Containment's Role in Energy Efficiency and Rapid ROI

SUBZERO / WHITE PAPER

By Gordon Johnson

INTRODUCTION

Everyone today is interested in saving money, and that's especially true in data centers. Between the cost of electricity and the increasing trend for higher power densities per rack (20 kW and above is no longer uncommon), the desire to be energy efficient and to reduce cost on the annual utility bill is a major concern throughout the data center industry.

So what can be done to save energy and thus save money? How can we lower our PUE *(Power Usage Effectiveness)* while increasing energy efficiency without sacrificing reliability? What technology will deliver a rapid ROI, often between 6 and 18 months? Containment is the answer.

How does containment provide energy savings for data centers? Is there a way to estimate the annual savings and PUE for containment installations? This White Paper will provide an answer to these questions while discussing the following topics:

- Current Data Center Power Consumption Trends and Forecasts
- Containment's Vital Role in the Data Center
- Bypass Air, Recirculation Air, and Once-Through Cooling
- PUE *(Power Usage Effectiveness)*
- Server Inlet Temperature's Role in Energy Efficiency
- Estimating Annual Cost to Operate a Data Center
- Data Center Without Containment
- Cold Aisle Containment Versus Hot Aisle Containment
- Data Center With Cold Aisle Containment
- Data Center With Hot Aisle Containment
- Full Containment Versus Partial Containment
- Estimated Savings With Full Containment

CURRENT DATA CENTER POWER CONSUMPTION TRENDS & FORECASTS

Data Center power consumption for 2016 was estimated at 416.2 TWh *(terawatt hours)*, which equates to approximately 3% of total global electricity demand, with some believing this figure and usage to be on the conservative side. To put this consumption into perspective, the 416.2 TWh of electricity used in 2016 was significantly higher than the UK's total consumption of about 300 TWh[1]. With experts forecasting large future increases in data center power consumption, the need to operate efficiently is more important than ever.

CONTAINMENT'S VITAL ROLE IN THE DATA CENTER

With rising data center costs, including the increasing cost of electricity, containment is now considered an integral component of any data center. Just like you wouldn't think to design a data center without the standard hot/cold aisle configuration, neither should you think about designing or operating a data center without containment. Containment separates the cold supply and hot exhaust air, preventing them from mixing and moving freely at will throughout the data center. This separation of air improves data center efficiency by increasing the cooling capacity and energy efficiency of the cooling units.

With containment, the data center makes increasingly efficient use of the same or less cooling, which in turn reduces the cooling portion of the total energy bill. This often results in being able to power down one or more CRAC units, which saves energy and maintenance costs *(the acronym CRAC is used throughout this paper regardless if referring to a Computer Room Air Conditioner or a Computer Room Air Handler)*. Containment also allows for higher allowable temperatures in the data center. Higher temperature data centers save more money due to lower fan speeds, increased temperatures in chilled water, and increased use of free cooling[2].

As can be seen from the previous paragraph, containment saves money, big money! According to the U.S. EPA, containment can reduce fan energy consumption by up to

25% and deliver 20% savings at the cold water chiller. Further, it makes running racks at high densities more reasonable so that data centers can include new IT equipment such as blade servers. Data center containment brings the power consumption to cooling ratio down close to a 1 to 1 match in kW consumed, meaning containment can save a data center approximately 30% of its annual utility bill without adding additional CapEx *(Capital Expenditures)*[3]. That means that most data centers installing full containment will see a very fast ROI, after that it's money in the bank!

And the benefits don't stop there. Besides energy bill savings, IT equipment reliability increases since containment provides consistent uniform inlet air temperature from the bottom to the top of the racks, which results in eliminating hot spots in the data center. This means increased up-time and longer hardware life or mean time between failures *(MTBF)* for the servers. Once hot spots are eliminated, rack power density can often be increased due to more power available for the IT equipment.

