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# Investigation of influence of linear diffuser in the ventilation of operating rooms

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**Abstract.** Air quality in hospitals has always concerned hospitals' health officials due to its dangerous particles and gases. Because of the importance of air conditioning in the operating room, a system must be embedded in operating rooms to direct the contaminated air outside, and inject fresh filtered air from outside back into the room. In this study, laminar flow air conditioning system is implemented in the operating room by slot linear diffusers and with the help of air curtain. For this, stimulation Computational Fluid Dynamic (CFD) was used due to its efficiency. The aim of the present study was to find a proper solution to overcome the unfavorable factors, namely, contamination, humidity, and also temperature, velocity and pressure inside the room. These factors were implemented with different values and then stimulated through FLUENT software program. Results showed that the aforementioned factors can be overcome using air curtain and slot linear diffusers.

**Keywords:** operating room air conditioning; computational fluid dynamics; slot linear diffusers; operating room contamination; air curtain

## 1. Introduction

Tests performed on the hospital staff show that the operating room staffs are at a higher risk of various diseases and dangers compared to others. An important reason is operating room staff's lack of work sanitation; for instance, contact with blood and diseases such as hepatitis and AIDS that can be transmitted through blood, occur only due to negligence and lack of personal and work sanitation. But other factors, which are not personal, are also important in the higher risk that operating room staffs are exposed to; for example, anesthesia gas emissions to the environment and operating room's unhealthy air which are concerns related to hospital equipment and air conditioning. Louis studied the effect of operating room air distribution on contaminations in the operating room, and concluded that the optimal air distribution system plays an important role in properly maintaining operation room space (Lewis 1993). "Bloser" and "Crowe" can be referred to as pioneers in the operating room air conditioning industry. In 1960, they tried to build a clean room using a piston downward flow in which air would come out of distributors all over the ceiling. However, due to the body temperature of people in the room, lamps and also low velocity

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of blowing, it was impossible to make a direct proper air flow. Computational Fluid Dynamics progression in numerical modeling of operating room air conditioning was originated in early 1970's by Landrew Spalding (2005). Common operating room air distribution and air conditioning systems are fully satisfying when there is a proper design and the operating room is protected. Proper control of airborne particles, hazardous chemicals and radioactive equipment, odors, viruses and micro-organisms transmitted by air is of particular importance to people in the room. This was investigated in the study conducted by Leedwel in 1998. ASHRAE provided orders for design and construction of hospitals and medical facilities. Treating patients alongside convenience conditions is one of the main points of air conditioning in hospitals (ASHRAE 2003). In 1992, Chen could calculate airflow and particle concentration in the room through numerical simulation. Other researchers have improved airflow in the sterilization area through the upgraded method of $K$-$\varepsilon$. If there is a turbulent flow outside these areas, the flow is primarily unidirectional. In 1992, Memarzade and Manning (2003) used the model of laminar air flow and sequence of particles motion in a study, to compare the risks of contamination in the operating room and particle contamination on tables. Hartang and Kagel (1998) in 1998 offered a two-dimensional model for the operating room. Other researchers estimated that people in the room and the surgical lights can affect the air flow. So, a two-dimensional model is not suitable for any kind of operating room and does not show air distribution correctly. After this set of studies, Kameel and Khalil (2003) calculated the function of the flow near the wall in 2003 using a simple algorithm with turbulence properties by improved model, and found that optimal air distribution depends on the outlet channel position and the operating table direction. Bibak and Qods (2000) studied the operating room personnel from five different hospitals and investigated the effect of halothane gas on enzyme induction. They concluded that SGPT enzymes that are more specific factors in liver injury are significantly different in operating room personnel compared to other employees. Many patients need specific conditions of temperature, humidity and air cleanliness for treatment and healing promotion. In the surgery room the patient’s limb under surgery is usually in direct contact with the ambient air and very vulnerable to any kind of contamination, since they can easily enter their body. Also, Keshtkar and Ashtiani (2012) analyzed and modeled a three-dimensional laminar flow air conditioning system with air curtain in the operating room. They found that by air curtains operating room atmosphere approaches a better and safe condition and that it plays a main role in reducing contamination . In recent years, there have been a number of simulation studies related to various aspects of operating room and preoperative processes. Denton *et al*. (2010) investigate the optimal allocation of surgery blocks for operating rooms utilizing block scheduling policies, and Marjamaa *et al*. (2009) utilize simulation to study workflow in the operating room. In addition, Ballard and Kuhl (2006) utilize simulation to conduct a capacity analysis of surgical suite of operating rooms, and Segev *et al*. (2012) conduct a simulation study of patient transportation and the impacts productivity of preoperative processes. Fügener *et al*. (2014) develop a master surgery scheduling model incorporating ICU bed requests as well as multiple wards; several exact and heuristic algorithms are introduced to minimize the downstream costs. Door opening affects on operating room pressure during joint arthroplasty investigated by Simon and Stephen (2015). They investigated the number and duration of operating room door openings during hip and knee arthroplasty procedures and the effect of the door openings on room pressure. They tested the hypothesis that door openings defeat positive pressure, permitting air flow into the room. Room pressure and door status were monitored electronically during 191 hip and knee arthroplasty procedures. Zhain and Osborne (2013) investigated the air distribution inside a hospital operating room (OR) to protect the patient and staff from cross-infection while maintaining occupant comfort and not affecting the facilitation of surgical tasks. In ORs, HEPA-filtered air and vertical (downward laminar air flow are often used to achieve a unidirectional flow of fresh air from ceiling, washing over the patient and flowing out of exhaust vents on the side walls, near the floor. Previous research has shown that this method does not necessarily achieve the desired unidirectional flow pattern or adequately achieve optimal air asepsis. The results from this study showd that maximizing the area of the laminar flow diffusers remedies this issue and provides very low contamination levels. The use of air curtains as specified by manufacturers of commercial products may not provide satisfactory results, with noticeable contamination levels at the wound site.

