(REFEREED RESEARCH)

THERMO-PHYSIOLOGICAL COMFORT OF LAYERED KNITTED FABRICS FOR SPORTSWEAR

ÇEVRESEL PARAMETRELERİN ELEKTROSPİN YÖNTEMİYLE ÜRETİLMİŞ POLİTRİMETİLEN TEREFTALAT LİFLERİNİN MORFOLOJİSİ ÜZERİNDEKİ ETKİLERİ

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ABSTRACT

The thermal comfort properties of different bi-layer knitted structures made from Polyester yarn as an inner layer and Modal/Bamboo yarn as an outer layer have been studied. Four bi-layer knitted fabrics were developed and then analyzed objectively and subjectively for their comfort properties. The air permeability, thermal conductivity, water vapour permeability, wicking ability and drying rate were found to be higher and moisture absorbency was found to be lower for bi-layer knitted fabric with one-tuck point made out of Bamboo as an outer layer compared to all other fabrics. The same structure showed good ranking on subjective rating of thermal environment scale. ANOVA analysis and Friedman One-Way Analysis of Variance were discussed with 95% significant level.

Keywords: Subjective evaluation, Sportswear, Layered knitted fabric, Thermal comfort

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1. Introduction

The human body strives to keep its core temperature at 37°C and the metabolic heat generation for a person engaged in physical activity is in the range of 800-1300W. The extra body heat is produced causing the nervous system to react by sweating. Sweat glands pump perspiration through pores, body heat is transferred to the sweat, causing it to evaporate and cool the body [1, 2]. The impact of clothing on comfort and performance of individuals at work or sport are of particular importance because physiological loads may decline the physical and mental capacity of the person [3]. Wear comfort can be divided into four main aspects such as physiological, psychological, ergonomic and skin sensorial aspects [4]. Thermo-physiological comfort is a general expression of factors such as the thermal properties, water vapour transmission, sweat absorption and drying ability of fabrics [5-7]. The enclosed still air and external air movement are the major factors that affect heat transfer through fabric [8, 9] and it is influenced by the fabric construction, thickness and material [10].

Water vapour permeability plays a very important role when there is only little sweating, or insensible perspiration or else very little sweating [11]. The garment should have the ability to release the moisture vapour held in the microclimate to the atmosphere to reduce the dampness at the skin [12]. During heavy activity when liquid perspiration production becomes high, to feel comfortable the clothing should possess good liquid transmission property [13]. Wicking is an important property to uphold a feel of comfort during sweating conditions. It applies the capillary theory to rapidly remove sweat and moisture from the skin's surface, transport it to the fabric surface, and then evaporate it [14].

Many studies have been focussed on double-face structures to achieve high level of comfort [15-18]. The performance of layered fabric in thermo-physiological regulation is better than single layer textile structure [19, 20]. In the inner side of a multiple layer textile, a synthetic material with good moisture transfer properties, such as polyester, nylon, acrylic or polypropylene is used whereas on the outside, a material which is a good absorbent of moisture such as cotton, wool, viscose rayon or their blends can be placed [21-24]. Layering of fabrics used as garments has the major effect on properties such as thermal conductivity, air permeability and moisture vapour transmittance worn together [25] and are used to achieve high level of comfort. Synthetic sportswear shows better performance with significant improvement in the mean skin temperature and comfort sensation rating during exercise [26]. Knitted fabrics made by using micro-fibre polyester show excellent moisture-related comfort properties like absorption, wicking and rate of drying [27]. Cellulosic fibres like cotton and viscose absorb moisture easily and retain the moisture, thus making liquid transportation difficult [28]. Hydrophilic fibres like viscose can absorb liquids into the fibre structure thus preventing the spread of liquids, including sweat, along the fabrics [29].

The thermal resistance of multi-layered fabrics increases with increase of mass per unit area [29].The moisture content of one layer is not only dependent on its material properties but also on the material properties of neighbouring layer [31]. Different types of yarns are used in the inner and outer layer of multilayered fabrics to improve the moisture management properties of the fabrics [32]. Fabric knitted with polypropylene filament on the inner side and facing the skin is reported to have better wicking, water holding capacity and moisture vapour transmission when combined with viscose and cotton on the outer side of fabric. Two layer fabrics with polypropylene on the inner side and cotton on the outer side is reported to have good overall moisture management capacity due to quick transfer of liquid from inner to outer side. It provides high level of comfort and can be preferred for summer, active and sportswear [12].

