Numerical Investigation to Study the Effect of Inlet Inclination on the Turbulence Intensity of the Naturally Ventilated Room Using CFD

Ghogare Abhijeet Ganesh, Shobha Lata Sinha, Tikendra Nath Verma, and Satish Kumar Dewangan

1 Introduction

The study of indoor thermal comfort deals with the effect of various factors that contribute to maintaining a favorable environment for an indoor human being. The term comforts in indoor environment quality studies psychological sensations and physiological factors such as the combination of acoustics, thermal conditions, and visual and indoor air quality with the help of a mechanically controlled heating/cooling ventilation system [1]. Indoor environmental quality defines the combination of all the above factors. For many years, these factors were studied separately by different experts in the field. Studies show that there is a direct relationship between indoor environment quality (IEQ), occupant health, comfort, and productivity [2]. The four major components of IEQ are thermal comfort, indoor air quality, acoustic comfort, and visual comfort. Thermal comfort is the situation of the mind that expresses gratification with the thermal environment. Many factors influence the thermal comfort of the building occupants. These factors are: metabolic rate, mean radiant temperature, air temperature, clothing insulation, operative temperature, airspeed, relative humidity, and turbulence intensity [3]. All the above factors were studied carefully by many of the researchers but the effect of turbulence intensity is paid less attention by the many studies. The inlet boundary conditions get affected by the turbulence intensity [4]. In this study, efforts have been made to study the effect of inlet fresh air inclination on indoor turbulence intensity of airflow. This paper focuses on the following important sections.

G. A. Ganesh · S. L. Sinha · S. K. Dewangan
Department of Mechanical Engineering, National Institute of Technology, Raipur 492013, India

T. N. Verma (✉)
Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal 462003, India

P. Verma et al. (eds.), *Advancement in Materials, Manufacturing and Energy Engineering, Vol. II*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-8341-1_49

2 Physical Problem

2.1 CFD Model and Case Description

The 3D CFD model of the office with a size of 4.8 × 2.6 × 2.4 m (L × H × W) was created with ICEM CFD software. The same office design was previously used in Oleson et al. in experimental work [5] and numerical work in Ganesh et al. [6]. The paper can refer to the details of the geometry. The room modeled by CFD is an empty office room with a double-panel radiator. The empty room was considered to study the indoor environmental conditions. Figure 1 shows the empty room, which consists of a double-panel radiator used for cold air heating purposes, window, insulated walls including the ceiling and flooring, a modifiable inlet, and an exhaust vent. The complete description of the geometric model is discussed in detail in the previous study [6]. The occupied zone has been created in the modeled empty office. The occupied zone in the office is the area 0.6 m away from every wall and up to the height of 1.8 m, which is generally the preferred zone for a human being for occupation. To analyze the comfort parameters in the occupied zone, four observation lines (l_1, l_2, l_3, and l_4) were drawn at a distance of $X = 0.6$, 1.8, 3.0, 4.2 m in the modeled fluid field of the office. The median plane that passes through the origin and is upright to