Laminar airflow (LAF) systems investigated in clean prosthetic implant surgery by McHugh *et al*. (2014). Several studies have demonstrated decreased air bacterial contamination with LAF using bacterial sedimentation plates placed in key areas of the operating room. However, a part from the initial Medical Research Council study, there are few clinical studies demonstrating a convincing correlation between decreased surgical site infections (SSI) rates and LAF. Moreover, recent analyses suggest increased post-operative SSI rates. It is premature to dispense with LAF as a measure to improve air quality in operating rooms where prosthetic joint surgery is being carried out. However, new multi-center trials to assess this or the use of national prospective surveillance systems to explore other variables that might explain these findings such as poor operating room discipline are needed, to resolve this important surgical issue.

In this paper, we focus on the simulation of a three-dimensional laminar flow air conditioning system with air curtain in the operating room and we try to find the optimum velocity of air curtain to conduce the lowest contaminants in surgical zone.

## 2. General design

### *2.1 Dangers of working in the operating room*

Operating room staff and personnel are exposed to several risks including wasted anesthesia gases, blood-borne pathogens, latex allergies, smoke and laser hazards, hazardous chemical agents, risks of equipment and tools, sliding and falling, ergonomics (risk of lifting the patient) and contact with rays Heymann and David L. (2006) and Miller Ronald (2009). Vapors and gases that are gradually released in and around the operating room during medical operations are waste anesthesia gases including nitrogen oxides, halogen compounds vapors such as chloroforms and halothane. Exposure to such waste gases is usually the result of working unprofessionally during anesthesia, holes or worn gas connections, lack of or inappropriate storage conditions for the devices, or the patient's breathing when recovering after surgery. Some of the effects of exposure to anesthesia gases are: nausea, dizziness, headache, fatigue, irritability, sterility, birth defects, anemia, cancer and liver and kidney diseases. To prevent these diseases, it is quite vital to follow safety rules. Turning off anesthesia gas machine when it is not being used, using face masks, and checking anesthesia devices every four months will help a lot. Among the other dangers that threaten operating room personnel is the risk of working with lasers. During surgical procedures with laser or electrical surgical devices, thermal destruction of tissue produces smoke and also byproducts. Researchers have confirmed that these diffractions contain toxic gases and vapors such as benzene, hydrogen cyanide, formaldehyde, bioaerosols, living or dead cell material in blood droplets, and viruses. At high concentrations the smoke causes vision problems and hurts upper respiratory tract in health care workers, and also causes visual problems for the surgeon. Researchers have suggested that this smoke may act as a carrier for cancer cells that may be inhaled by the surgical team and other people exposed to such types of smoke (Miller Ronald 2009). But the most important and the best way to reduce the effects of laser vapor, viruses, bacteria and other substances that have an undeniable and irreversible impact on the personnel and patients, is to design an appropriate system of conditioning and dilution in operating rooms that considerably reduces the concentration of gases in the room.

### *2.2 Points in designing an operating room*

Operating rooms should not be so large that require much time to commute, and not so small that equipment gets contaminated. Large operating rooms for heart surgery or major surgeries requiring more equipment are slightly larger than usual. The walls and ceiling of the operating room should be solid, fireproof, waterproof, seamless, soundproof, and washable. In addition to the aforementioned conditions, operating room floor must be resistant to chemicals. Also, if it is too hard or too soft it would lead to fatigue in operating room personnel. Geometrically, the room should be designed with as few sharp edges as possible, so that flow rotation or dirt accumulation in those areas is prevented. Air quality in hospitals has always concerned hospitals' health officials due to its dangerous particles and gases. Because of the importance of air conditioning in the operating room, a system must be embedded in operating rooms to direct the contaminated air outside, and inject fresh air from outside back into the room; the system filters the fresh air that is being led back to the room. The air purification filter reduces particles larger than 0.5 microns to 1 to 5 in number per cubic foot. In general, operating room air conditioning system is designed for 15 to 20 air changes per hour. Usually these areas' air pressure is positive so that particles from outside are kept outside the room. Federal 209 Standard is a simple and general approach to classify clean rooms based on the number of particles per volume unit of room's air. In this classification operating room is placed on the 100th level, meaning that the number of particles with a diameter equal to 0.5 micron is 100 per cubic foot in the room. Overhead air inlet diffusers in the operating room are divided into two categories: grille and diffuser. In grille, vents are mounted on the ceiling and air flow jets straight down, but in diffuser, the input fresh air gets mixed with the air in other parts of the room before reaching the table. Research shows that grille is the best kind of air intake diffusers for operating rooms (AIA 2001).