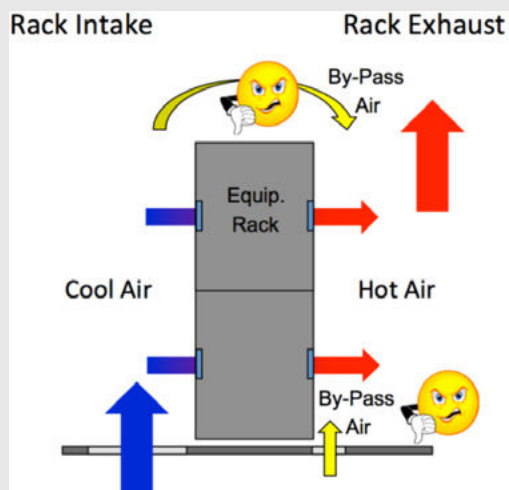## BYPASS AIR, RECIRCULATION AIR, AND ONCE-THROUGH COOLING

FIGURE 1: BYPASS AIR
Graphics courtesy of DCEP Training Program[4]

In order to have an efficient and reliable data center, it's important to understand bypass air and recirculation air and the negative impact they have on the data center.

Bypass air is defined as air that does not participate in cooling the IT equipment in the rack (see Figure 1). As its name suggests, the cold supply air bypasses the server racks and blows back to the cooling units. Bypass air is wasted air which is an expensive problem because it costs money to cool and blow cold air. Bypass air typically occurs when CRACs are providing an excess of cold supply air to the servers. Failure to follow airflow management "best practices" will also contribute to this problem, such as misplaced perforated tiles, missing blanking panels, cable cutout floor leakage, etc.
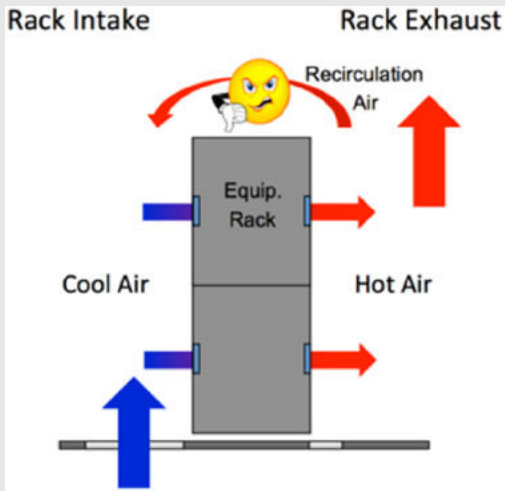
FIGURE 2: RECIRCULATION AIR
Graphics courtesy of DCEP Training Program[4]

FIGURE 3: ONCE-THROUGH COOLING
Graphics courtesy of DCEP Training Program[4]

Recirculation air is when there's not enough supply air to satisfy the servers, so the hot exhaust air recirculates above the racks and around the end of the aisles into the server inlets, resulting in overheating of the IT equipment (see Figure 2). Recirculation air can also be caused by missing blanking panels, gaps between racks, etc.

The goal is to get the cold supply air as close to the IT equipment as possible without mixing with the hot exhaust air. The IT equipment is designed to pull in the cold supply air at the front of the rack *(air intake)*, use it to cool the equipment, then evacuate the hot air *(air exhaust)* from the rear of the rack and move it back to the CRACs where it is cooled again and the process starts over[5]. This is referred to as one-through cooling (see Figure 3).
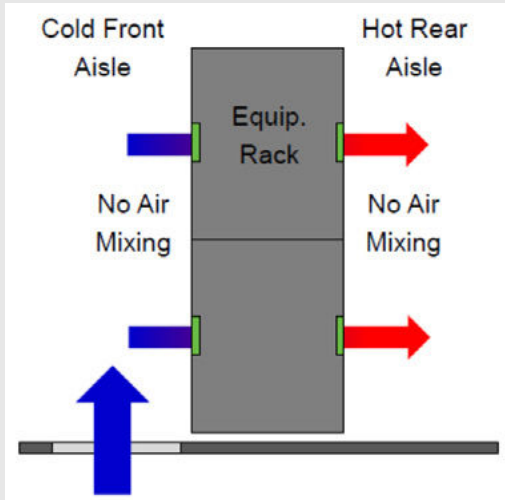
The solution to managing and eliminating bypass and recirculation air starts with containment. As we'll see later in this paper, containment isolates the cold supply and hot exhaust air from each other, resulting in increased efficiency. Without containment, it's not uncommon for data centers to supply 2X, or more, the required airflow to the IT equipment to negate the effects of recirculation air *(hot spots)*. Containment *(and following airflow management "best practices")* results in most data centers reducing supply airflow from the CRACs so that the demand airflow is approximately 85-90% of the supply airflow required to cool the IT equipment.

