Optimizing Capacity and Efficiency in a Diverse and Variable Load Environment

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Modern IT hardware has steadily increased in density over the past decade and has reached a point where an individual rack can consume over 30,000 watts of energy. This energy is dissipated as waste heat into the environment, and the state of the art data center cooling infrastructure must be capable of supplying sufficient air flow where needed to meet these demands. The same data center may also have racks with loads 1/10 of the highest density hardware deployed. Often the same dense IT hardware has the ability to modulate its airflow and energy requirements based on current IT workload demands. With the further development of high performance (HPC) and cloud computing, the variability in large scale IT loads has never been greater.

The introduction of local and dynamic airflow delivery technology, and the parallel introduction of high total air capture airflow products for raised floor design allows for sufficient air flow delivery to the IT load, while allowing for precisely the correct amount of air to be delivered to the IT equipment. This whitepaper explains the need for these technologies and illustrates how these technologies work together with existing IT cooling systems to meet this variable load demand while maintaining high reliability and lowering energy costs.

Introduction

The data center space has continued to grow, driving business productivity, and in many cases become the primary money making portion of the business as a whole. This drive, along with increasing power requirements of the IT hardware that makes up singular components of the data center, continues to push the data center's energy requirements year over year. The drive to slow this energy growth has drawn the focus of the data center owners, governmental institutions and providers of the data center hardware. This focus has lead to improved efficiency at the IT hardware level and the infrastructure level as each portion seeks to do their part. These trends can be broken down into the following points.

1. Increasing IT Load: The average IT load per rack is still climbing. Current surveys indicate that the average load per rack has reach 7.4kW with expected density to reach 11kW in two years, and 17kW in 10 years. (DCUG, 2009)

2. Diverse Load Profiles: IT Racks, while on the average have risen, still present a diverse load profile to the data center manager, racks in the average data center can be found to have 0W of load (empty, yet to be filled), to as high as 30kW (dense blade server environments).

3. Variable Load Profiles: Server manufactures, driven by efficiency goals, now produce servers that can significantly reduce their power consumption during idle and partial load situations, while typical data centers are design for the expected maximum load.

4. Drive to Efficiency: The new Energy Star program for data centers encourages user to lower their infrastructure overhead portion that is used to compute their site's PUE, while C-suite officers set internal energy reduction requirements.

5. Availability Must Remain Unchanged: Incremental energy savings are insufficient to justify the adoption of unproven technologies, where minutes of down time would heavily offset any gains realized.

To understand the current design practices within most data centers, it's helpful to look at the methods used for addressing these points with existing technology, and how emerging technologies help address these requirements while increasing the efficiency of the data center and improve the site availability. This whitepaper will take an iterative approach to the optimization of the airflow products used in the raised floor data center, examining the energy impact of each step, and the benefits that can be realized above and beyond energy savings.

Capacity Delivery

The typical airflow path in the data center utilizing a raised floor plenum can be seen in figure 1 below. Air is fed into the raised floor plenum from the air handling units installed on the floor, pressurizing the underfloor plenum. Air then is forced through perforated panels installed in the data center, typically arranged in cold aisle at the face of the IT racks and equipment. Part of this air stream enters the IT rack and then the equipment, while part may bypass the equipment and return to the air handling units. The air that enters the servers is heated and exhausted from the servers where it returns to the air handling units. Typically some intermixing of the hot and cold air paths I expected due to improper sealing in the rack, or recirculation above and around the sides of the IT rack rows.

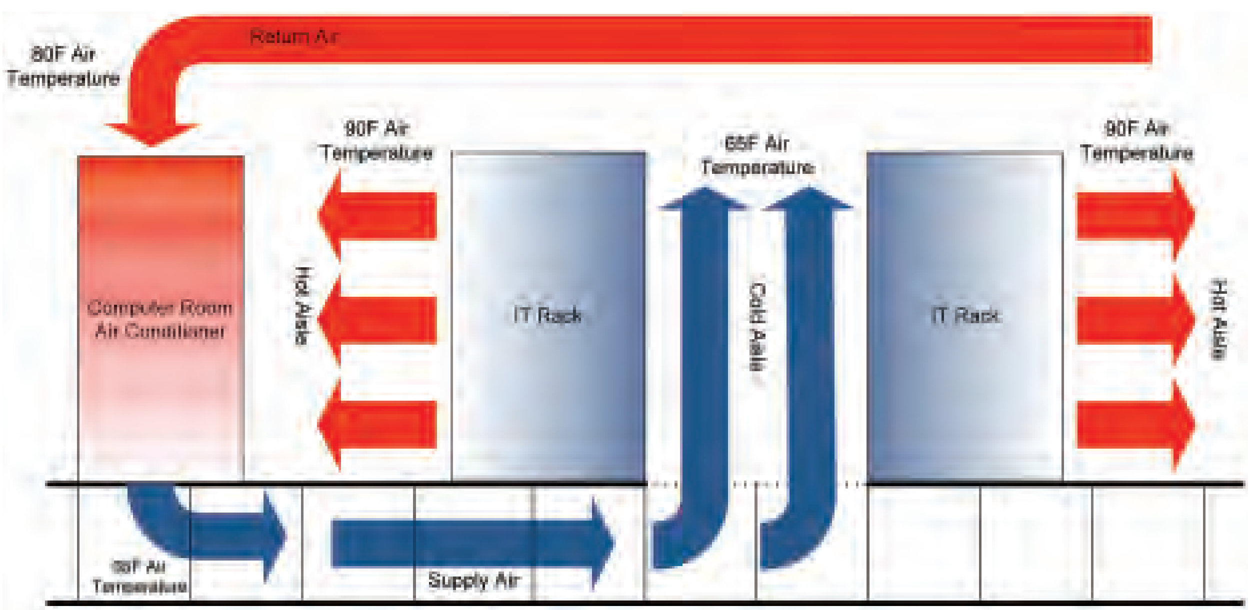


Figure 1 - Typical Airflow Path Utilizing Raised Floor

Perforated Panels

Historically perforated panels similar to the solid panels used in the raised floor have been used to provide cold air to the IT equipment. These panels are typically perforated to provide an open area of approximately 25%. An example of these perforate panels can be seen in figure 2.

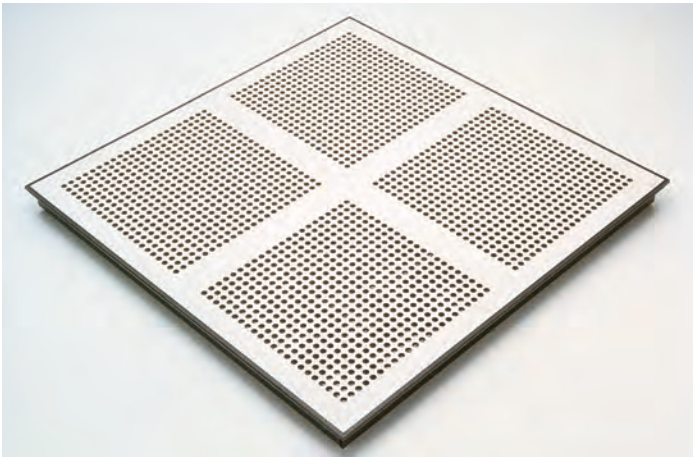


Figure 2 - Perforated Panel, 25% Open Area

Airflow delivery from these panels is a function of the differential pressure across the panel, in this case the air the panel is providing air into is assumed to have a pressure of 0.00" of water, while the static pressure below the raised floor in the plenum space typically ranges from 0.02"-0.20". Figure 3 below shows the typical air flow rate versus static pressure for these panels.

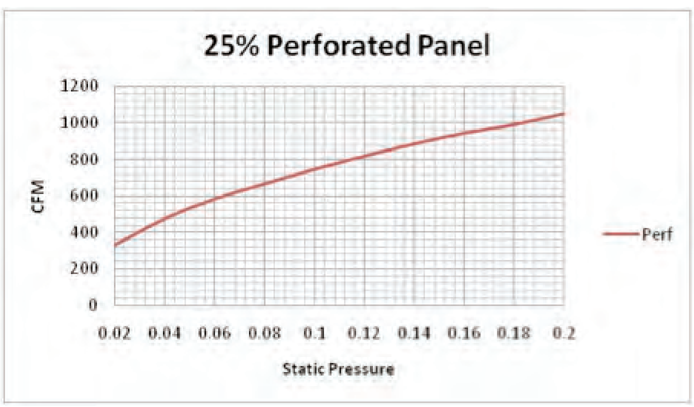


Figure 3 - Static Pressure vs. Flow Rate for 25% Perforated Panel

The curve above can be very closely represented by the polynomial equation 1 below.

$$CFM = -11515*Static\ Pressure^2 + 6349.1*Static\ Pressure + 228$$

Equation 1 – 25% Open Area Perforated Panel

The limitations of this design can be seen on the curves above. The maximum expect CFM exceeds 1000 CFM per panel, however, due to increasing kW dissipation per rack; the CFM requirements of modern IT hardware, when fully deployed can exceed the maximum flow rate that can be provided with perforated panels.

Grate Type Panels

Additional panels have been designed to increase the flow rate versus underfloor air pressure to meet these demands. One common design is that of a grate type panel. These panels often have a far greater open area than the previous 25% perforated panel above, with the best designs at least doubling the open area, with the maximum open areas of approximately 56% as can be seen in figure 4.

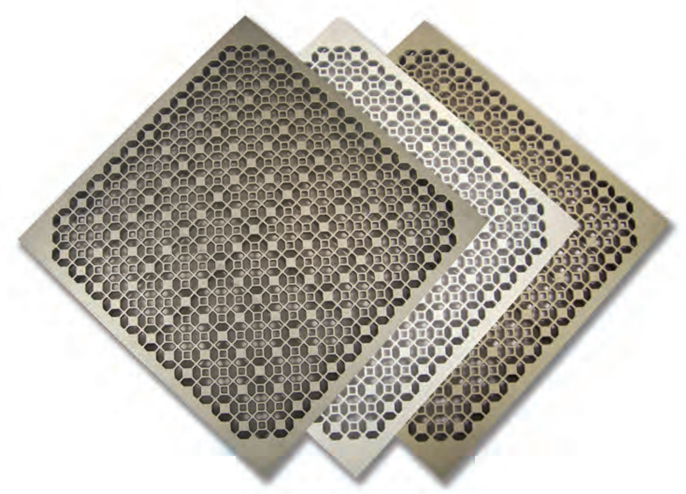


Figure 4 - Typical 56% Grate Panel

The greater open area on these grates results in higher flow rates versus static pressure. This increase can be seen in figure 5 below. The resultant curve can also be represented accurately by a 2nd order polynomial equation; it appears below in Equation 2.

$$CFM = -27462*Static\ Pressure^2 + 17289*Static\ Pressure + 634$$

Equation 2 – 56% Open Area Grate Panel

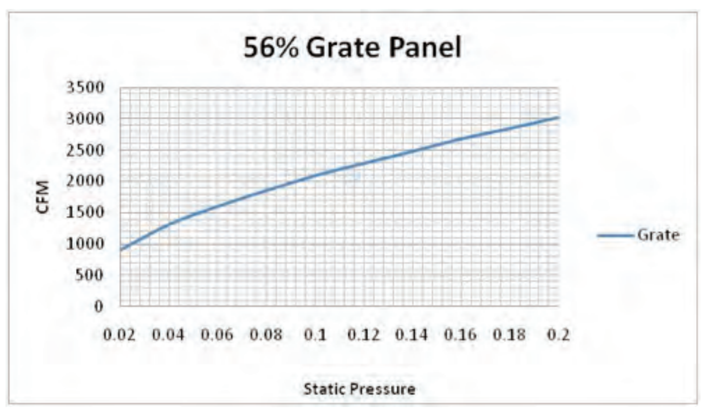


Figure 5 - Static Pressure vs. Flow Rate for 56% Grate Panel

These grate designs provide a maximum airflow of approximately 3000 CFM, nearly 3 times that realized with 25% perforated panel.

