Improved data center efficiency—incorporating air stream containment

The cold aisle containment advantage

Viewpoint Paper

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The ever increasing power requirements for new denser servers has created the need for supporting higher density compute platforms within traditional datacenters. HP partnered with Rittal Corporation and Liebert Corporation to establish a test environment for measuring and validating the benefits of cold aisle containment and validating the constraints of operating in a 24 inch raised floor plenum using direct expansion computer room air conditioners (CRAC). Test results show that Cold Aisle Containment (CAC) enables higher density loads, provides a more consistent air supply, and uses mechanical cooling equipment significantly more efficiently.

Executive summary

To sustain growth, data centers are facing the challenge of supporting computer equipment with higher densities in kilowatts per rack and managing the environmental impact. Initiatives are being put in place to identify and implement cooling solutions that will produce efficiencies while reducing facilities' energy expense per server.

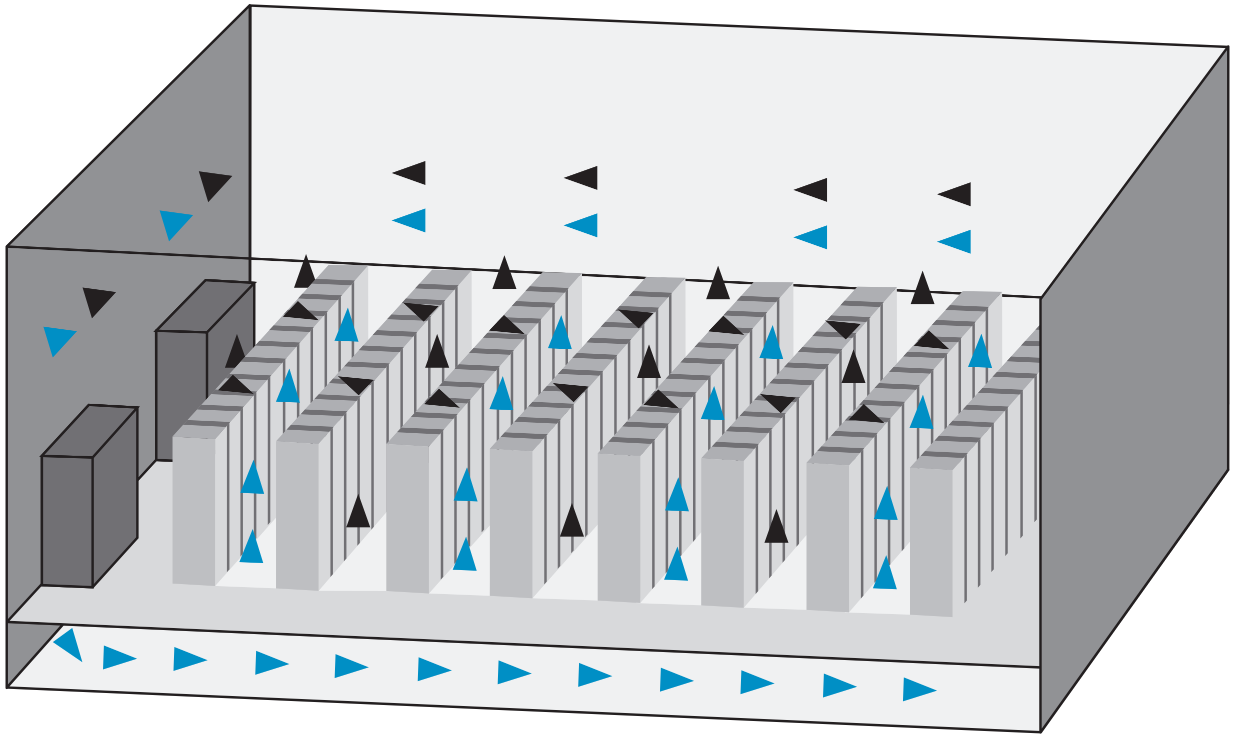
One major industry approach of "air stream containment" improves data center cooling efficiencies and enables greater server density per rack. Two major benefits to this approach are reduction in energy consumption and expenses, and a reduction in raised floor space.

HP partnered with Rittal Corporation and Liebert Corporation to establish a test environment for measuring and validating the benefits of cold aisle containment and validating the constraints of operating in a 24 inch raised floor plenum using direct expansion computer room air conditioners (CRAC).

The test results are highlighted below:

- The test results show that fully isolating the hot and cold air streams with a Cold Aisle Containment (CAC) system enables support of higher density loads, provides a more consistent inlet air supply, and utilizes mechanical cooling equipment more efficiently.
- When compared to an open or non-contained environment, CAC energy efficiency improvements range from 14% to 41%. As 100% sensible loads were returned to the Liebert CRAC units, the testing demonstrated a 50% load improvement as supply and return temperature deltas increased from 20 to 30 degrees across the evaporator coils
- Traditional data centers are, on average, designed to support densities of approximately three kilowatts per rack. This testing proved that CAC environments can be built within traditional data centers to support up to 17 kilowatts per rack.
- In addition to the energy and cooling efficiency benefits of a CAC environment, higher densities were achieved by increasing the air flow using higher flow rate perforated floor panels.
- There are several variables to be considered in arriving at an optimum kW/rack load value. They include adjusting for outside temperature, maintaining an acceptable hot aisle work environment temperature, and controlling humidification. These factors must be evaluated for each site as part of an engineering build plan.
- As a part of this study, various power and cooling failure scenarios were tested to understand the effect on the loads and operational risk. The study concluded that for the scenarios tested, CAC does not pose any new or additional risk to information technology operations.
- Unlike a traditional uncontained configuration where rack inlet temperatures vary by up to 20 degrees, the CAC tests showed that temperature stratification of the cold aisle supply air from the bottom to the top of the rack varied only one degree or less. This uniform supply temperature directly improves the reliability of the IT hardware.
- All testing was done using direct expansion type of CRACs. The author predicts that efficiency improvement would be even greater using chilled water units with variable frequency drives on the fans.

