

PAPER • OPEN ACCESS

Medical Staff's Posture on Airflow Distribution and Particle Concentration in an Operating Room

To cite this article: K Y Wong *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **884** 012103

View the [article online](#) for updates and enhancements.

You may also like

- [Current situations and discussions in Japan in relation to the new occupational equivalent dose limit for the lens of the eye](#)
Sumi Yokoyama, Nobuyuki Hamada, Toshiyuki Hayashida et al.
- [Impact of the implementation of the new radiation quantities recommended by ICRU/ICRP for practical use in interventional radiology: a Monte Carlo study](#)
Mahmoud Abdelrahman, Pasquale Lombardo, Jérémie Dabin et al.
- [Radioactive seed localization is a safe and effective tool for breast cancer surgery: an evaluation of over 25,000 cases](#)
D Miodownik, D Bierman, C Thornton et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Medical Staff's Posture on Airflow Distribution and Particle Concentration in an Operating Room

K Y Wong¹, H M Kamar^{1,2}, and N Kamsah¹

¹School of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia

E-mail: haslinda@utm.my

Abstract. During a surgical procedure, each of the medical staffs would have different postures. Supporting medical staff such as anaesthesiologist would stand in upright condition with straighten-forearm, while medical staff that is performing surgical procedures is in bent-forearm posture. The positioning of forearm might interrupt the air supplies from the ceiling-mounted diffuser, that serves to remove the airborne particles from the surgical zone. Consequently, the movement of particles in the surgical zone is affected, and the tendency of particles to fall onto the patient's wound is increased. This situation could elevate the chances of a patient contracting surgical site infections and could increase the risk of death. The present study aims to examine the effects of medical staff's forearm posture on the number of particles falling onto the patient. A simplified computational fluid dynamics (CFD) model of the operating room was developed and validated based on the published data. An RNG k- ϵ turbulence model based on the Reynolds-Averaged Navier-Stokes (RANS) equations was used to simulate the airflow, while a discrete phase model was used to simulate the movement of the airborne particles. Results show that bent-forearm of medical staff obstructed the downward airflow to remove the particles released by the medical staff. Approximately 37 particles/m³ accumulated in the chest region of the medical staff. A high particle accumulation is also observed at the gap between the staff's legs due to the stagnant airflow.

1. Introduction

An operating room (OR), also known as an operating theatre, is a healthcare facility that enables surgeons to carry out surgical operations. The majority of ORs worldwide employ cleanroom technology to provide a highly controlled and clean environment for both the patients and the hospital's personnel. It is necessary to maintain a contaminant-free environment for the patient during surgical procedures. Recent studies concluded that 98 % of surgical site infections (SSI) were due to the settlement of airborne particles on the patients' wounds [1, 2]. A study conducted by Karlatti and Havannavar [3] found that post-operational SSI rates were increased when the surgery was performed in unclean surroundings. It has been estimated that nearly 3 % to 5 % of patients who underwent surgery in clean environments developed SSIs [4], whereas surgical procedures performed in ultra clean environments were associated with an SSI incidence rate as low as 1 % [5].

This article presents a numerical study to investigate the transport of airborne particles inside an OR in a private hospital in Malaysia. The particles were assumed to be discharged from the exposed

² To whom any correspondence should be addressed



faces of the surgical staff at a given mass flow rate. The objective is to examine the transport paths and concentration of the particles in the vicinity of the operating table, under a steady-state condition. A simplified model of the operating room was developed using Fluent Computational Fluid Dynamics (CFD) software and validated for flow analysis. An RNG k- ϵ turbulent model was employed to simulate the airflow, while a discrete phase model (DPM) was used to simulate the transport of the airborne particles.

2. Description of the CFD Model

A CAD software was used to construct a computational domain representing the OR. The dimensions are as follows: 6 m (length) $\times$ 5.5 m (width) $\times$ 3 m (height), with the configuration as seen in Figure 1(a). The boundary conditions prescribed on the CFD model are shown in Figure 1(b).

