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Design of air distribution system in operating rooms -theory versus practice

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SUMMARY

Air distribution systems need to secure a good indoor air quality in operating rooms (ORs), minimize the risk of surgical site infections, and establish suitable working conditions for the surgical team through the thermal comfort. The paper presents an overview of the design and decision process of air distribution systems in ORs. The study was done by conducting a literature review, interviews with designers and decision makers, and observations in ORs. Literature, experiments and computational simulation have been used to support designers. Interviews indicate that designing and selecting systems is a great challenge for designers and decision makers. Observations allowed for a confirmation that the system not always meet users´ needs and that surgical teams are not always using the system correctly. There is a strong need for future researches and areas to be focused on during the design and decision process of ORs air distribution systems.

PRACTICAL IMPLICATIONS

The study denotes the limitations of current performance assessment of air distribution system designs, and identify aspects that could influence the quality of the OR environment.

KEYWORDS

Ventilation system, operating theatre, numerical simulation and performance based design.

1 INTRODUCTION

Operating rooms (ORs) are complex and dynamic environments that require special attention in terms of the control of infection among patients and the surgical team. The rates of surgical site infection (SSI) have decreased significantly as a result of new methods of infection control, technological advances in medical equipment, improved efficiency of the air distribution systems, and the use of antibiotics. However, SSI rates for certain types of surgery remain relatively high. (Knobben, 2006, PREZIES, 2004; CDC and HICPAC, 2003; OSPA and OMS, 2001)

The main challenge in preventing SSI in ORs is the control of contaminants. (Lehto and Buck, 2008 and Kameel and Khalil, 2003) Lewis (1993), shows that the air distribution system plays an important role in securing an adequate indoor air quality (IAQ), minimizing the risks of SSI. Several air distribution system designs for use in ORs are available throughout the world, however, designing and selecting a system that is able to accomplish the required performance requirements and fulfilling the needs of the client, is a great challenge for designers. Problems have been identified in ORs resulting from inadequate performance of air distribution systems, including increased risk of crossinfection, thermal discomfort complaints and health problems of both the surgical team and the patient. (CDC, 2003; and Mora, 2001) These problems often require remediative actions, which incurs direct, indirect and intangible costs. (Wu, 2011; Dascalaki et al., 2008; Knobben, 2006; and Haddix and Schaffer, 1996).

One way to tackle the above problems is to encourage and facilitate good practice during the design process. For that, it is essential that at the start of the design phase the performance requirements for the air distribution system are defined unambiguously and that they can be checked by an adequate and objective evaluation procedure in the design process. (CIB, 2005)

This paper presents a picture of the problem in the status quo in the design process of air distribution systems, and indicate further directions for future work.

2 MATERIALS/METHODS

The method consisted of literature review, interviews and observations. The literature review encompassed books, academic research and literature, and evaluation of standards and guidelines from the USA, Europe and Brazil to understand the design problem. Designers and decision makers were interviewed. Qualitative and a semi-structured approaches were defined. The samples comprise three Dutch leading companies that design air distribution systems for health care facilities, and hospital managers and hospital project leaders in three hospitals. Non-participating observations in ORs were carried out in an Hospital in the Netherlands. A small sample of nine observations was defined. It consisted of observing and recording the actions of others to collect information on the several aspects, including number of people present, the layout used during the surgeries and the type and position of the air distribution system. The data collected in this study refers to specific period in time that the PhD research was developed by Melhado (2012).

3 RESULTS

Design process of air distribution systems in ORs – literature review

The literature review provides an overview of the available air distribution system designs used worldwide in ORs and the implications of use each system. A summary of these main results is presented in Table 1. In the sequence is presented what aspects and evaluation methods have been considered in the design process of such systems.

Table 1. Overview of air distribution systems used in ORs and performance assessments (Note: N/A - not available; Exp – experiment(s))

Air distribution systems	**Advantages**	**Disadvantages**	**Evaluation Methods**	**Performance Aspects Evaluated x Zone evaluated**	**References**
Laminar Airflow (LAF)	Reduces contamination level in the operating area in ORs Has potential to protect the patient	• Can be disrupted, e.g., by surgical light (vertical syst.) and by Staff (horizontal system) • Requires high running and installation costs • Requires large space for installation • Results in increased particle dispersion due to "air shower" over the head and upper body part	Exp. CFD	• IAQ: Particles concentration ➢ Zones: room, wound, staff and instrument /back tables	Loomans et al., 2008; Memarzadeh & Manning, 2002; Friberg, 2002; Dharan & Pittet, 2002; Friberg, 1998; Lidwell et al., 1983; Lidwell et al., 1982

