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# NUMERICAL SIMULATION OF AIR VELOCITY AND TEMPERATURE DISTRIBUTION INSIDE A TWO DIMENSIONAL OFFICE ROOM

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## Abstract

A two dimensional turbulence **(SST, k-ω)** model is used to predict the distribution of air velocity and temperature in a 2-D office room, containing one person and office furniture for two ventilation conditions. This study use a commercial **CFD code FLUENT (version 6.3)** for solving the Navier Stocks, energy and turbulence equations using finite volume techniques. The results were presented as velocity vectors with quantitative velocity and temperature distribution.

The result can be divided into two parts, First part compared with published result and gives good theoretical agreement, the second part was taken at boundary conditions **($V_{in}$, $T_{in}$ and $T_{wall}$)** according to the Iraqi environmental condition depend on the Iraqi cods of cooling 2012.

**Keywords: Room Heat Transfer, Air Distribution, Temperature Distribution,Numerical Simulation.**

# محاكاة نظريه لتوزيع سرعه ودرجه حرارة الهواء داخل غرفه مكتبيه ثنائية الأبعاد

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## الخلاصة

نظام الاضطراب المسمى **(SST, k-ω)** استخدم لتنبؤ توزيع سرعة ودرجه حرارة الهواء في غرفه مكتبيه ثنائيه الأبعاد, تحتوي على شخص واحد وأثاث مكتبي لنوعين من ظروف التهوية. قد استخدم في هذه الدراسة البرنامج الحاسوبي **FLUENT (الإصدار 6.3 )** لحل معادلات **Navier Stocks** ومعادلات الطاقة والاضطراب باستخدام تقنية الفروقات المحددة **(Finite Volume Technique)**. النتائج عرضت على شكل متجهات للسرعة داخل الحيز ومقادير كميه لتوزيع سرعة ودرجة حرارة الهواء.

يمكن تقسيم النتائج إلى قسمين , الأول تمت مقارنته مع نتائج لبحوث سابقه وقد كانت النتائج النظرية مطابقة للبحوث المنشورة , والقسم الثاني اخذ عند ظروف حديه **($V_{in}$, $T_{in}$ and $T_{wall}$)** وفقا للأجواء المناخية للعراق بالاعتماد على المدونة العراقية للتبريد 2012.

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## 1. Introduction

Understanding of indoor air distribution characteristics is essential to the design of ventilation systems and to the control of room thermal and air quality conditions. The indoor environment design requires detailed information about air distribution such as air flow, velocity, temperature and pollutant concentration. **CFD** has been widely applied to various engineering problems. A field in which **CFD** is becoming increasingly active for system design, optimization and diagnosis is heating and ventilation in buildings. The literature includes many investigations related to the topic of ventilation inside an enclosure. **Bartak et al. (2001),** presented results from experimental and numerical study of a room with mixing ventilation, focused on the local mean age of air **(LMA).** An important issue is that the coarse grid computations are reasonably close to the measured values, which allows the computation of **(LMA)** to be made on relatively coarse numerical grids sometimes (as in the present study) as low as approximately 1000 grid points. **Mora et al. (2002),** checked the effectiveness of both zonal and coarse **grid k-$\varepsilon$** to predict air flow and temperature profiles in a two-dimensional building zone. They concluded that zonal models are suitable tools to assess thermal efforts in rooms, and the coarse grids k-$\varepsilon$ is an appropriate method to quickly estimate details of air flow in rooms. **Hanaa, (2003),** study three-dimensional, turbulence recirculating flows within mechanically ventilated enclosure and demonstrate that the flow behavior depend on several parameters, such as the inlet\outlet sizes, temperature differential and inlet velocity. **Abdul-Jabar, (2004),** reported a numerical study of two-dimensional, turbulent buoyant recirculating flow within mechanically ventilated room. These studies demonstrate that the flow behavior depends on several parameters, such as airflow rate equal to (5,10,16,and 21$m^3$/s), size and temperature of heated obstruction and air change per hour (17,25,and 35). Each of these parameters was modeled separately to understand how each parameter affects the airflow characteristic inside the ventilated room. Khudheyer **S. Mushatet, (2007)**, used a two-dimensional turbulence k-ε model to predict the distribution of air velocity, temperature and turbulence kinetic energy in a ventilated room using different positions of inlet and outlet apertures. This study focused on the prediction of turbulent recirculating flows in large indoor spaces. The results show that the wall jet region and recirculation regions are affected by the position of inlet and outlet apertures. Also the results indicate that recirculation regions are increased with increasing Reynolds number and decrease with decreasing aspect ratio. **Q. Kong, B. Yu, (2008),** presented a numerical prediction using computational fluid dynamics **(CFD)** utilized to investigate air temperature stratification in a room with an underfloor air distribution **(UFAD)** system. The results show that the effect of three parameters, heat load, supply volume flux and supply air velocity, on room air temperature would be expressed by the length scale of the floor supply jet. **Cuimin Li and Jianing Zhao, (2012),** analyzed the indoor temperature field for Gravity air-conditioning, which is a new technology. The result shows that in working area, the maximum temperature gradient is about 3°C and the percentage dissatisfied **(PD)** is less than 4%, which can meet the thermal comfort requirement. The temperature in working area is in the range of 23°C ~ 28°C in the experiment, which can meet the cooling requirement. The indoor temperature field presents uniform temperature distribution in the horizontal level and layered distribution in the vertical direction, which is consistent with the normal distribution of displacement ventilation.

