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DOES AIR SUPPLY DIFFUSER POSITIONING AFFECT PARTICLE SETTLEMENT ON PATIENTS? NUMERICAL ASSESSMENT IN OPERATING ROOM

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ABSTRACT

Operating Room (OR) is a specialized facility in a hospital where surgery is conducted in a sterile environment. This article aims to propose the optimum ventilation strategy to reduce particle settlement on patients, as well as in the vicinity of the surgical zone. Baseline and proposed OR models are constructed using Computer-Aided Design (CAD) software, while the fluid and particle interaction were simulated using Computational Fluid Dynamics (CFD) software. The OR CFD model was validated using onsite measurement data, prior to the case studies. The validated CFD model of OR is then used to examine the particle dispersion and airflow distribution for both baseline and parametric cases. Based on results, it is identified that baseline vertical laminar airflow provides an optimum ventilation rate, which can reduce the particle settlement on the patient up to 1.31×10^{-13} kg m^{-3}.

KEYWORD

Operating room, ventilation strategies, Computational Fluid Dynamics, Mobile Air Supply Unit, Surgical Site Infection

INTRODUCTION

Operating Room (OR) or known as Operating Theatre (OT) is a specialized facility within a hospital where surgeries are conducted hygienically. Various types of surgeries are conducted in OR but are not limited to plastic surgery, neurosurgery, coronary bypass, transplantation surgery including kidney transplantation, ophthalmic surgery and orthopaedic surgery (Alexander & Smith, 2016). These surgeries are performed by the surgical room staff ranging from 4 to 14 people which includes 1-3 surgeons depending on the complexity of the surgery, 1-7 operating room nurse, 1 anaesthesiologist, 1 surgical technologist, 1 scrub assistant and 1 operating room supporting staff (Zheng, Panton, & Al-Tayeb, 2012). To ease the OR staff in conducting a smooth surgery, modern OR are equipped with advanced medical technology which includes surgical instruments, anaesthesia ventilators, surgical lamp, Cardiopulmonary resuscitation (CPR) device etc. (Aganovic, Cao, Stenstad, & Skogås, 2019). Based on ASHRAE-170 which describes the ventilation requirements for the OR, the OR must adhere to the design such as the temperature in the OR must be maintained between 20-23°C. Besides, the relative humidity in an ISO class 7 cleanroom OR should be between the range of 30-60%. Besides that, ASHRAE-170 specifies air change rate per hour (ACH) in OR should be maintained between 20-25 ACH. In addition, the air velocity of the OR must range from 0.25 to 0.38 m/s. If the design of ORs is not following rule set by ASHRAE-170, hence this potentially caused the patient experiences Surgical Site Infections (SSIs). To the best of authors' knowledge, numerous studies suggests that vertical laminar airflow is appropriate ventilation strategies to enhance cleanliness in operating rooms, however, there remains a gap of the airborne particle concentration reduced when mounting the laminar airflow on the wall and the wall-mounted laminar airflow with tilted 20°. This paper aims to propose the Mobile Air Supply unit that potentially optimize the ventilation rate from the present study to reduce the airborne particle concentration presence in the OR. This study also aims to ensure the safety of the patients in the OR by mitigating the risk of wound infections experienced by the patients during the surgical procedures.

METHODOLOGY

In this study, there will be a total of five scenarios of case studies are conducted. The first scenario is the baseline study in which the air supply diffuser is mounted on the ceiling as illustrated in Figure 1. There were four parametric case study with the MAS mounted horizontally on the wall, for example, a horizontal laminar airflow mounted on the wall with 0° tilted at xy plane with height z = 2.7 m, (Case 1), a horizontal laminar airflow mounted on the wall with 0° tilted at xz plane with height of y = 0.9 m (Case 2), a horizontal laminar airflow mounted on the wall with 20° tilted at xy plane with z = 2.7 m, (Case 3), a horizontal laminar airflow mounted on the wall with 20° tilted at xz plane with height of y= 0.9 m (Case 4). Besides that, for Case 1-4, the exhaust grills are mounted on the other end of the wall where x = 0 m which opposite the MAS with a coordinate of (0, 0.35, 1.075) m, (0, 1.35, 1.075) m, (0, 0.35, 4.425) m and (0, 1.35, 4.425) m while the air supply diffuser is located at x = 6 m and the center of the wall with a coordinate of (6, 1.5, 2.75) m. The boundary conditions applied for Case 1-4 at air supply diffuser, exhaust grills, medical staffs, patient, etc. elements in the OR are the same as the baseline study. Figure 1. illustrates the diffuser layout of case 1-4.

