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Analysis and Performance Prediction of Data Centre with Different Configurations using CFD

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***Abstract*-This paper presents computational fluid dynamics (CFD) analysis of airflow, temperature and pressure distribution of the data centre with different configuration. These configurations were under floor supply with ceiling exhaust, under floor supply with horizontal exhaust, overhead supply with horizontal exhaust. The parametric and its optimization were used to determine the best possible layout for cooling strategies. The simulation results predict the high temperature zone within the computer rack in the data centre, and provide a detailed three dimensional analysis of the movement of cold air through the data centre. The position with optimum performance will be taken as the solution. The results of the simulation were discussed using temperature, airflow and pressure contours.**

Keywords—Airflow organization, CFD modeling, Data center cooling, Temperature distribution

I. INTRODUCTION

Data centers are growing exponentially (in number and size) to accommodate the escalating user and application demands. Likewise, the concerns about the environmental impacts, energy needs, and electricity cost of data centers are also growing. Network infrastructure being the communication backbone of the data center plays a pivotal role in the data center's scalability, performance, energy consumption, and cost. The data centre is a facility used to accommodate computer systems and associated components, such as telecommunications and storage systems. It usually includes redundant or backup power supplies, redundant data communications connections, air conditioning, fire suppression and security devices. Data centers have strictly regulated air parameters; the heat dissipation from the data-com equipment in the canters is high, not uniformly distributed and variable. The increased compactness of the computer equipment, as well as the increased industrial demand for information technology.

Most of the data centers use the under-floor plenum below a raised floor to supply cold air to the equipment. The computer room air conditioner (CRAC) units push cold air into the plenum, from where it is flowing into the computer room through opening. Due to the interactive effect of different parameters, the resulting flow distribution is usually not uniform. This means that the computer servers in some areas get too much air, while others get too little. Whenever the cooling-air requirements of any server are not met, its cooling is compromised. The necessary and sufficient condition for good thermal management is supplying the required airflow through the perforated tile(s) located at the inlet of each computer server.

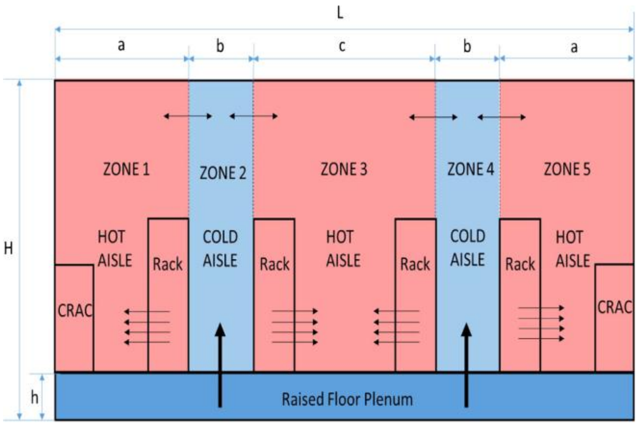

Fig.1 Data Center Model

Data center floor layouts are designed using Computational Fluid Dynamics (CFD) modeling offers a more scientific and comprehensive design approach. A typical Data centre model is shown in Fig 1. The cooling infrastructure is an important part of a data centers CFD model used to calculate the three-dimensional (3D) velocity, temperature and pressure distributions in the data centre. The local pressure drop across individual CRAC'S then determines the corresponding flow rate. The 3D model has been used to predict flow rate distribution in an actual data center, and the results are compared with measurements. Which help to minimize hot spots by predicting the high temperature zone within the computer rack with different configuration in the data centre and to provide a detailed 3D analysis of the movement of cold air through the data centre

II. METHODOLOGY

A :Data Centre Description

CFD consists of three parts-Pre-Processing, Solver, Post-processing. Pre-Processing includes geometry creation and Meshing. Here CATIA and ANSYS workbench will be used for Pre-Processing. The geometry will be modeled in CATIA. This software is extensively used in industries and is capable of making the required surfaces with precision. This model will be imported to ANSYS DESIGN MODELLER in STEP form. The domain will be meshed and the mesh quality will be checked .The most appropriate turbulence equation will be used in the solver