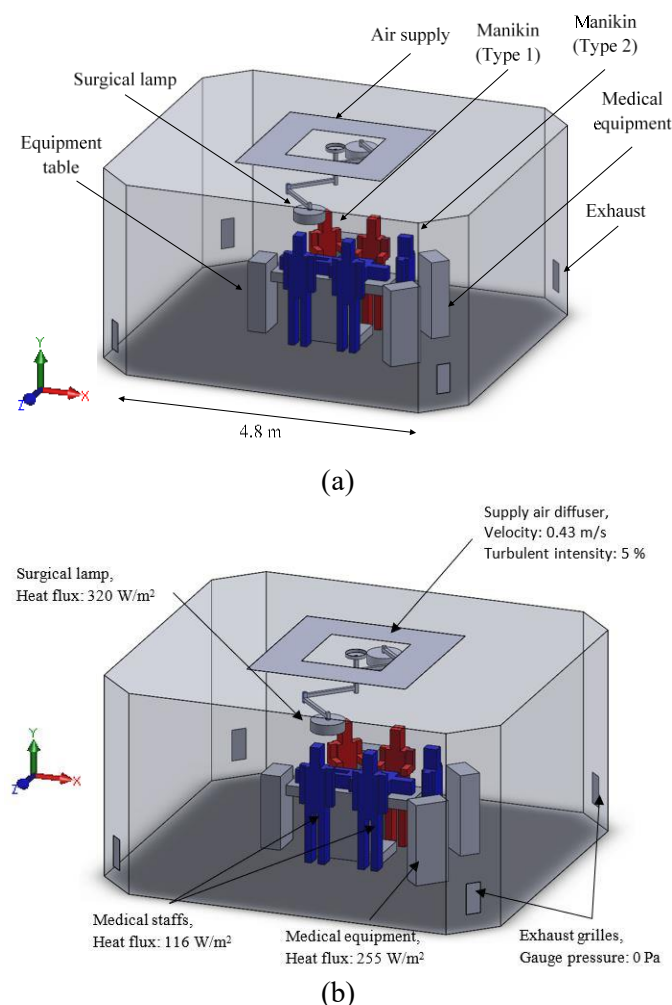


Figure 1. (a) Computational domain of the OR with manikins and furniture, (b) Boundary conditions specified on the CFD model

Clean air was supplied into the room through ceiling-mounted air supply diffusers. About 14 % of the total ceiling area was covered by the air supply diffusers and surgical lamp fixtures. The outgoing air was extracted via four exhaust grilles placed on four corners of the wall at 0.25 m above floor level. The door's gaps were not modelled in the computational domain due to the opening being very small. The effect of gaps on airflow changes is assumed to be negligible, and the intrusion of particles is not possible due to the positive pressurisation in the OR.

The boundary conditions were prescribed, and the fluid and particle properties were applied on the CFD model of the OR. An inlet air flow condition was specified at the ceiling-mounted diffusers. The magnitude of the airflow velocity was similar to that obtained from the field measurement. All airflow boundary conditions were specified in the direction normal to the respective surfaces. A zero-gauge pressure condition was set at the exhaust grilles, which served as the air outlets. The air flow inside the OR was assumed to be incompressible. Under this assumption, the air cannot be compressed and has a constant density. A no-slip condition was applied at all the walls of the OR. With this condition, the fluid sticks to the walls, and its flow velocity gradually increases away from the walls. The heat flux condition was applied to all medical staff, the patient, the surgical lamps and the medical equipment. With this application, the heat is transferred to the environment through the surfaces of the objects. For the particle boundary conditions, an escape condition was specified at the air supply diffusers and exhaust grilles, while a trap condition was set on the patient, walls, surgical lamp, medical equipment and equipment table. The airborne particles were released from the surfaces of the medical staff at a rate of 600 particles/minute. This is equivalent to a mass flow rate of 1.31×10^{-13} [6]. Airborne particles with an aerodynamic diameter ranging from $5 \mu\text{m}$ to $10 \mu\text{m}$ are widely considered as bacteria-carrying particles [6, 7]. Hansen, Krabs, Benner, Brauksiepe and Popp [8] found that particles that cause SSI have diameters ranging from $5 \mu\text{m}$ to $10 \mu\text{m}$. For indoor simulation purposes, Liu, Wang and Wen [6] reported that the predicted particle distribution using particle diameter of $5 \mu\text{m}$ was almost identical to that using the particle diameter of only $7 \mu\text{m}$ or $10 \mu\text{m}$. This is due to these particles having negligible differences in size and density. Therefore, this study did not consider particles with a diameter of $7 \mu\text{m}$ and $10 \mu\text{m}$, but considered only $5 \mu\text{m}$. The airborne particles with an aerodynamic diameter of $5 \mu\text{m}$ had a density of 2.0 g/cm^3 [6]. The dispersion of particle due to turbulence was modelled using the Stochastic tracking feature of the ANSYS CFD software.

