A local ventilation system for the operating theatre

JELLE LOOGMAN
Department of the Built Environment
Unit Building Physics and Services
Eindhoven University of Technology
The Netherlands
jelle.loogman@rhdhv.com

IVO DE VISSER
Department of the Built Environment
Unit Building Physics and Services
Eindhoven University of Technology
The Netherlands
ivodevisser@hotmail.com

Supervisors: Helianthe Kort[1], Marcel Loomans[1], Remko Noor[2], Nard van der Sanden[2], Erik Burgmeijer[3], Peter van Wieren[3]

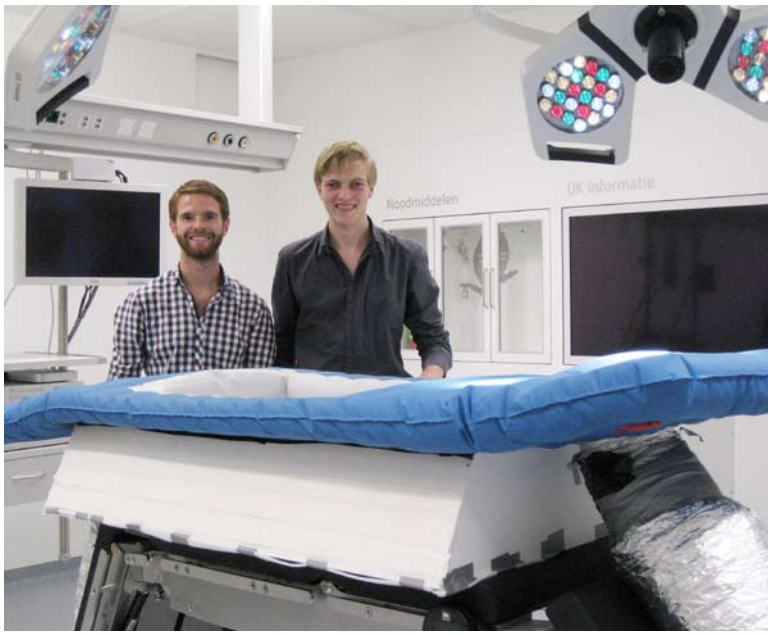
[1] Department of the Built Environment, Unit Building Physics and Services, Eindhoven University of Technology, Eindhoven, The Netherlands
[2] Royal HaskoningDHV, Eindhoven, The Netherlands
[3] Interflow, Wieringerwerf, The Netherlands

Clean air in operating theatres is of major importance to reduce infection risk. This article describes the performance of a new solution for ventilation in operating theatres based on full-scale measurements. The main advantages are an optimized airflow pattern, from urgent to less urgent areas, higher comfort for the surgeons and lower energy consumption.

Keywords: Surgical site infection, air quality, relative particle concentration, operating theatre, hospital environment, personal ventilation, experiment, CFD.

Introduction

A surgical site infection (SSI) occurred in 2.9% of all surgical operations in conventionally ventilated operating theatres (OT) in The Netherlands (PREZIES, 2012). A SSI is associated with a serious health risk of the patient and increased healthcare costs. Lidwell et al. (1982) found a significant positive correlation between the contamination of the air and the number of SSIs in OT. As a result, the effectiveness of unidirectional flow (UDF) ventilation systems have been studied increasingly and such a system was prescribed in Dutch guidelines. Although the system performs properly in an at rest situation, several studies showed concerns related to the position of the surgical light, limited space available for the operating team and instrument tables. Furthermore, clean air first passes the surgeon before reaching the wound, while research has shown that persons are the main source of bacteria in the OT.



Authors Ivo de Visser (left) and Jelle Loogman (right).