Blending wool with polyester or wool with bamboo has improved comfort properties of the fabrics in comparison to 100% wool and 100% bamboo fabrics [33]. The double-layer knitted structures were developed where the inner (contact) layer is made of polypropylene yarns and the outer layer is made of cotton or viscose yarns [16]. Two layer fabrics made using 30% Tencel and 70% polyester in the outer layer gives better thermal comfort compared to 100% polyester. Combinations of PET with thermo-regulating viscose Outlast gives better wicking ability but poor drying capability [34].

In this research work, an attempt has been made to analyze the thermal comfort properties of bi-layer knitted structures made out of Polyester-Modal and Polyester-Bamboo union fabrics. The aim of this study is to develop a bi-layer knitted fabric that will achieve a high level of clothing comfort for active sports wears.

2. Experimental

2.1. Materials

The bi-layer knitted structures were prepared using Polyester (40 Ne), Modal (40 Ne) and Bamboo yarn (40 Ne). All samples were produced in circular multi-track weft knitting machine (Kemyong-KILM-72AV) with 28 inch diameter, 68 feeders, 18 gauge and 3168 needles. In this experimental work, the bi-layer fabric is developed in which the inner layer is made of polyester that is hydrophobic and has good wicking rate. The outer layer is made up of regenerated fibre such as Modal or Bamboo which has more absorption character and rapid evaporation. The yarn which has to form as an outer layer is fed into the dial needle and as an inner layer is fed into the cylinder needle. The two bi-layer knitted structures were developed: one is 5 course repeat in which dial needles knit at 2, 4, 7 and 9th feeders and cylinder needles knit at 3, 5, 8 and 10th feeders. The tuck frequency takes place at 1, 6 and 9th feeders. The next structure is developed with 18 course repeat, the dial needles knit at all odd feeders and cylinder needles knit at all even feeders. The cylinder needles form tuck stitch at first feeder of every repeat. The visual appearance of the structures, the sample code and fabric layers with different views are mentioned below in Figure 1. The graphical representation of the bi-layer knitted fabric is shown in Table 1.

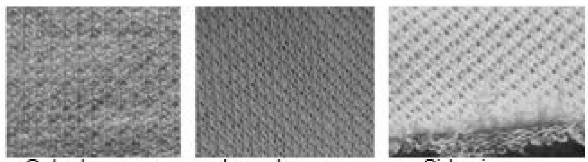
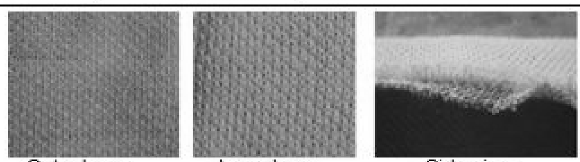
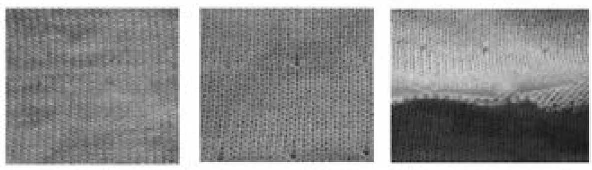
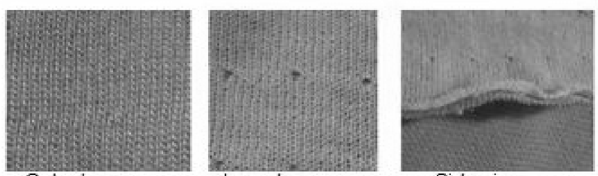
Fabric type	Inner layer	Outer layer	Fabric layer different views
Type 1	Polyester (40%)	Modal (60%)	 Outer layer Inner layer Side view
Type 2	Polyester (40%)	Bamboo (60%)	 Outer layer Inner layer Side view
Type 3	Polyester (40%)	Modal (60%)	 Outer layer Inner layer Side view
Type 4	Polyester (40%)	Bamboo (60%)	 Outer layer Inner layer Side view

Figure 1. Fabric specifications with different views of bi-layer knitted fabric structures

Table 1. Graphical representation of bi-layer knitted structure

Fabric type	Graphical representation of bi-layer knitted fabrics
Type 1 and Type 2	(see below)
Type 3 and Type 4	(see below)

Type 1 and Type 2

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
DN1	o	X	-	X	-	-	X	-	X	-
DN2	-	X	-	X	-	o	X	-	X	-
CN1	o	-	X	-	X	-	-	X	o	X
CN2	-	-	X	-	X	o	-	X	-	X

