Evaluation of the comfort properties of functional knitted fabrics for people with special needs

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ABSTRACT – REZUMAT

Evaluation of the comfort properties of functional knitted fabrics for people with special needs

In this study, several comfort properties of knitted fabrics were investigated. Seven types of knitted fabrics made of combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) were produced. The knitted samples were subjected to several comfort tests, including air permeability, thermal resistance and water vapour resistance assessments. To determine the correlations among the comfort properties of the fabric, fabric structural properties, such as fabric weight and fabric thickness, were considered. Moreover, statistically significant differences were found in terms of dry thermal resistance, water vapour resistance and air permeability depending on the structural parameters of the fabric.

Keywords: *knitted fabrics, thermal comfort, air permeability, water vapour resistance, thermal resistance*

Evaluarea proprietăților de confort ale tricoturilor funcționale pentru persoanele cu nevoi speciale

În acest studiu, au fost investigate mai multe proprietăți de confort ale tricoturilor. Șapte tipuri de tricoturi au fost realizate din combinații de fibre naturale (de exemplu, bumbac, lână și bambus), fibre artificiale (de exemplu, modal) și fibre sintetice (de exemplu, poliester și acrilice). Probele tricotate au fost supuse mai multor teste de confort, inclusiv permeabilitatea la aer, rezistența termică și evaluările rezistenței la vapori de apă. Pentru a determina corelațiile dintre proprietățile de confort ale tricoturilor, au fost luate în considerare proprietățile structurale ale materialelor, cum ar fi masa și grosimea. În plus, s-au constatat diferențe semnificative statistic în ceea ce privește rezistența termică uscată, rezistența la vapori de apă și permeabilitatea la aer în funcție de parametrii structurali ai tricotului.

Cuvinte-cheie: *tricoturi, confort termic, permeabilitate la aer, rezistență la vapori de apă, rezistență termică*

INTRODUCTION

Herein, we analyse and evaluate the comfort properties of knitted fabrics used for functional clothing items. These items are guaranteed to meet the performance and/or functionality requirements of people with special needs, such as elderly people, people with atypical conformations, people who work under variable temperature conditions, and infants and young children. For these groups of people, the comfort of clothing is crucial. Clothing comfort can be divided into four categories: psychological, thermophysiological, sensorial (tactile) and garment fit comfort [2]. The thermophysiological comfort of clothing is influenced by internal heat exchange, air permeability and moisture evaporation. This type of comfort is achieved when the exchange of heat and humidity between the body and environment through clothing occurs under conditions in which the thermal and moisture management of the body is balanced and when a microclimate arises next to the skin [4–5]. The indicators that define thermophysiological comfort are thermal insulation capacity, air permeability, vapour permeability and water impermeability. Much research has focused on the improvement of thermal comfort performance in clothing. Özkan et al. investigated the thermophysiological comfort properties of polyester knitted fabrics. They found that textured polyester yarn knitted fabrics showed the highest air permeability values than moisture management polyester in the same yarn count and knit structure. Also, lower filament number fabrics show higher thermal resistance values in the same yarn count of fabrics [5].

The sensorial comfort of clothing is a result of the interactions among the fabric, human skin, the human sensory system and the atmospheric conditions, resulting in at least one of the following feelings: softness, stiffness, smoothness, itchiness, prickliness, warmth, and coolness.

Psychological comfort is determined by the mental state of the wearer, which is contributed to by their confidence in their appearance, their style of dressing, whether the style conforms to that of their location, whether the general style is in agreement with that of the wearer in terms of their socioeconomic status, and whether the style is in agreement with that of their acquaintances, including their colleagues, friends, and associates [3].

