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Analysis of clothing microclimate conditions for lower body part workwear dedicated for motor impaired employees

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ABSTRACT

Workwear dedicated for motor impaired employees was designed. The woven fabrics used meet the requirements for light to moderate effort according to PN-P-08525:1998, reaching suitable level of water vapor resistance meanwhile. The workwear's design was carefully chosen to meet the requirements of motor impaired employees during their work activities. The analysis of microclimate was carried out to investigate the garment's ability to transport water vapor outside from gaps between body part and item of clothing. Two sets of workwear were tested, showing that both garments' construction and woven fabrics properties influence thereon.

1 Introduction

An issue concerning the function of textile usage comfort that improves the quality of human life is subject of research mainly in terms of shaping the factors influencing the functional comfort of clothing products. Clothing dedicated to people with motor disabilities plays a special role here. Disabled people with mobility impairments may have variety levels of motor skills. The subjects of vocational activation of people with disabilities are widely discussed in both the legal as well as organizational context. Adapting the work environment and equipping workstations according to the needs resulting from the motor system disability, apart from rooms and surroundings, should include the use of personalized wheelchair seats to prevent skin lesions (bedsores) [1-3].

In the sitting position, repetitive activities are most often performed at production lines and machines adapted to sitting work as well as office work at the computer.

In the field of clothing design for disabled people in wheelchairs, solutions increasing usage comfort and clothing functionality have been proposed [4,5]. For the group of paralyzed people, the study was performed on the comfort of clothing for outdoor activities [6]. Works were conducted on the development of clothing providing thermal comfort that protects users from cold and weather conditions.

In recent years, research work has been carried out in the field of clothing design for people with disabilities and the elderly, who are long-term immobile in a lying or sitting position, on the impact of textile materials on improving their quality of life [7-9]. For personalization and optimization of garment designs, 3D non-contact scanning systems and software applications for shape modeling of freely extended surfaces are used [11-13].

In the process of manufacturing of clothing products with dedicated use, the selection of textile materials with thermal properties enabling moisture transport is the important issue. Several publications [14-17] present a comparative analysis of methods for assessing the physiological comfort parameters of textile products, including the ability to transport heat and moisture. Reference 18 presents selected test methods for measuring the thermal insulation properties of clothing materials for workwear under cold conditions. Instruments used to measure the thermal properties and the ability to transport water vapor are described, such as: a device using the model of a sweating thermally insulated plate, the instruments Alambeta, Permetest as well as Thermo Labo II. In addition, information was provided on thermal insulation mannequins used to measure the thermal insulation of clothing products.

In the field of physiological comfort, research is also carried out on the impact of usage conditions [19] and degree of fitting of the garment to the user's silhouette [20] onto the thermal comfort. The research on the impact of thermal insulation and the degree of fitting of the garment to the user's silhouette on the user's thermal comfort confirmed that the selection of the appropriate clothing size has a significant and positive impact on the user's thermal comfort sensations [20].

The analysis and assessment of the conditions in the sub-clothing microclimate during physical effort is the subject of many research studies [21-28]. The influence of gender on thermal comfort sensation and moisture transport outside the sub-clothing zone [21] was assessed on the basis of temperature, humidity and sweat output in the sub-clothing microclimate and comfort level. It was found that for the women participating in the study, despite the lower recorded values of humidity, the amount of sweat produced indicated a lower level of perceived comfort than men, while reaching the state of thermal equilibrium faster after the end of physical effort.

In order to analyze the series of temporary changes in temperature and humidity in the sub-clothing microclimate under treadmill training conditions, tests were carried out on the changes in the sensation of the body's thermal balance based on the recorded values of changes in skin temperature, body temperature, heart rate and skin-galvanic reactivity (EDA) [22].

The results of the measurements were used as input data for the model of the human organism's response to the thermal load caused by intense physical effort. The authors of the publication stated that the average values of temperatures considered separately for the phases of rest, exercise and rest are the significant factors in the assessment of thermal alliesthesia. However, in terms of indicators describing the heart rhythm and its variability, the results were not satisfactory.

