Data Center Cooling Development with Air-Cooled Cabinet Cooling

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Public

Your Mileage May Vary

- The examples in this presentation are the results of our experimentation in maximizing operating efficiencies while minimizing Total Cost of Ownership (TCO) when building our Data Centers (DCs).
- Unless specifically stated, the examples here are illustrations of what we have learned and do not necessarily reflect test data.

Purpose of Presentation

- Definition of air conditioning, airflow efficiency, and why this is relevant
- Show evolution of air cooled data centers at Intel
  - 2-4 kW Cabinets
  - 4-8 kW Cabinets
  - 8-14 kW Cabinets
- Current development of 8-25 kW 1U or blade servers
- Planning ahead

kW = Kilo Watt

1U = 1.75” standard rack division marking

Air Conditioning Efficiency

- In the past, general purpose and manufacturing computing DCs, air conditioning (A/C) systems have been poorly utilized.
  - Packaged Computer Room Air Conditioners (CRAC) units are capable of 26° - 30° F Delta-T coil conditions (Temp In – Temp Out)
  - A/C System Delta-Ts have been measured as low as 4° F !
- Air conditioning airflow efficiency is defined as “The amount of heat that can be removed per cubic feet per minute (CFM) of cooling air” ($Watts_{heat}$/cfm).

DC Cooling Development

- Processors across the board are growing in kW power consumption and corresponding heat output
- The next slides are based on a Normalized Data Center
  - (Cabinet quantities and air handler sizes are fixed for demonstration purposes)
- These slides help visualize increasing power/heat densities and required facility infrastructure responses
- Examples are driven by the increasing quantity of processors that can be placed within a server cabinet
- Designing a Data Center to be scaleable while keeping pace with changing technologies is a challenging task
- Our goal is to provide just in time DC capacity and minimize idle capacity

2-4 kW Cabinet Loads

DATA CENTER AIRFLOW CALCULATOR

28	Number of Cabinets in Module				16	Work Cell Size (sq ft)		28	Quantity of Diffusers
1,248	Module Area Including AHU rooms (sq ft)				100%	Overall DC Module Server Utilization		24	RMF Height (inches)

QUANTITY (% of CABINETS)	SIZE (kW)	# OF CABINETS	Cabinet Work Cell W/sf	CFM /Cabinet	TOTAL CABINET WATTS	Velocity Above Floor Tiles (fpm)	Module Statistics
50%	2	14.0	125	316	28,000	79	13,252
50%	4	14.0	250	631	56,000	158	**17,890**
0%	0	0.0	0	0	0	0	26,836
0%	0	0.0	0	0	0	0	**8,945**
0%	0	0.0	0	0	0	0	**639**
0%	0	0.0	0	0	0	0	24
100%	**Must add up to 100% !**	28	**Total load of all cabinets**		**84,000**	**Watts**	**188**
					93,333	**VA**	67

3	# of CRU/RAH's	Motor Heat (Watts)	12,922			**3,000**
20	Equipment Delta-T (deg F)	SCFM per RAH at operating conditions (All units running)	**5,963**	Minimum Coil Design Delta-T (deg F)	**17.53**	448
35%	Airflow Bypass	Lighting Heat (Watts)	2,496	Total ChW to	29	22
						4.7

For demo purposes AHU size is ~ 10,000 cfm

Total Design Airflow to Servers w/o redundancy or cabinet

Total Design Airflow to Cold Aisle (scfm)

Total Design RAH scfm w/ redundancy and cabinet bypass

Design SCFM per RAH w/ redundancy and cabinet bypass losses

Average scfm per Perf w/ cabinet bypass losses

Chiller Tonnage (Cabinet heat only, no lights, people or CRU

W/sf @ 16 Sq Ft Work Cell

W/sf based on Total Area

Average watts cooling per diffuser

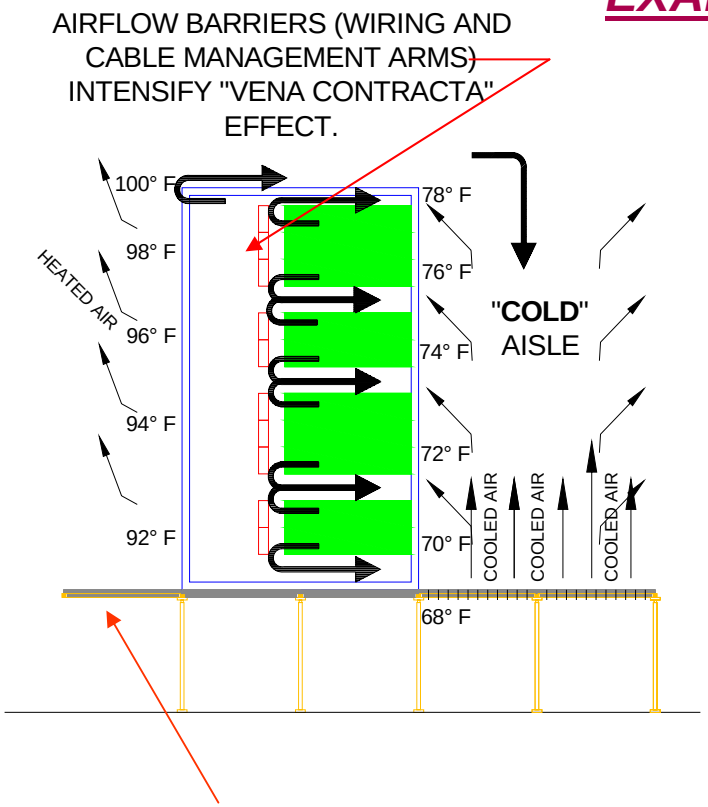
TOTAL AMOUNT OF WORK CELL AREA (CABINETS, COLD, AND HOT AISLES)

Layout Efficiency (cabinets per kSF)

A/C SYSTEM EFFICIENCY W/CFM

2-4 kW Conventional Data Center

EXAMPLE



VENA CONTRACTA; THE RELATIVELY HIGH VELOCITY AIR IN THE COLD AISLE CREATES A LOW PRESSURE REGION THAT DRAWS IN HEATED AIR FROM THE SERVER EXHAUST.

