THE IMPACT OF RAW COMPOSITION, KNITTED FABRIC PARAMETERS AND FINISHING OF 1X1 RIB KNITWEAR ON WATER VAPOR RESISTANCE

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Abstract: *Clothing comfort is very important feature which is considered as a result of different process of heat exchange between human body, clothing and environment. The purpose of this paper is to analyze the impact of raw composition, knitted fabric parameters and finishing on the heat water vapor resistance. The measurements was carried out on commercially 1x1 RIB knitted fabrics used for the production of next -to-skin shirts. The one group of samples are made from 100% cotton yarn and another with 96% cotton and 4% Lycra. It is noticed that knitted material composition affected the change in water vapor resistance. Also, this paper presents and verifies the correlation between the measured values of water vapor resistance (Ret) and the knitwear thickness (d_{pl}), mass per unit area (m_{pl}) the tightness factor (K), the porosity (ε) and the surface coefficient (δ_p). Based on these results, a mathematical model for calculating water vapor resistance is proposed. Comparing the results obtained with the proposed equation and the measured results, we can see that the deviations are minimal. The lowest deviation for sample CP3 is less than 0.0008%, while the largest deviation for sample CL1 is 0.023%.*

Keywords: *thermo physiological comfort, porosity, tightness factor, surface coefficient*

INTRODUCTION

The development of science and technology, as well as the improvement of social standards, moved the requirements of customers who prefer garments that provide a satisfactory level of comfort to a higher level. Today, many people are exposed to different atmospheric influences from heat to cold and frequent weathering factors, which is depended by nature of their work [1]. Therefore the clothing with appropriate protective properties as well as satisfactory level of comfort has a huge importance and it represent one of the key factors during the clothes selection, and a decisive factor in the evaluation of the clothing quality [1]. The garments can be seen as a heat exchange layer between the body and its environment. Thermo physiological comfort is directly related to physiological processes of human body and is the result of the balanced process of heat exchange between the human body, the clothing system and the environment. [2]

The thermal properties of clothing that demonstrate the ability to transfer heat and moisture from the surface of the human body to the environment are the dominant determinants of the thermal comfort of clothing. The measuring values that are related to the ability to evaluate the heat exchange of the human body with the environment, and are related with the human perception of comfort are thermal resistance or thermal insulation (Rct) and resistance to water vapor flow on clothing (Ret). The impact of clothing and air trapped in clothing and around the body can be assessed by thermal comfort properties, which provide the ability to assess the effect of clothing on thermal balance in a particular environment [2,3].

The speed of water vapor flow from the skin surface trough the layers of clothing into the environment is an important parameter that defined the usable characteristic of clothing. During the sweating of human body, sweat is taken to the environment through clothes.

The speed at which the evaporated sweat will be removed largely depends on the type of clothing, i.e. parameters of the material and the raw material composition. This means that it is possible to balance the rate of sweat evaporation by choosing the right clothes [4,5].

The aim of this paper is to investigate the influence of structural characteristics (knitwear's thickness, mass per unit area porosity, tightness factor and surface coefficient) on the water vapor resistance of Ret in ribbed 1x1 knitwear. The effect of incorporation of elastane fibers into the knit structure on water vapor resistance was also analyzed. For this purpose ribbed 1x1 knitwear are made with four different linear densities of yarn made from 100% cotton and from a mixture of cotton/elastane yarns.

WATER VAPOR RESISTANCE (RET)

The measuring device KES FB 7 - Thermo Labo II (Figure 1) was used to test the water vapor resistance of knitted samples. In the wind tunnel of the device, there is a measuring body that simulates the skin temperature and it is heated to 35°C. There is a constant air flow of 1 ms^{-1} and a constant air temperature of 20° C $\pm$ 2 in the wind tunnel. Water vapor resistance was determined only by the contact method, where the sample is placed directly on the hot plate because the knitwear i.e. T-shirts were used for the experiment, intended for carrying next to the body.

