COMPARISON OF COOLING PERFORMACE OF OVERHEAD AND UNDERFLOOR SUPPLY WITH REAR DOOR HEAT EXCHANGER IN HIGH DENSITY DATA CENTER CLUSTERS

by

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ABSTRACT

COMPARISON OF COOLING PERFORMACE OF OVERHEAD

AND UNDERFLOOR SUPPLY WITH REAR DOOR

HEAT EXCHANGER IN HIGH DENSITY

DATA CENTER CLUSTERS

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The power trend for server systems continues to grow thereby making thermal management of Data centers a very challenging task. Although various configurations exist, the raised floor plenum with Computer Room Air Conditioners (CRACs) providing cold air is a popular operating strategy. In prior work, numerous data center layouts employing raised floor plenum and the impact of design parameters such as plenum depth, ceiling height, cold isle location, tile openings and others on thermal performance of data center was presented. The air cooling of data center however, may not address the situation where more energy is expended in cooling infrastructure than the thermal load of data center. Revised power trend projections by ASHRAE TC 9.9 predict heat load as high as 5000W per square feet of compute servers' equipment footprint by year 2010. These trend charts also indicate that heat load per product footprint has doubled for storage servers during 2000-2004. For the same period, heat load per product footprint for compute servers has tripled. Amongst the systems that are currently available and being shipped, many racks exceed 20kW. Such high heat loads have raised concerns over limits of air cooling of data centers similar to air cooling of microprocessors. A hybrid cooling strategy that incorporates liquid cooling along with air cooling can be very efficient in such situations. The objective of this paper is to study and compare the performance of hybrid cooling solution in two widely used air supply configurations namely Overhead supply and Underfloor supply focusing on rack inlet temperature. The numerical models of a representative data center employing Overhead and Underfloor supply with hot aisle-cold aisle arrangement are constructed using a commercial CFD code. The effect of these configurations on rack inlet temperature is discussed.

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CHAPTER 1

INTRODUCTION TO DATA CENTERS

1.1 Background

Data centers are the buildings with high concentrations of computers and digital electronic equipment dedicated to hosting websites, supporting ecommerce and providing an essential service for the new digital economy [1]. Data centers centralize and consolidate Information Technology (IT) resources, enabling the organizations to conduct business around the clock and around the world. [2]

Data centers house a high density of digital electronics and computer technology requiring higher quality and more reliable electric power than most commercial buildings. They are essentially building shells packed with computers, power conditioning equipment, control electronics, and backup power systems along with air conditioning systems to keep the equipment cooled to optimum operating temperatures, generally 68-70°F. The computes used in data centers are generally known as servers. Multiple servers are secured in racks that typically have 2 foot by 21/2 foot footprint and 70 to 87 inches high. These racks are placed on a raised floor, which serve as a plenum allowing cooled air to move below the racks, then up through perforated floor tiles to cool the racks. This cool air is sucked in the racks aided by fans and the heated air thus rejected by these server racks is drawn back by the A/C systems. Power supplies, conditioning equipment, and back up generators are placed separate from raised floor area. [3] Figure 1.1 shows a typical raised floor data center.

Figure 1.1: Raised floor data center showing racks and perforated tiles [14]

1.2 Types of Data Centers

Data centers fall into two major categories,

1) Private Data Centers (PDC)

2) Internet Data Centers (IDC)

Private data centers are owned and operated by private corporations, institutions or government agencies for the prime purpose of supporting data processing and web oriented services for their own organizations.

Internet data centers are owned and operated by traditional telecoms, and regulated competitive service providers or other types of commercial operators to provide outsourced IT services, access through internet connectivity.

There are functions common to any data center, for the most part, all data centers provide,

- Internet access and wide area communication
- Application hosting
- Content distribution
- File storage and back up
- Database management
- Fail safe power supply
- Adequate HVAC and fire suppression
- High performance cabling infrastructure
- Security

1.3 ASHRAE Power Trends & Heat Density Issues

In recent years data center facilities have witnessed rapidly increasing power trends that continue to rise at an alarming rate. The combination of increased power dissipation and increased packaging density has led to substantial increases in chip and module heat flux. As a result, heat load per square feet of server footprint in a data center has increased. Recent heat loads published by ASHRAE [4] as shown in Figure 1.2 indicate that for the period 2000-2004, heat load for storage servers has doubled while for the same period, heat load for compute servers has tripled. According to these trends, compute server rack heat fluxes in 2006 around 4,000 W/ft^2. This corresponds to 27,000 W for a typical 19 inch rack. There are 19 inch racks commercially available in market that dissipate more than 30KW which corresponds to 4,800 W/ft^2 rack heat flux. Figure 1.3 shows the measured values for average and hot spot high-density computing data center heat fluxes based on measurements carried out in the last three years by Schmidt and co-workers [5-8]. In one of the 2005 measurements, a server cluster test facility showed extremely high hot spot heat fluxes of 720 W/ft^2 (7750 W/m^2) over areas of 440 ft^2 (40.1 m^2), or an 11 × 10 grid of tiles. These high powered clusters are focus of this study.

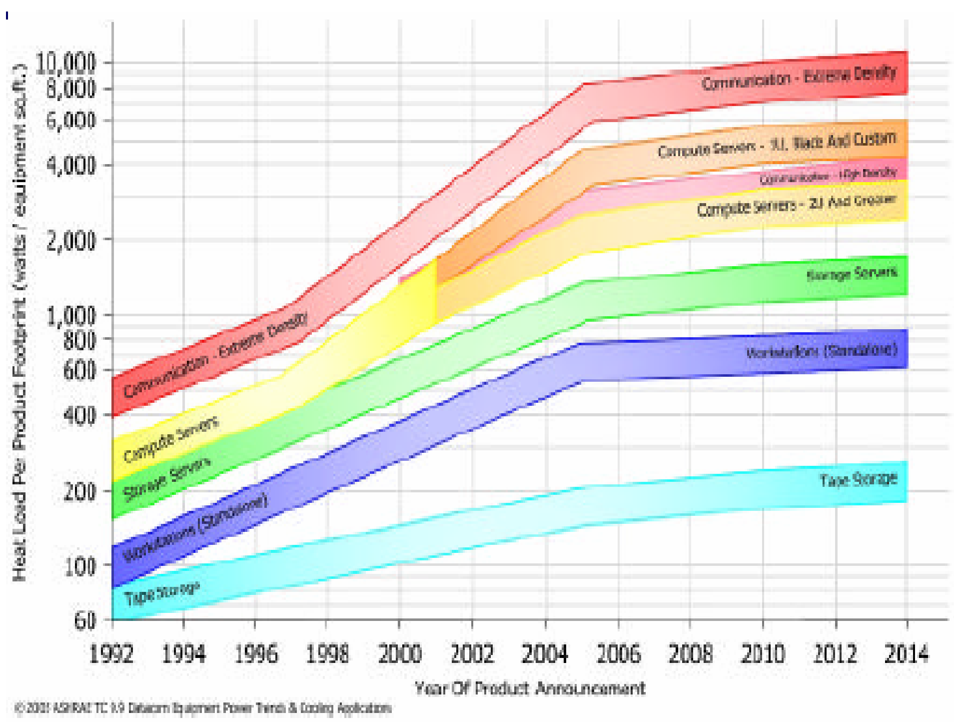

Figure 1.2: Heat load trends [4]

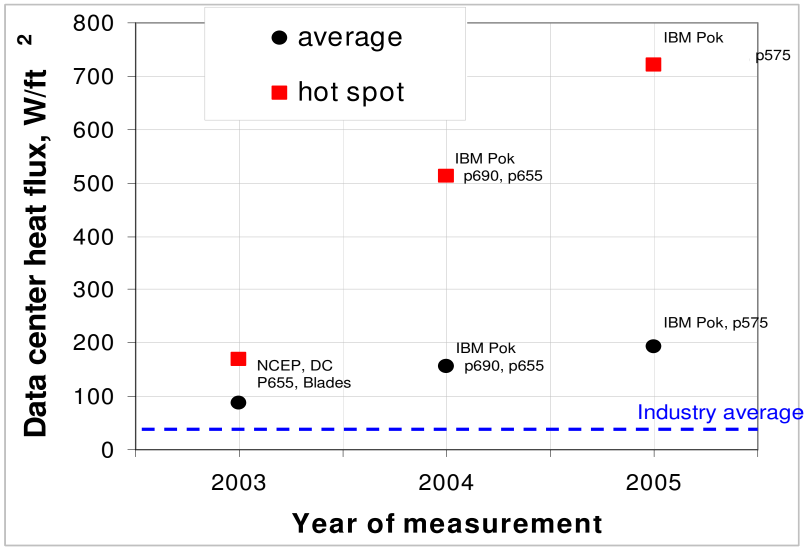

Figure 1.3: Data center hot spot heat flux [7]

ASHRAE Modified Power Trends extended up to 2014 is given as below:

• All trends projected out to 2014

• The Servers & Disk Storage Systems trend was split into two distinct categories with different trend projections:

– Compute Servers

– Storage Servers

• The Compute Servers trend was further split into two categories to indicate another trend Projection split:

– Compute Servers 1U, Blade and Custom

– Compute Servers 2U and Greater

• The Communication Equipment trend was split into two categories with different trend projections:

– Communication Equipment – High Density

– Communication Equipment – Extreme Density

1.4 The functional allocation of gross space within a typical data center

Proper allocation of floor space is a major issue in good data center design. Table 1.1 provides information on the raised floor area usage. A good design must take care of all variables to deliver high density and availability, with adequate cooling and cabling infrastructure flexibility.

