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RESEARCH OFTHERMO-PHYSIOLOGICAL COMFORT OF SINGLE JERSEYKNITTED STRUCTURES WITH METHOD OF THERMO-VISION ANALYSIS

Sonja J0RDEVA, Sonja KJORTOSEVA, Nikola KALOJANOV

Abstract: *The term comfort is defined as "the absence of displeasure or discomfort" or "a neutral state compared to the more active state of pleasure". Clothing comfort includes three main considerations: psychological, sensorial and thermo-physiological comfort. The thermo-physiological comfort, entails both thermoregulation and moisture management. It is known that fiber type, yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting thermo-physiological comfort.In this paper, the influence of structural propertiesand characteristics of the fiber on the air and water vapor permeability, thermal properties (thermo-physiological comfort), of single jersey knitted fabricswas investigated.Thermal conductivity of knitted fabrics was determined according to new method of thermo-vision analysis developed by researchers. The main advantage of the method is the possibility of non contact determination of the temperature change rate coefficient of the knitted fabric. The results indicate more significant influence of structural characteristics on thermo-physiological comfort, compared with thecharacteristics of the fibers. Knitted fabric of 50/50%PAN/cottonwith the highest density and mass per unit areahas lower air and water vaporpermeability, thermal conductivity and higher thermal resistance compared with knitted fabrics of 100% wool and 100% PAN.*

Key words: single jersey, thermo-physiological comfort, airpermeability, water vapor permeability,thermo-vision analysis

1. INTRODUCTION

The term comfort is defined as "the absence of displeasure or discomfort" or "a neutral state compared to the more active state of pleasure". Clothing comfort includes three main considerations: psychological, sensorial and thermo-physiological comfort. The thermo-physiological comfort, the subject of this research, entails both thermoregulation and moisture management. It is known that fiber type, yarn properties, fabric structure, finishing treatments and clothing conditions are the main factors affecting thermo-physiological comfort (N. Oglakcioglu, A. Marmarali, 2007),[1].

Over the last few years many studies have been conducted for thermal comfort properties of textile fabrics. Anand (Anand S. 2003), reported that the open construction has better water vaporpermeability than micromesh, pique, and rib structures,[2].

Milenkovic (Milenkovic L. et al, 1999), proved that fabric thickness, enclosed still air and external air movement are the major factors that affect the heat transfer through fabric. Greyson andHavenith, mentioned that heat and water vapor resistance increases with the increment of material thickness and air entrapped,[1].

Hes, et.al developed a new functional knitted fabric possessing double layers by using different yarn components(like polypropylene and cotton) in order to maximize the transport moisture,[3].Thermal properties of 1×1, 2×2 и 3×3 rib knit fabrics were compared by Ucar and Yilmaz (UcarN., YilmazT., 2007).They noted that a decrease in rib number leads to a decrease in heat loss; the use of 1×1 rib and tight structure would provide better thermal insulation,[4].The mathematical models developed by several researchers (Maxwell 1904; Vary 1952; Kunii and Smith 1960; Woodside and Messmer 1961; Zenner and Schlûder 1970; Bauer et al. 1991; Bogaty and Collar 1987; Fricke 1993) show that the relation between the thermal conductivity of porous surrounding and its thermo-physical properties are non-linear,[5].

Investigation of thermal comfort properties of double layered knitted fabrics with different yarn componentsshow that thermal resistance depends more on synthetic thread type than on natural fiber yarns,[6]. It was found that the structure of the knitting fabric (the knitting pattern structure)highly influences the heat transfer process as distinct from the rawmaterial content of knitted fabric.Investigations were carried out on double- layered knitted fabrics made from cotton or man-made bambooyarns in the outer (located outer from the skin) layer and PP, PA, PES yarns in the inner (located next to the skin layer),[7].