People with special needs still want to be fashionable, even if they often need to wear clothes that can hide specific body parts affected by disability and transformation, such as weight gain and skin sensitivity. The comfort of knitted fabric depends mainly on the basic properties of the yarn, the knitting structure, the weight and thickness of the knitted fabric and the presence of chemical treatments. Research has shown that it is impossible to obtain all the comfort requirements needed for clothing products intended for a certain group of users by using only one type of yarn [6–8]. A combination of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) is an optimal solution. An example of this combination is COOLMAX (polyester with channels), which has excellent moisture-wicking capacity. Modal, which is a form of regenerated cellulose, is more biodegradable and softer than viscose, and it is stronger, lighter, more breathable, and 50% more absorbent than cotton. Many researchers investigated the properties of knitted or woven fabrics made of regenerated cellulosic fibres. Sarioglu et al. investigated some comfort properties of different woven fabrics produced from cotton and polyester fibres blended with varying ratios of regenerated cellulosic fibres. The authors concluded that fibre type, fibre blend components and blend ratio have a significant effect on some comfort properties such as air permeability, wicking rate and absorption ratio. However, those parameters did not have any significant effect on the water vapour permeability [6]. Çeven et al. investigated some comfort properties such as thermal property, water vapour permeability, water vapour resistance, air permeability and bursting strength of single jersey knitted fabrics made of different raw materials including combed cotton, carded cotton, Cupro, TencelTM, Modal and Umorfil® yarn. They found that the regenerated cellulosic yarn type of knitted fabrics and the process type (untreated greige fabric or dyed fabric) were generally significant [8]. Kumar et al. investigated moisture management properties and drying behaviour of various knitted fabrics produced by changing the blend percentage of wool/acrylic, the number of filaments in polypropylene yarn and the structure of the knitted fabric. The authors concluded that the higher wool content in fabrics gives better moisture management and drying behaviour.

Polypropylene fabrics having a high number of filaments in the constituent yarn show better moisture management and drying behaviour than wool/acrylic fabrics [9]. Knitted fabrics are preferred by people with special needs, as these fabrics have greater elasticity and stretchability than woven fabrics. These materials provide unrestricted freedom of movement and transmission of body vapour to the next textile layer in the clothing system [1].

The objective of this study is to investigate the thermophysiological comfort properties of different fabrics knitted from combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) for people with special needs (e.g., elderly people, people with disabilities, and people who work in variable temperature conditions). According to the test results, some evaluations are made regarding the knitted fabrics, such as thermal resistance, air permeability, and water vapour resistance.

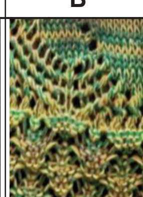
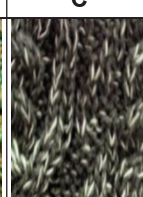
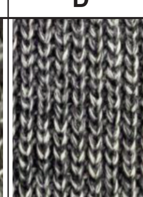
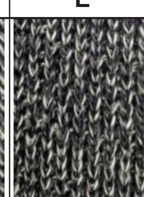
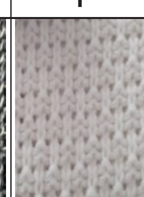
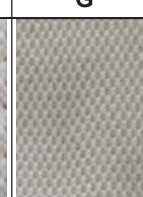
MATERIALS AND METHODS

Materials

In this study, seven knitted fabrics with fibres of varying compositions and knit structures were manufactured by Datsa Textil S.R.L. on the flat knitting machine CMS 530 ki. Detailed construction parameters are given in table 1.

Table 1

CONSTRUCTION PARAMETERS OF KNITTED FABRICS

Sample cod	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Appearance							
Fibre type	Cotton/ acryl/ bamboo	Cotton/ acryl	Wool/ cotton/ modal/	Wool/ cotton/ modal/	Wool/ cotton/ modal/	Wool/ acryl/ Coolmax	Wool/ acryl/ Coolmax
Knit structure	Single jersey	Single jersey and openwork	Rib 1x1	1x1 Rib	1x1 Rib	Honeycomb	Honeycomb
Gauge of knitting machine	E 7.2	E 7	E 2.5	E 7	E 7	E 10	E 10
Fabric mass per unit area (g/m^2)	329.6	541.5	509.5	764	728.4	511.8	537
Fabric thickness (mm)	1.8	4.68	4.64	5.61	5.39	4.19	3.08

Methods

Before testing, all fabric samples were conditioned in a standard atmosphere for 24 hours at a temperature of 20±2°C and a relative humidity of 65±2%.

Two physical parameters of the developed knitted fabrics fabric thickness (mm) and fabric mass per unit area were evaluated according to the SR EN ISO 5084 and SR EN 12127 test methods, respectively.

Comfort properties including air permeability (l/m^2/s), thermal resistance (m^{2}K/W) and water vapour resistance (m^{2}Pa/W) were measured.

Air permeability has been described as the rate of airflow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. Air permeability tests of the knitted fabrics were performed according to the SR EN ISO 9237 test method using a head area of 20 cm^2 and differential pressure of 100 Pa. Air permeability was measured on a TexTest air permeability tester (model FX 3300).

Many of the test methods to measure thermophysiological, comfort try to mimic the heat and mass transfer from the human skin to the environment through the textile layers. One of the most widely used methods is the sweating-guarded hot plate to measure the water vapour resistance or the thermal resistance of material samples.

