand, if the number of racks is kept constant while their heat loads is increased (e.g. from 5kW to 15kW), the cooling capacity of this architecture cannot readily be increased to maintain healthy operating conditions. Instead, a complex solution can be retrofitted to increase the cooling capacity, however this requires drastic, and therefore costly, alterations to the data centre infrastructure. As such, these traditional architectures provide, for the most part, a static cooling solution.





# **3** Next Generation Data Centre Architectures

The next generation data centre architecture reduces and eradicates the shortfalls of the traditional architecture. These architectures employ cooling solutions on a row by row scale, or even a rack by rack scale, rather than on a room scale. This is facilitated by the removal of perimeter cooling, in the form of CRAC Units, and the replacement with In-Row coolers. These In-Row coolers are contained in a 300mm, 600mm or 900mm wide cabinet that fits directly into the rows of racks in the data centre. This arrangement is shown in Figure 2.



Figure 2: A typical next generation data centre architecture with In-Row cooling in a hot/cold aisle arrangement.

The coolers comprise fans that draw air directly from the hot aisle of the data centre, cool this air and expel it directly into the cold aisle. There are a number of advantages that this architecture has over its traditional counterpart, including:

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#### • Minimal air mixing

The abundant air mixing present in traditional architectures is reduced by decreasing the distance between the exhaust air and the return air of the cooler. As this air now only has to travel a small distance, it is less likely to recirculate into the cool air stream. Like-wise, the cool air is less likely to recirculate into the hot air stream, leading to more effective and more efficient cooling. The magnitude of this effect differs depending on the specific design used, as discussed in the following section.

#### • Reduced distance between the source of cool air and the equipment

The fans that distribute the cool air to the equipment are no longer located at the perimeter of the room, rather they are located directly adjacent to the racks. As such, a smaller fan power is required to move cool air into the inlet air stream, leading to energy savings and greatly reduced data centre costs.

#### • A modular and adaptable solution to heat load changes

The biggest advantage of this new architecture is its variable capacity that can provide effective cooling to low, medium and high power densities across a single data centre. The coolers have variable capacities (up to 74kW) that allow for the appropriately sized cooler to be matched with the capacity of the racks it is cooling. The one to one matching with the cooling requirements ensures money is not wasted on surplus cooling, while the modular nature of this design allows for a highly adaptable data centre that grows with ease. Take, for example, a row of racks within a data centre that has a power density of 10kW per rack, as shown in Figure 3. As can be seen, 20kW In-Row coolers are located between every second rack to provide 10kW of cooling to each of the racks adjacent to it. The future plan for this data centre, however, is to increase the power density of two of the racks to 20kW per rack. In a traditional data centre, there would be limited options to provide effective cooling to these racks and any solution would require a comprehensive and costly overhaul to data centre

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infrastructure. In contrast, a next generation architecture allows for another 20kW In-row cooler to be placed between the two racks that have increased in power density.



Figure 3: The process of growing a next generation data centre's cooling capacity with minimal infrastructure changes.

Figure 3 shows a solution that is implemented locally with no effect on other racks located within the row. As such, this next generation architecture solves many of the problems associated with traditional architectures.

There are a number of design variables in next generation architectures, namely containing the hot or cold air, or both. The next section describes the cooling efficiency obtained by implementing some of these design parameters.





### **4** The Efficiency of Next Generation Architectures

The efficiency with which next generation data centre architectures operate is heavily dependent upon the design implemented. The basic design involves the traditional Hot/Cold Aisle arrangement, where only the racks serve as a physical barrier between the two airstreams. This is the least efficient design as there remains a tendency for these two airstreams to mix (albeit a more localised effect than that in a traditional architecture), leading to reduced efficiency, effectiveness and hotspots. In addition, under this configuration the air from the In-Row cooler is blown directly in the opposite direction to the inlet direction of air into the equipment. The cold air must completely reverse its direction to reach the server inlet.

The efficiency of an uncontained In-Row data centre implementation was tested and found that despite a supply temperature of 15.4°C from the In-Row cooler, the inlet temperature on the rack was 20.1°C, only 0.1°C below the ambient temperature of 20.2°C. Thus, without physical partitioning to control airflow mixing the In-Row cooling system is only 2% efficient at transferring cool air from the In-Row cooler to the equipment inlet.<sup>3</sup>.

In order to control these airflows, the Hot or Cold Aisles can be contained (as shown in Figure 4 and 5). This containment provides a physical barrier preventing air mixing and limiting heat transfer to conduction or radiation through the barrier medium. However, when only one airstream is contained, the uncontained air will mix with the ambient room air, which is typically a different temperature.

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 $<sup>^{3}</sup>$ For a description of the experimental Set-up, see Appendix A. For a discussion of the expression used to calculate efficiency, see Appendix B.

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Figure 4: An example of containing hot air in next generation data centre architecture.



Figure 5: An example of containing cold air in next generation data centre architecture.