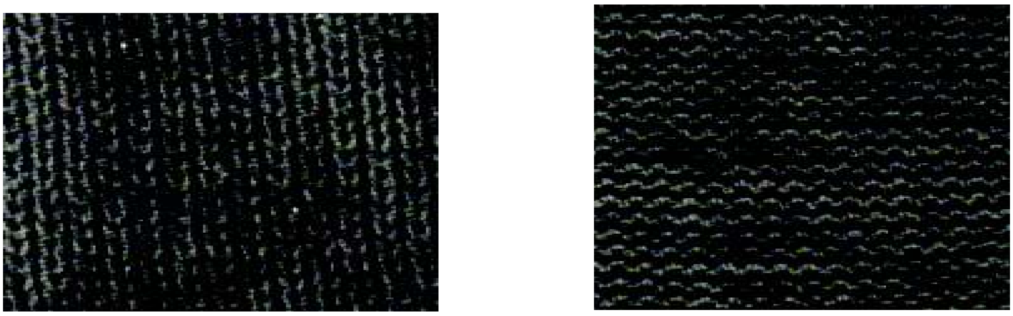
Thermal conductivityis an intensive property of material that indicates its ability to conduct heat, [8].***Thermal resistance*** is a measure of the thermal insulationof the material. It is defined as the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions, and when the heat transfer is dependent only on temperature.As we can see from the definition, it is necessary to know the rate of heat transfer through the material in order to be measured its thermal resistance, [9].

In this paper, the influence of structural characteristics and raw material content of single jersey knittedfabrics on the air and water vapor permeability, thermal properties (thermo-physiological comfort), was investigated.
Thermal conductivityof knitted fabrics was determined according to new method of thermo-vision analysis developed by researchers.

2. EXPERIMENTAL

2.1.Materials

Single jersey structures were knitted using 100 % PAN (acrylic), 50/50% PAN/cotton and 100 % wool. Knitting process of the single jersey knitted fabrics was performed on an flat knitting machine STOLL CMS 12. All knitted fabrics are made of yarn count T_t=33x2x2 tex.



a) b)

Figure 1-Single jersey structure a)faceb)back

2.2. Methods and instruments

2.2.1. Structural properties of knitted fabrics

Structural properties of knitted fabric (course density,D_h,cm^{-1} andwale density,D_v,cm^{-1}), fabric thickness, ***h****(mm)* mass per unit area ***m*** *(g/m²)*, loop length,***l***) are determined according to standard methods. Tigtness factorTF and porosityP are calculated according to the equations (1,2):

$$TF = \frac{\sqrt{T_t}}{l} \quad (\text{tex}^{1/2}\text{cm}^{-1}) (1) \qquad P = \left(1 - \frac{m}{\rho \cdot h}\right) 100(\%) (2)$$

where:
$\boldsymbol{T_r}$–yarn count (tex),$\boldsymbol{l}$-loop length *(mm)*,$\boldsymbol{\rho}$–mass density *(kg/m)*^{3},$\boldsymbol{h}$-fabric thickness *(mm)*

2.2.2. Air permeability

Investigation of the air permeability was performed according to the standard EN ISO 9237:1999. An FF-12 Metrimpex instrument was used with difference in contact pressure of 20 Paand area of the sample10cm^2,[10].

2.2.3. Water vapor permeability

The investigation of water vapor permeabilitywas performed on a sample with 15x15cm dimensions. All the measurements were done under standard climatic conditions with apparatus consisting of thermostat and glass with 62cm^2 surface (internal diameter 89mm).Water is put in the glass untill the level of water rises up to 35mm below the upper glass edge. The glass is covered with the sample and is put under the influence of water vapor with temperature of 50 ^{0}C forfour hours. After 4 hours the loss of water is determined and the mass increment of the sample, P_v, and the procedure is repeated under the same conditions for four more hours. According to the given results the water vapor permeability is calculated with the following relation, [11]:(3)

$$PVP = m_v - \frac{P_v}{A \cdot t} \cdot 100\ (\%)\ (mg/cm^2h) \qquad (3)$$

where :$\boldsymbol{m}_v$ – loss of water in the glass*(g)*; $\boldsymbol{Pv}$- increment of the mass of the sample*(g)*; $\boldsymbol{A}$-active surface of the sample*(cm^2)*; $\boldsymbol{t}$ –time of procedure*(h)*
The results are the average value from three measurements in each sample.

