Penerbit Akademia Baru

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

A Review on the Assessment of Airborne Particles Settlement and Various Airflow Distributions in Hospital Operating Room

*K. Y. Wong, H. Mohamed Kamar**, F. Mohd Zawawi and N. Kamsah*

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia
**haslinda@mail.fkm.utm.my*

Abstract – *Healthcare facilities in a hospital has diverse indoor cleanliness due to the different health needs by the patients. Among the facilities, an operating room was identified as a critical space that required high cleanliness environment. In recent years, an ISO 14644-1 Standard of Class 1 to Class 7 is prescribed in operating room for better particles concentration and airflow controlled. The objective of this article is to review the assessment of airborne particles transportation and airflow distribution in an operating room. This study shows that two main types of ventilation strategies have been widely installed to control airborne particles trajectory, namely unidirectional airflow system and mixing airflow system.*

Keywords: Operating room, airflow, airborne particles, surgical site infection

1.0 INTRODUCTION

The selection of ventilation system in a building is highly depends on its suitability. Architects and engineers always take the indoor air quality, comfort, energy consumption and costing into consideration. However, when come to healthcare facilities, the main factor that's come into consideration is safety. Healthcare facilities in a hospital has diverse indoor cleanliness due to the different health needs by the patients. Among the facilities, an operating room was identified as a critical space that required high cleanliness environment. In recent years, an ISO 14644-1 Standard of Class 1 to Class 7 is prescribed in operating room for better particles concentration and airflow controlled. The allowable particle concentration for each class as shown in Table 1.

In an operating room, the room pressure is always positive compared to adjacent zones. This could prevent the contaminated air from adjacent zones being drawn into operating room. Up to date, there is no consensus on specifying the pressure value that should be maintained in operating room. Hence, each of the countries practiced different pressure value based on their adopted reference. In Malaysia, the differential pressure should more than +5 Pa for operating room to control room and more than +8.5 Pa for operating room to corridor [2]. Whereas, a pressure of +25 Pa is practiced in Hong Kong operating room [3].

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

Table 1: Selected airborne particulate cleanliness classes for cleanroom [1]

Classification Numbers (N)	Maximum concentration limits (particles/m^3 of air) for particles equal to and larger than the considered sizes shown below					
	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1.0 µm	5.0 µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1000	237	102	35	8	
ISO Class 4	10000	2370	1020	352	83	
ISO Class 5	100000	23700	10200	3520	832	29
ISO Class 6	1000000	237000	102000	35200	8320	293
ISO Class 7				352000	83200	2930
ISO Class 8				3520000	832000	29300
ISO Class 9				35200000	8320000	293000

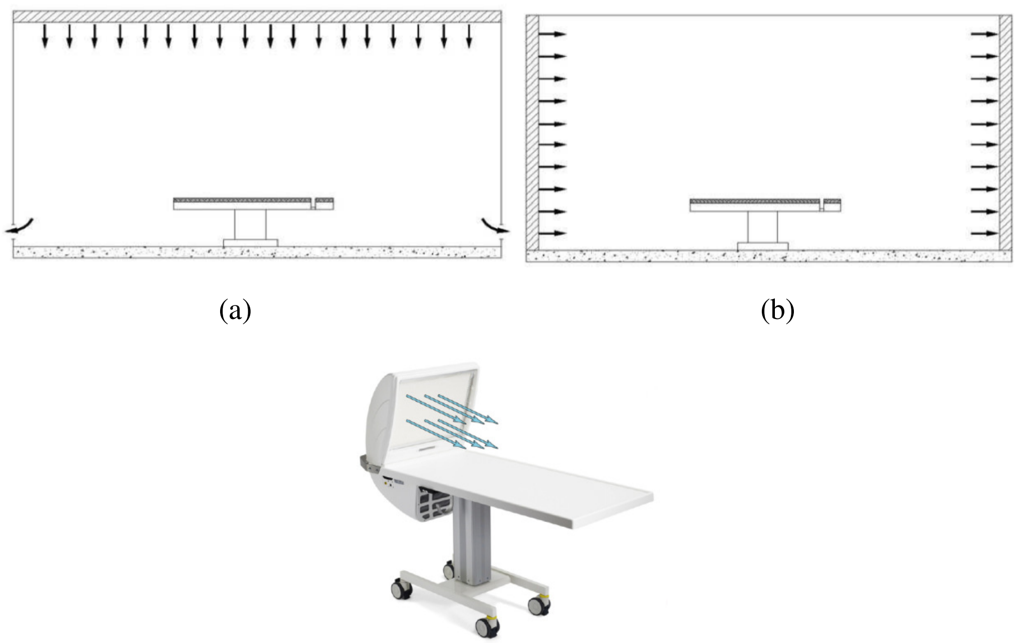
Some literature has discussed the applicability of airflow distribution in an operating room. With the purpose to reduce the particles settlement in surgical table, unidirectional airflow distributions have been introduced into conventional operating room and their performance has been acknowledged by many researchers. However, there are some discrepancies in the reported findings, especially on the techniques used for investigation, novel type of ventilation strategy, advantages and limitations of various airflows, and others. Therefore, in the present paper, we attempt to thoroughly review the assessment of airborne particles settlement and airflow distribution in hospital operating room that has been published previously. To the best of authors' knowledge, there is no comprehensive literature on the subject.