## 3. Materials and methods

### *3.1 Modeling operating room*

According to the Standard of ASHRAE, breathing zone of people inside the room is an area surrounded by hypothetical walls with a distance between the ceiling to 1800mm from the floor and 600mm from the sidewalls of the room. Desired conditions should be examined inside this area. Here, the room is a 7×7 square, 3.66 meters high. The room is designed with chamfered corners and the operating room is simulated using the software program Gambit. Since equipment and operating table are usually placed in the middle of the room and the room is a square, to expedite problem-solving half of the room can be simulated and the answer paralleled based on the line of symmetry. To model the operating room and find the type and dimensions of the inlet and

Table 1 Geometry dimensions created in Gambit

| Dimensions (mm) | Model |
|---|---|
| 3.66×7×7 | Room |
| 0.4×0.2×1.8 | The doctor or nurse |
| 0.4×0.2×1.8 | Patient |
| 0.7×0.7×1.1 | Anesthesia machine |
| 0.46×0.41×0.25 | Monitor |
| 0.61×0.3×1.1 | Monitor Stand |
| *D*=0.3 | Surgical Lights |
| 0.6×3 | Ceiling lights |

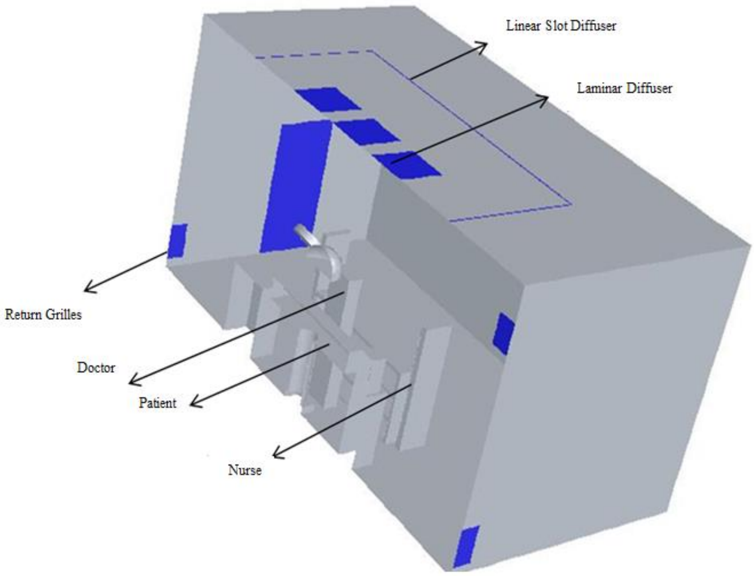



Fig. 1 Full geometry of the simulated model

outlet diffusers, first the total volume of required input air should be calculated. To do so, the total volume of the room should initially be calculated. The room's total volume=length×width× height=179.24 cubic meters. In this model one doctor, two nurses, one patient, anesthesia machines, monitor and its stand, two surgical lights and two LED lights on the ceiling are designed. All equipment and people inside the operating room are modeled according to the real state (Table 1). The three-dimensional schematic figure of the operating room can be seen in Fig. 1.

Now with regard to the room volume, air exchange per hour should be calculated. According to standards of ASHRAE, air exchange is assumed 25 times per hour for the operating room. Then, using the following equation total volume of required inlet air is calculated.

$$\frac{Number\ of\ \ air\ change\ \ per\ \ houre \times Total\ \ room\ volume}{60} = 1244\ lit\ /\ s \qquad (2)$$

After determining the amount of required input air and using the linear and overhead cranes

Table 2 Intake diffusers details

| Amount | Description |
|---|---|
| $3.66\times4.27$ m$^2$ | The space between slot linear diffusers |
| $4.27\times3.66$ m$^2$ | Linear diffusers dimensions |
| 0.02 m$^2$ | Groove width of slot linear diffusers |
| 868.38 Lit/s | Intake air volume of slot linear diffusers |
| $1.22\times0.61$ m$^2$ | Dimensions laminar flow diffusers |
| 439.19 Lit/s | Intake air volume flow diffusers |
| 1302.57 Lit/s | The total intake air volume |
| 26 NC | The entire system volume |

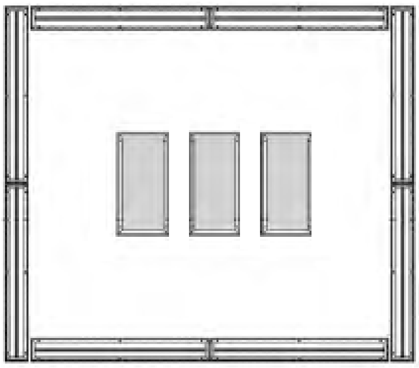


Fig. 2 Modeled laminar flow distribution system with air curtain

catalog, the characteristics of laminar flow system with air curtain are attained. These characteristics are shown in Table 2. Ultimately, the return air volume should be calculated for determining exhaust diffusers dimensions. It must be noted that the inlet and outlet air volume difference should not be so much that prevents contaminated air dilution.