Delivering Air Where It's Needed – Air Flow Presented and Captured

Before the rack load capacity in terms of kW that the two previous designs can provide can be determined, consideration must be made for air that bypasses the IT rack. Testing methods using fog plumes can provide visual guidance, and further measurements of CFM entering a rack can also be taken. Both methods were used to determine the expected airflow that truly enters a rack during typical operations. Plume profiles were first used to determine the expected air flow impingement on the rack surface. The rack outline shown in figure 6 below illustrates this concept. This test however is done with no true rack in place, and no fans drawing air into the rack as would be the case in a data center environment.

As can be seen, the presentation rate was less than 1/3 of the total air provided from the 56% open area grate in question, resulting in a large portion of air bypassing the test racks altogether. This is not surprising, given the overall shape of the vertical plume, and the limited exposure realized at the rack level to this plume. The high velocity of the air column close the floor results in relatively low air flow impinging on this zone, while the plumes spreading cone nature results in a large portion of the air column moving away from the rack face once the full height of the rack is reached.

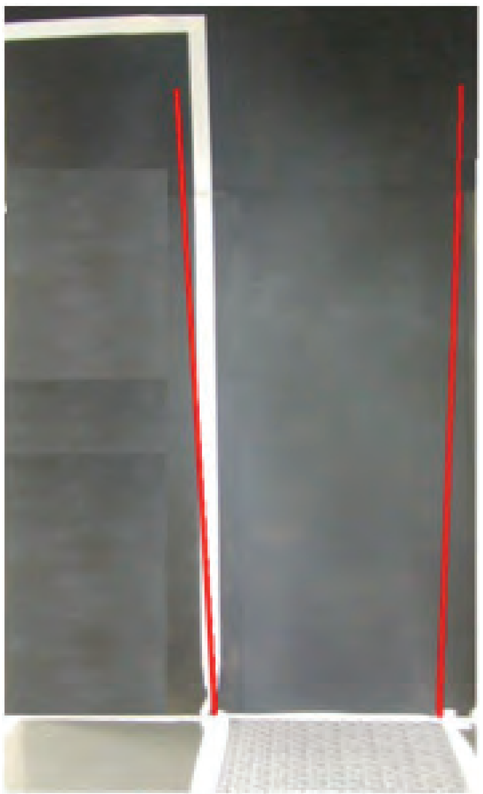


Figure 6 - Plume profile provided by 56% Grate Panel

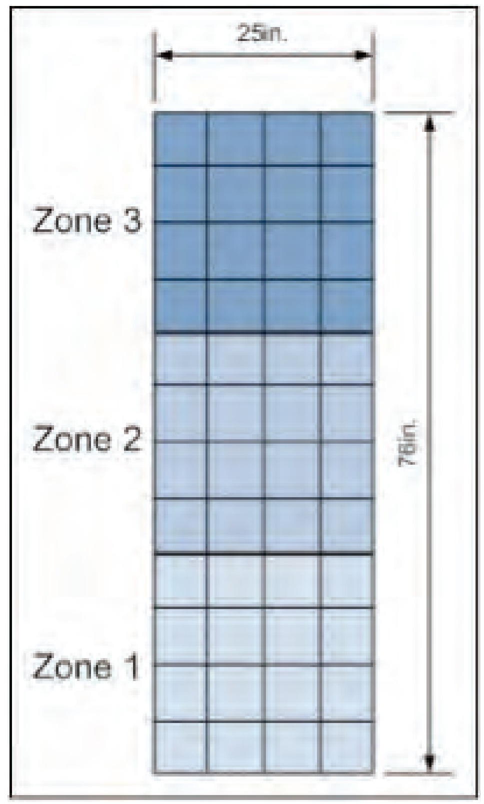


Figure 7 - Gridded Rack Surface for Airflow Testing

Next a rack configuration was setup and gridded to allow for accurate measurement of the airflow entering the rack surface when installed along with a typical 56% grate. This setup appears in figure 7 below.

Tests were run again to determine the airflow entering the rack face during typical static pressures below the floor. Total Air Presented results were defined in the chart, where Total Air Presented (TAP) is calculated as shown in equation 3. These results are tabulated in table 1 below.

$$\textit{Total Air Presented} = \frac{\textit{Total Airflow Measured at Rack Face}}{\textit{Total Airflow From Panel}}$$

Equation 3 – Equation defining Total Air Presented

Determination of the racks true **Total Air Capture (TAC)** rate requires a real world test where fans draw the air into the rack, the air is heated and returned to the hot aisle. (See equation 4) To verify these results, additional load testing was complete by installing two load banks capable of 8.7kW each into the rack, illustrated in figure 8 below.

$$\textit{Total Air Capture} = \frac{\textit{Total Air Captured at IT Load}}{\textit{Total Airflow From Panel}}$$

Equation 4 – Equation defining Total Air Captured

At 0.1" Air Distribution		Test #1	Test #2	Test #3	Average	Percentage of Air Presented	Total Air Presented
Total Airflow		2056	2012	1955	2008		
	Top Zone	282	371	361	338	17%	31%
	Mid Zone	204	298	282	261	13%	
	Bottom Zone	8	31	15	18	1%	
	Bypass Zone	1518	1312	1297	1390	69%	

Table 1- Airflow Presented to Various Zones in a typical IT Rack

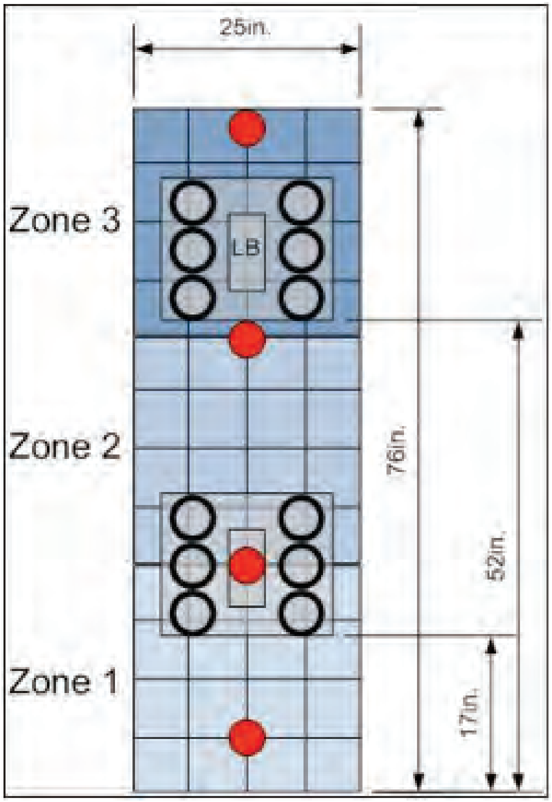


Figure 8 - TAC Testing Configuration – Red circles indicated temperature reading locations

The results of this capture test appear below in table 2.

The table below was recorded with a typical 56% open area grate, installed on a raised floor environment with an underfloor static pressure of 0.10" of water. As can be seen the first 3 steps show results with minimal to no recirculation of air based on the similar front temperature at the rack face versus the temperature provide from the panel.

The testing at a load of 5.76kW results in a total required IT airflow of 691 CFM, at 0.10" our previous TAP tests show that 651 CFM of air is expected to be presented to the rack face (table 1), just slightly below the required airflow. The peak delta T illustrates that additional recirculation; air from the rear of the rack is now being pulled to the front on the rack, and to the IT hardware intake, has begun to occur, as the load banks were set specifically to maintain a 25 F delta T.

The test parameter required a test stop when the entering air to the equipment exceeded ASHRAE's maximum inlet air temperature of 80.6F. This result was reached with a load of 10.32kW per table 2. This would indicate that the maximum load per rack supportable by a 56% grate would be 10.3kW at a 0.10" static plenum pressure. The load at this point requires 1238 CFM, suggesting a TAC of 50%. This TAC value is a derived average, from the values shown in table 2, taking the average computed TAC value from the 3 peak values above in table 2.

This result does not contradict the earlier TAP results of 31%. During operation, the IT hardware will attempt to pull air from any source available including over the top and from the sides of the rack. Bypass air from the panel that is not presented to the face of the rack mixes with the heated air from the rack, resulting in a somewhat lower air temperature in the surrounding space. It is from this air that the rack pulls in the additional CFM needed to meet the current IT load demand. This recirculation and mixing, while not inherently desirable, may be safe for operation when the resulting surrounding space temperature is below that required by the IT rack. In cases of operation with supply temperatures approaching recommended maximums it is important to realize that this overhead above the 31% predicted by the TAP results may be smaller than 50%. The results from the testing above show that a 6F difference between maximum recommended (80.6F) and the supply air temperature (74.6F) may still produced results that can be achieved in most data center environments.

One final method of determining the actual TAC value associated with a particular panel takes the following form. Figure 9 below illustrates the airflow paths that must be considered for the 10.32kW load condition outlined above.

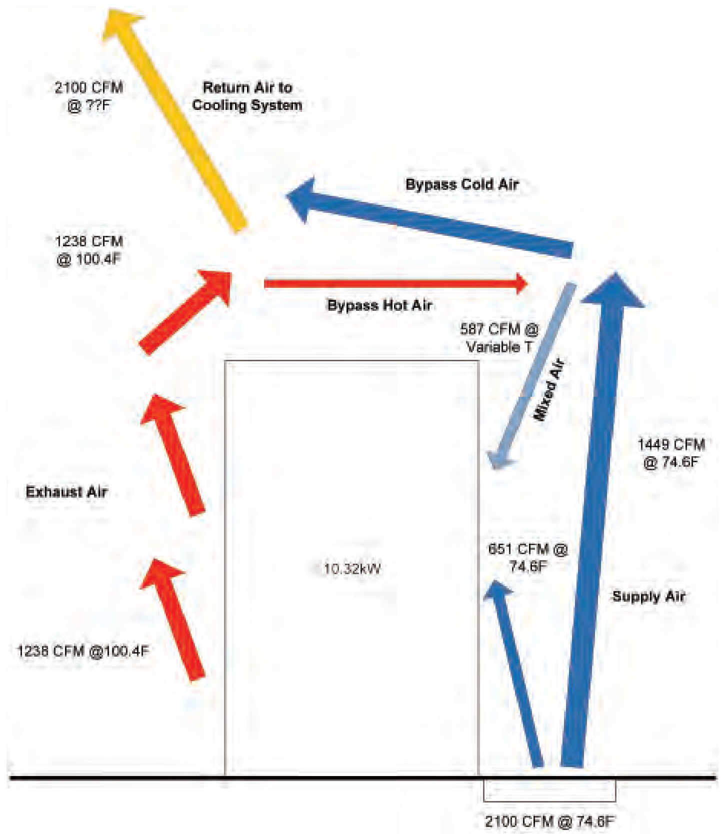


Figure 9 - Airflow paths used to calculate TAP

kW Load	Front Temperature - Limit 80.6F				Rear Temperature				Average	Supply	Peak	Actual Airflow	Load Bank CFM	Notes
Rack 1	Pos 1	Pos 2	Pos 3	Pos 4	Pos 1	Pos 2	Pos 3	Pos 4	Delta T	Air Temp	Delta T	Pos 1	Requirement	
0.84	72.5	72.5	72.0	72.3	77.6	76.3	81.8	79.0	6.3	71	9.8	2100	101	Load Satisfied
2.88	72.9	73.1	72.0	72.1	78.2	76.9	94.1	83.2	10.6	71.4	22.1	2100	346	Load Satisfied
4.8	73.3	73.7	72.6	72.7	79.6	78.6	99.1	84.7	12.4	71.5	26.5	2100	576	Load Satisfied
5.76	74.3	74.5	73.2	73.1	81.7	80.7	101.8	87.4	14.1	71.8	28.7	2100	691	Load Satisfied - Recirculation Detected
7.68	74.5	74.9	73.8	74.3	82.5	80.9	103.0	94.0	15.7	72.6	29.2	2100	922	Increasing Front Temperatures
9.6	76.2	76.4	75.2	76.2	85.2	83.6	104.9	99.4	17.3	73.9	29.7	2100	1152	Increasing Front Temperatures
10.32	79.4	76.7	76.7	80.5	92.1	99.7	107.7	102.1	22.1	74.6	31	2100	1238	Widespread Recirculation