Depending on the reduction of supply airflow and how high the supply air temperature to the IT equipment is increased, there can be a significant reduction to the PUE *(Power Usage Effectiveness)* of the data center. PUE is a popular metric used to determine the energy efficiency of a data center. PUE is determined by dividing the amount of power entering a data center by the power used to run the computer infrastructure within it[6]. PUE is expressed as a ratio, with overall efficiency improving as the PUE decreases closer 1.0 (see Figure 4). A data center with a PUE of 1.6 or less is considered efficient, and a PUE of 1.2 or less is considered very efficient.

$$PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}$$

FIGURE 4

With the exception of the IT equipment, the dominant part of data center power utilization has to do with cooling *(includes the cooling units, chillers, CRACs, etc.)*. Some estimate that for every kW of IT equipment you put into a room you burn another kW trying to get the heat back out of the room, so a PUE of 2.0 is not uncommon in data centers without containment.

SERVER INLET TEMPERATURE'S ROLE IN ENERGY EFFICIENCY

ASHRAE *(American Society of Heating, Refrigerating, and Air-Conditioning Engineers)* provides server intake temperature guidelines for both upper and lower temperature ranges of the IT equipment in the data center. ASHRAE separates these operational parameters into "Recommended" and "Allowable" ranges. The recommended range is where the IT equipment is designed to operate reliably. The allowable range is where manufacturers have verified IT equipment will continue to work, but the MTBF may be reduced if the equipment is subjected to extended periods within this range. Equipment subjected to temperatures above or outside the allowable range *(which varies depending on Server Class)* may fail or void the manufacturer's warranty. The goal is to raise server inlet temperatures, but to stay within the recommended range. Regardless of the Server Class, ASHRAE recommends that the temperature at the server inlets be no higher than 80.6°F (27°C).   In addition, some suggest temperatures at or above 77°F (25°C) may cause the internal fans within the servers to turn on or ramp up, thus negating any energy savings achieved by running above these temperatures.

But one thing is for certain — A data center without containment either has server inlet temperatures above 80.6°F caused by recirculation air, or there is an excess of cold supply air or bypass air in order to minimize or reduce IT equipment overheating. This is wasted energy and wasted money! You wouldn't operate the air conditioning in your house at its lowest thermostat setting while opening all the doors and windows on a hot day, so why do the same by operating a data center without containment.

Containment in a data center can save lots of money. According to industry sources and based on best practices, the U.S. General Services Administration estimated it could save between 4% and 5% in energy costs for every 1°F that the server inlet temperature is increased[7].   Later we'll show how to estimate savings after containment, but first let's review how to estimate the annual cost to operate a data center, regardless of whether the data center is small, medium, or large.

ESTIMATING ANNUAL COST TO OPERATE A DATA CENTER

In this example, we have a 5,000 square foot data center with IT equipment energy totaling 480 kW. There are 8 Liebert CW084DCS CRACs at 12,100 CFM per unit, and each are equipped with Variable Frequency Drives *(VFDs)*. The SATSP *(Supply Air Temperature Set Point)* of the CRACs is set at 62°F (16.7°C), and with all 8 CRACs running at 100% fan speed the total supply airflow is 96,800 CFM. The IT heat load *(kW)* varies per rack throughout the data center, so higher flow perforated tiles have been placed in front of the racks with the higher kW load *(typical)*.

Since we do not have the PUE of the data center, let's assume it to be 2.0 *(if the PUE is known use that number instead)*. Using the formula for PUE (see Figure 4) and solving for the Total Facility Energy, we get 960 kW *(2.0 * 480)*. The cost of electricity at this site is $0.10/kWh, and since there are 8,760 hours per non-leap year, the annual cost to operate this data center is $840,960 *(960 * 0.10 * 8,760)*.
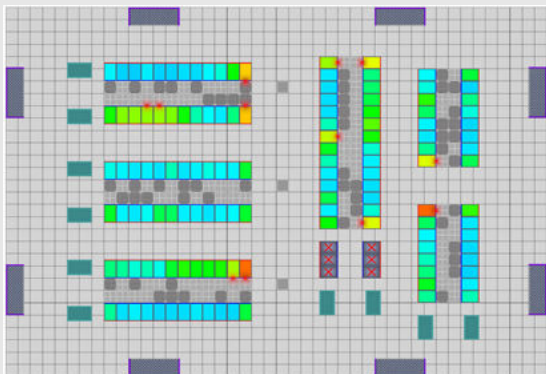
DATA CENTER WITHOUT CONTAINMENT

