Thermal comfort in operating theatres for different types of ventilation systems

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Thermal comfort in operating theatres is a less addressed research component of the indoor environment in operating theatres. The air quality naturally gets most attention when considering the risk of surgical site infections. However, the importance of thermal comfort must not be underestimated. In this research, the current thermal comfort situation of staff members is investigated. Results show that the thermal comfort for the members of a surgical team is perceived as not optimal. Application of the PMV and DR models needs further attention when applied for operating theatres. For the investigated ventilation systems, the differences in thermal comfort outcomes are small.

Keywords: Operating theatre, thermal sensation, non-uniform thermal comfort, surgical team, HVAC systems, post-operative wound infections, down flow ventilation, mixing ventilation

In an operating theatre, the most important requirement is that the patient receives the best possible care during surgery. The assumption is that by efficiently supplying sufficient clean air into the room the occurrence of post-operative wound infections will be minimized. Therefore, the design of an operating theatre is mainly based on air quality for contamination control (see **Figure 1**). In case of an operating theatre, the possible sources of pollution are the surgical staff, the surgical instruments and the patient itself. Because, based on these sources, the amount of air that needs to be supplied is considerable (in an operating theatre the air change rate is in the order of 15-30 h-1 [1]), theoretically efficient unidirectional downflow (UDF) ventilation systems are often chosen over mixing systems.

Until 2014, The Netherlands prescribed a UDF system for class I operating theatres, i.e. highest air quality requirements. After 2014, a more performance-driven approach was chosen which made it possible to look beyond conventional systems, offering possibilities for new design solutions. In the entire discussion about the quality of an operating theatre, the effect of the work environment of the surgical staff on the result of an operation is generally overlooked. Good lighting is self-evident and translated, e.g., into operating lamps. Sound/speech intelligibility is a point of attention, but also thermal comfort plays an important role in achieving an optimal work environment. This study focused on the latter aspect. Some earlier research is available [2] and literature also shows some numerical analysis of the thermal conditions in an operating theatre [3]. The objective of this research was to analyze the performance of existing operating theatre ventilation systems and new developments in this field with respect to thermal comfort, and identify which system(s) may be preferred from a thermal comfort point-of-view.

Methodology

As part of the research is perception based, and limitations in the numerical analysis are significant the work is performed experimentally. In the study, in-situ measurements have been performed in several operating theatres with different types of ventilation systems (see **Figure 2** for an impression). The systems studied are UDF (two-temperature [2T] system), Opragon and Halton. The measurements have been carried out in operating theatres in two different hospitals (UDF 2T, Opragon) and in two mock-ups of an operating theatre at the relevant manufacturers of the systems (Avidicare [Opragon] in Sweden; Halton in Finland). Thermal comfort measurements were derived according to ISO 7730 [4] (Predicted Mean Vote [PMV]/ Predicted Percentage of Dissatisfied [PPD]). Additionally, non-uniform thermal comfort conditions (draught, vertical temperature gradients, floor temperature and radiant asymmetry) have been determined. Where possible, the measurements have been carried out for three different use situations:

1. No subjects in the room,
2. Under static conditions (i.e. real persons in fixed positions, or represented as heat sources),
3. Under dynamic conditions (i.e. real persons moving around as if a real surgery is performed).