Dial needles: Two tracks (Modal or Bamboo Yarn)
DN1-Dial Needles Track 1; DN2-Dial Needles Track 2
Cylinder needles: Two tracks (Polyester yarn)
CN1-Cylinder Needles Track 1; CN2-Cylinder Needles Track 2
F1, F2.....F10-Feeders; X-Knit stitch; o-Tuck stitch;
- -Miss stitch

Type 3 and Type 4

	F1	F2	F3	F4	F5	F6	F7	F8	..... F36
DN1	X	-	X	-	X	-	X	-	-
DN2	X	-	X	-	X	-	X	-	-
CN1	-	X	-	X	-	X	-	X	X
CN2	-	X	-	X	-	X	-	X	X
CN3	o	X	-	X	-	X	-	X	X

Dial needles: Two tracks (Modal or Bamboo Yarn)
DN1-Dial Needles Track 1; DN2-Dial Needles Track 2
Cylinder needles: Three tracks (Polyester yarn)
CN1-Cylinder Needles Track 1; CN2-Cylinder Needles Track 2; CN3-Cylinder Needles Track 3
F1, F2.....F36-Feeders; X-Knit stitch; o-Tuck stitch;
- -Miss stitch

2.2. Methods

The testing of double face knitted fabrics was carried out in the standard atmospheric conditions of 21°C ±2° and 65% RH ±5%.

Dimensional properties

The bi-layer knitted fabrics were measured for their loop length, stitch density, tightness factor, thickness and areal density. The thickness measurement of the fabric was carried out according to ASTM D1777-96 [35].

Air permeability

The air permeability of the clothing was determined by the rate of air flow passing perpendicularly through a set area under given pressure over a given time period. The air permeability properties of the fabrics were measured using Atlas air permeability instrument according to BS 5636 [36] standard with 100 Pa air pressure. It is expressed as the quantity of air, in cubic centimetre passing per second through a square centimetre of fabric.

Thermal conductivity

Thermal conductivity is an intrinsic property of material that indicates its ability to conduct heat. Lee's Disc instrument was used to measure the thermal conductivity according to ASTM D7340 standard [37].

Water vapour permeability

The water vapour permeability was determined on Shirley water vapour permeability tester according to standard BS 7209:1990 [38]. The cup method is a very common method for testing the moisture transfer ability of fabrics. In this method, the sample covers a cup containing distilled water and is placed under controlled environment (20 °C temperature and 65% relative humidity) [39]. The Water vapour permeability (WVP) in g/m^2/day is calculated by the following equation:

$$WVP = 24\ M / At \qquad (3)$$

where M is the loss in mass of the assembly in grams over the time period t. t is the time between successive weighing of the assembly in hours and A is the area of the exposed test fabric in m^2.

Vertical wicking

Vertical wicking was measured in accordance with BS 3424 standard, a strip of 20cm×2.5cm test fabric at 20ºC, 65% RH was suspended vertically with its lower edge (0.5cm) immersed in a reservoir of distilled water. The rate of rise of the leading edge of the water is then measured for every five minutes till it reaches consistency [40].

Transverse wicking

Transverse wicking was measured according to standard procedure AATCC 198-2011 [41]. The horizontal wicking rate and the average wicking rate for each sample were calculated by the following formula:

$$W = \pi (1/4) (d1) (d2)/t \quad (5)$$

where *W is the* wicking rate in mm^2/s; d1 is the wicking distance in length direction in mm; d2 is the wicking distance in width direction in mm and t is the wicking time in seconds.

Moisture absorbency

Static immersion method which follows the standard BS 3449 [42] was used to evaluate the amount of water absorbed by the fabric. The ratio of mass of water absorbed to its original mass and its percentage gives the moisture absorbency percentage.

Drying behaviour

The fabrics got wet according to static immersion method were dried in drying oven at 30^0C for 30 minutes to simulate the natural drying [42]. After they were taken out, the fabrics were weighed and the amount of water loss was calculated from subtracting the wet and dry mass. And also, the drying time of the fabrics was determined by which the wet fabrics reach their dry mass.