3. Main Results

The present CFD model represents an OR that utilised the ceiling-mounted diffusers to supply clean air into the room, and the air was then exhausted through the four exhaust grilles that was mounted at the low level of the four corner walls. A total of five medical staff and one patient were incorporated into the CFD model. The medical staff were positioned around the operating table with a standing posture, while the patient was placed on the operating table in a recumbent posture. Each member of the medical staff constantly released the bacteria-carrying particles from their exposed surfaces. The contour plots of airflow velocity distribution on a y-z plane that cuts through the medical staff 2 and 4, and a y-z plane that cuts through the surgical lamps are shown in Figure 2 (a) and (b), respectively.

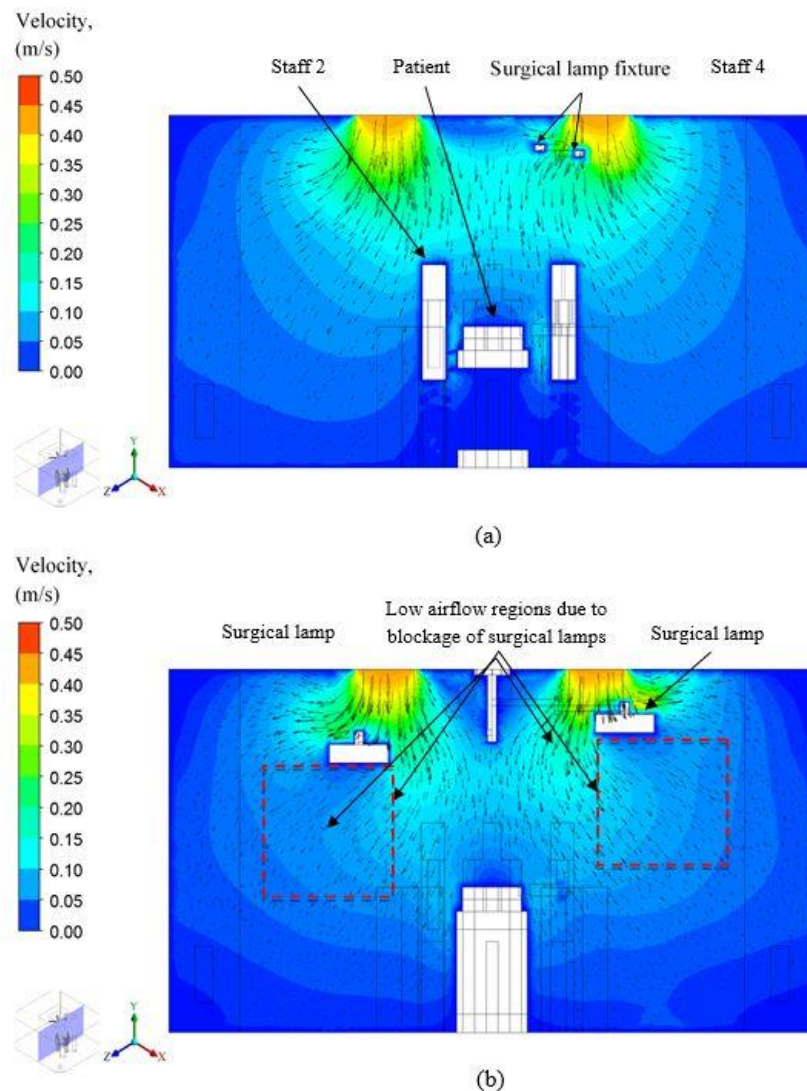


Figure 2. Contour of airflow velocity distribution with the airflow vector on a y-z plane at coordinate (a) $x = 3.4$ m that cuts through medical staff 2 and 4, (b) $x = 3$ m that cuts through two surgical lamps

As seen in Figure 2 (a), the air velocity of 0.43 m/s was supplied into the OR. A high airflow was observed near the air supply diffuser, located near the ceiling of the room. A low air distribution was identified at the bottom of the room, especially the region below the operating table. As the OR is furnished with the ceiling-mounted air supply diffuser, the unidirectional airflow was found to be easily interrupted by the lamp's fixture and the surgical lamp, as shown in Figure 2 (b). Low airflow regions which are bounded by the red-dotted boxes occur due to the obstruction by the surgical lamps. Under the similar type of ceiling-mounted air supply diffuser, Aganovic, Cao, Stenstad and Skogas [9] discovered that the sizing and positioning of the surgical lamp affected the airflow distribution in the surgical zone and the number of particles that settled on the operating table. Cao, Storås, Aganovic, Stenstad and Skogås [10] also claimed that the surgical lamp significantly affects the airflow path and velocity in the proximity of a patient. All these findings indicate that inappropriate placement of the surgical lamp can significantly hinder the clean air supply over the surgical zone.

