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Influence of Sportswear Made from Polyester and Man-Made Cellulosic Fibres on the Energy Cost of Physical Effort

Abstract
In the over-saturated global textile market , consumers have growing expectations towards its goods. The producers who develop new technologies for giving textiles additional functions can gain a considerable advantage in the clothing market. This trend is forcing scientists to investigate new methods of clothing evaluation because present physical-mechanical tests do not guarantee the creation of a multi-faceted opinion on the properties of a textile. One of the new methods applied for clothes investigation was developed at the Institute of Natural Fibres. This method involves the use of electromyographic EMG medical records for the determination of the influence of clothing on muscle activity. The results of the study showed that everyday clothing can be the cause of an increased tendency to tiredness. The aim of the current study was the investigation of the influence of different types of sportswear on the physiological parameters and energy cost of volunteers in sports conditions. The garments tested were prepared with the application of cellulosic and synthetic fibres. This paper presents the results of the experiment conducted within the studies. The volunteers taking part in the experiment were asked to wear test clothes made from 100% TENCEL® fibres, 100% polyester fibres, or a TENCEL®/polyester blend and do 10-minutes of physical exercise on a running track. Physiological as well as respiratory and circulatory system parameters for estimation of the energy cost of physical effort were monitored in the case of each subject wearing different types of sportswear. The results of the study show statistically significant differences in the parameters measured for the different types of sportswear tested. Especially, the energy cost of the volunteers' physical effort was lowest with garments made from a TENCEL®/polyester blend. This effect can be connected to better moisture management, which supported the body's temperature regulation, leading to a lower energy cost of the given performance.

Key words: *sportswear, polyester, Tencel®, energetic cost, physical effort.*

Introduction

The aim of the study was the investigation of the influence of different types of sportswear made from cellulosic man-made fibres and polyester fibres on the energy cost of the effort of volunteers in sports conditions.

The study covered 3 types of clothing made from knitted fabrics:
1. Made from 100% TENCEL®,
2. Made from a blend of TENCEL®/PES,
3. Made from 100% PES.

The study was conducted according to methodology developed by the Laboratory of the Physiological Influence of Textiles on the Human Body in collaboration with Poznan University of Physical Education.

Table 1. *Fiber parameters.*

Parameter	CLY fibre	PES fibre	PES filament
Staple length, mm	38	40	filament
Linear density, dtex	1.3	1,3	0,63
Shape of cross- section	Oval	Round	Round
Type	TENCEL®	Trevira 350	

Table 2. *Density of the knitted fabrics.*

Type of raw material	100% PES		TENCEL®/PES		TENCEL®	
Density, number of loops per 10 cm	courses	wale	courses	wale	courses	wale
	220	161	270	182	314	184
Thickness, mm	0.50		0.52		0.54	

Material of the study

The objects of the study were sportswear prepared from different raw materials. A set of clothes was made from knitted fabric single jersey, characterised by a sporty design and comprising of a long-sleeve shirt and long trousers. Two main groups of raw materials were used for the sportswear preparation: TENCEL®, a man-made cellulosic fibre of the generic fibre type, Lyocell (CLY) [1] from Lenzing AG, Austria, and Polyester (PES). A blend of the fibres was tested as well. Characterisation of thes fiber is shown in ***Table 1***.

Table 3. *Knitted fabric characteristics.*

Raw materials	Composition of raw material in knitted fabric	Yarn used for knitted fabric	Knitted fabric
TENCEL®	97% Tencel®, 3% Elasthane	TENCEL® Elasthane	Single jersey, plated Elasthane on reverse side.
TENCEL®/ PES	32% Tencel®, 32 % PES, 30% Micro PES, 6% Elasthane	Spun TENCEL®/PES 50/50% Micro PES filament Elasthane	Single jersey, triple plated Front side: TENCEL® /PES 50/50% Reverse side: Micro PES filament
PES	PES staple fiber: Trevira 350, 1.3 dtex, 40 mm PES micro-filament (texturised, Trevira), Elasthane	PES 10/1 tex PES micro filament, 50 dtex f 80 Elasthane	Single jersey, triple plated. Front side: PES spun. Reverse side: PES Micro filament fused Elasthane