Table 1.1: Approximate usage of raised floor space area.
Source: Uptime Institute

Area	Usage
Computer hardware footprint (servers, rackmounted equipment, and telecommunication frames)	25-30%
Service clearance around products (allows for movements of cooling air and personnel)	30-35%
Main aisles, support columns, other non electrified areas	20%
Infrastructure support equipment (in room UPS's, PDU's, Cooling systems, Air handling equipment and other support electronics)	20%

Racks, Cables and Support Infrastructure: Data centers employ a wide variety of racks, enclosures, electrical and communication path connectivity products like cable tray and ladder racking. They must in all ways, individually and together, support four key areas of need:

(i) Climate control, (ii) Power management, (iii) Cable management and (iv) Security and monitoring.

Redundancy and Path Diversity: These are the issues concerning cabling, power, internet access and carrier services. Tolerance for downtime measured against equipment costs and floor usage must be closely examined and matched against success criteria. Data centers must carefully weigh the cost of downtime with respect to their revenue model.

Security: Data centers are the nerve centers of new digital economy. Company and customer data should be treated like money in the bank vault. PDC and IDC's must take very definitive measures to limit access only to authorized personnel, ensure use of proper fire prevention and life safety systems while minimizing the potential equipment damage.

Storage: As the volume of stored data escalates and management of content becomes more challenging, additional or complimentary connectivity concerns must be addressed in data center design to accommodate for more flexibility and most efficient and effective use of space.

Flexibility and Adequate Connectivity: This is the key in bringing users online quickly and effectively, whether in PDC or IDC environment. Time is very critical whether provisioning new data center customer, upgrading their bandwidth, or leased services, or providing a quick, coordinated and efficient move/add/change services to a corporate user base. Therefore performance, flexibility, headroom, patching and error-resistance are all the variables in the same crucial design formula.

1.5 Data center configurations

In their thermal guidelines for data processing environment [9], ASHRAE TC 9.9 has introduced four environmental classes based on steady state temperature, relative humidity, dew point temperature and rate of temperature rise. It is essential to maintain inlet temperature and humidity within limits specified by the manufacturer. Air cooling is vastly employed to achieve this controlled environment. Shown in figure 1.4 and 1.5 are two commonly used configurations of air supply namely Underfloor and Overhead.

A typical arrangement of Underfloor air supply configuration is shown in Figure 1.4. The Computer Room Air Conditioning unit (CRAC) delivers the chilled air into the space below raised floor. This chilled air enters the room through perforated tiles, passes through the racks and gets heated up. This hot air then returns to CRAC intake. In Overhead supply configuration (Figure 1.5), chilled air enters the room via Overhead diffusers. After passing through racks, the heated air then exits room via vents on the wall. This hot air eventually passes through heat exchanger and is then supplied back as chilled air.

Both these configurations use hot aisle – cold aisle layout in an attempt to isolate chilled air supply from hot air. The front face of rack, which generally is air inlet for the equipment, is placed facing perforated tiles. The backside of rack from where hot air exhausts, faces backside of another rack forming a hot aisle. In a large data center with such an arrangement, zones with very high heat load may exist due to use of high performance equipments. Airflow requirements for such high performance racks lies within 1500 to 3500 cfm (0.7 to1.4 m^3/s). These requirements become difficult to meet when packaging density is very high. The inability of Underfloor configuration to have flexibility of entry points for chilled air compounds the problem. This results in fractional supply of chilled air to racks causing severe recirculation. The hot air exiting in hot aisle is then drawn to the cold aisle and it makes up for shortage of supply. This leads to complex flow patterns and unusually high inlet temperatures.

The high temperature gradients at inlet indicate ineffectiveness of air cooling for high powered clusters. A hybrid cooling solution that consists of air cooling assisted by a liquid to air heat exchanger can be effective in such cases. A method to reduce the effect of the hot air recirculation in a data center is to use water cooled heat exchanger attached to the rear door of the rack. The heat exchanger removes a large portion of the heat from the rack as well as significantly lowering the air temperature exhausting the rear of the rack. The heat exchanger can be comprised of a conventional fin and tube design or a plate fin and flat tube "radiator" type design. The heat exchanger is of a planar geometry and aligns with the rear of the frame and receives hot exhaust air at its inlet for one coolant stream (hot). For the cold coolant stream the heat exchanger received chilled water. Flexible hose lines couple the heat exchanger to inlet and exit water plumbing headers. The objective of this study is to understand the effects on flow patterns, recirculation and mixing of hot and cold air and eventually on the temperature gradients at inlet if hybrid solution as shown in Figure 1.6 is employed in high heat flux situations.

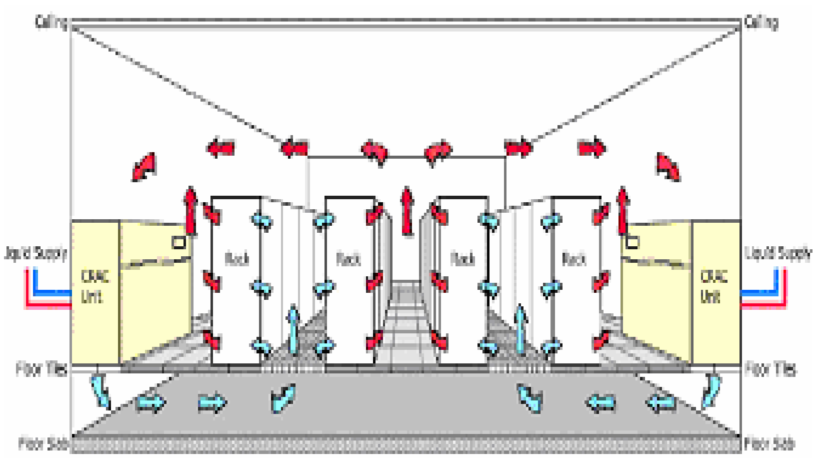

Figure 1.4: Underfloor air supply configuration [4]

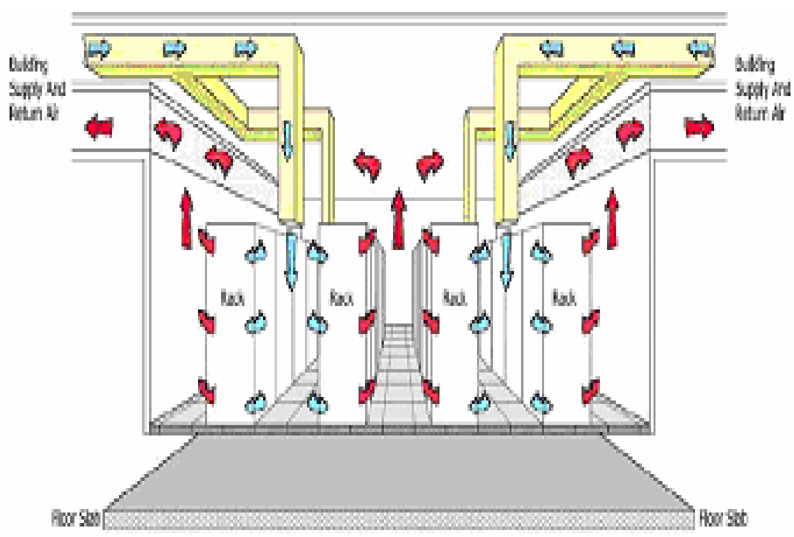

Figure 1.5: Overhead air supply configuration [4]

Figure 1.6: IBM’s Rear door heat exchanger [10]

1.6 Most common issues faced in Data Center design

Energy efficient technologies, smart design and proper preventive maintenance procedures can significantly decrease data center energy demands. During the time of rapid data center expansion for many people in the internet hosting industry, getting a new data center online as fast as possible was the overriding factor in designing and building data centers. However haste to install data centers, lack of accepted and standardized design guidelines, and lack of financial incentives to save energy has led to inefficient design, poor design implementation, and use of energy-inefficient technologies in data center.

