Karunakaran Kadapalayam Chinnasamy[1], Prakash Chidambaram[2,*]

Influence of the Bamboo/Cotton Fibre Blend Proportion on the Thermal Comfort Properties of Single Jersey Knitted Fabrics

DOI: 10.5604/01.3001.0010.5371

[1] **K S Rangasamy College of Technology, Department of Textile Technology,** Tiruchengode – 637 215, Tamil Nadu, India

[2] **Sona College of Technology, Department of Fashion Technology,** Salem-636005, Tamil Nadu, India
* E-mail address: dearcprakash@gmail.com

Abstract
The main aim was to find out the influence of the blend ratio and linear density on the thermal comfort properties of regenerated bamboo cotton blended single jersey knitted fabrics. An increase in the regenerated bamboo fibre ratio in the fabric influences the thermal comfort properties. Knitted fabrics prepared from regenerated bamboo blended yarns have lesser thickness and inferior mass per square meter than cotton fabrics. The proportion of regenerated bamboo fibre increases in the yarn as the value of thermal conductivity decreases in knitted fabrics. Water vapour permeability and air permeability confirm a similar increase as the proportion of regenerated bamboo fibre increases. 100% regenerated bamboo fabrics have superior air permeability values compared with regenerated bamboo/cotton blended fabrics. The statistical investigation also showed that the results are significant for the thermal comfort properties of regenerated bamboo cotton knitted fabrics.

Key words: *regenerated bamboo, blend ratio, cotton, linear density, thermal comfort, knitted fabrics.*

Introduction

Clothing comfort is an exceptionally complex occurrence and has drawn the attention of many textile researchers. Thermal comfort properties are among the most significant features of textiles. Thermal comfort is distinct as 'The state of mind which expresses satisfaction with the thermal surroundings'. It is the aspect governed by the progress of heat, moisture and air through fabric. The maintenance of thermal balance is most likely the important aspect of clothing and has been the consideration of many textile workers. The main difficulty related to thermal comfort is the inappropriateness between the requirement of heat conservation through low metabolic action and heat dissipation at the high energy stage. There are several factors about the circumstances of thermal comfort, such as age, sex, adaptation, season and heat-flow conditions in addition to physical surroundings accessible next to the skin surface.

Natural and man-made fibres are necessary as part of routine acts of the textile industry. There are various products made of these fibres, giving apparel the highest comfort [1-5]. Bhat and Bhonde [6] stated that comfort relates to wear situations, involving thermal and non-thermal components. The thermal comfort of people depends on the combinations of clothing, climate and physical activity. ISO 7330 defines thermal comfort as that state of mind which expresses pleasure with the thermal surroundings. The thermal comfort properties of textile fabrics are essentially influenced by the fibre, yarn and fabric properties, as reported by Majumdar, Mukhopadhyay and Yadav [7]. In the comfort properties of fabrics, the type of fibre, spinning technology, yarn linear density, twist and hairiness of yarn, as well as the thickness, cover factor and porosity of the fabric and finish play a vital role in determining the properties. Havenith [8] proved that there is an increase in material thickness and air entrapped in fabric with an increase in heat and water vapour resistance. Hes [9] talked about the end use of a garment and suggested cotton yarns for hot days to get a cool feeling for ideal clothing comfort. Onofrei, Rocha and Catarino [10] found that the raw material and fabric structure were the major factors in affecting thermal comfort properties. Pac, Bueno and Remer [11] investigated the thermal properties and friction behaviour of fabrics as influenced by the fibre morphology and yarn and fabric structures. In their work, they convey that fabrics provide a warmer sensation when more air is entrapped on a hairier fabric surface and when the contact interface area between the skin and fabric was small for rough fabrics. They also confirmed that the fibre type as well as the yarn and fabric structure change the structural roughness and warm-cool feeling of fabrics.

