EVALUATION OF COOLING ARCHITECTURES AND CONTROL STRATEGIES IN AIRFLOW PROVISIONING A MODULAR DATA CENTER

by

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Abstract

EVALUATION OF COOLING ARCHITECTURES AND CONTROL STRATEGIES IN AIRFLOW PROVISIONING A MODULAR DATA CENTER

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To achieve energy efficiency and reduce operational costs in data centers with modularized Information Technology and cooling infrastructure there is an ongoing trend to minimize the use of mechanical cooling and instead use outdoor air in favorable environmental conditions for cooling purposes. The cooling module can comprise of evaporative cooling systems which use direct, indirect or a combination of direct/indirect evaporative cooling units to provide adequate cooling. The degree of cooling achieved in the IT module depends on the effective airflow provisioned and the air distribution methods employed.

In this study, a modular data center which is equipped with a direct/indirect evaporative cooling unit is considered. The IT module consists of a row of four 42U racks populated with 1U web servers. The conditioned air is supplied through a ducted vent flooding into the cold aisle and the return hot air is exhausted out when not necessary and utilized for mixing purposes otherwise when operating in economizer mode.

Commercial CFD tool- 6SigmaRoom is used to develop a CFD model of modular data center and validated with existing research facility in Dallas, TX. To ensure adequate airflow provisioning, a comparison of temperature-based and pressure differential based measurements in IT module is carried out to control the supply fans in the cooling module. Also, different cooling architectures are studied to determine the impact on thermal performance and efficiency of the cooling solution. The results shall be used to optimize the air distribution on existing research data center facility.

Table of Contents

List of Illustrations

Nomenclature

CRAC	Computer Room Air Cooling
CA	Cold Aisle
HA	Hot Aisle
ASE	Air Side Economization
I/DEC	Indirect and Direct Evaporative Cooling
CFD	Computational Fluid Dynamics
CAC	Cold Aisle Containment
HAC	Hot Aisle Containment

Chapter 1

Introduction

Data Center and Its uses

Increasing use of electronic transactions, Internet-based communication and entertainment such as audio-video streaming, satellite navigation results in increasing demand for data processing and storage. Government and industrial sectors are also seeking for very large data storage, processing. Data Centers are infrastructure facilities to house computers, servers and networking system equipment which typically involves storing, processing and serving a large amount of data.

Data centers are equipped with power conversion and backup equipment to maintain reliable power supply and cooling facilities to maintain proper temperature and humidity conditions within the data center. Within the last two decades the amount of digital data generated, stored and transmitted has greatly increased due to the rapid evolution of IT and telecommunication products and technologies. In 2011, IDC [1] reported that the zettabyte barrier was surpassed in 2010 and estimated that the amount of information created and replicated will surpass 1.8 zettabytes (1.8 trillion gigabytes) in 2011 a nine-fold increase in just five years. The size of the digital world is predicted to increase by a factor of 44 by 2020 [2].

Figure 1. Data Center Facility [27]

Modular Data Center

A modular data center system is an alternate way to construct the traditional data center in a portable way. Modular data center systems can offer scalable data center capacity with multiple power and cooling options. The modular data center can be shipped anywhere in the world to be added, integrated or retrofitted into the customer’s existing data center footprint. Modular data centers can be the best solution for energy efficiency, reduction in both cost and development time.

Figure 2. IBM Modular Data Center [3]

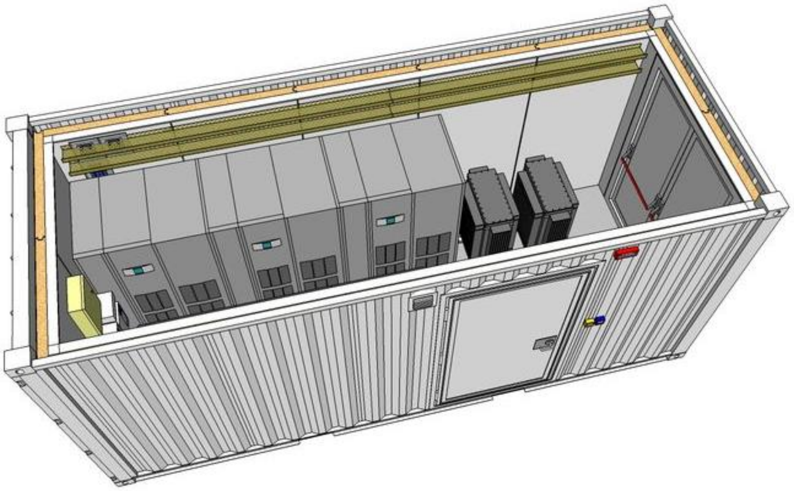

Figure 3. Modular Data Center [4]

Data Center Energy Consumption and Energy Breakdown

According to report released by the United States Environmental Protection Agency (EPA), in 2006, data centers in the United States consumed about 61 billion kWh which equals to 1.5% of total US electricity consumption [5]. Electricity used in 2010 by global data centers was estimated to be between 1.1% and 1.5% of total electricity use and for the US this number was between 1.7% and 2.2% [6]. This energy consumption is estimated to increase up to 140 billion kWh by 2020 [7].Total power supplied to the data center is consumed to power all the Information technology equipment for computing services and to operate the cooling system in order to remove the heat generated by IT equipment. In addition data center uses power for power delivery infrastructures such as UPS and other lighting purposes. The breakdown of power usage in a data center and cooling system is illustrated in Figure 3 and Figure 4.

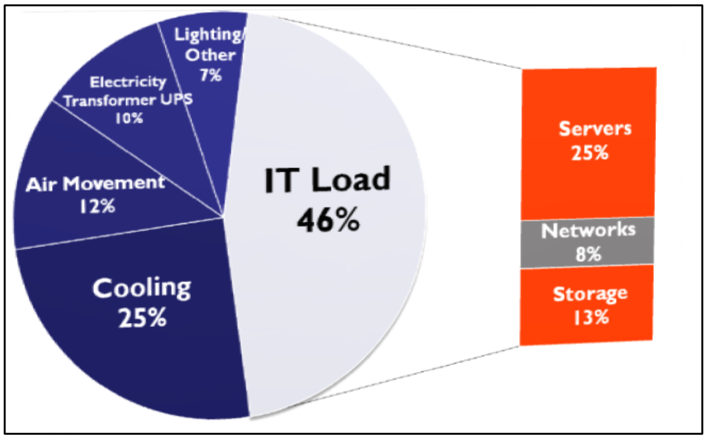

Figure 4. Energy Breakdown of Data Center [8]

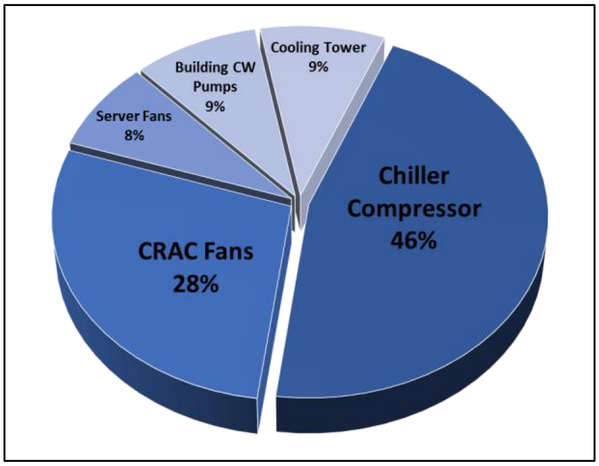

Figure 5.Energy Breakdown of cooling system

Major power consumers are CRAC fans (28%), chiller compressor (46%). To achieve energy efficiency and reduce operational costs there is an ongoing trend to use air–side economization (ASE commonly referred as free cooling) partially or completely in favorable environmental conditions by avoiding the use of mechanical cooling. In ASE cold air from the environment is directly supplied to the data center after filtration of particulate and gaseous contaminants. Use of ASE results in significant reduction of power consumption as compared to compressor based cooling system. The cooling module also uses direct-indirect evaporative cooling systems to provide adequate cooling in more efficient way.

Importance of Data Center Cooling and Airflow Management

The electrical power consumed by IT equipment is converted entirely into heat results in an increase of equipment temperature. The advancement of latest technologies and the miniaturization of electronic components resulted in high power dissipation in electronic equipment. The performance of equipment degrades at high temperature, for the reliable operation temperature of electronic equipment needs to be maintained at acceptable value. In today's computing environment 12 kW of power generation per rack is common. Large scale data centers can have hundreds of such rack which generates a tremendous amount of heat. Current trends show that data center cooling demand increased more in last five years than last 35 years [9].

Air-cooling is widely used cooling approach in data center industries. In air cooled method cold air is supplied to a data center by various airflow provisioning methods. The supplied cold air acts as an immediate heat sink for the heat produced by the rack units. Only provisioning of supply air to meet the heat load is not feasible from an economical and environmental perspective. Airflow distribution and thermal management play a vital role in efficient operation of the data center. Poor airflow management leads to serious problems like premature server failure, poor reliability and increase in operating cost.

According to a number of studies, if the infrastructure and cooling cost are included, operation cost of a $1,500 server over its lifetime is five times the cost of server [10].

Airflow Management Approaches

The degree of cooling achieved depends on the effective airflow provisioning and the distribution methods employed. Recent air cooling advancement includes three basic cooling options (a) room-based cooling, (b) row-based cooling and (c) rack-based cooling.

Room-Based Cooling: The CRAC units are associated with the room and operate to handle the total heat load of the room. Room-based cooling may consist of one or more CRAC units without any predefine air provisioning paths ducts, dampers, vents, etc. Sometimes in raised floor or overhead supply/return airflow provisioning the supply and/or return airflow can be partially constrained. The rroom level cooling significant fraction of the air from CRAC units bypass the IT loads and return directly to the CRAC. This bypass air represents CRAC airflow that is not assisting with cooling of the loads; which results in a decrease in overall cooling capacity.

Rack-Based Cooling: For row-based configuration, the CRAC units are associated with a row and operate to handle the heat load of a particular row. The CRAC units are located in between the IT racks or they may be mounted overhead. Compared with the traditional uncontained room-based cooling, all of the rated capacity of the CRAC can be utilized due to shorter and well-defined airflow path.