THIS IS AN EXAMPLE OF POOR AIR MANAGEMENT, HEATED AIR IS PERMITED TO FLOW FROM THE REAR OF THE CABINET INTO THE FRONT AND MIX WITH THE COOLED AIR. THIS REDUCES THE EFFECTIVE COOLING CAPACITY OF THE COOLING SYSTEM AND INCREASES THE ENTERING AIR TEMPERATURE FOR THE SERVERS AT THE TOP OF THE CABINET.

2kW - 4kW TRADITIONAL CABINETS WITH EMPTY SPACES BETWEEN SERVERS

67 W/sf TOTAL AREA

188 W/sf @ 16 Sq. Ft. WORK CELL

No perforated floor tiles in hot aisle.

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4-8 kW Cabinet Loads

DATA CENTER AIRFLOW CALCULATOR

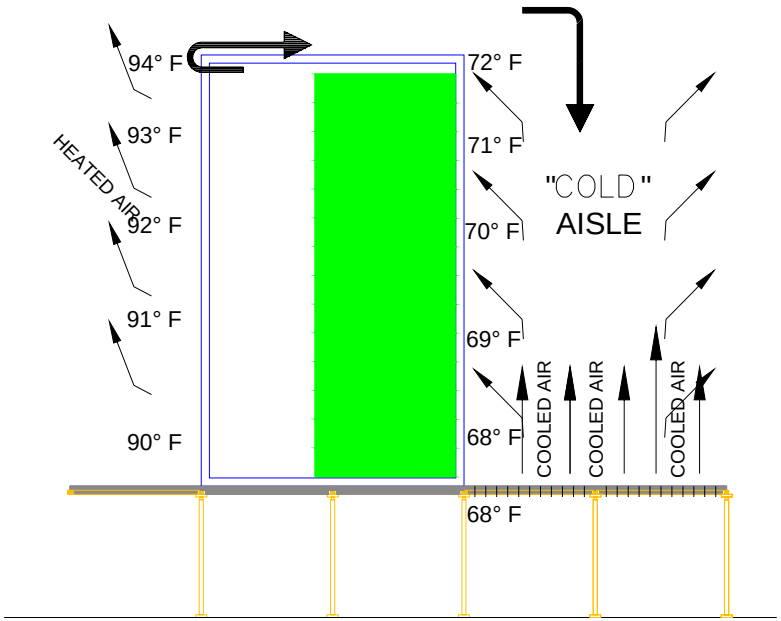
28	Number of Cabinets in Module			16	Work Cell Size (sq ft)		28	Quantity of Diffusers
1,248	Module Area Including AHU rooms (sq ft)			100%	Overall DC Module Server Utilization		24	RMF Height (inches)

QUANTITY (% of CABINETS)	SIZE (kW)	# OF CABINETS	Cabinet Work Cell W/sf	CFM /Cabinet	TOTAL CABINET WATTS	Velocity Above Floor Tiles (fpm)	Module Statistics	
50%	4	14.0	250	574	56,000	143	24,095	Total Design Airflow to Servers w/o redundancy or cabinet
50%	8	14.0	500	1,147	112,000	287	**30,118**	Total Design Airflow to Cold Aisle (scfm)
0%	0	0.0	0	0	0	0	40,158	Total Design RAH scfm w/ redundancy and cabinet bypass
0%	0	0.0	0	0	0	0	**10,039**	Design SCFM per RAH w/ redundancy and cabinet bypass losses
0%	0	0.0	0	0	0	0	**1,076**	Average scfm per Perf w/ cabinet bypass losses
0%	0	0.0	0	0	0	0	48	Chiller Tonnage (Cabinet heat only, no lights, people or CRU
100%	**Must add up to 100% !**	28	**Total load of all cabinets**		**168,000**	**Watts**	**375**	**W/sf @ 16 Sq Ft Work Cell**
					186,667	**VA**	135	W/sf based on Total Area
4	# of CRU/RAH's		Motor Heat (Watts)	21,754			**6,000**	Average watts cooling per diffuser
22	Equipment Delta-T (deg F)		SCFM per RAH at operating conditions (All units running)	**7,530**	Minimum Coil Design Delta-T (deg F)	**20.14**	448	TOTAL AMOUNT OF WORK CELL AREA (CABINETS, COLD, AND HOT AISLES)
25%	Airflow Bypass		Lighting Heat (Watts)	2,496	Total ChW to	56	22	Layout Efficiency (cabinets per kSF)
							5.6	**A/C SYSTEM EFFICIENCY W/CFM**

4-8 kW First Level Upgrade

Reducing Bypassed & Recirculated Air

AIRFLOW BARRIERS REMOVE CABLE MANAGEMENT ARMS AND ROUTE WIRE AND CABLE OUT OF AIRFLOW.



EXAMPLE ***Vena Contracta***

THIS IS AN EXAMPLE OF INPROVED AIR MANAGEMENT, HEATED AIR IS NO LONGER PERMITED TO FLOW FROM THE REAR OF THE CABINET WITHIN THE CABINET AND MIX WITH THE COOLED AIR. HOWEVER; HOT AIR IS STILL ENTERING THE COLD AISLE OVER THE TOP OF THE CABINETS AND AROUND THE ENDS OF EACH ROW. THIS RESULTS IN IMPROVED COOLING CAPACITY OF THE COOLING SYSTEM AND REDUCES THE INCREASE IN TEMPERATURE OF THE ENTERING AIR TEMPERATURE FOR THE SERVERS AT THE TOP OF THE CABINET.

