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Influence of fabric structure and loop length on thermal comfort properties of cotton/polyester knitted fabrics

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Thermal comfort characteristics of polyester and cotton fibres blends (100:0, 50:50 and 0:100) having in four different structures, such as single jersey, cross tuck, cross miss and twill, at two different loop lengths (0.29 cm and 0.32 cm) have been studied. The results evidently prove that the knitted fabrics made from 100% polyester show better thermal comfort properties, possessing an appreciable comfort level; hence they are applicable for active sportswear textiles. The structure and the loop length of the fabric influence the thermal property to a greater extent. The fabric knitted from 100% polyester with a cross-miss structure on a loop length of 0.32 cm shows an excellent thermal comfort characteristic as compared to other samples due to its suitable thermal conduction behavior.

Keywords: Cotton, Knitted fabrics, Knitted structures, Polyester, Thermal comfort

1 Introduction

The thermal comfort qualities between the human body and the outside environment are mostly determined by the clothing. It acts as a transmission medium for the thermal and liquid moisture[1]. Any active sportswear's primary feature is moisture management, which improves the level of fabric comfort. Comfort is defined by the wearers in many ways according to his / her perception. In general, comfort is described as the body's ability to regulate its temperature, which is greatly influenced by the wearer's physiological and psychological response. The textile's ability to transmit moisture has a significant impact on the user's thermo physiological comfort. Thermo physiological comfort is the maintenance of the thermal equilibrium, including all the various parameters, such as air transmission, water vapour transmission, thermal conduction, sweat absorption, etc[2-4]. In general, at normal conditions, the single jersey fabrics knitted from cotton are suitable for the sport textiles, but in conditions such as high active sportswear, the players sweat a lot, making the sweat get absorbed and cling on the surface of the fabrics. In general, cotton possesses a very less wicking characteristics so they are not suitable for high active sportswear, but fibres such as polyester, acrylic and polypropylene have excellent wicking property, making them suitable for active sportswear garments[5].

Transferring of water plays a major role in comfort characteristic determination of the sport textile. This transferring of water is wicking and the wicking activity takes place through the capillary action of the fibres. The pore diameter and surface energy of the material govern the capillary action in a porous material. Better capillary action occurs when the pore diameter is small or surface energy is more. Micro size fibres form capillaries which are narrow and this results in effective moisture transport[6]. The wicking occurs only when the liquid wet fibres assembled with capillary spaces between them. Spontaneous wetting in a capillary system result in the wicking of fibres. The micro and macro capillaries present in the fibre are mainly responsible for the wicking to take place. Through the kinetics for micro and macro capillaries, by using Wash burn equation it is found that short-term wicking takes place through the macro capillaries and long-term wicking takes place through the micro capillaries and it reaches a maximum height of wicking with a slow diffusion rate. Also, another key impact to wicking is produced by the surface

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tension influence. It is observed that wicking height increases as the surface tension increases[7]. Better moisture transport and wicking behavior are observed in the micro fibre having a denier<1.0. The diameter is apparently smaller if the fibres are closely packed in yarn which results in a ready wicking due to narrow capillaries[8]. Capillary force causes wicking, which is the spontaneous movement of liquid in a porous media. It is found that a liquid having non wetting property on the fibre have a non-wicking property on the fabric[9]. The shape of the fibre in the yarn or the fabric structure also influences the rate of wicking[10]. Wicking performance is also affected by the size of the pores and arrangement of void space in a fabric[11]. Theoretically, the wicking property can also be examined, considering the four different forces, viz. the capillary force, the force of gravity, the viscous drag, and the inertia[12,13]. Research was carried to study the wicking behavior of spun yarns by imparting various twist levels to the yarns. The study found that applying twist has a negative impact on the wicking behavior of the yarn. As the twist level increases the wicking height starts decreasing[14]. It is also stated that with the increase of twist, the wicking height descends. This means that the water molecules start dropping down the capillary pores that are formed between the fibre surfaces[15].

