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# Comparative Study on Thermal Comfort of a HVAC System with Two and Four Airflow Inlet using CFD Analysis for Commercial Building

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**Abstract**

This paper presented a thermal comfort comparison between two inlet and four inlet airflow of heating ventilation and air condition (HVAC) system using computational simulation for commercial building. The HVAC system design for commercial buildings is firstly started with the simulation of flow ventilation supplied from evaporator to study and understand the flow behaviour. In the present study to find out the thermal comfort accuracy by setting up the factors that influence on human comfort and evaluate the comparison results for 2 inlet and 4 inlet air flow system. In case of 2 inlet air for system the pressure variation inside the room is (3.20Pa to 3.08Pa), velocity ($3.19*10^{-2}$ m/s to $4.41*10^{-2}$ m/s), turbulence kinetic energy ($5.70*10^{-3}$ $m^2/s^2$ to $4.32*10^{-4}$ $m^2/s^2$), and temperature (21.3°C to 25.2°C). In case of 4 inlet air flow system pressure variation is (4.15Pa to 4.12Pa), velocity ($7.14*10^{-3}$ m/s to $2.27*10^{-2}$ m/s), turbulence kinetic energy ($2.85*10^{-3}$ $m^2/s^2$ to $3.51*10^{-4}$ $m^2/s^2$), and temperature (32.4°C to 21.8°C). Hence the results demonstrated that 4 inlet air flow system gives a better thermal characteristics compare to 2 inlet air flow system and the optimum value for study state condition in case of 4 inlet air flow system is 21°C.

**Keywords:** HVAC, CFD simulation, two inlets, four inlets, thermal comfort, temperature, velocity, turbulence kinetic energy.

## 1. INTRODUCTION

Energy efficiency in the global environment as well as the regulations that limit the energy consumption and greenhouse emissions it gives the more importance to the HVAC system [1]. To get optimum operational settings for learning and monitoring of HVAC system mathematical modeling is required. To find the optimum set points at a defined building system many methods and conditions were evaluated [2]. The target energy policy and the sustainable development there is a lack of validation for energy efficiency indicators (EEI), therefore a new approach for energy analysis of HVAC systems based on generation of efficiency, specific energy consumption and demand ratio for thermal energy efficiency [3]. As the HVAC system contains number of subsystems, and the balancing of heat transfer within the system depends on heat grain and losses in the building envelope. Hence whole system energy simulation is necessary for a real-world building and it demonstrates the framework could effectively quantify the HVAC system [4]. Around 50% of energy demand that affect the climate changes in the countries. Hence, a novel HVAC system was developed for optimization of energy system to enhance the energy efficiency. The data base management system for machine learning algorithms for prediction of HVAC system for mechanical ventilation [5]. To minimize the air pollution concentrations, experimental device was demonstrated with 1:4 scale to increase the performance of particular loading rate in the filters. The aspiration efficiency reducer (AER) acts as a passive form for air pollution control this reducing fan energy consumption. Hence a full scale AER device was developed to reduce the particulate matter entering the HVAC system by 34% of operational life cycle and reducing the energy consumption by 14% [6]. Variant Refrigerant Flow (VRF) technology enables gives a grater energy efficiency and cost savings compared with the traditional HVAC system [7]. Isolation of HVAC system will not always explain the issue of equipment efficiency of the building life [8]. Power supply installation of HVAC system plays a predominant role for energy efficiency. Hence decentralized power supply was installation of low voltage cables for long distance substations. It also saves the significant material loss and personal hours [9]. Energy codes for both commercial and residential buildings results in additional savings of 10% of electricity [10]. Development of HVAC system of non-residential buildings provides a policy makers gives strengthens the HVAC section to develop energy codes for regulations [11]. Different types of algorithms were developed to manage air-conditioners and heat pumps for small and medium size buildings will results in up to 20% of energy and cost savings [12]. In view of occupant comfort coordination with architect for efficient design results in low running cost. For commercial buildings implementation of load calculation phase required for inputs to develop a thermal loads [13]. Development of temporal and spatial correlation between data sensors used to find out the significant parameters using MATLAB/Simulink. This approach improved a thermal comfort by up to 75% [14][15]. Identification of static factors, architecture, number, size and orientation of the rooms and windows, dynamic factors gives the overall estimation of HVAC for the better efficiency of the system [16]. Analysis and simulation of energy gives the strong economy of system for thermal energy [17].

The present work mainly focused on comparison between two inlet and four inlet duct air flows using CFD modeling. To determine the optimum energy consumption which is based on the allocation of people's places according to the requirement of lightning, air conditioning and other related factors. The performance of air conditioning system and the level of thermal comfort by considering the factors such as Pressure, velocity, turbulence kinetic energy, turbulence eddy dissipation and temperature.

