



COOLSHIELD WHITE PAPER

# IMPROVING DATA CENTER EFFICIENCY AND CAPACITY WITH AISLE CONTAINMENT

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## EXECUTIVE SUMMARY

Data centers have experienced explosive growth in the last decade. For many, the amount and type of equipment that must now be supported by the data center power and cooling infrastructure is approaching or exceeding its capabilities. Additionally, there is rapidly increasing focus on reducing energy costs and maximizing efficiency within data centers due to the economy, green initiatives and regulatory oversight.

Aisle containment is an innovative solution that can help address these challenges. However, data center managers and executives have little information available to help identify the proper use and configuration of various aisle containment concepts and systems, or to accurately project the long term financial impact of such implementations. Additionally, there is no universally accepted best practice for implementing aisle containment systems, and unbiased information related to them is rare.

This report will provide greater clarity and understanding of the concepts of aisle containment, as well as providing clear, unbiased guidelines for designing an appropriate aisle containment system for a given environment. Additionally it will explore the financial benefits of aisle containment from both an ROI and Green Initiative perspective.

## OVERVIEW

Since the advent of the hot aisle / cold aisle concept in the mid 1990s, data center managers have become much more aware of the impact of mixing hot and cold air in the data center. However, in the last few years, increasing demand on data center infrastructure has begun to push the limits of the efficiency previously gained through implementation of the hot aisle / cold aisle concept. Although many data center managers are confronted by this challenge, very few have the luxury of being able to completely redesign their existing data center to overcome it. More often, data center managers are being asked to support increasing cooling loads utilizing the existing data center design and cooling infrastructure, which in many cases was designed at a time when such loads were unthinkable. The average data center in operation today was designed to support loads ranging from 3kW to 5kW per rack. Yet, in many cases data center managers are now being asked to support loads up to 20kW per rack using their existing infrastructure.

One of the main challenges presented by increasing the server density in a data center is the increase in the amount of heat produced by the server equipment. In most data centers, this heat is exhausted directly into the room where it can mix with the cool air being supplied to the servers. This increases the temperature of the cooled air, which then raises the temperature of the exhaust air, in a cycle that can result in dangerous overheating of equipment and unplanned downtime. This mixing of air also wastes energy due to overuse of the cooling systems. Data Center CRAC units are frequently set to supply air up to 15 degrees colder than what is required by the load, in order to offset the effect of mixing the supply and return air in the room. Additionally, CRAC units frequently draw in return air that is not as hot as the server exhaust due to this mixing. In this scenario, known as short cycling, a measurable portion of the heat energy never leaves the room and CRAC unit capacity is wasted.

