Holistic operating room hygiene control for air and surface cleanliness

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Abstract. Surgical site infections pose a severe risk for patients entering in a surgery. Surgical site infections are caused when microbes are entering to operation wound during surgery. Treatment of surgical site infections is very difficult and expensive, and it is expected that this will be even more difficult in the future due increased number of antibiotic resistant bacteria, such as MRSA, in hospitals.

The microbes may penetrate to patient wound principally through two routes: through air in a form of airborne microbes or by physical contact. In the later case the infection may be caused if an operating person touch a contaminated surface before accessing to the wound. Thus, to minimize surgical site infections it is utmost important to ensure that both operating room air and surfaces are maintained clean both during the operation and between consecutive operations.

The air cleanliness may be ensured with an appropriate ventilation system that is able to react according to surgical schedule also between operations. A throughout surface cleaning by cleaning staff is typically applied at the end of the day and additional cleaning takes place between operations. However, mechanical cleaning may leave some surfaces that are not fully cleaned and especially surfaces that are hard to reach or have complicated structures may remain untouched. To ensure better cleaning result it is possible to back up mechanical cleaning with a radiant disinfection. A blue light-based disinfection method can provide a safe to people cleaning both during operating room downtime and also between operations.

A novel, holistic integrated operating room cleaning system is developed to address simultaneously challenge of both air and surface cleaning. This system is managed by an intelligent control system that can automatically manage both air and surface cleaning processes through seamless interfacing with medical operations management system. Coordinated dimensioning is described to provide simultaneously optimal cleaning result of both airborne and surface bacteria. It is also described how the control system is set to provide cleaning cycles, personnel safety and comfort, and energy efficiency according to operational schedule.

Keywords. Operating Room, Hygiene control, Integrated design, Indoor environment
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1. Introduction

Operating rooms are used for surgical interventions to human patients. The focus is to provide safe environment for operations to minimize the adverse health effects caused to the patient during operation. In relation to indoor environment and ventilation this means a clean environment with low level of airborne microbes during operation that could cause an infection to the patient. The level of cleanliness needed is depending on the type of the operation and the general health condition of the patient.

In modern hospitals it is quite common to design most of the operating rooms for general use covering wide variety of operations, while specialized operating rooms are less in numbers. This necessitates the need to understand the different operational needs, when defining the design targets. Operating rooms with extensive use or imaging medical devices, so call hybrid operating rooms, enabling minimally invasive surgeries are increasing in numbers as well.

This paper discusses on the design challenges and infection routes in modern operating rooms and describes a holistic building services system that is designed taken into account the acknowledged challenges.

2. Operating room design challenge

Traditional thinking has been that the actual operational activity (clean zone) is taking place in the centre of the room, while most of the room is less used. This, however, is too simplistic approach in modern operating rooms, where the operational activity and the sterile instruments may occupy an extensive area of the room depending on the type of the operation.

Medical Installations occupy space in the ceiling and cause obstruction for airflow in the operation room. It is important to understand the medical layout and analyse it's effect to the design. The challenge does not only concern newbuild, but also the life-cycle of operation rooms – medical processes and development of medical technology drive need for flexibility for room renewal.

Thus, in modern operating rooms it is imperative to design ventilation and all building services systems in such a way that maximum space is given to current and future medical activities and installations. Ideally systems should also be made adaptable to medical operations rather than set requirements for medical staff.

A more detailed description of Operating room design challenges and design process is given in /1/

3. Infection routes in operating rooms

The main source of contamination in operation rooms is operating personnel or other persons entering operating room during and between operations. Other potential sources relating to ventilation is air leakage, especially during door openings. Eventual introduction of contaminated equipment and supplies to operating environment should be eliminated by medical protocols.

Infection carrying particles have multiple routes to patient wound, where they can potentially cause an operational infection.

The principal routes how infection carrying particles may enter into operating room air and ultimately to patient wound are illustrated in figures 1 and 2.

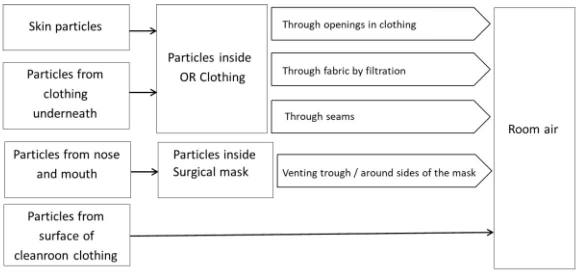


Fig. 1 – Airborne contamination routes in operating environment

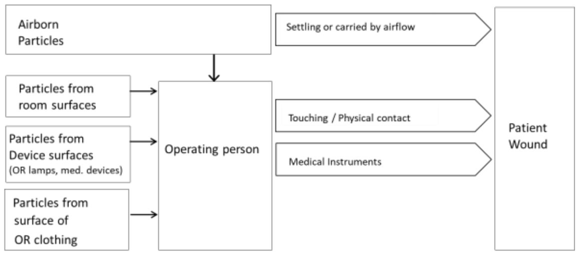


Fig. 2 – Potential routes for infectious particles to patient wound.

