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Evaluation of the Moisture and Thermal Characteristics of Knitted Sport Wear Fabrics

تقييم خواص انتقال الحرارة والرطوبة للملابس الرياضية

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الملخص

في هذا البحث تم دراسة تأثير نوع الخامة (١٠٠%قطن ، ١٠٠% بولى استر و ٦٥% بولى استر -٣٥%قطن) لأقمشة التريكو المستخدمة فى الملابس الرياضية على خواص انتقال الحرارة و الرطوبة والتى تؤثر على خاصية الراحة لتلك الأقمشة . ايضا تم دراسة تأثير ارتداء طبقة واحدة من الأقمشة التريكو (القميص الرياضى فقط دون الملابس الداخلية) أو ارتداء طبقتين من اقمشة التريكو (القميص الرياضى مع الملابس الداخلية) على الخواص الحرارية و الرطوبة لتلك الأقمشة حيث تم معمليا قياس خواص التوصيل والعزل الحرارى، امتصاص الحرارة وسريان الحرارة بالإضافة إلى معدل نفاذة البخار ونفاذية الهواء. وقد وجد انه هناك تأثير قوى المعنوية لنوع الخامة وأيضا استخدام طبقة واحدة أو طبقتين من القماش على الخواص الحرارية ونفاذية البخار والهواء لتلك الأقمشة الرياضية. كما وجد أنه هناك ارتباط قوى المعنوية بين سمك القماش، مسامية القماش، نفاذية البخار والهواء والخواص الحرارية للأقمشة الرياضية.

ABSTRACT

The main aim of this work was study the effect of fiber composition on the moisture and thermal properties for sport wear knitted fabrics. We also studied the effect of using single and double layer fabric on the moisture and thermal properties of these fabrics. To know how heat and water are transported through each fabric, measurements of their physical properties (thermal resistance, thermal conductivity, thermal absorptivity, heat flow, relative water vapor permeability and air permeability) were made in laboratories. The effects of fiber composition and the clothing assembly (one or two layers) have a highly significant effect on both moisture and thermal properties of sport wear knitted fabrics and also there were a high correlation between fabric thickness, fabric porosity, fabric air permeability, the relative water vapor permeability and fabric thermal properties.

Key words: thermal properties, moisture properties, sport wear, knitted fabrics, fabric porosity.

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1. Introduction

Garments manufactured for specific activities are growing worldwide. Many synthetic fibers produced by chemical processes are offered on the market, and clothes can be manufactured from numerous combinations of natural and synthetic fibers. Many different kinds of clothing are adapted for particular uses: sports, industrial jobs, very hot or very cold weather. The comfort of a garment is linked to several factors: lightness, heat and vapor transport, sweat absorption and drying, wind and impermeability. For example, winter sport clothes must have good vapor transfer properties. A garment's comfort depends on the properties of each fabric layer and the combination of all the layers worn [1].

The garment comfort of sportswear is an important quality criterion. It affects not only the well-being of the wearer but also his performance and efficiency. If, for example, an active sportsperson wears a clothing system with only poor breathability, heart-beat rate and rectal temperatures will increase much more rapidly than while wearing breathable sportswear [2,3]

Comfort is an important criterion by which customers judge their clothes via the interaction between the body and the textile. Clothing comfort is defined as "a state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" [4]. Thermal comfort refers to sensations of hot, cold, or dampness in clothes and is usually associated with environmental factors such as heat, moisture, and air velocity [5]. Water/moisture vapor transmission and air permeability are the important factors that affect the thermal comfort of textiles. Water/moisture vapor transmission is the rate at which water/moisture vapor diffuses through a fabric [6]. Fiber content and fabric geometry are two primary factors that may affect the water/moisture vapor transmission. Two common methods that measure water/ moisture vapor transmission of clothing materials are cup/dish tests (i.e., the ASTM test method of E96-80) [7] and sweating guarded hot plate devices (i.e., the ASTM test method of D1518-77) [8].

Air permeability is the capability of airflow through the fabric [9]. Many factors may affect air permeability, such as fabric cover factor, yarn twist, yarn crimp, fabric weave, fiber wetting, and the amount of finish and coating applied on the fabric. A common test method that measures air permeability is the ASTM Test Method D737 [10].

As a consequence, the wearer of the breathable clothing outperforms the other, as it is possible to withstand high activity levels for a longer period of time. Hence, it is appropriate to describe wear comfort as the 'physiological function' of sportswear. Wear comfort is also a major sales aspect. According to the journal World Sports Active wear, 'comfort is the most important thing in clothing, and it is coming from sportswear where consumers have become accustomed to the comfort' [11].