Now, return vents dimensions are calculated using return vents catalog

$$\text{The exhaust diffuser size} = 0.51 \times 0.51\ (\text{m}^2) \tag{3}$$

In this study, four exhaust diffusers are used, each on one side of the room. Each vent is placed 0.127 (m) above the floor. Fig. 2 shows the overall design layout of laminar vents alongside the air curtain used in the model.

### *3.2 Solution independence from mesh*

Generally, mesh production is a process of trial and error. This part requires the longest amount of time in three-dimensional analysis since quality of meshing strongly affects the convergence trend. Final meshing is the result of several repeat experimental processes. Overall, solving a CFD problem must be independent of mesh. Independence of mesh is defined as the capability of neglecting answers' changes as the network gets smaller. Based on the suggestion of McHugh *et al.* (2014), a grid refinement study was conducted on the four grids. Independent of mesh review is shown in Table 3. These grids were evaluated using the normalized root mean squared error

Table 3 Independent of mesh review

| The grid mesh size | The number of cells | Contamination rate |
|---|---|---|
| 87×73×57 | 395846 | $5.4\times10^{-5}$ |
| 106×91×70 | 876 925 | $5.2\times10^{-5}$ |
| 115×97×75 | 1282898 | $4.2\times10^{-5}$ |
| 122×101×85 | 1632748 | $4.1\times10^{-5}$ |

Table 4 Amount of contamination and humidity in the operating room

| Sources of contamination | Amount of contamination | Amount of humidity |
|---|---|---|
| Doctor | 0.002 | 0.002 |
| Nurse | 0.002 | 0.002 |
| Gate | 0.002 | 0.002 |

Table 5 Boundary conditions and modeling initialization

| Temperature or heat flux | Velocity | Boundary condition | Model |
|---|---|---|---|
| 19.27 ℃ | 2.37 | Velocity- Inlet | Slot linear diffuser |
| 19.27 ℃ | 0.38 | Velocity- Inlet | Laminar flow diffusers |
| 27 ℃ | - | Pressure-Outlet | The outlet diffuser |
| 5 W / $m^2$ | - | Wall | Surgical Headlamps |
| 200 W / $m^2$ | - | Wall | Surgical lights |
| 70 W / $m^2$ | - | Wall | Ceiling lights |
| 75 W / $m^2$ | - | Wall | Monitor |
| 40 W / $m^2$ | - | Wall | Anesthesia machine |
| 37℃ | - | Wall | Doctor |
| 37℃ | - | Wall | Nurse |

(NRMSE) of the CFD model results with different grids. The NRMSE of the predicted $U$ and $W$ direction velocity at the four measure poles across the center axis of the room) calculated and a comparison between the 395846, 876925, 1282898 and 1632748 meshes carried out. It reveals that there is generally a great improvement in error with the 1282898 mesh, and the computational error is typically below10%, and absolutely below 30%. Based on these, and in order to minimize the simulation time, the 1282898 mesh was chosen to be used for the parametric simulations.

### *3.3 Boundary conditions and the problem's initial value*

The generated mesh is a triangular mesh. Since the patient and physician's area is more important and flow analysis in these areas is more significant, it has finer meshes so that the results are closer to the actual values. The following details about the number of cells and nodes generated in the model are extracted from FLUENT software program. The number of cells produced is 1282898. Relative output pressure is assumed zero; also, system solutions are pressure based. The simple solution algorithm, which enjoys relatively high rate of convergence, is used. Also, second-order upwind discrete approach is used due to its higher accuracy compared to the first order. In general, there is no turbulence model that can be used for all modes and different issues, and choice of turbulence model depends on considerations such as flow physics, simulation experiences to specific problems, the degree of accuracy required, the power of computing resources, and the amount of time available for calculation. The simplest turbulent models that are relatively complete are two-equation models, since solving two separate transport equations leads to independent determination of confusion velocity and characteristic length. $K$-$\varepsilon$ Model is among these turbulent models and is one of the strongest turbulent models for engineering problems. Strength, economical calculations, and acceptable accuracy in a wide range of turbulent flows resulted in the popularity of this model. Numerical values of boundary conditions can comprehensively be seen in Tables 4 and 5.

