



Rittal White Paper 506: Cold Aisle Containment for Improved Data Center Cooling Efficiency

By: Daniel Kennedy

Executive Summary

Increasing power requirements for new servers have created the need to support higher density computing platforms in existing data centers. With kW per rack averages increasing from 3kW/rack to, in some extreme cases, more than 30kW/rack, the need for providing more efficient ways of cooling IT equipment is imperative.

A number of rack manufacturers, and data center operators alike, are now advocating the use of “air containment” systems for meeting this challenge. By preventing the mixing of hot and cold air streams, data center cooling can be made more efficient and Computer Room Air Conditioner (CRAC) performance can be significantly improved. When deployed in well-designed and operated facilities, these containment systems look promising.

This report documents the testing of a cold aisle containment system in a “live” data center. The goal of the test program was to benchmark the performance of Rittal’s Cold Aisle Containment (CAC) system by comparing data collected in the same data center operating under identical conditions with and without containment.

Overview of Test

The testing of the Rittal Cold Aisle Containment (CAC) system was conducted in the Dallas-Metro region of Texas in an operational data center with a 24" raised plenum floor. A separate test area, approximately 5,500 square feet, was isolated from the main data center by using insulated walls placed from the subfloor, through the raised floor and up to the drop ceiling—preventing any air from mixing with main data center spaces. The test setup consisted of 10 Rittal TS8 server racks placed in two facing rows of 5 racks each with a four-foot cold aisle between them. The individual racks were 24" wide and 48" deep, providing 42U of mounting space, and each one was isolated from the adjacent racks with an internal partition wall. Row ends were secured with sidewalls. The racks were configured with a standard 64% perforated single door on the front, split perforated rear doors and a perforated roof. Leveling feet and vertical air baffles were installed on the front 19" component mounting rails to ensure proper airflow and prevent any internal cabinet air recirculation and mixing.

The cold aisle was fully contained on the aisle ends with 180°-hinged double doors. The top of the aisle was covered and sealed with clear polycarbonate panels. Ten perforated floor tiles were installed in the contained cold aisle to provide cold air supply from the raised floor plenum. Numerous tests were performed utilizing perforated tiles with 25%, 65% and 80% open surface area. Nine (9) 2.4kW load banks were installed in each test rack, each occupying 4U of space, which allowed for a test range of up to 20kW per rack, or 200kW for the entire contained area. The load banks were designed to mimic server airflow patterns with a nominal ΔT (temperature change) of 45°F (as expected with newer, high density servers) and with fans that could deliver 300 CFM (Cubic Feet per Minute) per load bank.

Space cooling was provided by three (3) 20-Ton nominal, direct expansion Liebert CRAC units. Two of the units were Deluxe System 3 models (15 years old) and the third was a DS 077 unit (2 years old). See Figure 1 for the test layout.

Power was provided from a 225 KVA Power Distribution Unit (PDU). All equipment and ambient room spaces were instrumented, providing a complete array of temperature and environmental sensors to ensure accurate data collection. Measured points included:

- Three (3) points at the inlet of each rack
- Two (2) points at the exhaust of each rack
- Relative humidity at four (4) locations (two in the cold aisle at opposite ends, one in the hot aisle and one in the room ambient)
- One (1) ambient room temperature point
- Hot aisle temperature measured 3 feet from the rear of the racks
- CRAC supply and return temperatures, power consumption (amps), condenser head pressure, return airflow and fan RPM (Revolutions Per Minute)
- CFM at the return to the CRAC
- CFM to the cold aisle containment
- Pressure differential between the cold aisle and room ambient
- Pressure differential between the cold aisle and rack inlet
- Outside air temperature
- Load Draw – kW
- Pressure in the cold aisle containment area

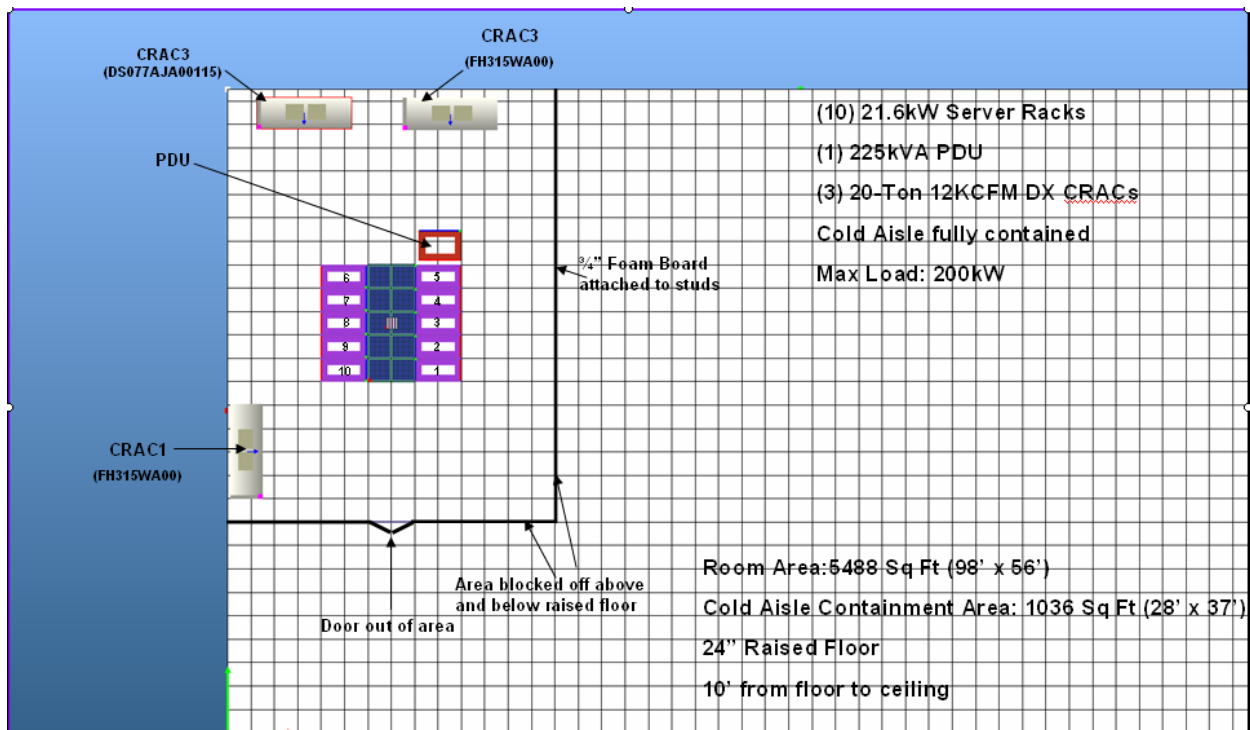


Figure 1 - Test Layout

Impact of Floor Tile Perforation Percentage on System Performance

During the first week of testing, steady state comparisons for the cold aisle containment system were measured to determine the operational capacity. Tests were completed with 25% and 65% perforated floor tiles. 80% perforated floor tiles were tested early in the second week. CFM data for each tile configuration was recorded to determine the total airflow in the CAC area. (See Figure 2) Average inlet air temperatures, outlet air temperatures, room ambient temperatures and hot aisle temperatures were recorded to capture steady state operation for all three scenarios. (See Figure 3)

Key Point: Note that the increase in floor tile open surface area reduced all temperatures when operating under the same load conditions, in this particular case, 20kW per rack.