Subjective evaluation

Short-sleeved T-shirts and shorts were produced from the developed bi-layer knitted fabrics. A total of 30 players were selected as the participants with mean age of 23-24 years (standard deviation of 1.4 year), body mass 59.3 kg (standard deviation of 3.6 kg), and height 1.6 m (standard deviation of 0.02 m). The subjective evaluation was conducted at conditions: air conditioning of indoor temperature 26-28^{o}C below the outside temperature 35-37^{o}C and 55% to 60% humidity. Each participant was informed about the general procedure and purpose of wear trial. They were asked to select the best fitting size for each of the layered fabric by wear and trial method. Participants were instructed to wear the sports garment for 2 hours by engaging in badminton activity and they completed the questionnaire immediately after the activity. The psychological phenomenon of thermal comfort during activity was assessed using ISO 10551 (1995) standard [43]. The questionnaire described the thermal comfort of garment using five subjective assessment scales of thermal state such as thermal perception, thermal comfort, thermal preference, personal acceptability, and personal tolerance.

Statistical analysis

Analysis of variance (ANOVA) tests were used to determine the significant difference between the thermal comfort properties of bi-layer knitted fabrics. In order to infer whether the parameters were significant or not, p values were examined. If the ‘p’ value of a parameter is greater than 0.05 ($p>0.05$), the parameter was not significant and should not be investigated. Friedman One-Way Analysis of Variance by Ranks [44] was used to evaluate the thermal sensation by subjective evaluation. It is a non-parametric analysis, used to find out the significant difference between the rankings of each thermal state parameter.

3. Results and Discussions

The physical and thermal comfort properties of developed bi-layer knitted fabrics were measured and the average values of ten samples are given in Table 2.

Table 2. Physical properties of bi-layer knitted fabrics

Property	Type 1	Type 2	Type 3	Type 4
Stitch density, loops/cm^2	253.8	245.0	210.7	197.2
Weight, g/m^2	232	215	175	169
Thickness, mm	0.94	0.86	0.69	0.64
Loop length, mm	2.5	2.7	2.5	2.7
Tightness factor	15.37	14.23	15.37	14.23

Table 3. Two-way ANOVA of bi-layer knitted fabric structures

Thermal comfort properties		F_{actual}	P_{value}	Tukey’s HSD		
				0.05 Level	0.01 Level	P_{value} (all groups)
Air permeability		950.59	<.0001	2.62	3.37	<0.01
Coefficient of thermal conductivity		360.73	<.0001	0.00	0.00	<0.01
Water vapour permeability		4888.84	<.0001	3.37	4.33	<0.01
Vertical wicking	Walewise	1250.98	<.0001	0.17	0.22	<0.01
	Coursewise	795.15	<.0001	0.21	0.28	<0.01
Transverse wicking		492.93	<.0001	0.27	0.35	<0.01
Moisture absorbency		126.48	<.0001	1.82	2.32	<0.01
Drying time		2563.91	<.0001	9.88	12.71	<0.01

Thermal Conductivity

Thermal conductivity is an intensive property of sportswear that indicates ability to conduct heat. Due to heat dissipation, heavy sweat is formed in the body that leads to accumulation of lot of moisture on the skin. Type 4 shows higher thermal conductivity followed by Type 3 and others is shown in Figure 2. The reason is thickness of Type 4 is lower than all other bi-layer knitted fabrics. It is also clear that, the thermal conductivity also decreases with the decrease of stitch density. For Type 1 and Type 2 bi-layer knitted fabrics, higher the thickness, greater is the air trapped in the loop structure which gives lower thermal conductivity value. By comparing similar structure Type 1 and Type 2, areal density (mass per unit area) is lower for Type 2 and the effect of interaction between the heat transfer in fibres and in the air becomes stronger thereby increasing thermal conductivity. It is also very warm in cold weather, because of the same micro structure of bamboo yarn as the warm air gets trapped next to the skin [45]. Among all bi-layer knitted fabrics, Type 3 and Type 4 possesses high tendency for heat dissipation. This is due to the presence of more tuck stitches in Type 1 and Type 2 fabrics, which accumulates yarn at certain places and possesses high thickness value. It is clear that thermal conductivity mainly depends upon on the geometrical properties of bi-layer knitted fabrics such as thickness, stitch density and areal density of the knitted fabric.

