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Impact of Cellulose Materials Finishing on Heat and Water Vapour Resistance

Abstract
The paper explores the impact of finishing on heat and water vapour transfer through knitted materials made from cotton, viscose, modal and lyocel. Tests were performed on raw samples, samples finished in accordance with a commercial recipe and samples additionally finished with a silicone-based agent. The results indicated that changes in the water vapour resistance of the fabric are significantly higher for the samples made from natural fibers than those produced from natural polymers. The above leads to the conclusion that the processes of finishing according to the recipes defined are more suitable for the samples made from natural fibers. Such finished fabrics will reduce water vapour resistance in warm environmental conditions, in which it is necessary to allow the transfer of large amounts of sweat from the skin to the environment, and finally to positively affect an individual's perception of comfort.

Key words: *cellulose materials, finishing treatment, silicone, heat resistance, water vapour resistance.*

Introduction

Nowadays, many people are, because of the nature of work they do, exposed to different cold and hot environmental conditions. For them, the importance to wear appropriate protective clothing, with the establishment of a satisfactory level of comfort, is extremely significant. Clothing plays an important role in preserving the balance of heat and moisture, and one of the major goals of researchers is to define the mechanisms of their transmission and influential factors.

The effect of different environmental conditions and physical activity of individuals was investigated in a series of papers [1 - 7]. Much effort has been made in the research of the parameters of textile structures that affect different properties essential for the assessment of overall comfort. Research conducted by textile experts has shown that there are certain differences in resistance to the transfer of heat and water vapour [8], but the question is whether these are large enough to change the perception of the subjects.

The diffusion of mass through a textile material can be only accomplished through the fibre, the space between fibres or through cavities in the structure of the textile fabric. Bearing in mind the above, recent studies have shown that the type of yarn in the manufacture of certain fabrics (such as terry fabrics) has great importance for the properties of the static absorption of water [9]. In a series of studies, the essential parameters of fabrics that significantly affect heat and water vapour resistance were pointed out. The mass per unit area, thickness and porosity are the parameters to be primarily distinguished [10 - 14].

The finishing process also has a positive impact on the mass transfer through fabrics. For this reason, in the final stages of finishing fabrics, the product is often finished using additional agents enhancing handle but also allowing the transfer of heat and water vapour. As far as the impact of finishing is concerned, Yasuda et al. showed in their study that the type of finishing has no significant effect on the diffusion of water vapour through the textile structure [15]. Tzanov et al. showed that finishing with softeners, depending on their concentration, affect the permeability of water vapour but not the permeability of heat [16].

This paper explores the impact of finishing on heat and water vapour transfer through materials made from natural cellulose fibres (cotton) and fibres of natural cellulose polymers (viscose, modal, lyocel). To understand the impact of process modifications, tests were performed on raw samples,, samples finished in accordance with a commercial recipe, and samples additionally finished with a silicone-based agent. Based on the results, a comparison of the effect of the finishing procedures is carried out and possible impacts on the establishment of the total thermophysiological comfort are stated.

