DATA CENTER
Frontier Special Report

High Density IT Cooling

Breaking the Thermal Boundaries

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Introduction

Data centers have seen an ongoing increase in average power density, especially over the past decade. Moreover, the power density per IT cabinet has seen an even greater increase as IT Equipment power density continues to rise to levels that seemed extreme only a few years ago, but are now the new normal. We have major ITE manufacturers which offer standard “commodity” 1U servers with 800 to 1,800 watt redundant power supplies which can require more than 1000 watts of cooling.

> There are multiple issues that influence how high the power density in air-cooled IT equipment in standard cabinets can be pushed. This has led to renewed efforts by ITE manufacturers and data center operators to push the boundaries of air cooling.

This is being driven by processor and IT equipment manufacturers which in turn are being held back because most mainstream data centers are hard pressed or unable to support more than 10-15 kW per rack. Processor power levels are escalating from 100 to 250 watts and chip manufacturers have product roadmaps for CPUs and GPUs that are expected to exceed 500 watts per processor in the next few years.

This trend has left many wondering if air cooled ITE has reached its power limits and if liquid cooling is really the only long term solution. Currently, some HPC IT equipment is available as liquid or air cooled versions, however the bulk of standard off-the-shelf ITE is still air cooled. And the majority of new mainstream data centers continue to be designed for air cooled ITE. In reality, there are multiple issues that influence how high the power density in air-cooled IT equipment in standard cabinets can be pushed. This has led to renewed efforts by ITE manufacturers and data center operators to push the boundaries of air cooling.

The basic principles of data center cooling are well known; remove the heat load generated by IT equipment and transfer it via one or more physical mediums (air, liquids, or solids) and one of more forms of thermo-mechanical systems to reject it out of the facility. However, as power densities of IT processors and other computing related components increased, this process has become more difficult to accomplish effectively and efficiently. For purposes of this report, we will discuss air and liquid cooling, with a primary focus on air-cooled IT equipment.

Power Density – Watts per What?

One of the more common issues that get discussed is what is the power density limit for air cooled ITE. Data center power density is typically expressed as average watt per SF. This is calculated based on the critical power available to the IT Load (watts or kilowatts), divided by the cooled area occupied by the ITE (whitespace). However, this does not really reflect the conditions of the cooled space occupied by the air-cooled IT equipment.

In the example below, we will examine a hypothetical 10,000 square foot whitespace area of a perimeter cooled raised floor data center. The critical load rating is 1,000 kW and 200 IT Cabinets at 5, 7.5 and kW average power.

Name	Description	Area (SF)	Power	Average Power Density
Entire Area Whitespace	Contains IT Equipment Cabinets, Cooling Units, and Power Distribution, etc.	10,000	1,000 kW	100 watts/SF
Effective IT Cabinet Area	Contains IT Equipment Cabinets	7,000	1,000 kW	143 watts/SF
IT Cabinet	Space per IT Cabinet: 24"-30" wide, 42"-48" deep (including ½ of 2 tile cold aisle and ½ of a 3-4 ft. hot aisle)	15-25 SF	5,000 watts 7,500 watts 10,000 watts	200-333 watts/SF 300-500 watts/SF 400-666 watts/SF
Cluster of Cabinet	20 Cabinets with Aisle Containment	300-400 SF	100 kW 150 kW 200 kW	250-333 watts/SF 375-500 watts/SF 500-666 watts/SF

Table 1 - Average power density by area

Air vs Liquid Cooling

The two greatest sources of heat in IT equipment are the processors (CPU, GPU, TPU, etc.) and memory. As mentioned, processor power levels are escalating from 100 to 250 watts and chip manufacturers have product roadmaps for CPUs and GPUs that are expected to exceed 500 watts per processor in the next few years (see AHSRAE Processor roadmap) and represent 50% or more of the ITE heat load. While the power level of working memory chips (DIMM, etc.) are relatively low in comparison, the total amount of memory has increased significantly and continues to rise, and can represent 20% or more of the heat load.

