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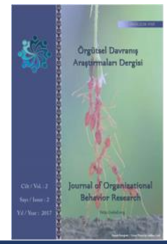

Numerical simulation of a hospital operating room air conditioning by employing computational fluid dynamics

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ABSTRACT

The control of temperature comfort condition, relative humidity percentage, air flow velocity, and the amount of air change per hour (ACH) in an operating room are essential things that should be considered in designing the heating, ventilation, and air conditioning (HVAC) system the air conditioning system.
The location and amount of the inlet and outlet air of the diffusers are essential factors in creating comfort conditions. In this paper, using numerical simulation with Ansys fluent software and the $k-\omega$ method, an operating room in a hospital in Dezful city located in Iran and is working well at the moment has been studied in terms of air conditioning. The geometry of the room model has a patient bed, four treatment staff members, a light for the surgery, and ceiling lights. Fresh air for ventilation is supplied to the operating room by ceiling diffusers and exited by grilles on the four corner walls. In this paper, the numerical simulation has been done by using computational fluid dynamics (CFD) modeling. The purpose of this study is to present and discuss the solutions to temperature, relative humidity percentage, and air velocity near the patient lying. All the actual conditions from the experimental data have been applied to this simulation. Finally, it has been concluded that comfortable temperature, humidity, and flow velocity conditions can be achieved using a sound ventilation system. Also, by selecting the best location for diffusers and grilles, the air around the patient bed area will be ventilated with high quality as world standards view.

Keywords: *Air-conditioning, Operating room, Computational fluid dynamics, Indoor air quality*

INTRODUCTION

1. Introduction

Controlling the particles of air and viruses is essential for protecting surgical room residents. It was investigated in research by O. M. Lidwell in 1998 (1). The computational fluid dynamics (CFD) model for the operating room and its developments were based on the work of Launder and Spalding in the early 1970s (2). In an experimental and area study, Blowers and Crew (1960) showed a relationship between the inlet airflow and the decline of the pollutants in the room. (3). Air Change per Hour (ACH) is essential in providing a clean room. The hospital rooms usually are designed by (2 ACH – 6 ACH).

Some important rooms can be designed based on 12 ACH. The essential spaces, such as the operating room, are supplied by (15 ACH – 25 ACH) as usual (4). Lewis studied the impact of air diffusion on the rate of infections in the operating room and concluded that the optimal HVAC system has a vital role in a healthy operating room. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) provided instructions for designing and building hospitals and medical facilities (5). “Measured indoor temperature ranged from 14°C to 29°C and relative humidity from 13 to 80%. The number of air changes per hour ranged from 3.2 to 58 ACH. The commonly encountered problems include insufficient indoor air exchange, poor control of indoor thermal conditions, bad space ergonomics that influence the ventilation system operation, poor technical installations maintenance, and understaffed technical departments”(6). Muhammad M. Rahman and his colleagues examined the operating room to determine if the air inlet was on the vertical wall, near the ceiling, and the outlet grills were on the opposite wall and near the floor. They obtained the airspeed pressure, temperature, and distribution of pollutants (7). Farhad Memarzadeh and Andrew P. Manning showed that the ventilation system is the best choice in laminar conditions by modeling the operating room and examining a wide range of air exchange rates (at least between 15 and 25 ACH). But this system needs to be carefully designed (8). Stamou and Katsiris used all the models found in four turbulence models to forecast flow rate and temperature distributions in an office room with ventilation. They also compared the results with the experimental measurements. All the models satisfactorily indicate the main qualitative flow qualities with the slightly best efficiency from the SST $k-\omega$ model (9).

2. Methodology: Experimental and numerical analysis

2.1. Theory (Governing equations)

2.1.1. Navier stocks equations (10)

The mass equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial \omega}{\partial z}=0$$

The momentum equations:

X-direction (U momentum):

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=X-\frac{\partial P}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2})$$

Y-direction (V momentum):

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=Y-\frac{\partial P}{\partial y}+\mu(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2})$$

Z-direction (W momentum):

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=Z-\frac{\partial P}{\partial y}+\mu(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2})$$

The energy equation:

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = K \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \mu \emptyset$$

$$\emptyset = 2 \left[(\frac{\partial u}{\partial x})^2 + 2(\frac{\partial v}{\partial y})^2 + 2(\frac{\partial w}{\partial z})^2 + (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2 + (\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x})^2 + (\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y})^2 \right]$$

2.1.2. Species Transport Equations (11)

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla.(\rho \vec{v} Y_i) = -\nabla.\vec{J_i} + R_i + S_i$$