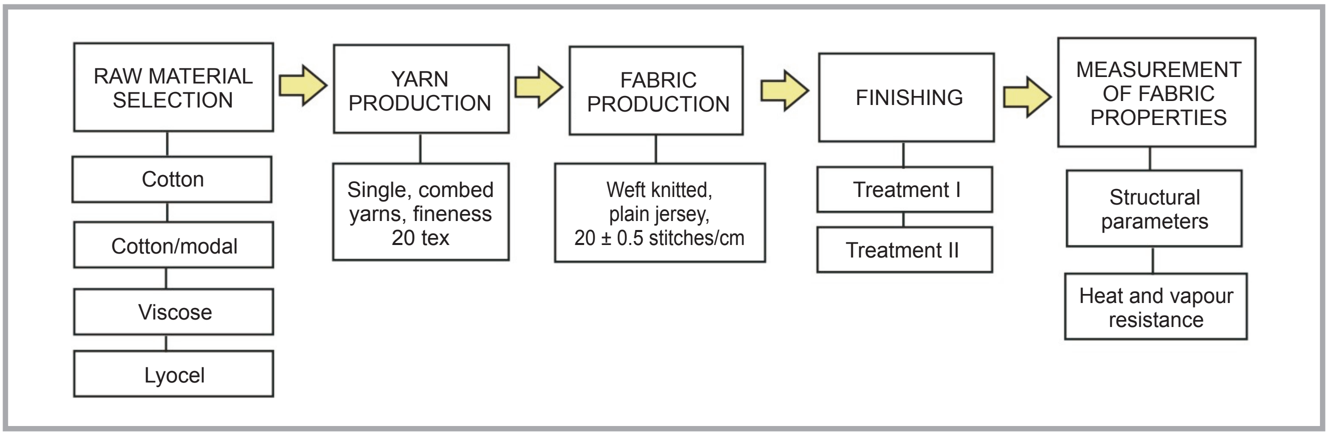


Figure 1. *Production stages.*

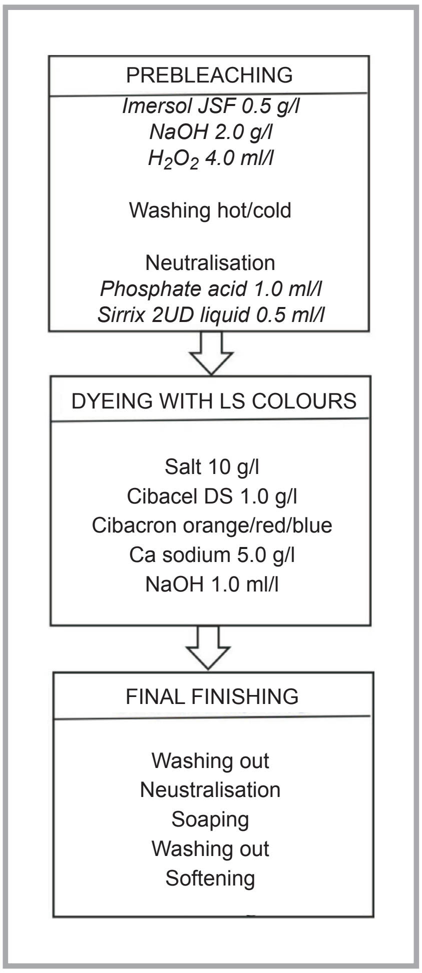


Figure 2. *Recipe of finishing treatment I.*

Experimental

Materials

The research presented in this paper was carried out on a series of samples of knitted structures. For the study knitted structures intended for making garments positioned directly on the skin were chosen (underwear, lightweight summer clothing). The process of fabric production consisted of 5 stages: selection of raw material, yarn production, fabric production and finishing treatments I & II (***Figure 1***, see page 61).

Among the fibres chosen were cotton, as 100% natural cellulose fibre and modal, and viscose and lyocel as natural cellulose polymers.

From these fibres, single combed yarns of 20 tex fineness were manufactured. The yarns produced were used for making weft-knitted plain jersey fabrics on a circular knitting machine - Relanit E, gauge E28 with 48 knitting systems, made by the manufacturer Mayer & CIE. When designing, all knitted fabrics had a defined vertical density of 20 ± 0.5 stitches per 1 cm. Therefore the machine was adjusted to allow the production of knitted fabric of this density. After relaxation, from each knitted fabric a piece was cut and made ready for testing in a raw state.

Material treatments

The remaining amount of material was finished according to a recipe that includes pre-bleaching, dyeing and finishing. The above finishing treatment is hereinafter referred to as finishing treatment I. The recipe of the treatment is shown in ***Figure 2***.

After finishing I, the knitted fabrics were additionally treated with agent Ultraphil® HMS (hereinafter finishing treatment II). Ultraphil® HMS is an auxiliary which improves the regulation of the transport of sweat through the textile material. The agent is based on a mixture of silicone, and it is suitable for the treatment of materials made from natural fibres, cellulose regenerated materials and their blends with synthetic fibre [17]. ***Table 1*** lists the parameters of finishing treatment II.

Table 2 shows the marks of individual knitted fabrics concerning the raw material composition, yarn fineness and finishing treatment type.