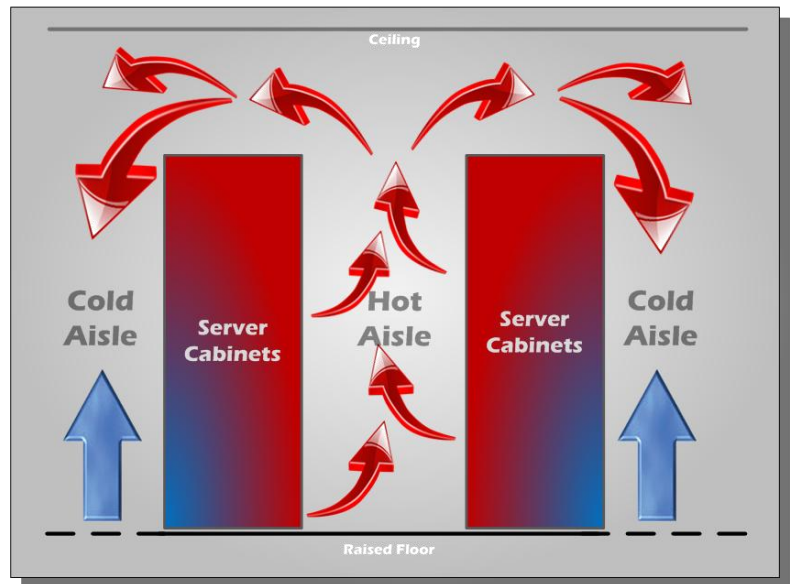


Figure 1: Hot Exhaust air mixing with cooled air in Cold Aisle

Recently the concept of aisle containment began to take hold as a viable tool to help address these challenges. Aisle containment works to increase the efficiency and capacity of a data center by physically separating the hot air and cold air in the data center through the use of a partitioning apparatus. There are several different approaches to aisle containment, and also several different types of products that can be used to create these containment systems.

## HOT AISLE CONTAINMENT

Hot aisle containment systems (HACs) force all the heat from the server exhaust to travel directly back to the returns on the cooling units, while preventing it from mixing with the supply air. Typically, the area above the racks is enclosed via a horizontal partition and both ends of the aisle are enclosed with vertical partitions. A sealed door may be installed in one or both ends to facilitate access into the aisle. In room based cooling environments, a duct system directs the exhaust air to one or more CRAC units directly, or more commonly, through the use of a shared return plenum. In environments that utilize in-row cooling, the exhaust air in the containment is recycled directly into the in-row cooling units in that aisle.

With HACs, the cooled air is unrestricted and flows throughout the room. This has advantages and disadvantages which will be discussed later in this report. Figure 2 depicts a typical HAC system.



Figure 2: A typical Hot Aisle Containment system

## COLD AISLE CONTAINMENT

Cold aisle containment systems (CACs) force a greater concentration of the cooled supply air from the CRAC units to stay within direct proximity of the air intakes of the critical equipment, while preventing it from mixing with the heated exhaust air. Typically, the area above the racks is enclosed via a horizontal or vertical partition and both ends of the aisle are enclosed with vertical partitions. A door may be installed in one or both ends to facilitate access into the aisle. These doors may be equipped with an automatic release mechanism to open the doors in the event of a disruption in cool air supply, to allow the servers to intake room air until the cooled air supply is restored. With CACs, the cooled air is restricted and flows only within the containment area, while the exhaust air may flow throughout the room. This also has advantages and disadvantages which will be discussed later in this report.



Figure 3: Cold Aisle Containment using vinyl strips

## CHOOSING THE RIGHT SOLUTION

Several major cabinet manufacturers have begun to offer containment solutions that are designed specifically to work with their cabinet products. However, there is no unanimous agreement among them as to which type of containment is the best practice. Consequently, some offer Hot Aisle Containment solutions while others offer Cold Aisle Containment solutions. Although consumers of a particular manufacturer's cabinets may benefit from the tight integration of that manufacturer's matching containment solution, there is no guarantee that it is the right solution for that particular room. In addition to these integrated solutions, a number of third party manufacturers have developed containment solutions that work with most types of cabinets and that can be used in either the hot aisle or the cold aisle.

Each data center is unique, and should be evaluated without bias toward a particular solution. In some cases, air flow disruption caused by the incorrect use of aisle containment can create more problems than it solves. It is therefore strongly recommended that data center managers employ the assistance of a qualified independent design consultant or mechanical engineer when evaluating potential solutions to these cooling challenges.

The fundamental difference between Hot Aisle Containment and Cold Aisle Containment is their respective abilities to increase efficiency and capacity in a particular type of data center. In many rooms, either solution would offer a measurable, although not equal, improvement in cooling capacity. However, the characteristics of the room will largely determine which solution will be most effective.

Real world testing in combination with computational fluid dynamics modeling of various data center environments reveals characteristic traits of each solution that can guide data center managers in their selection.