The thermal resistance, R_{ct}, is a quantity specific to textile materials that determines the dry heat flux between the two faces of a material relative to the area and temperature gradient. In addition, this parameter determines the heat insulation characteristics of a textile material. The higher the thermal resistance is, the lower the heat loss. Water vapour resistance, R_{et}, is a quantity specific to textile materials that determines the latent evaporative heat flux between the two faces of a material relative to the area and water vapour pressure gradient.

Each fabric sample was tested by using a sweating-guarded hot plate to evaluate the dry thermal resistance (R_{ct}) and water vapour resistance (R_{et}) characteristics, according to the SR EN ISO 11092 test method. The sweating-guarded hot plate consists of an electrically heated plate, which is located in a climatic chamber. Square samples are put onto the plate, and air at a defined temperature, relative humidity and velocity (1 m/s) is blown tangentially from a fan over the sample. The plate is heated to 35°C and the measuring surface is surrounded by a guard heated to the same temperature to avoid heat loss.

To analyse the obtained experimental data, a single factor analysis of variance (ANOVA) was applied. The null hypothesis was as follows: *There are significant differences between all analysed parameters of the knitted fabrics for people with special needs.*

RESULTS AND DISCUSSION

The experimental data analysed for the knitted fabric samples are mass per unit area, thickness, air permeability, water vapour resistance and thermal resistance.

The statistical parameters and interpretations of the experimental data for the physical and comfort properties of the knitted fabrics are illustrated in figures 1–5 and tables 2–5.

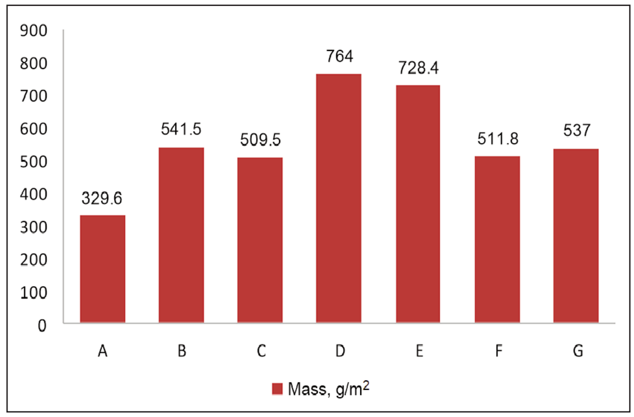


Fig. 1. Averages of experimentally determined values for mass (g/m^2)

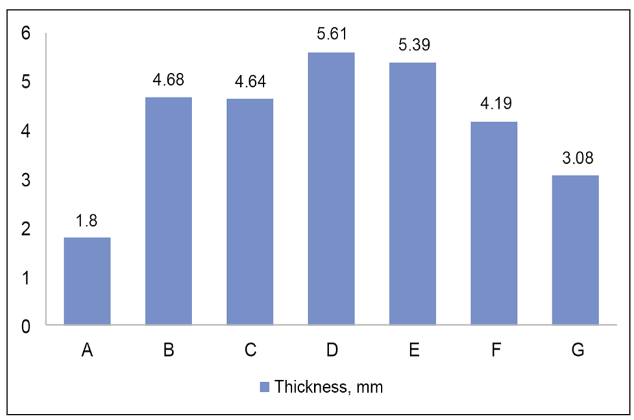


Fig. 2. Averages of experimentally determined values for thickness (mm)

Table 2

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR THICKNESS

Thickness (mm)	A	B	C	D	E	F	G
Mean	1.798	4.676	4.642	5.606	5.386	4.186	3.06
Standard Error	0.060117	0.089252	0.196962	0.057671	0.096312	0.042024	0.010488
Median	1.85	4.74	4.68	5.61	5.33	4.14	3.05
Standard Deviation	0.134425	0.199575	0.44042	0.128957	0.21536	0.093968	0.023452
Sample Variance	0.01807	0.03983	0.19397	0.01663	0.04638	0.00883	0.00055

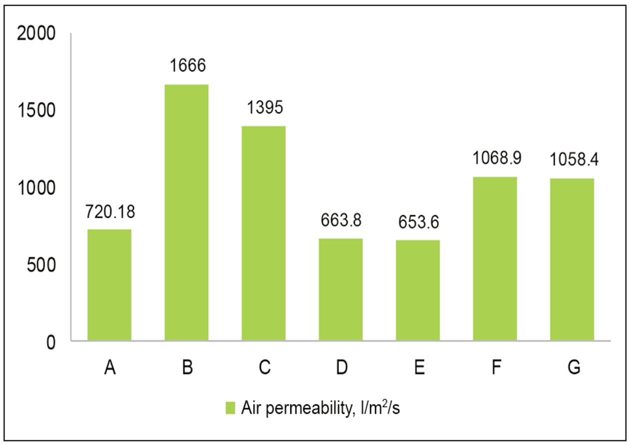


Fig. 3. Averages of experimentally determined values for air permeability (l/m^2/s)

