TESTING PHYSIOLOGIC COMFORT OF FUNCTIONAL CLOTHING

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Abstract

The subject of research work carried out at the Department of Clothing of the Faculty of Textile at the Technical University of Liberec was innovation and monitoring of physiologic properties of the first layer of functional clothing for sportsmen, army, firemen, police, etc.

Physiologic properties of clothing are ones of the properties requested from functional clothing and they are important because they significantly influence not only the wearer's feelings but also psyche and performance of sportsmen, soldiers, policemen, etc. No universal clothing, which would be suitable for all weather conditions and physical exercise of the wearer can be designed, however, more suitable textile materials and more elaborated designs of clothing for improvement of clothing comfort can be used. The focus of research work was laboratory testing with proband's simulated load with monitoring of temperatures and moisture in the limit layer of clothing. Based on the analysis of measured values and test results of set of T-shirts, a set of optimum structures of textile materials for functional clothing was designed.

Introduction

Clothing is an inseparable part of human life. The prime role of clothing is to protect body against unstable environs. Human body can be considered as an open system, which is always in the state of physical, chemical and biological interaction with the environs. Clothing is a protective system, in which heat and moisture penetrate. Penetration of heat and moisture

depends on the construction, cut, used textile material and parameters of the clothing layer. Clothing helps thermoregulation of the organism in the cases when the body itself is not capable of auto-regulation.

Comfort as such can then be defined as a state of organism when physical functions of organism are in optimum and when environs of the human, including clothing, do not produce any unpleasant perceptions.

1 Test methodology used for investigation

In view of the fact that comfort is directly related to physiologic process, it can be measured quantitatively. Comfort of clothing can be evaluated by measuring selected physical properties of textiles and clothing (water vapours and air permeability, thermal resistance, etc.) that influence physiologic comfort. A more objective way is to carry out testing with probands. These can be carried out under real conditions – using clothing in real conditions or under controlled climatic conditions and activities in a laboratory. Measurement under controlled conditions has significant advantages, testing conditions are reproducible and sensors can be connected to the person's body with the aim to gain objective data. Such data may include heart rate, temperature and skin moisture in various points of proband's body in the limit layer or in the clothing structure, including sensory assessment of clothing. Figure 1 shows how the test is carried out. The research activity consisted in testing the set of T-shirts proband's defined load and under defined conditions of the environment with the choice of monitoring selected quantities, which provide possibilities of clothing comfort evaluation.

Source: Own

Fig. 1: *Proband while testing the 1st layers of clothing in the laboratory of physiologic comfort.*

1.1 Theoretical analysis

Water vapours permeability is fundamental to functional clothing, during intense activities of a person, production of sweat can reach 1000g/hour and such quantity must be transported

through clothing. Increasing moisture on the skin, especially in liquid form, means immediate worsening of comfort and decreasing of person's performance and concentration and that is why transfer of moisture is important [1].

Water vapours permeability is closely connected with the material, from which the structure of clothing is created; it is also connected with the structure and porosity of the fabric. Porosity is a characteristic affecting the breathability of fabrics. It may be defined as the pore volume to the total volume of fabric. Porosity determines the amount of the volume of air contained in the fabric surface, but says nothing about the position, type and size of pores, or their mutual arrangement (1):

$$p = \frac{\rho_{fc} - \rho_V}{\rho_{fc}} * 10^2 [\%] \tag{1}$$

where: ρ_{fc} density of air conditioned fibers [kg·m^{-3}],

ρ_V material bulk density [kg·m^{-3}].

Basically, there are two factors – sorption capacity of fibres and desorption capacity and then surface tension on fibres, structure and wetting capacity of fibres. Sorption capacity of fibres can have positive effect in the first moments of dampening but on the other hand, fibre remains wet for a long time and so it does not contribute to good comfort of clothing [2]. The profile of fibres, which, in sophisticated construction, allows perfect wetting, and thereby intense transport of liquid moisture, is applied fundamentally.

The moisture transport generally proceeds also by other mechanisms (capillary, sorption), but we can presume that the diffusion way will be the more dominant.