Rack-Based Cooling: With rack-based cooling, the CRAC units are associated with a rack which is dedicated to meet heat load of a rack. The CRAC units are directly mounted to or within the IT racks. Compared with room-based or row-based cooling, the rack-based airflow paths are even shorter and exactly defined. Different airflow provisioning approaches are shown in Figure 5.

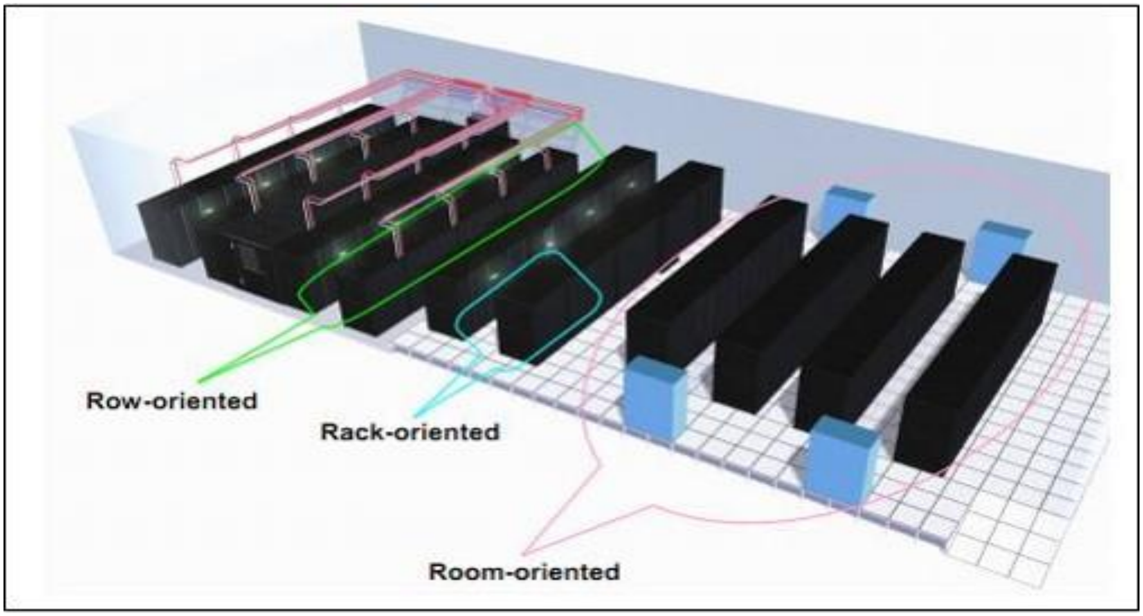

Figure 6. Data Center Airflow Provisioning Approaches [11]

This research presents optimization control strategies of airflow provisioning and comparison of various airflow provisioning methods for the modular data center. The computational fluid dynamics model was generated with rack units installed in the facility with emphasize on pressure distribution, airflow pattern, and rack inlet temperature. Study of the effect of different control strategies on server fan performance was carried out.

The candidate airflow provisioning configuration studied includes:

(1) Ducted supply and ducted outlet with containment (2) Raised floor with containment.

Different airflow control strategies considered for study:

(1) Fixed airflow and (2) Pressure differential (CA/HA Pressure differential) based control.

Chapter 2

Literature Review

Computational Fluid Dynamics

Flow nature inside the data center is always found to be complex due to the high flow rate of cooling air from the cooling unit which results in turbulent flow with large variability in flow velocity magnitude. This kind of complex flow inside the data center required computational fluid dynamics (CFD) and heat transfer to investigate thermal performance of data center. There are several commercially available CFD which can efficiently solve the problem of data center thermal performance. These CFD codes solve incompressible Navier-Stokes equation with k-∊ turbulence model and energy equation to compute flow and temperature distribution within the data center. The governing equations for the incompressible Newtonian fluid with constant thermal conductivity, k, are provided below [12].

Conservation of mass:

$$\boldsymbol{\nabla} \bullet \vec{V} = 0 \tag{1}$$

Conservation of linear momentum (NS Equation):

Where ν is the constant kinematic viscosity.

$$\frac{\partial \vec{V}}{\partial t} + \left(\vec{V}.\nabla\right)\vec{V} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\vec{V} + \vec{f} \tag{2}$$

Conservation of energy:

$$\rho c_p[\frac{\partial e}{\partial t} + \left(\vec{V}.\nabla\right)T] = k\nabla^2 T + \phi \tag{3}$$

Where C_p is specific heat, ϕ is the dissipation function representing the work done against viscous forces, which is irreversibly converted into internal energy. It is defined as $\phi = (\bar{\bar{\bar{\tau}}}.\nabla)\vec{V} = \tau_{ij}\frac{\partial v_i}{\partial x_j}$

The k-ε model

The k-ε model is the most common turbulence model in numerical modeling of data center due to its low computational expenses and better numerical stability. Turbulent viscosity is given by $\mu_t == \rho C_\mu \frac{k^2}{\varepsilon}$ where C_μ is a constant, k is the turbulence kinetic energy, and ε is its rate of dissipation. The parameters k and ε are obtained by solving two additional differential equations; for complete details, see Launder and Spalding (1974) [13].

Fan Affinity Laws

Change in fan speed (RPM) alters the air flowrate, static pressure rise, power necessary to operate at new speed.

1st law

$$Q_{N2} = Q_{N1}(\frac{N_2}{N_1}) \tag{4}$$

Where, N_1 and N_2 are fan speed (RPM), Q_{N1} and Q_{N2} are airflow rates corresponding to speed N_1 and N_2 respectively.

2nd law

$$\Delta P_{N2} = \Delta P_{N1}(\frac{N_2}{N_1})^2 \tag{5}$$

Where, N_1 and N_2 are fan speed (RPM), ΔP_{N1} and ΔP_{N2} are static pressure rise across the fan corresponding to speed N_1 and N_2 respectively.

3rd law

$$W_{N2} = W_{N1}(\frac{N_2}{N_1})^3 \tag{6}$$

Where, N_1 and N_2 are fan speed (RPM), W_{N1} and W_{N2} are fan power corresponding to speed N_1 and N_2 respectively.

Multiple fans system

Fans in series: "n" fans in series will increase pressure "n" times at a given flow rate, with no additional free delivery flow.

Fans in parallel: "n" fans in parallel will increase flow "n" times at a given pressure level, with no additional shutoff pressure generated.

$$\dot{V}_n = \dot{V}_1 \times n \tag{7}$$

Where, $\dot{V}_1$ is airflow rate of a single fan unit, n is number of fans within the system

Chapter 3.

Modular Data Center Modeling Approach

Existing Research Modular Data Center

To study efficient cooling approaches like Air-side economization, Direct and Indirect Evaporative cooling and effect of gaseous and particulate contamination, a modular data center has been built at Mestek Inc. Dallas, Texas. This data center is shown in Figure 6 and Figure 7. The schematic of IT pod is shown in Figure 9. IT pod is configured in a cold aisle (CA) / hot aisle (HA) configuration and contain four 42U Panduit P/N S6212BP cabinets. The cabinets contains total 120 HP SE1102 servers. Cold air from a cooling unit, Aztec Sensible Cooling Model ASC-15-2A11-00, is delivered to the cold aisle through a supply duct. Supply duct has inlet vent at one end which is configured with 45^o angled louvers to guide the airflow inside CA. Hot air from the hot aisle is being supplied to the cooling unit while return cycle is in operation (DEC and IEC) or exhausted to the ambient (ASE). The return duct has pressure relief dampers for pressure control. Description of the cooling unit’s construction can be found in its technical guide [14].

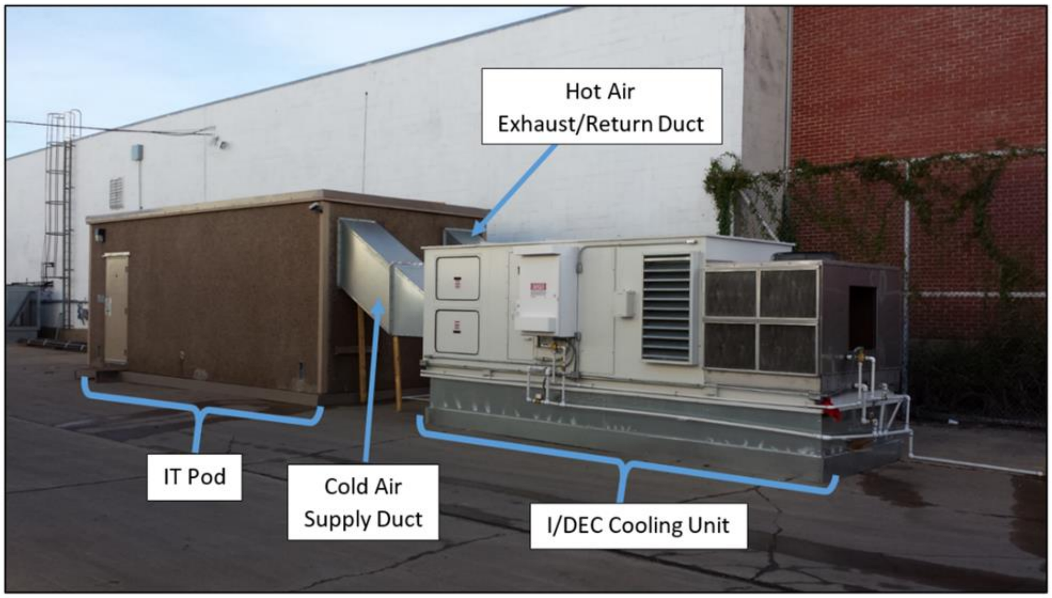

Figure 7. Research Modular Data Center [15]

Figure 8. Return Duct Arrangement of Modular Data Center [15]

Hot Aisle Hot Aisle Cold Aisle Cold Aisle

Figure 9. CA/HA Arrangement [16]

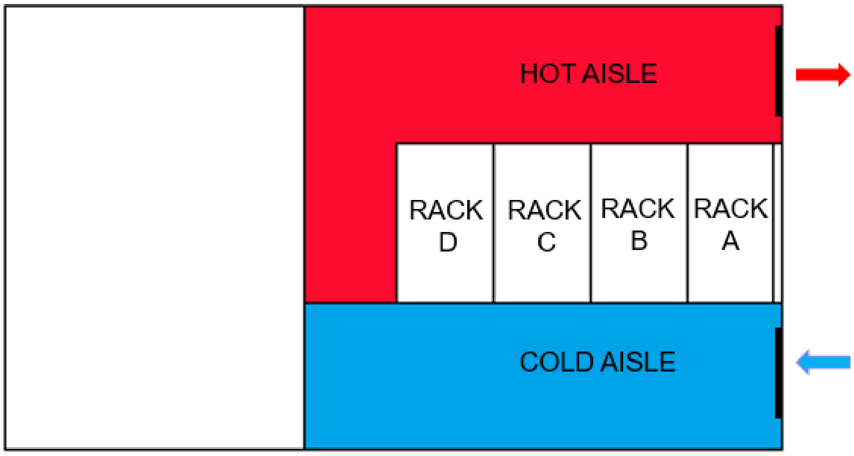

Figure 10. Schematic of IT pod

HP SE1120 Server Details

Internal details of the server are shown in Figure 10. Server contains a total of four Sunon PMD1204PJB-1 fans in parallel connection and one power supply fan. Details of the fan geometry and flow configuration can be found in manufacturer's manual [17]. Estimation of the power consumption and airflow requirement of the server is included in following sections.