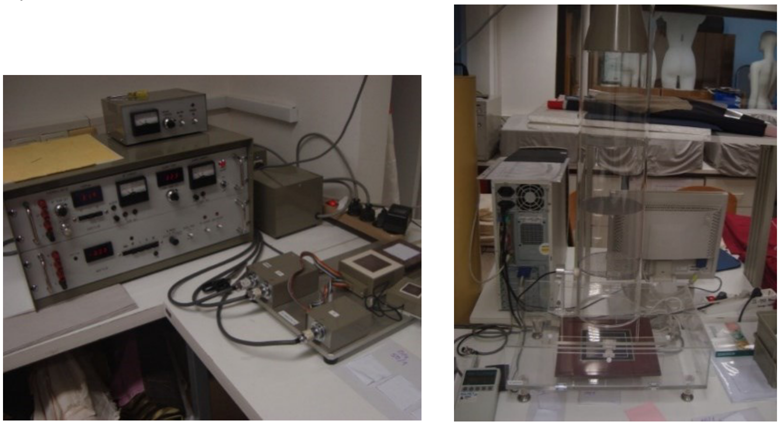

Figure 1. KES FB 7 - Thermo Labo II

Water vapor resistance Ret was determined according to the following equation :

$$\mathrm{R_{et}} = \frac{(\mathrm{p_s} - \mathrm{p_a}) \cdot \mathrm{A}}{\mathrm{H_{et}}} \tag{1}$$

Where is: $\mathrm{R_{et}} - water\ vapor\ resistance\ [\,Pa\, m^2\, W^{-1}]$, H_{et} – evaporated heat flow $[W]$, p_s- partial pressure on the surface of plate $[Pa]$,p_a- partial air pressure in wind tunnel $[Pa]$, A – plate surface $[m^2]$ [5].

MATERIALS AND METHODS

Experimental part of this paper was carried out using the knitwear that is commercially used for the production of clothes of next-to-skin-wear. This kind of clothes are worn either as one-layer summer wear or as the first layer that is in contact with human skin in cooler season of the year. The knitwear samples are produced with 1x1 RIB structure. Samples are made of 100% CO yarns and CO yarns in combination with Lycra (96% CO / 4 % LY). Linear density of Lycra which was used is 44dtex. CO yarn was used in four linear densities: 20 tex, 17, 14 and 12 tex. Samples in the bleached state and stained samples were examined (table 1).

Table 1: Basic characteristics of analyzed knitwear's samples

Sample	Structure	Fiber composition	Yarn linear density (tex/dtex)	Yarn twists (m-1)	Knitwear finishing
BP_1	1x1 RIB	100% CO	20	780	bleached
BP_2	1x1 RIB	100% CO	17	804	bleached
BP_3	1x1 RIB	100% CO	14	929	bleached
BP_4	1x1 RIB	100% CO	12	977	bleached
BL_1	1x1 RIB	96% CO / 4% LY	20/44	780/-	bleached
BL_2	1x1 RIB	96% CO / 4% LY	17/44	804/-	bleached
BL_3	1x1 RIB	96% CO / 4% LY	14/44	929/-	bleached
BL_4	1x1 RIB	96% CO / 4% LY	12/44	977/-	bleached
CP_1	1x1 RIB	100% CO	20	780	dyed
CP_2	1x1 RIB	100% CO	17	804	dyed
CP_3	1x1 RIB	100% CO	14	929	dyed
CP_4	1x1 RIB	100% CO	12	977	dyed
CL_1	1x1 RIB	96% CO / 4% LY	20/44	780/-	dyed
CL_2	1x1 RIB	96% CO / 4% LY	17/44	804/-	dyed
CL_3	1x1 RIB	96% CO / 4% LY	14/44	929/-	dyed
CL_4	1x1 RIB	96% CO / 4% LY	12/44	977/-	dyed

Knitwear are made on a circular knitting machine type Fv 2.0 of company Mayer & Cie. Characteristics of the machine are as follows: cylinder diameter 19 "(inch), the gauge is E18 and with 40 feeders, the knitting speed is 1.7 m / s. All of the samples are knitted under the same conditions on the same machine. A measuring device used to test the thermal characteristics of knitwear samples was KES FB 7 - Thermo Labo II.

