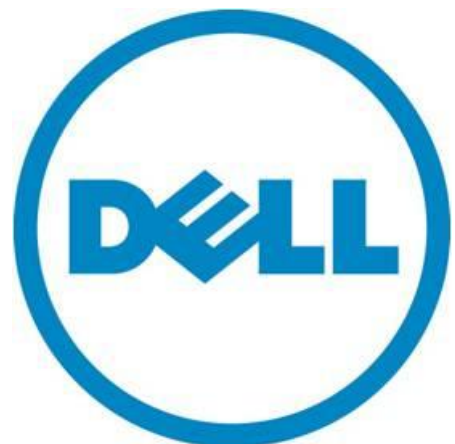


Managing Data Center Costs with Dell PowerEdge Energy Smart Containment Rack Enclosures

A Dell Technical White Paper

Dell | Data Center Infrastructure

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Introduction

Data center managers are faced with a multitude of options when considering the components that make up their IT cooling infrastructure. Room/row/rack, air/water/refrigerant, contained or not, passive/active...the list goes on. Dell believes there is no single right solution for everyone. The best option is the one that fits the needs of the data center and is the most cost effective for both capital and operating expenses (CapEx and OpEx). The Dell™ PowerEdge™ Energy Smart Containment Rack Enclosure fits this description for many organizations.

Containment Gains Ground

To operate efficiently, IT systems need a constant stream of cool air. IT inlets are almost exclusively located on the front of the equipment. Concentrating the room venting in a cold aisle and orienting the racks accordingly can take advantage of that concentrated delivery. Leveraging the hot/cold-aisle orientation strategy can provide the proper airflow and enable dramatic increases in rack density.

This is a smart strategy, but it can be improved by using containment, which is a growing industry trend. Without containment, the above-floor room dynamics are left to chance. Cold air is distributed into the whole room, and in order to provide enough air to the installed equipment, it may be necessary to overprovision the airflow. Additional air handlers are often employed, raising both OpEx and CapEx. Cold air bypass mixes and cools hot return air. Hot air infiltration into the cold aisle creates hot spots.

Why not contain either the delivery or the return? Containment provides intentional separation of the cold supply from the hot return, resulting in better distribution of air and elimination of hot spots. Whether using chimneys, curtains, hard panels, cold side, hot side, or the creation of a contained rear cavity when installing a rear-door heat exchanger, the industry is embracing this strategy to improve efficiency and reduce costs in the data center. It makes sense to cool the equipment, not the room.

If you have not implemented containment in your data center, you might want to consider some of the potential energy benefits that are highlighted in previous Dell studies on containment.^{1,2} Even if you are not concerned with energy, you might consider how containment can simplify your job. How often have you been uncertain if you were putting new systems into a location with adequate cooling? Containment can increase the certainty with which you deploy IT hardware.

¹ "The Energy Advantages of Containment Systems" by David Moss, 2009, <http://content.dell.com/us/en/enterprise/d/business~solutions~whitepapers~en/Documents~dci-energy-advantages-of-containment-systems.pdf.aspx>

² "Universal Application of Air Containment: A Practical Guide" by David Moss, 2009, <http://content.dell.com/us/en/corp/d/business~solutions~whitepapers~en/Documents~containment-systems-considerations-12182009.pdf.aspx>

A New and Different Containment Solution

Dell has developed a new containment solution to address the cooling concerns in the data center. The PowerEdge Energy Smart Containment Rack Enclosure adds some additional parts to our standard rack frame, transforming it into a stand-alone, front, cold-air containment system.

The front of the rack is extended almost six inches and has a solid, clear front door that forms a vertical air plenum in front of the IT equipment. For most of the rack's depth, an air channel in the lower section is compartmentalized, segregating it from the IT area and connecting it to the front plenum so that air coming from under the rack reaches the front plenum. This lower air channel (horizontal plenum) forms a tight seal to the floor, and it surrounds the floor venting with brushes placed around the perimeter of the plenum area. This tight seal is what allows the passive rack to deliver some unique advantages beyond what is achievable with other forms of containment. (This seal is not depicted in Figure 1.)