2.2.4. Thermal conductivity

In order to measure the thermal conductivity coefficient of the knitted fabrics *λ(W/mK)*the method of thermo-vision analysis is used. The apparatus (figure 2) consists of:

- *infrared camera) FLIR P-45;*
- *temperature measurement instrumentand online software monitoring:TESTO 635-2;*
- *heating and cooling thermostat.*

The measuring was conducted according to the following procedure:

- samples of knitted fabrics with 250x250mm dimensionsare put on the thermostat;
- the infrared camera is set to a 15 min interval and 5 pictures are captured every 3 minutes;
- the online monitoring software generates data that is automatically noted while the shooting takes place. Data is generated for: the exact time of each picture, temperature, air relative humidity rH(%), and the temperature plate of the thermostat $\boldsymbol{T_w}$;
- the investigations are conducted with air temperature of 22,0 + 0,3 ^{0}C and the air relative humidity of 63,4±0,5%;
- during the picture capturing the thermograms are generated for each sample;
- the pictures taken are processed with special software – FLIR;
- the temperature in the center of the sample is displayed on the thermogram *($\boldsymbol{T_{sp1}}$)*(°C). Also, the temperature of another dot ($\boldsymbol{T_{sp2}}$)(°C) located outside the square area is displayed. Finally, the thermogram displays the average temperature $\boldsymbol{T_{arp1}}$(°C) of the fabric squared area. The temperature change dependence from the time of capture for each sample diagrams are drown T_{sp1},$T_{arp1}$and T_w. The values of the time in hours-**t** (3/60), are applied on the **x**-axis, while the values of natural logarithmLn(T_{sp1},T_{arp1}, T_w) of the temperature are applied on the y-axis.;
- the temperature change rate coefficient of the knitted fabric $\mathbf{m_1}$ is determined from the linear line equation for average value of the temperature of the knitted fabric T_{arp1}, i.e.y=ax +b, where**y** = $\mathbf{T_{arp1}}$and**a** =$\mathbf{m_1}$.

Figure 2-Thermo-vision device

The determining of the thermal conductivity coefficient λ, according to the thermo-vision analysis is based on the theory of the regular temperature regime, i.e. on Kondratievs' second theorem [12]: (4) and(5)

$$m_1 = K \cdot a \ (4) \qquad a = \frac{m_1}{K} (5) \quad \text{and} \quad a = \frac{\lambda}{c \cdot \rho} \qquad (6)$$

where:$\boldsymbol{m_1}$–temperature change rate coefficient (heating or cooling of the material(s^{-1});**K** – proportionality coefficient; **a**- thermal diffusion *(m^2/s);* **ρ**- fabric density (kg/m^3); **c**- specific heatcapacity *(J/kgK)*

$m_1$coeficient depends on the physical characteristics, the dimensions and the geometry of the material.K coefficient depends only on the geometry of the material and for flat plate is calculated according to the formula (7)

$$K = \left(\frac{\pi}{2h}\right)^2 \qquad (7)$$

where:**h**- thickness of the material (mm)

The specific heat capacity of more component fabrics is calculated according to the equation (8).

$$c = \sum_{i=1}^{i=n} c_i \cdot p_i \quad (J/kgK) \qquad (8)$$

where:$\boldsymbol{c_i}$- components' specific heat capacity; $\boldsymbol{p_i}$ - mass percentage of the component

The volume mass or the fabric density ρ is calculated according to the equation (9).

$$\rho = \frac{m}{h} \quad \left(\frac{kg}{m^3}\right) \qquad (9)$$

where:**h**- fabric thickness *(m);* **m**- mass per unit area of the fabric *(kg/m^2).*
(ρ for more component fabrics is calculated considering the mass percentage of the components).