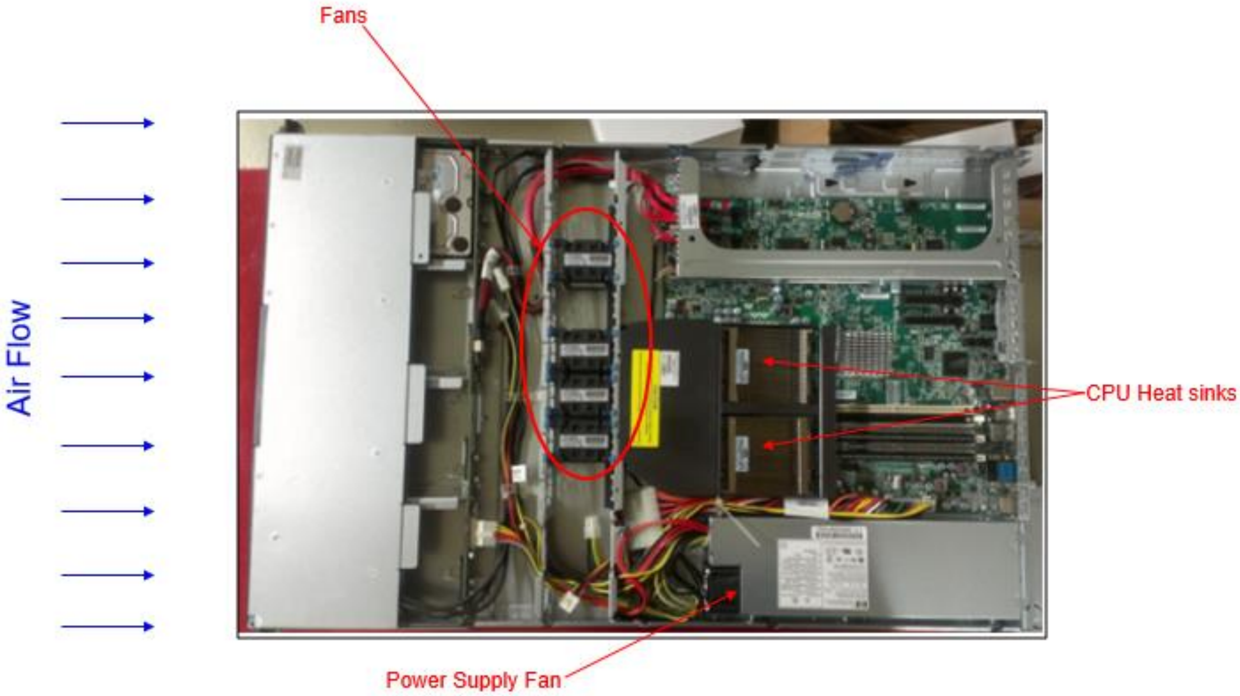

Figure 11. HP SE1102 Server

Power Estimation of HP SE1102 Server

B.Gebrehiwot [16] investigated estimated power consumption of HP SE1102 server using Lookbusy test and Prime 95 test. I have included results of the prime 95 test which provides a good estimation of power consumption. When the server is stressed using the Small FFTs setting, it draws about 180 W as shown in Figure 11 whereas when it's stressed using In-place large FFTs setting, it draws about 195 W as shown in Figure 12.

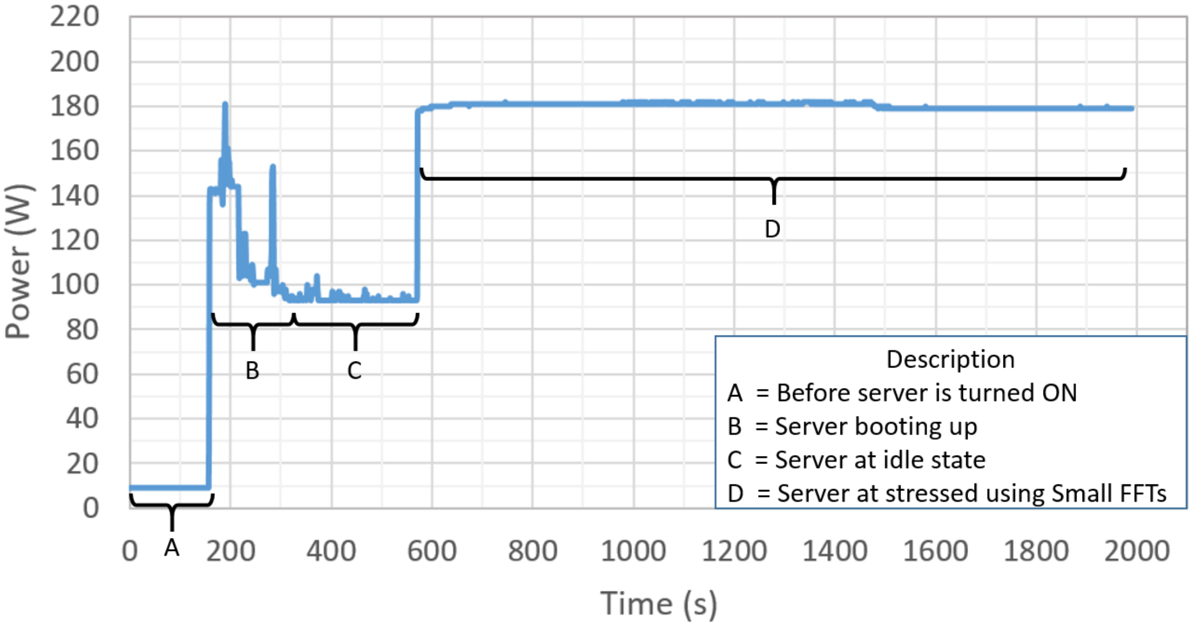

Figure 12.Server Power Estimation Result Prime95 Test (Small FFTs) [16]

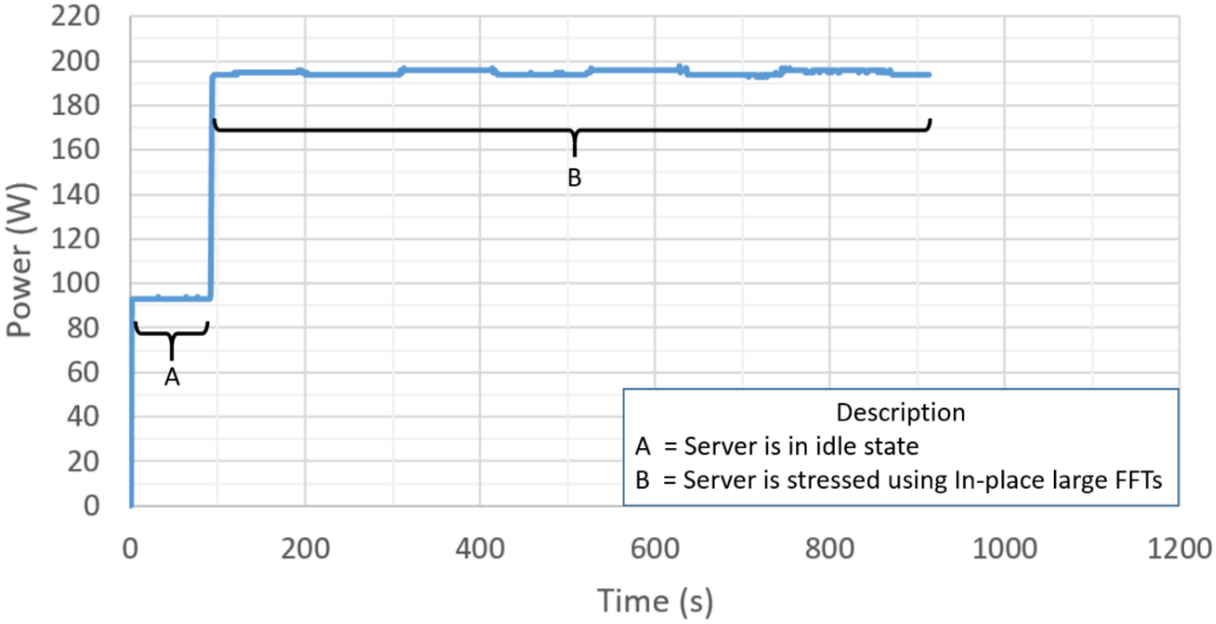

Figure 13. Server Power Estimation Result Prime95 Test (Large FFTs) [16]

IT pod Air Flow Requirement

<u>Airflow Calculation for Fixed Airflow Provisioning</u>

Airflow required by the IT pod was calculated using the relation between CFM and KW

$$CFM = \frac{Watts}{0.316 \times \Delta T} \tag{8}$$

Where, CFM (Cubic Feet per Minute) airflow rate, Watts= Total power of IT pod, ΔT= Temperature Difference across Rack in℉. For this study total power of IT pod was 24 KW, ΔT= 25℉ which results in 3037 CFM. This CFM value is considered for fixed airflow provisioning.

To estimate the airflow require by the server first fan manufacturer’s data [17] is considered. Using fan affinity laws discussed below, total airflow require for a single server is estimated to be 60 CFM for free air delivery (design) point. Single fan curve, server impedance curve, and total fan curve are shown in Figure 14.The fan curve indicated by 4048 is used for the study.