As mentioned, liquid cooling is being primarily used to address the higher power processors. While there are many variations of liquid cooling technologies and methodologies, they generally fall into three categories:

- Liquid Cooling for Air-Cooled ITE
- Liquid Cooled ITE
- Immersion Liquid Cooling

Liquid Cooling for Air-Cooled ITE

The ITE is standard unmodified equipment. The process starts at the processor chip and the heat is typically transferred to an attached air-cooled heat sink. All the heat is transferred to room based cooling units, or to close coupled cooling: Inrow cooling, Rear Door Heat Exchanger (RDHX) or other types such as overhead aisle based cooling units.

Liquid Cooled ITE

The process starts with internal components; the processor chip and memory the heat is typically transferred to an attached liquid cooled heat sink (cold plate), also sometimes referred to as direct liquid cooling. Typically, a portion (50-75%) of the heat is transferred to a liquid loop, the remainder of the heat goes to room based cooling units, or to close coupled cooling: Inrow, RDHX, or other similar systems.

Immersion Liquid Cooling

The entire ITE is submerged in a dielectric fluid, which engulfs the chassis and all the components. Virtually all the heat is effectively transferred to the fluid.

These are generalized summaries of three categories. Each have advantages, limitations and trade-offs, however the more granular aspects of Liquid Cooled ITE and Immersion cooling raises the complexity, (due to the varies methodologies, fluid types and operating temperatures), which makes further discussion of these factors beyond the scope of this report.

Crossing Thermal Boundaries – Chip to Atmosphere

In order to better understand the issues, it is important to examine the path, thermal boundaries and follow how the heat is transferred from the chip to the external heat rejection systems. Starting at the processor chip, there is typically about 1 to 1.5 square inches at the top of the case that needs to transfer 100-150-200 watts of heat to an attached heat sink (integrated heat spreader) via conduction (effectively 7,000 to 14,000 watts/SF). From there, multiple fans draw intake air from the front of the IT equipment case, directing it to the fins of the heat sink though the equipment chassis, and also cooling the other IT components and then exhausted out of the rear of the ITE case. For a typical modern 1U server with multi-processors, drawing 500 watts it would require 80-100 CFM to cool it. However, the case only has a very limited area (2-4 square inches) for the air to enter and exit the openings. This results in relatively high airflow velocities and pressures in the IT cabinet. When (40) 1U servers are stacked in a typical 42U cabinet, this creates another set of challenges *(see more about this in the Rack Hygiene section)*.

> When the case only has a very limited area (2-4 square inches) for the air to enter and exit the openings, the result is relatively high airflow velocities and pressures in the IT cabinet.

Airflow 101: Understanding the Physics

The basic physics of using air as the medium of heat removal is well known. This is expressed by the basic formula for airflow (BTU=CFM x 1.08 x ΔT °F), which in effect defines the inverse relationship between ΔT and required airflow for a given unit of heat. The traditional cooling unit is designed to operate based on approximately 20°F differential of the air entering the unit and leaving the cooling unit (i.e., delta-t or ΔT). For example, it takes 158 CFM at a ΔT of 20°F to transfer one kilowatt of heat. Conversely, it takes twice that amount of airflow (316 CFM) at 10°F ΔT. This is considered a relatively low ΔT, which increases the overall facility cooling unit fan speeds to deliver more air flow to ITE.

The left side of *Table 2* below shows the results of the required airflow in relation to the ΔT of the IT equipment. The right side of the table shows the airflow per supply floor over a range of power level of 5-15 kW.

