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Simulation of Ventilation Parameters for an Office Room with Displacement Ventilation

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Abstract: This study will investigate the local mean age of air, temperature and velocity gradient, predicted mean vote, predicted percentage dissatisfied, air diffusion performance index (ADPI) and ventilation effectiveness. The effect of turbulence model, the number of points of mesh, the number of taken points from the room on ADPI also will be studied. The AIRPAK software will be utilized for the simulation of theoretical study. The flow rate is constant at 0.1425 m^3/s, while the velocity of supplied air studied is (0.25, 0.275, 0.3, 0.325 and 0.35 m/s). The temperature of supplied air studied is (18, 19, 20 and 21 °C). Three models of turbulence will be used that are RNG K-ε model, two equations model and Spalart-Allmaras model. The results showed that, the mean local age of air increase with height and decreases with increase the supply air velocity. So the maximum mean air age was 317.9 s at height of 2.5 m and mean velocity of air supply 0.25 m/s, predicted mean vote, predicted percentage dissatisfied are zero, the local velocity increases with height. So, the maximum local velocity for pole (1) was about 0.138 m/s at mean velocity of 0.3 m/s and height of 2.5 m/s, the RNG K-ε model is the best between the turbulence models, the maximum value of ADPI for the RNG model at 0.3 m/s is about 61.84%, Ventilation effectiveness increases with the mean air supply temperature. so the maximum value of effectiveness is 1.488 at velocity of 0.35 m/s. This is caused by the decrease in local temperature with velocity increasing of supplied air and the ADPI increases with the number of mesh and the number of points.

Keywords: *Displacement Ventilation; Thermal Comfort; Air Diffusion Performance Index; Temperature; Velocity; Mean Age of Air; Ventilation Effectiveness.*

1. Introduction

In the air distribution systems design, the occupants thermal comfort might not be the first request in comparison to others main parameters like the room heat loads offseting, fresh air supplying and performance of power related to the HVAC system choice. Only it is stringent in assuring the well-being and output of the room conquerings.

displacement ventilation was used for the past little decades in commercial and industrial constructions. Due to its high efficiency of ventilation, displacement ventilation has been utilized in countries the United Kingdom and The Netherlands for factories and workshops ventilation due to existing a higher grade of dissipation of heat or contamination of air. For some utilizations, displacement ventilation is a suitable technique. So, the displacement ventilation will be used for ventilating an office room to get best indoor air quality, [1].

Lastovets et al., [2] presented a model for the dynamic temperature gradient for DV and evaluated the thermal mass effect on the stratification of temperature. The model was proved with the output of experimental works of the lecture room using displacement ventilation. The results showed that, the model gave better robustness for predicting the thermal output at various working circumstances by picking up the building system dynamic characteristics accurately. Furthermore, the model took into account the heat loads time schedules. Moreover, the two-capacity prototype could estimate the temperature gradient of indoor air in dynamic circumstances by picking up the building system dynamic characteristics accurately. The model could be used at design of DV at different dynamic circumstances.

Patrick Daffin, [3] investigated the circumstances at which it might be possible for implementing a displacement ventilation device in a residential construction. An experimental analysis of the effect on a mechanical air cooling system of a vertical location of the inlet and outlet vents was achieved. It might have been found that, for higher high heat loads, the low inlet high outlet setup might have been fit will uphold give or take the same temperature in the taken zone with respect to a less heat load, same time creating a strong two layers stratification inside the room such-and-such those outlet temperature might have been altogether higher over those encompassing temperature in the bring down possessed area of the room.

Yakoob et al., [4] checked a modern ventilation concept: displacement ventilation (DV) helped for customize ventilation (PV) which might have been evaluated to enhance indoor air quality. That approach might move forward ventilation system plan that might much furnish single person domination about indoor microclimate. RNG, k-ε turbulence models were assessed to show how the shape and site of ventilation systems and occupants might influence the air quality and thermal environment in the space. For DV supply temperature of 18°C and PV air supply temperature extend for 18°C to 22°C, it might have been found that PV toward stream rate 10 L/s (21. 19 cfm) furthermore of the circulation about occupants could enhance inhaled air quality in the breathing area. And that these sets up towards an office room for these air supply diffuser DV and PV joined together provided for human thermal comfort agreeable contingent upon that extent from claiming air appropriation execution list (ADPI) and effectiveness of temperature (ε_t) which were progressed over 71% and around 1. 8 separately.

Shi et al., [5] determined a modern theoretical model of the ventilation device and compared the computations with the experiments to check the theoretical model and conducted the effect of the main factors of ventilator on the dynamics of the ventilated respiratory system. It had been found that, with the rise in the active area of the exhalation valve, the peak exit air flow of the lung rises more and more slowly, for an increment in the tidal volume of the ventilator, the maximum pressure in the lung rises proportionally, However, the point when the tidal volume will be bigger over 600 mL, the maximum pressure in the lung rises slowly. At the tidal volume less than 600 mL, the peak exit lung air flow proportionally enhances with the expand in the tidal volume. But, when the tidal volume is bigger over 600mL, the peak exit lung flow rises more and more slowly.

Shi et al., [6] carried out analyses in a full-scale ecological chamber with the displacement ventilation (DV) - passive chilled beams (PCB) framework to get air flow velocity, temperature and contaminant concentration information. A computational fluid dynamics (CFD) model might have been formed to estimate air distribution alongside an encased surroundings with the DV-PCB system, that might have been then approved toward the measured information. The outcomes demonstrate that PCBs were exactly effective in diminishing those temperature gradient made toward DV. However, those chilly descending plane produced toward the PCBs made a "zone with high draft" under those PCBs, and the extent of the draft might have been determinedly associated with the cooling load removed by those PCBs and the size of the PCBs. Moreover, those descending air jet created by the PCBs Might upset the contaminant stratification as well as rise the air mean age in the involved zone.

There are commercial codes and standards that reckon the estimation and submission of thermal comfort used practically in the industry like the concepts of the PMV and PPD, air change effectiveness (ACE), effectiveness of ventilation, etc. As a design device to choose and space air terminal outlets for achieving a spatially regular distribution of air and thermal climate in the room [1]. The objective of the current paper is to clarify the air local mean age, temperature and velocity gradient, predicted mean vote (PMV), predicted percentage dissatisfied (PPD), air diffusion performance index (ADPI) and ventilation effectiveness that influences the thermal comfort as well as the quality of indoor air.

2. Cases Description

One of the most important ventilation design parameters is the indoor air movement, which is needed to determine thermal comfort in buildings. Redundant undesirable motion of air makes residents grumble due to unwanted cooling of some human body parts causes an air motion 'draft'. Due to this cause, values of the air velocity ought to be dominated in the design for maintaining better index of thermal comfort. Air velocity values are utilized for evaluating the effective draft temperature (EDT), that is substantial for predicting the air diffusion performance index (ADPI). This factor is useful in evaluation of air diffusion output for diffusers in a ventilated place. The effective draft temperature (EDT) is estimated from the following equation, [7]**:**

$$EDT = (Tx - \mathrm{Tav}) - 8 * (Vx - 0.15) \qquad \ldots(1)$$

Where,

T_x : local temperature (K)

T_{av} : mean temperature of room (K)

V_x : local velocity of air (m/s)

The air diffusion (distribution) performance index (ADPI) is a proportion which is determined by the points number measured in an occupied place where EDT is meanwhile the set confine ($-1.7\ ℃ < EDT < 1.7$ °C) over the total number of points measured, [8]. The ADPI at 80 and above is better for air distribution. The ADPI rating of an air diffusion system relies on a number of parameters:

1. The type of outlet
2. Load of Room
3. Dimensions of room and the mode of diffuser
4. The throw of outlet

When properly chosen, most of outlets can perform an allowable ADPI rating. The greater the ADPI rating, the greater the quality of air diffusion of room meanwhile the place. Commonly, an ADPI of 70-80 % can be considered allowable. Fig 1 shows a schematic diagram for the chosen office room, where there are two persons and two personal computers in the room, while Fig 2 shows the plane view of the office room. Table I explains the details of the occupant cooling load.

