RESEARCH ON BIOPHYSICAL PROPERTIES OF PROTECTIVE CLOTHING

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Abstract:

The aim of this research was to assess thermal insulation properties of select protective suits by performing appropriate tests on a thermal manikin according to Polish standards. The research was conducted for three variants of the user's positions, which change during work. It has been demonstrated that different body positions, as well as movement of particular body parts, have a significant impact on changes of thermal insulation values of the tested clothing.

Keywords:

biophysical properties of clothing, thermal comfort, antibacterial materials, protective clothing

1. Introduction

Nowadays, advances in production technology has set high requirements for manufacturers to ensure safety and health at work. It is necessary to use personal protective equipment, in particular at the workplace. One example of such equipment is protective clothing; however, its special properties can lead to imbalance of thermal equilibrium of organism [1], human metabolism by-products in the production of human skin secretions and to create the conditions for the growth of microorganisms and their associated skin diseases [2]. The crucial aspect here is the need to explore and learn heat properties: thermal insulation of available protective clothing. The proper selection of personal protective equipment can provide thermal comfort and allow employee to work effectively, without losing his health [1,3] and allows the creation of new personal protective equipment at a high level of technological advancement in various fields of life. Currently, an attempt was made in research in the Institute of Architecture of Textiles Lodz to create overalls for spelaeologist, which may meet all of technological requirements during tasks in harsh environments.

This article discusses the concept of thermal comfort, which is the basis of thermal insulation tests and it also referred to protective clothing commonly used as a means of personal protection [4]. The computation model used in the measurements performed with the manikin is described [4]. The final result of this study is to compare select sets of protective clothing according to a set of criteria for the type and position of the test manikin [5]. Using a variety of body positions, it was demonstrated that the posture and movement of individual body parts has a significant impact on the thermal insulation of the tested clothing [4]. Two suits of different severities, but similar in purpose, were chosen. It was assumed that the laboratory work is often performed in the sitting position, standing or moving at an average speed of walking. At the same time, the study was conducted in a normal weather, which reflected the conditions in the laboratory.

2. Experimental

2.1. Materials

The aim of the research was to study the biophysical properties of protective clothing used in laboratory work. Therefore, it was necessary to imitate the conditions prevailing there. As normal climate conditions are common in the laboratory, it was the basic assumption for research. In order to characterize the basic properties of studied nonwovens, the following tests were conducted: air permeability (Fig. 2) and thermophysical properties of protective suits. During the research, two suits that comply with the requirements for protective clothing were investigated. The Microgard 2000 Standard suit is made of nonwoven, which constitutes a microporous membrane and laminate (Table 1). The double-layer membrane with micropores allows effective protection from liquids and, at the same time, it can efficiently transport the excess moisture from the user's body outside. The design of Tyvek material used in DuPont Tyvek Classic suits is based on the same principle. The microfiber construction of Tyvek is an impermeable barrier, simultaneously allowing to drain the excess sweat from layers next to the skin. Both suits provide protection against dust and chemical spray and are classified as types 5 and 6 protective clothing.

Table 1 Summary of basic parameters characterizing the tested fiber

Features woven	Microgard 2000 STANDARD	DuPont Tyvek Classic
Thickness, mm	0,32	0,19
Mass per unit area, g/m ²	67	41
Density, kg/m ³	209,375	215,790

2.2. Methods

Studies of air permeability of the nonwovens used in protective suits were performed using the Hungarian apparatus FF-12. The tests of protective clothing with the use of a thermal manikin (Fig. 1), according to PN-EN ISO 15831:2006, allowed us to determine:

- The total thermal insulation of clothing—for the variants in which the manikin remained stationary.
- The resulting total thermal insulation of clothing—for the variants in which the manikin moved (eq. 1).

$$I_T = \frac{t_{SK} - t_O}{H}, \frac{m^2 \cdot K}{W} \quad (1)$$

where:

t_{SK} – the average temperature of the skin surface, in degrees Celsius,

t_O – the operating temperature in degrees Centigrade,

H – dry heat loss per square meter of skin surface, in watts per square meter [1].

