Simulation on the effect of local exhaust ventilation in removing surgical smoke

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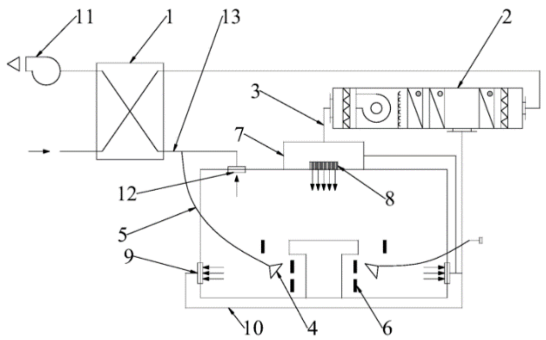
Abstract. The indoor environment of the operating room has a significant impact on the health of personnel. Compared with the pollutants released from occupants, the amount of pollutants generated by surgical equipment is greater, which easily affects the health of patients and doctors. In this study, local exhaust ventilation (LEV) is applied to an operating room and LEV is mounted near the operation zone to remove the surgical smoke from the surgical equipment. CFD technique is used and the surgical smoke concentration reduction potential under different inlet air volumes and different inlet areas of LEV is studied. The results show that compared with the traditional method, when the inlet area of each LEV is set to 0.030 m^2, the surgical smoke concentration can be reduced by 10.8%-39.2% as the inlet air volume increases from 0.003 to 0.027 m^3/s; when the inlet air volume of each LEV is set to 0.015 m^3/s, the surgical smoke concentration can be reduced by 24.7%-31.6% as the inlet area varies from 0.015 to 0.060 m^2. This study shows that the LEV has a good potential in reducing surgical smoke concentration in the operating room.
Keywords: operating room, local exhaust ventilation, laminar airflow, surgical smoke, CFD

1 Introduction

Electrosurgical equipment and technology have been widely used in the operating room with the rapid development of medical technology. However, a large amount of surgical smoke can be generated by the electrosurgical equipment, which remains a potential occupational health hazard for the patient and medical staff exposed to the polluted environment [1]. Actually, approximately 77% of the particles in a surgical smoke plume are less than 1.1 μm [2]. These particles are often not filtered by surgical masks and may be inhaled by personnel in the operating room [3]. However, most medical staffs in the operating room and administrators ignore the hazards of surgical smoke.

Traditionally, laminar airflow (LAF) ventilation has been used to provide low levels of pollutant concentration in the surgical site, thus protecting the patient from being infected [4]. However, compared with the pollutants released from occupants, the amount of surgical smoke is greater in a short period, which prevents the rapid dilution of surgical smoke by LAF ventilation.

To solve this problem, Li et al. proposed an air purification system in the operating room [5], as shown in Fig. 1. In this system, local exhaust ventilation (LEV) is mounted near the operation zone to remove the surgical smoke in an operating room. Therefore, the concentration of surgical smoke is reduced, and the health of doctors and patients is guaranteed. However, the performance of the system has not been quantitatively investigated, so the surgical smoke concentration reduction potential will be investigated with LEV at different inlet air volumes and different inlet areas.



1. Heat recovery device; 2. Fresh air handing unit; 3. Supply Air duct; 4. LEV; 5.LEV duct; 6. LEV interface; 7. Supply air device; 8. Filter components; 9. Return air outlet; 10. Return air duct; 11. Fan; 12. Exhaust air outlet; 13. Exhaust air duct.

Fig. 1. Air purification system with LEV in the operating room [5].