Due to multidisciplinary work involved in the design and construction of data center, various issues need to be addressed beforehand. These issues are critical because once data centers are up and running, they have zero tolerance for downtime and other problems caused by poor design or flawed installations. Following is the list of issues that needs to be addressed by the scientific community.

- **Professional Engineering:** With many electrical, mechanical and communication variables involved, successful data center design and constructions needs professional engineering. Data centers are unique environments, so developers can benefit from the architect, engineering and consulting community, along with construction firms with experience in designing and building data centers.

- **Power Requirements:** Packing as many servers as possible into a rack or cabinet means more revenue generated per square foot. Data centers today often specify 100 W per square foot and many are provisioning for double of that. Servers are supplied with dual power supplies, each having own power cord. So racks and cabinets must be designed must be designed to provide plentiful power strips and cable routing. Environmental monitoring (fan control, incoming voltage and UPS) and access control can provide additional and management.

CHAPTER 2

CFD MODELING OF DATA CENTER

2.1 Overview of computational fluid dynamics (CFD)

The solution procedures in ICEPAK are based on CFD techniques [11]. CFD is concerned with the numerical simulation of fluid flow, heat transfer and related processes such as radiation.

The objective of CFD is to provide the engineer with a computer-based predictive tool that enables the analysis of the air-flow processes occurring within and around electronics equipment, with the aim of improving and optimizing the design of new or existing equipment.

The CFD techniques that are in use today evolved from techniques developed in response to the stimuli of the `high-technology' aerospace and nuclear power industries. Today CFD applications are to be found in many industries, research institutes and universities.

Icepak™ is a powerful CAE software tool that allows engineers to model electronic system designs and perform heat transfer and fluid flow simulations that can increase a product's quality and significantly reduce its time-to-market [11]. The Icepak program is a total thermal management system that can be used to solve component-level, board-level, or system level problems. It provides design engineers with the ability to test conceptual designs under operating conditions that might be impractical to duplicate with a physical model, and obtain data at locations that might otherwise be inaccessible for monitoring.

Icepak uses the FLUENT computational fluid dynamics (CFD) solver engine for thermal and fluid-flow calculations. The solver engine provides complete mesh flexibility, and allows you to solve complex geometries using unstructured meshes. The multigrid and segregated solver algorithms provide robust and quick calculations.

Icepak provides many features for thermal and fluid-flow analysis. These features include the following:

• accurate modeling of non-rectangular devices

• contact resistance modeling

• anisotropic conductivity

• non-linear fan curves

• lumped-parameter heat sink devices

• external heat exchangers

• automatic radiation heat transfer view factor calculations

2.2 Program Structure [11]

Icepak package includes the following components:

• Icepak, the tool for modeling, meshing, and postprocessing

• FLUENT, the solver engine

• filters for importing model data from Initial Graphics Exchange Specification (IGES), AutoCAD (DXF), Intermediate Data Format (IDF), and FLOTHERM (ECO) files

Icepak is used to construct model geometry and define model. Import model data from other CAD and CAE packages in this process [11]. Icepak then creates a mesh for the model geometry, and passes the mesh and model definition to the solver for computational fluid dynamics simulation. The resulting data can then be postprocessed using Icepak, as shown in Figure 2.1.

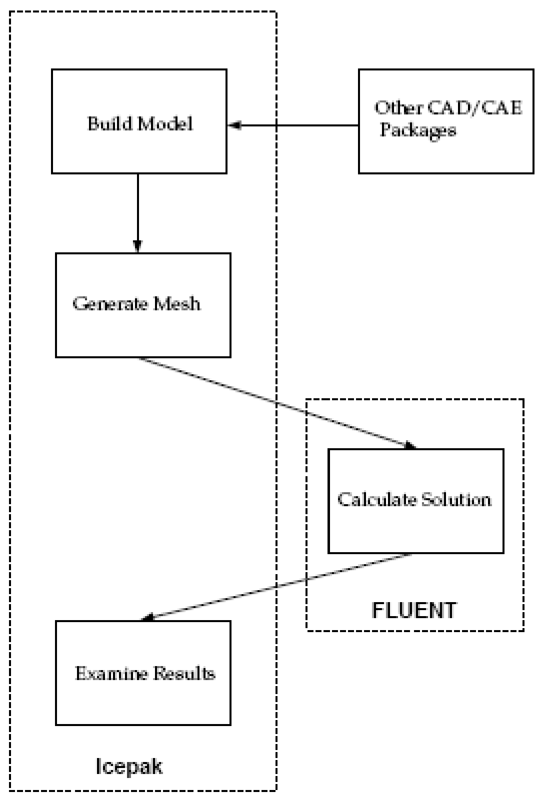

Figure 2.1: Basic Program Structure [11]

2.3 Program [11]

Icepak uses object-based model building with predefined objects

– cabinets

  – networks
  – heat exchangers
  – wires
  – openings
  – grilles
  – sources
  – printed circuit boards (PCBs)
  – enclosures
  – plates
  – walls
  – blocks
  – fans (with hubs)
  – blowers
  – resistances
  – heat sinks
  – packages
- macros
  – JEDEC test chambers
  – printed circuit board (PCB)
  – ducts
  – compact models for heat sinks
- 2D object shapes

– rectangular

– circular

– inclined

– polygon

• complex 3D object shapes

– prisms

– cylinders

– ellipsoids

– elliptical and concentric cylinders

– prisms of polygonal and varying cross-section

– ducts of arbitrary cross-section

2.4 Program Capabilities [11]

2.4.1 Meshing

• automatic unstructured mesh generation

– hexahedra, tetrahedra, pyramids, prisms, and mixed element mesh types

• meshing control

– coarse mesh generation option for preliminary analysis

2.4.2 Boundary Conditions

• wall and surface boundaries with options for specification of heat flux, temperature, convective heat transfer coefficient, radiation, and symmetry conditions

- openings and grilles with options for specification of inlet/exit velocity, exit static pressure, inlet total pressure, and inlet temperature
- fans, with options for specified mass flow rate and fan performance curve
- recirculating boundary conditions for external heat exchanger simulation
- time-dependent and temperature-dependent sources
- time-varying ambient temperature inputs

2.4.3 Solver

For its solver engine, Icepak uses FLUENT, Fluent Inc.'s finite-volume solver. Icepak's solver features include:

- segregated solution algorithm with a sophisticated multigrid solver to reduce computation time
- choice of first-order upwinding for initial calculations, or a higher-order scheme for improved accuracy

2.4.4 Initializing the solution

Before starting CFD simulation, Icepak must be provided with the number of iterations to be performed and the criteria Icepak should use to check for convergence. The following values should be specified in the Solver setup panel.

- Specify the Number of iterations to be performed by Icepak during the calculation. This specifies the number of solution iterations to be performed in a steady-state calculation. The calculation will stop when these iterations have been performed or the Convergence criteria are satisfied, whichever happens first. For relatively simple models, the default of 100 should be sufficient for the solution to converge, but for more complex models the value should be increased.

- Specify the Convergence criteria. These are the solution-residual values used to determine convergence. Solution residuals measure the error or imbalance in the conservation equations that Icepak solves. When all solution residuals are less than or equal to their specified convergence criteria, the solution will be considered converged. If you click Reset in the Basic settings panel, Icepak will adjust the convergence criteria to values that are suitable for the type of problem you are trying to solve.

CHAPTER 3

COOLING PERFORMANCE OF OVERHEAD AND UNDERFLOOR SUPPLY

3.1 Objective

- Study and compare the performance of hybrid cooling solution in two widely used air supply configurations namely Overhead supply and Underfloor supply focusing on rack inlet temperature.
- The effect of hot aisle-cold aisle configuration on rack inlet temperature for Overhead and Underfloor supply are discussed.
- The objective of this study is to understand the effects on flow patterns, recirculation and mixing of hot and cold air and eventually on the temperature gradients at inlet if hybrid solution is employed in high heat flux solutions.

3.2 Numerical Modeling [12]

A representative data center with Underfloor configuration as shown in Figure 3.1 is modeled using commercially available CFD code [11]. The Overhead supply configuration is shown in Figure 3.2. The half symmetry model of data center "cell" has 40 racks arranged in cold aisle – hot aisle layout as shown in Figure 3.3.