## 2. ENERGY PERFORMANCE OF HVAC SYSTEMS

### 2.1 Building descriptions and boundary conditions

In this study a medium size (Room 1 = 8.5*10.4m, Room 2 = 8.5*10.4m) as mentioned in the Fig. 1 & 2 were selected to perform the energy efficiency of 2-inlet and 4-inlet. The length, width and height of 2 & 4 -inlet ducts are 9.60m, 10.00m and 3.20m respectively. Fig. 3 shows the 2-dimensional view of the room 1 and 2. Building is created in Pro-E software to perform the thermal comfort. In both 2 and 4 inlet consists of two rooms, out of which first room have a reception, manager chamber and waiting hall whereas the second room have a work station. But in this study the second room is considered for the analysis of thermal comfort by considering the two variants based on the requirements.

The main focus of this study is to compare the performance such as pressure, temperature, velocity and turbulent kinetic energy for 2 & 4 inlet duct air flows. The model will developed based on Pro-E model and derived the results using CFD analysis. The efficient and effective way to optimize the energy consumption in the room is based on the persons present in the room and the effective utilization of lighting, air conditioning and other related systems. In this study the performance of air flow and thermal comfort for occupants by simulating the pressure, temperature, turbulent kinetic energy and turbulent eddy dissipation by using CFD method.

To apply the boundary conditions mesh the model of 2 and 4 inlet duct for commercial building, an unstructured mesh was developed and the grids are refined in and around the openings, servers and vents. Around 1,61,142 cells, 5,03,912 faces and 1,73,475 nodes were generated

Hence, the defined mesh was meet the following specifications: the change in density of the nodes domain should be based on the variables, and the change in elements in the total solution should be accurate. According to the geometry of the data room1 is the minimum volume was $2.961 \times 10^{-7}$ $m^3$ and the maximum was $8.001 \times 10^{-3}$ $m^3$. And room2 is the minimum volume was $2.961 \times 10^{-7}$ $m^3$ and the maximum was $8.001 \times 10^{-3}$ $m^3$. This grid level is used to check all CFD data for a numerical comparison with the zonal modelling.

The quality of the mesh was satisfactory because the calculated face alignment was greater than 0.7, hence no elements had been severely distorted. Cold air is supplied by an HVAC air conditioner at a rate of 3.6 – 10 $m^3$/s. The cold air rose from the raised floor plenum through ducts and hot air returned to the air conditioner. In first room the allocation were made like four members, one Xerox machine, and one computer. Whereas in the second room the allocations were made like nine persons, nine computers as shown in Fig. 1 & 2. The total power consumption of the building was 9.6 KW when it is in idle condition and 13.6 KW at full utilization.

