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Evaluation of Clothing Comfort Properties Using the Cycloergometer Test

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Abstract
The aim of study was to present an evaluation of sports underwear under different conditions and applying two measurement techniques. The test was performed on a ergometer simulating real conditions of wearing clothes. Moreover, the material parameters of knitted fabric selected were evaluated according to standards. The utility tests performed by the ergometer allow one to assess fabric under the action of the human thermoregulation mechanism. and therefore such tests more effectively characterise the article under testing. Test results of the underclothing micro-climate of sports underwear showed a statistically significant dependence on the person participating in the tests.

Key words: *biophysical comfort, clothing comfort, humidity balance, microclimate, sports underwear.*

Introduction

The basic function of clothing is to maintain a proper human body temperature under variable environmental conditions and energy expenditure to provide thermal balance as well as thermal and humidity comfort. The thermal and humidity comfort of clothing materials is characterised by parameters such as heat insulation ability, the wind shielding capacity permeability of water vapour and air, hygroscopicity, capillarity and water-resistance. In the research investigation made by Senthilkumar and others [1], the effect of fibre type in yarns forming woven fabric with a plain weave on thermal comfort was analysed, showing that cotton-polyester fabric has better thermo-insulating properties than that made of viscose-polyester blend. Fabric containing viscose fibres has better air permeability. Skenderi and Cubric [2] analysed the thermal comfort parameters of knitted fabrics made of cotton, viscose and Tencel viscose fibres. They showed that fabrics characterised by high heat absorption and low diffusion slow down the process of evaporation heat release and inhibit activation of the sweating mechanism, whose aim is to cool the user's body. In some other studies [3-4] the authors also analysed the effect of raw materials used to make fabrics on their thermal and bio-physiological comfort. Phase change materials (PCM) were widely used to improve thermal comfort properties. In the publication of Bartkowiak and Dąbrowska [5], the properties of two types of knitted fabrics made of yarn with PCM compound were investigated. Comfort properties such as thermal resistance, water vapour resistance, air permeability and hygroscopicity were analysed, together with thermoregulation properties tested in dynamic conditions – using a device simulating the thermal behaviour of human skin. Researchers from Yeungnam University [6] designed a water-repellent outdoor winter jacket coated with PCM for better thermal and water vapour transportation properties. It was found that the amount of PCM materials used in the coating process was insufficient to obtain desired properties, and further investigation was needed. Many researchers have also analysed the parameters of the underclothing microclimate. A publication presented by a group of researchers from Ghent University (Belgium) and Bahir Dar University (Ethiopia) showed not only a wide range of thermal comfort assessments of a garment but also evaluations of ergonomic comfort as well [7]. Researchers from the Central Institute for Labour Protection – National Research Institute (CIOP-PIB) [8] analysed the impact of equipment type and garment assembly designated for a mine rescue team for parameters such as the internal body temperature, and the temperature and humidity in the underclothing microclimate. They used air ventilated cooling vests as an undergarment to take heat expenditure away from the clothing microclimate, when the outer atmosphere temperature was 32 °C or 38 °C. They found that even active cooling vests were not able to maintain safe thermal conditions of the users, which meant a necessity for further investigation in this field. Another example of microclimate tests is in research paper [9], which presents the results of analysing the microclimate inside caps during wearing. These tests were aimed at the determination of optimal cap fabric properties to provide the user with both thermal comfort and safety of use with respect to protection against head overheating. In the research work realised at the Indian Institute of Technology [10], the subjective and objective evaluation of jackets dedicated for cold weather conditions was carried out. High values of the correlation coefficient between the subjective and objective evaluations were found, but only at ambient temperature. The jacket showing maximum thermal insulation in objective evaluation was found to fail in giving a comfortable feel during the wear trial. Researchers from the University of Innsbruck (Austria) [11] investigated gender influence on underclothing microclimate conditions. Wear trial tests, including exercise and rest phases, were carried out in cold conditions (12 °C, relative humidity 40%). Test subjects were outdoor jackets dedicated for use in cold conditions. They concluded that females were more sensitive to an increase in humidity in-

