Improvement of the Indoor Environment and Airborne Contamination Control in an Operating Room

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Abstract. Modern operating rooms are increasingly turning to contamination control by ventilating technology for the infectious control. The objective of this study is to present the strategic approach on performance improvement of the ventilating system for a hospital operating room under limit budget. A physical partition curtain has been proposed and conducted around the high efficiency particulate air (HEPA) filter of an operating room to validate the improvement of air distribution and contamination control. Numerical simulation of a full-scale operating room has been carried out at a district hospital. The results from computer simulation revealed that the improvement of airflow could be achieved satisfactorily by the application of a physical partition curtain at the length of 1.2 m. Ventilation performance could be assessed extensively not only by airflow distribution and concentration profile but also by the calculation of contamination concentration decay.

Introduction

The process of infection prevention for surgery often comprises complex procedures for different application. Surgical site infection risk due to airborne bacteria is a key consideration in developing the ventilating design in the operating room. Chow [1] reviewed the recent research extensively on operating room ventilation development against airborne infection. Their study also identified and demonstrated the control strategies which could reduce the risks of airborne contamination in operating infection. Furthermore, Woloszyn [2] investigated the airflow pattern and the diffusion of contaminants in an operating room with a diagonal air-distribution system using both experimental measurement and numerical modeling. The results revealed that the contaminant distribution depended strongly on the presence of obstacles such as personnel and medical apparatus. Hansen [3] conducted particle counts and microbial counts during 105 operating procedures under laminar air flow condition.

Computational fluid dynamics (CFD) simulation technique is a scientific technique that allows improvement of cleanroom configuration without interfering with normal processes. The CFD codes were successfully used to simulate the air distribution and contamination decay in a model room as well as comparison of indoor particle concentration in different rooms by Zhao [4]. Besides, three-dimension air flow field for improving the ventilation performance of a minienvironment has been investigated by Rouaud [5]. They found that the numerical and experimental approaches led to useful information and the ventilation performance in the minienvironment might be improved enormously by adjusting the location of the HEPA filter. Zhang [6] investigated the biological contaminant control strategies under different ventilation models in the hospital operating room by using CFD simulation. Numerous parameters intended to characterized air flow pattern and diffuser discharge...
velocity on ventilation performance in an operating room. The dispersion of infectious particles from both surgical team and patient were examined through CFD analysis.

In this study, the strategic approach on performance improvement of the ventilating system for an operating room under limited budget will be presented. A physical partition curtain has been proposed and conducted around the high efficiency particulate air (HEPA) filter of an operating room to validate the improvement of air distribution and contamination control. Numerical simulation of a full-scale operating room will be carried out in a district hospital. Ventilation performance could be assessed extensively not only by airflow distribution and concentration profile but also by the calculation of contamination concentration decay.

System Description and Numerical Simulation

The typical layout of the investigated operating room in a district hospital in Taiwan is shown in Fig. 1. The measured cleanroom with the dimension of length(L)×width(W)×height(H)=5.5m×4.3m×3.0m. There were 3 surgical staff members and some equipment including anesthesia system, surgery appliance, cabinet and computer in the operating room. The patient lies on the operating table just under two medical lamps supported at the center of HEPA filter coverage. This facility with cleanliness level class 10000 (ISO class 7) is equipped with 12 high efficiency particulate air (HEPA) filters, ensuring air filtration efficiency over 99.97% for the particles size above 0.5µm. The supply air coverage area consists of 12 pieces of HEPA filters with the total supply air area of 5.04 m². Four return air grilles are included at the corner of operating room.

A commercial CFD code, STAR-CD [8], was used to simulate the airflow of operating room. The governing equations solved by STAR-CD include the three-dimensional time-dependent incompressible Navier-Stokes equation, time dependent convection diffusion equation and k-ε turbulence equations. These formulated equations can be found in the STAR-CD user’s manual [8] as well as any CFD text books and will not be repeated here. For the k-ε turbulence equation, the empirical turbulence coefficients were assigned as: \( \sigma_k=1.0, \sigma_\varepsilon=1.22, \sigma_{\varepsilon_1}=1.44, \sigma_{\varepsilon_2}=1.92, \) and \( C_\mu=0.09 \) respectively. The well-known finite control volume method with a Pressure Implicit with Splitting of Operator (PISO) algorithm was adopted to solve all the governing equations simultaneously. After the flow field was obtained, the unsteady state CO\(_2\) concentration field was calculated.