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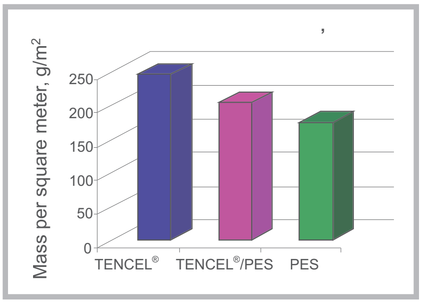

***Figure 1**. Mass per square meter of the knitted fabrics;PN-P-04613.*

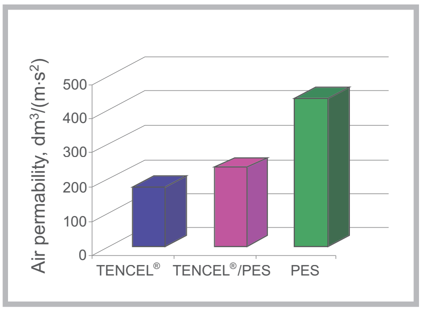

***Figure 2**. Air permeability of the knitted fabrics; EN ISO 9237 (Test pressure – 200 Pa).*

All the types of knitted fabric were tested to determine their biophysical properties. The materials were provided by Lenzing AG, Lenzing, Austria. The garment design was from Chillaz International, Vomp/Schwaz, Austria.

Visualisation of the metrological characterisation of three types of knitted fabric made from 100% TENCEL® fibres, 100% polyester fibres and a TENCEL®/PES blend are presented in ***Figures 1 – 7***, the characteristics of which are shown in ***Table 2*** and ***3***.

As ***Figure 1*** shows, the mass per square meter of the knitted fabric made from polyester had the lowest value, which was mainly as a result of the lower density of its loops. The knitted fabric made from TENCEL® was quite the opposite of the polyester fabric – the mass per square meter was of the highest due to the high density of its loops and high thickness**.** The structural parameter of the textiles tested influenced the level of air permeability. The air permeability of a textile material is strongly connected with its structure – a low density and low surface mass result in a higher value of air permeability. It was found that the air permeability of the knitted fabric made from polyester was the highest, as shown in ***Figure 2***.

The properties of the knitted fabric connected with hygroscopicity (***Figure 3***) and the ability of water sorption (***Figure 4***) were considerably worse for the polyester fabric; textile from cellulosic man-made fibres in a pure form or in a blend with polyester show a higher level of hygroscopicity and ability of sorption, respectively. The highest time needed to soak up a drop of water on the fabric surface was found for 100% PES fabrics.

Textile made of cellulosic fabrics does not accumulate electrostatic charge on its surface, as is shown in ***Figure 5***. The highest level of surface resistance was found for 100% polyester knitted fabric. Even a 32 % TENCEL® share in blends with polyester in fabrics reduces their ability to accumulate electrostatic charge.

Two biophysical parameters: thermal resistance and water vapour resistance (***Figures 6*** and ***7***), measured using the Sweating Guarded Hot Plate test method, showed a strong correlation with the type of knitted fabric.

The loose structure, in which the lowest number of loops per 1 dm means a higher amount of air trapped between threads, of polyester knitted fabric resulted in the highest level of its thermal resistance. As regards water vapour resistance, the construction of TENCEL®/polyester knitted fabric facilitated water vapour transport through the textiles, which means that in terms of moisture transport, the best properties were found in knitted fabric made from TENCEL®/polyester blended fibres, because they had the lowest level of water vapour resistance.

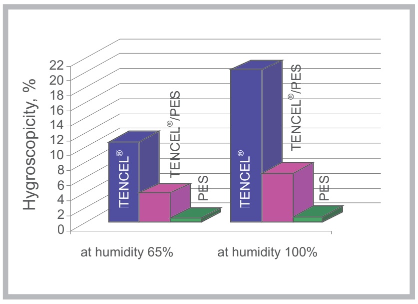

***Figure 3**. Hygroscopicity of knitted fabrics tested the 65% and 100% relative humidity of air; PN-P- 04635.*

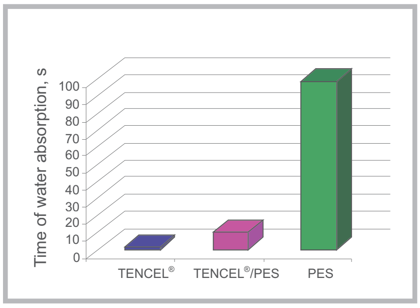

***Figure 4**. Time of water absorption – Drop method; JS No.59/L 1096 – 199.*

Methodology

Young male volunteers constituted the test group in the studies. Ten volunteers (only men, clinically inspected) were selected from a population of healthy people aged 21 – 23 with a similar body constitution, with a height from 175 to 190 cm and weight from 71 to 100 kg.