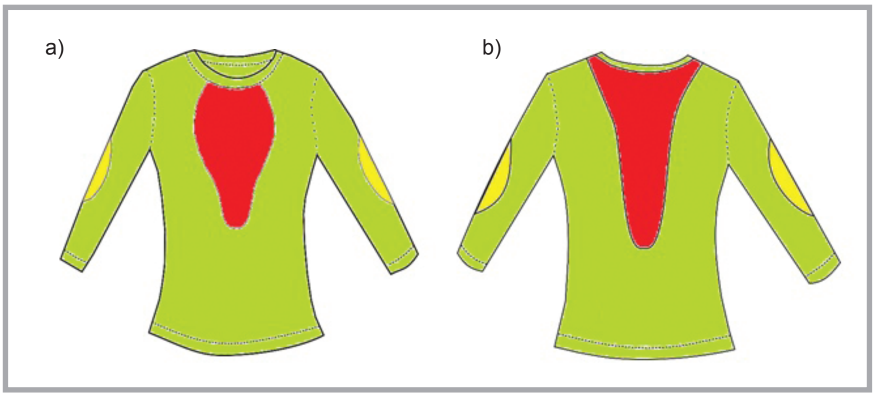

***Figure 1.** Model of t-shirts: a) front, b) back.*

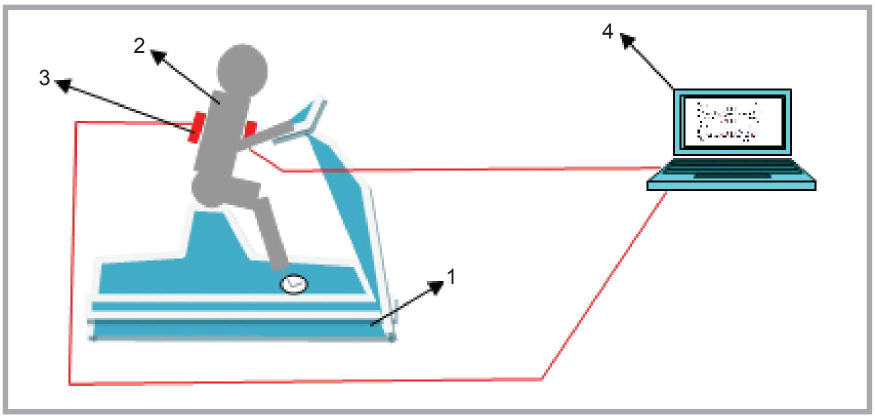

***Figure 2.** Measurements stand.*

side the underclothing microclimate, especially during the rest phase of the test. Another issue dealt with by researchers was maintenance of the thermal-humidity comfort of clothing during its wearing in intensive physical exercise (sports practice) [12]. The aim of that study was to determine an optimal set of materials for sports clothing (T-shirts) that could provide thermal and humidity comfort during intensive physical exercise. It was found that the type of fibres used for making the fabrics tested exerted a considerable effect on heat and humidity transport during exercise. In the research work carried out by Shinjung and Eunae [13], the influence of the multilayer combination in a garment was investigated. The researcher concluded that a combined array (consisting of fleece fabrics and a ePTFE membrane attached to the outermost fleece fabric) gave a better result in the scope of water vapour permeability. Besides the above-presented test method of assessing the environmental conditions of a clothing microclimate, a number of researches concerning mathematical simulation were carried out [14-16]. The rate of heat and moisture transfer from air gaps to the outer environment was calculated on the basis of material properties and outer conditions; especially, a cold environment was considered. In summary, the analysis of microclimate conditions during an exercise test with the participation of a man allows one to characterise the fabric's capability to transport water vapour from the underclothing microclimate during the real process of sweating and cooling of the body surface. Therefore, assessment of clothing fabric efficiency in providing utility comfort, including its thermal, moisture and sensory elements, should be carried out under real conditions. In addition, the fabric material properties determined can constitute initial data for the process of designing clothing fabric structures.

***Table 1.** Characteristics of the sport's shirt.*

Parameter/part of shirt	Value/stitch	Test method
Linear density of yarn, dtex – polyamide + elastan – polypropylene	 84 56	Test procedure IW:51
Upper part of front and back	jacquard	PN-EN ISO 8388:2005
Middle part of shirt	plain plated	
Elbow part	plain jacquard plated	
Knitted fabric 1		
Average surface weight, g/m^2	249 ± 9	PN-P-04613:1997
Plain plated knitted fabric Number of courses/1 cm Number of wales/1cm	 19,3 ± 0,1 19,0 ± 0,2	PN-EN 14971:2007 method A

