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Pre-investigation into sensitivity analysis of use and design parameters to the ventilation efficiency in an operating room

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SUMMARY

This paper presents the pre-investigation for a sensitivity analysis of design and use parameters of an operating room on the spread of airborne bacteria. The sensitivity analysis will use CFD (computational fluid dynamics) simulations to evaluate the airflow and spread of bacteria in a room. The pre-investigation consists of a grid study and an evaluation of two different methods of performing the sensitivity analysis.

KEYWORDS

Operating theatre, sensitivity analysis, CFD, ventilation system.

INTRODUCTION

The purpose of a ventilation system in an operating room is to keep airborne bacteria away from the wound of a patient. To accomplish this, modern operating rooms generally are equipped with a laminar downflow system. Clean air is supplied through the ceiling, so that it can flow down towards the patient before being contaminated.

The performance of a ventilation system of an operating room depends on many factors. Of course the design of the system itself, but also design choices made in the rest of the room may influence how the system performs. Also the use of the room influences ventilation effectiveness. This results in a large number of design parameters that have to be decided on. Given the number of parameters present, it is important to gain knowledge on the relative importance of the different parameters towards specified performance indicators. For the operating room, the air quality near the operating area is a very important indicator.

Knowledge of the important parameters for, e.g., the ventilation effectiveness is a first step to a performance based design methodology. This applies to design parameters, such as the actual dimensions of the ventilation system, as well as use parameters, such as the placement of instrument tables.

Important use parameters provide a set of situations that a designer needs to take into account. Important design parameters provide a set of choices a designer has to be aware of with regard to the consequences for the ventilation effectiveness. Less important use parameters may be disregarded for this purpose, while the value of less important design parameters may be determined using other criteria than ventilation effectiveness.

For the identification of the important parameters sensitivity analysis may be applied. With respect to ventilation efficiency the Computational Fluid Dynamics (CFD-) technique should be applied to identify the efficiency. Several examples of application of this technique for operating rooms may be found in literature (Brohus, 2006) (Chow and Yang, 2003).

For the definition of the cases for the sensitivity analysis, based on the chosen parameters, two basic techniques are available to define the pattern of variation: Monte Carlo analysis and Morris analysis. In Monte Carlo analysis, all input parameters change between identified cases, while in Morris analysis only one parameter is changed for each next case.

With Monte Carlo analysis a larger part of the search space will be reached. Therefore the variation due to the variation in a certain parameter will be tested under a large number of different circumstances. However, as other parameters change as well, it is less clear which parameter a certain change should be contributed to. If nonlinear relationships need to be demonstrated, the number of required cases increases rapidly.

In Morris analysis only one input parameter is changed between two subsequent simulation cases. Therefore, a change in the result between two cases can be linked directly to a certain input parameter. An example of an earlier study that applied the Morris technique in combination with CFD was presented by Brohus et al. (2007).

This paper will focus on the procedure that is being developed to perform a sensitivity analysis towards identified design and use parameters for the ventilation system in an operating room. The objective is to define minimum requirements for the analysis technique. In a next step results from the sensitivity analysis will be used to aid to the design of future physical experiments in an operating theatre.

METHODS

For the development of the sensitivity analysis it is important to have a clear performance indicator that can be used to assess the effect of design and use parameters quantitatively. In this work the Protection Factor as defined by VDI 2167 (2007) is used as the indicator that identifies the ventilation efficiency as provided for by a ventilation system. In this case particles are released on 6 points on the floor around the operating area. No particle tracking is being used, but instead the particles are assumed as passive scalar. The Protection Factor (PF) then is calculated from

$$PF = -\log\left(\frac{C}{C_{ref}}\right) \quad (1)$$

where C the calculated concentration at a position in the room and C_{ref} is a reference particle load which is based on the concentration in an ideally mixed situation.

The Protection Factor in this study is calculated on three points at the operating table and on the middle of all five instrument tables that are part of the operating room design in this study.