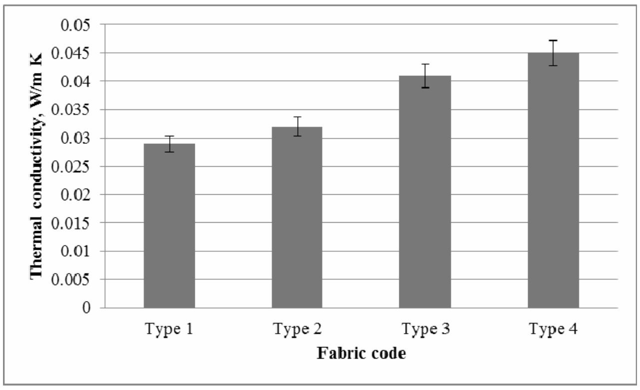


Figure 2. Thermal conductivity of bi-layer knitted fabrics

Air permeability

Air permeability is the most important property of knitted fabrics for sportswear application. A look at Figure 3 shows that Type 4 made up of bamboo as an outer layer and polyester as an inner layer has higher air permeability than Type 3, Type 2 and Type 1 bi-layer fabrics. This is due to the less number of loops occupied in the unit area of Type 4 bi-layer fabrics. The increase of loop length decreases the stitch density of Type 2 fabric and hence the air passage is higher than Type 1 bi-layer fabric. In addition to that, micro-gaps in the structure of bamboo fibre lead to higher air permeability than modal fibre [46]. Type 1 structure interloops very closely and the surface of the fabric becomes tighter than Type 2. Though the tightness factor remains same for Type 2 and Type 4 fabrics, the air permeability is higher for Type 4, this is due the variations in the bi-layer structure of knitted fabric. The accumulation of tuck loops at particular place is less for Type 4 when compared to Type 2. As a result, Type 3 and Type 4 bi-layer fabrics are slacker than Type 1 and Type 2 which results in high air permeability value. The higher thickness and mass per unit area of other bi-layer knitted fabrics are more resistant to passage of air through fabric. Type 4 bi-layer knitted fabrics shows higher air permeability, provides good ventilation to the microclimate part and the wearer feels more comfortable.

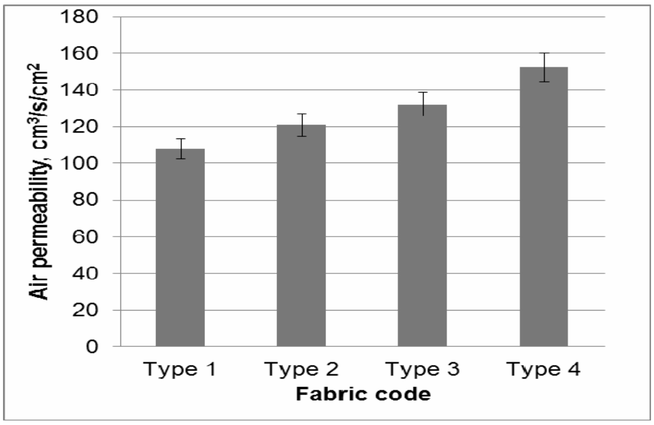


Figure 3. Air permeability of bi-layer knitted fabrics

Water vapour permeability

Water vapour permeability is an essential property for fabrics used for badminton sportswear. When overheating of human body occurs, perspiration is formed and the body heat evaporates it. From the Figure 4, it is apparent that Type 4 has higher water vapour permeability than all other bi-layer knitted fabrics. The thickness of Type 4 is lower than Type 3 and it is a vital feature and establishes the distance through which moisture vapour pass through from one side of the fabric to the other side. Type 1 and Type 2 shows lesser water vapour permeability due to increase of thickness of fabric. The decrease of loop length in Type 1 and Type 3 bi-layer knitted structure decreases the water vapour permeability of fabric than Type 2 and Type 4 respectively. In addition to that, the hygroscopic character of bamboo yarn in Type 2 and Type 4, which has higher vapour diffusivity and with this unparallel micro structure; it can absorb and evaporate human sweat more quickly than the Type 1 and Type 3 fabric in which inner layer is made up of modal yarn [47]. It is concluded that the geometrical properties and the nature of material affects the water vapour permeability of bi-layer knitted fabrics significantly.

