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# Thermal Sensations of Surgeons During Work in Surgical Gowns

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*Standards for surgical procedures and medical clothing, designed for use in the operating theatre, have been gradually developed with the progress in science and technology. Standard No. EN 13795:2011, determining the requirements concerning materials for production of surgical gowns, was introduced in 2003. It concerns, e.g., resistance to microbial penetration. Little attention is given to thermal comfort, even though it is well known that thermal discomfort can have an adverse effect on the quality and efficiency of work. During a real-life test and laboratory tests, 2 male surgeons and 8 male volunteers were asked to describe their subjective sensations before and after work. The results of the real-life test and the laboratory tests are comparable. They show a clear lack of thermal comfort when medical clothing designed for the operating theatre is used.*

thermal sensation thermal comfort surgical gowns

## 1. INTRODUCTION

Standards for surgical procedures have evolved with the progress in science and technology. The history of surgical procedures dates back to 1653, when the first report or, more precisely, the first illustration presenting craniotomy appeared [1, 2]. Realistic pictures or illustrations were then the only form of keeping medical records of conducted surgical procedures. From the illustrations, it can be concluded that personal protective equipment was not given too much consideration. Neither the surgeon nor the patient were protected against pathogens or infectious biological material in body fluids or blood because people were then unaware of the risk of infection.

It was not until the late 19th century (more precisely, until 1889) when Thomas Eakins in his paining entitled *The Agnew Clinic* immortalized the very first protective gown used for protection of both the surgeon and the patient [2]. The question whether surgical gowns fulfilled their protective properties was raised in the 1950s. In 1952, Willam Beck initiated the first study on barrier properties of medical clothing materials and co-authored an article on cotton surgical gowns "False Faith in the Surgeon's Gown and Surgical Drape". That study showed that a cotton surgical gown tended to transmit bacteria from nonsterile to sterile areas. Furthermore, he proved that microorganisms were able to penetrate immediately the cotton "barrier" and they were able to do it in either direction [2].

In 1963, Beck and Carlson introduced a definition of the aseptic barrier [3]. The barrier was described as material placed between an aseptic surface (the place where the patient was operated on) and a surface with dangerous microorganisms. Its main role was to prevent the spread of bacteria in the sterile area [2].

Shortly after World War II, Quartermaster (USA) produced cotton with addition of a waterproof

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agent, Quarpel. Studies conducted in 1967 revealed that medical use of this agent reduced bacterial transmission. In 1975, Laufman showed that various fabrics and textiles were characterized by different protection time against infection. In 1980, Moylan and Kennedy proved that a reduction in postsurgical infections could be achieved by using disposable surgical gowns [2].

To this date, studies are being carried out to develop new materials which would be suitable for the production of surgical gowns [4, 5]. The studies mostly focus on providing surgeons (and patients) with the best possible protection against pathogenic bacteria. It should be remembered that the key function of medical clothing designed for use in the operating theatre is precisely this, protection, i.e., assuring safety against bacterial penetration and against fluid-borne harmful pathogenic agents [6]. Unfortunately, the same emphasis is not put on thermal comfort of users of medical clothing. Comfortable conditions, ensured by a proper selection of workers' clothes or by modification of already existing clothing ensembles, translate into, e.g., improved concentration, reduction of mistakes and accidents, and, by the same token, into enhanced efficiency and quality of work [7].

In 2003, Standard No. EN 13795:2011 was introduced [8]. It set requirements for materials used to produce medical clothing. The standard primarily addresses resistance to microbial penetration and resistance to fluid penetration. Thermal comfort is mentioned only in appendix A to the first part of the standard, where recommendations for surgical gowns can be found; in addition to barrier properties, they should also have properties that minimize physiological stress.

Thermal discomfort felt by surgeons is caused by an excessively high ambient room temperature, characteristic of the operating theatre [9], which protects the patient against the risk of hypothermia. Air temperature over 23 °C and low air velocity impair heat transfer from the body [10].