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The aim of this paper is to evaluate the usefulness of **CFD** techniques in modeling room air flow. This evaluation process involves numerical simulation to continuity, momentum and turbulence equations for steady incompressible flow in ventilated room by using shear-stress transport (SST, k-w) model to predict the velocity and temperature distribution inside a 2-D office room.

## 2. Mathematical Model

Figure 1, shows a two-dimensional schematic diagram of the office room investigated. All necessary information regarding the room is clearly indicated on this drawing.

As can be seen from this Figure the office room is equipped with standard office material. This has been kept to a minimum with one person, a chair, a desk, and a shelf. Numerous different alternatives are possible, however, the choice made is sufficient for the purpose of this investigation **[S. Baskaya 2006].**

### 2.1 Governing Equations

The governing equations of motion based on Navier-Stockes equations conservation form for continuity, momentum and transport equations of turbulence **(SST, k-w)** are as follows: **[ Abdul-Jabar, 2004],[ FLUENT 6.3 Documentation,2006]**

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad \text{...eq.(1)}$$

$$\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+2\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial v}{\partial x}\right) \quad \text{...eq.(2)}$$

$$\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial x}+2\frac{\partial}{\partial y}\left(\mu_{eff}\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial x}\left(\mu_{eff}\frac{\partial u}{\partial y}\right) \quad \text{...eq.(3)}$$

$$\rho u\frac{\partial T}{\partial x}+\rho v\frac{\partial T}{\partial y}=\frac{\partial}{\partial x}\left(\Gamma_{eff}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_{eff}\frac{\partial T}{\partial y}\right) \quad \text{...eq.(4)}$$

$$\mu_{eff}=\mu+\mu_t \quad \text{...eq.(5)}$$

Where $\mu_{eff}$ is combined laminar and turbulent stresses and $\Gamma_{eff}$ is effective exchange coefficient.

The shear-stress transport **(SST, $\kappa$-$\omega$)** model was developed by Menter to effectively blend the robust and accurate formulation of the $\kappa$-$\omega$ model in the near-wall region with the free-stream independence of the $\kappa$-$\varepsilon$ model in the far field. To achieve this, the $\kappa$-$\varepsilon$ model is converted into a $\kappa$-$\omega$ formulation. Other modiffcations include the addition of a cross-diffusion term in the $\omega$ equation and a blending function to ensure that the model equations behave appropriately in both the near-wall and far-field zones.

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$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_k\frac{\partial k}{\partial x_j}\right)+\widetilde{G_k}-Y_k+S_k \quad \text{……………………………………eq.(6)}$$

And

$$\frac{\partial}{\partial t}(\rho w)+\frac{\partial}{\partial x_i}(\rho w u_i)=\frac{\partial}{\partial x_j}\left(\Gamma_w\frac{\partial w}{\partial x_j}\right)+G_w-Y_w+S_w+D_w \quad \text{……………..……………eq.(7)}$$

### 2.2 Boundary Conditions

The shelf, desk, and chair were assumed adiabatic, because at steady operation these surfaces will be at approximately the same temperature as the fluid surrounding them. The sitting person's outer surface temperature was taken to be a calculated cloth temperature of 25.4℃.**[S. Baskaya 2006].** Velocities at the walls are zero because of the no slip condition. Supply air inlet velocity $U_{in}$, inlet temperatures $T_{in}$ and wall temperatures $T_{in}$ were taken as given in **Table 1**. The inlet and outlet duct dimensions were taken as 0.2 m.

