Analysis of Thermal Comfort in an Office Space Using Two Typical Ventilation Modes.

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***Abstract*—This paper carried out a comparative study to evaluate the air-conditioning performance of an office space using two typical ventilation modes (displacement and mixing ventilation system). A wall supply diffuser is located outside the occupied zone for the mixing ventilation case, whereas, the supply diffuser is at the floor level for the displacement ventilation case. In both cases, the exhaust grill is located at the ceiling. From the result of the simulation, the researchers observed that the displacement ventilation system could have a higher risk of discomfort relating to vertical temperature gradient than when compared to the mixing ventilation case. More so, the simulation result indicates that the temperature distribution in an office building is a function of the type of ventilation system adopted and marginally affected by the diffuser arrangement.**

***Index Terms*—CFD; Thermal comfort; Temperature gradient; Displacement ventilation; Mixing ventilation.**

I. Introduction

Research on the indoor environment has received more attention recently because of the increase in reports of health symptoms related to indoor environment basically known as sick building syndrome.

Indoor air quality and thermal comfort are the most important characteristics of an indoor environment [1].

HVAC systems should provide appropriate air temperature by removing heat from the occupied zone while avoiding drafts, large air temperature gradients and large radiant asymmetry.

Note that in a ventilated room, two mechanical ventilation modes are widely used. These are the mixing ventilation and displacement ventilation. Most of the heating, ventilation and air conditioning (HVAC) systems used in Nigerian buildings are mixed ventilation.

Mixing ventilation has been the most important ventilation principle since the introduction of mechanical ventilation [2].

In mixing ventilation, stale warm room air are continually diluted by cooled fresh air blown at high speed (turbulent inlet jet) usually at a temperature of 16℃ into the room. The entrainment of the room air in the supply jet causes a high degree of mixing to take place. Fresh air is normally introduced and extracted at the ceiling level. Because air is supplied and extracted at the ceiling level, it will be difficult to achieve complete air mixing with this mode of ventilation because, some of the supplied fresh air may short circuit by being drawn into the extract grills which effectively reduces its cooling and pollutant dilution potential [3].

To improve indoor air quality, displacement ventilation seems to be a good alternative. Displacement ventilation is entirely buoyancy driven. In the displacement ventilation mode, fresh cold air is introduced at the floor level at low velocity. The supply air spreads out across the floor forming a reservoir of cool fresh air. Any heat source in the room will generate a positively buoyancy driven plume rising upward. The reservoir of cooled air is induced upward by rising convection flows from heat source in the room and then extracted at ceiling level.

According to [4], the air temperature gradient of a room with displacement ventilation supply system depends on:

1. Measuring point position (horizontal temperature distribution)
2. Cooling load
3. Ventilation rate
4. Diffuser shape

According to convention design practice and BRE investigation, displacement ventilation system in office(with floor to ceiling height up to 3m) are limited to $25^{w}/_{m^2}$ cooling capacity because the room air temperature gradient would become very high and would not be acceptable in terms of thermal comfort. In light of this, [5] while using CFD to predict thermal comfort parameters within an office environment however discovered that thermal discomfort associated with high temperature gradient observed in the displacement ventilation system can be avoided by optimizing the air supply velocity and temperature.

Reference [6], also opined that the volumetric air supply rate and temperature are very significant factors in determining the level of thermal comfort within an office space.

II. Methodology

A. CFD Model

The office space in the model contains an occupant, computer, window, table, diffuser and exhaust. The layout of the room is shown in Fig 1. The room is assumed to be thermally isolated on three sides and its base.

Reference [7], recommends that air velocity onto people should not normally exceed 0.15 to $0.2^{m}/_{s}$ depending on air temperature and turbulence intensity. For the displacement ventilation model, cold air enters the room from a plane wall floor mounted swirl diffuser (inlet) at temperature and flow

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velocity of 19℃ and 0.2m/s respectively. And for the mixing ventilation, the cold air enters the room from a mounted diffuser place outside the occupied zone with an air temperature of 16℃ at a flow velocity of 0.74m/s. For both CFD models, the stale air leaves the room through a ceiling mounted grill (outlet) as shown in Fig 1.