The distributions of particle concentration on a y-z plane that cuts through the medical staff 2 and 4, and a y-z plane that cuts through the surgical lamps are shown in Figure 3 (a) and (b), respectively.

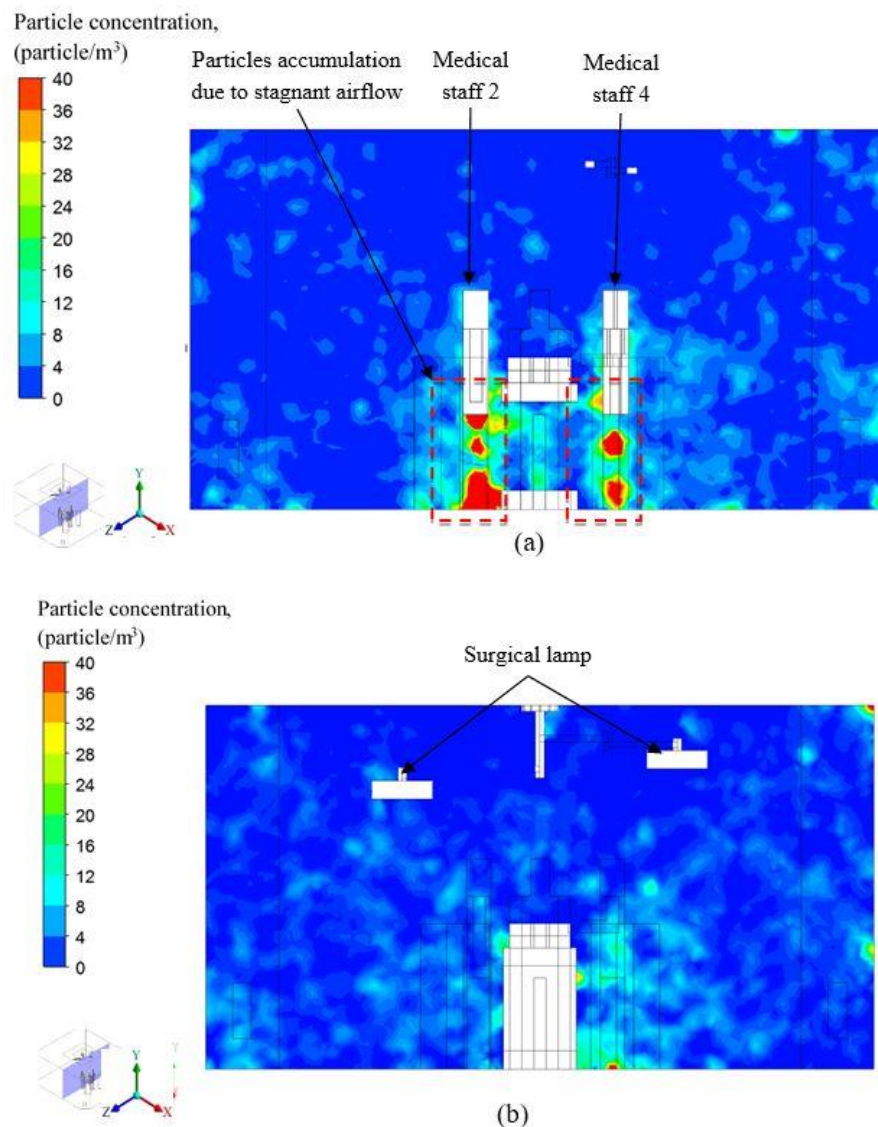


Figure 3. Distribution of particle concentration on y-z plane at coordinate (a) $x = 3.4 \text{ m}$, (b) $x = 3 \text{ m}$

Insignificant particle concentrations can be identified at the medical staff's upper body as shown in Figure 3(a). However, a high particle concentration can be found in the regions between the medical staff's legs, which is due to a stagnant airflow. The presence of a stagnant airflow region should be prevented, as it could increase the accumulation of particles in the OR. Also, the accumulated particles could possibly re-enter the surgical zone when there is a circulating flow. As seen from Figure 3(b), there is no particle build-up in the region under the surgical lamps. However, the particles were found to be dispersed to the surrounding environment due to the weak downward air supply. This finding indicates that a stronger downward air supply could reduce the dispersion of particles and promotes the removal of airborne particles from the surgical zone.