Table 2 - TAC testing results with 56% open area grate

Using the experimentally derived TAP value for this condition, 651 CFM of air can be expected to be presented to the rack, at the supply air temperature which in this case was 74.6F per table 2. A total of 587 CFM of air must be drawn from the space to satisfy the CFM requirements of the current load. The average air temperature over the face of the rack is found to be 78.3F using the data from table 2 again. With these variables, the unknown temperature of the air recirculating to the rack can be calculated using equation 5.

$$\text{Ave Rack Inlet Temp} = \frac{\text{TAP CFM}}{\text{Total Load CFM}} * (\text{Supply Air Temp}) + \frac{\text{Recirculated CFM}}{\text{Total Load CFM}} * (\text{Recirculated Temp})$$

Equation 5 – Equation to determine recirculating air temperature

Using this formula and solving for the recirculated temperature, the result 82.4F is found. Determining the ratio of the mixture entering the rack is now important as we can determine how much of the supply air is used to effectively cool the IT load. Two equations are required to find these values, see equations 6 and 7 below.

$$\text{Supply Air CFM} + \text{Exhaust Air CFM} = \text{Recirculated CFM at Rack}$$

Equation 6 – Equation to determine recirculating CFM at Rack

$$\frac{\text{Exhaust CFM}}{\text{Supply CFM} + \text{Exhaust CFM}} * \text{Ave Exhaust Temp} + \frac{\text{Supply CFM}}{\text{Supply CFM} + \text{Exhaust CFM}} * \text{Supply Air Temp} = \text{Recirculated Temp}$$

Equation 7 – Equation to find Supply Air and Exhaust Air CFM

Using these two equations and the results from equation 5, it is found that the portion of the exhaust air that is recirculated to the rack face is approximately 177 CFM, while an additional 409 CFM of air from the supply is taken into the rack. This additional 409 CFM is added to the known 651 CFM provided from the TAP calculations, resulting in a total CFM delivered by the panel and captured by the IT hardware of 1060 CFM, resulting in a TAC value of approximately 50%.

The results for the 10.32kW and 9.6kW tests are summarized in the table below.

IT Load	10.32kW	9.6kW
Average Rack Inlet Temperature	78.3	76
Average Exhaust Temperature	100.4	93.3
TAP CFM	651	651
Recirculated Air CFM Required	587	501
Supply Air Temperature	73.9	72.6
Total Load CFM	1238	1152
Recirculated Temperature	82.4	78.7
Exhausted Air CFM (Recirculated)	177	124
Supply Air CFM (Recirculated)	410	377
Intake CFM Supplied from Grate	1061	1028
Calculated TAC	50%	49%

Table 3 - Summarized Test and Calculated Data for determining TAC

These results should make sense based on the testing data. Direct usage of the testing data suggests that 50% of the air from the panel is captured. The calculation results in table 3 suggest that 50% of the cold is captured while an additional 177 CFM of air is in constant recirculation from the exhaust air of the rack. This 177 CFM is the additional 8-9% of air supplied to the rack. This recirculation air should not be considered in the TAC calculation, as it is dependent on site conditions, such as exhaust air return locations, temperature of supply air, and other factors beyond the scope of this whitepaper. For this reason, TAC for a typical 56% grate has been determined to be approximately 50%.

Determining Rack kW Capacity with Typical Perforated Panels and Grates

This data can allow the user to determine the maximum supportable kW per rack given the underfloor air pressure and the expected best case capture rate of approximately 50%. The testing above showed a capture rate of approximately 31%, without the addition of fans. For the purpose of this paper, a survey was created to determine the average CFM requirement per kW of available IT hardware. These numbers were found to range from as low as 60 CFM per kW (Dell 1950, fully configured) to as high as 160 CFM per kW (networking gear). A balanced value of 126 CFM/kW was chosen, as it provides for a 25F delta T across the IT hardware. Using equation 8 below table 4 was generated.

Load Capacity	25% Perforated Panel Uncontained	56% Grate Uncontained
Per Rack kW Capacity at 0.20" Static Pressure	4.12	11.88

Table 4 - Estimated Load Capacities for uncontained perforated and grate type panels

$$\text{kW Capacity} = \frac{\text{CFM delivered by panel}}{126\ \text{CFM / kW}} * \text{Capture Rate}$$

Equation 8 – Equation to determine kW per panel

Methods for improving rack kW Capacity with typical perforated panels and grates

It is clear that capture rate plays an important part in determine the effective cooling capacity of a given perforated or grate type panel. Improving this capture rate would clearly increase the effective kW capacity of a given panel. One such method for improvement is the use of aisle containment, in either a cold aisle form or a hot aisle format.

In either format the cold or hot air supplied to or capture from the IT equipment is contained, allow for very limited mixing of the air flow paths. This provides for nearly a 100% air capture rate, table 5 below shows the expected increase in load capacity per panel.

Load Capacity	25% Perforated Panel Uncontained	56% Grate Uncontained
Per Rack kW Capacity at 0.20" Static Pressure	8.23	23.79

Table 5 - Estimated Load Capacities for Contained perforated and grate type panels

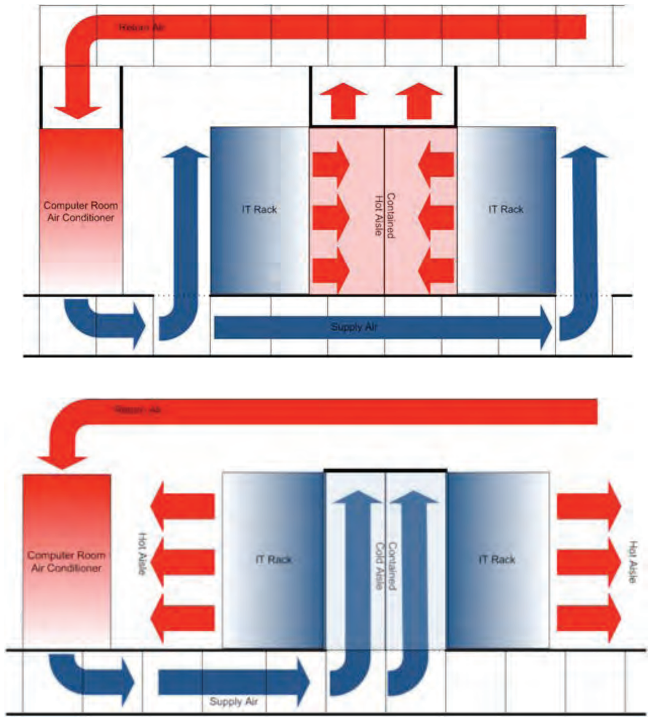


Figure 10 - Hot and Cold Aisle Containment Examples

The use of cold aisle ad hot aisle containment systems is nothing new in the data center market, but comes with certain design considerations that must be taken into account. While capacity increases at the rack level, and efficiency increases due to the dramatic reduction in cold/hot air mixing, design issues such as fire code implications and human comfort must be considered. Flexibility may also be limited due to some containment designs that incorporate rigid structures, as they may impede the removal and addition of racks.

Availability issues with aisle containment strategies

The primary drawback of containment solutions is availability, specifically the ride through time limitations that may occur in the data center space during transient events connected to the cooling system such as air handler shutdowns, or power failures to large mechanical equipment. By their nature of restricted airflow paths, a temporary interruption of air flow or temperature variation during sustain IT equipment operation may result in IT hardware failure. Cold aisle containment system have limited volumes of air in the cold aisle in the under floor plenum. During an interruption of airflow, the equipment may become starved for supply air, although the temperature may be below the required high temperature threshold, still resulting in higher than operationally acceptable temperature at the internal components of the IT equipment. Hot aisle containment may provide for a similar failure mode. Interruptions to the cooling cycle will result in air being drawn from the large cold air space, but no extraction of hot air from the hot aisle will result in backpressure against the internal server fans, creating similar over temperature situations internal to the server.

New Methods for improving Rack kW Capacity with Directional Grates

The drawbacks seen with aisle containment can be addressed at the raised floor level through straightforward improvements to the grates that provide the airflow from the underfloor plenum. Slight increases in open area will gain the user additional kW capacity through higher airflow, but the air must be delivered precisely to the IT equipment. The vertical plume profile observed for grates and perforated panels is inefficient in its air delivery method whereas providing a directional air flow into the face of the rack will dramatically increase the capture rate.

Total Air Capture Improvements

This new term is meant to define the amount of air that is capture at the IT equipment while under load as a ratio of the total air delivered by the supplying panel or grate. (See Equation 9)

Equation 9 – Equation to determine TAC

$$\textit{Total Air Capture} = \frac{\textit{Total Airflor captured at IT Load}}{\textit{Total Airflow from Panel}}$$

As mentioned previously the total air capture rate realized with typical perforated and grate type panels is often found to be between 30-50%. These panels, when used with aisle containment strategies can realize a complete total air capture value of 100%, although they do have design and availability ramifications that must be considered.

Directional grates on the other hand can provide up to 93% TAC with no form of containment, while offering higher flow rates vs. CFM values.

Directional Grates

Directional grates may take many forms, but one to be considered would be a steel constructed design, laid out in a grid arrangement, with the necessary angle built into the structural components as to provide the desired plume of air to the face of the IT rack. Figure 11 illustrates a possible grate design, while figure 12 illustrates the airflow plume into the rack face.