Jordeva, Kjortoseva and Kalojanov [12] investigated the thermo-physiological comfort properties of single jersey knitted fabrics with respect to the influence of structural properties and character-

Table 1. Details of fibre properties of cotton and regenerated bamboo fibres

Characteristics	Cotton fibre	CV%	Regenerated bamboo fibre	CV%
Fibre length, mm	27	1.18	36	1.73
Fibre length uniformity ratio, %	82.5	1.19	92.7	1.09
Fibre fineness, dtex	1.70	0.51	1.52	0.67
Tenacity, g/tex	26.7	0.32	22.84	1.13
Specific density, g/cm^3	1.52	0.18	1.32	0.31
Elongation, %	6.5	1.35	21.2	1.20
Moisture regain, %	7.5	0.37	11.42	0.41
Trash content, %	0.19	1.43	–	–
Maturity ratio, %	82.53	1.58	–	–

istics of the fibre. They pointed out that the thermo-physiological comfort of knitted fabrics have the main influence on structural characteristics, as opposed to the raw material content. The air and water vapour permeability and thermal characteristics of knitted fabrics are determined by the density, mass per unit area and tightness factor. Kothari [13] reported on the influence of fibre properties on the comfort characteristics of fabric. He pointed out how fibre blending in the yarn process can lead to fabrics having the desired comfort characteristics. Jirsak, Sadikoglu, Ozipek and Pan [14] reported that thermal conductivity and thermal resistance decrease with rising material density up to the maximum value, before the heat conducted by the fibres becomes noticable. Fibre fineness affects a fabric's thermal conductivity. Fabrics made with coarse fibres show high thermal resistance. Bedek, Salaun, Martinkovska, Devaux and Dupont [15] studied the relationship between thermal comfort and textile properties. They suggested that the comfort-related properties of fabrics are affected by the fibre type, together with the moisture regain and knitted structure characteristics. The thermal properties and thermal behavior of cellulose textile fabrics (air permeability, porosity) were investigated by Stankovic, Popovic and Poparic [16], from which they conclude that the air permeability and heat transfer fabrics are closely related to the capillary structure and surface characteristics of yarns.

Cotton and blended fabrics therefore have become attractive to people, being a universally used fibre due to its superior characteristics. However, cotton fibre also has some restrictions like a short fibre length, harsh feel, and is less lustrous when compared to man-made fibres. With the rising demand for new, comfortable, improved and environmentally friendly products, new kinds of synthetic and regenerated fibres which are a substitute for conventional fibres like cotton have gained significance in apparel and home textiles. One of the modern developments in new fibre researches is making use of regenerated bamboo fibre in a combination of textile products [17]. Sankar 6 cotton fibres and regenerated bamboo fibres were obtained from industrial resources, the technical parameters of which are given in ***Tables 1*** and ***2***. 100% regenerated bamboo, 100% cotton and regenerated bamboo/ cotton blended yarns of 70:30, 50:50 and 30:70 possessing the same twist coefficient ($\alpha_e = 3.6$) were spun on LR G5/1 ring spinning machines with linear densities of 29.53 and 14.76 tex. For blending bamboo and cotton fibres, each of the two components was opened manually and sandwiched well to produce a homogeneous blend. A predetermined quantity of fibres to be blended was mixed and processed in a Trutzschler's blow room line. The yarns were spun by the following processes – blowroom, card, draw frame, simplex and ring frame. The regenerated bamboo fibre has proven intrinsic properties superior to those of cotton fibre. It has also been claimed by the manufactures that fabrics primed out of regenerated bamboo fibre have excellent moisture absorbency, a soft feel and a superior dye ability to that of cotton. Therefore a methodical study was conducted to study the appropriateness of a regenerated bamboo fibre blend with cotton for providing the thermal comfort property in fabrics.

Materials and methods

Materials

Knitted fabric samples were produced on a plain knitting machine (Mayer and Cie, Germany) for measuring the thermal comfort behaviour. Samples were produced with a loop-length of 3.0 mm. Knitted samples were subjected to subsequent relaxation treatments as recommended by 'Starfish'. Cut samples were placed on a flat surface in a conditioning cabinet in a tension free state for 48 hours. A standard atmosphere of 21 °C ± 1 and relative humidity of 65% ± 2 were maintained in the cabinet. Knitted fabric samples were immersed in a stainless steel water bath with 0.05 g/l of wetting agents, with the water temperature maintained at 38 °C, which was allowed to settle with minimum agitation for 24 hours. Knitted fabric samples were then hydro-extracted for 1 minute and laid on a plane surface for 48 hours. After washing, the fabric samples were taken back to standard

Table 2. Details of yarn properties of cotton and regenerated bamboo fibres.