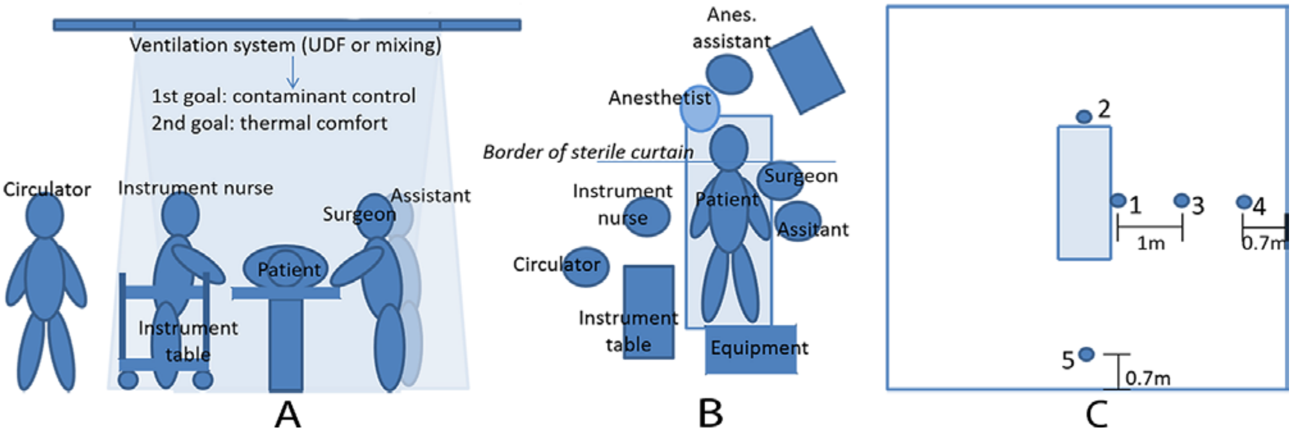


Figure 1. View and plan of a typical operating theatre with a downflow-based ventilation system [1A, 1B]. Figure 1C gives an impression of the typical positions of the surgical team members (1=surgeon/assistant, 2=anesthetist, 3=instrument nurse, 4/5=circulator), where positions 1-3 are often positioned in the direct influence of the downflow system.

Figure 2. UDF (2T) [left] – Opragon [middle] – Halton [right].

Reproducibility of the measurements has been tested by performing similar measurements for equal boundary conditions. The results show that ΔPMV ≤ 0.1 and the draught rate and vertical temperature gradient were within the accuracy level of the applied sensor.

In addition to the objective measurements, subjective analysis has been performed through online surveys on thermal comfort perception of surgical staff members during surgeries. General thermal comfort was examined, but also non-uniform thermal conditions such as draught. For these surveys use has been made of literature [2][5]. This subjective analysis was performed parallel to the experimental research.

For the subjective part of the research, 42 Dutch hospitals (out of 81) were approached to participate in the study. In total, 12 hospitals eventually cooperated and survey results of 341 participants (surgical staff members) were collected. All members of an operating team were represented in the response, while UDF (one-temperature [1T]/2T plenums in particular) was present as a system. For the statistical analysis of the data SPSS Statistics 25 has been used. Significance is assumed at $p < 0.05$. Further details of the research can be found in [6].

Results

Subjective data - An example of the subjective results of the survey is shown in **Figure 3**. There is a difference in perception of the thermal conditions between the members of the surgical team. One can derive that, on average, the staff members are feeling cold, with the anesthesiology assistant being significantly colder than the other members.

In case of non-uniform thermal comfort, the differences are less pronounced (**Figure 4**). In general, hands and arms are often perceived as cold as a result of draught. The surgeon generally has fewer complaints. The anesthesiology assistant has significantly more complaints in comparison to the other members of the surgical team.

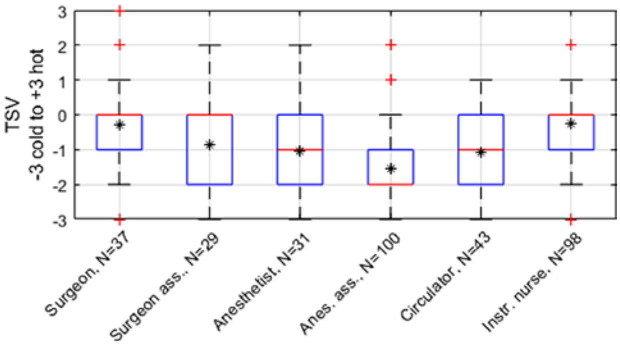


Figure 3. Survey results – uniform thermal comfort. The TSV (Thermal Sensation Vote) is an index on the 7-point thermal sensation scale ranging from -3 (cold) to +3 (hot) with 0 as neutral.