In addition to indoor air parameters, thermal sensation is conditioned by clothing insulation. Thermal insulation of medical clothing was studied by, e.g., Bogdan, Sudoł-Szopińska and Szopiński [11]. It has been estimated that medical thermal insulation amounts to ~1.3 clo. Furthermore, it should remain within the limits of 0.18–0.80 clo for thermal comfort of surgeons. Skin and clothing wettedness was not analysed then. Pamuk, Abreu and Öndoğan also confirmed that insulation values were similar regardless of the type of material used to manufacture the gown [12]. Cho, Tanabe and Cho analysed the effect of materials used to produce gowns on their thermal insulation and thermal sensations of surgeons [13]. They found that the type of material had no significant influence on users' thermal and moisture sensations. They noted, however, that insulation values of ensembles varied. According to Türler, Türler, Ladurner, et al., if surgeons are given a choice, they opt for cotton gowns rather than modern barrier gowns [14]. This choice is justified by better thermal comfort during surgical procedures, most likely attributable to better sweat absorption by cotton. For this reason, Umbach's laboratories use a Hohenstein quality label "Breathability". This label is granted to clothing characterized by water vapour resistance, which measured on a skin model in conformity with Standard No. EN 31092:1993, is under 20 $m^2 \cdot Pa/W$ [15]. This value was set during a study that determined a correlation between resistance of barrier material to water vapour permeation and the maximum ambient temperature perceived by a user as thermally comfortable [16]. Schoenberger wrote about surgeons' thermal comfort [17]. Moreover, Issa, Abreu, Schacher, et al. studied the influence of sterilization of surgical gowns on their thermal properties [18].

The quest to improve thermal sensations experienced by surgeons is far from over. This article describes results of subjective assessments of doctors using new-generation surgical gowns. The main objective of this study was to test only surgical gowns and their influence on the human body. Consequently, the impact of the face mask and a cap was outside the scope of the analysis.

## 2. METHODS

Experiments were performed to test subjective assessment of thermal comfort during the use of medical clothing designed for the operating theatre. The experiments involved a real-life test and laboratory tests.

Volunteers were asked to determine their subjective assessment concerning thermal sensation, using a 7-point scale [19], as well as skin wettedness and clothing moisture according to the scales of Nielsen, Berglund, Gwosdow, et al. [20] (Tables 1–3).

**TABLE 1. Subjective Assessment Scale Used in Real-Life and Laboratory Tests: Thermal Sensation**

| Score | Thermal Sensation |
|---|---|
| –3 | *cold* |
| –2 | *cool* |
| –1 | *slightly cool* |
| 0 | *neutral* |
| +1 | *slightly warm* |
| +2 | *warm* |
| +3 | *hot* |

**TABLE 2. Subjective Assessment Scale Used in Real-Life and Laboratory Tests: Clothing Moisture**[1]

| Score | Clothing Moisture |
|---|---|
| 1 | *dry* |
| 2 | *slightly moist* |
| 3 | *moist* |
| 4 | *wet* |

*Notes.* 1 = Nielsen, Berglund, Gwosdow, et al.’s scale [20].

**TABLE 3. Subjective Assessment Scale Used in Real-Life and Laboratory Tests: Skin Wettedness**[1]

| Score | Skin Wettedness |
|---|---|
| 1 | *drier than normal* |
| 2 | *normally dry* |
| 3 | *some body parts moist* |
| 4 | *larger body parts moist* |
| 5 | *some body parts wet* |
| 6 | *larger body parts wet* |
| 7 | *sweat drips in some places* |
| 8 | *sweat drips in many places* |

*Notes.* 1 = Nielsen, Berglund, Gwosdow, et al.’s scale [20].

Data from the laboratory experiment were analysed statistically. To assess the significance of differences between responses obtained before and after the experiment, the nonparametric Wilcoxon test was used ($p < .05$). To determine whether the type of surgical gown used had a significant effect on the responses both before and after the study, the Kruskal–Wallis test was applied ($p < .05$).

Next, the predicted mean vote (*PMV*) index was estimated. The index describes thermal comfort [21]. According to Fanger, thermal sensation within the limits of $1 \le PMV \le +1$ is comfortable [19]. Considering environmental conditions in which surgeons perform their work and individual factors (metabolic rate and clothing thermal insulation), it is possible to estimate *PMV*. Furthermore, it is also possible to estimate the range of temperatures in which the user can feel thermal comfort.