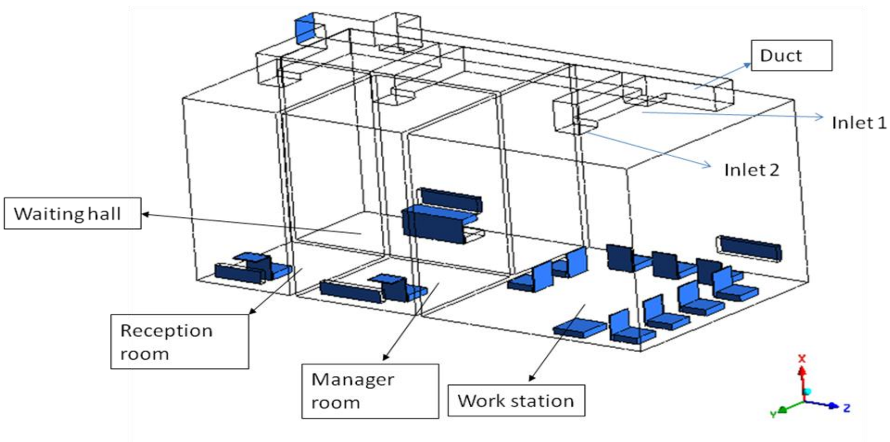


**Fig. 1** Detail view of work station with duct and 2-inet air flow

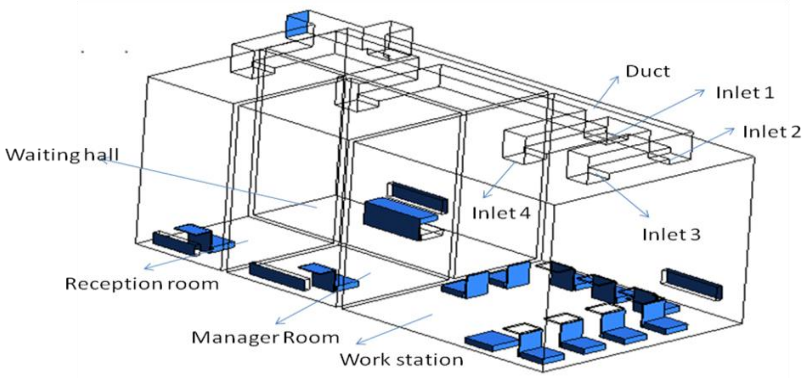


**Fig. 2** Detail view of work station with duct and 4-inet air flow

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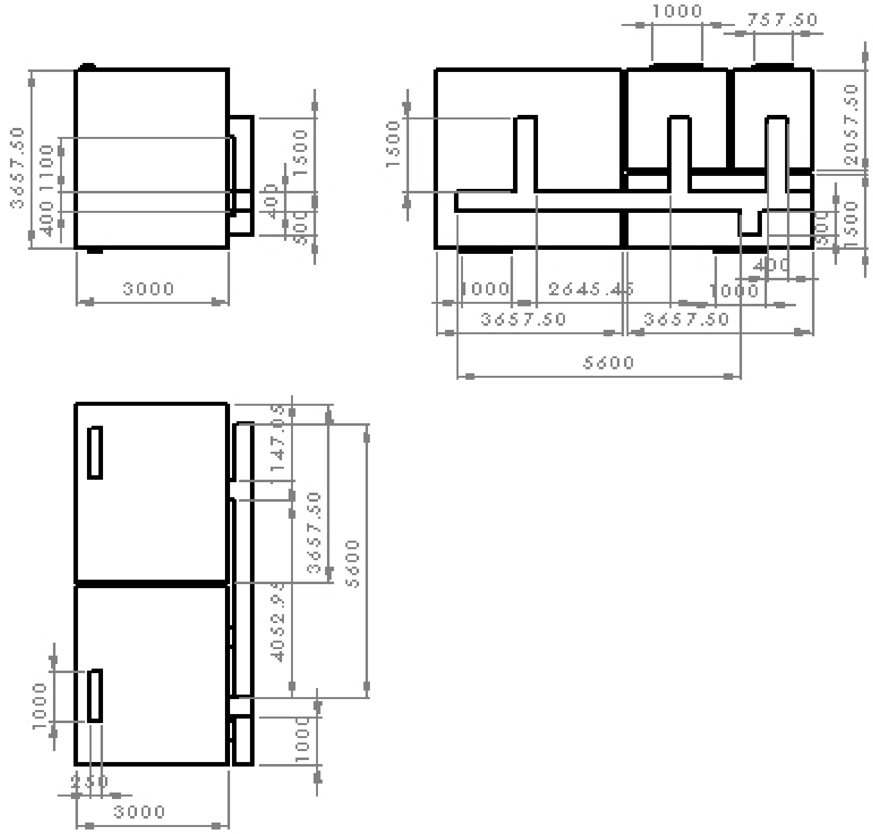


**Fig. 3** Two dimensional view of model with 2 and 4 inlets in the cabin

## RESULTS AND DISCUSSION

This study considered a commercial building with an air supply and defined a target model to provide boundary conditions for simulation and identify the pattern of airflow and confirm the results. To carryout these process, firstly the developed CFD model is analyzed based on the reference coordinates system and it is starting from (0, 0, and 0) and ending points (8.5, 3, and 10.4). The output of the indoor space for two and four inlet airflow for the thermal comfort levels by considering the four thermal characteristics such as pressure, temperature, turbulence kinetic energy and velocity. During the simulation, both the rooms are isolated and the heat transfer effect at the outside is neglected and adiabatic walls were considered for both the room and chassis as a heat source. To measure the thermal characteristics of the closed building is based on the inlet air flow and wide range of variation inside the HVAC system energy. The isolated system effect has a predominant role. Fluent 15 was used to determine the temperature distribution of various characteristics and scheduling algorithms for cooling efficiency of the commercial building in a confined space and is shown in Fig. 4 & 5. The overall mesh consists of 37959 nodes with 188990 elements for 2 inlet air flow and in case of 4 inlet air flow 38567 nodes with 191255 elements was used.

