CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 5

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 5*. Department of Civil Engineering, Aalborg University.

A new ventilation system principle for operating rooms: Temperature-Controlled Air Flow

Sasan Sadrizadeh[†1] and Peter Ekolind[2]

[1] Divisions of Fluid and Climate Technology, Department of Civil and Architectural Engineering, KTH Royal Institute of Technology, Stockholm, Sweden

[2] CEO, Avidicare AB, Lund, Sweden

[†] Corresponding email: ssad@kth.se

SUMMARY

A new operating theatre ventilation system principle, that is, Temperature-Controlled Air Flow (TAF), was examined using computational fluid dynamics. TAF combines two well-known mixing and vertical laminar airflow ventilations that were explored using a validated numerical calculation scheme. A Realizable k-ε turbulence model mapped the airflow field, and a Lagrangian model tracked the particle phase. A recovery test gauged the viability of the operating theatre ventilation system. The results showed that the TAF system provides an environment safe enough for surgical procedures, with about the same performance as the well-known laminar airflow ventilation system.

Keywords: Temperature-Controlled Airflow Ventilation system, Operating theatre, Computational fluid dynamics, Infection, Airborne contamination

1. INTRODUCTION

The overall post-surgical wound infection rate depends on such factors as the type of surgery, medical procedures, equipment cleanliness, operating theatre (OT) air quality, and levels of airborne bacteria-carrying particles (BCPs). Airflow , as a reservoir for microorganisms, can play an essential role in enclosed environments such as OTs [1]. Contamination is usually reduced via a ventilation system to dilutes and evacuates airborne contaminants from the OT [2] increasing staff clothing performance to prevents bacteria shedding from staff clothing [3], as well as by reducing the number of people and their activity in the OT [4]. The OT ventilation system is the most important component that supposes to have easy control over the airflow pattern; however, its initial and operational costs are quite high. There are three common OT ventilation systems: turbulent-mixing, displacement, and the Laminar Airflow system (LAF). Conventional turbulent-mixing ventilation supplies turbulent streams of conditioned air to create a fully mixed flow throughout the entire OT. Several studies claim that this type of system is unstable [5,6] and never can have generate fully mixed airflow in practice [7]. Displacement ventilation, by contrast, supplies fresh air by a low-induction diffuser. Cool air spreads through the floor of the OT, and then rises as it warms due to heat exchange within the OT, finally exiting the room at ceiling height. The third ventilation category, so-called Laminar Airflow system (LAF), attempts to avoid turbulence by supplying parallel conditioned air with identical speeds to deliver ultra-clean airflow over the surgical area [7]. It is widely accepted that LAF is the most efficient OT ventilation system;

nevertheless, installation is relatively cost-inefficient. Recently, some other types of ventilation systems have been considered that improve efficiency by combining the above-mentioned principles, leading to a hybrid ventilation system; see Figure 1.