All volunteers were informed about the aim of the examination, and they gave a signed consent to participate in the study.

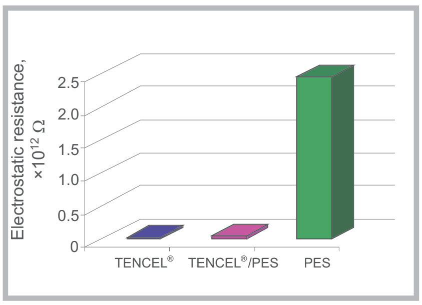

***Figure 5**. Electrostatic surface resistance of the knitted fabrics (humidity of air - 50%).*

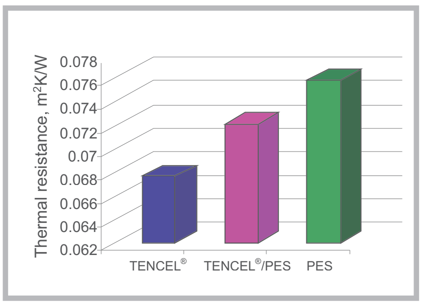

***Figure 6**. Thermal resistance of knitted fabrics; EN 31092/Ap1 (ISO 11092:1993).*

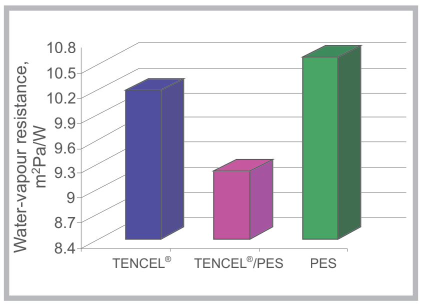

***Figure 7**. Water vapour resistance of knitted fabric -EN 31092/Ap1 (ISO 11092:1993).*

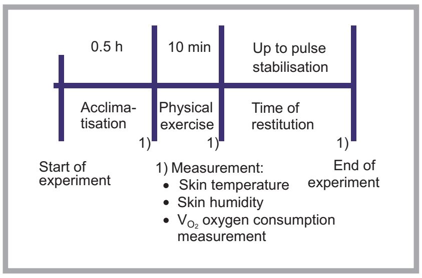

***Figure 8**. Scheme of experiment.*

The authors of the study obtained the permission of the Bioethical Commission at the University of Medical Science in Poznan to conduct this investigation.

Experiments were conducted in an air conditioned chamber (21 ± 2 ºC) at a constant humidity of 40 ±5%, between 11 am and 3 pm, from 10th September to 25th September 2008. According to previous studies [2, 3] at that time of day the activity of muscle motor units is optimal with the circadian rhythm.

Every volunteer wore one type of test clothing during one day of the experiment and other types of clothes in the following days. Each type of set was worn on three different days. Each volunteer was examined while wearing each type of sportswear as well as without any test garment. Finally, 30 full measurements were performed for each type of sportswear in accordance with the experiment scheme shown in ***Figure 8***.

After half an hour of acclimatisation, each volunteer did physical exercise using a running track Woodway (treadmill) – duration of the exercise – 10 minutes:
- 1st min – run with a speed of 8 km/h
- 2nd min – run with a speed of 10 km/h
- remaining 8 min – run with a speed of 12 km/h

The tests were conducted as follows:
- First day - physical exercise conducted without any test clothing (according to the scheme),
- Second day – physical exercise conducted in clothes made from the TENCEL®/PES blend,
- Third day – physical exercise conducted wearing clothes made from 100% polyester,
- Fourth day - physical exercise conducted wearing test clothes made from 100% TENCEL®.