Three models will be used to simulate the (ADPI) of the tested room namely are RNG K-ε model, two equations model and Spalart-Allmaras model.

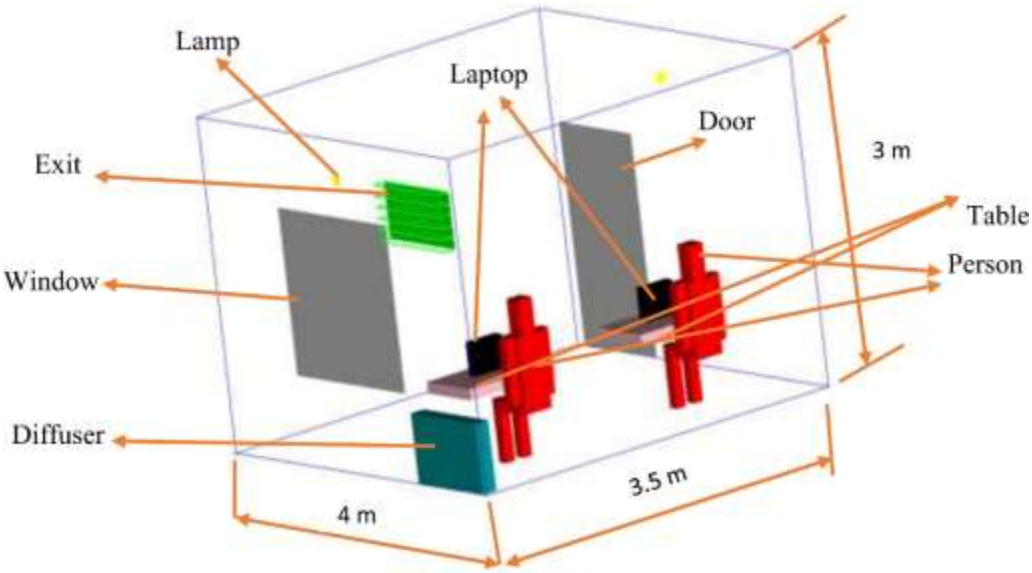


Fig 1: schematic diagram of the selected office room.

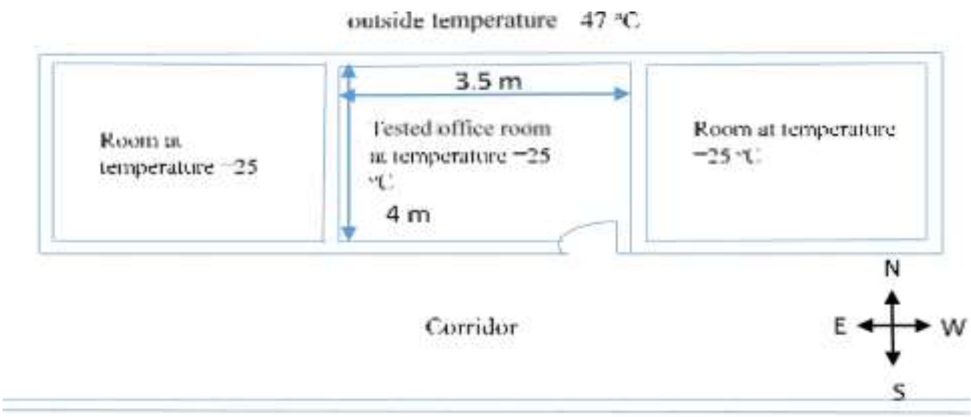


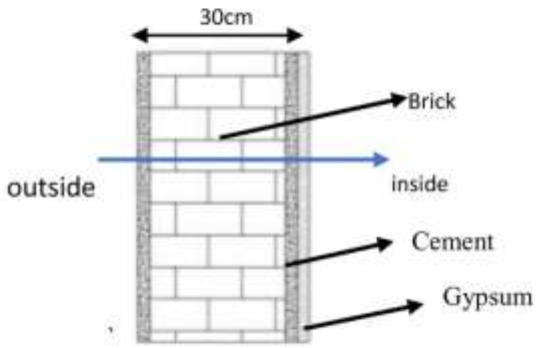
Fig 2: plane view of an office room model

Table 1: occupants and equipment's heat load summary

Items	No.	Power [W]	Power per floor area [W/m^2]
Person	2	75 W per person	18.75
Lights	2	120	30
Personal Computer	2	60	15

2.1. Side Wall Description

The walls in most of buildings in Iraq are considerably made of multiple layers of various materials. The wall thickness is about 30 cm and consisted of four layers arranged from inside to outside (gypsum plaster 2 cm, cement plaster 2 cm, common brick 24 cm, cement plaster 2 cm as show in Fig 3. The Details and thickness of wall materials is listed in table II, [9].



`Fig 3: wall materials components, [9].

Table 2: details of materials for classroom walls

Material	Thickness mm	Thermal conductivity k [9] W/m.ºC
Brick	240	0.69
Gypsum	20	0.48
Cement	20	1.16
Wood	30	0.28
glass	6	0.78

3. Theoretical Analyses
3.1. Office Room Cooling Load

Cooling load is computed by utilizing the techniques mentioned in ASHRAE Handbook, 2013, [10]. Outside heat gain is due to heat transfer through walls, doors and windows. While the inside heat gain is from the lights, occupants, computers and others as shown in table (1). Evaluating the temperature of supplied air and the air flow rate rely on the total load as shown in equations (10-11).

The heat transfers through windows, doors and walls is evaluated by utilizing the cooling load temperature difference $(CLTD)_C$ technique as show in ASHRAE Handbook, 2013, [10]:

$$Q = U*A*CLTD_c \quad \ldots(2)$$

$$U= 1/ R_{th} \quad \ldots(3)$$

$$R_{th} = \frac{1}{h_i} + \frac{x_1}{k_1} + \ldots\ldots + \frac{1}{h_o} + \frac{x_n}{k_n} \quad \ldots(4)$$

CLTDc is calculated as follows:

For walls:

$$CLTDc = (CLTD + LM)\times K + (25.5-Ti) + (T_m-29.4) \quad \ldots(5)$$

$$T_m = T_o - DR/2 \quad \ldots(6)$$

For windows and door:

$$CLTD_c = CLTD + (25.5-T_i) + (T_m-29.4) \quad \ldots(7)$$

The window heat gain by solar radiation is given as shown:

$$Q_r = A*SC*SHG*CLF \quad \ldots(8)$$

The temperature of corridor is obtained as follows, [11]:

$$T_{corridor}= T_i + \frac{2}{3}(T_i - T_o) \quad \ldots(9)$$

The estimation of outside heat gain outcomes of the examined office room is explained in table III.

