International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Influence of Subjective Cooling Zone Flow Field on Human Comfort Level

Wajdi Qassim Hussen*

Mechanical Eng. Dept., Engineering Technical College–Baghdad, Middle Technical University, Iraq

Accepted 15 Jan 2017, Available online 25 Jan 2017, **Vol.7, No.1 (Feb 2017)**

Abstract

The flow field produced by subjective cooling conduits for a room at 39°C was studied experimentally and numerically. A typical office room was chosen and temperature measurement was conducted in the subjective cooling site. The numerical simulation was used to estimate the air velocity and distribution throughout the volume under consideration. Depending on the position of the air jets and the horizontal plane, the air velocity through room volume was ranged from 0.1 to a 0.4m/s. More uniform temperatures of 23°C were measured for the case of 0.6m width space. While the temperature variation, through room volume, for the other cases was in the range of 24 to 27°C.

Keywords: *Air distribution system, Subjective Cooling, Air conditioning.*

1. Introduction

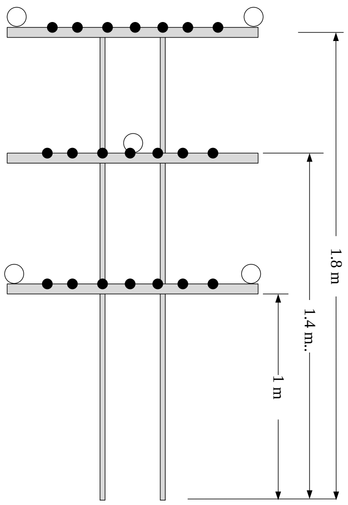
Subjective cooling is appealing to engineers in terms of energy saving and the flexibility in customizing near zone region to accommodate occupants comfort. As it is well known, that human comfort affects their health, life quality, and productivity (ASHRAE, 2004). However; undesirable outcome associated with air velocities higher than say 0.2 m/s (Modeste *et al*, 2014; Fountain, and Arens, 1993).Vertical temperature gradient as well as annoying turbulence intensities were documented (Fountain, and Arens, 1993). Many variables interact in a complicated manner to affect human comfort, such as temperature, humidity, air movement, turbulence level, and other personal/environmental parameters.(Modesta *et al*, , 2014) investigated the mutual effect of temperature and air speed on human comfort with the aid of field measurements and feedback from many voters. They concluded that more than 75% of the voters requested higher air velocities than measured values. (Djamila, *et al*, 2014) discussed the reasons that make natural breeze and winds seem more comfortable to occupants than constant air movement generated by traditional air conditioning devices. They also incorporated the effect of turbulence characteristics in their study. They concluded that it is the inconsistence nature of winds is what makes it more comfortable. (Zoran, *et al*, 2012) have prepared a questionnaire to examine the thermal sensation of three males and three females sitting on chairs with different designs to accommodate subjective comfort. They concluded that there is no correlation between actual temperature and relative humidity for subjects' sensation on different parts of their bodies. An older work of (Hayato, *et al*, 2007) presented the opinions of six males subjected to single diffusers supply. The subjects felt the draught on their heads while other body parts were warm. (Henna, *et al*, 2016) in a most recent work studied the effect of subjective cooling jets on the cognition ability of 29 students. They found positive responses from the subjects regarding cognition and comfort in a large office which otherwise could not be environmentally controlled. In this work the supply air was distributed among six jets at different heights in an effort to improve the understanding of a subjective cooling site generated flow field. A set of experiments was conducted as well as a numerical simulation. It was aimed to measure and visualize the temperatures, and air velocities, all around the generated field.

2. Experimental setup

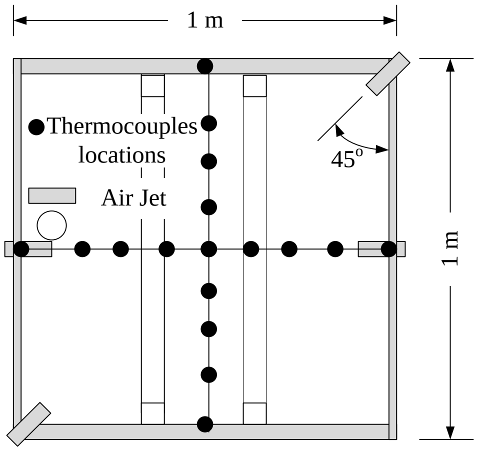
A typical office room of dimensions (3m x 4m x 2.5m) was chosen to carry out the intended experimental sets. The room was furnished with three laboratory supervisor desks and chairs. It has one 4m side wall (facing west) exposed to the outdoor environment while all other walls were internal. The west wall has a (2m x 2m) window. The (1.5m x 2m) door is located in the north wall. An Aluminum structure of (1m x 1m x 2m) was assembled to hold the supply conduits and all

