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Optimization of recirculating laminar air flow in operating room air conditioning systems

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Abstract. The laminar flow air conditioning system with 100% fresh air is used in almost all operating rooms without discrimination in Turkey. The laminar flow device which works with 100% fresh air should be absolutely used in Type 1A operating rooms. However, it is not mandatory to use 100% fresh air for Type 1B defined as places performed simpler operation. Compared with recirculating laminar flow, energy needs of the laminar flow with 100 % fresh air has been emerged about 40% more than re-circulated air flow. Therefore, when a recirculating laminar flow device is operated instead of laminar flow system with 100% fresh air in the Type 1B operating room, annual energy consumption will be reduced. In this study, in an operating room with recirculating laminar flow, optimal conditions have been investigated in order to obtain laminar flow form by analyzing velocity distributions at various supply velocities by using computational fluid dynamics method (CFD).

Keywords: Laminar flow; numerical modeling; CFD; recirculating air; operating room.
AMS Classification: 60G12

1. Introduction

Operating rooms (ORs) are among the most demanding healthcare work areas. Therefore, the infection risks are quite high in these areas. In this sense, because the surgical site infection has negative effect on recuperation time or patient mortality and cost of healthcare services, forming of bacteria colony that caused infection should be under control. Because of reasons aforementioned above, the selection of an appropriate air conditioning system is the first requirement to preserve air quality including remove airborne bacteria, chemicals like waste medical gases used for anesthesia and disinfection and other particles such as skin squames shed by operation team and odors from ORs. The quality of air in an operating room is essentially assessed with regard to how effective the air distribution strategy is in minimizing the possibility of risks mentioned above. In addition, the OR air conditioning system should provide thermal comfort for surgical team to facilitate their demanding work during operations. For this purpose, environmental factors such as temperature, humidity and air velocity should be steerable through various methods.

In practice, achieving of zero contamination in an OR is impossible. But it should be kept at minimum levels. Air contamination less than 10 colony-forming units (cfu)/m^3 is

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internationally accepted as definition of ultra clean air [1]. In practice in Turkey, DIN 1946-4 standard is generally taken into consideration. According to DIN 1946-4 standard, the ranges of temperature, relative humidity and air velocity parameters mentioned in this standard should be under control at a range of 19–26 ºC, 30–60% and 0.23-0.30 m/s, respectively [2]. At 1200 mm height from floor, desired the air velocity is at the range of 0.23-0.25 m/s (Figure1).

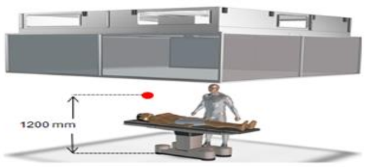


Figure 1. Operating room

In literature, there are a lot of studies on OR air conditioning. Woloszyn et al. (2004) studied diagonal air-distribution system for operating rooms experimentally and by using computational fluid dynamics (CFD) modeling. They revealed that the contaminant distribution depended strongly on existing obstacles such as medical equipment and operation team [3]. Comparing of mixed and laminar airflow systems and the influence of human factors were studied by Andersson et al. (2014). This study was achieved experimentally in a Swedish orthopedic center. Their study shows that laminar airflow air conditioning system used in operating rooms offer high-quality air throughout surgery, with very low levels of (cfu)/m3 close to the surgical wound [4]. Baskan et al. investigated scalar modes for a periodic laminar flow experimentally and computational used finite element method (FEM) [5]. There are a lot of various studies on ORs such as indoor thermal conditions in hospital operating rooms [6,7], impact of different-sized laminar air flow on bacterial counts in the operating room during surgery [8], impact of airflow systems on bacterial burden [9,10] and economical assessment of air-conditioning systems [11].

The air conditioning system in an OR should be carefully designed to ensure thermal comfort conditions and also without infection risks mentioned above. The inlet velocity of air supplied to mixing chamber, the placement of filters and the structure of air grille are highly effective to achieve desired velocity and temperature distributions. The usage of vertical filter has adverse effect on laminar air flow to be achieved. Due to turbulence and the formation of dead volumes in the mixing chamber, a homogeneous air distribution can not be obtained at grille outlet (Figure 2).

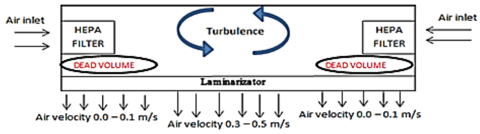


Figure 2. OR Air-ceiling unit with vertical HEPA filter

The use of horizontal filters helping to stabilize the turbulence in the mixing chamber facilitates to obtain a uniform air distribution in air ceiling output (Figure 3).