IT Equipment Airflow Requirement		CFM per Tile at 100% Capture Index			
Airflow per kilowatt of heat transferred		CFM per Floor Tile at “X” kW			
Delta-T (°F)	Required CFM / kW	5 kW	7.5 kW	10 kW	15 kW
10	316	1,580	2,370	3,160	4,740
15	210	1,050	1,575	2,100	3,150
20	158	790	1,185	1,580	2,370
25	126	630	945	1,260	1,890
30	105	525	788	1,050	1,575
40	79	395	593	790	1,185

Table 2 - ITE Airflow Requirement vs Delta and corresponding CFM per supply floor tile

**Note: For purposes of these examples, we have simplified the issues related regarding latent vs. sensible cooling loads (dry-bulb vs. wet-bulb temperatures). The airflow table is based on dry-bulb temperatures.*

In order to deliver the higher airflow for raised floor systems, higher underfloor static pressures are required to provide the pressure for the perforated tile or floor grate supplying air to the cold aisle. In the majority of data centers the cold aisle is typically two tiles wide, which means that there is one supply tile per ITE cabinet. There is a wide range of perforated floor tiles, grates and grills—as listed in *Table 3*.

Underfloor Static Pressure vs Airflow of Perforated Floor Tiles and Grates

Static Pressure	Perforated		Grills and Grates	
(Inches H_2O)	25% Open	32% Open	56% Open	68% Open
0.02	370	530	920	1120
0.04	440	745	1320	1615
0.05	480	835	1470	1830
0.06	515	890	1600	1995
0.08	575	1010	1860	2300
0.10	700	1120	2100	2580
0.12	Not Rated	1235	2300	2780
0.14		1345	2485	2935
0.16		1430	2685	3170
0.18		1500	2850	3330
0.20		1600	3025	3400

Table 3 - This table represents a generic range of values of commonly available products without adjustable dampers—it is not manufacturer specific. The CFM ratings are for units without adjustable dampers. Dampers would reduce the CFM rating.

While not an absolute statement, typical under floor systems average pressures range from 0.04-0.08 inches H_2O. These pressures are just a stated design average, in an operating data center underfloor pressure can vary widely (-100% to +100%) and are affected by many factors.

Of course, the higher the power density of an ITE cabinet or cluster of cabinets, the higher the CFM required per tile. As a result, underfloor pressures need to increase in order to deliver the required CFM. Moreover, as can be seen in *Table 3*, an increase in static pressure does not directly result in a proportional increase in airflow CFM. For example, doubling static pressure (0.04 to 0.08 Inches H_2O) only results in an approximately 130-145% increase in CFM per tile. (As highlighted in *Table 4*).

Static Pressure	Perforated		Grills and Grates	
(Inches H_2O)	25% Open	32% Open	56% Open	68% Open
0.02	370	530	920	1120
0.04	**440**	**745**	**1320**	**1615**
0.05	480	835	1470	1830
0.06	515	890	1600	1995
0.08	**575**	**1010**	**1860**	**2300**
0.10	700	1120	2100	2580

Table 4 - Doubling static pressure (0.04 to 0.08 Inches H_2O) only results in an approximately 130-145% increase in CFM per tile.

Capture Index

While *Table 3* shows the projected CFM performance in relation to static pressure, it should not be assumed that all the airflow leaving the floor tile enters the IT cabinet. The capture index (also called capture ratio) represents the percentage of the air leaving the tile to the amount of air entering the face of the IT cabinet. However, this does not guarantee that all the air is getting to the air intake of the ITE inside the cabinet (See Mind the Gaps.)

For uncontained cold-aisles, there is a significant percentage of cold supply airflow which does not reach the face of the IT cabinet (reducing the net CFM and capture ratio). In addition, there is mixing of hot and cold air, all of which reduces the overall supply of cool air to the cabinet, as well as increasing ITE air intake temperatures. Therefore, it is common practice to deliver higher airflow (oversupply), to help reduce mixing, which causes hotspots. Of course, higher airflow requires more underfloor pressure, and also increases airflow velocity in a given tile. This oversupply also increases the fan energy of the facility cooling units required to cool the rack.

> While a relatively complex subject, in general, the higher the velocity the greater the impact. This is often overlooked; however an accurate CFD model will show the impact of this.

However, the increased pressures also increase leakage in several categories:

- Cable opening in Floor
- Seams between solid floor panels
- Gaps
  - Under the bottom of ITE Cabinets
  - Between ITE Cabinets
  - Inside IT Cabinet

The leakage can become a significant factor as pressures increases, which in turn requires cooling unit fans to increase speed and raise the energy required to cool the racks.