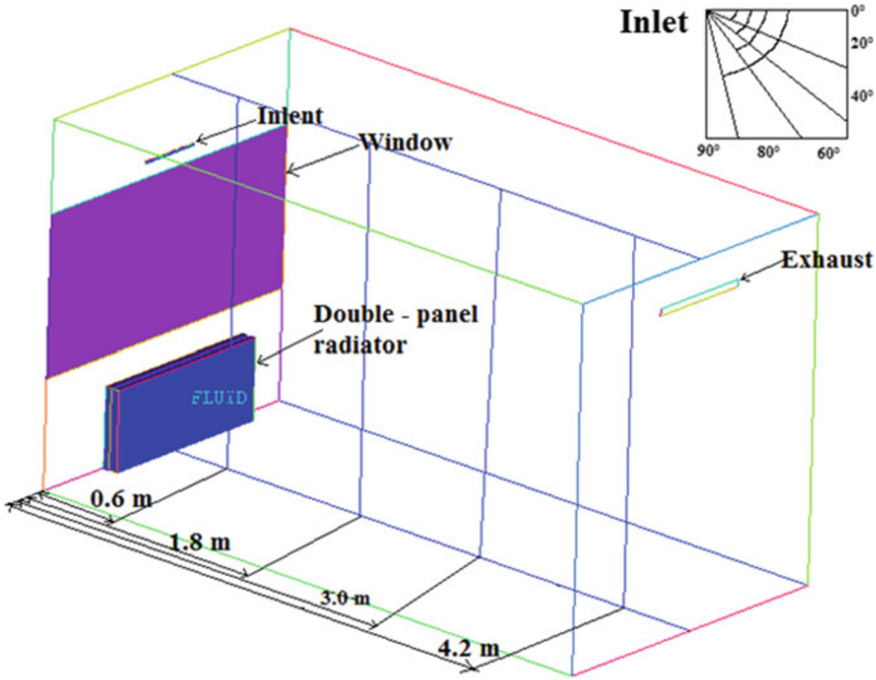


Fig. 1 Schematic representation of 3D modeled office

Table 1 Case study table

Case no	Inlet inclination (Degrees)
Inclination angle (1)	0
Inclination angle (2)	20
Inclination angle (3)	40
Inclination angle (4)	60
Inclination angle (5)	80

the *YZ* plane ($Z = 0$) was likewise traced to study the overall comfort condition in the room (Fig. 1).

The above office was modeled to analyze the indoor comfort environment required for the modeled room in cold weather conditions. Ambient thermal conditions in winter can be very cold, and therefore, the fresh −5 °C inlet air stream was taken from a modifiable inlet. The initial indoor air temperature was patched to 16 °C. All the walls were perfectly delimited and isolated to avoid the interface of heat between the interior and exterior environment of the room. For a favorable indoor environment, the temperature in the occupied zone should be kept in the range of 20–23 °C [3]. The constant heat flux for the dual panel radiator was provided to retain indoor thermal comfort. For a required indoor environment, the inlet air change rate kept constant at 7.3 l/s (0.8 h^{-1}) [7].

2.2 *Case Description and Boundary Conditions*

The detailed case studies performed are listed in Table 1. The present study carried out numerically using the following five cases. The five independent models were used to study the effect of inlet air inclination on turbulence intensity of airflow. The basic boundary conditions used in the study are listed in Table 2.

3 Numerical Methodology

Numerical study of the above problems needs to solve the governing equations of mass, momentum, and energy listed below, in Eqs. (1–5) [8]. For all types of flows, ANSYS FLUENT resolves conservation equations for mass and momentum. The problems involving heat interaction, energy conservation equations must be solved. Different types of turbulent models are available in Ansys fluent, the suitable turbulent model needs to be selected for the flow field analysis.

$$\frac{\partial \rho}{\partial t} + \nabla.\left(\rho_{\vec{V}}\right) = 0 \tag{1}$$

Table 2 Boundary conditions

Geometry	Boundary conditions
Inlet (1) Temperature (2) Air velocity	$T_{air} = -5$ °C $\dot{V}_{air} = 0.7$ m/s
Exhaust	Outflow
Window surface temperature	$T_W = 14$ °C
Walls	Insulated
Double-panel radiator	Constant heat flux To maintain 40–42 °C surface temperature
Turbulent model	k–ε Standard
Radiation scheme	DO Radiation
Pressure scheme	SIMPLE algorithm, 2nd order

$$\frac{\partial(\rho u)}{\partial t} + \nabla.\left(\rho u \vec{V}\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x \tag{2}$$

$$\frac{\partial(\rho u)}{\partial t} + \nabla.\left(\rho v \vec{V}\right) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} + \rho f_y \tag{3}$$

