# Performance based design for ventilation systems of operating rooms supported by numerical simulation - discussing the methodology

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# "Performance based design for ventilation systems of operating rooms using numerical simulation - discussing the methodology"

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## SUMMARY

This paper discusses a methodology to support the performance assessment of ventilation systems of operating rooms (ORs), with a further focus on the application of numerical simulation tools in this design assessment. The performance based design will provide good information quality that advises the needs and expectation of the stake holders. The methods consist of literature review, the development of an information matrix to assess ventilation systems of ORs, and two case studies that will elucidate the approach and verify its applicability. The methodology chosen combines the performance base approach with the Building Evaluation Domain Model. The results will permit to identify which type of numerical simulation tools is best applicable for the assessment of a specific performance indicator and how the assessment should be performed. The conclusions will indicate directions for future work and which areas need to be focused on.

## INTRODUCTION

The ventilation system in an OR is responsible for keeping a good indoor air quality in ORs. Previous research has shown that some types of ventilation systems used in ORs can contribute to the reduction of surgical site infection [1, 2, 3, 4 and 5]. They furthermore establish working conditions for the operating staff.

Several different ventilation systems/strategies are available for application in ORs. However, no general assessment methodology is available to compare different ventilation systems for a given design problem towards identified performance requirements (e.g. indoor air quality). The focus in the research therefore is on the design decision support information that will provide a methodology to support the design assessment for the ventilation system in ORs.

The objective is to discuss a methodology to support designers and decision makers in the objective performance assessment of here applied as an example, the ventilation design for ORs. The performance based should allow for a good information quality, and balances the needs and expectations of the stake holders. It will permit application for different types of ventilation system and surgeries.

This paper discusses the primary results of a PhD study [6]. After a brief introduction, the method will be described which has been used in order to develop the "Performance Based Design for Ventilation Systems of ORs". The result will be presented in a matrix, and will be used to discuss some points and two case studies. Finally the conclusions will indicate directions for future work.

## METHODS

The methods consist of literature review, the development and the discussion of an information matrix of the assessment of design for a ventilation system of ORs supported by numerical simulation, and finally, two case studies will be presented to elucidate the approach and to verify the applicability of the evaluation proposed.

The development of the performance assessment methodology has a basis in the Building Evaluation Domain Model (BEDM) that was developed by Mallory-Hill, 2004 (see Figure 1). This model can be visualized as a three dimensional matrix. The three axes in this case refer to ‘Human Systems’, ‘Building Systems’ and ‘Architectural System’ levels. A subdivision is provided for each axis. The Human System level (HSL) focuses on the stakeholders ranging from the individual occupants to the global community and the performance specifications that are set by them. Naturally, the individual occupant is most interested in the basic performance value (e.g. working conditions). For the global community, e.g., the functional value is more important. The Building System level (BSL) is subdivided in several levels that relate to the number of changes that may occur during the building life time. Finally, the Architectural System level (ASL) has levels that subdivide the level of detail for decision making.

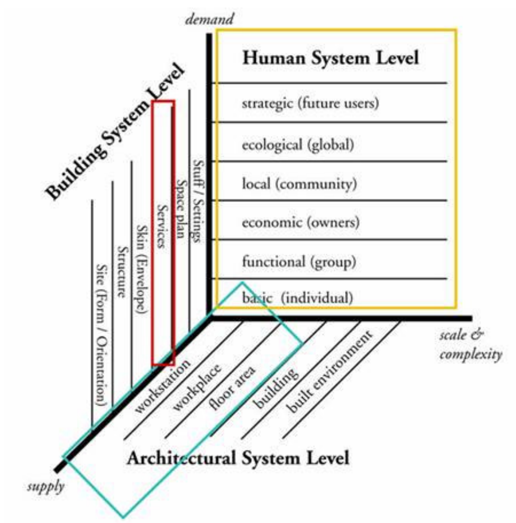


Figure 1. Building Evaluation Domain Model [7]

For example, for the ASL, the operating room is divided in workstations, workplace and floor area. The workstations now are defined as the zones of the patient, surgeon and auxiliary nurse, and supporting staff including the anaesthesiologist. The workplace encompasses the total environment of the operating room, while the floor area includes also the hallways, antechamber, storage and other adjacent areas that are directly connected to the operating room. For the HSL in principle all levels may be included with respect to the operating room. Focus, naturally, is on the individual, group, future users and owner level. The individual refers to the individual persons in the operating room and the group to the surgical team as a whole. The future users, in this case, need to accommodate the needs of many different occupants and, for example, deals with the adaptability for developments in the medical field.

The BEDM encompasses the whole building. For the assessment of the ventilation system in an operating room, only parts of the model are of interest. Figure 1 indicates the parts of the model that at first instance will be taken into account. One can see that the attention is focused to one slice of the matrix.

Next step is to identify for each point in the model the performance requirements that can be set. Figure 2 presents a part of the Performance Assessment Methodology. One can notice the axes of the BEDM. Now for each point Functional requirements have to be identified and performance indicators have to be related to these requirements. For this development literature study, in combination with expert interviews and information from attending surgical operations have been used. The list of requirements and indicators is quite large, nevertheless, several indicators overlap. Furthermore, only those indicators that have an evaluation possibility in the design (simulation) and use (measurement) phase are regarded, in order to adhere to the performance based approach.