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| Test Configuration      | Supply (°C) | Inlet (°C ) | Ambient (°C) | Efficiency |
|-------------------------|-------------|-------------|--------------|------------|
| Uncontained (5kW)       | 15.4        | 20.1        | 20.2         | 2%         |
| Hot Contained (5kW )    | 15.8        | 18.3        | 18.9         | 19%        |
| Cold Contained (5kW)    | 15.2        | 15.6        | 27.3         | 97%        |
| Hot Contained (8-10kW)  | 18.0        | 18.6        | 19.2         | 50%        |
| Cold Contained (8-10kW) | 17.7        | 17.9        | 27.0         | 98%        |

### Table 1: Aisle Containment Test Results

Take, for example, a data centre with an inlet air temperature of  $20^{\circ}$ C and an exhaust air temperature of  $35^{\circ}$ C. The ambient room temperature may be close to  $25^{\circ}$ C or  $30^{\circ}$ C due to (but not limited to):

- External air entering the data centre
- People inside the data centre
- Data centre lighting
- Radiant heat from the racks

Therefore, the process of containing just the hot or cold air will leave the other airstream open for mixing with the ambient room air. In the case of containing the cold airstream, the hot air will mix with the ambient air and reduce in temperature, which reduces the operating efficiency of the cooler. Alternatively, by containing the hot airstream the cold air will mix with the ambient air and increase in temperature, reducing the capacity of the data centre to provide effective cooling.

Analysis of these two containment options was performed by reconfiguring the test data centre for both hot and cold aisle containment and running two test simulations, one with a lower load of 5kW per rack (comparable to the uncontained test) and one with a high load of 8-10kW per rack. The results of this testing is outlined in Table 1

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The testing shows the advantage of containing both the Hot and Cold Aisles over a basic uncontained system. The Hot Aisle containment results showed reduced server inlet and ambient temperatures with a slight increase in the supply temperature when compared to the uncontained test, with a drop of 1.8°C and 2.3 with a drop of 1.8°C measured at the server inlet and ambient respectively. These reductions in temperature for Hot Asile containment over the uncontained system increase the cold air transfer efficiency from 2 to 19% efficiency, a rise of 17%. In addition to the increase in efficiency, the Hot Aisle containment also increased the effectiveness of the data centre through the 1.8°C temperature drop at the server inlet. It may also be seen that when the rack heat load was increased from 5kW to 8-10kW that the efficiency of the Hot Aisle containment increased to 50%. This increased may be linked to two key variations. Firstly, it may be seen that due to the increased heat load, the supply temperature has increased, approaching that of the ambient air, reducing effect of air mixing. Secondly, the airflow from the In-Row cooler was increased from 45% to 100% of the fan speed, resulting in an approximately doubled cool airflow, thereby halving the expected temperature rise due to ambient mixing.

In comparison, the Cold Aisle containment may be seen to have significantly higher cool air transfer efficiencies of 97-98%, irrespective of the heat load and the fan speed of the In-Row cooler. This efficiency increase is combined with an effectiveness increase, as Cold Aisle containment recorded inlet temperatures of 2.7°C and 0.7°C below that of the Hot Aisle containment. Although providing more efficient and effective then Hot Aisle containment, it may be seen that a side effect of Cold Aisle containment is a significant increase in the ambient temperature. It increases from 18.9°C for Hot Aisle, 20.2°C for uncontained, to 27.3°C for the Cold Aisle containment due to the mixing of the Hot Aisle air with the ambient.

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# 5 Conclusion

There are a number of problems associated with traditional Data Centre architectures. Next generation architectures provide solutions to many of these problems by providing:

- reduced air mixing,
- a modular and adaptable solution to heat load changes, and
- cooling in close proximity to racks.

This paper is concerned mainly with air mixing and the effectiveness and versatility of the traditional and next generation architectures. There are also several other advantages to using next generation architecture, including:

- reduced time in engineering the Data Centre for contained systems as they are independent of the room,
- increased speed of deployment as the system is pre-engineered,
- redundancy in the coolers

Through experimental testing of In-Row cooling architectures several conclusions were drawn about the cool air transfer efficiency, effectiveness and limitations of uncontained, Hot Aisle contained and Cold Aisle contained configurations. The uncontained system resulted in the lowest effectiveness due to an inlet temperature of 20.1°C and worst efficiency of 2% due to air-mixing between the hot, cold and ambient airstreams. A significant improvement was shown through the containment of hot air stream with a 1.8°C increase in effectiveness and a gain in efficiency with values of 19% and up to 50% when the In-Row cooler fan speed and rack heat load was