4kW - 8kW CABINETS WITH NO EMPTY SPACES BETWEEN SERVERS

135 W/sf TOTAL AREA

375 W/sf @ 16 Sq. Ft. WORK CELL

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8-14 kW Cabinet Loads

DATA CENTER AIRFLOW CALCULATOR

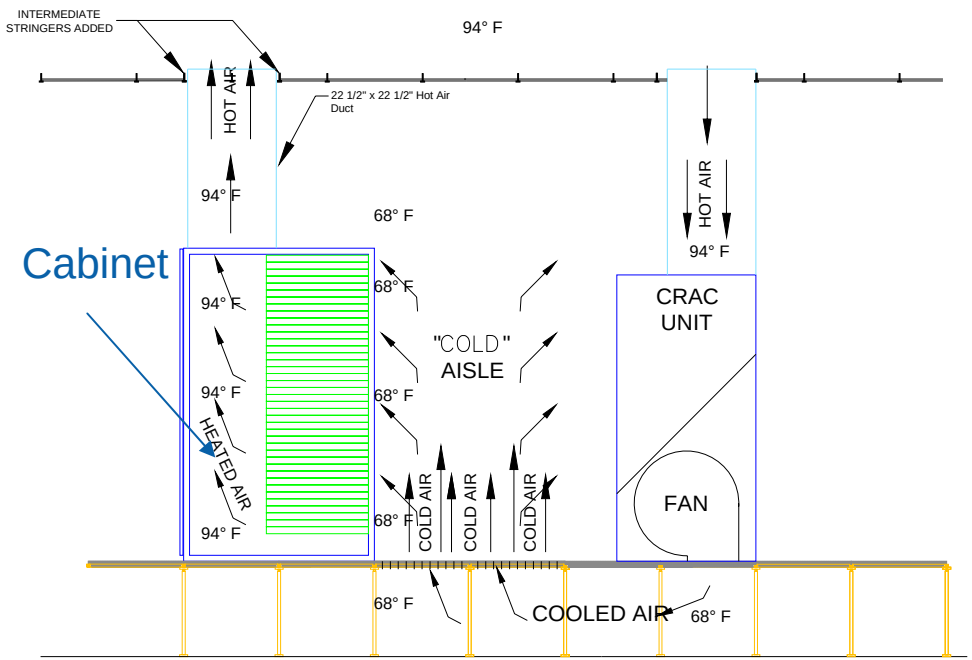
28	Number of Cabinets in Module				16	Work Cell Size (sq ft)		28	Quantity of Diffusers
1,248	Module Area Including AHU rooms (sq ft)				100%	Overall DC Module Server Utilization		24	RMF Height (inches)
QUANTITY (% of CABINETS)	SIZE (kW)	# OF CABINETS	Cabinet Work Cell W/sf	CFM /Cabinet	TOTAL CABINET WATTS	Velocity Above Floor Tiles (fpm)	Module Statistics			
50%	8	14.0	500	971	112,000	243	37,378	Total Design Airflow to Servers w/o redundancy or cabinet		
50%	14	14.0	875	1,699	196,000	425	**41,116**	Total Design Airflow to Cold Aisle (scfm)		
0%	0	0.0	0	0	0	0	51,394	Total Design RAH scfm w/ redundancy and cabinet bypass		
0%	0	0.0	0	0	0	0	**10,279**	Design SCFM per RAH w/ redundancy and cabinet bypass losses		
0%	0	0.0	0	0	0	0	**1,468**	Average scfm per Perf w/ cabinet bypass losses		
0%	0	0.0	0	0	0	0	88	Chiller Tonnage (Cabinet heat only, no lights, people or CRU		
100%	**Must add up to 100% !**	28	**Total load of all cabinets**		**308,000**	**Watts**	**688**	**W/sf @**	**16**	**Sq Ft Work Cell**
					342,222	**VA**	247	W/sf based on Total Area		
5	# of CRU/RAH's		Motor Heat (Watts)	29,697			**11,000**	Average watts cooling per diffuser		
26	Equipment Delta-T (deg F)		SCFM per RAH at operating conditions (All units running)	**8,223**	Minimum Coil Design Delta-T (deg F)	**26.11**	448	TOTAL AMOUNT OF WORK CELL AREA (CABINETS, COLD, AND HOT AISLES)		
10%	Airflow Bypass		Lighting Heat (Watts)	2,496	Total ChW to	98	22	Layout Efficiency (cabinets per kSF)		
							7.5	**A/C SYSTEM EFFICIENCY W/CFM**		

New Development in Air Cooled Cabinets

- We recently worked with one of our cabinet vendors to increase the cooling capacity of an air cooled cabinet. We achieved excellent results.
- The cabinet depth was increased and a Plexiglas panel door was added to allow for a “chimney flue” path for the heated server exhaust.
- The chimney flue was designed to connect directly to the return space above the false ceiling.
- The room cooling unit returns are also connected directly to the ceiling return space.

8-14kW Second Level Upgrade

Hot air is returned through the plenum above the drop ceiling, but there is still leakage through tiles and limits to the amount of negative pressure to draw air out of the cabinets.



THIS IS AN EXAMPLE OF OPTIMIZED AIR MANAGEMENT, HEATED AIR IS CONTAINED AND ISOLATED FROM THE COOLING AIR. THIS RESULTS IN OBTAINING MAXIMUM COOLING CAPACITY OF THE COOLING SYSTEM AND EQUALIIZES THE TEMPERATURE OF THE AVAILABLE AIR FOR THE SERVERS AT BOTH THE TOP AND BOTTOM OF THE CABINET.