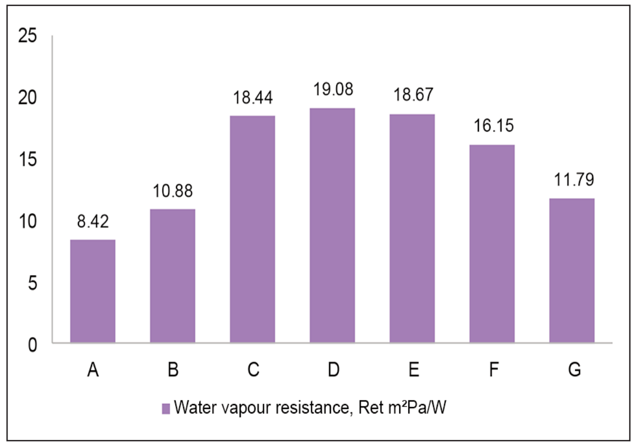


Fig. 4. Averages of experimentally determined values for water vapour resistance R_{et} (m^{2}Pa/W)

Table 3

STATISTICAL PARAMETERS OF THE EXPERIMENTAL DATA FOR AIR PERMEABILITY							
Air permeability (l/m^2/s)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	720.16	1666	1395	663.8	653.6	1068.9	1058.4
Standard Error	62.00293	83.30933	16.21042	6.621178	5.641513	12.84476	17.97232
Median	646	1720	1410	665	648	1070	1045
Standard Deviation	196.0705	263.4472	51.26185	20.938	17.84003	40.61869	56.83348
Sample Variance	38443.63	69404.44	2627.778	438.4	318.2667	1649.878	3230.044
Maximum	1133.6	2020	1460	701	682	1140	1150

Table 4

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR WATER VAPOUR RESISTANCE							
Water vapour resistance R_{et} (m^{2}Pa/W)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	8.42	10.984	18.437	19.078	18.671	16.225	11.791
Standard Error	0.003944	0.00718	0.069635	0.01052	0.018705	0.081025	0.01402
Median	8.42	10.985	18.385	19.08	18.685	16.14	11.78
Standard Deviation	0.012472	0.022706	0.220204	0.033267	0.059151	0.256223	0.044335
Sample Variance	0.000156	0.000516	0.04849	0.001107	0.003499	0.06565	0.001966

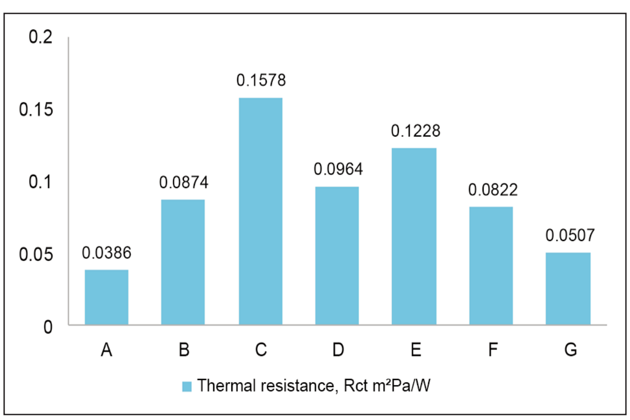


Fig. 5. Averages of experimentally determined values for thermal resistance R_{ct} (m^{2}K/W)

The ANOVA test is conducted to evaluate the statistical hypotheses. In addition, averages, variances (dispersions), proportions, and other statistical tools are implemented to form frequency distributions with known patterns (tables 6 and 7).

We test the null hypothesis, in which we predicted the absence of any interactions among the variables. If the *P* value is lower than 5%, the null hypothesis can be rejected. Thus, there are interactions between the analysed variables. Next, we analyse the correlations among some of the experimentally determined values.