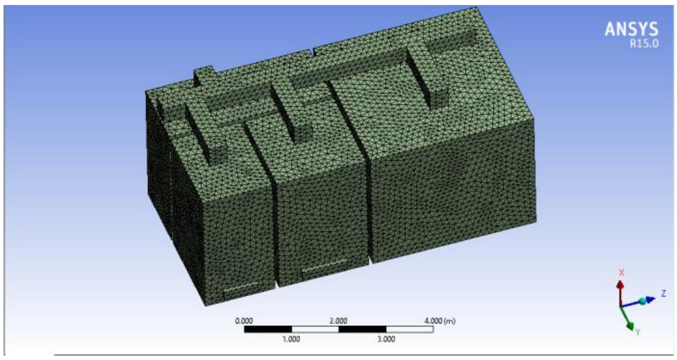


**Fig. 4** CFD mesh for 2 inlet airflow duct

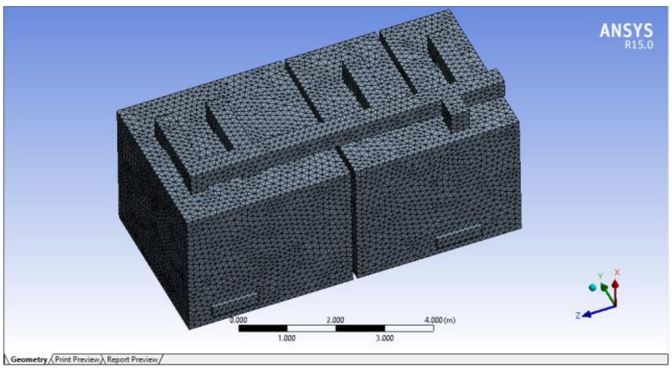


**Fig. 5** CFD mesh for 4 inlet airflow duct

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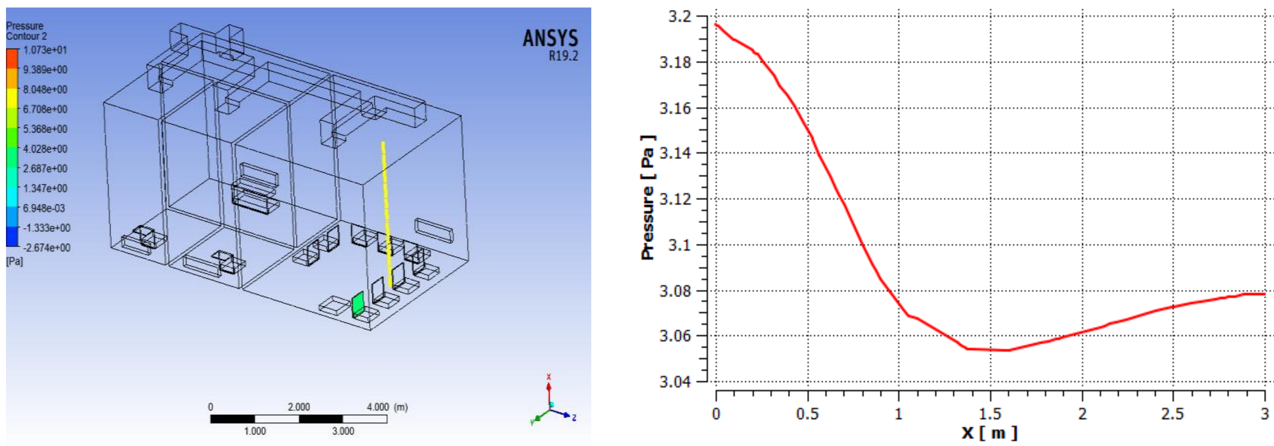
Based on the ASHARE data sheet standards the temperature buoyancy conditions were simulated. Hence the air was considered as an ideal gas for the reference and a density of 1.173 kg/m$^3$. The outdoor parameter were calculated such as dry bulb temperature at 32°C, indoor dry bulb temperature at 20°C and humidity of 40°C. At the outset the external at the south wall was considered for constant heat flux boundary and 16.8 w/m$^2$ heat transfer density.

Front wall was considered with 21.8°C, left wall with 21°C, right wall with 20.2°C, back wall with 20.4°C, floor with 19°C and ceiling with 20.2°C respectively. In case of air outlet flow; the direction of air in y-axis the velocity is 2.5 m/s and supply air temperature is at ambient condition was considered (Hosseini et al.)