It is evident that for operative infection both airborne and physical contact routes are important. Both of these can be impacted by means of ventilation, but it is also important to ensure that surface cleanliness is properly maintained.

Surface cleanliness in operating rooms are carried by physical manual cleaning at the end of working day and between operations according to planned schedules in hospitals. Despite distinct protocols manual work has always natural variance in its quality and especially complex structures for example in medical devices or lamps may leave spots that are not so easily reachable and may not get as well cleaned. This quality variance was recognized for example in Norway where the quality of hospital bed cleaning was studied.

4. Operating room ventilation principles

So called laminar flow ceilings have been common in ultraclean operating rooms, while for standard operation rooms more simple mixing ventilation systems have been commonly used. In traditional thinking there has been very big difference between two approaches and for example the airflow rate has typically been 5 to 6 times bigger in laminar flow systems.

The latest development in operating rooms, such as use of whole room area, new medical practices and equipment have, however, challenged old mantras and brought to stage the challenges and needs that traditional systems are no able to meet. In addition to cleanliness requirements in current operating room design maybe the most important customer need is flexibility, both operational and for unspoken future upgrade needs during life cycle. Also, the need to ensure staff wellbeing and comfort is gaining higher emphasis.

To address both traditional and future needs of ultra-clean operations a new ventilation approach, controlled dilution ventilation system was developed. Figure 3 shows an illustration of such ventilation system, a more detailed description and information about the performance validation can be found from /2/.

Fig. 3 – Illustration of controlled dilution flow system airflow pattern.

One of the significant new advantages of the new ventilation approach is that it leaves much more ceiling space and flexibility for medical installations than traditional laminar flow system.

5. Surface disinfection in operating rooms

As mentioned earlier mechanical cleaning may leave some surfaces that are not so well cleaned, which may serve as bases for microbial growth.

Currently there are advanced technologies that may be used to enhance surface cleaning and disinfection. In cleanrooms for example UV -light fixtures and gas cleaning, such as H2O2, has been used to enhance the room cleanliness. Gas cleaning has been typically used as a periodic disinfection method, while UV – light has sometimes been used more for daily cleaning during shut-down period. The advantage of irradiation is that it can penetrate also to areas that may not be easily reachable by manual cleaning.

Use of traditional UV – light for such purpose is not trouble free, because precautions have to be implemented to protect users from entering the space during cleaning period, which limits its usage. UV has also effect on surfaces and materials that may wear out due to UV irradiation.

One, very promising new technology is to use visible blue light for surface disinfection. It is proven that specific wavelengths of visible blue light are capable of eliminating microbes from the surfaces. /3,4/ Figure 4 illustrates the efficiency of photon disinfection in inactivation of *Staphylococcus aureus* (ATCC 6538) at low intensity (blue light 0,7 mW/cm2).

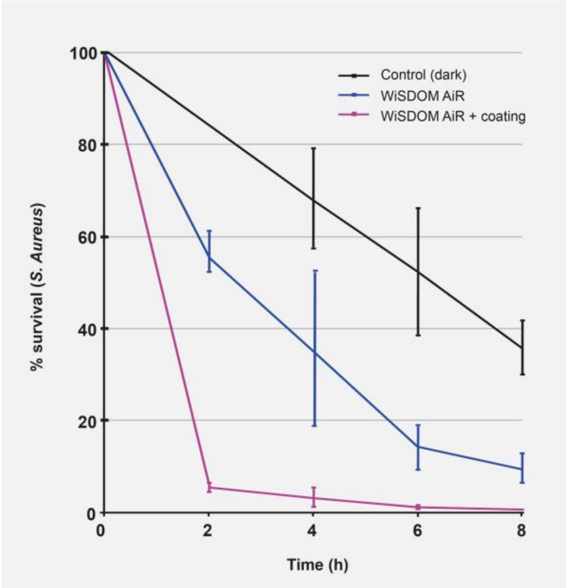


Fig. 4 – Blue light efficiency in inactivation of S. aureus bacteria (blue curve - blue light only, purple curve – blue light with catalytic coating)/4/

The advantage of blue light compared to UV irradiation is that blue light is not causing any harm for people nor surfaces. Thus, even if it is not recommended to use strong blue light irradiation during occupation it is not dangerous to enter the space. This makes blue light much more usable in operating rooms, where the entrance control is not as tight as in cleanrooms and allows the use of such disinfection except during shut-down period also during the day between operations.