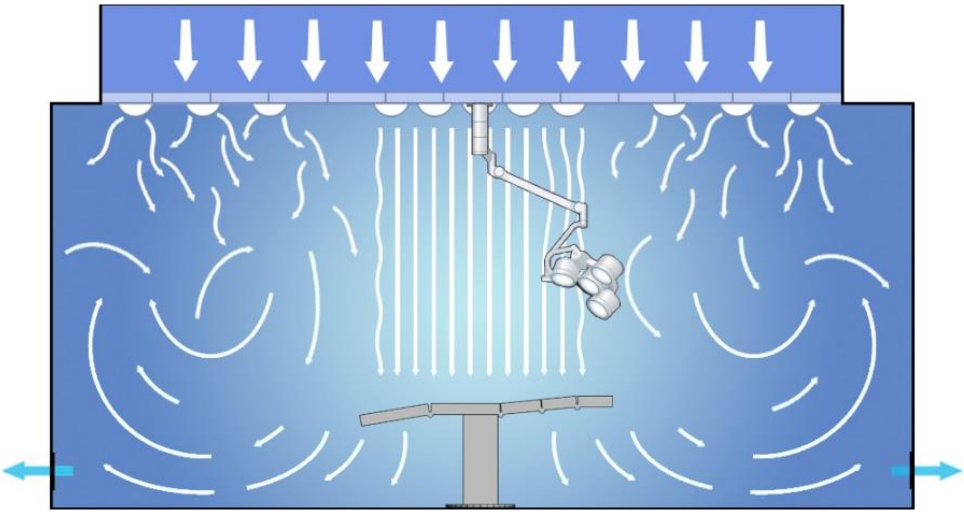

Fig. 1: Desired design principle behind the hybrid ventilation systems

Poor OT ventilation not only creates financial burdens for healthcare facilities, but also may increase the infection rates and result in prolonged and unnecessary patient suffering. Consequently, it is a key issue and challenge to plan and design a ventilation system that provides clean air with low operating and installation costs. A lack of unified standards on overall OT ventilation requirements is a further challenge. This study assesses the temperature-controlled airflow (TAF) hybrid ventilation system, which was first installed in an OT in 2007.

2. METHODOLOGIES

The physical configuration of the OT which was considered in the present study was shown in Figure 2. The OT measured 8.5 m × 7.7 m, with a total height of 3.2 m. The OT contained an operating table, two instrument tables, one mayo stand table, double medical lamps, two pieces of medical equipment, and 10 surgical personnel.

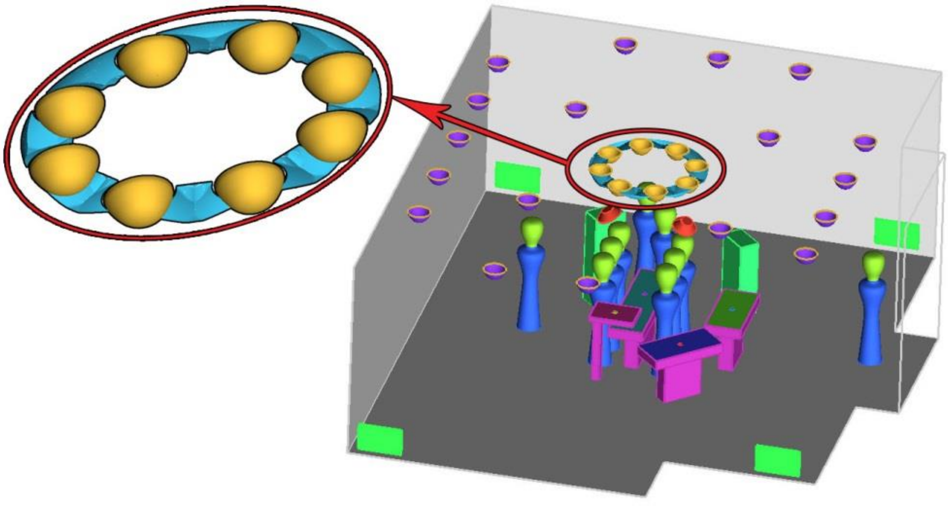

Fig. 2: Isometric view of operating room

The entire OT was ventilated with a TAF ventilation system. The incoming air was supplied through eight central air showers at 18.5 ^{o}C and 18 peripheral air showers at 20 ^{o}C, each with an airflow rate of 350 m^3/h, giving a total airflow rate of 9,100 m^3/h.

2.1. Mathematical modeling

Particle motion and airflow modeling based on computational fluid dynamics (CFD) is determined by iteratively solving the fundamental conservation equations for mass, momentum, and energy. The airflow was modeled with Realizable k–ε turbulence, with the Lagrangian approach used for the particle phase. A detailed description of this simulation, including the validation work, has previously been given by the authors [4,8]. The commercial CFD code, Fluent, was used to simulate the airflow. An independence test was performed to make sure that the grid was sufficiently fine and the calculated results only yielded very small changes during simulations. Model validation was also carried out with published experimental data from the literature.