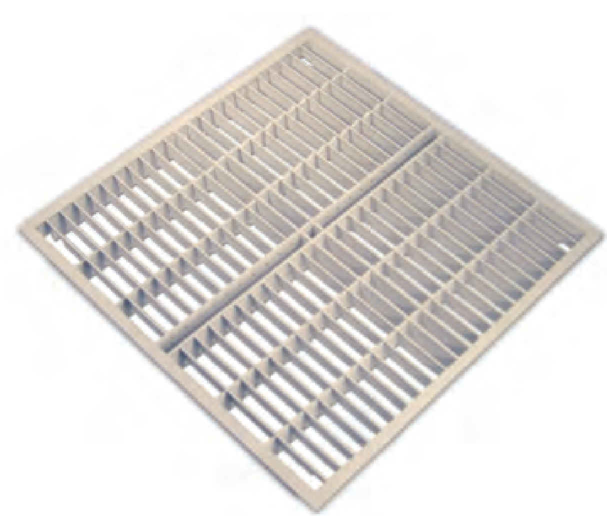


Figure 11 – Directional grate design

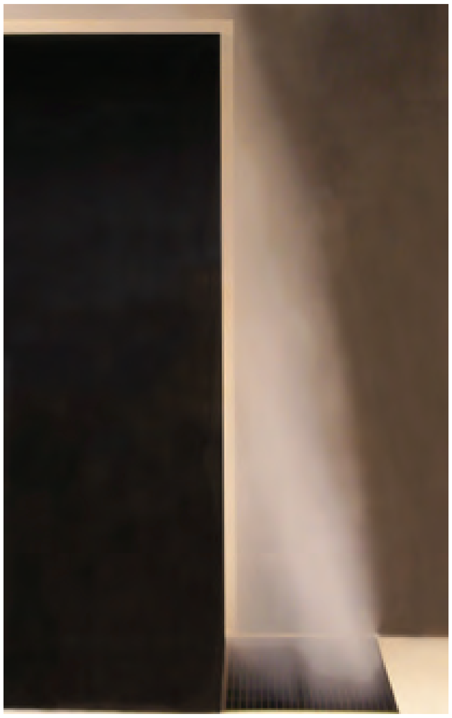


Figure 12 - Plume provided by directional grate

Similar tests as those completed with the perforated panel and grate above were completed to determine the airflow distribution across the face of the rack. Table 6 includes this data.

It can be seen from the collected data and plume profile, that airflow directionality has a large impact on the airflow distribution to the equipment installed in the IT rack. Compared to non-directional grates, (30-50%) directional grates drastically improve the total volume of air delivered to the IT hardware. (90%)

As with typical grates, TAP is not the only value of consideration. Increased TAC can be expected, as was seen in grate load testing in table 3 above. Table 3 shows that approximately 28% of the bypass air was used by the IT equipment when the kW per rack exceeded the maximum value suggested by the TAP percentage. (410 CFM / 1449 CFM = 28%) The same recapture during recirculation can be expected with directional grates. The above values show and average bypass air of 261 CFM, resulting in 73 CFM serving the IT load when recirculation might occur. This further boosts the CFM capacity of panel, primarily in the top zone of the rack. Table 7 below shows the additional impact of this recirculated air.

The directional grate shown in figure 11 above also has a greater open area compared to conventional perforated panels and non-directional grates. This further boosts the maximum capacity for a given directional grate. The airflow versus static pressure curve for this directional grate appears in figure 13 below.

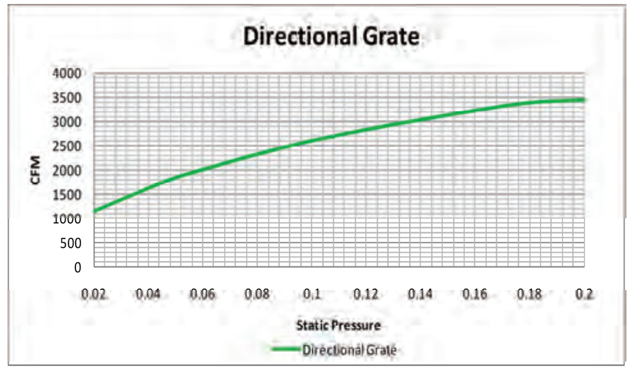


Figure 13 - Static Pressure vs. Flow Rate for 68% Directional Grate Panel

This airflow curve can be modeled by the following 2nd order polynomial equation appearing as equation 10 below.

$$CFM = -51106 * Static\ Pressure^2 + 23655 * Static\ Pressure + 746$$

Equation 10 – Equation Curve for 68% Open Area Directional Grate

Capacity comparison of perforated non-directional and directional grate type panels

The impact of total air capture rate, whether it is influenced by aisle containment, or directionality must be examined. Previous examples in tables 3 and 4 illustrate the impact of the nearly 100% TAC realized with aisle containment. Table 8 below contains the comparative values for each type of panel discussed so far.

At ~0.1" Air Distribution TAP		Test #1	Test #2	Test #3	Average	Percentage of Air Delivered	Total Air Presented at Server
	Top Zone	598	671	725	665	25%	90%
	Mid Zone	907	815	897	873	33%	
	Bottom Zone	834	879	744	819	31%	
	Bypass Zone	279	253	252	261	10%	

Table 6 - Air flow distribution and Total Air Presented at Server Rack

At ~0.1" Air Distribution TAC		Test #1	Test #2	Test #3	Average	Percentage of Air Delivered	Total Air Captured at Server
	Top Zone	671	744	798	738	28%	93%
	Mid Zone	907	815	897	873	34%	
	Bottom Zone	834	879	744	819	31%	
	Bypass Zone	206	180	179	188	7%	

Table 7 - TAC for 68% directional grate

Load Capacity	25% Perforated Panel Uncontained	56% Grate Uncontained	25% Perforated Panel Uncontained	56% Grate Uncontained	68% Directional Grate Uncontained	68% Directional Grate Uncontained
Per Rack kW Capacity at 0.20" Static Pressure	4.12	11.88	8.23	23.79	25.34	27.25

Table 8 - Load Capacity Comparison Contained and Uncontained

Energy Usage Comparison for Various Airflow Panels

Determining the impact of energy usage on the data center cooling infrastructure is important to further the understanding of the benefits of total air capture. It has been shown that the greater open area results in greater airflow per panel, and that the rate of total air capture has a significant impact in the capability of that airflow to be provided to the face of the rack where it can serve as a transport medium for the heat generated by the IT equipment. Air that does not enter the IT equipment bypasses the system and is returned mixed with the heat air from the server to the air handling equipment. This bypass air requires the same amount of energy to move from the air handler to airflow panel and back to the air handler as does airflow that is passed through the IT equipment. The impact on the air handling equipment is also significant, in terms of efficiency of heat rejection given the lower than designed delta T expected at the air handler's cooling coil, but this is currently beyond the scope of this paper.

The fan energy required to move a 1000 CFM of air is dependent on the efficiency of the fan used to move the airflow. A typical centrifugal belt driven blower in an average 60 ton chilled water air handler consumes approximately 11kW to move 17,000 CFM of air at typical data center external static pressures. (Emerson, 2010) A variable figure based data from air handler manufacturers is dependent on under floor static pressure is used to determine the energy required to move the necessary air at a given static pressure.

Fan Energy Modeling Tool

To ease these calculations, a model was built to automatically determine the effect of various variables on the performance of grate type panels previously discussed. This modeling tool and instruction document can be downloaded from Tate's website. Table 9 below shows the required user inputs into the model in step 1.

User Inputs - Data Center Characteristics

New or Retrofit	Retrofit
User IT Load (kW)	2000
Number of IT Racks	300
Calculated Rack Density Average (kW)	6.7
Maximum IT Load Per Rack (kW)	10.8
Per kWHr Cost	0.12
Expected IT Equipment Actual Power Usage (50-100%)	65%

*Note: Cells in Red denote user input fields

Table 9 - Inputs into data center fan energy model

Practical Example using energy modeling tool

The user must first chose of the data center design is a new build or a retrofit of an existing facility, and then enters the User IT Load in kW. The user then enters the umber racks in the data center space in the appropriate cell. Density per rack is automatically calculated, for this example we have chosen a 1720 kW data center containing 200 racks at approximately 8.6kW per rack on average. A peak rack density of 12.5kW is chosen to allow the model to plan for racks denser than the estimated 8.6kW. Additionally, and cost per kWhr is set at $0.08. Finally an expected IT Equipment Utilization that is the percentage of the operating cycle that the IT hardware is expected to draw the user IT Load in kW is entered. A few site assumptions for the model are also entered. See table 10 below.

The fan energy requirements for this stage of the calculations is set to be 0.64 kW/kCFM for belt driven centrifugal blowers with typical grates and DirectAire directional grates with belt drive fans. A value 0.45 kW/kCFM for EC fans which will be addressed later in the paper is also used. The final value for DirectAire, SmartAire ad EC fans will be calculated automatically based on the required underfloor air pressure needed to meet the design load, and server utilization will be used later in the model.

Step 2 now calculates the CFM and energy requirements of the solution. The user must input the expected TAC, which is this case, is a typical grate and is expected to be ~50%. At this point, the user data entry is completed, and the values are computed as shown in table 11.

Site Assumptions	Typical Grate	DirectAire	DirectAire & EC Fans	DirectAire, SmartAire & EC Fans
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Calculated CFM per kW (CFM)	120	120	120	120
Fan Energy (kw) Required Per kCFM (Belt Driven Fans)	0.64	0.64	0.45	0.23

Table 10- Site Assumptions

	Base Case
Perimeter CRAH Unit Design	**Typical Grate w/Belt Drive Centrifugal Fans**
Rack Density for Calculation (kw)	12.5
Expected TAC %	50%
Total Required CFM to be delivered (CFM)	600134
CRAH Units Required (CFM/Tonnage specified below)	32
Total Fan Power Required (kw)	384.1
Estimated Annual Energy Consumption (kWh)	3364589
Fan Annual Energy Cost $	**$269,167**
Recommended Solution (Yes/No)	**YES**
Cost Per DirectAire and/or SmartAire	—
Number of Units Required	—
Total Cost of DirectAire and/or SmartAire	—
CRAH Unit Reduction	—
Fan Upgrades (EC Tech)	—
Cost of Upgrade	—
Annual Energy Savings	—
Payback in Months (simple)	—
3 Year Savings	—
PUE Impact	[illegible]
Mechanical Assumptions for Above Calculations	
CRAC or CRAH unit	CRAH
Enter Tonnage of Unit	50
kW Draw CRAC or CRAH Fans – Belt Driven	12.36
kW Draw CRAC or CRAH Fans – EC	8.58
CFM per CRAC or CRAH Unit	19000
Purchase cost of CRAC or CRAH Unit	$25,000.00
Install cost of CRAC or CRAH Unit	$10,000.00
EC Fan Upgrade Cost	$11,000.00
Cost of Typical Grate in New Build Situation	$175.00

	Base Case
Technical Results	Typical Grate w/Belt Drive Centrifugal Fans
Expected Load Per CRAC or CRAH Unit (Tons)	12.4
Capacity Utilization of CRAC/CRAH units	24.7%
Required CFM Per Rack (CFM)	1,456
Required CFM Per Panel (CFM)	2,912
Required Static Pressure Required to Meet Demand	0.19
Total Required CFM by IT Equipment (CFM)	232941
Expected CRAC or CRAH Delta T (F)	7.2

Table 11 – Typical Grates energy calculation

As we can see in the results, this solution is recommended as a viable solution. Based on the calculations, the panel will need to provide 1500 CFM of air to meet the 12.5kW peak load per rack. This will require an underfloor air pressure of 0.20”, the peak acceptable value for this model. Note that the PUE is fixed at 1.80 for this baseline comparison. Also of interested are the energy requirements of the solution. Approximately 384kW is consumed moving air in this example data center, or approximately 12.4% of the incoming electrical energy. The annual cost of this energy is approximately $269K. The PUE for this facility is shown graphically in figure 14 below.