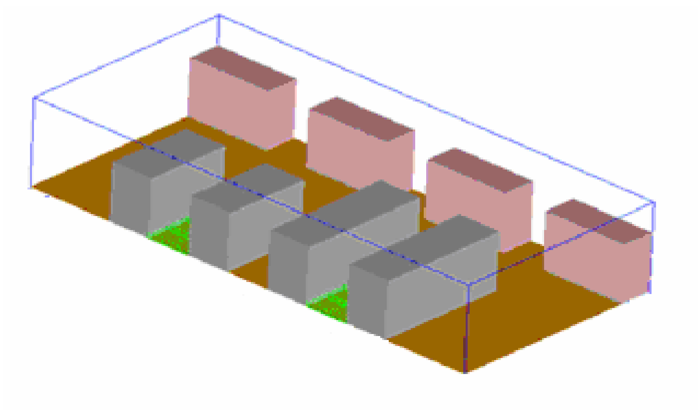

Figure 3.1: Representative model of data center with Underfloor supply configuration

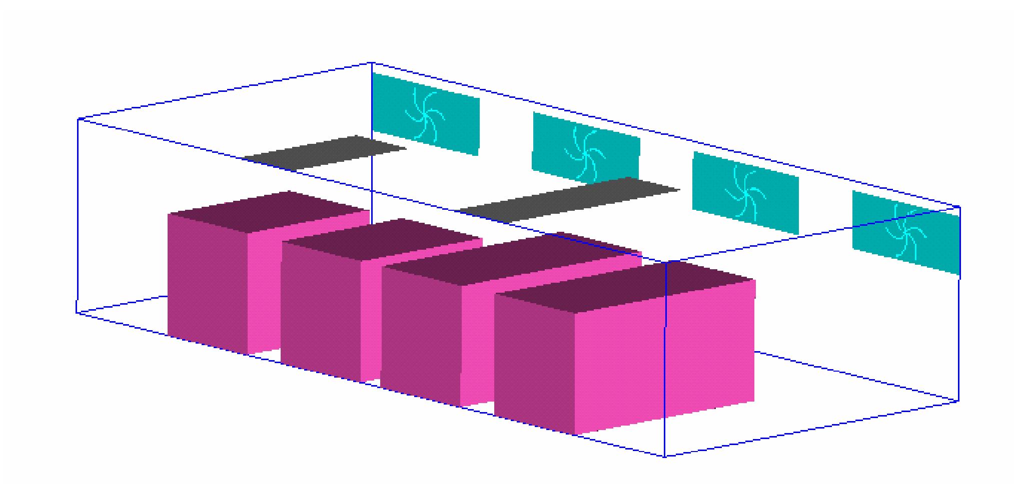

Figure 3.2: Representative model of data center with Overhead supply configuration

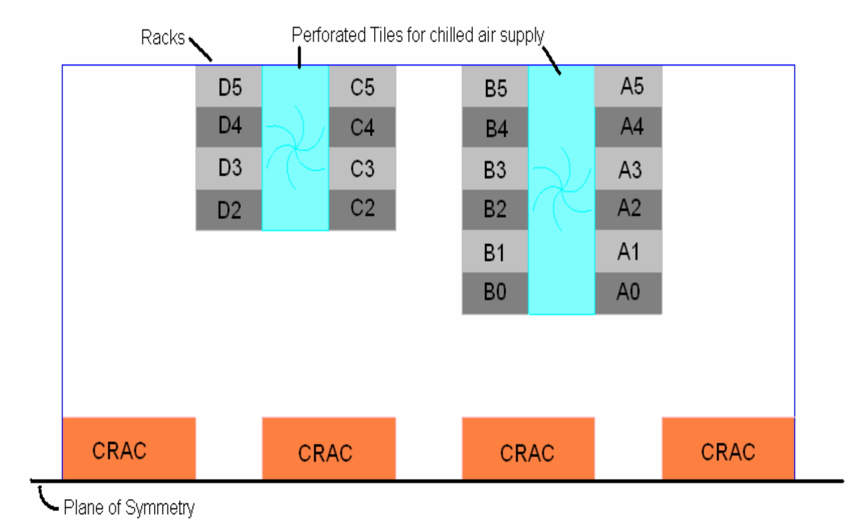

Figure 3.3: Data center layout

From Figure 3.1, the footprint dimensions of the half-symmetry "cell" are 20ft (6.09 m) by 44 ft (13.42 m), and the room was 10 ft (3.048 m) tall. The computer racks were assumed to be one tile wide (0.61 m or 2 ft.), two tiles deep (1.22 m or 4 ft.), and 1.8 m (6 ft) tall. The air-moving device inside the racks is assumed to force air straight through the rack, with a constant velocity across the front and back of the racks. Each rack is assumed to be a high-performance 32 kW (109,194 Btu/h) rack, with a rack airflow rate of 2905 cfm (1.371 m^3/s). This corresponded to an air temperature rise through the rack of 20°C (36°F). The temperature of the chilled air entering the room through the perforated tiles was fixed at 13°C (56°F). The CRAC unit had a 3 ft × 8 ft (0.91 m x 2.44 m) footprint and was 1.8 m (6 ft) high. Figure 3.3 shows the racks to be arranged in four rows, A, B, C, and D, respectively, with A0, B0, C2,and D2 being closest to the CRAC units and A5,B5, C5 and D5 located farthest away from the CRAC units.

The CRAC units are replaced by diffusers/Overhead ducting in Overhead supply configuration. This is modeled by using flow device macros at ceiling and the return air is modeled using vents or exhaust.

Three different cases of chilled air supply are considered with CRAC units supplying 60%, 80% and 100% of rack airflow requirement. For each air supply fraction, heat exchangers were employed at various locations. In CFD model, symmetry boundary condition was applied to the wall touching the racks. The elements count was within 300,000 to 500,000. On a high end PC, convergence for temperature and continuity was satisfactorily achieved in about 2000 iterations within 8-10 hours. For each rack, inlet temperature was monitored at 300mm, 600mm, 900mm, 1200mm, 1500mm and 1800mm above floor level. Also, inlet and exit temperatures for heat exchangers were monitored at same locations. Figure 3.4 shows CFD model of Data center with Underfloor supply configuration.

Racks A0, B0, C2, and D2 are referred to as outside racks, and racks A5, B5, C5, and D5 are referred to as inside racks. Racks A1-A4, B1-B4, C3, C4, D3 and D4 are referred to as middle racks. Table 3.1 shows the modeling details.

Table 3.1: Modeling Details

Half symmetry model	20ft by 44ft and 10ft tall
Underfloor CRAC unit Overhead vents	3ft by 8ft and 6ft high 8ft by 3ft
Computer Racks No. of racks Heat Load Flow rate	2ft by 4ft and 6ft tall 20 racks 32 kW 2905 cfm
Underfloor supply a. Long cold aisle b. Short cold aisle Overhead ducts a. Long ducts b. Short ducts	 12ft by 4ft 8ft by 4ft 12ft by 4ft 8ft by 4ft
Heat exchanger	2ft by 6ft tall
Temperature of chilled air entering the room	13 ° C

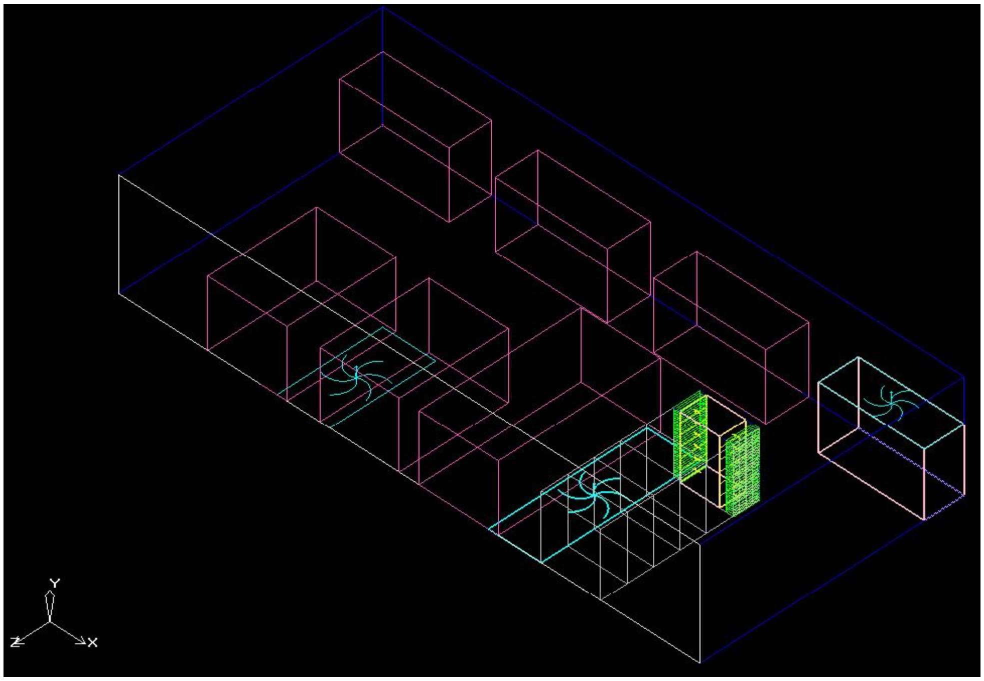

Figure 3.4: CFD model of Data center with Underfloor supply configuration

3.3 Hybrid cooling with Overhead supply configuration

Figure 3.5 shows the variation in rack inlet temperatures in each rack along the height for Overhead supply configuration with 60% supply. This configuration includes rear heat exchanger at each rack.