Yarn linear density	29.53 tex					14.76 tex				
Blend ratio Regenerated bamboo/Cotton, %	100/0	70/30	50/50	30/70	0/100	100/0	70/30	50/50	30/70	0/100
Diameter, mm	0.247	0.253	0.268	0.280	0.292	0.194	0.202	0.206	0.212	0.222
Unevenness, %	7.76	7.49	7.28	7.18	6.89	9.48	8.97	8.75	8.49	8.33
Thick/km (+50%)	7	7	5	4	3	11	10	9	8	8
Thin/km (-50%)	4	2	2	1	1	3	1	2	1	1
Hairiness longer than 3 mm/km	998	1106	1476	1769	1888	628	795	938	1218	1349
Neps/km	16	13	9	9	6	19	15	15	12	12
Tenacity, cN/tex	15.75	14.89	14.49	15.48	16.85	17.18	16.25	15.49	16.45	17.99
Elongation, %	12.79	10.88	9.39	8.25	7.18	10.26	9.89	8.08	7.47	6.49

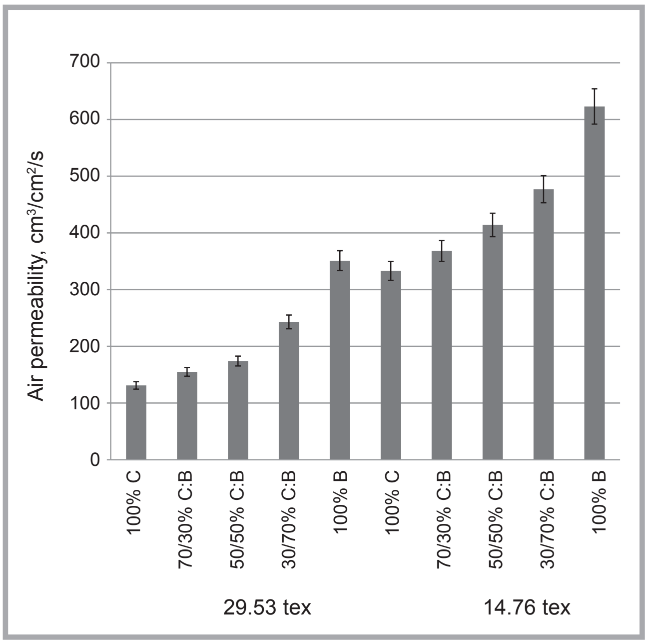

***Figure 1.** Air permeability values of single jersey knitted fabrics.*

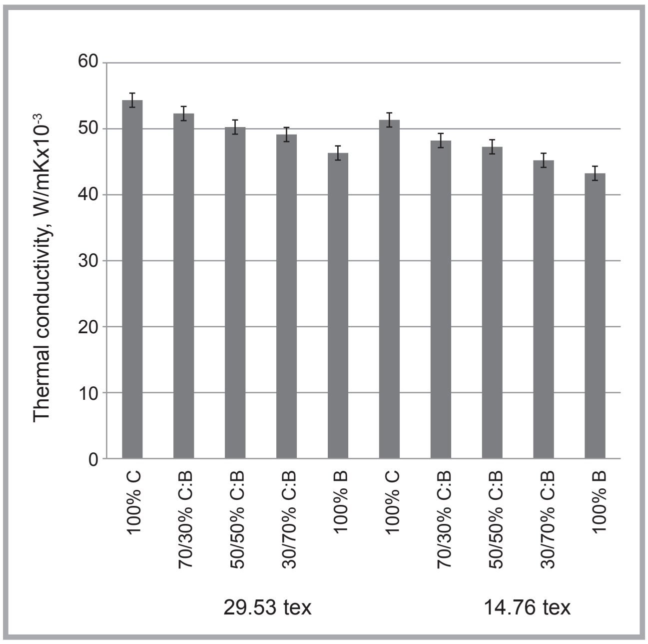

***Figure 2.** Thermal conductivity values of single jersey knitted fabrics.*

conditions of 21 °C ± 1 and relative humidity of 65% ± 2 for 48 hours, free of tension. Wet relaxed knitted fabric samples were washed by hydro-extraction for 1 minute and tumble dried for 60 minutes at around 70 °C. The samples were then laid on a plane surface in a conditioning cabinet of 21 °C ± 1 and relative humidity of 65% ± 2 for 48 hours free of tension. All the relaxation treatments were carried out according to ASTM D 1284-76.

