# Thermal comfort in a hospital isolation room – A laboratory study

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**ABSTRACT**

The aim of this study is to examine thermal comfort, perception of air movement, and perceived symptoms of persons lying in patient bed in a hospital isolation room. The study had a repeated measures design with two test conditions: 1) baseline overhead mixing ventilation and 2) local downward ventilation over the patient bed with background mixing ventilation. Ten volunteers participated. The room air temperature was 23.1 °C and supply airflow rate was 9 l/s,m$^2$ in both conditions. Thermal comfort, perception of air movement and perceived symptoms were assessed.

The mean thermal sensation vote in both test conditions was "Neutral" and there were no significant differences in thermal comfort, perception of pleasantness of air movement or perceived symptoms between test conditions. The results of this study can be utilized in the development of thermally comfortable solutions that reduces the health care workers exposure to patient exhaled airborne contaminants during patient treatment.

## INTRODUCTION

It has been estimated that 30-40 % of building sectors primary energy worldwide is used in HVAC (heating, ventilation and air conditioning) systems (Huovila et al. 2007). Hospitals have a particularly high energy consumption and significant part of energy is used in HVAC systems. The energy consumption of HVAC equipment can comprise even up to 50 % of the total energy use in buildings (Perez-Lombard et al. 2008).

Ventilation system has an impact on indoor thermal environment and occupants' thermal comfort. According to ASHRAE standard (2010), thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment. It is an important factor affecting occupants' wellbeing and work performance (Clements-Croome, 2006; Maula et al., 2016; Seppänen et al., 2003; Seppänen et al., 2006). An indoor temperature that is optimal to all occupants is difficult to achieve in hospitals due to great variety of different building users. The study by Skoog et al. (2005) indicated that hospital staff and patients cannot be considered as coherent group when predicting the optimal operative temperature. This is mainly due to the differences in activity levels. There is a need to study different ventilation solutions with human subject experiments to get a better understanding about the perception of different occupant groups, and to see which solutions are best for hospital patient rooms.

Ventilation and air distribution are important especially in isolation rooms, where they have an essential role in protecting healthcare workers e.g. from patient emitted contaminants. Therefore, the air change rate (ACH) is kept higher than in normal patient room. In optimal case, the supply air distribution should be able to mix and dilute the contaminants close to the source (patient). However, this is not always the case with traditional mixing ventilation systems.

Previous studies have shown that local downward ventilation above the patient's bed is effective in reducing the healthcare workers exposure close to the patient (Kalliomäki et al. 2020). However, it can be challenging to provide thermally comfortable downward ventilation towards patient with low activity level (Kalliomäki et al. 2020). There is a need to gain more information of the perception regarding thermal environment while lying in patient bed in isolation room having downward ventilation.

The aim of this laboratory study is to examine thermal comfort, perception of air movement, and perceived symptoms of persons lying in patient bed in a hospital isolation room.

## METHODS

### Experimental design

The experiments were carried out in autumn 2020 in a full-scale isolation room mock-up at Turku University of Applied Sciences' (TUAS) HVAC laboratory (Figure 1). The study had a repeated measures design with two test conditions: 1) baseline overhead mixing ventilation (MV) and 2) local downward ventilation over the patient bed with background mixing ventilation (LDV). In the test condition 1, the room air temperature was $T_{room}$=23.1 °C, relative humidity of room air was $RH$=42 %, supply air temperature was $T_{supply}$=20.0 °C, and supply airflow rate was $Q$=170 l/s (corresponding to ventilation rate 9 l/s, m$^2$ and 12 air changes per hour (ACH)). Similarly, in the test condition 2, $T_{room}$=23.1 °C, $RH$=25 %, $T_{supply}$=20.0 °C in mixing ventilation and $T_{supply}$=20.4 °C in local downward ventilation, and $Q$=170 l/s (130 l/s in mixing ventilation and 40 l/s in downward ventilation). The exposure time was one hour in each test condition. Above-mentioned indoor environment parameters are averages from the averages of each 60-minute sessions.