Table 3: heat gain for the side wall, windows and door

Surface	West	East	North	south	ceiling	Window	Door
Heat, W	0	0	204.5	194.8	878	188.2	90.8

3.2. Air Flow Rate and Supply Air Temperature

For designing and operating a displacement ventilation device, the technique given by (Chen and Glicksman), [12] and (Skistad et al.), [13] is utilized. ASHRAE Standard 55, 2010, [14] explained that the higher temperature difference between the indoor air and supplied air causes thermal discomfort due to draft. It should not be greater than 5.5 ^oC. The air flow rate and the temperature of supplied air (T_s) are estimated by equations (10 & 11) respectively, [12].

$$V_{DV}=\frac{0.295q_{oe}+0.132q_l+0.185q_{ex}}{\rho C_p \Delta T_{hf}} \quad \ldots(10)$$

$$T_s=T_{dr}-\Delta T_{hf}-\frac{A_f CL_{DV}}{0.584V_{DV}^2+1.2A_f V_{DV}} \quad \ldots(11)$$

$$CL_{DV}=q_{oe}+q_l+q_{ex} \quad \ldots(12)$$

q_{oe}: heat from persons and computers

q_l: heat from lights

qex: heat from the surrounding

$$CL_{DV}=\rho Q_{DV} C_p (T_e-T_s) \quad \ldots(13)$$

The dry bulb temperature (T_{rd}) of office room design is 25 ^oC. The optimum temperature difference between foot and head (ΔT_{hf}) is 2^{o}C for seated person according to ASHRAE Standard 55, [14].

4. Selection of Air Supply Diffuser

Depending on the air flow rate of (0.1425 m^3/s) and to get low air velocity (0.25 m/s), the one- way rectangular diffuser with an area of (0.57 m^2) and dimensions of (90 cm width, 53 cm height) is chosen to transfer cooled air at 0.25 m/s as shown in Fig 4. The persons seated at one side of the room, along the side of the air supply.

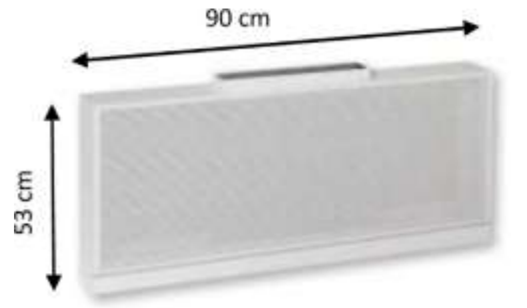


Fig 4: one-way rectangular diffuser

5. Computational Fluid Dynamics (CFD) Models

5.1 CFD Software

The commercial CFD software used in this work is (AIRPAK.3.0.16). AIRPAK is a technology to analysis and predict ventilation systems, [15].

Many researchers in a field DV/CC system have used (AIRPAK) software in their numerical analyses as Gao S. et.al, [16], Ayoub. et. al, [17], and Yang. et. al, [18].

5.2. Governing Equations

The Reynolds Averaged Navier-Stokes equations that reckon the continuity equation, momentum equation and energy equation at constant density in the Cartesian coordinates which can be displayed as bellow:

1-Continuity equation
For steady incompressible three dimensional flow, [19 and 20]:

$$\frac{\partial}{\partial x}(u)+\frac{\partial}{\partial y}(v)+\frac{\partial}{\partial z}(w)=0 \quad ...(14)$$

2- Conservation of Momentum equations,
For steady incompressible three dimensional flow, [19 and 20]:

X-direction:

$$\frac{\partial}{\partial x}(\rho uu)+\frac{\partial}{\partial y}(\rho uv)+\frac{\partial}{\partial z}(\rho uw)=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\mu\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\mu\frac{\partial u}{\partial y})+\frac{\partial u}{\partial z}(\mu\frac{\partial u}{\partial z})$$
$$+\frac{\partial}{\partial x}(-\rho\overline{u'u'})+\frac{\partial}{\partial y}(-\rho\overline{u'v'})+\frac{\partial}{\partial z}(-\rho\overline{u'w'})+\rho g_x \quad ...(15)$$

Y-direction:

$$\frac{\partial}{\partial x}(\rho uv)+\frac{\partial}{\partial y}(\rho vv)+\frac{\partial}{\partial z}(\rho vw)=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\mu\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}(\mu\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\mu\frac{\partial v}{\partial z})$$
$$+\frac{\partial}{\partial x}(-\rho\overline{u'v'})+\frac{\partial}{\partial y}(-\rho\overline{v'v'})+\frac{\partial}{\partial z}(-\rho\overline{v'w'})+\rho g_y \quad ...(16)$$

Z-direction:

$$\frac{\partial}{\partial x}(\rho uw)+\frac{\partial}{\partial y}(\rho vw)+\frac{\partial}{\partial z}(\rho ww)=-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}(\mu\frac{\partial w}{\partial x})+\frac{\partial}{\partial y}(\mu\frac{\partial w}{\partial y})+\frac{\partial}{\partial z}(\mu\frac{\partial w}{\partial z})$$
$$+\frac{\partial}{\partial x}(-\rho\overline{u'w'})+\frac{\partial}{\partial y}(-\rho\overline{v'w'})+\frac{\partial}{\partial z}(-\rho\overline{w'w'})+\rho g_z \quad ...(17)$$

3- Energy equation

The three dimensional energy equation per unit volume for steady flow is, [19 and 20]:

$$\frac{\partial}{\partial x}(\rho UT)+\frac{\partial}{\partial y}(\rho VT)+\frac{\partial}{\partial z}(\rho WT)=\frac{\partial}{\partial x}\left(\Gamma\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma\frac{\partial T}{\partial z}\right) \quad ...(18)$$

The above set of equations is estimated by the Renormalization Group Method (RNG k- ε) which is found as a good choice for numerical analyses in this study. Chen Q., [21] showed that the (RNG K-Ɛ) model was better than other models of turbulent with ventilation system, and Yakhot, [22] proved the (RNG K-Ɛ) model was the better model in comparison to other examined models.

6. **Boundary Conditions**

To generate further sets of data for DV system under Iraqi climate an office room is considered. In ventilation applications the AIRPAK.3.0.16 software is used to generate the simulation model because it is specialized for ventilation. The following boundary conditions are set:

1-Air supply is set as inlet velocity.

2-No slip condition for walls.

3-Constant Heat flux for walls, door and window.

4-Occupants and lights simulated as constant heat.

5-Zero pressure condition used for exit air.

7. Mesh Strategy

For modeling the flow by using the AIRPAK software, it is necessary to divide the room geometry into cells and to choose an acceptable mesh strategy, so the acceptable mesh was 350138 Nodes. Fig 5 shows part of the meshed model. The selected strategy is Hexa Cartesian that is very suitable for the tested case.

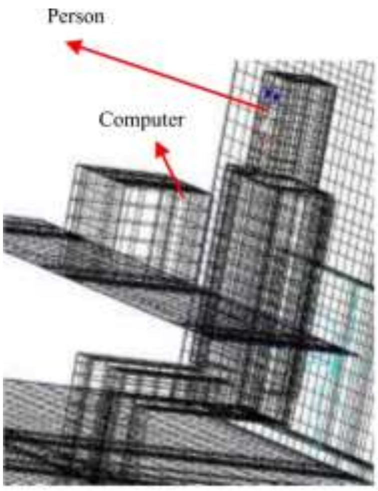


Fig 5: part of the meshed model

Fig 6 explains the relation between the ADPI and the number of mesh. It can be shown that the ADPI increases with mesh and the ADPI has a higher value of 61.84% for the number of mesh 350138 and due to increasing of the accuracy with the increase the number of meshes and then fluctuate about this value with small difference. So the mesh 350138 will be utilized through the solution.