Measurements of the knitted fabrics

For each knitted fabric, the basic structural parameters were determined: coefficient of knitted fabric density, knitted fabric thickness, mass per unit area, cover factor and fabric porosity. Measurements were carried out as follows:

- The density coefficient (C) is the ratio between the horizontal and vertical fabric density, and is defined as the ratio of the number of stitches in a course and wale of the knitted fabric,
- The fabric thickness (t) was experimentally determined using a fabric thickness gauge with a pressure of 10 cN cm^{-2},
- The mass per unit area (m) was determined by weighing samples of knitted fabrics with an area of 1 dm^2 on an analytic scale,
- The cover factor (C_f) was determined as the ratio between yarn fineness and thread consumption in a stitch,
- Fabric porosity (ε) was determined as the ratio of fabric density and density of the yarn forming the knitted fabric.

Table 1. *Parameters of finishing treatment II.*

Ultraphil® HMS	
Amount in solution	1-4%
pH of solution	5-5,5
Time of finishing	20-30 min
Temperature	30-40ºC
Treatment after finishing	Dry on flat area

To test the resistance of the fabric to the transfer of heat (R_{ct}) and water vapour (R_{et}), a hotplate was used. The hotplate simulates the processes close to the human skin. It consists of three parts which are heated separately: the plate used for testing and two insulation rings to prevent radial heat flow. The heating regulator maintains the temperature of the heating unit constant with a deviation of ± 0.1 ºC. During the testing of water vapour resistance, additional water is supplied from the dosing feeder to the porous plate through channels which are located in the heater. The plate is covered with a foil or micro porous film to prevent the contact of water with the fabric, allowing only water vapour transfer.

Table 2. *Knitted fabrics and their properties.*

Nr.	Designation	Raw material	Finishing treatment
1	Cr	100% cotton	-
2	CMr	50/50% cotton/modal	-
3	Vr	100% viscose	-
4	Lr	100% lyocel	-
5	Cf1	100% cotton	I
6	CMf1	50/50% cotton/modal	I
7	Vf1	100% viscose	I
8	Lf1	100% lyocel	I
9	Cf2	100% cotton	II
10	CMf2	50/50% cotton/modal	II
11	Vf2	100% viscose	II
12	Lf2	100% lyocel	II

Tests were conducted in accordance with the ISO standard [18]. In accordance with the standard mentioned, the following conditions were established and maintained in the air-conditioning chamber:

- during the testing of heat resistance: 20 °C and 65% relative air humidity
- during the testing of water vapour resistance: 35 °C and 40% relative air humidity.

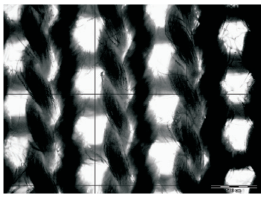
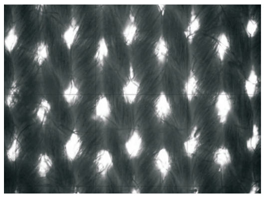
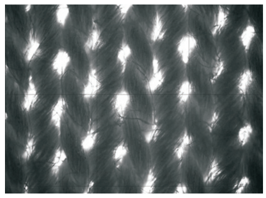
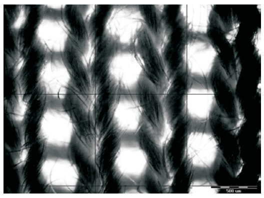
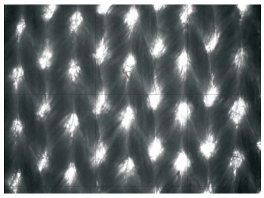
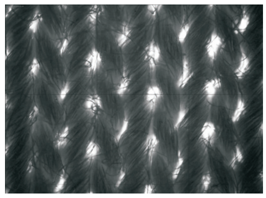
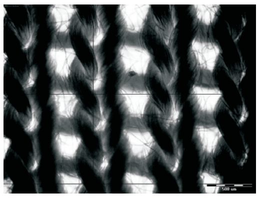
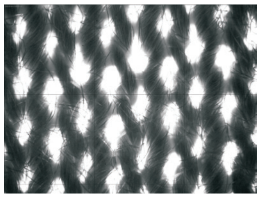
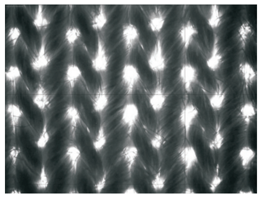
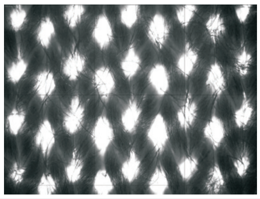
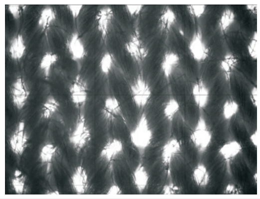
The air flow velocity in both cases was 1 m s^{-1}.