*Corresponding author: **Wajdi Qassim Hussen**

measuring instruments as shown in Figure 1. Six supply conduits were used, four conduits are installed at the two opposite corner of the first and third levels, while the other two conduits are installed at the middle of the second level as shown in figure (1b). The heights of the levels from the floor are 1, 1.4, and 1.8 m. The cold air supply conduits were of circular cross section tubes of 30mm diameter. The angle of the conduits installed at the first and third levels is 45 °C, as shown in figure (1b.) The room temperature was 39°C.



a-Front view of the aluminum frame



b-Top view of the aluminum frame

Fig. 1 Thermocouples and air jets location

The cold air temperature and relative humidity were held constant in the whole sets of experiments as it was supplied from a nearby air conditioning facility. Inlet air velocity was changed for each experiment from 1 to 1.5m/s. A cluster of 54 thermocouples of type K were distributed throughout the domain confined by the structure, as shown in figure (1).

A second set of experiments was performed after adjusting the dimensions of Aluminum frame structure to (0.6m x 0.6m x 2m) keeping all other configurations fixed.

3. Numerical solution

The Navier-Stokes equations were solved in the three dimensional domain surrounded by the structure as well as the continuity, energy and turbulence model equations. The air is assumed as incompressible gas except for the density variation with temperature (Boussinesq approximation). The field is assumed steady and turbulent (k-ε turbulence model was used) (Mathias Cehlin *et al*,2006):

The continuity equation:

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

The three dimensional momentum equations in vector form:

$$\rho \frac{DV}{Dt} = -\nabla P + \mu \nabla^2 V + \rho_0 \beta (T_o - T) g\hat{k} \qquad (2)$$

The energy equation in tensor form:

$$\frac{\partial}{\partial x_i}\left[\rho\, u_i \left(E + \frac{P}{\rho}\right) + q_i\right] = 0 \qquad (3)$$

The kinetic energy of turbulence equation in tensor form:

$$u_i \frac{\partial k}{\partial x_i} = \tau_{ij} \frac{\partial ui}{\partial xj} - \epsilon + \frac{\partial}{\partial xj}\left[\left(\upsilon + \frac{\upsilon_t}{\sigma_k}\right)\frac{\partial k}{\partial xj}\right] \qquad (4)$$

The turbulence energy dissipation rate equation in tensor form:

$$u_j \frac{\partial \epsilon}{\partial xj} = C_{\epsilon 1} \frac{\epsilon}{k} \tau_{ij} \frac{\partial\, ui}{\partial xj} - C_{\epsilon 2} \frac{\epsilon^2}{k} + \frac{\partial}{\partial xj}\left[\left(\upsilon + \frac{\upsilon_t}{\sigma_\varepsilon}\right)\frac{\partial \epsilon}{\partial xj}\right] \qquad (5)$$

Closure Coefficients and Relations:

$C_{\varepsilon 1}$ = 1.44, $C_{\varepsilon 2}$ = 1.92, $C_{\varepsilon\mu}$ = 0.09, σ_k = 1.0, σ_ε = 1.3, β = $1/T$, $\nu_t = C_{\epsilon\mu} k^2/\varepsilon$, $\tau_{ij} = \upsilon_t\left(\frac{\partial ui}{\partial xj} + \frac{\partial uj}{\partial xi}\right)$

An open source C++ software (CYCLONE Fluid Dynamics B. V. Dolphyn ver. 0.60) was used to perform the numerical computations. A text input file is required with no automatic mesh generator or visual display; thus the input data were coded manually.

The output of the simulation was directed to a text file and then processed by graphics software (Microsoft EXCEL). The boundary conditions imposed on the solution domain were the inlet air velocity, temperature, and turbulence intensity as well as room walls no slip and heat conductive conditions (figure 2).