VDI 2167 also provides for an assessment procedure that includes information on the operating team and operating table. The set-up of this procedure is applied as starting point for the development of the case. The general room dimensions are similar to a mock-up of an operating room that was used for earlier measurements (Zoon et al. 2007). The room lay-out (ventilation design and use) parameters were the subject of the sensitivity analysis and have been categorised as summarised in Table 1. An example configuration that was part of the investigation is shown in Figure 1.

Table 1. Summary of the design and use parameters subject to the sensitivity analysis.

Design parameters	Use parameters
Width plenum	Position lamp along the table
Width middle plenum	Distance lamp to table
Length plenum	Angle lamp
Air exhaust in top corners	Number of instrument tables left side operating table
Temperature difference inlet plenums	Number of instrument tables right side operating table
Inlet speed	Number of instrument tables near feet of the patient
Lower inlet speed side plenums	Power auxiliary lights
Skirt length	Number of people around the operating table
Power additional wall heating	Power of equipment in the periphery
Length of the room	Movement in the operation area
Height of the room	Movement in the periphery
Width of the room	
Lamp choice	

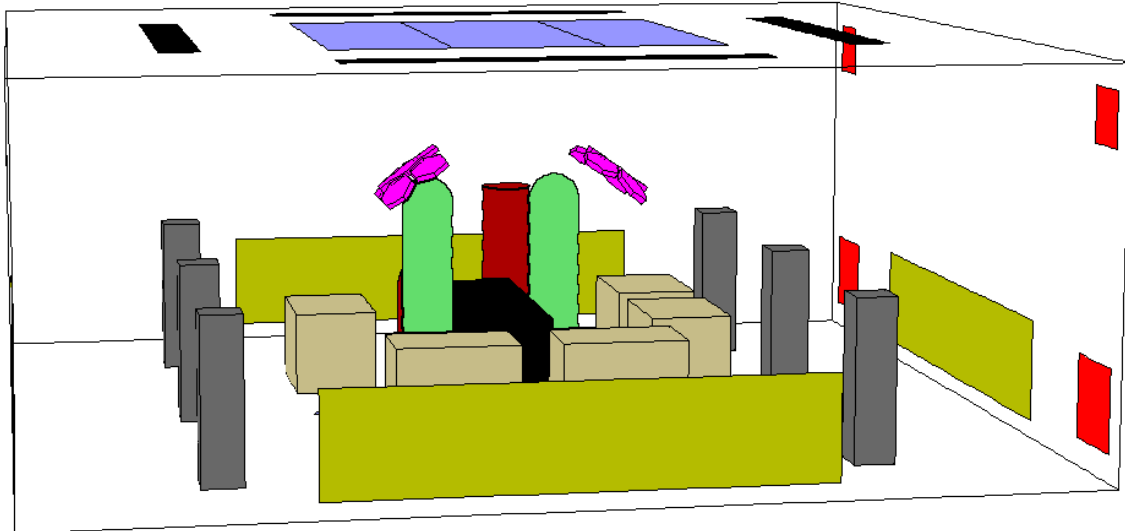


Figure 1. Example of one of the investigated configurations of the operating room.

In the design phase use of the Computational Fluid Dynamics (CFD) technique is required to identify the Protection Factor. A first assessment CFD-study applying the approach given in VDI 2167 is described in Zoon et al. (2007).

Grid dependency study

For the Monte Carlo as well as the Morris analysis the number of simulations required is directly related to the number of parameters that are included in the investigation. That means that, given the number of parameters mentioned in Table 1, for the development of the individual CFD-cases automation is required. Grid development is part of this automation. In a first step a uniform (tetrahedral) grid is applied and investigated for different grid sizes (from 0.3m gradually reduced to 0.1m cell dimension). Examples of these are shown in Figure 2. The convergence of the individual simulations has been monitored through the change in the above defined Protection Factor for the individual positions. For the CFD simulations the Fluent code (Fluent 2005) has been used.