Figure 1. Traditional installation—hot aisle/cold aisle diagram



Introduction

The ever increasing power requirements for new denser servers has created the need for supporting higher density compute platforms within traditional data centers. The kW per rack requirement is increasing from 3kW/rack to 20kW/rack, and is driving the need to look for more efficient ways of cooling the equipment and containing the energy costs associated with operating the computer equipment.

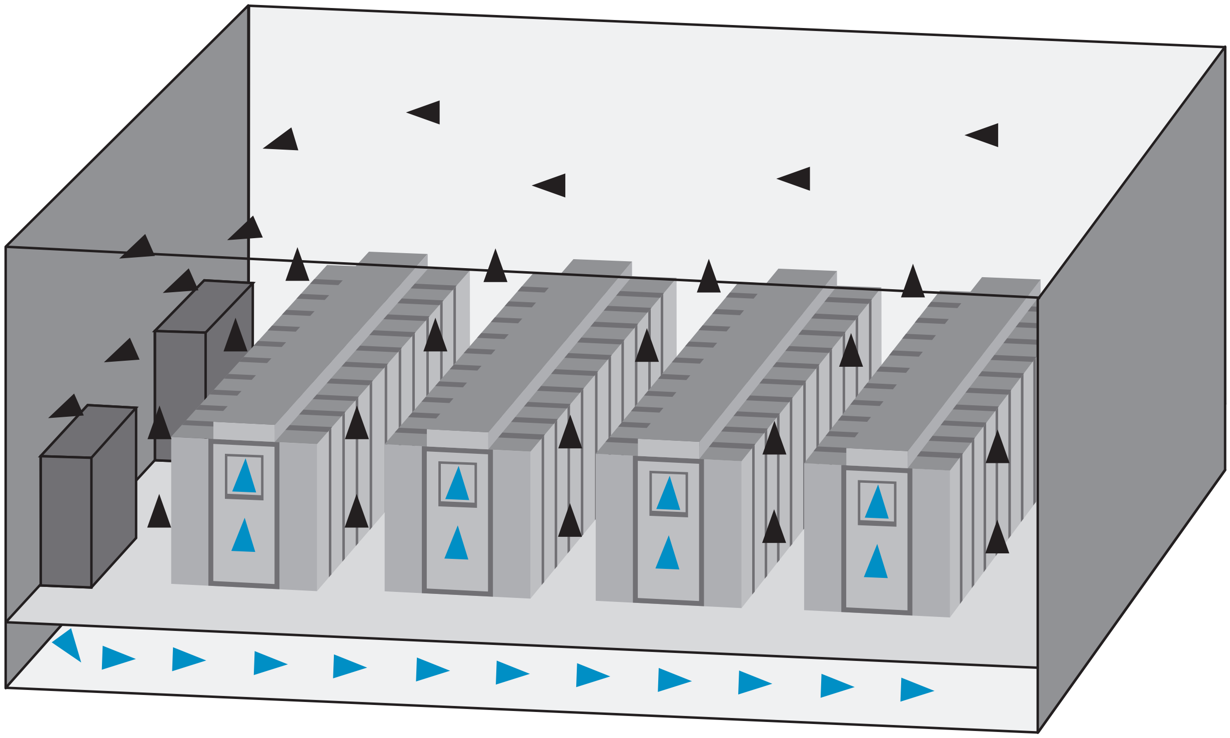
Traditional computer equipment installation

The current best-in-class server installation approach incorporates a "hot aisle/cold aisle approach "which requires the high density equipment to be spread out across a larger footprint which evenly distributes the server heat loads across lower density space.

The majority of installed computer equipment is placed in racks that are designed to intake cold air from the front and exhaust hot air through the rear of the cabinet. This has driven an industry standard of "hot aisle/cold aisle", where the racks are aligned to ensure that the equipment is taking in air from perforated floor panels placed in the cold aisle and exhaust from the equipment is discharged into the hot aisle. As shown in Figure 1, the problem with this method is that the cold and hot air mix across the top of the racks and along the ends of aisles.

The "air stream containment" approach (hot or cold) marketed by multiple suppliers prevents the mixing of hot and cold air streams. This method improves data center cooling, and computer room air conditioner efficiencies. Many traditional data centers have a 24 inch raised floor used as a plenum for providing cold air to the servers with an open air return which provides for an easier adoption approach for cold aisle containment versus the structural work associated with installing duct work chimneys required to facilitate hot aisle containment. This document focuses on Cold Aisle Containment and the results of extensive testing conducted at an HP facility.

Figure 2. Cold aisle containment diagram



Cold aisle containment

The system design fully contains the cold air to the front intake of the racks and prevents mixing with the hot air exhaust. As shown in Figure 2, this approach encloses the ends of each cabinet row and uses clear panels to contain the air across the top of the cabinets while allowing for existing lighting to illuminate the contained aisle.