3.4 Hybrid cooling with Underfloor supply configuration

Figure 3.6 shows the variation in rack inlet temperatures in each rack along the height for Underfloor supply configuration with 60% supply. This configuration includes rear heat exchanger at each rack.

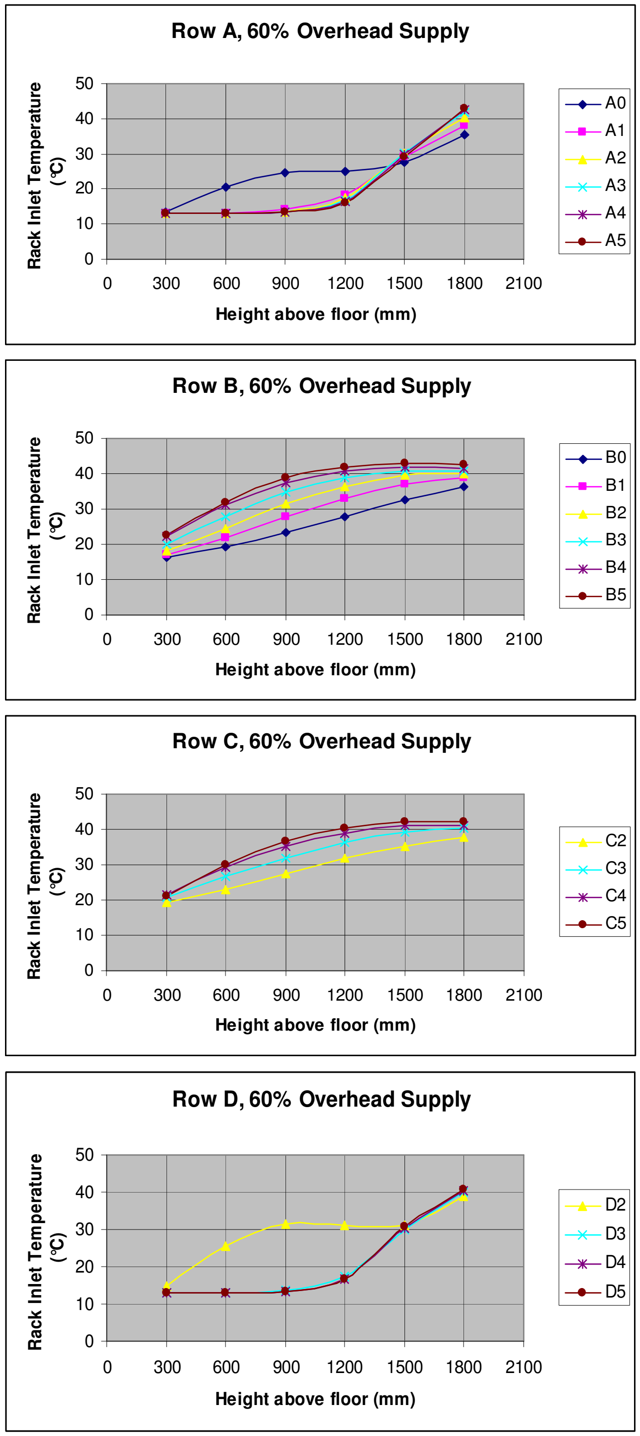

Figure 3.5: Rack Inlet Temperature Variation in Hybrid Cooling with Overhead Supply Configuration

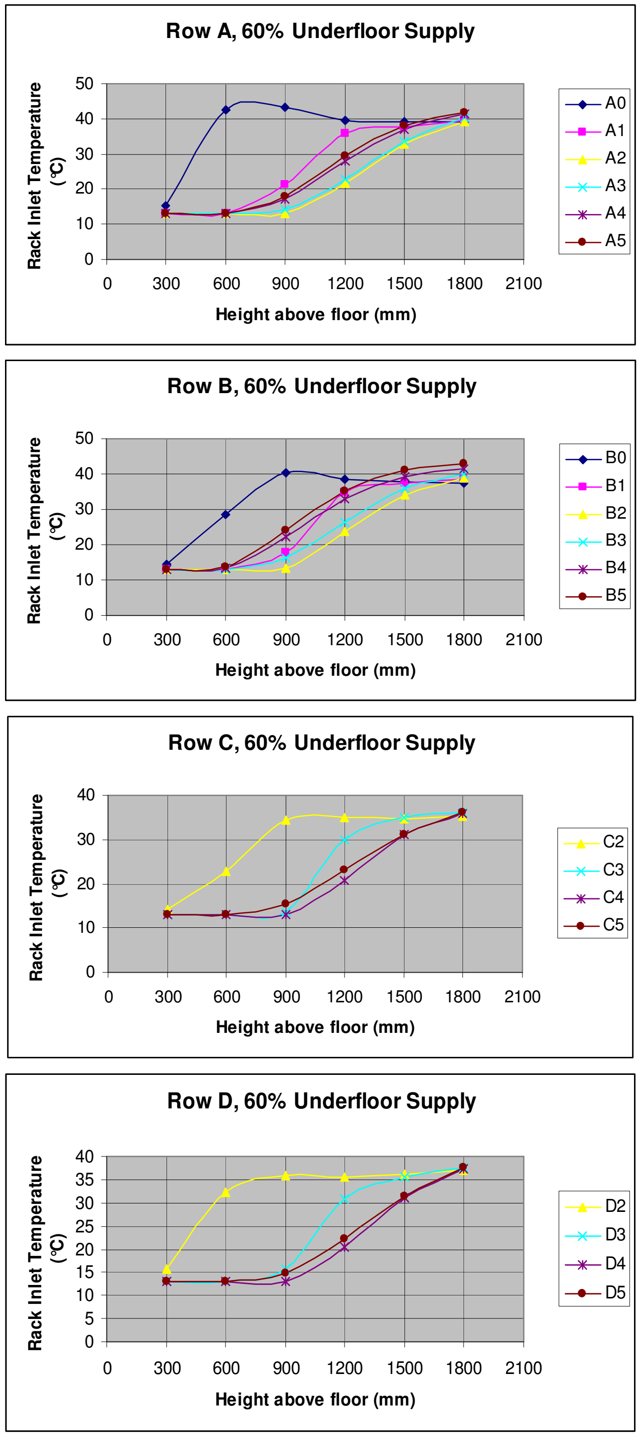

Figure 3.6: Rack Inlet Temperature Variation in Hybrid Cooling with Underfloor Supply Configuration

3.5 Variation of rack inlet temperatures in outer racks for Overhead supply configurations

Figure 3.7 shows variation of rack inlet temperatures in outer racks for Overhead supply configurations. The various cases include 60%, 80% and 100% Supply with and without rear heat exchangers.

3.6 Variation of rack inlet temperatures in outer racks for Underfloor supply configurations

Figure 3.8 shows variation of rack inlet temperatures in outer racks for Overhead supply configurations. The various cases include 60%, 80% and 100% Supply with and without rear heat exchangers.

3.7 Variation of rack inlet temperatures in inner racks for Overhead supply configurations

Figure 3.9 shows the rack inlet temperature variations in inside racks for abovementioned cases for Overhead supply configurations.

3.8 Variation of rack inlet temperatures in inner racks for Underfloor supply configurations

Figure 3.10 shows the rack inlet temperature variations in inside racks for abovementioned cases for Overhead supply configurations.