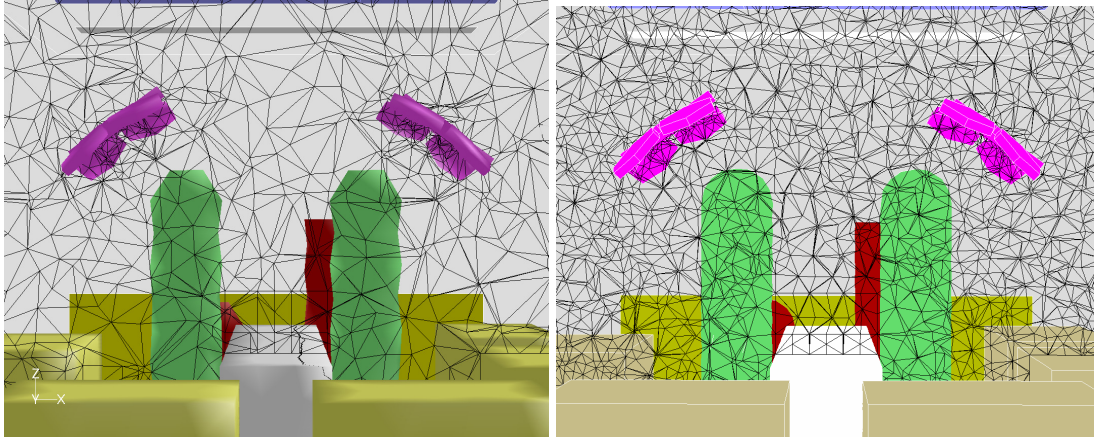


Figure 2. Examples of two different grid sizes (left: 0.20 m; right: 0.10 m).

Sensitivity analysis technique

Besides the grid sensitivity, the Monte Carlo technique was applied for the described operating room. In this case a coarse grid was used to identify the applicability of the analysis technique. Also, only seven parameters were investigated in this preliminary study. The goal of this study was to evaluate if the Morris analysis would give meaningful information for this particular problem, and how many simulations would be needed for this. The alternative approach is to use Morris analysis, which is not performed here. For comparison of the method, the analysis made by (Brohus et al, 2007) is used.

The parameters considered in this investigation can be found in table 2.

Table 2. Variables considered in the preliminary Monte Carlo analysis.

Variable	minimum value	maximum value
plenum width [m]	2.8	3.6
width central plenum [m]	0.8	1.4
inlet velocity [m/s]	0.2	0.35
inlet temp diff [K]	0	2
heating power [W]	0	3000
length skirts [m]	0	1
air extraction top corners [%]	0	40

RESULTS

Figure 3 presents data for the vertical temperature gradient in the periphery of the room for the different grid sizes investigated. The gradient is taken halfway between the end of the plenum near the feet of the patient, and the back wall of the room.