2 Methodology

2.1 Physical model

Based on the traditional operating room at Ling's work [6], LEV is added and investigated. The operating room contains an operating table, four surgeons, and three medical equipment. One air supply outlet and one air

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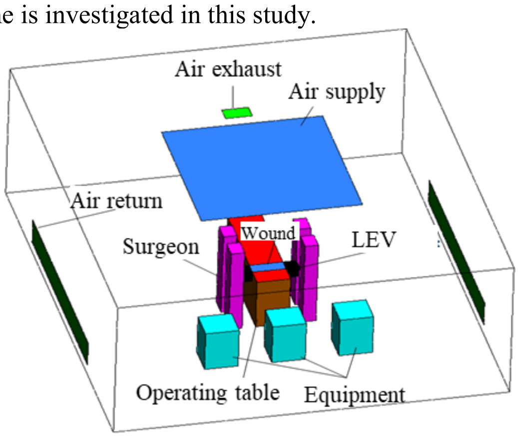
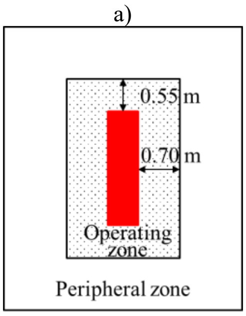
exhaust outlet are arranged on the roof; two return air outlets are arranged on the side walls; two LEVs are arranged on both sides of the operating table. The supply and exhaust air velocity are 0.4 m/s and 2.78 m/s, respectively [6]. The physical model of the operating room is shown in Fig. 2 a), and the dimensions of the models are listed in Table 1. In addition, the operating room space is divided into operating zone (0 m < Z < 2 m) and peripheral zone, as shown in Fig. 2 b). The average concentration of surgical smoke in the operating zone is investigated in this study.



a)



b)

Fig. 2. Physical model of the simulated operating room. a) Perspective, b) Division of operating zone and peripheral zone.

Table 1. Dimensions of the models.

Objects	X (width, m) × Y (length, m) × Z (height, m)
Room	5.9×7×2.8
Supply air outlet	2.4×2.6
Exhaust air outlet	0.4×0.25
Return air outlet	3.6×0.5
Operating table	0.5×1.9×0.8
Equipment	0.5×0.5×0.8

2.2 Mathematical model

In this study, the computational fluid dynamics (CFD) technique was used to study the effect of LEV.

Two-equation model was used to predict the turbulent airflow in the operating room. The finite volume method was used to discretize control equations, and the SIMPLE algorithm was used to solve the equations. The constant heat flux boundary condition is applied for each person and medical equipment, and the constant heat flux of each person and medical equipment are 70 W and 100 W respectively; the adiabatic boundary condition and the no-slip velocity are set at other wall boundaries.

For the particle transport simulation, Ai et al. pointed out that the motion of fine particles less than 3 μm can be well represented with tracer gas simulation [7, 8]. In this study, the species transport model was employed to predict the steady-state particle motion. A wound zone (0.1 m^2) on the body surface of the patient was considered as a particle emission source with a constant emission rate of 0.2 mg/min [9].

2.3 Grid independence

The grid independence was checked using ten monitoring points (y-axis direction) above the operating table. The results of surgical smoke concentration under three grid sizes were compared, as shown in Fig. 3. The results from 0.82 and 1.14 million girds were very close. Hence, considering both the computational cost and results accuracy, a total of 0.82 million grids were adopted in this study.

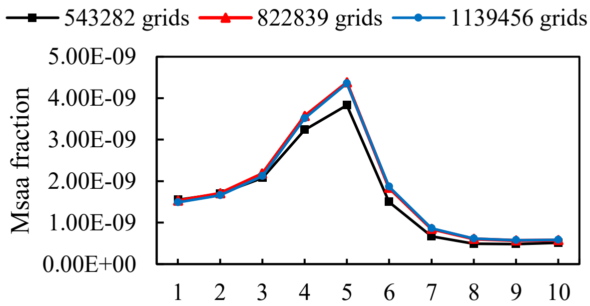


Fig. 3. Check of grid independence.

2.4 Validation

To ensure that the obtained simulation results are reasonable, the numerical model was validated by the velocity data of Xu's experiments [10]. The comparison between the experimental and simulated results was shown in Fig. 4. It proved that the simulation results had acceptable accuracy.

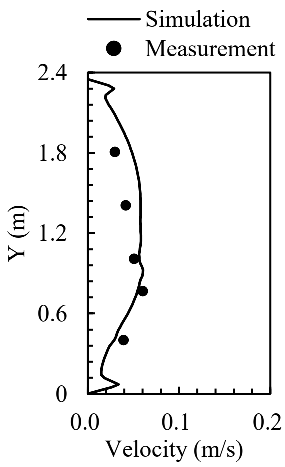


Fig. 4. Comparison of measured and simulated velocity.