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increased. This variation however shows that the efficiency of this configuration depends upon external variables and the flooding of the Cold Aisle due to heat transfer between the ambient and cold airstreams. The highest efficiency measured was that of the Cold Aisle containment configuration, with efficiencies of 97 and 98% where no variation with rack based load or In-Row cooler fan speed was detected. The most effective inlet temperature was also recorded with Cold Aisle containment with a  $4.5^{\circ}$ C increase in effectiveness compared to an uncontained system. The effectiveness of each configuration is proportional to their efficiency, with an uncontained system providing  $20.1^{\circ}$ C air, while the hot containment configuration resulted in  $18.2^{\circ}$ C inlet air with the cold aisle containment resulting in the most effective  $15.6^{\circ}$ C air supplied to the rack inlet. None of these solutions are 100% efficient, however it is possible to combine the best attributes of each. Hot and Cold Aisle containment would provide the independent effectiveness and efficiency of a contained Cold Aisle with the low and now independent ambient temperature of a contained Hot Aisle, thereby prevent air mixing and providing the most effective and efficient cooling.





### 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 Data Centre with a 30kW Stulz Chilled Water I-Row cooler providing air to two fully equipped 42RU (600mm x 1050mm) SRA racks with standard Class C perforated front and rear doors. A third 42RU rack was located within the room with a load of  $\sim$ 3kW to provide more heat to the room. The two test racks contained 5 *server simulators* each, with each simulator consisting of a 4RU server chassis containing 3 fans and a variable resistive load (0-2kW). The remaining unused vertical space within the rack was covered using blanking panels. The simulators' airflow was measured at a volume of  $\sim$ 60l/s in accordance with flows measured through a variety of real servers for a 2kW load. 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 compare the efficiency of each containment option, two test situations were compared. The first situation allowed the direct comparison of uncontained, Hot Aisle contained and Cold Aisle contained configurations, the second allowed for high rack load comparison of Hot and Cold Aisle containment. In the first situation the server simulators were set to a heat load of  $\sim$ 1kW, totalling a load of 5kW per rack. This limited test was required given dangerously high heat levels developed within the room during a validation run with no containment. The second situation involved two test racks, one with a 10kW heat load with the second with an 8.2kW heat load. This allowed for comparison and analysis of high rack load cooling performance.

In order to measure the efficiency of a particular In-Row arrangement, three temperatures were measured: the ambient room temperature, the supply air temperature and the inlet air temper-

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ature with a total of 12 thermal sensors. This data was used in conjunction with the expression for efficiency detailed in Section 7. The inlet and supply air temperatures were measured using 4 thermal sensors each, one at a distance of 300mm from the floor, then 3 evenly spaced at 500 mm intervals up the door. Each sensor was placed external to the door, centred horizontally within the perforated region. The ambient temperatures were measured at corresponding heights in the centre of an isolated section of the data centre, thereby limiting air disturbance due to the In-Row cooler. Containment was simulated using shaped cardboard shells around the front or rear of the racks and In-Row cooler using a double layer corrugated cardboard. Each experimental run was until a steady state was achieved to prevent transient effects altering the outcome.

A TREND Control Data Acquisition System was used to measure temperatures and electricity consumption. The temperatures were measured using NTC Type thermistor with a published accuracy of  $\pm 0.2^{\circ}$ C. The electricity consumption (heat load) was measured with a TREND EM-MPO/STAR3DIN electricity meter with a maximum error of 0.3% on the Active Power.

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# 7 Appendix B: Derivation of Cool Air Transfer Efficiency

The cool air transfer efficiencies quoted throughout this paper were calculated from the following efficiency expression:

$$Efficiency = 100 \times \frac{T_{Ambient} - T_{Inlet}}{T_{Ambient} - T_{Supply}}$$
(1)

Where  $T_{Ambient}$  is the ambient room temperature,  $T_{inlet}$  is the inlet air temperature in the rack, and  $T_{Supply}$  is the supply air temperature of the In-Row cooler.

The efficiency calculated from this expression is approximately representative of the percentage of air from the In-Row cooler entering the rack. For example, when the inlet air is made up completely of ambient room air and no In-Row cooler air, we have

$$T_{Inlet} = T_{Ambient} \Rightarrow T_{Ambient} - T_{Inlet} = 0$$
<sup>(2)</sup>

$$\therefore \textit{Efficiency} = 100 \times \frac{T_{Ambient} - T_{Inlet}}{T_{Ambient} - T_{Supply}} \tag{3}$$

$$= 100 \times \frac{0}{T_{Ambient} - T_{Supply}}$$
(4)

$$= 0\%.$$
 (5)

On the other hand, when the inlet air is made up completely of In-Row Cooler air and no ambient room air, we have

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$$T_{Inlet} = T_{Supply} \Rightarrow T_{Ambient} - T_{Inlet} = T_{Ambient} - T_{Supply}$$
(6)

$$\therefore Efficiency = 100 \times \frac{T_{Ambient} - T_{Inlet}}{T_{Ambient} - T_{Supply}}$$
(7)

$$= 100 \times 1 \tag{8}$$

$$= 100\%.$$
 (9)

The percentages scale linearly between these upper and lower bounds.