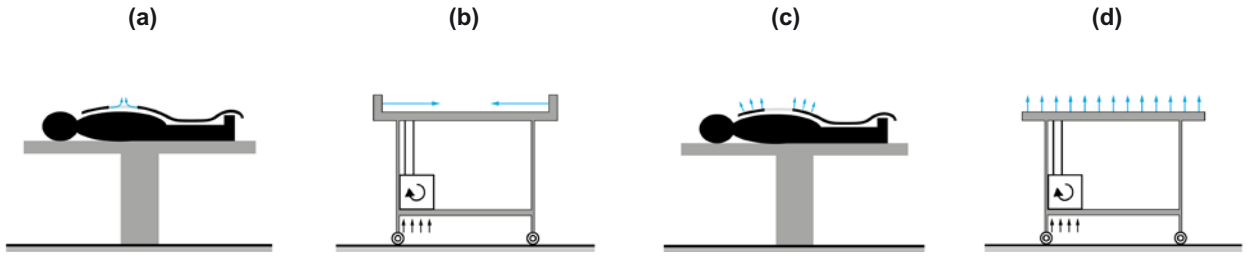


Figure 1. Impression of the local ventilation system; (a, b) configuration 1 with clean air supply around and parallel to the wound area and instruments, (c, d) configuration 2 with clean air supply from the top surface of the blanket and instrument table.

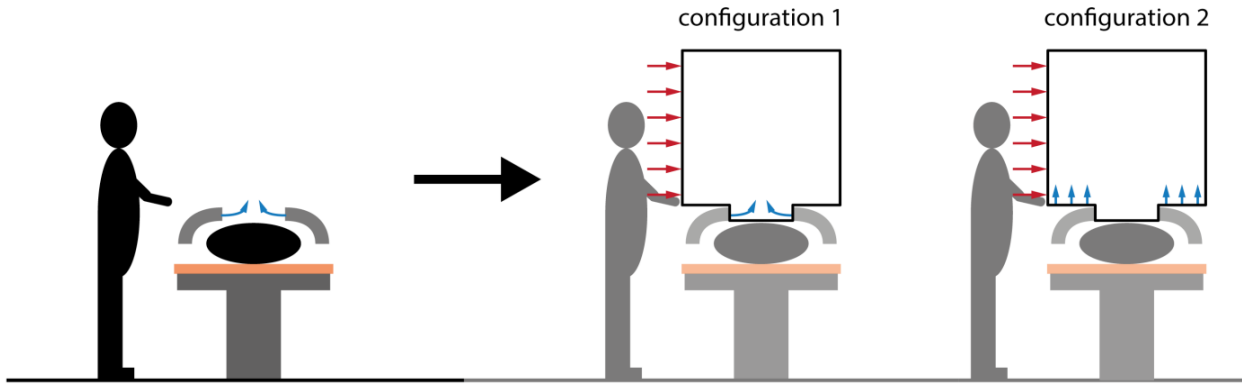


Figure 2. Origin of the geometry for the parameter study. The geometry represents the wound area with a contaminated airflow (red arrows) coming from the side of the surgeon and HEPA-filtered airflow (blue arrows) supplied at the wound area (configuration 1) or from the top surface of the blanket (configuration 2). The outlet was located at the right side, opposite to the contaminant supply.

Contrary to the previous Dutch guideline, in 2014 a performance based guideline was introduced which offered the opportunity to develop alternative ventilation systems for the OT (WIP, 2014). Therefore, a new ventilation system is researched in this study which makes use of a reversed airflow direction, from critical to less critical areas. The clean air supply is released around the wound area from a blanket which is spread out over the patient's body during the operation. Two configurations were designed: configuration 1 concerns a blanket where HEPA-filtered air is supplied around and parallel to the wound area (**Figure 1a**); configuration 2 makes use of HEPA-filtered air which is supplied from the top surface of the blanket, perpendicular to the wound area (**Figure 1c**). Similar approaches were applied to the instrument tables as well (**Figure 1b and d**). The performance of the local ventilation systems was studied in a full-scale experimental set-up. However, first a parameter study was applied in order to evaluate a wide range of situations.