The provided information highlights the critical role of fabric composition, structure, and loop length in determining thermal comfort and moisture management properties of sportswear textiles. It emphasises the advantages of 100% polyester fabrics for active sportswear due to their superior moisture-wicking capabilities, compared to cotton. However, while the study sheds light on several factors influencing comfort, it also reveals potential gaps in knowledge. The existing research has shown that fabric structure and loop length are influential, but a more comprehensive understanding of the interplay between these factors and their specific effects on thermal and moisture-related properties is needed. Additionally, the study alludes to the impact of fibre characteristics, such as surface energy and capillary action, on wicking behavior, but the precise mechanisms and relationships between these factors remain somewhat unclear. Therefore, the objective of this study is to address these knowledge gaps by conducting a systematic investigation into the complex interactions between fabric composition, structure, loop length, and fibre properties. By doing so, the research aims to provide a more nuanced understanding of how these variables collectively influence the thermal and moisture management properties of sportswear textiles. Ultimately, the study seeks to contribute to the development of sportswear materials that enhance wearer comfort and performance, especially in high-intensity athletic scenarios.

2 Materials and Methods

Polyester fibres (150 denier) and cotton fibres (36s) were blended in the ratios of 100:0, 50:50 and 0:100 for preparing the fabric with four different structures (Fig. 1), such as single jersey, cross tuck, cross miss and twillat two different loop lengths (0.29 cm and 0.32 cm) in circular knitting machine (Mayer & Cie, model 2016) with a diameter of 28inch and 29 gauge, at 20 rev/min.

2.1 Dimensional Properties

The four distinct knitted materials' loop length, thickness, and areal density were measured. The ASTM D 3887 standard was used to evaluate the number of wales and courses per unit length. Shirley thickness gauge was used for measuring the knitted fabrics thickness as per the ASTM D1777-96 standard. The knitted fabrics' areal density was determined using the ASTM D3776 standard. Knitted fabrics were produced using Mayer and Cie knitting machine of 24 inch gauge, 24 inch diameter and 72 feeders for assessing moisture management behaviour of the fabrics. Table 1 gives the technical details of the fabric produced. All the samples produced were

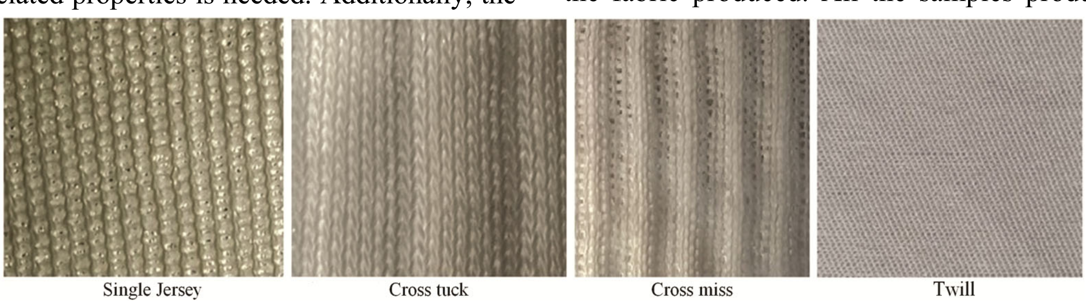

Fig. 1 — Images of knitted fabrics

Table 1 — Geometrical properties of the knitted fabrics

Structure	Loop length cm	Fabric	GSM g/m^2	Thickness, mm	Course per inch (CPI)	Wales per inch (WPI)
Single Jersey	0.29	Cotton	173.33	0.683	30	40
		Cotton:Polyester (50:50)	155.56	0.599	26	38
		Polyester	143.37	0.555	24	35
	0.32	Cotton	155.23	0.593	26	36
		Cotton:Polyester (50:50)	137.4	0.537	24	33
		Polyester	133.37	0.491	22	31
Cross Tuck	0.29	Cotton	215.66	0.855	34	46
		Cotton:Polyester (50:50)	195.66	0.782	33	44
		Polyester	175.66	0.687	30	40
	0.32	Cotton	190.35	0.742	32	42
		Cotton:Polyester (50:50)	167.23	0.632	28	39
		Polyester	150.4	0.573	26	36
Cross Miss	0.29	Cotton	156.37	0.601	28	38
		Cotton:Polyester (50:50)	145.23	0.555	24	35
		Polyester	120.3	0.437	21	30
	0.32	Cotton	145.23	0.56	25	35
		Cotton:Polyester (50:50)	110.23	0.401	20	30
		Polyester	100.1	0.387	20	27
Twill	0.29	Cotton	188.23	0.736	30	41
		Cotton: Polyester (50:50)	185.23	0.691	30	41
		Polyester	157.23	0.605	28	38
	0.32	Cotton	170.35	0.663	28	40
		Cotton:Polyester (50:50)	150.35	0.571	26	35
		Polyester	135.56	0.533	23	33

allowed to relax for 24 h under standard atmospheric conditions and then used for the further analysis.