***Table 2.** Characteristics of participants.*

Participant No.	Gender	Age	Height, cm	Weight, kg	BMI index	Shirt size
1	female	43	163	52	19.6	S
2	female	56	160	74	28.9	L
3	female	57	160	60	23.4	M
4	male	35	182	75	22.6	S
5	male	43	184	82	24.2	M
6	male	38	172	80	27.0	L

Materials and methods

Seamless sport shirts with long sleeves were used to analyse the underclothing microclimate. These were made of knitted fabric with the following raw material composition: 56% polyamide fibres, 39% polypropylene fibres, and 5% elastomeric fibres. The seamless shirts were close fitting, with barely no air gaps existing between the user's body and the garment. Each participant wore a shirt in a size (***Table 2***) appropriated to their chest size, according to the manufacturer size's declaration. The parts of the shirt were manufactured with various stitches, described in detail in ***Table 1***. The distribution of stitches in particular parts of the shirt is presented in ***Figure 1***, where red colour means a jacquard stitch, green – plain plated, and yellow – plain jacquard plated. The plain plated stitch (marked as knitted fabric 1) was the object of analysis of parameters which describe the utility comfort of shirts. Characteristics of the knitted fabric technological parameters are given in ***Table 1***.

In the scope of the work, two types of textile assessment were carried out. Firstly, the following material parameters of knitted fabric 1 were evaluated: permeability to air, water absorption, hygroscopicity, porosity, resistance to water vapour, and sorption features. The above mentioned parameters enable to assess knitted fabric 1 with respect to its ability to exchange heat and moisture streams from the clothing microclimate to the outer environment. The next step of the research study was to carry out tests of utility comfort in similar- to -real use conditions. The aim of the test was to simulate the real- use effort of the person participating in the analysis in laboratory conditions. Moreover, during the test, the temperature and humidity in the near-skin layer of the clothing microclimate were recorded. A long- sleeved sport shirt was assessed with regard to its ability to transport heat and water vapour from human skin to the environment. Tests of microclimate comfort were carried out using a measurement stand previously designed in the scope of project [17] with further modifications, presented in ***Figure 2***. The cycloergometer (1) makes it possible to select the participant's load assumed in the test (2). Typically, the load was 50 W. Measurement sensors (3) directly collect the values of temperature and relative humidity in the underclothing micro-climate. Data from the measurement system are recorded and presented in the form of a graph (4). Tests were carried out in conditions according to PN-EN 139:2006+A1:2012 (temperature 20 °C, 65% RH).

Sensors were located in the following body zones:
- zone A , chest area (the middle part of the chest, the sternum position)
- zone B, back area (the upper part of the back, between the shoulder-blades)
- zone C armpit areas (the sensors were situated 15 cm below the height of the shoulders).

The participants were healthy persons with good physical fitness, but different values of the BMI index. Involving participants with a width range of BMI index values in the test reflects the conditions in which the sports underwear could be used. This type of underwear is designed predicted for different groups of people, including persons that practise a sport only for leisure and relaxation. ***Table 2*** presents detailed information about the participants.

The test procedure consists of three phases:
- phase I, lasting 15 min, with the participant at rest. The temperature and relative humidity in the near-skin air layer are recorded.
- phase II, lasting 30 min, with the participant doing exercise (cycling) with a constant energetic expenditure of 50 W. The temperature and relative humidity in the near-skin layer are continuously recorded.
- phase III, lasting 30 min, with the participant at rest after exercise. The parameters of the underclothing micro-climate are continuously recorded.

Results and discussion

Material parameters of knitted fabric

Table 3 contains average values of material parameters related to the comfort of knitted fabric 1.

The test results for water vapour resistance and air permeability were evaluated according to CEN/TR 16422:2012 [18]. The following performance levels were used: A (very good), B (good) and C (acceptable), according to values of the above-mentioned parameters, garment utility and climate type. Summing up the results of the knitted fabric No. 1 for material physical parameters related to comfort, it may be concluded that:
- a value of air permeability above 100 mm/s is sufficiently high to ensure the appropriate ventilation and air transmission of shirt, which corresponds to the grade A performance level for both warm and cold climate conditions. However, it also shows low values of porosity, which is the relationship of the empty space area in the knitted fabric structure to the whole area of fabric.
- the resistance of water vapour slightly above 5 m^{2}Pa/W is considered as high for a one layer garment for skin contact material, reaching only performance level C in warm conditions and B in cold ones. It means that the knitted fabric is able to transmit water vapour through its structure, but in heavier outer conditions (warm and humid atmosphere) water vapour cannot be transmitted effectively enough.