Next to be considered are the directional grates discussed before. As shown earlier in the paper, the directional grates offer a 93% TAC vs. 50% TAC. This would be expected to lower the overall CFM requirements of the air handling units, either reducing the number of air handling units required in operation, or reducing the average fan size required in the air handling units.

The same values were used again to create our sample data center. These results appear in table 13 below.

The fan CFM required for the total data center is dramatically reduced from 600kCFM down to ~338kCFM due to the far greater total air capture rate. This leads to a reduction in fan energy and power, reducing these values to 206.5kW and the power cost to $144k annually, approximately a 46% reduction. This same energy reduction allows for a lower computed PUE for our example data center, now down to 1.70 vs. the earlier 1.80 value for a typical grate design. This impact is shown graphically in figure 15.

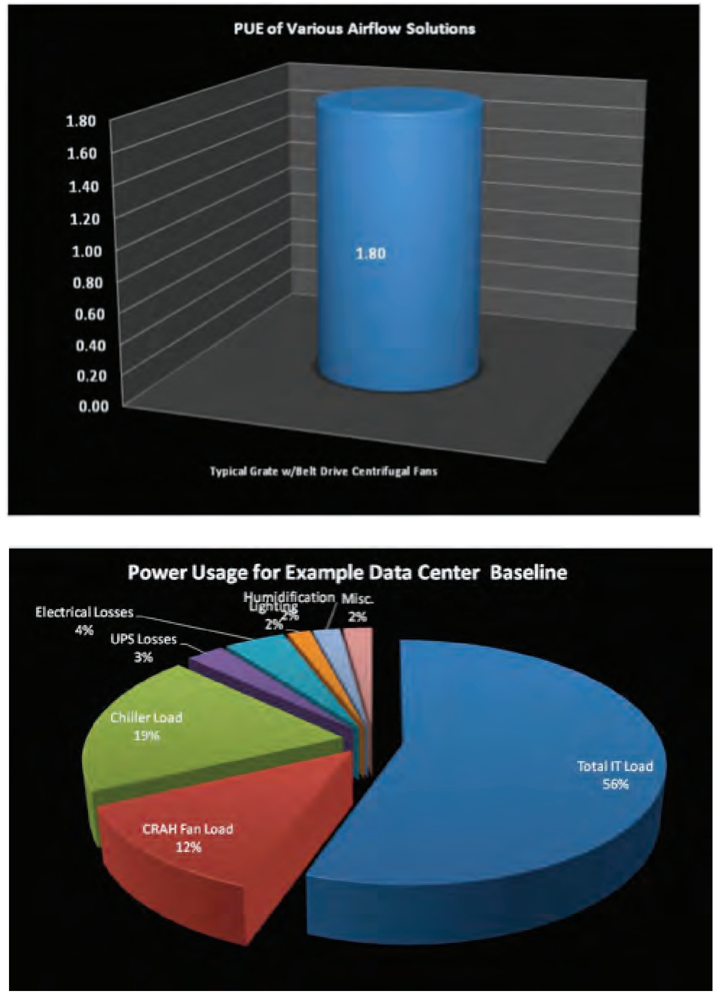
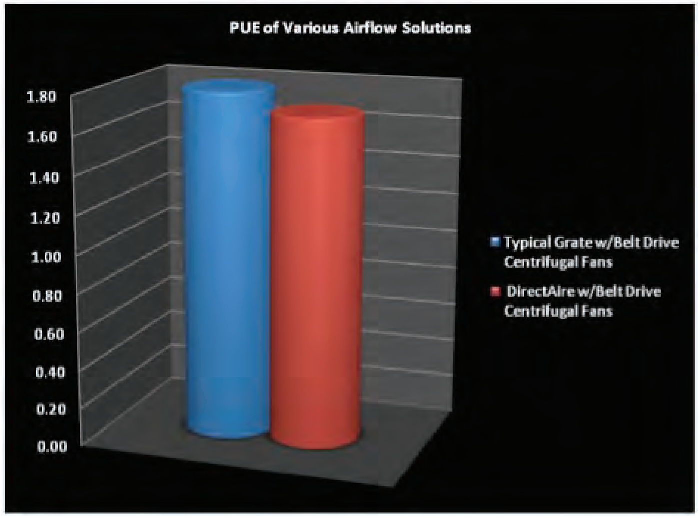


Figure 14 - Initial PUE ad energy makeup of Base Model

Perimeter CRAH Unit Design	Base Case Typical Grate w/Belt Drive Centrifugal Fans	Option #1 DirectAire w/Belt Drive Centrifugal Fans
Rack Density for Calculation (kw)	12.5	12.5
Expected TAC %	50%	93%
Total Required CFM to be delivered (CFM)	600134	322653
CRAH Units Required (CFM/Tonnage specified below)	32	17
Total Fan Power Required (kw)	384.1	206.5
Estimated Annual Energy Consumption (kWh)	3364589	1808919
Fan Annual Energy Cost $	**$269,167**	**$144,714**
Recommended Solution (Yes/No)	**YES**	**YES**
Cost Per DirectAire and/or SmartAire	—	-$300
Number of Units Required	—	200
Total Cost of DirectAire and/or SmartAire	—	-$60,000
CRAH Unit Reduction	—	$0
Fan Upgrades (EC Tech)	—	$0
Cost of Upgrade	—	**-$60,000**
Annual Energy Savings	—	**$124,454**
Payback in Months (simple)	—	**5.8**
3 Year Savings	—	**$313,361**
PUE Impact	1.80	1.70

Table 13 - 68% Directional grate panel energy calculation



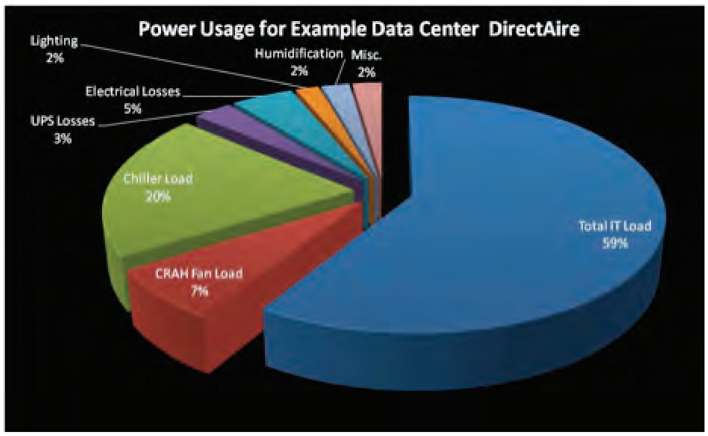


Figure 15 - PUE Impact of Directional Grates

Energy Consumption Comparison

As previously discussed, one method to ensure nearly 100% TAC is to utilize complete aisle containment. Table 14 compares the expected annual energy cost for the contained and uncontained solutions, as well as the maximum capacity per rack that can be supported at a maximum underfloor static pressure of 0.20".

1720kW Data Center Example	56% Grate Uncontained	56% Grate Contained	68% Directional Grate Uncontained	68% Directional Grate Contained
Estimated Annual Energy Usage (kWh)	3,363,840	1,681,920	1,808,516	1,681,920

Table 14 - Annual Fan Power Consumption with various airflow tiles

Summary

This table illustrates that in uncontained situations, a 46% annual energy savings could be realized over grate panels, and a 126% increase in per rack capacity is possible using directional grates when compared to traditional non-directional grates.

Practical methods to realize energy efficiency improvements offered by Directional Grates

Previous sections of this whitepaper have shown the potential for greater capacity with the use of directional grates, and also illustrated the potential energy savings that could be realized by reducing the overall airflow to the floor due to the higher TAC and limited bypass airflow.

Methods for achieving this may be limited to substituting lower HP fans that can achieve the require flow rate at the lower static pressures that can be employed when using directional grates. Another option would be to shutdown existing units by placing them into a standby mode. A recent trend in air handler designs, specifically in CRAH (Computer Room Air Handlers) purpose built units is the addition of VFD equipped fans, or EC plug type fans. (Electrically commutated)

These fans have the ability to reduce their speed to meet the flow requirements of the data center design. For instance, a data center equipped with CRAH units with EC fans that is currently using a typical grate, maybe able to manual turn down their EC fans after the installation of directional grates due to the higher capture rate. Retrofit kits are currently available at the time of this writing that allows user with fixed speed CRAH unit fans to retrofit their units with EC fans.

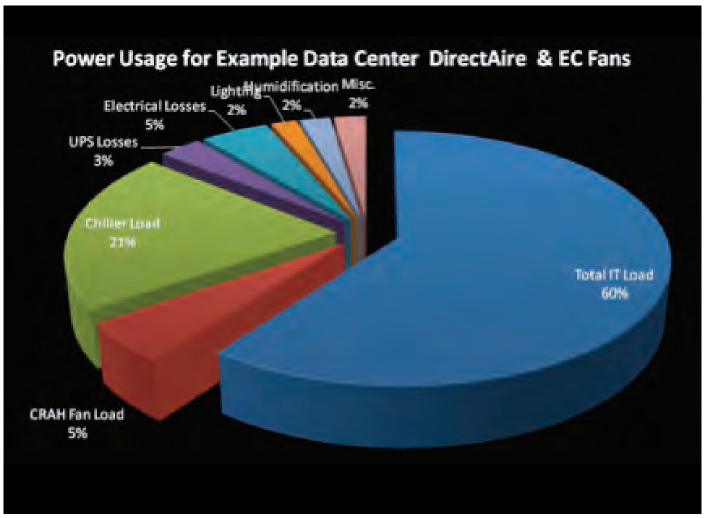
One key advantage of EC fan technology is the 100% load condition energy saving. A data center user making the switch to EC fans would immediately see a 30% reduction in energy usage while maintaining the same airflow volume and static pressure. (Emerson, 2010) The sample data center was reconfigured to take advantage of these energy savings, producing table 15 below.

The 30% reduction in energy usage in addition to the 46% savings realized when using directional grates, a mentioned before, is realized in the example above. The underfloor static pressure requirements remain quite low, and PUE drops further still to 1.66 vs. the baseline value of 1.80. This is shown graphically in figure 16 below.

The consideration above only considers the 100% full fan speed operation. In the following sections it will be clear that this operation mode, while often the case in many data centers, can be drastically improved.