Another case that we can encounter while imitating human work is position change to a sitting one [3]. The experiment was performed with a wooden chair with a backrest. Its construction can be compared to a wooden stool. The thermal insulation of the seat – wooden stool is 0.01 clo (0.002 m² * K / W) [1].

The protective suit was tested every time in a set with underwear and light sport shoes. The commonly used t-shirts – 100% cotton and leggings – 85% Nylon / 15% Spandex were used as the underwear. The same tests were also performed for underwear only. The measurements were taken according

to the PN-EN ISO 15831:2006 Polish standard [4], assuming measurements of three garments of a particular type, or triple measurement of the same item. Each time the dummy was undressed and dressed again between measurements.

Calculations were performed according to PN-EN ISO 15831:2006 in which there are two types of calculations of thermal insulation.

1. Serial model – thermal insulation determined as the weighted mean of the areas of dummy segments (Eq. 2).

$$I_t \text{ or } I_{tr} = \sum_i f_i \cdot \left[\frac{(T_{Si} - T_a) \cdot a_i}{H_{Ci}} \right], \frac{m^2 \cdot K}{W} \quad (2)$$

where:

I_t – the total thermal insulation of clothing

I_{tr} – the resulting total insulation of clothing

T_{Si} – the coating surface temperature of the i -th segment of the dummy (°C)

T_a – air temperature in the climate chamber (°C)

H_{Ci} – by passing the value of the i -th segment of the dummy (W/m²)

f_i – coefficient of the surface area of the i -th segment of the “naked mannequin” (Eq. 3)

$$f_i = \frac{a_i}{A} \quad (3)$$

where

a_i – the surface area of the i -th segment dummy (m²)

A – the total area of the “naked” body of the dummy (m²)

2. Parallel model - thermal insulation averaged for the manikin surface area; it takes into account the total heat flux flowing out of dummy (Eq. 4) [4,5].

Figure 1. Thermal manikin in the same position the dummy.

$$I_{l \text{ or } I_{tr}} = \frac{[T_s - T_a] \cdot A}{\sum_i H_{Ci}}, \frac{m^2 \cdot K}{W} \quad (4)$$

where:

T_s – average temperature of the dummy shell (°C), (Eq. 5):

$$T_s = \sum_i f_i \cdot T_{Si} \quad (5)$$

For both thermal models, thermal insulation was calculated in the same way, regardless of movement or resting stationary position of the manikin. The study was performed on a thermal manikin manufactured by PT TEKNIK Danish company, which specializes in the construction of this type of equipment (Fig. 1). The mannequin is owned by the TUL Department of Clothing Technology and Textronics. The “pernelle” model, divided into 24 body segments, represents a female figure. Each of the segments has a separate controller, which calculates the temperature of the entire surface by means of two measurements: nickel resistance and power needed to heat that part of the body.

3. Results and discussion

The obtained results are presented in the charts. In Figures 3 and 4, the position of the manikin in the same suit is the criterion and the criterion is thermal insulation of different suits for the same dummy position. The results are shown for the parallel and serial calculation model for both aforementioned criteria.

Criterion 1: different manikin positions in the same suit.

The analysis of the results begins with a comparison of thermal insulation of the tested clothing taking into account the criterion of position. In both the tested suits, both the parallel and serial models showed that the thermal insulation of clothing is the highest in the sitting position and the lowest in the case of walking. The differences are within the (0.016–0.348 clo)

Figure 2. Air permeability test fabrics.

range. Higher thermal insulation of the suits while sitting was caused by extra insulation provided by the chair. This value was also influenced by the position of the dummy; the back was covered by the backrest, the buttocks and a part of the thighs by the seat. It caused both an increase in thermal insulation in the boundary layer of air and no ventilation in the parts that were in direct contact with the chair. The contact of the human body with a large object also increases the heat transfer by conduction [6]. When the dummy was wearing the underwear

Figure 3. Thermal insulation test sets of clothing a parallel model.