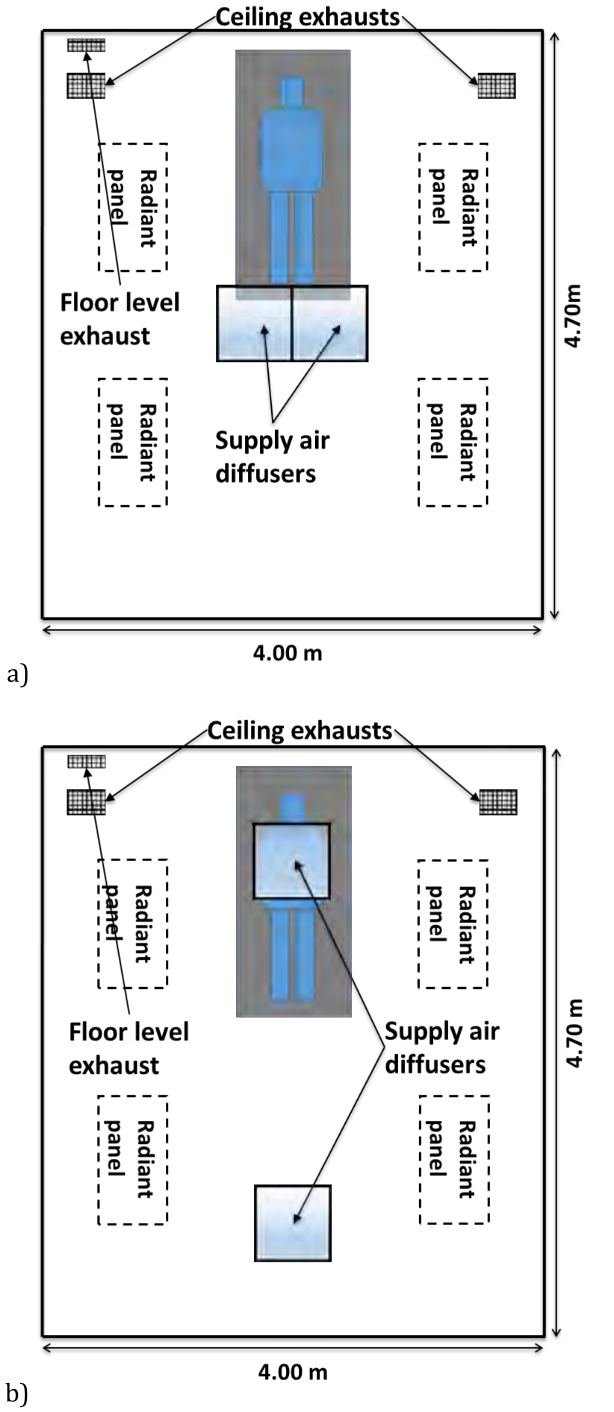


*Figure 1. The layout of a) test condition 1 (mixing ventilation, MV), and b) test condition 2 (local downward ventilation over the patient bed with background mixing ventilation, LDV).*


*Figure 2. Smoke visualizations of supply airflow patterns in a) test condition 1 (MV) and b) test condition 2 (LDV)*