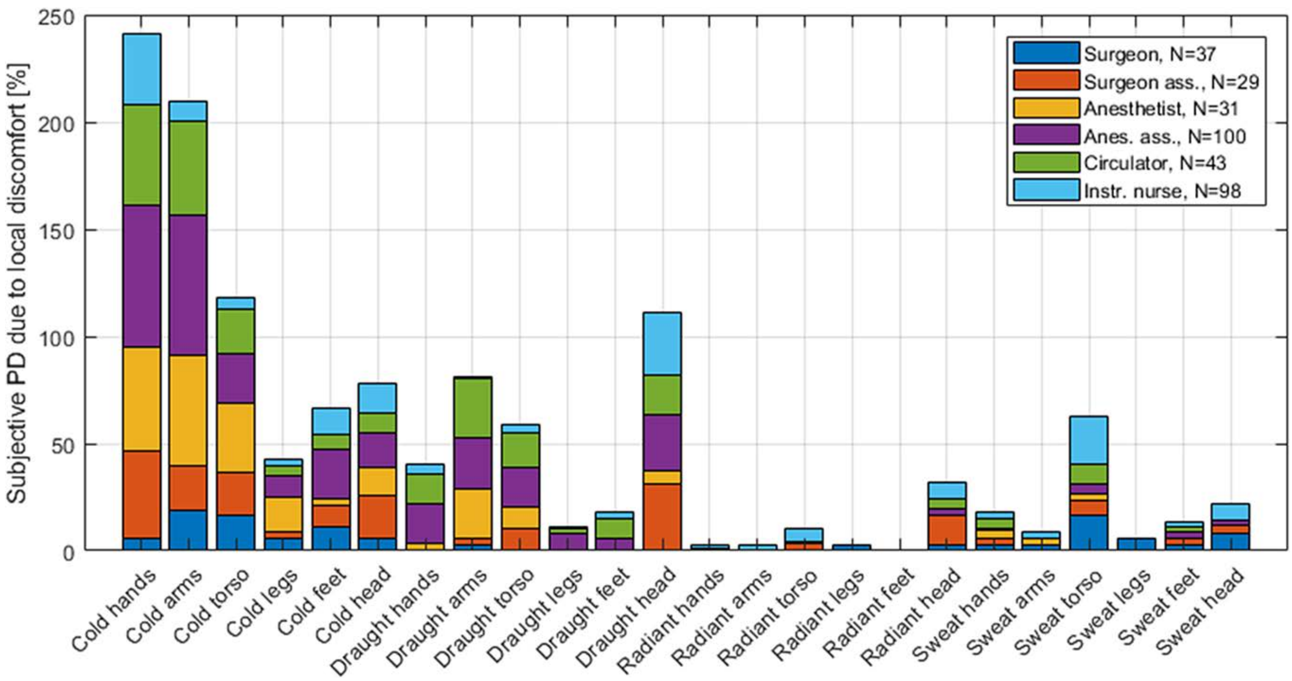
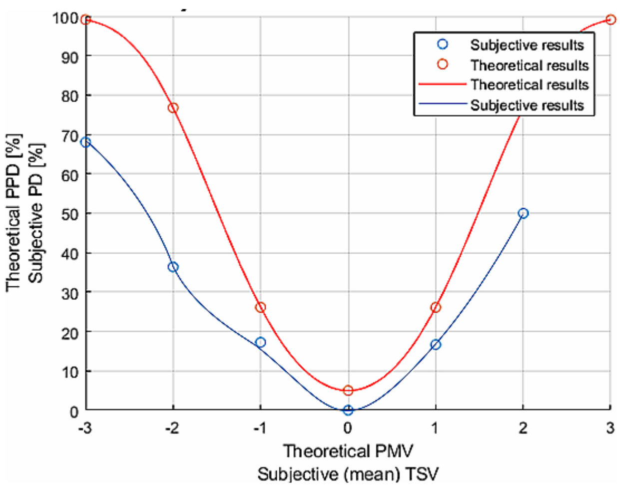
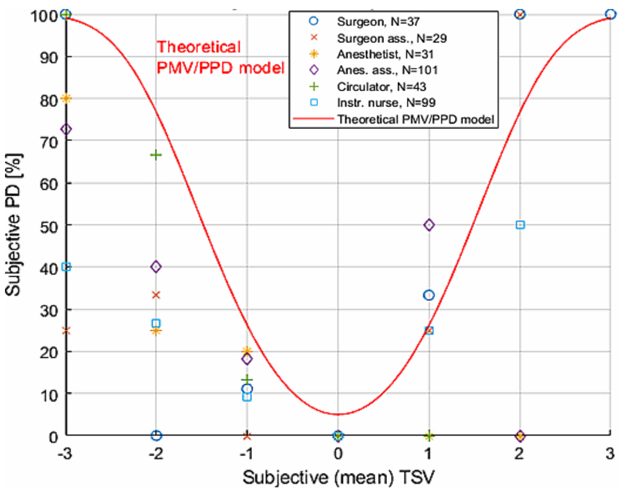


