Power and Cooling for Ultra-High Density Racks and Blade Servers

White Paper #46
Introduction

The Problem

- Average rack in a typical data center is under 2 kW
- Dense deployment of blade servers (10-20 kW per rack) would greatly exceed the power and cooling ability of the typical data center
- Providing 10-20kW of cooling per rack is technically infeasible using conventional methods
Introduction

The Solution

- There are practical strategies for installing, powering, and cooling high density racks either singly or in groups

- Some of these strategies challenge prevailing industry thinking on high-density deployment
Introduction

The Risk

- Wrong choices in designing for high density can increase Total Cost of Ownership for NCPI by many times.
Introduction

**The Surprise**

- Extreme compaction of data centers (over 6 kW per rack) creates the need for extreme cooling infrastructure, which ...
  - **Negates** the space savings of high-density IT equipment
  - **Increases** data center TCO
High Density’s Challenge to Conventional Cooling
The Cooling Challenge

18 kW POWER

3 kW
3 kW
3 kW
3 kW
3 kW

18 kW COOLING

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APC
Legendary Reliability
The Cooling Challenge

18kW

3 kW

3 kW

3 kW

3 kW

2500 cfm

2500 cfm
The Cooling Challenge

Exhaust drawn from itself or from neighboring racks

Less than 2500 cfm supplied

18 kW

3 kW

3 kW

3 kW

3 kW

3 kW

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The Cooling Challenge:
(For this 18kW rack)

- Supply 2500 cfm of cool air to the rack
- Remove 2500 cfm of hot exhaust air from the rack
- Keep the hot exhaust air away from the equipment intake
- Provide all these functions in a redundant and uninterrupted manner
CHALLENGE # 1:

Supply 2500 cfm of Cool Air to the Rack
Typical Raised-Floor Airflow

One 300 cfm vented tile per rack
Perforated Tiles?

- 18kW rack would require 8 perforated tiles
- Aisle width would need to be substantially increased
- Spacing between racks would need to be substantially increased

Perforated tiles cannot cool an 18 kW rack in a typical data center
Floor Tile Cooling Ability

Rack Power (kW) that can be cooled by one tile with this airflow

Typical Capability

With Effort

Extreme

Impractical

Blade Servers

Standard IT Equipment

Tile Airflow (cfm) [L/s]
Floor Tile Cooling Ability

Requires careful raised floor design, careful CRAC placement, and control of under-floor obstacles (pipes/wiring).

Rack Power (kW) that can be cooled by one tile with this airflow

Typical Capability  With Effort  Extreme  Impractical

300-500 cfm

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Floor Tile Cooling Ability

- Additionally requires grate-type tiles

Rack Power (kW) that can be cooled by one tile with this airflow

- 0 - 100 cfm airflow
- 100 - 200 cfm airflow
- 200 - 300 cfm airflow
- 300 - 400 cfm airflow
- 400 - 500 cfm airflow
- 500 - 600 cfm airflow
- 600 - 700 cfm airflow
- 700 - 800 cfm airflow
- 800 - 900 cfm airflow
- 900 - 1000 cfm airflow

Typical Capability
- 0 - 100 kW
- 100 - 200 kW
- 200 - 300 kW
- 300 - 400 kW
- 400 - 500 kW
- 500 - 600 kW
- 600 - 700 kW
- 700 - 800 kW
- 800 - 900 kW
- 900 - 1000 kW

With Effort
- 0 - 100 kW
- 100 - 200 kW
- 200 - 300 kW
- 300 - 400 kW
- 400 - 500 kW
- 500 - 600 kW
- 600 - 700 kW
- 700 - 800 kW
- 800 - 900 kW
- 900 - 1000 kW

Extreme
- 0 - 100 kW
- 100 - 200 kW
- 200 - 300 kW
- 300 - 400 kW
- 400 - 500 kW
- 500 - 600 kW
- 600 - 700 kW
- 700 - 800 kW
- 800 - 900 kW
- 900 - 1000 kW

Impractical
Increased Floor Depth?

Airflow variation decreases as floor plenum depth increases.
Increased Floor Depth?