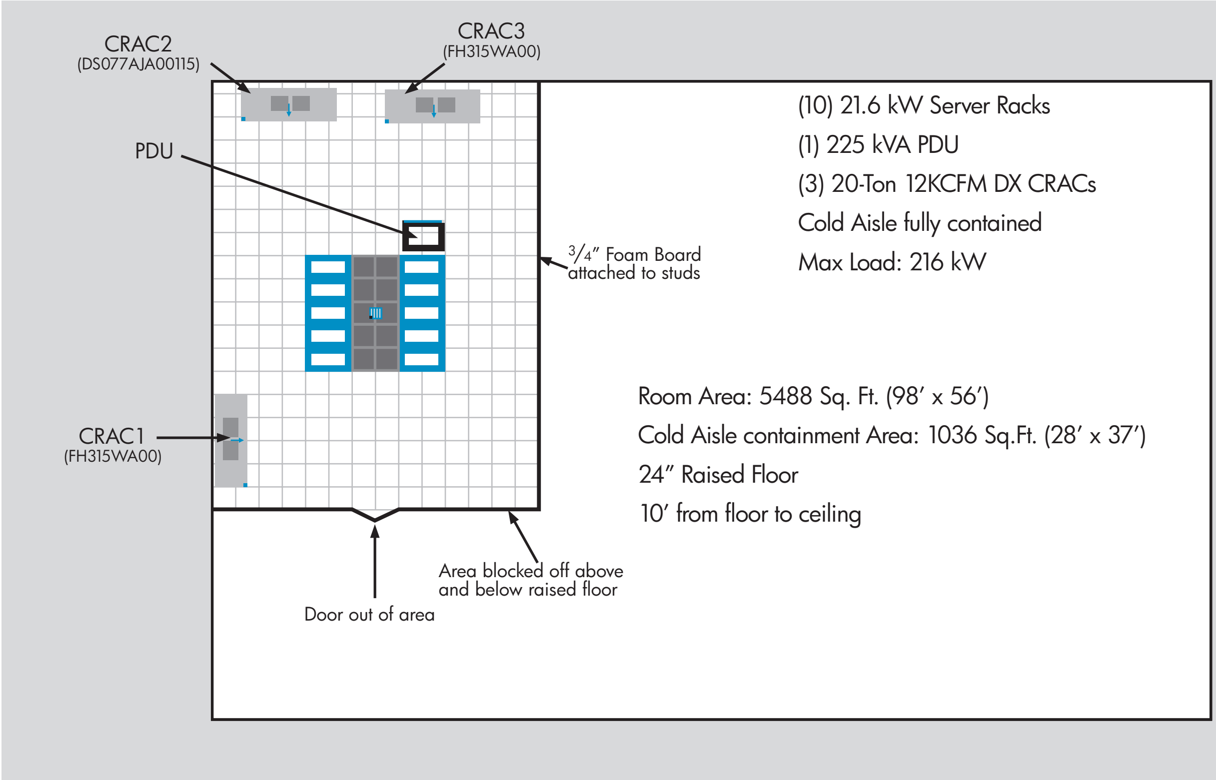
HP partnered with Rittal Corporation and Liebert Corporation to test the Rittal Corporation cold aisle containment system. HP constructed a fully walled off laboratory environment to perform testing and validation of benefits.

Cold aisle containment—validation benchmark

Test environment

A test area of 1,100 square feet of data center space was established and was completely isolated above and below the raised floor. Ten Rittal Corporation TS8 racks were configured with five racks facing each other and four feet of cold aisle between them. Each rack was 42U in height, 24 inches wide, and 48 inches deep with partition walls attached to each side to provide air flow barriers and isolation. The ends of the rack rows were enclosed with sidewalls bolted to the rack frame. Each rack had a 64% perforated single door on the front, split perforated doors on the rear, perforated roof, leveling feet, and air baffles in the front to ensure proper airflow. The cold aisle was fully contained with 180-degree opening double doors on the ends and clear polycarbonate panels enclosing the top. All floor penetrations for cabling, piping, and other elements, were sealed to limit bypass air from escaping the under floor plenum. Ten perforated tiles were installed in the containment area providing the cold air supply from the 24 inch raised floor plenum. Tests were performed using 25%, 65%, and 80% perforated tiles.

Figure 3. Testing environment and layout



Each rack had nine 2.4kW load banks (server simulator devices) occupying 4U of space allowing testing up to 21.6 kW per rack and 216 kW maximum for the entire enclosure.

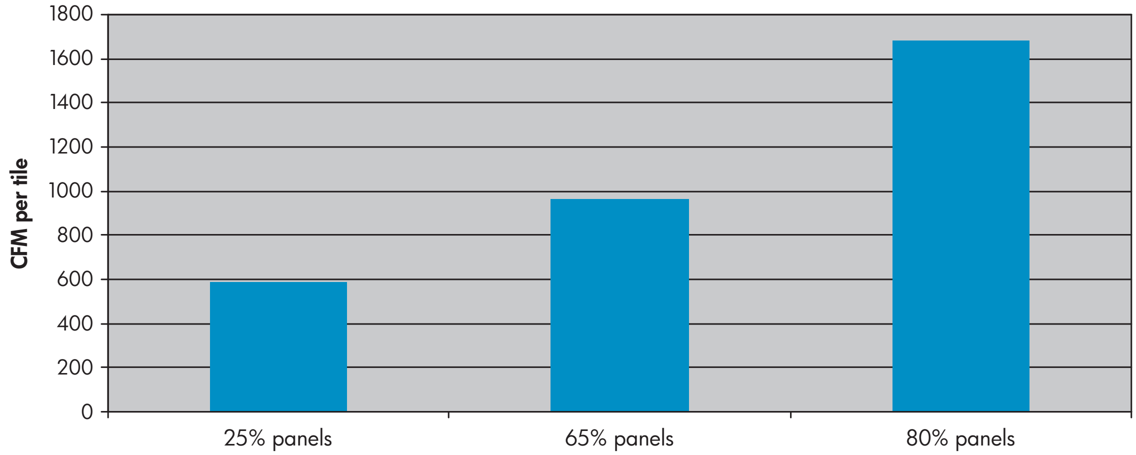
Cooling was provided using three nominal 20-Ton direct expansion Liebert CRAC units with air-cooled condensers. Two Liebert units are Deluxe System 3 models (more than fifteen years old) and one Liebert DS 077 unit that is two years old. Figure 3 is a diagram of the testing configuration.