## 2.1. Materials

Medical clothing ensembles had been tested beforehand for their effective thermal insulation ($I_{\text{cle}}$) [11]. The volunteers as well as the surgeons (in real-life conditions) wore surgical underwear (composed of a blouse and trousers made of polyester fabric with carbon fibre, $I_{\text{cle}}$ = 0.99 clo) and one of the following ensembles:

- A cotton surgical gown for single use ($I_{\text{cle}}$ = 1.49 clo);
- B barrier surgical gown for multiple use, worn during standard-risk operations, made of polyester with carbon fibre, the gown critical area (front and sleeves) made of high-resistance fluid-proof fabric ($I_{\text{cle}}$ = 1.30 clo);
- C barrier surgical gown for multiple use, worn during high-risk operations, made of polyester with carbon fibre at the back, the gown critical area (front and sleeves) made of laminate with polytetrafluoroethylene (PTFE) membrane ($I_{\text{cle}}$ = 1.41 clo).

In real life, in addition to those ensembles, surgeons also wear underpants, socks, shoes and headgear, so to calculate total insulation of the tested ensembles, a value 0.08 clo had to be added.

Ensembles B and C complied with Standard No. EN 13795:2011 [8]. Ensemble A (made of cotton) did not meet the criteria, mostly due to the lack of resistance to microbial penetration through the cotton material.

### 2.2. Real-Life Test

The test in real-life conditions was carried out with the participation of 2 male surgeons: surgeon 1 (age 38 years, height 178 cm, weight 81 kg) and surgeon 2 (age 45 years, height 180 cm, weight 103 kg).

The experiment was performed during real surgical procedures in one of Warsaw, Poland, hospitals in the urological ward. The surgeons performed the operations assuming standing positions and slightly leaning towards the patient. Throughout the surgery, the microclimate parameters were monitored. They were as follows: average air temperature ($t_a$) 24 °C, radiative temperature ($t_r$) 24.1 °C, relative humidity (*RH*) 60%, air velocity ($v_a$) 0.02 m/s. Microclimate meters were located in the nearest possible distance from the surgeon. Germicidal lamps were switched off and a ventilation and air conditioning system with laminar air flow were enabled. The place of surgery was illuminated with lamps mounted above the operating table. The lamps, however, did not cause a considerable amount of heat gain in the room. There were no other items that could be treated as an additional source of heat.

All operations were of the same type (kidney operations). Total time of surgery and the test closed up in 1 h 40 min. Operations during which the survey was conducted began at the same time, at 8:00. The metabolic rate of the surgeons was calculated on the basis of Standard No. EN ISO 8996:2004 [22]. It was estimated to be 2.4 met. The surgeons were asked to describe their subjective thermal sensations before and after the surgical procedure.

### 2.3. Laboratory Experiment

In addition to real-life tests, laboratory tests were conducted to eliminate the stress linked to surgical procedures. They comprised a group of 8 male volunteers (age 23.1 ± 0.4 years, height 179 ± 5 cm, weight 75.9 ± 4.7 kg, physical fitness $V_{\mathrm{O2max}}$ 48.81 ± 4.73 ml $\mathrm{O_2}\cdot\mathrm{kg}^{-1}\cdot\mathrm{min}^{-1}$). Each subject took part in the tests three times, i.e., with all types of ensembles. The tests were conducted in a WK23′ climatic chamber (Weiss, Germany). Inside the chamber, thermal conditions characteristic of the operating theatre were simulated ($t_a$ and $t_r$ 24 °C, *RH* 60%, $v_a$ 0.1 m/s). The volunteers described their subjective sensations after each phase of the test (according to the experimental design in Table 4). Physical load was divided into three 10-min phases, during which the load was gradually increased on a 50-W cyclometer.