Mixing	Provides uniform conditions in the room	• Results in increased risk for joint sepsis • Does not provide an aseptic environment	Exp. CFD	• IAQ: Particles concentra-tion and air temperature • Thermal comfort: air temperature ➢ Zones: room and instrum. /back tables	Memarzadeh & Manning, 2002; Awbi, 1991; Lidwell et al., 1983; Lidwell et al., 1982
Laminar with air curtain	Provides a barrier protecting the clean zone	Presents high installation and running cost	CFD BES	• IAQ: particles concent., air temp. and RH • Thermal comfort: air temp., RH, PMV-index • Hypothermia : air velocity ➢ Zones: room and instrument /back tables	Swift et al., 2007; Cook and Int-Hout, 2007; Melhado,2003 ; Memarzadeh and Manning, 2002
Laminar + body exhaust suit	• Reduces the contamina-tion level due to source control • Has significant impact on SSI	Reduces comfort, mobility and flexibility of operating team	Exp.	• IAQ: Particles concentration ➢ Zones: N/A	Friberg, 1998; Technology Assessment Team, 1997; Lidwell, 1982
Mixing + Mobile laminar screen	Reduces particle concentra-tion locally, achieving same level of ultra-clean LAF	N/A	Exp.	• IAQ: Particles concentration ➢ Zones: wound, patient and instrument /back table	Friberg et al., 2003; Friberg et al., 2002
Green house + body exh. suit	Reduces significantly the deep incision SSI	N/A	Exp.	• IAQ: Particles concentration ➢ Zones: N/A ➢	Walenkamp, 2002 (literature review)

Floormaster (upward displacement)	Improves the thermal comfort; reduces gases concentration in the workstation	Results in increased particle concentration and risk of SSI	CFD Exp.	• IAQ: Particles concentration ➢ Zones: wound, patient and instrument /back tables	Memarzadeh & Manning, 2002; Friberg et al., 1996

Evaluation methods are split up in engineering calculations, experimental and computational simulation. Experimental research to predict performance of air distribution system designs for ORs comprises of two main types: experiments in real ORs, and laboratory experiments in models of ORs, which are further divisible into 'full scale' and 'small scale' models. Currently, three main simulation methods are available to support the performance assessment of the air distribution systems: Building Energy Balance Models (BES), Zonal Airflow Network Models (AFN), and Computational Fluid Dynamics (CFD). Coupling of these individual methods is also applied and researched (Djuneady, 2005).

The prediction of the performance of air distribution systems for application in ORs, the use of computational simulation, more specifically CFD, is mostly applied. Simulation has been used to complement, but also to replace experiments and the application of simplified calculation methods. Some authors [e.g., Nielsen et al., 2007] indicate that CFD is the most suitable evaluation method to apply in early design stages (conceptual and basic), but also in the detailed design of air distribution systems, since it permits the flexibility to change the design options and variables considered in the evaluated model.

BES is not commonly used to support the design process and the analysis of air distribution systems for ORs. On the other hand, Trcka (2008), Daly (2006) and Crawley et al. (2005) discuss applications of the BES method to calculate thermal comfort, to compare different air distribution systems and to predict indoor variables in the occupied zones and in the room.

Although AFN has had limited attention in research literature with respect to OR studies, it has its application in deriving the pressure hierarchy in operating departments in The Netherlands (Ham, 2002). AFN can support the designer in the evaluation of air exchange between rooms, bearing in mind that ORs are a critical environment and the dispersion of contaminants between the OR and adjacent areas is an important indicator to assess the protection level provided by the air distribution system design.

In terms of the impact of standards and guidelines for the assessment of performance of air distribution system designs in ORs, in general, the majority of reviewed standards do not provide much information to support the design process. Some standards do imply the application of LAF-systems. The majority of the standards identify performance requirements related to the IAQ, while VDI 2167 (2007), DGKH (2002) and the ASHRAE (2003) also discuss the importance of the thermal comfort in ORs. VDI 2167 describes a relative detailed evaluation procedure of the applied system for the use phase. In terms of information on how to assess the performance of an air distribution system in the design process no further details were found in the reviewed documents. Use of computation simulation in the design phase by using CFD in conjunction with measurements is mentioned in ASHRAE (2003) and CBZ (2004). However, little details on the evaluation procedure are provided.

Assessment of the practice in the Netherlands

This topic provides a picture of the design of air distribution system design for ORs in practice, and performance aspects that have been considered in the assessment.