The thermal resistance is defined with the equation (10).

$$R_{ct} = \frac{h}{\lambda} \left(\frac{m^2 K}{W} \right) \qquad (10)$$

where: R_{ct}–thermal resistance *(m^2K/W)*; ***h***–fabric thickness*(m)*; ***λ***–thermal conductivity*(W/mK)*.

3. RESULTS AND DISCUSSION

3.1. Structural characteristics

In Table 1 the structural characteristic of single-jersey fabrics with different raw material content are given (figure 3).

Table 1*- Structural characteristics of the single jersey knitted fabrics with different raw material content*

No.	***Raw material content (%)***		***D_h (cm^{-1})***	***D_v (cm^{-1})***	***D (cm^{-2})***	***l (mm)***	***m (g/m^2)***	***h (mm)***	***TF ($tex^{1/2}cm^{-1}$)***	***P (%)***
1	100 PAN	$\bar{x}$ Cv(%)	5,50 (0,55)	7,75 (0,45)	42,6	7,30 (3,20)	412 (3,54)	1,245 (3,75)	15,7	71,0
2	50/50 PAN/cotton	$\bar{x}$ Cv(%)	5,75 (0,45)	9,00 (0,71)	51,7	6,90 (2,40)	472 (4,23)	1,280 (1,27)	16,6	71,0
3	100 Wool	$\bar{x}$ Cv(%)	6,00 (0,45)	8,00 (0,55)	48,0	6,95 (3,40)	440 (4,10)	1,314 (1,25)	16,5	73,9

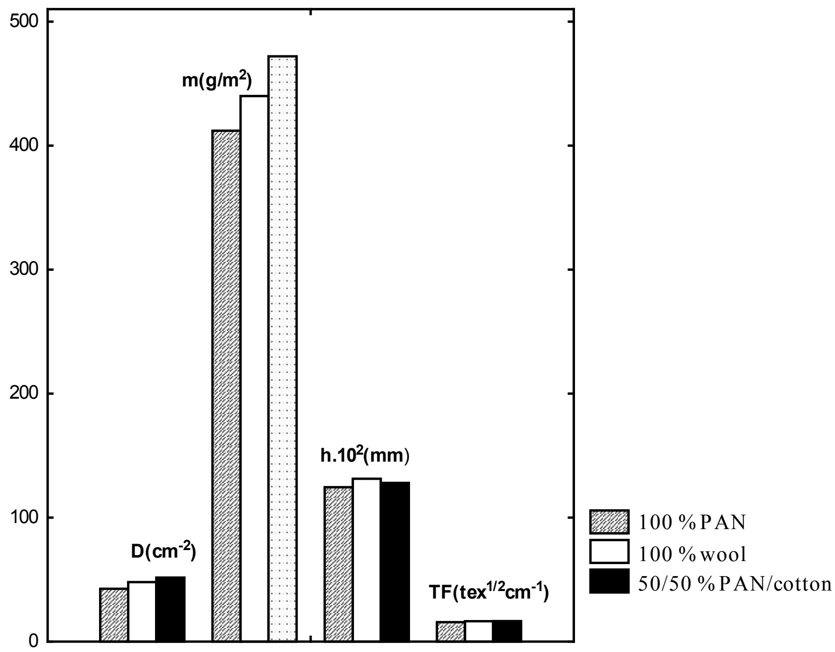


Figure 3 -Density(D),mass per unit area (g/m^2), thicknes(h) and tightness factor(TF) of the single jersey knitted fabrics with different raw material content

As the density ***(D)*** increases, the mass per unit area ***(m)*** and tigtness factor ***(TF)*** also increase, but not the thickness as a result of the different raw material content of the fabrics.