The correlation analysis is used to compare the relation between the resulting values of water vapor resistance (R_{et}) and the resulting values of knitwear thickness (d_{pl}), porosity (ε), surface coefficient (δ_p) and tightness factor (K).The correlation coefficients present the strength of the association between two variables. The coefficient of determination (R^2), was used to measure the strength of the linear association between variables. The value of coefficient of determinations ranges between -1 and 1. The positive value of coefficient of determination means that the values obtained with two methods are proportionally linear. If the coefficient of determination is +1 this presents the maximum of positive correlation. If the correlation coefficient is zero, this means zero correlation.

RESULTS AND DISCUSSION

Experimentally obtained results of knitwear thickness, porosity, surface and volume coefficients, tightness factor, and water vapor resistance are presented in table 2.

Table 2:

EEXPERIMENTALLY OBTAINED RESULTS OF KNITWEAR THICKNESS, POROSITY, SURFACE COEFFICIENT, TIGHTNESS FACTOR, VOLUME COEFFICIENT AND WATER VAPOR RESISTANCE						
Sample	**Mass per unit area (m_{pl})**	**Knitwear thickness (d_{pl})**	**Porosity (ε)**	**Surface coefficient (δ_p)**	**Tightness factor (K)**	**Water Vapor resistance (R_{et})**
	($g\ m^{-2}$)	(mm)	-	-	($tex^{1/2}cm^{-1}$)	(m^2PaW^1)
BP_1	194,71	1,073	0,88	1,16	15,8	8,5187
BP_2	178,55	1,062	0,89	1,23	14,4	8,4723
BP_3	140,25	0,965	0,91	1,32	13,4	8,4192

BP_4	115,44	0,914	0,92	1,40	12,4	8,3981
BL_1	279,44	1,217	0,85	0,84	15,9	8,9018
BL_2	243,43	1,171	0,86	0,90	14,6	8,8234
BL_3	207,14	1,205	0,89	0,92	13,2	8,5311
BL_4	189,94	1,164	0,89	0,96	12,2	8,4377
CP_1	206,89	1,116	0,87	1,16	15,7	8,9007
CP_2	177,99	1,036	0,89	1,11	14,4	8,3381
CP_3	146,41	1,002	0,91	1,31	13,5	8,1727
CP_4	129,16	0,920	0,91	1,38	12,5	8,2102
CL_1	279,48	1,225	0,85	0,86	15,9	8,6172
CL_2	255,54	1,228	0,87	0,86	14,5	8,8424
CL_3	211,37	1,196	0,88	0,93	13,0	8,7758
CL_4	188,81	1,158	0,89	0,96	12,1	8,4776

The correlation between the water vapor resistance and knitwear thickness, surface coefficient, porosity and tightness factor are shown in figures 2-11.

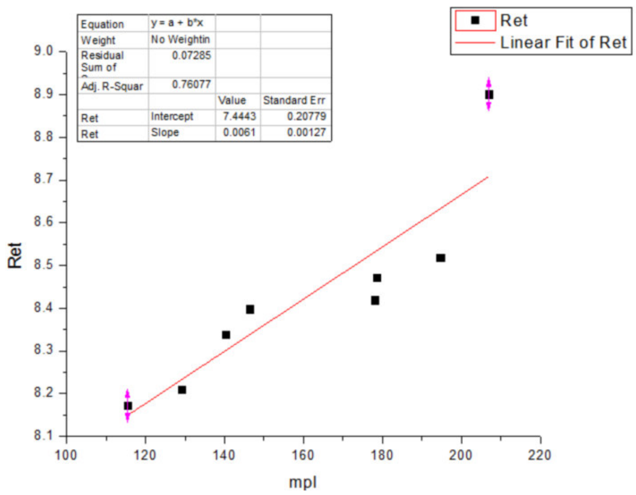

Figure 2: Relationship between R_{et} and m_{pl} in 100%Co bleached and dyed knitwear, R^2=0,7607