Perimeter CRAH Unit Design	Base Case Typical Grate w/Belt Drive Centrifugal Fans	Option #1 DirectAire w/Belt Drive Centrifugal Fans	Option #2 DirectAire & EC Fans
Rack Density for Calculation (kw)	12.5	12.5	12.5
Expected TAC %	50%	93%	93%
Total Required CFM to be delivered (CFM)	600134	322653	322653
CRAH Units Required (CFM/Tonnage specified below)	32	17	17
Total Fan Power Required (kw)	384.1	206.5	145.2
Estimated Annual Energy Consumption (kWh)	3364583	1808919	1271896
Fan Annual Energy Cost $	**$269,167**	**$144,714**	**$101,752**
Recommended Solution (Yes/No)	**YES**	**YES**	**YES**
Cost Per DirectAire and/or SmartAire	—	-$300	-$300
Number of Units Required	—	200	200
Total Cost of DirectAire and/or SmartAire	—	-$60,000	-$60,000
CRAH Unit Reduction	—	$0	$0
Fan Upgrades (EC Tech)	—	$0	-$187,000
Cost of Upgrade	—	**-$60,000**	**-$247,000**
Annual Energy Savings	—	**$124,454**	**$167,415**
Payback in Months (simple)	—	**5.8**	**17.7**
3 Year Savings	—	**$313,361**	**$255,246**
PUE Impact	1.80	1.70	1.66

Table 15 - Impact of Directional Grates ad EC Fan Technology



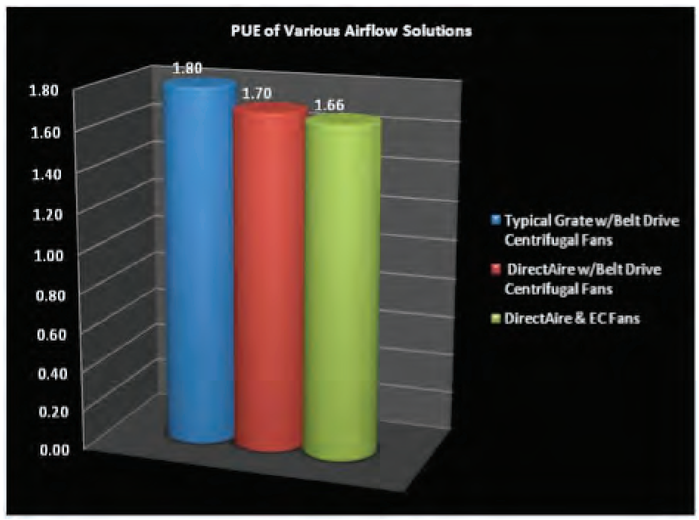


Figure 16 - PUE reduction realized from DirectAire and EC Fans

Diverse and Variable Load

The typical data center rarely ever presents a homogenous load profile to the cooling equipment tasked to handle the cooling requirements of the data center. Although increasing load density per rack seems a sure thing, rack load diversity will without a doubt remain. Many racks in the average data center have yet to be fully deployed, or may have equipment installed that fully occupies the available space but requires very little airflow, while other segments may be deployed fully with high density equipment requiring 10-20 times the airflow of the rack directly beside it. This variation has led to many approaches to balance the air distribution throughout the data center floor.

Diverse Airflow Panels for Diverse Load

One approach often used to more precisely provide the correct amount of air where it is needed is the use of different airflow panel designs based on the airflow requirements of the rack the panel is to serve. As seen previously in this whitepaper, the three panel types examined have different flow characteristics given a constant static pressure. This allows the user to correctly choose the panel most closely suited to the equipment being cooled. Table 16 below may help the reader determine what rack load levels can be expected with the 3 different panels discussed.

Static Pressure	25% Perforated Panel	56% Grate	68% Directional
0.02	332	916	976
0.04	476	1320	1431
0.06	584	1608	1882
0.08	666	1860	2235
0.1	746	2096	2618
0.12	818	2292	2869
0.14	886	2484	3058
0.16	944	2684	3250
0.18	990	2848	3457
0.2	1050	3024	3681
1-4 kW			
4-12 kW			
12-27 kW			

Table 16 - Load Capacities in Uncontained Situations

Another method or a joint method to manage load diversity throughout the data center environment is the use of dampers. Figure 17 below shows an example of a manually controlled sliding damper assembly.

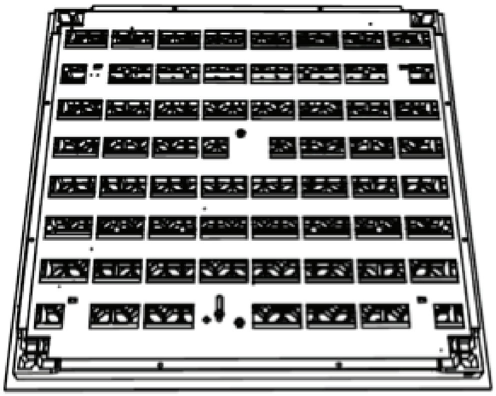


Figure 17- Manually Installed Damper on 56% Grate Panel, Bottom View

These dampers allow variable, manual control of allow airflow to be tuned to the rack airflow requirements. Dampers restrict the flow through the panel, as a segment of the panel is continuously blocked, reducing the maximum flow per panel. The impact on total capacity can be significant a can be seen in table 17 below.

Manual adjustment to dampers throughout the data center environment, and the removal of those dampers to increase capacity where need is often the method used for accurately meeting static load demand.

The careful balancing of airflow is not without its difficulties, especially when the air handling equipments fans are of the fixed speed variety. The process of determine the CFM currently exiting an airflow panel, adjusting the damper to meet the rack requirements, and then moving to other panels in the system can result in changes in the static pressure throughout the site, again requiring additional iterations before balance is achieve. Any additional moves, adds or changes at the rack level may require this tedious process to be repeated throughout the environment.

Variable Airflow for Variable Load

An additional complicating factor in determining proper airflow balance is the variability of the load in any one given rack. Advances in cloud computing, the process of pooling the compute resources of multiple servers throughout the data center, on which the business applications run, has resulted in a greater amount of load variability throughout the day. The cloud only uses the necessary resources to operate the current demand, only bringing additional resources online as required. These additional resources may simply be servers operating in an idle mode, or may actually be in a sleep stage, utilizing far less energy, and therefore producing far less heat and requiring little to no airflow. As these machines become active, the heat load profile in data center can swing dramatically. If manual adjustments to airflow are made, they must be made to account for the maximum requirements during high utilization. During the off peak stages, significant air recirculation should be expect due to little or no demand at the server level. Figure 18 below shows a typical load profile per rack of a private cluster that's utilization peaks during the middle of the business day on the east coast of the United States.

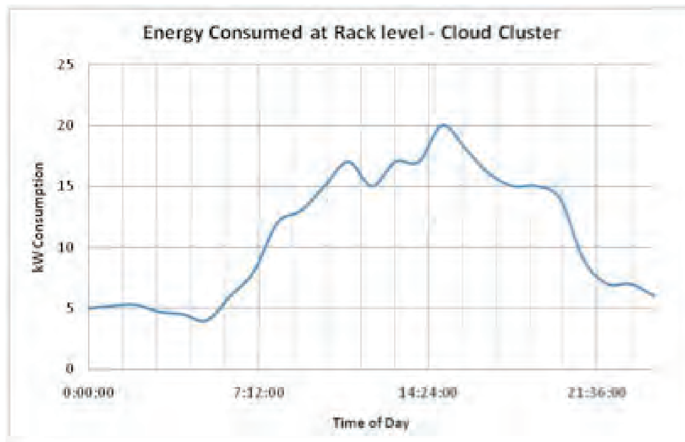


Figure 18 - Cloud per Rack Energy Usage Throughout a 24 hour period

Additionally, IT hardware operating off the cloud will still experience variability of its load profile, impacting the airflow requirements and heat rejection values during off peak usage. While the swings may not be as great as that expected of computing systems running on the cloud, efficiency increases in future servers will likely increase the load variability for standard IT hardware.

Static Pressure	25% Perforated Panel	25% Pef w/Damper	56% Grate	56% Grate w/Damper	68% Directional
0.02	332	237	916	504	976
0.04	476	328	1320	712	1431
0.06	584	402	1608	876	1882
0.08	666	461	1860	1008	2235
0.1	746	515	2096	1128	2618
0.12	818	582	2292	1232	2869
0.14	886	620	2484	1332	3058
0.16	944	669	2684	1416	3250
0.18	990	699	2848	1496	3457
0.2	1050	756	3024	1580	3681
1-4 kW					
4-12 kW					
12-27 kW					

Table 17 - Effect of Damper Restriction on Airflow of Various Panels

The Challenges of Addressing Load Variability

Many methods have been proposed to address load variability at the rack level. Rack and row based cooling solutions can often provide variable cooling capacity to accurately match the load seen at their level of granularity. Rear door cooling systems, overhead cooling system, and direct to the chip cooling methods all provide for methods of addressing individual rack load variability, but all require significant investments in specific technology that may or may not fit the data center design concept as a whole.

At the room level, air handling unit manufacturers have attempted to address these issues through the use of throttling valves and variable speed fans similar to those discussed early. These fans can be adjusted to compensate for a lower delta T detected at their supply and return ducts, allowing for the system to reduce its energy consumption based on their global return and supply temperatures. These methods have merit, but only when the load profile is relatively uniform, and the turn down rates are even across the systems served by this particular cooling unit. In the case where a few individual racks maybe operating at a high level of utilization, and generating significant heat while requiring their peak CFM requirements, other servers may at the same time be entering idle states. This imbalance would be average as the air is returned to the air handling equipment resulting in the appearance of a constant or reducing load, reducing the overall CFM provided to the floor, impacting the equipment that is still at a high rate of utilization.

It is clear that some form of rack level, temperature or airflow specific control system is required to deliver precisely the correct amount of air to the IT equipment at a granular level. The system must be dynamic as well to meet instantaneous changes in demand.

The Solution – Local Variable Airflow Control

The commercial office space addressed the issue of load variability over time in the 1960s-1970s. Variable air volume dampers were integrated into airflow ducts and raised floor plenums to control the amount of air delivered to the individual dampers throughout the climate controlled space. Load variance in the commercial office environment has large swings in load profiles due to solar loading throughout the day, increased occupation rates and technology usage. For many years this technology has reduced energy usage in the commercial office space through more efficient fan energy usage, as well as increased comforted for the occupants of the space.

In many ways the IT space has begun to mimic the commercial office space. Products that were developed years before now have application in the data center space. Load diversity and variability now reflect that commercial office space but with even greater variance over shorter periods of time, increasing the energy savings that might be realized in this space.

Adapting these technologies to create the most elegant solution for controlling airflow delivery to the IT rack could take the form of a variable flow device installed below each airflow panel sized to handle the volume of air expected. Each panel can be thought of as an individual zone to further draw out the commercial office space analogy. This variable flow device could measure the incoming air temperature at the face of the rack, adjusting the flow to ensure that the temperature at the face of the rack was never above the maximum allowable set point provided by the user. Coupled with directional air flow grates, the system would be able to account for any bypass air, as well as for any additional local climatic events.

The system would also be able to provide indirect feedback to the air handling equipment on the required airflow through pressure transducers installed in the raised floor plenum. These sensors would provide information back to the air handling equipment to allow for throttling of fans to reduce energy consumption at the fan level. The system would be design in such a way as to ensure that the airflow control devices fail in the fully open mode, ensuring the flow would always be provided to the rack the panel serves. Neighboring airflow control devices would also provide a redundant aspect to the system in case of mechanical failure, as panels could compensate in partial load conditions for many failures.

The Process

The process of control is illustrated in the following figures 19-21. For the purposes of the illustrations, the variable air volume damper will be referred to by its trade name, SmartAire™.

It should be clear from the below operational diagrams the potential energy savings that can be realized through automated damper control. A large scale facility, would provided for stable operation of the fans speed control system while allows for predictable transient responses from the individual dampers.

Airflow through the damper system and then through the directional grate would be impacted by the additional restrictions at the damper. Initial testing produced the airflow curve shown in figure 22 below.