3.2. AIR AND WATER VAPOUR PERMEABILITY

In table 2 air and water vapor permeability values are given (figure 4a and 4b.)

Table 2-Air and water vapor permeability of the single jersey knitted fabrics with different raw material content

No.	***Raw material content (%)***	***Air permeability Q (dm^3/h)***	***Coefficient of variation Cv(%)***	***Coefficient of air permeability $B_{\Delta p}$ (m/s)***	***Water vapor permeability 4 hours (PVP,4h)***	***Water vapor permeability 8 hours (PVP,8h)***
1	100 PAN	1640	3,1	0,455	62,90	55,03
2	50/50 PAN/cotton	355	5,5	0,098	52,34	46,80
3	100 Wool	1110	4,4	0,308	62,31	53,95

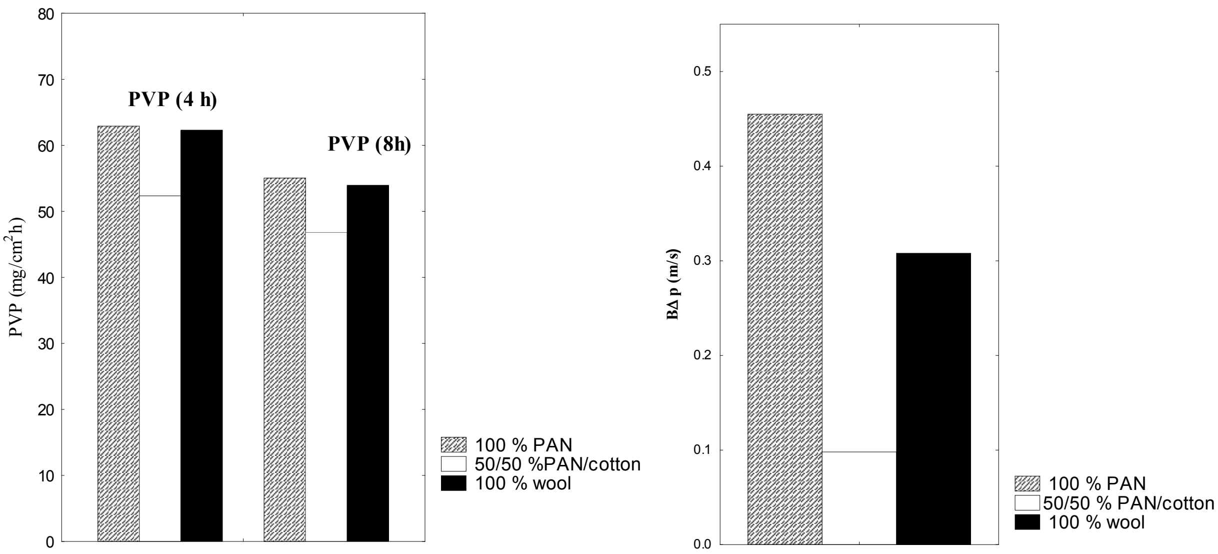


Figure 4: a)water vapor permeability(PVP 4 and 8hours) and b) coefficient of air permeability($B_{\Delta p}$)

Air permeability($B_{\Delta p}$)and water vapor permeability (PVPfor 4 and 8 hours) have the same trend of increase, i.e. their value decreases as the mass per unit area and tightness factor TF of the fabric increase. More dominant influence of the structural characteristics on the air and water vapor permeability compared to raw material content is noticeable.

3.3. Thermalcharacteristics

On figure 5 a thermogram for one sample of the examined fabrics is given. The values obtained from the thermograms of all samples and their natural logarithms are given in Table 3.