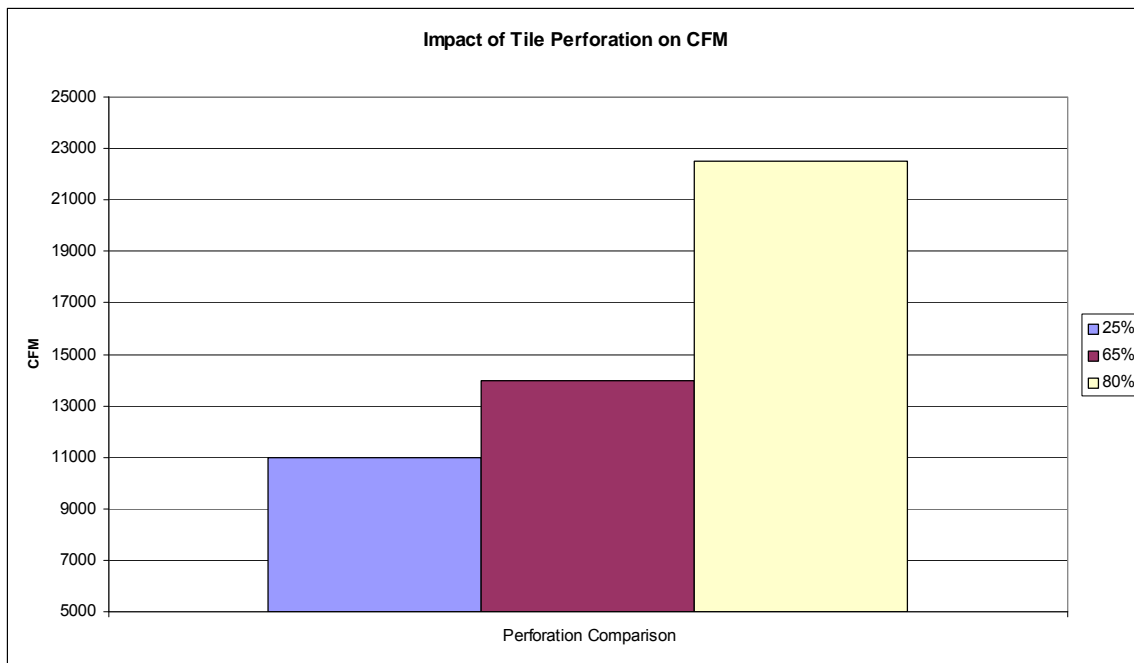


Figure 2 - Comparison of Air flow versus open percentage of tiles

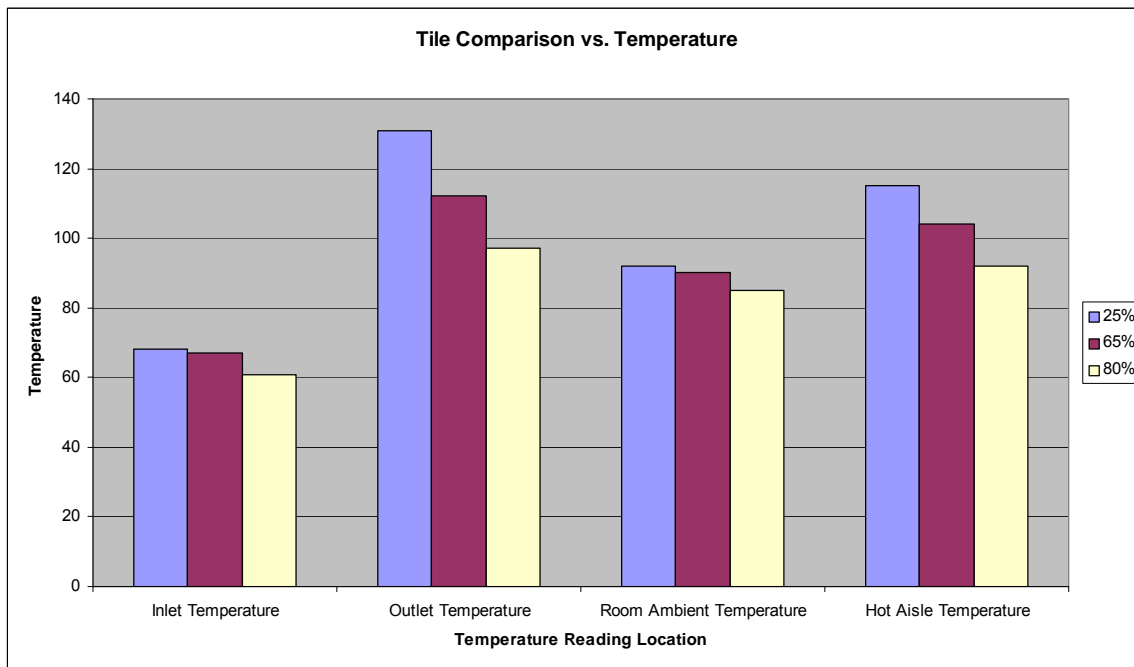


Figure 3 - Temperature Comparisons at 20kW Load per Rack

Maximum Load Achievement with Various Floor Tiles

During the test, a maximum allowable ΔT of 45°F was established. Since newer, high density servers have much higher outlet air temperatures than older servers, testing with the higher Δ is desirable. This is illustrated simply by comparing a variety of new 1U and blade server chassis, which can have ΔT 's as high as 52°F (Dell, 2008, Capacity Planner). Using this guideline, Figure 4 was created.

Key Point: Note the positive impact on ΔT achieved with 80% perforated tiles, and that acceptable results were also reached using 65% perforated tiles.

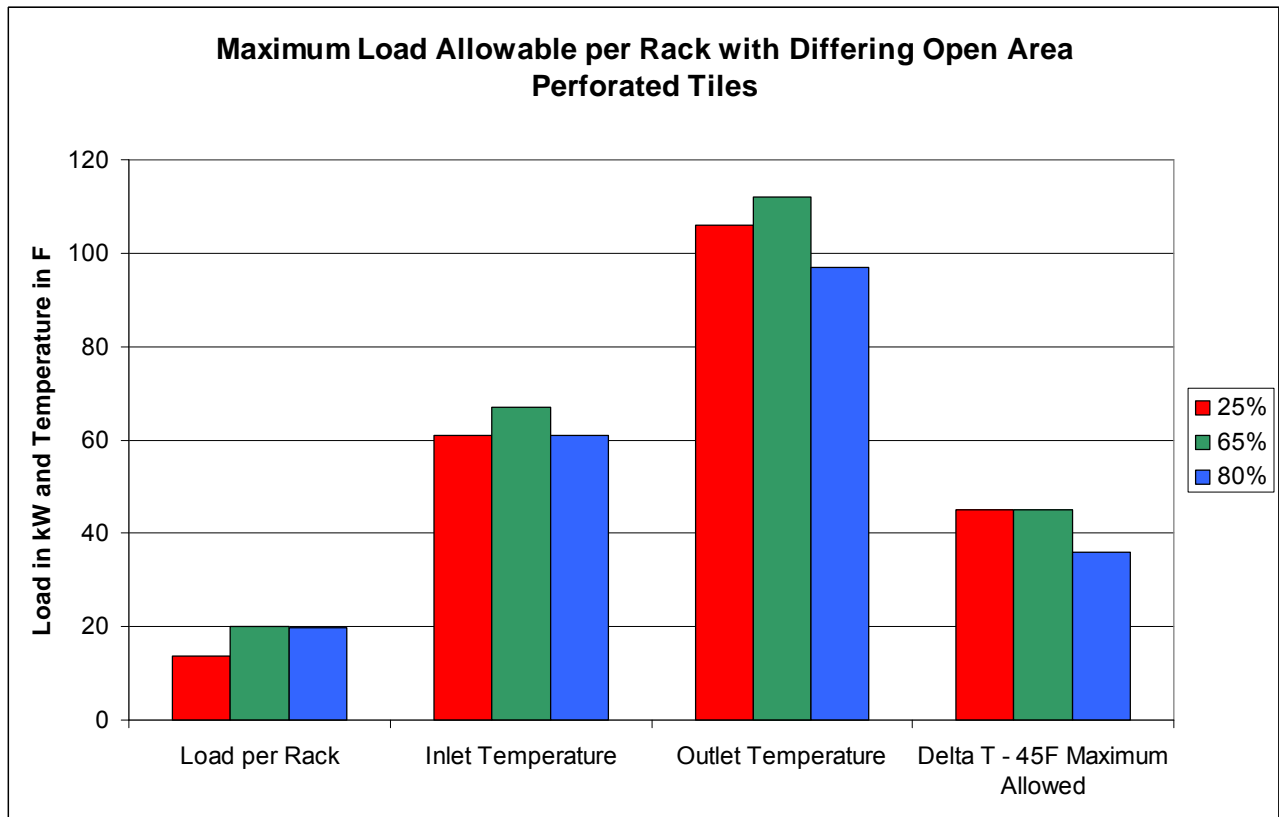


Figure 4 - Maximum Allowable Load

Operation with 25% Perforated Tiles

Since 25% perforated floor tiles continue to be deployed in data centers, a base line of data using these tiles was considered desirable. (Figure 5) During testing, the CRAC units were turned on as required until all three units were running at full capacity. The noticeable dips in test data show the points where CRAC's were turned on. Inlet temperature increased slowly as the CRAC units were loaded, but more importantly, the ΔT in many cases was deemed unacceptable. During lower load testing, a single CRAC unit was unable to maintain the ΔT within an acceptable range. This was apparently the result of the high pressure drop caused by the 25% perforated tiles. Running multiple CRAC units simultaneously would have alleviated this issue, but, as will be shown, increased floor tile perforation percentage showed a reduced pressure drop without the added cost of operating additional CRAC units.