4. Results and Discussion

Figure 3 displays the measured temperature across the horizontal plane located at the first level of 1m from the floor of set 1. The temperature gradient across the main diagonal direction, through the area of interest in which the subject supposedly sitting or standing, is around 2°C. The gradient is slightly higher across the minor diagonal direction. This plane hypothetically passes through the chest of the sitting person and the hip of a standing person.

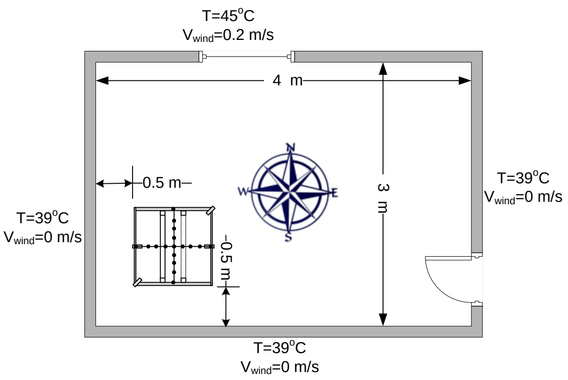


Fig. 2 The room plan showing the frame and the boundary conditions

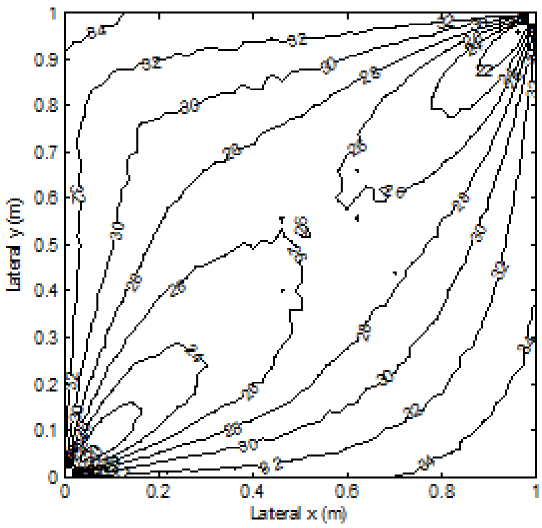


Fig. 3 Measured Temperature gradient at height of 1m and 1 m/s jet velocity

Figure (4) shows the vectors are shown for set 1 experiment, in which the x-y velocity components are drawn to scale showing their tendency to disperse towards the center. The total velocity contours that shown in figure 5 are comfortably low in the subject's area which varies from 0.1 to 0.2m/s, although it varies from person to person, and depends on many other factors such as thermal history, turbulence level, etc. (Catalina, *et al*, 2009; Djamila, *et al*, 2014). When the jet outlet velocity increases to 1.5m/s, a higher temperatures were observed in the subjective region but with a more uniform value of around 26°C as shown in figure 6. Meanwhile Figure 7 shows a higher total velocities, the range of the total velocities were ranging from 0.2 to 0.4m/s which almost double what were produced by the 1m/s jets. As the second subjective envelope was used, a lower but uniform temperature of (24°C) was observed with slightly higher velocities ranged from 0.1 to 0.3m/s as shown in figures 8 and 9.

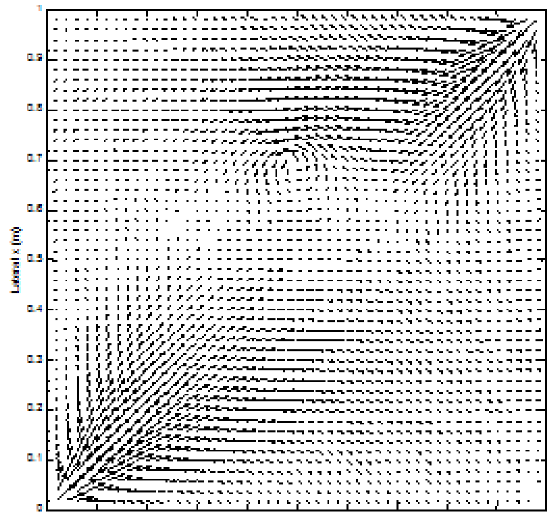


Fig.4 Velocity vectors in a 1m height horizontal plane of set 1

Decreasing subjective area have more preferable effects than increasing jet velocity in terms of temperature uniformity and level, and in terms of velocity magnitude from thermal sensation perspective. At the next level of 1.4m from the floor, set 1, in which the jets are aligned midway along the opposite sides, the temperature distribution has almost the same shape as in the figure (8), for set 2 but with narrower temperature bands was observed as shown in figure (10) which implying higher gradients. This plane may represent the near head level for sitting subjects or chest level for standing subjects.

