COMPUTATIONAL ANALYSIS OF IMPACT OF THE AIR-CONDITIONER LOCATION ON TEMPERATURE AND VELOCITY DISTRIBUTION IN AN OFFICE-ROOM

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Abstract – *For an effective and efficient design of air-conditioned room, it is very important to determine the optimized position of the air-conditioner. This paper focuses on the numerical study of the temperature field and air flow inside a room during summer with different positions of the air-conditioner unit using computational fluid dynamics (CFD) method. For these investigations, a CFD model of an office-room has been built and four different cases have been analyzed by placing the air-conditioner unit in north, south, east and west walls of the room separately using the same boundary conditions and heat sources. Numerical analyses have shown distinct relationship between the position of air-conditioner and thermal environment in the room. However, mass-weighted average velocity in room almost same in all the cases, but considerable differences in temperature distribution are observed w.r.t the position of the air-conditioner.*

Key Words: Air-conditioner Position, CFD simulation, Temperature distribution, velocity distribution, Energy consumption.

1. INTRODUCTION

In modern society, most of the people spend a great part of their lifetime staying indoors. As a result, demand of air-conditioner increases day by day. Satisfaction with the thermal environment is important for its own sake and because it influences productivity and health. Office workers, who are satisfied with their thermal environment, are more productive [1]. However, often higher consumption of energy is the main problem with air-conditioned building. Therefore, it is very important to predict and evaluate the indoor thermal environment scientifically, reasonably and effectively. Installation position of the air-conditioning unit is one of the important parameters to create an optimum energy efficient design. Using CFD numerical simulation method, this analysis can be done scientifically and effectively. The continuous progress of CFD in recent times has disclosed the potential of economical yet effective way for improving air-conditioning building design.

A good number of studies have been made in the past using Computational Fluid Dynamics to study the thermal environment of an air-conditioned building. Begdouri (2005) [2] analyzed the impact of the location of a window type air-conditioner on thermal comfort and consumption of energy in an office room. Huo et al. (2009) [3] studied the influence of locations of diffusers on air flow field in an office building. Bonefacic et al. (2015) [4] examined the impact of air-conditioner position in different heights in temperature and air flow filed in a modeled room. Jusoh et al. (2015)[5] computationally analyzed a thermal building in a non-uniform thermal environment and found that indoor environment increases more in higher temperature compared to lower temperature setting.

2. MATHEMATICAL MODEL

The problem is solved using the following basic equations-

Conservation of Mass equation:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \qquad (1)$$

Where u_i = mean velocity component in x_i direction.

Conservation of Momentum equation:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial P}{\partial x_j} + \rho\beta(T_o - T)g_i + \frac{\partial}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \qquad (2)$$

Where ρ = Air density, u_j=Velocity component in x_j direction, P =Pressure, T_o=Temperature of a reference point, T= Temperature, β=Thermal expansion of air, μ_{eff} = Effective dynamic viscosity.

$$\mu_{eff} = \mu_t + \mu_l \quad (3)$$

Where μ_t=Turbulent viscosity, μ_l=Laminar viscosity

Conservation of Energy equation:

$$\frac{\partial \rho T}{\partial t} + \frac{\partial(\rho u_j T)}{\partial x_j} = \frac{\partial P}{\partial x_j}[\left(\frac{k}{C_p} + \frac{\mu_t}{\sigma_t}\right)\frac{\partial T}{\partial x_j}] + S_T \quad (4)$$

Where k=Thermal conductivity, C_p=Specific heat capacity of fluid, S_T =Source term allowing for the rate of thermal energy production.

Turbulence was modeled using k-ε model which consist of transport equation for turbulence kinetic energy 'k' and its dissipation rate 'ε'.

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_i k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\varepsilon \quad (5)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho u_i \varepsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k} C_{1\varepsilon}\mu_t 2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \quad (6)$$

Where E_{ij}=Components of rate of deformation, μ_t=Eddy viscosity. σ_k, σ_ε, $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are constants.

3. CFD MODEL

The size of the office room: Length (X) x Width (Z) x Height (Y) = 6.08m x 3.8m x 3.14m. The room consists of a Door and a Ventilator in the North wall, one window is in the East wall. It consists of some occupants and heat loads, which are-two almirahs, three tables, one sofa, two persons, one computer and two tube-lights on the roof.