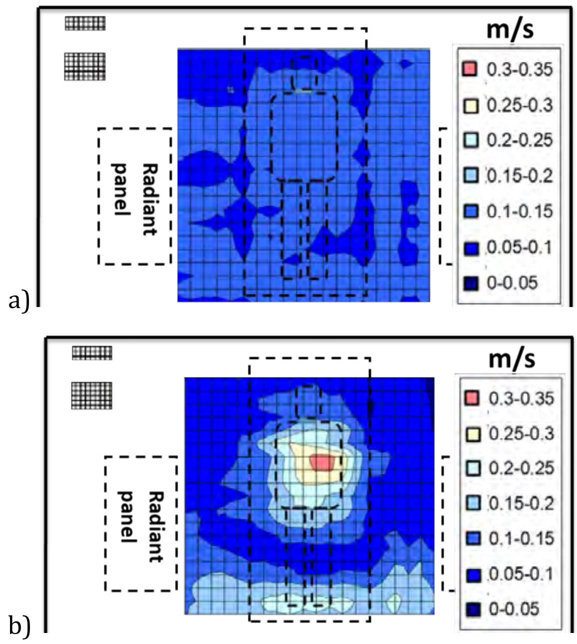


*Figure 3. The measured air speed fields above the hospital bed (at 1.1 m height from the floor) in a) test condition 1 (MV) and b) test condition 2 (LDV). The measurement grid density was 0.1 m x 0.1 m.*

The flow pattern was visualized with smoke (Figure 2). The air speed field at horizontal plane above the hospital bed (at 1.1 m height from the floor) was measured with hot-sphere anemometers (Dantec Dynamics A/S, Denmark, accuracy of 5% of reading ±0.01 m/s). Figure 3 shows the mean air speeds sampled for 3 min in each measurement point.

**Participants**

Ten volunteer research group members (aged between 28 and 64 years, mean 45 years) participated in the experiment. One of them participated only in the test condition 1 (MV), and one only in the test condition 2 (LDV). Rest 8 participated in both test conditions, so that each test condition had nine participants (8 male). The participants wore standard patient clothing and they were reclining in a hospital bed, having hands on top of the blanket, and listened to an audio book (Figure 4). Their activity level was 0.9 (McMurray et al. 2014). The thermal isolation of patient clothing, blanket, pillow and mattress was 1.5 clo, measured with thermal manikin (Pernille, PT Teknik A/S, Denmark).

*Figure 4. Participants' position, clothing and the adjustment of the blanket during the experiment.*

## Questionnaires

Thermal comfort, perception of air movement and symptoms were assessed with questionnaires (Webropol 3.0), which were repeated every 15 minutes throughout the session (Figure 5.). Participants answered questionnaires altogether 5 times in each test condition. Overall thermal sensation was asked using seven-point response scale from ISO standard 7730 (2005): Hot (3), Warm (2), Slightly warm (1), Neutral (0), Slightly cool (-1), Cool (-2), and Cold (-3). Besides overall thermal sensation and comfort, local thermal comfort, thermal satisfaction and pleasantness of the air movement, was asked. Symptoms, such as headache, feeling unwell, and nose, throat and eye symptoms were assessed with five-point response scale (1 = Not at all, 2 = Slightly, 3 = To some extent, 4 = Quite a lot 5 = Very much).

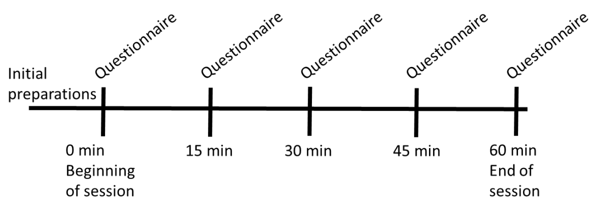


*Figure 5. The procedure of the session*

## Analysis

Statistical analyses were conducted to those 8 participants who took part in both test conditions. Analyses were done with IBM SPSS Statistics for Windows, Version 25.0 (Ar-monk, NY: IBM Corp.). The effect of test conditions and an interaction of test condition and exposure time was analysed. The normality of the data was tested with Shapiro-Wilk test. A repeated-measures ANOVA was used for normally distributed data. The Greenhouse-Geisser correction was applied when Mauchly's test indicated violation of sphericity, and the corresponding p-values are reported. Friedman and Wilcoxon's tests were used for variables that were not normally distributed

## RESULTS AND DISCUSSION

The study examined reclining participants' thermal comfort, perception of air movement, and perceived symptoms in two test conditions: 1) baseline overhead mixing ventilation (MV) and 2) local downward ventilation over the patient bed with background mixing ventilation (LDV).