Results and discussion

Knitted fabric structural parameters

The coefficient of fabric density, which represents the ratio of horizontal and vertical density, ranges from 0.6 to 0.7 for the raw knitted fabrics. After finishing treatment I, a significant increase in the coefficient of density of all test samples occurred. The reason for the significant change in the coefficient should be interpreted as a significant variation in the dimensions of the knitted fabric after finishing treatment I. After the finishing treatment of the knitted fabric, a dimensional change occurs in such a way that the horizontal density of the knitted fabric increases (the number of stitches in a course per unit of length increases), while the vertical density decreases (the number of stitches in a wale of the knitted fabric decreases) per unit of length. In other words, after finishing, the fabric shrinks in width and stretches in length. Thus the density coefficients of the finished fabrics (ranging from 0.8 to 0.9) were obtained, which are closer to Dalidovič's recommended ideal value, which for optimal end-use of knitted fabric is defined by his stitch model, equal to 0.87 [19]. The finishing process carried out according to recipe II caused a decrease in overall densities for all fabrics investigated. However, all the values are still around 0.8, which is close to Dalidovič's value.

Table 3. Microscopic images of knitted fabrics tested.

	Raw	Finishing I	Finishing II
100% cotton			
50/50% cotton/ modal			
100% viscose			
100% lyocel			

The effects of chemical processes performed on the material structure are clearly seen from microscopic images of the raw knitted fabrics and those finished by finishing treatments I and II (***Table 3***). It is evident that after finishing treatment I, relaxation of the knitted fabric occurred, which allowed the formation of a uniform structure and 'opening' of courses that were suppressed in the raw knitted fabric. This increases the pores within stitches of the suppressed courses, while simultaneously reducing pores in the dominant wales of stitches. The result is a uniform structure in which the equal distribution of pores is in all wales. As stated earlier, finishing treatment II caused additional minor changes in the coefficient of density, which could also be seen in the microscopic images presented (***Table 3***).

Determination of the knitted fabric thickness is relatively complex due to the structure of the fabric, which consists of parts filled with yarn as well as pores within and between the stitches. The thickness of the raw knitted fabric