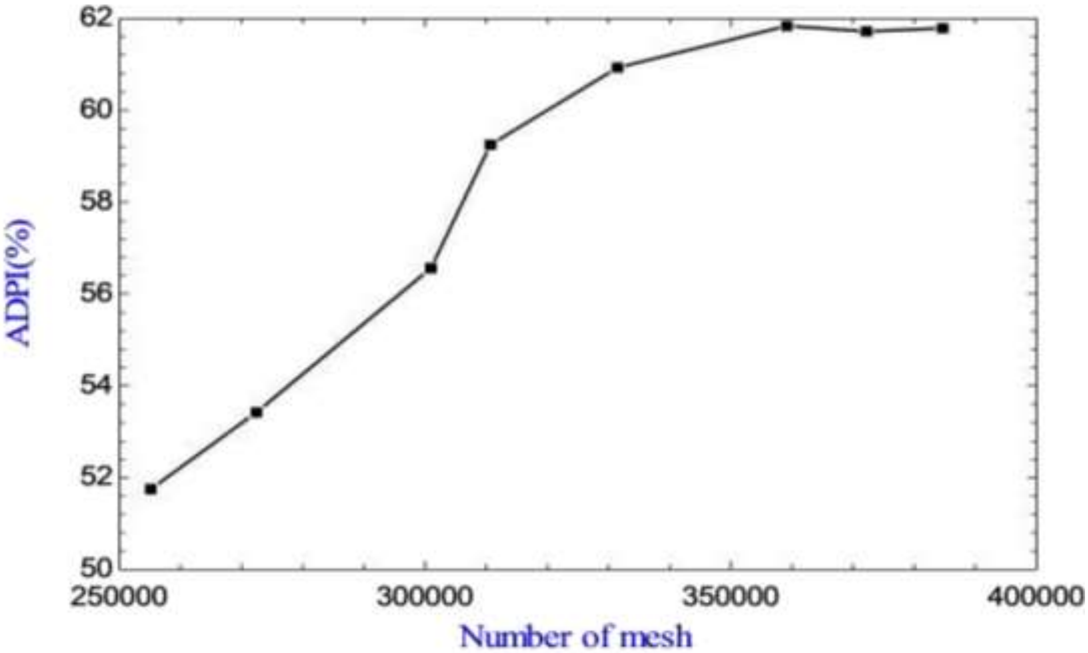


Fig 6:the relation between the ADPI and the number of mesh at T_s=20 °C and V=0.3 m/s.

8. Numerical Solution Procedure

The flow is assumed as steady and incompressible. For its solver engine, Airpak package uses FLUENT, Fluent Inc.'s finite-volume solver. Airpak's solver features include:

1- segregated solution algorithm with a sophisticated multigrid solver to reduce computation time.
2- choice of first-order upwinding for initial calculations, or a higher-order scheme for improved accuracy.

Energy, temperature and velocity will be described by using the second order upwind scheme. Pressure is described as PRESTO (Pressure Staggering Option) and used with body force weighted. The SIMPLEC (Semi-Implicit) scheme is used for the coupling between pressure and velocity. Under relaxation factors used to solve the equations are listed in Table IV.

Table 4: under-relaxation factors

Item	Pressure	Temperature	Body Force	Momentum	Turbulent Kinetic Energy	Turbulent dissipation Rate	Turbulent Viscosity
Under-relaxation factor	0.3	1	0.1	0.7	0.5	0.5	1

Residual error is inversely proportional to the accuracy of the numerical results. Table 5 shows the residual error for continuity, velocities, turbulent dissipation rate, turbulent kinetic energy and energy equation.

Table 5 : residual error for tested cases

Equation	Continuity	X-velocity	Y-velocity	Z-velocity	Energy	K	ε
R. error	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-6}	10^{-3}	10^{-3}

Fig 7 shows the relation between the ADPI and the number of points. It is noted that, the ADPI increases with the number of points until the number of points of 30000 then fluctuate in value with small amplitude and its greater value of (49.92%) at 50000 number of points. So, its value taken at number of point of 50000 at calculating the ADPI value.

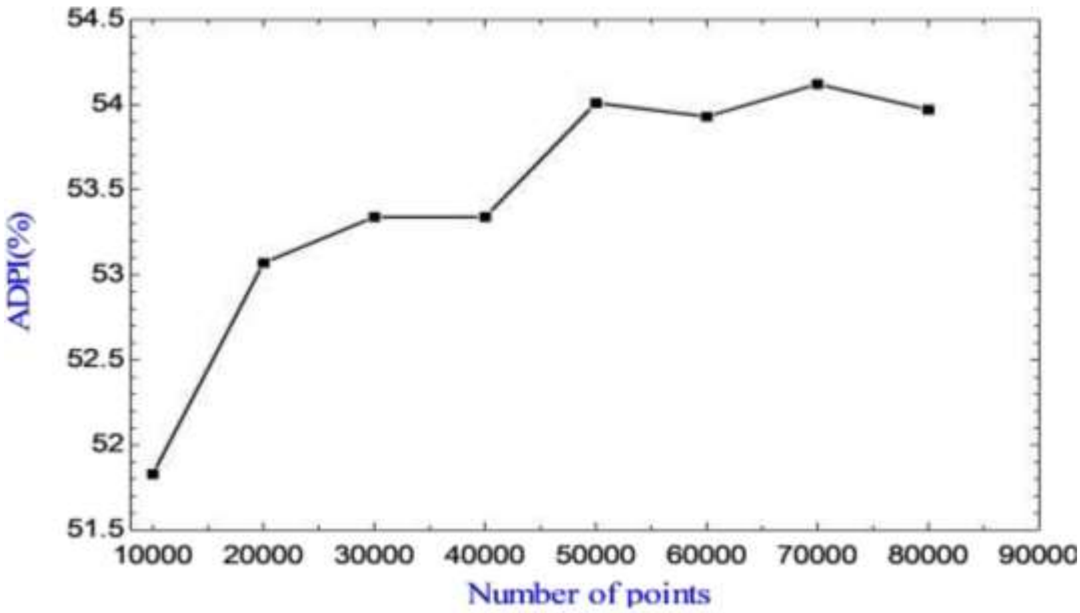


Fig 7: the relation between the ADPI and the number of points.

9. Predicting Indoor Air Quality Parameters (IAQ)

After completing the cases analyses by AIRPAK software, the indoor air quality (IAQ) parameters such as the air mean age, air velocity and temperature distributions, predicted mean vote (PMV), predicted percentage dissatisfied, air diffusion performance index (ADPI) and ventilation effectiveness for temperature distribution can be predicted.

9.1. Age of The Air

Age of the air is defined as "ventilation system ability to exchange the old air in the room by new fresh air", [23]. The nominal time constant is calculated by used equation (19).

$$\tau_n = \frac{V}{Q_{DV}} \qquad \ldots(19)$$

If the room or ventilated space has a known exit of air, Sandberg, [24] showed that the nominal time constant equals to the air mean age at its exit:

$$\tau = \tau_n \qquad \ldots(20)$$

Where (τ) is the air mean age of room which is less than half the nominal time constant.