Figure 1. Dell PowerEdge Energy Smart Containment Rack Enclosure

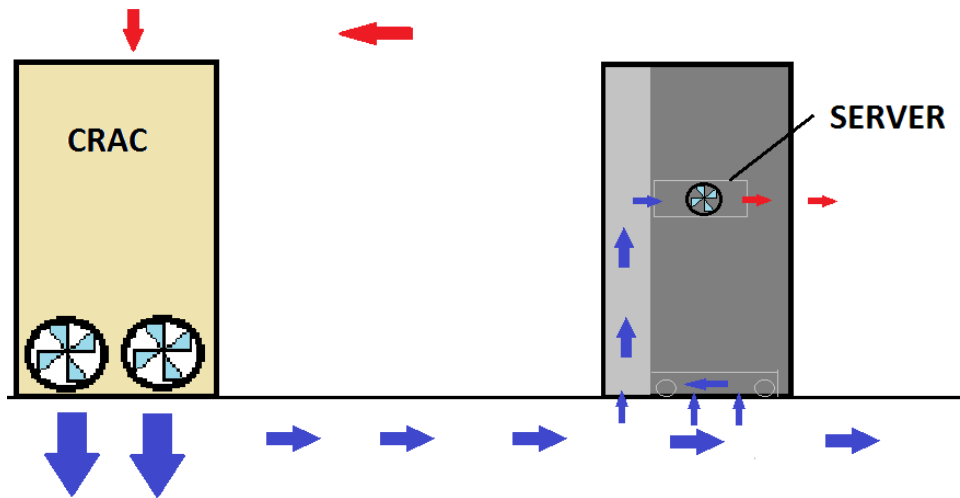


The Rack Design Difference

Most containment solutions still rely on room airflow dynamics for volumetric delivery. In cold-aisle containment, for example, the under-floor dynamics decide how much airflow reaches the cold aisle enclosure. Insufficient delivery relative to IT air consumption will result in warm air entering the typical loosely-contained cold aisle. With exhaust containment, such as aisle or chimney, you may need to be careful how many vents are placed in and around the cold aisle. If the IT equipment is consuming more air than is delivered to its cold aisle, the air will be drawn from elsewhere in the room. One benefit of hot aisle containment is that you can position vents outside but close to the perimeter of the cold aisle. However, if there are areas of the data center without exhaust containment, a cold-aisle deficit could cause air to be drawn in from the exhaust of another rack.

One of the key design elements of the PowerEdge Energy Smart rack is its ability to couple tightly to the raised floor. The rack's plenum becomes an extension, in effect, to the floor plenum, with the perforated vent tile under the rack providing airflow resistance. Even though the rack is passive, the IT equipment turns it into an active part of the solution. IT fans are strong and can overcome the relatively low-flow resistance across a floor grate. The fan algorithms in IT systems ensure that they receive the volume of air required to keep their internal components cool, even if that requires pulling more air from the floor than it would normally deliver on its own.

Figure 2. Energy Smart Rack Operation



Pulling Air Out of the Floor

In operation, there are two independent air-moving systems working on the raised floor plenum. The computer room air conditioning (CRAC) units are working collectively to push air into the floor, and the servers in the Energy Smart racks are working to pull air out of the floor. Where the CRACs leave off, the rack takes over. Typically, there is a point between 500-700 CFM (moving through an Energy Smart rack) where the pressure in the front plenum turns from positive (CRACs driving the flow rate) to negative. At this point, the servers boost what can be delivered from the floor through the rack.

When installing any amount of hardware, it is important to calculate how much air is needed for proper cooling and how the demand may impact other systems, whether they are all in one Energy Smart rack or across several racks with multiple air vents. The servers in the rack will always drive to consume their requirements, even if that means they are stealing air. When pulling more air through the rack than the floor can deliver, the servers are actually consuming slight increases in fan energy to ensure the flow is adequate. In a rack full of 1U servers, for instance, it would be about 1 watt per server (feasibly a quarter of one percent of the server's total energy). When the servers are pulling harder against the pressure within the rack, they are tapping into reserve fan speed.