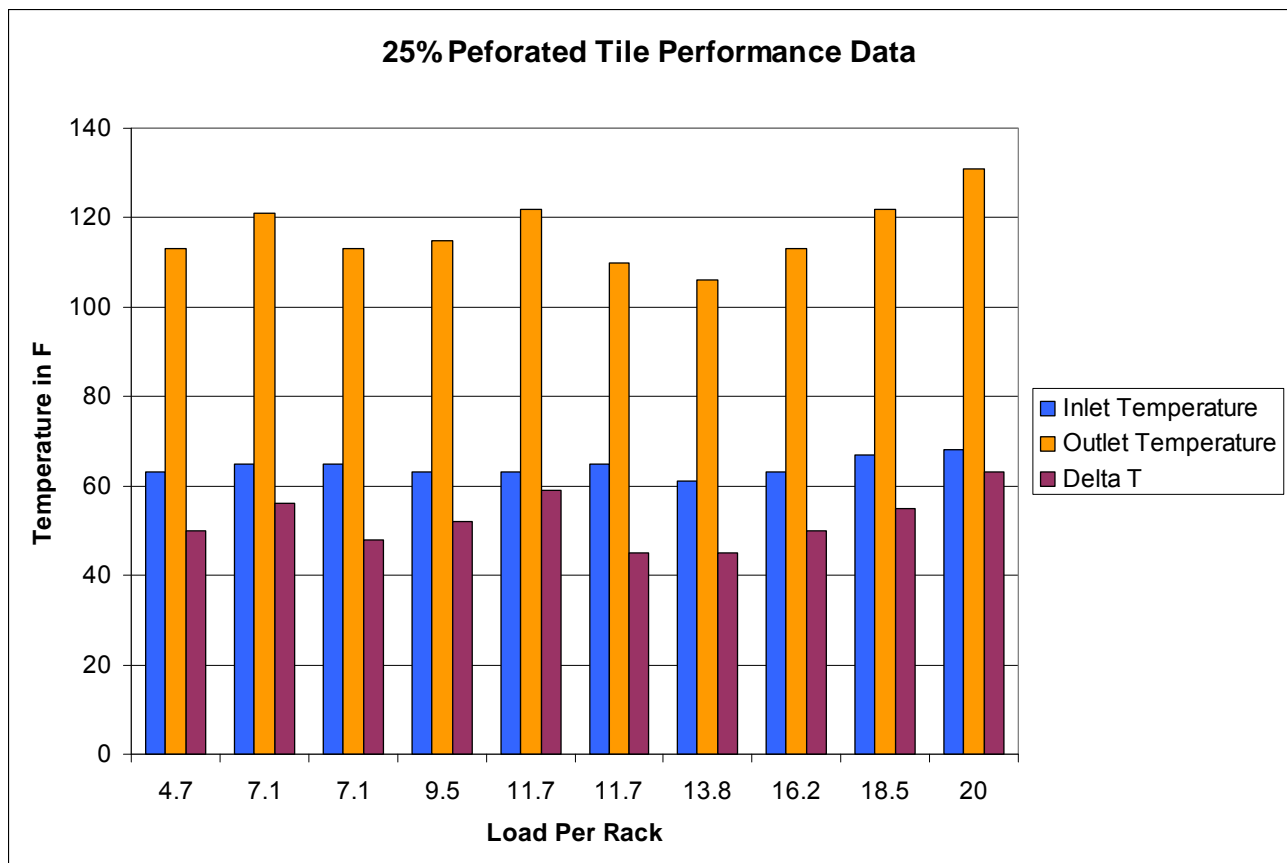


Figure 5 - Performance with 25% Perforated Tiles

Operation with 65% Perforated Tiles

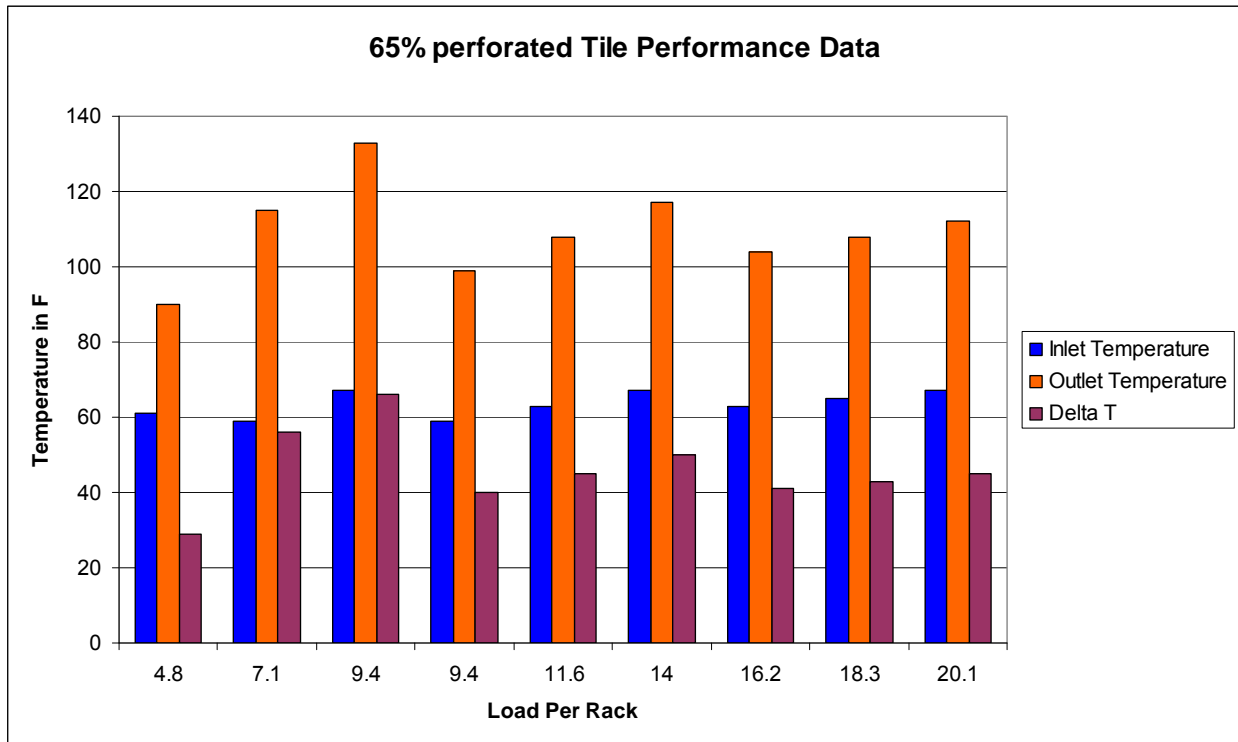


Figure 6 - Performance with 65% Perforated Tiles

65% Perforated tiles were chosen as an operational standard. The majority of testing conducted during both weeks utilized 65% tiles. See Figure 7 for details of system operation clearly showing the ΔT values reduced to acceptable levels. Figure 7 also shows the steady state operation of the system. Each rack was set to a 20kW load with all 3 CRAC units operated at full capacity. Each CRAC unit brought all of its compressors online to handle the maximum load, with steady state operation achieved after approximately one hour. Peak temperature increases were not noted until the full thermal capacities of the CRAC units were reached, at which time the load was reduced. The average ΔT was approximately 30°F, not the worst-case scenario of 45°F as described earlier.

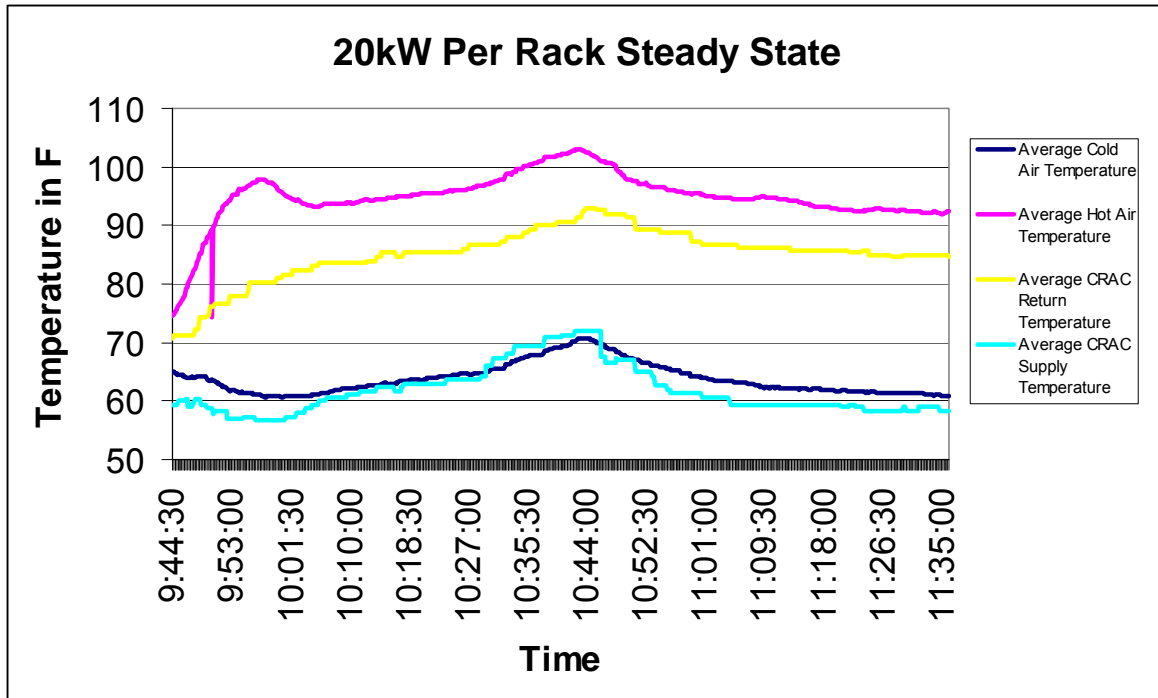


Figure 7 – Steady State – 65% Perforated Tiles 20kW Per Rack

Operation with 80% Perforated Tiles

Testing with 80% perforated tiles was conducted only at a 20kW/rack load after determining that the 65% perforated tiles had performed adequately at all test load points. The purpose of the 80% perforation testing was to see if any significant improvement in the ΔT numbers over the 65% perforated tile testing could be realized. Figure 8 shows the steady state comparison. Note that the ΔT remains very similar, averaging in the 30°F range, when compared to the 65% perforated tiles. This indicates that the load banks received sufficient air volume when using the 65% perforated tiles. The greater volume of airflow utilizing the 80% perforated tiles did, however, reduce the peak temperatures noted during the test shown previously in Figure 4. With ΔT considered a greater concern than peak temperature (provided the peak temperatures were deemed acceptable), the tests demonstrated that the 65% perforated tiles performed as well as the 80% perforated tiles.