As a next evolution of future fit operating room system a blue light disinfection system has been integrated into control dilution flow ventilation terminal in such a way that both ventilation and surface disinfection performance are simultaneously optimized. By integration it is possible to add more value for the end users without using even more critical ceiling space to be used for medical installations. A module of integrated unit is shown in Figure 5.

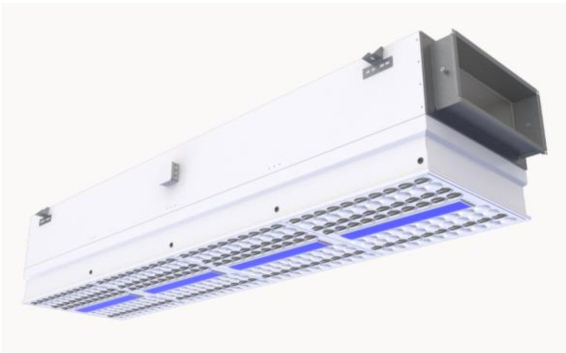


Fig. 5 – Integrated terminal for operating room ventilation and surface cleaning

The blue light disinfection system was designed to provide 99% disinfection performance during 3,5 hours in the whole operating room and even in 1 hour in the most critical room center. A simulation of the system performance in 7,0m by 8,7m size operating room is shown in Figure 6.

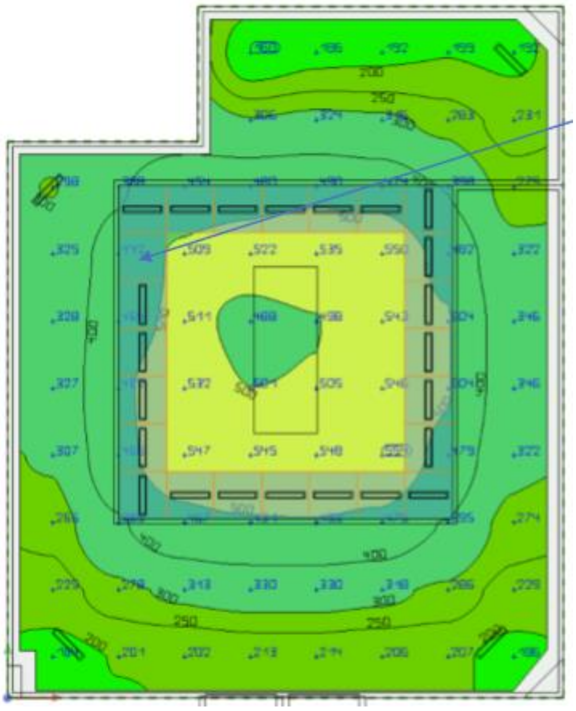


Fig. 6 – Performance of the integrated blue light disinfection system

6. Total OR Environment concept

6.1 Integrated Building services

In addition to ventilation, also general lighting is a major ceiling space occupier in operating rooms. Thus, also integrating also the general OR lighting as part of the integrated disinfection development was taken as a target. This added one more optimisation challenge to ensure that the performance of all utilities, ventilation, surface disinfection and general lighting are functioning according to customer demands. This was solved by developing an integrated light fixture that can provide both high quality general lighting and by changing operational mode also blue-light disinfection.

This was ensured by light simulation and ultimately by measurements of physical installation. An illustration of lighting simulation is shown in Figure 7.

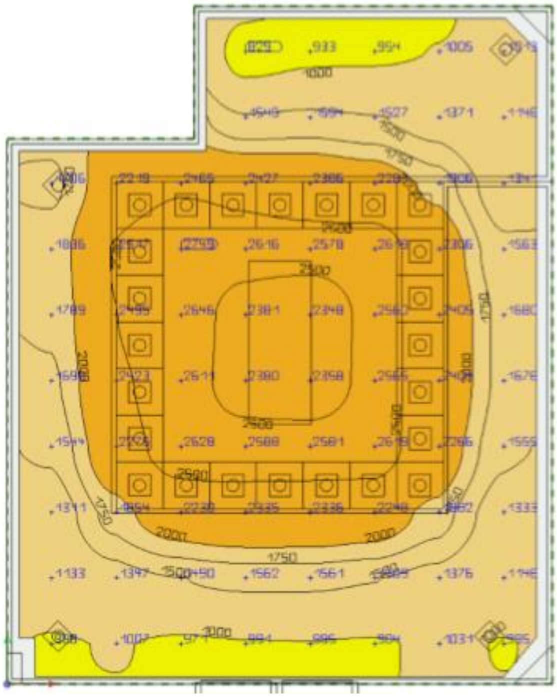
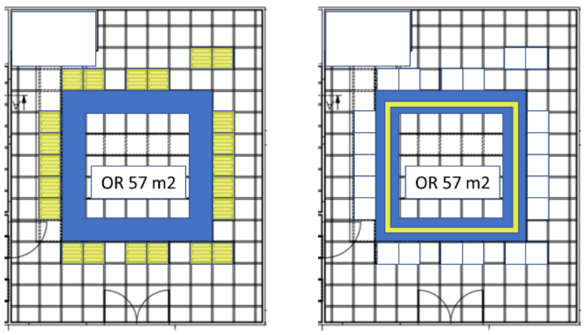