**TABLE 4. Design of the Laboratory Experiment With Volunteers**

| Phase I | Phase II | | |
|---|---|---|---|
| | Physical Load (10 min) | | |
| Sitting in climatic chamber (20 min) | IIa<br>50 W | IIb<br>100 W | IIc<br>150 W |

## 3. RESULTS AND DISCUSSION

### 3.1. Real-Life Test

The test in real-life conditions provided data on thermal sensations, skin wettedness and clothing moisture experienced by surgeons in individual ensembles designed for the operating theatre. Their responses indicated that both surgeons considered work in ensemble B (a polyester gown) to be the most comfortable (both before and after the surgery) (Table 5). Ensemble B was characterized by the lowest thermal insulation value and received the highest number of most favourable opinions concerning clothing moisture (1 = *dry*), both before and after the surgery. Similarly, responses regarding skin wettedness revealed that ensemble B was the best option. After the surgery, both surgeons selected 3 = *some body parts moist*.

### 3.2. Laboratory Experiment

#### *3.2.1. Thermal sensation*

With a view to precise mapping of thermal conditions in the operating theatre, tests were conducted in a climatic chamber with the participation of volunteers. Changes in responses regarding thermal sensations were also analysed. The obtained mean data indicated that any physical

**TABLE 5. Surgeons' Subjective Sensations Before and After the Real-Life Test**

| Surgeon | Ensemble | Time | Thermal Sensation | Clothing Moisture | Skin Wettedness |
|---|---|---|---|---|---|
| 1 | A | before | –1 | 1 | 2 |
| | | after | 3 | 4 | 8 |
| | B | before | 0 | 1 | 2 |
| | | after | 0 | 1 | 3 |
| | C | before | 0 | 1 | 2 |
| | | after | 3 | 4 | 5 |
| 2 | A | before | 0 | 1 | 2 |
| | | after | 3 | 4 | 8 |
| | B | before | 0 | 1 | 2 |
| | | after | 1 | 1 | 3 |
| | C | before | 1 | 1 | 2 |
| | | after | 1 | 1 | 3 |

*Notes.* For a description of the ensembles, see section 2.1.; for the scales see Tables 1–3.

load resulted in exceeding the limits of thermal comfort ($-1 \le PMV \le +1$) (Figure 1). Responses obtained before the test for all ensembles were similar. Nonetheless, for ensemble B, the volunteers marked more often 0 = *neutral* and 1 = *slightly warm*, i.e., responses within the limits of thermal comfort.

After the first phase of the test, 61.5% of responses for ensembles A and B stayed within the enlarged limits of comfort ($-1 \le PMV \le +1$), compared to 50% for ensemble C. The same relation was noted for phase IIa.

During phase IIb (after a 20-min physical load), only 12.5% for ensembles A, B and C fit within the aforementioned limits, whereas during phase IIc, none of the subjects could feel thermal comfort. For each tested ensemble, most responses to the thermal sensation after the test was 3 = *hot*, i.e., the highest value on the thermal sensation scale.