The solver used will be ANSYS FLUENT. Inside the solver we can give the required materials, give appropriate boundary conditions and select the proper numerical methods to solve the case.
CFD POST will be used for Post-Processing. Here we can take the required results like temperature, velocity, pressure contours, streamlines, vectors etc.
The data centre was modeled and analyzed using CFD code "Fluent" to study the effectiveness of cooling within the racks of the data centre. The flow field and temperature distribution in the Rack are reported.
Data centre Geometry consists of 36 no of rack, four inlet (CRACK), and three hot air aisle. Fig 1 and 2shows 2D and 3D views of data centre our manuscript electronically for review.

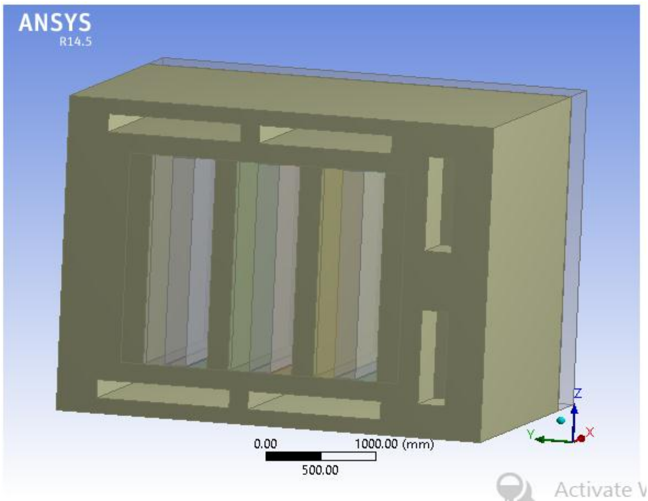

Fig.2. 3D Data centre model

B:Data Centre Features

The data center is 4 meter long, 3 meter wide and has a height of 3 meter, height from raised floor to ceiling of 2.48 meter. The racks which are holding the server has a length of 2 meter, breadth of 0.2 meter and a height of 2 meter. These racks are six in number. Each rack consist of 36 server. There are four inlet (computer room air conditioner (CRAC) units) openings with a length of 2 meter and breadth of .2 meter. These unit are capable of pushing cold air into the plenum, from where it is flowing into the computer room through opening
Description of Data centre and data centre components, air flow through the rack and vent tiles are summarized below.

- Room dimensions = 4*3*4 m^3
- No of CRAC unit = 4
- Room Floor Area =12 sq. m
- Supply plenum height =0.52meter
- inlet temperature=286.15K
- Total flow through CRAC units =11m^3/s
- Supply Air cooling capacity= 22680watt
- Total no of Vent tile =4
- Average flow through each vent tile =.78m^3/s
- CFM per server = 150(.0708m^3/s)
- server wattage(Power supply per server) = 450Watt
- heat density in each rack =3409w/m^3
- Mass flow rate of cold air =1.5605kg/s
- Total no of servers = 36
- Total flow through Racks unit is 2.548m^3/s
- Total Rack heat load 16200 watt
- Required Data centre temperature not below 10^o C and not above 28^{o}C

C:Meshing

The grids are generated using *FLUENT*. The basic principle in meshing is that it should have finer elements to get better accuracy of the result. At the same time, number of grids should not exceed available computational capacity. The geometry imported to *ANSYS work bench 14.5* is not necessary to get a converged solution with a particular mesh element or using fine meshes so mesh quality need to be checked. The suitable mesh has been computed using triangular mesh over the surface of the module the mesh should be very fine near the module. Orthogonal Quality ranges from 0 to 1,where values close to 0 correspond to low quality. Fig shows Meshed geometry of under floor supply with ceiling exhaust