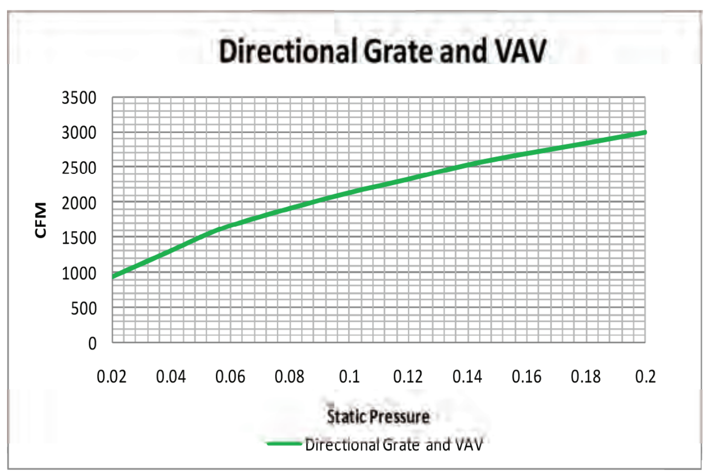


Figure 22 - Airflow through Automatic Damper and Directional Grate

Airflow through the panel and damper can be calculated using the 2nd order polynomial in equation 11.

$$CFM = -34524 * Static\ Pressure^2 + 18549 * Static\ Pressure + 628$$

Equation 11 – Equation Curve for 68% Open Area Directional Grate and Automatic Damper

Operation Example

1. IT load is idle over night at 4kw and 480CFM per rack
2. SmartAire is nearly closed which increases the static floor pressure, until the CRAC unit fan speeds are reduce to meet the desired static pressure, while at the same time meeting the inlet temperature requirements at the rack. (~75F)

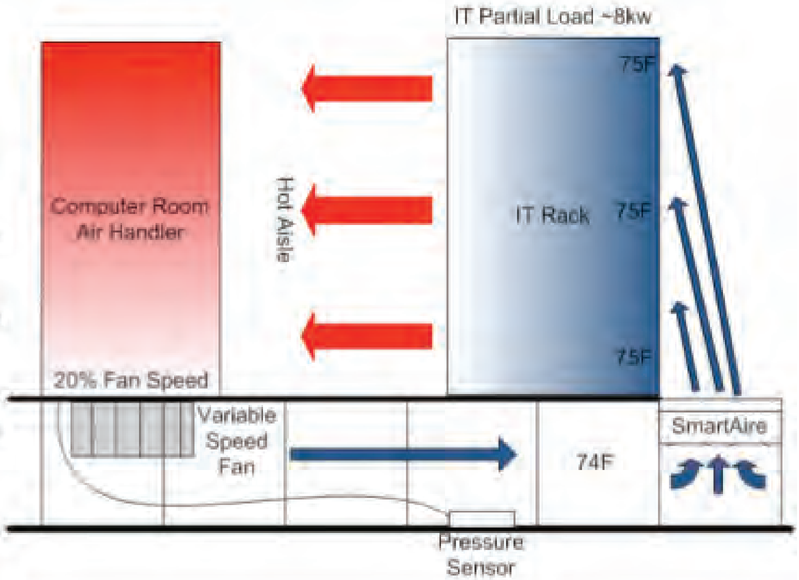


Figure 19 - Idle load condition for variable flow damper

Operation Example

5. IT load has increased to full load during the day at 14kw and 1680 CFM.
6. SmartAire opens fully, and the CRAC unit fans increase their speeds to hold a constant underfloor static pressure. Airflow to the racks is sufficient to keep all temperatures at the face of the rack at the desired set point. (~75F)

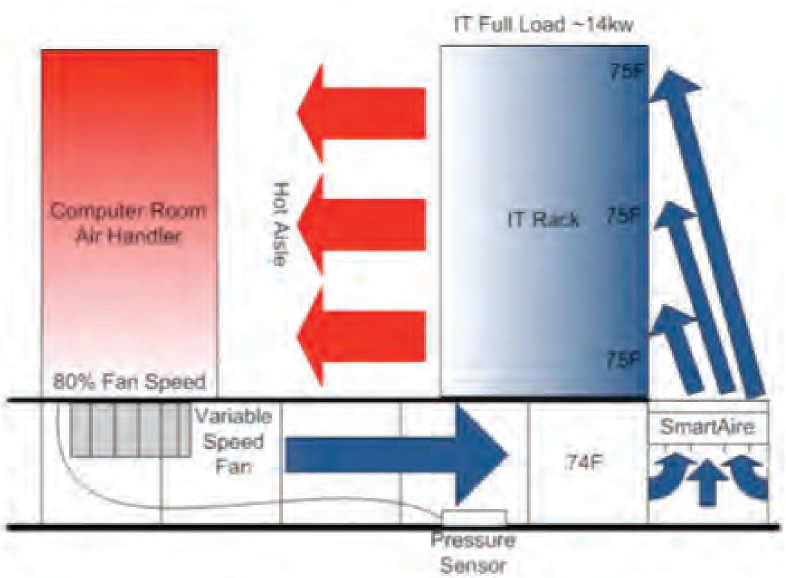


Figure 20 - Partial Load condition for variable flow damper

Operation Example

3. IT load has increased to partial load during the day at 8kw and 960CFM.
4. SmartAire begins to increase the open area of the dampers, increasing the airflow to the rack while decreasing the static pressure, which is increased to the set point by the CRAC unit as it monitors the pressure sensor, temperature to the rack remains stable.

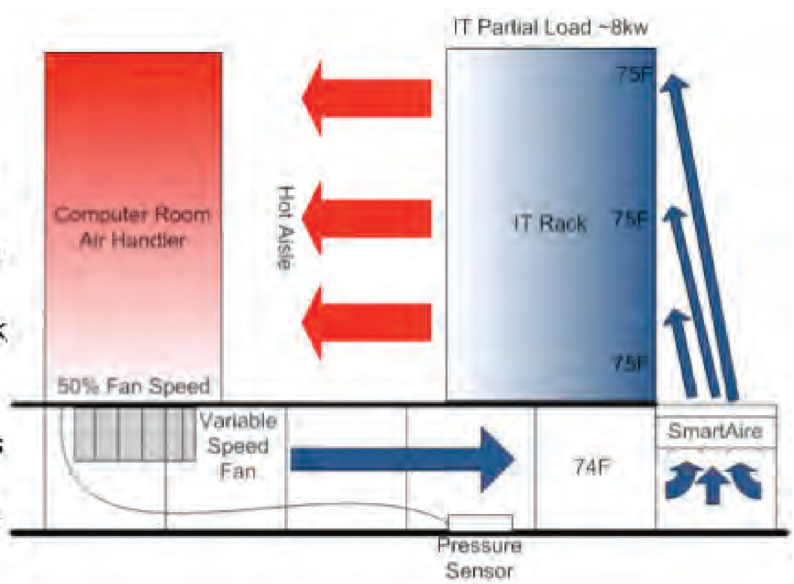


Figure 21 - Full Load condition for variable flow damper

Energy Impact

The ability to reduce the fan energy consumed in the data center can play a large role in reducing the overall power consumption of the data center, while meeting the availability requirements of the facility. Previous energy calculations made in this paper show the reductions realized by increased total air capture ratios offered by directional grates, coupling this technology with variable air flow devices allows for significant reductions during off peak server utilization when demands are lower. This further reduction is analyzed in our previously modeled example data center in table 18 below. The model now contains a data center retrofitted with directional grates, EC fans in the air handling equipment, and now the addition of automatic variable airflow dampers. (SmartAireTM)

As before in earlier examples, the TAC rate is 93% for directional grates. A 25F average delta is used as before, producing a 126 CFM/kW requirement for the typical IT equipment in the model. CFM totals and requirements are calculated for peak requirements when considering designs incorporating variable air volume dampers (SmartAireTM). The average total fan energy required is the averaged fan energy requirement based on the 70% average utilization number enters by the IT user. This reflects the average CFM and heat production requirements at the server level and is used to calculate the fan energy requirements. Figure 23 below provides the energy reduction curve for EC fans as a function of CFM delivered versus typical belt driven centrifugal fan systems.

Using the curve in figure 23, equation 12 below can be used to calculate the overall reduction in energy usage at the fan level in the data center environment.

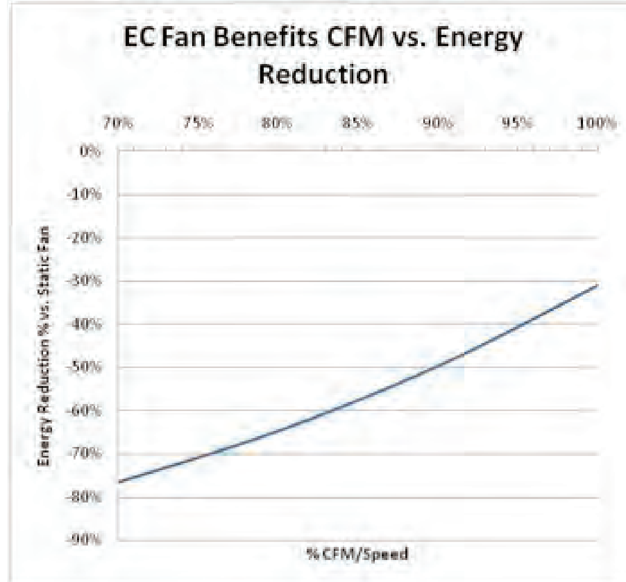


Figure 23 - Energy Reduction vs. Fan Speed

*Percent Energy Reduction = 1.725 * Fan Speed Percentage² - 1.4175 * Fan Speed Percentage - 0.6168*

$$\text{Percent Energy Reduction} = 1.725 \cdot \text{Fan Speed Percentage}^2 - 1.4175 \cdot \text{Fan Speed Percentage} - 0.6168$$

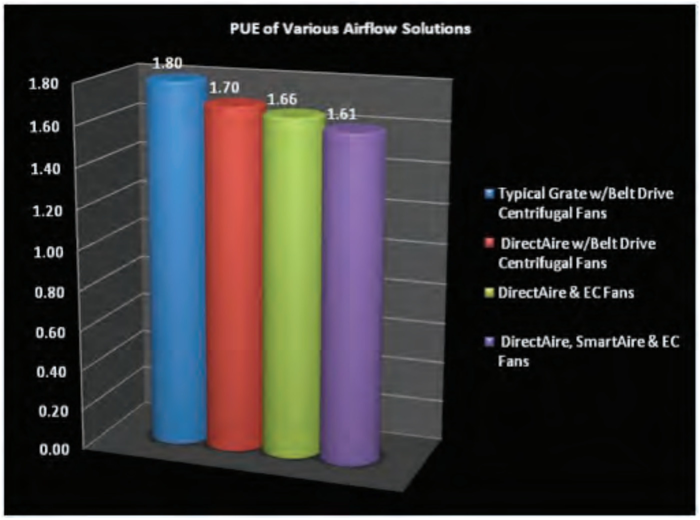
Equation 12 – Impact of reduction in fan CFM output to accommodate IT load variability

This reduction in annual fan energy usage has a large impact in the overall energy savings in the data center. The original annual fan energy cost using typical non-directional grates was estimated to be $269K vs. the new estimate of $37K, or over a 86% reduction in fan energy cost, all while providing reliable IT cooling direct at the IT equipment that requires airflow when and where it is needed as demands change in the environment. The PUE benefit of this final step in optimizing airflow is illustrated on the next page.