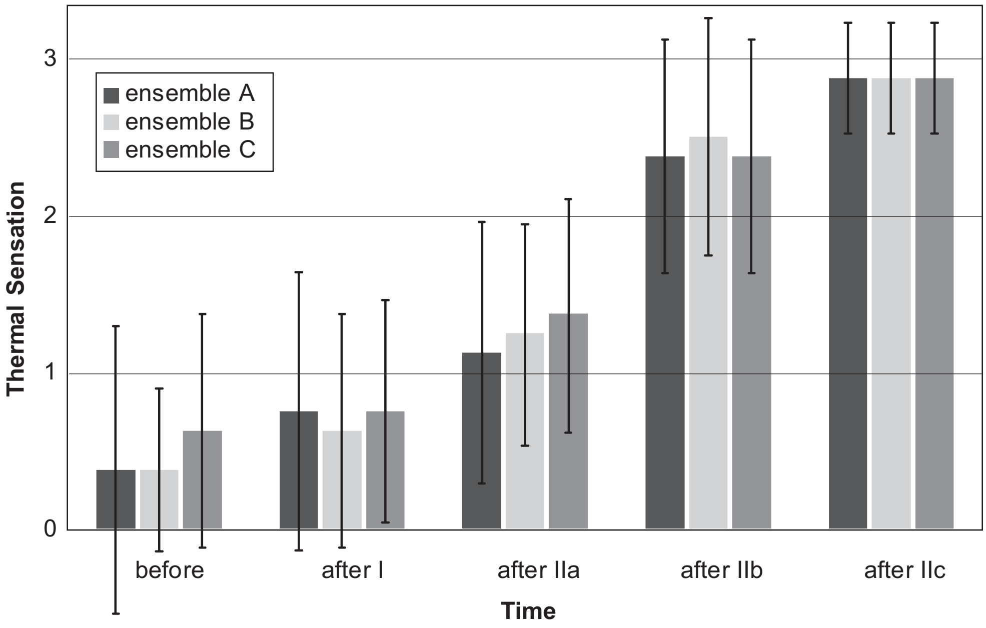

**Figure 1. Thermal sensation: mean results of laboratory experiment.** *Notes.* Error bars denote standard deviation; $n = 8$; IIa, IIb, IIc = phases, see Table 4.

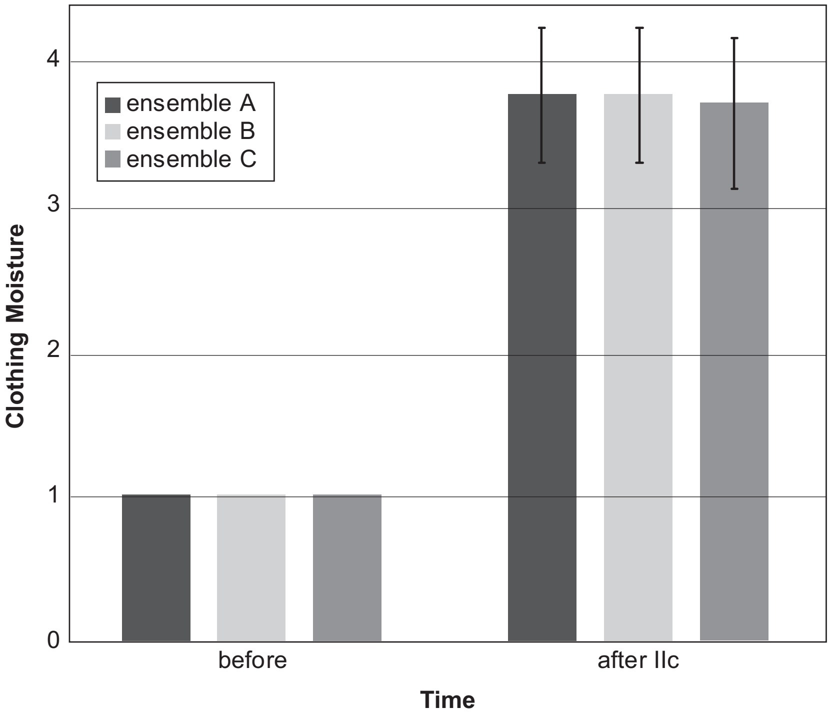

**Figure 2. Clothing moisture: mean results of laboratory experiment.** *Notes***.** Error bars denote standard deviation; $n = 8$; IIc = phase, see Table 4; results on Nielsen, Berglund, Gwosdow, et al.'s scale [20].