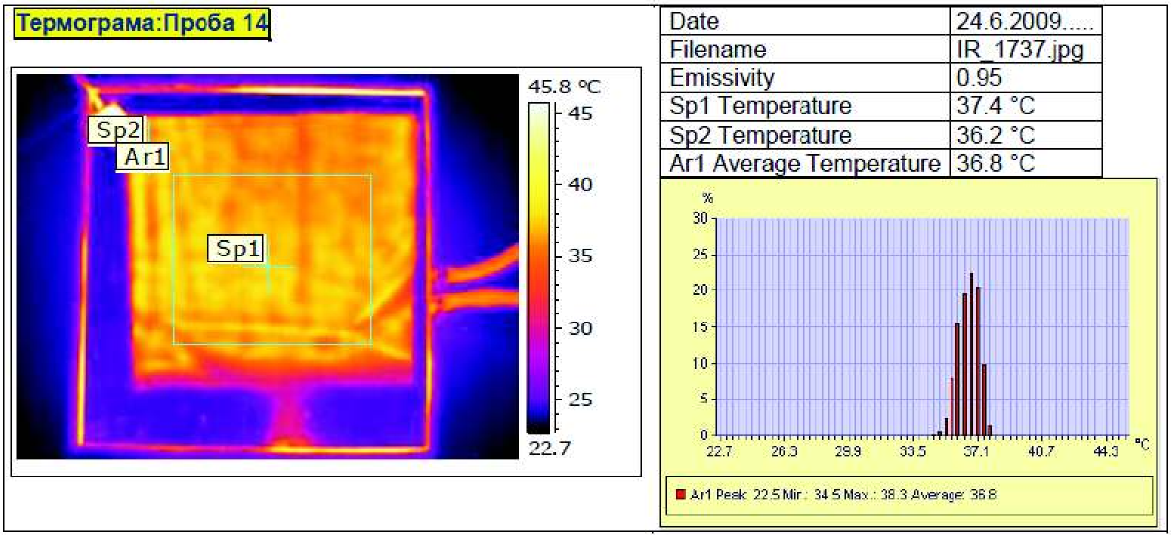


Figure 5- Thermogram for single jersey of 100% PAN

Table 3-*Data obtained from thermograms (Tsp_1u $Tarp_1$u T_w) for single jersey knitted fabrics with different raw material content and the temperature of the plate(Tw)*

Raw material content (%)	***Picture number***	***Tw (°C)***	***Tsp_1 (°C)***	***Tsp_2 (°C)***	***$Tarp_1$ (°C)***	***ln Tw***	***ln Tsp_1***	***ln $Tarp_1$***
PAN 100	1	47.38	37.4	36.2	36.8	3.8582	3.6217	3.6055
	2	46.01	37.0	35.8	36.6	3.8289	3.6109	3.6000
	3	44.44	36.1	35.0	36.0	3.7941	3.5863	3.5835
	4	42.91	35.9	34.3	35.4	3.7591	3.5807	3.5667
	5	41.46	35.0	34.0	34.7	3.7247	3.5553	3.5467
PAN/cotton 50/50	1	34.19	30.2	30.5	30.1	3.5319	3.4078	3.4045
	2	33.57	30.5	30.6	30.5	3.5136	3.4177	3.4177
	3	33.07	30.0	30.4	30.2	3.4986	3.4012	3.4078
	4	32.57	29.7	30.1	29.8	3.4834	3.3911	3.3945
	5	32.05	29.4	29.5	29.5	3.4673	3.3810	3.3844
Wool 100	1	51.75	35.5	38.4	35.8	3.9464	3.5695	3.5779
	2	51.03	37.3	39.9	37.1	3.9324	3.6190	3.6136
	3	49.80	37.4	40.2	37.7	3.9080	3.6217	3.6296
	4	48.22	37.3	40.0	37.4	3.8758	3.6199	3.6217
	5	46.79	36.9	39.4	37.3	3.8450	3.6082	3.6189

In figures 6, 7 and 8 the linear line equation of the examined fabrics are given, based on which the coefficient for temperature change rate $\mathbf{m_1}$ is determined.