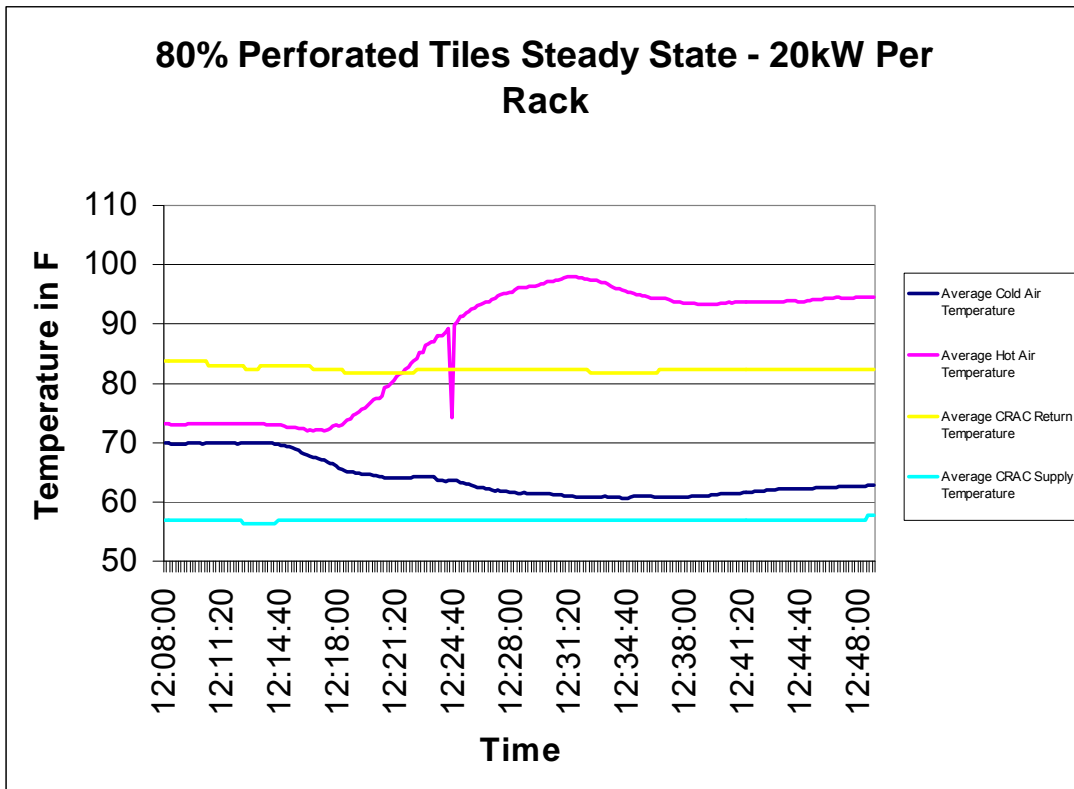


Figure 8 - 80% Steady State Averages - 20kW Per Rack

Key Point: A lack of stratification of cold air temperatures delivered to the load banks in the CAC was observed during all tests. During the 80% testing, the standard temperature deviation averaged 1.87°F, considered excellent given typical readings taken in most data centers.

Removal of Cold Aisle Containment

Data centers are not typically built with any means to separate and/or contain the cold or hot air streams in data center spaces. Recirculation and mixing occur, reducing the overall ability of the mechanical system to reject the heat from IT loads. Comparing data with containment to data without containment was one goal of the test and considered necessary to determine the true load capacity of the mechanical cooling system. This comparative data illustrates the gains achieved by using a cold aisle containment system.

To demonstrate this, the doors and roof panels of the cold aisle containment system were removed and the aisle was fitted with standard 65% perforated tiles. The system was started with a single CRAC unit operating, with additional CRAC's brought online to prevent server temperature runaway as additional load was added. (See Figure 9)

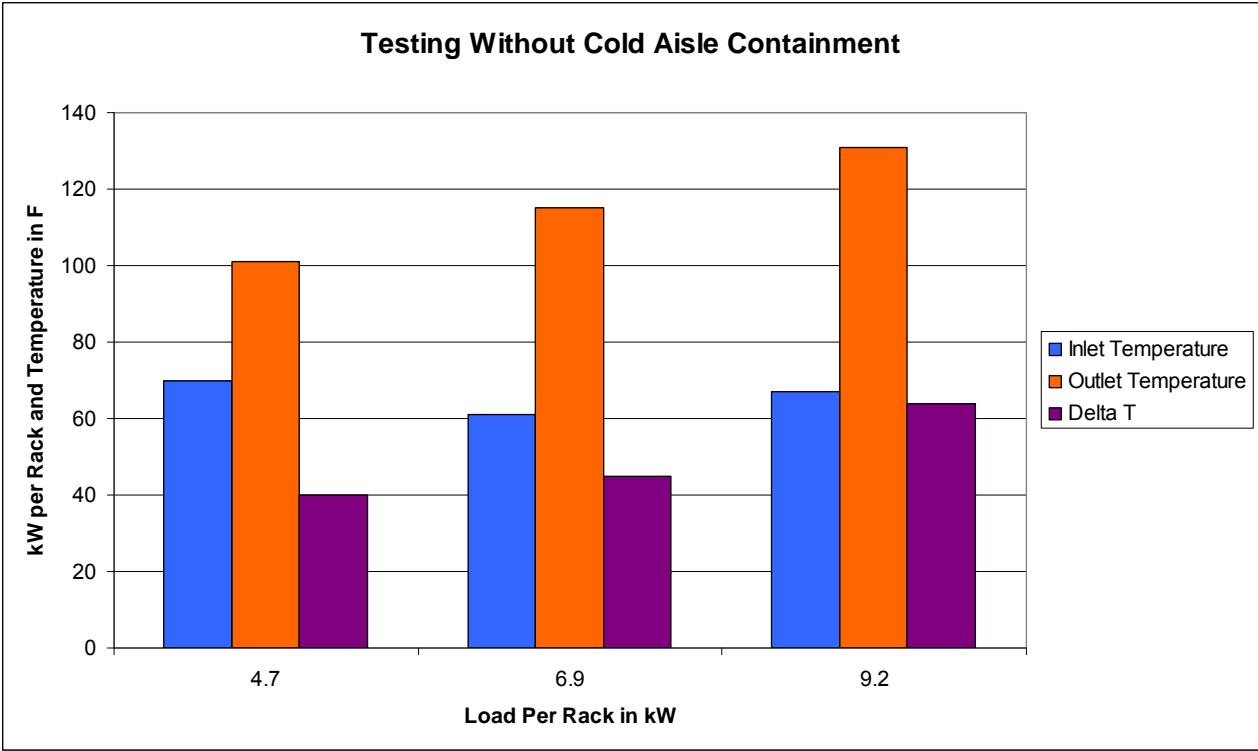


Figure 9 - Load Testing Without Cold Aisle Containment

Please note that for all testing above 6.9kW per rack, the ΔT observed was found to be unacceptable. Even assuming high ΔT servers, the maximum load achieved during testing without containment was 11.5kW per rack. The maximum load was determined when the load banks went into thermal overload, much like a typical server would. It is clear from the data that cold aisle containment resulted in significant performance improvements over the non-contained aisle testing. This is assumed to be a result of the complete elimination of air mixing and the slight pressurization of the cold aisle when the containment system was utilized.

Comparing Cold Aisle Containment to Traditional Open Systems

Further analyses of collected data are necessary for IT and facility personnel to determine whether or not a data center architecture utilizing a cold aisle containment system is suitable for their needs. There are two easy ways to compare the systems. First, to employ PUE (Power Usage Effectiveness). This is simply comparing the ratio of energy consumed by the entire system, to the power consumed by the IT load. Figure 10 illustrates this.

Figure 11 illustrates the impact on a second important efficiency number from a cooling perspective—kW/Ton, which is the number of kW required to provide a given ton of cooling.