The time, τ_a, needed mean for replacing the air presented in the place is double of the room air mean age, [25]:

$$\tau_a = 2\,\tau \qquad \ldots(21)$$

Then the air exchange efficiency (η_a) is represented as:

$$\eta_a = \frac{\tau_n}{2\langle\tau\rangle} \qquad \ldots(22)$$

9.2. Predicted Mean Vote (PMV)

It is an index utilized for predicting the thermal comfort and the human conditions which is calculated by equation (23), [26],

$$PMV = [0.303\exp(-0.036M) + 0.028]L \qquad \ldots(23)$$

The PMV value is classified to seven points as (from +3 at cold indoor air to -3 at hot indoor air). Depending on (ASHRAE standards) the best rang of (PMV) for allowable internal comfort is (-0.5 to +0.5), [27].

9.3. Predicted Percentage Dissatisfied (PPD)

The predicted percentage Dissatisfied (PPD) of people is the feeling of too hot or too cold. PPD is calculated from the predicted mean vote (PMV) using equation (24), [20].

$$PPD = 100 - \exp - [0.03353(PMV)^4 + 0.2179(PMV)^2] \qquad \ldots(24)$$

The limit of PPD for allowable environment for common comfort is 10%, according to $-0.5 \le PMV \le 0.5$, [27].

9.4. Air Diffusion Performance Index (ADPI)

The (ADPI) is utilized for satisfying the comfort limits. It is calculated as the ratio of the number of points of draft temperature in the taken place that have EDT value between -1.7 and 1.1ºC to the whole temperature points number in the place, [28].

9.5. Ventilation Effectiveness for Temperature Distribution

The local ventilation effectiveness for the temperature distribution describes the ventilation system ability to satisfy thermal comfort in a ventilated space. The local ventilation effectiveness (ε_t) is calculated as, [28]:

$$\varepsilon_t = \frac{T_e - T_s}{T_{av} - T_s} \qquad \ldots(25)$$

10. Results and Discussion

The displacement ventilation system is analyzed numerically in an office room under Hilla city climate conditions in IRAQ at maximum summer temperature. The displacement ventilation supply air temperature is varied as (18, 19, 20 and 21 ºC). The airflow rate is fixed at 0.1425 m^3/s (6.32 air changes per hour). Two poles are considered throw the study. The first pole is at (X=1 m, Z=2.75 m) near the person and the second pole is at (X =3, Z= 1 m) at heights of (0, 0.5, 1.1, 1.5, 2, 2.5 m). The RNG k-ε model has a better output in comparison to the other models with regard to accuracy, computing efficiency, and robustness, [29].

Figs (8-9) show the relationship between the air mean age and room height for the poles (1) and (2) at two different velocities. It can be shown that, the increase of height increases the age since the high points are far from the air supply, so the change of air is small. Increasing the velocity of air decreases the mean age of are due to increasing air change with increasing velocity. So the maximum mean air age was 317.9 s at height of 2.5 m and mean velocity of air supply 0.25 m/s. It can be shown that, there is difference in age of air between the two velocities at the high points for pole one because the pole is at the line of air supply, while at the second pole there is no difference because the pole located at a dead zone.

Figs (10-11) explain the relationship between the local velocity and the height for the poles (1) and (2) at different average velocities of air supply. It is noticed that, the velocity at height 0.5 m is high because it is in the vicinity of air supply and then decreases with height and increases at high points due to buoyancy effect in the displacement ventilation. So, the maximum local velocity for pole (1) was about 0.138 m/s at mean velocity of 0.3 m/s and height of 2.5 m/s.

Figs (12-13) show the relation between the local temperature and the height for the poles (1) and (2) at different average velocity of air supply. It is remarked that, the local temperature increases with the height increase because of density gradient where the hot air stay at top. Also the increase of air supply mean velocity decreases the local temperature so the minimum local temperature at the highest air supply mean velocity (0.35 m/s). So the maximum local temperature at velocity of 0.25 m/s and height of 2.5 m that about 30.63 ℃ for pole (1).

Fig 14 explains the relation between the ventilation effectiveness and the average velocity of air supply. It is noted that, the increase of velocity increases the ventilation effectiveness, so the maximum value of effectiveness is 1.488 at velocity of 0.35 m/s. This is caused by the decrease in local temperature with the increase of air supply velocity.

The predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD) have a value of zero, so the zone is comfortable.

Fig 15 explains the relation between the ADPI and the mean velocity of supplied air at different temperatures of air supply. It can be noted that the increase of velocity decreases the ADPI value for all supply temperatures only 20 ºC supply temperature where ADPI increases with mean velocity. Also the ADPI increases with supply temperatures, so the maximum value of ADPI is 63% at velocity of 0.25 m/s and supply temperature of 21ºC.

Fig 16 explains the relationship between the ADPI and the supply air mean velocity for the three simulation models. It can be shown that the ADPI increases with mean velocity and reaches maximum value at 0.3 m/s for all models. However, the RNG model gives higher ADPI values than other models. The maximum value of ADPI for the RNG model at 0.3 m/s is about 61.84%. The RNG model is the best in comparison to other models in terms of ADPI value and in accuracy in results. So, it was used in this study.

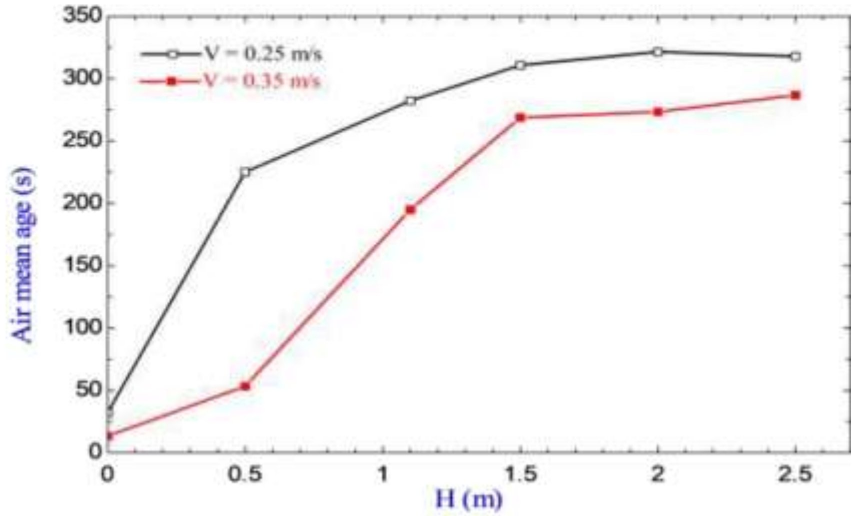


Fig 8: the relation between the mean age of air and height of room for pole (1) at two different velocities.