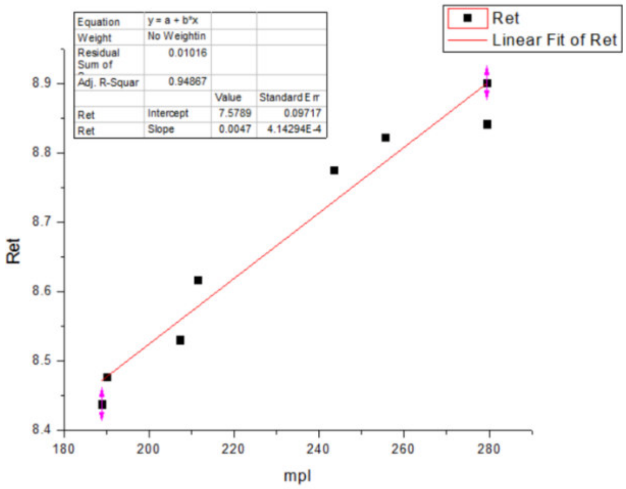

Figure 3: Relationship between R_{et} and m_{pl} in in 96%Co /4%Ly bleached and dyed knitwear, R^2=0,9486

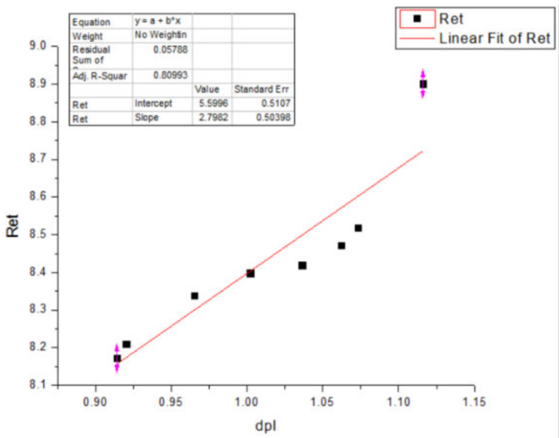

Figure 4: Relationship between R_{et} and d_{pl} in 100%Co bleached and dyed knitwear, R^2=0,8099

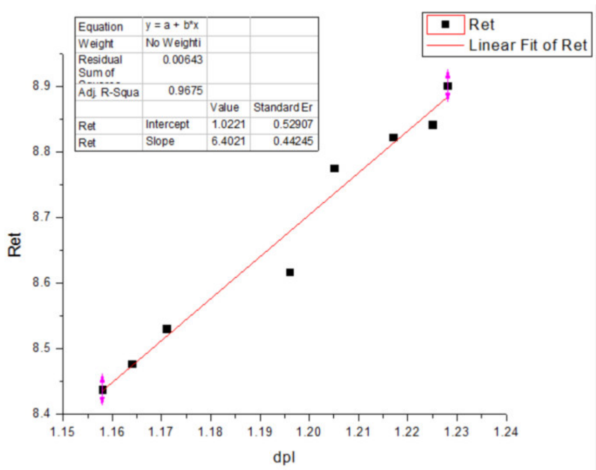

Figure 5: Relationship between R_{et} and d_{pl} in 96%Co /4%Ly bleached and dyed knitwear, R^2=0,9675