2.2. Recovery test

A recovery test is usually performed to determine the ability of the OT ventilation to remove BCPs within the time that the particle concentration decays by two orders of magnitude. According to DIN 1946-4 [9], the BCP concentration should be reduced by 99 % within a time limit of 25 minutes. Here, the OT was exposed to 3,500 particles/m^3 of air (0.5 μm) and was followed by a recovery test.

1. RESULTS AND DISCUSSION

1.1. Airflow field

Figure 3 shows velocity vectors in two vertical planes passing through the surgical table's centerline, as well as the OT periphery. The air velocity pattern shows a strong and unidirectional down-flow in the critical surgical zone.

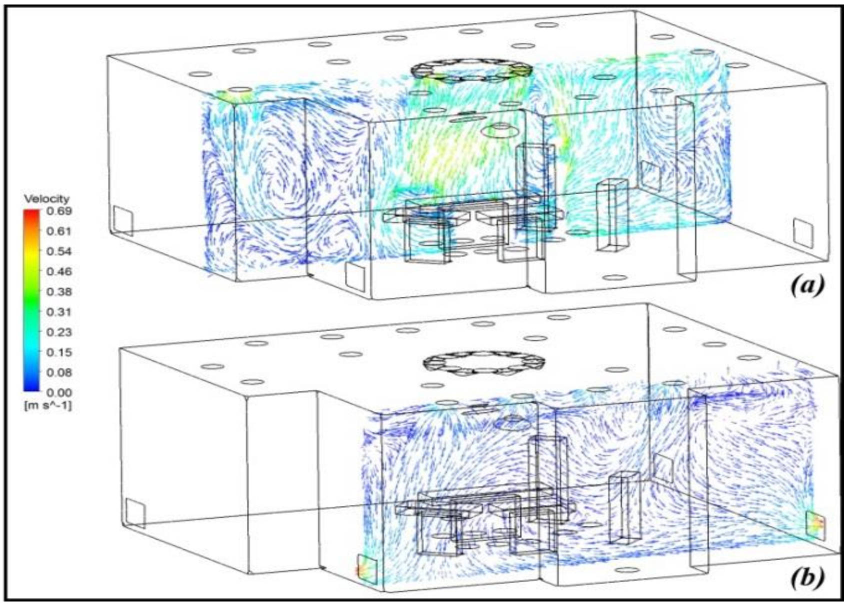

Fig. 3: Velocity vector plots at two different vertical planes: (a) passing through operating table; and (b) OT periphery

As shown in Figure 3(a), a fresh, unidirectional airflow was induced over the surgical area. The air velocity above the operating table was high enough to wash off all the released bacteria-carrying particles. The heat sources in the OT had a negligible effect on the airflow pattern, as the air in this area had quite low temperature (18.5 ^{o}C). The low airflow temperature can easily displace the heat plumes. The temperature difference between the air supplied from the central and peripheral diffusers subdivided the OT environment into two distinct zones. In the center, the convention flowed from heat sources as staff and medical equipment efficiently directed the BCPs to the floor and finally to the exhausts. Figure 3(b) shows the airflow pattern in the OT periphery. The airflow in this area was closer to the fully mixed airflow that is based on the dilution principle. The particles that washed off from the OT center with unidirectional airflow were diluted with fully mixed airflow in the OT periphery and evacuated by the exhaust openings. The hybrid system can benefit both fully mixed and laminar airflow ventilation. The TAF principle works with other temperatures as well.

1.2. Recovery test

Figure 4 shows the recovery test results for TAF ventilation system. The recovery time was 4:08 min. The reported recovery time for TAF ventilation system is well below the upper limit proposed by ISO 14644-3:205 [10].