## 4. Results and discussion

After applying initial and boundary conditions on the equations and using FLUENT, the following results were obtained. It is noticeable that in all cases the residual values for all parameters considered equal to, $10^{-7}$. In Fig. 3 distribution of operating room contamination can be seen on the screen. As can be seen from the figure, the highest contamination intensity is located outside the surgery section. The contamination that comes from an external source outside the surgical area approaches the area and is directed outwards by the air curtain. Since the vertical flow in the operating room often has an unpredictable behavior and leads to flows in the room that do not provide optimal sterile conditions, the air curtain sterilizes the vertical flow and creates conditions closer to ideal. Air curtain flow acts as a physical boundary that keeps contaminant particles outside the sterile surgical area. Contamination of doctors and nurses is inhibited by the laminar flow system. This contamination that is related to the surgical site and is produced by doctors and nurses is driven out by laminar flow. As illustrated in the figure, contamination on the patient rates lower than the average. In Fig. 4 mass fraction of $H_2O$ contour is drawn in the atmosphere of the operating room and in the center. Humidity is mainly derived from doctors' and nurses' bodies. Another source of humidity is sudden opening of the room entrance. Humidity

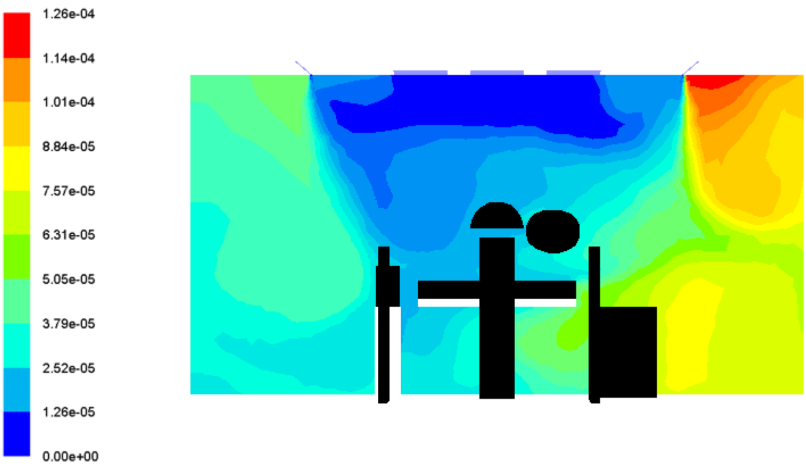



Fig. 3 Contours of mass fraction of contaminant

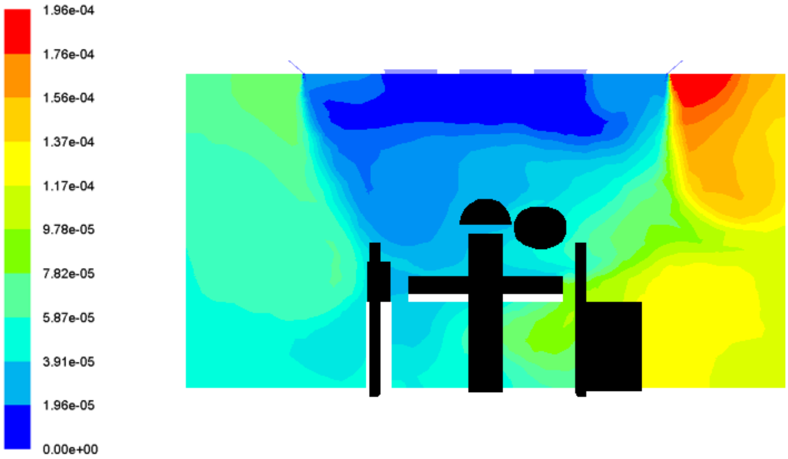



Fig. 4 Contours of mass fraction of $H_2O$


Fig. 5 Contours of static temperature

caused by the entrance is controlled by the air curtain. Doctors and nurses perspire as a result of different activities; the perspiration humidity is drawn to the patient's body and then minimized through the laminar flow distributed from diffusers on the ceiling. The air curtain is a barrier to humidity entering the surgical site. As can be seen, increasing the velocity decreases humidity around the patient. In this section it can be concluded that the air curtain system decreases moist in the surgical site.

Fig. 5 shows the temperature distribution on operating room's central screen. Ceiling lights, doctors, nurses, patients and operating room equipment are the heat sources. We aim to create favorable conditions and comfort for the patient. As the figure shows, changes in temperature are more frequent near the ceiling lights and operating room equipment, and in the surrounding environment temperature distribution is almost even. Temperature around the patient is 300$^{o}$ Kelvin, which is almost equal to the room temperature. In fact, laminar flow has created favorable

