Numerical Simulation on Conventional Ventilation System for Hospital Operating Room

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Abstract

Communities in the poor countries suffer from poor quality of health services. In the Republic of Yemen as one of those countries, some hospitals especially medium and small suffer of many problems which adversely affect health community life. This paper presents a case study conducted in a hospital operating room in Yemen, also computational fluids dynamics (CFD) analysis of the airflow, and temperature distribution are presented and discussed. The operating room model includes a patient lying on an operating table, four surgical staff, two air supply and four air exhausts. Results of simulation show a good agreement with experimental data from the literature and adopted standard. It is found that the airflow and air velocity significantly affects the thermal comfort of all workers in the operating room. Therefore, the air that enters the operating room is very importance and affects the room temperature. It is observed that the application of CFD in hospitals will give rise to design the internal environment and improved health outcomes especially in a country like Yemen.

Keywords: Operating Room, CFD, Numerical Simulation, Thermal Comfort.

1. Introduction

People spend major of their time indoor, so they want comfort environment to feel comfortable. The design of Heating, Ventilating, and Air-conditioning (HVAC) system for operating room is aimed at preventing risk of infections during operations as well as maintaining a proper comfort condition for the patient and the staff. In recent years, increasing development of computational fluids dynamics (CFD) has opened the possibilities of low-cost and effective method for improving HVAC systems in design phase, with fewer experiments required [1].

In hospitals, to provide a healthy and comfortable environment for people such as patients, workers, and visitors, it is necessary to implement a good design of ventilation and air condition .In operating rooms, the need to maintain an adequate comfort condition for patient and surgeons is most important, so the design of a heating, ventilating, and air-conditioning (HVAC) system must be included [2].

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In both developing and developed countries, poor indoor air quality are recognized as important risk factors for human health. Healthy indoor air is recognized as a basic right. A review by [3] was done to study the environmental controls in operating rooms. They have demonstrate that the infections in operation rooms particularly surgical site remain a major problem in recent medicine. The quality of air they breathe in those buildings is very significant for their health and comfort [4].

The previous research have reported that, 80% to 90% of bacterial infection existing in an open wound comes easily from the indoor air. By concentrating on the control of indoor air quality in hospitals, the spread of air contamination particles and other infections can be decreased.

The staff in operating rooms is considered as the main sources of infectious particles and bacteria in an operating room due to their activities [5]. If an airflow pattern formed to isolate patient from these staff, the preventing of spread the contamination particles will be achieved [6]. The study by [7] mentioned that the ventilation system and the type of airflow in indoor environments could be contribute the transmission of infectious diseases.

The research by [8], which studied the improvement of operating room contamination control using cleaning room technology, indicated that there is a relation between contamination in the air during surgeries and rates of infection in surgical site. According to [7], it has been shown that the ventilation system and the type of airflow in indoor environments such as hospitals, could be contribute the transmission of infectious diseases. They recommended that the computational fluid dynamics (CFD) is a suitable predicting technique for air distributions and a prefer tool on an hospitals operating room ventilation system designing. The research in [1], studied the influence of room air distribution on the infection rate in the operating room. The results concluded that to achieve a proper environmental condition within a surgical room, the ventilation system must maintain an optimal air distribution.

This paper aims to study air velocity and temperature distribution in a hospital operating room. CFD modeling approach is used to find the numerical solution for the fluid flow and heat inside the operating room. By using this simulation technique ,many experiments iteration applied with low cost to achieve a suitable thermal comfort and healthy environment to staff and patients. Also the air inside the operating room plays an important role in creating an appropriate exit of pollutant air, so the applied ventilation system should be achieves.

2. Mathematical model

To predict the indoor air quality, it is necessary to determine air parameters which affect the airflow like, velocity, temperature, and relative humidity. Air flow modeling based on (CFD), which solves the fundamental conservation equations for mass, momentum, and energy, is established well in this work.

Computer-based numerical procedures are the only means of generating complete solutions of these sets of equations [9]. Our study, makes the use of FLUENT simulation program from ANSYS 14.0 to predict velocity, and temperature for an operating room. The given equations are based on ASHRAE Handbook—Fundamentals 2009 (American Society of Heating Refrigerating and Air-Conditioning Engineers) and [10].