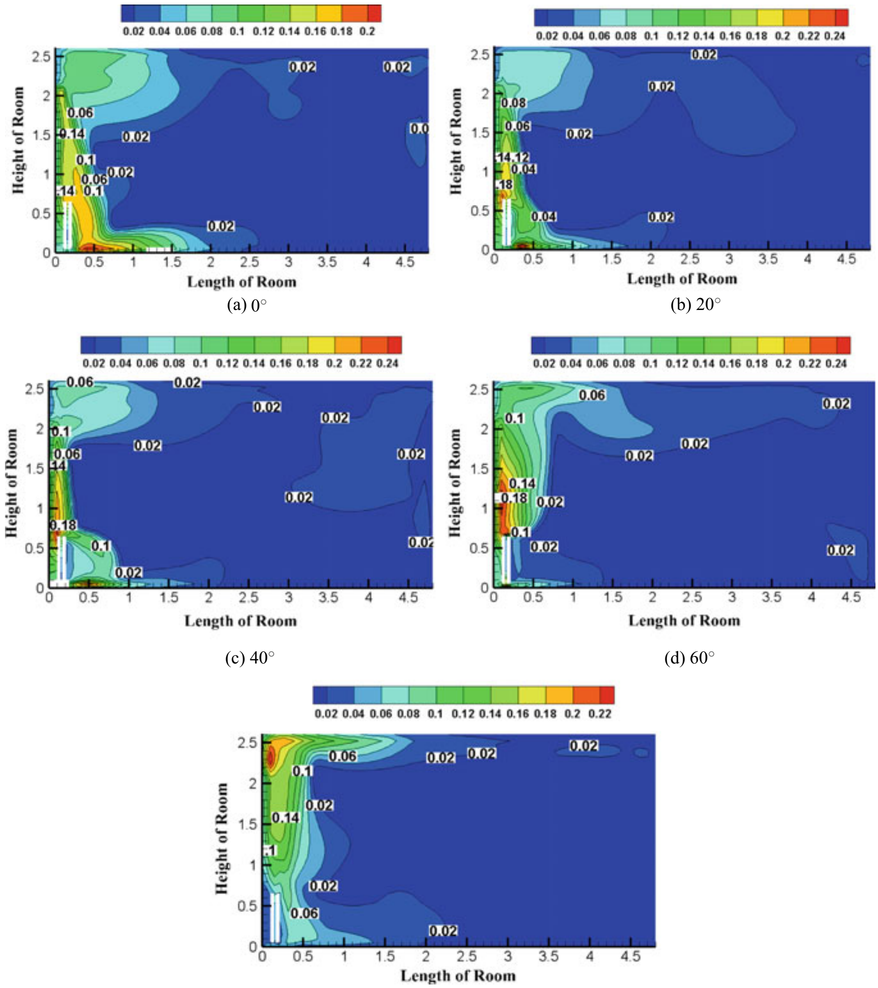
$$\frac{\partial(\rho w)}{\partial t} + \nabla.\left(\rho w \vec{V}\right) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f_z \tag{4}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{V}(\rho E + p)\right) = \nabla.\left(k_{eff}\nabla T - \sum_j h_j \vec{J_j} + \left(\overline{\overline{\tau}}_{eff} \cdot \vec{V}\right)\right) \tag{5}$$

Reynolds averaged Navies–Stokes equation was solved using k–ε turbulence model. The DO radiation model was employed to analyze the effect of thermal bands of the radiator.

4 Result and Discussion

The thermal comfort in the office room has been obtained using the heating double-panel radiator. The cold air entering the office is being heated by a double-panel radiator. The room air temperature was maintained at 23 °C for the thermal comfort of the indoor occupants. Figure 2 indicates the turbulent intensity variation due to the inlet air inclination. As the cold air enters from the inlet located exactly above the radiator, the cold air current tries to settle down on the ground due to its high density. Subsequently, the inlet cold air near the radiator gets heated and tries to move upward toward the ceiling. This flow of cold and downward flow of indoor air occurs due to the buoyancy effect. The buoyancy effect is stronger near the heating radiator