2.0 AIRFLOW DISTRIBUTION AND AIRBORNE PARTICLES IN OPERATING ROOMS

Airflow distribution plays a vital role in governing the trajectories of airborne particles. Throughout the literatures, there are four main types of ventilation systems, namely unidirectional airflow, mixing airflow, displacement airflow and local exhaust airflow. However, only mixing and unidirectional airflow systems are installed in operating room. A displacement airflow system is less appropriate to be used in operating room due to unpredictability of airborne particles transmission. The installation of local exhaust airflow is less preferable due to mobility restriction on surgical staffs. Over the past few decades, mixing ventilation system is widely used in operating room as the air in the room mixed quickly and evenly. Hence, provoking a rapid dilution of the tenor of airborne particles [4]. However, there is no literature reported the efficiency of mixing ventilation system on airborne particles settlement. Melhado and his co-workers have extended their study, they claimed that this system is not an ideal choice for the used in operating room [5]. They revealed that the air present in the surgical zone is contaminated and not up to ASHRAE Class 1 specification. In recent decades have witnessed vast research on the implementation of unidirectional airflow system. It has been reported for its outstanding performance in terms of reducing airborne particles in surgical zone. The most preferable unidirectional airflow system are: vertical type, horizontal type and mobile type as shown in Figure 1 (a), (b) and (c) respectively. Melhado et al. [5] and Friberg et al. [6] have investigated the effects of particles settlement on surgical table by employing additional mobile type unidirectional airflow. Amazingly, both of

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

them came across with diverge findings. Melhado and his co-workers claimed that there is no significant difference in terms of settlement reduction. However, a significant improvement of settlement reduction was found by Friberg et al. [6]. More recently, Sadrizadeh and Holmberg have further extended the study by using the same research method. They found out that mobile unidirectional airflow system managed to reduce airborne particles settlement relatively well [7].



(a) (b)

(c)

Figure 1: Types of air supplies (a) Vertical [8] (b) Horizontal [8] (c) Mobile [9]

For a vertical type air delivery, the air supply diffuser is usually mounted on the ceiling. Whereas the air-return grille is low wall-mounted at each corner of the room. Due to the overwhelming responses for vertical type air delivery system, Wagner and co-workers had conducted an experiment on three basic vertical designs: air curtain (AC), multi-diffuser array (MDA) and single large diffuser (SLD) [10]. Each of these designs managed to provide unidirectional and controlled airflow significantly well [10]. However, the performance was found to be different with all other conditions (temperature, airflow velocity, air-return grille and equipment placement) being equal [10]. Jennifer discovered that single large diffuser performed the best in terms of reducing the settlement of contaminants in the surgical site.