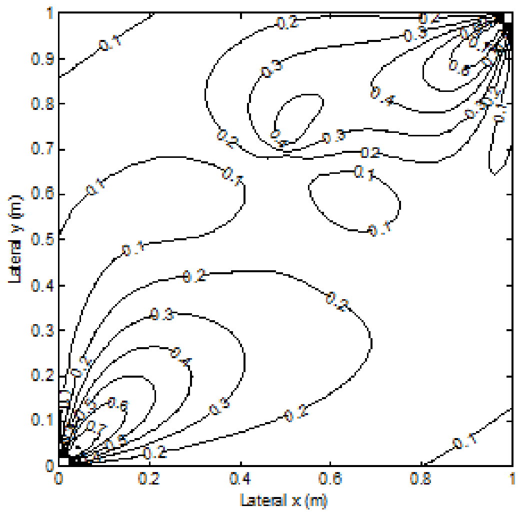


Fig. 5 Total velocity contours at height of 1m and 1 m/s jet velocity of set 1.

The velocity contours for this plane ranged from 0.1 to 0.2m/s that is shown in figure (11). The last level, of 1.8m from the floor, is representing the near head region for a standing person.

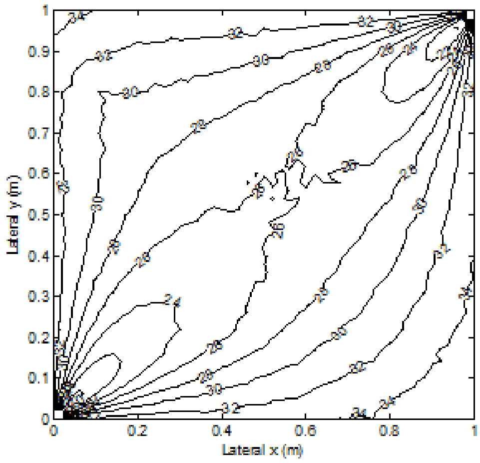


Fig.6 Measured Temperature at height of 1m and 1.5m/s jet velocity of set 1

The temperature values for this plane are higher than that for other planes, with an average temperature around 27°C as shown in figure (12). This temperature is slightly higher than the comfortable levels. The velocities are also higher and ranged from 0.1 to 0.3m/s which may be preferred to compensate for the higher temperatures.