**Table1 : Conditions of the Cases Studied.**

| Case No. | Inlet/outlet location | Summer/ winter | $U_{in}$ (m/s) | $T_{in}$ (℃) | $T_w$ (℃) |
|---|---|---|---|---|---|
| 1 | Inlet4-3 outlet1-2 | Summer | 0.5 | 18 | 30 |
| 2 | Inlet4-3 outlet1-2 | Summer | 0.5 | 20 | 30 |
| 3 | Inlet1 outlet2-3 | Winter | 0.75 | 30 | 18 |

Inlet/outlet location numbers are shown in **Figure 2**. The results are analyzed in detail for various profiles of the room. The profiles chosen are numbered in **Figure 3.** These profiles are chosen around the sitting person, because the person's comfort conditions are important.

### 2.3 Grid and Numerical Solution

This study used a commercial **CFD** code **FLUENT (version 6.3)** for solving the **Navier Stocks,** energy and turbulence equations using finite volume techniques. The simulations were achieved with 100×64 cell numbers in the x-y coordinate directions. The criterion of convergence of the numerical solution is based on the absolute normalized residuals of the equations that were summed for all cells in the computational domain. Convergence was considered as being achieved when these residuals become less than $10^{-3}$, which was the case for most of the dependent variables. Semi Implicates Methods for Pressure Linked Equation **(SIMPLE)** is used to linked the velocity field to temperature field in order to satisfy the continuity.

## 3. Results and Discussion

For verification of the problem definitions used for the present code, case (1) in **Table 1**, were used. **S.baskaya and E.eken(2006)** used the standard $\kappa$-$\varepsilon$ model to predict the velocity and temperature distributions inside an office room. **Figure 4-a**, represent the velocity vectors predicted by **S.baskaya and E.eken** using standard $\kappa$-$\varepsilon$ model and **Figure 4-b** represent the velocity vectors from the present study using **(SST, $\kappa$-$\omega$)** model. Air in the both figures is distribute approximately in the same way. Furthermore **Figure 5-a and 5-b** represent the quantitative velocity distribution about $K_1$ and $K_2$ respectively (see **Figure 3**). In **Figure 5-a** the quantitative velocity distribution about $K_1$ predicted from the present study using the (SST, $\kappa$-$\omega$) turbulence model is compared with that one of **S.baskaya and E.eken,2006** which predicted by using standard $\kappa$-$\varepsilon$ model. **Figure 6** represent the quantitative temperature distribution about $K_3$ (see **Figure 3**), in **Figure 6** quantitative temperature predicted from the present study using the **(SST, $\kappa$-$\omega$)** turbulence model is compared with that one of **S.baskaya and E.eken,2006** which predicted by using standard $\kappa$-$\varepsilon$ model.

The results are presented in **Figures 4, 5 and 6** show a comparison between the predictions of the present code with that of **S.baskaya and E.eken**, the comparison shows a relatively good agreement.

For this study, same room geometry as S.baskaya and E.eken, was used, because it contain all necessary office occupants. **Figure7**, show the velocity vectors plots for summer case studied (case 2). Occupants prevent the full size recirculation in the room from formed and only a small recirculating were created above the air inlet supply. **Figure 8**, show the velocity vectors plots for winter case studied (case 3), also the full recirculated is prevented by the occupants and create a small recirculation near the inlet supply and another one in counter clockwise direction created behind the chair due to the small area and relatively high velocity inlet.

It is important to see the actual distributions of temperature and velocity components for certain relevant profiles chosen at important locations shown in **Figure 3**. Velocity distributions for profiles $K_1$ and $K_2$ for cases 2 and 3 are shown in **Figures 9 and 10** respectively, and temperature distributions for profiles $K_3$ for cases 2 and 3 are shown in **Figures 11 and 12** respectively. All figures use full lengths of the room for the x and y axis. The gaps in the profiles are due to the occupants.