In the past few years, a novelty air supply concept has been proposed by Nilsson, founder of Johnson Medical [11]. He and his co-workers claimed that vertical unidirectional airflow system caused re-circulated contaminated air in the operating room. Then, his research team designed a diagonal 45 ° airflow system. This design consisted of low velocity airflow, guided by a high velocity ultra-clean air stream that was fed in by an air jet. Amazingly, the operating room achieved an ultra-clean state by having particle concentration of less than 10 cfu/m^3 [11]. However, there has been little discussion on diagonal air-supply. The research to date has tended to focus on vertical and horizontal air-supplies rather than diagonal air-supply.

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

3.0 ASSESSMENT METHODS ON AIRFLOW AND PARTICLES SETTLEMENT IN OPERATING ROOMS

There are two widely used methods in conducting indoor airflow field and particles distribution studies: numerical simulations [12-25] and experimental measurements [14, 16, 20, 21, 25-28]. Experimental measurement approach provides a more reliable data of indoor air distribution or local air velocity around occupant [29]. However, experimental measurement is usually difficult and time-consuming. Numerical simulation can provide both global and detailed airflow quantities under various cases at relatively low cost, which is very helpful for the design and assessment of indoor ventilation system. However, conducting numerical simulation always relies on accurate measurements at the boundary conditions. The simulated results is not fully reliable unless being validated by corresponding high quality experimental data. Hence, experimental measurement is still the necessary and fundamental step of indoor airflow study.

3.1 Experiment Method on Airflow Distributions and Particles Settlement

3.1.1 Particle Image Velocimetry

Particle image velocimetry (PIV) is a non-intrusive laser optical measurement technique, which designed for flow visualization study. The purpose of using PIV study is to obtain instantaneous velocity measurements and related properties in fluids. In 2013, Sattari and Sandberg conducted PIV study to investigate the effect of flow variations of stagnant zones, the levels of the turbulent kinetics energy and the relative turbulence intensity [30]. In recent years, particle image velocimetry has gradually become the popular and promising technique for airflow field measurement in indoor environment. Cao et al. reviewed that in indoor PIV measurements, small-scale models are the most appropriate and convenient [29]. However, he also stated that small-scale models suffer from scaling problems and might not be able to represent the real conditions. On the other hand, Peren et al. [31] employed the particle image velocimetry for the purpose of validating their CFD simulation. A good agreement was found between the simulation results and PIV experiment data. Particles resuspension analysis has also been conducted by Barth et al. [32] by using similar technique, he figured out that larger particles require lower fluid velocities for the removal compared with smaller particles. In most recent study, Stevenson and Jeter [33] investigated the effects of thermal plume at surgical site under transient state. A reasonably good agreement between the PIV and CFD results was also found. They further concluded that PIV imaging analysis and standard CFD simulations are suitable tools for investigating airflows in operating room.

3.1.2 Airflow Testing

In order to maintain the surgical zone cleanliness, a unidirectional airflow over the surgical table as prescribed in ASHRAE Standard 170 is favourable. The airflow pattern is significantly affected by ventilation layout design [34]. Smoke studies were usually employed to visualize the airflow pattern. Basically, smoke study is a key activity that utilised to provide visual evidence of airflow direction [35]. The main idea of employing this approach is to assure the airflow is in unidirectional manner. As shown in Figure 3, the smoke sources were injected at the air handling unit to ensure a well–mixed conditions at the air-supply diffusers [34]. In previous study, a water-glycol based theatrical stage fog was chosen due to its accurate airflow visualization [34].

Penerbit Akademia Baru
Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

Figure 3: Airflow visualization smoke study [10]