2.1.3. k − ω Shear Stress Transport (SST) Turbulence Model

The k-ω SST model is one of the most appropriate models for calculating the flow in the area close to the wall (12). Although it assimilates to the classical k-ω model, the turbulent viscosity is altered, and which k-ω SST blending function and rotating tensor are included in the calculation area (12,13). The turbulence kinetic energy (k) and the specific dissipation rate (ω) are attained as we have demonstrated in the following section (11):

$$\frac{\partial}{\partial_t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\Gamma_k \frac{\partial k}{\partial x_j}\right] + G_k - Y_k + D_k + S_k$$

$$\frac{\partial}{\partial_t}(\rho \omega) + \frac{\partial}{\partial x_i}(\rho \omega u_i) = \frac{\partial}{\partial x_j}\left[\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right] + G_\omega - Y_\omega + D_\omega + S_\omega$$

"where G_ω represents the generation of ω, G_k represents the generation of k due to mean velocity gradients, Γ_k and Γ_ω represent the effective diffusivity of k and ω, respectively. Y_ω and Y_k represent the dissipation of ω and k in the turbulence, δ_ω represents the cross-diffusion term. S_ω and S_k are user-defined source terms" (14).

2.2. Geometry

The operating room is located in Dezful hospital in Iran. The room is mainly used for general surgeries, and it is also isolated. The room dimensions are $6.65\ \mathrm{m}\ (\mathrm{W}) \times 3.2\ \mathrm{m}\ (\mathrm{H}) \times 5.9\ \mathrm{m}\ (\mathrm{L})$. A patient lying placed in the center of the room. Also it included four surgical staff members. Cubic geometries have modeled them. A surgical lamp and fourteen ceiling lights are also in the geometry. Table 1 and figure 1 demonstrate the details of geometry.

Table 1. Details of Geometry

Objects	Symbol	Dimensions	The number
Exhaust grilles	A	24" × 8"	4
Supply diffuser	B	12"×12"	4
Ceiling lights	C	0.6×0.6 (m)	14
Surgical light	D	D=0.7(m)	1
Surgical staff members	E	H=1.8 (m)	4