Each subject covered a distance of 1900 m during the experiment. The level of physical effort was indirectly determined by physiologists from The University School of Physical Education based on their experience and previous studies conducted with a similar group of volunteers.

The full measurement, which was conducted during the experiment: after 0.5 hour of acclimatisation, after physical effort and after 15 minutes of rest, included tests of the temperature and moisture of skin under the sportswear, and monitoring parameters of the respiratory and circulatory system for estimation of the energy cost of physical effort for each subject wearing different types of sportswear. ***Figure 9*** presents photos from the on-going experiment.

The tests were done by the calorimetric method with Oxycon Mobile application. The method is based on the dependence between the amount of oxygen intake by the organism and the energy produced as a result of oxidation, where oxygen is used. In the air exhaled, the oxygen, carbon dioxide and volume of air exhaled per minute were measured. This allowed to determine the amount of thermal energy produced and then the value of energy used for the physical effort made.

***Figure 9**. Monitoring of the parameters of the respiratory and circulatory system with the application of Oxycon. Mobile during physical effort on a running track (photos:a,b,c), as well as of the back skin temperature and moisture measurement in the hole of the shirt (photo d).*

The principle of the method is the relation between the oxygen intake by the organism and the energy produced in oxidation, where oxygen is used. Therefore indirect calorimetry determines heat production by the organism based on measurements of oxygen consumed and carbon dioxide exhaled. To perform the measurements during physical activity, the person tested breathes through a mask connected directly to a gas analyser. In the air fractions of oxygen exhaled, the carbon dioxide and air volume per minute are recorded.

In order to determine metabolism levels, the values of oxygen intake per minute and the breathing index are measured by the analyser. The breathing index indicates the share of nutritional components in the metabolism. When different food components (proteins, sugars, fats) undergo oxidation, they provide different amounts of thermal energy.

In turn, the oxygen caloric index equals the thermal energy produced when 1 litre of oxygen is used for burning nutritional components. This value is correlated with the kind of energy substance being burned and thus may be derived from the value of the breathing index [8]. On average the index hovers around 4.8 Kcal (20 kJ).

The value of oxygen intake measured in the test multiplied by the caloric index (derived from the breathing index) is the value of thermal energy produced by the organism. To determine the value of energy spent on physical activity only, it is necessary to subtract the value of the metabolism at rest from the total metabolism.
The results of the studies were subjected to statistical analysis. The normality of the data distribution was tested using the Shapiro-Wilk test. As some of the features did not have a normal distribution, the non-parametric Wilcoxon couple test was used. The calculations were performed using Statistica 8.0. software ($p < 0.05$*, $p < 0.001$**)

Results

Skin – clothes microclimate

The main parameters of the skin - clothes microclimate measured under the sportswear tested are shown in ***Figures 10 - 15***. (The straight lines show only tendencies and not real temperature-time or moisture-time dependencies). Results of the measurements of the physiological parameters of the volunteers' skin confirm that physical effort has a big influence on skin temperature and humidity.

Temperature measurements were conducted of back and thigh skin at each stage of the experiment using a thermometer (Teca) with a contact sensor placed on the skin during measurement.

Changes in the back skin temperature were strongly related to the type of sportswear and whether the body of the volunteer was covered by a garment or not. A similar tendency was observed with respect to temperature changes in the tests on undressed volunteers and those dressed in garments made from the TENCEL®/PES blend: The back skin temperature fell, hit a minimum at the end of the run, and then rose during restitution. The back skin temperature of volunteers wearing TENCEL®/PES clothes reached the same level after restitution as at the beginning of the experiment. The temperature decrease after the running phase resulted from a triggering of the human thermoregulatory system and peaking skin moisture. In the next stage of the experiment, the temperature of back skin increased, resulting in uncovered skin drying out. In the case of sportswear made from the TENCEL®/PES blend, moisture was transferred outside. The temperature dip of uncovered back skin was large because the evaporation surface of the sweated back was large, resulting in the quick cooling of the skin.

As regards sportswear made from TENCEL®, the back skin temperature soared, peaking during running, which is quite the reverse from what occurred with the blend of TENCEL®/PES and during uncovered tests. A possible explanation is that during the run, sweating did not cause such a quick temperature drop because sweat produced by the human thermoregulatory system was absorbed by man-made cellulosic fibres and did not cool the skin. The heat of absorption could help to keep the back skin temperature a little bit higher. After restitution the temperature of the back skin of volunteers wearing a TENCEL® garment returned to the initial level.