Special test benches with a treadmill and a series of wireless sensors are used to evaluate protective clothing with a share of PCM (phase change materials) [23] and to describe the physiological comfort analysis of waterproof and vapor permeable products [23, 24]. Sub-clothing microclimate conditions were evaluated to analyze the effectiveness of clothing products that absorb and emit heat [25]. The corresponding chapter of monograph Ref. 27 presents the measurement procedure for the assessment of changes in the value of temperature and humidity in the sub-clothing microclimate during intense exercise on the training treadmill. A statistical evaluation of the developed method was presented, based on the results of the series of measurements with the participation of groups of women and men actively practicing running.

On the other hand, Ref. 28 assessed the conditions in the sub-clothing microclimate while driving the cyclo-ergometer. The conditions in the test room, defined as normal climate according to PN-EN 139, were 20 °C (temperature) and 65% (relative humidity). It has been shown that the lack of thermal and humidity equilibrium determined on the basis of measurements before and after physical effort corresponds to the user's feeling of discomfort. It was determined that the equilibrium state can be assumed when the temperature values in the sub-clothing microclimate before and after physical effort do not differ more than by 1 °C.

The examples of research works in the field of analysis and evaluation of the sub-clothing microclimate confirm that the environmental conditions, the intensity of physical effort and gender influence the state of thermal alliesthesia and the subjective perception of the moisture balance in the underwear area.

2 Method

Clothing products, designed for workers with motor disability to meet ergonomic and comfortable requirements, were subjected to the study of sub-clothing microclimate conditions. The fabrics, from which workwear for disabled people were made were subjected to an examination of physical properties describing the biophysiological comfort parameters. Additionally, in order to compare the design solutions developed, the standard workwear, available on the market, in typical design was also tested.

2.1 Test objects

2.1.1 Textile materials for garments

The characteristic of two fabrics, which the clothing products were made of, are presented in Table 1. The fabrics are marked by 1 and 2, whereas fabric 3 is the material used in design of commercially available workwear.

Table 1. Fabrics characteristic.

Parameter (unit)	Test method	Fabric		
		1	2	3
Raw material (%)	PN-72/P-04604 PN-92/P-04846 PN-93/P-04847.10 PN-EN ISO 1833-11:2017-12	65% PES, 35% CO	65% PES, 35% CO	87% CO, 12% PA, 1% CF
Areal weight (g/m^2)	PN-ISO 3801:1993 p.6.7	243	204	265
Density (1/dm) - weave - weft	PN-EN 1049-2:2000	 344 200	 410 244	 240 170
Air permeability (mm/s)	PN-EN ISO 9237:1998	136	73.6	145
Water vapor resistance (m^{2}Pa/W)	PN-EN ISO 11092:2014-11	2.58	2.79	4.20
Thermal resistance (m^2 K/W)	Permetest Instrument, Sensora, Czech Republic	0.005	0.003	0.01

The knitted fabric which the underwear set was made of and which was used in tests of sub-clothing microclimate conditions, also was subjected to the examination of biophysical properties. The results are presented in Table 2.

Table 2. Underwear characteristics.

Parameter (unit)	Test method	Results
Raw material (%)	PN-93/P-04847.06 PN-EN ISO 1833-7:2017-12	93% PA, 7% EL
Areal weight (g/m^2)	PN-EN 12127:2000	242
Stitch density (1/cm) - warps, - courses	PN-EN 14971:2007	 17 32
Water vapor resistance (m^{2}Pa/W)	Permetest instrument, Sensora, Czech Republic	3.09
Thermal resistance (m^2 K/W)	Permetest instrument, Sensora, Czech Republic	0.01

The fabrics meet the requirements of the PN-P-84525:1998 for workwear and the PN-EN ISO 13688:2013-12 containing general requirements for protective clothing. In order to reduce the effects of prolonged contact and pressure of the fabric on the skin, fabrics with appropriate values of indicators describing biophysiological comfort were taken into account in the process of designing the work clothes for people with motor disabilities. The fabrics are characterized by high air permeability and low resistance to water vapor transmission. The knitted fabric of which the underwear set is made is characterized by very low thermal resistance, while the water vapor resistance does not exceed the values obtained for fabrics 1 and 2 significantly, for fabric 1 differs the most – by ca. 16%, in comparison to the water vapor resistance reached by fabric 3, where the difference increased up to 36%.