Porosity and thickness are determinant factors in the coupled heat and moisture transfer in porous textile media [12,13] since the mechanisms of heat transfer in porous textiles include conduction by the solid material of the fibers, conduction by intervening air, radiation, and convection. Also, water vapor transmission mechanisms include vapor diffusion in the void space and moisture sorption/desorption by the fibers as well as the forced convection mechanism [13]

2. Aspects of wear comfort

After recognizing the importance of wear comfort and the physiological function of sportswear, one should define in more detail what wear comfort entails. In fact, wear comfort is a complex phenomenon, but in general it can be divided into four different main aspects [11]

- The first aspect is denoted as thermo physiological wear comfort, as it directly influences a person's thermoregulation. It comprises heat and moisture transport processes through the clothing. Key notions include thermal insulation, breath ability and moisture management.
- The skin sensorial wear comfort characterizes the mechanical sensations, which a textile causes at direct contact with the skin. These perceptions may be pleasant, such as smoothness or softness, but they may also be unpleasant, if a textile is scratchy, too stiff, or clings to sweat-wetted skin.
- The ergonomic wear comfort deals with the fit of the clothing and the freedom of movement it allows. The ergonomic wear comfort is mainly dependent on the garment's pattern and the elasticity of the materials.
- Last but not least the psychological wear comfort is of importance. It is affected by fashion, personal preferences, ideology, etc. The psychological aspect should not be undervalued: who would feel comfortable in clothing of a color he or she dislikes?

2.1 Garment comfort as a measurable quantity

Thermo physiological comfort is based on the principle of energy conservation. All the energy produced within the body by metabolism M, has to be dissipated in exactly the same amount from the body:

$$M - P_{ex} = H_{res} + H_c + H_e + \frac{\Delta S}{\Delta t}$$

With P_{ex} the external work, H_{res} the respiratory heat loss because of breathing, H_c the dry heat flux comprising radiation, conduction and convection, and, last but not least, the evaporative heat flow H_e caused by sweating [11]. If more energy is produced than dissipated, the body suffers from hyperthermia. On the other hand, too high a heat loss leads to hypothermia. Both lead to a change in the body's energy content ΔS with time Δt. ΔS may be either positive (leading to hyperthermia) or negative (hypothermia), and is zero for steady state.

2.2 Skin Model:

An important laboratory test method that fulfils the above- mentioned criterion of correlation to wearer trials data is the so-called Skin Model. The Skin Model is a thermoregulatory model of the human skin . It tests the thermophysiological wear comfort of textile materials. The Skin Model is internationally standardized (ISO 11092) . For protective clothing, it is the only test method for breathability which is accepted within European standardization.

A photo and a schematic drawing of the Skin Model is given in Fig. 1 The measuring unit shown is made of sintered stainless steel. Water, which is supplied by channels beneath the measuring unit, can evaporate through the numerous pores of the plate, just like sweat out of the pores of the skin. Additionally, the measuring unit is kept at a temperature of 35C°. Thus, heat and moisture transport are comparable to those of the human skin [11].

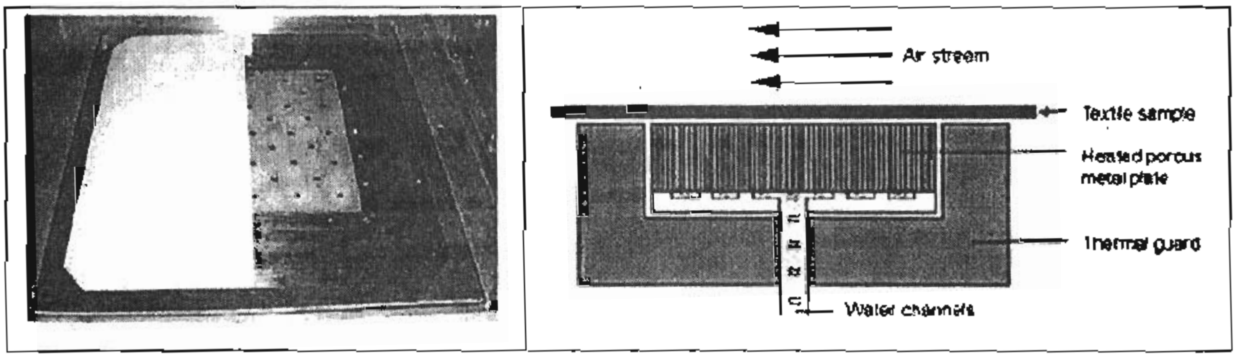


Fig. 1 Photo and schematic drawing of the Skin Model according to ISO 11092

2.3 Wear Situations:

Normal wear situations are characterized by an insensible perspiration, i.e. the wearer does not recognize that he is sweating. Nevertheless, at least 30 grams per hour of water vapor is evaporated through the semi-permeable membrane skin.For normal wear situations, thermal insulation R_{ct} (10^{-3}) (m^2 K (kelven) / W(watt)) and water vapor resistance R_{et} (m^2) P_a/W) ('breathability') of the textiles are especially important according to ISO 11092 [14] where P_a is (Pascal) and W is (watt) .

If textiles are identically constructed, the thicker one always has the higher (and thus poorer) water vapor resistance R_{ct} (m^2 P_a/W). In order to take into account its benefit of a higher thermal insulation, the ratio is defined as the water vapor permeability index (i_{mt}), which is a measure of the breathability with respect to a fabric's thermal insulation.

$$i_{mt} = 60\left(\frac{P_a}{K}\right)\left(\frac{R_{ct}}{R_{et}}\right)$$

- With heavier sweating, e.g. when walking upstairs, the wearer recognizes that he has started to sweat, but he is not sweat-wetted yet. In these situations, the skin produces vaporous sweat impulses, which can be simulated with the Skin Model by measuring the buffering capacity against vaporous sweat F_d according to BPI 1.2 [15].