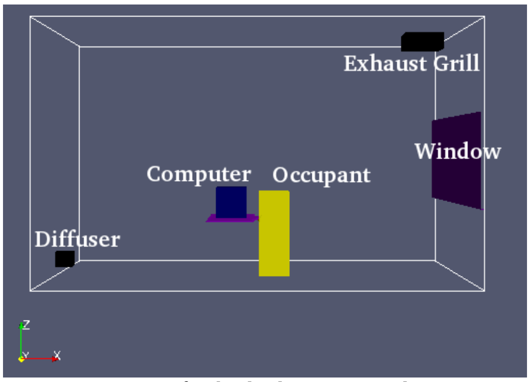

Fig. 1. Room Layout for the displacement ventilation scenario.

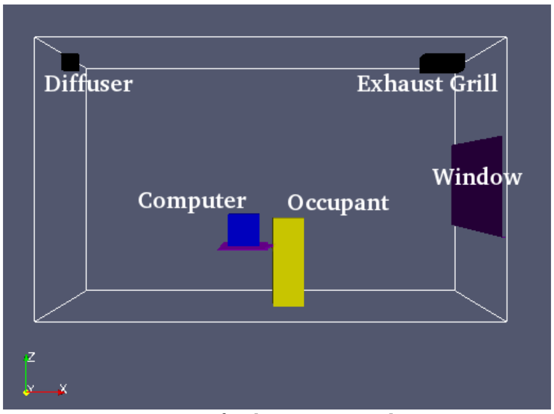

Fig. 2. Room Layout for the mixing ventilation scenario.

The heat sources are summarised below.

TABLE I: BOUNDARY CONDITION FOR HEAT SOURCE IN THE OFFICE

Heat source	Power(watts)
Occupant	75
Computer	40

For the study, the authors used "turbulent flow" and "heat transfer" in fluids in order to obtain airflow and thermal comfort due to forced convection in the office room. These physics solved the Navier stokes equation and continuity equation for air as well as the convection-diffusion equation for heat. SIMFLOW commercial CFD code was used to perform the simulation. Simple algorithm was used for pressure-velocity coupling; second order discritization scheme was used for both the convective and viscous terms of the fluid flow governing equation. Since the flow is turbulent and buoyancy driven, buoyant simple foam compressible flow solver was adopted. Gradient limiters were used in the gradient terms in order to avoid over and under shoots on the gradient computation.

The steady state analysis used to develop the adaptive mesh was carried out using an RNG KE turbulence model since it has been proven to be more accurate than the standard K.E turbulence model for indoor airflow simulation [6]. Convergence was observed by monitoring temperature variable at a boundary and by checking for overall flux conservation.

B. Thermal comfort

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment [7]. The main factors influencing thermal comfort are air temperature, radiant temperature, air velocity, humidity, clothing and activity.

The current study used the following parameter to evaluate the thermal comfort in the office building:

- Percentage of dissatisfied people due to draft(PD)
- Percentage of predicted dissatisfied people(PPD)
- Temperature gradient

According to the equation of percentage of dissatisfied people (PD) as stipulated in [7],

PD= $(34-T)(u-0.05)^{0.62}(3.14+0.34uT_u)$
Where $T_u = 100(2K)^{0.5}/u$ for PD>100%, PD=100%

The formula for calculating PPD can also be found in [7]:
PPD = $100-95e^{(-0.03353pmv^4-0.2179pmv^2)}(100\%)$

The PMV (predicted mean vote) = $(0.303e^{-0.036m} + 0.028)L$

Where L = thermal load on the body, L= difference between heat production and heat loss to the actual environment.