Figure 14. SUNON PMD1204PJB1-A fan performance curve [17]

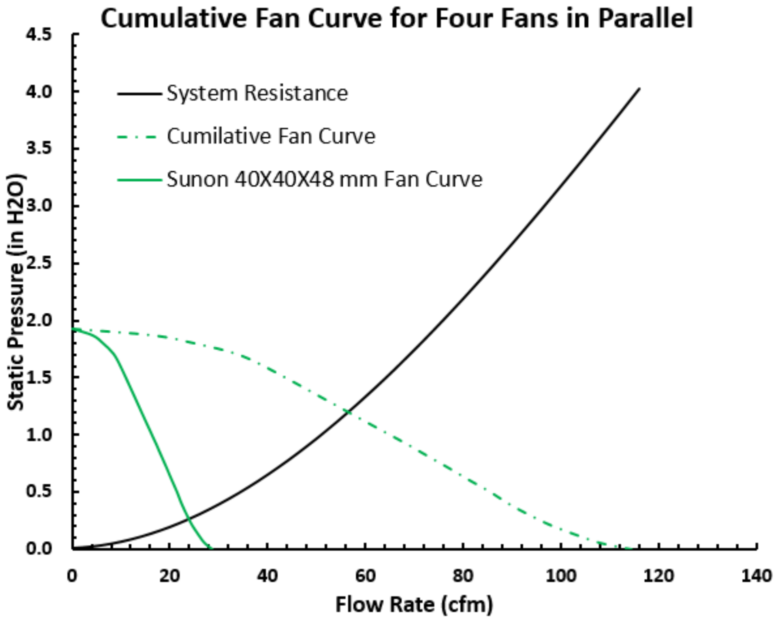

Figure 15. Cumulative Fan Curve for Four Fans in Parallel

Active Flow Curve Approach for Airflow Estimation

To estimate total airflow required for the IT pod, an HP SE1102 server is first tested on a 30-inch diameter airflow bench to find out how much airflow is required for its operation. Active flow curve methodology is used to obtain the flow curve as discussed in the literature. The server is mounted on the airflow bench as shown in Figure 16. General guidelines for setting up the airflow bench test and methodology to obtain active flow cure are followed as provided in [18].

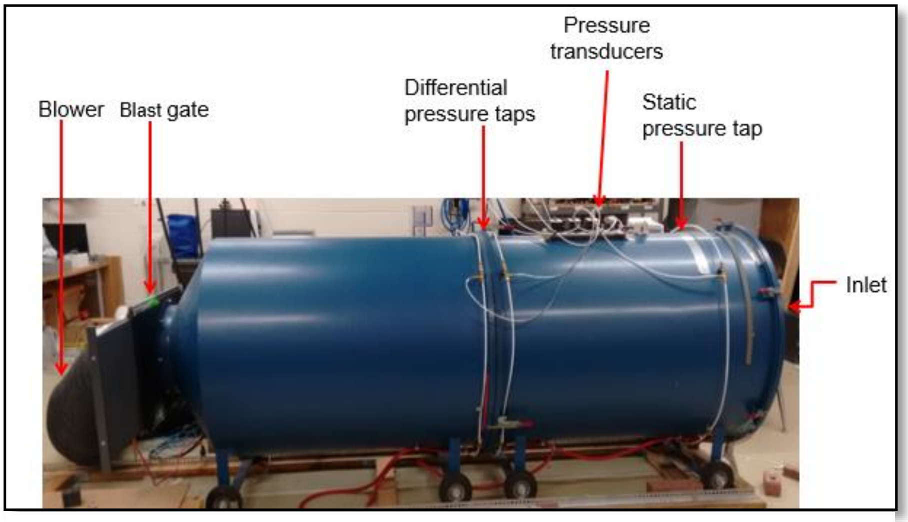

Figure 16.Airflow Bench with 30 Inch Dia.

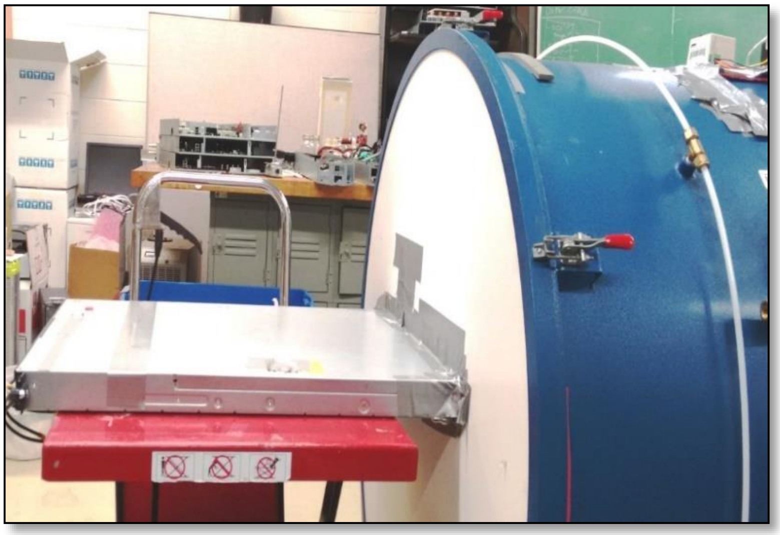

Figure 17. HP SE1102 Server Mounted on Airflow Bench

Experimental results and comparison with theoretical data are shown in Figure 17. Results from the test indicate that server required 36.5 CFM approx for free air delivery condition which was in very good agreement with the research carried out by A. Husam [19].

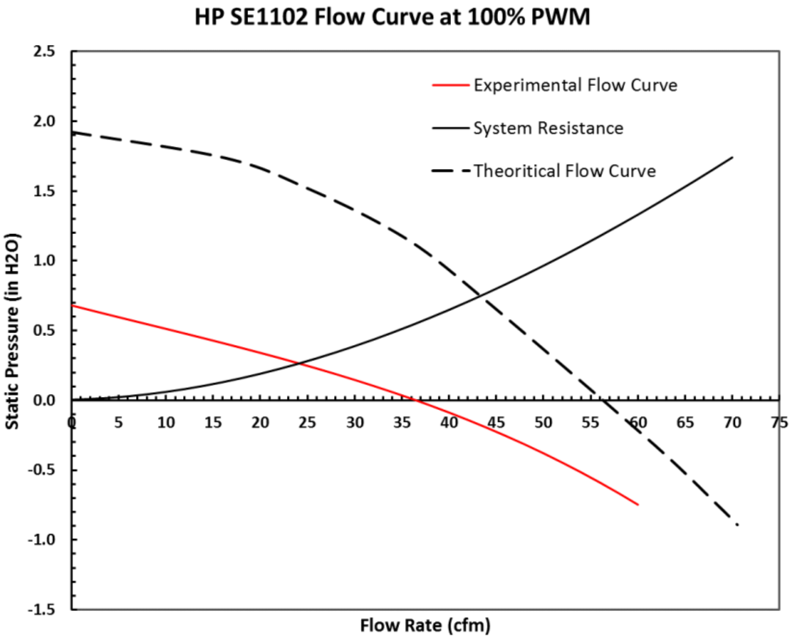

Figure 18.Active Flow Curve

For the 120 servers inside the IT pod, a minimum of 36.5 CFM x 120 server = 4380 CFM is needed. This calculation did not take into account the air flow requirement of additional IT equipment, such as switches, expected increase in airflow rate if inlet air temperature is at a higher temperature, or possible increase in the number of servers in the future.

CFD Model of Research Modular Data Center

Security and reliability concerns allow limited access to operating data center for thermal characterization and airflow behavior study. Large data center facilities exhibits constrain for temperature and pressure data measurement across the facility. Use of computational fluid dynamics and heat transfer is the most common approach to predict the airflow and temperature distribution inside the data center.6Sigma DC commercially available CFD code was used to develop a numerical model of research data center. The component of data center includes total 4 racks. Racks are populated with total 120 HP SE1102 servers, servers are mounted in similar pattern to existing stacking pattern in research data center. The effective active flow curve was obtained by mounting the server to airflow bench and varying the flow rate and pressure while the server fans were operating. CFD model of a modular data center is shown in Figure 18.

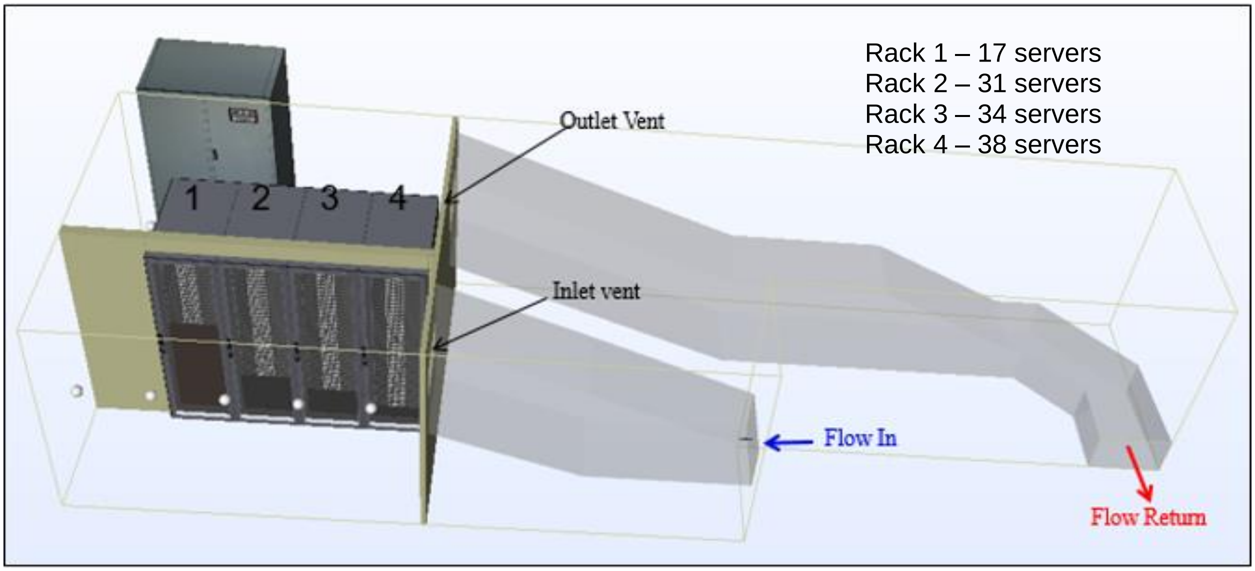

Figure 19. CFD Model of Modular Data Center

In actual data center facility airflow entering the CA at very high-velocity results in large amount of recirculation of airflow inside CA. Recirculation creates low-pressure area at the center of the circulation and makes it harder for server fans, which are close to the center of circulation, to draw in air. Another reason for maldistribution of air flow through the servers is that air enters the cold aisle at high speed and perpendicular to the direction of air intake to the servers. This kind of maldistribution further increases the difficulty in drawing air in. With an increase in IT load, the amount of volume flow rate that needs to leave from HA increases but due to insufficient outlet vent area airflow gets trapped inside HA which results in high pressure in HA.