In this study air-conditioner has been installed in the center of the wall at a height of 2.81m in all the cases.

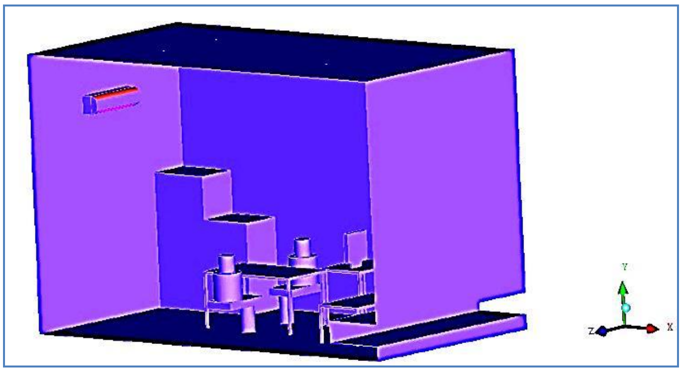

Fig -1: AC is mounted in the North wall (Case -I)

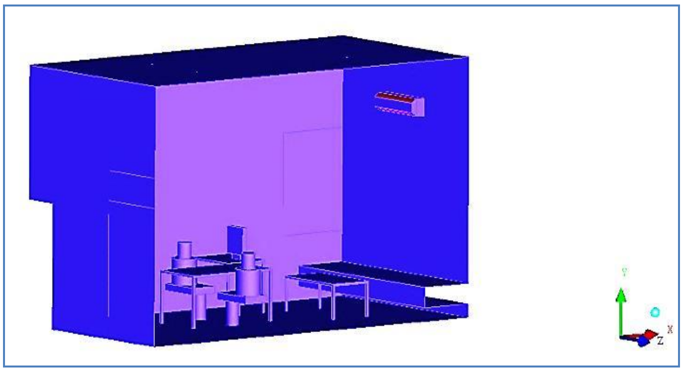

Fig -2: AC is mounted in the South wall (Case -II)

Fig -3: AC is mounted in the East wall (Case -III)

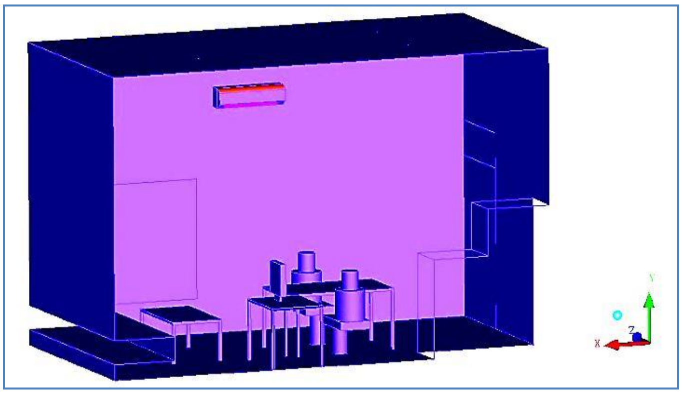

Fig -4: AC is mounted in the West wall (Case -IV)

4. BOUNDARY CONDITION

For this study constant reference air-conditioner inlet velocity (V_{in}) = 2 m/s and inlet supply temperature (T_{in}) = 283 K is considered for all the four cases.

It is considered that only roof of the office room is exposed to the sun but walls are surrounded by the other rooms of the building. So no direct solar radiation is considered in case of walls. The value of solar radiation for horizontal surface (roof) is 751W/m^2 at external air temperature 313.4K [6]

The turbulence kinetic energy (k) = 0.0084375 m^2/s^2, dissipation rate (ε) = 0.0033215737m^2/s^3 [7]

Table –1: Heat production rate of occupants

Occupants	Rate of heat production (W/m^2)
Computer	33
Tube light [8]	33.5
Human (Sitting, Normal office work)[9]	55