A server fan will operate well below 50% of its maximum speed at 25°C (77°F) or less, assuming a typical server configuration and utilization profile. The reserve exists to cover full configurations running at 35°C (95°F) and under intense utilization. Some servers may have enough reserve left to handle most or all of the airflow loss during a fan failure. There is no specific density limitation for the Energy Smart rack other than limitations incurred by installed IT equipment in which the fan reserve has been depleted (maxed out on configuration, utilization, and temperature).

Distinct Advantages

High Density Support

Because the Energy Smart rack governs the amount of air coming out of the floor, it can attain higher densities, potentially replacing standard racks that are only partially full. It is no longer subject to the

dynamics under the floor. High densities can even be achieved in low pressure or congested areas: shallow raised floors, wire-cluttered raised floors, and even dead spots can all be overcome by the rack's ability to adjust flow from the floor. These three challenges, along with other variables such as raised floor pressure and the type of vent tile, all determine how hard the servers in the rack must work relative to how much of a role the CRACs play.

There is typically a large difference between operation at 35°C and 25°C. This difference results in a large fan reserve when running at 25°C or less. Dell plans to cover the density limitations and considerations in more detail in subsequent documentation.

One target benchmark is 25 kW at 25°C. Because of the large fan reserve typical at 25°C or less, the amount of fan reserve needed to counter pressure at flow rates typical of a 25 kW rack is less than the fan reserve required to operate at 35°C. If the intended operating temperature is 25°C then a 25 kW deployment should be achievable with most products, since the Energy Smart rack keeps temperatures very consistent within the plenum.

No Density-Based Segregation

It is often common to see density zones in a data center. Denser equipment will be segregated and treated separately from nominal racks. It may even be cooled by a completely separate strategy than the remainder of the data center. With the Energy Smart rack, there is no need to segregate. A 2 kW rack can easily coexist next to a 20 kW rack.

Energy Advantages

The Energy Smart rack enjoys the same advantages as other containment systems. The consistency of airflow temperatures resulting from directly integrated containment can enable increases in facility temperature resulting in dramatic energy advantages. Since it uses tight containment, it will control temperatures more consistently than most aisle containment systems (especially curtains). This offers increased savings opportunities. Furthermore, since containment helps correct the above-floor dynamics, using the Energy Smart rack in a data center can also lead to utilizing fewer CRAC units and reduced CRAC fan power if the recommended methods of control are in place.

At the system level, when containment corrects hot spots, there is an immediate drop in IT fan power for an instant savings. The tighter containment and consistent temperature of the Energy Smart rack may control the server temperatures better and result in a larger drop in fan power at a corrected hot spot.

Simplified Deployment

The Energy Smart rack can be deployed quickly, anywhere in the room, on an individual basis or in multiples. The rack is easily installed by positioning it over a ventilated tile. The data center room does not even have to adopt the hot/cold aisle strategy since the cold delivery is isolated from the room.

In contrast, aisle containment is built around a pod of racks aligned in multiples of two. It takes a special design using customized lengths, some cut to fit, and on-site assembly to deploy a pod of aisle containment. There are aisle containment pods in some of Dell's data centers that may take months to fill with IT systems. Until that time, racks sit empty of equipment and full of blanking panels. If using row coolers, they may be left mostly off until enough hardware is deployed to require them.

Although the pod strategy is a great way to create a repetitive, predictable pattern of deployment, it requires a significant up-front investment and doesn't effectively leverage the "pay as you grow"

benefits of modularity. In contrast, the Energy Smart rack can be purchased and deployed one at a time.

Although there are other rack products or containment solutions that may provide similar functionality, only the Energy Smart rack offers a completely passive stand-alone containment system that pulls only the amount of air the IT equipment consumes. It has no restrictions on the airflow CFM it can handle. With no modifications needed to data center facilities for power, water, or refrigerant, the Energy Smart rack is easier and more cost-effective to deploy.

Lower the Cost of Redundancy

The Energy Smart rack can help even out distribution deficits during a failure. Consider the example in Figure 3.