In **Figure 9**, the velocity about $K_1$ is very fast decay in small distance behind the chair as well as it impact with the chair while from the other side the velocity will be damped due to the floor. About $K_2$ the smallest value of velocity approximately in the middle of the profile and it is increase with approach to the exhaust.

In **Figure 10,** due to the inverse recirculation created behind the chair (see **Figure 8**), the velocity in $K_2$ profile is zero at $x = 0$ and increase until get the maximum value in the middle of this distance ($x = 0.65$m) and then decease and also it is equal to zero at $x = 2.5$m and increase in direction of exhaust. Maximum value of velocity is recorded at $x = 0$ in K2 profile which is near the inlet air supply and this magnitude decay in the middle of room and gradually increase toward the exhaust.

**Figures 11 and 12** show the vertical temperature distribution about $K_3$ at low supply air velocity, vertical temperature differences in occupant zone are large. As supply air velocity increase, smaller vertical temperature differences formed. The thermal conditions of cases 2 and 3 around the person satisfies the Iraqi code of cooling 2012.

## 4. Conclusions

**(SST, $\kappa$-$\omega$)** model is used with finite volume technique to predict the two dimensional turbulent flow inside an office room with different positions of inlet and outlet. The **(SST, $\kappa$-$\omega$)** model gives acceptable results to estimate the structure of turbulent recirculating flow inside a ventilated room. Effects of the occupants under different inlet/outlet and summer/winter configurations on the airflow have been analyzed for two different supply jet velocities. Airflow in a room is highly influenced by persons and occupants present in the room space, as well as inlet/outlet configurations. Vertical temperature distributions depend largely on supply air velocity, As supply air velocity increases, it is observed clearly that vertical temperature difference decreases. Thus, thermal comfort is maintained by the regulation of supply air velocity.

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**Nomenclature:**

$\mu_t$ **:** Eddy Viscosity.

$\varepsilon$ **:** Turbulence Dissipation Rate.

$\rho$ **:** Density.

**CFD :** Computational Fluid Dynamics.

$G_K$ **:** The Generation of Turbulence Kinetic Energy**.**

$G_w$ **:** The Generation of Specific Turbulence Dissipation Rate.

**K :** Turbulence Kinetic Energy.

**SIMPLE:** Semi Implicates Methods for Pressure Linked Equation.

**SST :** Shear-Stress Transport .

**T :** Temperature .

**V :** Velocity.

**W :** The Specific Turbulence Dissipation Rate.

$Y_k$ **&** $Y_w$ **:**The Dissipation of k and w due to Turbulence.

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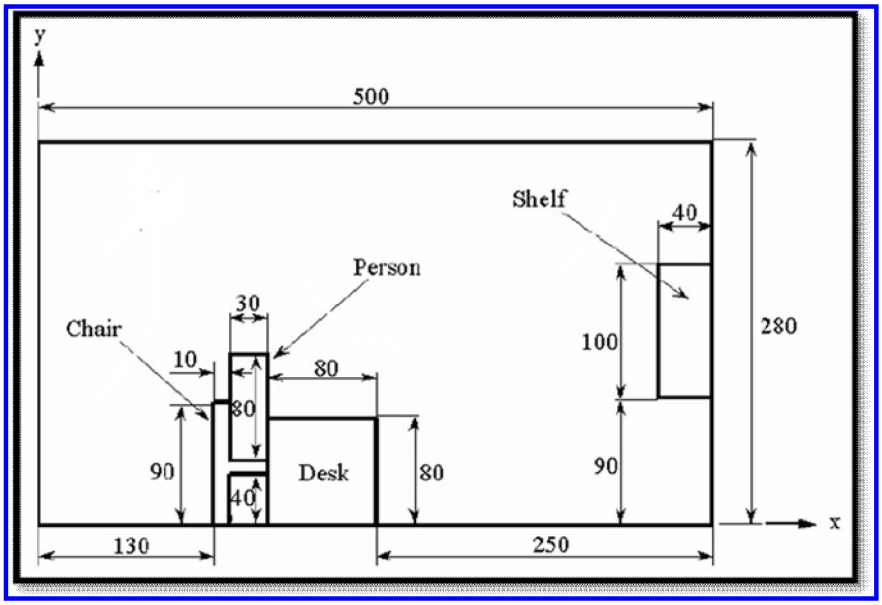