ANOTHER VERSION OF THIS MODEL WOULD BE WITHOUT A RAISED METAL FLOOR

8kW - 14kW CABINETS WITH NO EMPTY SPACES BETWEEN SERVERS

247 W/sf TOTAL AREA

688 W/sf @ 16 Sq. Ft. WORK CELL

Managed Cabinets perform same function as Hot Aisle Enclosures

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14-25 kW Cabinet Loads

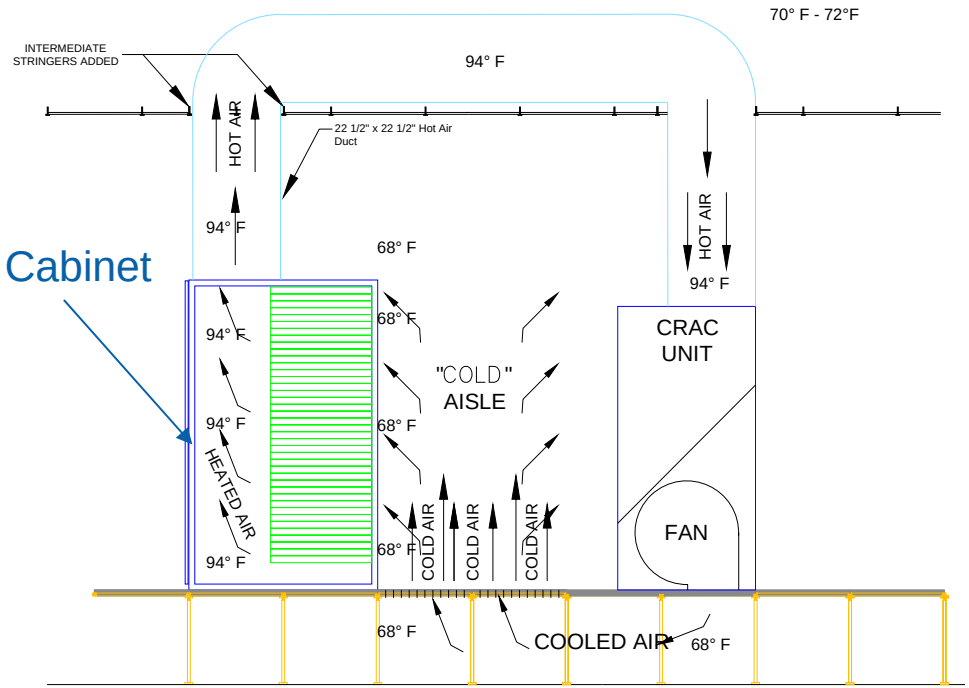
DATA CENTER AIRFLOW CALCULATOR

28	Number of Cabinets in Module			16	Work Cell Size (sq ft)		28	Quantity of Diffusers
1,248	Module Area Including AHU rooms (sq ft)			100%	Overall DC Module Server Utilization		24	RMF Height (inches)

QUANTITY (% of CABINETS)	SIZE (kW)	# OF CABINETS	Cabinet Work Cell W/sf	CFM /Cabinet	TOTAL CABINET WATTS	Velocity Above Floor Tiles (fpm)	Module Statistics	
50%	14	14.0	875	1,699	196,000	425	66,261	Total Design Airflow to Servers w/o redundancy or cabinet
50%	25	14.0	1562.5	3,034	350,000	758	**66,923**	Total Design Airflow to Cold Aisle (scfm)
0%	0	0.0	0	0	0	0	76,484	Total Design RAH scfm w/ redundancy and cabinet bypass
0%	0	0.0	0	0	0	0	**9,560**	Design SCFM per RAH w/ redundancy and cabinet bypass losses
0%	0	0.0	0	0	0	0	**2,390**	Average scfm per Perf w/ cabinet bypass losses
0%	0	0.0	0	0	0	0	155	Chiller Tonnage (Cabinet heat only, no lights, people or CRU
100%	**Must add up to 100% !**	28	**Total load of all cabinets**		**546,000**	**Watts**	**1219**	**W/sf @ 16 Sq Ft Work Cell**
					606,667	**VA**	438	W/sf based on Total Area
8	# of CRU/RAH's		Motor Heat (Watts)	48,337			**19,500**	Average watts cooling per diffuser
26	A/C System Delta-T (deg F)		SCFM per RAH at operating conditions (All units running)	**8,365**	Minimum Coil Design Delta-T (deg F)	**28.14**	448	TOTAL AMOUNT OF WORK CELL AREA (CABINETS, COLD, AND HOT AISLES)
1%	Airflow Bypass		Lighting Heat (Watts)	2,496	Total ChW to	171	22	Layout Efficiency (cabinets per kSF)
							8.2	**A/C SYSTEM EFFICIENCY W/CFM**

Third Level Upgrade

Ducting to connect the cabinets to the CRAC units reduce leakage to 1% and creates more negative static to draw more air thru cabinets. MAX kW CABINETS!



THIS IS AN EXAMPLE OF A CLOSED LOOP SYSTEM, hEATED AIR IS DRAWN OUT OF THE CABINET INTO THE CRAC UNIT WITH A HIGHER NEGATIVE PRESSURE. tHIS WILL INCREASE AIRFLOW THROUGH THE SERVERS AND CABINET. AN ADDITIONAL BENEFIT OF THIS DESIGN IS THAT THE SPACE ABOVE THE CEILING DOES NOT HAVE TO BE PLENUM RATED.