2.1 Continuity Equation

The law of conservation or mass continuity is shown more applicability to the model of room, which serves as the control volume. Therefore, the time rate of change of mass in the room (first term on equation) must be correspond to the difference between the mass entering and exiting the room. This principle is described by the equation as the following:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = 0 \qquad (3.1)$$

Where v is the velocity vector [m/s] and ρ is the air density [kg/m3].

2.2 Momentum Equation

The momentum equation can be expressed by Navier-Stokes equations by describing Newton's second law of fluid flow. This equation can be expressed in vector form as:

$$\nabla.(\rho \vec{v} \otimes \vec{v}) = \nabla.(\mu_{tot} \nabla \vec{v}) - \nabla p + \vec{F}_g + \vec{F}_{\Delta T} \qquad (3.2)$$

Where v is the velocity vector, ρ is the fluid density, p is the pressure [Pa], μ_{tot} [kg/m . s] is the sum of molecular and turbulent viscosity in turbulent flows, and $\vec{F}_g + \vec{F}_{\Delta T}$ contain parameters such as thermal differences, which give the extra momentum to the flow.

2.3 Energy Equation

The energy equation is used to obtain a description for the temperature distribution throughout the non-isothermal flow domain. Energy, E, in the air is defined as the sum of internal thermal energy, kinetic energy of velocity components and the gravitational potential energy, typical in buoyancy-driven flows. Conservation of energy at steady state is described as:

$$\nabla.(\vec{v}(\rho E + p)) = -\nabla.\left(\sum_j h_j J_j\right) + S_h \qquad (3.3)$$

Where J_j is the diffusion flux of species j, h_j is the enthalpy of species j, and S_h includes the heat or any other volumetric heat sources defined in the simulation process.

3. Numerical model and solution

The computer simulation software can significantly contribute in the studying, analyzing and selecting appropriate ventilation system to operating rooms because it characterizes by work of many different models of these systems. CFD modeling approach is used to find the numerical solution for the fluid flow and heat inside the operating room. A simplified 3D model of a typical operating room is shown in figure(1), in terms of the number of surgical staff, operating table, and patient (lying on operating table) , side wall supply grilles and exhaust air grilles was considered for the baseline model for the CFD simulations. The standing surgical staff are modeled by vertical rectangles by the side of the operating table. The lying patient was modeled as the horizontal rectangle at the middle of the room. The air supply inlets of the room is located at high position on the right wall. In the same way the two exhaust grille positions have been reproduced in the left wall of the room. There is also an additional two-exhaust outlet placed at low position on the right wall near the floor.