## HOT AISLE CONTAINMENT SOLUTIONS

Hot Aisle Containment solutions are based on the principle of separating heated air from the room and directing it back to the cooling units. This allows the room to be free from the effects of mixing air, and allows the cooling system to be run at a higher set point. Since the delta between intake air and exhaust air of servers can be 30°F or more, setting the temperature of the supply air to 72°F (the ASHRAE TC 9.9 standard) will yield exhaust air that approaches 102°F. Since the exhaust air is contained in the HACs, this increased exhaust temperature has no effect on the temperature in the room. However, it does have a desirable effect on the efficiency of the cooling units. Since the exhaust air will not mix with cooler air as it returns to the cooling units, it will remain at or near its maximum temperature when it reaches them. The hotter the return air is at the intake of the cooling unit, the more efficient the heat exchange within the cooling unit will be. The cooling unit will remove more heat per kilowatt of power it consumes. In a typical room without containment, achieving this highly efficient 30° F delta between the intake air and the cooled air at the cooling unit would be extremely difficult. On average, the maximum practical delta is typically 15° F - 20° F without containment.

The most significant benefit of this type of containment is an overall increase in cooling efficiency, which translates into reduced operational costs. While there is an increase in overall cooling capacity that results from HACs implementations, they do not address one of the most significant factors for increasing server density, which is providing increased cooled air flow volume to the servers.

HACs are most cost-effective in environments where in-row cooling is used as opposed to typical “room based” cooling. This is due largely to the fact that the need for extensive duct work and return plenums is eliminated. In typical environments with room based cooling, maximum effectiveness of a HACs solution can be achieved only if all hot aisles are contained. Since they are designed to increase overall cooling system efficiency, HACs are not generally effective as a spot fix for a particular aisle unless the aisle utilizes dedicated in-row cooling.

Additionally, in ducted hot aisle containment systems, careful consideration must be given to devices that exist outside the containment area, such as free standing mainframe or storage equipment, to assure proper heat removal for these devices.

### COLD AISLE CONTAINMENT

Cold Aisle Containment solutions are based on the concept of maintaining the separation of the cooled air from the warmer room air and directing it to the air intakes on the critical equipment. This effectively makes the cold aisle an extension of the under-floor plenum. In a typical raised floor environment without containment, the cooled air mixes with the room air immediately upon passing through the vented tiles. The temperature of the cooled air begins to rise as it makes its way to the air intakes on the critical equipment. In some cases, the temperature can rise more than 10° F by the time it travels from the floor to the critical equipment near the tops of the cabinets. For this reason, most cooling units are set to deliver air that is up to 15° F colder than the ASHRAE TC 9.9 recommendations, in order to assure that the air delivered to the critical equipment falls within those recommendations. This is a significant loss of efficiency. Additionally, without containment the air will travel in all directions equally, throughout the entire room. Leading industry experts have estimated that over 40% of the cooled air produced by the cooling units never reaches the air intakes on the servers at all. This essentially wastes nearly half the power, and therefore money, used on cooling in the data center. Additionally, it significantly diminishes the available cooling capacity in each row, limiting how much power can be deployed there.

By containing the cold aisle, data center managers can control and manage the cooled air flow directly to the air intakes on the critical equipment where it will provide its maximum benefit. Since there is no mixing of the exhaust air and the supply air, the temperature distribution throughout the contained aisle is consistent with the temperature under the floor, allowing data center managers to maintain ASHRAE recommended set points on the cooling units. This avoids the over-cooling problem that is common in most data centers.

The most significant benefit of cold aisle containment is increased cooled air flow to the critical equipment, enabling higher densities within the racks. While CACs do improve overall cooling system

efficiency, they are less effective at this than HACs are, due to the fact that they do not control how the heated air returns to the cooling unit. Since the cold aisle is contained, no cool air reaches the room itself which increases the ambient temperature of the room. In some cases, the room temperature could easily exceed human comfort levels. Attempting to overcome this effect by cooling the room with additional perforated tiles or auxiliary coolers will diminish the efficiency of the CRAC units, thereby diminishing some of the efficiency gains of the CAC system. Additionally, non-contained free standing critical equipment such as large storage arrays, mainframe equipment, and telecommunications equipment, may be adversely affected by the increase in ambient room temperature.

