INNOVATION IN VENTILATION: ALIGNING INFECTION PREVENTION WITH ENERGY EFFICIENCY

Alyson Prince, Senior Consultant, Archus, UK
Kathy Warye, Principal, Infection Prevention Partners, San Francisco, USA

Introduction

Reducing the risk of infection in healthcare can, at times, conflict with environmental goals. In the case of controlling airborne contamination, reducing transmission risk has typically required higher expenditure of energy, because of complex air handling requirements. In the operating room, this situation presents decision makers with a difficult trade-off between protecting patients and personnel from risk of exposure or protecting the environment. Over the last decade, a growing body of evidence has suggested that conventional Laminar Air Flow ventilation (LAF) is negatively correlated with infection risk.[1,2] LAF can also be energy inefficient, because of the high air changes their mode of operation requires and the resulting energy consumptive air handling. Temperature-controlled Air Flow (TcAF), designed for the modern operating room, offers the opportunity to more effectively protect patients and surgical teams from airborne microbial contamination without compromising on environmental sustainability goals.

Background

Over 60 years of evidence supports the contribution of airborne microbial contamination to Surgical Site Infection (SSI). HTM 03-01 Part A states, *"it is thought that up to 25% of infections that occur as a result of a surgical intervention are caused by the airborne route. The source of these infections are predominantly as a result of airborne microorganisms, typically skin scales, liberated during the surgical procedure becoming airborne and landing in the wound or on surgical instruments. These then become a means of inoculating the patient, instruments and implants with the contaminant."*[3] Two large multi-center studies found that in rooms with over 50 CFU/m^3 of air patients were two and a half times more likely to develop an SSI.[4,5] With exponential growth in infection sensitive procedures, it is imperative to bring airborne microbial contamination in the operating room to an irreducible minimum.

Analysis of Alternative Ventilation Systems

A growing body of evidence has shown that conventional LAF systems are not as protective against SSI as originally thought. There are several explanations for the variable results.

Air speed
HTM 03-01,12.82 sets forth minimum requirements at 0.38 m/s 2m above the floor. A typical LAF system streams inlet air at the ceiling at approximately 0.4m/s. However, velocity has been shown to decelerate with distance so that by the time the air reaches the wound, air speed is closer to 0.25-0.3m/s.[9] As a result, LAF systems can be easily disrupted by objects, such as lamps, imaging equipment and robotic arms. Without sufficient velocity, air becomes trapped under these objects creating bacteria reservoirs.

Limited Clean Zone
Perhaps the most important limitation is that these systems do not address the area outside of the immediate surgical field. LAF was designed to create a limited clean zone immediately around the operating field. Investigators have found as much as 55-fold higher levels of airborne contamination outside of the protected zone than inside the zone (Fig 1).[6]

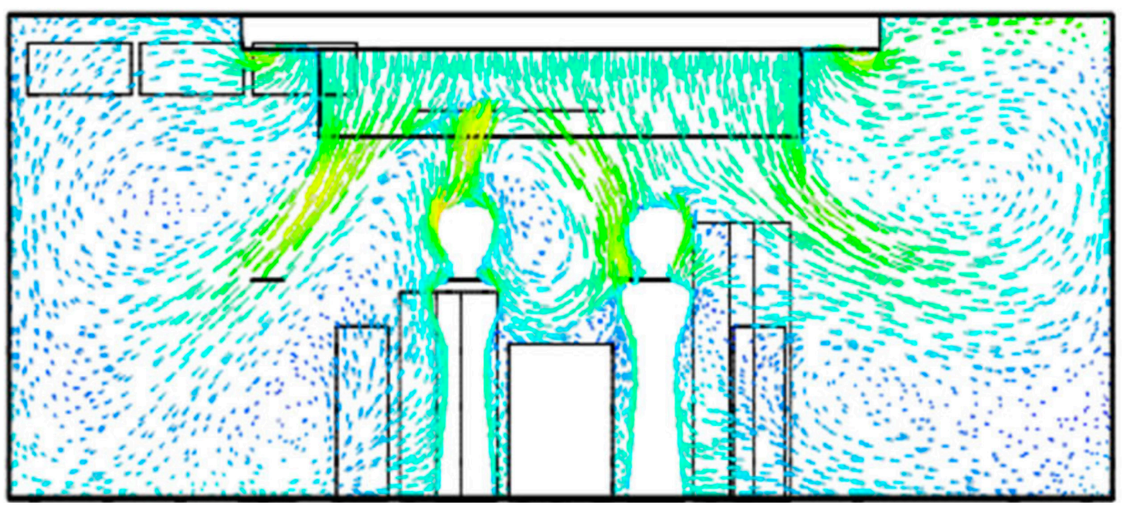


Fig. 1. CFD simulation of LAF system, Royal Inst. of Technology, Sweden. LAF challenged by turbulence in periphery