Testing of fabric parameters

The fabric structural and physical properties like aerial density and thickness were evaluated. The aerial density of the fabric was calculated as per ASTM D 3776-96 using a standard cutter, and the mean value of the five samples was reported. Fabric thickness was calculated as per ASTM D 1777-07 at 10 different places for each specimen, and the average was taken for further analysis. The porosity (P) of the knitted fabrics was calculated using the following expression [7].

$$P\% = \left[1 - \frac{\overline{\mathrm{GSM(g/m^2)}}\ /\ h(\mathrm{m})}{\rho(\mathrm{g/m^3})}\right]100$$

Where, GSM = fabric mass per square meter, h = thickness, and ρ = density of the fibre, respectively.

A Textest FX 3300 air permeability tester (Textest AG, Switzerland) was used to evaluate the air permeability of the fabric at a pressure of 100 Pa (ASTM D737). The water vapour permeability was measured on a Permetest instrument (Sensora Company, Liberec, Czech Republic) according to ISO 11092. According to ISO 11092, the thermal conductivity and resistance of the fabrics were evaluated using an Alambeta instrument (Sensora, Czech Republic) [9]. All measurements were performed under standard atmospheric conditions of 21±1 °C (70±2 °F) and 65±2% relative humidity (RH), as recommended by ASTM D 1776. Ten readings were taken and then the averages calculated for each of the knitted fabrics.

Results and discussion

Dimensional properties of knitted fabrics

Table 3 shows the fabric thickness and weight have a decreasing propensity to increase in the regenerated bamboo fibre ratio in the fabric. Due to the lower bending rigidity of regenerated bamboo blended yarns, the knitted loops in the structure can be packed together easily,

***Table 3.** Geometrical and thermal comfort properties of regenerated bamboo/cotton single jersey knitted fabrics.*

Linear density, tex	Blend ratio % cotton: regenerated bamboo	Loop length, mm	Thickness, mm	Mass per unit area, g/m²	Porosity, %	Air permeability, cm³/cm²/s	Water vapour permeability, %	Thermal conductivity, W/mK x 10⁻³	Thermal resistance, m²K/W x 10⁻³
29.53	100 : 0	3.0	0.822	188	84.95	131	45.13	54.33	19.77
	70 : 30		0.730	184	80.67	155	45.67	52.31	18.64
	50 : 50		0.693	178	77.86	174	46.36	50.26	18.46
	30 : 70		0.652	170	74.34	243	46.93	49.13	17.77
	0 : 100		0.587	161	65.72	351	47.63	46.33	17.21
14.76	100 : 0		0.691	122	88.38	333	48.33	51.34	20.60
	70 : 30		0.632	111	86.53	368	49.26	48.22	20.19
	50 : 50		0.583	102	84.92	414	49.24	47.27	19.44
	30 : 70		0.544	94	82.99	477	51.24	45.22	19.23
	0 : 100		0.499	83	79.21	623	53.29	43.25	18.53