For this reason CACs are most effective in environments where increased server density takes priority over cooling system efficiency and also in situations where a localized solution may be needed to increase rack density in a particular area of the data center. Careful analysis should be performed prior to implementing a localized aisle containment solution to avoid introducing negative disruptions to the room’s air flow dynamics.

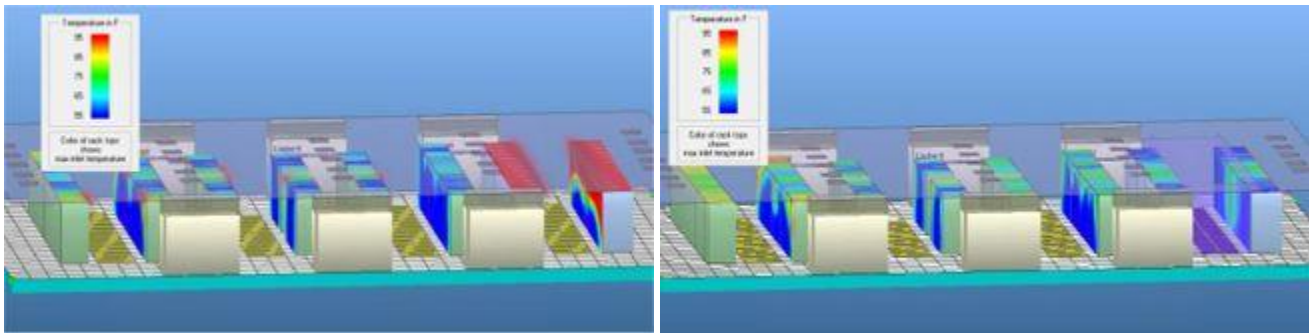


Figure 4: On the left, a thermal illustration of a room that includes one aisle of high density 12kW racks without Cold Aisle Containment. On the right is a depiction of the same room after CACs has been installed on that aisle only. Note that the problem area has been addressed without negatively impacting other areas of the room.

## COMPLETE CONTAINMENT SOLUTIONS

In an effort to realize the benefits of both solutions, some data center managers may deploy containment on both the cold aisle and hot aisle. While this is possible, it can be more challenging to manage than either HACs or CACs are by themselves, due to the dynamics of air flow in the space. If imbalances exist between the amount of air that is being supplied and the amount of air that can be evacuated through the returns, either a buildup of static pressure or a vacuum can develop that could affect the air flow through the critical equipment. When only one type of containment system is used, the room itself helps to equalize any pressure differentials that exist. A computational fluid dynamics model of the proposed solution can reveal potential problems prior to installation, so that adjustments can be made in the planning stages to avoid this.

Careful consideration should also be given to freestanding devices that are not housed within the containment. If such devices exist and generate significant heat in the room, there would be no mechanism to remove this heat, due to the presence of the HAC system. Aside from that situation, the area

outside of the containment systems is less likely to experience temperature extremes, since the ambient room temperature is not affected by either the cold or hot aisles. However, perforated tiles can sometimes be placed strategically in the uncontained space to manage the ambient room temperature for small freestanding devices and for the comfort of the human occupants of the room. When properly designed and managed, this configuration can provide both maximum density and maximum cooling efficiency.

**PERFORMANCE**

The following data presents average results to be used as a guideline for performance expectations, based on published real world testing results performed in actual data center environments, along with computational fluid dynamics modeling of common data center configurations. It reveals dramatic increases in capacity and efficiency resulting from the implementation of CACs and HACs solutions. Naturally each data center is unique and actual results will vary, sometimes widely, from these performance guidelines.