ANOTHER VERSION OF THIS MODEL WOULD BE WITHOUT A RAISED METAL FLOOR

14kW - 25kW CABINETS WITH NO EMPTY SPACES BETWEEN SERVERS

404 W/sf TOTAL AREA

1128 W/sf @ 16 Sq. Ft. WORK CELL

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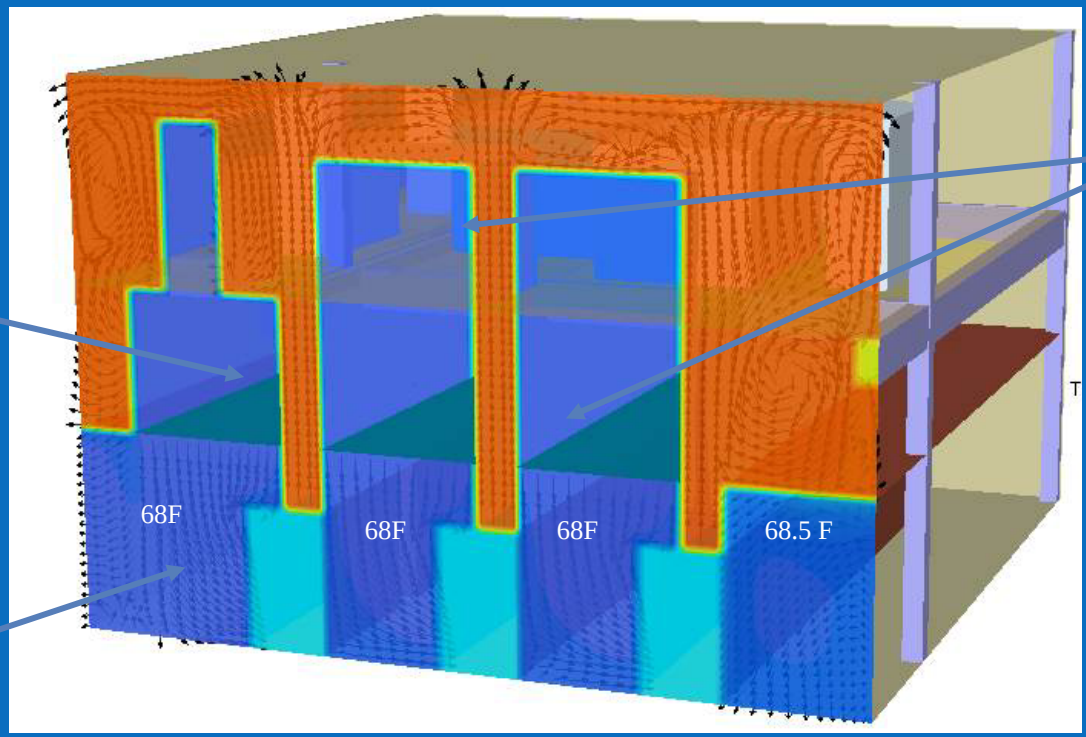
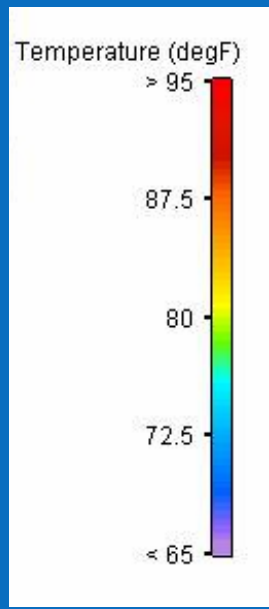
Complete Air Management

Hot air leaving servers is ducted to AHUs

Server & People at 68F



AHU noise is reduced with ductwork and locating AHUs in mezzanine.



Temperature Section

This model shows dramatic effect of managing heat. Data Center area is at a comfortable 68 F (20C). Required airflow is minimized. Heat transfer from air to air handling unit (AHU) coils maximized. This results in the lowest total operational cost for the heating, ventilating and air conditioning (HVAC) system/kW.

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Air Conditioning Efficiency

HEAT LOAD	Required Airflow	Total Equipment kW	Airflow per kW	Watts cooling per CFM
2-4 kW	17890	84	213	**4.7**
4-8 kW	30118	168	179	**5.6**
8-14 kW	41116	308	133	**7.5**
14-25 kW	66923	546	123	**8.2**

By preventing the cold air from bypassing cabinets and "short circuiting" back to the CRAC units, A/C airflow efficiency is increased by 75%

CRAC vs. RAH Cooling

- Computer Room Air Conditioners (CRAC)
  - Cost ~$2.00 to $3.00 per CFM
  - Traditionally installed on DC raised metal floor (RMF) space
  - Factory assembled units with integral control valves
  - Packaged units (65 W/sf)
  - Custom units (<250 W/sf)
  - MAX CFM ~ 17,000 CFM
  - Limited Filter Space
- Recirculation Air Handling Units (RAH)
  - Cost ~$1.00 per CFM
  - Encased in a larger cabinet
  - Usually placed in area adjacent to DC RMF space
  - Custom vertically stacked
    - Top Return down-flow units w/ direct drive fans
    - Utilize adjustable frequency drives to align airflow w/ equipment load
    - Front motor / filter access to mechanical space, better access/maintenance
    - Facilities access can be moved outside of controlled access server area
    - Bottom discharge into space below RMF
  - Designed for > 250 W/sf
  - 18,000 – 50,000+ CFM
  - Large Efficient Filter Area
  - More Flexible Economy of Scale
  - More available space for IT equipment defined as # Cabinets/kSF

Planning Ahead

- Using the previous models to plan for growth:
  - Use 4 RAH Cooling Units for initial install
  - Final potential kW load 812
    - 92,765 CFM
    - 29° Delta T F°
- Initial cost difference
  - 8945 CFM *3 CRAC Units *$3.00 /CFM = $80,505.00
  - 30,922 CFM * 4 RAH Units *$1.00 /CFM = $123,688.00
  - $43,183.00 larger investment to gain 728 kW in future capacity