Patient lying	F	0.65×1.95×0.7 (m)	1

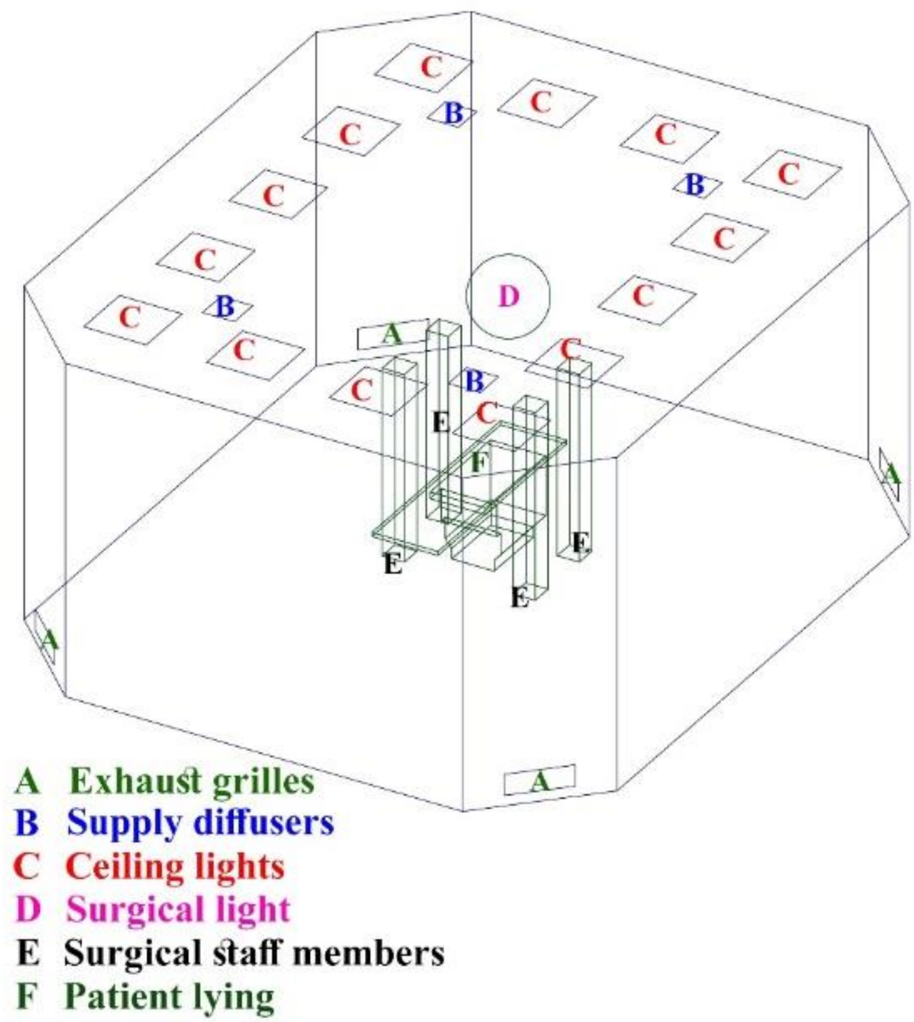

Figure1 . The geometry of operating room

2.3. Boundary conditions

The supply airflow is turbulent and enters the room via four diffusers in the ceiling. Four outlet grilles are located in the lower corners of the walls on the four sides. They are located on the walls at a distance of 0.2 (m) from the floor. The airflow rate is 350 Cubic feet per minute (CFM) for each diffuser, so according to their diffuser size, the velocity inlet is 1.778 $^{m}/_{s}$ for each inlet, and the Reynolds number for the inlet calculated $Re = 35863.57$. zero pressure state is set on the four outlets on the room walls, representing an atmospheric pressure, and the gravitational acceleration on the y-axis has been set as -9.81 $^{m}/_{s^2}$. The inlet air temperature and relative humidity are 294.93 (k) and 47.46%, respectively. The heat load for the ceiling lights has been calculated at 248.248 $^{btu}/_{hr}$ for each lamp. Also, the surgical light's heat load has been calculated at 903.65 $^{btu}/_{hr}$. In this simulation 245 $^{btu}/_{hr}$ sensible load has been considered for each person (15,16).

3. Results

3.1. Mesh study

The simulation started with 178643 cells and continued simulating to 4661504 cells. So we found that the best cell number for this study was 2272126. The number of cell steps has been written in table 2. Also, the amount of mesh has been studied through outlet temperature (t- out (k)), velocity outlet (v-out (m/s)), maximum temperature (t- max (k)), and outlet relative humidity (R.H. % Out). There are the results drawn from figure 2 to figure 5.