In the case of the garment made from polyester, a slight fall in the back skin temperature of volunteers was visible,

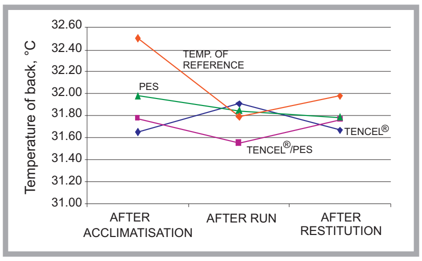

***Figure 10**. Temperature of the back skin of volunteers wearing the sportswear tested, measured after acclimatisation, after a run and after a time of restitution. The temperature of the reference means a test of uncovered volunteers.*

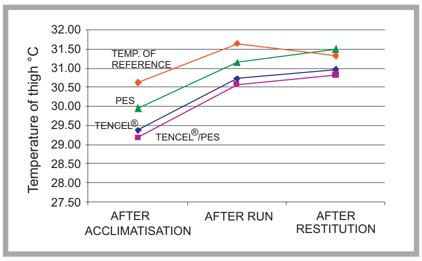

***Figure 11**. Temperature of the thigh skin of volunteers wearing the sportswear tested, measured after acclimatisation, after a run and after a time of restitution. The temperature of the reference means a test of uncovered volunteers.*

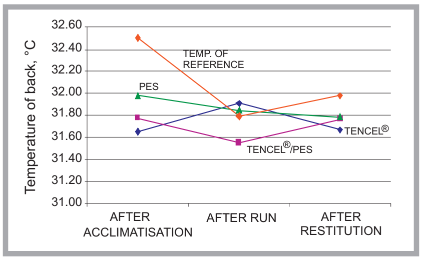

***Figure 12**. Moisture of the back skin of volunteers wearing the sportswear tested, measured after acclimatisation, after a run and after a time of restitution.*

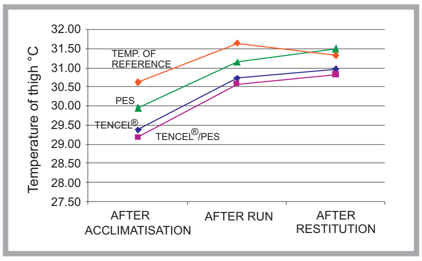

***Figure 13**. Moisture of the thigh skin of volunteers wearing the sportswear tested, measured after acclimatisation, after a run and after a time of restitution.*

from acclimatisation through the run to restitution.

Big differences in the initial temperature (after acclimatisation) of back skin, shown in ***Figure 10***, resulted from differences in ambient conditions; the air temperature was within the range of 21 to 23 °C.

Statistical analyses of the back skin temperature of volunteers wearing a test garment showed significant differences only between the temperature of volunteers in TENCEL® clothes and those made from the TENCEL®/PES blend, measured after run.

The thigh skin had a smaller surface of evaporation and covered working muscles of the legs. For this reason its temperature changed in a different way when compared to back skin. The thigh temperature rose after the run because working muscles "produced heat". Even the time of restitution did not stop the soaring of the thigh skin temperature. Only the temperature of the uncovered thigh slightly decreased after restitution due to the cessation of muscle activity and the easy, unhindered evaporation of sweat. Statistical analysis of the thigh skin temperature of volunteers wearing a test garment showed significant differences in the changes of temperature measured after acclimatisation and after the restitution of volunteers wearing a garment made from polyester, as well as amongst volunteers wearing a garment made from the TENCEL®/PES blend and those without any garment.

Moisture measurements were conducted for the back and thigh skin over the muscles examined at each stage of the experiment using a CM 825 corneometer. The corneometer apparatus, which is based on the capacitance method [19], measured the dielectric constant of the water absorbing superficial layers of the stratum corneum with the application of a contact sensor. The measurement involves recording the different dielectric constants of the water - 81 and other substances – mostly less than 7. The measuring capacitor shows changes in the capacitance according to the moisture content of samples. The corneometer is sensitive to the variable dielectric constant of the skin, which increases with the water content. Measurements are given in arbitrary units, known as the CM value, ranging from 0 for very dry to 120 for very wet skin.