3.1.3 Particles Sampling

The quantification of airborne particles in indoor is becoming an increasingly important field of study [36]. Two common types of sampling methods have been employed to quantify the particles concentration: air sampling and surface sampling. Recently, Dai demonstrated a novel method for air sampling by using fluorescent particle counter. He claimed that the performance of this method is outstanding [37]. Unfortunately, however, this counter is not yet commercially ready. In recent years, Traversari et al. [16] and Healy et al. [36] employed other particle counter to conduct active air sampling. Traversari and research team used Two Biotest Diagnostics' RCS Plus Centrifugal Air Samplers whereas Healy and co-workers employed Waveband Integrated Bioaerosol Sensor to perform airborne particles sampling. Healy et al. justified the used of that particle counter due to ability to measure individual particles, to interpret number-size distributions in two pre-defined size ranges and to supply simultaneous information on particle asymmetry [36]. Unfortunately, no explicit explanation from Traversari et al. regarding the use of Two Biotest Diagnostics' RCS Plus Centrifugal Air Samplers. According to Centers for Disease Control and Prevention's finding, surface sampling is more suitable for quantifying larger particles (>1 µm). A dusting cloth (DC) pad was identified as the most effective and favourable surface sampling method to be used in clean environments such as operating room or semiconductor manufacturing cleanroom [38, 39]. Up to date, there is no common standard method used to determine bacterial threshold limits in the operating room. Hence, Dharan proposed that there is a need to reach a consensus on the method of sampling especially in operating room [40]. He also recommended that it is important to differentiate between cleanroom technology developed for industry and that used in hospitals.

3.2 Numerical Method on Airflow Distributions and Particles Settlement

In recent years, Computational Fluid Dynamics (CFD) has been widely used as a tool to simulate the indoor air flow and particles trajectory. Its well-validated features make it favourable to be used in operating room analyses. Basically, CFD is a branch of simulation software that uses numerical methods and algorithms to analyse problems that involve fluid mechanics. The analysis is achieved by solving a set of partial differential equations representing the conservation of mass, momentum and energy. The advantages of using CFD are its ability to design and optimize the configurations of ventilation system in cost and timesaving manner [14], and to predict phenomena that unable to be done by experiment. In some cases, CFD was used to troubleshoot already existing installations.

In the past, several flow models have been employed to solve the air flow inside the computational domain. These are standard k-ε [25, 41-46], realizable k-ε [14, 33, 47], RNG k-ε [7, 9, 12, 13, 48-52], SST k-ω [12], RSM [12], LES [53] and DES [53, 54]. Throughout these models, it was discovered that the used of standard k- ε model is less preferable in simulating airflow and particles dispersion in hospital operating room. In predicting the unidirectional and low-speed airflow in an operating room, McNeill revealed that k-ε model is not suitable due to underlying physics of the air distribution are significant different [34]. Nielsen [55] also agreed that standard k-ε model only valid for a fully-developed turbulent flow, which will not presented in operating room air distribution. McNeill concluded that the realizable k-ε and the RNG k-ε models are more reliable in terms of predicting the indoor airflow [34]. Undoubtedly, this statement is further supported by Romano's finding. He investigated the similar study and found out that the results simulated by realizable k-ε model provided a good agreement with measurement data [14]. In addition, Sadrizadeh agreed that RNG k-ε model is a good approach for this study as RNG k-ε model capable to handle the effects of smaller scales of motion significantly well [12]. Surprisingly, in the year of 2015, Yang claimed that RNG k-ε model did not performed well in predicting the indoor airflow [48]. Yang and his research team discovered that LES and DES models provided high reliability results in predicting unstable flow field simulation. The only limitation of the LES model is that it required high computational cost and memory. Recently, a very good agreement between simulation results and experiment data is shown by using SST k-ω and RSM models [12]. In the extension of Sadrizadeh study, he claimed that the used of SST k-ω required very fine meshes close to the computational domain walls [12]. Sadrizadeh also discovered that several flow models could be used for same case study as long as the models have presented a good agreement with the actual field measurements [52].

In modeling indoor particles dispersion, there are two main models which are: Lagrangian-based model and Eulerian-based model. Sadrizadeh proposed that the selection between them is based on the research field and the required computational cost [12]. However, Andrew et al. claimed that Lagrangian approach could be more accurate than Eulerian approach in predicting particles dispersion and distribution [56]. In the same field of study, Zhang and Chen have different opinion with Andrew. They revealed that both Eulerian and Lagrangian approaches are well predicting the particle concentration distribution as long as the simulation is conducted under steady-state condition [57]. In general, authors noticed that both Lagrangian and Eulerian approaches are widely used operating room studies [12, 14, 19, 58]. However, the justifications for the use of Lagrangian and Eulerian approaches are limited. In 2014, Sadrizadeh and co-workers suggested that additional user-defined function is needed if employing Lagrangian approach in predicting particle dispersion in operating room [12]. This is due to Lagrangian approach does not directly calculate the particle concentration. A more recent study conducted by Wang and Chow, they employed Eulerian approach for their particle dispersion simulation [19]. The authors justified that Eulerian approach is adopted due to its convenience for post-processing particle concentration. The use of Eulerian approach also has been supported by another research team where they found out that Lagrangian approach is time-consuming in terms of conducting statistical works [58].