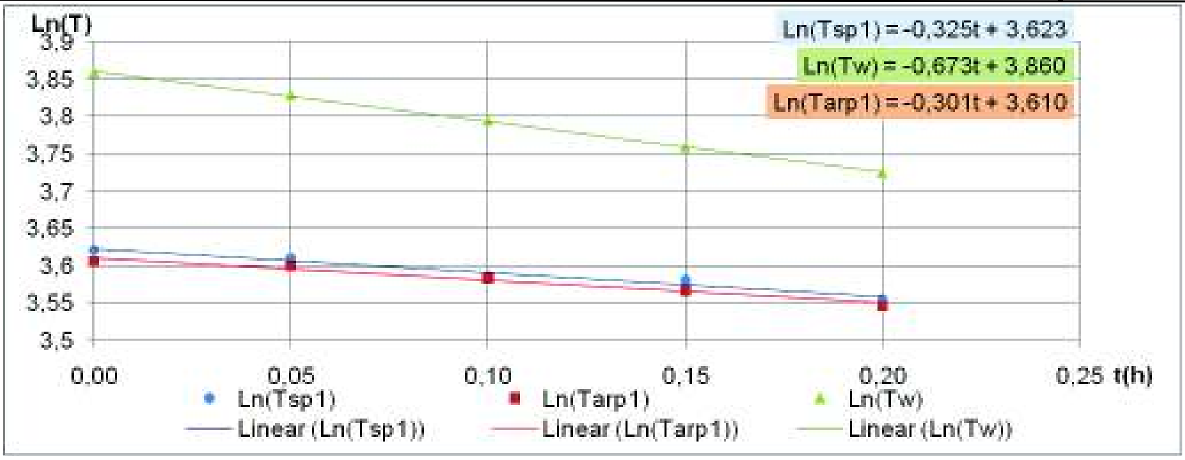


Figure6 – The temperature change dependence from the time of capture T_{sp1}, T_{arp1} and T_w for single jersey of 100% PAN

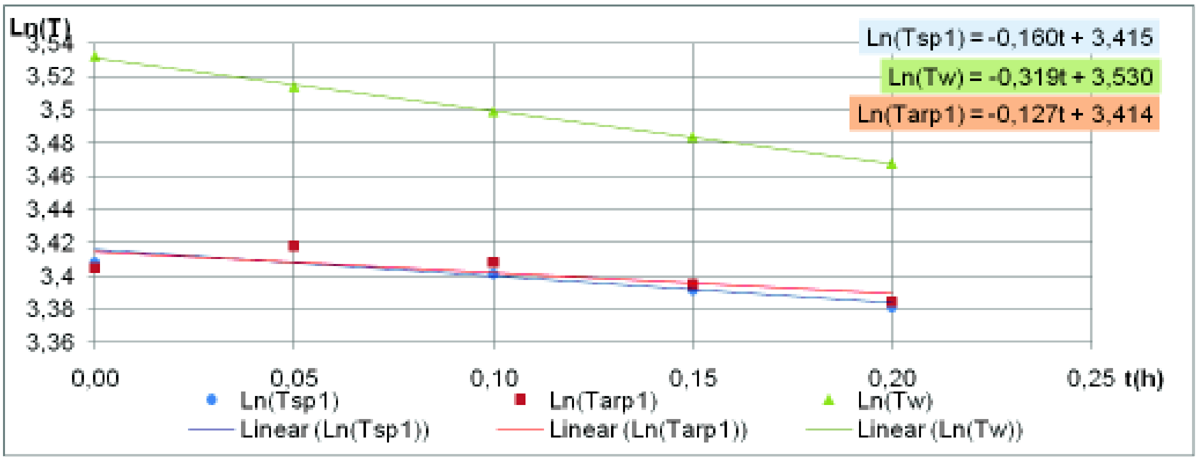


Figure7– The temperature change dependence from the time of captureT_{sp1}, T_{arp1} and T_w for single jersey of 50/50% PAN/cotton