The velocity of the airflow coming from the supply floor tile or grate can also influence the amount of air actually entering the ITE cabinet, as well as drawing unwanted warm air if there are gaps under the bottom of IT cabinets. While a relatively complex subject, in general, the higher the velocity the greater the impact. This is often overlooked; however an accurate CFD model will show the impact of this.

The percentage open rating for a floor tile or grate will directly affect the discharge velocity of the air for a required amount of airflow. It is also influenced by the type of grate or grill (directional louvers or undirected).

Required CFM	Tile % Open	Velocity Feet per Minute
700	25%	700
700	32%	560
700	56%	310
700	68%	256

Table 5 - Example of the tile rated percent open vs velocity (figures are approximations—not manufacturer specific)

Mind the Gaps

As the velocity of the air increases the impact of the Venturi effect, which comes into play if there are gaps under the cabinet. It creates a negative air pressure drawing warm airflow though the gaps under the bottom of the rack. These gaps can range from one half-inch to 2 inches high, allowing warm air to be drawn beneath the cabinet and mix with the cold supply air coming up from the tile in front of the cabinet. *Table 6* shows the open area for an under-cabinet gap, based on its size. While there are several variables that determine the relative differential pressure at the gap area, in general the larger the area and velocity, the greater the CFM drawn under the cabinet.

Individually and collectively, these gaps can be a significant cause of hot air mixing with the supply air in cold aisle containment, increasing the actual intake temperatures reaching the ITE. This issue becomes more severe as more air flow is required to meet increase power levels.

Height of Gap (inches)	24" wide Cabinet Open Area (sq. inches)	30" wide Cabinet Open Area (sq. inches)
0.5	12	15
1.0	24	30
1.5	36	45
2.0	48	60

Table 6 - Approximate open area for an under-cabinet gap, based on gap height


BlueMamba, courtesy of TechnoGuard

Less obvious and often overlooked, but potentially as significant, are the gaps between cabinets as shown in *Table 7*. These gaps between the cabinets can also significantly impact airflow between the hot and cold aisles. There are various devices which can address this problem, some more effective than others. In general, devices that can fully adapt to various size inter-cabinets spaces, such as those with a flexible compressible and expandable material, are more effective at fully sealing the vertical gaps.

Width of Gap Between Cabinets (inches)	42U Cabinet (sq. inches) 78" tall	48U Cabinet (sq. inches) 90" tall
0.25	20	22
0.375	30	33
0.50	40	44

Table 7 – Open area of gaps between cabinets (figures rounded for clarity)

Understanding ITE Dynamic Delta-T

Moreover, modern IT equipment has a highly variable airflow dependent on its operating conditions, as well as its computing load. This means that ΔT may vary from 10˚F to 40˚F during normal operations as ITE fans increase or decrease speed in response to intake temperatures and IT computing loads. This in itself creates airflow management issues resulting in hotspots for many data centers that are not designed to accommodate this wide range of varying temperature and airflow differentials. This can also limit the power density per rack if not accounted for.

There are various levels of containment that influence the severity of this potential issue. This can be quantified by monitoring pressure in contained cold aisles.

Unexpected Consequences of Energy Star Servers

Virtually all modern servers generally control the speed of their fans in relation to air intake temperatures and processing loads. In the case of Energy Star rated servers, one of the key parameters is significantly reduced power while at idle, as well as minimizing power draw at 100% computing load. In order to achieve maximum energy reduction, the thermal controls may vary fan speeds more aggressively, resulting in wider range of CFM requirements, as well as delta-T.

ASHRAE Thermal Guidelines

- Recommend and Allowable Environmental Ranges 2004 to 2021
- The Processor Thermal Road Map
- The New H1 Class of High Density Air Cooled IT Equipment

ASHRAE's TC9.9 Thermal Guidelines for Data Processing Environments (thermal guidelines) have been created with the participation of IT equipment and cooling system manufactures. It is followed by data center designers, owners and operators. The range of recommended temperatures originally was relatively limited (68˚F to 77˚F), when it was first released in 2004. In 2011, the 3rd edition of the thermal guidelines the recommended temperature range increased to 64.4˚F to 80.6˚F, it introduced much broader allowable temperatures A1 to A4.