Figure 4. Survey results – non-uniform thermal comfort. The surgical staff members are subdivided per function and were able to give multiple answers regarding local discomfort. Therefore, the total percentage of dissatisfied people can exceed 100%.



A



B

Figure 5. Subjective perception versus the percentage of dissatisfied persons [PD] and a comparison with the theory (A: all members of the surgical team together; B: subdivided by function) [3].

The effect of the type of ventilation system on the assessment of the general thermal sensation and acceptance does not show any significant differences. Every type of ventilation system seems to have its own specific complaints with respect to local discomfort. But these differences are not significant based on the available data. In the survey three different type of ventilation systems were compared: 1T plenum (*N*=72), 2T plenum (*N*=165) and Opragon (*N*=24).

Comparing the subjective data with theory, an assessment can be made of the extent to which the existing ISO7730 standard is applicable to the operating theatre (**Figure 5**). It is assumed that the outcome for the TAV (Thermal Acceptance Vote) is representative for the degree of dissatisfaction (PD: Percentage of Dissatisfied people).

The results show that in case of the operating theatre the theory underestimates the number of satisfied people. The subjective results do show the same trend as the theoretical model. The individual results per team member show that there are clear differences in thermal perception (**Figure 5B**). Preferences are both on the cool and on the warm side. This clearly shows the complexity of the problem in the design of such systems.

Objective data – The comparison of the objective data (measurements) for the different systems (at an average set point temperature of 20°C) shows that the PMV (Predicted Mean Vote) ends up on the cold side (≈–1) of the thermal sensation scale. The systems that are studied show little differences. The variation is also comparable for each position where measurements took place (see **Figure 1C**). The anesthesiology assistant (position 2 and 4) has the worst thermal sensation (lowest PMV value). For the instrument

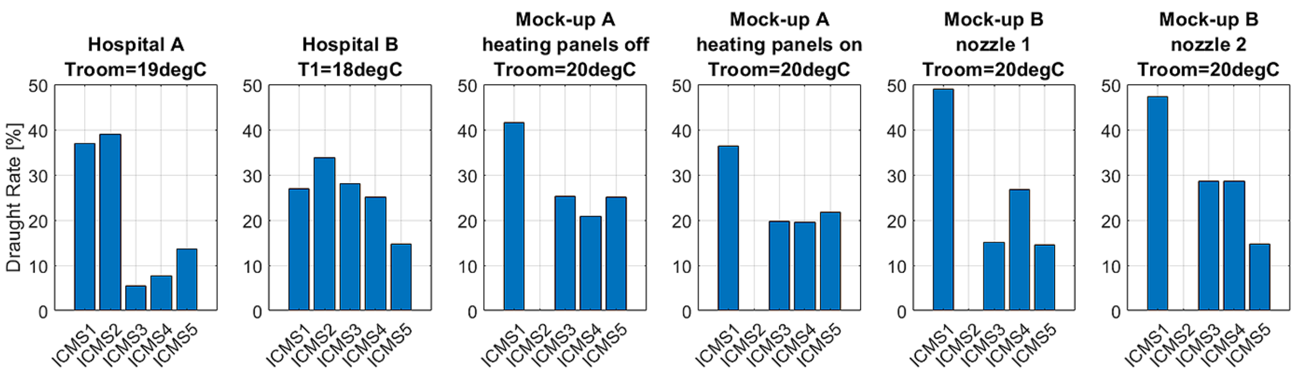


Figure 6. Theoretical percentage of draft complaints (PD) based on objective measurements for the different positions in an operating theatre (see Figure 3) with different types of systems and conditions (For Opragon and Halton it was not possible to measure at position 2 [ICMS2] due to a non-functioning sensor).

nurse (position 3) the situation is somewhat better based on the PMV value. With regard to local discomfort, especially draught is a problem (see **Figure 6**). The positions under the ventilation system are most critical, although at Hospital B the differences with the other positions are not significant. The vertical temperature gradient and floor temperature pose little or no problems.