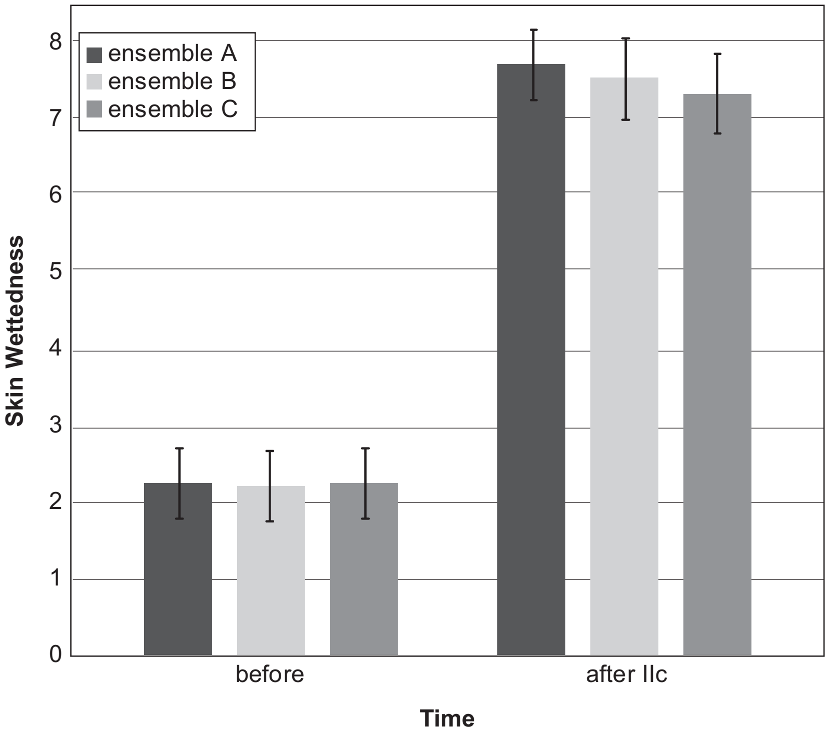

**Figure 3. Skin wettedness: mean results of laboratory experiment.** *Notes***.** Error bars denote standard deviation; $n = 8$; IIc = phase, see Table 4; results on Nielsen, Berglund, Gwosdow, et al.'s scale [20].

### 3.2.2. Clothing moisture

Nielsen et al.'s scale of 1–4 describes subjective sensations concerning clothing moisture [20]. In the laboratory experiment, the results were similar. More favourable responses (1 = *dry* before the test, 3 = *moist* after the test) were given to ensemble C. Most volunteers, however, when asked about clothing moisture after the test, marked the highest value 4 = *wet* (Figure 2).

### 3.2.3. Skin wettedness

Nielsen et al.'s scale of 1–8 describes subjective sensations concerning skin wettedness [20]. In the laboratory test, the highest number of responses of 8 = *sweat drips in many places* was noted for ensemble A (75%), and the highest number of responses of 7 = *sweat drips in some places* was obtained for ensemble C (62.5%). For ensemble B, after the surgery, 50% of volunteers marked 7 and 8 (Figure 3).

### 3.2.4. Statistical analysis

Responses given before and after the real-life experiment regarding thermal sensations, skin wettedness and clothing moisture for each ensemble showed statistically significant differences (Wilcoxon test, $p < .05$). The Kruskal–Wallis test showed no significant effect of the type of surgical gowns used on the assessment made before and after the surgical procedures.

Taking into account the phases during physical load in the laboratory experiment, statistically significant differences were observed in several cases (Table 6). The analyses showed a significant decline in the number of favourable opinions with regard to thermal sensations, skin wettedness and clothing moisture for all types of gowns where greater physical effort was required. A comparison of assessments made before the tests and after phase IIa (physical load of 50 W) showed no statistically significant differences with respect to all parameters for ensemble A. Ensembles B and C, however, caused a decline in thermal comfort. Moreover, ensemble C caused discomfort with regard to skin wettedness.

Addition of further physical load (phase IIb) (equivalent to 100 W, typical work of a surgeon) resulted in statistically significant worsening of thermal sensation in all studied parameters (thermal feeling, skin and clothing wettedness) as compared to responses obtained in phase IIa. For very heavy physical load (equivalent to 150 W, phase IIc), there was a statistically significant decrease in skin wettedness and clothing moisture only. There were no differences with regard to thermal sensations because the volunteers already earlier declared their thermal sensations as hot.

**TABLE 6. Statistical Significance of Differences in Assessment of Sensations Before and After Physical Load**

| | | Ensemble | | |
|---|---|---|---|---|
| **Sensation** | **Time** | **A** | **B** | **C** |
| Thermal sensation | before IIa–after IIa | *ns* | * | * |
| | before IIb–after IIb | * | * | * |
| | before IIc–after IIc | *ns* | *ns* | *ns* |
| Skin wettedness | before IIa–after IIa | *ns* | *ns* | * |
| | before IIb–after IIb | * | * | * |
| | before IIc–after IIc | * | * | * |
| Clothing moisture | before IIa–after IIa | *ns* | *ns* | *ns* |
| | before IIb–after IIb | * | * | * |
| | before IIc–after IIc | * | * | * |

*Notes.* * $p < .05$. For a description of the ensembles, see section 2.1.; IIa, IIb, IIc = phases, see Table 4.