**Two inlets airflow**

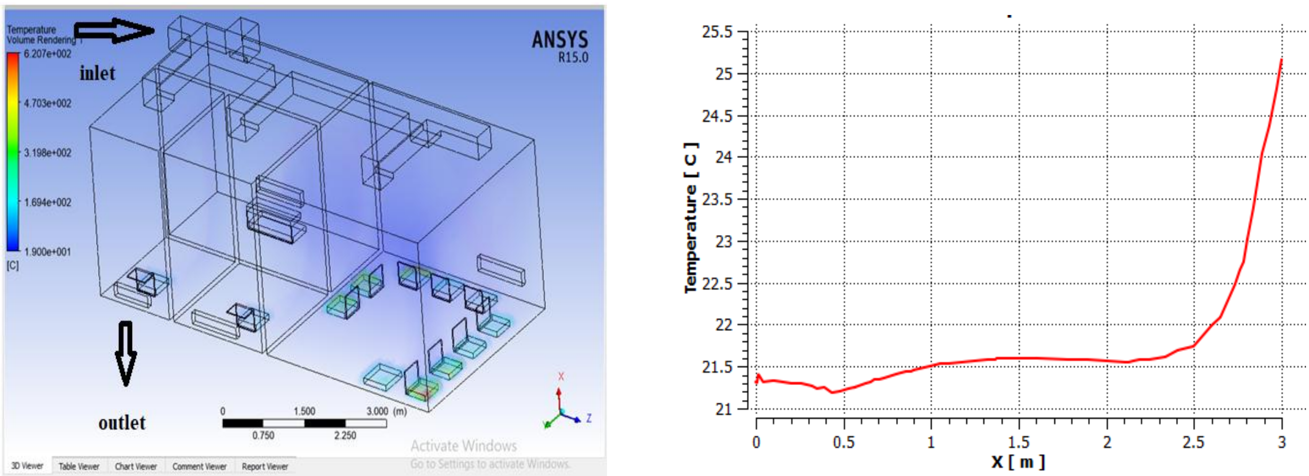
In this study the thermal characteristics for commercial building with confined space were analyzed using CFD analysis (Ansys Fluent). The tests were performed based on the velocity variations, pressure variations, temperature and turbulent kinetic energy distribution in the confined space.




(a) (b)

**Fig. 4** (a) Pressure variation of the developed model in the workstation (b) Graphical representation of the pressure variation inside the workstation for 2 inlet flow

The results shows that for 2 inlet air flow conditions the pressure distribution in the room 2 is shown in Fig. 4(a). the pressure varied from 3.20 Pa (9.06*10$^{-3}$m) to 3.05 Pa (1.558m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average pressure of 3.08 Pa (3 m) and is shown in Fig. 4(b).




(a) (b)

**Fig. 5** (a) Temperature variation of the developed model in the workstation (b) Graphical representation of the temperature variation inside the workstation for 2 inlet flow

The results shows that for 2 inlet air flow conditions the temperature distribution in the room 2 is shown in Fig. 5(a). The temperature varied from 21.3°C (1.19*10$^{-2}$m) to 21.52°C (3.00m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average temperature of 21.3°C and is shown in Fig. 5(b).

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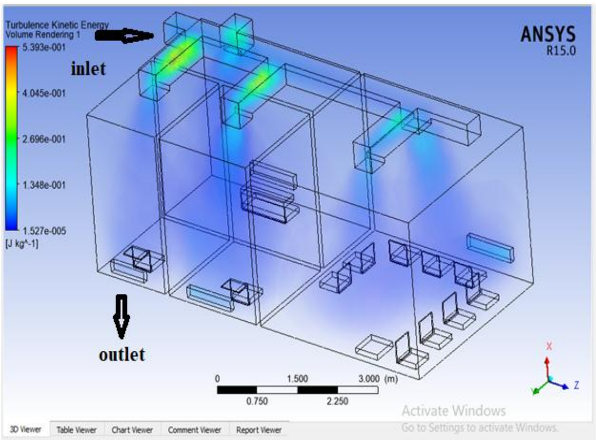
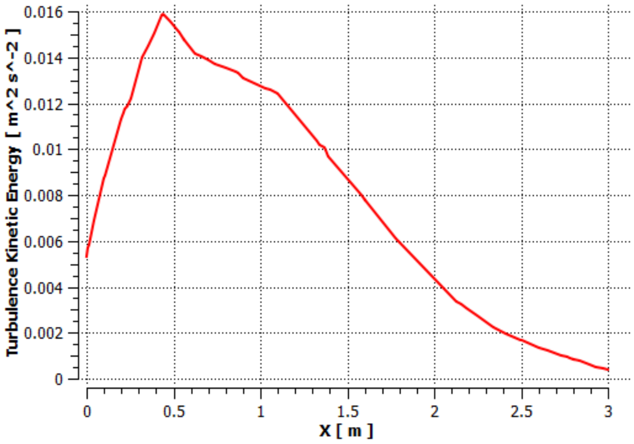
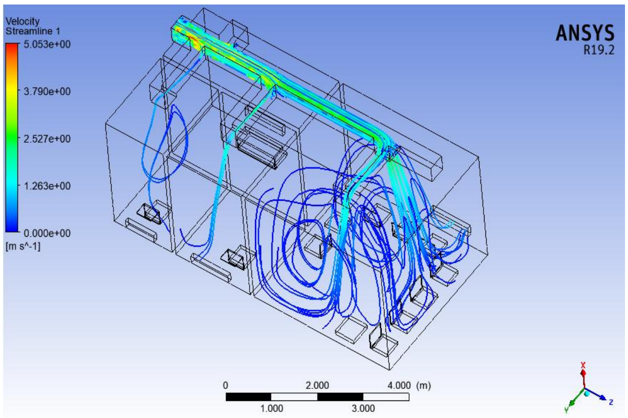