Surgical guidance recommends that previously sterilized items be placed in the clean zone, however, with LAF the limited size of the protected area can make this difficult, if not impossible (Fig. 2). After marking the perimeter of the clean zone with tape, one study found that sterile items were in the clean zone in only 36-52% of procedures.[7]

Fig. 2. Limited clean zone inhibits proper placement of sterile items

Temperature-controlled Air Flow (TcAF)
TcAF was designed with three goals in mind, to: 1) Bring airborne bioburden to an irreducible minimum, 2) optimize energy consumption and 3) improve the comfort of surgical personnel. In a TcAF system, HEPA filtered air is dispersed via air-showers at 1.5° C cooler than the ambient room temperature. This temperature differential creates a robust gravity-driven, vertical down-flow of air consistent throughout the entire room (Fig. 3).[8] In contrast to LAF, the air velocity accelerates as it drops enabling the system to more effectively navigate obstacles and heat convection. In over 300 measurement events, TcAF was shown to maintain air quality in the *entire room* at ultraclean (<10CFU/m^3) levels providing more effective protection for instruments, implants, patients and surgical personnel.

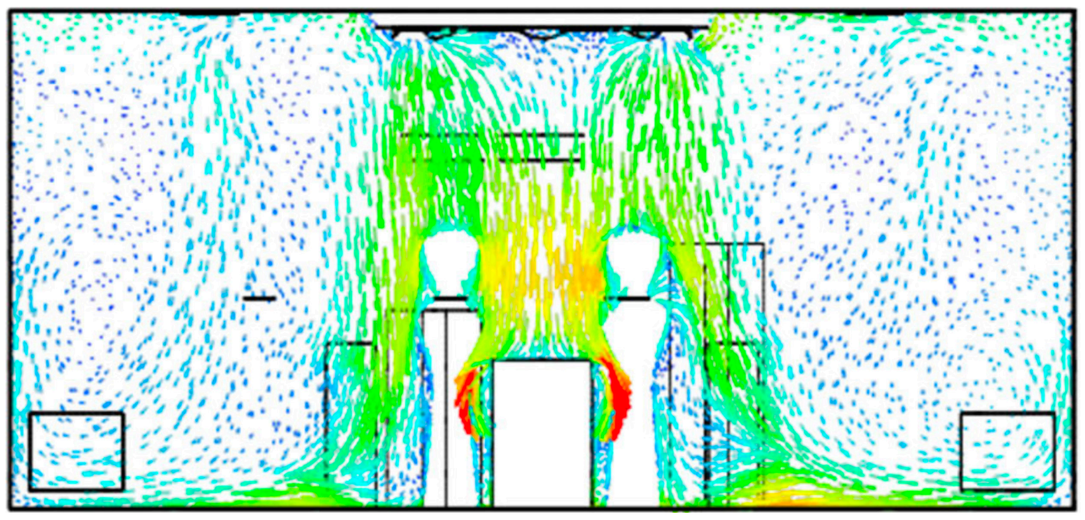
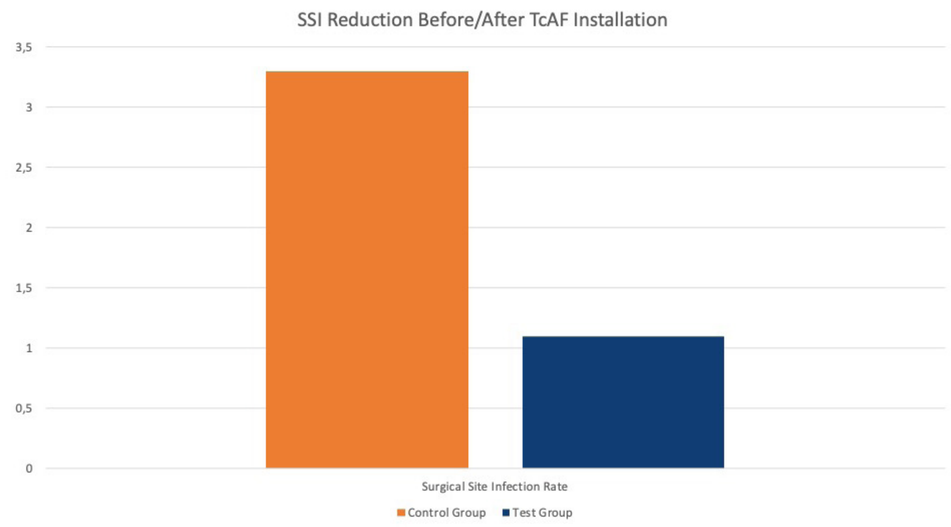