FIGURE 5: SERVER INLET TEMPS WITHOUT CONTAINMENT

Using CFD *(Computational Fluid Dynamics)* modeling, Figure 5 shows server inlet temperatures for the data center without containment. The "Red Dots" on the racks represent hot spots or racks with server inlet temperatures above the ASHRAE recommended temperature of 80.6°F (27°C), despite the SATSP of the CRACs set at 62°F (16.7°C) and ample supply airflow to the servers. Note that if a CRAC fails or needs to be taken off line for maintenance, there will be additional overheating in the data center with server inlet temperatures possibly above the ASHRAE allowable temperature range.
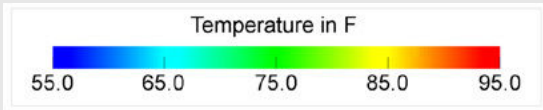
FIGURE 6: CFD TEMPERATURE SCALE

FIGURE 7: 6' HORIZONTAL XY PLANE
WITHOUT CONTAINMENT

FIGURE 8: 3D AIRFLOW WITHOUT
CONTAINMENT

The temperature scale (see Figure 6) represents the Fahrenheit temperature range for the data center thermal models throughout this white paper.
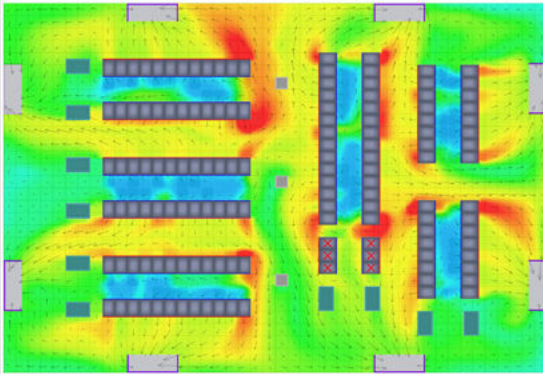
Figure 7 shows the "XY" or "Horizontal Temperature Plane" of the data center at 6'. Note the hot recirculation air above the racks and around the end of the aisles, causing the cold supply air and hot exhaust air to mix in the cold aisles.
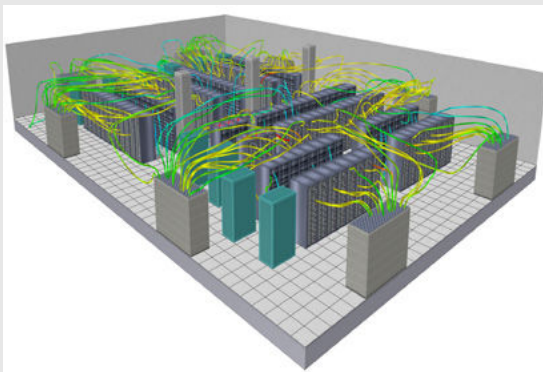
Figure 8 shows the "3D Airflow" cycle of the data center. Note bypass air escaping above the cold aisles, thus failing to contribute to the cooling of the IT equipment, and in some instances returning directly back to the CRACs.
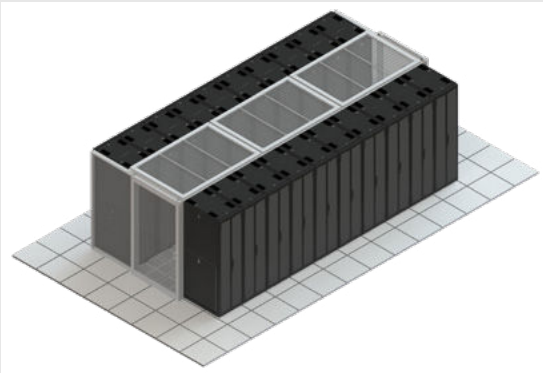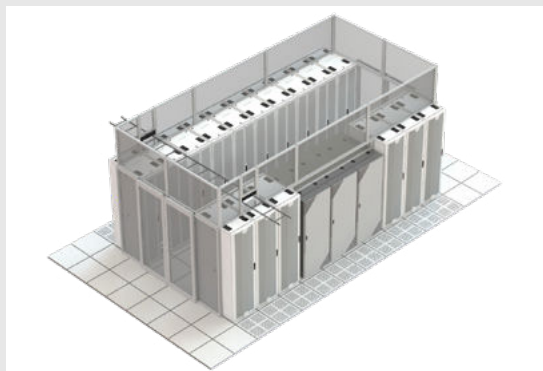
FIGURE 9: COLD AISLE CONTAINMENT EXAMPLE