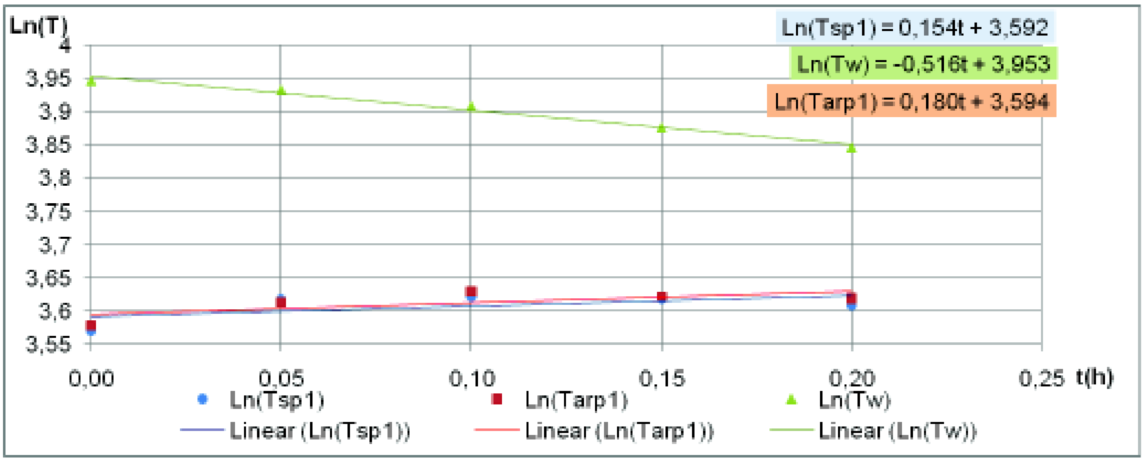


Figure8 – The temperature change dependence from the time of captureT_{sp1}, T_{arp1} and T_w for single jersey of 100% wool

Based on the thermograms and the linear line equations the coefficient of the temperature change dependence from the time of capture $m_1$is determined. After that the coefficient K is calculated. This data is needed to determine the thermal conductivity λ and thermal resistance R_{ct}(table 4).

Table4–*Thermal characteristics of single jersey knitted fabrics with different yarn components*

No.	*Yarn component (%)*	$K=(\pi/2h)^2$	m_1	*c (J/kgK)*	*ρ (kg/m³)*	*λ (W/mK)*	R_{ct} (m^2K/W)
1	100 PAN	1591823	0,3017	1200	331	0,0753	0,0165
2	50/50 PAN/cotton	1505960	0,1270	1270	369	0,0395	0,0324
3	100 Wool	1429035	0,1803	1300	335	0,0549	0,0239

It can be noticed that the thermal conductivity decreases as the density and mass per unit area of the fabric increase, while the thermal resistance rises respectively. The fabric made of 100% PAN, which has the highest air and water vapor permeability, also has the highest thermal conductivity, i.e. the lowest thermal resistance.

4. CONCLUSION

The results indicate that the structural characteristics of the knitted fabric have dominant influence on thermo-physiological comfort, as opposed from the rawmaterial content. The density, mass per unit area and tightness factor of the knitted fabrics determine the air and water vapor permeability and thermal characteristics. The final assessment of the thermo-physiological comfort depends on the wearing conditions. According to this, a single jersey made of50/50%PAN-cotton will provide the best comfort when being worn on lower temperatures, while a single jersey of 100%PAN on higher temperatures. The single jersey made of 100%wool did not show the highest thermal resistance as expected because of its raw material content, which is a result of the structural characteristics i.e. lower density of the fabric.

One of the aims of the investigation was to check the possibility for using the method of thermo-vision analysis when investigating the thermal properties of knitted fabrics as important element of thermo-physiological comfort. The results from this research provide a huge area for further investigation.

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