- Very important for sport textiles are heavy sweating situations with a high amount of liquid sweat on the skin. Here, the buffering capacity against liquid sweat K_f and the liquid sweat transport defined as 'moisture permeability' F_l (BPI 1.2) are most import ant for a good wear comfort.

- Finally, the wear situation directly after an exercise is also of great relevance to sport textiles. Then, the textile might be soaked with sweat and has lost its thermal insulation. This leads to the so-called post-exercise chill, which is very unpleasant. The post-exercise chill can be avoided by a short drying time Δt, according to BPI 1.3 [16].

In general, it should be pointed out that wear comfort is never the consequence of only one single parameter like 'use of micro fibers'. On the contrary, all physiologically relevant construction parameters have to be adjusted to the intended field of application (e.g. sportswear), in order to achieve a good wear comfort.

Many investigators [17-19] have found that hydrophilic textiles such as cotton seem to have beneficial influences on thermal physiological response as well as overall comfort during and after exercise, when compared with hydrophobic textiles such as polyester, nylon and polypropylene. The rise of core temperature, heart-beat rate, amount of sweat, metabolic heat production was found to be greater in the subjects wearing clothing ensembles made of weak hygroscopic material versus clothing ensembles made of strong hygroscopic material in various exercise conditions.

3. Experimental work

To know how heat and water are transported through each fabric, measurements of their physical properties (thermal resistance, thermal conductivity, thermal absorptivity, heat flow, relative water vapor permeability and air permeability) must be made in laboratories.

3.1 Materials Used:

The tested set of fabrics consisted of commercial knitted sport wear fabrics that were supplied by fabric producers. These were consisted of the following materials: 100% cotton, 65%polyester/35% cotton and 100% Polyester as listed in table (1).

Sample Charactrestics

Sample No.	Fabric Composition	Clothing Assembly	Fabric structure	Fabric thickness (mm)	Fabric weight (g/m^2)
1	100% C	Single Layer	Single jersey	0.723	168
2	65% PE 35%	Single Layer	Single jersey	0.743	203
3	100% PE S.L.	Single Layer	Single jersey	0.598	127
4	100% C UW	Single Layer	Single jersey	0.693	130
5	100% C	Double Layers	Single jersey	1.416	168+130
6	65% PE 35%	Double Layers	Single jersey	1.436	203+130
7	100% PE	Double Layers	Single jersey	1.291	127+130

Aim of selection of these fabrics (some structural parameters as thickness and porosity.

Sample names C.. cotton, PE .. polyester, UW.. Under wear, Single Layer = the Sample itself. Double Layers = the Sample itself + the under wear sample (100% cotton).

3.2 Measuring the thermal comfort properties of garments

Thermal properties are among the most important features of textiles. Most of the studies carried out have been devoted for measuring static thermal properties such as thermal conductivity, thermal resistance, and thermal diffusion. Kawabata & Yoneda pointed out the importance of the so-called 'warm-cool feeling' [20]. This property tells us whether a user feels 'warm' or 'cool' upon the first brief contact of the fabric with the human skin. Hes introduced the term of 'thermal absorption' as a measure of the 'warm-cool feeling' of textiles [21].

These samples were prepared and measured on the ALAMBETA for their thermal resistance, thermal conductivity, thermal absorptivity, fabric thickness and heat flow by means of the computer-controlled Alambeta device, which enables rapid measurement of the steady-state and transient-state thermal properties of any plain compressible non-metallic materials such as textile fabrics, plastic or rubber foils, paper products, liquids, pastes and fine powders [22, 23].

The simplified scheme of the ALAMBETA instrument is shown on Fig. 2.

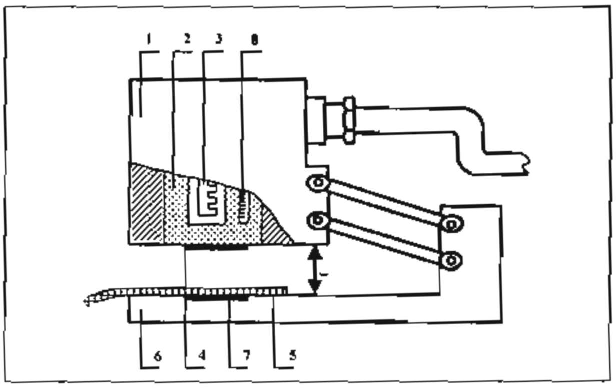


Fig. 2 Principle of the ALAMBETA instrument.

The simplified scheme of the instrument is shown on Fig. 2. The principle of this instrument depends on the application of ultra thin heat flow sensor 4, which is attached to a metal block 2 with constant temperature, which differs from the sample temperature. When the measurement starts, the measuring head 1 containing the mentioned heat flow sensor drops down and touches the planar measured sample 5, which is located on the instrument base 6 under the measuring head. In this moment, the surface temperature of the sample suddenly changes and the instrument computer registers the heat flow course. Simultaneously, a photoelectric sensor measures the sample thickness. All the data are then processed in the computer according to an original programme, which involves the mathematical model characterising the transient temperature field in thin slab subjected to different boundary conditions [23]. To simulate the real conditions of warm-cool feeling evaluation, the instrument measuring head is heated to 32°C (see the heater 3 and the thermometer 8), which correspond to the average human skin temperature, while the fabric is kept at the room temperature 22°C. Similarly, the time constant of the heat flow sensor, which measures directly the heat flow between the automatically moved measuring head and the fabrics, exhibit similar value (0,07 sec), as the human skin.. Thus, the full signal response is achieved within 0,2 sec.