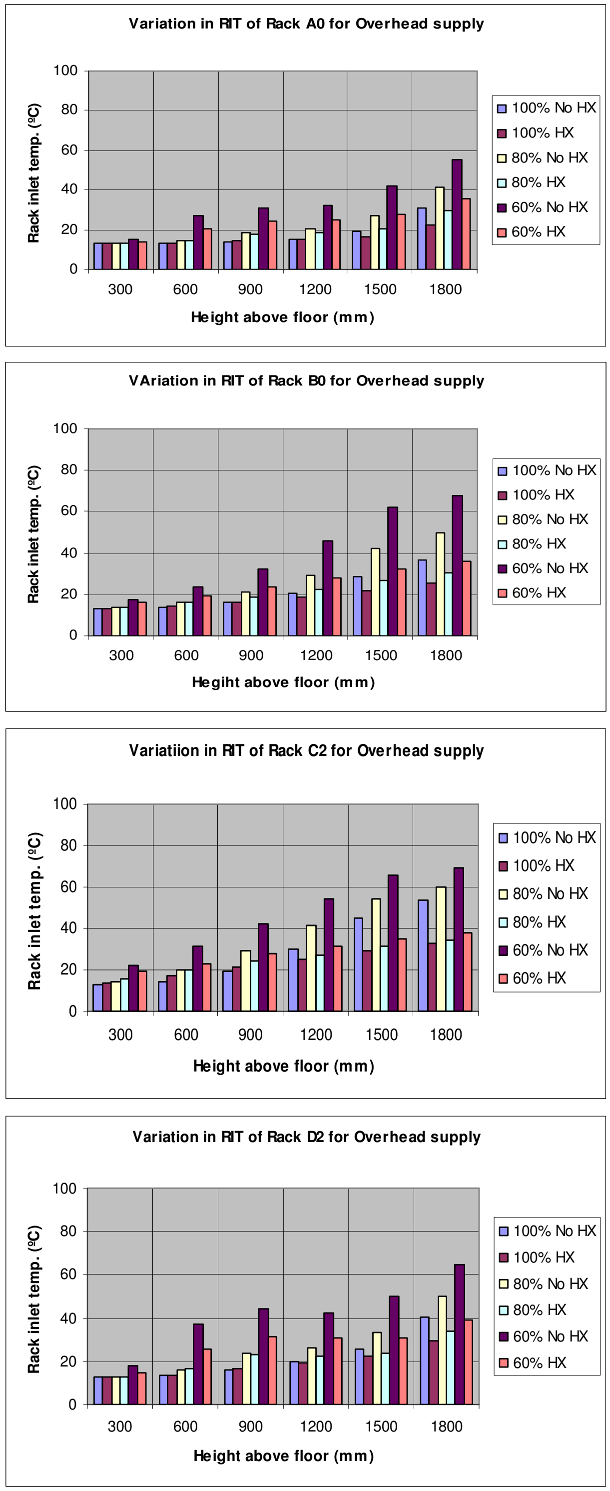

Figure 3.7: Rack Inlet Temperature Variation in Outer Racks (A0, B0, C2, D2) for various cases of Overhead Supply.

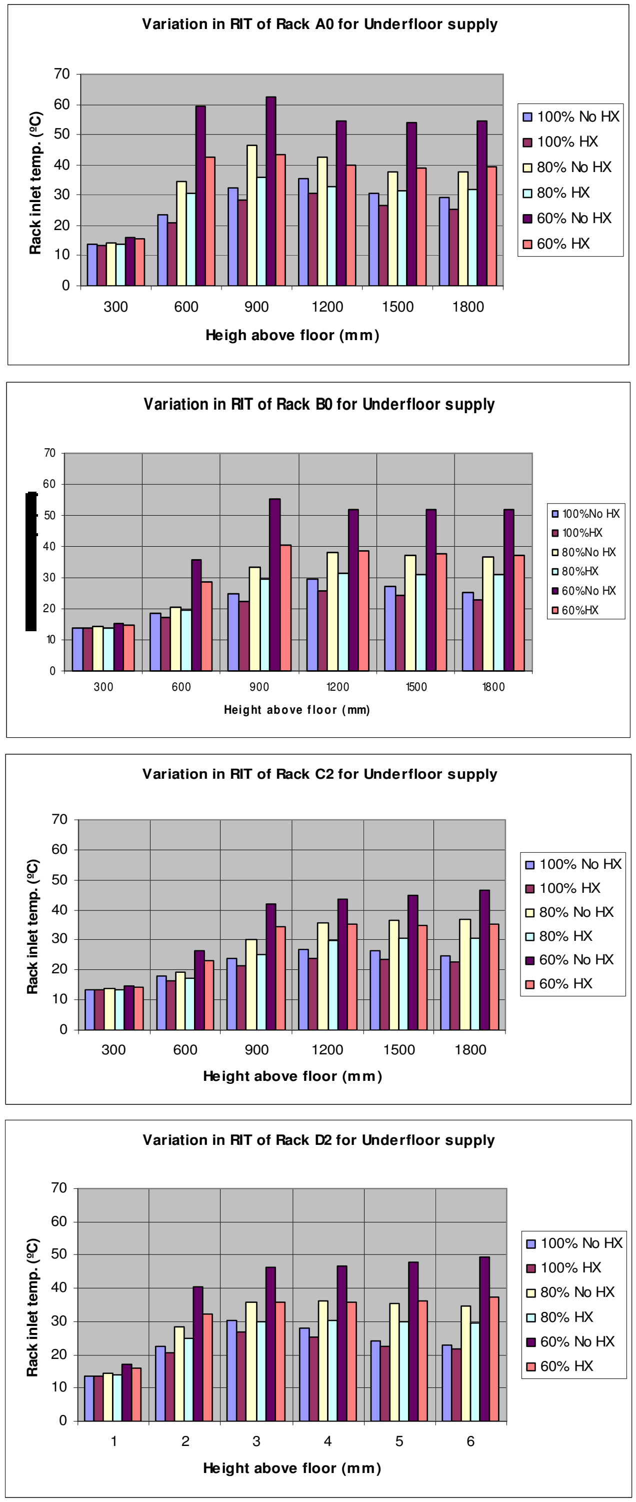

Figure 3.8: Rack Inlet Temperature Variation in Outer Racks (A0, B0, C2, D2) for various cases of Underfloor Supply.

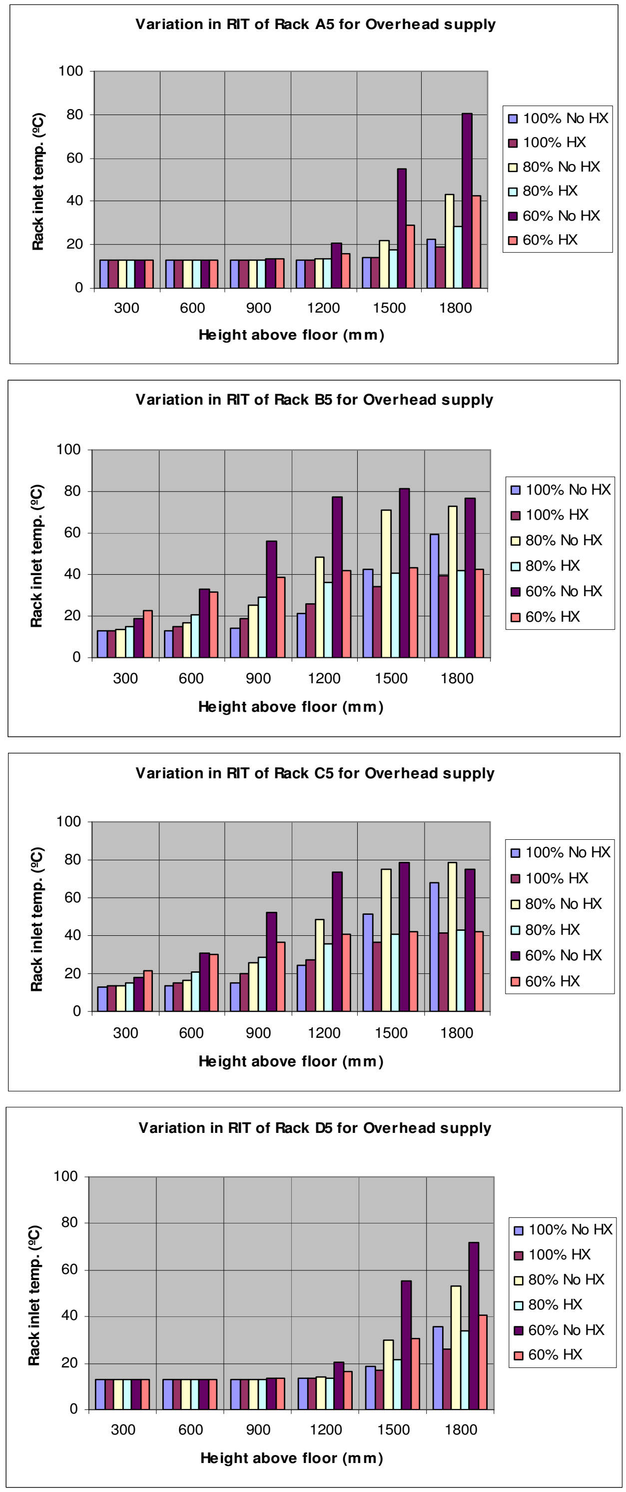

Figure 3.9: Rack Inlet Temperature Variation in Inner Racks (A5, B5, C5, D5) for various cases of Overhead Supply.

