The effect of the type of protective suit on the thermophysiological comfort of surgeons in an operating room

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Abstract. Surgical gowns and medical clothing have to protect the surgeons from the patient and vice versa. However, all players in the operating room (OR) have to be in a state of thermophysiological comfort. The comfort of the surgeons is of special importance, as they are exposed to stressful situations, which could influence their performance negatively. The study presents an analysis of the thermophysiological comfort of the surgeons in an OR, using protective clothing ensembles with different clothing insulation and protection: a surgical scrub suit (SSS) and a clean air suite (CAS). The analysis is based on the calculation of PMV-PPD indexes, following Fanger's model. Different combinations of thermal environment parameters and clothing insulation are tested and analysed.

1. Introduction

The thermophysiological comfort of people is based on the complex interaction between the human body and the environment. Several parameters influence this interaction, such as air temperature and humidity, air velocity, human activity, clothing insulation and many others. Some of them are time-dependent (activity, stress); others can be considered as constant (clothing insulation).

The original function of the surgical cloths is to protect the patient from a possible impact of the surgical team. Later on, with the development of the knowledge on blood-borne pathogens, additional functions were added to the surgical clothing: to protect the surgeons from the patient himself [1].

The ISO 7730 [2] standard, does not make a difference between types of indoor spaces in terms of thermal comfort. Therefore, surgical scrub suits (SSS) or clean air suits (CAS), used in the OR, have to assure the thermophysiological comfort of the surgeons as the business suit in an office room. SSS are applied not only in the ORs, but they are used as a kind of uniform outside the OR. CAS are specially designed for surgeons and belong to Class I medical devices (Medical Devices Directive 93/42/EEC, amended by 2007/47/EC [3]).

Clothing is the most significant difference between the medical players in the OR. The environmental conditions are also different: the surgeons that use the most insulated protective clothing and devices (including SSS and CAS), stay under the surgical lights, where the temperature is the highest, due to the radiation.

The problem of the thermophysiological comfort of the surgeons in an OR has been investigated from different points of view: the ventilation system [4, 5], the flow around the human bodies [6], the clothing insulation [7-9]. Some of the studies were based on the calculation of the Predicted Mean Vote (PMV) or Predicted Percentage of Dissatisfied (PPD) indexes [10,11], which are used in the present study's well.

The developed by Fanger in 1972 [12] Predicted Mean Vote (PMV), is the most applied model for assessing the thermal comfort in the indoor environment. It is based on the calculation of the joint influence of the heat balance of the human body, sweat rate and mean skin temperature. The related
index, namely the Predicted Percentage of Dissatisfied (PPD) [12] allows predicting the quota of the occupants that would feel uncomfortable in the particular thermal environment.

Our study applies the PMV-PPD indexes as a point for an analysis of the thermophysiological comfort of surgeons, protected by two types of surgical ensembles: a surgical scrub suit (SSS) and a clean air suit (CAS). Different environmental conditions were tested. A computational program for the prediction of the heat strain, following ISO 7933:2004 [13], was applied to calculate the PMV-PPD indexes [14].

2. Methodology

Three groups of factors were taken into account when calculating the PMV-PPD indexes for the surgeons in an OR: clothing, environmental factors and body activity.

2.1 Clothing

Two types of clothing ensembles were considered for the determination of the thermophysiological comfort of the surgeons in the OR:

- a reusable surgical scrub suit (SSS) – Fig. 1a;
- a reusable clean air suit (CAS) – Fig. 1b.

The composition of SSS is 67% polyester (PES) and 33% cotton fibres, with thermal insulation of 1.39 clo. The composition of CAS is 99% PES and 1% carbon fibres, with thermal insulation of 1.31 clo [8].

2.2 Environmental factors

The ASHRAE standard 170-2013 [15] suggests the air temperature of an OR (Class B and C) to be from 20°C to 24°C. The air temperature under the lights could be with up to 3°C higher [16], but the measurements in [17] did not find such a difference. The temperature during the calculations was changed from 18°C to 24°C with a step of 1°C. The relative humidity (RH) of the OR was set to be 40%, 50% and 60% [15, 17]. The air velocity was set to 0.02 m/min [17].

2.3 Factors related to human body activity

Moderate activity (145 W/m²) of the surgeons was considered for the calculations. An average male body was taken with height 175 cm, weight 85 kg and body surface area 2.0 m² [18]. The time of surgery was set to 1 h 40 min, which corresponds to a kidney operation [17].

2.4 Cases

Forty-two cases were simulated all together.