Fig. 7 – General lighting simulation of operating room with integrated building services unit

Available ceiling space with integrated building services unit can be further increased by 20 % compared to disintegrated services, see Figure 8.



Free area: 40,4 m2 Free area: 48,4 m2

Fig. 8 – Available ceiling space with integrated building services unit compared to disintegrated services. Yellow squares on the left hand layout show the location of separate light fixtures in the ceiling.

6.2 Operating room control system

In earlier stage, a comprehensive on-demand management system integrating predictive cleanliness and controlled dilution flow ventilation system was developed, which enables improved safety and sustainability. /2,5/ With the help of controlled flow principle it is possible to implement safely demand based ventilation also in operating environment. This is made by utilizing the knowledge of the operational clothing quality and it's influence on microbial source strength in operation./6/T o enhance usability of the system it has also been integrated to general operating room

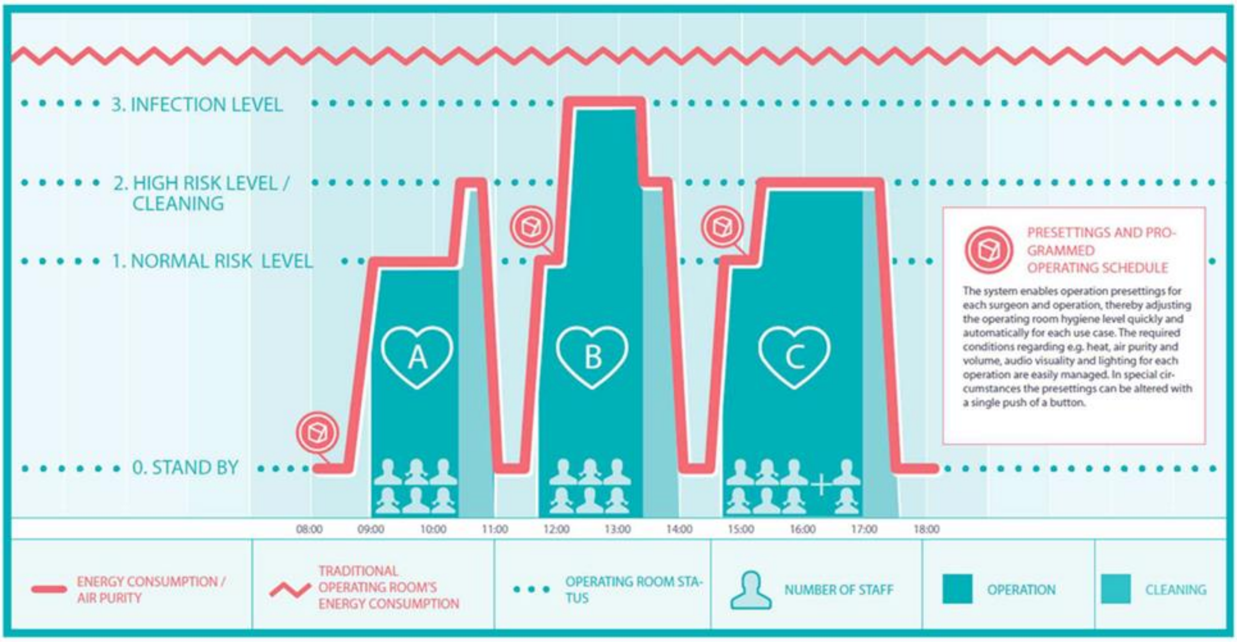


Fig. 9 – Illustration of operation mode based control.

process management system. This integration enables usage of operation mode-based system control by activation of medical personnel depending on their stage of work. The principle of operation mode based control is presented in Figure 9.

This same system can now be extended to control the whole integrated building services system of ventilation, blue-light disinfection, and general lighting, which simplifies the working process of operation room personnel and enables optimal use of room with integrated building services based on the actual operation mode.

7. Acknowledgement

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Data sharing not applicable to this article as no datasets were generated or analysed during the current study.