The operating room was built to operate at cleanliness level of class 10000 (ISO class 7) and the full-scale geometric model along with personnel, surgery table and medical apparatus of operating room is shown in Fig. 2. Some airflow improvement strategies with a physical partition curtain were proposed and analyzed by numerical simulation. The face velocities of HEPA filter were steadily maintained at 0.2 m/s and the uniformity of the velocity distribution has been confirmed based on field test data. The supply air temperature was fixed at 293 K (20°C). The initial concentration at 3000 ppm of CO\(_2\) of the operating room was assumed. Background CO\(_2\) concentration level was presumed at 415 ppm according to CO\(_2\) concentration of outdoor provided by Environment Protection Administration of Taiwan. According to the airflow improvement strategies proposed, the numerical simulation of different curtain length (L) were conducted and assessed extensively.

Results and Discussion

The full-scale steady simulation for different curtain length of velocity distribution at cross section of \( y = 2.15 \) m are displayed in Fig. 3. As shown in Fig. 3(a), the case of length L=0.0 m, which corresponds the base case without physical partition curtain. The airflow vector extends outward after leaving the supply air vents of HEPA filters. It also presents obvious vortex velocity vector above the surgery table. However, the vortex velocity vectors can be reduced effectively and apparently by adding the partition curtain at length of 0.4 m, as shown in Fig. 3(b), which could provide satisfactory air flow pattern to achieve uni-directional flow. As it is presented for case (c) in Fig. 3 (c), it depicts more satisfactory improvement for air flow distribution compared with case (b). However, there
might be a limitation to lengthen the curtain length unrestrictedly. The design constraint is that it might not impose a considerable restriction on the surgical team and positioning of medical instruments as well.

As it is shown in Fig. 4, the concentration profile for different curtain length was simulated with CO2 concentration decay method after 30 seconds. The darker area presents the higher concentration level according to the legends in Fig. 4. It reveals that the contamination level above the surgery table can be reduced obviously with the adding of physical curtain. The trend of concentration profile also corresponds with the velocity vectors shown in Fig. 3, although there exists minor cross contamination by mixing with the higher concentration air outside the coverage area of HEPA filter in case (a) and case (b). It will be improved apparently at the curtain length of 1.2 m in case (c) because the partition curtain provides a physical barrier between critical area (surgery area) and peripheral area outside the coverage of HEPA filter.

To evaluate the ventilation performance and to investigate the effect of concentration field under different curtain length, two critical monitoring points with star sign (point A and point B) were chosen as shows in Fig. 5. Point A was chosen to survey the concentration decay rate above the surgery table, while point B was chosen to monitor the area under the medical lamp. Fig. 5(a) depicts the transient simulation of concentration decay rate at specified monitoring point A. It revels that the concentration decreases fasters when the curtain length L increases. The concentration decay curve at L=1.2 m also demonstrates less time needed to reach a certain limit of concentration level, which represents better ventilation performance as well. For the case at point B, as shown in Fig. 5(b), the similar trend is found with increasing of curtain length. However, the concentration decay rate becomes flatter or even increase a little bit due to mixing turbulence under the lamp.

Fig. 1 Layout of the investigated operating room
Fig. 2 Geometric model of the operating room

Fig. 3 Velocity vectors for different curtain length (at y = 2.15 m)
Conclusions

This study investigated the performance improvement of the indoor environment in an operating room by numerical simulation and field measurement. The performance improvement strategy with a physical partition curtain could be assessed and identified through the technique of CFD simulation for airflow distribution and the concentration decay calculation at specified monitoring points. Improvement of contamination control was accessible with less expenditure by adding the proper length of partition curtain. Results in this study should provide valuable information to the facility engineer facing the high particle counts and microbial counts in the operating room for infection control. It also revealed to identify the best practice under limited budget as well as to reduce the trial-and-effort while modification have to be carried out.

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References

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