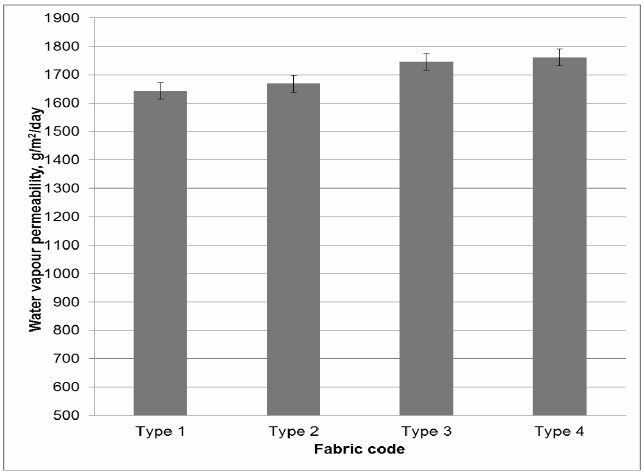


Figure 4. Water vapour permeability of bi-layer knitted fabrics

Wicking

Wickability of the fabric mainly depends upon the fibre type, fabric construction and thickness of material. It can be observed from the Figure 5 and 6, longitudinal and transverse wicking is high for Type 4. This is due to the structures ability to act like a capillary system and removes and transports water to the outer system. Looser the construction of Type 4 than Type 3 structure, easier for liquid moisture to diffuse through the fabric. It can also be observed that, Type 2 and Type 4 possess good wicking ability than Type 1 and Type 3 bi-layer knitted fabrics respectively. This is due to the presence of bamboo yarn in Type 2 and Type 4 as an outer layer which wicks away the moisture quickly than modal yarn in Type 1 and Type 3. Type 4 has higher wicking rate due to its lowest stitch density and lowest thickness than Type 3. Analysis of transverse wicking characteristics of bi-layer fabric is more important than longitudinal wicking because perspiration transfers from the skin involves its movement through the lateral direction of fabric. It is also shown in Table 2, the wickability is more for Type 4 in wale-wise direction as compared to course-wise direction. This is due to the fact that the transfer of water is easier in wale-wise direction due to the better capillary action in wale-wise manner. Due to various micro-gapes and micro-holes in cross-section of bamboo fibre, it has better wicking ability than modal yarn [45]. Even though polyester which has same characteristics and plays as an inner layer for all the structures; the wickability values differ for all the structures due to composite fabric wicking effect.

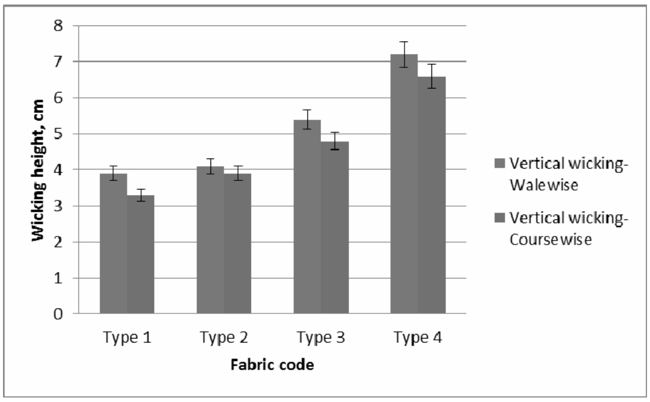


Figure 5. Vertical wicking of bi-layer knitted fabrics

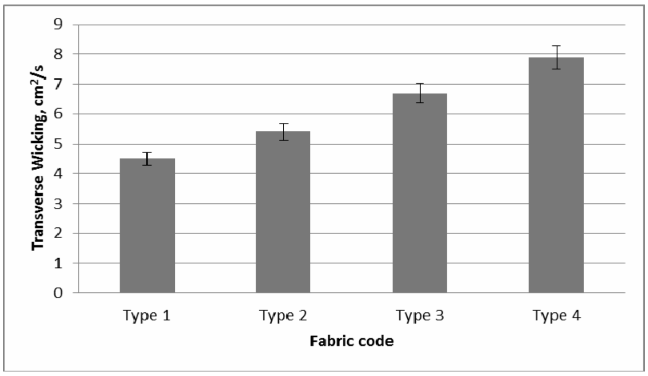


Figure 6. Transverse wicking of bi-layer knitted fabrics

Moisture absorbency

When fabric is subjected to heavy sweating conditions, sweat is absorbed by the fabric and given off to the atmosphere instantaneously. So to prevent the wearer from feeling wet and clammy, the moisture should be stored in the fabric.

Maximum absorbency was found in Type 1 and Type 2 followed by Type 3 and Type 4 fabrics. From the Figure 7, it is clearly shown that the bi-layer knitted structures with five tuck points are having high amount of water absorbency when compared to one tuck point structures. Higher the stitch density of Type 1, more the amount of moisture that can be stored by the fabric better would be the performance of the fabric under moderate to heavy sweating conditions. The thickness and weight of the fabrics were higher for five-tuck point bi-layer knitted fabrics (Type 1 and Type 2) than one-tuck point (Type 3 and Type 4) bi-layer knitted fabrics and greatly influences the moisture absorbency of fabric.