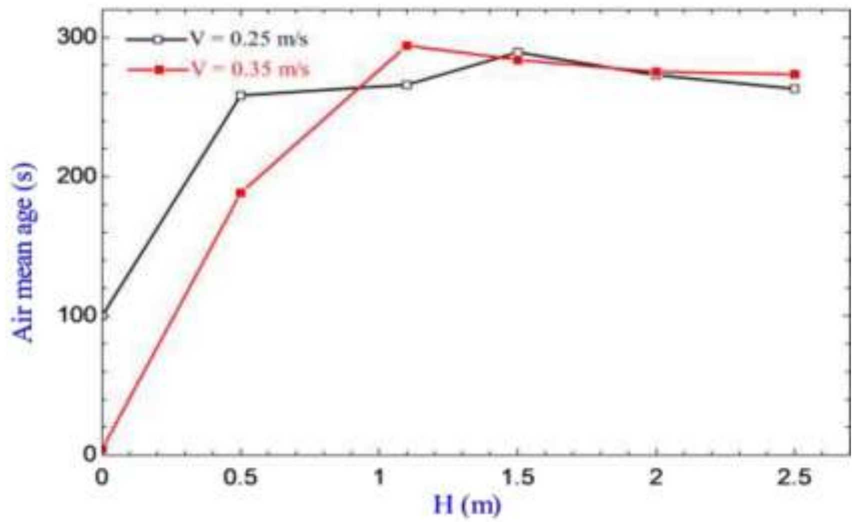


Fig 9: the relation between the mean age of air and height of room for pole (2) at two different velocities.

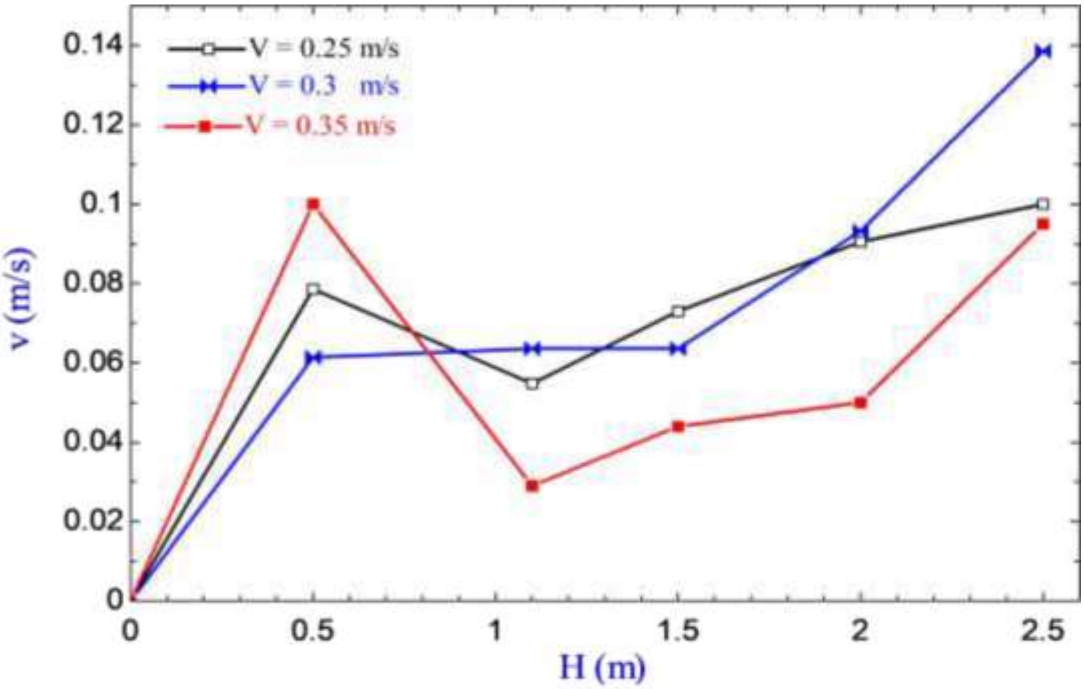


Fig 10: the relationship between the local velocity and the height for pole (1) at different average velocities of air supply.

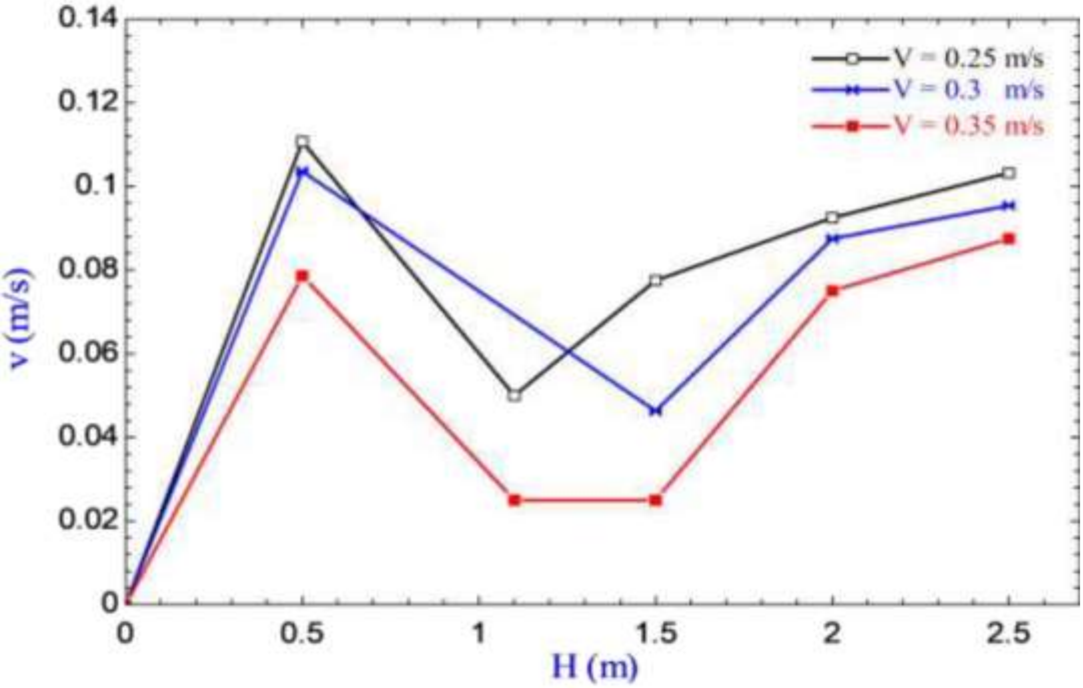


Fig 11: the relationship between the local velocity and the height for pole (2) at different average velocities of air supply.

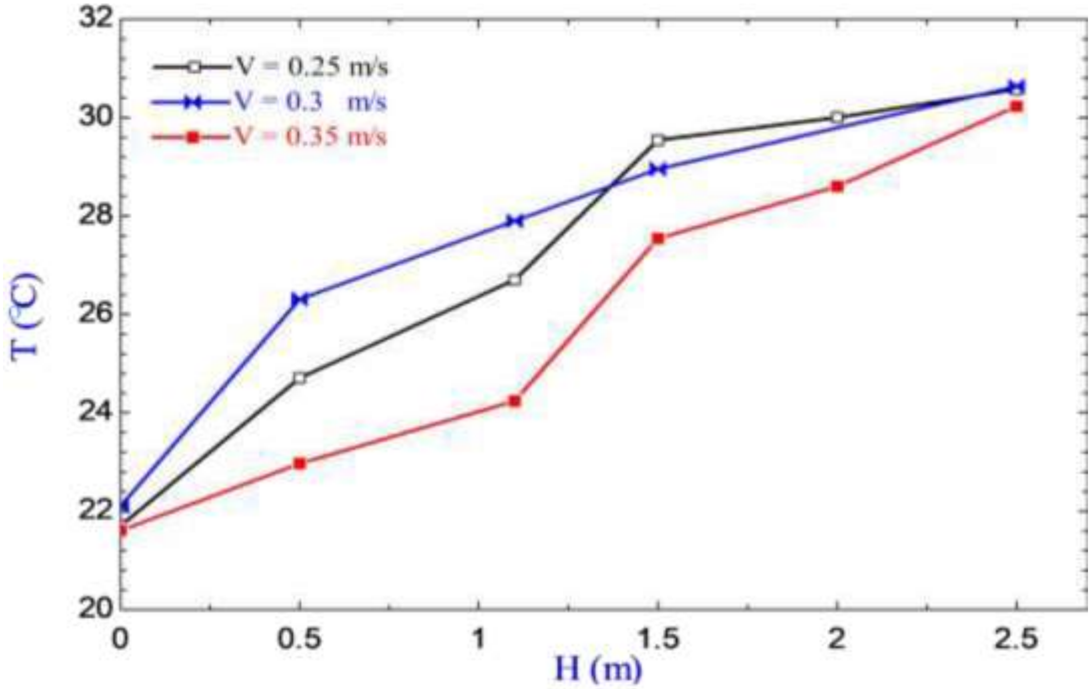


Fig 12: the relation between the local temperature and the height at different average velocities of air supply fore pole (1).