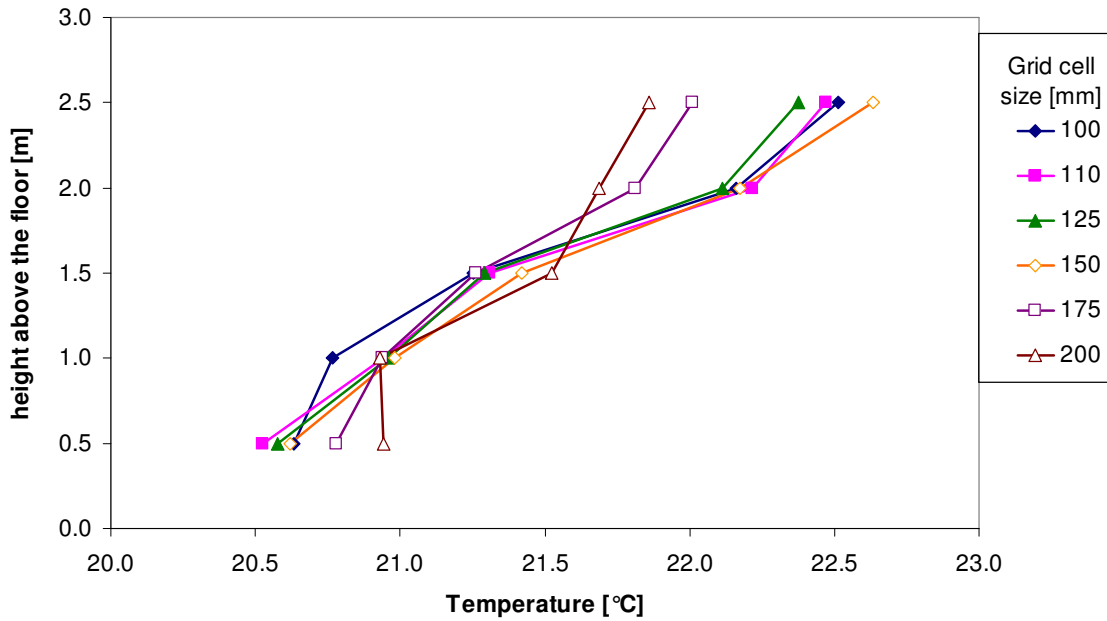


Figure 3. Vertical temperature gradient in the periphery of the room for different grid sizes.

Figure 4 focuses on the protection factor for the different positions on the instrument tables for the different grid sizes. A small grid size in this case indicates to a more fine grid.

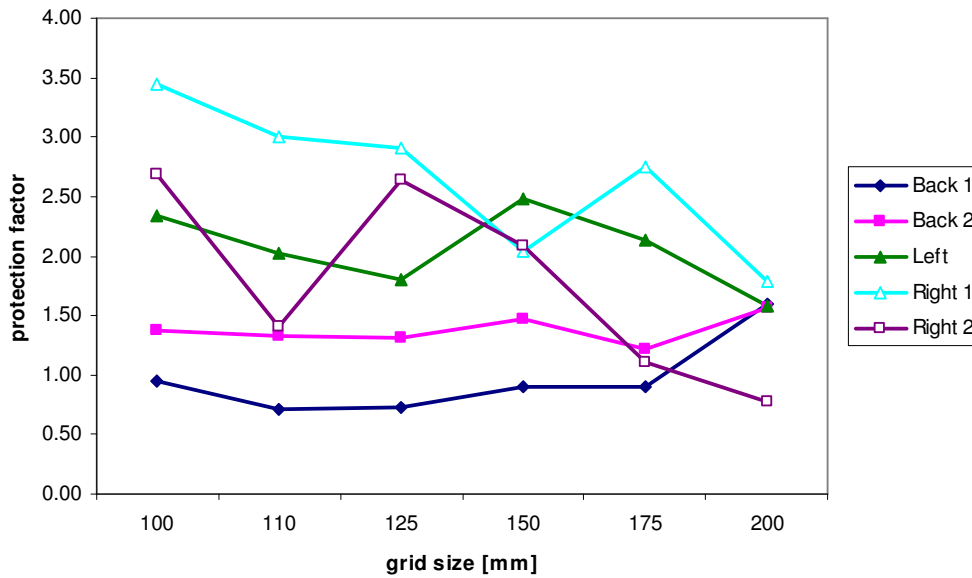


Figure 4. Protection factor on the instrument tables as a function of the grid size.

Results of the preliminary Monte Carlo analysis on 7 parameters using a coarse grid is shown in figure 5, indicating that the temperature difference between the inlet plenums is the most

important parameter. Figure 6 shows how these correlation coefficients developed over the simulations.