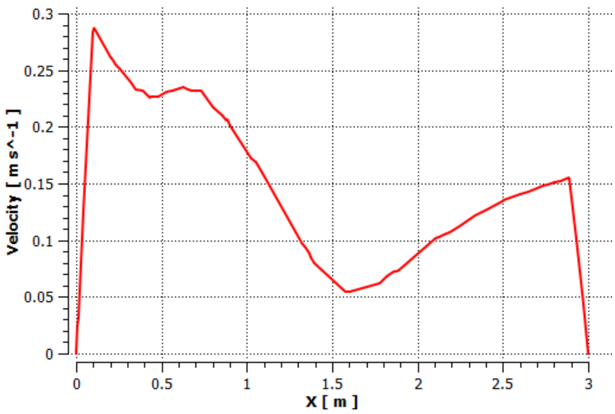




(a) (b)

**Fig. 6** (a) Turbulent kinetic energy variation of the developed model in the workstation (b) Graphical representation of the turbulent kinetic energy variation inside the workstation for 2 inlet flow

The results shows that for 2 inlet air flow conditions the turbulent kinetic energy distribution in the room 2 is shown in Fig. 6(a). The turbulent kinetic energy varied from $5.70*10^{-3}$ $m^2/s^2$ ($9.06*10^{-3}$m) to $4.34*10^{-4}$ $m^2/s^2$ (3.00m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average turbulent kinetic energy of $9.93*10^{-3}$ $m^2/s^2$ and is shown in Fig. 6(b).




(a) (b)

**Fig. 7** (a) Velocity variation of the developed model in the workstation (b) Graphical representation of the velocity variation inside the workstation for 2 inlet flow

The results shows that for 2 inlet air flow conditions the velocity distribution in the room 2 is shown in Fig. 7(a). The velocity varied from $3.19*10^{-2}$ m/s ($1.19*10^{-2}$m) to $4.41*10^{-2}$ m/s (2.97m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average turbulent kinetic energy of $9.70*10^{-2}$ m/s and is shown in Fig. 7(b).

Finally, the distribution of air in HVAC systems for energy consumption in terms of temperature, pressure, turbulent kinetic energy, and velocity for the human thermal comfort and health status. Two inlet air flow system shows that, airflow streamlines injected from the two separate channels by a angle of 45°. As the airflow duct system is located at the ceiling, hence there is no effect of utilizing the partitions in room 1. Because the dissipation of study sate temperature is as per the ASHRE standards. In case of room 2 as the present study is focused based on the thermal characteristics. The room 2 is not maintained the ASHRE standard, hence the temperature flow is high in room 2 at occupants 6 and 7. It is concluded that the airflow is extremely high for 6 and 7 occupants that leads to discomfort for the human. The average air speed in this room 2 is at 1.077 m is less than 0.5 m/s. the fig. 4 (a), 5(a), 6(a) and 7(a) clearly shows that the occupant 9 is at discomfort with a 25% of the area and the temperature in room 2 has a higher ASHRAE 55-2013 standard.