FIGURE 10: HOT AISLE CONTAINMENT EXAMPLE

As stated earlier, containment is a key strategy implemented in data centers to improve efficiency and lower PUE.

Let's review the different types of containment. Cold aisle containment *(CAC)* encloses the cold aisle, ensuring that only cold supply air flows into the air intakes of the IT equipment, thus separating the cold supply and hot exhaust air (see Figure 9). When you contain the cold aisles, the rest of the data center is basically one large hot aisle.

Hot aisle containment *(HAC)* encloses the hot aisle to collect the IT equipment's hot exhaust air, ensuring that only hot exhaust air returns to the CRACs, thus separating the cold supply and hot exhaust air (see Figure 10). When you contain the hot aisles, the rest of the data center is basically one large cold aisle.

Which type of containment should be installed? It depends on the layout and configuration of the data center and any constraints that may exist. For example, what if the data center has a drop ceiling that can be used as a plenum return back to the CRACs? Then hot aisle containment may be an excellent choice in this particular data center. What if there isn't a drop ceiling, or perhaps there's an excessive amount of obstructions above the racks? Then cold aisle containment likely will be the best choice. How about a data center cooled via In-Row Coolers instead of CRACs? Often row-cooled hot aisle containment is preferred. To summarize, the right containment solution depends on various factors.

But from a thermodynamics point of view, it really doesn't matter; either type of containment will have similar results because they're ultimately both doing the same thing — preventing the cold supply and hot exhaust air from mixing in the data center. There are no efficiency differences between the two. Both systems help to lower CRAC fan speeds, increase the

energy density in the server racks, and operate the data center according to the upper limit of ASHRAE recommendations[8]. Let's implement containment into our data center example to see why this is true.

DATA CENTER WITH COLD AISLE CONTAINMENT
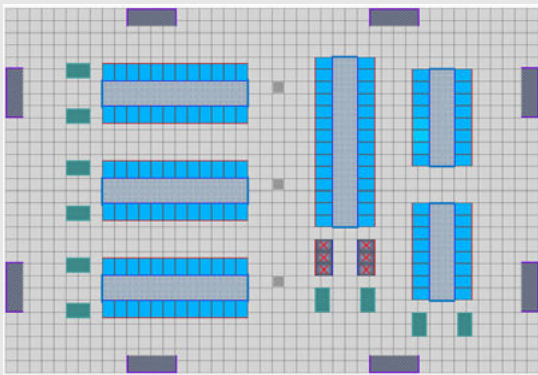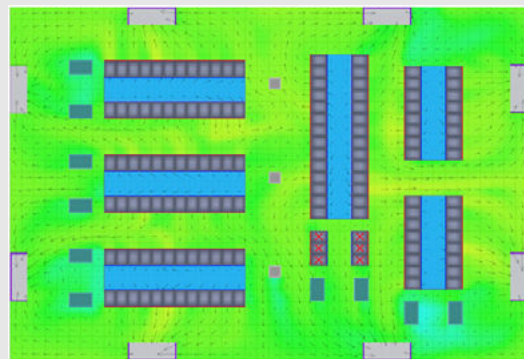

FIGURE 11: SERVER INLET TEMPS WITH CAC

FIGURE 12: 6' HORIZONTAL XY PLANE WITH CAC

Using CFD, Figure 11 shows server inlet temperatures for the data center with cold aisle containment. Without containment several racks had hot spots representing overheating, but now all server inlet temperatures are well below the ASHRAE recommended temperature of 80.6°F (27°C). Since the SATSP of the CRACs is still set at 62°F (16.7°C), the maximum server inlet temperature is only 64°F (17.8°C).