As regards other parameters, such as water absorption, hygroscopicity and sorption/desorption, it was found that:
- knitted fabric No. 1 absorbs water into its structure very well, as well as water vapour from a humid atmosphere. Sweat could be easily taken out from the skin surface and absorbed by the knitted fabric structure, which corresponds to the values of sorption velocity and sorption time, which are high enough to enable quick water transport through the knitted fabric. On the another hand, the value of desorption velocity is relatively low comparing to that of the sorption velocity, which means that the knitted fabric absorbs water quickly, but takes it out significantly slowly in a normal atmosphere (20 °C, 65%), according to EN 139.

Taking into account only physical parameters of utility comfort, the shirts tested should provide thermal and moisture exchange comfort. It should be mentioned, however, that the assessment of shirt thermal and humidity comfort carried out on the basis of material parameters may differ from that made under cycloergometer test conditions. Therefore, a comprehensive assessment of this comfort was performed after the analysis of test results obtained with the use of the cycloergometer.

Evaluation of comfort involving the cycloergometer test

In the test series, six participants took part, three women and three men. As a result of each test, two diagrams were

Table 3. *Comfort parameters of knitted fabric 1.*

Parameter	Result	Test method
Air permeability, mm/s	136 ± 22	PN-EN ISO 9237:1998
Water absorption, g/m^2	719 ± 44	PN-P-04734:1972
Hygroscopicity, %	4.79 ± 0.8	PN-P-04635:1980
Porosity, %	0.08 ± 0.04	Test procedure IW:60
Resistance of water vapour, m^{2}Pa/W	5.18	PN-EN ISO 11092-2014-11
Sorption factors: – sorption values, μl/cm^2 – total sorption time, s	 86.2 21.8	Test procedure IW:14/1
Desorption factors: – desorption value, μl/cm^2	 9.06	Test procedure IW:14/2

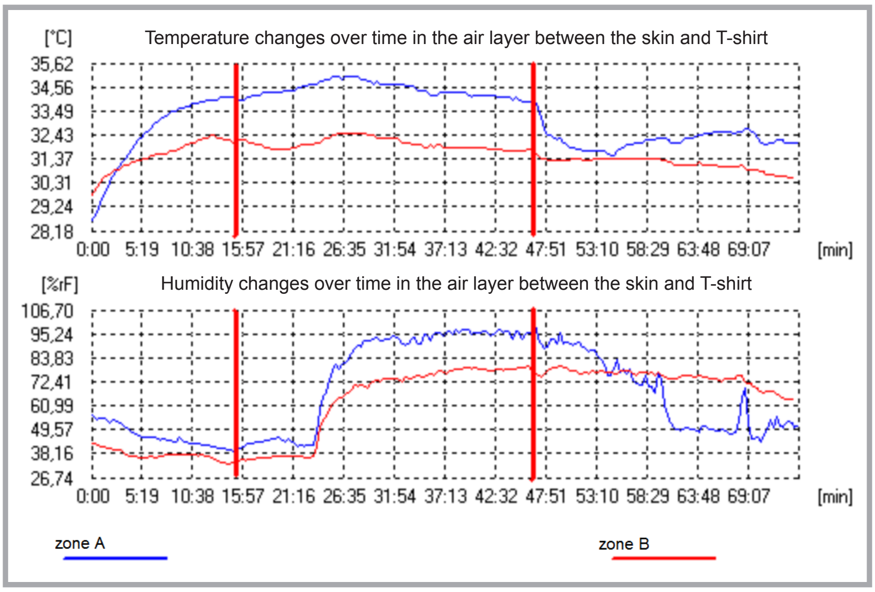

Figure 3. *Temperature and humidity changes for evaluated shirt – participant No. 3 (zones A and B).*