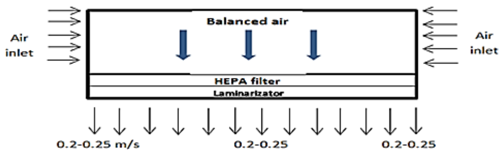


Figure 3. OR Air-ceiling unit with horizontal HEPA filter

This study focuses on a detailed analysis of the air distribution in an operating room under the laminar airflow condition by using CFD analysis method. In an operating room with recirculating laminar flow and horizontal HEPA filter, optimal conditions have been investigated in order to obtain laminar flow form by analyzing velocity and temperature distributions at various supply velocities by using CFD method.

2. Materials and method

2.1. Realizable k-ε turbulence model

There are various turbulence models such as k-epsilon (k-ε) models (e.g. Standard k-ε model, Realisable k-epsilon model, Re-Normalisation Group (RNG) k-ε model), Spalart-Allmaras Model, k-w models, v2-f model, Reynolds stress equation model and Large eddy simulation (LES) model [12]. In this study, realizable k-ε turbulence model is used because of the most common model used in CFD to simulate mean flow characteristics. The original impetus for the k-epsilon model was to improve the mixing-length model, as well as to find an alternative to algebraically prescribing turbulent length scales in moderate to high complexity flows [12].

The first transported variable determines the energy in the turbulence and it is called turbulent kinetic energy (k). The second transported variable is the turbulent dissipation (ε) which determines the rate of dissipation of the turbulent kinetic energy. In realizable k-ε model, turbulent kinetic energy (k) and its the rate of dissipation (ε) together with turbulent viscosity and turbulent conductivity were stated as follow [12].

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\epsilon \quad (2)$$

where k is turbulent kinetic energy (m^2/s^2), ϵ is the rate of dissipation of the turbulent kinetic energy (m^2/s^3), ρ is density (kg/m^3), μ is dynamic viscosity (Pa.s), μ_t is turbulent viscosity (Pa.s), $\sigma_k$andσ_ϵ are turbulence Prandtl constants, $C_{1\epsilon}$andC_2 are model constants for k-ε turbulence model, $G_b$is turbulence depending on buoyant force, $S_k$andS_ε are source terms defined by the user and Y_M is the effect of compressibility on turbulence.

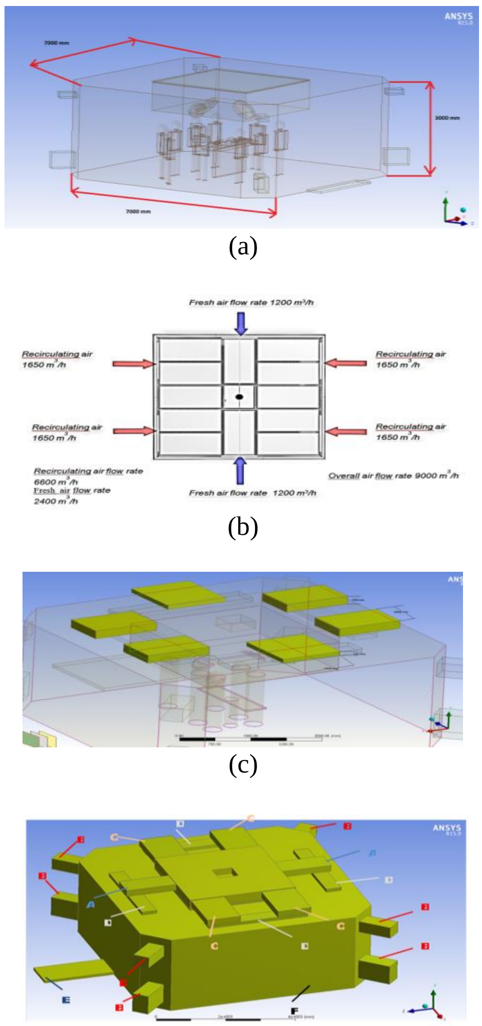
$C_{\epsilon 1} = 1.44$, $C_2 = 1.92$, $\sigma_k = 1.0$, $\sigma_\epsilon = 1.2$ [12].