3.3 Measuring Relative water vapor permeability (%)

We tested our samples for their relative water vapor permeability using the PERMETEST devise which developed by Hes [24]. The PERMETEST is a new fast response measuring instrument (skin simulator), for measuring of the water vapor permeability of textile fabrics, garments, nonwoven webs and soft polymer foils, by measuring the evaporative heat resistance. It works on the principle of heat flux sensing. The temperature of the measuring head is maintained at room temperature for isothermal conditions. The heat supplied to maintain the temperature of the measuring head, from where the supplied water gets evaporated, is measured. The heat supplied to maintain a constant temperature with and without the fabric mounted on the plate is measured. This instrument provides the relative water vapor permeability% (RWVP%) of the fabric in the steady state isothermal condition.

$$\mathrm{RWVP\%} = \frac{\text{Heat lost when the fabric is placed on the measuring head}}{\text{Heat lost from the bare measuring head}} \times 100$$

$$RWVP\% = \frac{q_{hs}}{q_{h0}} \cdot 100\%$$

The PERMETEST can be used according to both BS 7209 and ISO 9920 standard. If the ring above the measuring head is used, a separating air layer will be created between the measuring head (simulated skin) and the fabric layer, thus providing the measuring condition according to BS 7209. On the other hand, if the ring above the measuring head is not used, the fabric will be in direct contact with the measuring head, i.e. according to the conditions used for the ISO 9920 standard.

Principle of the PERMETEST instrument

Slightly curved porous surface is moistened (either continuously or on demand) and exposed in a wind channel to parallel air flow of adjustable velocity (Fig. 3). A tested sample is located in a small distance from the wetted area of diameter about 80 mm and characterized by high thermal conductivity. The amount of evaporation heat of liquid water taken away from the active porous surface is measured by a special integrated system.

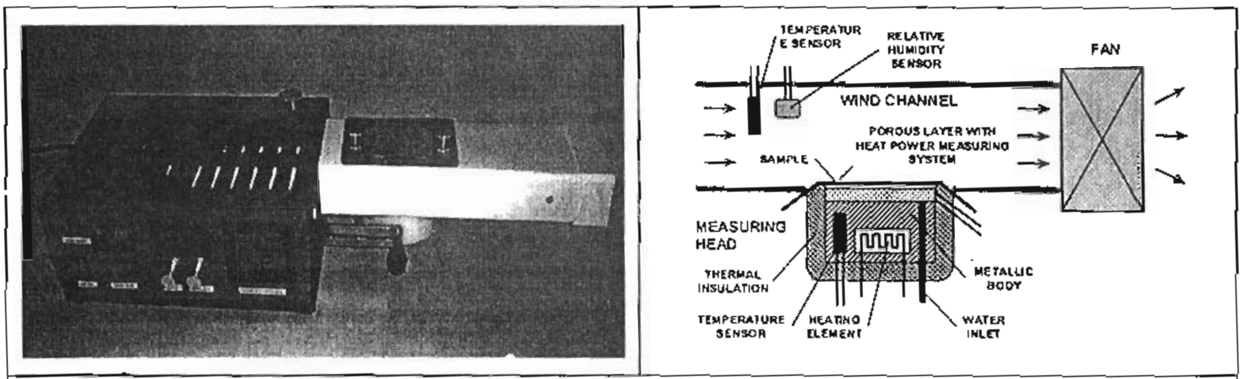


Fig. 3 Working principle of the PERMETEST skin model

At the beginning of the measurement, heat flow value q''_{h0} without a sample is saved. If water was regularly distributed and the head temperature was properly controlled the signal becomes quite stable but will include some small turbulent variations which cannot be avoided.

In the next step, the measuring head pulls down and a sample is inserted between the head and the cut out in the wind channel. Then the measuring head moves back to the channel and squeezes the sample. After short period when the signal reflects the effect of different temperature of the sample, the signal becomes steady and new value q''_{hs} which quantifies heat loses of moist measuring head covered by a sample is read [25].

Relative water vapour permeability of the textile sample $RWVP\%$ is calculated from the formula:

$$RWVP\% = \frac{q_{hs}}{q_{h0}} \cdot 100\%$$

4. Results and Discussion

Thermal parameters:

Table 2 shows the effect of fabric composition and clothing assembly on the fabric thermal parameters.

Table 2 fabric thermal properties.