CFD analysis is used to provide the prediction of the airflow distribution, pressure, and temperature distribution. Blanking panels were installed in racks in the absence of the server. Blanking panels were provided with 5% equally distributed leakage over the panel area to monitor the effect of negative pressure differential across the server rack. In pressure differential control configuration, a pressure controller is used to control the airflow rate of the CRAC upon satisfying the specific pressure differential. Five pressure sensors are placed in CA and HA each, the average of the sensor at each side is taken then the pressure differential is measured and checked to meet the set point criteria.

The pressure differential $\Delta P = P_{cold} - P_{Hot}$ .Pressure differential set point considered for the study was 0.04 in/H_2O (over provisioning).

Chapter 4

Results and Discussion

Fixed Airflow Provisioning

Pressure distribution plot for the fixed airflow provisioning is shown in Figure 19. As results indicate due to high pressure in HA and low pressure in CA, the pressure differential across the server racks is $-0.202\ in.\ H_2O$. Negative pressure differential causes entrainment of hot air from the HA to CA (backflow).

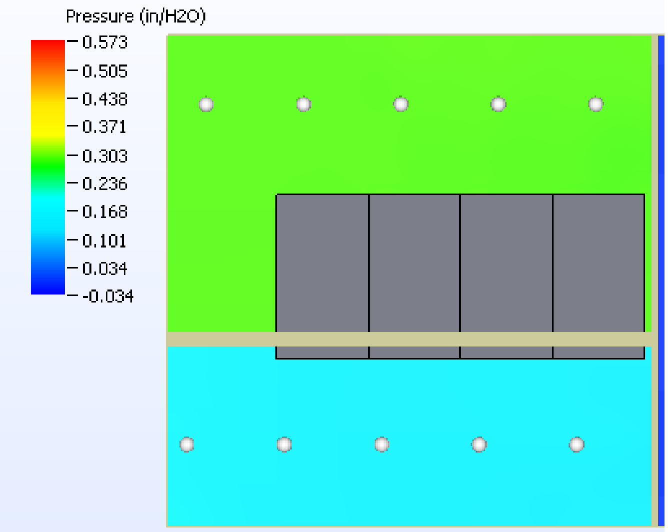

Figure 20. Pressure Distribution in CA-HA

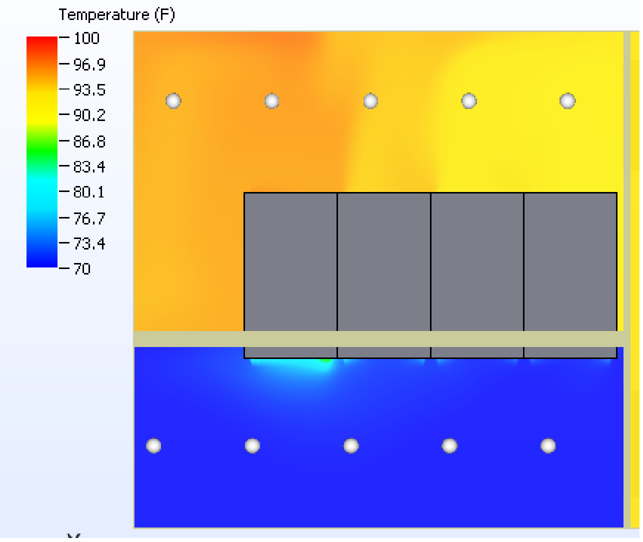

Figure 21. Temperature Distribution in CA-HA

Temperature distribution in CA-HA indicates that hot air from the HA gets mixed with cold air at the inlet of a server rack. Due to backflow, the temperature at the rack inlet increases which results in decrease in cooling capacity of the cold air. Temperature plot at the server inlet is shown in Figure 21 indicates some temperature hot spots at server inlet that may cause effects as drastic as a failure of the server component.

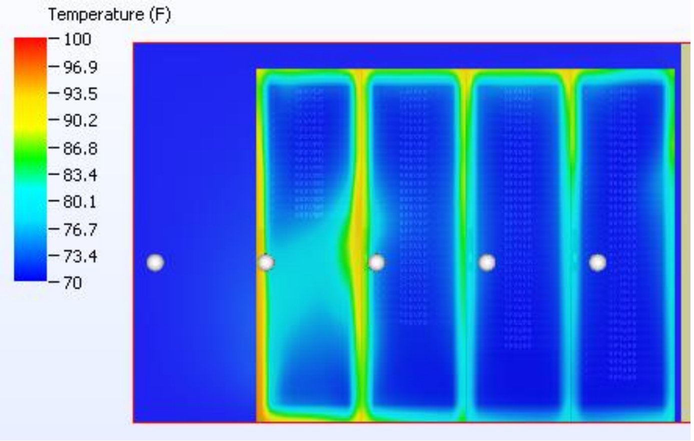

Figure 22. Temperature Distribution at Rack Inlet

To avoid the adverse effect of recirculation of hot air into cold aisle perfect containment of the CA and HA can be the solution. The temperature distribution plot at the inlet of the racks in for the perfectly contained CA and HA in Figure 22 indicates that there is no hot air mixing with cold air due to recirculation. In practical application perfect containment of the CA and HA is impossible to achieve because always there between racks, under racks, door seams and between blanking panel.

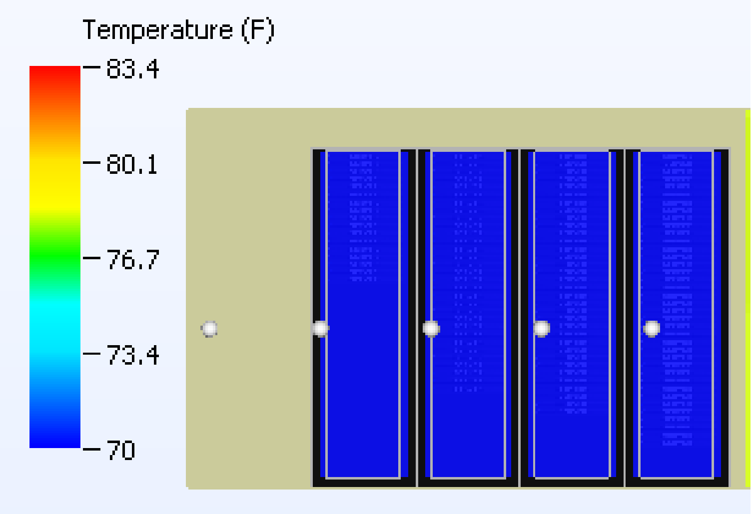

Figure 23. Temperature Distribution at Rack Inlet for Perfect Containment of CA-HA

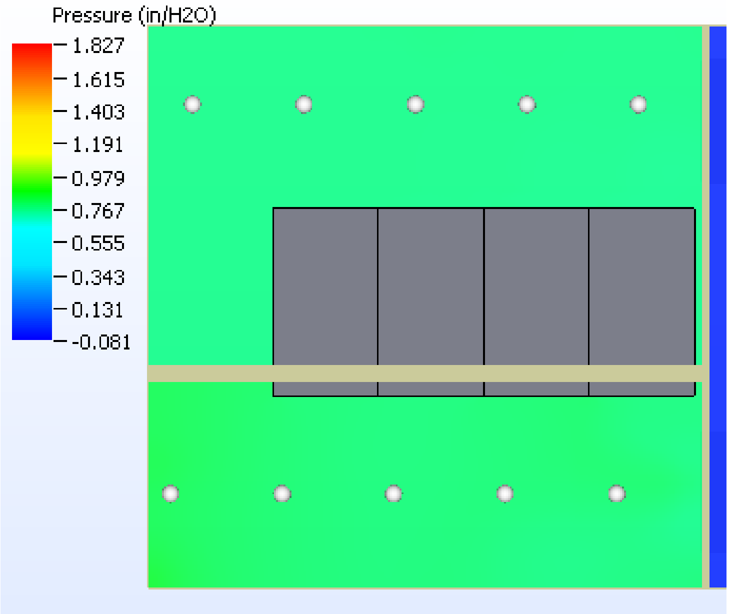

Figure 24. Pressure Distribution in CA-HA

Pressure distribution in CA and HA is shown in Figure 23 indicates that pressure differential across the server rack is at set point 0.04 in/H_2O. CFM required to obtain set point pressure differential was 4912 CFM. Temperature distribution in CA and HA as well as at inlet of server rack is shown in Figure 24 & 25.

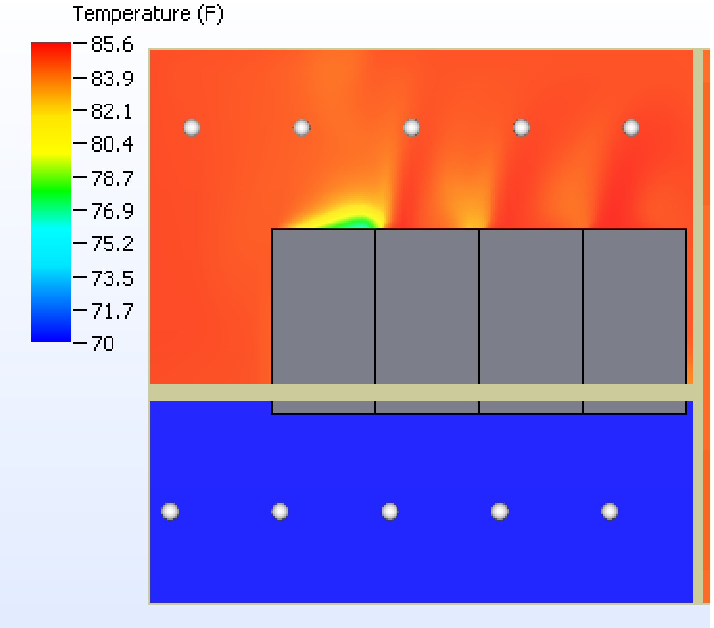

Figure 25. Temperature Distribution in CA-HA

Temperature distribution indicates that due to high pressure in cold aisle there is no back flow from the hot aisle. Even though backflow problem is solved, Figure 24 indicates that due to a positive pressure differential cold air from the CA is directly passed through the leakage and get mixed with hot air in HA which results in low-temperature CRAC return air. Low-temperature CRAC return airflow reduces CRAC unit efficiency. Iterative study to investigate the pressure differential set point to just remove the backflow effect can stop cold airflow mixing with hot air directly through leakage.