2.2. Boundary conditions

Although an intensive structure of mesh provides a better numerical accuracy since physical accuracy of calculation is limited to physical accuracy of model, unrelated details are avoided. In order to achieve high quality numerical mesh, quality ratio of elements is desired to be in the range of 0.1-1 [13]. If this ratio is close to 1, it indicates high quality of the used components. Automatic mesh method was not used to increase the mesh quality and the element number in the critical domains. In geometry, there are 7783036 mesh elements and 2723271 nodes. Maximum skewness and minimum orthogonal values are equal to 0.79 and 0.24, respectively. In addition, it is assumed that HEPA filters and laminarizator have a porous structure. CFD analysis details are given in Table 1. In analysis; supplying air is fed from the laminar flow air ceiling unit in size with 3200x3200 mm towards the OR in size with 7000x7000x3000 mm (Figure 4). Exhaust air at 2200 m^3/h is sucked from four corners via suction grilles. 2400 m^3/h of fresh air treated by air conditioner is fed into a laminar flow unit. 6600 m^3/h of re-circulated air is sucked from grilles placed at the ceiling and then it is blown into the laminar flow air ceiling unit.

Table 1. Solution methods and fluent adjustments

Fluent adjustments	Solution Methods
Precision: Double Precision	Scheme: Simple
Viscous Model: Standard k-epsilon	Gradient: Green-Gauss Node Based
Inlet Turbulent Intensity: %5	Pressure: Second Order
Inlet Turbulent Viscosity Ratio: % 5	Momentum: Second Order Upwind
Outlet Turbulent Intensity: %5	Turbulent Kinetic Energy: First Order Upwind
Outlet Turbulent Viscosity Ratio : % 5	Turbulent Dissipation Ratio: First Order Upwind
	Energy: Second Order Upwind



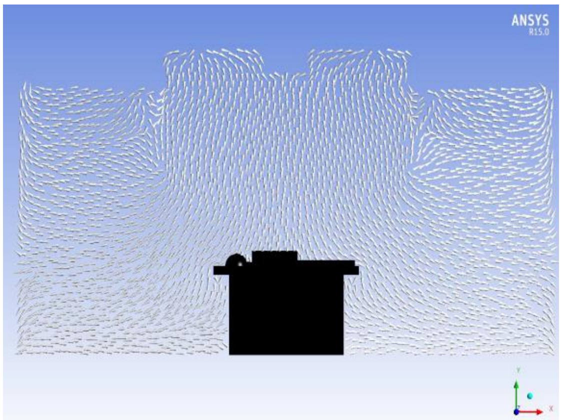
Inlet Velocity = A, Outlet Velocity = B, Recirculating air Inlet = C, Recirculating air Outlet = D
Outlet Pressure = E, Wall = F

Figure 4. Dimensions (a), air ceiling unit (b), grille locations and description (c and d) of analysed OR model

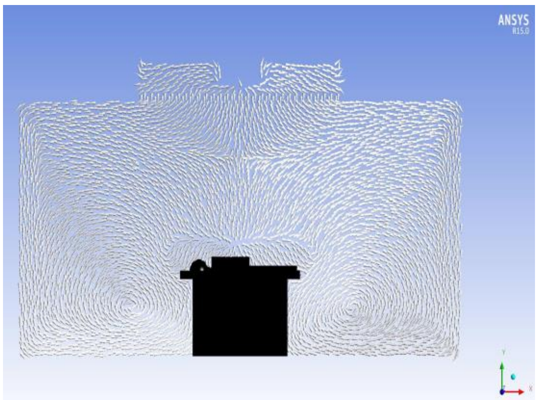
Firstly, numerous analyses have been made to determine the location and area of the suction grilles. In this regard, the analysis which is nearest to desired air distribution has been selected and presented evaluation about it. Each recirculating exit area for analysis is at 1.35 m^2.

3. Results

The effect of crystal curtain usage can be seen in Fig.5. When the crystal curtain which helps direct the laminar flow air towards the surgical area is not used, instabilities and high turbulent intensity are seen. As an improvement on desired air distribution, the design of crystal curtain includes a physical barrier which surrounds the surgical zone on all four sides. In this respect, the analysis was carried out for air ceiling model with crystal curtain. Besides, because laminar air ceiling dimensions are 3200x3200 mm, sterile laminar air flow covers not only operating table but also surgery team and medical equipment. Accordingly, area of high hygienic environment in the ORs is increased.