It is possible to describe moisture transport by a relation (2) for mass transport [3][4]:

$$q_{dif_i} = -D_i \cdot \nabla \cdot \rho_i \tag{2}$$

where: D_i coefficient of diffusion transport of mass for the ith – component [m^2·s^{-1}],

$\nabla\rho_i$ gradient of partial mass density for the ith - component [kg·m^{-3}].

For a unit flow of moisture as a compound of gaseous environs with a partial pressure of p_i' (p_i' – partial pressure inside of porous clothing material, p_i'' – partial pressure outside the porous clothing material) it is possible to use a relation (3):

$$q_{dif_i} = D_i \frac{M_i}{RmT} \frac{p_i' - p_i''}{s} \tag{3}$$

where: Rm universal gas constant [kJ·kmol·K^{-1}],

M_i molar mass [mol],

T temperature [K],

S layer thickness [m].

Based on the results of theoretic analysis of physiologic comfort, the following experiments had been planned and consequently carried out:

a) testing the selected set of T-shirts, from natural materials to modern Smart textiles during simulated load on stationary bicycle when monitoring heat and moisture and measuring temperature fields using Thermocam.

b) measuring the properties determining clothing comfort in the laboratories of physiologic comfort at different temperatures and moisture in a set of knitting suitable

especially for the first layer of clothing allowing comparison of classical and modern synthetic fibres of these fabrics [5].

2 Simulating load of proband with T-shirt

The experimental measurement was carried out in the Laboratory of Physiologic Comfort at the Clothing Department, Faculty of Textile, Technical University of Liberec.

Proband performed physical activity on stationary bicycle in air-conditioned room. Temperature in the room was set to 21 ± 1°C, humidity to 60 ± 5%. Physical exercise was carried out at a defined heart rate for 45 minutes. Load was set to reach and maintain the value of heart beat ranging between 140-145 beats per minute. Proband maintained heart beat within this interval for all the time of testing. Heart beat was monitored using heart beat sensing band attached to proband's trunk.

13 T-shirts of different material composition and weight were tested. Material parameters of tested T-shirts are stated in Table 1.

Tab. 1: *Material parameters of tested T-shirts*

Marking	Material	Producer / Origin	Structure	Thickness [mm]	Weight [g/m^2]	Air permeability [l/min/m^2]	Resistance against water vapours R_{et} [m^2.Pa.W^{-1}]	Thermal resistance R_{ct} [m^2.K.W^{-1}]
T-shirt 1	100% CO	KAJA s.r.o / Armed forces of the Czech Republic	weft single plain	0.69	170.22	2089.00	2.56	0.019
T-shirt 2	100% WO	DEVOLD MSM / Norway	weft double	0.94	216.85	>12000.00	2.59	0.037
T-shirt 3	100% PP	SPOLSIN s.r.o. / Czech Republic	weft interlock	1.51	189.16	6060.00	5.12	0.046
T-shirt 4	100% PL	ADIDAS / Philippines	weft interlock	0.59	132.19	9750.00	2.00	0.011
T-shirt 5	95%CO/ 5% EL	SPOLSIN s.r.o. / Czech Republic	weft single plated jbutted	0.77	225.69	1620.00	4.15	0.025
T-shirt 6	100% CO	French Armed Forces	weft single plain	0.67	161.17	5057.00	3.06	0.020
T-shirt 7	100% CO	Romanian Armed Forces	weft single plain	0.91	220.02	1993.00	3.78	0.017
T-shirt 8	50%CO/50%PL	United Stated Army	weft single plain	0.72	153.86	5786.00	3.23	0.024
T-shirt 9	100% CO	Italian Armed Forces	weft single plain	0.69	151.61	5014.00	2.92	0.015
T-shirt 10	50%CO/50%PL	Macedonian Armed Forces	weft single plain	0.67	156.95	6600.00	2.82	0.020
T-shirt 11	100% CO	British Army	weft single plain	0.83	215.89	1294.00	3.38	0.018
T-shirt 12	100% PL	Polartec / USA	weft interlock	0.92	179.42	>12000.00	3.14	0.003
T-shirt 13	100% PL	Polartec / USA	weft single plated jbutted	0.57	124.17	4170.00	1.30	0.008

Source: Own

2.1 Procedure and conditions of testing T-shirts

Before the test, 5 sensors were attached, always in equal placement, to a T-shirt. The sensors were placed into vapour-permeable "pockets" made of "Neoshell-Polartec" material. Before the measurement, the tested T-shirt was placed into an air-conditioned room with the temperature of 21 ± 1°C and moisture of 60 ± 5% for 30 minutes. See [6] for detailed data.