A Liebert 225 KVA power distribution unit was used to provide the power.

The following sensors and meters were installed:

- Three sensors on each rack to monitor the inlet temperature to the rack
- Two sensors on each rack to monitor the outlet temperature from the rack
- Relative humidity sensors at four locations, two in the cold aisle at opposite ends, one in the hot aisle, and one located in the farthest corner of the room
- Ambient room temperature was measured at the farthest corner of the room
- Hot aisle temperature sensor located three feet from the exterior of rack
- Meters for CRAC supply and return temperatures, amps, condenser head pressure, return air flow in cubic feet per minute (CFM), and fan rotations per minute
- Shortridge meter ADM 880C measuring the CFM at the return of CRAC
- Alnor balometer measuring CFM to the cold aisle containment area
- Pressure differential meter between the cold aisle and the computer room
- Pressure differential meter between the cold aisle and the air plenum
- Sensor for outside air temperature
- KW load meter for draw of the server simulators

Figure 4. Comparison of air flow versus open percentage of tiles



Perforated panels

Impact of perforation percentage of floor tiles

First steady state comparisons for the CAC system were tested to determine the operational capacity of the system. Three tile scenarios were tested. Tiles with different perforation percentages of 25%, 65%, and 80% were used with one CRAC running, to measure the CFM for each tile configuration. The 80% perforated panel was manufactured from metal grating and is not currently marketed. The CFM per tile results are shown in Figure 4.

Data center environment

Raised floor air flow

Traditionally, air distribution throughout a data center is accomplished by using 25%t flow rate perforated tiles. The impact of this tile configuration along with higher flow rates and containment configurations were measured and evaluated during testing. Several configurations were tested including a traditional environment with 3 kW per rack and no aisle containment, to 20 kW per rack with containment. Peak thresholds for each configuration were monitored to ensure the environment maintained inlet temperature rise, operable air stratification, and compliance with IT hardware specifications. The summary findings are listed below:

- 3 kW per rack, with 25% perforated tiles, no aisle containment
- 7 kW per rack, with 25% perforated tiles, with aisle containment
- 7 kW per rack, with 65% perforated tiles, no aisle containment
- 20 kW per rack, with 65% perforated tiles, with cold aisle containment

Figure 5. Impact of cold aisle containment (72 kW load—CRAC 3 operating—14% improvement)

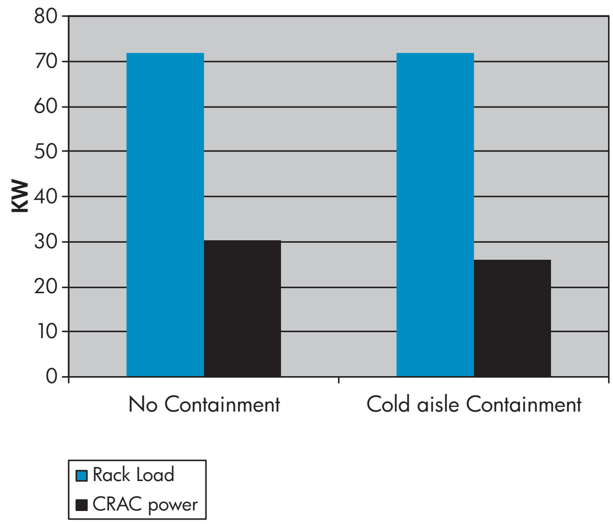
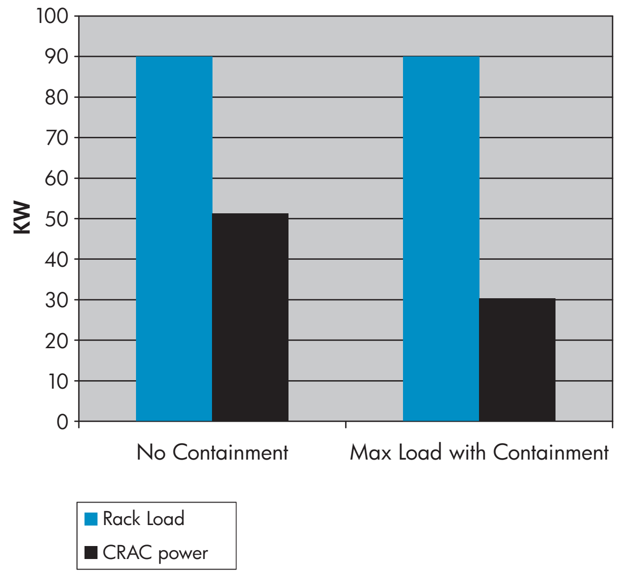


Figure 6. Impact of cold aisle containment (90 kW load—CRAC 3 operating in CAC, CRAC 3 and 1 operating in non-contained environment with 41% improvement)