The equation of the correlation coefficient, *r* = *CORREL*(*X, Y*), is as follows:

Table 5

STATISTICAL PARAMETERS OF EXPERIMENTAL DATA FOR THERMAL RESISTANCE							
Thermal resistance R_{ct} (m^2K/W)	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Mean	0.03862	0.08743	0.1572	0.09636	0.111802	0.0822	0.05073
Standard Error	3.59E-05	6.84E-05	0.000653	9.33E-05	0.011065	8.56E-05	0.000117
Median	0.0386	0.08745	0.15785	0.09625	0.1228	0.08215	0.0508
Standard Deviation	0.000114	0.000216	0.002063	0.000295	0.034991	0.000271	0.000371
Sample Variance	1.29E-08	4.68E-08	4.26E-06	8.71E-08	0.001224	7.33E-08	1.38E-07

Table 6

SUMMARY			
Groups	**Sum**	**Average**	**Variance**
Mass (g/m^2)	3921.8	560.2571429	21467.16619
Thickness (mm)	29.39	4.198571429	1.807114286
Air permeability ($l/m^2/s$)	7225.88	1032.268571	151962.0962
Water vapour resistance, R_{et} (m^2Pa/W)	103.43	14.77571429	18.91569524
Thermal resistance, R_{ct} (m^2Pa/W)	0.6359	0.090842857	0.001660453

Table 7

STATISTICAL ANOVA OF THE THERMOPHYSIOLOGICAL COMFORT						
Source of variation	**SS**	**df**	**MS**	**F**	**P value**	**F crit**
Between groups	6021801.931	4	1505450.483	43.39724982	4.62E-12	2.689628
Within groups	1040699.921	30	34689.99738			

Note: SS – sum square, df – degree of freedom

$$Correl(X, Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2\sum(y-\bar{y})^2}} \quad (1)$$

The correlation coefficient r has values between –1 and 1.

A brief interpretation of the coefficient r is as follows:

- r [0; 0.2] – very weak, nonexistent correlation
- r [0.2; 0.4] – weak correlation
- r [0.4; 0.6] – reasonable correlation
- r [0.6; 0.8] – high correlation
- r [0.8; 1] – very high correlation (very tight relationship between variables)

Thus, we determine the value of the correlation coefficient for the following parameters given in table 8.

Table 8

VALUES OF THE CORRELATION COEFFICIENT	
Average values correlation	**r**
Mass – Thickness	0.8752
Mass – Air permeability	–0.2902
Mass – Water vapour resistance	0.7559
Mass – Thermal resistance	0.4265
Thickness – Air permeability	0.0680
Thickness – Water vapour resistance	0.8316
Thickness – Thermal resistance	0.7290
Air Permeability – Water vapour resistance	–0.2145
Air Permeability – Thermal resistance	0.2922
Water Vapour Resistance – Thermal resistance	0.7825

The air permeability values of the fabrics used in the experiments were compared, as shown in figure 3. The lowest air permeability value was observed in sample E, which had the second highest thickness and fabric mass per unit area among the experiments. The highest air permeability value was observed in sample B, which had the third highest thickness and fabric mass per unit area. According

CONCLUSION

In this study, the thermophysiological comfort properties of seven different knitted fabrics made of combinations of natural fibres (e.g., cotton, wool, and bamboo), artificial fibres (e.g., modal) and synthetic fibres (e.g., polyester and acrylic) were investigated. All fabrics were compared in terms of their thermal resistance, water vapour resistance and air permeability. The correlation coefficients were analysed to identify the strengths and impacts of the relationships.

to the correlation coefficients obtained r = 0.2902, r = 0.2145 and r = 0.2922, air permeability was weakly correlated with the fabric mass per unit area, water vapour resistance and thermal resistance,

The thermal resistance properties of the fabrics used in the experiments were found, as shown in figure 5. The highest thermal resistance value was seen in sample C, which had the fourth-highest thickness and the sixth-highest fabric mass per unit area value among the evaluated specimens. The lowest thermal resistance value was observed in sample A, which had the seventh-highest thickness and fabric mass per unit area among the tested specimens. The correlation coefficient obtained, r = 0.4265, indicated a reasonable correlation between thermal resistance and fabric mass per unit area. Furthermore, r = 0.7290 indicated a high correlation between thermal resistance and thickness.

The water vapour resistance properties of the fabrics used in the experiments were found, as shown in figure 4. The highest water vapour resistance was observed in sample D, which had the highest thickness and fabric mass per unit area value. The lowest thermal resistance value was observed in sample A, which had the lowest thickness and fabric mass per unit area value. The correlation coefficients obtained were as follows: r = 0.7559, which indicated a high correlation between water vapour resistance and fabric mass per unit area; r = 0.8316, which indicated a very high correlation between water vapour resistance and thickness; and r = 0.7825, which indicated a high correlation between water vapour resistance and thermal resistance.

The results of this study showed that there were statistically significant differences in dry thermal resistance, water vapour resistance and air permeability depending on the structural parameters of a knitted fabric.

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