Table 1: Aisle Containment Efficiency & Capacity

	No Containment	Hot Aisle Containment	Cold Aisle Containment
<b>Maximum Practical Power Density per rack –Room Based Cooling</b>	5 kW	10kW	16kW
<b>Maximum Practical Power Density per rack - In-Row Cooling</b>	8kW	20kW	16kW
<b>Cooling Unit Efficiency – (kW of energy consumed to cool 1 kW of heat)</b>	0.92kW (92%)	0.42kW (42%)	0.50kW (50%)

\*\*1 Ton is equal to 3.516 kW of energy (heat)

To realize the impact of the data in the table above, consider that based on these figures, a data center manager could increase his server density from 5 kW per rack to over 10kW per rack with no OpEx or CapEx increase in cooling costs, just by implementing a properly designed aisle containment system. Conversely, in certain circumstances, a data center manager could reduce his cooling costs significantly by implementing aisle containment in their existing environment without increasing density. These cost reductions result from the reduction in the number of active CRAC units required to cool the equipment, the ability to increase set points on the active CRAC units, and the overall increased cooling efficiency. Data Center Managers that are planning new data centers or expansions to existing facilities can utilize aisle containment to help reduce the number of active cooling units required for the new space, potentially reducing project costs significantly.



This data is also supported by computational fluid dynamics modeling. In the illustrations below, we see a small raised floor room which contains 320kW of equipment ( 32 10kW Racks) being cooled by three typical 26 ton CRAC units with a 55°F set point. The total cooling capacity of these CRAC units is 250kW which is only 78% of the “required” cooling capacity for the load. This demonstrates the effect of increased server density demands over-burdening existing infrastructure.

In Figure 5 we see the room without containment. The image shows the temperature throughout the room at a height of approximately 5 feet. Note that the temperature range is 60°F to 157°F. This CFD image illustrates the expected result of a severely under-cooled room. Temperatures have spiraled out of control, with average temperatures well over 120°F in the cold aisle, and areas exceeding 150°F within the room. These temperature extremes would be intolerable to the equipment, the fire suppression system, and most importantly, the human occupants of the room.

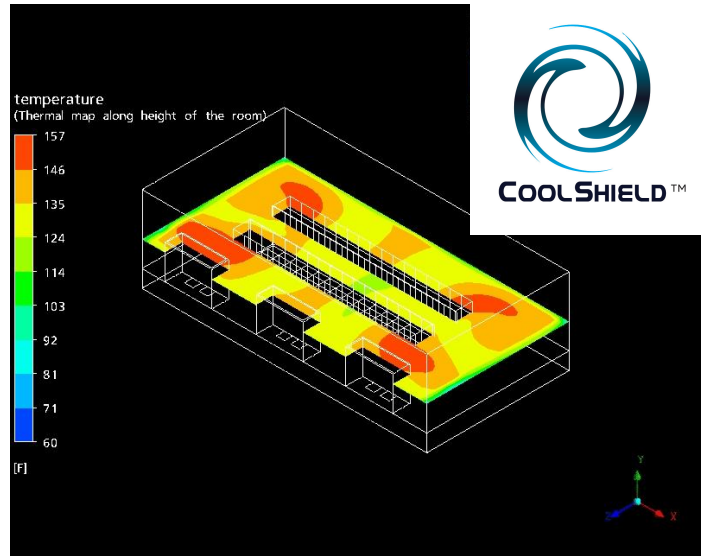


Figure 5: 32 10kW racks with No Containment

In Figure 6, we see the same room, with the only difference being the installation of Cold Aisle Containment. Note that the temperature range is 55°F to 95°F, a much narrower range than in Figure 5 above. At a height of approximately 5 feet, the temperature within the contained aisle remains below 64°F while the temperature at the inlet of the CRAC units is nearly 90°, a delta T of nearly 30°F. In this example, simply adding containment increased cooling capacity by thirty percent with no increase in energy consumption or operational costs (OpEx), and no additional cooling infrastructure other than the containment system (CapEx).