**Fig.1 : Schematic illustration of the Office Room[Şenol BAŞKAYA, Emre EKEN,2006].**


**Fig.2: Inlet/Outlet Locations Studied[Şenol BAŞKAYA, Emre EKEN,2006].**

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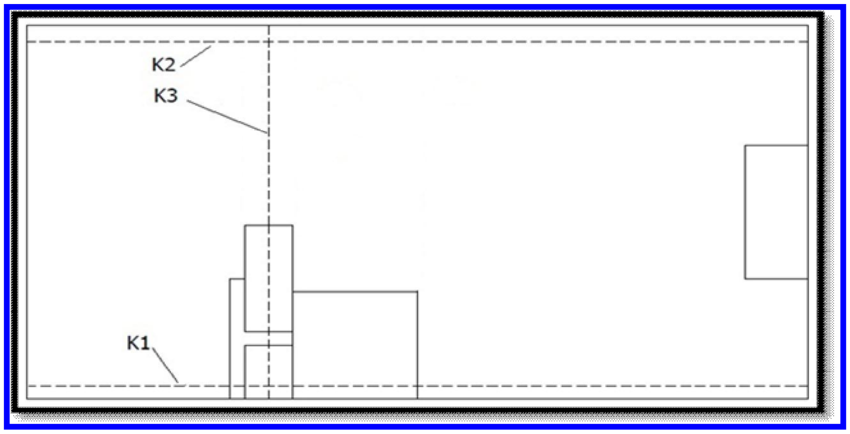


**Fig.3 : Profiles Chosen for Presentation of Results[[Şenol BAŞKAYA, Emre EKEN,2006].**

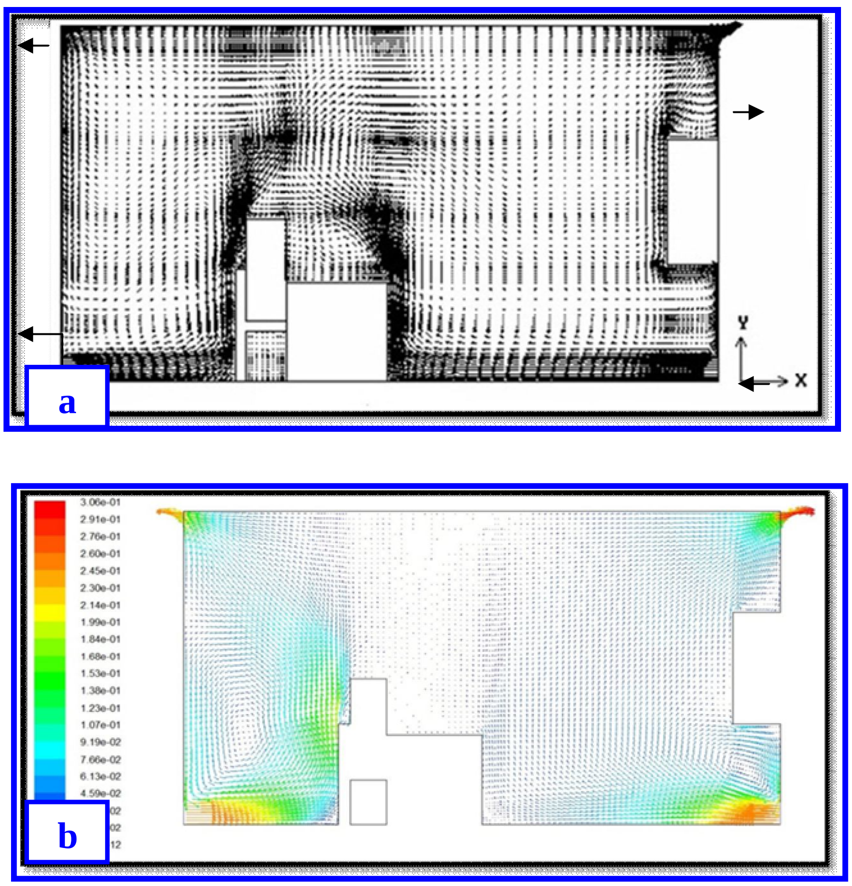


**Fig.4 : (a )Velocity Vectors Predicted by Ref [[Şenol BAŞKAYA, Emre EKEN,2006].**
**(b )Velocity Vectors of Present Study for Case 1.**