2.2 Experimental Method

The manufactured fabrics were tested for the thickness (per ASTM D 1777), areal density (per ASTM D 3776), wales and courses per unit length (per ASTM D 3887: 1996 (RA 2008)), and loop length, along with other physical and structural characteristics (ASTM D 3887). The details of physical and structural properties evaluated for the fabrics are given in Table 1.

2.3 Comfort Properties

KES-F8 AP1 at BS 5636 1990 standard was used to measure the knitted materials' air permeability in accordance with the standard. Using a Lee's disc device in accordance with Standard ASTM D7340, the thermal conductivity of knitted materials was measured. According to Standard BS 7209:1990, the knitted fabrics' water vapour permeability was evaluated.

3 Results and Discussion

The geometrical properties of knitted materials have been examined, and average results from 15 different sample tests are taken. Table 1 clearly shows that the change in yarn type, fabric structure and blend proportion influence the physical properties of the fabrics, such as course and wales per centimetre, thickness and GSM. As the yarn type changes, the areal density of the fabric gets changed. For every knitted fabric, 15 tests are conducted to analyze the thermal comfort properties, and the average values are used (Table 2).

3.1 Air Permeability

The air flow between the intersections of the yarn spaces provides a good breathability and comfort nature to the wearer during a very hot and humid natured climate. Yarn blend, structure of fabric and length of loop play a major role in the air permeability, influencing the air channels and shape, through which the flow of the air exists. As the polyester content of the yarn increases, it is observed from the experimentation and Fig. 2 that the knitted materials' air permeability increases. As the polyester content increases the fabric becomes thinner and lighter in weight, as compared to other blends, resulting in a lesser air flow resistance, which, in turn,

Table 2 — Thermal comfort properties of the knitted fabrics

Structure	Loop length cm	Fabric	Air permeability $cm^3/cm^2/s$	Water vapour permeability %	Thermal conductivity W/mK × 10^{-3}	Thermal resistance $m^2K/W \times 10^{-3}$
Single Jersey	0.29	100 % Cotton	157	40.55	39.91	16.66
		Cotton :Polyester (50:50)	184	43.22	43.63	13.99
		Polyester	205	47.83	49.52	12.77
	0.32	Cotton	188	44.58	44.44	15.03
		Cotton :Polyester (50:50)	209	47.77	48.89	13.33
		Polyester	225	50.99	53.33	11.45
Cross Tuck	0.29	Cotton	118	38.01	36.04	22.22
		Cotton :Polyester (50:50)	134	41.01	39.43	18.77
		Polyester	155	43.08	44.52	16.66
	0.32	Cotton	148	42.03	40.54	20.79
		Cotton :Polyester (50:50)	169	45.89	43.99	18.05
		Polyester	195	49.22	47.03	15.36
Cross Miss	0.29	Cotton	177	43.75	43.31	15.36
		Cotton :Polyester (50:50)	202	46.02	48.63	12.89
		Polyester	235	49.99	53.53	11.77
	0.32	Cotton	202	46.88	47.04	14.03
		Cotton :Polyester (50:50)	239	49.97	50.88	12.33
		Polyester	273	52.99	56.33	10.45
Twill	0.29	Cotton	137	36.01	37.01	17.22
		Cotton :Polyester (50:50)	154	39.11	40.33	15.99
		Polyester	175	41.88	46.52	14.67
	0.32	Cotton	168	40.03	43.44	16.69
		Cotton :Polyester (50:50)	189	43.99	45.89	15.01
		Polyester	215	48.32	50.03	13.11