Parameter study

A parameter study was performed on a simplified model, which represents the wound area of the patient and its immediate surrounding (**Figure 2**). Both particle measurements and computational fluid dynamics (CFD) simulations were performed to investigate the performance. Particles of size 0.5-0.7µm were measured in the center of the wound at 0.12m height (**Figure 3**). Next to this, Steady-state

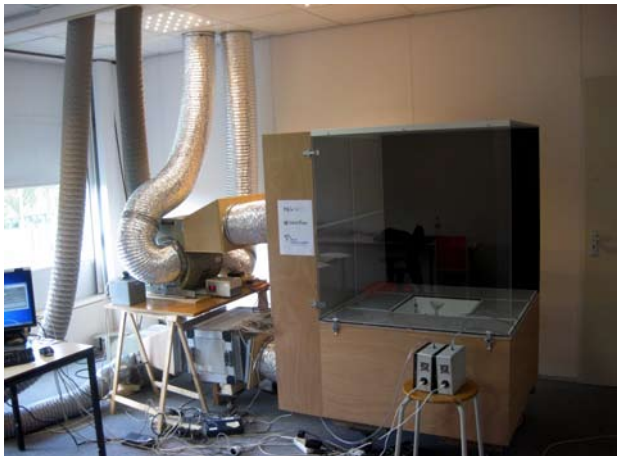


Figure 3. Impression of the measurement model at the TU/e, which was used for the parameter study.

RANS CFD simulations using a RSM model were performed on a replica of the experimental model. Contamination was modeled as a scalar.

The supply velocity and supply temperature of the clean airflow were the two most critical parameters. For the non-isothermal situation the supply temperature of the clean airflow was 22°C higher than the contaminated air in order to prevent for hypothermia of the patient. For configuration 2 a supply temperature of 5°C lower than the contaminated airflow was considered to increase comfort for the surgeons.

Measurement results of configuration 1 showed that a higher supply velocity of the filtered airflow significantly reduced the particle concentrations, while a higher supply temperature significantly increased the particle concentration. No significant differences were observed for different velocities and temperatures of the filtered airflow regarding configuration 2. Furthermore, under isothermal conditions, comparison of configuration 1 and 2 showed no significant difference in the measured relative particle concentration at a supply velocity of 0.40m/s and 0.30m/s respectively. The smoke visualization and CFD simulations demonstrated that for both configurations a layer of clean air is created around

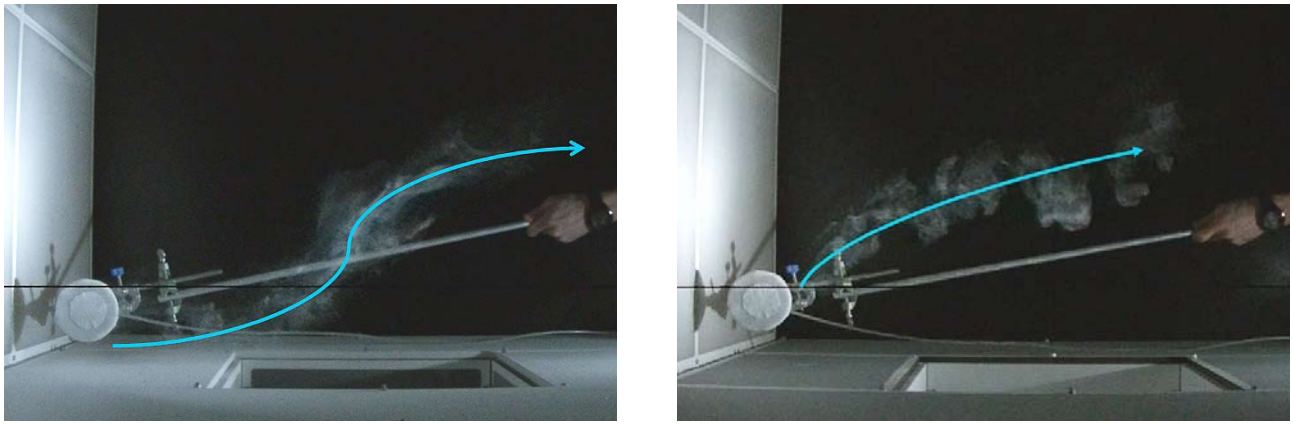


Figure 4. Smoke visualization of the contaminated airflow in the measurement model under isothermal condition of configuration 1 (left) and configuration 2 (right). In both situations it is clear that the contaminated air is lifted over the wound area.