Classes	Degrees Celsius	Degrees Fahrenheit
Recommended (suitable for Classes A1 to A4)	**18 to 27˚C**	**64.4 to 80.6˚F**
A1	15 to 32˚C	59 to 89.6˚F
A2	10 to 35˚C	50 to 95˚F
A3	5 to 40˚C	41 to 104˚F
A4	5 to 45˚C	41 to 113˚F

Table 8 – ASHRAE Thermal Guidelines 5th edition 2021 Temperature Ranges

This has effectively remained unchanged (humidity ranges have broadened since them). New data center designs and expected operating conditions for A2 rated ITE has driven data center supply temperatures higher to save energy. Many colocation data center service level agreements (SLA) are based on maintaining ASHRAE recommended range during normal operations, with excursions into the A1 allowable range during a cooling system problem.

In 2021, ASHRAE published a whitepaper the "Emergence-and-expansion-of-liquid-cooling-in-mainstream-data-centers". The whitepaper included a chart "Air cooling versus liquid cooling, transitions, and temperatures". This effectively presented a Thermal Road Map for air vs cooled processors based on data provided by chip manufacturers.

The roadmap ranges indicated rapid rises in power requirements and thermal transfer limits from the chip case to the heat sink (air or liquid cooled).

> ASHRAE 2021 Reference Card notes that H1 Class ITE should be located in "a zone within a data center that is cooled to lower temperatures to accommodate high-density air-cooled products".

The thermal roadmap and the 5th edition clearly indicated that as processors went beyond 200 watts, the characteristics of liquid cooling becomes a more thermally effective choice. However, the whitepaper also recognized that many IT equipment users were unwilling or unable to use liquid cooling in existing data centers.

As a result, the new H1 Class of High Density Air Cooled IT Equipment was created to allow operation in air cooled data centers. The H1 allowable range is 59˚F to 77˚F, however, the recommend temperature range is limited to 64.4˚F to 71.6˚F. These higher power and power density requirements effectively create much more stringent requirements for ensuring proper airflow to the ITE.

ASHRAE 2021 Reference Card notes that H1 Class ITE should be located in "a zone within a data center that is cooled to lower temperatures to accommodate high-density air-cooled products".

As noted above, in light of the more restrictive H1 recommended temperature range (64.4˚F to 71.6˚F) it becomes relatively difficult to implement H1 class IT equipment in the same data center space with raised floor cooling distribution (which normally operates in the ASHRAE recommend range 64.4˚F to 80.6˚F). However, in many cases the cold air supply temperature is typically much colder 50-60-65˚F to allow for airflow mixing. This would allow the use 50 to 65˚F underfloor supply air with careful airflow management by means of well-sealed cold aisle containment *(see Containment Strategies)*.

Another solution is to create an isolated zone utilizing complete cold aisle containment, without floor supply tiles or grates. Cooling would be provided by Inrow type units or other forms of close-coupled cold aisle cooling to ensure H1 recommended temperatures.

Containment Strategies

Cold Aisle vs Hot Aisle

One of the most asked questions and "hotly" debated answers to the Cold Aisle vs Hot Aisle containment which is better question are: Cold, Hot or the classic "it depends". Here are some of the issues which relate to the type of facility design and other related factors. Note that all statements below are based on the following assumptions: ITE delta-T range is 20°F to 25°F (*see Table 2*), there is sufficient underfloor pressure to produce the desired airflow (CFM) for the type of perforated floor tile or grate (adjusted for the capture index), the temperature of the supply air from the floor tile or grill is within ASHRAE recommended 64.4 to 80.6°F, and that there is good rack hygiene in place.