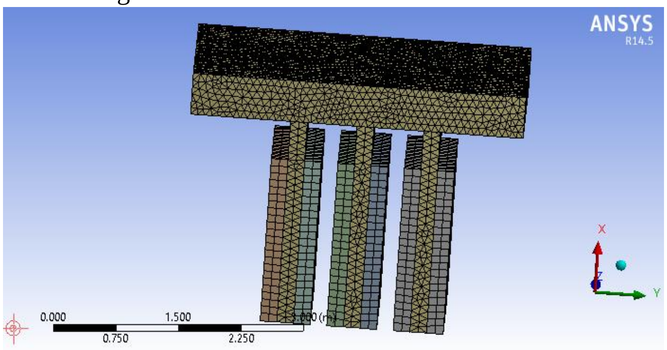

Fig.3. Meshed Geometry

Mesh quality and statistics of different configuration:

1. under floor supply with ceiling exhaust.

- Minimum Orthogonal Quality = 5.90306e-01
- Maximum Aspect Ratio = 3.90007e+00
- Mesh type = triangular mesh
- No of element: 350309
- Nodes :75527

2. under floor supply with horizontal exhaust

- Minimum Orthogonal Quality = 5.70306e-01
- Maximum Aspect Ratio = 2.90007e+00
- Mesh type = triangular mesh
- No of element: 282434
- Nodes : 69615

3. Over head supply with horizontal exhaust

- Minimum Orthogonal Quality = 4.8.70306e-01
- Maximum Aspect Ratio = 3.430007e+00
- Mesh type = triangular mesh
- No of element: 290035
- Nodes :71204

D:Boundary condition

The boundary conditions are: inlet temperature=286.15 K, Total CFM=5400(taken as mass flow inlet).CFM per server is taken as 150(0.078 m^3/s).The power supply per server is taken as 450 watts. Heat equation is switch on. The servers are taken as porous zones and necessary heat flux is given. As a turbulence model, the realizable k-" function is used. The mass flow rate and the flow direction normal to the boundary are imposed at the inlet.

The meshing model then transferring to solver section where the boundary conditions are applied. The standard *k-epsilon* model was used to calculate the turbulent viscosity this model allows for a more accurate near wall treatment. At the walls of the plenum and at other solid surfaces, stationary walls and the usual no-slip boundary conditions are used

III. RESULTS AND DISCUSSIONS

The CFD simulation was performed for the model shown in Fig 2.The results of CRAC performance, velocity, temperature and pressure distribution, the room and rack thermal maps, effect on the CRAC return temperatures, are reported. temperature, and pressure distribution for different configuration by considering a plane 2m height from the bottom are shown in the Fig 4 through 8. As discussed earlier, there are 4 CRACs units and the total flow through CRACs is 2.548 m^3/sec. From these Figures, it can be seen that the mixing of hot exhaust air with cold air leads to substantial increment of cold inlet temperatures which cause raising of the racks inlet temperature above the supply air temperature.

The flow of air in case of under floor supply with ceiling exhaust, is passing through vent to the cold aisle, from where cold air is moved into the server inlets and moved out of the back of the servers into the hot aisle. The hot air is then moved to the sides of the room where it is passed into the CRAC's. Such hot temperature zones cause rise in temperature leading to reliability issues of computer components. Hence proper cooling of data centre is very essential to keep data centre temperature within desired limit.ie required Data centre temperature not below 10^o C and not above 28^{o}C.

From three different configuration of data centre we can seen that the temperature distribution in case under floor supply with horizontal exhaust and over head supply with horizontal exhaust is above ASHARE recommended limit.

Thermal map at a height of 2m from bottom for three different configurations are shown in Fig 4 through Fig 6.