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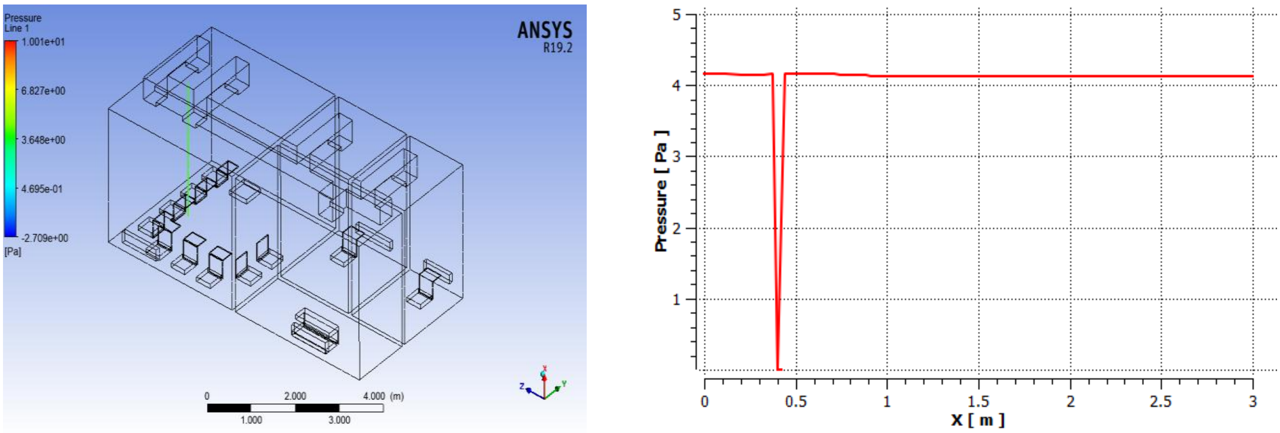
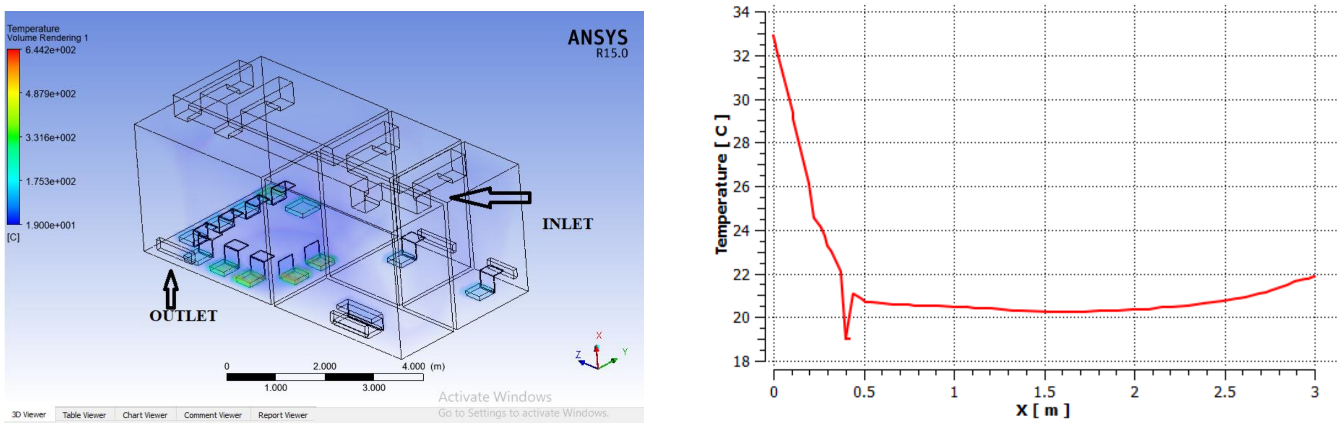
**Four inlets airflow**




(a) (b)

**Fig. 8** (a) Pressure variation of the developed model in the workstation (b) Graphical representation of the pressure variation inside the workstation for 4 inlet flow

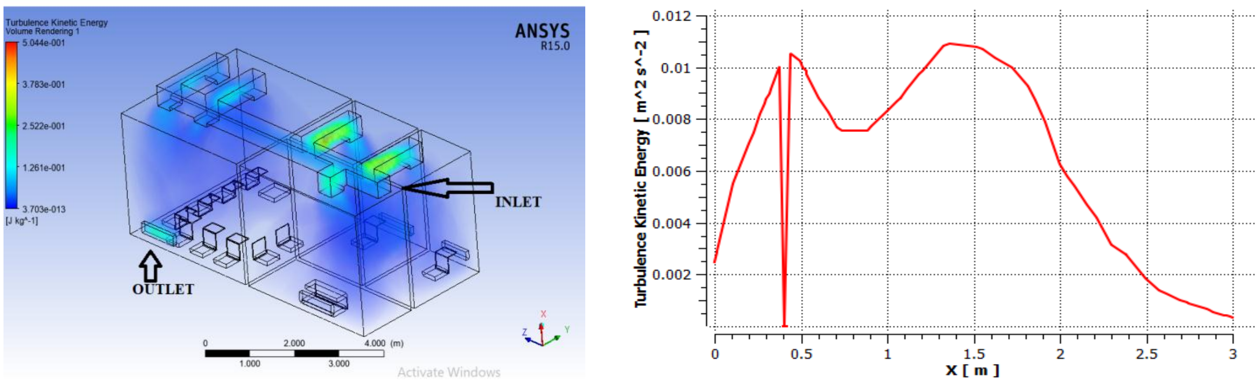
The result shows that for 4 inlet air flow conditions the pressure distribution in the room 2 is shown in Fig. 8(a). The pressure varied from 4.15 Pa ($1.28*10^{-2}$m) to $1.02*10^{-10}$ Pa ($4.01*10^{-1}$ m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average pressure of 4.16 Pa (3 m) and is shown in Fig. 8(b).