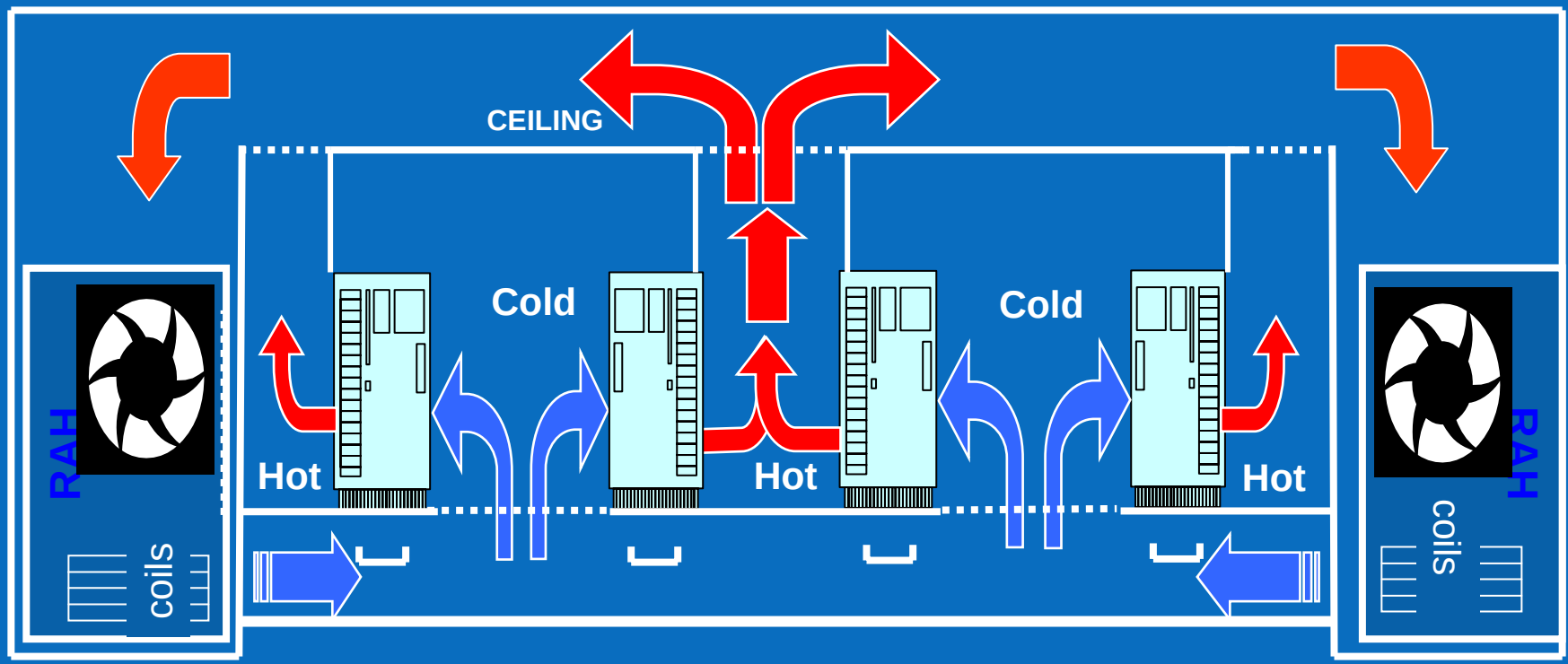
Heat Load	Required Air Flow	Total EQ kW	DC SF	CABINETS	COOLING UNITS	Delta T°F	CFM Capicity per Colling Unit
2-4 kW	17,890	84	1248	28	3 CRAC	20	8945
4-8 kW	30,118	168	1248	28	4 CRAC	22	1039
8-14 kW	41,116	308	1248	28	5 CRAC	26	9560
14-25 kW	66,923	546	1248	28	8 CRAC	26	9560
21-37 kW	92,765	812	1248	28	4 RAH	29	30922

Summary

- More power in the same 1U chassis; result is a higher cooling air temperature increase = Delta-T
- DC design has decreased the amount of cooling air bypassing cabinets resulting in less AHU units and cost, (on a per kW basis)
- The current managed cabinet provides Intel's highest a/c system efficiency by eliminating bypassed air completely.
- Cabinets ducted to CRAC units draw the hot air directly out of the servers and can achieve Intel's highest kW per cabinet (25kW x 3414)/(26° x 1.081) = 3,036 cfm.
  - The entire DC stays at a constant 68°F temperature.
  - No need for hot aisle enclosures.
  - No Raised Metal Floor systems required, can use ceiling A/C diffusers to supply cooling air into the DC.
  - Expected reduction in noise levels with use of acoustical abatement in supply and return ductwork and separating AHUs from server area.