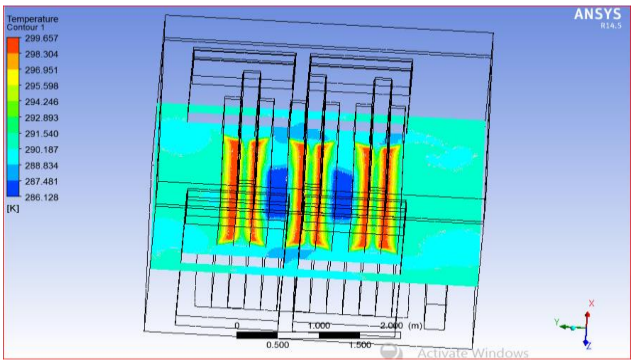

Fig.4.Thermal map at 2m height for bottom inlet and ceiling exhaust

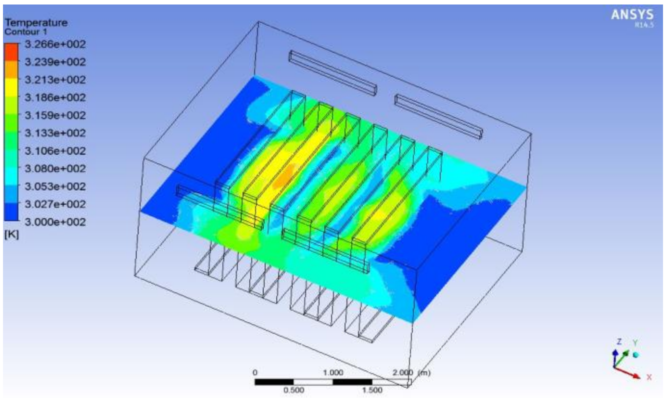

Fig.5.Thermal map at 2m height for bottom inlet and horizontal exhaust

From these figure it is shown that temperature variation in Fig 5and 6 is above 27^{0}c.High temperature zone was found along height in which maximum temperature around 50^{0}c in a configuration of bottom inlet with horizontal exit, the max temperature in case of top inlet with horizontal exhaust was found to be 65^{0}c.But max and Min temperature in under floor supply with horizontal exit is varies from 14 to 26^{0}c. These temperature limit also meeting ASHARE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) guidelines

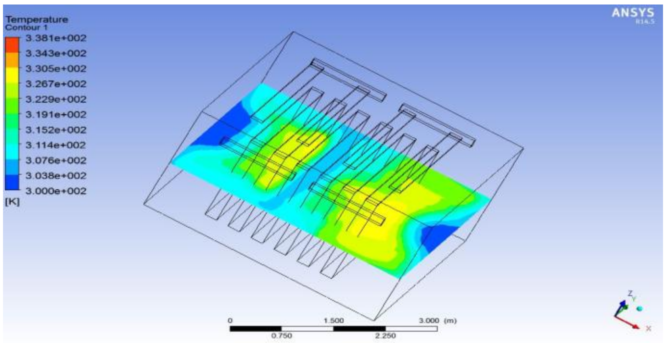

Fig.6.Thermal map at 2m height for top inlet and horizontal exhaust

The effectiveness of data centre cooling is measured by its ability to maintain data center equipment from overheating despite of the power density of the room