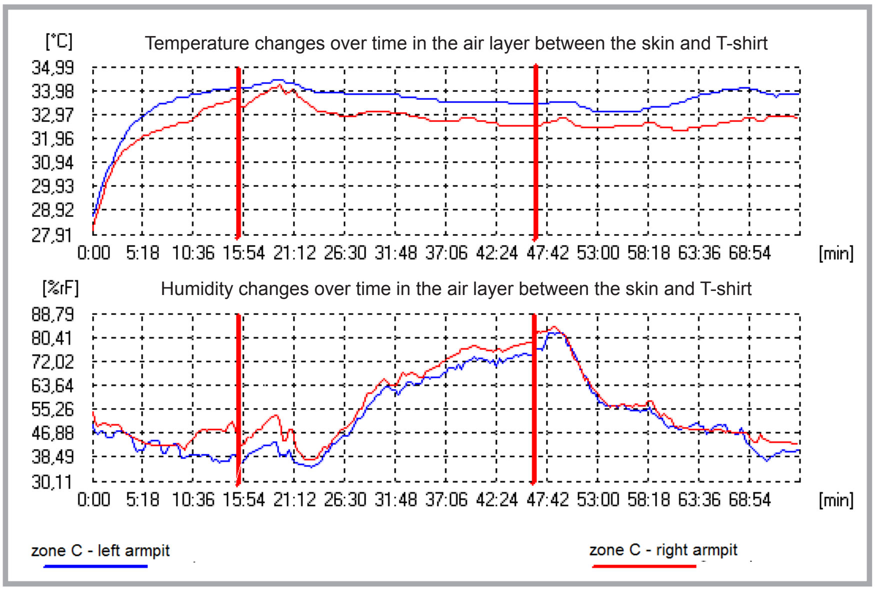

Figure 4. *Temperature and humidity changes for evaluated shirt – participant No. 3 (zone C).*

obtained presenting the time distribution of temperature and relative humidity in zones A, B and C of the underclothing micro-climate near-skin layer. If the equilibrium state for the zone investigated was achieved, the values of temperature and humidity at the end of phase I and III were reckoned to be the same. If the above-mentioned condition is not met, the garment assessed will not properly transport heat and moisture outside the under-clothing microclimate. Below are presented selected test results of underclothing comfort for the sports shirt. The first pair of diagrams, presented in ***Figures 3*** and ***4***, were obtained during the test with participant No. 3. The next two, ***Figures 5*** and ***6***, show results obtained for participant No. 6.

The investigation presented below regards the results selected and shown in the figures above. Taking into account the variety of results obtained for male and female participants, both genders were evaluated separately. Firstly, analysis of microclimate conditions for female participants was conducted.

Evaluation of temperature as well as humidity alterations in the near-skin layer was carried out in all zones by comparison between the values of the above-mentioned indicators recorded at the end of phase I of the test and those recorded at the end of phase III . In zones A and B the difference between the temperature of the phases analysed averaged about 2.0 °C (***Figure 3***). With respect to humidity changes, a state of equilibrium did not occur in relation to the humidity value in the final portion of the rest phase for the zones mentioned. The humidity values were higher by more than 5% in relation to that in the rest phase (***Figure 3***). Regarding zone C, the temperature remained steady in the parts of test phases investigated (***Figure 4***). The humidity values in zone C reached the equilibrium state after an average of 26 min of the rest phase.

Secondly, in the tests carried out for male participants, the following results were obtained and assessed in the same way as in the case of female participants. Differences in the temperature of the near-skin layer in zones A and B varied from 0.5 °C to 2.0 °C, both cases being higher at the end of the test (***Figure 5***). Humidity values attained a state of equilibrium in zone B in the final part of the rest phase; but in zone A the difference between the end parts of the phases analysed was 30%, which means that no equilibrium state was achieved (***Figure 5***). Moreover, during the exercise and rest phases, 100% humidity was recorded, which is connected with the huge level of evaporation, unable to be managed and go out of the near-skin layer microclimate. The temperature values recorded in zone C during the test maintain the same level in the parts of test analysed (***Figure 6***). Another such case took place when the humidity was evaluated in zone C, where the armpits showed significant differences in removing the deluge of moisture produced by the human body. In one case, the humidity values went up as high as 100% in the middle of the rest phase, without a further decrease. For the second armpit, an equilibrium state of the moisture content in air gaps was achieved after 16 min of rest.