Comparing the measurements results for the draught rate (DR) with the subjective (survey) data, it is noticed that the surgeon has few draught complaints (position ICMS1), while the measured data indicates otherwise. Referring to the survey results, the Opragon system also shows more draught complaints compared to the other systems ($DR_{Opragon}$ = 46% compared to DR_{UDF_T1} = 36% and DR_{UDF_T2} = 34%). This is not reflected in the measurement results ($DR_{Opragon}$ = 25% compared to DR_{UDF_T2} = 24%).

Discussion

The results provide interesting insights into the current situation in operating theatres in the Netherlands with regard to thermal comfort of the surgical team. These results show that improvement is possible and desirable for better thermal conditions. Although no statement can be made about the effect on work performance, it may be suspected that in line with what is known about the office environment [7], this performance is affected by thermal comfort. In this case, work performance must be translated in the quality of the execution of the surgery. This could be one of the reasons why, in theory, more efficient systems (based on air quality) perform less than expected [8].

The results of the survey indicate that there are fewer complaints than theory suggests based on the average thermal sensation (PMV). This is not in line with the hypothesis that people would be more critical since the adaption possibilities in an operating theatre are limited. It may be assumed that the focus on the patient makes the own thermal comfort a bit more subordinate. If that is the case, it is questionable whether that is a good choice. However, the PMV model has been developed especially for an office environment [4]. At individual level (member of the surgical team) the agreements are better. This is in line with the results from Van Gaever et al. [2].

Draught perception is experienced differently in an operating theatre than theory indicates. The measurements show high percentages of draught complaints, especially underneath the plenum. The subjective data show, however, that the surgeon has almost no draught complaints. Contrary, other members clearly show more draught complaints than the measurements (and therefore theory) suggest. The different systems show some differences in the evaluation of draught, but generally reveal the same pattern with higher values underneath the plenum.

The limitations in the research must also be mentioned. Clothing and metabolism have an important effect on the PMV values. No specific data were available for surgical staff and, on top of that, the survey showed that there were clear differences in clothing levels between the different hospitals. Additionally, a standard operating theatre with a standard setup has been assumed during the research. In combination with information from literature, clothing insulation (I_{cl}) and metabolism (M) have been set for the different members of the surgical staff (I_{cl} = 0.5 – 0.69 clo; M = 1.5 – 1.6 W/m²). This may not be applicable for specific surgeries. Furthermore, it is assumed that some survey questions were not interpreted correctly in a few cases. If misinterpretation was assumed based on the response to the other questions, the results were excluded from the analysis.

The measurements could not be performed simultaneously with an actual surgery due to hygienic reasons. The location of heat sources and settings of the operating theatre were somewhat limited by the applicable rules. Besides, it was not feasible in this study due to limitations of the reserved research time, to perform measurements for all three use situations in all variants. For those cases where this was possible, measurement situation 2 (static) and situation 3 (dynamic) led to similar conclusions in terms of thermal comfort.

Conclusion

This research shows that the thermal comfort in operating theatres for the members of a surgical team is perceived as not optimal. The distinction in perceived satisfaction for the different members is also evident. Application of the theoretical PMV and DR models needs further attention when applied for operating theatres. Future research may focus on this issue.

The direct effect of thermal (dis)comfort on the outcomes of a surgery is unknown since specific information for the operating theatre is missing. However, it seems appropriate to give this aspect a more prominent role in the development of ventilation systems for operating theatres than has been the case until now. Disconnecting the air quality issue about the thermal issue seems to be an interesting option in order to find an optimal combination about both aspects [9].

Possible improvements can also be found in clothing adjustments. It is expected that the possibility of covering arms, hands and neck against cold and draught will contribute positively to the thermal sensation of the individual staff members. In all cases, the most important goal remains the health and safety of the patient. In an operating theatre, there is little discussion about this. ■

Acknowledgement

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The whole report can be found here: https://pure.tue.nl/ws/portalfiles/portal/108242086/Jacobs_0815645.pdf

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