M = Rate of metabolic heat production $({}^{W}/{}_{m^2})$ = $58.15\,{}^{W}/{}_{m^2}$

Reference [7], also provides the mean radiant temperature equation for forced convection as follows:

$T_r = [(t_g + 273)^4 + \frac{1.1\times10^8 u^{0.6}}{\varepsilon d^{0.4}} \times (t_g - t_a)]^{0.25} - 273$

For a standard globe value of ε = 0.95 and d = 0.15m

III. RESULT AND DISCUSSION

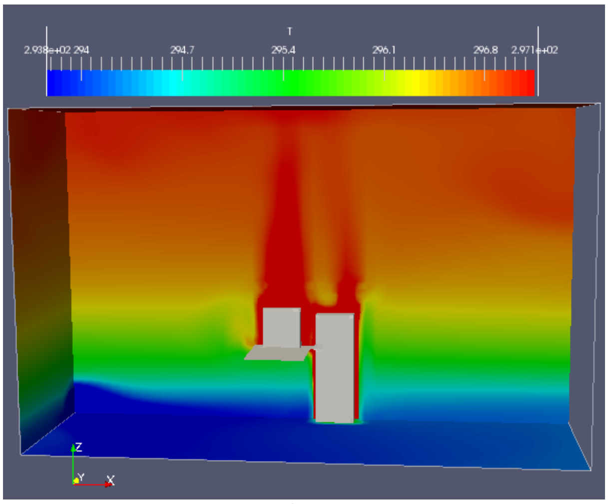

Fig. 3. Temperature distribution for the displacement ventilation case

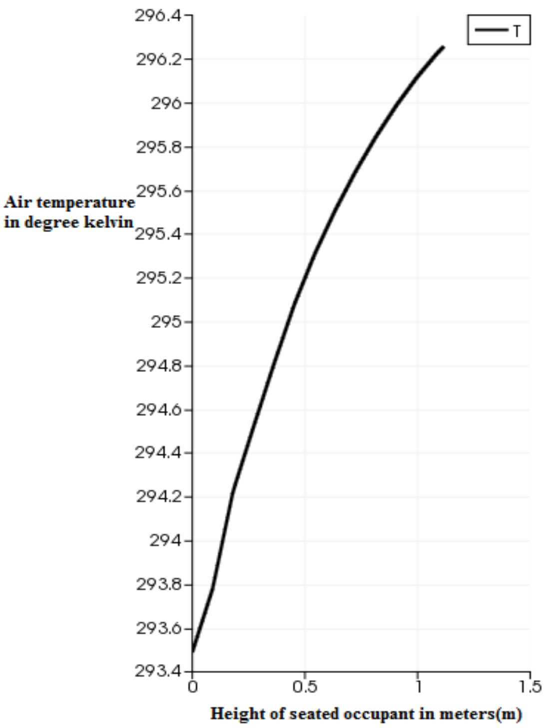

Fig. 4. Air temperature at head region of seated occupant for the displacement ventilation case.

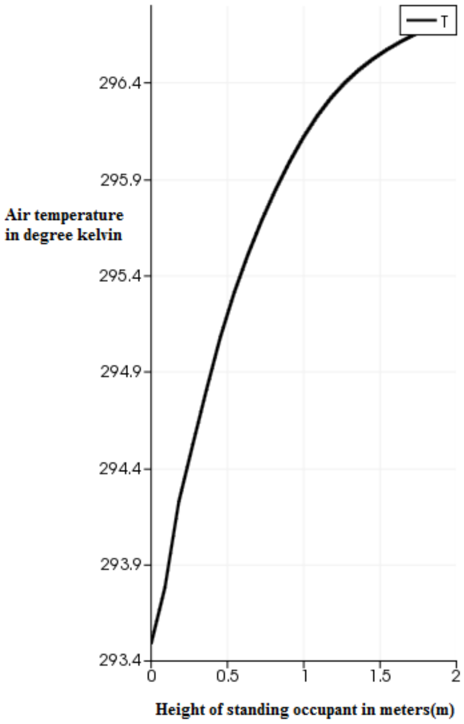

Fig. 5. Air temperature at head region of standing occupant for the displacement ventilation case.