Airflow variation decreases as floor plenum depth increases.
Increased Floor Depth?

With grate-type tiles, airflow in some cases reverses!

Variation is large even for very deep plenum

Max % Tile Airflow Variation

56% Open Tiles (grate)

25% Open Tiles (perforated)

Floor Plenum Depth

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Grate-Type Tiles?

- Grate-type tiles dramatically alter under-floor pressure gradients, making cooling non-uniform and unpredictable.
- Grate-type tiles in one area impact airflow in neighboring areas.
- Large airflow variations when using grate-type tiles mean some locations will NOT receive enough cooling.
- Even if an “extreme” cooling design could solve these large airflow variations, it would still take 3-4 grate-type tiles to cool one 18kW rack.
Conventional Cooling Won’t Work

A conventional data center layout with one vented tile per rack simply cannot cool racks over approximately 6 kW per rack over a sustained area.
CHALLENGE # 2:

18kW

Remove 2500 cfm of Hot Air From the Rack
Removing Heat

3 Ways to Remove Heat:
- Through the room
- Through a duct
- Through ceiling plenum

18kW

2500 cfm
Removing Heat

*The ideal:*

Hot exhaust air from equipment is taken directly back to the cooling system

- Unobstructed, direct return path
- No chance to mix with surrounding air
- No chance to be drawn into equipment intakes

2500 cfm through a 12” round duct goes 35 mph

1180 L/s through a 30 cm round duct goes 56 km/h
Removing Heat

Typical methods used in data centers

- High, open ceiling with bulk air return at a central high point
- Return ductwork
- Suspended ceiling plenum
- Bulk air return across the room, under ceiling that is just a few feet above the racks

These methods present high-density design challenges due to high air velocity
Removing Heat

More than **400 cfm** (189 L/s) airflow per rack – either supply or return – over a sustained area requires specialized engineering to ensure performance and redundancy.
CHALLENGE  # 3:

Keep Hot Exhaust Air Away From Equipment Intake
Preventing Recirculation

- The shortest path for air to reach the equipment intake is recirculation from the equipment’s own exhaust

- In high density environments, high airflow velocities become subject to resistance in ductwork, which degrades airflow patterns

Supply and return paths must dominate airflow near potential recirculation paths to keep equipment from ingesting its own hot exhaust
Cooling the data center
CHALLENGE  # 4:

Provide Cooling in a Redundant and Uninterrupted Manner

- **Redundant**
  - Cooling must continue during downtime of a CRAC unit

- **Uninterrupted**
  - Cooling must continue during failover to generator backup
Redundant Cooling: Conventional Solution

- Multiple CRAC units feed a shared raised floor or overhead plenum
- Plenum is assumed to sum all CRAC outputs and provide consistent pressure throughout
- System is designed to meet airflow and cooling requirements when any one CRAC unit is off
Redundant Cooling: High Density Challenge

- Airflow in cooling plenum increases
- Fundamental assumptions about shared-plenum system begin to break down
- With one CRAC unit off, local airflow velocities in the plenum are radically altered
- Airflow at an individual tile may even reverse, drawing air down into floor from venturi effect

Under fault conditions, cooling operation becomes unpredictable
Uninterrupted Cooling: Conventional Solution

- Conventional system puts CRACS on generator, not UPS
- Temperature rise during 5-20 second generator startup is acceptable: 1°C (1.8°F)
Uninterrupted Cooling: High Density Challenge

- In high density environment, temperature rise during uncooled 5-20 second generator startup can be 8-30°C (14-54°F)

- CRAC units may additionally have up to 5-minute “settle” time after power outage before they can be restarted

With high power density, CRAC fans and pumps (CRAC units, in some cases) must be on the UPS to provide continuous cooling during generator startup

CRACs on UPS are a major cost driver and a major barrier to HD deployment
Five Strategies That Work
5 Strategies for Deploying High-Density Racks and Servers

1. Design room for peak rack density

Or design room BELOW peak rack density, and...