5. RESULT AND DISCUSSION

Case -I: Air-conditioner is mounted in the North wall

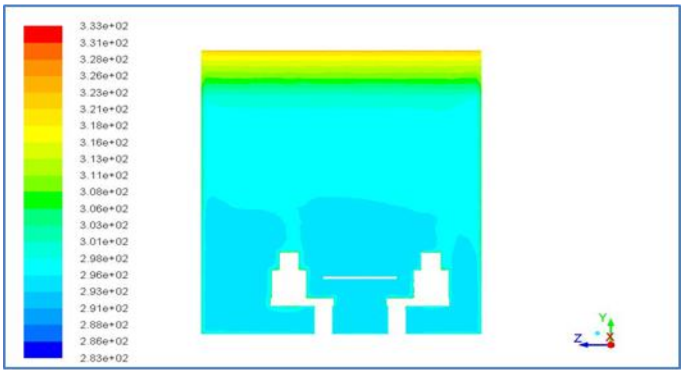

Fig -5: Static Temperature contours at X=2.6m

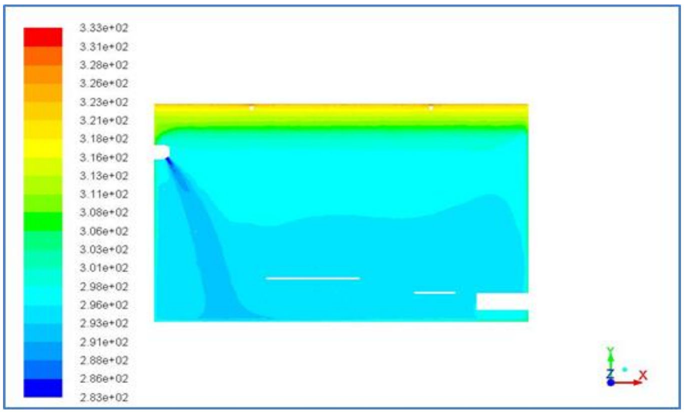

Fig-6: Static Temperature contours at Z=1.57m

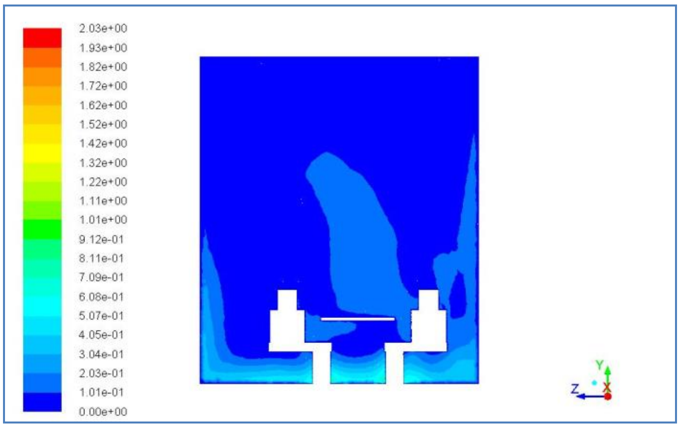

Fig-7: Velocity contours at X=2.6m

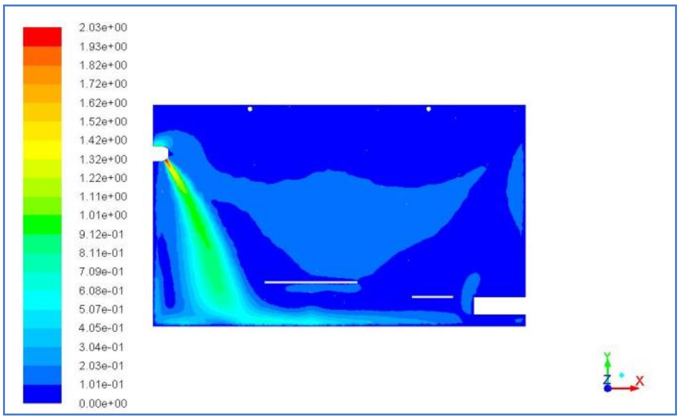

Fig -8: Velocity contours at Z=1.57m

Case -II: Air-conditioner is mounted in the South wall

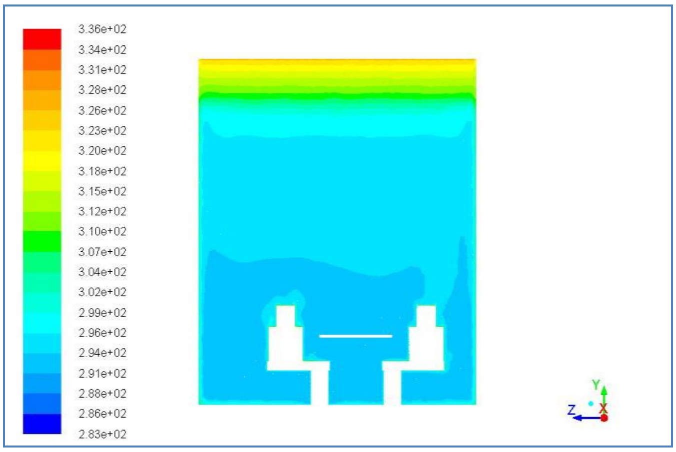

Fig -9: Static Temperature contours at X=2.6m

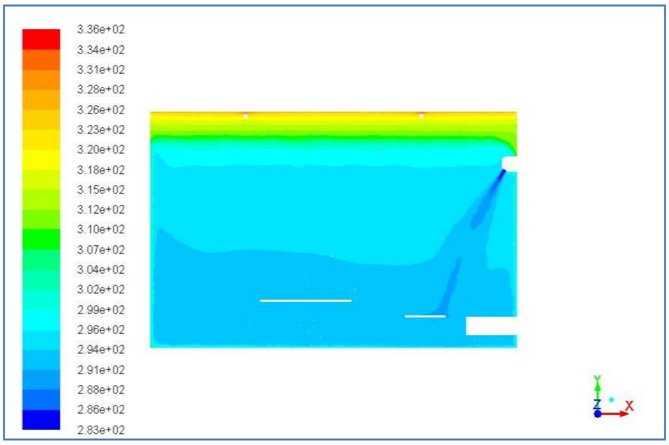

Fig -10: Static Temperature contours at Z=1.57m

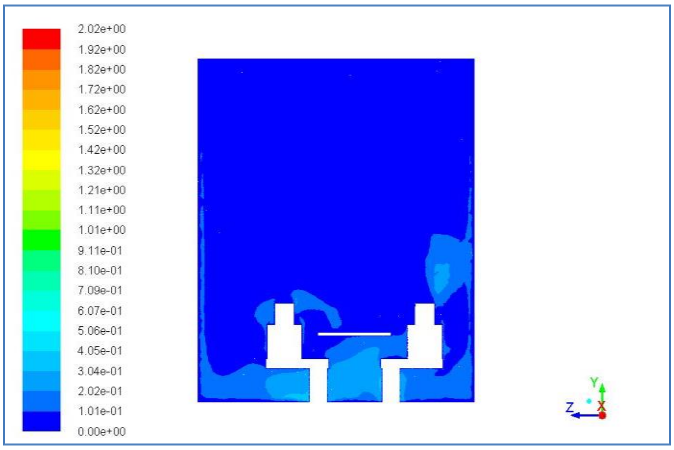

Fig -11: Velocity contours at X=2.6m