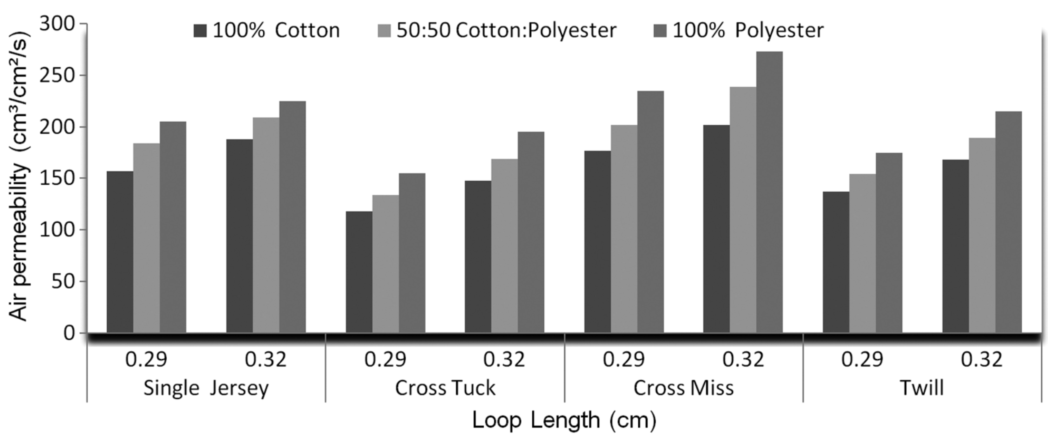

Fig. 2 — Air permeability values of knitted fabrics

increases the air permeability. The cotton fibre has the convolutions which results in the increase of contact between air and surface of the fibre. A less tortuous and undisturbed path is needed for the free flow of air through the path. But cotton fibre has more protruding nature which results in the decrease in the air permeability. Thus, it is abundantly clear from the outcomes that adding more cotton to the fabric reduces its air permeability. The graph clearly indicates that 100% polyester cross-miss fabrics with a loop length of 0.32 cm show the maximum air permeability value. The outcomes evidently prove that for a fabric structure of single jersey, tuck, miss and twill composition, the air permeability is found to be very effective in the twill structure. As the length of the loop increases the surface of the fabric becomes

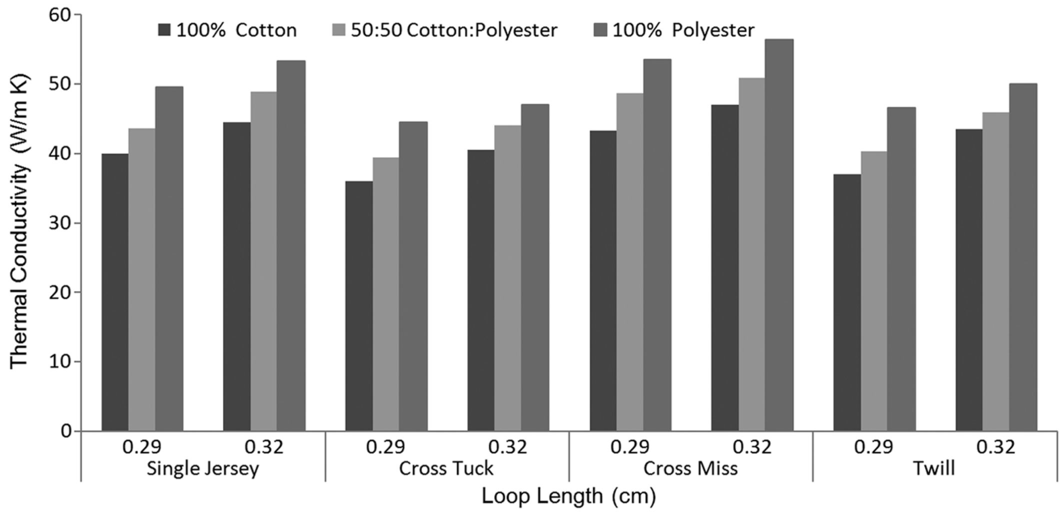

Fig. 3 — Thermal conductivity values of knitted fabrics

more porous and looser, resulting in increased air permeability. The fabric's structure has a significant role in determining a fabric's air permeability. The fabric's thickness affects the air permeability. The thickness of the fabric is significantly influenced by the yarn's structure. The permeability of a fabric reduces as its thickness increases. The fabric knitted from 100% polyester with a cross-miss structure on a loop length of 0.32 shows a higher air permeability value as compared to all other knitted samples. Polyester without any restricting air passages possesses a good porous nature, making it more suitable. From this, it is evident that air permeability is directly proportional to the porous nature of the fabric. Cross-miss structure shows a lesser bulkiness to the fabric, making the air flow well through the structure.

3.2 Thermal Conductivity

The fabric should be made more suitable for the climate depending on the ability to transfer heat. In hot climatic conditions, a higher degree of thermal conductivity is required and a relatively lower level of thermal conductivity is required in cold climatic conditions. The amount of air trapped inside the fabric and the fabric's composition both have a significant impact on heat conductivity of cloth. With the use of 100% polyester in the fabric, the thermal conduction take place at an appreciable rate, as these structures possess more voids, allowing a good transfer of heat to pass through and supporting the conduction to takes place well[16].