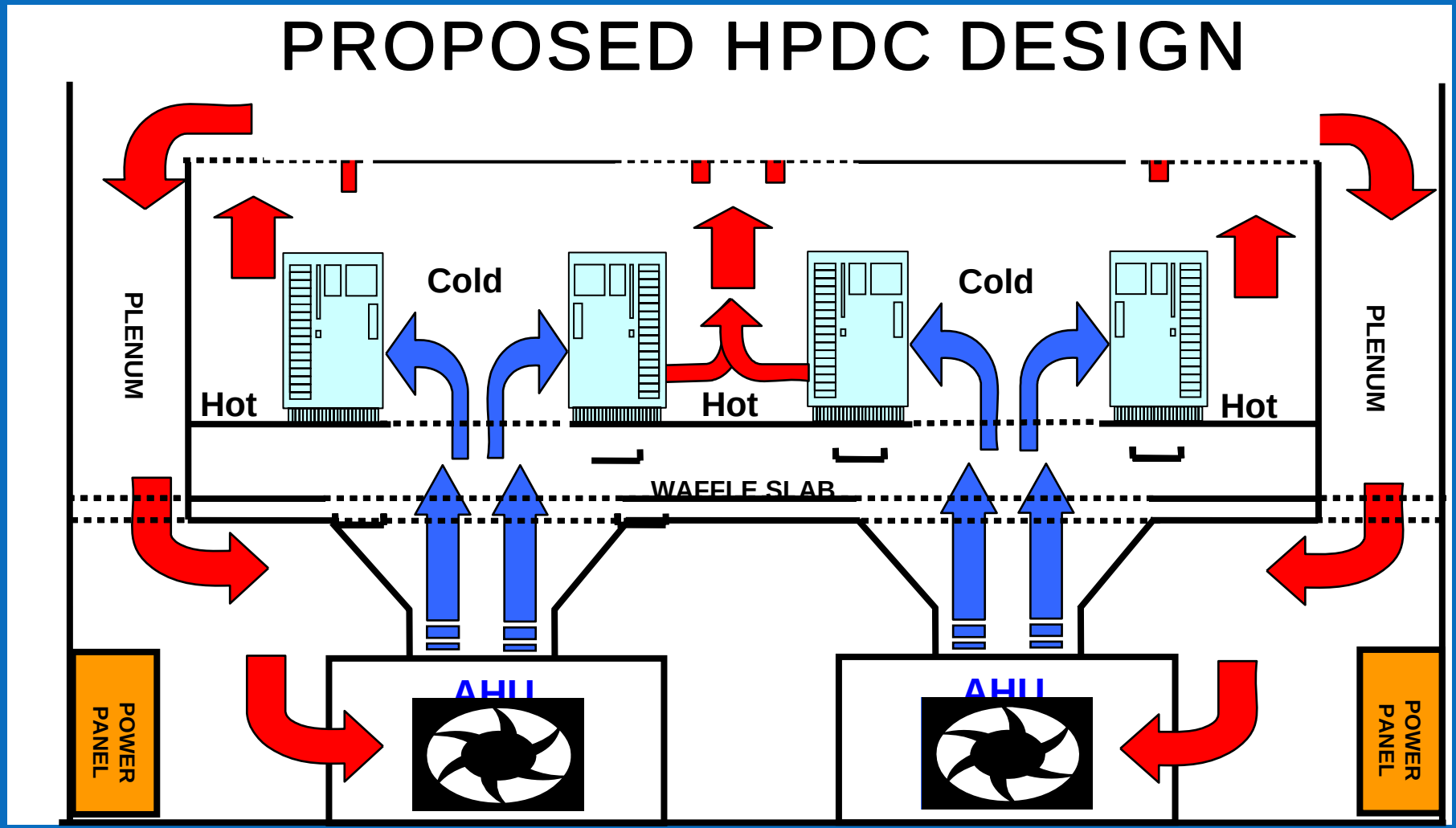
Backup Slides

HPDC 1 Story Air Distribution 8-14kW Cabinets



Use of Hot Aisle Enclosures to Reduce Bypassed and Recirculated Air

HPDC 2 Story Air Distribution 18 kW Cabinets

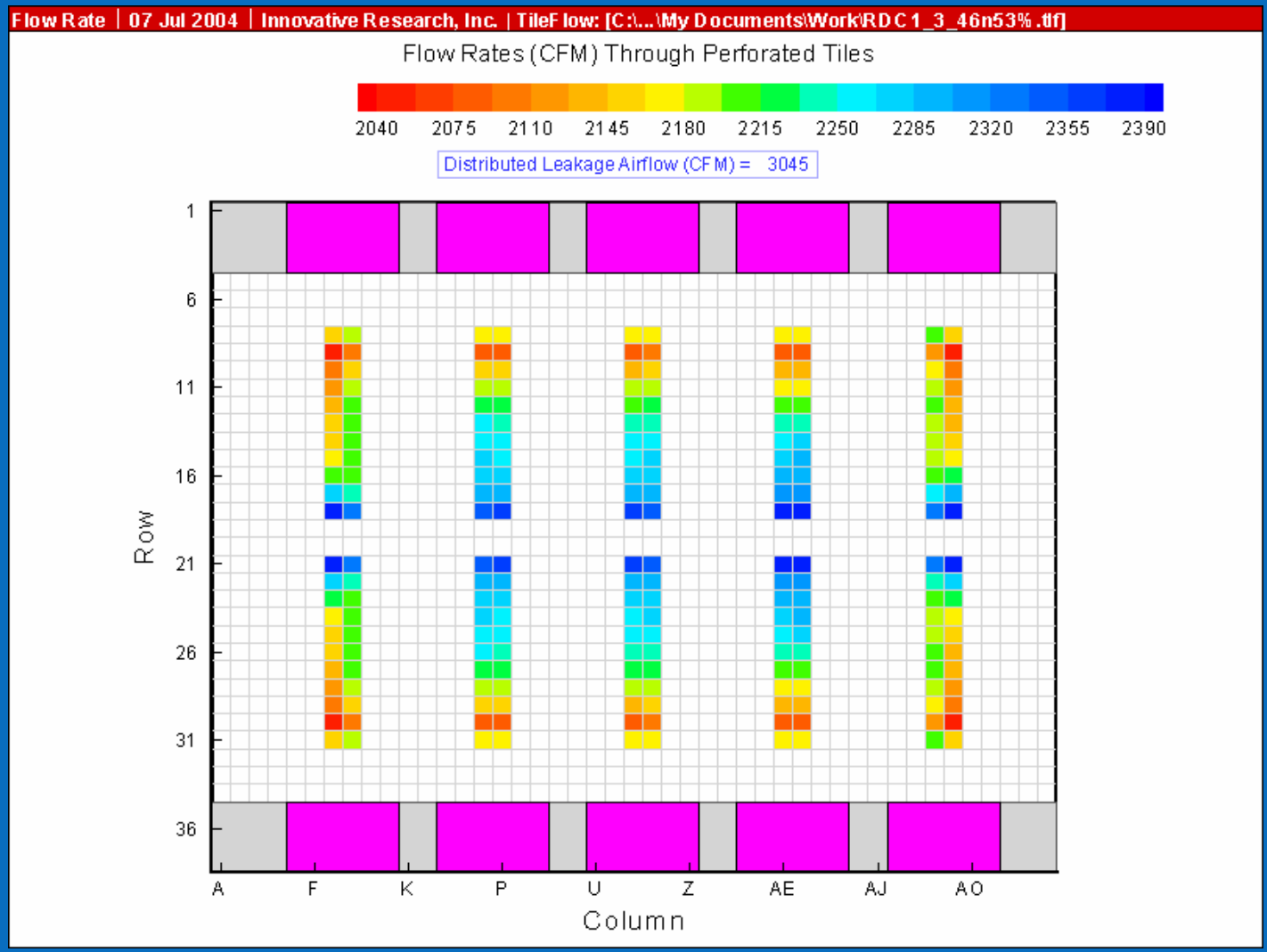


Airflow Model-1 Story / 36” RMF

2,169 CFM average required

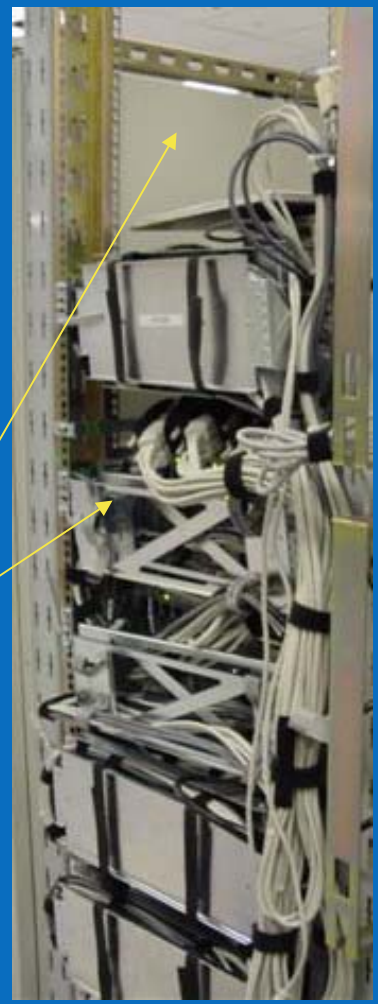
Model Conditions

- 36 inch high RMF
- Wire way under hot aisles,
- Three 6"x6" wireway per each row of 11 cabinets
- 49,000 cfm per RAH



Poor Airflow Control and Wire Management

- Air flow from servers is blocked; cable support arms become heat sinks.
- Open spaces allow hot air to flow through cabinet and mix with cooling air.