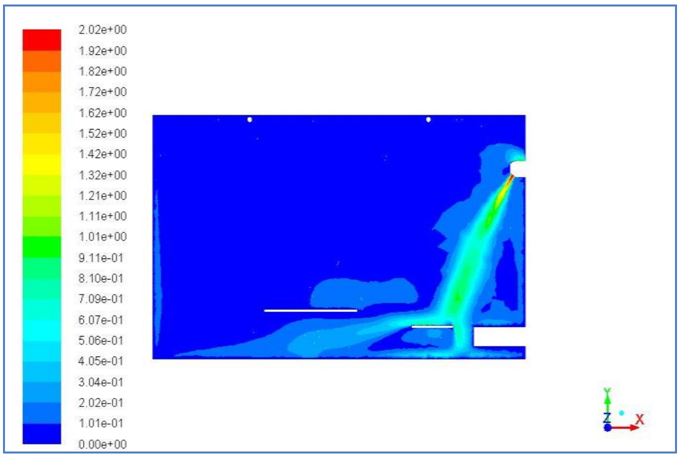

Fig 12: Static Temperature contours at X=2.6m

Case -III: Air-conditioner is mounted in the East wall

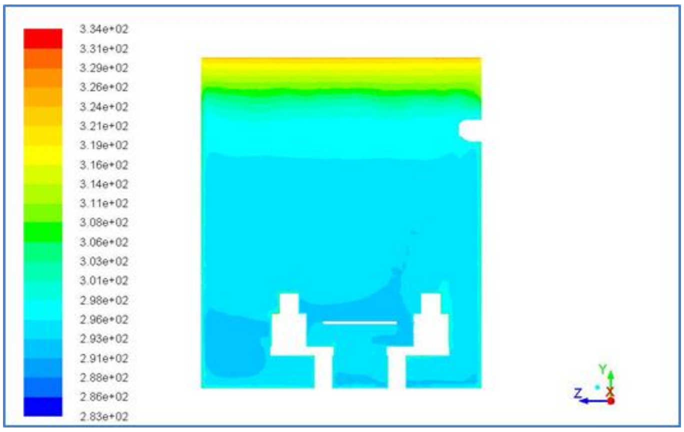

Fig -13: Static Temperature contours at X=2.6m

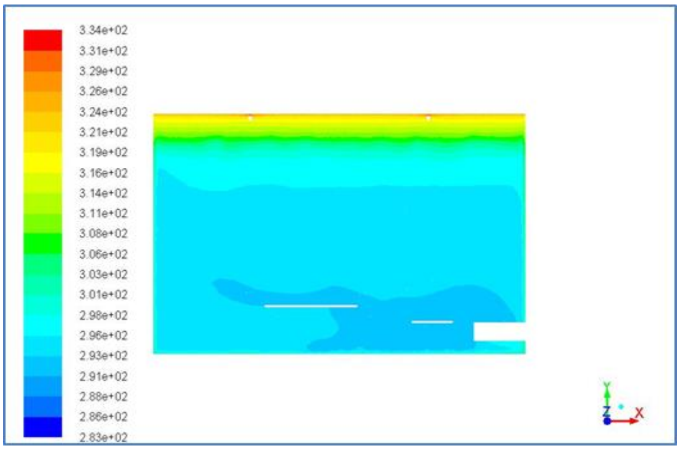

Fig -14: Static Temperature contours at Z=1.57m

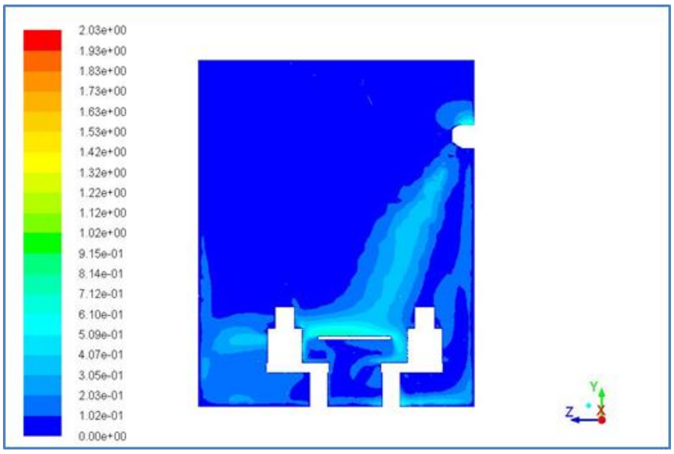

Fig -15: Velocity contours at X=2.6m

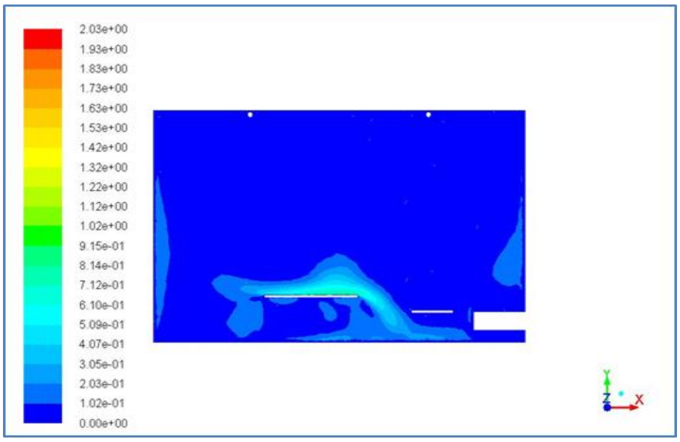

Fig -16: Velocity contours at Z=1.57m

Case -IV: Air-conditioner is mounted in the West wall

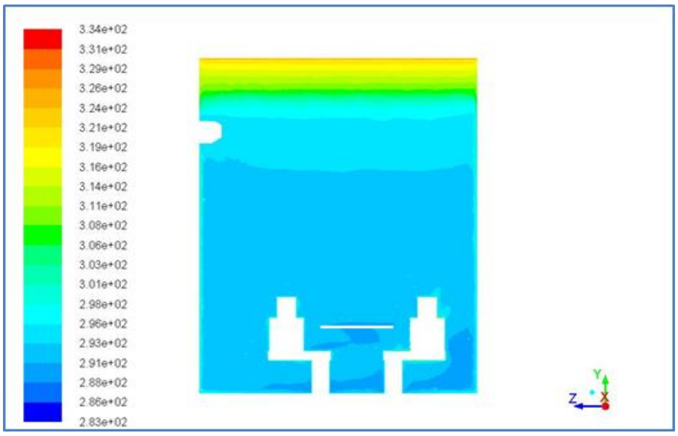

Fig -17: Static Temperature contours at X=2.6m

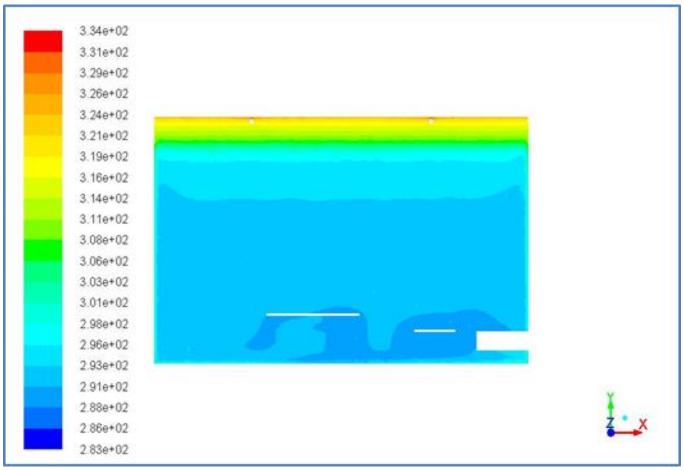

Fig -18: Static Temperature contours at Z=1.57m