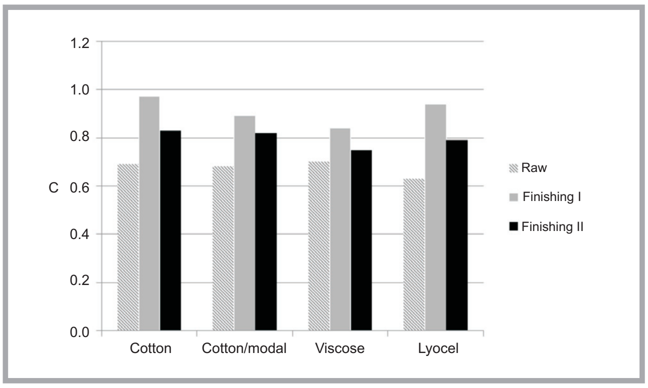


Figure 3. *Results of the coefficient of fabric density.*

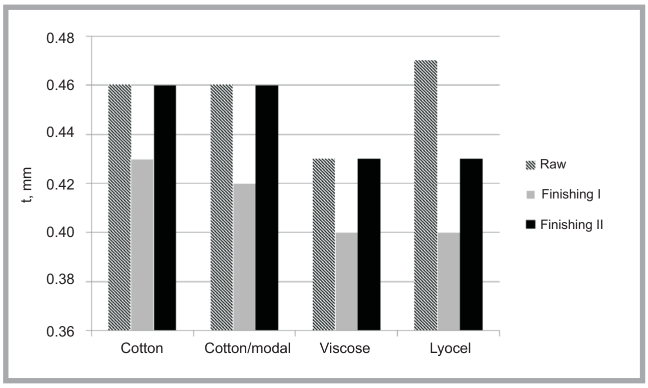


Figure 4. *Results of fabric thickness.*

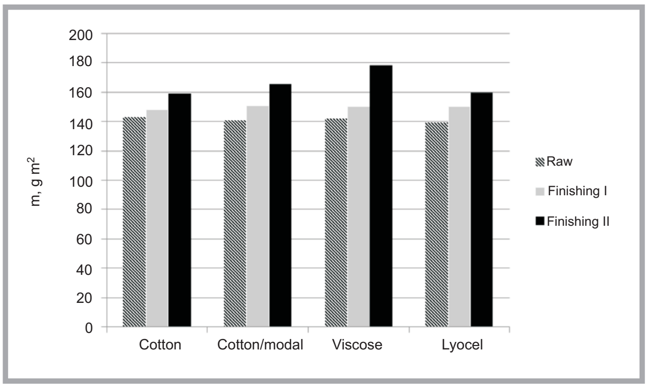


Figure 5. *Results of fabric mass per unit area.*

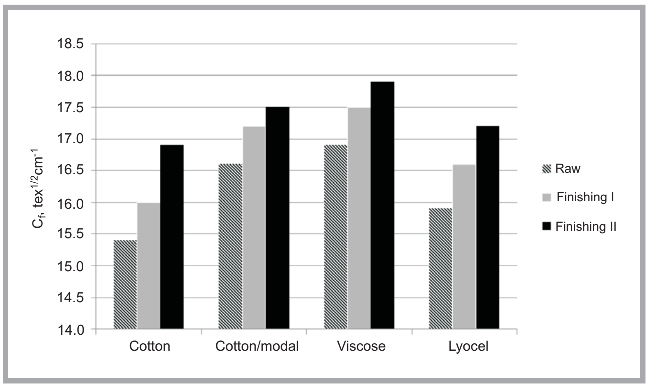


Figure 6. *Results of fabric cover factor.*

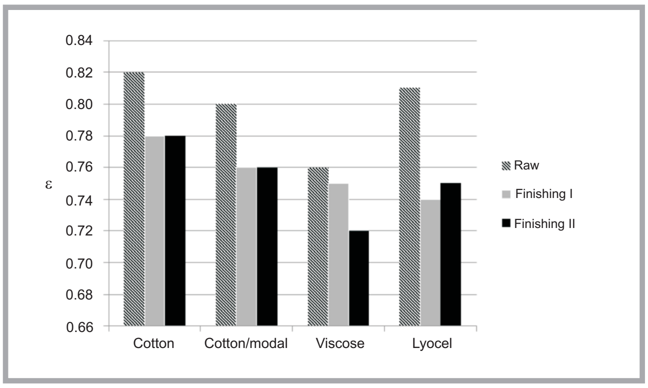


Figure 7. *Results of fabric porosity.*

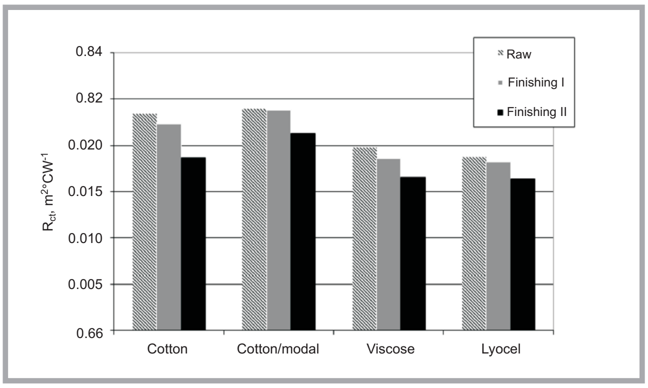


Figure 8. *Heat resistance.*

measured ranges from 0.40 to 0.45 mm. As can be seen in ***Figure 4***, finishing treatment I causes a significant reduction in the fabric thickness compared to that of the raw fabrics. The changes in thickness are up to 14%, with the biggest being measured for the fabric produced from lyocel fibres. Finishing treatment II increases the thickness of the fabrics again, values of which are close to those obtained for raw fabrics. The change in fabric thickness leads to the conclusion that the geometrical shape of the stitch changes significantly after finishing, especially considering yarns of different raw material (extremely low values are obtained for viscose).