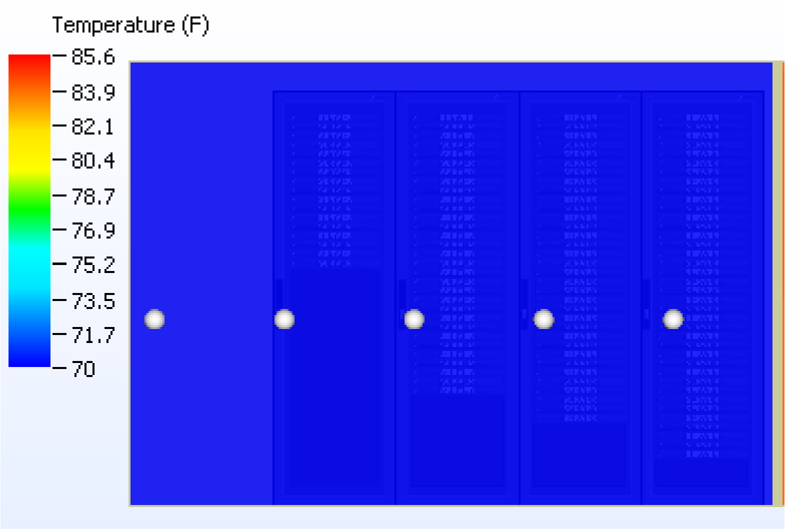

Figure 26.Temperature Distribution at Rack Inlet

Effect of Airflow Provisioning on Server Performance

To understand the effects of different control strategies airflow provisioning on server performance and impact on total energy consumption three servers from the each rack was monitored for this comparative study. From each rack top, middle and lower most server was taken under consideration. In CFD study equipment inlet temperature and airflow rate of server fans were consider as monitor criteria and measured for both fixed airflow provisioning method as well as provisioning method to maintain positive pressure gradient across the racks.

Effect on Equipment Inlet Temperature

Equipment inlet temperature results are shown as a chart form in Figure 26 and Figure 27. Equipment inlet temperature is most likely to rise due to backflow effect. Hot air penetration into the cold aisle plays a significant impact on inlet temperature. At top of the rack due to the presence of the gap and at bottom of the rack due to blanking panel leakage backflow is most likely to take place. A temperature rise of the equipment is a result of backflow which leads to high-temperature value of top and bottom server as compared to middle one. On the other hand equipment temperature for overprovisioned pressure differential control airflow provisioning falls under the acceptable range of ASHRE 2011 compliance [22] and uniform over the rack.

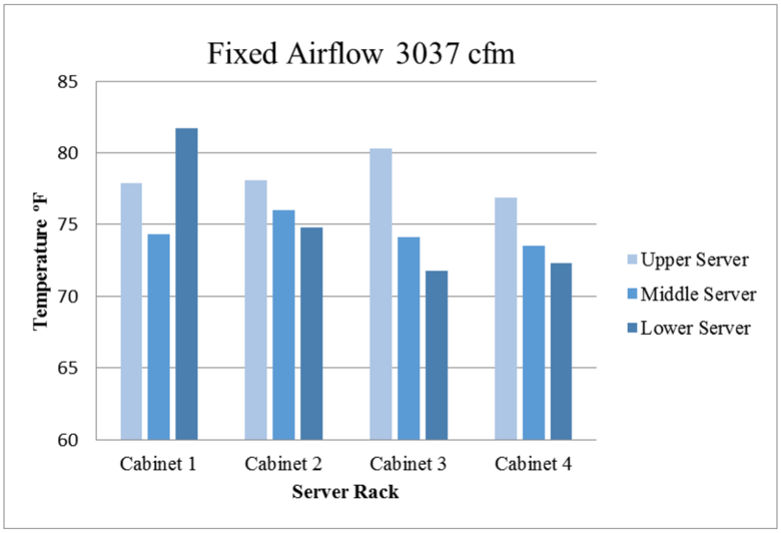

Figure 27.Equipment Temperature for Fixed Flow Provisioning

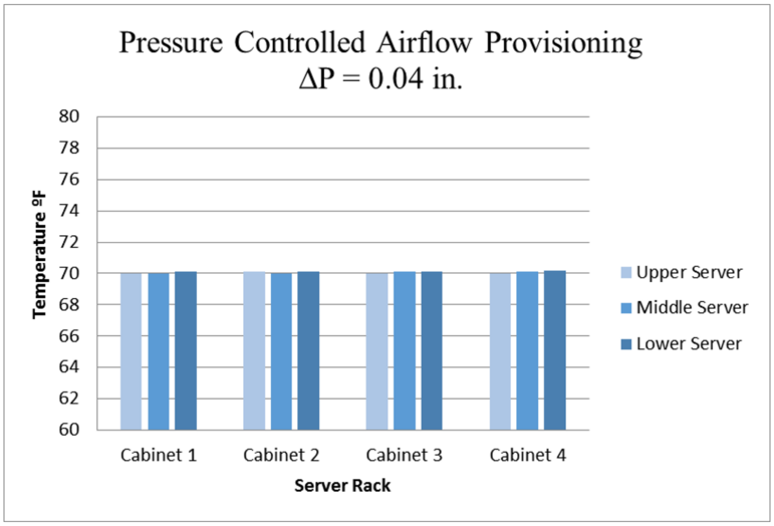

Figure 28. Equipment Temperature for Over Provisioning of Airflow

Effect on Server Flow Rate

Figure 28 and Figure 29 demonstrate server flow rate for lower, middle and top server for fixed and over provisioned airflow provisioning. Operating flow rate of the server is governed by the experimentally measured flow curve discussed in earlier section. Free air delivery point on active flow curve is 36.5 CFM.

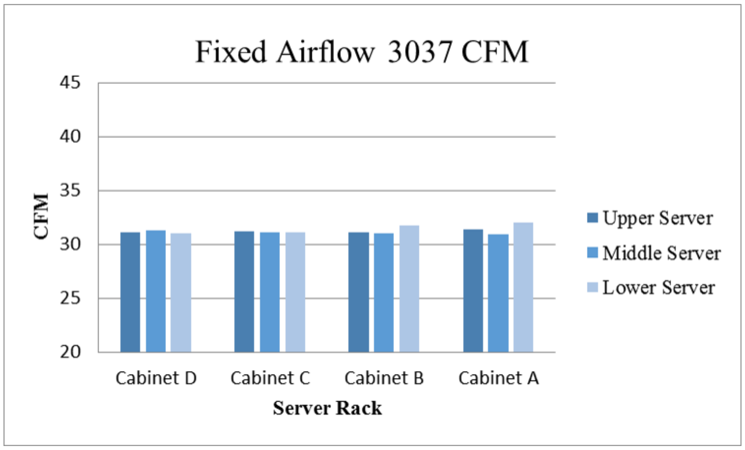

Figure 29.Server Flow Rate for Fixed Provisioning

High pressure in HA generates resistance for flow to pass through the server for fixed airflow provisioning. As shown in Figure 28 for fixed airflow provision servers are operating at lower flow rate than free air flow rate and operating point falls in the hindering region on flow curve. Reduction in server flow rate can create the adverse effect on server performance like an increase in temperature and more power consumption to meet the design criteria.

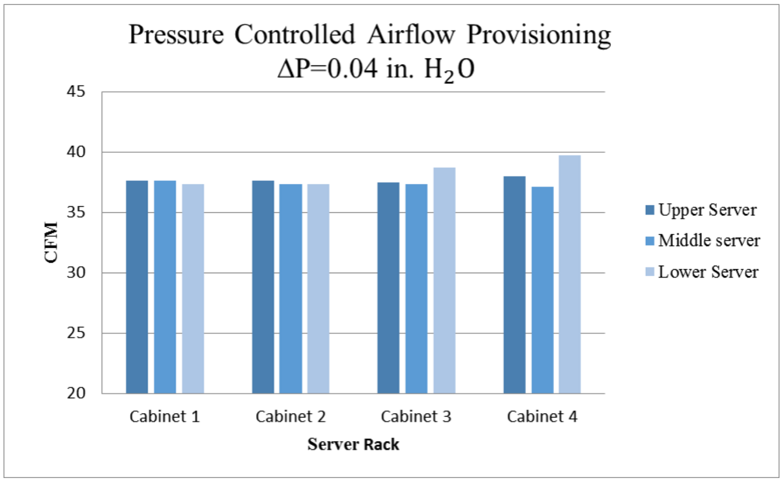

Figure 30. Server Flow Rate for Overprovisioning of Airflow

For over-provisioned airflow supply due to higher pressure in cold aisle server flow rate exceeds the free air delivery point 36.5 CFM. Airflow operating point lies in aiding region of the active flow curve. The increase in flow rate helps in improvement of server performance by keeping the temperature value in the acceptable range.

Over-provisioning of airflow by maintaining positive pressure gradient across the server rack can be useful to avoid hot air penetration from HA to CA up to certain threshold value of leakage (perforation in containment). The threshold value for the leakage is 15% of total containment area [21]. For the leakage ratio less than the threshold value, overprovisioning can be used to get high enough pressure distribution in CA to prevent hot air leakage in CA. For leakage greater than threshold value any overprovisioning of airflow will result in loss of cold air. A higher value of leakage may allow cold air to pass directly through the perforation instead of servers will results in loss of cold air.