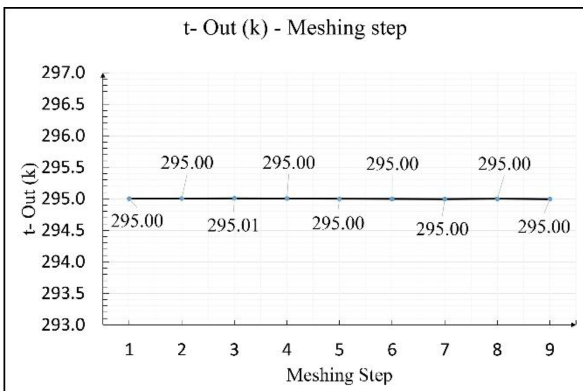

Figure 2. t- Out (k) - Meshing Step

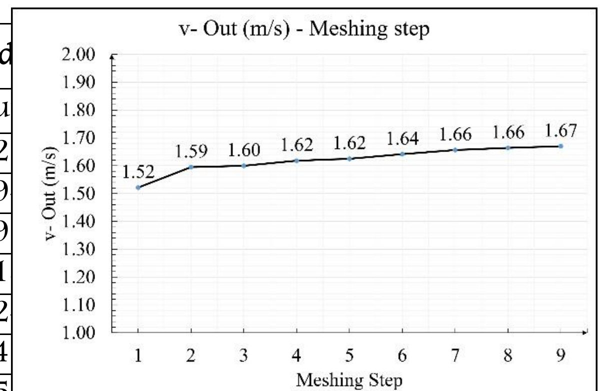

Figure 3. v- Out(m/s) - Meshing Step

9	4,661,504	294.99511	1.6699816	363.41182	48.087133

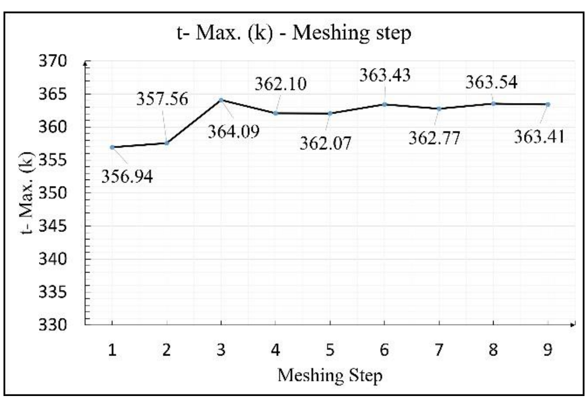

Figure 4. t- Max. (k) - Meshing Step

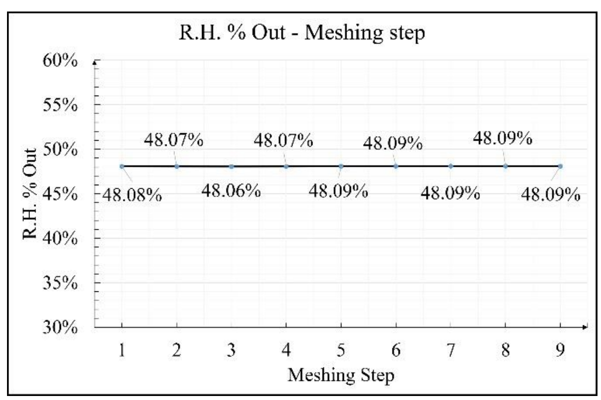

Figure 5. R.H. % Out - Meshing Step

3.2. Simulation results and discussion

According to the Guidelines for the design and instruction of hospital and health facilities recommended plan for the operating room’s best temperature is between 68°F and 75°F and also, Relative Humidity percentage (R.H. %) is 30%-60%, and finally, 15 of the air change per hour (ACH) for the operating room (17).On other hand, thermal comfort will occur at 1 m/s to 2 m/s of the air velocity (18).

As seen in figure 6, the maximum temperature occurred on the corner ceiling lights by 376.055 (k). Also, with this position of the supply diffuser and exhaust grilles, the comfort temperature between 68°F (293.15 k) and 75°F (297.09 k) on the lying patient area will get (Figure 7 to figure 10). On the other side, the relative humidity percentage in this area is almost 48 %, which is between 30% to 60% (Figure 11, 12). Also, air velocity in this area is lower than 0.25 m/s, which is a reasonable flow rate (Figures 13 to 17).

Finally, the best position for the supply diffusers and exhaust grilles is as much as possible along the length of the operating room where the patient and the treatment staff are present. If the supply diffusers are at **a** distance from the surrounding wall, they should be **2a** away, as shown in figure 18.