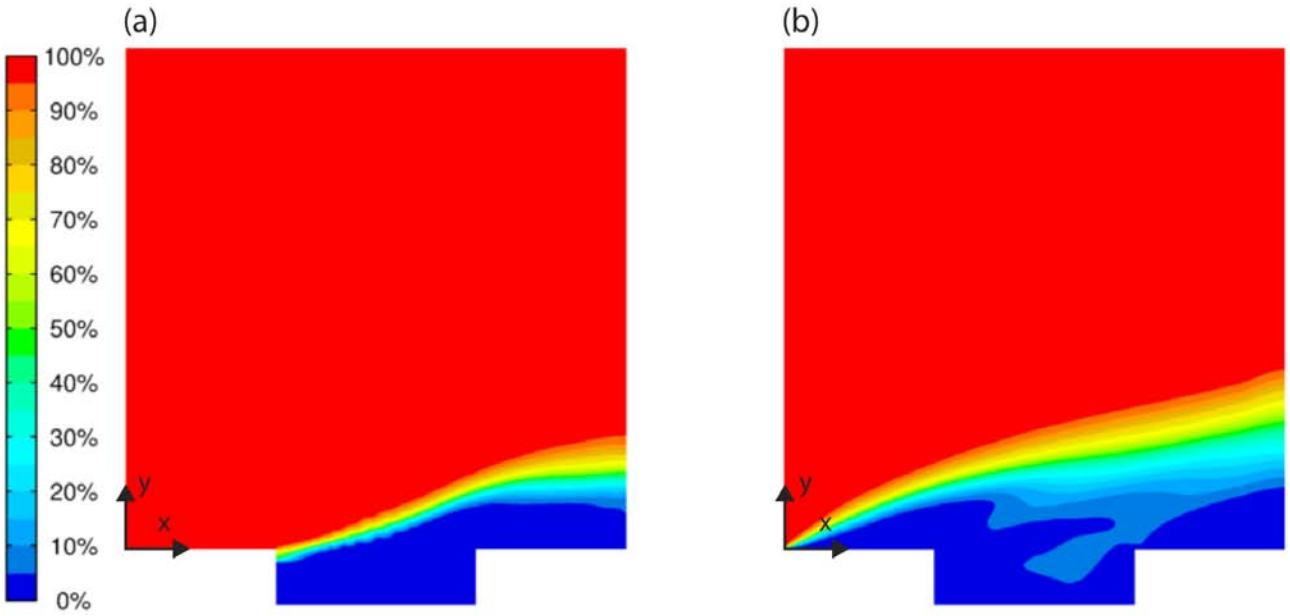


Figure 5. Concentration field of the relative particle concentration at section z = 0.4m for (a) configuration 1 and (b) configuration 2. Contaminated air velocity was 0.30m/s, HEPA-filtered air velocity was 0.10m/s.

the wound (**Figure 4 and 5**). In general, simulated particle concentrations showed similar trends as the measurement results although results were more positive compared to the measurements.

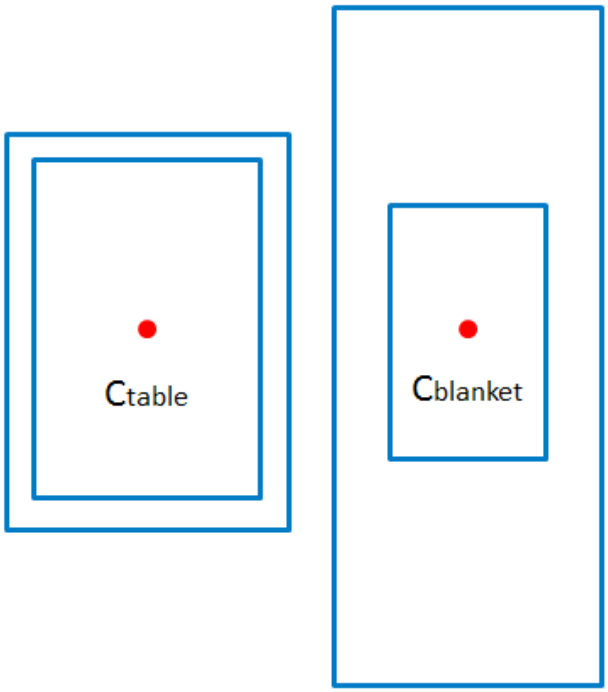
In conclusion, based on the results of the parameter study a supply velocity of 0.40m/s and 0.30m/s was used in the full-scale setup for configuration 1 and configuration 2 respectively. Furthermore, for configuration 1 the non-isothermal situation could not be neglected in the full-scale setup and was therefore taken into account as well.