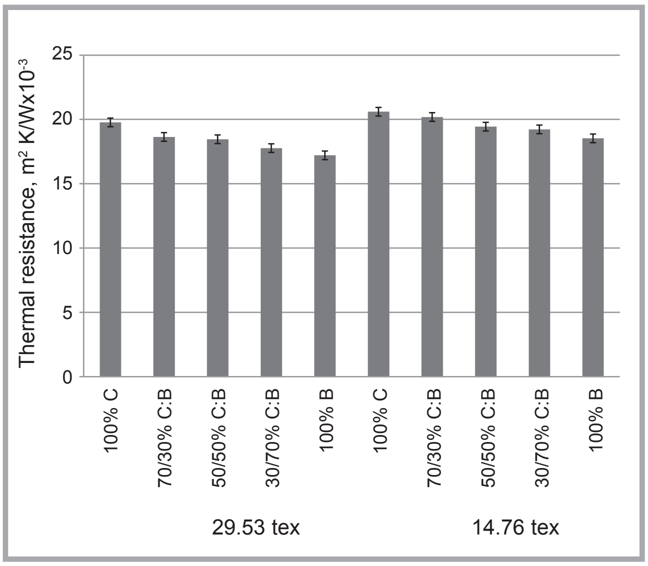

Figure 3. *Thermal resistance values of single jersey knitted fabrics.*

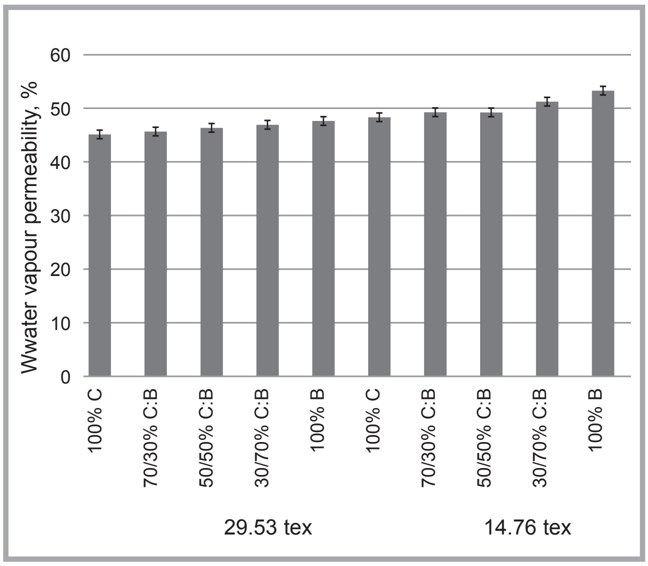

Figure 4. *Water vapour permeability values of single jersey knitted fabrics.*

thereby decreasing the fabric thickness. In our study, we used both cotton and regenerated bamboo fibres, which are different in fineness, to prepare fabrics with different blend ratios. The differing fineness of regenerated bamboo and cotton fibres eventually varies the mass per square meter of the fabrics. The thickness of the fabrics decreases at a quicker rate, However, the ratio of the mass per square meter and thickness increases, and for that reason the porosity decreases. Our results show that the thickness of knitted fabric depends on the yarn linear density, fabric structure and relative closeness of the loops, as concluded by Kane, Patil and Sudhakar [18].

Air permeability

Figure 1 shows the relationship between the linear density and blend ratio of air permeability values of regenerated bamboo/cotton knitted fabrics. The results clearly show that 100% regenerated bamboo fabrics have the uppermost air permeability value. In addition, blending regenerated bamboo with cotton fibres produces a lower air permeability value. It is clear that with an increasing ratio of bamboo fibre, irrespective of the linear density of the fabric, the air permeability increases. Due to micro spaces in the fibre structure of regenerated bamboo fibre, it also gives superior air permeability. The air permeability value of the 100% cotton fabric produced is lower than that of the regenerated bamboo fabric sample, which may be partially attributed to the fact that regenerated bamboo fibre has some striated cracks scattered above the longitudinal surface and that it also has many voids in the cross section [19]. The thickness and mass per square metre of regenerated bamboo fabrics are also consequently lower than those of the corresponding cotton fabrics. The results showed that the air permeability values of the bamboo/cotton blended knitted fabrics had a considerable effect on the fabric thickness, since the thickness tended to decrease with air permeability values, irrespective of the blend proportion. It is commonly accepted that the air permeability of a fabric depends on its air porosity, which influences its openness. The bigger the porosity of the fabric, the more porous fabric is obrained. Porosity data confirm an increasing trend with an increase in linear density, which results in an increase in air permeability.

Table 4. *ANOVA multivariable data analysis.* ***Note:*** **Significant for α = 0.05.*

Various analysis	p-value			
	Air permeability, $cm^3/cm^2/s$	Water vapour permeability, %	Thermal conductivity, W/mK	Thermal resistance, m^2K/W
Between yarn linear density	0.000148*	0.001359*	0.000118*	0.000138*
Between blend ratio	0.000183*	0.041825*	0.000153*	0.000173*

Thermal conductivity

Figure 2 shows that the thermal conductivity of knitted fabrics decreases as the proportion of regenerated bamboo fibre increases. As investigational by Prakash, Ramakrishnan and Koushik [17], cotton yarns have a higher amount of hairiness than the equivalent regenerated bamboo yarns. When added together, the porosity of regenerated bamboo blended fabrics is lower than that of cotton fabrics. As a result, regenerated bamboo blended fabrics can be expected to show superior thermal conductivity than fabrics made from cotton yarns. The thermal conductivity increases due to an increase air voids [20]. It was revealed by Pac, Bueno and Remer [11] that different varieties of the same fibre type may influence the heat transfer.