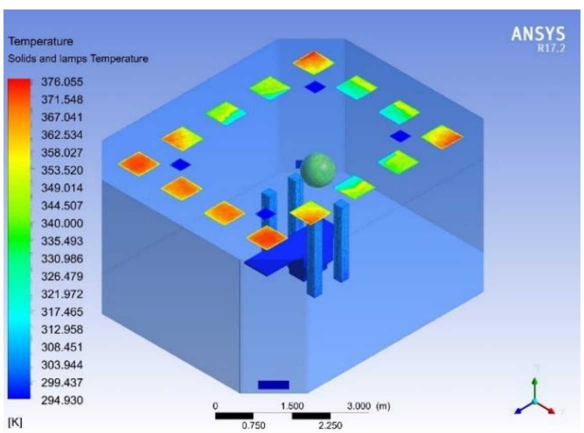

Figure 6. Solids and lamps temperature 3D view

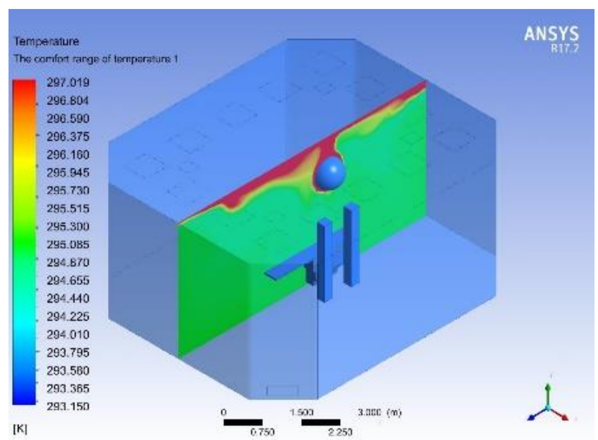

Figure 7. The comfort range of the temperature 3D view

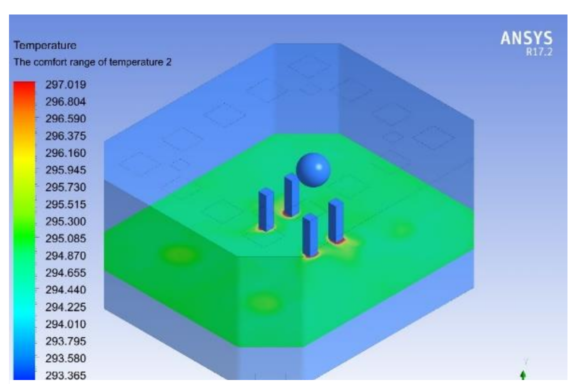

Figure 9. The comfort range of the temperature 3D view

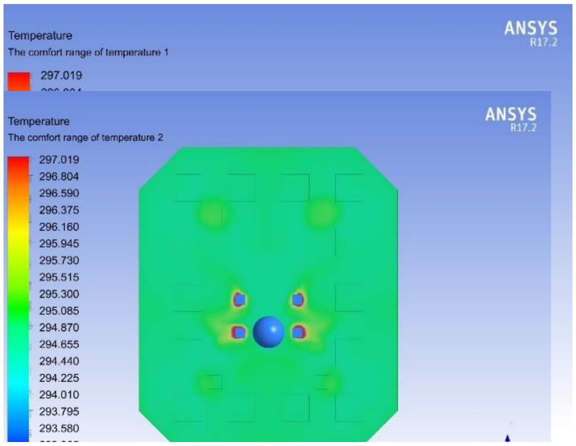

Figure 8. The comfort range of the temperature side view

Figure 10. The comfort range of the temperature top view

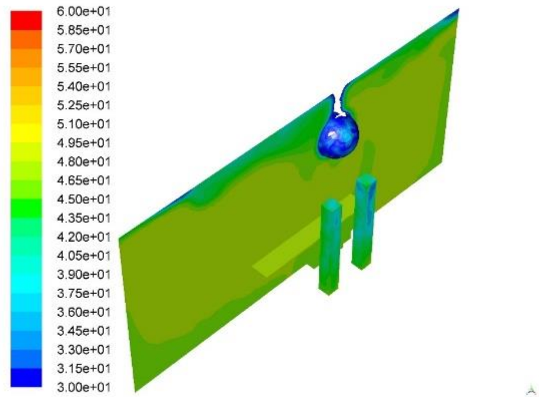

Figure 11. The comfort range of the R.H.% 3D view

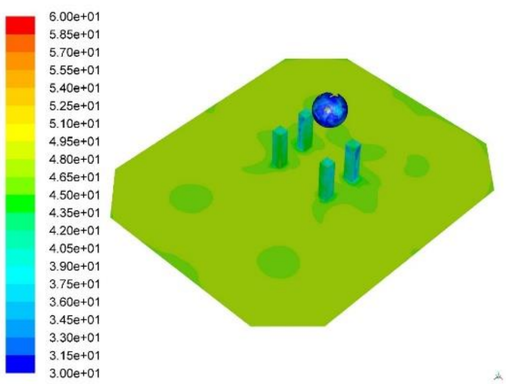

Figure 12. The comfort range of the R.H.% 3D view

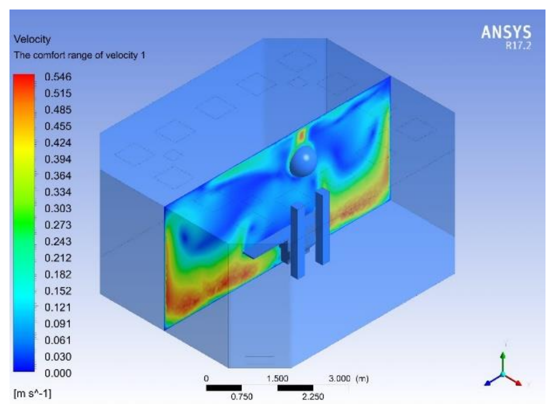

Figure 13. The comfort range of the velocity 3D view

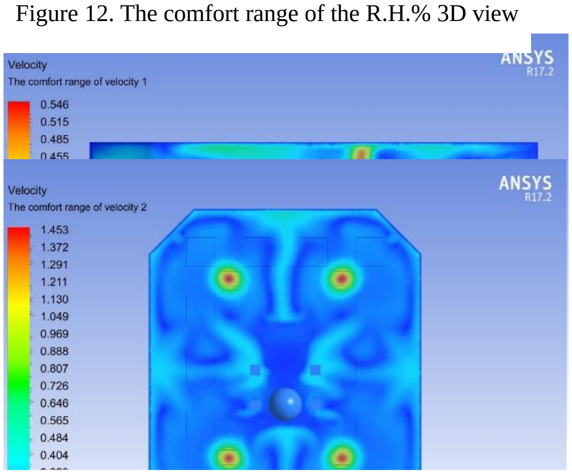

Figure 14. The comfort range of the velocity side view

Figure 16. The comfort range of the velocity top view

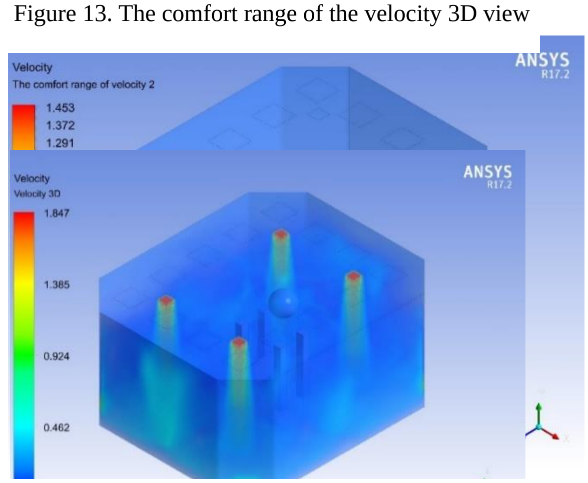

Figure 15. The comfort range of the velocity 3D view

Figure 17. The comfort range of the velocity 3D view

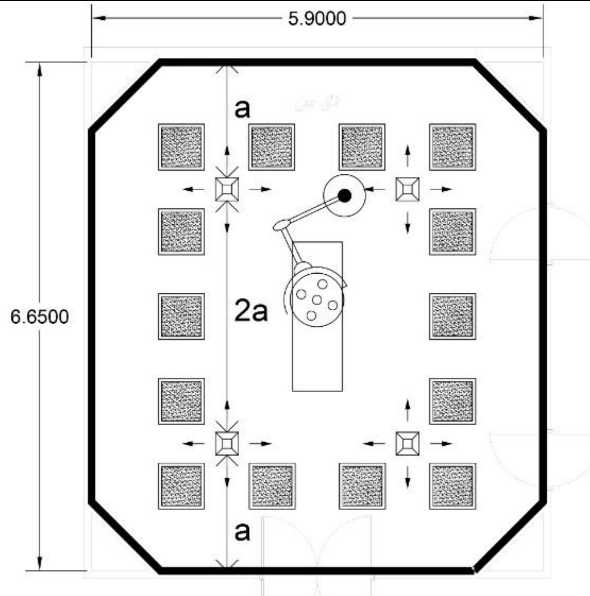

Figure 18. position of the supply diffusers

3.3. Validation

The results of this study regarding the validation of the results of this work, which is an entirely subjective and specific work, it should be said that the only possibility of complete validation for this study is to compare the results obtained from the numerical simulation with the same case of the operating room that the data obtained through experimental or analytical means—considering that the sample under study is operating in perfect conditions and compatible with the simulation results. As a result, the simulation results can be assured because the study of this work is in a specific operating room and does not have a general state. But with an article, the results of a relative comparison are made (19). This article states that by applying proper ventilation, lower temperature gradients and more comfortable conditions are obtained in the room. It means to emphasize the correctness of the results of the present work of this article.

4. Conclusion

The proper position of the supply diffusers and exhaust grilles and the appropriate architecture of the operating room to create comfortable conditions of temperature, humidity, and flow speed in the operating room, are essential things that should be considered in the design. In the mesh study section, considering 2272126 cells in the entire computing volume, as well as the calculation and comparison of the temperature factor, relative humidity percentage, and flow velocity were followed in the continuation of the calculation process.

The comfort factors of temperature, humidity, and flow rate in this study after applying the mentioned ventilation are very influential in the comfort of the patient and the treatment staff. For example, the drawn temperature contours show that after ventilation in the room, the temperature, humidity, and flow rate around the patient lying are very favorable. On the other side, 19.77 ACH has been done in this room and around the patient's bed, treatment room, and other areas; this thermal comfort is visible in the forms and results.

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Conflict of Interest:

We declare no conflict of interest in conducting this research, as it was entirely self-funded.

Funding:

This research was self-funded, and no external funding was received.

Ethical statements:

Our study was conducted using experimental methods. The primary data used in our research was obtained from a hospital in Iran. We ensured that our study adhered to ethical guidelines and received necessary permissions from relevant authorities.

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