At the beginning and during the test, sensory perception of clothing comfort by proband was monitored. The aim of the monitoring was to evaluate the first layer of clothing on the base of the monitored individual's feelings during a long-term physical exercise, and the following parameters were found out:

- proband's thermal sensations (criterion: thermal receptiveness), rating scale 1-10 – 1- thermal balance, 10 – too warm or too cold
- proband's sensations of moisture (criterion: dampness), rating scale 1-10 – 1- no sensation of dampness, 10 – extreme dampness
- proband's sensory sensations (criterion: prickliness, rustling), rating scale 1-10 – 1- very pleasant, 10 - unpleasant
- proband's physical activity (criterion: physical fatigue), rating scale 1-10 – 1- not tired, fresh, 10 – tired out

2.2 Evaluation of the experiment

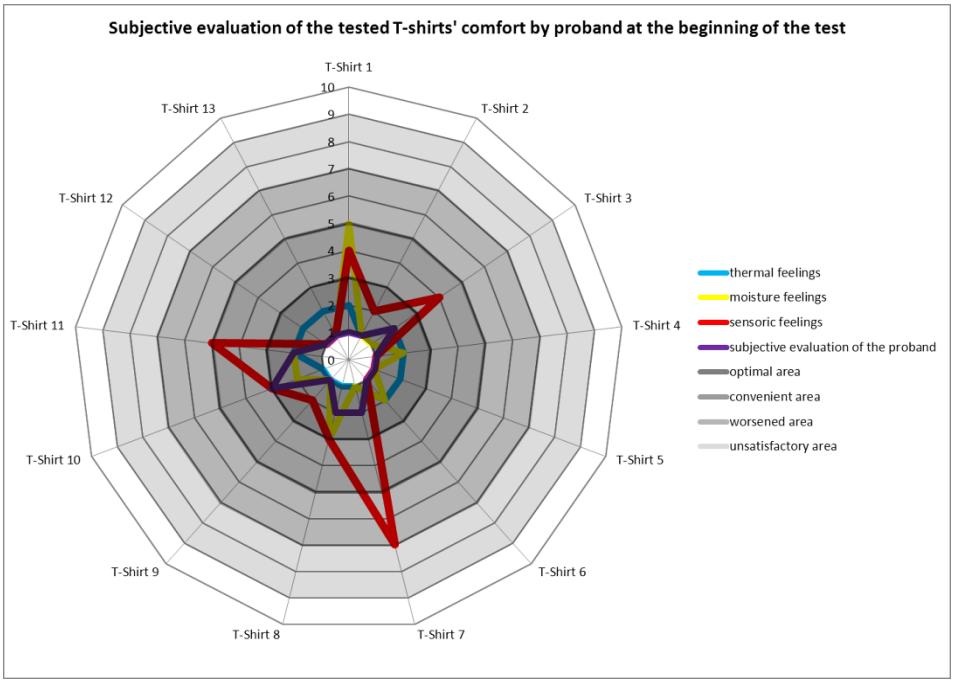
Within the phases, the experiment continuously focuses on three parts important for overall evaluation of T-shirts:

1. Material evaluation of T-shirts
2. Objective evaluation of T-shirts
3. Subjective evaluation of T-shirts

This paper primarily focuses on subjective evaluation of T-shirts, which is an important part of overall evaluation of functional clothing by the wearer. Phases 1 and 2 will be subjects of the following papers.