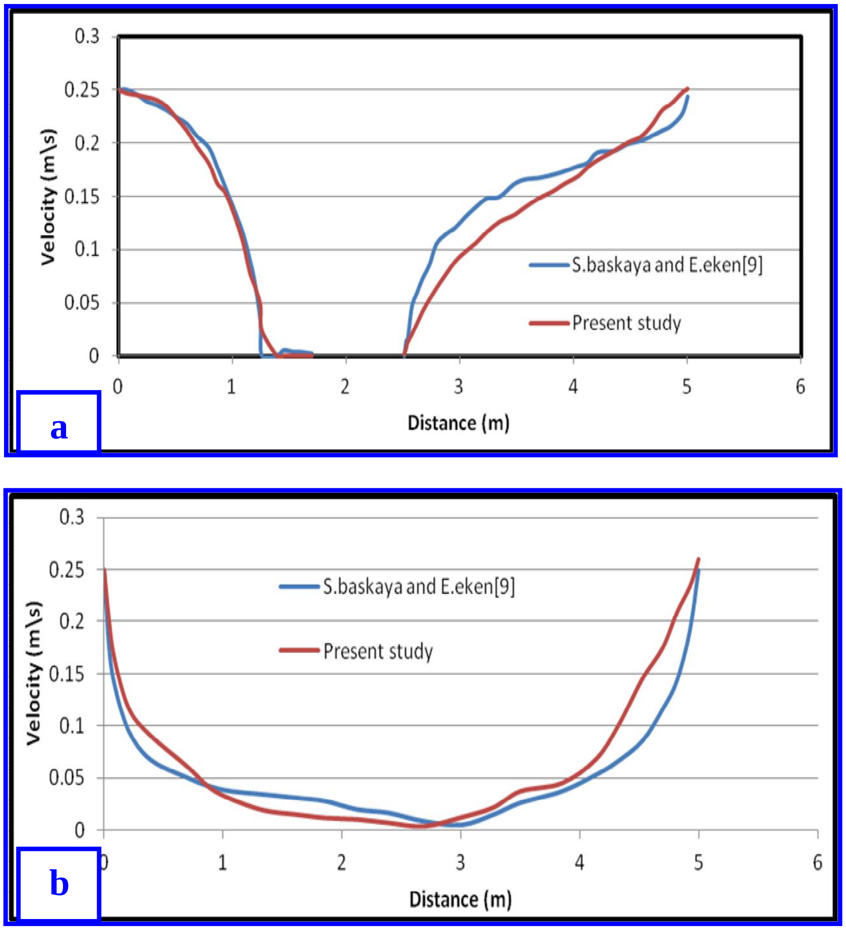


**Fig.5 : A Comparison of the Velocity Distribution between the Present Prediction and that of S.baskaya and E.eken at(a) $K_1$, (b) $K_2$.**