Thermal resistance

From ***Figure 3***, the thermal resistance is found to drop off as the proportion of bamboo increases. The trend is reversed in our study. The reliable consideration used in this study was varying the blend proportion of bamboo. The higher heat conductivity of bamboo fibres is one of the reasons for the decrease in thermal resistance. It has been stated by a number of workers [21-22] that the most important fabric factor which determines the thermal lagging of fabric is the fabric thickness, the extent of which depends upon the pressure applied while carrying out the measurements. It was found that as the yarn gets finer the thermal resistance drops off. The amount of reduction in thickness is more than the amount of decrease in thermal conductivity, with the thermal resistance also decreasing. Due to the bamboo fibre microstructure, being filled with a bunch of air pockets, it can receive a great amount of air [23].

Water vapour permeability

Figure 4 shows that as the water vapour permeability increases, the proportion of regenerated bamboo fibre increases. The superior water vapour permeability of regenerated bamboo blended fabrics can be seen in the lower values of thickness and fabric mass per square metre, facilitating the easy movement of water vapour through the fabric. Water vapour transmission due to diffusion may also be higher for fabric made from regenerated bamboo due to the fact that the moisture regain of regenerated bamboo fibre is higher than that of cotton. Prahsarn, Barker and Gupta [24] reported that the water vapour transmission rate was strongly correlated with fabric thickness and fibre-related factors such as the cross-sectional shape and moisture absorbing properties. On the other hand, although the regain of bamboo fabric was almost as high as for cotton fabric, the air permeability of bamboo fabric was nearly twice as high as that of the cotton fabric, which might explain the higher water vapour transfer rate of bamboo fabric.

Data analysis: variance statistics

The SAS System (version 8 for Windows) was used to assess the experimental data, and ANOVA (analysis of variance) at a 95% confidence level was used to measure the significance of the blend ratio and linear density on the thermal comfort properties of the regenerated bamboo/cotton knitted fabrics. To conclude whether the parameters were significant or not, p values were examined. From ***Table 4***, the statistical analysis reveals that the thermal comfort properties of regenerated bamboo/cotton knitted fabrics are significant factors for the blend ratio and linear density, with $p > 0.05$ respectively. These data are clearly an indication of the consistency of our experimental design.

Conslusions

The thermal comfort properties of 100% cotton, 100% regenerated bamboo and regenerated bamboo/ cotton blended yarn single jersey fabrics were investigated in this study. In general, the thermal comfort properties of the fabrics depend on their fibre content and the linear density of the component yarns. The presence of regenerated bamboo fibre in the fabric is proved to have an effect on the thermal comfort properties. 100% regenerated bamboo fabric was found to have the highest air permeability and relative water–vapour permeability, with the lowest being for 100% cotton fabric. 100% regenerated bamboo fabric has lower thermal conductivity and resistance properties than 100% cotton fabric, with the level of reduction increasing with increasing regenerated bamboo fibre content in the fabric.