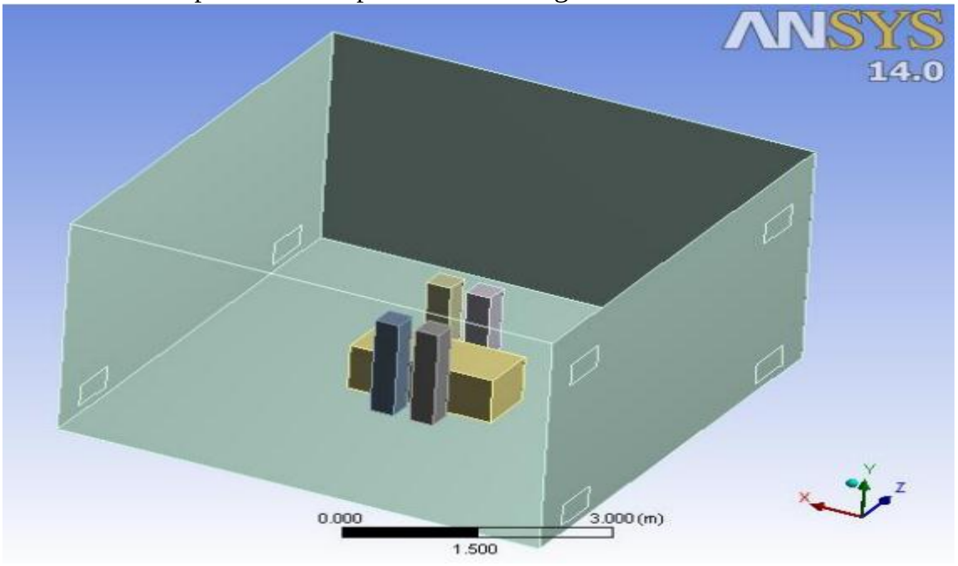


Figure (1): 3-D fo mrodeling an Operating Room

For the numerical simulations used in this paper, the standard k-ε model was employed to solve the air distribution. This model represents the most appropriate choice of model as it provides reasonable accuracy and extensive use in other applications. No other turbulence model has been developed that is as universally accepted as the k-ε turbulence model [11].

In CFD modeling as shown in figure (1), the human model was modeled in a simplified block-shape. The body of staff and the patient was simulated to have a skin temperature of 306K. The system in these case was set the air supply velocity to 0.4 m/s. The temperature of the air supplied to the operating room is in the order of 290K which then heats up from heat sources within the room. Numerical values and details of the boundary conditions used for the solution are given in Table (1).

Table(1): Boundary condition settings for simulating an operating room

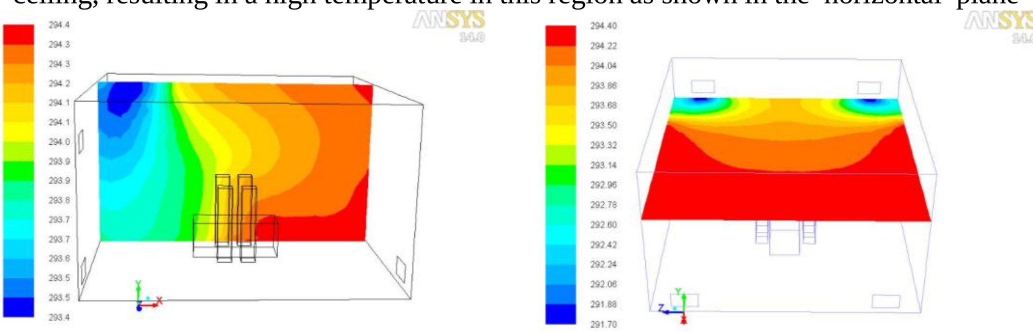
Entity	Velocity	Temperature	Heat Dissipation
supply grilles	V=0.4 m/s	T= 290 K	None
exhaust grilles	Unknown	T=295 K	None
Walls	zero	T=295 K	Adiabatic condition
Surgical staff	zero	T=306 K	100 W each
Patient	zero	T=306K	Exposed head dissipates 46w

DOI: 10.20428/JST.21.1.3

The simulation was performed by using four tools of ANSYS as follows: Design Modeler, Meshing, Fluent and CFD-Post. These tools allow users to perform the simulation in a single interface.

4. Results and discussion

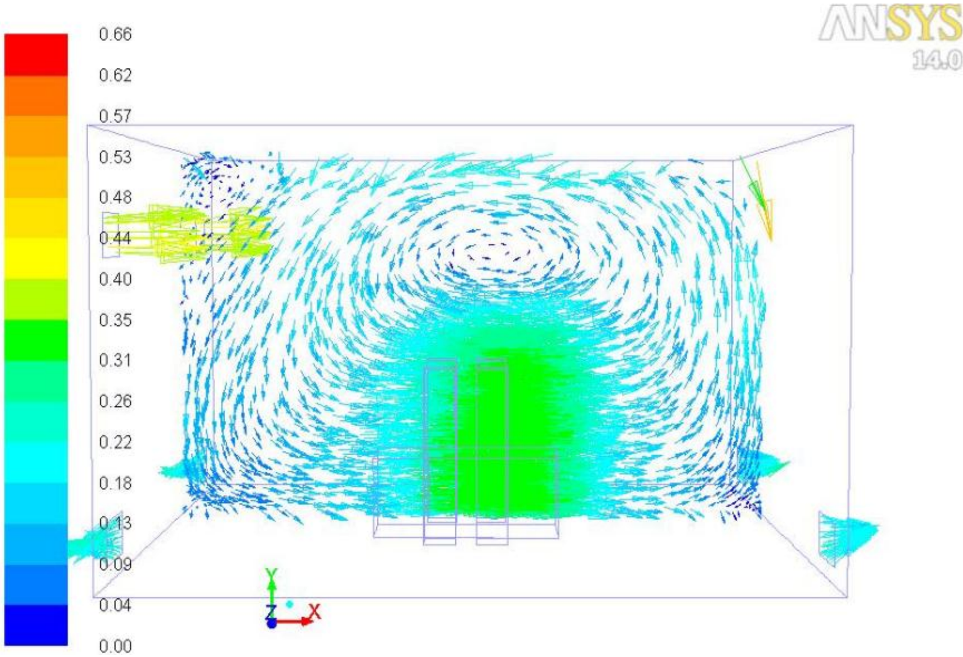
Figure (2) shows the contours of temperature in a central vertical plane and in a horizontal plane in which the occupied area (surgical site) is approximately between 20°C and 22°C. This is within the recommended comfort range of 16.7 °C to 26.7 °C [11] and also within the ranges 20 °C to 24.4 °C (ASHRAE 2009) and 22.3 °C to 23.5 °C [1].The neighboring area next to the inlets of air supply creates a low temperature region , where the air enters to the operating room is cold. In the surgical site, heat released from the staff induces natural convection flows that carry the heat up to the ceiling, resulting in a high temperature in this region as shown in the horizontal plane