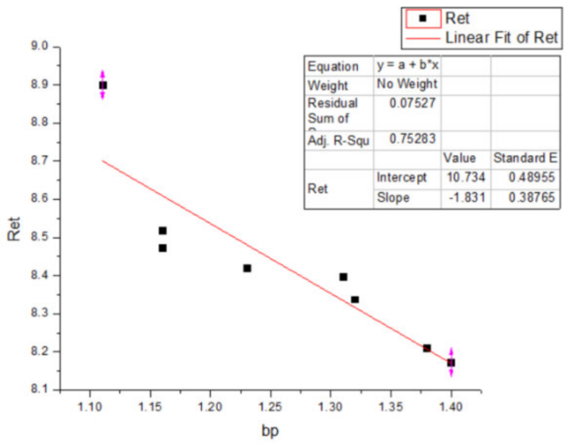

Figure 6: Relationship between R_{et} and δ_p in 100%Co bleached and dyed knitwear, R^2=0,75283

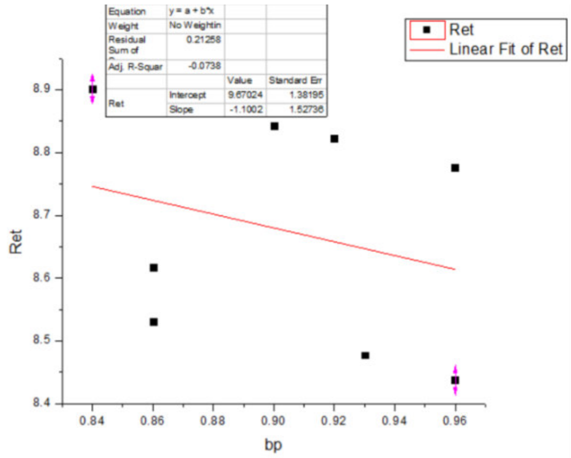

Figure 7: Relationship between R_{et} and δ_p in 96%Co /4%Ly bleached and dyed knitwear, R^2=-0,0738

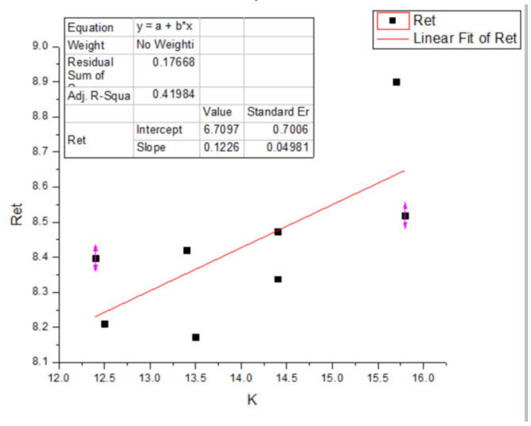

Figure 8: Relationship between R_{et} and K in 100%Co bleached and dyed knitwear, R^2=0,41984

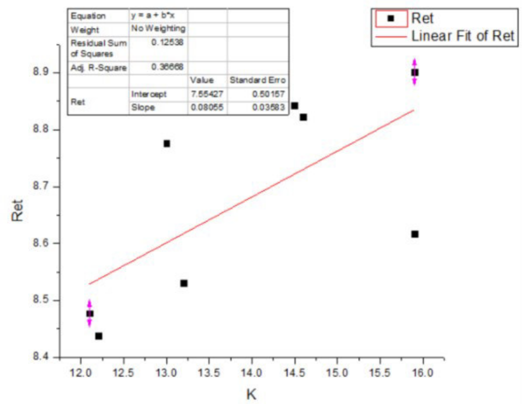

Figure 9: Relationship between R_{et} and K in 96%Co /4%Ly bleached and dyed knitwear, R^2=0,36668