(a) (b)

**Fig. 9** (a) Temperature variation of the developed model in the workstation (b) Graphical representation of the temperature variation inside the workstation for 4 inlet flow

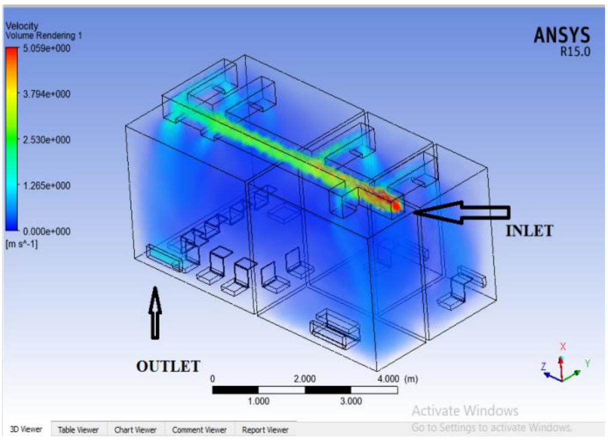
The results shows that for 4 inlet air flow conditions the temperature distribution in the room 2 is shown in Fig. 9(a). The temperature varied from 32.4°C ($1.28*10^{-2}$m) to 21.8.0°C (3.00m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average temperature of 21.0°C and is shown in Fig. 9(b).



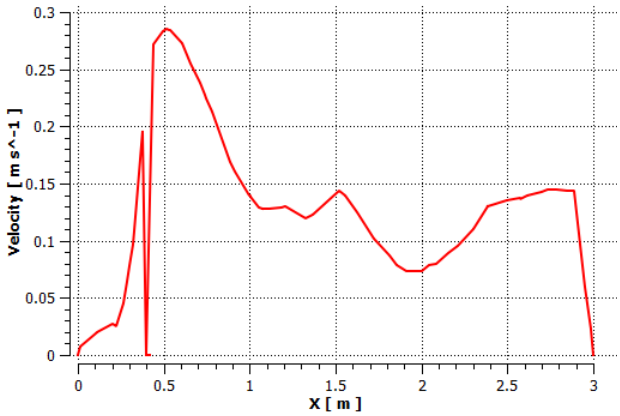

(a) (b)

**Fig. 10** (a) Turbulent kinetic energy variation of the developed model in the workstation (b) Graphical representation of the turbulent kinetic energy variation inside the workstation for 4 inlet flow

The results shows that for 4 inlet air flow conditions the turbulent kinetic energy distribution in the room 2 is shown in Fig. 10(a). The turbulent kinetic energy varied from $2.85*10^{-3}$ $m^2/s^2$ ($1.28*10^{-2}$m) to $3.51*10^{-4}$ $m^2/s^2$ (3.00m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average turbulent kinetic energy of $9.87*10^{-3}$ $m^2/s^2$ and is shown in Fig. 10(b).




(a)




(b)

**Fig. 11** (a) Velocity variation of the developed model in the workstation (b) Graphical representation of the velocity variation inside the workstation for 4 inlet flow

The results shows that for 4 inlet air flow conditions the velocity distribution in the room 2 is shown in Fig. 11(a). The velocity varied from $7.14*10^{-3}$ m/s ($1.28*10^{-2}$m) to $2.27*10^{-2}$ m/s (2.98m) at the entrance of the room 2 and it distributed continuously throughout the room 2 at an average turbulent kinetic energy of $8.71*10^{-2}$ m/s and is shown in Fig. 11(b).

Finally, four inlet air flow system shows that, airflow streamlines injected from the four separate channels by a angle of 45°. As per the ASHRAE 55-2013, the thermal comfort of psychological conditions for the thermal environment, for fangler method the minimum temperature is 21°C inside the room for the commercial building, to maintain the proper thermal characteristics. The present investigation clearly says that the 2 inlet air flow using CFD analysis by considering the value of pressure, temperature, turbulent kinetic energy and velocity of air flow measures 23°C whereas in case of 4 inlets air flow measures 21°C inside the room condition. Hence 4 inlets give a better performance and human comfort for thermal environment.

## CONCLUSIONS

In the present study 2 and 4 air flow inlet system were considered to determine the thermal characteristics (pressure, temperature, velocity and turbulent kinetic energy) of human comfort in the confined room by using CFD analysis. The overall thermal performance of the selected parameters for 2 and 4 inlet air flow revels that, 2 inlet air flow using CFD analysis by considering the value of pressure, temperature, turbulent kinetic energy and velocity of air flow measures 23°C whereas in case of 4 inlets air flow measures 21°C inside the room condition. Hence, 4 inlet air flow system gives a better thermal characteristics compare to 2 inlet air flow system and the optimum value for study state condition in case of 4 inlet air flow system is 21°C as per the ASHRAE 55-2013 standard.

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