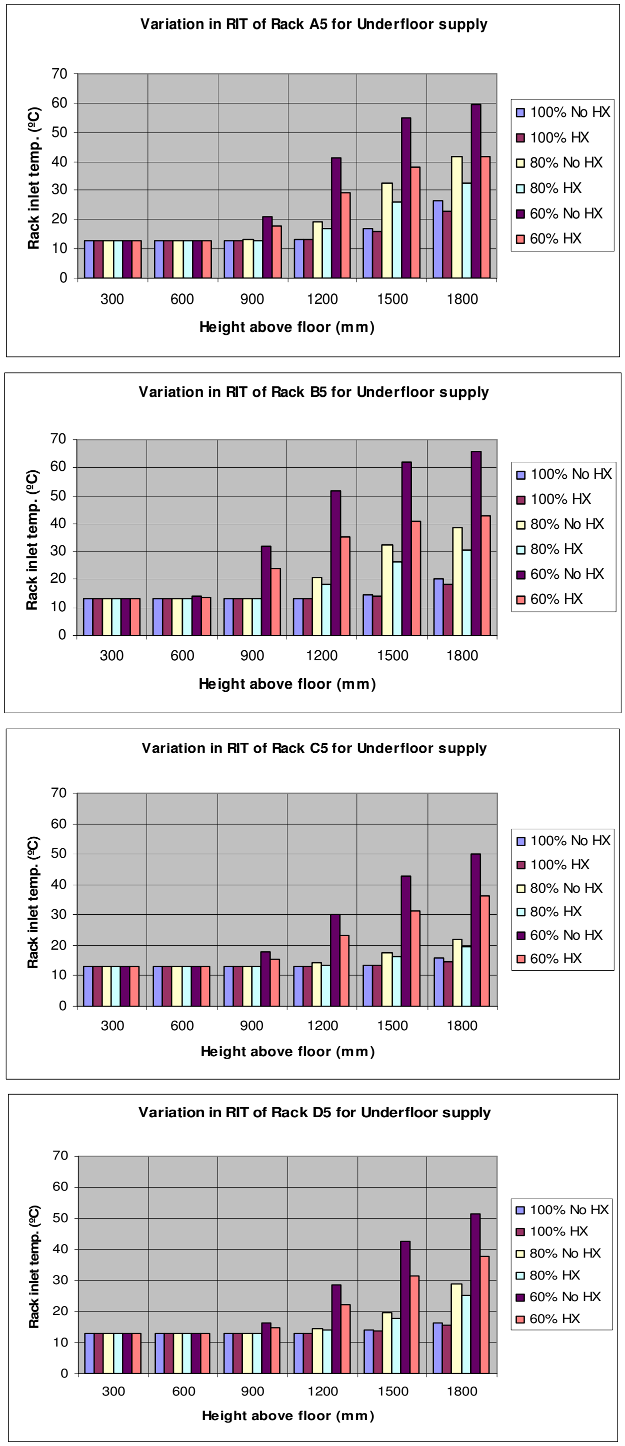

Figure 3.10: Rack Inlet Temperature Variation in Inner Racks (A5, B5, C5, D5) for various cases of Underfloor Supply.

3.9 Discussion

For all cases, large temperature gradients exist at outside racks. Severe recirculation pattern is observed at outside racks as hot air exiting into hot aisle is drawn into cold aisle from the side as well as from top of the racks. For inner racks, although hot and cold air mixing is present, it is less than the outside racks as the air is only drawn from top. This can be confirmed from the graphs as we can see for the outer racks, rack inlet temperatures even at lower heights from floor are high whereas for inner racks, only at higher heights from floor are the rack inlet temperatures higher.

Supply airflow equals demand only for the case with 100% air supply from the tiles. For the 80% and 60% cases, the rack flow rate is more than the perforated tile chilled-air supply. So in the 60% and 80% cases, some of the air leaving the tiles goes directly into the rack, and some of it mixes with the room air and is then pulled into the racks.

The air supply from tiles for three cases each for the Underfloor and Overhead supply configurations are 100%, 80%, and 60%, respectively. Some of the air from these end racks bypasses the rack, but there is no way to measure how much air "short-circuits" to the CRAC units. This is seen as higher temperature values for the intake of air in front of the racks.

In some cases blocking the cold aisle entrance can help, especially at the outside racks. However, if the supply is less than the rack flow, the racks will feed themselves with air from somewhere. So sealing the entrance, the air will probably be pulled from above or from the rear. For 100% supply, sealing the cold aisle completely (top and sides) so that there is no infiltration of hot air from outside the aisle volume. However, many server racks need in excess of 2000 cfm and sometimes more than 3000 cfm. It is very difficult to provide 100% airflow to such a cluster in a high-density configuration. A fairly open tile can only supply 500-800 cfm may be a bit more in exceptional cases. So, each rack will need three to five tiles to satisfy its airflow and not get starved (with total sealing). This will then drive wider cold aisles and compromise density. This is not necessarily a bad thing, but it can be contrary to how some data centers are optimized, especially if floor space is expensive.

From figure 3.5, we can see that the temperature profiles follow certain pattern for rows B and C. For rows A and D, entirely different pattern can be seen. From the data, it can be said that in Overhead supply configuration, inside racks display higher rack inlet temperatures than the outside racks. Further, as the rows B and C are arranged in such a way that they share a hot aisle, these two rows display higher temperatures than other rows. This could also explain the reason behind two distinct patterns for temperature profiles.

Unlike Overhead supply, the temperature profiles for all the rows in Underfloor configuration are fairly similar. As indicated by figure 3.6, the outer racks indicate higher rack inlet temperatures than the other racks. This is attributed to recirculation of hot air as discussed above.

From figure 3.7 – 3.8 and figure 3.9 – 3.10, it can be concluded that Overhead supply configuration tends to be more effective for lower supply fraction whereas at higher fractions, the Underfloor supply is promising. But use of hybrid cooling solution can make Overhead supply configuration comparable to Underfloor supply even at higher fractions.

CHAPTER 4

IMPACT OF HYBRID SOLUTIONS

In air-cooled racks, with airflow nominally front-to-back, the chilled-air supply, whether from a raised-floor tile or via diffusers from the ceiling, is typically only a fraction of the rack airflow rate. This is due to the limitation of tile or diffuser flow rate. The remaining fraction of the supply-side air is made up by ambient room air through recirculation. This recirculating flow is often extremely complex in nature and can lead to rack inlet temperatures that are significantly higher than expected. There is significant recirculation of hot exhaust air, which can be detrimental to the performance and reliability of computer equipment. Elimination of this recirculation with barriers above the datacom racks is typically not a viable alternative because of fire code restrictions. Data processing equipment is typically designed to operate for rack air inlet temperatures in the 10°C to 35°C range. Because of recirculation, there could be a wide range of inlet air temperatures across the rack. For a raised-floor layout, the inlet air temperature can range from 10°C–15°C at the bottom of the rack close to the chilled air supply to as much as 30°C–40°C at the top end of the rack, where the hot air can form a self-heating recirculation loop. Since the rack heat load will be limited by the rack inlet air temperature at the “hot” part, this temperature distribution correlates to inefficient utilization of available chilled air. Also, since data center equipment almost always represents a large capital investment, it is of paramount importance from a product reliability, performance, and customer satisfaction standpoint that the temperature of the inlet air to a rack be within the desirable range. The efficient cooling of such computer systems and the amelioration of localized recirculation currents of hot air returned to the rack constitute a focus item.

The temperature variation at outside and inside racks is presented in figure 3.7 – 3.8 and 3.9 – 3.10. As evident from figure 3.5 – 3.10, severe recirculation exists at outside racks which results in ambient mixing causing high inlet temperatures.

These outside racks therefore become prime target for employment of hybrid cooling solution, that is air cooling assisted by liquid cooling. From graphs it is clear that significant temperature reduction occurs at number of monitor points. Reduction at outer racks is mostly prominent than the reduction at inner racks.