Subjective assessments provided by the volunteers did not yield any clear-cut indication of which tested ensemble had the best properties; the responses were fairly regularly distributed. It can only be speculated that in terms of thermal comfort, ensemble B was the best solution because it was characterized by the highest percentage of responses within the limits of thermal comfort. It should be noted that ensemble B had the lowest thermal insulation.

When testing ensembles, subjective sensations regarding skin wettedness and clothing moisture did not vary significantly. In the real-life test, ensemble B proved to be the best option both for skin wettedness and clothing moisture.

In the laboratory tests during phase IIc, responses concerning skin wettedness were fairly regularly distributed between 7 = *sweat drips in some places* and 8 = *sweat drips in many places*. Ensemble C had the highest number of favourable responses. However, there was no clear answer to the question of the type of gown with the best skin wettedness properties.

As regards assessment of clothing moisture, 38.5% of responses concerning ensemble C amounted to 3 = *moist,* whereas for ensembles A and B, this reply was at the level of 25%. For the remaining responses, 4 = *wet* was chosen.

There was no marked change in subjective assessment concerning the gowns. It can only be speculated that in the laboratory tests, ensemble C was the best gown in terms of clothing moisture, i.e., the polyester gown with carbon fibre, in which the critical area (front and sleeves) was made of laminate with PTFE membrane.

The results of statistical analysis showed that even light physical load (50 W) caused discomfort. This was due to excessive accumulation of sweat under the gown and was independent of the type of ensemble (B or C). Only cotton ensemble A enabled the drainage of moisture. An increase in the work load resulted in a statistically significant worsening of thermal sensations, as compared to the previous phase with less physical load. These results indicate that modern gowns cause discomfort to surgeons, regardless of the work load. There is an unfavourable microclimate between the skin and the inner surface of the gown, characterized by a high temperature and *RH*. Some volunteers even compared the microclimate formed under the gown to a sauna effect.