Participants reported to be dissatisfied with the thermal environment in 20 % if responses in test condition 1 (MV), and in 11 % of responses in test condition 2 (LDV). Table 1 shows the percentage of participants dissatisfied with thermal environment in each exposure time. The distributions of all thermal sensation votes in test conditions 1 and 2 are shown in Figure 6. The mean thermal sensation vote was "Neutral" in both test conditions and thermal comfort did not differ significantly between studied ventilation solutions.

Figure 7 shows the distributions of thermal sensation votes in each exposure time. In figure 7, the box contains the middle 50 % of the votes, the central bold line is the median of the distribution, the whiskers reach to the smallest and largest observed votes and circles represents outliers. The distribution is lacking the box if the middle 50 % of the votes are placed on together with the median. Thermal sensation votes tend to decrease towards the end of condition 2 (LDV). However, there were no interaction of test condition and exposure time.

*Table 1. The percentage of participants dissatisfied [%] with thermal environment in each exposure time. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation.*

| Test condition | Exposure time | | | | |
|---|---|---|---|---|---|
| | 0 min | 15 min | 30 min | 45 min | 60 min |
| 1 (MV) | 0 | 0 | 33 | 33 | 33 |
| 2 (LDV) | 11 | 0 | 0 | 22 | 22 |

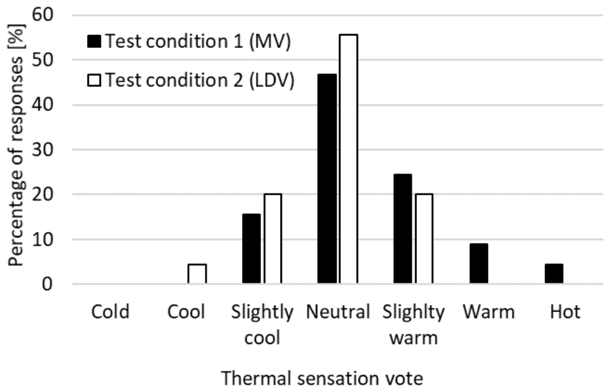


*Figure 6. The distributions of all thermal sensation votes. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation.*

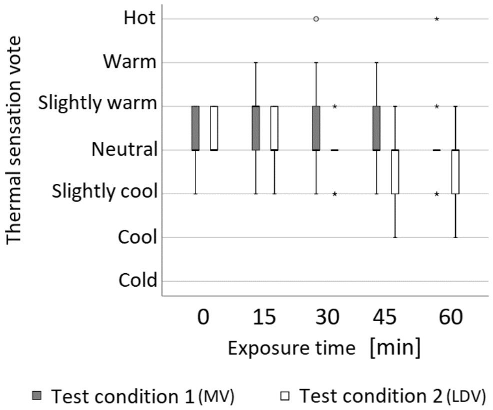


*Figure 7. The distributions of thermal sensation votes in each exposure time. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation. The distribution is lacking the box if the middle 50 % of the votes are placed on together with the median.*

In test condition 1 (MV), air movement was experienced in 64 % of responses although there were no direct supply air jet towards the hospital bed and the mean speeds above the bed were low (Figure 3). This might be a consequence unstable airflow fields and turbulence caused by rather high air change rate.

Air movement was experienced in 91 % of responses in test condition 2 (LDV). Most of the participants did not experience the air movement to be pleasant or unpleasant (Figure 8).