No Containment

Setting aside the potential fan energy efficiency saving, generally speaking it is possible to maintain sufficient airflow and ITE intake temperatures at 5-6-kW per rack without any containment. It requires more fan energy and becomes much more difficult to go much higher power levels without some level of containment.

Cold Aisle Containment

Partial Containment

END OF AISLE DOORS
The first stage is end of aisle doors, which creates a "bathtub" of cold air. This will usually help increase and maximize the available airflow to ITE installed in lower portion of the racks. Power per cabinet 5-8 kW.

COLD AISLE WITH COLLAR WITH OPEN TOP
This adds an 18-36" containment collar around the cold aisle in addition to the end of aisle doors, which prevents hot air from being drawn into ITE located closer to the top of the rack. This allows more ITE to be stacked higher raising the effective power range to 10-12 kW.

Generally speaking, both partial containment options listed above will avoid issues with local fire codes.

Complete Cold Aisle Containment

This option offers the best level of airflow concentration and allows much higher power levels, assuming there is sufficient cooling airflow available. This can support 20-25 kW with a 2 tile cold aisle, however by going to a 3 tile cold aisle it is possible to support 30 kW or more per cabinet.

One of the concerns about adding complete containment is local fire codes, which may require extending fire suppression discharge nozzles into the contained aisle. However, there are several solutions that can avoid this. Most of the solutions are based on some methodology to have the roof of the contained area drop down, or open up, once a specific temperature is reached, or if smoke or fire detection system detects a pre-action or other trigger conditions.

It should be noted that any of these options must be approved by the local fire codes and that some Fire Marshalls may consider anything drop-down a potential hazard to first responders. A containment roof system which can be tied into existing fire system and automatically open without dropping anything down may alleviate the need for costly sprinkler system modifications.

CloudCover, courtesy of TechnoGuard

COLD AISLE WIDTH
The above is based on a 2 tile cold aisle. One of the benefits to consider is increasing the cold aisle width to 3 tiles. This requires less under floor pressure per tile, for the same total required CFM. This reduced pressure, in turn decreases floor leakage, as well as the velocity related Venture effect issues as discussed above. Collective result reduced cool unit fan energy, improving the facility PUE.

> As a rule of thumb, a one degree increase of chiller supply temperature results in approximately a two percent energy savings, depending on age and type of chiller.

For raised floors facilities without a plenum ceiling, cold aisle containment is usually the easiest to install and offers the most flexibility. While the cabinet power density ranges were based on an ITE D-T of 20-25°F, with higher density ITE operate a higher D-T (30-40°F) to allow for higher power densities at the lower facilities with lower available airflow. However, it is important to understand the rest of the space effectively becomes at or near the ITE exhaust temperature. If the average cold aisle supply temperatures are 70-75°F, the resulting hot aisles are 90-100°F or even beyond 110°F with high Delta-T IT equipment.

Another factor to consider, is the type of cooling systems; for chilled water with CRAHs higher return temperatures (90°F or higher) are usually no problem. In fact they increase the net cooling capacity of the CRAH and also allow the chilled water temperature to increase saving chiller energy. As a rule of thumb, a one degree increase of chiller supply temperature results in approximately a two percent energy savings, depending on age and type of chiller. Of course several caveats apply; the range of improvement is specific to the chiller specifications such as; the maximum supply, return and chiller D-T.

For DX CRACs, the maximum return temperature is typically more limited (85-90°F), especially for older units. Some newer CRACs have somewhat higher air return limits (90-100°F), however, generally the benefits in performance and energy saving increases are not as great as chilled water based systems.

Hot Aisle Containment

Unlike cold aisles, which typically require raised floors (or overhead supply ducts), hot aisle containment can be used with or without a raised floor. The three most common configurations are raised floor and slab floor, either with or without a plenum ceiling.

Partial Hot Aisle Containment

End of aisle doors and an 18-36" containment collar around the hot aisle, in addition to the end of aisle doors, which also prevents hot air from being drawn back into the ITE intake closer to the top of the rack in the cold aisle. This allows more ITE to be stacked higher, raising the effective power range to 10-12 kW.