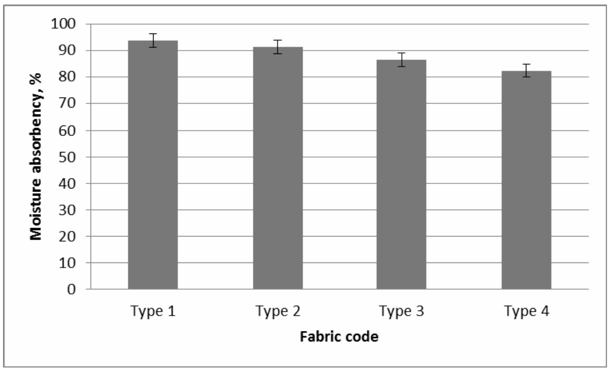


Figure 7. Moisture absorbency of bi-layer knitted fabrics

Drying time

Moisture transfer is a critical factor for thermoregulation of the body heat. Moisture on skin or clothing increases the heat loss of the body and also affects the overall performance and endurance of the body [46]. Figure 8 shows that the drying ability rate is higher for Type 4 and Type 2 layered fabrics compared to Type 3 and Type 1 respectively. In bi-layer knitted fabrics, Type 4 and Type 3 required less time to dry or to reach the initial dry mass of fabric. This is due to low mass per unit area, thickness and high moisture vapour transmission. The drying ability of bi-layered knitted fabrics was primarily affected by mass per unit area and thickness and secondarily by the knitted structure parameters. With the unparalleled micro-structure of bamboo fabric absorbs and evaporates sweat very easily, and hence gives comfortable feel [45].

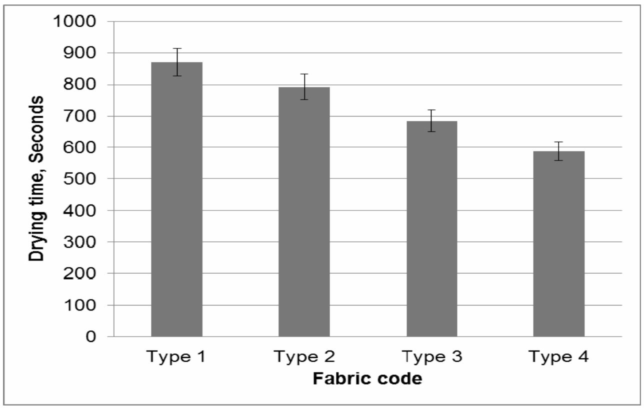


Figure 8. Drying behaviour of bi-layer knitted fabrics

Effect of thermal comfort properties on bi-layer knitted fabrics using ANOVA multivariate analysis

In this study, two-way ANOVA is analyzed and the selected value of significance for all statistical tests is 0.05 level and the degree of freedom for analyzing the bi-layer structure is 3, 19 and the $F_{critical}$ is 3.24. The results of ANOVA are listed in Table 3, which analyzes the significant difference of thermal comfort properties of bi-layer knitted fabrics. The value of $F_{critical} < F_{actual}$ proves that the changes in surface structure and fibre type are highly significant on the above discussed thermal comfort properties. Tukey's Honest Significant Difference (HSD) test is used to find the possible group-wise (pair-wise) differences of means. The $Q_{critical}$ at (3, 16) value is 3.24 and $Q_{critical}$ is lesser than Q_{actual} for all paired means of bi-layer fabrics and there is a significant difference between paired samples of layered fabric (Type 1, Type 2, Type 3 and Type 4) is shown in Table 3.

Subjective Analysis

Figure 9 shows the subjective rating on thermal environment scale which includes five thermal parameters. It was found that Type 4 showed good ranking on five subjective judgement scales which describes the thermal state of player. The five subjective judgment scales includes thermal perception, thermal comfort, thermal preference, personal acceptability and personal tolerance and rating points are shown in Table 4. The Type 4 bi-layer fabric with one tuck point, in which inner layer is made up of polyester and outer layer is made up of Bamboo can be preferred for sportswear followed by Type 3 and Type 2. Table 5 shows the values of Friedman One-Way Analysis of Variance by Ranks. The number of sample is 15 and hence Chi square is analyzed. The selected significant difference is 0.05, the degree of freedom is 3 and the F value is 7.82. The obtained F value is less than the critical value of chi-square, which proves that there is a significant difference between rankings of layered knit fabrics. The significant difference between the rankings was found for all five subjective judgement scale thermal state parameters