Figure 3. Pressure Map Under Floor

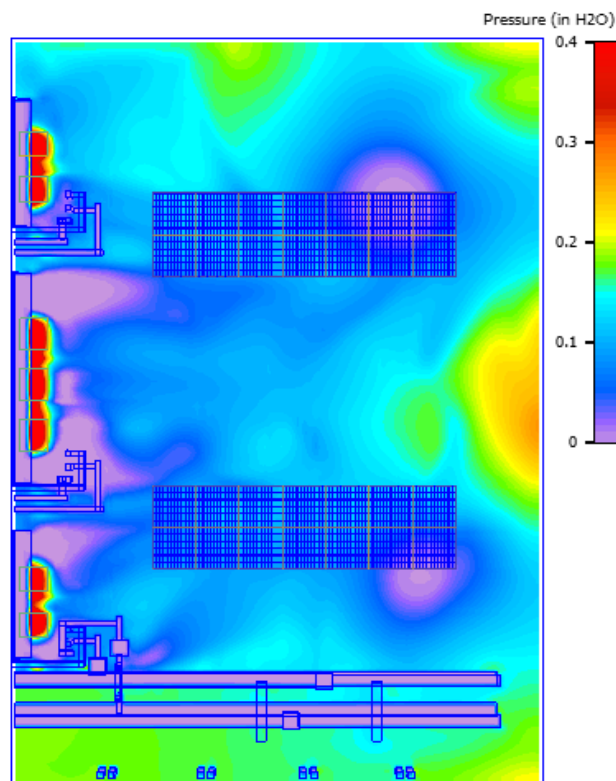


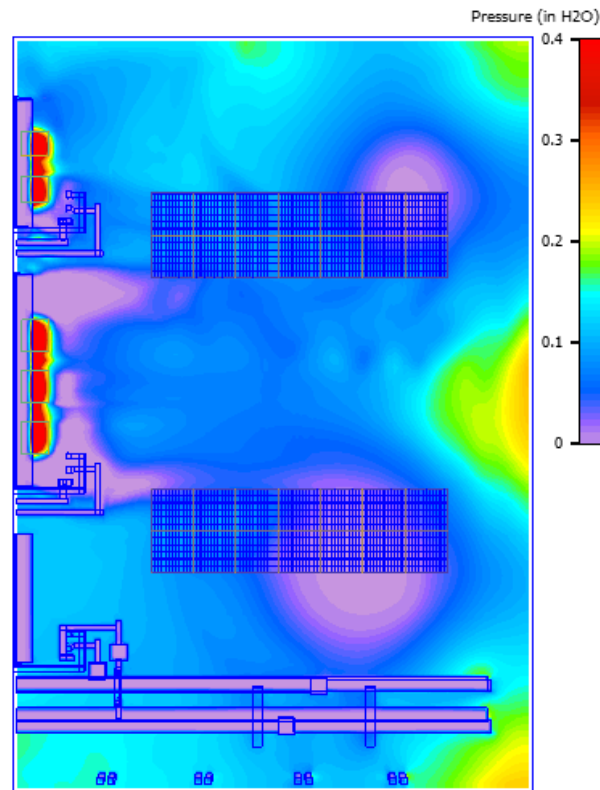
Figure 3 shows a pressure profile of the under-floor cooling of a research lab at Dell. Red shows high pressure, purple indicates zero or negative. There are three CRACs along the left wall; the middle delivers twice the flow of the two flanking CRACs. There are two cold aisles; each has a low pressure region due to a natural vortex where the air wraps back around itself. These are common occurrences where air streams of different CRAC units meet or hit walls. Vents above each vortex are severely affected.

Since the top one is more prominent and has a larger intersection with the vents, the flow to that aisle is less than the flow to the lower aisle. Of the total flow from three working CRACs, 47% gets to the top aisle, and 53% gets to the bottom. Imagine hot aisle containment applied to this scenario. The flow

discrepancy probably would not matter. You could deploy just as much equipment in either aisle. Now imagine cold aisle containment with this scenario. The captured upper aisle is only receiving 47% of the flow. To deploy equal amounts of equipment in the upper aisle, you'd either have to increase the venting in the upper aisle or decrease it in the lower aisle.