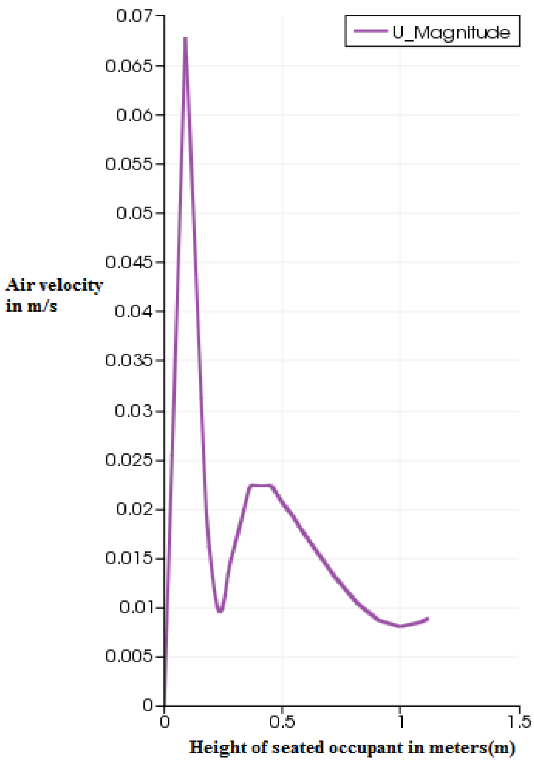

Fig. 6. Air velocity at head region for seated occupant for the displacement ventilation case.

As can be seen in the displacement ventilation scenario (Fig. 3), two distinct stratified layer zone containing warm air and a lower zone containing cooler cleaner air is separated by a boundary layer. This causes a vertical temperature gradient to develop between the supply and extract grills respectively resulting in higher uncomfortable temperature at ceiling level than in the mixing ventilation scenario. The air temperature recorded at the ankle and head region for the displacement ventilation simulation is at approximately 23.1℃ and 20.7℃ respectively leading to a temperature gradient of 2.3℃.

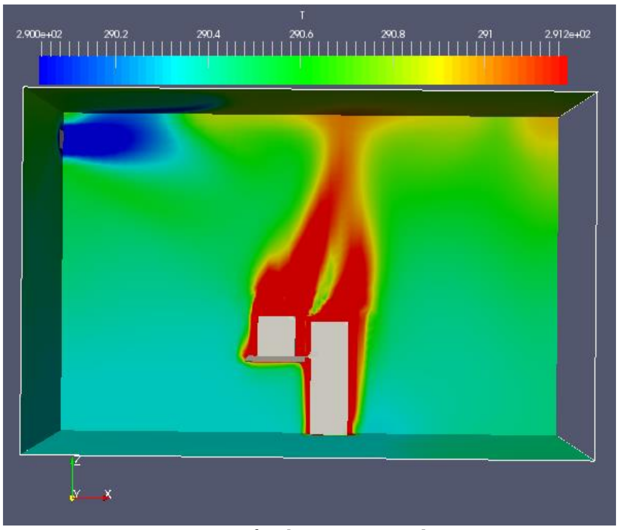

Fig. 7. Room Layout for the mixing ventilation scenario.

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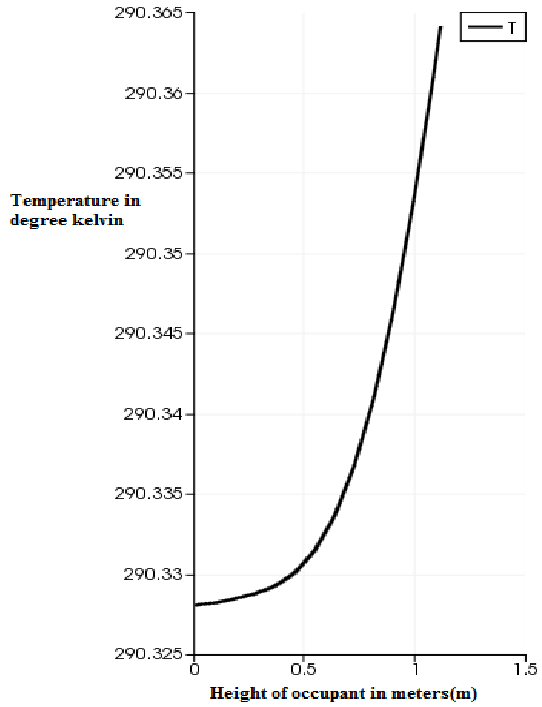