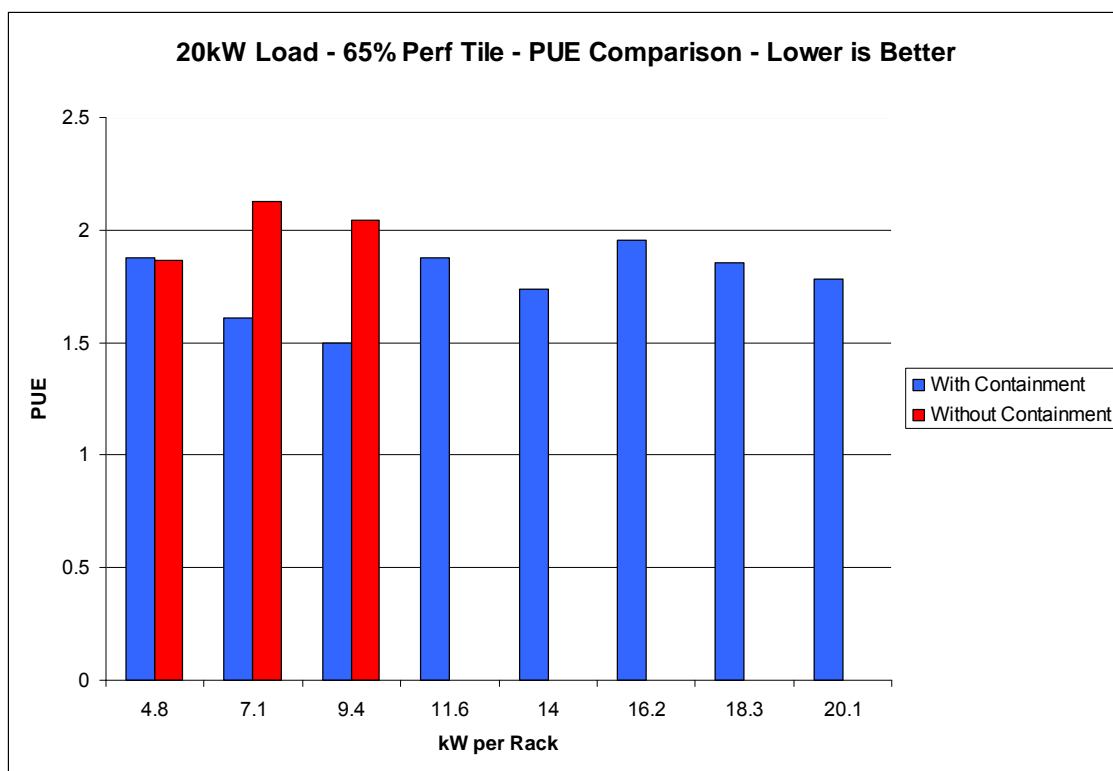


Figure 10 - Impact of Cold Aisle Containment on PUE

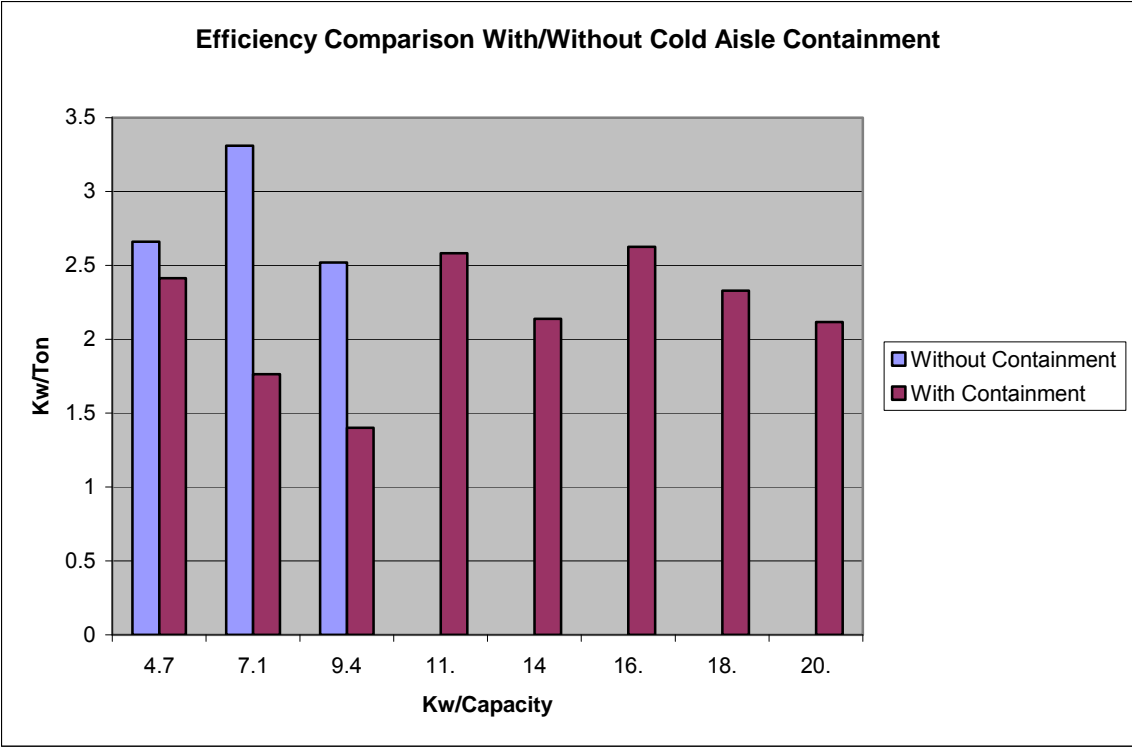


Figure 11 - kW/Ton Comparison

Failure Analysis: What happens when something goes wrong?

Typical data centers operate with some level of facility, system and component redundancy. The ability to overcome unforeseen failure events is critical for any data center. During the second week of testing, a number of failure scenarios were simulated to determine the impact of the cold aisle containment on different fault condition scenarios.

Generator Startup / UPS Fail Over

Most data centers are designed with a UPS (Uninterruptible Power Supply) system that provides emergency power to IT loads during a loss of utility power. Usually, these systems supply power only to the IT load when utility is lost, resulting in the loss of cooling. To replicate this failure during the cold aisle containment testing, a steady state load consisting of 10 racks at 20kW apiece was established. All CRAC units in the test setup were running. At precisely the same instant, all of the CRAC units were de-energized at their disconnects, resulting in the total loss of air flow to the cold aisle containment system. After approximately 30 seconds (to simulate emergency generator start up) the 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 single load bank was lost on a thermal overload. Figure 12 shows the impact on the temperatures in the data center.

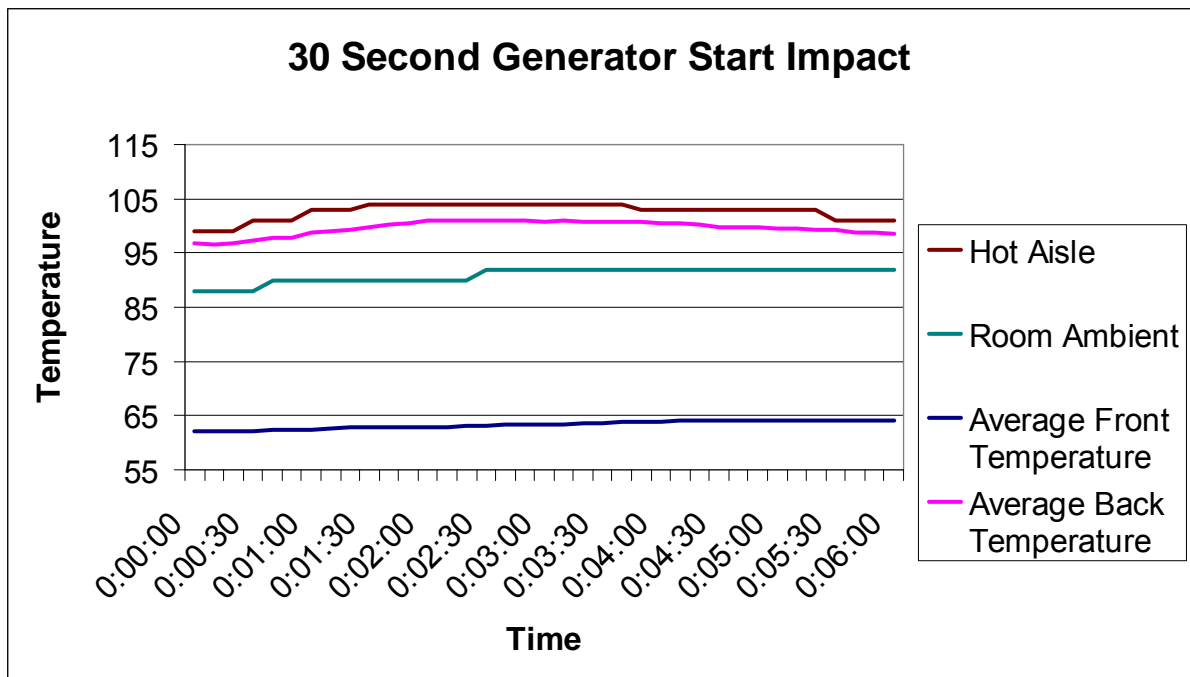


Figure 12 - 30 Second Generator Start Impact

As seen in Figure 12, the generator restart resulted in a temporary increase in the hot aisle temperature, as was expected due to the loss of airflow. The shutdown also impacted the cold aisle temperature; undoubtedly due to the extra thermal energy that the CRAC units were required to dissipate after restart.