2.1.2 Garment construction

In the process of designing the work clothes for people with motor disabilities, the focus was on improving the working conditions of a person in a wheelchair for a long period of time in a forced sitting position and on providing the work comfortably, taking into account the different needs and expectations of these workers. The designed workwear dedicated to people with motor disabilities minimizes everyday loads, such as manipulation difficulties when dressing and undressing, and its design takes into account the topography of particularly sensitive places in relation to the figure in a sitting position. For example, in the lower body part, such stresses occur around the knees and buttocks, at the seat seam, while in the upper body part the lower back, upper back, shoulder height and elbows are particularly sensitive areas.

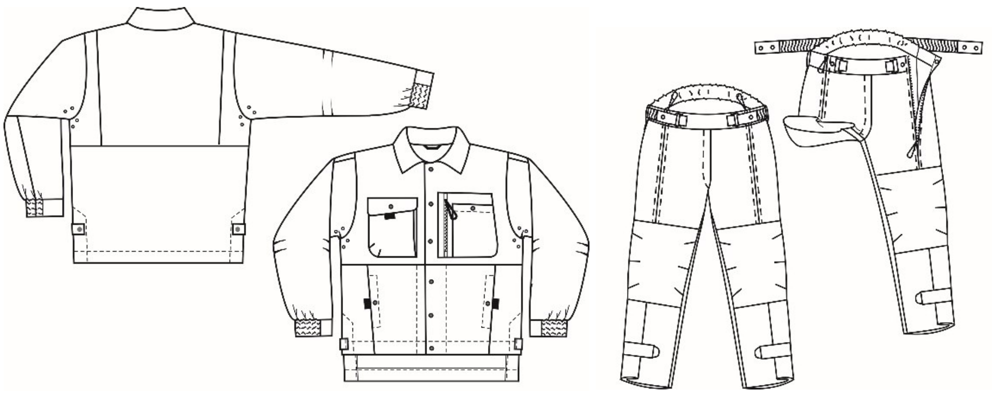

Fig. 1 Flat drawing of garments 1 and 2.

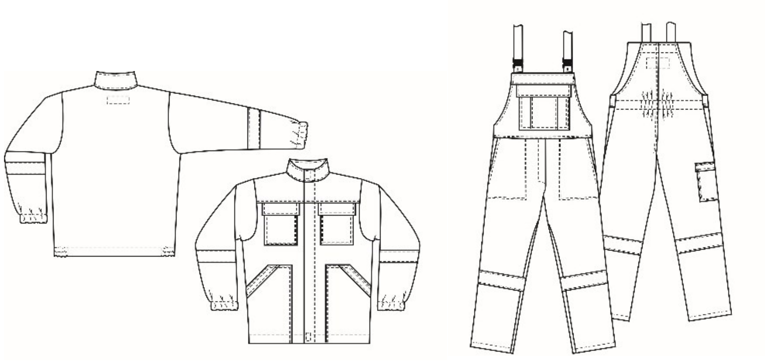

Fig. 2 Flat drawing of garment 3.

Taking into account the above considerations, two types of work clothes for employees with motor disabilities were made, garment 1 and garment 2. The design of these garments is the same, but they differ in the fabric used. Moreover, in order to compare the new developed design and material solutions, workwear (garment 3), available on the market in typical design and made of fabric meeting the required standards, was selected. Figure 1-2 present model drawings of the tested garments.

2.2 Measurement stand

The tests of temperature and humidity conditions in the sub-clothing microclimate were determined in accordance with the Research Procedure No. 72 developed at the Textile Research Institute. The measurement principle is based on recording changes in temperature and humidity with the help of sensors placed in the area between the user's skin and the clothing during the measurement session. The conditions inside the room met the criteria of normal atmosphere according to PN-EN ISO 139:2006, that means temperature (20±2) °C and humidity (65±4)%. The station is equipped with LB-516A wireless sensors that record the temperature and humidity with a measurement uncertainty ±0.2 °C and ±3%, respectively. The resolution for temperature measurement is 0.1 °C and for humidity is 0.1%. Due to the subject of the study, i.e. workwear dedicated to people with motor disabilities, the measurement procedure was modified for use with a wheelchair.