Consider what happens if one of the CRAC units fails, as shown in Figure 4. If one of the outer units fails, approximately a quarter of the total flow has been lost (again, the middle CRAC delivers about twice the flow as the outer two CRACs).

Figure 4. Pressure Map Showing Failed CRAC



The vortex at the bottom has grown significantly. Its effect on the air available to that aisle causes a drastic drop in flow. Even though the total flow dropped 25%, the bottom aisle is receiving only 30% of the original flow, and the top aisle receives 45%. If you were to size the equipment deployment in the bottom aisle to survive a failure of the bottom CRAC, you could only count on 30% of the total room flow.

Similarly, when the top CRAC fails, the top vortex grows. Its effect drops the top aisle flow to only 25% of the total. So if you were to size the equipment deployment for both aisles and want to ride through a CRAC failure, you could only rely on 30% and 25% of the total flow rate. Because of under-floor dynamics, the disparity of flow would cause you to plan on the loss of flow rate of almost two entire CRACs to cover the failure of either one of the two outside CRACs.

The Energy Smart rack corrects these disparities since it consumes only what it needs and can redirect flow under the floor. In this particular example, you need N+1 to cover a failure using Energy Smart

racks; you would have to resort to N+2 to cover the same amount of equipment with cold aisle containment.

Energy Benefits

There are some interesting methods of CRAC control which can stretch CapEx and improve OpEx. Coupled with the Energy Smart rack, the benefits are augmented. Under-floor static pressure control for CRAC unit airflow is not yet common, but it is gaining in popularity and it is a perfect match for the Energy Smart rack.

When the servers in the rack cause a change in flow out of the floor, they would cause a change in under-floor pressure if the CRACs are constant speed or have temperature-based airflow control. If the racks affect the pressure, and the CRACs are controlled by pressure, there is essentially a dynamic coupling opportunity through the raised floor. When new racks are added, they take their required consumption from the floor, and the CRACs can respond with additional air. If the racks scale dynamically throughout the day, the CRACs can also respond.

Static pressure control can also help adjust to today's hotter (or more efficient) IT equipment. In the quest to save energy, today's IT equipment consumes much less airflow per watt than its predecessors. As a consequence, the temperature rise (delta-T) through the equipment is much higher. In fact, the temperature rise is exactly proportional to the IT power (heat) and exactly inversely proportional to the flow rate, per the equation below:

$$Q = m C_p \Delta T$$

Q is the power (heat), m is the mass flow rate, C_p is the specific heat or the amount of heat the fluid (air) can hold, and ΔT is the temperature rise (delta-T).

Several years ago, we might have used 25 CFM to cool 200 watts, whereas today we may be cooling 400 watts with the same 25 CFM. A 50°F delta-T is not impossible or unrealistic. Unless you purchase a high delta-T cooling coil, it is typically designed for a delta-T of around 25 degrees which is quite a mismatch with some IT equipment.

Figure 5. Temperature Rise for IT Equipment



$\Delta T = 25^\circ$



$\Delta T = 50^\circ$

How do you cool equipment with 50°F delta-T with infrastructure that only supports 25°F delta-T? The easiest answer is probably the most prevalent: use twice as many CRAC units.

The extra air bypasses the IT systems and cools the return air and turns it into a net 25°F product. This is obviously not the best answer. The CRAC unit can be stretched to an extent. As it hits 100% utilization, the valve will not open any further, and the fans are running full speed. If return

temperature continues to climb, the unit can take on more heat and, in a sense, overdrive on tons. The supply air temperature will start to rise at some point as well. By overdriving the unit, its delta-T may be approaching a 50°F delta-T (but it is not likely to get close to this).

There is another way to further increase the CRAC's delta-T and hopefully cool more equipment with fewer CRAC units. The previous equation also works for CRAC units. If you can lower the mass flow for the same heat absorption, you can raise the delta-T. Static pressure control is one way to do this, and it is a perfect match for the Energy Smart rack. If CRAC units are operating based on return air temperature, rather than static pressure control, they will still be compatible with the Energy Smart rack, but they will not be able to respond to the server demands as effectively and will be less efficient in terms of fan energy (which translates to higher costs of operation). Dell recommends using static pressure control as the optimal configuration for CRACs being used with the Energy Smart rack. The best way to illustrate this is using test data.