4.1 Impact of Hybrid Solution on data center with Underfloor supply

The impact of hybrid solution in Underfloor supply configuration is summarized in figure 4.1 for different air supply fractions. For 60% air supply case, the heat exchanger removes 55% of the total 32KW heat while reducing the rack inlet temperature by 18.7°C. For the cases of 80% and 100% supply, the heat removal is 43% and 38% respectively and the maximum reduction in rack inlet temperature 8.3°C and 7.3°C respectively.

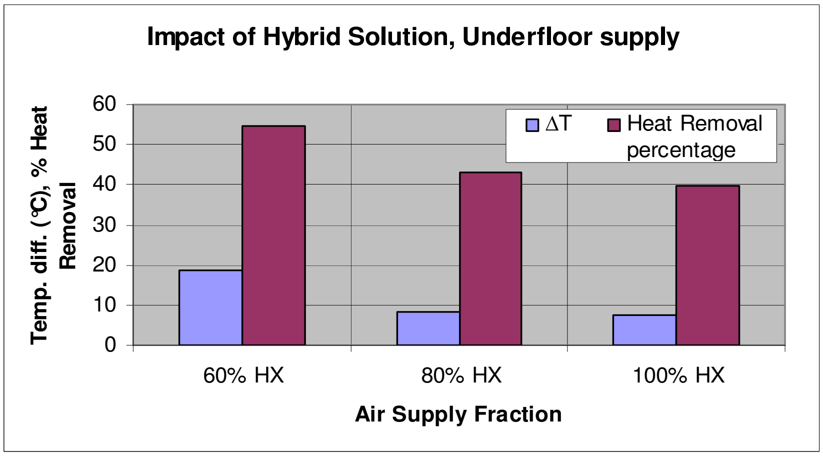

Figure 4.1: Impact of Hybrid Solution on data center with Underfloor supply.

4.2 Impact of Hybrid Solution on data center with Overhead supply

Figure 4.2 indicates the impact of hybrid solution in case of Overhead supply. For Overhead with 60% air supply case the heat exchanger removes 35% of the total 32 kW heat while reducing maximum rack inlet temperature by 20 °C. For the cases of 80% and 100% supply, the heat removal is 36% and 38% respectively and the maximum reduction in temperature is 30.3 °C and 38 °C. The heat removal and reduction in maximum rack inlet temperature reduces with reduction in air flow supply.

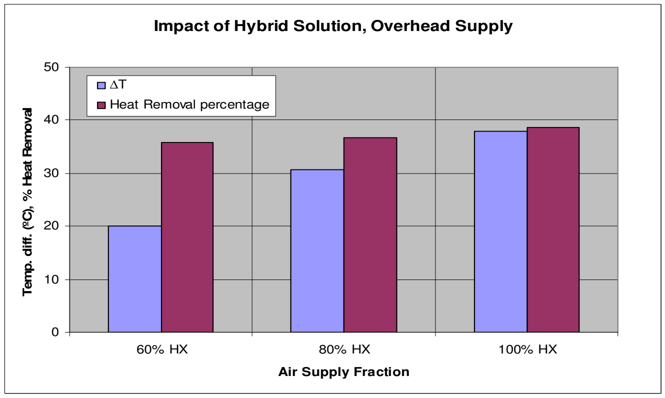

Figure 4.2: Impact of Hybrid Solution on data center with Overhead supply.

4.3 Return Air Temperature

Another metric to determine the effectiveness of this solution is temperature of air returning to CRAC units.

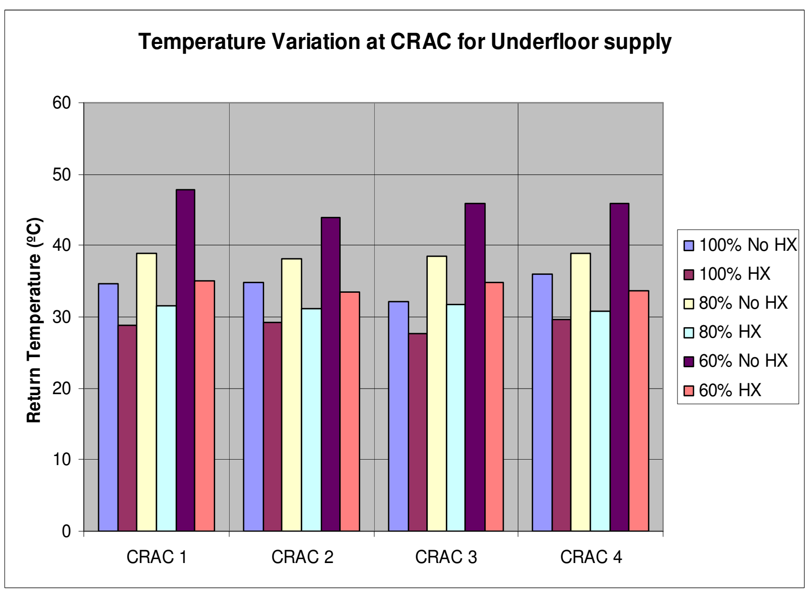

Figure 4.3: Return Air Temperature Variation for Underfloor Supply.

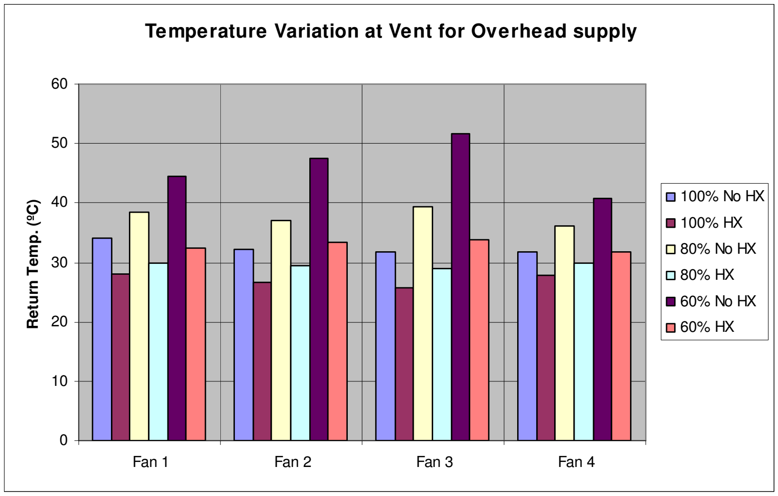

Figure 4.4: Return Air Temperature Variation for Overhead Supply.

It can be seen from figure 4.3 and 4.4, that hybrid solution help reducing overall maximum temperature and hence the temperature of air returning to CRAC intake. It can be argued that if designed for 100% air, then hybrid solutions may not be required or beneficial. This requires a thorough analysis involving total cost of ownership (TCO). The reader is directed to work of Schmidt and others [13], where authors have described the solution hardware in detail. They have presented test results showing significant heat removal from the rack and reduction in inlet temperature due to rear door heat exchangers. A CFD modeling results are shown. A TCO comparison is presented which showed significant cost advantage for hybrid solution.

4.4 Conclusion

Two dominant air supply configurations employed by industry are discussed with hybrid cooling strategy. Representative data center is modeled using commercially available CFD code. The change in rack inlet temperatures, recirculation, the impact of hybrid cooling on rack inlet temperature and return air temperature is discussed. A qualitative assessment shows that the hybrid cooling strategy aides the improvement in data center thermal management. The Overhead supply configuration seems to be effective at lower supply fractions. The Underfloor supply configuration with hybrid cooling shows significant heat removal.

APPENDIX A

LIST OF VARIABLES USED IN THIS METHODOLOGY

CFD: Computational Fluid Dynamics

CRAC: Computer Room Air Conditioning

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

IBM: International Business Machines

IT: Information Technology

A/C: Air Conditioner

PDC: Private Data Centers

IDC: Internet Data Centers

HVAC: High-voltage alternating current

cfm: Cubic feet per minute

CAE: Computer-aided engineering

IGES: Initial Graphics Exchange Specification

CAD: Computer-aided design

IDF: Intermediate data format

PCB: Printed Circuit Board

JEDEC: Joint Electron Device Engineering Council

PC: Personal Computer

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Ravi Udakeri did his undergraduate degree in Mechanical Engineering from Visveshwaraiah Technological University – Karnataka, India. He enrolled in University of Texas at Arlington in the program of Master of Science in Mechanical Engineering in Fall 2006. His major area of interest was Thermal Engineering. He joined the Electronics, MEMS and Nanoelectronics Systems Packaging Center and received his Master of Science degree in Mechanical Engineering in August 2008.