Fabric Composition	Thermal parameters					
	λ	a	B	r	H	q
100% C S.L.	22.7 ± ·.071	0.168 ± ·.009	56 ± 1.62	31.8 ± ·.60	0.715 ± 0.006	0.0103 ± ·.00025
65% PE 35% C S.L.	21.6 ± ·.068	0.206 ± ·.024	50 ±3.6	47.1 ± ·.19	0.7425 ± 0.005	0.0087 ± ·.000245
100% PE S.L.	19.1 ± ·.108	0.231 ± ·.046	41 ± 3.51	31.3 ± ·.63	0.5925 ± 0.013	0.0077± ·.00025
100% C S. L. UW	22.8 ± ·.093	0.165 ± ·.0163	57 ± 2.09	64.6 ± ·.37	0.6925 ± 0.006	0.0088 ± ·.00037
100% C D.L.	23.1 ± ·.3444	0.178 ± ·.0106	55 ±1.48	64.2 ± 2.17	1.416 ± 0.033	0.0097± ·.0005
65% PE 35% C D.L.	22.4 ± ·.068	0.152 ± ·.024	59 ± 3.6	65.0 ± ·.46	1.437 ± 0.008	0.008 ± ·.00037
100% PE D.L.	21.6 ± ·.27	0.249 ± ·.0339	45 ± 2.95	61.2 ± 1.1	1.291 ± 0.013	0.0072 ± ·.0002

Where Thermal properties
λ: thermal conductivity [W/mK]
a: thermal diffusitivity [m2s-1]
b: thermal absorbtivity [W.m-2s1/2.K-1]
h: thickness [mm]
r: thermal resistance [K.m2/W]
q: heat flow [W/m2]

Table 3 shows the effect of fabric composition, fabric porosity and clothing assembly on the relative water vapour permeability and Air permeability.

Table 3 relative water vapour permeability and Air permeability.

Fabric Composition	Fabric porosity	Vapor and Air permeability	
		Air permeability $(l/m^2/s)$	Relative water vapor permeability (%)
100% C S.L.	0.847	1403 ± 40.1	56.14 ± ·.2891
65% PE 35% C S.L.	0.811	1416 ± 18.1	52.98 ± ·.2709
100% PE S.L.	0.847	1670 ± 13.3	68.36 ± ·.7146
100% C S. L. UW	0.878	645 ± 13.2	58.4 ± ·.2846
100% C D.L.	0.718	561 ± 16.0	39.66 ± ·.2977
65% PE 35% C D.L.	0.682	546 ± 15.2	42.38 ± ·.2311
100% PE D.L.	0.716	658 ± 21.6	48.62 ± ·.2634

Figure 4 shows the effect of fabric composition on the fabric porosity which declared that the fabric porosity for the single layer was higher than the two layer fabrics.

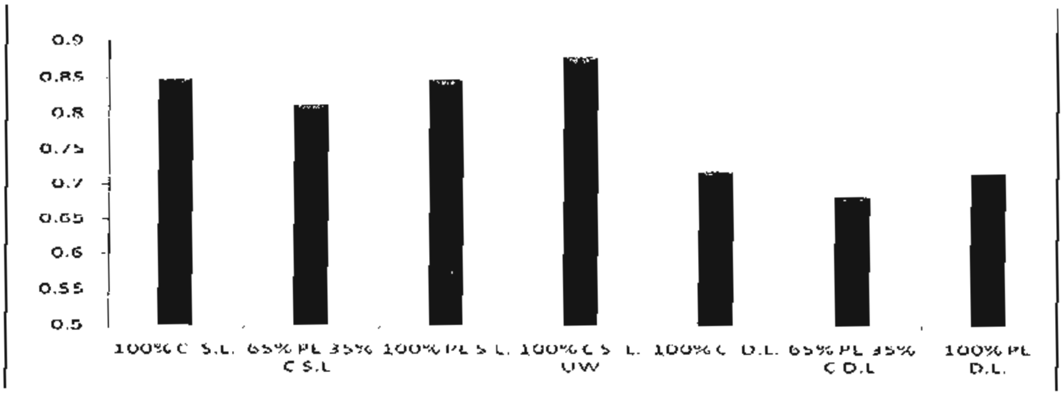
Figures 5, 6 showed the fabric thermal parameters dependencies on the fabric composition and the clothing assembly. The fabric thermal conductivity for the cotton fabric are higher than of the polyester fabric as shown in figure (5-a). The fabric thermal resistance increases with double layer than with the single layer as shown in figures (5-d, 6-d).

From the measurements made on the PERMETEST (Sensora) instrument (fig. 7) resulted, that water-vapour permeability of the measured outer ware and underwear fabrics depends more on their composition, and that in all cases the relative vapour permeability was very good, exceeding 40%.

The effect of fabric composition and the clothing assembly almost identical with fabric relative water vapour permeability and air permeability as shown in figures (7,8)

Table 4 the correlation coefficients between Fabric thickness, fabric porosity (FP), relative water vapor permeability (%) of the fabrics, the fabric air permeability (AP) and thermal parameters.

	h	*FP*	*RWVP*	*AP*	*λ*	*a*	*B*	*r*	*q*
h	1.000								
FP	0.957	1.000							
RWVP	0.912	0.850	1.000						
AP	0.785	0.629	0.755	1.000					
λ	0.436	-0.247	0.690	0.664	1.000				
a	-0.119	-0.005	0.343	0.343	-0.703	1.000			
b	0.286	-0.144	0.536	-0.532	0.875	-0.949	1.000		
r	0.716	-0.592	-0.719	-0.953	0.579	-0.265	0.455	1.000	
q	-0.150	0.301	-0.145	0.101	0.607	-0.624	0.593	-0.206	1.000