Impact of Opening the Cold Aisle Containment Doors

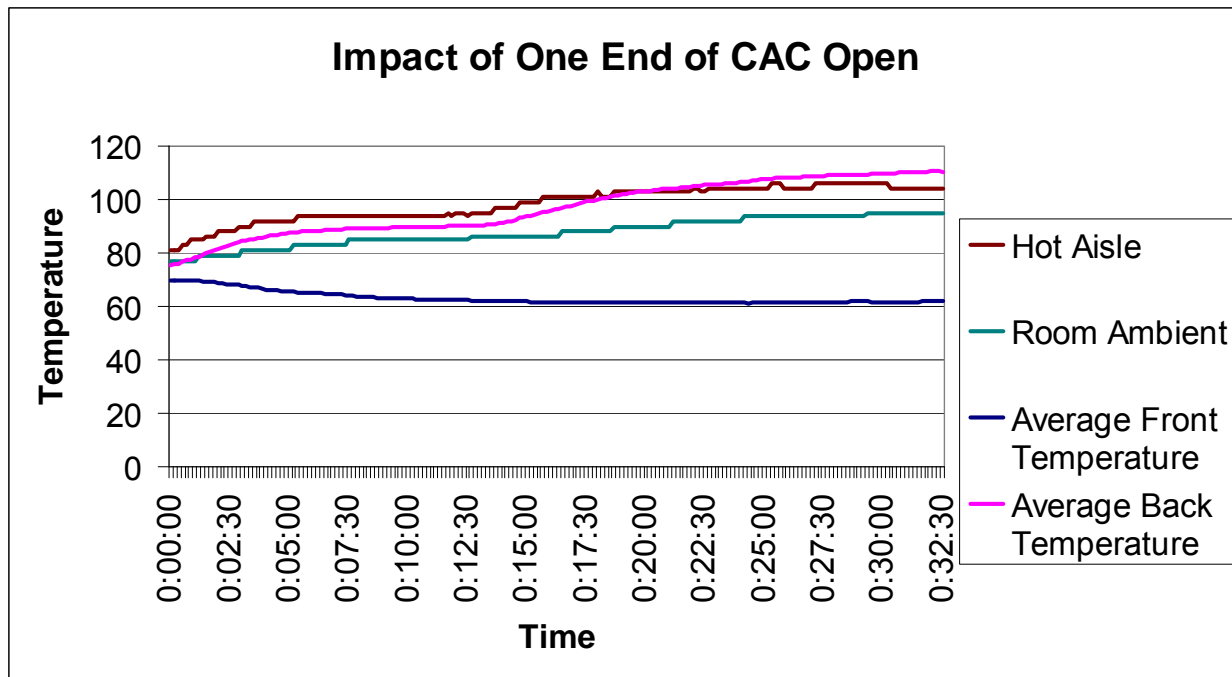


Figure 13 - Impact of One End of Cold Aisle Containment Open

Personnel activity is a normal, day-to-day reality in a data center. Unfortunately, these movements can disturb the air paths that are required to maintain a sealed cold aisle containment system. These impacts are usually momentary, but what if a row end door of the cold aisle containment space was opened for over 30 minutes when running at 20kW per rack? Figure 13 illustrates the impact of this condition. As can be seen, room ambient temperature, as well as hot aisle temperature, increased due to the short cycling of air from the cold aisle back to the CRAC units. This did reduce cold aisle temperature due to the lower temperature of air being cycled directly to the CRAC units. Even in this state, however, the air temperature to the servers was maintained within the normal operating range, and although the ΔT rose due to lower air volumes being provided to the servers, the ΔT was still within established guidelines.

Impact of Losing a Single CRAC Unit

The system that was tested would be considered an "N" redundant solution since all CRAC units were required to be operational to support the 20kW/rack IT test load. Although many data centers operate in at least an N+1 redundant configuration, what if this weren't the case? During the second week of testing, the system was operated at a steady state of 20kW/rack, and then a single CRAC unit was shut down. The results are shown in Figure 14.

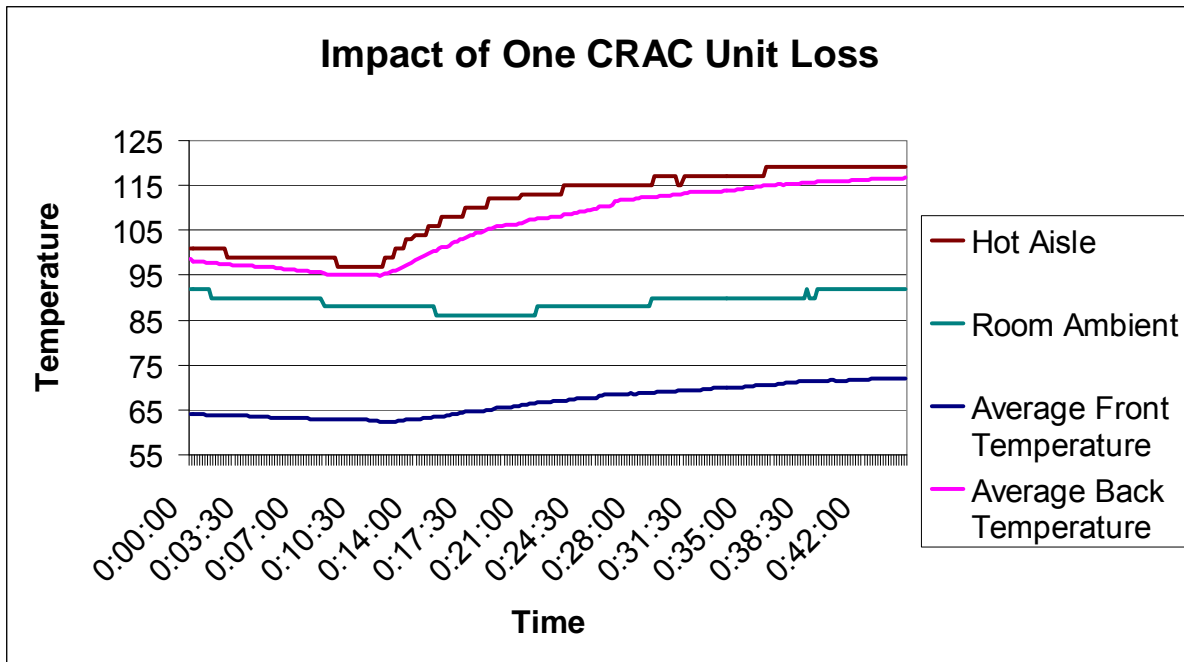


Figure 14 - Loss of a single CRAC unit

Notice that the ΔT increased quite rapidly, and inlet temperature to the load banks was affected over time. The two remaining CRAC units were rated for a theoretical 70kW capacity each, but with the loss of one of the CRAC units, the remaining two units were able to support 100kW each. By the end of the test, it was determined that the load was indeed stable at these conditions, allowing sufficient time for repair of the “failed” CRAC.

Impact of Losing Two CRAC Units

In the above scenario, it was shown that the loss of a single CRAC unit did not cause a failure of the system and that the test load was supported. If a second CRAC unit were lost after the two units had initially stabilized the load, what would the impact be? This scenario was simulated and the results are shown in Figure 15. As can be seen, the system quickly goes to a critical thermal runaway resulting in the loss of the IT hardware within only a few minutes.

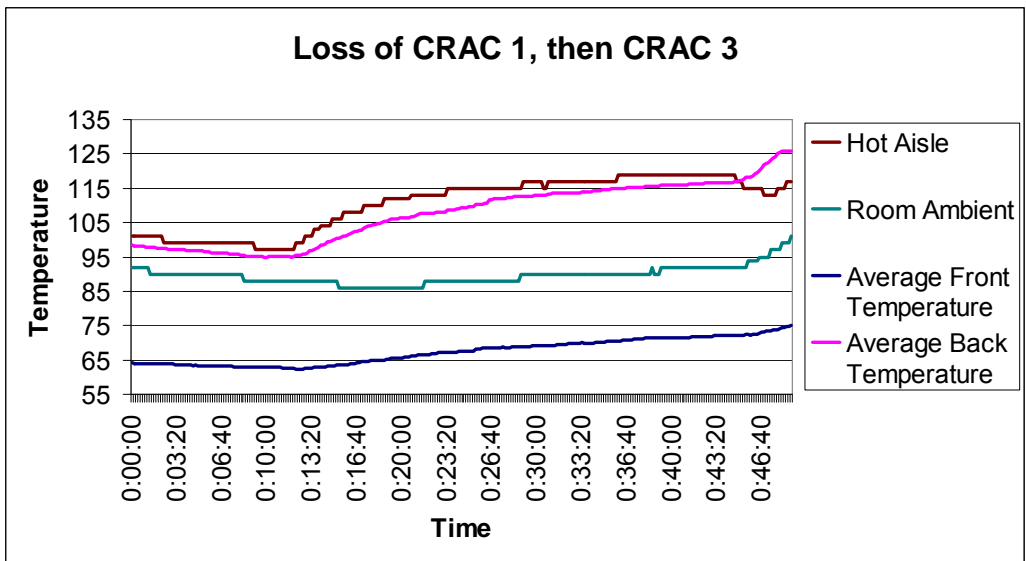


Figure 15 - Loss of CRAC Unit 1 than CRAC unit 3

Impact of losing two CRAC units simultaneously

In this failure scenario, the load was brought to a stable point of 20kW/rack, and then two CRAC units were shut down simultaneously. As shown in Figure 16, the temperature rise was steady, but the load was not lost for approximately 14 minutes. This, and the previous scenario, illustrate the necessity of redundant CRAC units to support various failure conditions.