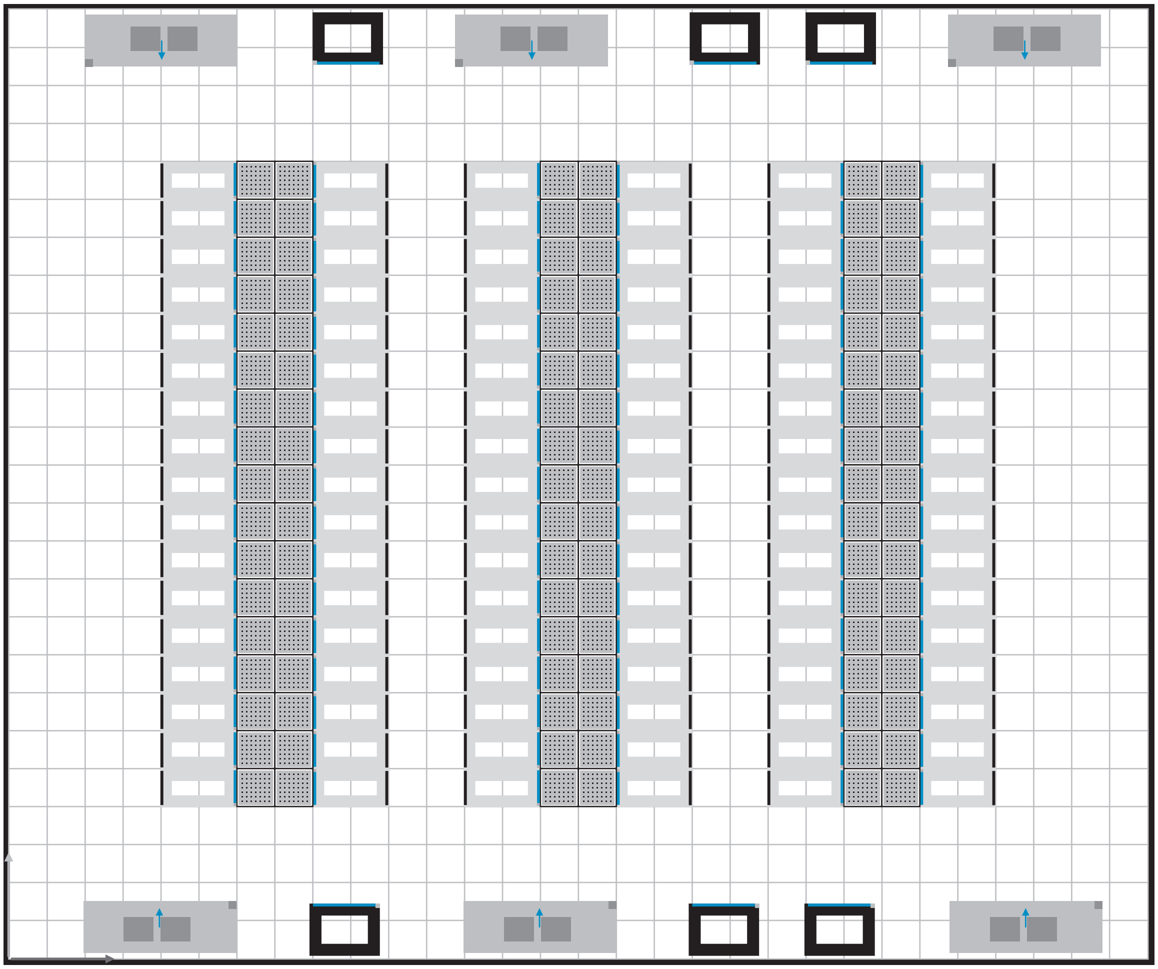
Measuring efficiency

Comparing cold aisle containment to traditional non-containment

The data demonstrates the benefits of cold aisle containment when compared to a non-contained environment. The power efficiency of cold aisle containment is measured as a percentage by dividing the power the IT load consumes by the power the entire system consumes. Figure 5 shows the benefit of containment with an average load of 7.2 kW per rack with one CRAC operational. For this scenario, the efficiency benefit of containment is 14%.

Figure 6 shows the benefit of containment with an average of 9 kW per rack with one CRAC operational in the cold aisle containment test. For this scenario, the contained aisle configuration showed a 41% efficiency improvement over the non-contained configuration which required the use of two CRAC units.

Figure 7. 306 kW load install using traditional installation design

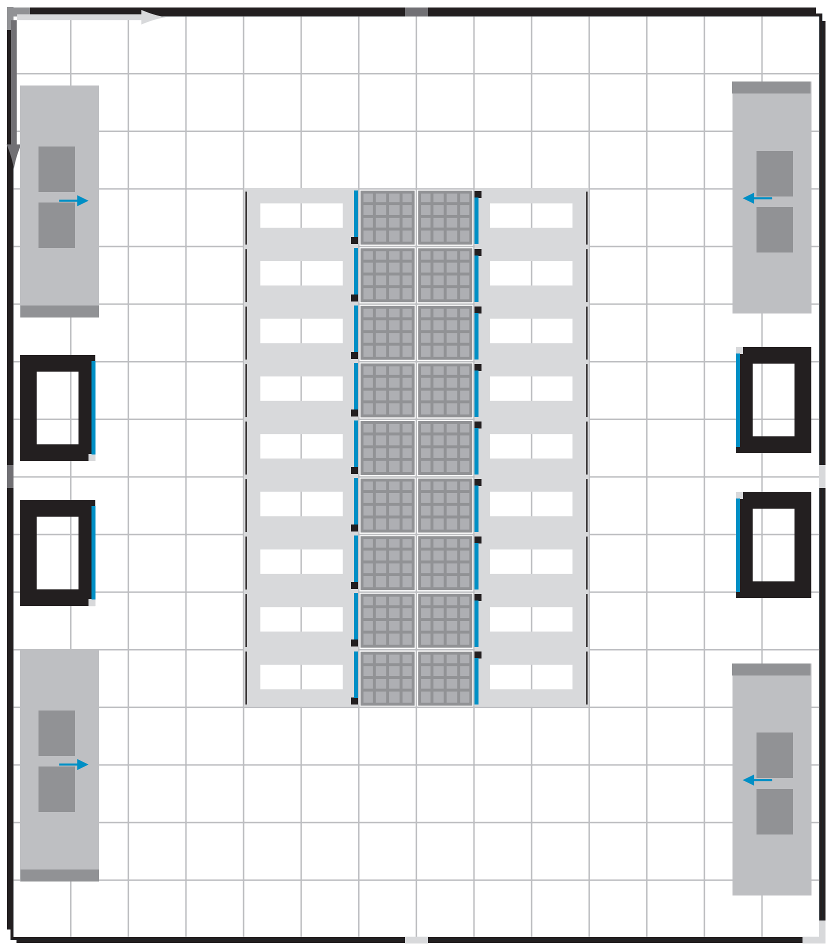


Modeling CAC vs traditional install approach
Scenario: 306 kW load installed using traditional design