Fig. 7 through 9 reports the pressure distribution in the data centre

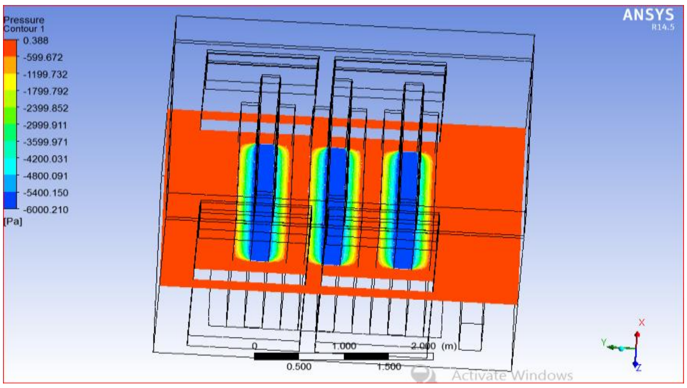

Fig.7. static pressure map for bottom inlet with ceiling exhaust

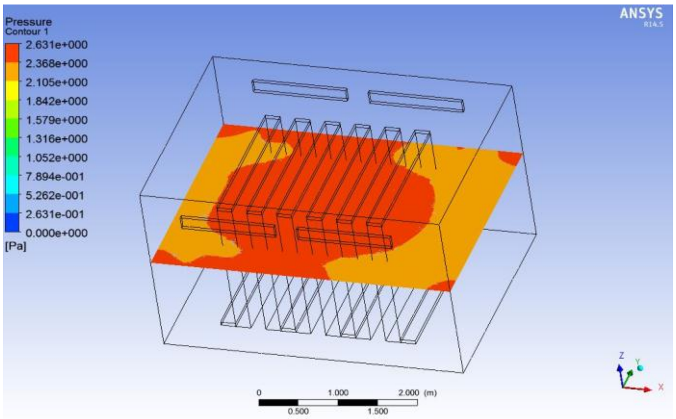

Fig.8.static pressure map for bottom inlet with horizontal exhaust

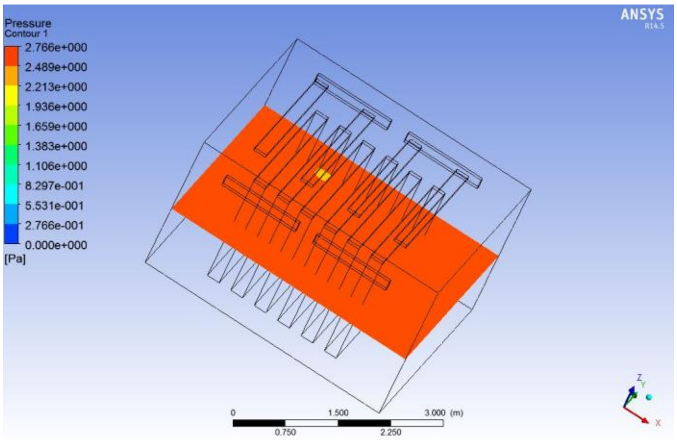

Fig.9. static pressure map for top inlet with horizontal exhaust

Fig 7 shows that pressure in bottom inlet with ceiling exhaust. distribution. where pressure is varies from nearly -3000 Pa to -200 Pa. lower pressure in the data centre room create lower enthalpy ie lower enthalpy is indication of evaporative cooling.In Fig 8 static pressure varies from 0.26pa to 2.631pa .Since the cooling flow is decreases, resulting in an small amount of airflow to the horizontal exhaust. . In Fig 9 pressure in uniformly distributed, static pressure is varies from 2.4pa to 2.7pa. this is due there is no need of hot and cold air aisle to convey air from one end to other end.

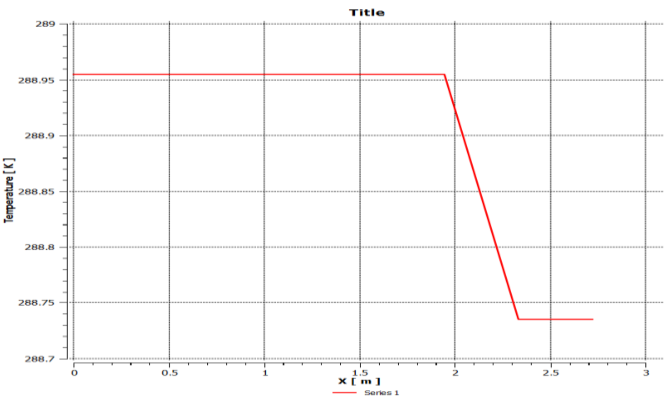

Fig.10.Temperature variation vs length in rack for bottom inlet with ceiling exhaust

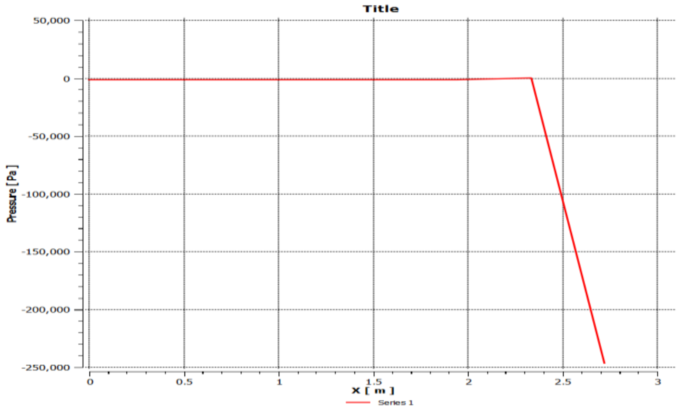

Fig.11. Pressure variation vs length in rack for bottom inlet with ceiling exhaust