4.0 CONCLUSION

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

Up to date, the employment of experimental assessment on airflow pattern in operating room is limited. Previous studies have shown that the airflow research are mainly conducted through the use of CFD simulation. Various type of assumptions, predictions and simplifications have been made of CFD models. Hence, the simulated results might not be able to fully reflect the actual conditions in operating room. For future study, a mock operating room and surgical procedure will be useful to reflect the actual airflow system and the settlement of particles counts. For the particles sampling studies, the researchers were focused on new sampling method rather than employing a standardize method to quantify the particle counts. The inconsistent of sampling methods will cause the data comparison across different researches become imprecise and insignificant. It is highly recommended that a standardize method for particles sampling in operating room could be established for the ease of data analysis.

REFERENCES

[1] ISO, Cleanrooms and associated controlled environments -- Part 1: Classification of air cleanliness, ISO 14644-1, 1999.

[2] ISO, Cleanrooms and associated controlled environments -- Part 3: Test methods, ISO 14644-3, 2005.

[3] T.T. Chow, A. Kwan, Z. Lin, W. Bai, Conversion of operating theatre from positive to negative pressure environment, Journal of Hospital Infection 64 (4) (2006) 371-378.

[4] M.L. Pereira, A. Tribess, A review of air distribution patterns in surgery rooms under infection control focus, Engenharia Térmica (Thermal Engineering) 4 (2) (2005) 113-121.

[5] M.A. Melhado, J.L.M. Hensen., M. Loomans, Review of ventilation systems in operating rooms in view of infection control, Proceedings of the 6th International Postgraduate Research Conference in the Built and Human Environment, 2006, p. 478-487.

[6] B. Friberg, M. Lindgren, C. Karlsson, A. Bergstrom, S. Friberg, Mobile zoned/ exponential LAF screeen: a new concept in ultra-clean air technology for additional operating room ventilation, Journal of Hospital Infection 50 (4) (2002) 286-292.

[7] S. Sadrizadeh, S. Holmberg, Effect of a portable ultra-clean exponential airflow unit on the particle distribution in an operating room, Particuology 18 (2015) 170-178.

[8] A. Nilsson, Ventilation systems in operating theatres, aspects to consider, A Johnson Medical Bulletin (2002).

[9] S. Sadrizadeh, S. Holmberg, Effect of a portable ultra-clean exponential airflow unit on the particle distribution in an operating room, Particuology 18 (2015) 170-178.

[10] Jennifer A. Wagner, K.J.S., Ralph Conen, Using cleanroom technology improving operating room contamination control. ASHRAE Journal, 2014. February: p. 18-27.

[11] Nilsson, A., Ventilation systems in operataing theatres, aspects to consider. A Johnson Medical Bulletin, 2002.

[12] Sasan Sadrizadeh, A.T., Peter Ekolind, Sture Holmberg, Influence of staff number and internal constellation on surgical site infection in an operating room, Particuology 13 (2014) 42-51.

[13] S. Sadrizadeh, S.H. Ann Tammelin, A numerical investigation of vertical and horizontal laminar airflow ventilation in an operating room, Building and Environment 82 (2014) 517-525.

[14] L.M.F. Romano, J. Gusten, C. M. Joppolo, Numerical and experimental analysis of airborne particles control in an operating theatre, Building and Environment 89 (2015) 369-379.

[15] P.L. Carla Balocco, Assessing ventilation system performance in isolation rooms. Energy and Buildings 43 (2011) 246-252.

[16] A.A.L. Traversari, C.A.G., E. Dusseldorp, A. Bode, F. Keuning, M.S.J. Pelk, M.C. Vos, Laying-up of sterile instruments in the operating theatre: equal or superior protection by using a horizontal unidirectional air flow system, Journal of Hospital Infection 85 (2013) 125-133.