Qty (102) 3kW racks, Load = 306kW room area: 3000 Sq Ft (60′ x 50′)

24″ raised floor 10′ from floor to ceiling

Figure 8. 306 KW load install using CAC design



Scenario: 306 kW load installed using Cold Aisle Containment design

Qty(18) 17kW racks, Load = 306kW room area: 896 Sq Ft (32′ x 28′)

24″ raised floor 10′ from floor to ceiling

Figure 9. Modeling Comparison of containment vs. Non-containment

Cold Aisle containment Analysis of DX Air Conditioners

Number of Cabs	KW Per Cab	Total KW	Without containment 72KW per 20 Ton Unit Number of CRAC units	With containment 90KW per 20 Ton Unit Number of CRAC units	Benefit Less A/Cs Required	A/C Annual Energy Benefits	A/C Purchase & Install Benefits	3-year Benefit Total
10	4.8	48	0.7	0.5	0	$ —	$ —	
	7.1	71	1.0	0.8	0	$ —	$ —	
	9	90	1.3	1.0	1	$28,611.00	$49,500.00	$135,333.00
20	4	80	1.1	0.9	1	$28,611.00	$49,500.00	$135,333.00
	6	120	1.7	1.3	0	$ —	$ —	
	8	160	2.2	1.8	1	$28,611.00	$49,500.00	$135,333.00
	10	200	2.8	2.2	0	$ —	$ —	
40	4	160	2.2	1.8	1	$28,611.00	$49,500.00	$135,333.00
	6	240	3.3	2.7	1	$28,611.00	$49,500.00	$135,333.00
	8	320	4.4	3.6	1	$28,611.00	$49,500.00	$135,333.00
	10	400	5.6	4.4	1	$28,611.00	$49,500.00	$135,333.00
60	4	240	3.3	2.7	1	$28,611.00	$49,500.00	$135,333.00
	6	360	5.0	4.0	1	$28,611.00	$49,500.00	$135,333.00
	8	480	6.7	5.3	1	$28,611.00	$49,500.00	$135,333.00
	10	600	8.3	6.7	2	$57,222.00	$99,000.00	$270,666.00
80	4	320	4.4	3.6	1	$28,611.00	$49,500.00	$135,333.00
	6	480	6.7	5.3	1	$28,611.00	$49,500.00	$135,333.00
	8	640	8.9	7.1	1	$28,611.00	$49,500.00	$135,333.00
	10	800	11.1	8.9	3	$85,833.00	$148,500.00	$405,999.00

Air Conditioner Costs	
Annual Energy (KW) to run .1 per KW/hr	$28,611.00
Purchase cost for DX AC & condenser (22 ton)	$30,000.00
AC Installation costs	$19,500.00

Benefit modeling of cold aisle containment

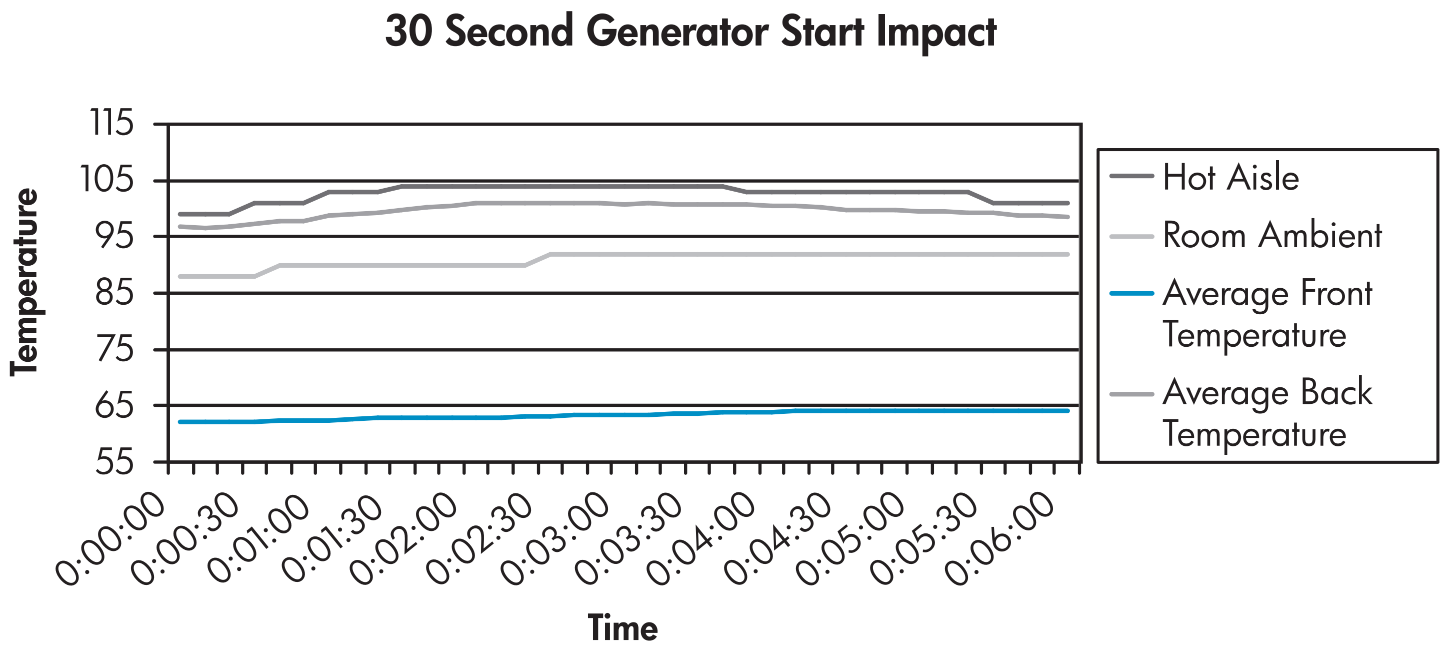
Figure 9 shows the benefit of aisle containment modeled for a larger number of racks. These CAC test scenarios used only 10 racks. This chart projects the results of increasing the number of racks to 20, 40, 60, and 80. It shows energy efficiency savings plus the capital cost avoidance of purchasing and installing CRAC units.