The mass per unit area of knitted fabric is a significant technological and economical parameter thereof because it unifies almost all significant parameters of the knitted fabric structure, such as yarn fineness, yarn consumption for the formation of a stitch, and the horizontal and vertical density of the knitted fabric. ***Figure 5*** shows that after finishing, the mass per unit area of all the knitted fabrics increases. The mass per unit area of knitted fabric is largely a function of the horizontal and vertical density of the fabric. Therefore one of the reasons for the previously mentioned change in mass, in addition to the chemical processes of binding molecules of the substances used to treat the fabric, is a significant change in the horizontal fabric density after finishing. Finishing treatment II additionally increases the mass per unit area in comparison to that of the knitted fabric treated according to recipe I; those changes are even higher (up to 11%).

As seen from the ***Figure 6***, finishing treatment I changes the cover factor of the test samples, and the increase continues after the finishing treatment II.

The results for fabric porosity, as a property that indicates the portion of pores in the structure of knitted fabrics, indicate that the structures observed are very porous (the porosity values range from 0.72 to 0.82). The finishing treatments conducted reduce the porosity of the samples, as a result of earlier discussed significant changes in the density of the material.

Heat and water vapour resistance

From the results shown in ***Figures 8*** and ***9***, it is evident that finishing treatment I reduces both heat and water vapour resistance for all the knitted fabrics investigated. However, it should be stated that there is a difference between the intensity of reduction: While the reduction in heat resistance is up to 6% (for the viscose fabric), that of water vapour resistance

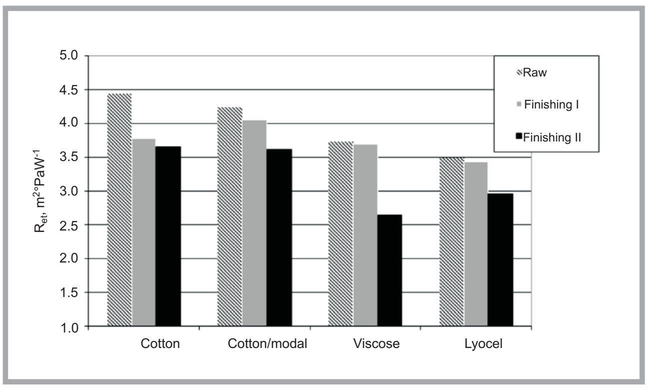


Figure 9. *Water vapour resistance.*

reaches up to 14% (for the cotton knitted fabric). Such a reduction is considerably high. It is to be expected that such change may affect the comfort perception of a person wearing clothing produced from the fabric observed. The reason for this decrease in both resistances (heat and water vapour) after finishing should be sought in changes in the structure of the fabric that are caused by chemical processes carried out. Namely, as discussed in the previous section, after finishing treatment I, stabilisation of the structure occurred. Observing all the results, it should be concluded that the changes in the coefficient of fabric density described and the considerable reduction in fabric thickness surely affected the reduction in heat and water vapour resistance of the knitted fabric measured.

By reducing the thickness and mass per unit area, the porosity of the fabric and portion of pores in the structure increased. This higher portion of pores in the fabric structure is the main reason for the reduction in heat resistance. It may be observed that changes in water vapour resistance after finishing treatment I are significantly higher for samples made from natural fibres and blends with natural fibres (changes up to -16%) than in those made from natural polymers (changes to -3%). The above leads to the conclusion that the process of finishing according to the recipe defined is more suitable for fabrics made from natural cellulose fibres than those made of polymers. Considering the fact that the knitted fabrics observed are intended for the production of light summer wear, the decrease in water vapour is very welcome as such fabrics are usually worn in warm weather conditions when water vapor resistance definitely should be reduced. The remark stated should be taken into account when fabrics are commercially produced in order to apply the finishing recipe to a preferred group of materials (those produced from natural fibres). At the same time, the use of such a recipe for fabrics made of natural polymers should be reexamined.

As can be seen from ***Figure 8***, the heat resistance of the knitted fabrics treated according to recipe II is smaller than that of both raw fabrics and those treated according to recipe I; in comparison to the raw knitted fabrics, it means a reduction up to 20%. The biggest change in resistance is measured for the fabric made of cotton yarn. The results for linear regression also show a positive correlation between both the heat and water vapour resistance of the knitted fabrics treated, as well as the additionally treated knitted fabrics (***Table 4***).