Plenum ceilings

A plenum ceiling that is fully coupled to the cooling units return (typically by means of ducted collar to the ceiling), improves partial containment performance, assuming the ceiling return grills are properly aligned over the hot aisles. This also improves uncontained hot aisle layouts. A plenum ceiling is essential for full hot aisle containment.

Complete Hot Aisle Containment

This option offers the best level of return airflow control and allows much higher power levels, assuming there is sufficient cooling capacity available. Similar to the CAC this can support 20-25 kW with a 2 tile cold aisle, however by going to a 3 tile cold aisle is possible to go 30 kW or more per cabinet.

> One of the benefits of “flooded room” systems is avoidance of trying to match various types of floor tiles to the CFM requirements for different power densities.

It is also the first choice for fan-wall cooling units, and other “flooded room” designs, such as rooftop cooling units with overhead ducts, with or without raised floors.

One of the benefits of “flooded room” systems is avoidance of trying to match various types of floor tiles to the CFM requirements for different power densities. When implemented correctly it also lessens the impact of varying underfloor plenum pressures.

Rack Hygiene

No matter how well a containment system is constructed and installed, its benefits can be reduced or negated if good "rack hygiene" practices are not followed. Poor practices can cause extreme cases of recirculation within the cabinet resulting in a 10-30°F rise in ITE intake temperatures above the cold aisle supply temperature.

Here are the basics that are relatively easy to implement, and at little or no cost.

- Use horizontal blanking plates for all empty spaces between ITE
- Wherever possible, keep ITE in the lower portion of the rack (especially important for uncontained or partial containment (end of aisle doors).
- Use vertical blanking components (flexible seals or brushes if cables from rear need to pass to front of ITE)
- Practice rear cable management to avoid blocking airflow. Use shorter cables (power and network) wherever possible.
- Install brushed collars (or similar devices) for all underfloor openings for power and network cables

In cases where there is a significant disparity in power density and exhaust airflow between opposing cabinets in a common hot aisle, the higher volume and velocity of the exiting airflow from high power cabinets can inhibit the low density cabinets from allowing the hot air to completely exit the cabinets which may cause them to overheat. If this occurs, an upward facing rear deflector on the higher density cabinet (or both cabinets) will help mitigate this issue.

> If cabinet overheating occurs, an upward facing rear deflector on the higher density cabinet (or both cabinets) will help mitigate this issue.

MoFlo, courtesy of TechnoGuard

Energy Efficiency Cost of Airflow Leakage

In effect, any supply airflow from the cooling system that is not passing only through the ITE is considered bypass airflow and wasted cooling and fan energy. This is also called oversupply or over ventilation. While it is nearly impossible to accomplish this as a practical matter, to ensure that ITE airflow requirements are met, a certain amount of oversupply is necessary. However, unnecessary and preventable leakage should be controlled wherever possible or practical.

While we have been discussing the technical aspects of airflow management, ultimately it also directly translates to increased or decreased fan energy usage and the cost of energy *(see Fan Laws)*.

Fan Laws

There are three basic fan laws, which express the how the change in relative fan speed, static pressure and horsepower (power) interact.

Fan Law 1
The change in fan speed is proportional to the change in airflow

Fan Law 2
The change in static pressure (increase/decrease) with the square of the change in airflow

Fan Law 3
The fan power (increases/decrease) with the cube* of the change in airflow (fan speed).
*(*in reality the exponent of the actual fan curve may be slightly lower than a cube "3" exponent)*

The chart in *Table 9* shows how bypass airflow can impact the fan energy.