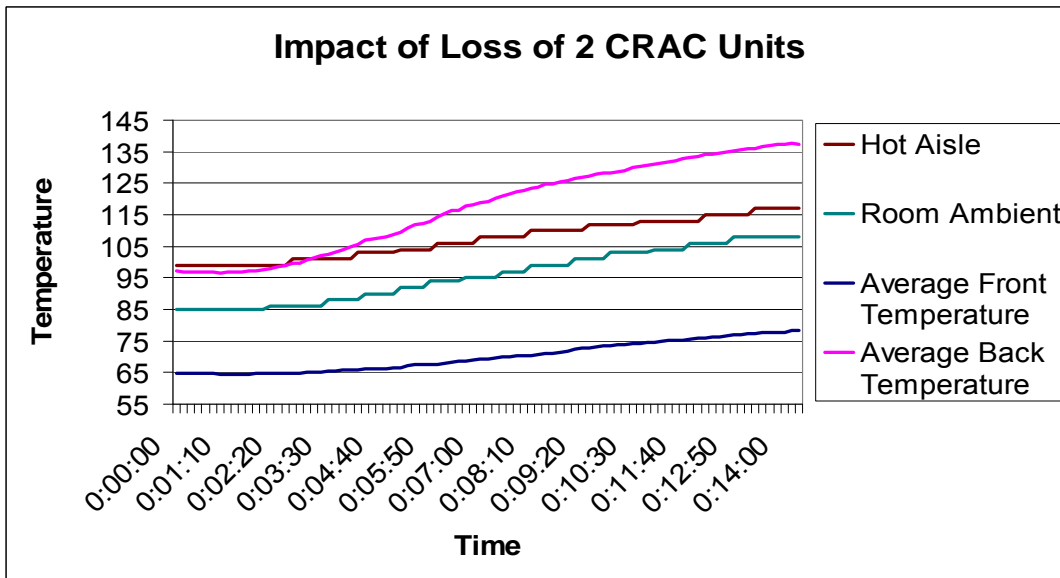


Figure 16 - Loss of Two CRAC units

Loss of All CRAC Units, Various Loads

A worst-case condition of complete failure of the mechanical cooling system was also considered. What would happen if the data center or cold aisle containment system were to lose all CRAC units at once and they were not restored? Figures 17-20 show the impact of this condition under various rack loads.

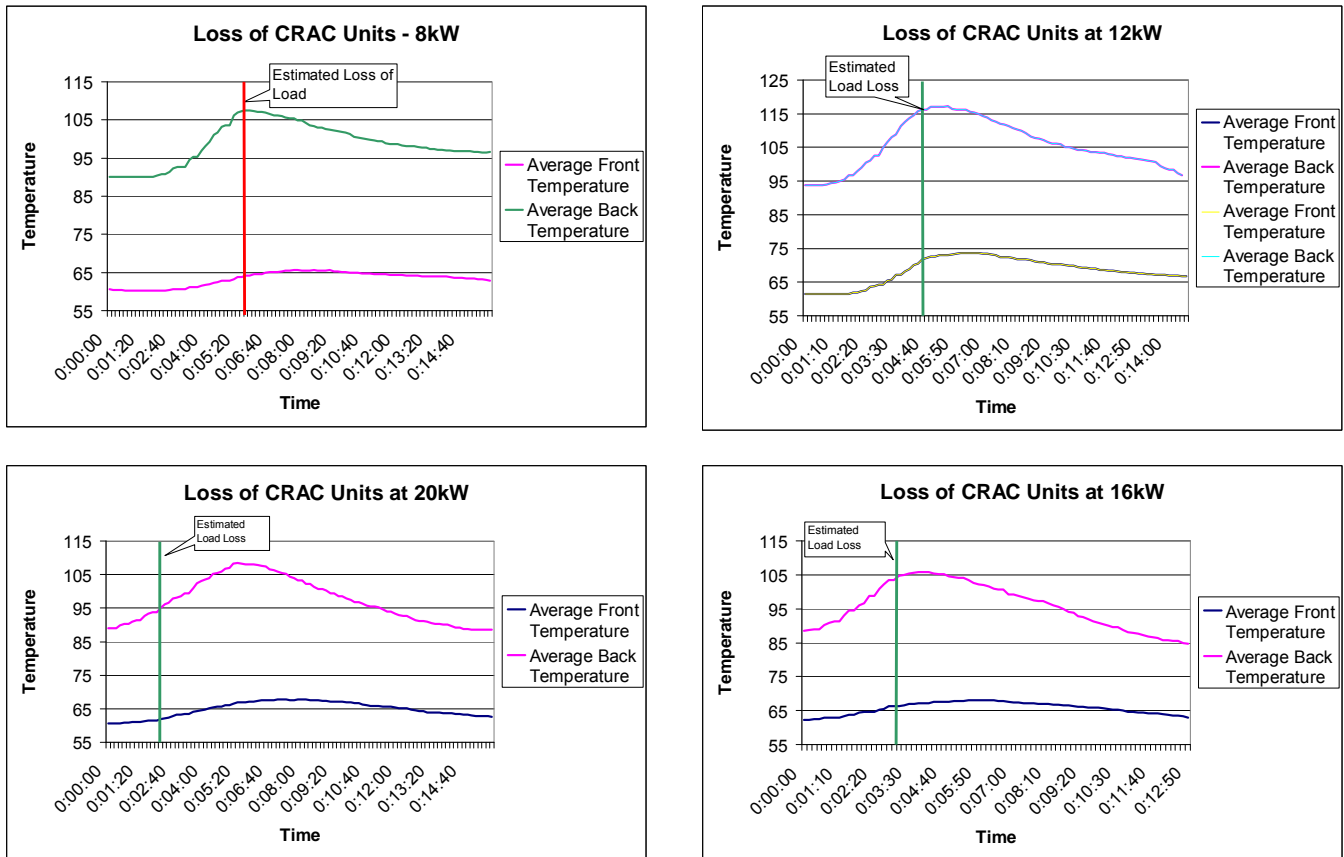


Figure 17-20 - Loss of CRAC units at various loads.

Removal of Tiles Throughout the Data Center

Another possible failure scenario that could occur would be the removal of multiple tiles in the data center for under-floor work such as running cable. These types of intrusions into the raised floor are important to understand, as the loss of cold air from the raised floor may result in a reduction of air supplied to the cold aisle. Figures 21-26 show the impact of this scenario on both supply and return air temperatures.