Single layer Double Layer

Fig. 4 shows the effect of fabric composition on the fabric porosity

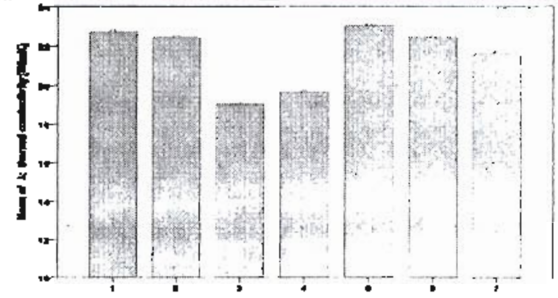


Fig. 5-a Effect of fabric composition on the fabric thermal conductivity

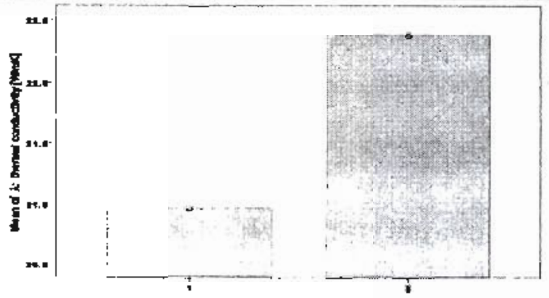


Fig. 6-a effect of Clothing assembly on the fabric thermal conductivity

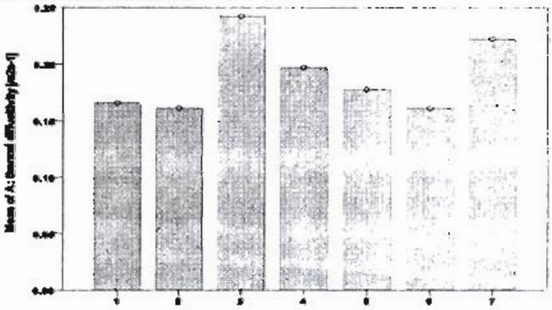


Fig. 5-b Effect of fabric composition on the fabric thermal diffusivity

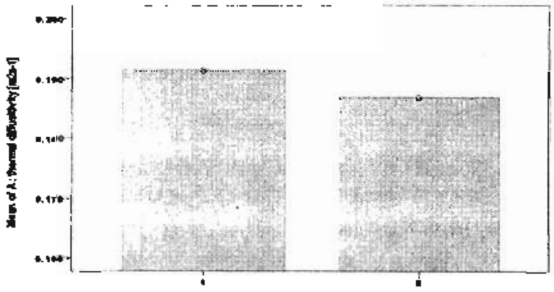


Fig. 6-b Effect of Clothing assembly on the fabric thermal diffusivity

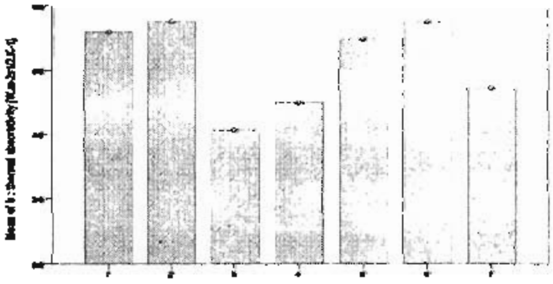


Fig. 5-c Effect of fabric composition on the fabric thermal absorbtivity

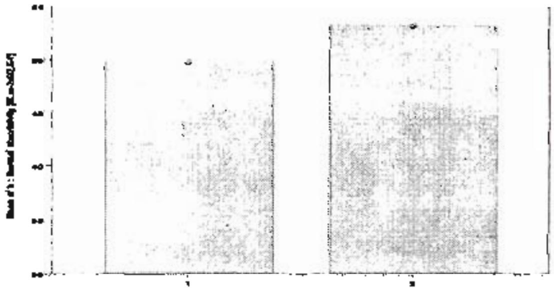


Fig. 6-c Effect of Clothing assembly on the fabric thermal absorbtivity

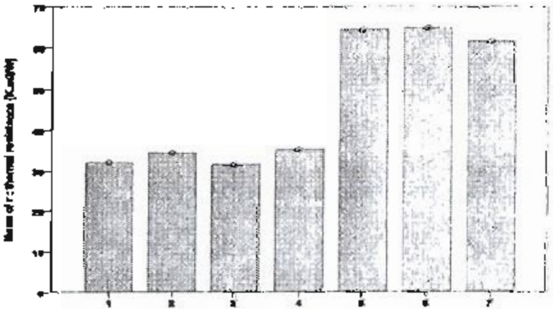


Fig. 5- d Effect of fabric composition on the fabric thermal resistance

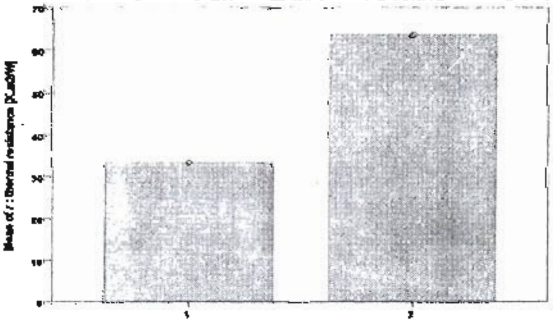