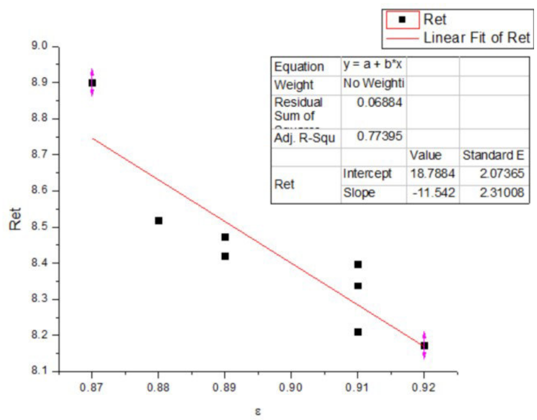

Figure 10: Relationship between R_{et} and ε in 100%Co bleached and dyed knitwear, R^2=0,77395

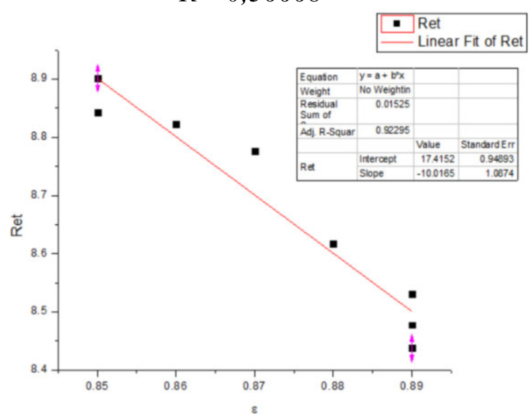

Figure 11: Relationship between R_{et} and ε in 96%Co /4%Ly bleached and dyed knitwear, R^2=0,92295.

From the previous considerations it can be seen that there is a correlation between the parameters of knitwear and the water vapor resistance of the same knitwear. Therefore, it is proposed a suitable mathematical model in order to calculate the Ret values of the 1x1 rib knitwear samples tested, based on the experimentally measured values of knit thickness (dpl), tightness factor (K), surface coefficient (δ_p) and porosity (ε). The coefficients for the proposed formula are shown in Table 3 and they are given separately for 100% cotton bleached ribbed knitwear made from cotton yarns with linear densities of 20, 17, 14 and 12 tex, for 100% cotton ribbed colored knitwear made from cotton yarns 20, 17. 14 and 12 tex, for ribbed bleached knitwear of 96% cotton and 4% Lycra made from cotton yarns linear densities 20, 17, 14 and 12 tex and for ribbed dyed fabrics of 96% cotton and 4% Lycra made from cotton yarn linear densities 20 , 17, 14 and 12 tex.

The mathematical model for calculating the value of R_{et} has the following form:

$$R_{et} = c_1 * d_{pl} + c_2 * K + c_3 * \delta_v + c_4 * \varepsilon \quad (2)$$

where c_1, c_2, c_3, c_4 are coefficients, d_{pl} is knitwear thickness, K is tightness factor, δ_p is surface coefficient, ε is knitwear porosity.

The coefficients for the proposed formula (2) are shown in Table 3 and they are given separately for 100% cotton bleached ribbed knitwear made from cotton yarns with linear densities of 20, 17, 14 and 12 tex (BP1-BP4), for 100% cotton ribbed colored knitwear made from cotton yarns 20, 17. 14 and 12 tex (CP1-CP4), for ribbed bleached knitwear of 96% cotton and 4% lycra made from cotton yarns linear densities 20, 17, 14 and 12 tex (BL1-BL4) and for ribbed dyed fabrics of 96% cotton and 4% lycra made from cotton yarn linear densities 20 , 17, 14 and 12 tex (CL1-CL4)."

Graphical representation of the deviations between calculated and measured values of Ret using the equation 3 are shown in Figure 11.