The results of the skin moisture tests are shown in ***Figures 12 – 15***. A rapid increase in skin moisture on the back and

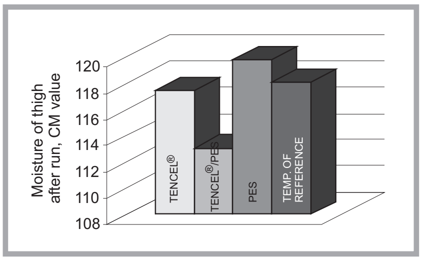

Figure 14. *Moisture of the thigh skin of volunteers wearing the sportswear tested, measured after the run.*

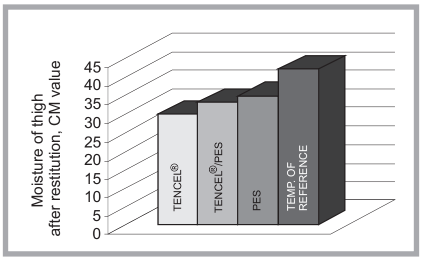

Figure 15. *Moisture of the thigh skin of volunteers wearing the sportswear tested - measured after a time of restitution.*

Table 4. *Energy cost of physical work for volunteers wearing the sportswear in kJ/10 min.*

Energy Cost	Without garment	TYP I TENCEL®/PES	TYP II 100% TENCEL®	TYP III 100% PES
Average	**543.74**	**527.79**	**537.58**	**546.96**
SD	15.01	12.51	12.90	12.04
min	394.98	421.36	432.12	476.42
max	645.77	624.63	634.34	638.32

Table 5. *Energy cost of restitution after physical work for volunteers wearing the sportswear in kJ/5 min.*

Energy Cost	Without garment	TYP I TENCEL®/PES	TYP II 100% TENCEL®	TYP III 100% PES
Average	**62.17**	**59.79**	**62.13**	**67.57**
SD	3.91	3.88	4.75	3.80
min	27.93	29.68	38.43	40.15
max	96.25	87.13	87.08	96.55

Table 6.: *Energy cost of physical work and time of restitution for volunteers wearing the sportswear in kJ/15 min.*

Energy Cost	Without garment	TYP I TENCEL®/PES	TYP II 100 % TENCEL®	TYP III 100%PES
Average	**607.17**	**587.57**	**602.35**	**614.66**
SD	16.87	14.86	15.96	13.95
min	452.72	466.33	473.95	530.80
max	724.65	706.10	716.74	717.91

thigh after running was visible in all conditions of the experiment regardless of the garment worn. After reaching a peak, skin moisture decreased during restitution.

In the case of the thigh, during running, the highest level of skin moisture was observed for polyester sportswear; the moisture was higher than even that of uncovered skin. The humidity of skin under sportswear made from TENCEL®/PES was the lowest. After restitution the moisture of skin reached the highest level for an uncovered thigh and one covered with polyester clothes.

In the case of back skin, a faster return to the initial level of moisture was observed after reaching a peak when wearing a garment made from TENCEL®. The moisture of back skin after restitution covered by polyester sportswear did not recover to the same level as before physical effort. Polyester showed a low ability of moisture absorption and a high level of water vapour resistance, hence not permitting moisture to be transported from the back skin to the air.

Energy cost – results and discussion

Monitoring of the parameters of the respiratory and circulatory system started before physical effort and continued throughout the volunteers' run and for 5 minutes of restitution. The following parameters were recorded: oxygen consumption, minute ventilation, production of CO_2, the respiratory exchange ratio (RER) and heart rate. The parameters allowed for the determination of the energety cost by an indirect method in an open system [6, 7]. The results obtained are shown in ***Tables 4*** – ***6***.

Results of the study showed that the lowest energy cost of physical work and the time of restitution of volunteers wearing the sportswear was obtained for a garment made from the TENCEL®/PES blend, whereas the highest energy cost was recorded for a garment made from 100% PES. From a sport – physiological point of view, the lower the level of energy usage, the more favourable it is for the human organism, because it allows the body to conduct more intensive physical exercise without disturbing homeostasis. Statistical analysis of the results of the study showed that there are statistically significant differences between the **I type** of garment (TENCEL®/PES) **and the II (**100 % TENCEL®) **and III type** (100% PES) of sportswear.