Previously there was a large temperature delta from the bottom to the top of the racks. Besides causing reliability issues, there was no opportunity to increase efficiency by raising supply air temperatures or lowering CRAC fan speeds. But with cold aisle containment this changes since the temperature delta from the bottom to the top of the racks is very small, in this case 2°F (1.1°C) or less. As long as the cold aisles have positive pressure compared to the hot aisles *(slightly higher supply airflow from the perforated tiles versus demand airflow from the IT equipment)*, this temperature delta will remain the same regardless of where the temperature is measured on the rack or in the aisle.

Figure 12 shows the "XY or "Horizontal Temperature Plane" of the data center at 6' with cold aisle containment. Note the hot exhaust air returns directly to the CRACs instead of mixing with the cold supply air in the cold aisles since hot air recirculation has been eliminated. By containing the cold aisles, the rest of the data center is now one large hot aisle.
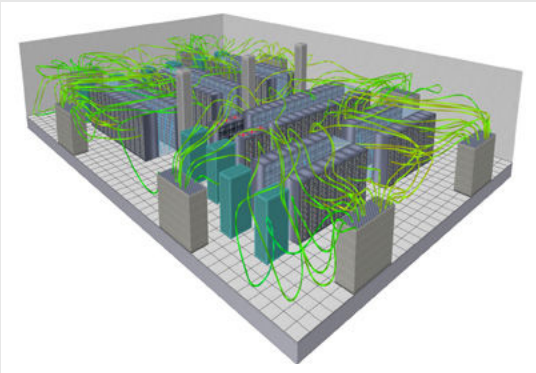
FIGURE 13: 3D AIRFLOW WITH CAC

Figure 13 shows the "3D Airflow" cycle of the data center with cold aisle containment. Note bypass air is non-existent due to aisle end doors and a lid or roof system above the cold aisles.

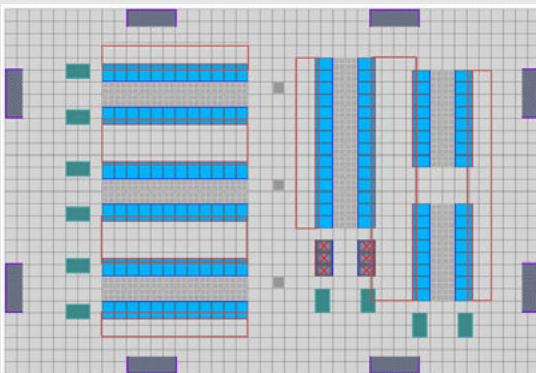## DATA CENTER WITH HOT AISLE CONTAINMENT

FIGURE 14: SERVER INLET TEMPS WITH HAC

Using CFD again, Figure 14 shows server inlet temperatures for the data center with hot aisle containment. CRAC extensions or hoods have been installed on top of the CRACs, extending the CRAC's return up to drop ceiling which is now being used as a return plenum. Return vents or grilles have also been added above the hot aisles. As was the case with cold aisle containment, all server inlet temperatures are well below the ASHRAE recommended temperature of 80.6°F (27°C), with the maximum server inlet temperature still only 64°F (17.8°C).

Hot aisle containment maintains the temperature delta from the bottom to the top of the racks at 2°F (1.1°) or less. Similar to cold aisle containment, this temperature delta will remain consistent as long as the cold aisles have positive pressure compared to the hot aisles. As previously mentioned, reducing the supply airflow from the CRACs so that the demand airflow is approximately 85-90% of the supply airflow required to cool the IT equipment will result in a very efficient data center.
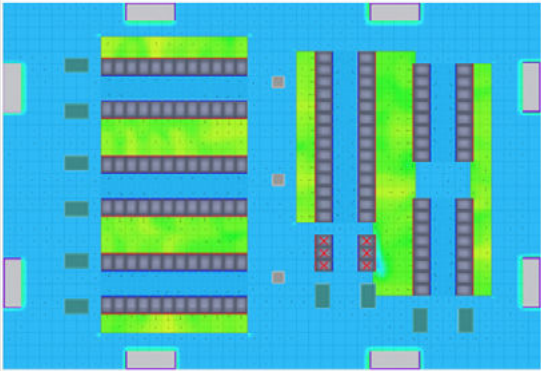
FIGURE 15: 6' HORIZONTAL XY PLANE WITH HAC

FIGURE 16: 3D AIRFLOW WITH HAC

Figure 15 shows the "XY" or "Horizontal Temperature Plane" of the data center at 6' with hot aisle containment. By containing the hot aisles, the rest of the data center is now one large cold aisle.