Table 3: Values of coefficients c_1, c_2, c_3, c_4 used for calculating Ret belached and dyed RIB 1x1 knitwear

Sample	**Finishing**	**Coefficient c_1**	**Coefficient c_2**	**Coefficient c_3**	**Coefficient c_4**
BP1-BP4	bleached	-0,0017	0,2990	0,2654	1,9562
CP1-CP4	colored	0,0403	-0,5189	0,3977	5,6841
BL1-BL4	bleached	-0,00073	-1,4085	-3,5746	68,924
CL1-CL4	colored	-0,0347	-0,253	-2,6753	46,279

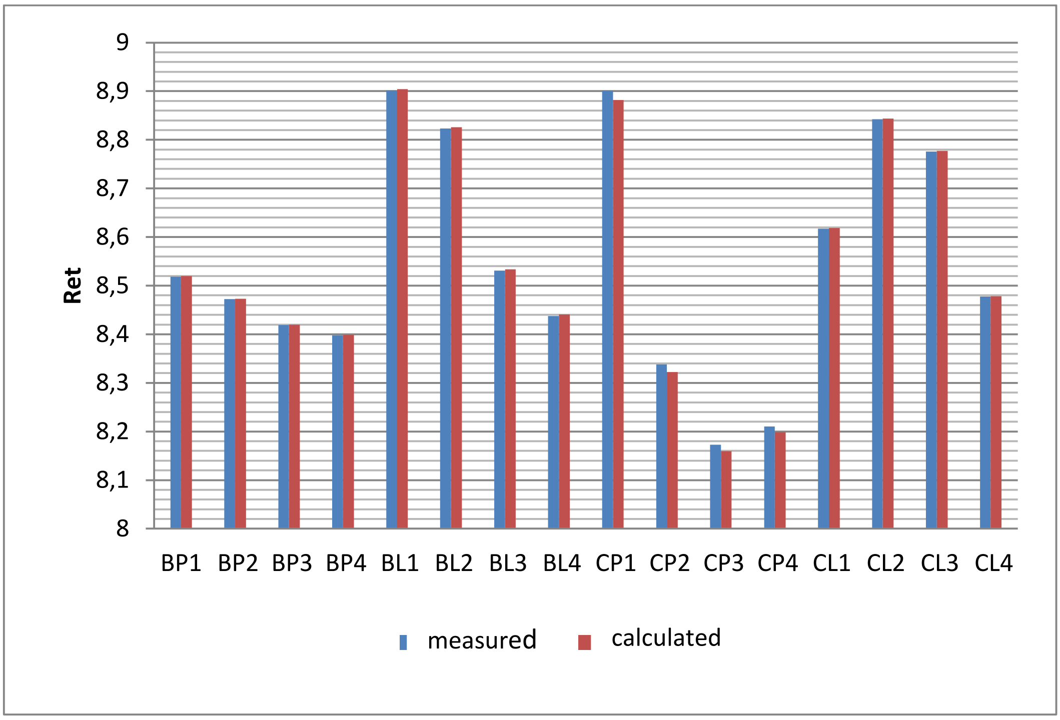

Figure 11: Graphical representation of the deviations between calculated and measured values of Ret

On figures 8 and 9 we can see that tightness factor (K) have a small coefficient of correlation for both raw compositions with water vapor resistance (R_{et}). Therefore it is replaced in mathematical model with mass per unit area (m_{pl}). Mass per unit area (m_{pl}) is in a strong correlation with water vapor resistance (R_{et}). Then the mathematical model will have a new form:

$$R_{et} = c_1 * d_{pl} + c_2 * m_{pl} + c_3 * \delta_v + c_4 * \varepsilon \qquad (3)$$

The coefficients for the proposed formula (3) are shown in Table 4 and they are given separately for sample groups BP1-BP4, CP1-CP4, BL1-BL4 and CL1-CL4. Graphical representation of the deviations between calculated and measured values of Ret using the equation 3 are shown in Figure 12.