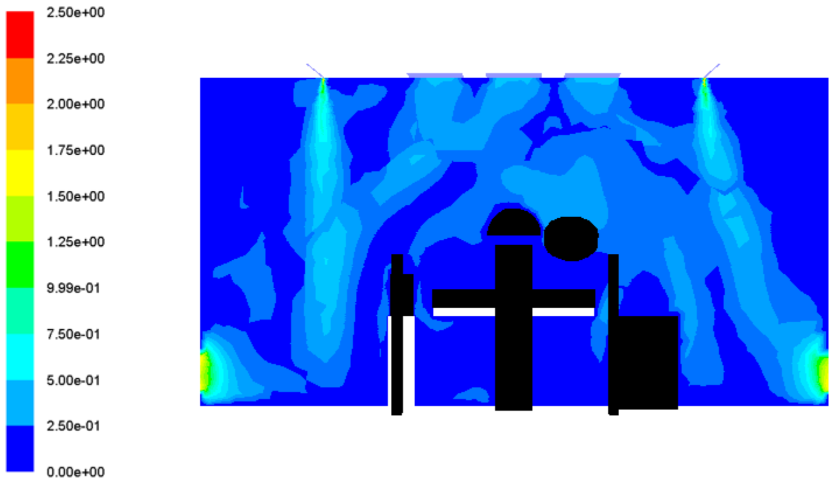
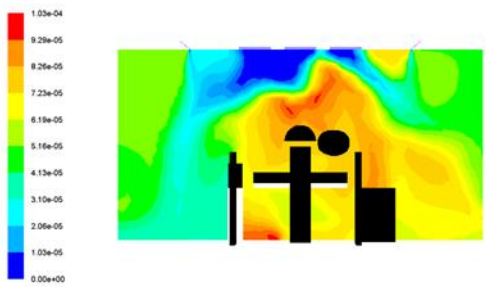
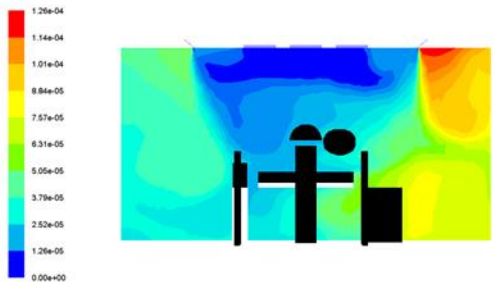


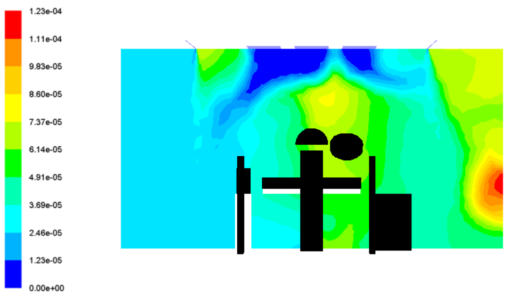

Fig. 6 Contours of velocity



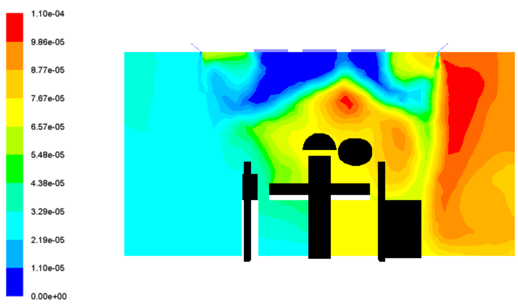
(a)



(b)



(c)



(d)

Fig. 7 Contamination contour of the operating room where air velocity is (a) 1.37 m/s (b) 2.37 (c) 3.37 (d) 4.37 m/s

conditions for the patient. The air curtain prevents transmission of heat to the surgical site, and the exterior heat exits directly through exhaust diffusers. In fact, the air curtain keeps the temperature at a more optimal level.

Fig. 6 shows velocity distribution in operating room's central screen. The highest velocity is observed near the air curtain (slot linear diffuser). As can be seen, the air curtain has created an optimum velocity near the patient and the surgical site. In fact, air curtain system keeps laminar air velocity constant. An advantage of using air curtains is to prevent flow's disturbance and also keeping the velocity at an optimal level. Inlet airflows move downwards and toward the floor due to lower temperature and higher density compared to the room average temperature (due to buoyancy force), and then mix with the upward warm flows with lower density, resulted from lamps, and make the flow move mainly downward. Only a small portion of the flow would move upward towards the ceiling then. Here, there are two types of heat transfer: free and forced movements. Free movement is a result of the same buoyancy force and forced displacement is caused by the air curtain and the laminar flow.

As can be concluded form Fig. 7 connectors, the lowest rate of contamination in the surgical site belongs to the slot linear diffuser with 2.37 meters per second of velocity. Air curtain flow not only acts as a physical boundary preventing contaminants from entering into the sterile area of the surgery, but also works as a drain diffuser and makes the laminar flow move downward and spread outward. This feature of the air curtain reduces recirculation zones in the operating room and prevents laminar flow turbulence. If improperly designed, air curtains would lead to a velocity higher than required. Such air curtain rapidly sucks the laminar flow and might draw out all the laminar flow before it reaches the operating table. An air curtain with insufficient effect on the laminar flow cannot control it properly either. Even the outlet flow of this curtain might be drawn into the laminar flow and the room would be restored to the same condition where only the vertical laminar flow was being used. According to the results, if the air curtain enjoys optimal exhaust velocity it will drastically reduce contamination and maintain more favorable conditions and a better flow pattern.

The graph in Fig. 8 shows the amount of contamination to the height of the operating room. As illustrated, contamination at one meter of height, where the operating table is, is lower. The air curtain is a barrier and blocks contamination, thus the surgical sterile site contamination is substantially reduced. The contamination rate near the patient's body is $4.2\times10^{-5}$.