2. Provide supplemental cooling for high-density racks

3. Establish rules for interspersed high-density racks to borrow cooling from adjacent racks

4. Spread out high-density equipment among multiple racks

5. Create a separate highly cooled area for high-density equipment
Strategy #1
Design Room For Peak Rack Density

- Handles wide range of future high-density scenarios
- Requires very complex analysis and engineering
- Capital and operating cost up to 4x alternative methods
- Risk of extreme underutilization of expensive infrastructure
- For rare and extreme cases of large farms of high-density equipment and limited space
Strategy #2
Supplemental Cooling for HD Racks

Types of supplemental cooling:

- Specialty floor tiles or fans to boost cool air supply to rack
- Specialty return ducts or fans to scavenge hot exhaust from racks for return to the CRAC
- Special racks or rack-mounted cooling devices to provide cooling directly to the rack
Supplemental-Cooling: Considerations

- Provides high density when and where needed
- Defers capital cost of upgrading to high-density infrastructure
- High efficiency
- Optimal use of floor space
- Limited to about 10 kW per rack
- Room must be designed in advance to allow it
Supplemental-Cooling: Applications

- New construction or renovation
- Mixed environment
- When location of high-density equipment is not known in advance
Filtered, Conditioned Air
- Increases life of equipment by supplying cool clean air

Dual Fans
- Increases airflow from top to bottom of rack

Air Filter
- Removes airborne particles from the rack

A-B Power Input Feeds
- Redundant power, Maximizes uptime

Independent Fan Control Switch
- Vary amount of airflow to equipment

Raised Floor Duct
- Allows air to be pulled into the rack directly from the raised floor

Rack Air Distribution Product Design Benefits
Rack Air Distribution Unit Airflow Diagram

- **Conditioned Room Air Is:**
  - Pulled in from underneath raised floor
  - Delivered from bottom to top of rack by dual fans
  - Drawn in by the IT equipment

- **Provides Cooler Air to the Rack**
  - Provides better cooling for IT equipment reducing heat related failures
  - Extends the life of equipment in the rack
ARU AIR FLOW
Fans pull in rack equipment exhaust air
  - Cable impedance is overcome by high powered fans

Ducted exhaust system (optional) delivers hot air to plenum
  - Eliminates hot air from mixing with room air

Proper airflow through the enclosure is ensured
  - Cool inlet air moves freely to equipment in the rack
ADU Air Flow

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ARU with Fully Ducted Return
Strategy #3
Borrow Cooling From Adjacent Racks

- Common and effective strategy in typical data centers
- Unused cooling capacity from neighboring racks can be used for up to 3x design density
- Uses rules for locating high-density racks to avoid creating hot spots
- Compliance can be verified by monitoring power consumption at the rack level
“Borrowed Cooling” Considerations

- No new equipment needed
- Essentially “free” in many cases
- High-density racks are limited to about 2x average density
- Requires more floor space than supplemental-cooling strategy (lower density)
- Requires enforcement of deployment rules
“Borrowed Cooling” Applications

- For existing data centers, when high-density equipment is a small fraction of total load
“Borrowed Cooling”
Example of Deployment Rules

START: New proposed load

Add up rack’s existing power plus new load

- **Does new rack power exceed avg. cooling power?**
  - **NO**
    - **Does either adjacent rack exceed avg. cooling power?**
      - **NO**
        - New load may be deployed
      - **YES**
        - **IS rack at the end of a row?**
          - **NO**
            - **Does avg. of new and 2 adjacent racks exceed avg. cooling power?**
              - **NO**
                - New load may be deployed
              - **YES**
                - **Does avg. of new and adjacent rack exceed avg. cooling power?**
                  - **NO**
                    - New load may not be deployed
                  - **YES**
                    - Split up load or try different location
          - **YES**
            - **Does avg. of new and 2 adjacent racks exceed avg. cooling power?**
              - **NO**
                - New load may be deployed
              - **YES**
                - **Does avg. of new and adjacent rack exceed avg. cooling power?**
                  - **NO**
                    - New load may be deployed
                  - **YES**
                    - Split up load or try different location

Strategy #3

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“Borrowed Cooling”
Example of Deployment Rules

“If the proposed rack averaged with its neighbors (only one neighbor if at the end of a row) does not exceed design average power, AND neither neighbor is already a high-density rack, then it’s OK to put it there”
Strategy #4
Split Up High Density Equipment