Further efficiencies:

Additional Cold Aisle Containment efficiencies can be realized by implementing enhancements to the air conditioning systems and system controls such as:

- Chilled water cooling system
- CRAC compressors (four step or digital scroll)
- Variable speed fans in CRAC units
- CRAC control system

Figure 10. Utility failure simulation—all CRAC's turned off 30 seconds



Failure analysis

Test data—what happens when something goes wrong?

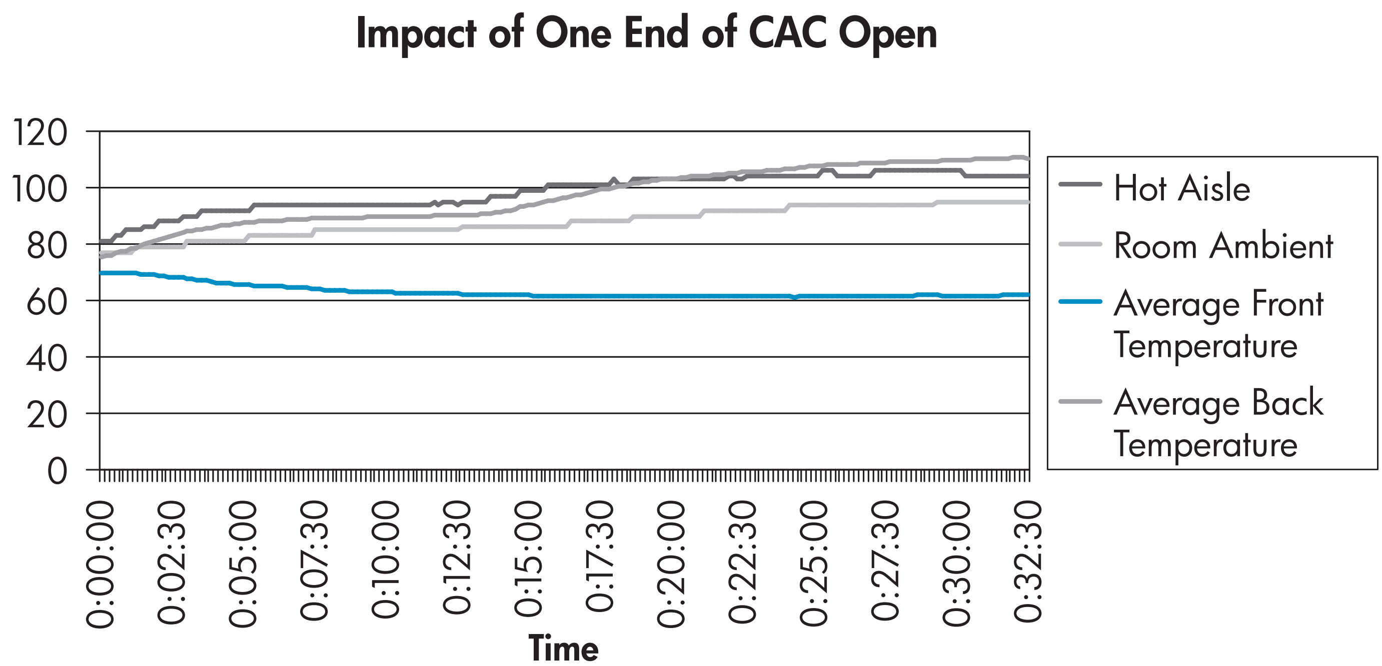
HP data centers must operate with some level of redundancy and the ability to deal with unforeseen events. Various scenarios were developed and tested to show the impact on the data center.

Test data—generator Startup/UPS fail over events

HP data centers are designed with a UPS system that provides emergency power to the IT load during a loss of electricity. These systems typically only power the IT load in the data center until the generation equipment comes up and restores power. For a short time, the cooling equipment is not functioning. To replicate this situation, HP first established a steady state system operating 10 20kW racks. All CRAC units in the testing configuration were running. At exactly the same time, all CRAC units were powered down via their disconnects, resulting in the total loss of air flow to the Cold Aisle Containment system. At approximately 30 seconds, all CRAC units were restarted and began to supply air to the equipment. Power requirements of the load were monitored at all times to ensure that no load bank was lost. The impact on temperatures in the data center can be seen in Figure 10.

Figure 10 shows the CRAC restart resulted in a temporary increase in the hot aisle temperature as would be expected due to the loss of airflow. The shutdown also increased the cold air temperature, undoubtedly due to the extra thermal energy the CRAC units required to dissipate after the restart.

Figure 11. Single door on CAC open for 30 minutes



Test data—impact of opening the cold aisle containment doors

IMAC efforts in the data center are a normal everyday function. These movements disturb the air paths with the cold aisle containment system. These disturbances would usually be momentary, but what if someone propped the door open for 30 minutes when running at 20kW per rack? Figure 11 shows the impact of this condition. The room ambient temperature and hot aisle temperature both increase due to the short cycling of air from the cold aisle back to the CRAC units. This reduces the cold aisle temperature due to the lower temperature of air being cycled directly to the CRAC units. Even in this state, the air temperature to the load banks was kept within the norms expected.