Fig. 8. Air temperature at head region for seated occupant in the mixing ventilation case.

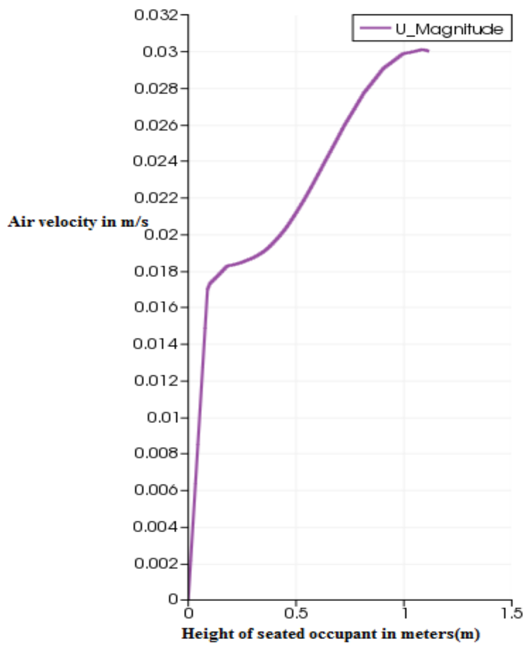

Fig. 9. Air velocity of seated occupant in the mixing ventilation case.

In the mixing ventilation simulation, a significant temperature gradient was not noticed between the ankle and head region for seated occupant. The mixing ventilation case recorded uniform temperature within the breathing zone (0-1.8m) unlike displacement ventilation in which a significant temperature difference was observed between the ankle and head region. As can be seen in the contour diagram (Fig. 4), the air temperature at the head and ankle region for the seated occupant is at approximately 17℃ respectively. Due to the placement of the diffuser and exhaust grill in the mixing ventilation case, the supply air was not short circuited. The hot air from the heat source was continually diluted by the cold fresh air from the diffuser as a result of the mixing process.

Average air temperature, air speed along with the mean radiant temperature, metabolic rate, relative humidity and clothing level are needed to estimate the predicted mean vote. The metabolic rate of an occupant doing sedentary office activity is 1.2met. The authors assume that the occupant is wearing trousers and a long sleeve shirt and therefore his clothing level is 0.6.

If the assumed relative humidity is at 50% and the calculated mean radiant temperature for the displacement and mixing ventilation case is 23.6℃ and 17.6℃ respectively.then the predicted mean vote (PMV) for the displacement and mixing ventilation simulation is at 0.23 and -1.85 respectively.

The result of predicted people dissatisfied shows that the probability of the occupant being dissatisfied with the office room temperature is 6.1% for displacement ventilation and 69.6% for mixing ventilation with the sensation of being cold.

IV. Conclusion

The study presents a CFD simulation of airflow in a ventilated room. The CFD simulation was performed to study airflow and thermal comfort of an office building using the displacement and mixing ventilation system. Several CFD simulations using the three dimensional steady state compressible Navier stokes equations with the RNG KE turbulence model was performed.

From the result of the simulation, indoor spaces with displacement ventilation system when compared to the traditional mixing ventilation, showed higher risk of experiencing thermal discomfort caused by the temperature stratification (vertical temperature gradient) between the ankle (0.1m) and the head level (1.8m) when there is a presence of higher cooling loads. However, the authors conclude that with proper placement of the air diffuser, mixing ventilation system can serve as a more efficient method in improving the thermal comfort of occupants within an office space.

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