- **Assumptions** (simplified for clarity)
  - Cooling System Design Rated 1,000 kW Critical load
  - 12 Units Total N+2 redundancy
  - Normal Conditions: Total of 12 CRAHs
  - Failure mode: 10 CRAHs needed for critical Cooling Unit Specifications
  - Cooling Unit Cooling Design Capacity 100 kW - Fan rated at 15,000 CFM fan power 10kW
  - Cooling load 100% D-T 25˚F (126 cfm/kW) 126,000 CFM: no leakage
  - 90% IT Load (900 kW) IT D-T 25˚F (126 cfm/kW) total required 113,400 CFM
- **Design vs Actual Operating Conditions**
  As *Table 9* demonstrates, 20% bypass airflow increases the fan energy use and cost by 83% (compared to a theoretical perfect match of CFM and D-T of IT equipment cooling system). While in reality it is virtually impossible for perfect airflow match to occur in an actual data center, the exponential nature of the third fan law shows the significant penalty or benefit for mitigating leakage which increases bypass airflow.

Operating Conditions Heat Load 900 kW 90% of Cooling Design Load	Cooling Unit Airflow (CFM)	Cooling Fan Speed	Total CFM	Unit Fan power*	Total Fan Power	Annual Fan Energy (kWh)	Annual Fan Energy Cost ($0.10 kWh)
12 CRAHs at 100% fan speed (Massive Wasteful oversupply)	15,000	100%	180,000	10 kW	100 kW	876,000 kWh	$87,600
100% Airflow Balance No bypass No Leakage (12 CRAH running) Not realistic	9,500	63%	114,000	2.4 kW	24 kW	210,240 kWh	$21,024
20% Bypass Airflow 20% oversupply	**11,400**	**76%**	**136,800**	**4.4 kW**	**44 kW**	**385,440 kWh**	**$38,544**

Table 9 – A hypothetical example of relative airflow vs fan power, simplified for clarity *(in reality the exponent of the actual fan curve will be slightly lower that the cube "3" exponent)

The Bottom Line

As this report demonstrates, airflow management is the key to effective and efficient high density air cooling. The ability to determine the amount of air flow is based on understanding the operational thermal characteristics (airflow and delta-t), not just power. It is also important to correlate and match that with the underfloor pressure and the type of floor tile or grate. Most data centers have a wide range of cabinet power densities which complicates the matching process.

> Regardless of type, a well designed and implemented containment system is an essential element to support current and future high density air cooled ITE requirements.

While it is possible to operate a data center without any containment, however, it inherently limits the maximum power density per cabinet. Moreover, it is further prone to hot spots from the recirculation and mixing of hot air with the cold aisle. It also requires more bypass airflow, as well as operating at cooling unit supply temperatures that are lower than necessary to try to mitigate hot spots.

Even partial containment increases cabinet power density and improves thermal compliance (ITE intake temperatures), and reduces fan energy. The decision to use containment (hot or cold), is a function of the room design (plenum ceiling and fire codes, etc.).

In addition, lower cooling supply temperatures reduce the effective number of hours/days per year for air-side or water-side economizer operation (aka, free cooling). Collectively, this uses more energy for cooling than necessary, increasing the annualized PUE.

The drive for improved energy efficiency has also escalated and accelerated the trend to increase temperatures to the cold aisle. This further intensifies the need to avoid mixing of hot and cold air due to leakage. The rise in IT cabinet IT power density continues and only magnifies the challenges for air cooled IT equipment which continues to be the majority in mainstream data centers. This is also reflected in the ASHRAE Processor thermal road map, and the introduction of the H1 class for air-cooled ITE in 2021.

Major colocation data center operators, as well as hyperscalers, have long realized the importance of airflow management and have utilized various types of containment solutions. It is the fundamental starting point for maximizing the available cooling capacity and energy efficiency at any power density level. Regardless of type, a well designed and implemented containment system is an essential element to support current and future high density air cooled ITE requirements.

About TechnoGuard

TechnoGuard is the leading data center services provider headquartered in Northern Virginia, offering services from airflow management and containment solutions to mission critical cleaning services and high-performance floor coatings.

Our mission is to improve the efficiency and aesthetics of your data center through our products and exceptional services.

Our technicians deliver timely, world-class service that's customized for your facility's particular needs. We pride ourselves on delivering expert service including installation and maintenance programs designed to meet the individual needs of your site's conditions on either a contract or ondemand basis.

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