- Most popular solution
- High-density equipment is spread out among many racks
- No rack exceeds design power density
- Predictable cooling performance
Splitting Up Equipment: Considerations

- No new equipment needed
- Essentially “free” in many cases
- High-density equipment must be spread out even more than in “borrowing” strategy
- Uses more floor space than full high-density racks
- Can cause data cabling problems
- Empty vertical space must be filled with *blanking panels* to prevent in-rack recirculation of hot exhaust air
Splitting Up Equipment: Applications

- For existing data centers, when high-density equipment is a small fraction of the total load
Blanking Panels

BEFORE

90°F 32°C
80°F 27°C
95°F 35°C

Rack front

83°F 28°C
72°F 22°C
70°F 21°C

SIDE VIEW

Strategy #4
Air Flow with no blanking panels
Blanking Panels

Blanking panels block internal recirculation

BEFORE

90°F 32°C
80°F 27°C
95°F 35°C
83°F 28°C
72°F 22°C
70°F 21°C

SIDE VIEW

Rack front

AFTER

79°F 32°C
73°F 32°C
73°F 32°C
73°F 32°C
73°F 32°C
72°F 32°C
70°F 32°C

SIDE VIEW

Rack front

Blanking panels
Air Flow with blanking panels
Blanking Panels

Strategy #4

Snap-in blanking panel
Strategy #5
Dedicated High-Density Area

- Supports maximum-density racks
- Doesn’t require spreading out of high-density equipment
- Optimal floor space utilization
- New technologies can deliver predictable, highly efficient cooling
Dedicated High-Density Area: Considerations

- Requires prior knowledge of number of high-density racks
- Need to plan high-density area in advance and reserve space for it
- Requires ability to segregate high-density equipment
Dedicated High-Density Area: Applications

- New construction or renovations
- Density of 10-25 kW per rack
- High-density co-location
Dedicated High-Density Area: Power / Cooling Technology

Strategy #5

- Ambient-temperature air is returned to room
- Integral rack power distribution system (UPS is optional)
- Door access to hot aisle and rear of IT equipment
- All exhaust air is captured within chamber and “neutralized” to ambient temperature
- Integral rack air conditioner
- Equipment racks take in ambient air from front
- Can operate on hard floor or raised floor
ISX High Density Air Flow Pattern
Summary and Recommendations

Seven Elements of an Optimal Cooling Strategy
Elements of Optimal Cooling Strategy

1. Ignore physical size of equipment and focus on functionality per watt consumed

Minimizes area and TCO
Elements of Optimal Cooling Strategy

2

Design the system to permit later installation of supplemental cooling devices

Allows for future supplemental cooling equipment where and when needed, on a live data center, in the face of uncertain future requirements
3. Choose a room average power density between 40 and 100 W / ft^2

0.4 – 1.1 kW / m2

- Avoids waste due to oversizing
- Keeps both routine and redundant performance predictable

Practical for most new designs:
80 W / ft2 or 2.8 kW / rack
0.9 kW / m2
Elements of Optimal Cooling Strategy

If the fraction of high density loads is high and predictable, establish high-density areas of 100-400 w / ft² (3-13 kW per rack)

1.1 – 4.3 kW / m²

- Requires planning ahead for specially equipped areas
- Adds significant cost, time, and complexity
- These areas do not use raised-floor cooling
Elements of Optimal Cooling Strategy

5

Establish policies/rules for allowable rack power based on location and adjacent loads

- Reduces hot spots
- Ensures cooling redundancy
- Increases system cooling efficiency
- Reduces electrical consumption
- More sophisticated rules and monitoring can enable even higher power density
Elements of Optimal Cooling Strategy

6

Use supplemental cooling devices where indicated

Boosts local cooling capacity up to 3x room design to accommodate high-density equipment
Elements of Optimal Cooling Strategy

7

Split up equipment that cannot be installed to meet the rules

- **Lowest cost, lowest risk option**
- **Consumes considerable space if there is more than a small fraction of high-density loads**
- **Chosen as primary strategy by users without significant area constraints**
Questions?