2.5 Simulation cases

In this study, the surgical smoke concentration reduction potential under different inlet air volumes and different inlet areas of LEV was focused. Therefore, firstly, the inlet area was set to a constant value, and the effect of the inlet air volume was studied. Then, the air volume was set to a constant value, and the effect of the inlet area was studied. The surgical smoke concentration of traditional LAF ventilation without LEV was used as the reference condition. The specific parameters are listed in Table 2 and the area variation is shown in Fig. 5.

Table 2. Simulation cases

Case	Inlet area of each LEV (m^2)	Inlet air volume of each LEV (m^3/s)
1	0	0
2	0.030 (0.10 m×0.30 m)	0.003
3		0.009
4		0.015
5		0.021
6		0.027
7	0.015 (0.05 m×0.30 m)	0.015
8	0.030 (0.10 m×0.30 m)	
9	0.045 (0.15 m×0.30 m)	
10	0.060 (0.20 m×0.30 m)	

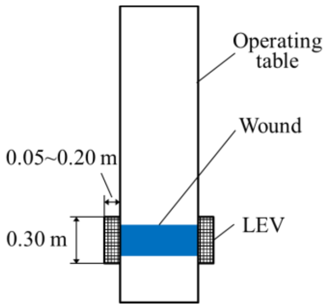


Fig. 5. Area variation of LEV.

3 Results

3.1 The effect of inlet air volume

As mentioned in Section 2.5, the inlet area of each LEV is set to a constant value of 0.030 m^2, and the inlet air volume of each LEV is varied from 0.003 to 0.027 m^3/s. The average concentration of surgical smoke in the operating zone and the concentration reduction ratio of Cases 2-6 relative to Case 1 are shown in Fig. 6. The surgical smoke concentration of Cases 1, 2, 4, and 6 are shown in Fig. 7.

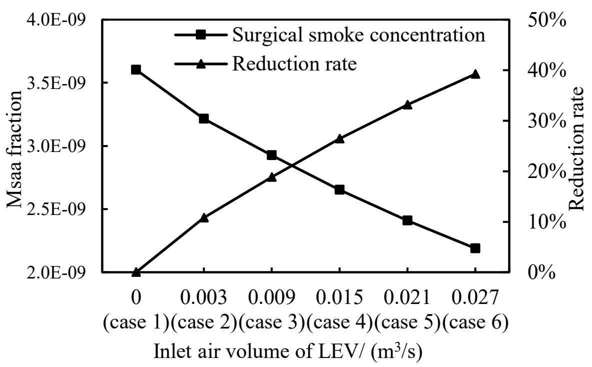


Fig. 6. Average concentration and reduction ratio of surgical smoke in the operating zone of Cases 1, 2, 4, and 6.