[17] F. Memarzadeh, A, Manning, Reducing risks of surgery, ASHRAE Journal (2003) 28-33.

[18] S.H. Ho, M. R. Muhammad, Three-dimensional analysis for hospital operating room thermal comfort and contaminant removal, Applied Thermal Engineering 29 (2008) 2080-2092.

[19] J. Wang, Influence of human movement on the transport airborne infectious particles in hospital, Journal of Building Performance Simulation 8 (2015) 205-215.

[20] X. Guang, D. Kray Luxbacher, S.A. Ragab, M.E. Karmis, Remote characterization of ventilation systems using tracer gas and CFD in an underground mine, Safety Science 74 (2015) 140-149.

[21] X. Guang, S. Ragab, S. Schafrik, Development of a remote analysis method for underground ventilation systems using tracer gas and CFD in asimplified laboratory apparatus, Tunneling and Underground Space Technology 33 (2013) 1-11.

[22] Z. Zhiqiang, Simulation-based feasibility study of improved air conditioning systems for hospital operating room, Frontiers of Architectural Research 2 (2013) 468-475.

[23] J.M. Villafruela, M. Ruiz de Adana, C. Mendez, P.V. Nielsen, CFD analysis of the human exhalation flow using different boundary conditions and ventilation strategies, Building and Environment 62 (2013) 191-200.

[24] Y.H. Yau, A case study on the air distribution in an operating room at Sarawak General Hospital Heart Centre (SGHHC) in Malaysia, Indoor and Built Environment 23 (2014) 1129-1141.

[25] H.Brohus, D. Jeppesen, Influence of movements on contaminant transport in an operating room, Indoor Air 16 (2006) 356-372.

[26] A. Tammelin, B. Reinmuller, Single-use surgical clothing system for reduction of airborne bacteria in the operating room, Journal of Hospital Infection 84 (2013) 245-247.

[27] A. E. Andersson, M. Petzold, I. Bergh, J. Karlsson, I. Bengt, Eriksson, K. Nilsson, 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 (2014) 665-669.

[28] P. Ninomura, T. Ninomura, Current trends for health-care ventilation. ASHRAE Journal (2014) 32-42.

[29] C. Xiaodong, N. Jiang, Q. Chen, Particle image velocimetry measurement of indoor airflow field: A review of the technologies and applications, Energy and Buildings 69 (2014) 367-380.

[30] A. Sattari, PIV study of ventilation quality in certain occupied regions of a two-dimensional room model with rapidly varying flow rates, International Journal of Ventilation 12 (2013) 187-194.

[31] J.I. Peren, B.C.C. Leite, B. Blocken, CFD analysis of cross-ventilation of a generic isolated building with asymmetric opening positions: Impact of roof angle and opening location, Building and Environment 85 (2015) 263-276.

[32] T. Barth, G. Muller, U. Hampel, Single particle resuspension experiments in turbulent channel flows, Journal of Aerosol Science 71 (2014) 40-51.

[33] T. C. Stevenson, Comparison of CFD simulations of hospital operating room air distribution with experimental PIV analysis, ASHRAE Transactions 119 (2013) 1-13.

[34] J. McNeill, Z. Zhai, Experimental investigation of operating room air distribution in a full-scale laboratory chamber using particle image velocimetry and flow visualization, Journal of Flow Control, Measurement & Visualization 1 (2013) 24-32.

[35] S. Klingenberg, Smoke studies: Clearing the mystery of air flow visualization, Journal of Validation Technology (2010) 11-17.

[36] D. A. Healy, J. R. Sodeau, Measurement of the particle counting efficiency of the "Waveband Integrated Bioaerosol Sensor" model number 4 (WIBS-4), Journal of Aerosol Science 47 (2012) 94-99.

[37] C. Dai, X. Ma, M. Yin, H. Zheng, X. Gu, S. Xie, H. Jia, L. Zhang, W. Zhang, Real-time measurements of airborne biologic particles using fluorescent particle counter to evaluate microbial contamination: Results of a comparative study in an operating theatre, American Journal of Infection Control 43 (2015) 78-81.