Figure 4. Thermal insulation test sets of clothing a serial model.

only, there were no significant differences between sitting and standing positions. The lowest thermal insulation was achieved in the case of walking. The results observed for the walking mannequin confirmed the so-called pumping effect, i.e. air exchange from the layer next to the skin into fresh one. It was the reason for more significant difference between the values of thermal insulation of clothing for walking versus sitting, or standing manikin. When a user starts moving, air permeability becomes an additional important parameter [7]. Movement is natural while working; thus, it can be expected that the actual values of insulation while sitting or standing will be lower than those obtained during the measurements. During the tests of air permeability for both selected vacuum levels, DuPont Tyvek Classic showed greater breathability of the fabric. This may have direct impact on the value of thermal insulation of the tested suits.

Criterion 2: Thermal insulation of different suits for the same dummy position.

The lowest thermal insulation was obtained for underwear, regardless of the position of the dummy. The DuPont Tyvek Classic suit was characterized by higher value of thermal insulation in a sitting position, whereas the highest value while standing and walking was achieved for the Microgard 2000 STANDARD suit. It can be concluded that Microgard 2000 STANDARD suits have better functional parameters – while sitting, the value of thermal insulation did not increase significantly in comparison to standing position, which allowed to minimize the impact of seat insulation. The differences in thermal insulation of the suits are mainly caused by the manufacturing technology of Tyvek and Microgard materials, despite the use of the same material, polyethylene (PE). One aspect which may slightly affect the value of insulation is the design of the suit. Microgard 2000 STANDARD suits have more potential applications (antiseptic barrier and pesticides protection added) than DuPont Tyvek Classic ones. Nevertheless, their insulation did not increase significantly and was lower while sitting.

Various ways of thermal manikin usage in research

Currently, the thermal manikin provides the most accurate representation of the human body. What is more, the dummy is a tool constantly improved by the introduction of new modules, division into a larger number of segments or separation of different parts of the body to obtain more accurate measurements. The undoubted advantage of the dummy, which can be noticed without detailed laboratory tests, is its similarity to the human, and thus the possibility of mapping the real situation. It is still possible to study heat transfer in the human–environment chain in all possible aspects. According to PN-EN ISO 15831:2006: “The obtained values of thermal insulation include clothing isolation and insulation of the boundary layer of air around the dummy. They only refer to the set of garments, which was tested and to specific conditions of the test, especially the movement of air around the manikin.” [4].

4. CONCLUSIONS

This study presents both findings obtained from tests with a thermal manikin, and calculated according to parallel and serial models. However, it can be expected that due to the definitions of the particular models, the parallel model would be better for the tested suits, whereas the serial model is more adequate for the underwear. In case of the parallel model, it is caused by taking into consideration the total heat flow coming out of the dummy through the suit. In case of the serial model, it is caused by division of the dummy according to the cut-off line of clothing into the upper and bottom parts. The study was conducted on a dummy with the full body surface due to the complex nature of the used clothing – overall suits. In the case of tests with particular body segments, a number of individual measurements should be performed. During such measurements, thermal insulation of the n -th segment for one-minute interval should be recorded and then the value should be referred to the area of the n -th segment. Owing to the research

conducted with the thermal manikin, we can determine the relationship between the position of the dummy and thermal insulation of clothing. The results presented in this study confirm the impact of physical activity and adopted posture on the thermal insulation of clothing. It is important to design personal protective equipment such as protective clothing, taking into account the impact of possible activities of the users on their thermal comfort while working in protective clothing. It has also been confirmed that increase in thickness of the textile material improves thermal insulation due to the increase in the volume of air in textile spaces. Air permeability tests confirm the correlation between permeability and thermal insulation. The higher the permeability, the lower the thermal insulation (for a constant temperature). On the basis of research comparing the standing and walking position variants, the "pumping effect" was observed. It was lower in the case of nonwoven with higher breathability and greater apparent density. This allowed a gradual gas exchange between the layer next to the skin and the environment. Suits made of this fabric exhibited a smaller decrease in thermal insulation when walking in comparison to the standing position. Thermal insulation of the tested suits, depending on the variant, remained at the same level. Therefore, it can be concluded that thermal insulation is not significantly differentiated from the point of view of the user.

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