Table 4: Values of coefficients c_1, c_2, c_3, c_4 used for calculating Ret belached and dyed RIB 1x1 knitwear

Sample	Finishing	Coefficient c_1	Coefficient c_2	Coefficient c_3	Coefficient c_4
BP1-BP4	bleached	0,1076	1,6001	1,4683	3,8389
CP1-CP4	colored	0,4191	-2,0477	6,4140	-0,78
BL1-BL4	bleached	1,8114	-21,8164	0,5115	4,8344
CL1-CL4	colored	-03292	16,5734	5,2720	-12,982

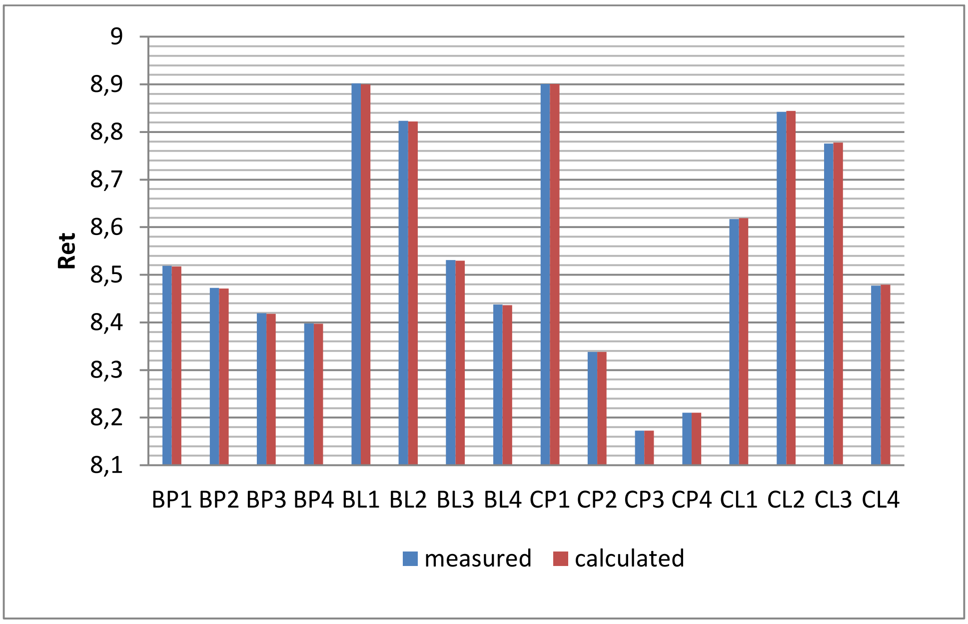

Figure 12: Graphical representation of the deviations between calculated and measured values of Ret using the equation (3)

CONCLUSIONS

According to the conducted research of the impact of yarn thickness and raw material composition, i.e. the influence of Lycra on thermal resistance in ribbed knitwear, following can be concluded:

- knitwear that, beside cotton yarn, has Lycra in their composition, are more compact and therefore water vapor resistance increases with these samples.
- with a change of linear density of the cotton yarn i.e. with a decrease in the thickness of cotton yarn and water vapor resistance decreases by 1,5% in cotton yarn knitwear and up to 8% in knitwear with Lycra in its composition.

From the obtained results we can conclude that in knitwear made from 100% cotton yarn, and linear density of 12tex shows the lowest water vapor resistance. While the highest water vapors resistance is observed in knitwear that has Lycra and cotton yarns linear density of 20tex in their composition.

Also, this paper presents and verifies the correlation between the measured values of water vapor resistance (R_{et}) and the knitwear thickness (d_{pl}), mass per unit area (m_{pl}), the porosity of the twists (ε) and the surface coefficient (δ_p). It is noticed that the tightness factor has a small correlation with water vapor resistance. Based on these results, a mathematical model for calculating water vapor resistance is proposed. Comparing the results obtained with the proposed equation and the measured results, we can see that the deviations are minimal. The lowest deviation for sample CP3 is less than 0.0008%, while the largest deviation for sample CL1 is 0.023%.

Based on the results obtained, we can conclude that knitwear intended for wearing to the body are made of 100% cotton yarn have lower values of water vapor resistance and are recommended for wearing in warmer weather, while knitwear with Lycra is recommended for wearing to the body in colder weather due to higher thermal insulation results.

ACKNOLEDGEMENTS

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