References

1. Prakash C, Ramakrishnan G, Koushik CV. A study of the thermal properties of bamboo knitted fabrics. *Journal of thermal analysis and calorimetry* 2013; 111, 1: 101-105.
2. Prakash C, Ramakrishnan G. Effect of blend proportion on thermal behaviour of bamboo knitted fabrics. *The Journal of the Textile Institute* 2013; 104, 9: 907-913.
3. Prakash C, Ramakrishnan G. Effect of blend ratio, loop length, and yarn linear density on thermal comfort properties of single jersey knitted fabrics. *International Journal of Thermophysics* 2012; 34, 1: 113–121.
4. Chidambaram P, Govindan R, Venkatraman KC. Study of thermal comfort properties of cotton/regenerated bamboo knitted fabrics. *African Journal of Basic & Applied Sciences* 2012; 4, 2: 60-66.
5. Prakash C, Ramakrishnan G. Study of thermal properties of bamboo/cotton blended single jersey knitted fabrics. *Arabian Journal for Science and Engineering* 2014; 39, 3: 2289-2294.
6. Bhat P, Bhonde HU. Comfortable clothing for defense personnel. *Asian Textile Journal* 2006; 11, 2: 73- 77.
7. Majumdar A, Mukhopadhyay S, Yadav R. Thermal properties of knitted fabrics made from cotton & regenerated bamboo cellulosic fibres. *International Journal of Thermal Sciences* 2010; 49, 10: 2042-2048.
8. Havenith G. The Interaction of Clothing and Thermoregulation. *Exogenous Dermatology* 2002; 1, 5: 221-230.
9. Hes L. An Indirect Method for the Fast Evaluation of Surface Moisture Absorptiveness of Shirt and Underwear Fabrics. *Vlankna textile* 2000; 7, 20: 91-96.
10. Onofrei E, Rocha A, Catarino A. The Influence of Knitted Fabric's Structure on the Thermal and Moisture Management Properties. *Journal of Engineered Fibres and Fabrics*. 2011; 6, 4: 10-22.
11. Pac MJ, Bueno MA, Remer M. Warm Cool Feeling Relative to Trilogical Properties of Fabrics. *Textile Research Journal* 2001; 71, 9: 806-812.
12. Jordeva S, Kjortoseva S, Kalojanov N. Release of Thermo-physiological Comfort of Single Jersey Knitted Structures with Method of Thermo-Vision Analysis. *Proceeding of the Fourth International Scientific-Professional Conference Textile Science and Economy* 2012; 35-48.
13. Kothari VK. Thermo Physiological Comfort Characteristics and Blended Yarn Woven Fabrics. *Indian Journal of Fibre and Textile Research* 2006; 31, 1: 179-186.
14. Jirsak O, Sadikoglu TG, Ozipek B, Pan N. Thermo-Insulating Properties of Perpendicular-Laid Versus Cross-Laid Lofty Non-Woven Fabrics. *Textile Research Journal* 2000; 70, 2: 121-128.
15. Bedek G, Salaun F, Martinkovska Z, Devaux E, Dupont D. Evaluation of thermal and moisture management properties on knitted fabrics and comparison with a physiological model in warm conditions. *Applied ergonomics* 2011; 42, 6: 792-800.
16. Stankovic SB, Popovic D, Poparic GB. Thermal Properties of Textile Fabrics Made of Natural and Regenerated Cellulose Fibres. *Polymer Testing* 2008; 27, 1: 41-48.
17. Prakash C, Ramakrishnan G, Koushik CV. Effect of blend ratio on the quality characteristics of bamboo/cotton blended ring spun yarn. *Fibres and Textile in Eastern Europe* 2011; 19, 6(89): 38–40.
18. Kane CD, Patil UJ, Sudhakar P. Studies of the influence of knit structure and stitch length on ring and compact yarn single jersey fabric properties. *Textile Research Journal* 2007; 77, 8: 572-582.
19. Xu Y, Lu Z, Tang R. Structure and thermal properties of bamboo, viscose, tencel and conventional viscose fiber. *Journal of thermal analysis and calorimetry* 2007; 89, 1: 197-201.
20. Chidambaram P, Govindan R. Influence of blend ratio on thermal properties of bamboo/cotton blended woven fabrics. *Silpakorn University Science and Technology Journal* 2012; 6, 2: 49-55.
21. Morse HL, Thompson JG, Clark KJ, Green KA, Moyer CB. Analysis of the thermal response of protective fabrics, Acurex Corporation Mountain View, California, 1973, p. 54.
22. Hoge H J, Fonseca G F. The thermal conductivity of a multilayer sample of underwear material under a variety of experimental conditions. *Textile Research Journal* 1964; 34, 5: 401-410.
23. Mahish SS, Patra AK, Thakur R. Functional properties of bamboo/polyester blended knitted apparel fabrics. *Indian Journal of Fibre and Textile Research* 2012; 37, 3: 231-237.
24. Prahsarn C, Barker R L, Gupta B S. Moisture vapour transport behaviour of polyester knits. *Textile Research Journal* 2005; 75, 4: 346-351.

Received 26.07.2016 Reviewed 05.06.2017