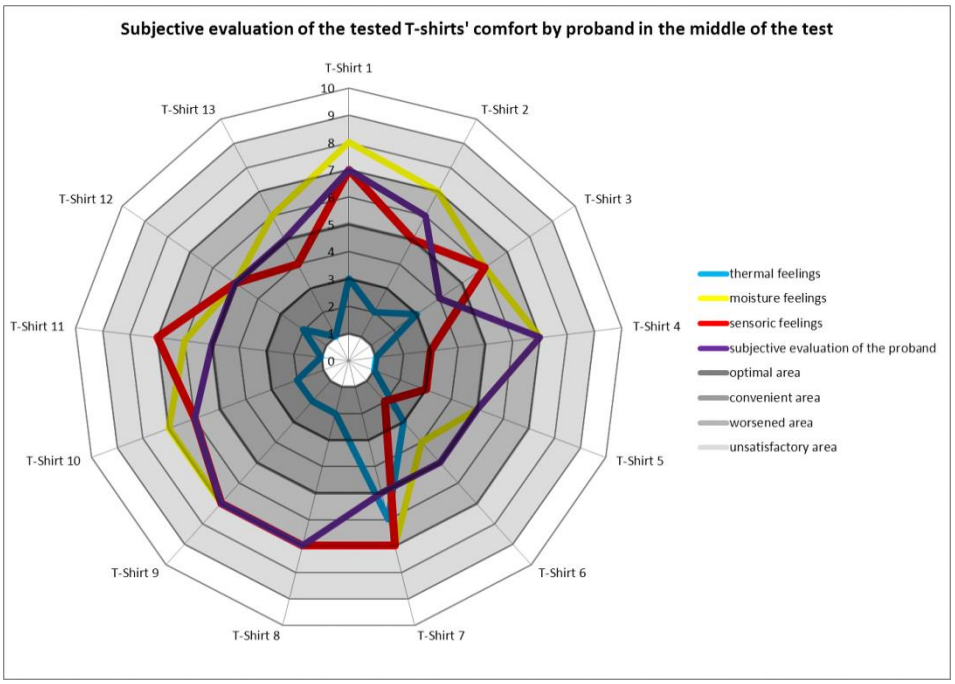
For each T-shirt, a questionnaire for subjective evaluation of T-shirt by the proband was designed and subsequently assessed.

Visual display of subjective evaluation of the T-shirt by proband and their mutual comparison before, during and at the end of the test is shown in the following radial diagrams. From the diagrams, see Fig. 2-4, it is evident that subjective sensing of the T-shirt by proband is getting worse during long-term physical exercise.