The final result will permit to identify which type of numerical simulation tool is best applicable for the assessment of a specific performance indicator and how the assessment should be performed.

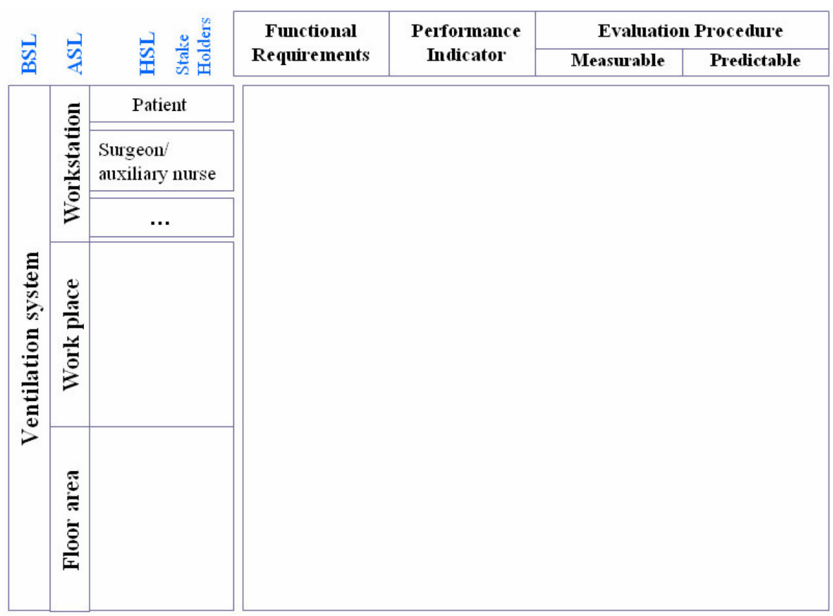

Figure 2. Performance Assessment Methodology [6]

## RESULTS AND DISCUSSION

Figure 3 presents a part of the matrix that has been developed. Notice that it specifically addresses the performance assessment of ventilation systems for an OR. Compared to Figure 2, three columns have been included: OR zones, Performance requirements and How. The 'OR zones' column was included to define the workstation for each stake holder. The assumption is that in ORs several subzones can be identified which can be given different Functional requirements. This column furthermore is important to identify stake holders that have more than one workstation, e.g. the surgeon. Next, the Performance requirement column indicates the physical parameters that should be assessed in order to determine the performance indicator. The columns 'How?' describe the steps that are required to evaluate the performance indicator using experiments and numerical simulation tools. This may be read as recipes for performing the assessment. Although several performance requirements have been evaluated, this paper will focus on the surgeon thermal comfort in the zone 2. The correspondent row is identified in grey in Figure 3. The example will be used to describe the procedure.

| | | Stake Holders | OR zones (involved) | Functional Requirement | Performance Requirement | Performance Indicators | Evaluation Procedure | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Measurable | How? | Predictable | How? |
| VENTILATION SYSTEMS | WORKSTATION | Patient | Zone 1 | Safety (SSI rate) | Airborne Infection | CFU/$m^3$ | | M1 | | P1 |
| | | | | | Hypothermia | | | M2 | | P2 |
| | | Surgeon | Zone 1 and Zone 2 | Ergonomic (health, productivity and satisfaction) | Indoor Air Quality | | | M3 | | P3 |
| | | | | | | | | M4 | | P4 |
| | | | | | | | | M5 | | P5 |
| | | | | | Thermal comfort | PMV index | Yes, but indirectly | M6 | Yes | P6 |
| | | | | | | Local Thermal Comfort | Yes | M7 | Yes | P7 |
| | | | | | Visual comfort | LUX / CRI | | M8 | | P8 |
| | | | | | Acoustic comfort | dBA / PNC / PSIL | | M9 | | P9 |
| | | Auxiliary nurse | Zone 1 and Zone 2 | Ergonomic (health, productivity and satisfaction) | Indoor Air Quality | | | | | |
| | | | | | Thermal comfort | PMV index | | | | |
| | | | | | | Local Thermal Comfort | | | | |
| | | | | | Visual comfort | LUX / CRI | | | | |
| | | | | | Acoustic comfort | dBA / PNC / PSIL | | | | |
| | | ... | | | | | | | | |

Figure 3. Performance Based Design for Ventilation Systems of ORs – draft version [6]

In order to better understand the evaluation and discussion of the literature review, two points will be explored: how previous researches assessed surgeon thermal comfort and what parameters were considered in the analysis. After that, the case studies will be discussed.