[38] D. D'Alessandro, M.G. Deriu, M.T. Montagna, I. Mura, C. Napoli, N. Vescia, Evaluation of fungal contamination in operating rooms using a dusting cloth pad: Comparison among different sampling methods, American Journal of Infection Control 41 (2013) 658-660.

[39] N. Vescia, J.F. Osborn, F. Cerquetani, R. Cavarischia, R. Grillot, D. Pharm, D. D'Alessandro, Field validation of a dusting cloth for mycological surveillance of surfaces, American Journal of Infection Control 39 (2011) 156-158.

[40] S. Dharan, Environmental controls in operating theatres, Journal of Hospital Infection 51 (2002) 79-84.

[41] C. Balocco, G. Cammarata, P. Vitali, R. Albertini, C. Pasquarella, Indoor air quality in a real operating theatre under effective use conditions, Journal of Biomedical Science and Engineering 7 (2014) 866-883.

[42] L. Taesub, B. Sean Kim, The predictions of infection risk of indoor airborne transmission of diseases in high-rise hospitals: Tracer gas simulation, Energy and Buildings 42 (2010) 1172-1181.

[43] M. Cheng, K.Y. Lam, W.J. Cai, E.L. Lee, Approaches for improving airflow uniformity in unidirectional flow cleanrooms, Building and Envionment 34 (1999) 275-284.

[44] J. Liu, W. Wen, Numerical simulation on a horizontal airflow for airborne particles control in hospital operating room, Building and Environment 44 (2009) 2284-2289.

[45] R. Zhang, T. Guangbei, Study on biological contaminant control strategies under different ventilation models in hospital operating room, Building and Environment 43 (2008) 793-803.

[46] T.T. Chow, Ventilation performance in the operating theatre against airborne infection: numerical study on an ultra-clean system, Journal of Hospital Infection 59 (2005) 138-147.

[47] K.G. Carine Habchi, N. Ghaddar, A. Shihadeh, Chair fan-enhanced displacement ventilation for high IAQ: Effects on particle inhalation and stratification height, Building and Environment 84 (2015) 68-79.

[48] Y. Changwei, X. Cao, J. Liu, F. He, Numerical simulations of the instantaneous flow fields in a generic aircraft cabin with various categories turbulence models, Procedia Engineering 121 (2015) 1827-1835.

[49] Z. Kang, H. Fan, G. Feng, Numerical simulation of coughed droplets in the air-conditioning room, Procedia Engineering 121 (2015) 114-121.

[50] J. Hang, R. Jin, The influence of human walking on the flow and airborne transmission in a six-bed isolation room: Tracer gas simulation, Building and Environment 77 (2014) 119-134.

[51] Z. Han, S.C. Fu, C. Yu-Hang Chao, W. Weng, Q. Huang, Effect of human movement on airborne disease transmission in an airplane cabin: study using numerical modeling and quantitative risk analysis, BMC Infectious Diseases 14 (2014) 1-19.

[52] S. Sadrizadeh, P. Ekolind, S. Holmberg, Influence of staff number and internal constellation on surgical site infection in an operating room, Particuology 13 (2014) 42-51.

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 4, No.1. Pages 20-30, 2014

[53] Y. Cheng Shih, O. Wang, Dynamic airflow simulation within an isolation room, Building and Environment 42 (2007) 3194-3209.

[54] M. Wang, Q. Chen, Advanced turbulence models for predicting particle transport in enclosed environments, Building and Environment 47 (2012) 40-49.

[55] P.V. Nielsen, Fifty years of CFD for room air distribution, Building and Environment 91 (2015) 78-90.

[56] A. Riddle, A. Sharpe, C. McHugh, J. Stocker, Comparisons between FLUENT and ADMS for atmospheric dispersion modelling, Atmospheric Environment 38 (2004) 1029-1038.

[57] Z. Zhang, Comparison of the Eulerian and Lagrangian methods for predicting particle transport in enclosed spaces, Atmospheric Environment 41 (2007) 5236-5248.

[58] C. Tin-Tai, Dynamic simulation on impact of surgeon bending movement on bacteria-carrying particles distribution in operating theatre, Building and Environment 57 (2012) 68-80.