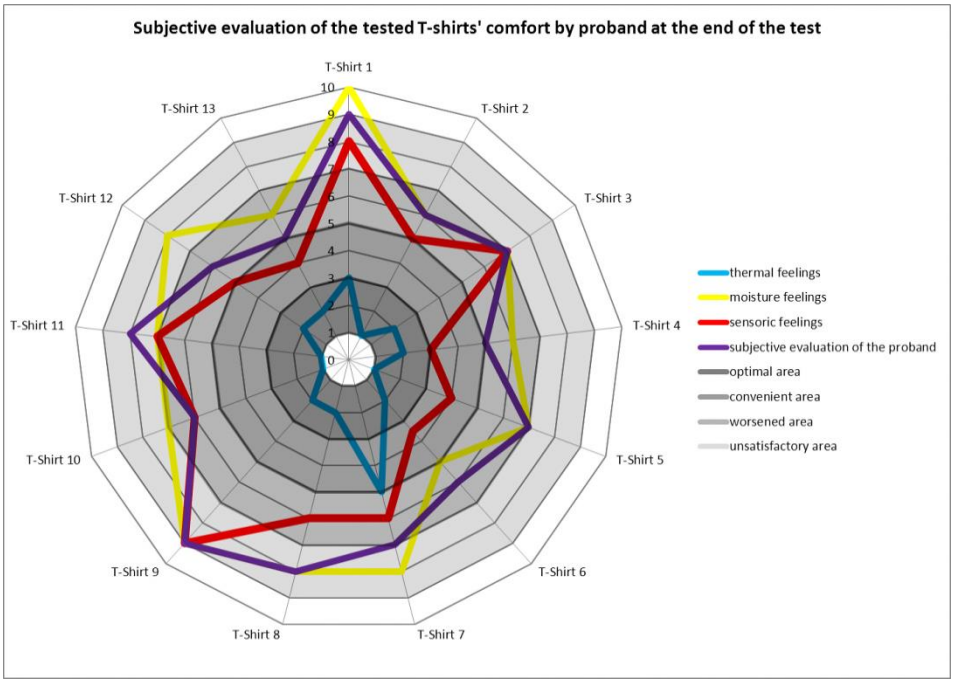
Source: Own

Fig. 2: *Subjective evaluation of the tested T-shirts' comfort by proband at the beginning of the test.*



Source: Own

Fig. 3: *Subjective evaluation of the tested T-shirts' comfort by proband during the test.*



Source: Own

Fig. 4: *Subjective evaluation of tested T-shirts' comfort by proband at the end of the test.*

The T-shirt, individual curves of which deviate from optimum limits, or correspond with the diagram area displayed in dark grey colour in the middle of the diagram, is assessed as the best. It applies that an ideal T-shirt would take up the area in the middle of the diagram with the radius of 1.

Overall subjective evaluation of clothing by proband is shown in the following Table 2. At the end of the test, each T-shirt was awarded an overall grade in accordance with commonly used school classification 1 – the best, 5 – the worst (extending the final mark by a plus or minus sign was allowed). The ranking of individual T-shirt is divided into 5 colour zones for better

comprehensibility. The final marks are used for assessment in multi-criteria assessment of clothing [6].

Tab. 2: *Overall subjective evaluation of T-shirts by proband.*

Proband		
Overall ranking of T-shirt	Marking of T-Shirt	Awarded grade
1	T-shirt 2	1
2	T-shirt 13	1-
3	T-shirt 12	2+
4	T-shirt 6	2
5	T-shirt 5	2-
6	T-shirt 10	2-
7	T-shirt 4	3
8	T-shirt 3	3
9	T-shirt 8	3-
10	T-shirt 11	4+
11	T-shirt 7	4-
12	T-shirt 9	5
13	T-shirt 1	5

Source: Own

Conclusion

The first layer of clothing, which is in contact with the skin and, in addition, must transfer moisture and heat in order to reach the area of temperature and moisture with good comfort is crucial for thermo-physiologic and sensory comfort of functional clothing.

Primarily the experiment focused mainly on the first layer of clothing, which influences the wearer's physiologic comfort most. Common materials of T-shirts such as for example cotton or the mixture of cotton/PL, or cotton/elastane as well as new sophisticated fibres and structures (Polartec, Adidas, and Moira) were selected for the set of tested materials.

The overall complex evaluation of T-shirts results from three independent aspects:

- Subjective evaluation of clothing by proband
- Monitoring temperature and moisture at proband's defined load under laboratory conditions
- Measured results of the properties in physiologic comfort laboratories FT-KOD, which influence clothing comfort

From the above mentioned diagrams, Fig. 2-4, it is evident that there are minimum differences in subjective perception of clothing comfort by the proband at the beginning of the test. With increasing long lasting exercise the different structures and material compositions of individual T-shirts start presenting themselves and the proband starts to feel worsening comfort of clothing. The greatest differences in perceiving the clothing comfort by proband,

compared to the beginning of the test, are found out at the end of the test. The T-shirt, in which the least deterioration of subjective sensory comfort is reached, can then be considered as the most appropriate first layer for a long time physical activity.

Based on the measured results of proband's subjective evaluation and based on the overall subjective evaluation of material stated in Table 1, T-shirt No. 12 (Polartec® Power Dry® FR) was selected for the next phase of testing as the first layer of functional clothing. T-shirt 12 and T-shirt 2 gained the best subjective evaluation of comfort by proband, and that is why these T-shirts have the best preconditions for achieving as good proband's physiologic comfort as possible during long-term exercise.