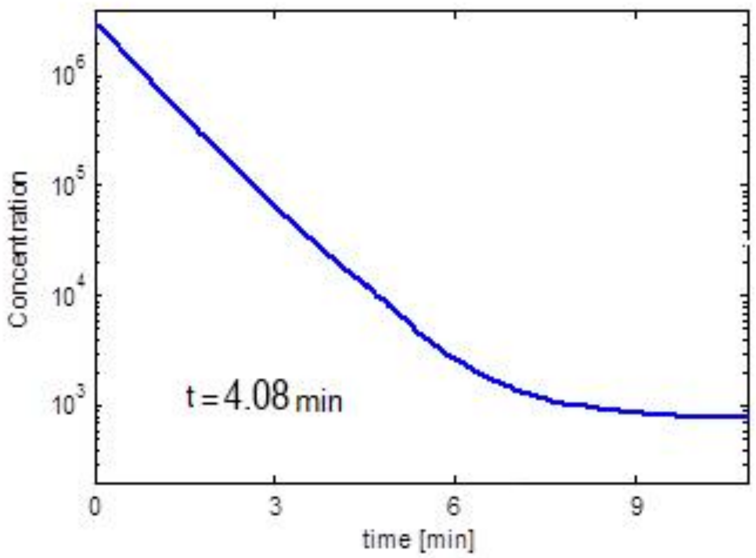

Fig. 4: Recovery test based on ISO 14644-3:205

The recovery test result of TAF system can confirm the ability of this system to eliminate the particles in a short time.

2. CONCLUSION

Temperature-controlled airflow is a new ventilation principle that combines the LAF system (in surgical zone) with mixed airflow patterns (in the OT periphery) to enhance the ventilation efficiency. As shown in the results, this system divided the OT environment into two distinct zones by supplying conditioned air with two different temperatures above the operating table. The central air showers created a laminar airflow in the surgical area; the external air showers, however, diluted the periphery-emitted particles via a mixed airflow. Incoming air from the central and marginal air showers evacuated at floor level, providing a uniform and conditioned airflow pattern in the entire OT. Recovery tests showed a short recovery time of 4.08 minutes, which is well below the required standards.

REFERENCES

1. Sadrizadeh S, Tammelin A, Nielsen P V, Holmberg S. Does a mobile laminar airflow screen reduce bacterial contamination in the operating room? A numerical study using computational fluid dynamics technique. Patient Saf. Surg. 2014; 8:27

2. Memarzadeh F, Manning A. Comparison of operating room ventilation systems in the protection of the surgical site. ASHRAE Trans. 2002; 108:3–15

3. Whyte W, Vesley D, Hodgson R. Bacterial dispersion in relation to operating room clothing. J. Hyg. (Lond). 1976; 76:367–78

4. Sadrizadeh S, Tammelin A, Ekolind P, Holmberg S. Influence of staff number and internal constellation on surgical site infection in an operating room. Particuology 2014; 13:42–51

5. Andersson P a, Hambraeus A, Zettersten U, Ljungqvist B, Neikter K, Ransjö U. A comparison between tracer gas and tracer particle techniques in evaluating the efficiency of ventilation in operating theatres. J. Hyg. (Lond). 1983; 91:509–19

6. Balocco C, Lio P. Assessing ventilation system performance in isolation rooms. Energy Build. 2011; 43:246–252

7. Sadrizadeh S, Holmberg S, Tammelin A. A comparison of vertical and horizontal laminar ventilation systems in an operating room: A numerical study. Build. Environ. 2014; 82:517–525

8. Sadrizadeh S, Holmberg S. Effect of a Mobile Ultra-clean Laminar Airflow unit on particle distribution in an operating room. Particuology 2014; 18:170–178

9. DIN standard 1946-4, Ventilation and air conditioning –Part 4: VAC systems in buildings and rooms used in the health care sector. 2008;

10. Cleanrooms and associated controlled environments - Part 3: Test methods (EN ISO 14644-3:2005) 2008-08-06.