	Base Case	Option #1	Option #2	Option #3
Perimeter CRAH Unit Design	**Typical Grate w/Belt Drive Centrifugal Fans**	**DirectAire w/Belt Drive Centrifugal Fans**	**DirectAire & EC Fans**	**DirectAire w/SmartAire & EC Fans**
Rack Density for Calculation (kw)	12.5	12.5	12.5	8.6
Expected TAC %	50%	93%	93%	93%
Total Required CFM to be delivered (CFM)	600134	322653	322653	221585
CRAH Units Required (CFM/Tonnage specified below)	32	17	17	12
Total Fan Power Required (kw)	384.1	206.5	145.2	50.4
Estimated Annual Energy Consumption (kWh)	3364583	1808913	1271896	441882
Fan Annual Energy Cost $	**$269,167**	**$144,714**	**$101,752**	**$35,351**
Recommended Solution (Yes/No)	**YES**	**YES**	**YES**	**YES**
Cost Per DirectAire and/or SmartAire	—	-$300	-$300	-$2,000
Number of Units Required	—	200	200	200
Total Cost of DirectAire and/or SmartAire	—	-$60,000	-$60,000	-$400,000
CRAH Unit Reduction	—	$0	$0	$0
Fan Upgrades (EC Tech)	—	$0	-$187,000	-$132,000
Cost of Upgrade	—	**-$60,000**	**-$247,000**	**-$532,000**
Annual Energy Savings	—	**$124,454**	**$167,415**	**$233,817**
Payback in Months (simple)	—	**5.8**	**17.7**	**27.3**
3 Year Savings	—	**$313,361**	**$255,246**	**$169,450**
PUE Impact	[illegible]	1.70	[illegible]	[illegible]

	Base Case	Option #1	Option #2	Option #3
Technical Results	Typical Grate w/Belt Drive Centrifugal Fans	DirectAire w/Belt Drive Centrifugal Fans	DirectAire & EC Fans	DirectAire w/SmartAire & EC Fans
Expected Load Per CRAC or CRAH Unit (Tons)	15.3	28.8	28.8	40.8
Capacity Utilization of CRAC/CRAH units	30.6%	57.5%	57.5%	81.5%
Required CFM Per Rack (CFM)	1,500	1,500	1,500	1,032
Required CFM Per Panel (CFM)	3,001	1,613	1,613	1,110
Required Static Pressure Required to Meet Demand	0.20	0.04	0.04	0.08
Total Required CFM by IT Equipment (CFM)	206446	206446	206446	206446
Expected CRAC or CRAH Delta T (F)	9.0	16.8	16.8	24.4

Table 18 - Revised Energy model for Variable Air Volume Dampers (SmartAireTM)



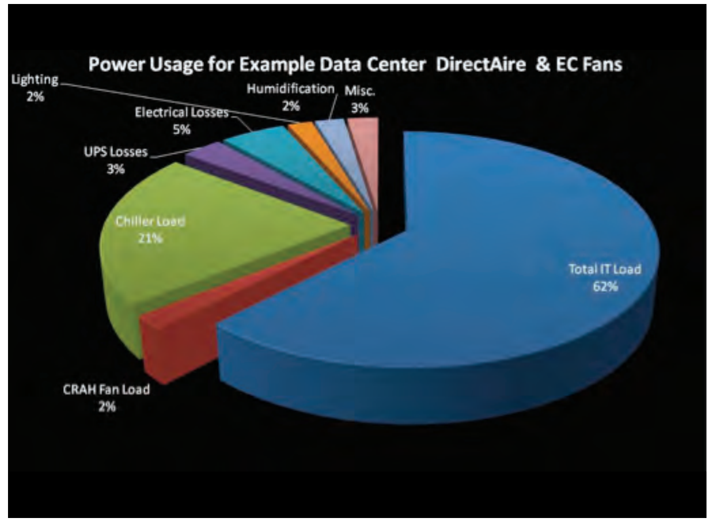


Figure 24 - PUE Impact of Continuous Airflow Improvement

Summary

Significant savings can be realized through the use of the data center airflow technologies discussed. Load diversity throughout the data center will remain for some time to come, load variability will continue to increase through the increased use of cloud computing, and increased efficiency at the server level to handle partial load conditions. Increased diversity can have a dramatic effect on the energy cost to cool a data center. Our previous model is reexamined below with a large difference in peak and average load, resulting in a design bypass that is much greater than previously examined. This increase in bypass air to cool the peak rack loads is often typical in the average data center environment. The impact on annual fan energy cost can be seen to be quite large in figure 25.

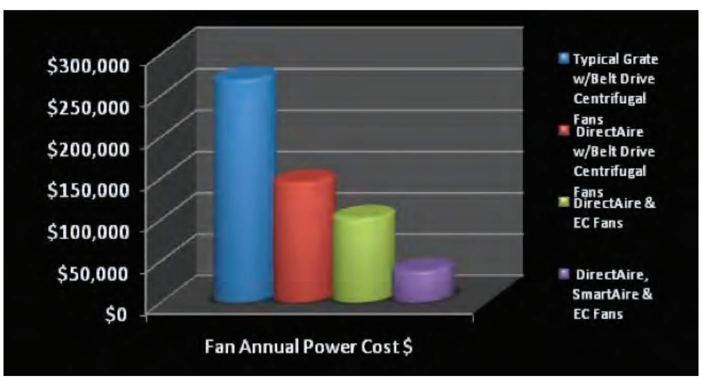


Figure 25 - Annual Fan Energy Cost

Payback Period Estimates

The feasibility of any new capital investment must be considered in the light of initial capital expenditure and the expected reduction in operational costs. As illustrated in earlier sections of this paper, significant energy cost reductions can be realized. Figure 26 helps to summarize the estimated cost to implement each solution step from the base model i.e. the upgrade of an existing facility from typical 56% open area grates, to full directional grates, variable airflow control devices and EC fan upgrades for the required air handling units.

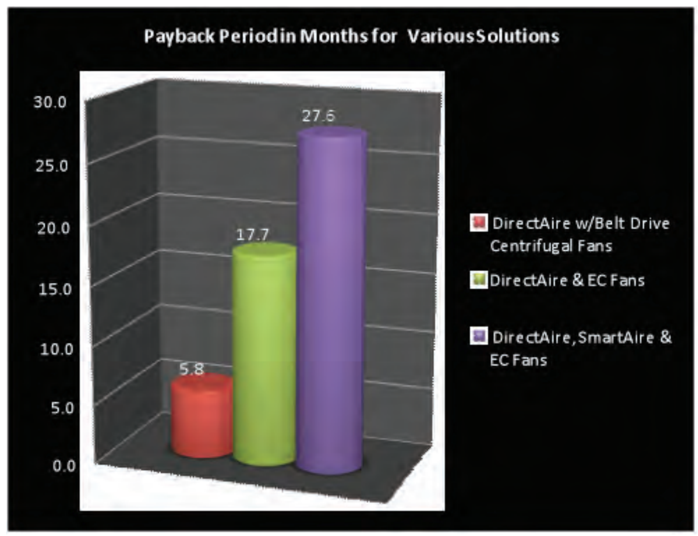


Figure 26 – Payback Period in Months for Airflow Upgrades – 1720kW IT Load, Retrofit

This however is not the end of the story. Although the payback period for the more complete solutions have a longer term, it's important to note the significantly higher energy savings seen annually with these solutions will quickly pay greater dividends over more time. Figure 27 ad 28 illustrates this impact.

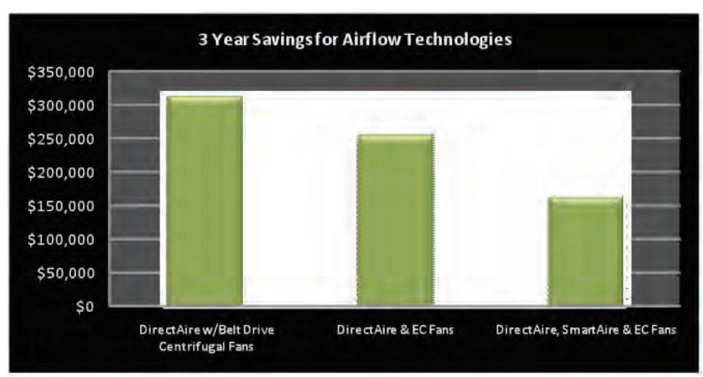


Figure 27 - Three Year Savings – 1720kW IT Load, Retrofit

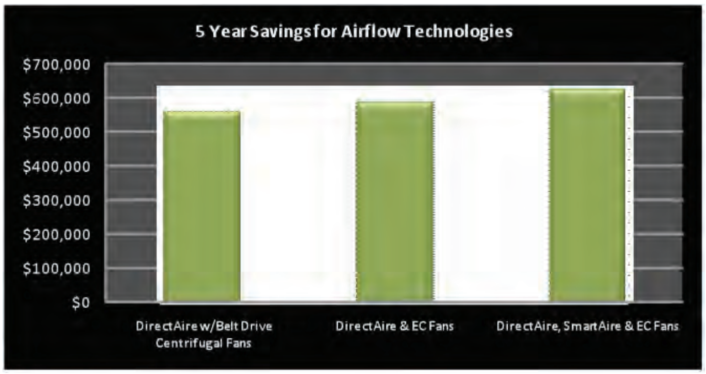


Figure 28 - Five Year Savings – 1720kW IT Load, Retrofit

The above examples have only considered the cost impact of retrofits into existing designs. As illustrated in the models previously shown, the energy savings are derived from reduction in fan energy year over year. When considering a new build however these numbers can be even more dramatic. The reduction in CFM directly impacts the required number of air handling units to meet the peak load demand. This reduction dramatically reduces the first cost impact, as each air handling unit not required for the build out to provide for bypass airflow has significant cost. This cost reduction results in a first cost savings above the cost of using the technologies covered in this whitepaper. Figure 29 shows the effect of this on the 3 year savings when using these technologies.

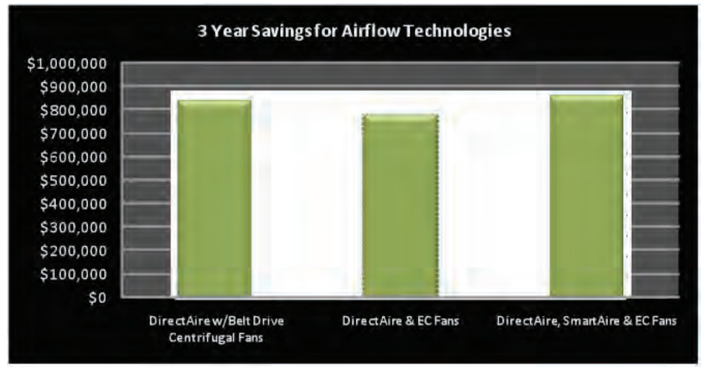


Figure 29 - 3 year savings, 1720kW IT Load, New Build

Conclusions

Data Center operators will continue to be challenged to reduce overall usage, both from an ecological perspective, and an economical view point. Reducing IT energy as shown in this whitepaper can be realized quickly and easily with little to no interruption in the day to day operation of the data center. The technologies discussed can help the IT manager meet the operational demands that currently exist, while continuing to play a role in the enterprise's energy reduction goals and in the case of new builds, they can dramatically lower first cost while have a dramatic impact on operational expense every year.