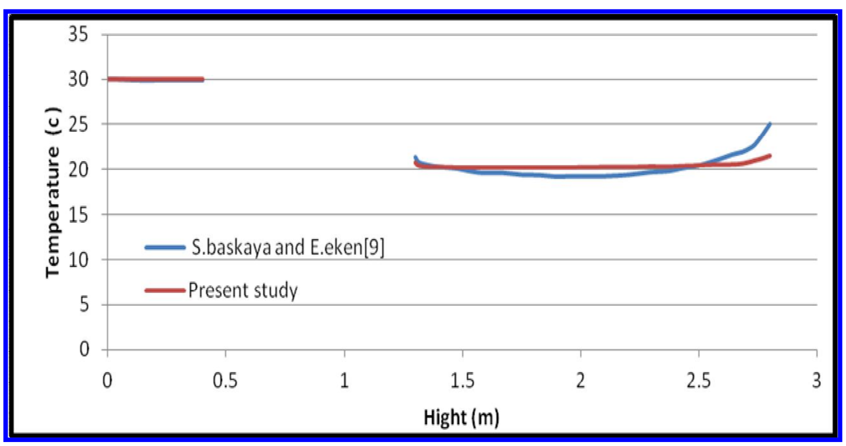


**Fig.6 : A Comparison of the Temperature between the Present Prediction and that of S.Baskaya and E.Eken.**

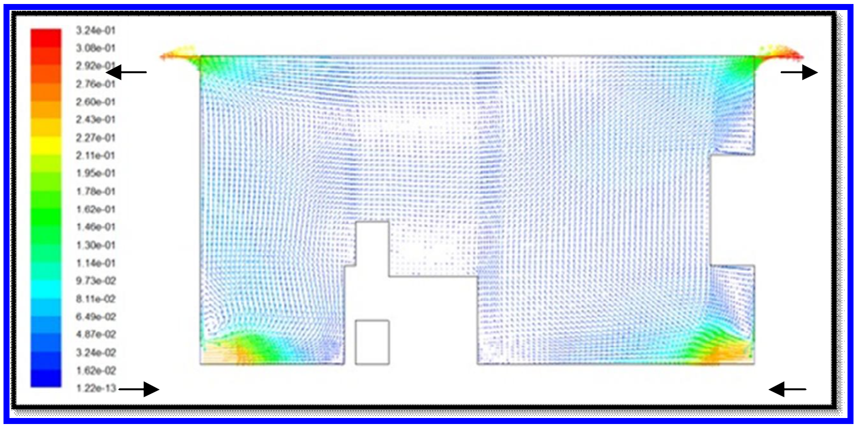

Fig.7 : Velocity Vectors for Case 2.

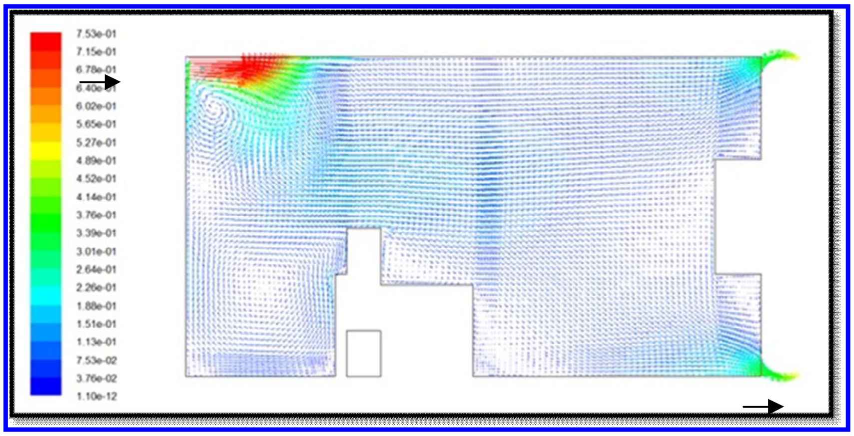

Fig.8: Velocity Vectors for Case 3.

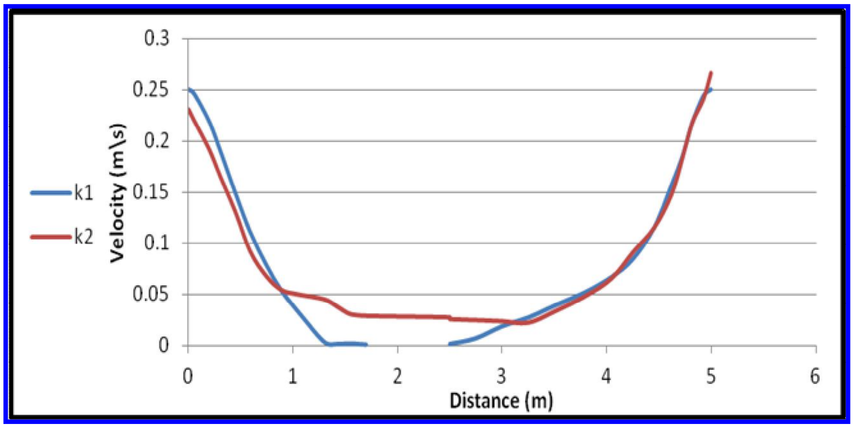


Fig.9 : Velocity Profiles along $K_1$ and $K_2$ for Cases 2.