Fig 10 and 11 shows that temperature and pressure variation in the rack when considering the plane along height. from the fig it can be seen that up to certain height(ceiling) temperature and pressure variation in the rack is uniform due to introduction of hot and cold air aisle . Usually, the flow of air is passing from the bottom into to the cold aisle, where the cold air is moved into the server inlets and moved out of the back of the servers into the hot aisle. The hot air is then moved to the sides of the room where it is passed into the CRAC's. In other two configuration that temperature and pressure in the rack are randomly distributed not uniform.

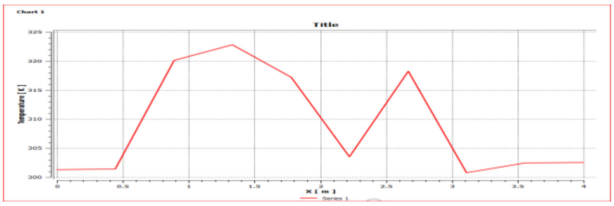

Fig.12.Temperature variation vs length in rack for bottom inlet with horizontal exhaust

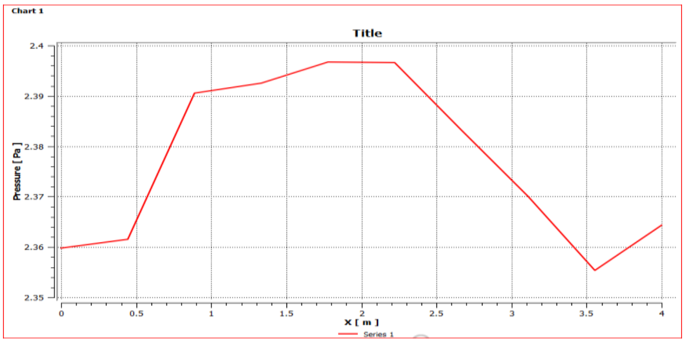

Fig.13.Pressure variation vs length in rack for bottom inlet with horizontal exhaust

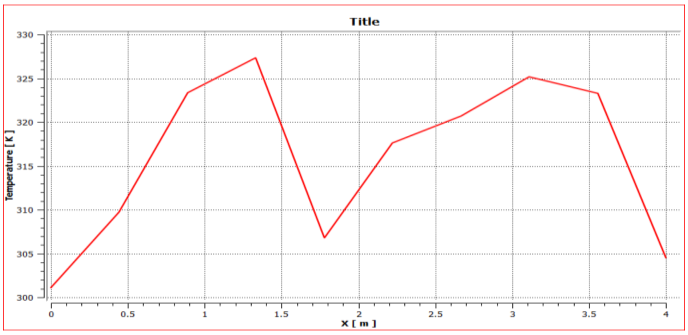

Fig.14.Temperature variation vs length in rack for top inlet with horizontal exhaust

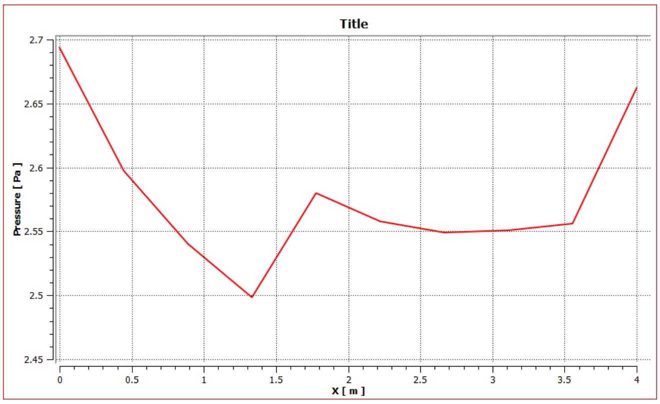

Fig.15.Pressure variation vs length in rack for top inlet with horizontal exhaust