A test was set up in the same research lab for Figure 3 and Figure 4. Rack loading was turned on to load the CRAC past its fully rated load so the chilled water valve would remain open. The lab is set up with static pressure control, and the IT load had a high delta-T. Static pressure readings drove the Variable Frequency Drive (VFD) (speed) control for the CRAC down to 78%. After stabilization, as seen in Figure 6, the supply air temperature was 60°F and the return was 98°F (a delta-T of 38 degrees). This is a unit whose delta-T at its highest-published return temperature of 85°F is only 27°F.

Figure 6. Static Pressure Control: 78%



In Figure 7, the CRAC fans were forced to 100% by turning up the static pressure set point. This drove the delta-T down to 30°F. It also drove the supply air temperature up three degrees. The first test was repeated and temperatures returned to original levels in Figure 8.

Figure 7. No Static Control: 100%

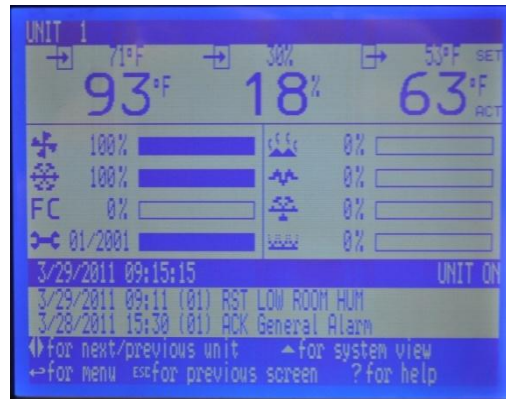
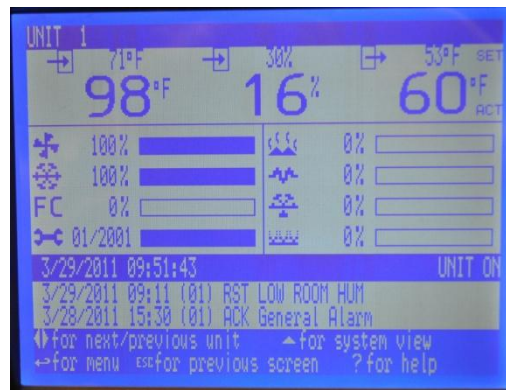


Figure 8. Test 3: Repeat of Test 1



Disregard the 100% reporting of flow rate in Figure 6–Figure 8. These depict the VFD signal internal to the CRAC, not the resulting operating point. The CRAC VFD is controlled externally, bypassing the internal control. The first and last tests are what you would expect with standard return air temperature control; the chilled water valve is 100% open, so the flow would also be at max speed. 0 is reflective of this lab’s static pressure control. The static pressure control allowed the CRAC fans to spin down 22%. This increased the delta-T 26%, due in part to a reduction in the supply air temperature (SAT).

Where was the extra air going when the CRACs were spun up to 100%? There are typical leaks around the room—floor tiles leak to an extent, there are a few minor floor penetrations, there are leaks around the CRAC units, and the other two CRACs were turned off (backflow).

Why did the SAT go down? There are two reasons:

- 1) Of the 3°F drop, part of it was a drop in CRAC fan power.
- 2) The remainder was due to the speed of the air through the CRAC. The slower the speed of air, the longer the air is in contact with the cold coil, and the lower the leaving air temperature is.

Our handy equation can also be used to figure out how much of a temperature increase the air should see as it passes by the CRAC fans. More than one third (1.2°F) of the 3°F decrease is due to the fans operating at 5.2 kW (78% speed) instead of 11 kW at full speed.

What can be done with that 3°F? Rather than operate 3°F cooler, it might be used to increase the room temperature to save energy. Data from a Dell test for a chilled water facility suggested as high as 2.5% was saved per degree in the cold region (sub-60°F air), but this diminished substantially as the air temperature got higher. Over a range of temperatures from 57°F to 70°F, our data suggested an average of 0.9% facility energy decrease per degree increase in SAT.