Summing up the whole set of results in the tests carried out with the sports shirt by means of the cycloergometer, it may be concluded that:
- temperature changes observed during the tests were relatively high. In 9 out of the 24 measurement series, the temperature differences occurring in some areas were higher than 2.0 °C. The seven successive measurement series were characterised by tempera-

ture differences above 1.0°C. The occurrence of considerable temperature changes during the rest phase shows that there is a necessity of the organism of the test participant to increase the skin temperature regulation rate, which is felt as discomfort in the form of shivers or heat sensation,

- in two cases (one in the women's group and one among the men) fluid sweat (100% relative humidity achieved) was recorded in the near-skin layer during the exercise phase. This phenomenon caused a feeling of strong discomfort in the person wearing the shirt under test,
- in five of the twelve cases, a state of humidity equilibrium was not reached in the near-skin layer of the underclothing micro-climate. This shows a relatively low fabric capability to transport uncondensed sweat from the near-skin air layer during testing under dynamic conditions,
- significant differences in the course of humidity and temperature changes were observed in the test phases within the women's and men's groups. These differences were subjected to separate statistical analysis. It should be mentioned that the tests carried out by means of the ergometer simulate real conditions of using the underwear and allow one to assess it under the action of the male thermo-regulation mechanism; therefore, these tests characterise the item tested more effectively.

Statistical analysis of the human influence on test results

Based on the measurement data collected for selected measurement areas, average values of the temperature and humidity in the near-skin layer of the underclothing micro-climate were calculated for each of the test phases and each test participant. To carry out statistical analysis of the influence of the participant on comfort parameters in the air layer between the skin and shirt tested, data collected in zones A and C were analysed. Average values of the temperature (T) and humidity (RH) for each of the three test phases for the selected zones for each participant are listed in ***Table 4***.

To establish the significance of the participant's influence on the test results obtained (temperature and humidity), one-way analysis of variance was carried out with the use of the STATISTICA module ANOVA. The analysis was carried out separately for both genders with the use

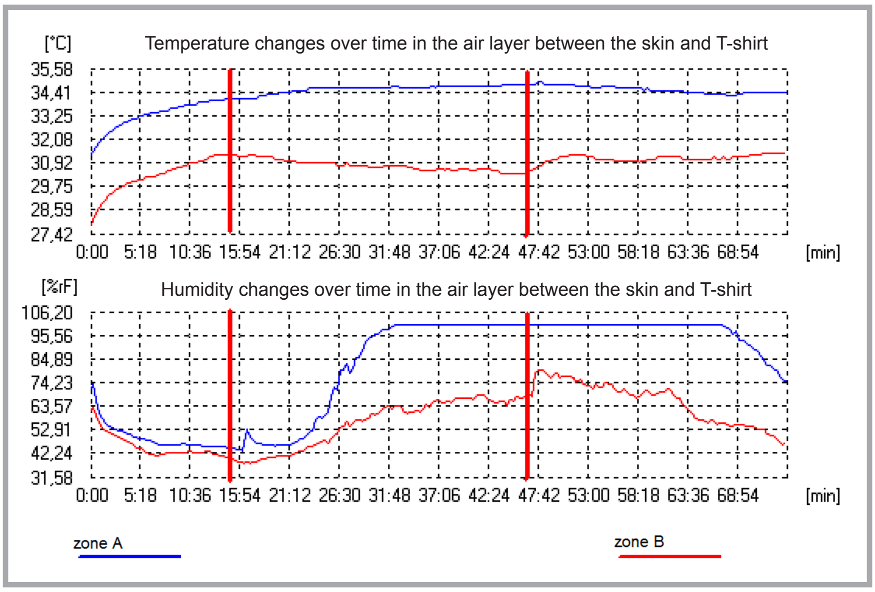

Figure 5. *Temperature and humidity changes for evaluated shirt – participant No. 6 (zones A and B).*