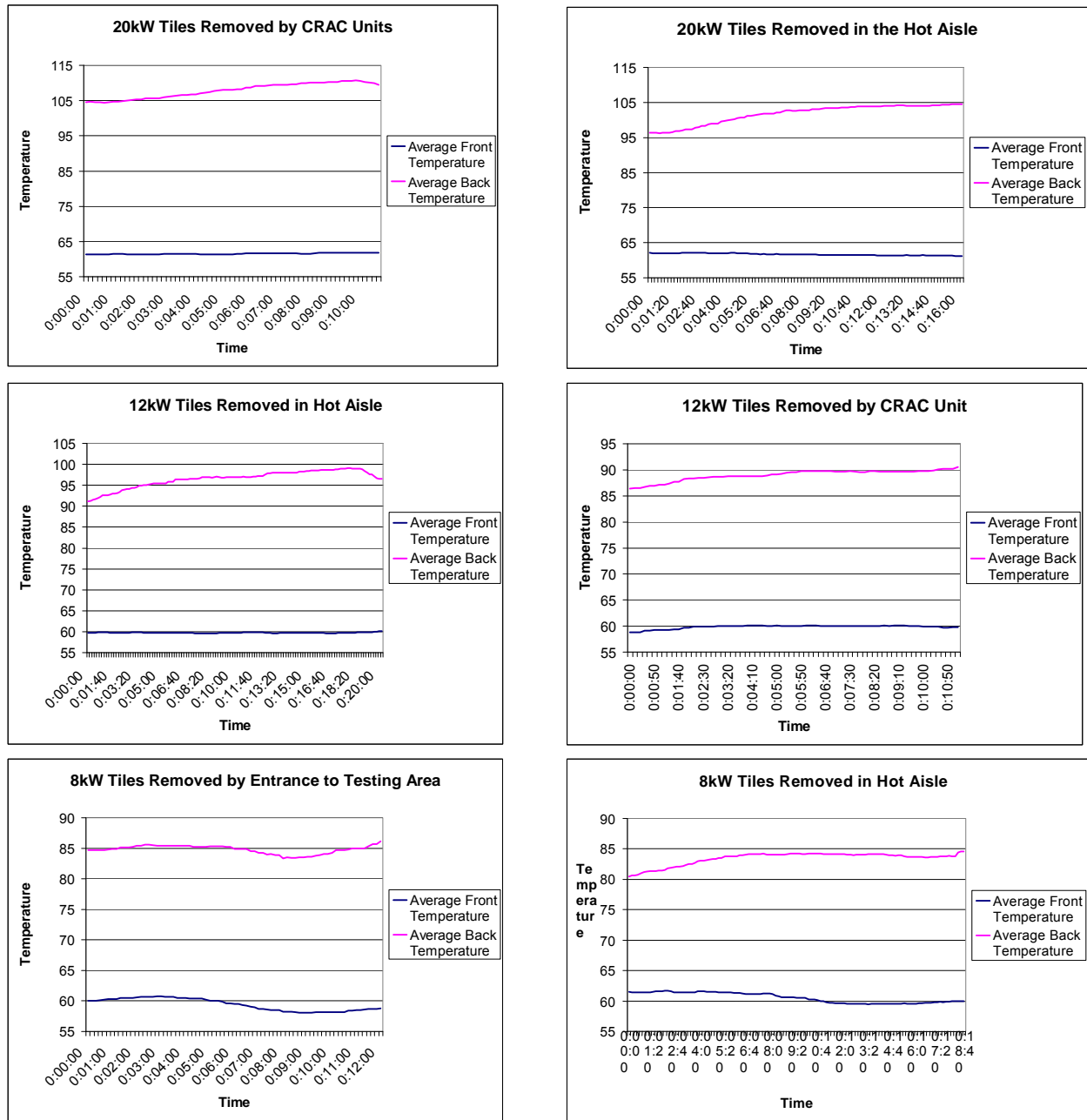


Figure 21-26 - Impact of Tile Removal

Impact of Outdoor Ambient Temperature

While not often considered, this subject is important to address when considering the use of DX (Direct Expansion) type air-cooled CRAC units (as used in this test program). During part of the

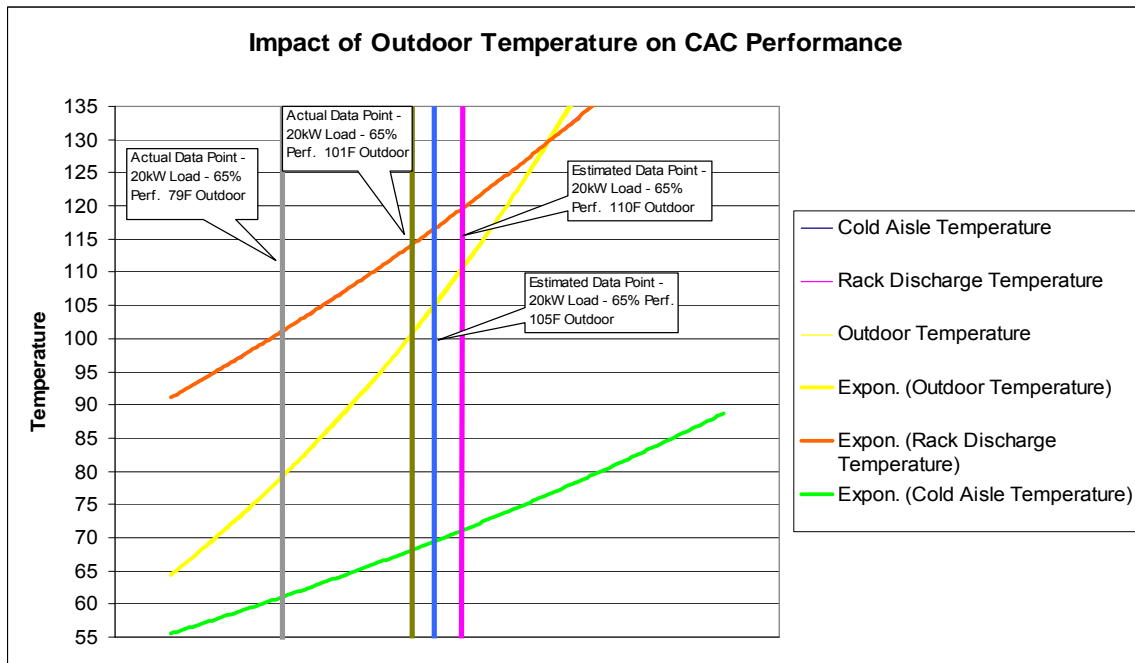


Figure 27 - Effect of Outdoor Ambient Temperature on CAC

testing, the outdoor ambient temperature was approximately 79°F, but in the first week of testing reached 101°F. The data showed a noticeable trend suggesting a link to the outdoor temperature. A worst-case outdoor temperature in the Dallas-Metro area was expected to be 110°F. This temperature point, as can be seen in Figure 27, was expected to result in cold air temperatures of up to 71°F and hot air temperatures of up to 120°F based on the values recorded earlier. These are expected to be maximum worst-case values. Average values would be reflective of the same temperature rise, but overall the operation of the installed equipment would be unaffected.

Cost Savings Analysis: CapEx and OpEx

Although the preceding data is valuable in understanding the operation of a cold aisle containment system, potential operational and installation cost savings are also important to explore. Table 1 illustrates the CapEx (Capital Expenditure) and OpEx (Operational Expenditure) savings that can be realized from a relatively small cold aisle containment system.

The operational efficiencies data seen in Table 1 show that, on average, when considering a load of 10kW/rack, a single 20-Ton CRAC unit has the effective capacity of 50kW when used without containment and a capacity of 70kW per unit with containment. This improvement results in a reduction of the total CRAC units required Day 1, thereby reducing CapEx costs and reducing overall costs throughout the year by virtue of lower OpEx.

Cold Aisle Containment Analysis of DX Air Conditioners

Number of Cabs	KW Per Cab	Total KW	Without containment 50KW per 20 Ton Unit Number of CRAC units	With containment 70KW per 20 Ton unit Number of CRAC units	Savings Less AC's Required	Annual Energy benefits	One time Purchase & install benefits
10	4.8	48	1.0	0.7	0	\$ -	\$ -
	7.1	71	1.4	1.0	1	\$ 28,611.00	\$ 49,500.00
	9.4	94	1.9	1.3	0	\$ -	\$ -
20	4	80	1.6	1.1	0	\$ -	\$ -
	6	120	2.4	1.7	1	\$ 28,611.00	\$ 49,500.00
	8	160	3.2	2.3	1	\$ 28,611.00	\$ 49,500.00
	10	200	4	2.9	1	\$ 28,611.00	\$ 49,500.00
40	4	160	3.2	2.3	1	\$ 28,611.00	\$ 49,500.00
	6	240	4.8	3.4	1	\$ 28,611.00	\$ 49,500.00
	8	320	6.4	4.6	2	\$ 57,222.00	\$ 99,000.00
	10	400	8	5.7	2	\$ 57,222.00	\$ 99,000.00
60	4	240	4.8	3.4	1	\$ 28,611.00	\$ 49,500.00
	6	360	7.2	5.1	2	\$ 57,222.00	\$ 99,000.00
	8	480	9.6	6.9	3	\$ 85,833.00	\$ 148,500.00
	10	600	12	8.6	3	\$ 85,833.00	\$ 148,500.00
80	4	320	6.4	4.6	2	\$ 57,222.00	\$ 99,000.00
	6	480	9.6	6.9	3	\$ 85,833.00	\$ 148,500.00
	8	640	12.8	9.1	3	\$ 85,833.00	\$ 148,500.00
	10	800	16	11.4	4	\$ 114,444.00	\$ 198,000.00

Actual readings

Air Conditioner	
Annual Energy (KW)	\$ 28,611.00
Purchase	\$ 30,000.00
Install	\$ 19,500.00

Table 1 - CapEx and OpEx Comparison

Conclusions

A key strategy to increase cooling efficiency that is currently being deployed in operational data centers and discussed by the IT market at large, is to maximize the separation of cold and hot air flow paths. Aisle containment has emerged as a relatively low cost and easy to implement solution. The testing of the Rittal Cold Aisle Containment system validated the assumption that utilizing a cold aisle containment system enables the data center environment to support higher density loads while providing a more efficient use of the environmental equipment. Increased efficiencies of up to 40% were achieved utilizing cold aisle containment in comparison to environments without containment. The CRAC units were able to support ΔT 's (supply/return) ranging from 75 – 100°F, depending on load conditions.

Environments can be built within existing data centers, utilizing cold aisle containment, to support 20kW/rack loads while most of today's data centers (without CAC) only support load densities of approximately 3-5kW per individual rack. These significant improvements can help extend the lifespan of many operational data centers. As a result, a reduction of the capital expenditure needed to maintain a company's computing environments is made possible by postponing the build-out of new data center space.

Although highly effective in existing data center spaces, when employed in the design of new data centers, Cold Aisle Containment can also help to maximize energy efficiency potentials and reduce both capital and operational expenses. In either case, Cold Aisle Containment provides a viable option to meet increasing computing demands in an efficient and cost-effective manner.

About the Author

Daniel Kennedy is Rittal Corporation's RimatriX Solution Center Coordinator and has been with the company since 2003. He holds a degree in Electrical Engineering and is the lead engineer for the design, implementation, and support of high density IT deployments in North America.