Fig. 3. CFD simulation TcAF system, Royal Inst. of Technology, Sweden. Robust vertical downflow.

Fig. 4. TcAF installation St.Maartensklinik, The Netherlands.

SSI Reduction *and* Net Zero Carbon
In a retrospective analysis of 2,000 cases of hip and knee arthroplasty, TcAF was correlated with a decrease in the rate of prosthetic joint infection from 3.3% to 1.1%.[9]



Finally, TcAF is more energy efficient than the alternatives. A standard TcAF operating room configuration uses approximately 6300m^3/h to meet the HTM03-01 requirement for velocity while maintaining the entire room at <10CFU/m^3. In contrast, an LAF installation would require approximately 10,000-12,000m^3/h to create a clean zone only.[10] TcAF makes SSI reduction possible without sacrificing net zero carbon goals.

Discussion

Acknowledging the growing body of evidence, both the World Health Organization (WHO) and the U.S. Centers for Disease Control and Prevention (CDC) withdrew previous recommendations for use of LAF for prosthetic joint procedures. However, standards for healthcare quality and patient safety have also not kept pace with innovation. In the case of HTM 03-01, the standard prescribes how a system should be designed not how it should perform. By focusing on design, the standard necessarily reflects the limitations of the technology available at the time of promulgation. The shortcomings of this strategy are clearly reflected in the current clean zone requirements where the approach to airborne microbial safety is constrained by the capabilities of existing ventilation systems. The emergence of innovative new technology, accompanied by strong evidence, should stimulate discussion of whether a different outcome should be considered. Rather than prescribing the design of a ventilation system, a standard reflecting how the system should perform, in this case setting forth limits on CFUs/m^3 would better serve the intent. Moving from a design standard to a performance-based standard would not only accommodate innovation, but potentially raise the level of protection for patients and personnel while ensuring best utilization of energy for optimal sustainability.

REFERENCES
1. Gastmeier P, et al. Influence of laminar airflow on prosthetic joint infections: a systematic review. J Hosp Infect. 2012;81(2).
2. Wang Q, et al. Association of laminar airflow during primary total joint arthroplasty with periprosthetic joint infection. JAMA Netw Open. 2020;3(10).
3. HTM 03-02: Specialised Ventilation for Healthcare Premises: Part A-Design and Validation, 22 June 2021
4. Charnley, J. and Eftekhar, N. (1969), Postoperative infection in total prosthetic replacement arthroplasty of the hip-joint with special reference to the bacterial content of the air of the operating room. Br J Surg, 56: 641-649.
5. Lidwell OM, et al. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. J Hosp Infect. 1983;4(2):111–131.
6. Benen T, et al. Influence of different ventilations systems upon the contamination of medical devices. Hyg Med. 2013; 38–41.
7. de Korne DF, et al. Safety by design: effects of operating room floor marking on the position of surgical devices to promote clean air flow compliance and minimise infection risks. BMJ Quality & Safety. 2012;21
8. Alsved M, et al. Temperature-controlled airflow ventilation in operating rooms compared with laminar airflow and turbulent mixed airflow. J Hosp Infect. 2018 Feb;98(2):181-190.
9. Vasiuk S, et al. Clinical validation and efficacy of a temperature-controlled ventilation system (TcAF) in the OR to reduce surgical site infections. Curr Dir in Biomed Eng. 2019:5 (1):1-3.
10. Nielsen, P. V. (2009). Control of airborne infectious diseases in ventilated spaces. Journal of the Royal Society Interface, 6(6), 747-755.