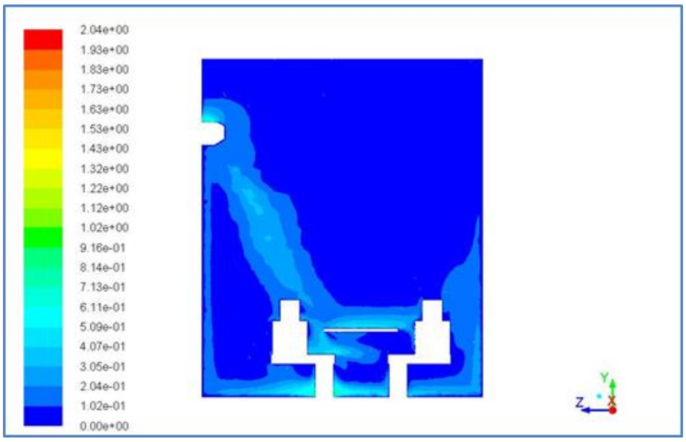

Fig -19: Velocity contours at X=2.6m

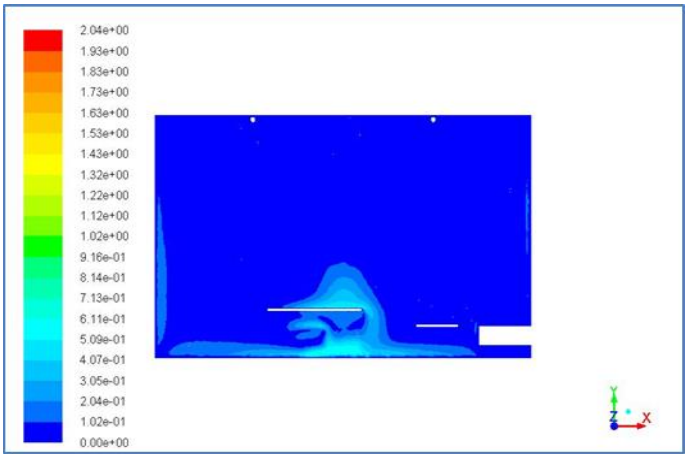

Fig -20: Velocity contours at Z=1.57m

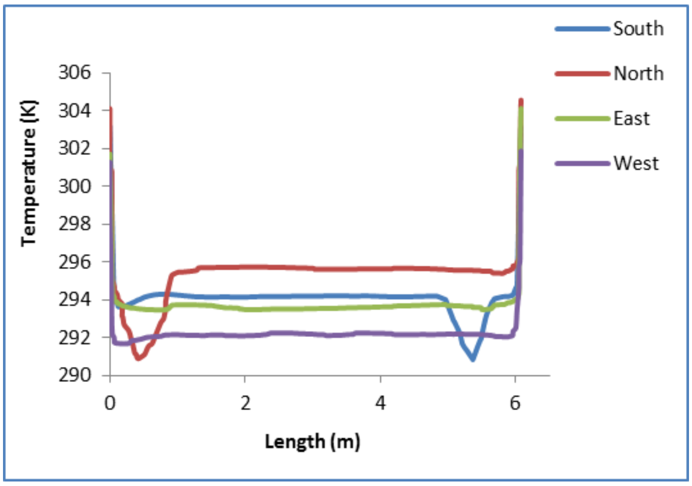

Fig -21: Temperature distribution along the center line X

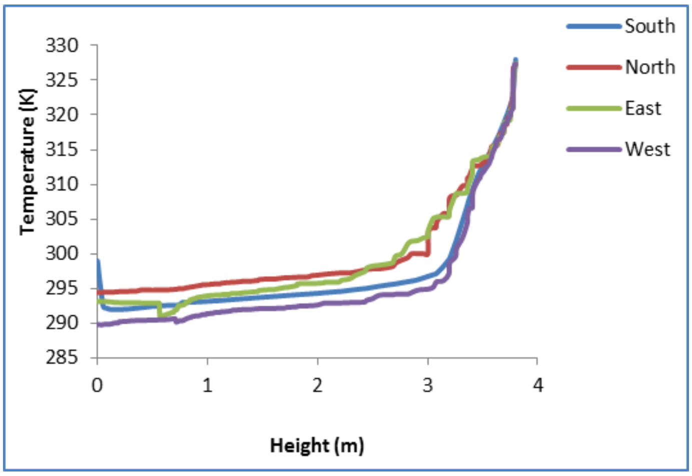

Fig -22: Temperature distribution along center line Y

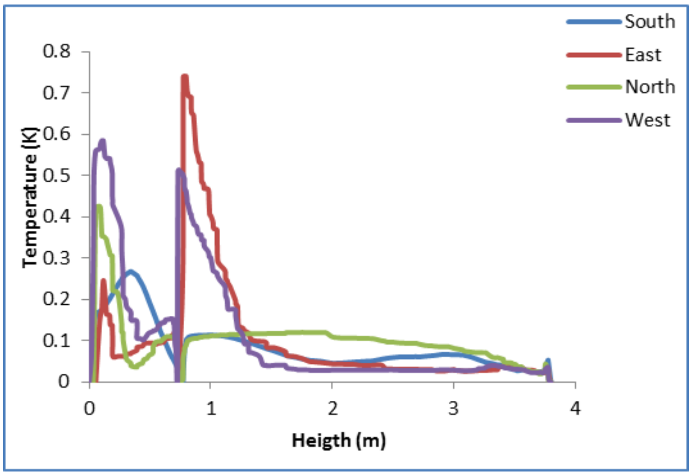

Fig -25: Velocity distribution along center line Y

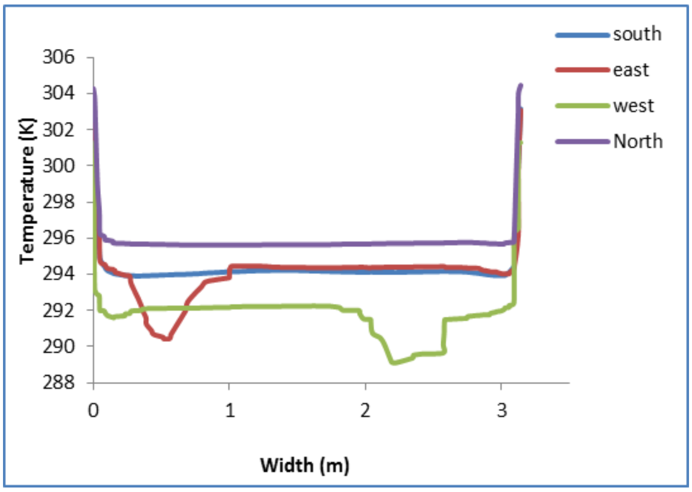

Fig -23: Temperature distribution along center line Z

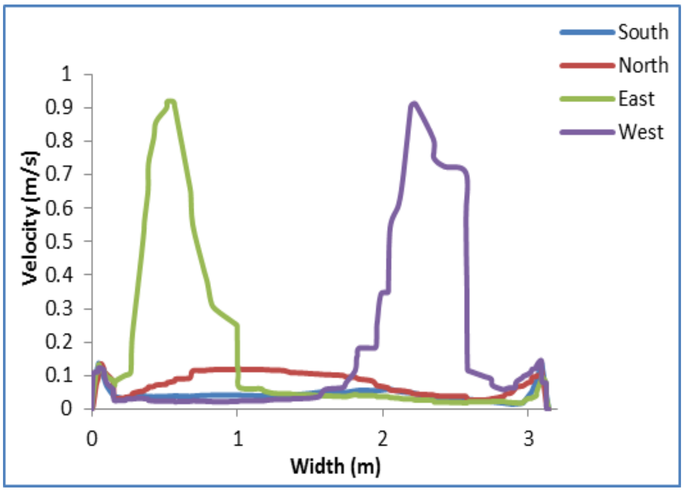

Fig -26: Velocity distribution along center line Z

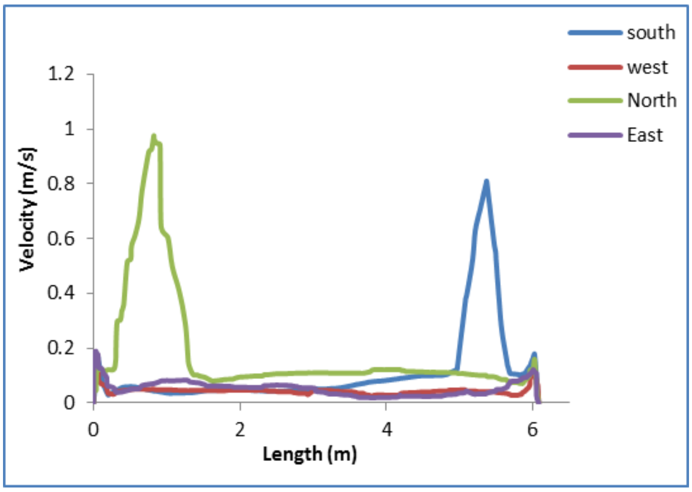

Fig -24: Velocity distribution along center line X