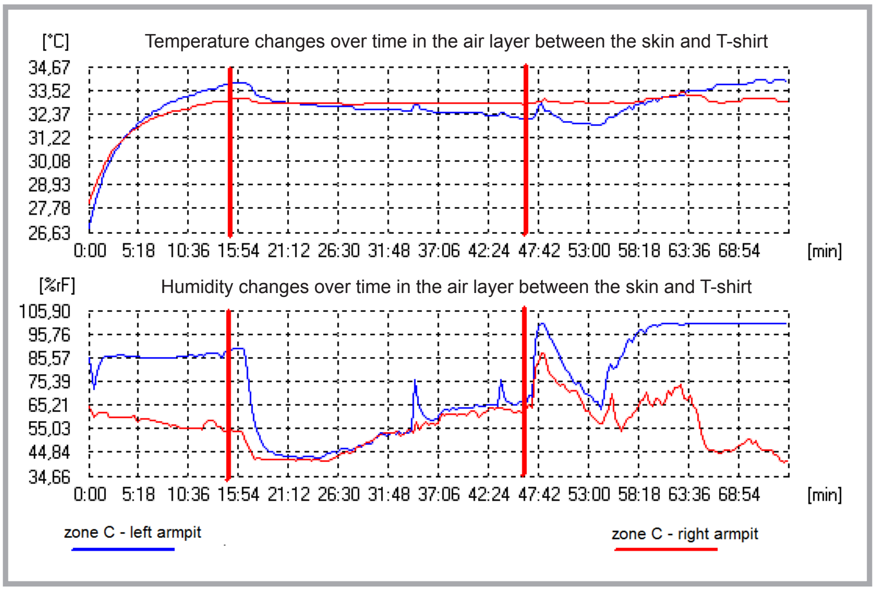

Figure 6. *Temperature and humidity changes for evaluated shirt – participant No. 6 (zone C).*

Table 4. *Average values of temperature and humidity in the air layer between the skin and shirt tested for each of the three phases for selected areas for each test participant.*

Participant	Phase I				Phase II				Phase III			
	T, °C		RH,%		T, °C		RH,%		T, °C		RH,%	
	zone											
	A	C	A	C	A	C	A	C	A	C	A	C
1	32.5	32.8	46.6	42.1	34.5	33.8	76.5	55.4	32.3	33.7	68.3	55.4
2	33.7	31.9	42.7	85.6	34.5	32.7	63.8	56.6	34.4	33.1	91.6	90.2
3	31.2	34.9	44.3	52.4	33.7	34.7	67.2	47.9	33.1	34.0	91.1	80.1
4	33.0	33.0	51.1	76.1	31.8	34.4	60.9	52.4	32.5	35.2	68.1	75.9
5	27.6	33.4	45.3	83.9	31.4	34.9	56.8	56.2	29.9	34.4	71.3	86.2
6	30.2	33.2	48.5	53.4	30.8	34.0	87.0	76.3	30.7	33.0	94.4	71.6

of the results obtained for the two zones selected. The assessment was made at the significance level $p = 0.05$. In all the cases analysed, a statistically significant effect ($p < 0.05$) of the test participant on the underclothing micro-climate parameters, measured using the ergometer, was found. The analysis made confirms the observation that the conditions of the underclothing micro-climate are closely connected with the individual features of the test participant. Therefore, to obtain a complete assessment of the clothing article tested, it is necessary to perform tests under conditions of real effort, with the participation of more than one person. It is also obvious that the results obtained can differ depending on the test participant. Interestingly enough, in the tests carried out with the participation of 3 women and 3 men; a generally better assessment of the sports shirts was made by men. Their subjective impressions, regardless of the test results obtained, concerning the comfort of wearing the shirts were positive, while women made a rather negative assessment of the clothing article tested.

Conclusions

1. The tests of underclothing micro-climate parameters carried out for the sports shirt showed a significant dependence of the test results obtained on the test participant. The temperature and humidity changes as well as the overall assessment of the shirt tested were connected with the individual features of the man or woman participating in the tests.
2. As regards the assessment of temperature changes during tests with the ergometer, it was found that in most measurement series, the locally appearing temperature differences between the end parts of the phases investigated were higher than 1.0 °C, and in some cases reached 2.0 °C. The occurrence of considerable temperature changes at the end of the rest phase showed the necessity of the participant's organism to increase the body temperature regulation rate, which was felt as discomfort in the form of shivers or heat sensation. Moreover, in two cases (one in the women's group and one among the men) fluid sweat was observed in the near-skin layer during the exercise phase. This phenomenon caused a feeling of strong discomfort in the person wearing the shirt under test.
3. The analysis of material parameters of the knitted fabric showed that the values of air and water vapour permeability were at an acceptable to very good performance level in dependence on outside conditions (warm or cold climate), according to CEN/TR 16422:2012, considering the utility of the shirt. The values of water absorption, water sorption and desorption, and hygroscopicity showed a very good ability of the knitted fabric to take liquid from the skin surface in a short time. Moreover, this fabric is not able to dry sufficiently quickly, especially in a humid environment.
4. The assessment of the physiological comfort of the sports shirt tested under real effort conditions differed from the evaluation of this comfort on the basis of physical parameters of the knitted fabric. This is due to the fact that tests performed by means of the ergometer simulate real but not extreme wearing conditions. However, it also allows one to assess physiological comfort under the action of the male thermoregulation mechanism; therefore such tests more effectively characterise the garment.
5. The statistical analysis performed to assess the influence of the test participant on the underclothing micro-climate parameters confirmed the observation that the conditions of this specific area are closely connected with the individual features of the person participating in the test. It was then found that correct characteristics of the product tested should be obtained with the participation of more than one person.