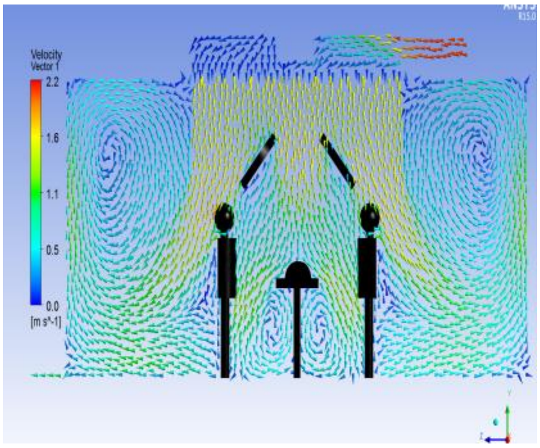
(a)



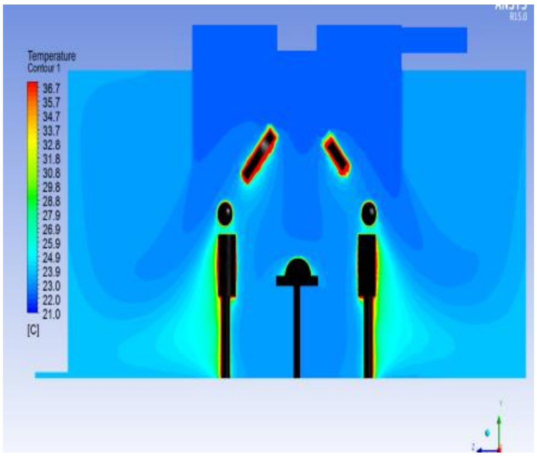
(b)

Figure 5. Comparison of air ceilings with (a) and without (b) crystal curtain unit

Following this identification, air velocity distributions in OR were investigated at different air inlet velocities. For example, for 2.2 m/s air inlet velocity, turbulent regions occur in the ORs and also, air velocities exceed the range of velocity mentioned in the standard (Figure 6a). As can be seen from Figure 6, the turbulent is formed in the upper regions out of crystal curtain, meanwhile, air velocities are changing at 0.5-1.1 m/s ranges. Air velocities in exit of crystal curtain are at 1.5-1.8 m/s ranges and these values exceed 6 times more than the desired value. Temperature values vary in the range of 21-27 ºC for the OR (Figure 6b).



(a)



(b)

Figure 6. Air velocity (a) and temperature (b) distributions in OR

In the result of optimization studies performed for 0.5 m/s air inlet velocity to the mixing chamber, the range of 0.23-0.30 m/s mentioned in standard could be achieved (Figure 7). But air inlet velocity will change according to air ceiling dimensions and needed air flow rates.