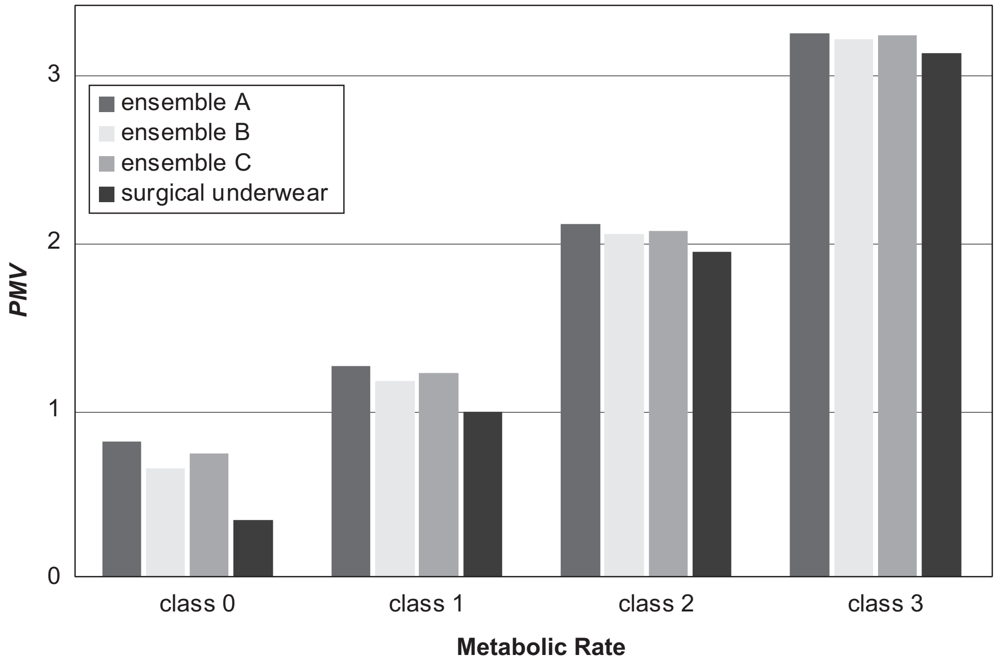

**Figure 4. Relation between thermal comfort (*PMV*) and metabolic rate by clothing ensemble.** *Notes. PMV* = predicted mean vote index; for a description of the ensembles, see section 2.1.; class 0 = 65 W/m$^2$, class 1 = 100 W/m$^2$, class 2 = 165 W/m$^2$, class 3 = 230 W/m$^2$.

### *3.2.5. Predicted mean vote (*PMV*)*

Several indices are selected to assess thermal load. One of them is *PMV*, which is used for a moderate environment. The analysis was carried out to assess the relationship between the activities performed (metabolic rate), thermal insulation and thermal comfort sensation (Figure 4). It was conducted with the software for calculating *PMV* and predicted percentage dissatisfied (*PPD*) presented in Standard No. EN ISO 7730:2005 [21]. Four values of metabolic rate were assumed, i.e., class 0 (65 $W/m^2$), class 1 (100 $W/m^2$), class 2 (165 $W/m^2$) and class 3 (230 $W/m^2$), and the following air parameters: $t_a$ 24 °C, $t_r$ 24 °C, $v_a$ 0.1 m/s, *RH* 60% (corresponding to the thermal conditions in an operating theatre).

The sensation of ideal thermal comfort extends within the limits of $-0.5 < PMV < +0.5$ [19]. From Figure 4, it can be concluded that when only a surgical gown is worn, and only in a resting phase, it is possible for users to experience thermal comfort. Any work (increase in metabolic rate) makes all ensembles uncomfortable. All the ensembles were within the extended scope of the perceived thermal comfort ($-1 \le PMV \le +1$) when metabolic class 0 was assumed. When light work is performed, it is only in a surgical gown that thermal comfort can be felt. A metabolic rate of class 2 or 3 generates thermal state at the level of *PMV* equivalent to or higher than +2 = *warm.*

## 4. CONCLUSION AND RECOMMENDATION

The results of the real-life and laboratory tests are quite similar. They show that medical clothing can exert thermal load on the human body. Subjective assessments clearly point to a lack of thermal comfort when medical clothing designed for the operating theatre is used.

Estimations of *PMV* are congruent with the data from the experiments conducted on human subjects. They show that any work performed in the tested ensembles results in exceeding the limit of thermal comfort. This conclusion can be supported by the analysis of physiological indicators, e.g., skin temperature or temperature and humidity in the space between the body and clothes, in other studies. The increase in skin temperature and high moisture accumulation in the space between the body and clothing could cause deterioration of surgeons' psychophysical condition [11, 23, 24, 25, 26].

The present article shows that the problem of thermal comfort concerning the use of medical clothes exists and should not be underestimated. Lowering thermal insulation of surgical clothes is a potential solution. This can be achieved through, e.g., application of new materials or certain technical solutions connected with heat transfer from the human body. Such materials should meet assumptions concerning a barrier against pathogens and, at the same time, their use should make it possible to experience thermal comfort. Thus structured, they would act as a selective barrier for micro-organisms and would ensure release of heat into the environment without causing thermal load to the body.

The problem can be also solved by, e.g., a cooling system or so-called smart materials, whose structure includes phase change materials (PCM). They would absorb excessive heat produced by the body. Tests aimed at creating a vest filled with PCM (Glauber's salt™) showed a positive effect by reducing skin temperature, for example [27]. That experiment was conducted in a climatic chamber ($t_a$ 27 °C, $v_a$ 1.5 m/s, *RH* 50%) with 6 volunteers wearing well-insulated protective clothing. When the subjects put on a vest of ~1.8 kg filled with PCM, there was a drop in relative temperature and relative humidity on the back of the volunteers. In some instances, the difference in relative humidity was up to 40%. Likewise, the subjects' assessment of thermal sensation was approaching conditions considered comfortable when the vest made of PCM was used [27].

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