Figure 16 shows the "3D Airflow" cycle with hot aisle containment. Note the hot exhaust air enters the drop ceiling and returns directly to the CRACs without the opportunity to mix with the cold supply air in the data center. Bypass air is non-existent due to aisle end doors and panels, or vinyl installed up to the drop ceiling above the hot aisles.
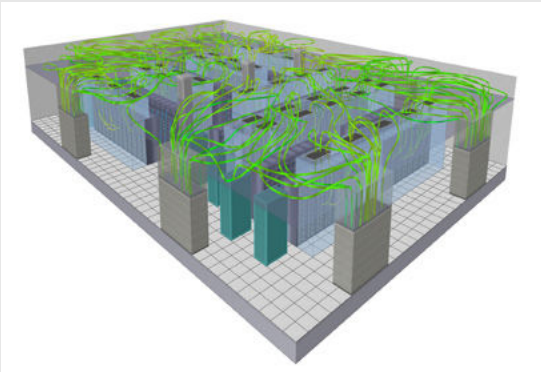
FULL CONTAINMENT VERSUS PARTIAL CONTAINMENT

No Containment

Partial Containment (Doors)

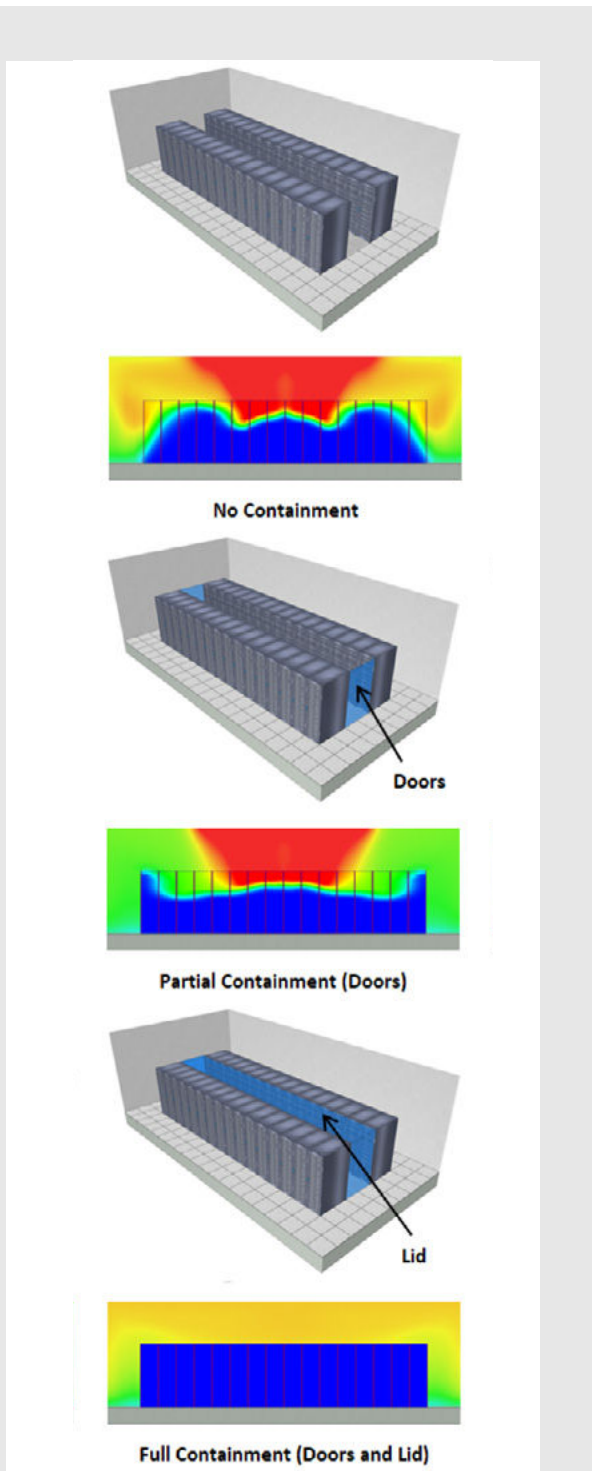**Full Containment (Doors and Lid)**

FIGURE 17: 3D AIRFLOW WITHOUT CONTAINMENT

What about employing partial aisle containment in a data center to improve efficiency? For example, some may wonder if just adding doors to the end of aisles is sufficient versus additionally adding a lid across the top of the cold aisle or running containment to the top of the ceiling.

Partial containment such as doors at the end of aisles will prevent hot exhaust air from recirculating around the end of the aisles, but will not have a large impact on improving any existing issues of hot exhaust air recirculating over the racks and back into the cold aisles (see Figure 17). The best way to eliminate this problem is with full containment.

What if overhead obstructions just below the ceiling, or even the fire suppression system, make it difficult or impossible to install full containment over the racks or up to the ceiling? Even containment 18" below the ceiling will have a substantial impact in preventing the mixing of the cold supply and hot exhaust air, thus improving efficiency.

ESTIMATED SAVINGS WITH CONTAINMENT

CFD modeling shows that regardless of installing cold or hot aisle containment, cooling supply temperatures can be increased which will increase efficiency and save money.

For example, increasing the SATSP at the CRACs by 10°F (5.6°C) from 62°F (16.7°C) to 72°F (22.2°C) results in very consistent server inlet temperatures, well below the ASHRAE recommended 80.6°F (27°C). Since the annual cost to operate the data center was $840,960, and assuming that for every degree (°F) that the supply temperature is increased there will be an overall cost savings of 4% to cool the data center, and estimating that cooling is 40% of the total cost to operate the data center, then our annual savings would be $134,554 *(840,960 * 10 *.04 * .40)*.