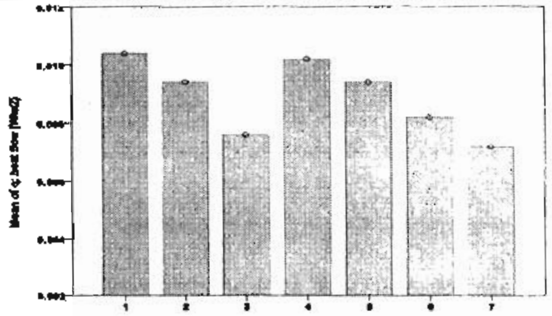
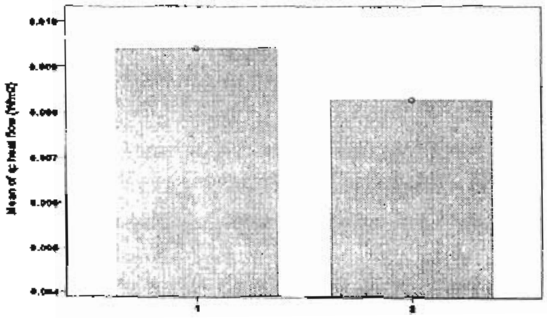


Fig. 6-d Effect of Clothing assembly on the fabric thermal resistance



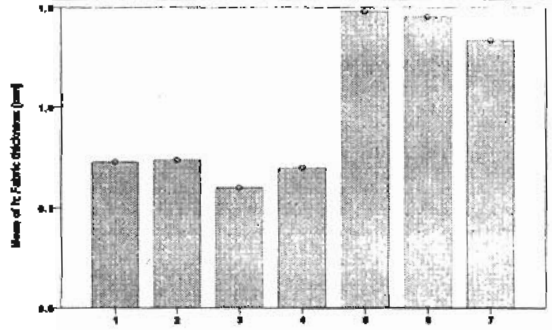
Sample No.

Fig. 5- e Effect of fabric composition on the fabric heat flow



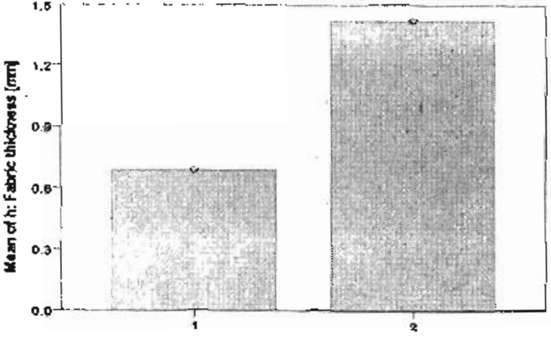
Clothing assembly

Fig. 6- e Effect of Clothing assembly on the fabric heat flow



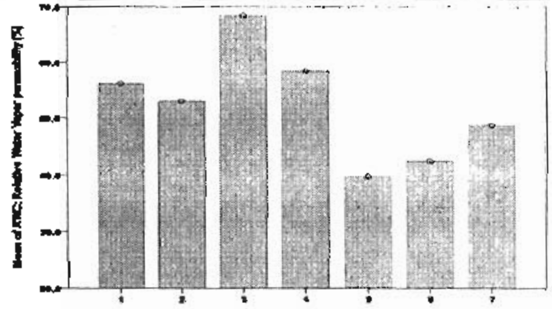
Sample No.

Fig. 5- f Effect of fabric composition on fabric thickness



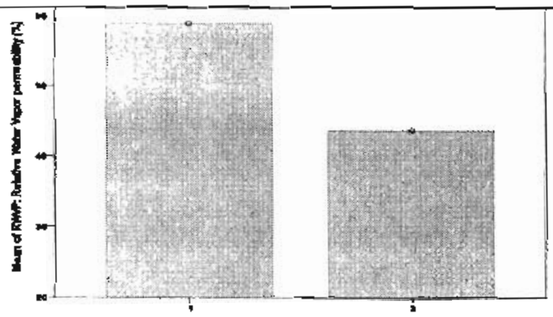
Clothing assembly

Fig. 6- f Effect of Clothing assembly on the fabric thickness



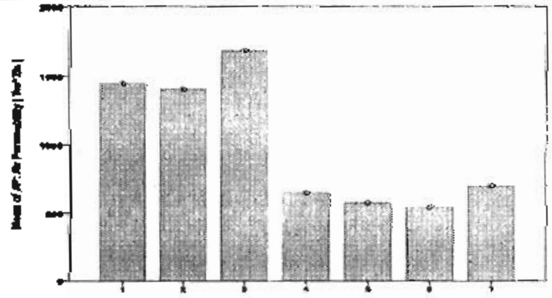
Sample No.

Fig. 7-a Effect of fabric composition on relative water vapour permeability%



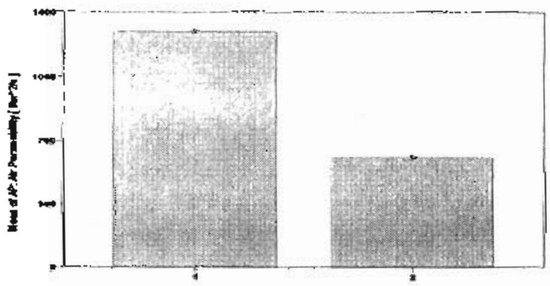
Clothing assembly

Fig. 7-b Effect of Clothing assembly on the relative water vapour permeability%



Sample No.