Test data—impact of losing a single CRAC unit

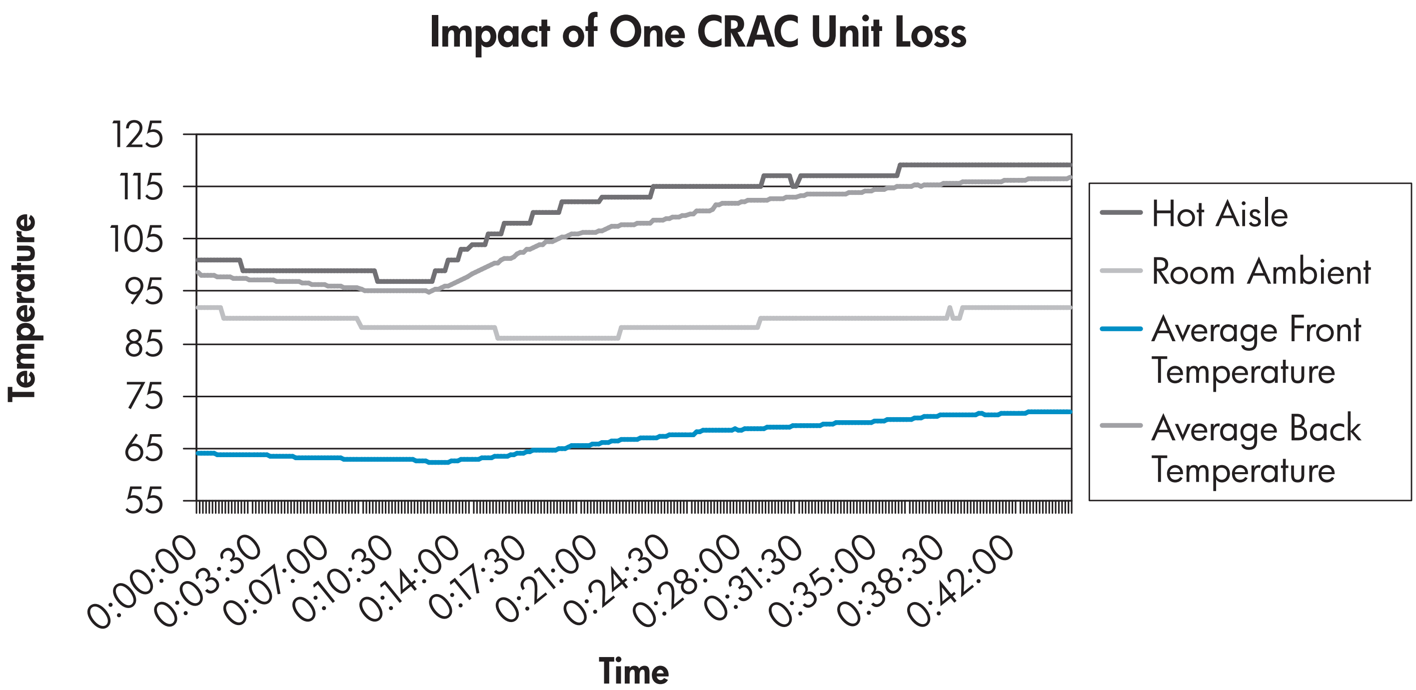
The system that was tested would only be considered an N redundant solution, as all CRAC units were required to support the IT load in place. Typically data centers operate in at least an N+1 redundant solution, but what if this wasn't the case? To test this scenario, the system was brought to a steady state of 20kW per rack, and then shutdown a single CRAC unit. Figure 12 shows the results.

Notice that the delta-T across the load banks increases rapidly from x to y and the inlet temperature of the rack is affected over time. The two remaining CRAC units were only rated for a nominal 70kW per unit, but were now required to handle 100kW each. Nearing the end of the test, the load was stable at these conditions, allowing sufficient time for repair of the failed CRAC unit.

Removal of tiles throughout the data center

Another scenario in the data center would be that of the removal of multiple tiles in the data center for under floor work such as running cables or removing power cords. This type of intrusion into the raised floor is important to understand, as the loss of cold air from the raised floor may result in less air being directed to the cold aisle. In this test case, six tiles were removed from the area along the hot aisle and in front of the CRAC-3 discharge. The loss of pressure was noted and the air (CFM) provided to the rack was reduced. The delta-T across the load banks increased but stabilized and did not starve the units nor cause an excessive temperature condition.

Figure 12. Loss of a single CRAC unit



Deployment considerations

The lesson learned in these test scenarios is that there must be detailed disciplined processes in the design and operation of a cold aisle containment area. The following considerations should be made when designing a Cold Aisle Containment.

- Overhead data cabling
- Seal all raised floor and wall penetrations to contain under floor air
- Power distribution (3 phase power to racks – [US region])
- Fire code detection/suppression based on local jurisdiction
- Operational best practices

Conclusion

The test results show that Cold Aisle Containment (CAC) enables higher density loads, provides a more consistent air supply, and uses mechanical cooling equipment significantly more efficiently.

- Compared to non-containment, CAC efficiency improvements ranging from 14% to 41%
- Liebert CRAC units supported supply and return temperature deltas of 30 degrees across the evaporator coils
- Environments can be designed and built within the existing data centers utilizing CAC to support up to 17kW per rack

Recommendations are based on the findings and results from the tests performed. There are several variables to be considered in arriving at an optimum kW/rack load value. They include adjusting for outside temperature, maintaining an acceptable hot aisle temperature suitable for a work environment, and controlling humidification. These factors must be evaluated for each site as part of an engineering build plan.

The air stream containment testing clearly demonstrates the significant efficiency gains in the cooling system and the corresponding increase in kW/rack capacity when a Cold Aisle Containment system is implemented.

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