From the above analysis it is found that the velocity distributions are nearly uniform in all the cases. The difference between the highest and lowest mass-weighted average velocity is only 0.015m/s. The difference of velocity distribution is 0.003 m/s when air-conditioner is mounted in south wall and west wall. Again the same is 0.002 m/s while the unit is mounted in the east wall and west wall.

But a significant difference is found in temperature distribution inside the room. Average temperature remains lowest when air-conditioner is mounted in the west wall, whereas highest temperature distribution is observed while air-conditioner is installed in the north wall. The difference between highest and lowest average temperature in the room is 3.05 K. It means during summer, installation of air-conditioner in the west wall gives the best cooling effect as compared to the other positions in this case.

Table -2: Average Temperature and Velocity

Position of air-conditioner	Mass-weighted Average Temperature (K)	Mass-weighted Average Velocity (m/s)
North wall	298.03	0.094
South wall	296.98	0.082
East wall	297.04	0.081
West wall	294.98	0.079

So energy consumption will be less when the AC is mounted in the west wall during summer. It will be highest when air-conditioner is mounted in the north wall. Thermal comfort can be achieved by setting the inlet air velocity and temperature in lower range when air-conditioner is kept in west wall, which consumes less energy as compared to other positions.

6. CONCLUSION

This paper is a comparative analysis on the indoor temperature distribution and air flow by placing the air-conditioner in different walls. Physical processes are modeled using the FLUENT computational fluid dynamics software. The analysis shows strong influence of position of air-conditioner in thermal environment of the building.

Proper installation of ac could help in reducing significant amount of energy consumption in a building. However there are scopes of further study to build more practical physical model by considering of time dependent boundary conditions, infiltration through the domain etc.

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