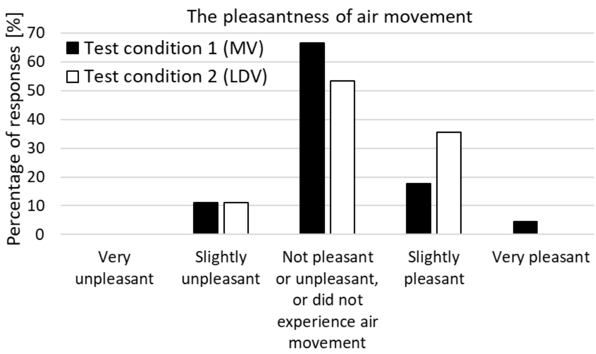


*Figure 8. The distributions of all votes of pleasantness of air movement. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation.*

The perception of air movement in test condition 2 (LDV) had a great variation between participants who perceived the air movement to be either pleasant or unpleasant: part of those participants reported the air movement to be draughty and the other part reported it to be refreshing. Part of the participants begin to experience air movement to be slightly unpleasant when exposure time exceeded 30 minutes (Figure 9). However, there was no statistically significant differences between test conditions nor interactions of test condition and exposure time on perception of air movement. The air movement was mainly sensed in hands and face.

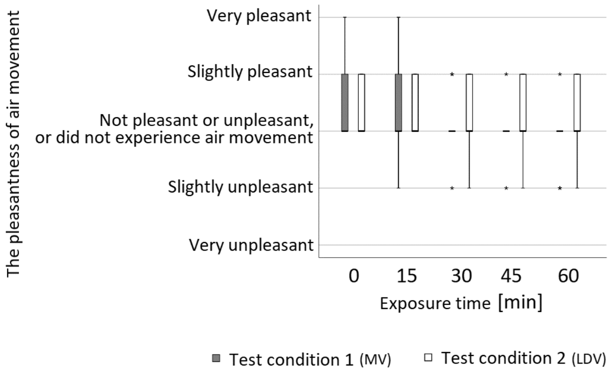


*Figure 9. The distributions of pleasantness of air movement in each exposure time. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation. The distribution is lacking the box if the middle 50 % of the votes are placed on together with the median.*

The intensity of all symptoms was low under both test conditions (Table 2). No statistically significant effect of test condition on symptoms was found. However, no conclusions related to eye symptoms can be drawn since a large part of the participants listened the audio book with their eyes closed. In addition, attention should paid to the fact that although participants' activity level and clothing insulation were kept close to values of real patient that is reclining, there are personal factors, such as patients' physiology and possible illness etc., which were not taken into account in this study.

*Table 2. The mean values (and standard deviations) of all responses related to perceived symptoms in both test conditions. MV is mixing ventilation and LDV is local downward ventilation with background mixing ventilation. The response scale is 1 Not at all, 2 Slightly, 3 To some extent, 4 Quite a lot, 5 Very much.*

| Symptom | Test condition | |
|---|---|---|
| | 1 (MV) | 2 (LDV) |
| Sweating | 1,32 (0,67) | 1,07 (0,25) |
| Nasal symptoms | 1,38 (0,49) | 1,16 (0,37) |
| Throat symptoms | 1,40 (0,54) | 1,33 (0,52) |
| Eye symptoms | 1,13 (0,40) | 1,16 (0,37) |
| Feeling of being unwell | 1,00 (0,00) | 1,02 (0,15) |

## CONCLUSIONS

This study examined thermal comfort, perception of air movement, and perceived symptoms of persons lying in patient bed in a hospital isolation room. Two test conditions were included: 1) baseline overhead mixing ventilation (MV) and 2) local downward ventilation over the patient bed with background mixing ventilation (LDV). The mean thermal sensation vote in both test conditions was "Neutral" and thermal comfort did not differ statistically significantly between studied ventilation solutions. In addition, there were no statistically significant differences in perception of pleasantness of air movement or perceived symptoms between test conditions.

The results of this study, together with previous study by Kalliomäki et al (2020), can be utilized in the development of thermally comfortable solutions that reduces the health care workers exposure to patient emitted airborne contaminants during patient treatment. However, the perception of thermal conditions with different ventilation solutions should be further studied with greater amount of participants and longer exposure times to see which kind of solutions are suitable for continuous use in hospital isolation rooms.

## ACKNOWLEDGMENTS

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