Before containment, our PUE was 2.0, but since the total facility energy decreased by 154 kW *(134,554 / (.10 * 8,760))*, then the new total facility also is reduced to 806 kW *(960 - 154)* for a new PUE of 1.7 *(806/480)*. But we're not done yet...

Since containment helps reduce or even eliminate bypass air, the 8 CRACs no longer have to run at 100% fan speed. In this example, with the CRAC fan speed reduced to 80%, there is still sufficient supply versus demand airflow in our data center. Based on the Fan Affinity Law, a 20% decrease reduces the total fan power from the CRACs by almost 50%, resulting in a savings of 3.66 kW per CRAC unit. With 8 CRACs running, that's an additional savings of $25,649 *(3.66 * 8 * .10 * 8,760)*.

This further reduces the total facility energy by 29 kW *(25,649 / (.10 * 8,760))*, resulting in a new total facility energy of 777 kW *(806 – 29)*. The PUE has decreased to 1.6 *(777 / 480)*, resulting in a more energy efficient data center with an annual savings of $160,203 *(134,554 + 25,649)*.

CONCLUSION

Either cold aisle or hot aisle containment is an excellent way to improve efficiency and power density, since both prevent the cold supply and hot exhaust air from mixing in the data center. This results in higher cooling supply temperatures, lower CRAC fan speeds, a lower carbon footprint, a lower PUE, and significant energy bill savings just to name a few. A ROI between 6 and 18 months is very common after most containment projects.

Whenever possible, existing data centers should be retrofitted with either cold or hot aisle containment, with containment always automatically included as part of any new data center design.

ABOUT THE AUTHOR

Gordon Johnson is the Senior CFD Engineer at Subzero Engineering, and is responsible for planning and managing all CFD related jobs in the U.S. and worldwide. He has over 25 years of experience in the data center industry which includes data center energy efficiency assessments, CFD modeling, and disaster recovery. He is a certified U.S. Department of Energy Data Center Energy Practitioner *(DCEP)*, a certified Data Centre Design Professional *(CDCDP)*, and holds a Bachelor of Science in Electrical Engineering from New Jersey Institute of Technology. Gordon also brings his knowledge and ability to teach the fundamentals of data center energy efficiency to numerous public speaking events annually.

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