Literature

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TESTOVANÍ FYZIOLOGICKÉHO KOMFORTU FUNKČNÍCH ODĚVŮ

Předmětem výzkumných prací, prováděných na Katedře oděvnictví Fakulty textilní Technické univerzity v Liberci, byla inovace a monitorování fyziologických vlastností první vrstvy funkčních oděvů pro sportovce, vojsko, hasiče, policii atd. Fyziologické vlastnosti oděvů jsou jednou z požadovaných vlastností na funkční oděv a jsou důležité, protože významně ovlivňují nejen pocity nositele, ale i psychiku a výkon sportovců, vojáků, policie atd. Nelze navrhnout univerzální oděv, který bude vyhovovat při všech povětrnostních podmínkách a fyzické zátěži nositele, ale lze použít vhodnější textilní materiály a propracovanější design oděvů pro zlepšení oděvního komfortu. Těžištěm výzkumných prací byly laboratorní testy při simulované zátěži probanda s monitorováním teplot a vlhkosti v mezní vrstvě oděvů. Na základě analýzy naměřených hodnot a výsledků testů souboru T-Shirt byl navržen soubor optimálních struktur textilních materiálů pro funkční oděv.

PRÜFUNG DES PHYSIOLOGISCHEN KOMFORTS DER FUNKTIONSKLEIDUNG

Gegenstand der Forschungsarbeiten, die an dem Lehrschul für Bekleidungsindustrie an der Textilfakultät der Technischen Universität in Liberec durchgeführt wurden, waren Innovationen und die Überwachung der physiologischen Eigenschaften der ersten Schicht der Funktionskleidung für Sportler, die Armee, die Feuerwehr, die Polizei etc. Die physiologischen Eigenschaften der Kleidung sind eine der erforderlichen Eigenschaften der Funktionskleidung und sie sind wichtig, da sie nicht nur die Gefühle des Trägers, sondern auch die Psyche sowie die Leistung der Sportler, der Soldaten, der Polizei etc. bedeutend beeinflussen. Es kann keine Universalkleidung entworfen werden, die allen Witterungseinflüssen und der physischen Belastung des Trägers entsprechen wird, aber es können geeignetere Textilmaterialien und ein durchgearbeitetes Kleidungsdesign für die Verbesserung des Kleidungskomforts verwendet werden. Der Schwerpunkt der Forschungsarbeiten waren Labortests bei einer simulierten Belastung einer Testperson mit der Überwachung von Temperaturen und der Feuchtigkeit in der Grenzschicht der Kleidung. Auf Grund der Analyse der gemessenen Werte und der Testergebnisse des T-Shirt-Komplexes wurde ein Komplex von optimalen Strukturen der Textilmaterialien für eine Funktionskleidung entworfen.

TESTOWANIE KOMFORTU FIZJOLOGICZNEGO ODZIEŻY FUNKCYJNEJ

Przedmiotem prac badawczych, prowadzonych w Katedrze Odzieżownictwa Wydziału Tekstylnego Uniwersytetu Technicznego w Libercu, była innowacja i monitorowanie właściwości fizjologicznych pierwszej warstwy odzieży funkcyjnej dla sportowców, wojska, straży pożarnej, policji, itd. Właściwości fizjologiczne odzieży należą do wymaganych właściwości odzieży funkcyjnej i są ważne, ponieważ w znacznym stopniu wpływają nie tylko na odczucia osoby noszącej, ale również na psychikę i wyniki sportowców, żołnierzy, policjantów, itd. Nie można opracować uniwersalnej odzieży, która będzie odpowiednia w każdych warunkach atmosferycznych i przy różnym obciążeniu fizycznym osoby noszącej, ale w celu poprawy komfortu można zastosować lepsze materiały tekstylne i lepiej opracowane wzornictwo odzieży. Głównym przedmiotem prac badawczych były testy laboratoryjne z symulowanym obciążeniem probanta i z monitorowaniem temperatury i wilgotności w warstwie granicznej odzieży. Na podstawie analizy pozyskanych wartości i wyników testów zespołu T-Shirt opracowano zbiór optymalnych struktur materiałów tekstylnych dla odzieży funkcyjnej.