The thermal comfort in relation to environmental variables depends on metabolic rate, clothing, air temperature, mean radiant temperature, air velocity and air humidity [8]. In ORs these variables can change in accordance with the type of surgery. Managing the thermal discomfort of the surgeon is complex, because it is usually not possible to reduce the amount of clothing, to alter the activity being performed, or to reduce the various heat sources used during the surgery.  This problem has been discussed and evaluated by several researchers [4, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19]. These researchers evaluated the surgeon thermal comfort using Fanger’s PMV model [20], with the exception of one study that used a thermal physiological model. Many of these studies were experimental and only few used numerical simulation to predict the thermal comfort. The surgeon thermal comfort reported in the literature review was between slightly warm and very hot - this difference resulted of the type of surgery performed, some times of the ventilation system used, or of the environment variables that were not necessarily the same.

Next, two case studies will be presented to verify if the approach proposed in Figure 3 is applicable, and with them, more details will be discussed. The focus is on the last column “How” for a specific performance indicator - the thermal comfort. This step is divided in three parts: first describing how the performance indicator can be assessed using numerical simulation; second describing the case studies; finally, the application will be discussed.

In accordance with Figure 3, the surgeon thermal comfort can be predicted, e.g., using PMV index and Local Thermal Comfort. The Local Discomfort can result of draught, vertical air temperature difference, warm and cool floors, and radiant asymmetry. The PMV index can be calculated using Building Energy Simulation models (BES), while the Local Thermal Comfort generally would require the use of the Computational Fluid Dynamic (CFD) technique. These approaches have different resolution level.

When the OR is in the use phase, the variables at the surgeon workstation can be assessed through experiments. In case the OR is in the design phase, it will be possible to predict the variables using numerical tools. If one applies CFD it is possible to zoom in at the surgeon workstation which will permit to look at the problem in detail, identifying the variables and parameters that influence the thermal comfort. From the literature and observations in ORs identified the parameters which need to be taken into account include: characteristics of the OR, medical equipment (type and number), position of the operating table and of the patient; requirements; layout performed in the surgery, people (number and function), types of clothes and ventilation system design. Another important parameter to consider is the surgical lights effects.

In the case studies, two types of surgery are evaluated: a Hip and a Foot, both orthopaedic surgeries. The characteristics of the OR: 36 $m^2$ and h = 3.50 m. A 'Large downflow Plenum' ventilation system is used and its area is represented thought the dash-line, corresponding to 9 $m^2$. The layouts performed in each surgery are reported in Figure 4, which were designed through observations in ORs. The numbers correspond to: surgeon (1); others people of the staff (2, 3, 4, 5 and 11); instrument tables (7); back table (8); and equipment – defibrillators and accessories (9), anaesthesia, respiratory ventilator and vital signs monitor (10), and X-ray (12). The surgical lights are also considered above the surgeon focussed at the wound.

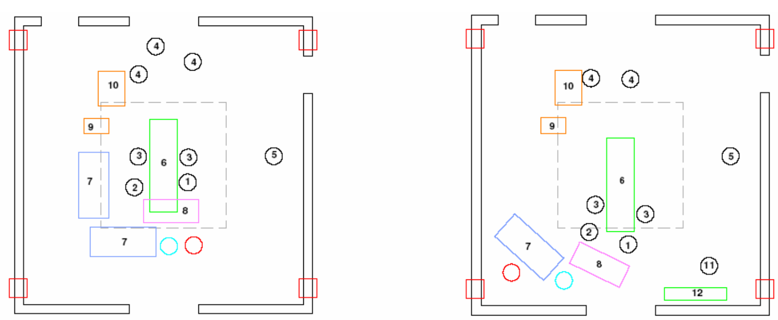

Figure 4. Layout Hip and Foot surgeries, respectively

In both surgeries the surgeon thermal comfort can be calculated using the PMV index. However, a more accurate evaluation, and in order to identify the local thermal discomfort caused by the supply air and the surgical lights will only be possible using CFD. In accordance with the layout performed in the Hip surgery, the draught could have a big influence on the local thermal discomfort, because the surgeon is positioned in the downflow area. Therefore, zooming in at this zone, it will be possible to see if the thermal discomfort is significant. In the Foot surgery the draught probably is not significant as the surgeon is not positioned in the downflow area. Therefore, calculating the PMV index would be enough. However, if we want to assess the local thermal discomfort caused by the temperature gradient, it is important to use the CFD. In the Foot surgery, the surgeon is in a mix zone, the same situation that occurs when there is mixing ventilation system in the OR. Probably, in the mix zone the surgeon will present more thermal discomfort than the surgeon below the supply air, because the air temperature will be higher and the velocity of the air is lower.

## CONCLUSION

The purpose of this paper was to discuss a methodology and the approach to support the design assessment for ventilation systems in ORs. The BEDM was important in the development of the Performance Based Design. The numerical simulation is a useful and important tool in design phase, permitting to observe if the ventilation system adhere to the needs for specifics surgeries. In the evaluation procedure, it was identified the types of numerical tools that could be applicable for the assessment of the surgeon thermal comfort. The case study permitted to identify benefits from the method and to verify the applicability of the evaluation proposed.

Concluding, although previous studies evaluated the thermal comfort in ORs, there is yet a strong need for future research to evaluate it. The directions for the future work, it is identify other performance indicators that permit to assess efficiently the thermal comfort in ORs. Next step will be to complete the matrix presented in Figure 3, to evaluate other stake holders, performance requirements and indicators, and the other architectural system levels.

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