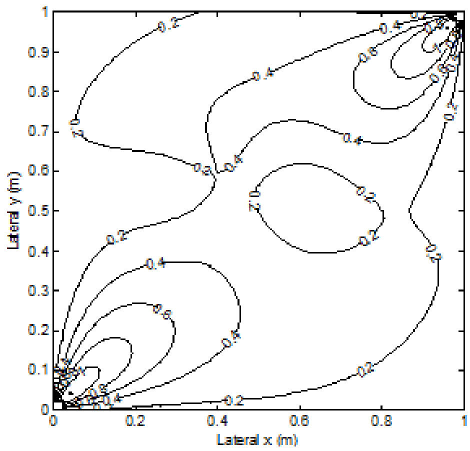


Fig.7 Total velocity contours at height of 1m and 1.5m/s jet velocity

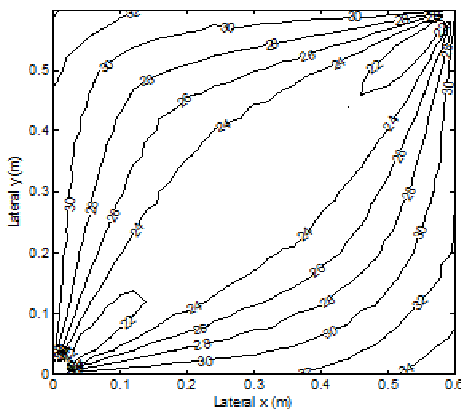


Fig. 8 Measured Temperature at height of 1m and 1m/s jet velocity of set 2

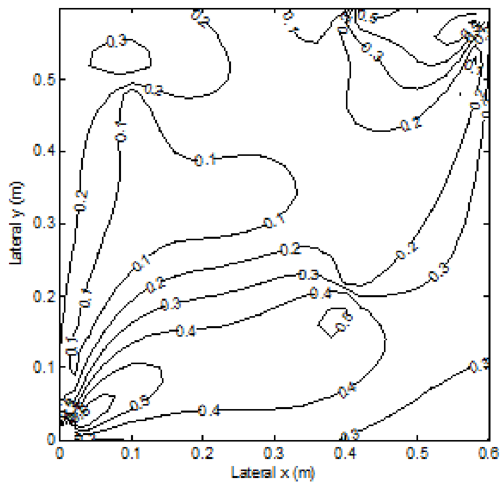


Fig. 9 Total velocity contours at height of 1m and 1.5m/s jet velocity of set 2

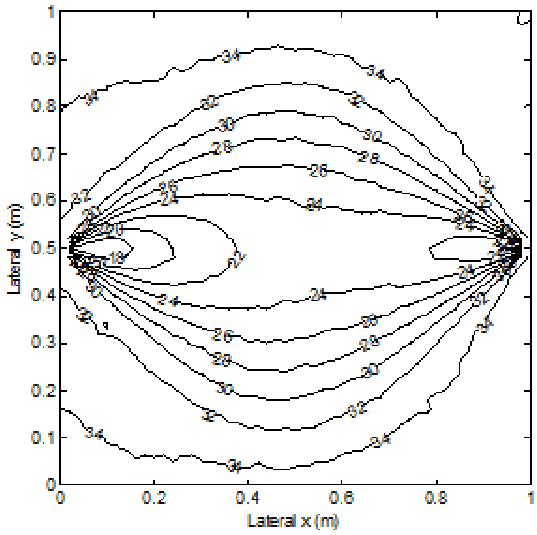


Fig.10 Measured Temperature at height of 1.4m and 1m/s jet velocity

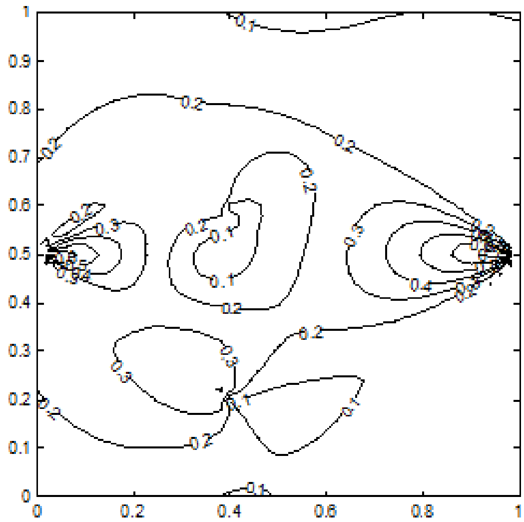


Fig. 11 Total velocity contours at height of 1.4m and 1m/s jet velocity

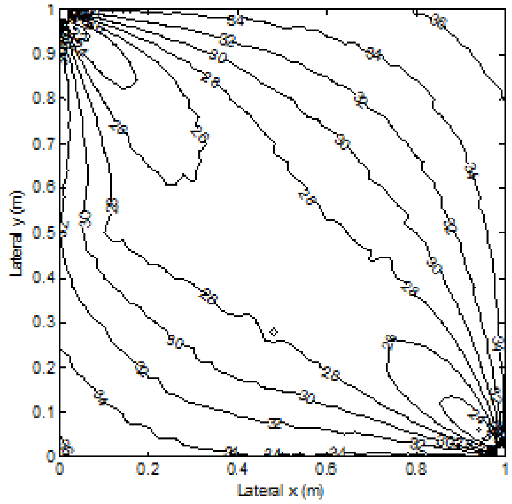


Fig.12 Measured Temperature at height of 1.8m and 1m/s jet velocity

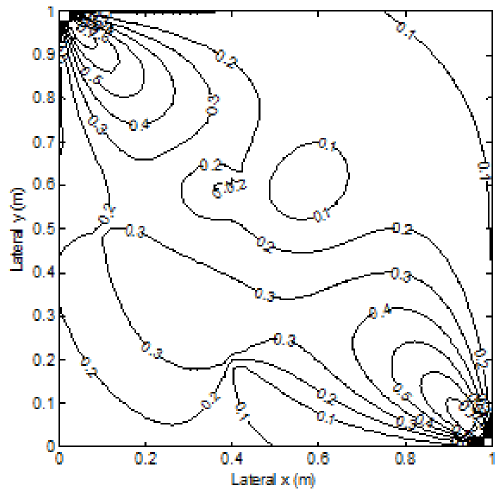


Fig.13 Total velocity contours at height of 1.8m and 1m/s jet velocity

Conclusions

1. The air Jets produced a temperature field with 2 °C temperature difference around the person, and the velocities below 0.2 m/s for level 1 of set 1.
2. Increasing jet velocity increases the temperature uniformity around 26 °C but increases air velocities to around 0.4 m/s.
3. Decreasing the controlled volume results in some more uniform lower temperatures of 24°C with slightly higher velocities of around 0.3 m/s, which is more useful than increasing jet velocity.
4. The last plane (1.8m height) showed higher temperature and velocity levels.

References

American Standards of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Standard 55-2004. Atlanta: ASHRAE, 2004.

Catalina, T., Virgone, J., and Kuznik, F. (2009), Evaluation of Thermal Comfort Using Combined CFD and Experimentation Study in a Test Room Equipped with a Cooling Ceiling, Building and Environment 44, no. 8;1740–50.

Djamila, H., Ming, C. C., and Kumaresan, S. (April 2014), Exploring the Dynamic Aspect of Natural Air flow on Occupants Thermal Perception and Comfort, Proceedings of 8th Windsor Conference, Windsor, UK, 10-13. London.