Fig. 8-a Effect of fabric composition on fabric air permeability



Clothing assembly

Fig. 8-b Effect of Clothing assembly on the fabric air permeability

Table 5 ANOVA Analysis for the effect of fabric composition on **thermal and moisture permeability**

		Sum of Squares	Df	Mean Square	F	Sig.
λ: thermal conductivity [W/mK]	Between Groups	75.03	6	12.5	77.9	.000
	Within Groups	4.49	28	.16		
	Total	79.52	34			
A: thermal diffusitivity [m2s-1]	Between Groups	.031	6	.005	1.5	.213
	Within Groups	.096	28	.003		
	Total	.127	34			
b: thermal absorbtivity [W.m-2s1/2.K-1]	Between Groups	1415	6	235.92	5.9	.000
	Within Groups	1123	28	40.13		
	Total	2539	34			
r: thermal resistance [K.m2/W]	Between Groups	7900	6	1316.7	261.8	.000
	Within Groups	140.8	28	5.0		
	Total	8041	34			
h:Fabric thickness [mm]	Between Groups	4.7	6	.783	637.7	.000
	Within Groups	.034	28	.001		
	Total	4.74	34			
q: heat flow [W/m2]	Between Groups	.000	6	.000	14.6	.000
	Within Groups	.000	28	.000		
	Total	.000	34			
RWVP: Relative water vapour permeability	Between Groups	2910	6	485	707.3	.000
	Within Groups	19.2	28	.686		
	Total	2929	34			
AP: Air Permeability	Between Groups	7123208	6	1187201	514.3	.000
	Within Groups	64632	28	2308		
	Total	7187840	34			

Table 5 shows the statistical analysis for the effect of fabric composition on the thermal parameters, T relative water vapour permeability (%) and Air permeability (l/m^2/s). Material will be having a very little effect on the air permeability but the fabric porosity is different. As shown from the statistical analysis fabric type has a very high significant effect on the fabric thermal parameters, vapor permeability and air permeability. Also table 4 showed that the correlation between fabric prosity, fabric thikness, the relative water vapor permeability%, the air permeability and thermal parameters are highly significant at the 0.01 level.

Table 6 ANOVA Analysis for the effect of Clothing assembly on thermal and moisture permeability

		Sum of Squares	df	Mean Square	F	Sig.
λ: thermal conductivity [W/mK]	Between Groups	17.12	1	17.12	9.1	.005
	Within Groups	62.4	33	1.89		
	Total	79.52	34			
A: thermal diffusitivity [m2s-1]	Between Groups	.000	1	.000	.045	.834
	Within Groups	.127	33	.004		
	Total	.127	34			
b: thermal absorbtivity [W.m-2s1/2.K-1]	Between Groups	102.42	1	102.42	1.39	.247
	Within Groups	2436.7	33	73.84		
	Total	2539	34			
r: thermal resistance [K.m2/W]	Between Groups	7817	1	7817.5	1154.	.000
	Within Groups	223.5	33	6.77		
	Total	8041	34			
h:Fabric thickness [mm]	Between Groups	4.58	1	4.58	989.7	.000
	Within Groups	.153	33	.005		
	Total	4.74	34			
q: heat flow [W/m2]	Between Groups	.000	1	.000	7.02	.012
	Within Groups	.000	33	.000		
	Total	.000	34			
RWVP: Relative water vapour permeability	Between Groups	2037	1	2037	75.35	.000
	Within Groups	892	33	27.04		
	Total	2929	34			
AP: Air Permeability	Between Groups	4048884	1	4048884	42.57	.000
	Within Groups	3138956	33	95120		
	Total	7187840	34			

Table 6 shows the statistical analysis for the effect of clothing assembly (single and two layers) on the thermal parameters, T relative water vapour permeability% and Air permeability (l/m2/s). As shown from the statistical analysis using single or/and two layers has a very high significant effect on the fabric thermal parameters, vapor permeability and air permeability except the thermal diffusitivity [m^2s^{-1}] and the thermal absorbtivity, which showed no and less significance respectively.

Conclusion

Knitted fabrics are the preferred structures in athletic wear in which demand for comfort is a key requirement. Heat and liquid sweat generation during athletic activities must be transported out and dissipated to the atmosphere. A key property influencing such behaviors is fabric porosity, fabric thickness and fabric material.

The effects of fabric composition and the number of layers have a highly significant effect on both moisture and thermal properties of sport wear knitted fabrics and also there were a high correlation between fabric porosity, fabric air permeability, the relative water vapor permeability and fabric thermal parameters.

Cotton sportswear, which are used to be common in sports fabric, has clear shortcomings in terms of moisture management as relative water vapor permeability varies between (56 to 58%) see table 3. Although perspiration is absorbed well, it remains close to the body, resulting in negative effects.

The synthetic fiber which were the polyester that lying against the skin transport perspiration quickly and effectively away from the body as its relative water vapor permeability was 68% which considered a very high as shown in table 3. The fabric which is in contact with the skin should be dry to the touch; otherwise heat, which flows from the body will increase, causing unwanted loss in body heat and a clammy feeling. For a sport wear end-use it is necessary to design fabrics with required moisture transmission properties.

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