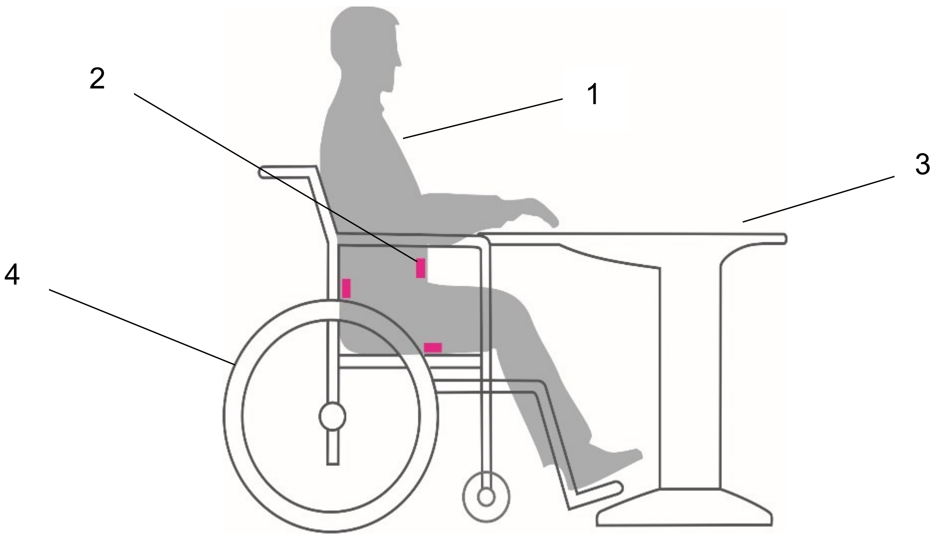

Fig. 3 Measurement stand for microclimate conditions assessment.

Figure 3 presents the scheme of measuring station. The person participating in the test (1) sits in the wheelchair of the typical design (4) at the station adapted to manual work (3). Four pieces of temperature measuring sensors and humidity (2) marked in Fig. 1 with red rectangles are placed in the following areas of the user's body:

- lumbar area – 1 sensor,
- inner surface of the thighs in contact with the surface of the wheelchair seat – 2 sensors,
- lower abdomen – 1 sensor.

The sensors were placed in the area of sub-clothing microclimate between tight-fitting underwear and the tested garment.

2.3 Test procedure

The measurement session consists of two phases – the first phase is rest, used to obtain the thermal-humidity balance before the actual measurement, lasting 15 minutes, and the second phase is the proper measurement, lasting 45 minutes. A female person, age 49, body mass index (BMI) 18.6, participated in the study. During the measurement, the participant performs manual activities with low energy expenditure according to Table 2 of ISO 8996 [29], i.e. with an approximate value of energy expenditure of 180 W. The type of work performed during the test is: writing, typing, manual work engaging hands and forearms. The temperature and relative humidity values were recorded throughout the study. The result of the measurement is the graph of the time course of changes in these values.

3 Test results

For each of the garments tested, a series of measurements was carried out according to the research procedure described in point 2.2. For each of the sensors, graphs of changes in temperature and humidity during measurement procedure were recorded. The phase I and phase II studies (black line) were separated on the graphs and the mean value for phase II (dashed line) was marked. An exemplary set of temperature and humidity change curves recorded for garment 1 is shown in Fig. 4-7.