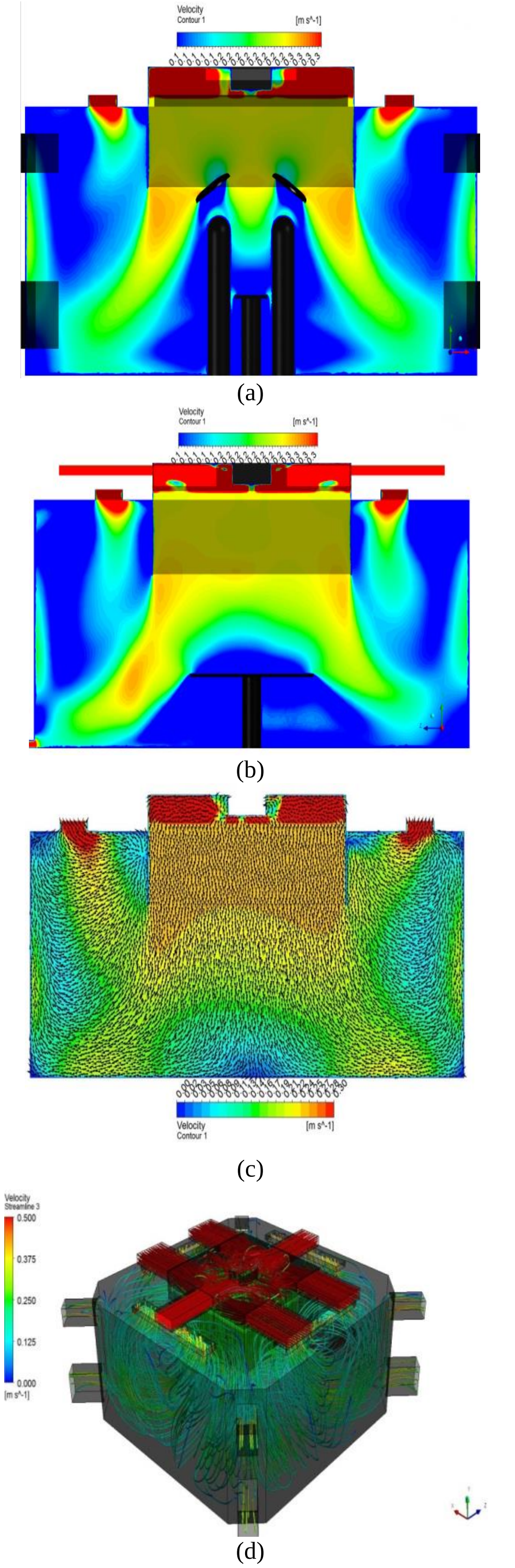


Figure 7. Optimized air velocity distribution for OR, (a) 2D xy coordinates (b) 2D zy coordinates (c) velocity vectors and (d) 3D air velocity distribution

4. Conclusion

The crystal curtain provides a barrier between the clean zone and the less clean zone. The CFD models clearly indicate that the directional flow from the laminarizator creates a customized air flow dynamic in the room. There is a significant increase in impact area for the OR. The analysis results are also evident that the equipment in the room causes turbulence that should be inhibited. At the laminarizator outlet, if air velocity is kept at 0.3 m/s or lower, turbulence will not occur. The majority of existing OR air conditioning systems are not convenient in terms of air mass flow rate, laminar flow air ceiling applications and dead volume forming. In this sense, the existing systems should be modified based on DIN 1946-4.

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References

[1] Friberg, B., Friberg, S. and Burman L.G., Inconsistent correlation between aerobic bacterial surface and air counts in operating rooms with ultra clean laminar air flows: proposal of a new bacteriological standard for surface contamination. Journal of Hospital Infection, 42, 287–293 (1999).

[2] Deutsches Institut fur Normung (German Institute for Standardization) DIN 1946-4:2005-02 Heating, ventilation and air conditioning systems in Hospitals.

[3] Woloszyn, M., Virgone, J. and Melen, S., Diagonal air-distribution system for operating rooms: experiment and modeling. Building and Environment, 39, 1171–1178 (2004).

[4] Andersson, A.E., Petzold, M., Bergh, I., Karlsson, J., Eriksson, B.I. and Nilsson, K., Comparison between mixed and laminar airflow systems in operating rooms and the influence of human factors: Experiences from a Swedish orthopedic center. American Journal of Infection Control, 42, 665-669 (2014).

[5] Baskan, O., Speetjens, M.F.M., Metcalfe, G. and Clercx, H.J.H., Experimental and computational study of scalar modes in a periodic laminar flow. International Journal

of Thermal Sciences, 96, 102-118, (2015).

[6] Balaras, C.A., Dascalaki, E. and Gaglia, A., HVAC and indoor thermal conditions in hospital operating rooms. Energy and Buildings, 39, 454–470, (2007).

[7] Dascalakia, E.G., Lagoudib, A., Balarasa, C.A. and Gaglia, A.G., Air quality in hospital operating rooms, Building and Environment, 43, 1945–1952, (2008).

[8] Diab-Elschahawi, M., Berger, J., Blacky, A., Kimberger, O., Oguz, R., Kuelpmann, R., Kramer, A. and Assadian, O., Impact of different-sized laminar airflow versus no laminar air flow on bacterial counts in the operating room during orthopedic surgery. American Journal of Infection Control, 39, 25-29, (2011).

[9] Hirsch, T., Hubert, H., Fischer, S., Lahmer, A., Lehnhardt, M., Steinau, H.U., Steinstraesser, L. and Seipp, H.M., Bacterial burden in the operating room: Impact of airflow systems. American Journal of Infection Control, 40, 228-232, (2012).

[10] Nilsson, K.G., Lundholm, R., and Friberg, S., Assessment of horizontal laminar air flow instrument table for additional ultraclean space during surgery. Journal of Hospital Infection, 76, 243-246, (2010).

[11] Ozyogurtcu, G., Mobedi, M. and Ozerdem, B., Economical assessment of different HVAC systems for an operating room: Case study for different Turkish climate regions. Energy and Buildings, 43, 1536–1543, (2011).

[12] Launder, B.E. and Spalding, D.B., Lectures in Mathematical Models of Turbulence, London, England: Academic Press, (1972).

[13] Ansys Fluent 15.0, Theory Guide (2014).

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