(a) 0°
(b) 20°
(c) 40°
(d) 60°
(e) 80°

Fig. 2 Turbulent intensity outlines at mid-plane ($Z = 0$) in an office with different inlet vent angles **a** 0°, **b** 20°, **c** 40°, **d** 60°, **e** 80°

and inlet vent location. This mixing of hot and cold air in this region results in air circulations and swirl. The area of this region can be termed as a mixing area. This high-intensity circulation of air in the mixing area is measured in terms of turbulence. The turbulence also affects the thermal comfort of an occupant. The higher amount of turbulence of indoor air results in intense cold sensation to occupant and creates discomfort. For acceptable thermal comfort, the turbulence region should not interact with the occupied zone. Hence in this study, to control and reduce the mixing area various inlet vent inclinations were analyzed. From Fig. 2a–e, it can be seen that the area of the mixing region varies as the inlet inclination increases. It is observed that as the inlet inclination increases the mixing region contracts at floor level and increases in the ceiling region. An increase in inlet inclination results in the mixing area since the cold air directly impinges on the radiator surface and gets heated immediately and reduces the mixing region length. From Fig. 2a–e, we can see that, as the inlet inclination increases the region of high turbulence (red-colored) of the fractional value of more than 0.2 shifts continuously upward in the y-direction. The higher turbulence in the ceiling region is acceptable as compared to the floor level. From Fig. 2e, we can see that the turbulence is minimum in the floor level and maximum in the ceiling region. This arrangement of inlet flow inclination is most favorable for thermal comfort as compared to the other inlet inclination settings.

5 Conclusions

Controlling only the turbulent intensity does not guarantee acceptable thermal comfort but there must be a proper balance between all the major thermal comfort parameters such as thermal comfort and air velocity [9]. But when analyzing the effect of inlet inclination on turbulence intensity the following outcomes can be drawn,

- The inclination of inlet flow affects the turbulence intensity in the mixing zone only.
- The buoyancy effect is predominant in the turbulence intensity.
- The increase in inlet inclination results in direct contact of cold and hot air, and it reduces the mixing zone.
- The occupancy in the mechanically controlled office should be away from the inlet vent and heating equipment to avoid discomfort due to turbulent intensity.
- For higher inlet inclination, the region of occupancy is larger and can be closer to the inlet vent and heating equipment.

References

1. Yang R, Wang L (2012) Multi-objective optimization for decision-making of energy and comfort management in building automation and control. Sustain Cities Soc 2(1):1–7. https://doi.org/10.1016/j.scs.2011.09.001
2. Yang W, Moon HJ (2019) Combined effects of acoustic, thermal, and illumination conditions on the comfort of discrete senses and overall indoor environment. Build Environ 148:623–633. https://doi.org/10.1016/j.buildenv.2018.11.040
3. International Standard Organization, ISO 7730 (2005) Ergonomics of the thermal environment-Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
4. Cao S-J, Meyers J (2013) Influence of turbulent boundary conditions on RANS simulations of pollutant dispersion in mechanically ventilated enclosures with transitional slot Reynolds number. Build Environ 59:397–407. https://doi.org/10.1016/j.buildenv.2012.09.004

5. Olesen BW, Mortensen E, Thorshauge J, Berg-Munch B (1980) Thermal comfort in a room heated by different methods, ASHRAE Transactions, Los Angeles Meeting, vol 86, Tech Paper no 2556
6. Ganesh GA, Sinha SL, Verma TN (2020) Numerical simulation for optimization of the indoor environment of an occupied office building using double-panel and ventilation radiator. J Build Eng. https://doi.org/10.1016/j.jobe.2019.101139
7. Al Assaad D, Ghali K, Ghaddar N (2018) The effectiveness of intermittent personalized ventilation assisting a chilled ceiling for enhanced thermal comfort and acceptable indoor air quality. Build Environ 144:9–22. https://doi.org/10.1016/j.buildenv.2018.08.005
8. ANSYS FLUENT 13 User's Guide. 2013. "Ansys Fluent Theory Guide." ANSYS Inc.,15317 (November): 724–746
9. Ganesh GA, Sinha SL, Verma TN (2020) Effect of inlet airflow direction on the indoor environment of a naturally ventilated room using CFD. ISSN: 2249-8958, vol 9, issue 3. https://doi.org/10.35940/ijeat.C5112.029320