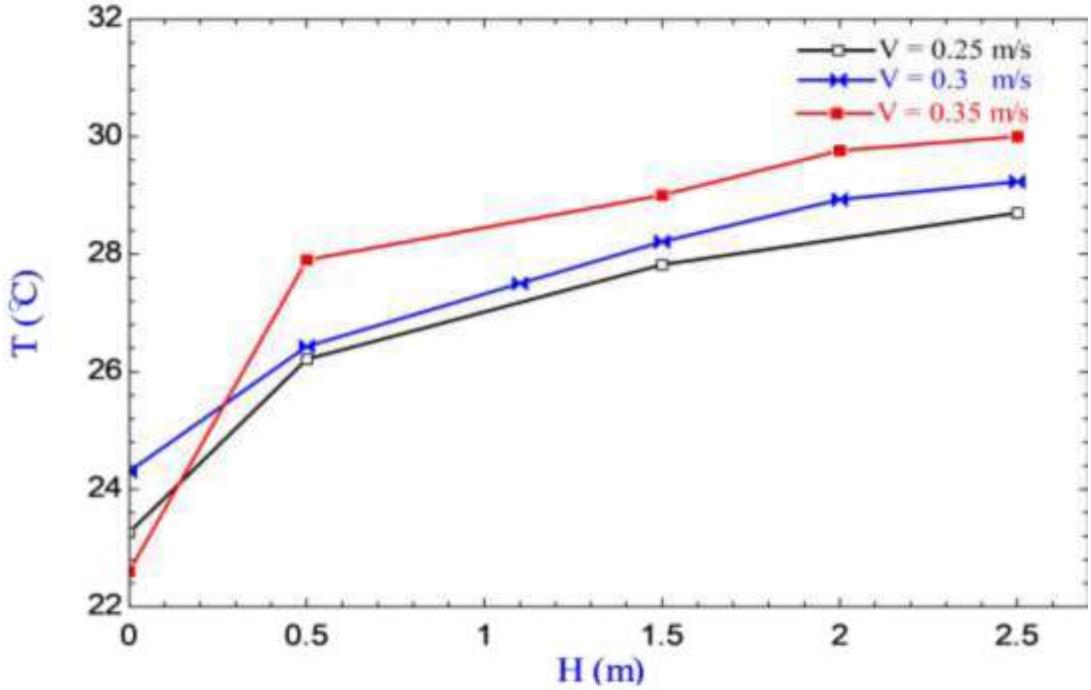


Fig 13: the relation between the local temperature and the height for poles (2) at different average velocities of air supply.

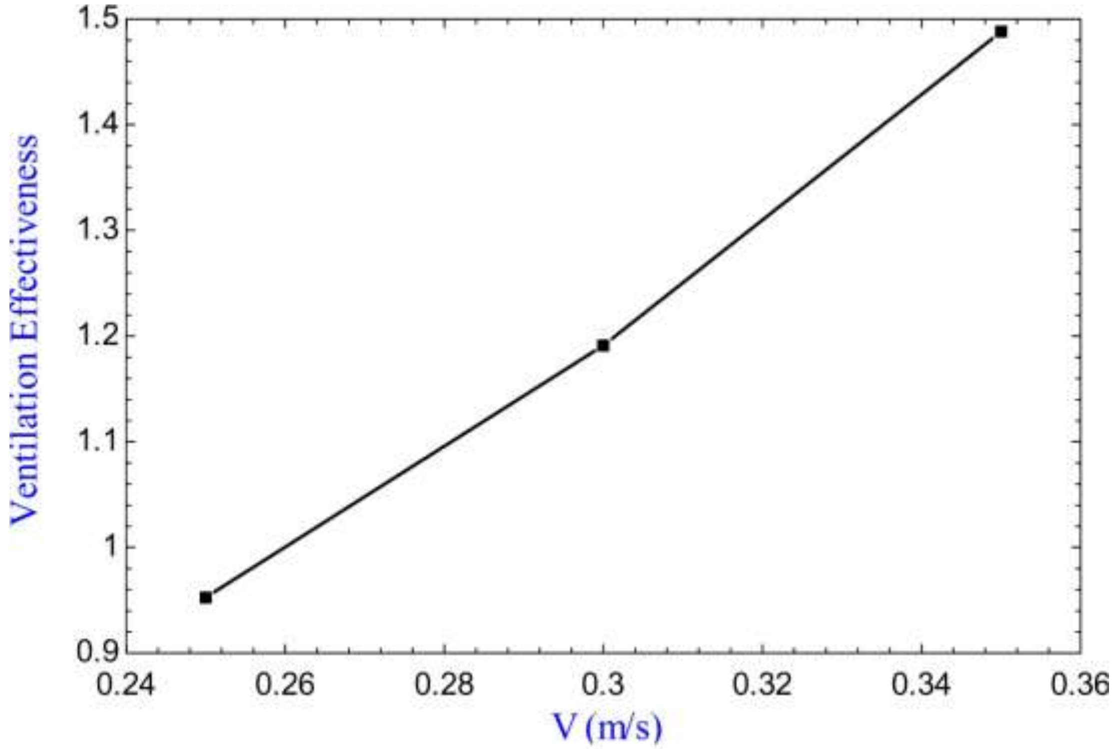


Fig 14: the relation between the ventilation effectiveness and the average velocities of air supply.