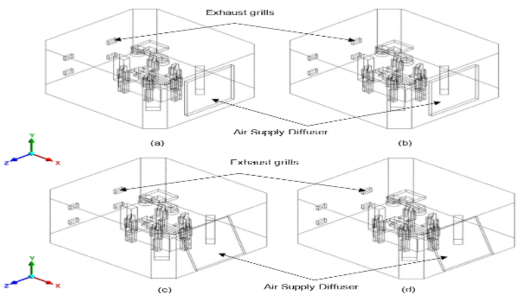

Figure 1: Layout of horizontal laminar airflow (a) case 1, (b) case 2, (c) case 3, (d) case 4

RESULT AND DISCUSSION

When air is supplied from the ceiling, the airflow is blocked by the surgical lamp, causing the average airflow velocity at the surgical site to be 0.086 m/s when visualized from Figure 2(a). During the visualization from Figure 3(a), when there is no large obstruction, the average airflow velocity behind the medical staff is as high as 0.40 m/s. As illustrated in Figure 2(b) and Figure 3(b), it demonstrated that the layout arrangements of the OR with 0° wall-mounted air supply diffuser. From Figure 2(b), medical staff obstruct the airflow velocity from the diffuser, due to the large size of air supply diffuser with a dimension of 2.3 m (L) × 2.3 m (W) causing high airflow velocity passing with up to 0.30 m/s through the surgical site. However, the average airflow velocity in Figure 3(b) is lower at approximately 0.258 m/s due to an obstruction by the medical equipment table causing the inadequate distribution of the airflow. As compared to Figure 3(a), the average airflow velocity behind the medical equipment table is higher by approximately 0.30 m/s due to the airflow passing through the medical equipment table with a negligible effect on the supplied air. For the wall-mounted air supply diffuser with 20°, the average airflow velocity at the surgical site as illustrated in Figure 2(c) is 0.35 m/s which is higher than the 0° wall-mounted air supply diffuser. As visualized from Figure 2(b), the zone that slightly above the surgical area have a constant and uniform airflow compared to Figure 2(c) although the surgical area has high average airflow velocity of up to 0.40 m/s, however, the airflow distribution is not even due to the air supply diffuser is 20° tilted when mounted on the floor and the airflow are obstructed by the human. The scenario as illustrated in Figure 2(c) is not preferable for an OR due to its insignificant air velocity at the surgical site that might reduce the sweeping effect of the airborne contaminant particle due to obstruction by the medical staff.

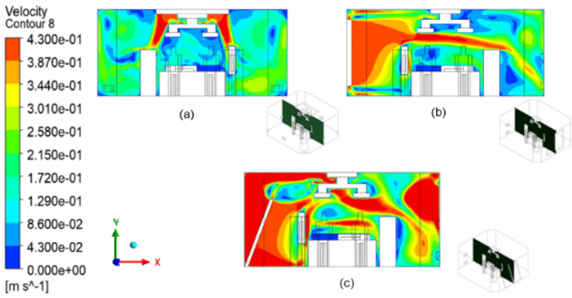

Figure 2: Air velocity distribution contour on plane xy, z = 2.7 m for (a) baseline case, (b) case 1, (c) case 3

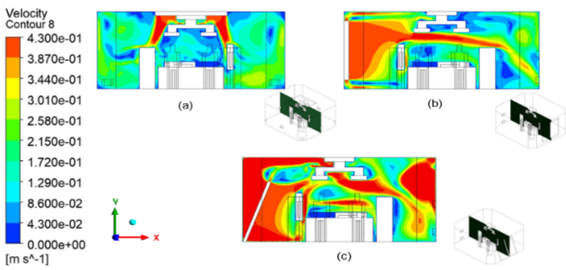

Figure 3: Air velocity distribution contour on plane xz, y = 0.9 m for (a) baseline case, (b) case 2, (c) case 4

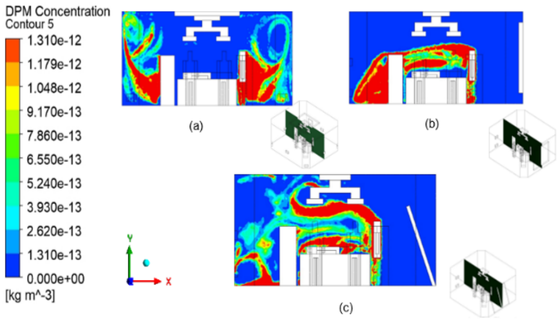

Figure 4: Particle concentration distribution contour on plane xy, z = 2.7 m for (a) baseline case, (b) case 1, (c) case 3