More air is being entrapped inside the fabric and leads to provide an excellent heat conduction. Thermal conductivity is primarily influenced by the fabric's thickness and mass per unit area. The area density of the cloth has an inverse relationship with its thermal conductivity. As the content of the cotton increases in the fabric blend the thermal conductivity range of the fabric decreases. From Fig. 3, it is evident that the fabrics made of 100% polyester show excellent thermal conductivity. Also, the loop length plays a predominant role in the conduction of the heat. The fabrics knitted with a loop length of 0.32 cm have more loose structure and hence more air spaces, making it more suitable for excellent thermal conduction. As the fabric becomes more compact with the increase of the loop length, the thermal conduction excels. The thermal conductivity is directly proportional to the loop length of the fabric. The fabric knitted from 100% polyester with a cross-miss structure on a loop length of 0.32 shows a higher thermal conductivity value as compared to all other knitted samples. Cross-miss structure has a lesser bulkiness, allowing the heat to pass well through the structure, resulting in good thermal conduction. Good capillary pores are created in the cross miss structure, maintaining the flow of heat. Next to the cross miss structure, the single jersey structure also shows good thermal conduction. The twill structure and cross tuck structure decrease the thermal conduction rate due to their compact nature and increased fabric thickness and areal density.

3.3 Thermal Resistance

The prevention of the heat flow through the material is called as thermal resistance. The fabric's thermal resistance is influenced by its blend and