What role did the Energy Smart rack play? This test could have been performed with cold aisle containment. With the right attention to venting in the cold aisle, the CRACs could have spun down similarly and still delivered adequate flow to each of the two cold aisles in the data center. It would have been a manual process to make sure each aisle was getting just enough flow (adjustment in the number and types of vents), but the Energy Smart racks take care of themselves.

The use of static pressure control with the Energy Smart racks allows the CRAC units to continuously seek the lowest energy state. This not only saves energy within the CRAC units, but it can lead to efficiency savings with the changing of set points. It can also lead to capacity increases associated with operating the CRAC units at a higher delta-T. This configuration may indeed have a positive effect on both OpEx and CapEx.

There is one other benefit to the use of static pressure control, and that is in CRAC deployment planning. Static pressure control enables the CRACs to reduce flow to a level that is approximately what the IT racks consume. This is automatic in the case of the Energy Smart rack, but it can also be achieved with manual adjustments in aisle containment. Since the flow is minimized, you can see what is left over. If the CRAC units are running at 70%, for example, you know there is a 30% reserve. By tracking the CRAC units' flow rate as you add more IT equipment, you can project when it will run out.

In a different experiment in the same lab, we were able to accurately track a 1% speed increase every time we added a new rack of 8 kW and 600 CFM. We could easily project forward on either a CFM or kW basis when we would run out of volumetric reserve.

Figure 9. CRAC Unit Response to IT Equipment Additions

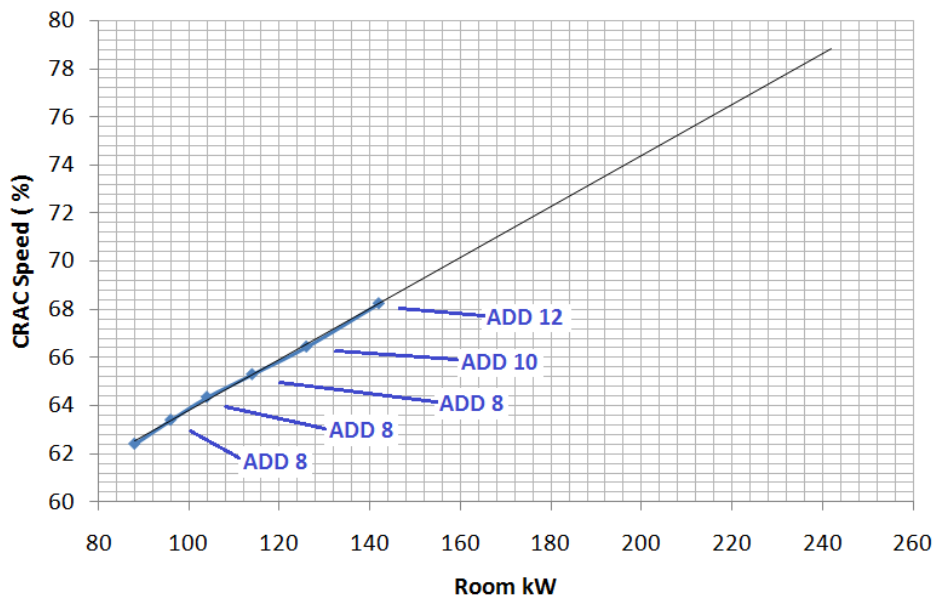


Figure 9 shows that the CRAC response is quite granular and linear in responding to small additions of IT equipment. We also failed either outside CRAC units, and in each case, the CRACs increased about 17%. This experiment stopped at 140 kW. The trend suggests reserve capacity for about another 120 kW at which time the CRACs would be just over 80% and trending close to the point (83%) where redundancy would be in question.

Conclusions

Selecting the right cooling and containment solution for a data center can be a daunting exercise in terms of balancing efficiency, utilization, and costs. The research evidence shown in this paper demonstrates the potential savings in both capital and operating expenses and the energy benefits for implementing containment by using the PowerEdge Energy Smart Containment Rack Enclosure together with a static pressure cooling system in a data center.

For more information about this rack enclosure, refer to:

<http://www.delltechcenter.com/page/Dell+PowerEdge+Energy+Smart+Containment+Rack+Enclosure>.