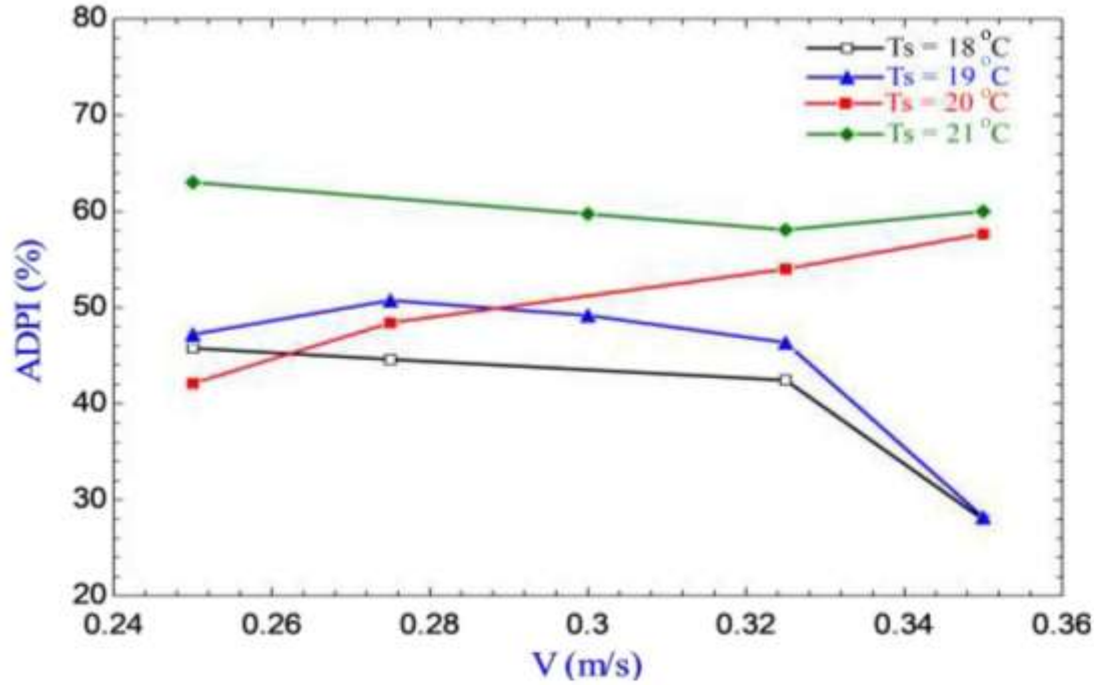


Fig 15: the relation between the ADPI and the mean velocity of supplied air at different temperatures of air supplied.

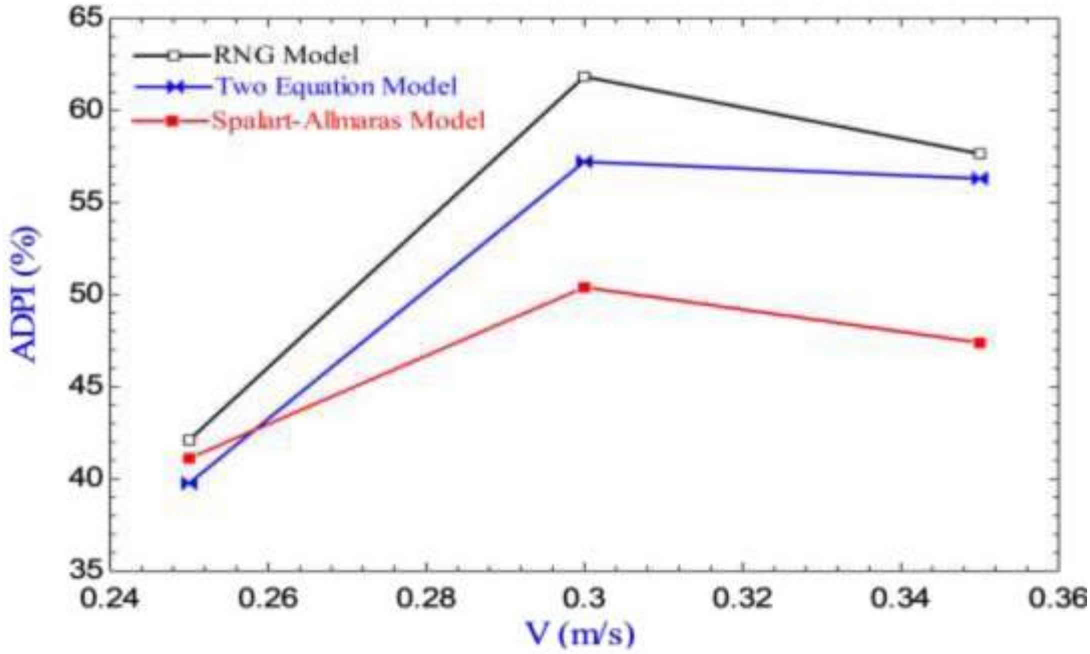


Fig 16: the relation between the ADPI and the supply air mean velocity at different simulation models.

11. Conclusions

The displacement ventilation system has been studied numerically by using ARIPAK software under Hilla city climate (hot and dry climate) in IRAQ. The strategy of study is based on changing the velocity of supply air at constant air flow rate by displacement ventilation. The temperature, velocity, mean age of air distribution and the thermal comfort of DV system for two poles are investigated numerically. The following main conclusions are found:

1- Mean local age of air increase with height and decreases with increase the supply air velocity. So the maximum mean air age was 317.9 s at height of 2.5 m and mean velocity of air supply 0.25 m/s.
2- (PMV) and (PPD) are zero, so the room is within comfortable zone.
3- The local temperature increases with height. So the maximum local temperature at height of 2.5 m that about 30.63 °C for pole (1).
4- The local velocity increases with height. So, the maximum local velocity for pole (1) was about 0.138 m/s at mean velocity of 0.3 m/s and height of 2.5 m/s.
5- The RNG model is the best between the turbulence models. The maximum value of ADPI for the RNG model at 0.3 m/s is about 61.84%.
6- Ventilation effectiveness increases with the mean air supply temperature. so the maximum value of effectiveness is 1.488 at velocity of 0.35 m/s. This is caused by the decrease in local temperature with the increase of air supply velocity.
7- The ADPI increases with the number of mesh. So, the maximum value of ADPI is 61.84% for the number of mesh 350138 and then fluctuate about this value with small difference, so this mesh was considered at the solution.
8- The ADPI increases with the increase of the number of points due to increasing of the accuracy with the increase the number of points. So, the higher value at the number of points of 50000 which is about 54.01%.

Nomenclature		**Abbreviations**	
A	surface area for wall, m^2.	AV	Average
C	Specific heat of air J/kg.°C.	amp	ambient temperature °C
CL	cooling load, W	CLTD	cooling load temperature difference depend on type of wall, °C.
DR	daily rang for outlet temperature, °C	CLF	cooling load factor.
dx dy dz	control volume	CFD	computational fluid dynamics
E	the mean rate of deformation tenser,	ADPI	Air Distribution Performance Index
g	. gravitational acceleration, m/s^2	DV	displacement ventilation
h	convection heat coefficient, W/m^2.K.	EDT	effective draft temperature
K		IAQ	indoor air quality

	color factor correct or conduction or heat transfer coefficient, W/m.K	N	The total number of points degrees draft temperature which measured in the occupied area
		PMV	predicted mean vote
L	corrector latitude	PPD	predicted percentage dissatisfied
M	Month		
P	pressure, N/ m^2	RNG	Re-Normalization Group
q	heat transfer through the wall, W	SC	shadow coefficient
R	thermal resistance, m^2.K/W	SHG	solar heat gain
T	temperature, ^oC	**Sub-Scripts**	
U	total heat transfer coefficient. W/m.K	c	correct
		f	floor
u,v,w	the component of velocity m/s	hf	head to foot level.
V	Air supply flow rate. m^3/s.	i	inside
x,y,z	coordinates direction in cartesian	i j k	location of point in a cartesian grid
		l	overhead light
Greek letters		n	nominal
ρ	air density, kg/m^3	o	outside
γ	diffusion coefficient (diffusivity)	oe	occupants and equipment
		p	person
τ	time constant, s	r	radiation
ε	Ventilation Effectiveness	rd	room design
ΔT	temperature difference, ^oC	s	supply
		x	local

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