Full-scale study – method

Next, the performance of a prototype of the local ventilation systems was explored in a full-scale mock-up OT at Interflow, illustrated by **Figure 6**. Particle measurements (≥0.5µm) were performed in

Figure 6. Full-scale test setup of the ventilating blanket and instrument table of configuration 1 (left) and configuration 2 (right) in the mock-up of the OT, the blue arrows indicate the clean airflows.

Table 1. Median (range) of the relative particle concentration [%] for particles ≥0.5µm (N=60). The topview at the right side shows location of the measurement positions.



	Series 1	Series 2
$C_{blanket}$		
Configuration 1	5.0 (1.0-10.5)	0.9 (0.2-6.7)
Configuration 2	1.7 (0.5-4.5)	6.1 (0.8-28.5)
C_{Table}		
Configuration 1	1.7 (0.5-3.1)	0.7 (0.3-1.9)
Configuration 2	0.0 (0.0-0.0)	N/A

Figure 7. Smoke tests for the long and short side for the configuration 1 blanket (left, middle) and the short side for configuration 2 (right).

an at rest situation, without people, according to the Dutch guideline (VCCN RL7, 2014). There was no additional ventilation in the OT and the fans for the local ventilation devices were placed outside the OT. A relative particle concentration was derived by comparing the particle concentration in the middle of the wound area and at the table with a reference point in the contaminated periphery. Measurements were divided over two series to improve the reliability of the data. Furthermore, smoke tests were conducted to visualize the airflows.

Full-scale study – results and discussion

The results of the full-scale measurements are demonstrated by **Table 1**. Regarding the ventilated blanket, a significant difference was observed between the two measurement series of the same configuration. The differences were probably caused by imperfections of the hand-made prototypes. Smoke tests showed that for configuration 1 turbulent air was supplied from the long side of the blanket, while a more constant airflow was supplied from the short side (**Figure 7**, left and middle). Regarding configuration 2, entrapment of contaminants in a local eddy above the wound area caused a high range of relative particle concentrations (**Figure 7**, right). Summarizing, configuration 1 yielded significant lower relative particle concentrations in the wound area than configuration 2. However, a relative particle concentration of 0.1%, as required by the WIP (2014), was not met for both configurations.

The instrument tables of both configurations demonstrated more uniform results compared to the ventilated blankets. The instrument table of configuration 2 satisfied the Dutch standard, while the instrument table of configuration 1 demonstrated significantly higher relative particle concentrations.

Future applications

According to the Dutch guideline the full-scale measurements showed that only the ventilated instrument table of configuration 2 was sufficient. For this reason, this could be a promising solution for application in OTs, for instance as an addition to the vertical UDF system to enlarge the clean area. Although results of the other ventilation devices did not satisfy the guideline, they might be used as an addition to OTs with a mixed ventilation system to improve the air quality at wound level and around the instruments. Furthermore, the local ventilation devices might be applied outside the OT where in that case operations can occur more safely (i.e. during field operations, operations in treatment rooms). ■

References

Lidwell OM, Lowbury EJ, Whyte W et al. (1982) Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomized study. British Medical Journal, 285, 10-14.

PREZIES (2012) Referentiecijfers module Postoperatieve wondinfecties 2002-2011. Preventie van Ziekenhuisinfecties door Surveillance (PREZIES). Available at: http://www.rivm.nl/Onderwerpen/P/PREZIES/Incidentieonderzoek_POWI/Referentiecijfers_POWI (accessed on 29-11-2013).

VCCN RL7 (2014) Methode voor testen en classificeren van operatiekamers en opdekruimtes in rust. Vereniging Contamination Control Nederland (VCCN).

WIP (2014) Luchtbehandeling in operatiekamer en opdekruimte in operatieafdeling klasse 1. Werkgroep Infectie Preventie (WIP)