The contour plots of airflow velocity and particle concentration that cuts through the two forearm-bending staff members are presented in Figure 4.

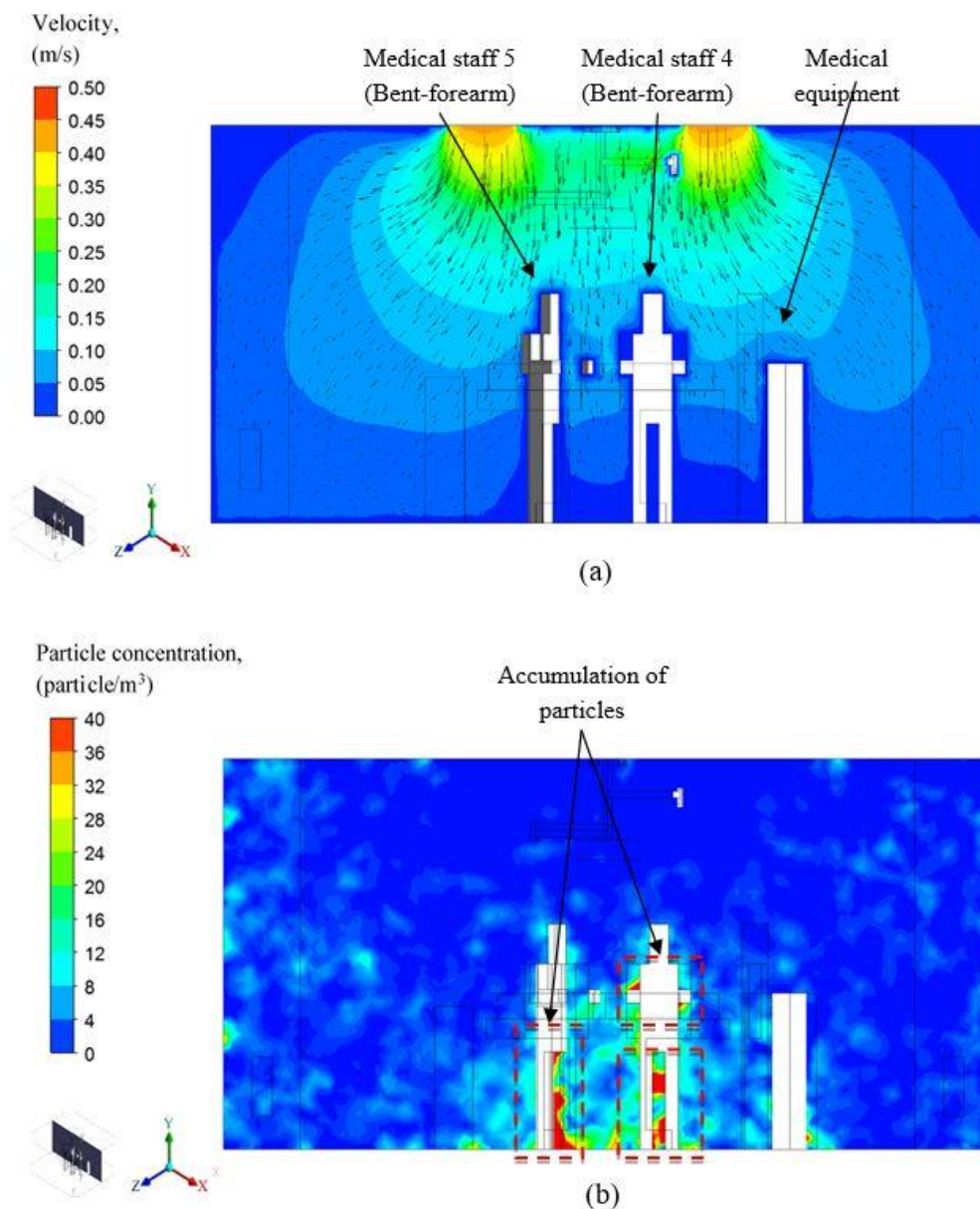


Figure 4. An x-y plane at coordinate of $z = 2.2$ m that cuts through two bent-forearm medical staff members (a) contour of airflow velocity with airflow vectors, (b) distribution of particle concentration