In practice, it was verified that the use of standards and guidelines is common in the three design companies. The performance assessment has been made by three supporting evaluation methods: engineering calculations, experiments, and computation simulation. The experiments are more common for validation purposes and to check the performance prior to the use phase. In terms of the computational simulation, only the CFD technique has been applied in practice, mainly in the early stages. CFD has been regularly used in two of the companies, while in the other company it was used only once.

Three air distribution system have been used in the Netherlands, the Large-Plenum downflow, the 2T-Plenum downflow, and the 3T-Plenum. However, it was verified that often project leaders/designers have a pre-determined preference towards specific air distribution system designs, based on their beliefs and also on their experience in practice and are not opened to evaluate and purpose other designs.

Another limitation in the performance assessment of air distribution system designs verified in one of the companies is the lack of scenarios considered in the design process. In multi-purpose ORs, it is important that different medical procedures be evaluated in order to check if the air distribution systems may adjust for them and vice versa. What can be concluded from these observations is that with limited evaluation and analyses, there is the risk that other performance requirements are not met and, therefore, it cannot be assured that an air distribution system design will perform well in other situations that were not considered in the analysis.

In the performance assessment of air distribution systems for ORs at the three design companies, it was verified that usually only the IAQ is considered. Particle distribution and concentration, and also the temperature and relative humidity are evaluated. Some performance indicators (e.g. gases concentration), they explain are only evaluated if the client request. Although some of the interviewed project leaders are aware of the importance of thermal comfort evaluation, it is only considered at client´s request.

An aspect observed in the interviews and that could be improved in the design process and decision process is the communication between project leader and clients. Although the interviewees did not directly report problems in this communication, it was verified that sometimes the clients provided limited information on needs with respect to the air distribution system for ORs. In addition, some project leaders did not check specific performance requirements and performance indicators, because the clients did not request it.

Regarding to the use of air distribution system designs in ORs, from the interviews at the companies, some project leaders reported that systems are not always used correctly by all users. Although these project leaders argued that in order to get best performance of the system it is important that the surgical teams use the system correctly, the literature and interviews both show that this is not common in practice. At the hospitals it was verified that decision makers and users are not always aware of the importance of using the air distribution system correctly, and the possible implications of incorrect use.

The observations in the specific ORs assessed if the air distribution system design met the needs of different medical procedures. The type of air distribution system used in the observed OR is a large-plenum downflow with dimensions of 2.8 x 2.8 m. The observations in the OR identified the higher complexity of use configurations, and allowed for a confirmation that the available system not always meet users´ needs, and that the surgical team is not always using the available system correctly. Melhado (2012) presents further information to clarify problems identified in the observed situations.

4 DISCUSSION

The results indicated that vertical laminar airflow systems have had most attention and are regarded most promising with respect to its effect on patient protection. However, no universal evaluation procedure has been applied in the investigated studies, which makes it difficult to determine which system design is best for which purpose(s). This may result in the application of inadequately designed systems, affecting the health, safety and comfort of the patient and surgical team. Therefore, to clarify important aspects that should be considered in the design process, it would be beneficial to have a procedure with information that should be evaluated and minimum aspects that should be considered in the performance assessment. An evaluation and comparison of different air distribution system designs, for different types of surgery and performance aspects is a fundamental step in the design process.

Regarding to the evaluation methods, despite the possibilities that CFD apparently has in the design phase, its adoption in practice is less apparent. It was observed that most of the time simulations are performed after the design decision for a system has been made. This seems to point out that the companies are not yet using the potential that computational simulation may provide in the design process, and, consequently, could also affect the decision process of the client. Some significant barriers to the current use of computational simulation have been identified. However, research is still in the process of addressing these areas.

The observations of situations and behavior in current ORs indicate that the users do not correctly use the air distribution system and also suggests that they are not aware of the consequences. Put otherwise, it can be stated that the applied system may not be correctly aligned with the apparent procedures applied. Therefore, before defining user situations to predict the performance, good alignment between medical procedures and (local) standard surgical procedures would be beneficial.

5 CONCLUSIONS

A state-of-the-art picture of the design process of air distribution systems in ORs allowed the identification of problems and gaps in the performance assessment. Results also indicate areas to be focused on during the design and decision processes and in the use phase of ORs air distribution systems.

There is clearly room for improvements regarding performance assessment of air distribution system designs for ORs. A standardized procedure to support the design process, as well for designers as for clients should be addressed in the future research.

An initial approach with the intention to support clients and designers in the design process is proposed in Melhado (2012). The results from this investigation will shed further light on if/which aspects should be improved in order for the approach to be adopted in practice. Some directions of how this evaluation could be made are provided in the research. Options and directions for improvements are specified.

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