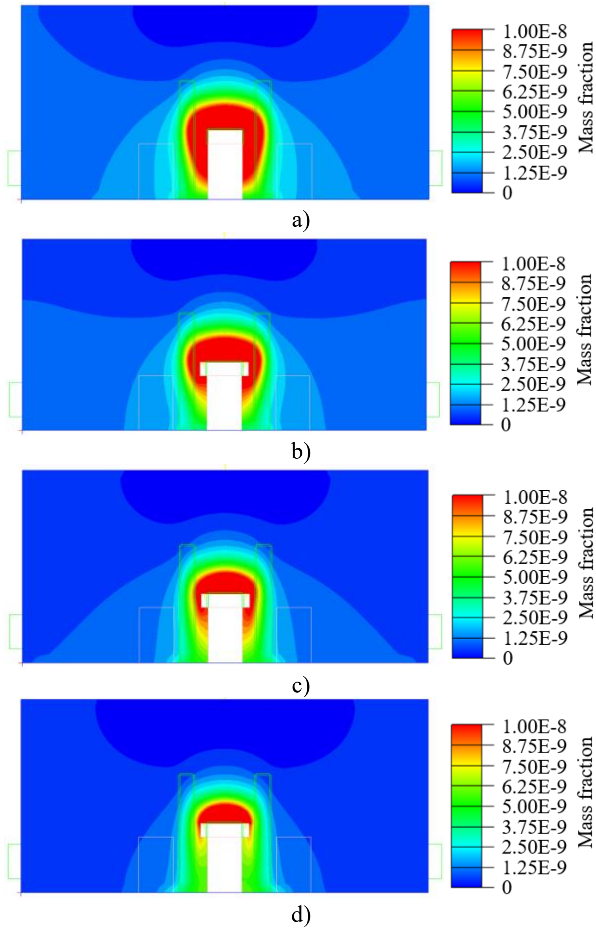


Fig. 7. Surgical smoke concentration distribution. a) Case 1, b) Case 2, c) Case 4, d) Case 6.

Fig. 6 shows that as the air volume is increased from 0 to 0.027 m^3/s, the average concentration of surgical smoke in the operating zone is gradually decreased from 3.60E-9 to 2.19E-9. In addition, compared with Case 1, Case 6 has the largest reduction rate, 39.2%, of surgical smoke concentration. Fig. 7 shows that as the air volume increases, the area of high concentration of surgical smoke decreases, which is consistent with the results of Fig. 6. The results in Fig. 6 and Fig. 7 demonstrate that LEV has the ability to reduce the concentration of surgical smoke effectively.

3.2 The effect of inlet area

In this section, the inlet air volume of each LEV is set to a constant value of 0.015 m^3/s, and the inlet area of each LEV is varied from 0.015 to 0.060 m^2. The average concentration of surgical smoke in the operating zone and the concentration reduction ratio of Cases 7-10 relative to Case 1 are shown in Fig. 8. The surgical smoke concentration of Cases 1, 7, 8, 9, and 10 are shown in Fig. 9.

Fig. 8 shows that with the increase of the area, the average concentration of surgical smoke in the operating area generally increases. Compared with Case 1, Case 7 has the largest reduction rate, 31.6%, of surgical smoke concentration. Fig. 9 shows that as the inlet width increases (i.e., the inlet area increases), the area of high surgical smoke concentration expands outward. The results in Fig. 8 and Fig. 9 show that at the same air volume, the effect of reducing the concentration of surgical smoke can hardly be improved by increasing the inlet area of LEV.

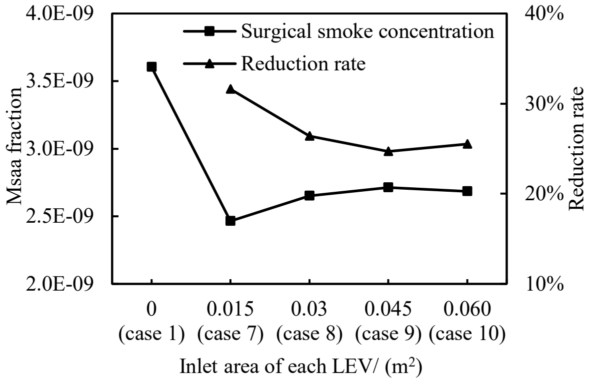


Fig. 8. Average concentration and reduction ratio of surgical smoke in the operating zone of Cases 1, 7, 8, 9, and 10.