Table 4. *Regression analysis results;* ***Legend****: a - constant, b - regression coefficient, r - correlation coefficient, r^2 - coefficient of determination.*

Independent variable	Dependent variable	a	b	r	r^2
Heat resistance of raw fabric	Heat resistance of finished fabric (finishing I)	-0,0014	1,029	0,9866	0,9734
Heat resistance of finished fabric (finishing I)	Heat resistance of finished fabric (finishing II)	0,0015	0,8083	0,9631	0,9276
Water vapour resistance of raw fabric	Water vapour resistance of finished fabric (finishing I)	1,9411	0,453	0,7748	0,6003
Water vapour resistance of finished fabric (finishing I)	Water vapour resistance of finished fabric (finishing II)	-3,0383	1,6722	0,8618	0,7427

Table 5. *Test of Spearman's ranks.*

Variable 1	Variable 2	Correlation coefficient
Fibre conduction	Fabric heat resistance	0.32
Moisture regain	Fabric water vapour resistance	0.74

Considering the results shown in ***Table 4***, the following models are established:

$$Rct_1 = -0.0014 + 1.029\ Rct_0 \quad (1)$$

$$Rct_2 = 0.0015 + 0.8083\ Rct_1 \quad (2),$$

where: Rct_0 - heat resistance of raw fabrics, Rct_1 - heat resistance of finished fabrics (finishing I), Rct_1 - heat resistance of finished fabrics (finishing II).

By comparison of the heat resistance of the samples made of yarns of the same fineness but of different raw material composition, minor differences between the knitted fabrics made of natural fibres and blends (cotton, cotton/modal) and those made from natural cellulose polymer fibres are perceived. However, it is difficult to conclude with certainty whether these differences were caused by fibre conductivity or by differences in the structure of the fabric.

Therefore the non-parametric test of Spearman's ranks was used to determine the correlation between fibre conductivity and fabric heat resistance (***Table 5***). The analysis of the ranks showed that the value of Spearman's correlation coefficient is 0.3. According to the value obtained, it could be concluded that the correlation between fibre conductivity and heat resistance is rather weak. Considering the results obtained, it can be concluded that the knitted fabric heat resistance basically does not depend on the fibres themselves, but on the air that occupies the holes within the stitches.

From the literature, it is known that at a relative humidity of 40%, the moisture regain (the amount of water a completely dry fibre will absorb from the air at a defined condition) of viscose fibre is 8 - 9%, 5% for cotton fibres and about 0.2% for polyester fibres [20]. Comparing the values of water vapour resistance of the knitted fabrics of the same fineness,but of different raw material composition, it is observable how the raw samples made of viscose fibres (which have the highest moisture regain among the samples) on average offer much lower water vapour resistance than those produced from the remaining raw materials studied. This shows that the raw materials or fibre type from which the knitted fabric is made, to some extent, affect the change in water vapour resistance. Furthermore the correlation between moisture regain and water vapour resistance of the knitted fabric is much stronger than that between conductivity and heat transfer resistance (correlation coefficient of Spearman's ranks Rc = 0.7). The above mentioned leads to the conclusion that raw materials affect the change in water vapour resistance of the knitted fabrics. The conclusion is in conformity with the outcomes of the series of papers named in the Introduction.

To compare the resistance of the raw and finished as well as finished and further treated samples, linear regression analysis was used. The analysis resulted in the establishment of the following models:

$$Ret_1 = 1.9411 + 0.453\ Ret_0 \quad (3)$$

$$Ret_2 = -3.0383 + 1.6722\ Ret_1 \quad (4)$$

where: Ret_0 - water vapour resistance of raw fabrics, Ret_1 - water vapour resistance of finished fabrics (finishing I), Ret_1

- water vapour resistance of finished fabrics (finishing II).

Conclusion

Since the purpose of the knitted fabrics manufactured is to produce garments which are mostly worn at temperatures of 20 - 35 ºC, it is expected that the finished knitted fabrics mentioned, due to lower heat resistance, contribute to an increase in total comfort. It may be observed that changes in the water vapour resistance of the fabric are significantly higher for the samples made from natural fibres and blends of natural fibres than those produced from natural polymers. The above leads to the conclusion that the processes of finishing according to the recipes defined are more suitable for the samples made from natural fibres. Such finished fabrics will reduce water vapor resistance in warm environmental conditions, in which it is necessary to allow the transfer of large amounts of sweat from the skin to the environment, and finally to positively affect an individual's perception of comfort. Bearing in mind the above, knitted fabric manufacturers should make calculations of the profitability of additional finishing treatment of the fabric and its application in the production process in order to increase the wear comfort of the knitted garment.