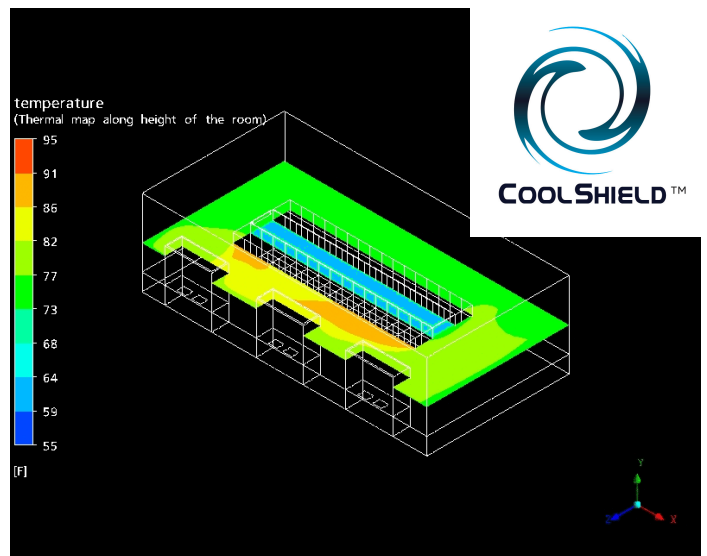


Figure 6: 32 10kW racks with Cold Aisle Containment



**DESIGN CONSIDERATIONS**

In order to determine if an aisle containment system will be beneficial in a given environment, data center managers should give careful consideration to the following:

<p><b>Is this a new data center build-out or an existing facility?</b></p>	<p>New Facility designs allow for installation of cooling infrastructure that is optimized for use with Aisle Containment</p>
<p><b>Is the floor a plenum raised floor or slab?</b></p>	<p>Cold Aisle Containment holds an advantage over Hot Aisle Containment in Raised Floor Plenum environments, while Hot Aisle Containment is typically preferable in non-plenum environments.</p>
<p><b>Does the data center support freestanding equipment outside of the contained area such as mainframe equipment or storage appliances?</b></p>	<p>Proper attention should be given to cooling these devices when containment is being used elsewhere in the room.</p>
<p><b>Is there a return plenum in the room?</b></p>	<p>The presence of a return plenum can help maximize efficiency of hot aisle containment.</p>
<p><b>If required by local fire code, can existing fire suppression systems be extended into the contained area?</b></p>	<ul style="list-style-type: none"> <li>• Fire Suppression studies are currently being conducted on the effectiveness of existing unmodified gas based room level fire suppression when containment systems are introduced into the room.</li> <li>• The use of fusible link technology to cause the aisle containment panels or strips to drop out of the way prior to gas or sprinkler system activation has been approved in some areas and is growing in both use and acceptance.</li> <li>• However, the best defense is the installation of fire detection and suppression within the contained space.</li> </ul>
<p><b>Will human occupants react negatively to somewhat increased temperatures in the “white space” areas of the room?</b></p>	<ul style="list-style-type: none"> <li>• Cold Aisle containment increases ambient room temperature outside the contained area</li> <li>• When working as designed, these temperatures can be quite warm.</li> </ul>
<p><b>Each type of containment system has strengths and weaknesses that need to be carefully evaluated prior to selecting one.</b></p>	<ul style="list-style-type: none"> <li>• Data Center Managers should strongly consider employing a cooling consultant to perform a computational fluid dynamics analysis of the space to determine the impact of implementing a containment system in a specific room.</li> <li>• Implementation of containment systems can cause undesirable and unanticipated effects in other areas of the room.</li> </ul>