Fountain, M.E., and E.A. Arens, (August 1993), Air movement and thermal comfort. Ashrae Journal, 35(8), , pp. 26-30.

Hayato, O., Hitomi, T., Shin-ichi, T., Ken-ichi, K., Hideaki, M., and Koji, K. (2007), Subjective Thermal Comfort in the Environment with Spot Cooling System, Proceedings of Clima, Well Being Indoors, FINVAC, Helsinki (Finland), 978-952-99898-2-9.

Henna, M., Valtteri, H., Hannu, K., and Annu, H. (April 2016), The effect of cooling jet on work performance and comfort in warm office environment, Building and Environment, 104

Mathias Cehlin (2006), Visualization of Airflow, Temperature and Concentration Indoors: Whole-Field Measuring Methods and CFD (Gävle), PhD theses.

Modeste, K.N., Tchinda, R., and Ricciardi, P. (2014), Thermal comfort and air movement preference in some classrooms in Cameroun, Revue des Energies Renouvelables Vol. 17 N°2 263 – 278.

Zoran, V., Danijela, D., Ivica, Ž., and Ivica, G. (2012), Thermal Comfort While Sitting on Office Chairs-Subjective Evaluations, Drvna Industrija, 63 (4), 263-270.

Notations

$C_{\varepsilon\mu}$: Constant used to calculate the turbulent viscosity.
$C_{\varepsilon 1}$, $C_{\varepsilon 2}$: Constants used in equation 5.
E: Total Energy (kJ/kg).
G: Acceleration due to gravity (9.81 m/s^2).
i,j: Tensor indices.
K: Kinetic energy of turbulence (m^2/s^2).
$\hat{k}$:Unit vector aligned with the gravity.
P: Pressure (kPa).
Qi: Diffusional heat fluxes (W/m^2).
T: Temperature (°C).
T_o: Reference temperature (°C).
Ui: Velocity components (m/s).
V: Velocity vector (m/s).
Xi: Spatial coordinates (m).
Β: Coefficient of thermal expansion (K^{-1}).
Ρ: Density (kg/m^3).
$Ρ_o$: Reference density (kg/m^3).
σ_k, σ_ε: Constants used in equations 4 and 5.
Ε: Turbulent energy dissipation (m^2/s^3).
Tij: Turbulent stress tensor (m^2/s^2).