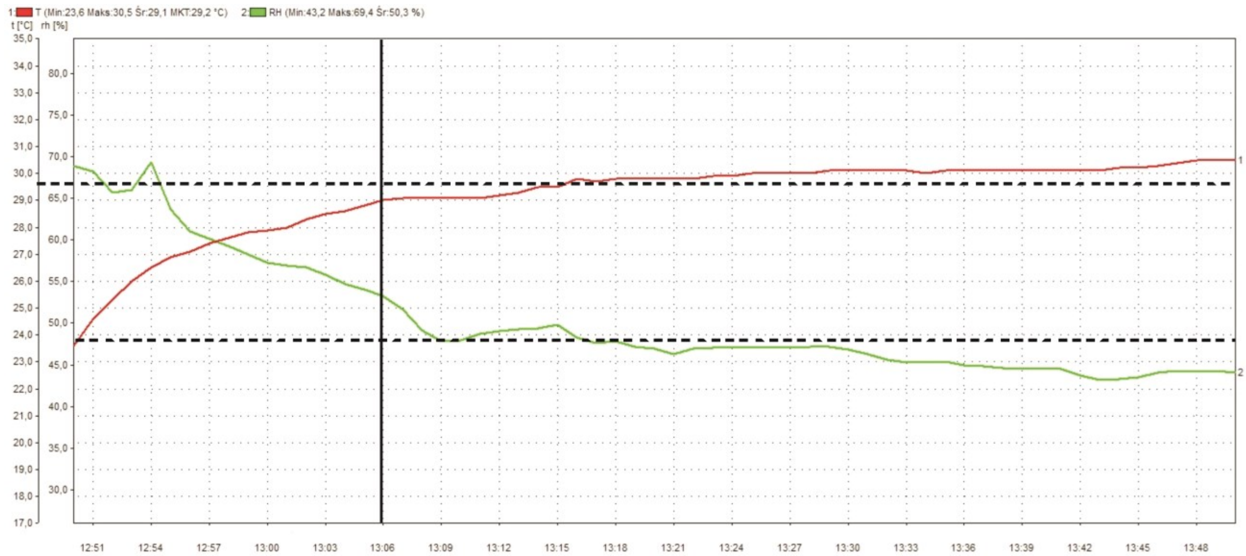

Fig. 4 Temperature and humidity changes for the lower abdomen.

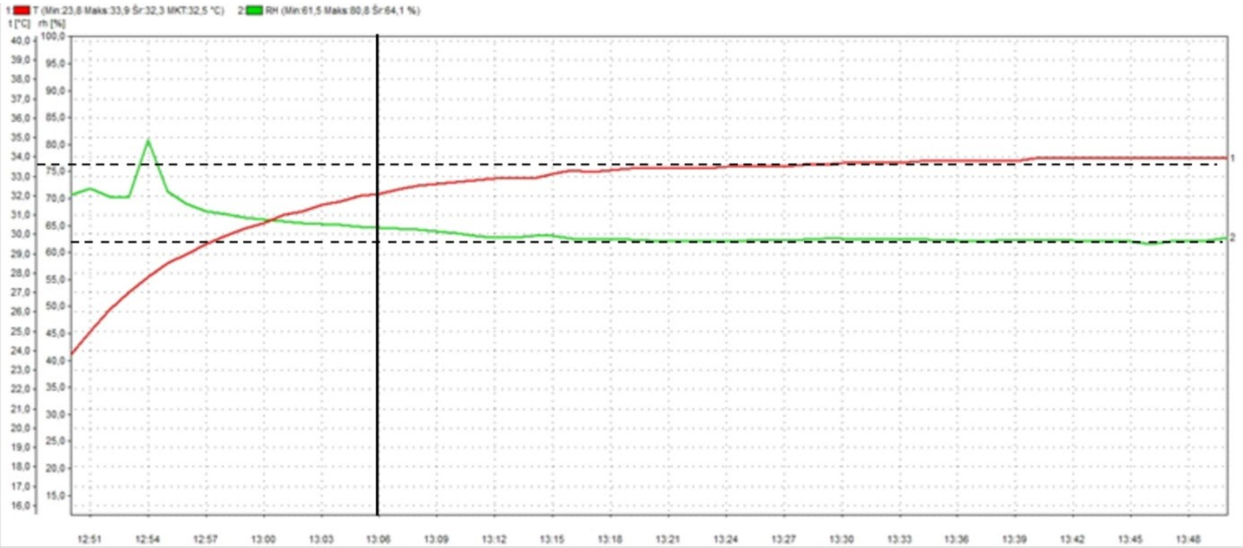

Fig. 5 Graph of temperature and humidity changes for the lumbar area.