**ECONOMIC ANALYSIS**

**POWER USAGE EFFECTIVENESS (PUE) & DATA CENTER INFRASTRUCTURE EFFICIENCY (DCiE)**

The Green Grid’s Power Usage Effectiveness ( PUE) and Data Center infrastructure Efficiency ( DCiE) efficiency benchmarks have become the industry standard for measuring power efficiency in data center operations. These metrics use slightly different calculations to reveal the relationship between the power consumed by the critical load as opposed to the overall power required to operate the data center. PUE expresses critical load as a factor of the total load, by dividing the total power consumed by data center operation by the power consumed by the critical load. DCiE expresses critical load as a percentage of the total load. Therefore, with PUE, a lower number indicates a more efficient operation, whereas with DCiE, a higher percentage indicates a more efficient operation. The Green Grid has indicated that a PUE of 1.2 would indicate a very efficient rating, while the industry average is approximately 2.5. The Green Grid has also identified that a DCiE of 83% represents a very efficient rating, while the industry average is 50%.

Given those parameters, we can extrapolate the impact of aisle containment on PUE and DCiE. Assuming a scenario where three data center managers are building three identical data centers, with the only difference among them being the presence ( or absence) of aisle containment, the following table represents the likely PUE and DCiE ratings for their respective data centers.

This table also assumes that the cooling infrastructure in each data center was sized and designed to work optimally with the aisle containment solution implemented.

Table 2: Aisle Containment Impact on PUE and DCiE

	Without Containment	Hot Aisle Containment	Cold Aisle Containment
<b>Total IT Load (kW)</b>	100	100	100
<b>Cooling Infrastructure ( kW)</b>	92	42	50
<b>Power System Load (kW)</b>	25	20	20
<b>Lighting Load (kW)</b>	2	2	2
<b>Total Facility Load (kW)</b>	219	164	172
<b>PUE</b>	2.19	1.64	1.72
<b>DCiE</b>	45.66%	60.98%	58.14%

Given the results above, we see that aisle containment can provide a very significant improvement toward reaching optimal efficiency as measured by PUE and DCiE.

## TOTAL COST OF OWNER SHIP (TCO)

Aisle containment solutions have a low TCO . They require little maintenance and have no operational costs in and of themselves. Failure rates are extremely low. However they do impact TCO of the systems they are designed to influence. The presence of more consistent and reliable cooling decreases the mortality rate of critical equipment components, and the increased efficiency of the cooling units provides increased performance and value for the operational costs of those components. Therefore TCO of the aisle containment solution typically is limited to the capital expenditure of the containment components, the installation costs, and the costs associated with any required modifications or additions to the fire suppression systems, while TCO of the critical equipment and cooling infrastructure is improved.

## RETURN ON INVESTMENT (ROI)

Given the industry average of \$1000 per kW per year as a typical data center operating energy cost, and a total implementation cost of \$125 per linear foot for the aisle containment solution, we can extrapolate ROI in a typical scenario as follows.

Assumptions:

1. 10,000 sq ft facility with 400 24" racks arranged in 20 rows ( 20 racks per row), with ten 4 ft aisles
2. Average of 10 kW per rack, totaling 4000kW of critical load
3. Total facility power consumption of 8,682kW prior to installation of aisle containment
4. Complete (Hot and Cold) Aisle Containment is implemented resulting in a 42% overall increase in cooling efficiency.
5. The increased efficiency results in a 1,860 kW reduction in total power consumption.
6. Total cost of Aisle Containment equipment & installation is \$110,000.00
7. Total cost of fire detection and suppression modifications is \$150,000.00

At \$1000 per kW per year, a \$260,000 (cost of aisle containment + cost of fire suppression modifications) investment to reduce power consumption by 1860 kW would result in a total return of investment in 51 days. Further, it would reduce annual operating energy costs by \$1,860,000.00 or 21.4%.

## CONCLUSION

Aisle containment solutions have emerged as a significant tool data center managers can employ to increase efficiency, density, and overall capacity in the data center. With careful planning and effective installation, aisle containment solutions can reduce operating costs, improve PUE, and lengthen the life cycle of the data center.