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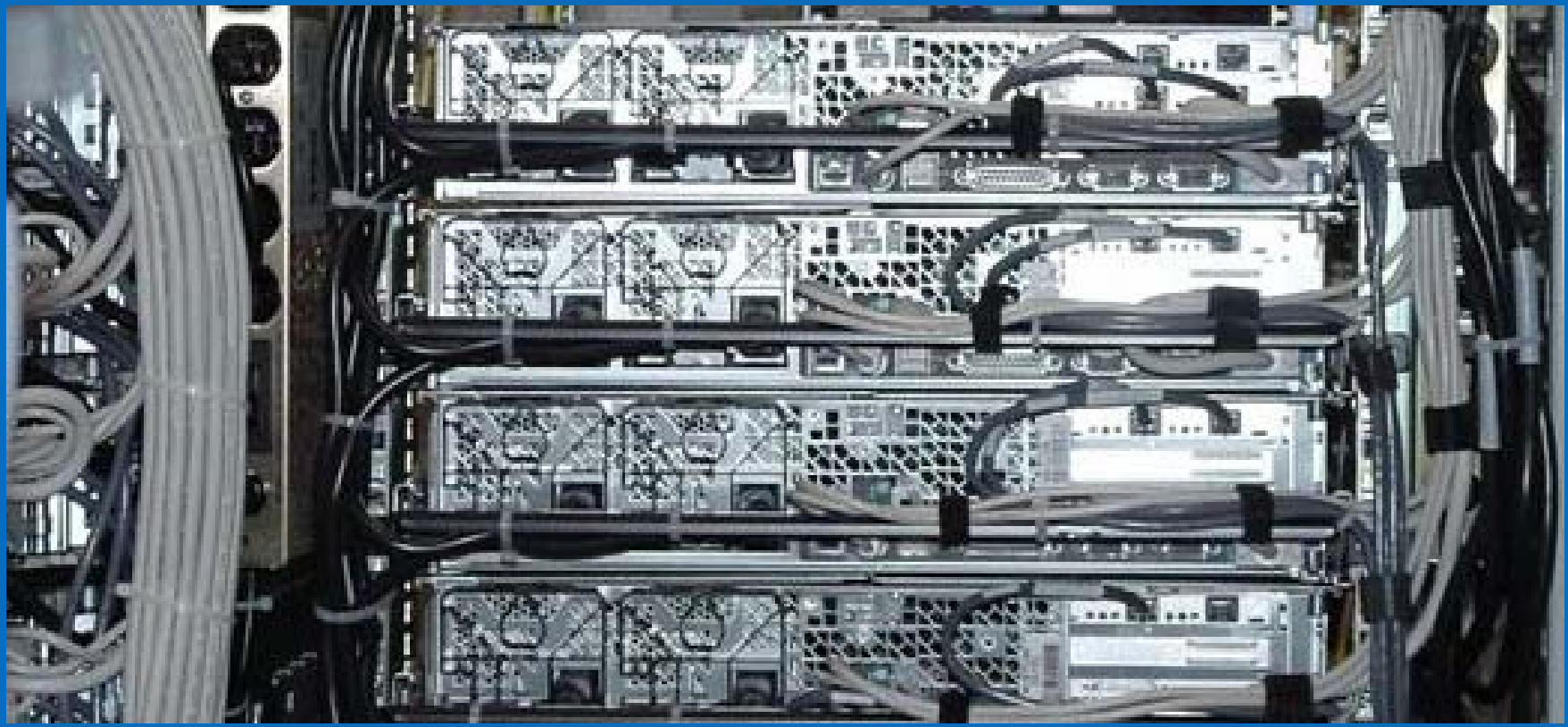
Minimize Air Flow Restriction

- Use custom length power cords rated for the proper amperage
- Use network patch cords of proper length (no service loops)



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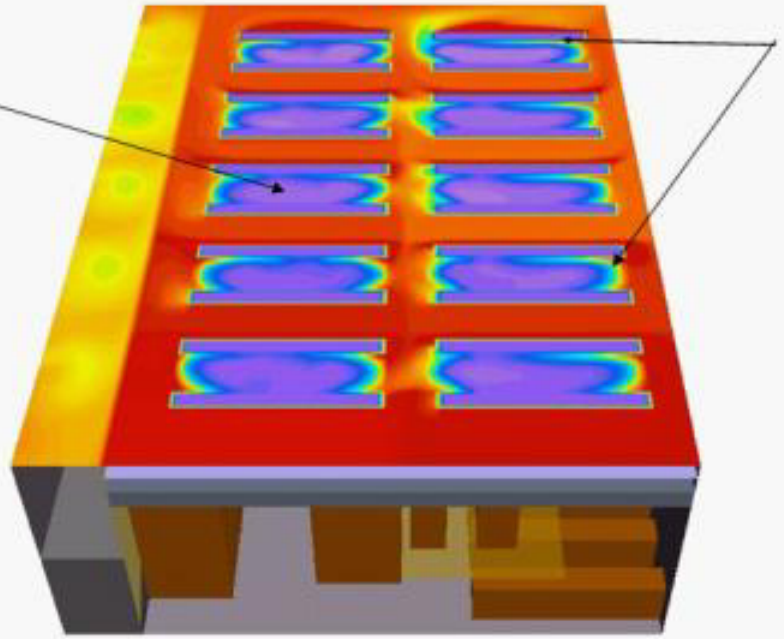
Vena Contracta

Vena Contracta Effect – The faster the air flows into the cold aisle, the more hot air is drawn in.



Hot air bypass around cabinet ends. Air moves to lowest pressure zone which is the server inlet !

BASE CASE
Temperature Plan - 3 ft above raised floor

Figure 1-3

BACK

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