The graph in Fig. 9 shows mass fraction of $H_2O$ to the height of the operating room. As presented in the graph, humidity has drastically decreased around the operating table. Humidity from the doctors, nurses and external sources is a source of contamination blocked by the air curtain and kept outside the surgical site. Humidity rate around the patient's body is $4.2\times10^{-5}$. The graph in Fig. 10 shows velocity to the operating room height in different areas. As shown in the

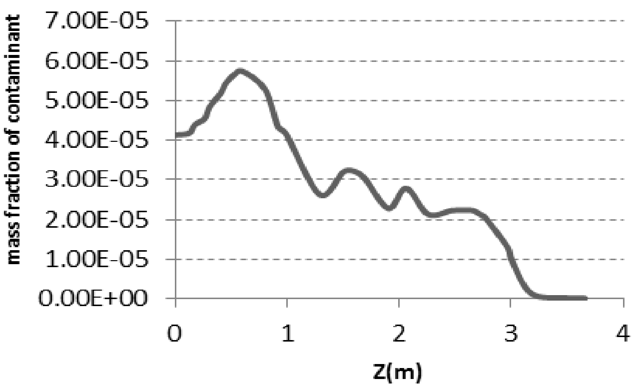



Fig. 8 Graph of contamination to the height of operating room

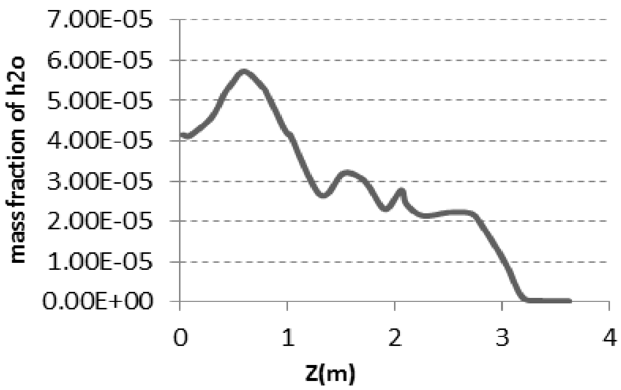



Fig. 9 Graph of mass fraction of $H_2O$ to the height of operating room

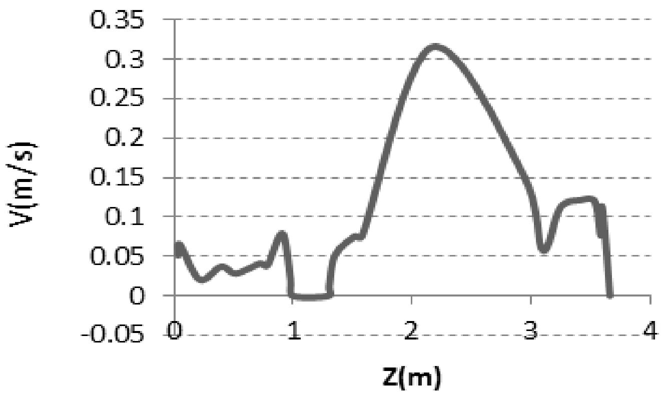



Fig. 10 Graph of velocity to height of the operating room

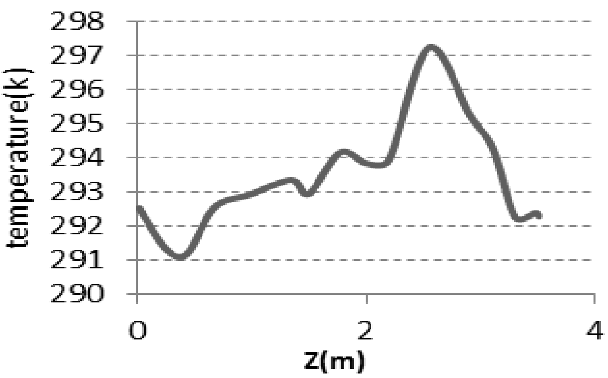



Fig. 11 Temperature graph to the height of the operating room

graph, velocity in the surgical site is kept at a favorable condition due to the air curtain. In fact, the air curtain keeps the laminar flow at a constant velocity and even reduces it around the operating table. At one meter of height, where the surgery table is located velocity is quite low and almost zero. Moreover, the air curtain can provide a standard velocity for patients, doctors, and nurses.

Higher velocities are in higher heights and near air diffusers.

The graph in Fig. 11 shows temperature in different heights of the operating room. As shown in the graph, temperature is almost uniform in different areas. The highest temperature is viewed around lamps, which is due to the lamps' heat flux, and almost 299 K around the operating table and the patient. The air curtain keeps the temperature in the surgical site at an optimal level and thus, comfort and standard conditions of temperature is provided for patients and medical staff.

Fig. 12 shows contamination rate to the length of the operating room. The area with the lowest contamination is between -1 and 1 meter around the operating table and as mentioned above, the air curtain acts as a physical boundary, keeping contamination out of this area. Highest amount of contamination is seen outside the surgical site, where they are blocked by the air curtain and prevented from entering the sterile surgical site.