(a) **(b)**

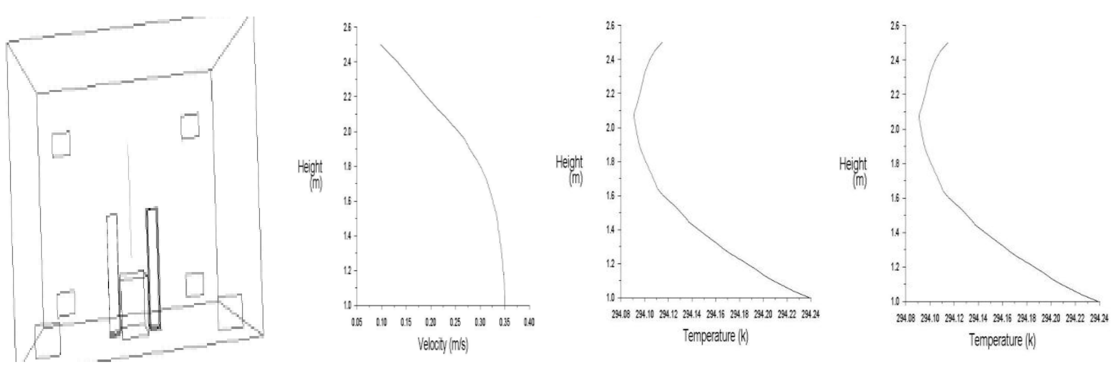
Figure(2): Temperature contours through the surgical site of the operating room

The cold airflow enters the room at full mean speed (0.4 m/s) through the supply opening located at high position on the right wall. Figure 3 shows the air distribution within the occupied area (surgical site). The air moves clearly crossing the operating table and surgeons to the exhaust grilles. It shows that one recirculation above occupied area due to lower air velocity and the heat dissipation caused by natural convection. The velocity vector also shows a vertical upward around this site due to thermal plumes induced by the staff on surgical site and obviously the air on this site is accelerated.