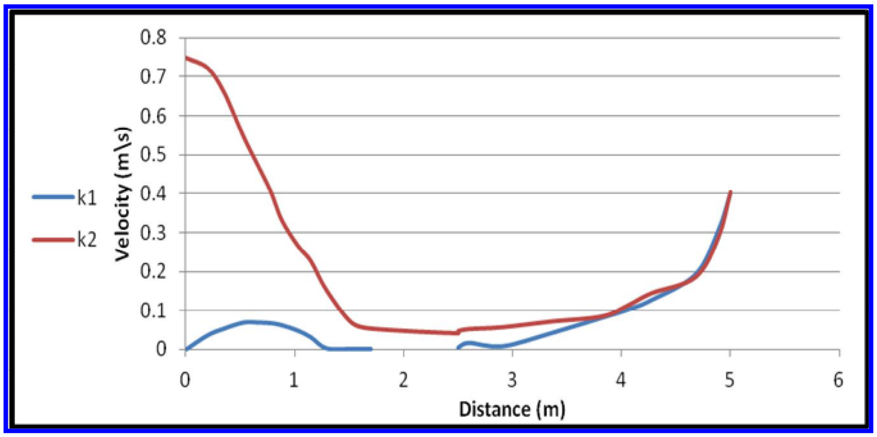


**Fig.10 : Velocity Profiles along $K_1$ and $K_2$ for Cases 3.**

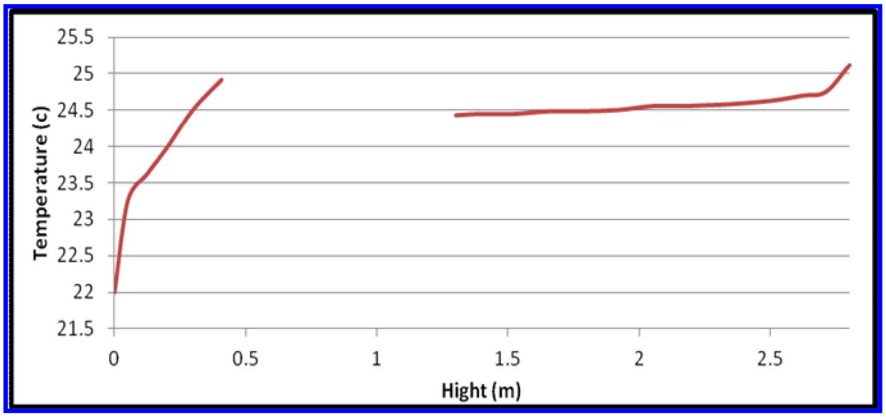


**Fig.11 : Temperature vs. Room Height along $K_3$ Cases 2.**

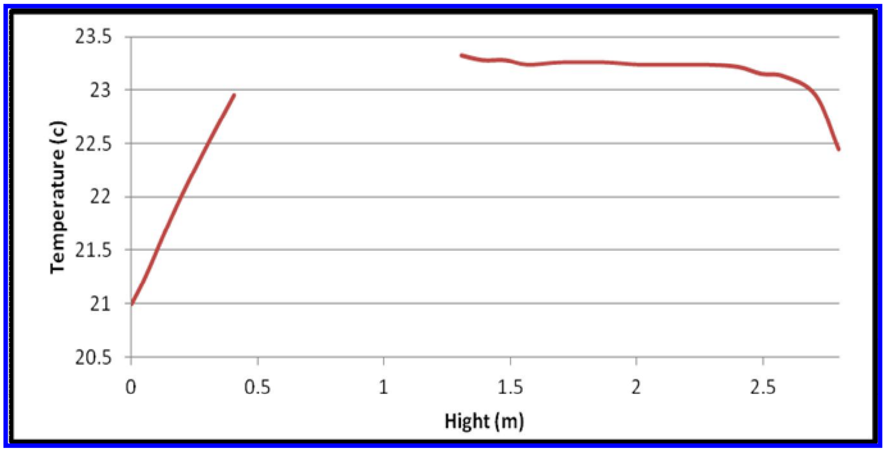


**Fig.12 Temperature vs. Room Height along $K_3$ for Cases 3.**