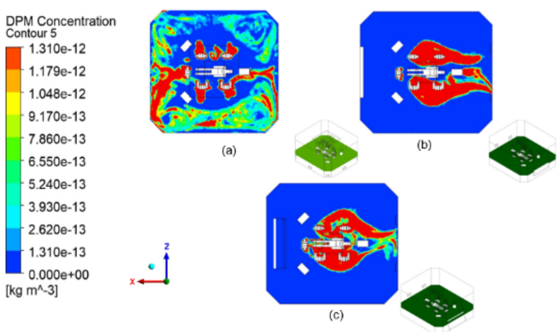

Figure 5: Particle concentration distribution contour on plane xz, y = 0.9 m for (a) baseline case, (b) case 1, (c) case 3

As observed in Figure 5(a) which is the baseline case study for the OR, it shows the lowest particle concentration with 0 kg m^{-3} which means that lowest particle is dispersed into the patient due to the particle tending to move down and eliminated from the exhaust grills located at the corners. While the exhaust grills location is changed from the corners to the wall at the coordinate of (0, 0.35, 1.075) m, (0, 1.35, 1.075) m, (0, 0.35, 4.425) m and (0, 1.35, 4.425) m and air supply diffuser is mounted on the wall with 0^o at x = 6 m together with air supply diffuser is mounted on the wall with 20°, it promotes more particle concentrations to be dispersed into the patient especially the case of wall mounted air supply diffuser with 20° tilted. The reason is due to wall-mounted (horizontal) air supply diffuser supply air that passes through the medical staff that are releasing particles and potentially cause particle settlement on the patient body. When visualized from Figure 4(b), the particle concentration on the surgical area is as high as 9.17×10^{-13} kg m^{-3} by using horizontal air supply diffuser as compared to Figure 4(a) with the use of ceiling mounted (vertical) air supply diffuser, the particle concentration at the surgical area is approximate to as 0 kg m^{-3}. Figure 4(c) shows a higher particle concentration at the surgical area which is up to 1.31×10^{-12} kg m^{-3}. One of the potential causes is due to the when the airflow hits the obstacle, it causes the airflow to recirculate throughout the OR that causes the airborne contaminant particle failing to be removed. In Figure 4(b), the particle concentration that is behind the medical equipment table is as high as 1.30×10^{-12} kg m^{-3} for a larger area as compared to the baseline study as illustrated in Figure 4(a) due to the low air velocity 0.172 m/s in Figure 2(b) as compared to Figure 2(a) which is 0.301 m/s due to poor air dilution of the contaminants in the OR. Stagnation of the airflow as in Figure 2(c) presented due to the obstacle by medical staff and equipment table also causes the accumulation of the particle concentration.

CONCLUSION

This study aimed to optimize the ventilation strategy for operating rooms (OR) to minimize airborne particle concentration and reduce the risk of surgical site infections (SSIs) by using CFD Simulations. The results indicated that the baseline model, with a ceiling-mounted air supply diffuser, was the most effective in reducing particle concentration and ensuring adequate ventilation throughout the OR. The baseline model demonstrated the lowest particle concentration, with zero kilograms per cubic meter (0 kg/m^3) at the surgical area. This was attributed to the air supply diffuser's ability to directly sweep away airborne contaminants, preventing their accumulation and subsequent dispersion onto the patient. In contrast, the wall-mounted MAS, especially those tilted at 20 degrees, were more likely to push particle concentrations released by medical staff through the surgical zone, increasing the risk of particle settlement on the patient's body. Based on the particle concentration distribution contour in Figure 4(c), the highest particle concentration is 1.31×10^{-13} kg m^{-3} for the case of wall-mounted air supply diffuser with 20° tilted followed by air supply diffuser with 0° wall mounted with particle concentrations of 1.28×10^{-12} kg m^{-3} as illustrated in Figure 4(b). Therefore, this study recommends the use of ceiling-mounted air supply diffusers in OR to maintain a clean and hygienic environment, minimizing the risk of SSIs and ensuring patient safety. Future research could explore additional ventilation strategies or modifications to the wall-mounted MAS to improve their performance and potentially reduce the need for ceiling-mounted solutions in certain scenarios.

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