3. Results and Discussions

The thermal sense scale of the PMV index varies from -3 to +3, as shown in Table 1. The PPD index changes from 0% to 100%. ISO 7730 [2] international standard suggests the limits -0.5 < PMV < 0.5 and the PPD index below 10% for a moderate thermal environment. These are, in fact, the limits of the thermophysiological comfort.
Though a temperature interval of 20 °C to 24 °C is suggested in an OR (RH 60%) [4], our first predictions showed that for the clothing insulation provided by the two surgery ensembles, the discomfort would appear very quickly in this thermal interval. Therefore our predictions were made for a larger temperature interval: from 18 °C to 24 °C and a larger interval of relative humidity: from 40% to 60%.

### Table 1. PMV Index sense scale

| Value | Thermal sense   |
|-------|-----------------|
| -3    | cold            |
| -2    | cool            |
| -1    | slightly cool   |
| 0     | neutral         |
| +1    | slightly warm   |
| +2    | warm            |
| +3    | hot             |

Figures 2-4 summarize the PMV index for surgeons, dressed in the two clothing ensembles, for RH 40%, 50% and 60%, respectively. The PMV index increases with the temperature, relative humidity and clothing insulation. The results show that 21 °C is the critical temperature in the investigated air temperature interval. The thermophysiological comfort of the surgeons would depend strongly on the relative humidity of the air and the type of protective clothing. A surgeon would feel comfortable during the operation, dressed in CAS (1.31 clo), if the RH is 40% or 50%. If the relative humidity increases to 60%, the surgeon would feel slightly warm, leaving the zone of the thermophysiological comfort. A surgeon, dressed in SSS (1.39 clo) would not be in a state of a thermophysiological comfort at a temperature, higher than 20 °C for all investigated cases of RH.
To avoid the influence of the type of protective clothing, the temperature in the OR should be up to 20 °C. This coincides with the discussed in [2] comfort temperature interval (20-22 °C). However, the discomfort could appear even if the temperature of the OR is up to to 20 °C, as the local air temperature under the OR’s lights, where the surgeons stay, could be higher.

Figures 5-7 present the results for the PPD index for the three investigated values of RH: 40%, 50% and 60%, respectively. It can be seen that for 24 °C, which is still in the suggested temperature interval for an OR, approx. 25% of the surgeons (for RH 40%, Fig. 5) and approx. 30% of the surgeons would complain (for RH 60%, Fig. 7) from the thermal environment.

![Figure 5. PPD index for surgeons, dressed in CAS (1.31 clo) and SSS (1.39 clo): air RH 40%](image)

![Figure 6. PPD index for surgeons, dressed in CAS (1.31 clo) and SSS (1.39 clo): air RH 50%](image)

![Figure 7. PPD index for surgeons, dressed in CAS (1.31 clo) and SSS (1.39 clo): air RH 60%](image)

The analysis of Figures 2-7 shows that temperature up to 20 °C is favourable for the thermophysiological comfort of the surgeons in the OR when using the investigated types of protective clothing. However, the decrement of the temperature is unfavourable for the patient, who is under anaesthesia, with lower insulation over a naked body. An option is to use local methods for warming the patient. Another option is to play to a certain level with the air humidity in the OR.

In fact, the human body does not have a sensory organ for air humidity [19]. The RH decrement is related to upper airways discomfort and irritation in eyes [20], but these symptoms usually appear after prolonged exposure to RH in the room below 30%. As for the work performance, it is barely affected, especially for short exposures (below 5 hours): dry air was found to have decreased the rate of performance by 3%-7% [21].

The predicted values for the PMV and PPD show that the thermophysiological comfort of a surgeon would be assured in an OR in the following thermal environment (the determination of the interval is done for the combination between lowest to highest temperature and from lowest to highest RH):
4. Conclusions

This study was performed to compare the effect of two protective clothing ensembles in an OR on the thermophysiological comfort of the surgeons. The difference between the clothing was the level of clothing insulation and the type of protection: a surgical scrub suit (SSS) and a clean air suit (CAS). The calculation of the PMV and PPD indexes was used to assess the thermophysiological comfort of the surgeons in the temperature interval from 18 °C to 24 °C and an interval of the air relative humidity from 40% to 60%.

The results obtained and their analysis showed that the surgeons would stay in the condition of thermophysiological comfort when the temperature of the OR is up to 20 °C. The relative humidity for 18 °C and 19 °C can change from 40% to 60% without affecting the comfort of the surgical staff. For a temperature of 20 °C, the humidity should be lower than 60%, if SSS is used. Clean air suits could also be used when the temperature of the OR is 21 °C, but the RH should be lower than 60%.

A recommendation for future work is to compare the thermophysiological comfort of different staff in an OR: surgeons, anaesthetists, nurses. The effect of the duration of the operations should also be investigated.

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