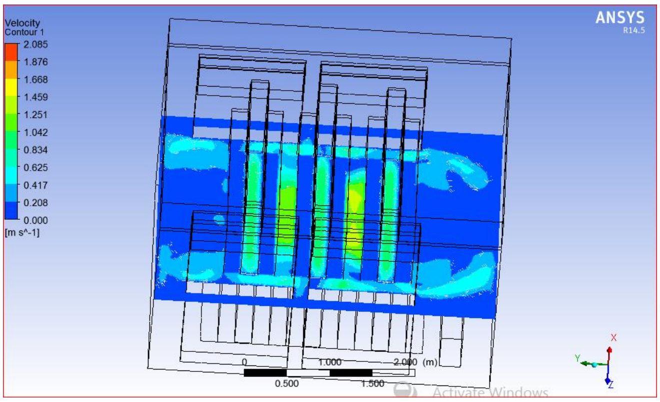

Fig 16 velocity distribution in bottom inlet with ceiling exhaust

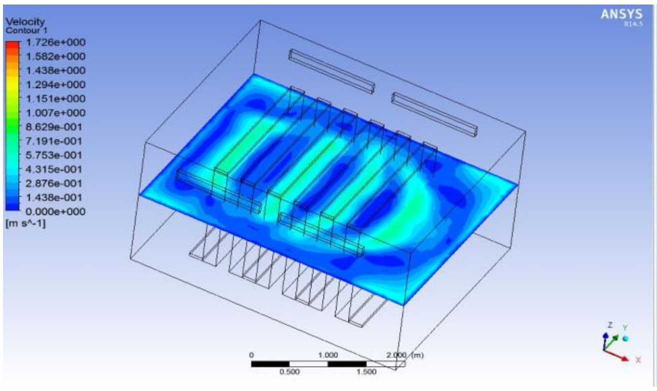

Fig 17 velocity distribution in bottom inlet with horizontal

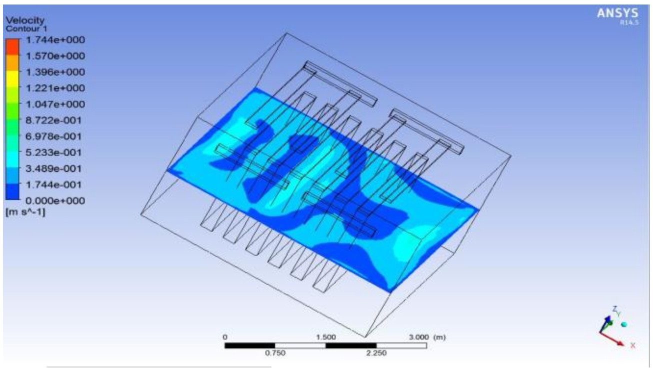

Fig 18 velocity distribution in top inlet with horizontal exhaust

Fig 16 through 18 shows that velocity distribution for different configuration. Maximum velocity differences is found to be 1.06m/s and 2.08m/s in the rack in bottom inlet with ceiling exit due to high density difference of air compared to other.

IV. CONCLUSIONS

This study establishes a process to determine the optimum supply air temperature ranges that minimizes the total cooling energy of a modular data center with various data centre configuration by considering supply air conditions, server thermal characteristics, cooling system configurations and locations. As a result, the optimum supply air temperature ranges are generally within 14^0C to 26^0C even though there are some differences in each the cooling system The high temperature zones were found at computer racks with configuration of under floor supply with horizontal exit and over head supply with horizontal exit. Maximum temperature around 50^0 C and 65^0C was observed in above two configurations which is above the limit of ASHARE guidelines. But maximum inlet and exit temperature to the rack in under floor supply with horizontal exit were observed as 14^0C to 26^0C. This is due to the usage of hot air aisle maintains a steady temperature within the data centre. so the required data center temperature is satisfied in bottom inlet with ceiling exhaust . This model could be used for a data centre design to develop a cooling strategy for achieving better thermal performance. This study provides a feasible cooling solution for high heat density data centre with configuration of bottom inlet and ceiling exhaust.

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