Figure(3): Velocity vectors through the surgical site of the operating room

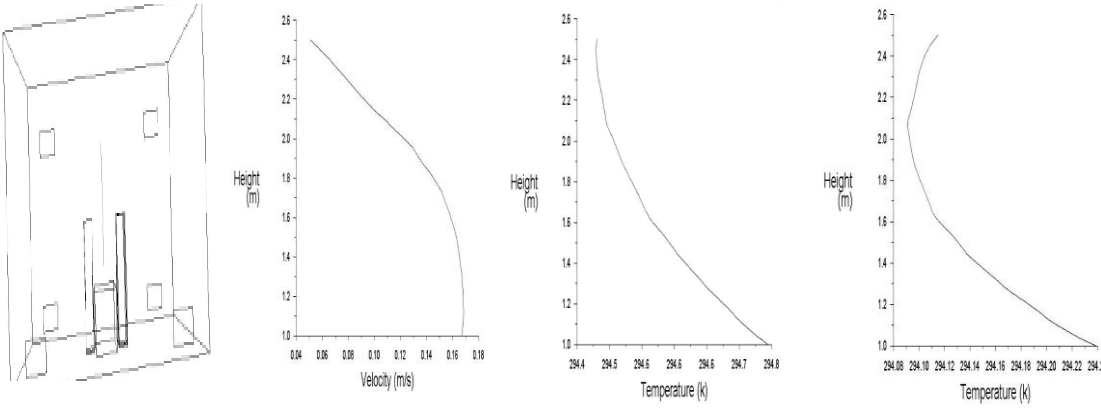
In figure (4-b), it can be seen that the plot of air in the surgical site from 1 m to 2.6 m above the operating table is below 0.35 m/s mean velocities within the approximately of air speed ranges to save the patient wound without drying [12]. Figure (4-c) shows the plot of temperature on the same region. The reduction of the average temperature can be observed, whereas the mean air velocity still high and vice versa.



(a) **(b)** **(c)**

Figure (4): position of simulated area(a) velocity (b) and temperature (c) over operating table

When the average air inlet velocity was decreased significantly to 0.2 m/s as shown in figure (5-b). It is clear that the temperature in this case differs from the previous case as a result of decreasing the air speed entering the room figure (5-c). Obviously, increasing air temperature at the occupied area as a result of the reduction of inlet velocity .



(a) (b) (c)

Figure (5): position of simulated area(a) velocity (b) and temperature over operating table as air inlet velocity was reduced to (0.2 m/s)

Figure (6), shows the air entrance into the room across the split unit on one side wall, by Streamline. These lines pass the surgery area toward the opposite sides and return, because there isn't any outlet. Therefore, the ventilation system must achieve air distribution and prevent the air pollutant inside the room especially the area where the surgical staff and patient are. This goal is inaccessible by this type of air supply at indoor environments.

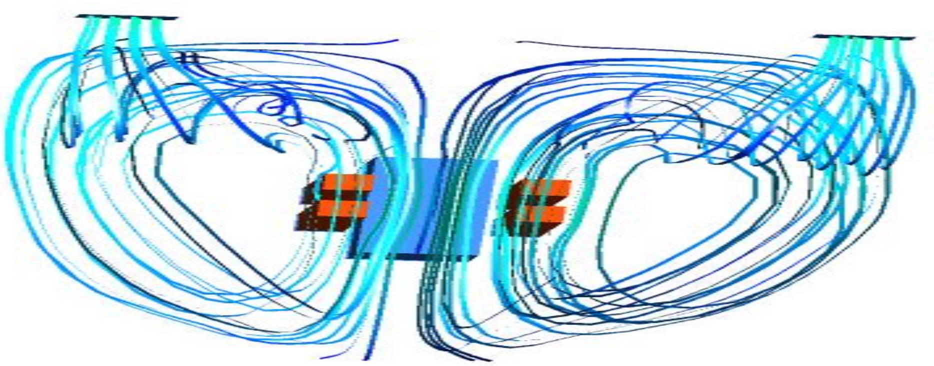


Figure (6): Streamline within all space on the OR in Yemeni hospital

5. Conclusion

A CFD analysis of the of airflow, and temperature distribution ,in a 3D hospital operating room with a conventional airflow, are presented and discussed. The simulation results show agreement with experimental data from the literature and standards. Using CFD simulation techniques allow visualization of the air flow and distribution of temperature by computer before built new hospital operating room. It permits to design and develop ventilation systems with low cost and minimal time. This paper presents a thorough analysis of air velocity and temperature distributions in an operating room. It is, also, found that airflow and air velocity significantly affects the thermal comfort of all workers in the operating room. Therefore, the air that enters the room is very importance and affects the room temperature. The air distribution indicates that the air velocity at the wound site is also within the required ranges. Also the average temperature in the surgical site is between 20°C and 22°C, within the recommended range of 17 °C to 26 °C. From the current observation, it can be deduced that the application of CFD in hospitals will give rise to design the internal environment and improve health outcomes especially in country like Yemen.

6. Reference

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