Satisfying the energy needs of the organism is linked with the metabolism at rest and during physical activity. During physical effort, as a result of the increased energy demand of working muscles, metabolic processes become intensified, leading to the production of high amounts of heat, which happens because only 15-25% of chemical energy is converted to kinetic energy; the remaining part generates heat [9].

The thermo-regulatory system of the human organism does not allow for an increase in temperature inside the body due to an increase in heat emitted during physical effort in sweat.

The transpiration of 1 litre of sweat leads to losing 580 kcal (2500 kJ) of heat. The efficiency of transpiration (i.e. removing heat) depends on several factors: mainly the fitness and hydration level of the organism. Moreover, environmental factors are of great importance, such as the temperature, air humidity, and air movement velocity. In the regulation of the internal temperature of the body, behaviour plays a role, for example in the selection of clothes worn. The factor that limits heat loss during transpiration is high air humidity [11]. If sweat is not removed from the skin-clothing area, air humidity will increase there, and the thermo-regulatory mechanism will be disturbed.

The increase in internal temperature greatly intensifies the functions of the respiratory and blood circulation systems, which may also lead to a growth in oxygen consumption by working muscles. Sweating itself is an active process, which raises the oxygen demand. Hinder-

Table 7*. Significant differences between the energy output of effort made in clothing of type I and that made in clothing of type II and III.*

Quantity	Type kind	
	TYP II	TYP III
TYP I - physical work	0.2133	**0,0175***
TYP I – restitution	0.0651	**0,0139***
TYP I - physical work **+** restitution	**0,0404***	**0,0087***

ing or facilitating the process of removing heat to the environment during physical effort has a profound effect on the energy cost of the effort. This becomes especially significant when the effort is made in unfavorable environmental conditions, such as a hot climate [10]. As a result of the integrated bodily response to the effort, a proper temperature of the body is maintained. However, it may happen that the organism's response is not adequate and over-heating occurs. If removing heat is efficient, then physical work is much less strenuous for the human organism, especially for the blood circulation system.

A lower energy cost of work is far more favorable as it allows to continue the effort for a prolonged time at a certain level of intensity without disturbing homeostasis inside the body.

During the study, it was found that the garment made from TENCEL®/PES had the most favourable effect on the energy cost, time of restitution, endurance and efficiency of the volunteers.

Comparison of the energy cost of the physical work of the volunteers when wearing the sportswear and without a garment proved that clothes made from 100% TENCEL® and those from TENCEL®/PES blended fibres can result in an improvement in endurance. This can be strongly related to the low water vapour resistance of both knitted fabrics, which improved the transfer of perspiration from the skin's surface and supported body temperature regulation, leading to a lower energy cost for the given performance.

After analysing the biophysical parameters of the knitted fabrics used for the production of the garments tested, as well as changes in skin temperature and moisture, it can be concluded that the properties of the sportswear raw material: TENCEL® and polyester fibres are responsible for the final results of the study.

Conclusions

1. Sportswear made from TENCEL®, polyester fibres and their blend was characterised by different bio-physical properties, which had a strong effect on the microclimate in the skin-clothes area in the form of changes in the moisture and temperature of the skin.
2. The parameters of the microclimate under the garment tested, such as skin moisture and temperature changed in a similar way regardless of the type of sportswear covering the volunteer's body. Physical effort was a very strong stimulus, influencing the skin temperature and moisture of the volunteers in a significant way. Garment type had a visible effect on the moisture of the skin.
3. Investigation of the energy cost of the volunteers' physical effort while wearing a test garment showed that garments made from a blend of Polyester and TENCEL® had the most favourable effect on the energy cost of physical work, as well as on the time of restitution, endurance and efficiency of the volunteers. The 100% TENCEL® garment was second best, better than in the case of uncovered effort.
4. Statistically significant differences were found between the energy cost of volunteers wearing a garment made from blended fibres TENCEL®/PES and the energy cost of volunteers covered with sportswear made from 100% TENCEL® and that made from 100% polyester fibres.

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