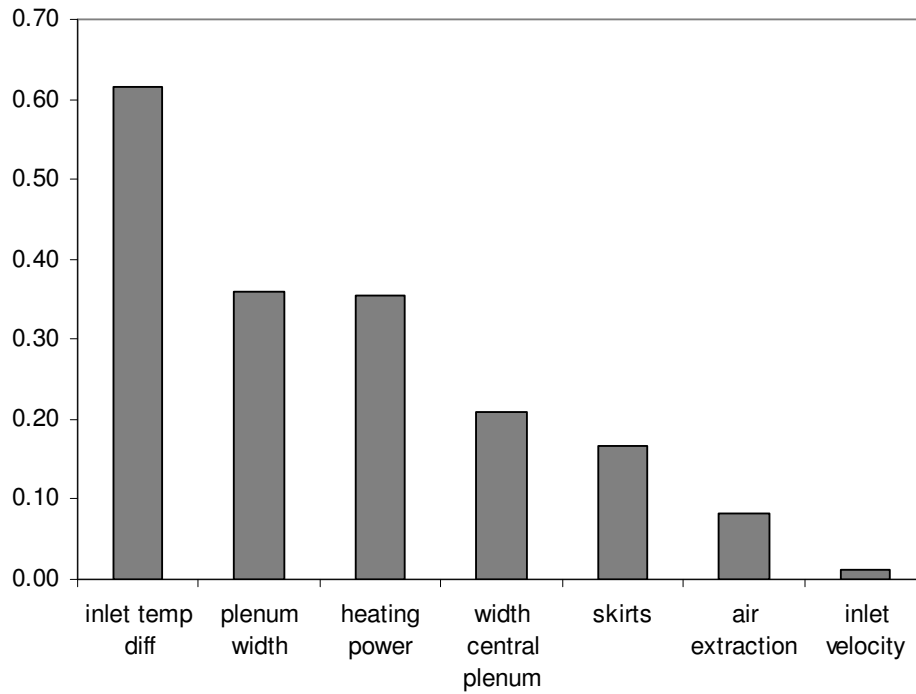


Figure 5. Absolute value of the correlation coefficient between the protection factor on the operating table and 7 different design parameters.

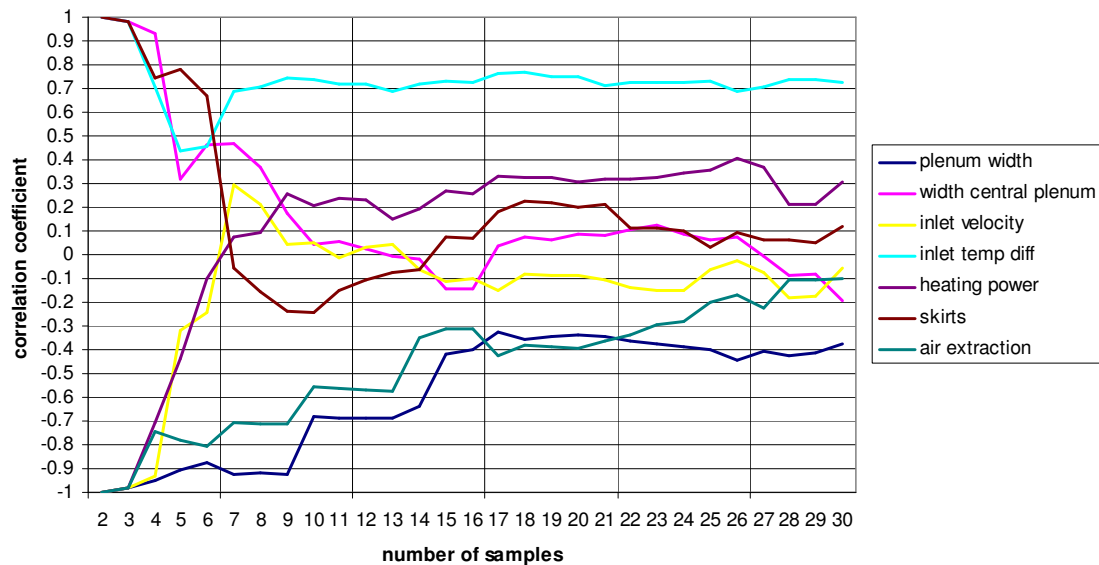


Figure 6. Development of correlation coefficient of the different parameters in the Monte Carlo analysis.

DISCUSSION

Using a uniform grid keeps the generation of simulation files for the sensitivity analysis uncomplicated, as there are no issues as to where the grid should be refined. The results from this grid study however shows that if a uniform grid is to be used, the cells need to be significantly smaller than 0.1 m if interest is put on the Protection Factor on some of the instrument tables. This is due to the large gradients found close to these instrument tables, which are for the investigated case near the edge of the downflow area. Figure 7 shows two examples of these gradients.