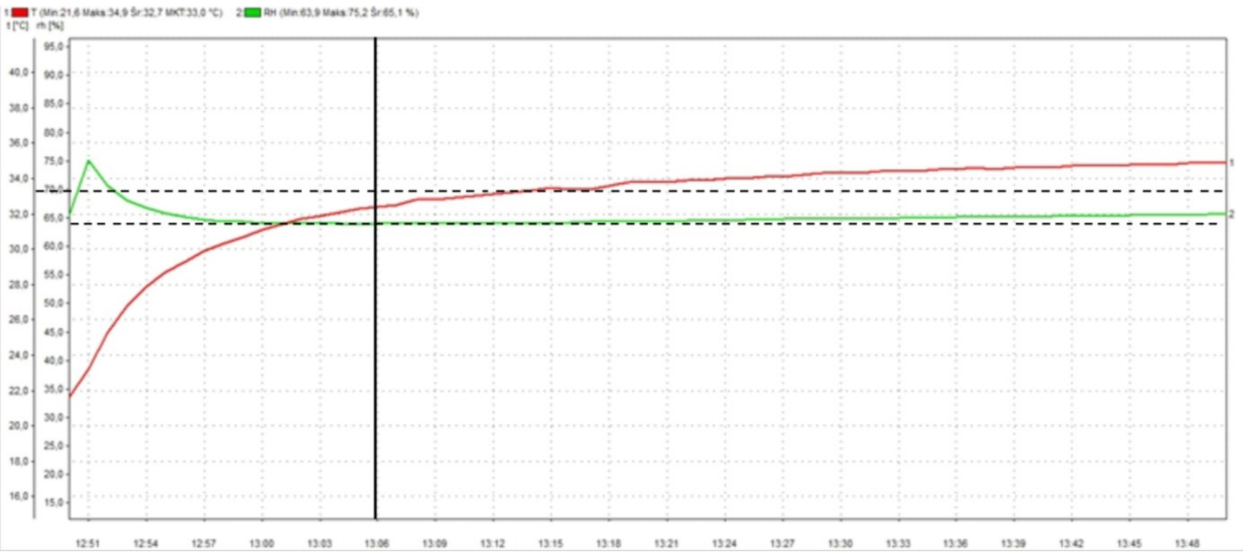

Fig. 6 Graph of changes in temperature and humidity for the left thigh.

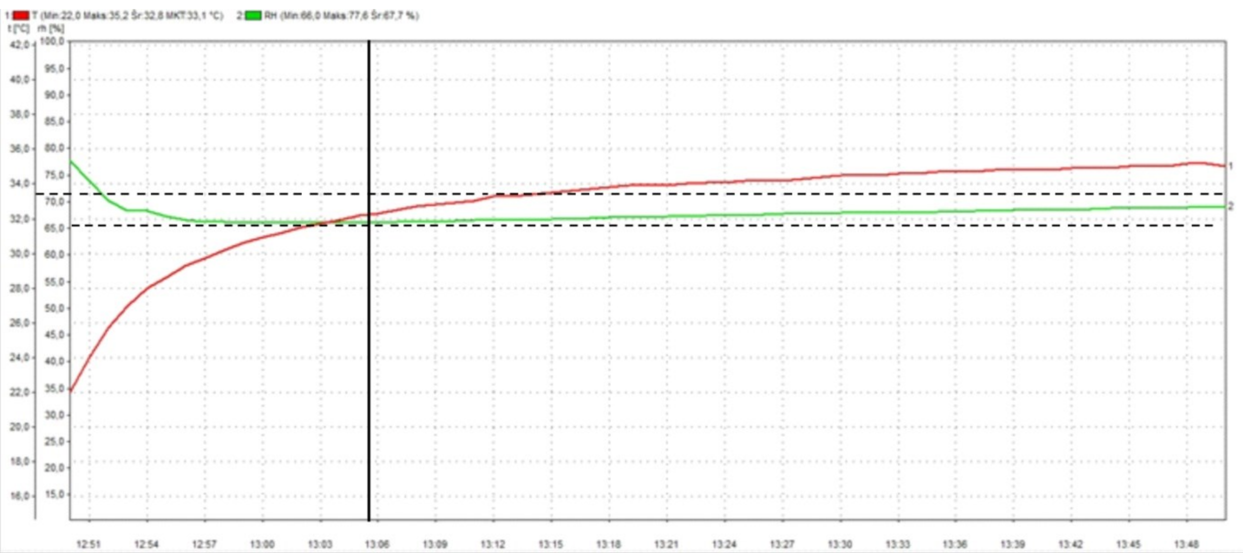

Fig. 7 Graph of changes in temperature and humidity for the right thigh.

For each phase, the mean values of the time course of temperature and humidity were determined. The values are summarized in Table 3.