Figure 4(a) shows that the medical staff 2 and 4 are blocking the airflow supplied from the ceiling-mounted air supply diffuser. A low airflow distribution can be identified at the gap between the staff's legs. This has subsequently increased the tendency of particles to be trapped in this region. Although the supply air complies with the NEBB Standard [11], the results show that the airflow velocity is considerably reduced before reaching the medical staff and the patient. When the air reaches the head of the medical staff, the airflow velocity is reduced to approximately 0.11 m/s. The air velocity becomes close to zero it reaches near floor level. Such a low airflow is not desirable in the OR, as it is not capable of removing the particles through the exhaust grilles.

As seen from Figure 4(b), approximately 37 particles/m³ accumulated in the chest region of the medical staff 4. The reason is that the bent-forearm of medical staff 4 obstructed the downward airflow to remove the particles released by the medical staff. A high particle accumulation is also

observed at the gap between the staff's legs due to the stagnant airflow. Under the present ventilation, the airflow distribution in the vicinity of the medical staff and the patient is low. Also, the supplied airflow in a downward direction was found to be insufficient to remove the airborne particles effectively. In an actual surgical procedure, these phenomena could increase the probability of particles settling on the patient's wound. Consequently, the chances of the patient getting an SSI are increased.

4. Conclusion

A computational fluid dynamic method was used to carry out simulations to predict the airflow distribution and the movement of airborne particles in a hospital operating room. The goal was to examine the effects of medical staff's forearm posture on the number of airborne particles settled on the patient. Results show that bent-forearm of medical staff obstructed the downward airflow to remove the particles released by the medical staff. Approximately 37 particles/m³ accumulated in the chest region of the medical staff. A high particle accumulation is also observed at the gap between the staff's legs due to the stagnant airflow.

References

- [1] Chauveaux D 2015 Preventing surgical-site infections: Measures other than antibiotics *Orthopaedics & Traumatology: Surgery & Research* **101** S77-S83
- [2] Talon D, Schoenleber T, Bertrand X and Vichard P 2006 [Performances of different types of airflow system in operating theatre]. In: *Annales de chirurgie*, pp 316-21
- [3] Karlatti S and Havannavar I 2016 A comparative prospective study of preoperative antibiotic prophylaxis in the prevention of surgical site infections *International Surgery Journal* **3** 141-5
- [4] Singh R, Singla P and Chaudhary U 2014 Surgical site infections: Classification, risk factors, pathogenesis and preventive management *Int. J. Pharm. Res. Health Sci* **2** 203-14
- [5] Olsen M A, Nickel K B, Margenthaler J A, Fox I K, Ball K E, Mines D, Wallace A E, Colditz G A and Fraser V J 2016 Development of a Risk Prediction Model to Individualize Risk Factors for Surgical Site Infection After Mastectomy *Annals of surgical oncology* 1-9
- [6] Liu J, Wang H and Wen W 2009 Numerical simulation on a horizontal airflow for airborne particles control in hospital operating room *Building and Environment* **44** 2284-9
- [7] Rui Z, Guangbei T and Jihong L 2008 Study on biological contaminant control strategies under different ventilation models in hospital operating room *Building and Environment* **43** 793-803
- [8] Hansen D, Krabs C, Benner D, Brauksiepe A and Popp W 2005 Laminar air flow provides high air quality in the operating field even during real operating conditions, but personal protection seems to be necessary in operations with tissue combustion *International Journal of Hygiene and Environmental Health* **208** 455-60
- [9] Aganovic A, Cao G, Stenstad L I and Skogas J G 2017 Impact of surgical lights on the velocity distribution and airborne contamination level in an operating room with laminar airflow system *Building and Environment* **126** 42-53
- [10] Cao G, Storås M C A, Aganovic A, Stenstad L-I and Skogås J G 2018 Do surgeons and surgical facilities disturb the clean air distribution close to a surgical patient in an orthopedic operating room with laminar airflow? *American Journal of Infection Control* **46** 1115-22
- [11] Standard N E B B 2009 Procedural standards for certified testing of cleanrooms. In: *Adjusting, and Balancing of Environmental Systems*, (USA: National Environmental Balancing Bureau)