References

1. Senthilkumar P, Kantharaj M, Vigneswaran C. Thermal Comfort Characteristics of Plain Woven Fabrics. *Journal of the Textile Association* 2010; 71(4): 188-195.
2. Skenderi Z, Cubric I. Influence of Yarn Type on Thermal Comfort. *Melliand International*. 2011; 17(3):156-157.
3. Tyagi G, Bhattacharya S, Kherdekar G. Comfort Behavior of Woven Bamboo-Cotton Ring and MJS Yarn Fabrics. *Indian J Fibre Text Res*. 2011; 36(1): 47-52.
4. Oglakcioglu N, Celik P, Ute T, Marmarali A, Kadoglu H.: Thermal Comfort Properties of Angora Rabbit/Cotton Fibre Blended Knitted Fabrics. *Textile Research Journal* 2009; 79(10): 888-894.
5. Bartkowiak G, Dabrowska A. Assessment of the Thermoregulation Properties of Textiles with Fibres Containing Phase Change Materials on the Basis of Laboratory Experiments. *FIBRES & TEXTILES in Eastern Europe* 2012; 90(1): 47-52.
6. Park Y, Kim E. Wearing Comfort of Temperature-Adaptable Textiles by Dual-Phase Coatings Between Phase-Change Materials And Silicon Carbide Particles. *Journal of Applied Polymer Science* 2012; 126 (SUPPL. 2): 151-58.
7. Teyeme Y, Malengier B, Tesfaye T, Ciesielska-Wrobel I, Musa ABH, Van Langenhove L. A Review of Contemporary Techniques for Measuring Ergonomic Wear Comfort of Protective and Sport Clothing. *Autex Research Journal* 2020. DOI: 10.2478/aut-2019-0076
8. Marszałek A, Bartkowiak G, Dąbrowska A, Krzemińska S, Łężak K, Makowski K, Bugajska M. Mine Rescuers' Heat Load During the Expenditure of Physical Effort in a Hot Environment, Using Ventilated Underwear and Selected Breathing Apparatus. *International Journal of Occupational Safety and Ergonomics* 2018; (24):11-13.
9. Youngmin J, Chung Hee P, Tae Jin K. Effect of Heat and Moisture Transfer Properties on Microclimate and Subjective Thermal Comfort of Caps. *Textile Research Journal* 2010; 80(20):2195-2203.
10. A Das, Shabaridharan, Gersak J. Physiological responses of different types clothing in cold weather condition – A wear trial study. *Indian J Fibre Text Res*. 2014; 39(1): 33-42.
11. Wenger S, Wright T, Bechtold T, Nachbaur W. Sex-Related Differences in Clothing-Microclimate and Subjective Perceptions while Wearing two Outdoor Jackets During Submaximal Exercise in a Cool Environment. *Journal of the Textile Institute* 2019; 110 (9): 1343-1351.
12. Wu H, Zhang W, Li J. Study on Improving the Thermal-Wet Comfort of Clothing During Exercise with an Assembly of Fabrics. *FIBRES & TEXTILES in Eastern Europe* 2009; 75(4): 46-51.
13. Shinjung Y, Eunae K. Wear Trial Assessment of Layer Structure Effects on Vapour Permeability and Condensation in a Cold Weather Clothing Ensemble. *Textile Research Journal* 2012; 82: 1079-1091.
14. Chan APC, Song W, Yang Y. Meta-Analysis of the Effects of Microclimate Cooling Systems on Human Performance Under Thermal Stressful Environments: Potential Applications To Occupational Workers. *J Therm Biol.* 2015; (49): 16-32.
15. Hamdan H, Ghaddar N, Ouahrani D, Ghali K, Itani M. PCM Cooling Vest for Improving Thermal Comfort in Hot Environment. *Int J Therm Sci.* 2016; (102): 154-167.
16. Ismail N, Ghaddar N, Ghali K. Effect of Inter-Segmental Air Exchanges on Local and Overall Clothing Ventilation. *Textile Research Journal* 2016; 86(4): 423-439.
17. Korliński W. Modeling and Design of Knitted Woven Structures Characterized by Planned Biophysical Qualities with Empirical Verification. Research Project No 4 T08E 014 22. 2004; Poland.
18. CEN/TR 16422:2012 Classification of Thermoregulatory Properties.

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