If the server fan can ramp down when possible depending on component temperature using intelligent fan speed control algorithm [22]. During overprovisioning, server fan can be ramped down to reduce airflow rate to certain level and server can still operate allowable temperature range of the component. Less server airflow results in the reduction of total airflow demand from the CRAC unit to save a significant amount of energy.

Chapter 5

Comparison of Different Airflow Provisioning Architecture

Introduction

Thermal management of data center incorporates various cooling techniques at the chip level, server level, rack level, and room level. At room-level cooling several alternate air delivery and return configurations are employed. Different provisioning architectures with containment are considered as a key cooling solution for data center industries. Containment configuration includes cold aisle containment (CAC) and hot aisle containment (HAC), which segregate cold and hot air inside the data center. Containment enhances energy saving by operating cooling unit to at high return temperature and avoid mixing of hot air with cold air.

Raised floor plenum cooling architecture is commonly used in data center industries because of liberty of server rack arrangement provided by it. Raised floor room-level cooling configuration is shown in Fig. perforated tiles are placed in the cold aisle which supplies cold air to rack. To complete the airflow loop hot air from the rear of the rack is extracted from the ceiling vent and returned to CRAC unit. Comparison between raised floor and ducted supply/return configuration is included in following part of a study.

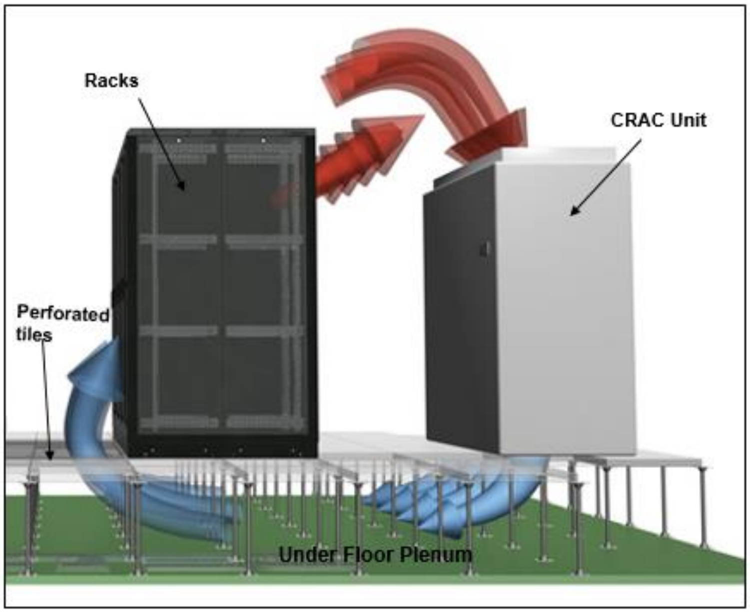

Figure 31. Raised Floor Data Center Configuration [22]

Figure 31 illustrates a raised floor data center, consist of a cooling unit, raised floor plenum with perforated tile arrangement to supply cold air to the cold aisle and ceiling return arrangement. Static pressure change of airflow as it passes through data center component shown in Figure 32. CRAC unit increases the static pressure of room return air and supply to under floor plenum. Airflow from the plenum enters the room via perforated tiles which enter in the server rack. Exhaust air from the rear of the rack is returned back to the CRAC unit using ceiling duct. As airflow passes through the data center facility static pressure reduces due resistance, flow recirculation and friction losses in air flow path.

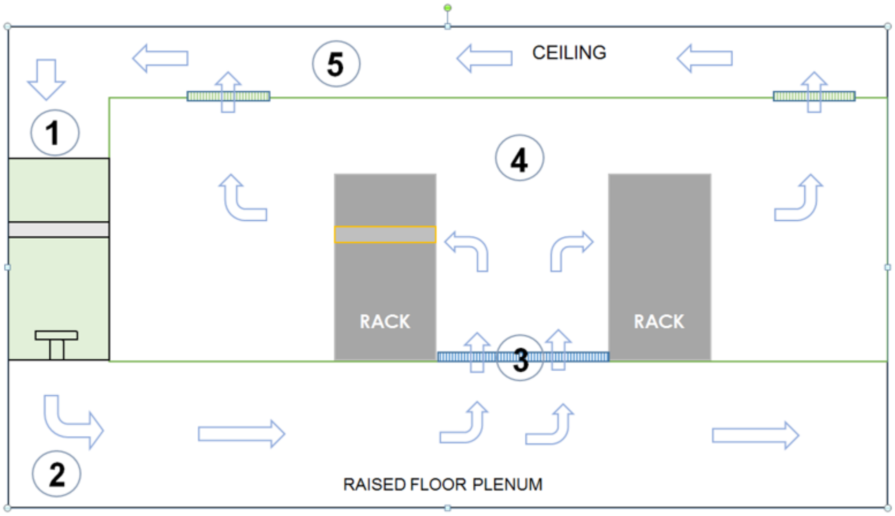

Figure 32. Schematic of Raised Floor Data Center [25]

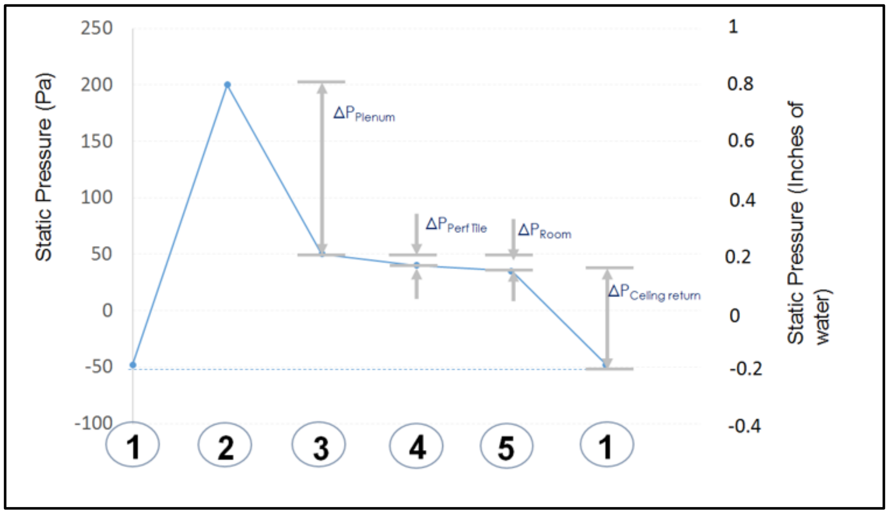

Figure 33. Static Pressure Profile [25]

CFD Modeling of Raised Floor Data Center Configuration.

Security and reliability concerns allow limited access to operating data center for thermal characterization and airflow behavior study. Large data center facilities exhibits constrain for temperature and pressure data measurement across the facility. Use of computational fluid dynamics and heat transfer is the most common approach to predict the airflow and temperature distribution inside the data center. 6Sigma DC commercially available CFD code was used to develop the numerical model of research a data center. The component of data center includes total 4 racks. Racks are fully populated with total 120 HP SE1102 servers.The effective active flow curve was obtained by mounting the server to airflow bench and varying the flow rate and pressure while the server fans were operating. CFD model of the modular data center is shown in Figure 33.

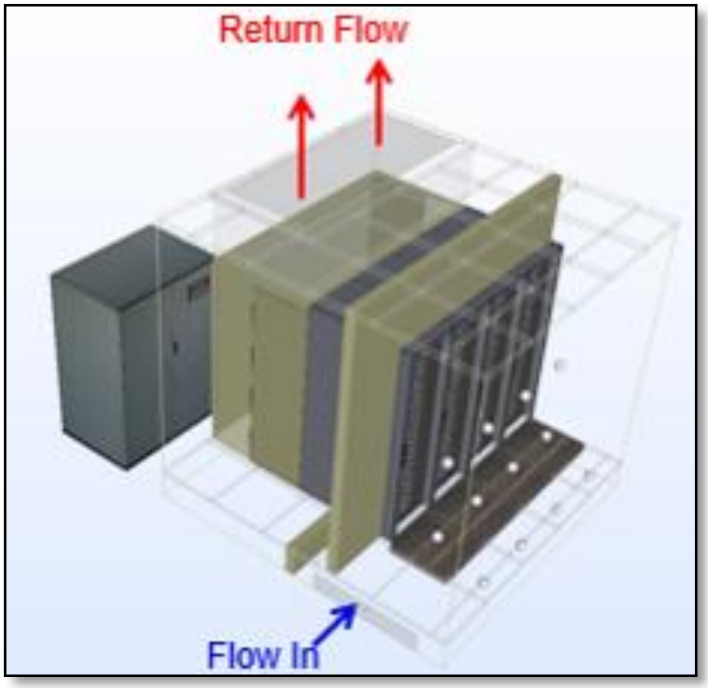

Figure 34. CFD Model of Raised Floor Data Center Configuration

Total IT load is 30.4 KW which required 4810 CFM to meet the power capacity. Perforated tile with 50% perforation area tiles is placed for each rack to supply cold air from the plenum. Parametric study and literature study is carried out for a suitable height of raised floor. For the floor are less than 1000 square feet area 12 inch raised floor height is suitable.[26]

Result and Discussion

Results include a comparison of thermal characteristics and airflow distribution of ducted supply/return and raised floor data center for the same heat load capacity.