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References

1. Meinander H, Anttonen H, Bartels V, Holmer I, Reinertsen RE, Soltynski K, Varieras S. Manikin measurements versus wear trial of cold protective clothing (Subzero project). *Eur. J. Appl. Physiol.* 2004; 92: 619-621.
2. Osczevski RJ. Water vapour transfer through a hydrophilic film at Subzero temperatures. *Text. Res. J.* 1996; 66: 24-29.
3. Salopek I, Skenderi Z. Thermophysiological comfort of knitted fabrics in moderate and hot environment. In: Mijovic B (ed) Ergonomics 2007, University of Zagreb, Zagreb, pp. 287-293.
4. Yang K, Jiao ML, Chen YS, Li J, Zhang WY. Analysis and Prediction of Dynamic Heat-Moisture Comfort Property of Fabric. *Fibres & Textiles in Eastern Europe* 2008; 68: 51-55
5. Konarska M, Sołtyński K, Sudoł-Szopińska I, Chojnacka A. Comparative evaluation of clothing thermal insulation measured on a thermal manikin and on volunteers. *Fibres & Textiles in Eastern Europe* 2007; 61: 73-79.
6. Tugrul Ogulata R. The Effect of Thermal Insulation of Clothing on Human Thermal Comfort, *Fibres & Textiles in Eastern Europe* 2007; 61: 67-72.
7. Skenderi Z, Salopek Čubrić I, Srdjak M. Water vapour resistance of knitted fabrics under different environmental conditions. *Fibres & Textiles in Eastern Europe* 2009; 17: 72-75.
8. Hollies NRS, Custer AG, Morin CJ, Howard ME. A human perception analysis approach to clothing comfort. *Text. Res. J.* 1979; 79: 557-654.
9. Karahan M, Eren R. Experimental investigation of the effect of fabric parameters on static water apsorption in terry fabrics. *Fibres & Textiles in Eastern Europe* 2006;56: 59-63.
10. Tarakcioglu I, Cay A. Effects of porosity on thermophysiological comfort parameters of woven fabric. In: Salonen R, Heikkilä P (eds) In: *7th Annual Textile Conference by Autex,* Tampere, 2007.
11. Salopek Čubrić I, Skenderi Z. Yarn and knitted fabric parameters that affect heat resistance. Melliand Int 2009;15:144-145.
12. Skenderi Z, Salopek, I, Srdjak M. The influence of yarn count to the transfer of heat and vapour through fabrics. In: Dragcevic Z (ed). In: *4th International Textile, Clothing and Design Conference Magic World of Textiles*, Dubrovnik, 2008, pp. 876-881.
13. Brojeswari D, Das A, Kothari VK, Fanguiero R, de Araujo M. Moisture transmission trough textiles, Part I: Processes involved in moisture transmission and the factors at play. *AUTEX Res J.* 2007; 7: 100-110.
14. Salopek I, Skenderi Z, Srdjak M. The role of fabric parameters in the achievement of thermophysiological comfort. In: Agapov I (ed). In: 44 Congres IFKT "Knitting round the clock", St. Petersburg, 2008.
15. Yasuda T, Miyama M, Yasuda H. Dynamic Water Vapor and Heat Transport Trough Layered Fabrics. Part II: Effect of the Chemical Nature of Fibres. *Tex. Res. J.* 1992; 62: 227-235.
16. Tzanov T, Betcheva R, Hardalov I. Thermophysiological comfort of silicone softeners-treated woven textile materials. *Int. J. Clo. Sci. Tech.* 1999; 11: 189-197.
17. Ultraphil® HMS, Ciba 2010.
18 ISO 11092: 1993 Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test).
19. Dalidovič AS. Osnovi teorii vjazanija. Legkaja ind., Moskva, 1970.
20. Pan N, Sun Z. Essentials of psychometry and capillary hydrostatics in Thermal moisture transport in fibrous materials. Woodhead Publishing Limited, Cambridge, 2006.

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