Table 4. Subjective perception of thermal environment

Parameter of thermal state	Measurement scale
Thermal perception	7-point scale: -3 (Cold), -2 (Cool), -1 (Slightly cool), 0 (Neutral), +1 (Slightly warm), +2 (Warm) and +3 (Hot)
Thermal comfort	4-point: 0 (Comfortable), +1 (Slightly uncomfortable), +2(Uncomfortable) and +3 (Very uncomfortable)
Thermal preference	7-point scale: -3 (Much cooler), -2 (Cooler), -1 (Slightly cooler), 0 (Neither warmer nor cooler), +1 (a little warmer), +2 (Warmer) and +3 (Much warmer)
Personal acceptability	Two category statement: 0 (Acceptable rather than unacceptable) and +1 (Unacceptable rather than acceptable)
Personal tolerance	5-point: 0 (Perfectly tolerable), +1 (Slightly difficult to tolerate), +2 (Fairly difficult to tolerate), +3 (Very difficult to tolerate) and +4 (Intolerable)

Table 5. Thermal state rating-Friedman One-way Analysis of Variance by Ranks

Thermal state parameters	Mean ranks of respective samples				Chi-square statistic χ^2_r	P-value
	Type 1	Type 2	Type 3	Type 4		
Thermal perception	3.9	3.2	2.1	1.0	39.60	<0.0001
Thermal comfort	3.8	3.2	1.8	1.2	39.62	<0.0001
Thermal preference	4.0	2.9	2.0	1.1	42.14	<0.0001
Personal acceptability	3.1	3.0	2.6	1.4	15.23	<0.0001
Personal tolerance	3.7	3.2	2.0	1.1	37.82	<0.0001

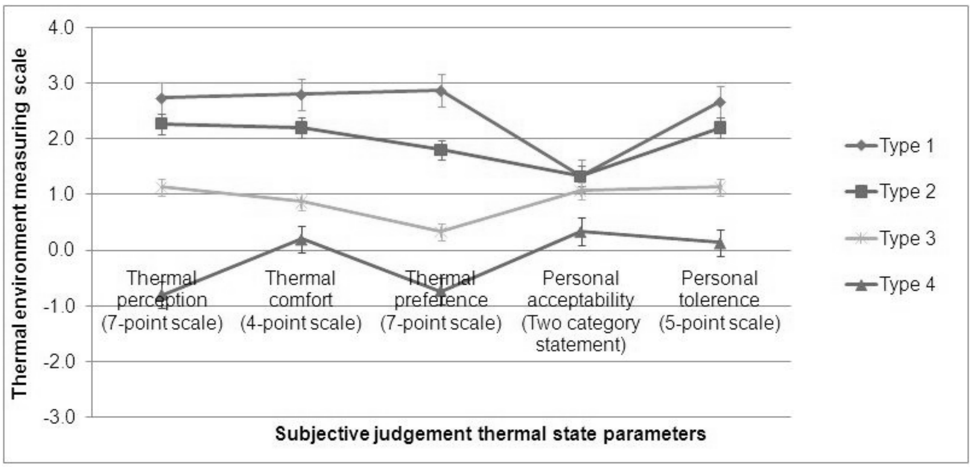


Figure 9. Subjective perception rating of bi-layer knitted fabrics

4. CONCLUSIONS

In this study, the thermal comfort characteristics of layered knitted fabric for sportswear were compared in the perspective of thermal conductivity, air permeability, water vapour permeability, wicking ability, moisture absorbency, and drying rate. The thermal conductivity and air permeability of bi-layer knitted fabric with one tuck point Type 4 are greatly influenced by thickness and stitch density of the fabric. Water vapour permeability of the bi-layer fabric increases with decrease of thickness and presence of openness of the fabric. Bi-layer fabric Type 4 with lower stitch density and lowest thickness showed higher amount of water take-up compared to other fabrics. The wicking characteristics of the bi-layer fabric were greatly influenced by thickness and stitch density.

It is observed that, moisture absorbency of bi-layer knitted structure increases with increase of stitch density and tightness factor. The frequency of tuck stitch also affects the moisture absorbency of bi-layer knitted fabric. The drying ability of bi-layer fabric with one tuck point is primarily influenced by thickness and mass per unit area and the secondarily by the structure. It can be concluded that, the bi-layer knitted fabric with one tuck point in which inner layer is made up of polyester and the outer layer is made up of bamboo showed better thermal comfort properties mostly suitable for active sportswear.

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