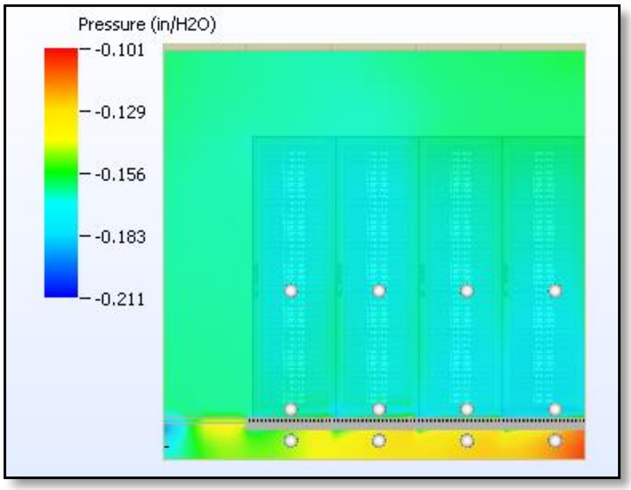

Figure 36.Pressure Distribution for Raised Floor

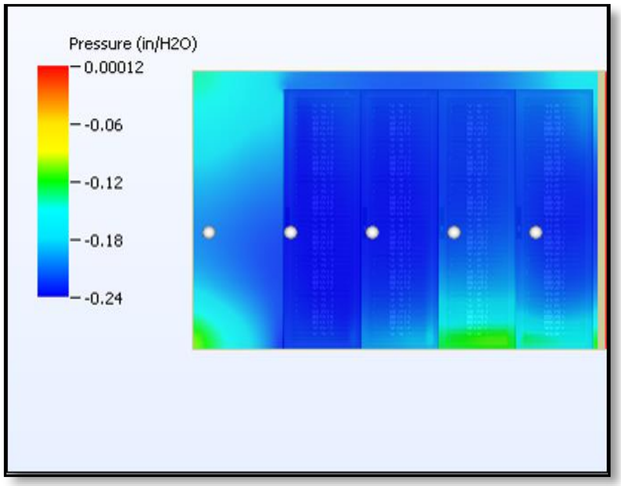

Figure 35.Pressure Distribution for Ducted System

Pressure distribution at the inlet of the rack is shown in Figure 34 and Figure 35 for ducted supply/return and raised floor data center respectively. The high momentum jets of air discharging from the perforated tile passes the bottom servers rapidly results in very less airflow through the bottom server. High-velocity airflow entering in cold aisle creates recirculation which is responsible for uneven pressure distribution across the rack face.

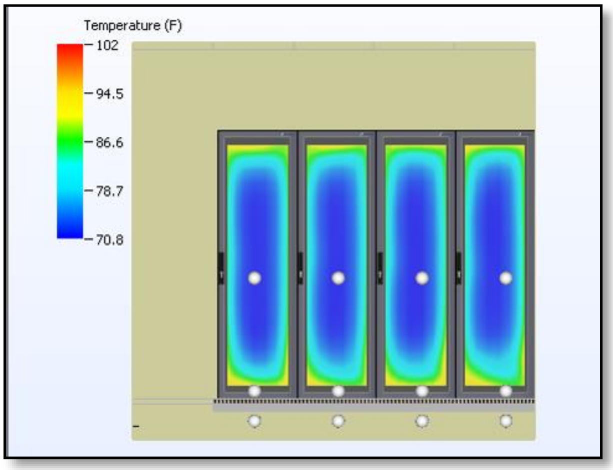

Figure 38.Temperature Distribution for Raised Floor

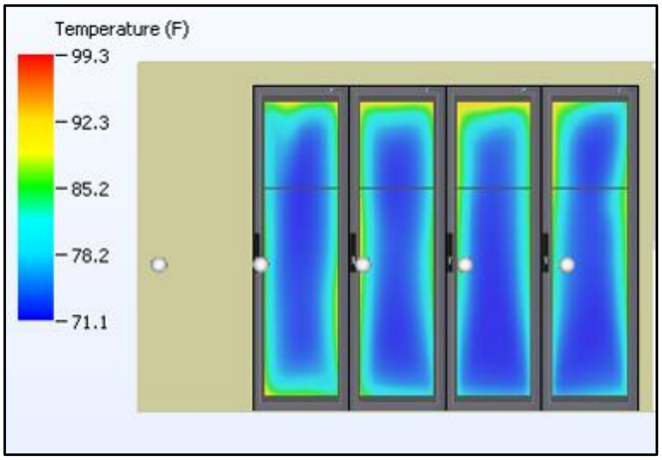

Figure 37.Temperature Distribution for Ducted System

Temperature distribution at the rack inlet is shown in Figure 36 and Figure 37 for raised floor data center and ducted supply/return configuration. Temperature at the bottom of racks is very high due to lack of airflow and temperature on the top of the racks increases due to recirculation of hot air into cold aisle through leakage. ASHRE thermal compliance plot in Figure 38 and Figure 39 represents equipment temperature which provides better comparative sight for thermal performance of different architectures. Results indicates that there are more number of server which falls in acceptable temperature range. In case of raised floor data center configuration very few servers are in acceptable temperature range.

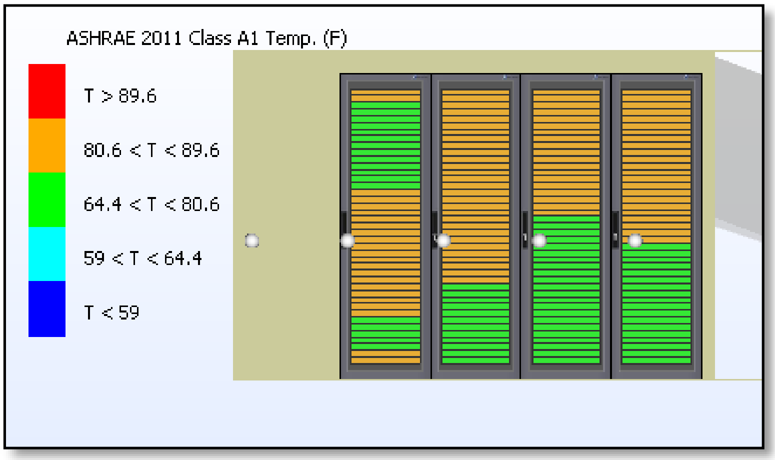

Figure 39. ASHRAE 2011 Class A1 Thermal Compliance for Ducted System

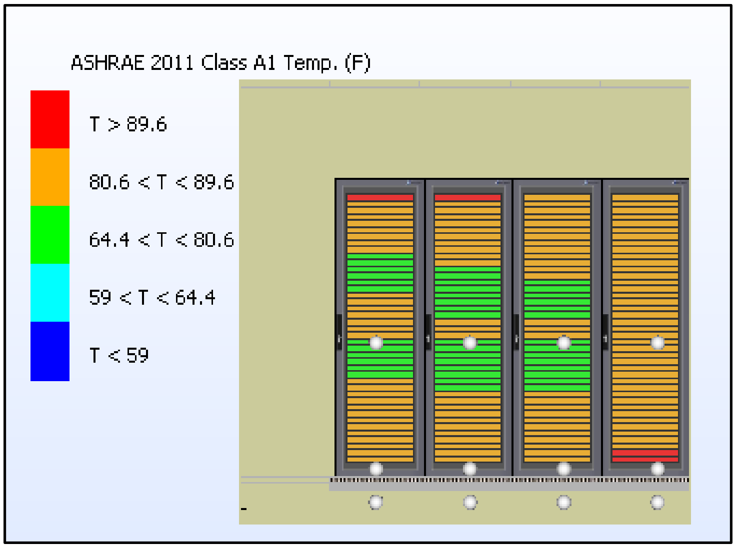

Figure 40. ASHRAE 2011 Class A1 Thermal Compliance for Raised Floor

Chapter 6

Conclusion

Data center houses IT equipment which is used for digital data storage, processing, and transmission. Use of high-performance microprocessor, high-density electronic packages and high heat load capacity racks in data centers resulted in high heat dissipation rate. For reliable data center operation, removal of dissipated heat and proper cooling has become the main concern of data center industries. Reduction in energy consumed by the cooling unit cooling unit can significantly improve the energy efficiency of data centers. Use of proper airflow provisioning and control system can significantly reduce airflow demand and proper extraction of heat can be done.

In this study, different approaches for efficient airflow management is discussed. Depending on the data center capacity and architecture different airflow provisioning can be deployed to meet the efficiency criteria. To study the effect of different airflow provisioning strategies research modular data center that uses direct and indirect evaporative cooling unit has been used. In actual data center facility, pressure inside CA is very low due to maldistribution of airflow. Also with the increase in IT load, the amount of volume flow rate that needs to leave from HA increases but due to insufficient outlet vent area airflow gets trapped inside HA which results in high pressure in HA. This kind of imbalance of pressure in CA and HA results in negative pressure gradient across the rack and increases the risk of backflow.

Estimation of power consumption in IT pod earlier research study results was considered. Airflow bench test to obtain active flow curve to determine the airflow requirement. Using practical data detail CFD model was created to get pressure and temperature distribution inside the IT pod for different airflow provisioning. Results suggest that to reduce the risk of backflow and to maintain positive pressure gradient across the rack instead of fixed airflow provisioning, pressure differential controlled airflow provisioning should be deployed. To estimate the correct amount of airflow requirement for IT pod additional efforts should be applied to determine pressure loss due to various factors like recirculation, Venturi effect, and losses due to friction presented by airflow path.

Different cooling architecture has its own benefits and drawbacks. The second part of the study is focused to determine the effectiveness and comparison of different data center cooling architecture. Rack inlet temperature highly depends on the airflow management. Configurations presented with various assumptions like inlet louvers angle, server fan operating speed, leakage ratio, and distribution, perforated tile design et cetera, depending on the performance requirements, configurations need to be changed. As per the results for efficient thermal performance of modular data center with small capacity ducted supply/return configuration, overhead supply/return system is suitable configuration. For data centers with large capacity and floor area raised floor data center is ideal due to liberty in rack arrangement.

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Biographical Information

Jaykishan Patel was born on October 18th, 1991 in the Gujarat state of India to his mother Rekhaben K Patel and father Kunjbihari R Patel. He attended the elementary education at St. Xavier's school. He earned his bachelor's degree in Aeronautical Engineering from Sardar Vallabhbhai Patel Institute of Technology in India.

Apart from this thesis work during his undergraduate studies he worked on different projects namely, "Experimental Analysis of Wind Rotor Blade With and Without Vortex Generators" accomplished under the company Suzlon Energy Limited. Detailed analysis of the blade for optimum aerodynamic performance by implementing Vortex Generators was carried out in the wind tunnel. Another project he worked on is "Anti-Torque and Yaw Control System for Helicopters Using Circulation Control Technique (Notar Configuration)" based on Numerical analysis of the tail boom of helicopters. The detailed analysis of the tail boom for optimum aerodynamic performance by implementing Coanda slots was carried out.

He joined the University of Texas at Arlington in August 2014 as a graduate student. He worked on thermal management project of the data center which is a part of National Science Foundation Center for Energy Smart Electronic Systems (ES2) consortium under the guidance of Dr. Dereje Agonafer.

He is always ready to learn new things and enjoys working with a team to solve thermal management problems. He is looking forward to exploring more about thermal management of data centers.