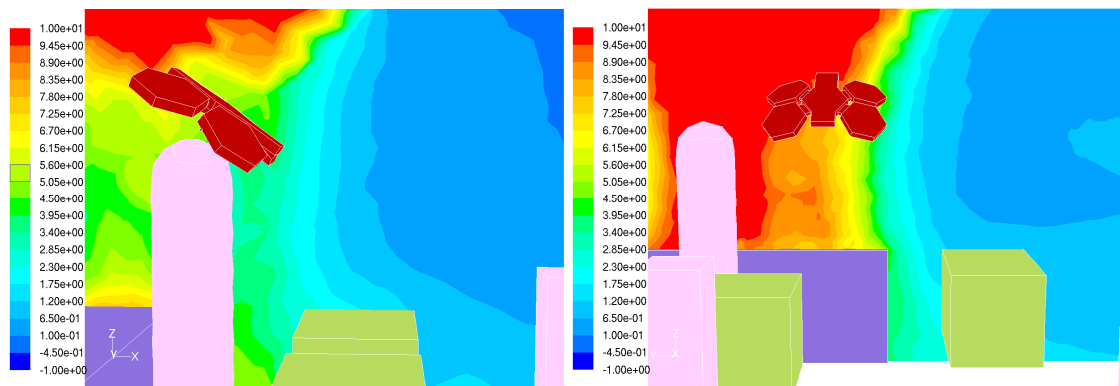


Figure 7. Examples of the calculated Protection Factor for a vertical plane in the operating room (left: instrument table on the side of the operating table; right: instrument table near the feet of the patient).

It is interesting to note that focus on the temperature gradient in the operating room (Figure 3) would allow for a coarse grid to be applied. For the Protection Factor this is not the case. Use of a uniform type of grid for the specific application would require a more fine grid and will result in significantly longer calculation times.

If criteria are set to the Protection Factor, e.g., minimum value 1.5 for the instrument table, than for some instrument table positions a coarser grid would already result in sufficiently accurate information (e.g. for 'Back 1', 'Back 2' and 'Left' and 'Right 1'). This would be in line with the Coupling Decision Procedure Methodology as described by Djuneady (2005) but would now focus on the grid requirement for this specific case.

Although the grid in the simulations was too coarse to give accurate results, the Monte Carlo analysis gave a clear ranking. After 30 simulations, the correlation coefficients still changed order, but some were clearly larger than others. This means that, in order to use Monte Carlo analysis for this purpose, at least 30 simulations need to be performed. For a similar Morris analysis, also with 7 parameters, 32 simulations need to be performed. (Saltelli et al, 2004)

CONCLUSIONS

The grid size needed for accurately predicting the VDI 2167 protection factor is significantly smaller than 10 cm when a uniform grid is used. Because it will take too much time to perform many simulations with such a fine grid, a grid that has smaller cells critical places has to be used for the final analysis.

The Monte Carlo analysis provides information about the linear correlation. Although in some cases this is a good indicator for parameter importance, it is not necessarily the case here.

Using Monte Carlo analysis does not reduce the number of simulations, so Morris analysis will be used in the final sensitivity analysis.

ACKNOWLEDGEMENT

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REFERENCES

Brohus H., Balling K.D., Jeppesen D., 2006, The effect of moving heat sources upon the stratification in rooms ventilated by displacement ventilation. *Indoor Air*, Volume 16 issue 5, pp. 356-372.

Chow T.T., Yang X.Y., 2003, Performance of ventilation system in a non-standard operating room, *Building and environment*, Volume 38, Issue 12 p.p. 1401-1411.

Brohus H, Nielsen P, Petersen A, Sommerlund-Larsen K, 2007, Sensitivity analysis of fire dynamics simulation, *Proceedings of Roomvent 2007*.

Zoon W.A.C., v.d. Heijkant S.A.M., Hensen J.L.M., Loomans M.G.L.C., 2007, Assessment of the performance of the airflow in an operating theatre, *Proceedings of Roomvent 2007*.

Djunaedy, E. 2005. External coupling between building energy simulation and computational fluid dynamics, PhD thesis Technical university of Eindhoven.

Saltelli A., Tarantola S, Campolongo F., Ratto M. 2004, *Sensitivity analysis in practice*, John Wiley & Sons Inc., England.