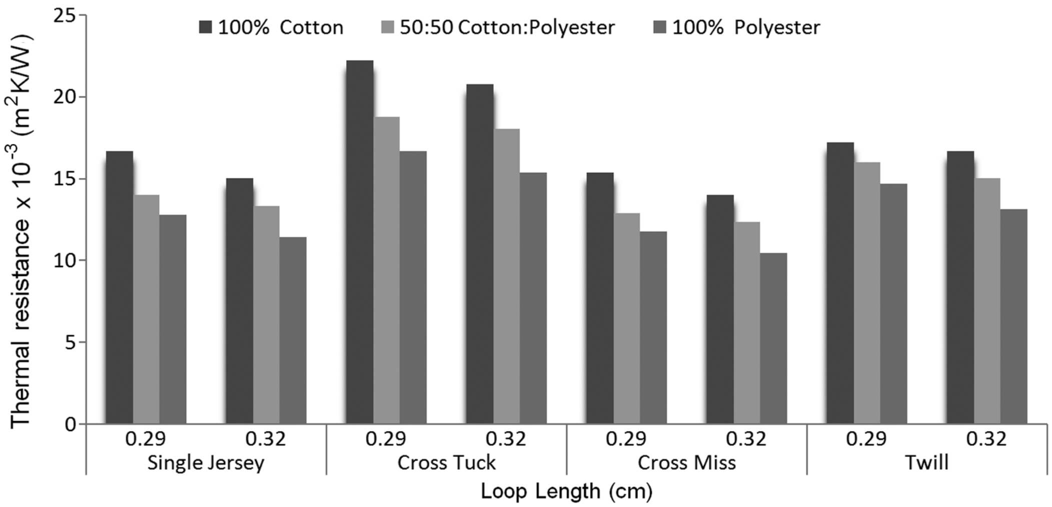

Fig. 4 — Thermal resistance of knitted fabrics

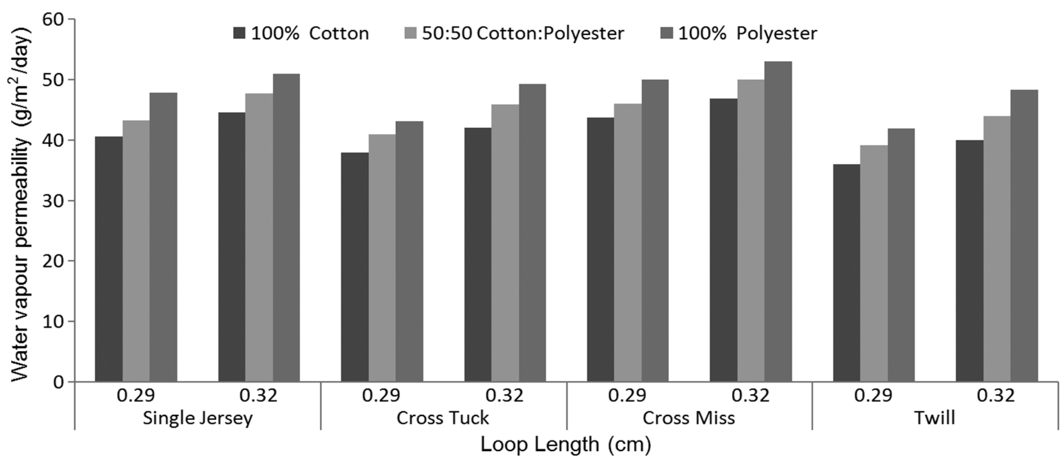

Fig. 5 — Water vapour permeability of knitted fabrics

structure. The structure of the fabric influences the fabric thickness and the air fraction volume. The thermal insulation improves with the increase in thickness of cloth. The relationship between the fabric's thickness and the sample's thermal resistance is directly proportional[16]. Figure 4 shows that thermal resistance increases as the proportion of cotton in blend increases. As the hairiness of the yarn rises, the thermal resistance increases. This hairiness structure results in a thicker fabric and forms an insulation layer. The increase in the ratio of the cotton fibre increases the specific heat, resulting in a high thermal insulation. A higher energy is needed in this case for the heat to get transmitted through the fabric structure. The loop length is also an important parameter fabric with 0.29 cm has a loop length more compact structure, making the heat to get insulated highly. The twill and cross tuck structures show high thermal insulation as compared to the cross miss and single jersey structures. The cross miss structure has more void areas, thus reducing the thermal insulation. The single jersey structure also possesses lessened thermal insulation behaviour as compared to cross tucks and twill structures.

3.4 Water Vapour Permeability

The water vapour transmission through the permeable of the fabric is termed as the water vapour permeability[17]. An excellent comfort is felt by the wearer only when the moisture is well transmitted from the human body to the environment. So, all the comfort related textiles should exhibit excellent water vapour permeability. Figure 5 represents the water-vapour permeability of fabric samples made out of different blends of polyester and cotton with a variesd knit structure and two variety of loop length (0.29 cm and 0.32 cm). The results obtained for the water-vapour permeability examination clearly evidences that sample made out of polyester fibre shows higher water-vapour permeability than that of the one made with the blend of cotton fibre or 100% cotton fibre. It is obvious that the fabric's air permeability nature interacts more harmoniously with the water vapour permeability values[18].

The fabrics made out of polyester possess good air permeability, lowest moisture regain nature, and excellent water vapour permeability. Due to the existence of convolutions and protruding fibres, the fabric's ability to retain moisture increases as the amount of cotton in it decreases, which also affects water vapour permeability. The fabric's structure is extremely important in determining the water vapour permeability. While determining the fabric's water vapour permeability, the areal density and thickness are crucial factors. The ability of water to travel through a fabric reduces as its thickness rises, which causes the permeability of water vapour to decrease as well. The cross-miss structured fabric with 100% polyester shows good water vapour permeability because of its lower areal density and thickness as compared to the other fabrics since the polyester yarns are more finer than the other yarns. Good water vapour permeability is obtained by the cross-miss fabric structure of 100% polyester, which has a smaller mass per unit area. With a longer loop, the water vapour permeability is generally high. On comparison with the two loop lengths chosen (0.29 cm and 0.32 cm), a tighter structure is obtained with a loop length of 0.29 cm and a looser structure is obtained at a loop length of 0.32 cm. The higher water vapour permeability is observed in the looser structure followed by the tighter structure, which is mainly influenced by the pores structure of the knitted fabric. The void nature of the fabric structure increasingly results in high water vapour permeability as the loop length increases. A larger surface area with a channeled yarn structure and higher number of pores is observed in the 100% polyester of cross-miss structure with a loop length of 0.32 cm showing a more suitable nature for water vapour permeability.

4 Conclusion

The study shows that the various thermal comfort properties depend on the blend, loop length and structure of the fabric. The presence of cotton fibre in the knitted fabric affects the thermal comfort characteristics. Air permeability, water vapour permeability and thermal conductivity are higher for 100 % polyester due to its finer nature and reduced thickness of the fabric. It’s evident that as the loop length increases the thermal comfort characters are getting enhanced due to the void structure in the fabrics. Also the knit structure influences the thermal comfort. The miss cross structure is more suitable followed by the single jersey structure and other two. The fabric knitted from 100% polyester with a cross-miss structure on a loop length of 0.32 shows excellent thermal comfort characteristics as compared to all other samples.

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