Table 3. Test results of sub-clothing microclimate conditions.

Place of measurement	Garment 1	Garment 2	Garment 3
lower abdomen			
- temperature (°C)	29.5	30.5	31.5
- humidity (%)	47.0	46.0	55.0
lumbar area			
- temperature (°C)	33.5	32.5	33.5
- humidity (%)	62.0	56.0	62.0
left thigh			
- temperature (°C)	33.5	33.5	33.5
- humidity (%)	64.0	65.0	66.5
right thigh			
- temperature (°C)	33.5	33.5	34.0
- humidity (%)	65.5	67.0	67.5

4 Discussion

The results of the study of the conditions existing in the sub-clothing microclimate obtained for the three tested garments were compared in terms of ensuring the biophysiological comfort of the user. The values of humidity in the epidermal layer of the sub-clothing microclimate depend on the temperature. The increase in temperature in the sub-clothing microclimate generates an increase in humidity, aiming to achieve a state of thermal equilibrium, i.e. cooling the skin surface. Comparing the values of temperature and humidity between the particular garments tested, it can be concluded that:

- the lowest temperature and humidity values were recorded for the lower abdominal area, with a significant difference (about 10%) between the humidity values obtained for garment 1 and 2 and garment 3 (standard), in favor of the garments designed with respect of needs of motor disabled people. In relations to temperature, the lowest values were obtained for garment 1, wherein these are 2 °C lower compared to garment 3 and 1 °C lower compared to garment 2.

- taking into account the lumbar area, the temperature values are on higher level in comparison with abdominal area (by approx. 2 °C), wherein humidity values increased by approx. 10%. It is related to higher thermal load of the lumbar area during staying for a long time in a sitting position. The lowest values of temperature and humidity were recorded for garment 2, with a humidity difference of 10% in relation to garments 1 and 3. Garment 2 was made of a fabric with greater density but with lower areal weight compared to fabrics 1 and 3.

- temperature and humidity values in the areas of both thighs are similar to each other. The temperature values for most measurements are 33.5 °C, similar to the measurements in the lumbar area. This indicates the occurrence of significant thermal load also in the areas of the underside of the thighs while sitting for long periods of time. Similarly, all values of humidity are also at the level of about 65% taking into consideration the measurement uncertainty of 3%. The lowest values of humidity were observed in the thigh areas for garment 1, with differences of 1-1.5% in relation to garment 2 and 2% in relation to garment 3.

- differences in the results of moisture measurements between the tested garments mainly occur in the lower abdomen and lumbar. In the thigh areas, the moisture values are at the similar high level for all tested garments.

Analyzing the results of the study of moisture conditions in the sub-clothing microclimate in the context of selected fabric parameters, it is observed that the values of moisture in the areas of the lower abdomen and lumbar are the lowest for garment 2, made of fabric with the lowest areal weight. At the same time, this fabric is characterized by the highest density in the warp system, while the density of weft system is similar to the other fabrics. In addition, fabric 2 has the lowest air permeability, relatively low water vapor resistance, and the lowest thermal resistance compared to the other two fabrics.

5 Conclusions

Summarizing the obtained results of the study of thermal and humidity conditions existing in the sub-clothing microclimate, taking into account also the structure of fabrics and the values of determined indexes connected with the assessment of comfort of use, it can be stated that for the lower abdominal and lumbar areas the most favorable conditions in the scope of humidity are provided by garment 2. However, for the areas of the inner thigh surface, at the same temperature values, the recorded humidity values are slightly lower for garments 1 compared to garment 2, but not exceeding the uncertainty value. Due to the same design of garments 1 and 2, it can be concluded that when designing workwear for people with motor disabilities, it is beneficial to use fabrics with different properties related to biophysiological comfort in the parts of the garment covering the upper and lower body part. In addition, garments 1 and 2, compared to garment 3 of typical design, have a better ability to provide thermal and moisture comfort to individuals who are in the seated position for long periods of time.

Author Contributions

Izabela Jasińska: conceptualization, methodology; Katarzyna Śledzińska: methodology, formal analysis, writing – original draft preparation; Lidia Napieralska: formal analysis, investigation; Violetta Jarzyna: methodology, test objects preparation; Ewa Witczak: conceptualization, writing – review and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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