The graph in Fig. 13 shows the mass fraction of $H_2O$ to the operating room length. As can be seen, in the range of -1 to 1 meter of the surgical site humidity is lower. Highest rate of humidity is outside the surgical site and prevented by the air curtain from entering the surgical site. Humidity caused by perspiration of the medical team will be controlled by laminar diffusers. Fig. 14 shows velocity at various points to the operating room length. As can be seen, the lowest velocity is in the range of -1 to 1 meter of the room length. Velocity is in an optimal and low range due to the air curtain. The air curtain creates standard velocity for the patient and medical team.

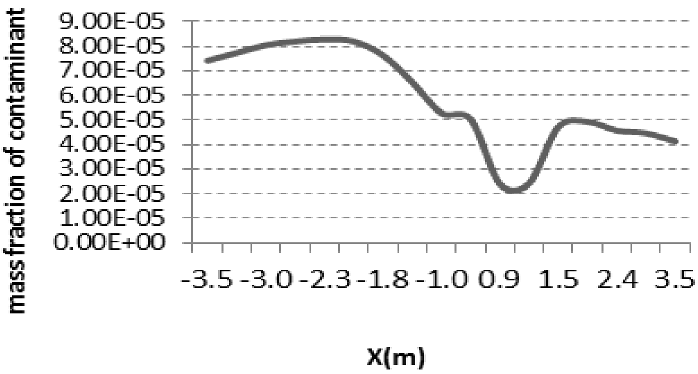



Fig. 12 Graph of contamination to the length of the operating room

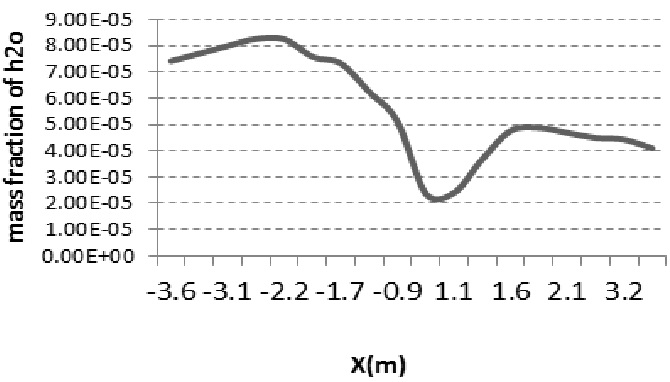



Fig. 13 Graph of volume fraction of $H_2O$ to the operating room length

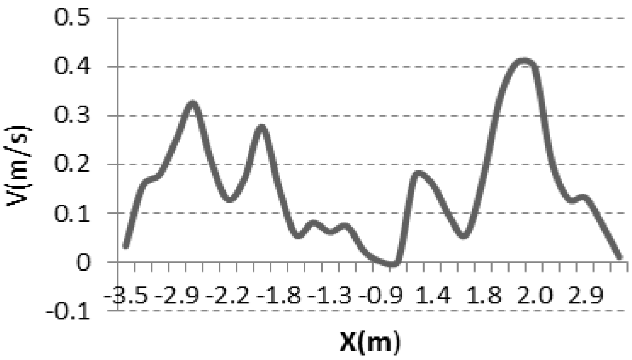



Fig. 14 Graph of velocity to the operating room length

Table 6 Comparison of contamination on the operating table at different velocities

| Contamination on the operating table | Laminar diffuser velocity | Slot linear diffuser velocity |
|---|---|---|
| $7.6\times10^{-5}$ | 0.38 | 1.37 |
| $4.2\times10^{-5}$ | 0.38 | 2.37 |
| $5.6\times10^{-5}$ | 0.38 | 3.37 |
| $6.5\times10^{-5}$ | 0.38 | 4.37 |

In Table 6 contamination on the operating table has been assessed at different velocities. As shown in the Table, the lowest contamination rate belongs to the slot linear diffuser with velocity of 2.37 m/s. Exhaust air velocity has a huge impact on reducing contamination and maintaining more favorable conditions and a better flow pattern. In case of improper design of air curtain, velocity will be higher than required and the curtain will suck the laminar flow rapidly. This is clearly seen in the contours. Air curtains that cannot sufficiently affect the laminar flow cannot properly control it. Even the output flow may be drawn into the laminar flow. This is seen in the contour with 4.37 m/s of slot linear diffuser velocity. Results show that the air curtain with an exhaust air optimal velocity drastically reduces contamination and creates more desirable conditions.

## 4. Conclusions

In this study, model of laminar air flow system with air curtain was designed considering the contamination factor caused by doctors, nurses, and patients, and also transmitted through the entrance of the operating room, in order to find and suggest the best area of the operating room (concerning contamination, velocity, air temperature, etc.). The study also compared the behavior of the system and its performance with and without the air curtain. Since vertical flow may have an unpredictable behavior and lead to flows in the room that disturb the optimal sterile conditions, the air curtain system optimizes the vertical laminar flow and takes it closer to the ideal “one pass, then exit” condition.

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