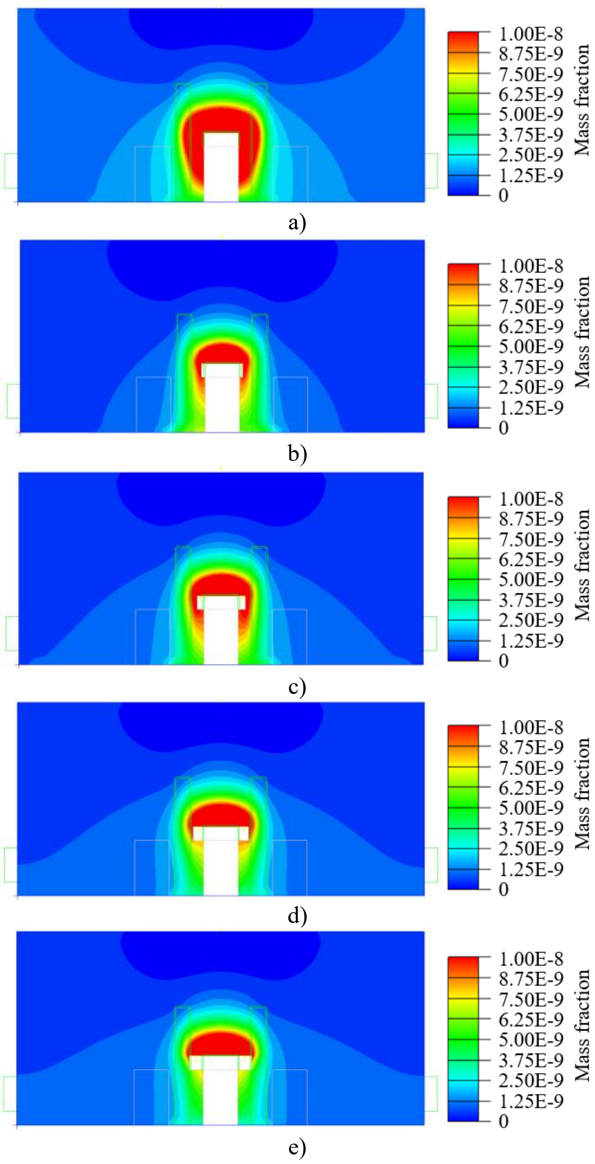


Fig. 9. Surgical smoke concentration distribution. a) Case 1, b) Case 7, c) Case 8, d) Case 9, d) Case 10.

In Section 3.1, when the inlet area is the same, the larger the air volume (that is, the higher the air velocity), the better the effect of reducing the concentration. In Section 3.2, when the air volume is the same, the smaller the area, the higher the inlet air velocity and the better the effect of reducing the concentration. Therefore, LEV with large inlet air velocity and small inlet area is recommended.

4 Conclusions

To improve traditional LAF ventilation in the operating room, LEV is added near the operation table to remove surgical smoke. CFD technique is used to compare the difference in surgical smoke between traditional LAF ventilation and LEV, and the surgical smoke concentration reduction potential under different inlet air volumes and different inlet areas of LEV are studied. The conclusions obtained are as follows.

(1) When the inlet area of each LEV is 0.030 m^2, as the inlet air volume of each LEV increases from 0 to 0.027 m^3/s, the average concentration of surgical smoke in the operating zone decreases from 3.60E-9 to 2.19E-9, with a maximum concentration reduction rate of 39.2%.

(2) With the increase of the inlet area of each LEV, the average concentration of surgical smoke in the operating area decreases. When the air intake volume of each LEV is 0.015 m^3/s, the maximum concentration reduction rate of 31.6% can be obtained at the minimum inlet area of 0.015 m^2.

(3) LEV has a good ability to reduce the concentration of surgical smoke, and LEV with large inlet air velocity and small inlet area is recommended.

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References

1. B. C. Ulmer. Aorn J, **87**, 4 (2008)
2. Y.Tomita, S.Mihashi, K. Nagata, S. Ueda, T. Hirohata. Mutat. Res.-Fundam. Mol. Mech. Mutagen, **89**, 2 (1981)
3. N. Mowbray, J. Ansell, N. Warren, P. Wall, J. Torkington. Surg. Endosc., **27**, 9 (2013)
4. S. Sadrizadeh, S. Holmberg, A. Tammelin. Build. Environ., **82** (2014)
5. X. Li, S. Jiang, W. Shi, B. Wang. *Operating room air purification system*. Beijing: CN210463435U (2020)
6. J. Ling, G. Tu. CC&AC, **S1** (2006) (in Chinese)
7. Z. Ai, C. M. Mak, N. Gao, J. Niu. Build. Simul. **13**, 3 (2020)
8. F. Chen, S. Yu, A. Lai. Atmos. Environ., **40**, 2 (2006)
9. G. Buonanno, R. Capuano, G. Cortellessa, L. Stabile. Build. Environ., **151** (2019)
10. Y. Xu , X. Yang, C. Yang, J. Srebric. Build. Environ., **44** (2009)